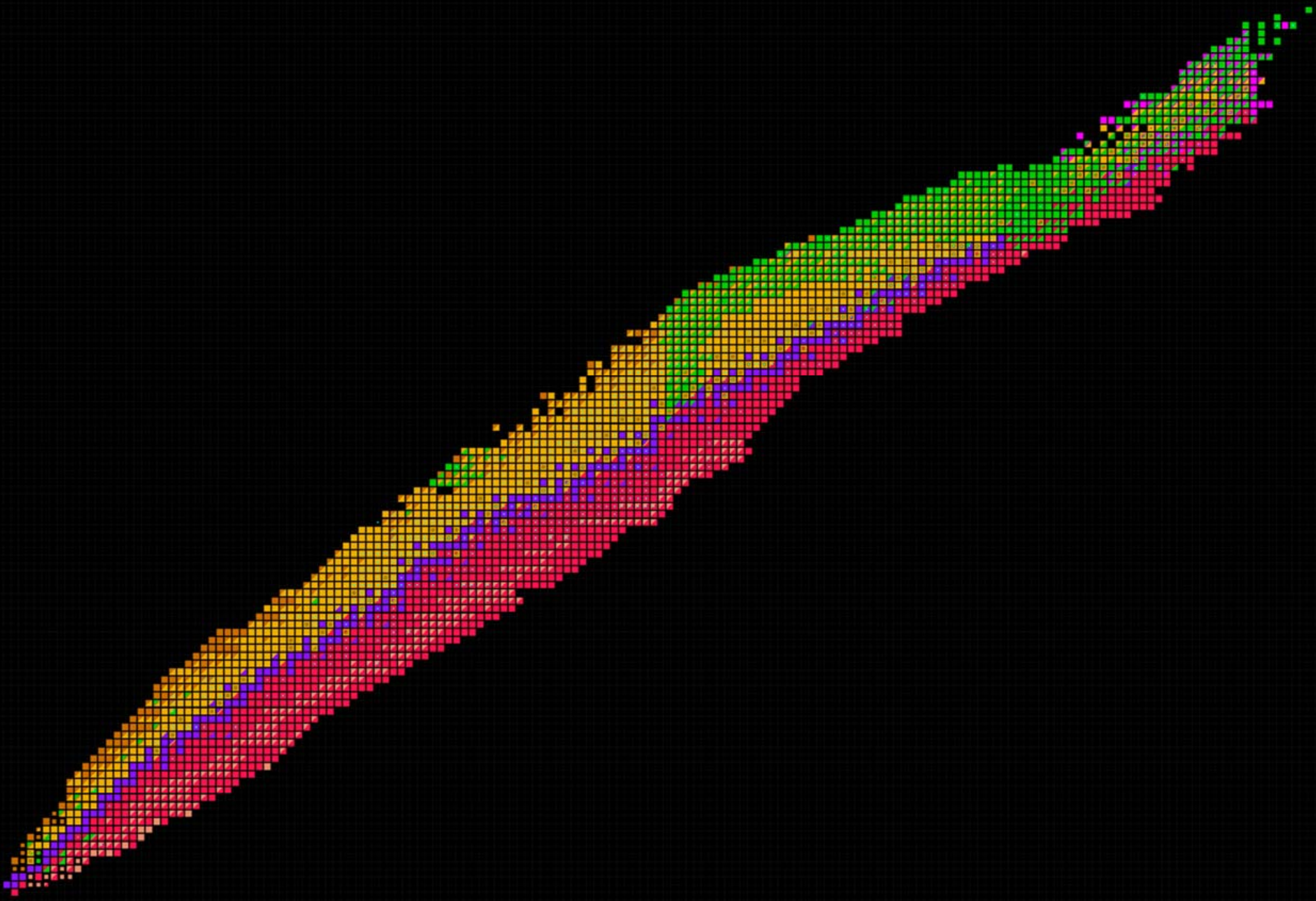
NUCLEAR PHYSICS IN POLAND 1996-2006



Polish Nuclear Physics Network
PNPN

NUCLEAR PHYSICS
IN POLAND
1996-2006

EURONS REPORT

DECEMBER 2007

NUCLEAR PHYSICS IN POLAND
1996 – 2006

edited by

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POLISH NUCLEAR PHYSICS NETWORK
PNPN

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NUCLEAR PHYSICS IN POLAND

1996-2006

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EDITORS NOTE

This Report is a result of the Polish Nuclear Physics Network (PNPN) action having as objective the mapping study of the basic and applied research in this domain in Poland. In the often employed slang it constitutes one of the "deliverables" of the EWON (East-West Outreach) Network, operating within the I3- (Integrated Infrastructure Initiative) EURONS, one of the Nuclear Physics projects in the Six Framework Programme (FP6). However, although prepared within the nuclear structure EURONS framework, this mapping study also reports on the activities in the hadron physics in Poland (organized in the FP6 within a second Nuclear Physics project I3-Hadron Physics) as well as in Nuclear Theory and Applications of Nuclear Physics. The Report contains references to activities and published papers from the last ten years: 1996 – 2006. In some cases also slightly older data are included, if necessary, for the completeness of the reported subjects.

The Report is organized as follows. After the information on Polish Nuclear Physics Network (a part of the EWON Network), a few overview papers describe the main domains of the PNPN scientific activity. The contents of these papers were previously presented during the NuPECC meeting, held in Kraków June 9, 2006.

A number (89) of more detailed contributions (together with appropriate references) emanating from various research groups follows the review articles. Some of the contributions provide concise summaries of wide research activities. Other authors preferred to report separately or individually on narrower topics. Most of the presented activities were conducted within the international collaborations. However, the adopted policy was that only Polish researchers are indicated as authors of the contributions, whereas the international collaborations are reflected by (all) authors of cited publications.

The Polish Nuclear Physics Long-Range Plan prepared recently by the Nuclear Physics Committee of the National Atomic Energy Agency articulates an outlook to the future in Section 5. Indices of contributing institutions and authors are provided in Sections 5 and 6. A list of addresses and other practical information on units belonging to PNPN is provided in Section 8. Finally, two lists (institution and alphabetical order) of Polish nuclear physicists, including PhD students, with their affiliation and e-mail address close this Report.

The Editorial Committee wish to thank all authors of review articles and contributed communications for their effort and collaboration. Help of Mrs. Iwona Tomaszewska in the editorial tasks is highly appreciated. The edition of this Report was supported by the grant no. 115/E-343/SPB/MSN/PO3/DWM724/2003/2005 from the Ministry of Sciences and Higher Education and by the EWON networking funds.

Editors

POLISH NUCLEAR PHYSICS NETWORK

Jerzy Jastrzębski
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In 2001-2002 the European nuclear physics community was involved in preparation of two large proposals with the intention to submit them for financing within the Six Framework Programme (FP6) as so called Integrated Infrastructure Initiatives (I3). The first of these proposals was prepared by FINUPHY ("Frontiers in Nuclear Physics") – an organization composed of European Large Scale Facility (LFS) heads and representatives of LSF user community. The submitted I3 – EURONS was mainly directed toward the nuclear structure research. In parallel a less formal group of physicists involved in research in hadron physics submitted a second nuclear physics I3 proposal, named I3 – Hadron Physics. The activities of both groups were supported by NuPECC – an Expert Committee of the European Science Foundation. Both I3 proposals were accepted by EC.

During the preparatory phase of EURONS the contribution of Polish groups to the European nuclear physics landscape was clearly recognized by both NuPECC and FINUPHY (cf. Fig. 1). It was suggested that Poland can enter to EURONS as a whole, forming one of the networks of this I3.

In June 2002 the representatives of thirteen Polish nuclear physics units (see Sect. 8 for the list) decided to create Polish Nuclear Physics Network (PNPN) and to contact Czech Republic, Hungary and Slovakia with a suggestion to establish a larger network of nuclear physics laboratories in these countries and in Poland. In spring 2003 North-East European Network (NEEN) was established. Its planned networking activities, their objectives and expected outcomes were submitted to EURONS Coordinator.

During the same period the nuclear physics laboratories from Bulgaria, Croatia, Greece, Romania, Serbia and Turkey formed South-East European Network (SEEN) and also applied for EURONS support. Eventually, following the EURONS advice, the merge of NEEN and SEEN was decided by representatives of both networks and, in 2004, a common network EWON (East – West Outreach) was included in the EURONS initiative.

Table I summarizes the participation of Polish teams in the 6FP nuclear physics activities.

NuPECC information to ESF (PESC)

Jan. 2001 (prepared 1998)

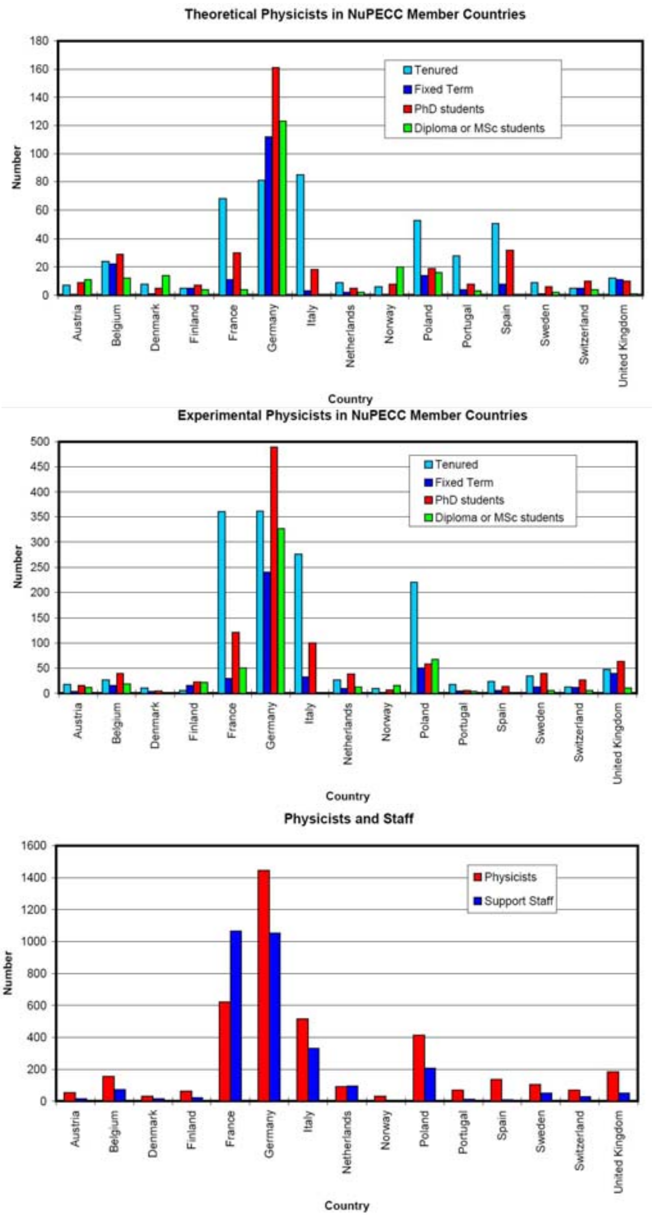

Fig. 1. *The European human potential in nuclear physics. Information collected by NuPECC in 1998.*

The indicated EU financial contribution to EWON includes only the support of NEEN, whereas SEEN, for practical reasons, is financed separately.

The nuclear physics activity in Poland can be conveniently divided into a few subgroups:

- experimental nuclear physics using local facilities;
- experimental nuclear physics using external facilities;
- theoretical nuclear physics;
- applications of nuclear physics to other domains of science;
- medical applications.

Polish NP participation In FP6

Program	Research or Network Activity	Polish Institution	EU financial Contribution €
I3 EURONS	JRA 2 AGATA	HIL WU INP - K	45 000
	JRA 6 INTAG	HIL WU	36 000
	Network EAST/WEST - OUTREACH	INP - K HIL WU	80 000
	JRA 9 RHIB	JAG U	75 000
I3 HP - Hadron Physics	JRA2: Fast compact EM calorimeters	INS	27 000
	JRA5: Generalized parton distributions	INS	42 500
SSA – Design Study DIRAC – secondary-Beams	Task 5: PANDA 4 Feasibility study to demonstrate the physics performance of PANDA	INS	33 900
EURISOL Specific Support Action	Task 5: Safety and radioprotection Task 10: Physics and instrumentation Task 11: Beam intensity calculation	HIL WU	72 000
		Total	411 400

Table I

Most of these activities are presented in this report, at least partly, in the form of review articles and short communications. Some supplementary information is given below.

Table II lists the main nuclear experimental facilities in Poland. With the exception of 30MW nuclear reactor (see www.cyf.gov.pl/reaktor.html and sect. 3.4) all other facilities are operated by PNPN units.

Local experimental facilities

Warsaw - Heavy Ion Cyclotron

Kraków - Light Particle Cyclotron

Kraków - Micro – Beam Facility

Kraków - Atomic Force Microscopy

Warsaw - VdG electrostatic accelerator

Świerk - Proton Cyclotron

Warsaw - PET Radiopharmaceuticals Production Centre
(in construction)

Świerk - Production of medical electron linear accelerators

Świerk - 30MW nuclear reactor

Table II

The Warsaw University Heavy Ion Cyclotron (see Fig. 2) is the largest of them. It is operated by Heavy Ion Laboratory (Fig. 3), a user facility with around 100 national and foreign users per year. The isochronous K_{max}=160 cyclotron delivers around 3000 h of heavy ion beams yearly ranging from B to Ar with energies between 2 and 10MeV/nucleon. The current research program comprises nuclear physics, atomic physics, material sciences, solid state physics, biology, particle detectors development and testing.

Fig. 2. The Kmax=160 heavy ion cyclotron of the Warsaw University.

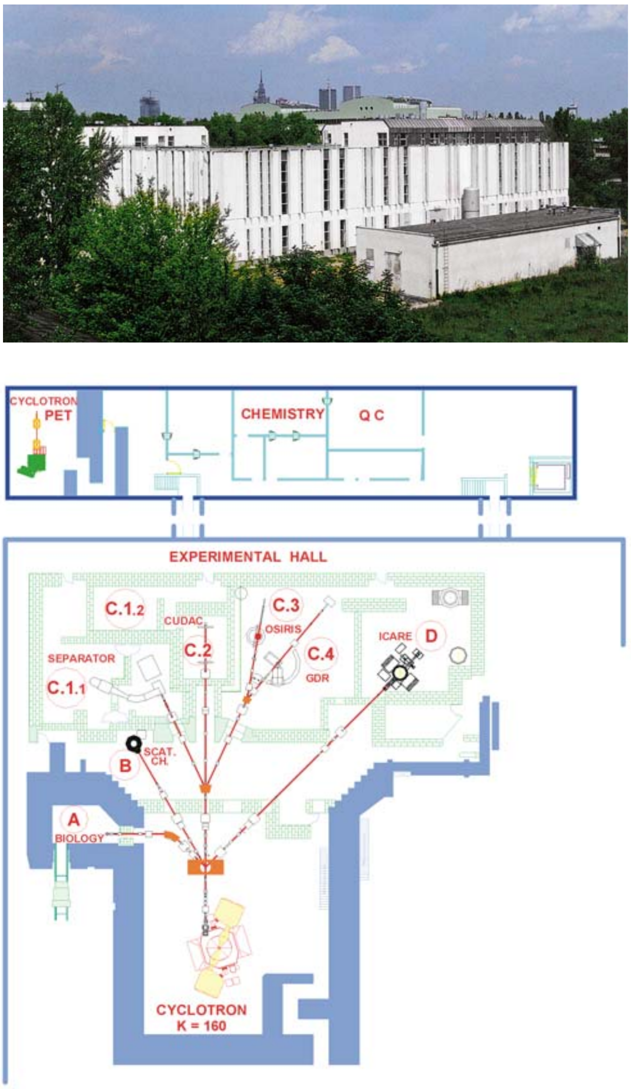

Fig. 3. Heavy Ion Laboratory building, the Kmax=160 cyclotron and its beam lines layout and the preliminary project of the PET Radiopharmaceuticals Production Centre.

Fig. 4. AIC-144, K=60 light particles cyclotron operating at Institute of Nuclear Physics in Kraków.

The Heavy Ion Laboratory is currently in its transformation phase to become the Warsaw University accelerator centre, operating two cyclotrons. The second commercial proton-deuteron cyclotron (E_p = 16.5 MeV) will soon be installed in the Laboratory building for the production of- and research on the radiopharmaceuticals for the Positron Emission Tomography (PET). Production of long–lived radiopharmaceuticals for other medical and life – science applications is also foreseen.

The second K=60, AIC-144 cyclotron accelerates light particles. It is operated by the Institute of Nuclear Physics (INP), Polish Academy of Science in Kraków (Fig. 4). Presently it is mainly used for medical isotope production. In its new experimental hall (see Fig. 5) the eye melanoma proton radiotherapy stand is in preparatory phase and will be operational in 2008. It is worth noting, that the AIC-144 is an intermediate solution, which will be followed by the installation in Kraków of a K=240 proton cyclotron for material science research and proton radiotherapy (see also sect. 3.4 and 5).

Another experimental set-up in INP is the 3.0 MV electrostatic generator with micro-beam facility. It is currently used for such interdisciplinary research as investigation of cells behavior under single ion hit (SIH), microparticle elemental analysis, rock dating etc.

Fig. 6 and Fig. 7 presents two other low energy accelerators, Warsaw 3 MeV van de Graaff and Świerk 30MeV proton cyclotron, respectively. Both these facilities are used for material science and solid state research.

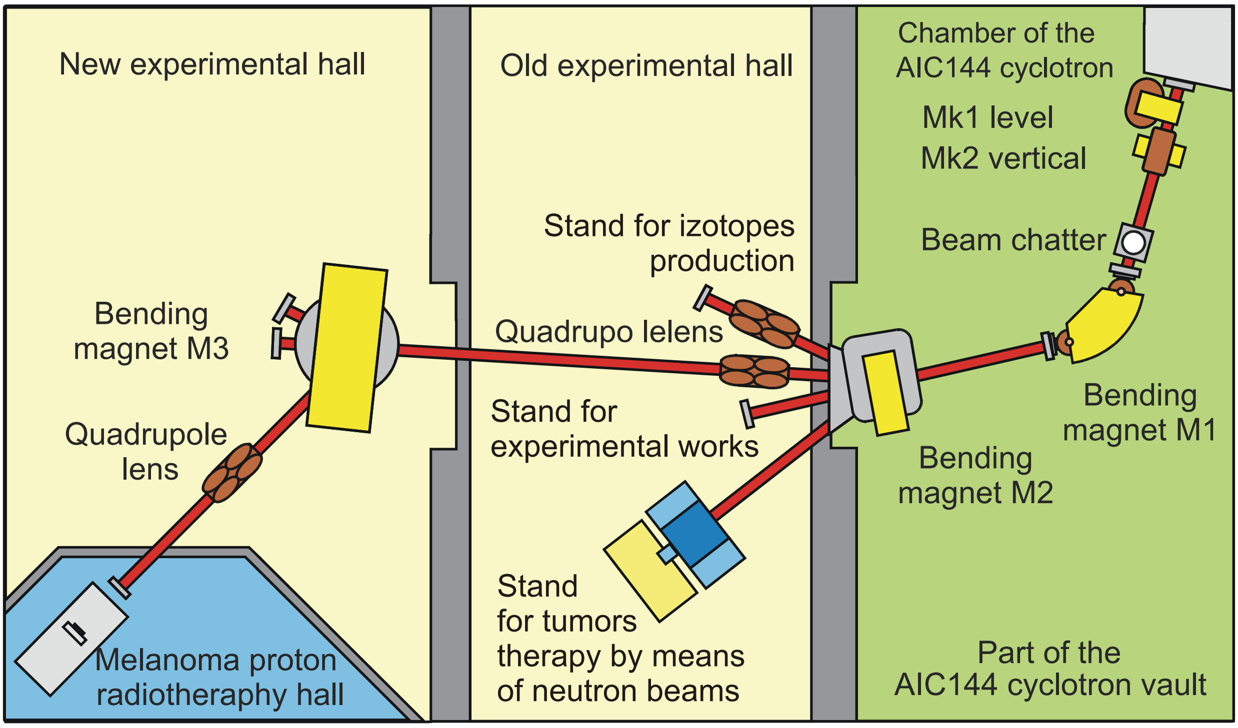

Fig. 5. The scheme of the transport of the Kraków cyclotron beams.

Fig. 6. Warsaw 3 MV Van de Graaf accelerator.

The fundamental research experiments performed using the Warsaw Cyclotron constitute only a small part of the experimental nuclear physics activity of Polish groups. Table III lists the nuclear facilities which were used during last ten years by individual researchers or working teams world-wide.

More information is given in sect. 4 and is summarized in sect. 5.

The special place in the Polish nuclear physics landscape occupies the theoretical physics. Not limited by severe financial restrictions which affects local experimental facilities, the flourishing of this domain is especially evident in the nuclear structure theory. The participation of Polish theoretical physicists in the European ECT* activities, American summer schools, long range planning preparation, visiting professor positions, various international reports redaction are a few examples.

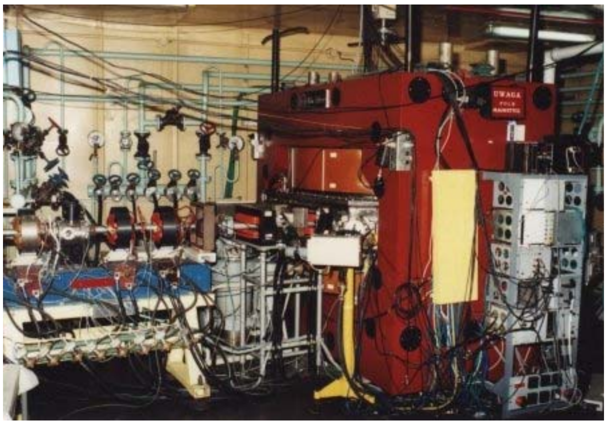

Fig. 7. Świerk near Warsaw, A. Sołtan Institute of Nuclear Sciences – 30 MeV proton cyclotron.

Main Large Scale Facilities used by Polish experimental teams

AGOR	Groningen
ATLAS	Argonne
CERN	Geneve
COSY	Juelich
DESY	Hambourg
GANIL	Caen
GRAN SASSO	Italy
GSI	Darmstadt
IRES	Strasbourg
JINR	Dubna
K 5OO	Texas A+M
LEGNARO	Padova
LNS	Catania
ORNL	Oak Ridge
RHIC	Brookhaven
SINQ	Villigen

Table III

The organization and activities of the Polish Nuclear Physics Network can be found at the PNPN web page: www.slcj.uw.edu.pl/pnpn.

OVERVIEW PAPERS

EXPERIMENTAL LOW ENERGY NUCLEAR PHYSICS IN POLAND

Bogdan Fornal
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Early days of nuclear science in Poland, as well as its later history, owe a lot to Maria Skłodowska-Curie - one of the greatest scientists of the 20’th century. Born in Warsaw, at age of 25 emigrated to Paris, studied physics and mathematic at Sorbonne and, while working on her PhD thesis, discovered Polonium and Radium. She then performed pioneering studies of those radioactive elements. She was the first to use the term “radioactivity” and she was the first to realize that radioactivity is a phenomenon related to the deep interior of the atom

There is no doubt that Maria’s fame influenced the development of nuclear physics in Poland. Already in the 30’s we had two centers for studies of radioactivity: the Warsaw University, equipped with the cascade generator that could deliver ions accelerated to energies of hundreds kiloelectronovolts, and the Stefan Batory University in Vilno where advanced investigations of radioactivity, using the Ra source, were conducted.

After the World War II the nuclear science in Poland was brought back to life by two great scientists: Andrzej Sołtan in Warsaw and Henryk Niewodniczański in Kraków. They begun the process of restoration of research activity in the field of nuclear physics already in the 40’s**.** By the beginning of the 50’s there was a 1 MV accelerator working in Warsaw; in Kraków instead the home built cyclotron U-48 started the operation.

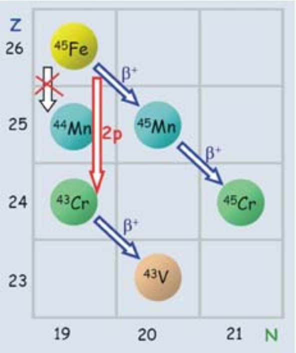
In 1955 the National Institute for Nuclear Research was created. Poland purchased from the Soviet Union two large devices: the nuclear reactor EWA and the U-120 cyclotron. They were installed in the newly built institutes in Świerk-Warszawa and in Kraków, respectively. The era of intense studies in the experimental nuclear physics began.

Present location of the research institutions, in which low energy experimental nuclear physics is an active field, was determined to a large extent by history. Warsaw, together with nearby Świerk, and Kraków are the biggest centers. The Warsaw center includes Nuclear Physics Division (ZFJA), Nuclear Spectroscopy Division (ZSJ UW), Heavy Ion Laboratory (SLCJ UW) of the Warsaw University as well as A. Sołtan Institute for Nuclear Studies (IPJ) located in Świerk and partly in Warsaw. In Kraków low energy Nuclear Physics groups work at the Henryk Niewodniczański Institute of Nuclear Physics of Polish Academy of Sciences (IFJ PAN) and at the Institute of Physics of the Jagiellonian University (IF UJ).

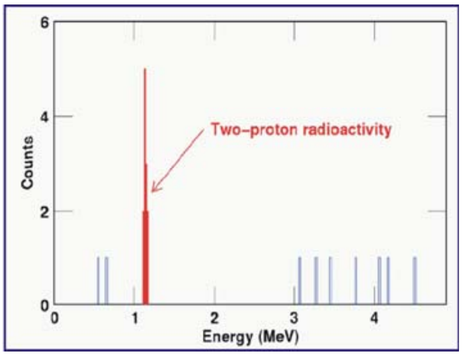
There are also very active groups at the Institute of Physics of the University of Silesia in Katowice, at the Institute of Physics of the University of Łódź and at the Maria Curie-Skłodowska University in Lublin.

The research activity of Polish nuclear physicists follows the main lines of inquiry of today’s nuclear physics research. We study structure of exotic nuclei, nuclei under extreme conditions, new symmetries in nuclei, nucleon-nucleon forces, superheavy nuclei, dynamics of nucleus-nucleus collisions, double beta-decay and neutron decay with the focus on time reversal conservation. Many experiments are carried out in the frame of international collaborations at various nuclear physics facilities around the world. Very important part of research is also being done at our home facility – at the cyclotron in SLCJ UW.

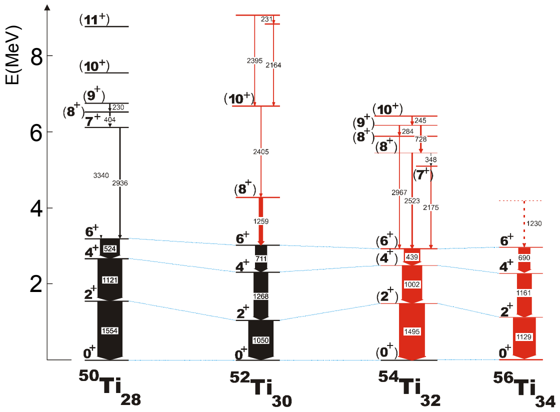
Most of the international collaboration started already in the 60’s, 70’s and 80’s. The list of scientific activities performed by each of these collaborations is very long. Let us only mention some major projects, in chronological order, that have been pursued recently with the lead of Polish physicists and delivered interesting results.



A successful study on the decay of proton drip-line nuclei was completed by the group of Polish physicists from the Nuclear Spectroscopy Division UW. This group, working in frame of a collaboration at GSI Darmstadt, observed for the first time two proton ground state radioactivity. It was done for the decay of ^{45}Fe ground state into ^{43}Cr, in which the emission of a single proton is energetically forbidden and the 2p emission is an alternative to the β-decay.

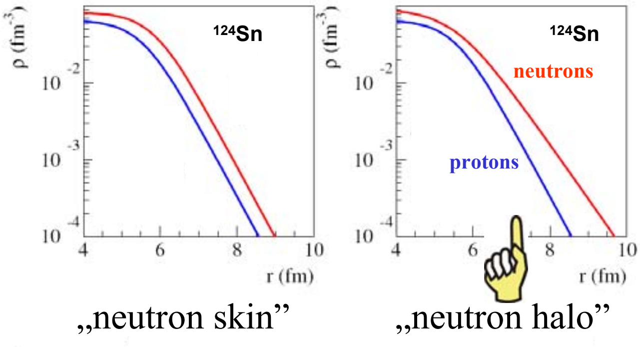


Fruitful investigations on the structure of previously inaccessible neutron-rich nuclei have been performed by the Kraków group from the Institute of Nuclear Physics PAN. This team developed a new technique for spectroscopic studies of neutron-rich species that relies on using deep-inelastic reactions and highly efficient gamma-ray detector arrays – the group is widely recognized as one of the leaders in gamma-ray spectroscopy in the hard-to-reach regions of the nuclear chart. The Kraków physicists, working in close collaboration with the American colleagues, proved the existence of a new neutron magic number at N=32 in neutron-rich nuclei. This was done in a series of experiments performed at Argonne National Laboratory which identified the yrast structure of the $^{52\text{-}56}$Ti isotopes.

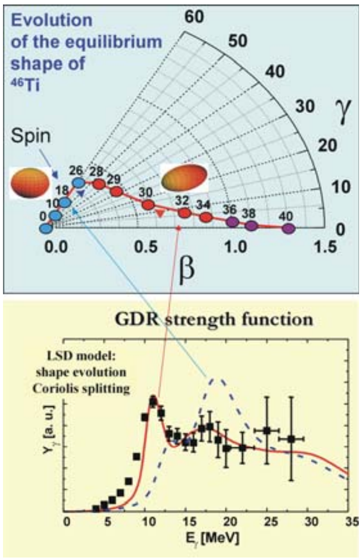


Important results concerning the neutron density distribution in nuclei were obtained by the research group from the Heavy Ion Laboratory in Warsaw, who proposed an experimental procedure allowing for studies of nuclear periphery with antiprotons. In the experiments that were done at CERN, the Warsaw physicists showed that the neutron density distribution is rather of a halo type and not of a skin-type. The method, supplemented later by the in-beam antiprotonic X-rays studies, provided another interesting outcome: the systematics of the differences between the neutron and proton distribution radii as a function of the asymmetry parameter (N-Z)/A.

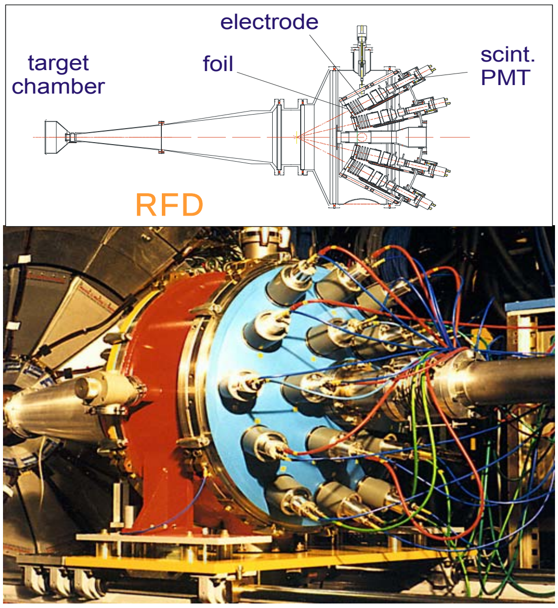
Successful studies of hot and rotating nuclei were carried out by the group from the Institute of Nuclear Physics PAN, who is one of the world leaders in studying the giant dipole resonance (GDR) at high excitation energy and high spin. This group, working with the colleagues from Milan, used gamma rays from the decay of GDR in fast rotating compound ^{46}Ti nucleus to trace the shape evolution at high spin. They showed for the first time evidence for the Jacobi shape transition, *i.e.* the drastic shape change from oblate to prolate occurring in a nucleus at high rotational velocity. Moreover, in the course of investigations they observed also the Coriolis splitting of the GDR strength, and it is again the first finding of such an effect.



Very important part of the involvement of Polish physicists in the international collaborations regards detector constructions. For example, physicists from the Institute of Nuclear Physics PAN, in cooperation with the colleagues from HMI Berlin, built the Recoil Filter Detector (RFD). The application of RFD as an ancillary detector for EUROBALL made feasible X-ray spectroscopic studies of fast recoiling nuclei in the light mass region, where deformed and highly deformed bands have been observed, as well as of heavy nuclei produced in fusion-evaporation reactions with a very low cross section.

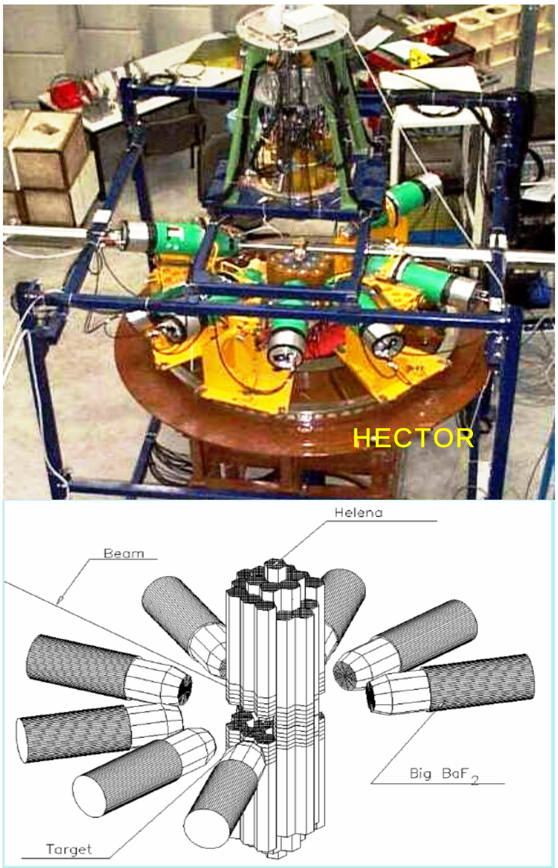


A large amount of crucial experimental information on hot and fast rotating nuclei has been provided by the HECTOR detector array constructed in the frame of collaboration between the Institute of Nuclear Physics PAN and INFN, Milano. The instrument consists of 8 large BaF2 crystals and a multiplicity filter composed of 38 smaller BaF2 crystals. HECTOR is primarily designed for measurements of high energy gamma rays ($5<E_\gamma<30$ MeV).



A 4π charged-particle multiplicity filter, based on epitaxial Si detectors, was designed and constructed at the Heavy Ion Laboratory in Warsaw. It may be used as an ancillary detector for large gamma-ray arrays to study the excited states in nuclei close to the proton drip line.

Gas detector construction and associated electronics development has been successfully pursued by the group from the Institute of Physics of the Jagiellonian University. The list of manufactured detectors includes: gas detector generating signal which is the convolution of the Bragg curve and a given partition function, multi-anode gas detector and ionization chamber. Recently, the group committed itself to the construction of a gaseous detector which will use inter alia gas scintillation. The detector will be installed at the detection system for superheavy nuclei at GANIL.



Physicists from the Warsaw University, who made the first observation of two proton ground state radioactivity, are presently developing a novel type of ionization chamber to obtain 3-dimensional topology of the two protons emitted from the ^{45}Fe ground state. The apparatus, called Optical Time Projection Chamber (OTPC), will consist of several parallel wire-mesh electrodes inside a gaseous medium which forms the conversion region and the multistage charge amplification structure. Selected gas mixture will provide a strong emission of UV photons during avalanche process. These photons will be converted into visible light and a CCD camera will record a 2-D image of the decay process. Drift time of primary ionization charge towards the amplification stage will provide the third coordinate.

Recently, the research team from the Institute of Nuclear Physics PAN, who specializes in the studies of GDR in hot nuclei at high spins, proposed to develop and build a novel gamma calorimeter, which simultaneously measure the high energy gamma rays (3-40 MeV) from the GDR gamma decay as well as the multiplicity, sum energy and low energy gamma-ray spectra. Such a device will partly consist of the existing European detectors, but a significant part of it will be constructed from the new detectors. To design such a novel gamma-ray calorimeter it is necessary to investigate possibilities which are offered by recent advances in scintillator technology. The project is lead by the Kraków physicists and gathers researchers from more than 10 European countries.

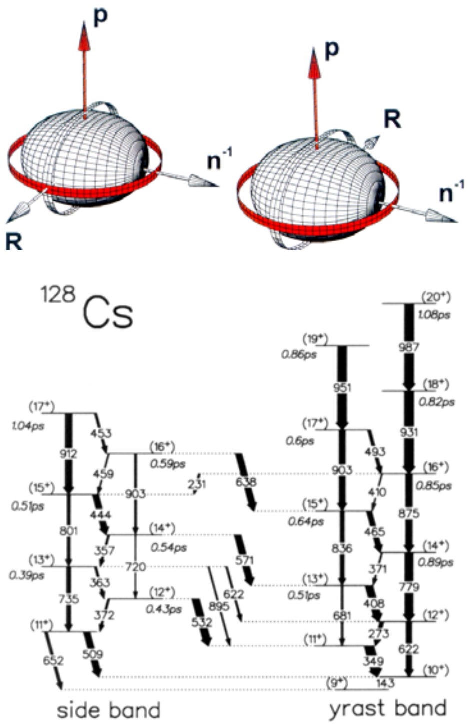
Last two decades showed that many projects in the low energy nuclear physics have to be pursued within large international collaborations. Polish research teams contribute to all major international collaborations that have been created in Europe in that field. For example Poland is one of the eleven partners in the Advanced Gamma Tracking Array (AGATA) project, where our responsibility mainly regards the development of the AGATA ancillary detectors interface (AGAVA) analysis of AGATA performance in connection to ancillary detectors and data analysis. Polish institutions contribute significantly to the Rare ISotope INvestigation (RISING) at GSI that gathers 16 countries - our commitment relies on the contribution to the running cost in amount of 7%. Poland and six other countries are involved in the ION Catcher collaboration which is aimed at developing techniques of the effective slowing-down, stopping in a gas cell and extraction of radioactive ions. In this case Polish participants are responsible for development of a helium thermalization gas cell and optimization of an ion extraction at WIGISOL. CHIMERA is another large project that involves 7 countries with the Polish participation – it is oriented towards studies of the isospin effects and one-body vs. two-body dissipation mechanism in nucleus-nucleus collisions. Many Polish research groups are looking forward to take part in the construction and experiments at the planned radioactive beam facility SPIRAL2 at GANIL (France) – the letters of intent are being prepared which will be followed by signing the memorandum of understanding and later the consortium agreement. Also a few laboratories are interested in contributing to the Facility for Low Antiproton Ion Research (FLAIR) at GSI (Germany) that is a part of the FAIR project.

The community of nuclear physicists in Poland, in spite of being so much involved in the international collaborations, a large part of its scientific activity devotes to research at the heavy ion cyclotron located at Heavy Ion Laboratory UW. The cyclotron is a K=160 heavy-ion machine in operation since 1994. It provides beams ranging from boron to argon with energies from 2 to 10 MeV/amu and intensities up to a few hundreds pnA. The beam-on-target time has recently reached about 3000 hours/year. Permanent set-ups installed on the beam lines include: JANOSIK – multidetector system consisting of a large NaI(Tl) crystal with passive and active shields and 32-element multiplicity filter, CUDAC – PIN-diode array particle detection system, WIGISOL – Scandinavian type on-line separator, OSIRIS II – a crystal ball consisting of 12 compton-shielded HPGe detectors, charged particle 4π mutiplicity filter (Si-ball), 50-element BGO γ multiplicity filter and sectored HPGe polarimeter, SYRENA - a large universal scattering chamber and ICARE - recently installed multidetector system for light charged particle spectroscopy.

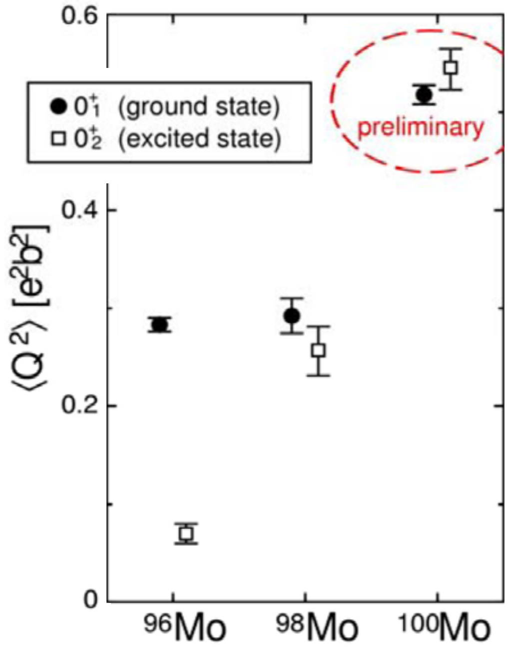
In the last months a new initiative has been proposed at Heavy Ion Laboratory of UW aimed at creating a collaboration of various Polish groups specialized in the studies of electromagnetic transition probabilities in nuclei. The idea is to combine the two methods: Coulomb excitation method and Doppler Shift Attenuation and Recoil Distance technique. To this end, a proposal is being prepared to build a new multidectetcor system EAGLE consisting of Ge Compton suppressed spectrometers, BaF2 detectors as a multiplicity filter, COULEX chamber with PIN silicon detectors, Si inner ball for proton and alpha multiplicity, and a few Ge polarimeters. The new instrument will be largely based on the existing equipment from OSIRIS and CUDAC.

The research at the cyclotron has proven to be successful in several domains. Outstanding results came from the investigations of shape coexistence in nuclei, from Giant Dipole Resonance studies, from fusion barrier distributions experiments. Very valuable results were also delivered by investigations of high-spin state structures (the confirmation of chirality), light nuclei reaction processes and the mechanisms of "hot" nuclei decay. Out of the series of achievements a few were selected for more extended presentation.

Recent theoretical and experimental works attracted attention to a phenomenon of chirality in nuclear spectroscopy. In nuclei in which the total spin is built out of mutually perpendicular spins of a valence proton, of a valence neutron and of the even core, one can expect the presence of two identical partner collective bands associated with the left-handed and right handed orientation of those spins. In a real system, such symmetry will be broken, although the bands should retain very similar properties in terms of energies, parities and electromagnetic probabilities. In an experiment with the OSIRIS array performed at the heavy ion cyclotron, physicists from the Nuclear Physics Division of the Warsaw University determined the transition probabilities in the two partner bands in ^{128}Cs, and showed that they were by far the best candidates for chiral bands in nuclei. It is a first demonstration of such a phenomenon in nuclear structure.



Exciting results are coming from the works of the Warsaw Coulex group from Heavy Ion Laboratory. This group has recently been engaged in the study of structural changes of the lowest 0^+ excitations in Mo isotopes. By using CUDAC particle detector system they performed a series of Coulomb excitation measurements and succeeded in determining the quadrupole moments of the 0^+ g.s. and of the second 0^+ state in ^{96}Mo and ^{98}Mo. In ^{96}Mo the ground state was found to be significantly deformed, whereas the second 0^+ state exhibits spherical properties. In ^{98}Mo both 0^+ excitations are deformed. Similar situation occurs in ^{100}Mo, again both low lying 0^+ states show pronounced deformation and the this deformation quickly increases as compared to ^{98}Mo.



In a series of experiments performed for various projectile-target combinations, statistical decay of GDR, built on highly excited states in self-conjugate nuclei, was studied by researchers from the Warsaw University with the objective of establishing the isospin mixing. The JANOSIK detection system was employed. The team proved that the isospin mixing probability in conjugate nuclei at high excitation and at similar temperature increases with atomic number Z. The dependence was confirmed for atomic numbers ranging from 16 to 30.

The Coulomb barrier height "felt" by the reaction partners approaching each other varies. It can be characterized by a distribution which depends on the structure of the colliding nuclei. The collaboration lead by physicists from Nuclear Spectroscopy Division UW studied the reactions induced by a ^{20}Ne beam on Sn and Ni targets. While a fair agreement between calculated and measured distributions was observed for the Ni target, a significant discrepancy was noticed when Sn target was used. A hypothesis has been put forward that in case of Sn the distribution is smoothed out by the neutron transfer channels – these channels cannot be neglected for the Sn target, whereas they are not important for the Ni targets

Physicists, with the main participants from the A. Sołtan Institute for Nuclear Studies, performed the investigation of the reactions induced by the ^{10}B, ^{11}B, ^{12}C, ^{14}N and ^{18}O ions from the heavy ion cyclotron up to an energy of 5-10 MeV/A on the ^{6,7}Li, ^{9}Be, ^{12,13,14}C targets. The experimentally obtained angular distributions of the reaction products were analyzed by means of the coupled-reaction-channels method. The parameters describing the structure of the nuclei and mechanisms of nuclear reactions as well as nucleus-nucleus interactions were deduced. One of the spectacular outcomes was the determination of the quadrupole deformation parameter to the 7.012 MeV (2^+) excited state in ^{14}C.

One has to admit that the experimental low energy nuclear physics in Poland is a very active field of research. We have groups that carry out various studies in the frontiers of the area in collaboration with most of the major laboratories in the world. We have a good experimental potential at home. We are involved in many large international collaborations and we have plans to develop new instrumentation at our labs. However, we have to continue making efforts to attract young people. We can do it by advertising attractiveness of the low energy nuclear science. This attractiveness arises from both the close perspective for reaching very exotic neutron-rich nuclei that may reveal unexpected phenomena, and from the fact that our field, in spite of the complexity of experiments and the most advanced technologies and techniques used, it is still an area in which one person is able to follow the whole project from the beginning to the very end.

While planning our research, our involvement in collaborations, or preparing the future projects, we cannot forget that the success in scientific studies relies first of all on the appropriate attitude of the researcher towards research. It was nicely expressed by Maria Skłodowska-Curie: “A scientist in his laboratory is not a mere technician: he is also a child confronting natural phenomena that impress him as though they were fairy tales”.

HADRON PHYSICS IN POLAND

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In this report I would like to present, from my point of view, main activities and achievements in hadron physics of Polish groups over last 10 -15 years. I will also shortly discuss plans and perspectives for the nearest future.

The basic aim of the hadron physics is to understand the structure of hadrons and their interactions as well in elementary interactions as in complex heavy ion collisions in the energy regime where quark and hadronic degrees of freedom interleave. The underlying theory is quantum chromodynamics (QCD), which is commonly accepted as the fundamental theory of the strong interaction. This theory is well understood on the short distance scales (0-1 fm) which are probed, e.g., in reactions at high momentum transfer ($Q^2 > 1\ GeV^2$) where the basic quark-gluon interactions are weak and perturbation theory is applicable. At high energy densities quarks and gluons are predicted to move freely without coalescing into hadrons. High energy strong interaction processes can thus be described quantitatively and analytically by perturbative QCD. This energy regime is experimentally explored by means of high energy e^+e^- annihilation, lepton–nucleon scattering or proton-proton reactions at CERN, DESY, Fermilab or RHIC.

As the energy scale drops non-perturbative processes like confinement and chiral symmetry breaking set in. In this domain a quite different realization of QCD is observed, namely bound states classified according to their quark content as baryons, like protons and neutrons, and mesons like the pion. At sufficiently low energies, it is safe to regard these physically observed particles as the relevant degrees of freedom, and use them in the description of hadron interactions. Here, the application of effective field theories, accounting for the symmetries of QCD, is a very promising step in this direction with a high scientific potential. Nevertheless, theoretical predictions are necessarily model-dependent, and progress in this field has been, and will continue to be, driven by experiment for the near future. Indeed, looking into available experimental data one can quickly realize that 20 years after first pioneering experiments performed in 60 and 70'ies at CERN, Berkeley or Dubna new generation of hadron machines and dedicated detectors started to provide numerous and precise data exactly for this purpose.

Polish groups took active part in this second generation experiments with broad research programs which can be grouped into three interconnected topics:

- Interaction and structure of hadrons
- Hadron properties in nuclear matter
- Properties of hadronic matter under extreme conditions

Precise spectroscopy of hadronic states, investigation of their properties (as decay modes) in vacuum and the strong interaction of hadrons in two or three-body final states is the main subject of the first topic. In particular precise measurements of hadron production cross sections (total and differential) in p-p, d-p reactions near kinematic threshold provided valuable results from which many still awaits theoretical explanation. So far, most of these activities concentrated on hadrons build from light (u,d,s) quarks and used proton or deuterium beams provided by SATURNE, CELSIUS or COSY machines. With the future PANDA detector at FAIR these investigations will be extended on the charm sector by means of proton-antiproton annihilation reactions.

The strong interactions experienced by hadrons in a compressed nuclear medium (e.g. created in course of heavy ion collisions) can modify the basic hadron properties as masses, life times (widths) because of increased temperature and/or density. Such changes have been predicted by various theoretical models and are often discussed in connection to spontaneous chiral symmetry breakdown, a phenomenon of fundamental importance for our understanding of QCD and nature of hadron mass generation. Experimental studies are on-going and mainly concentrate on kaon and vector meson properties probed in heavy ion and proton induced reactions. Obtained results demonstrate sizable effects which have stimulated large theoretical interest and provided motivation for upcoming new experiments facilities as FAIR at GSI, with PANDA and CBM detectors or J-PARC in Japan.

Hadronic matter can be compressed and heated by means of heavy ion collisions. At low energies phase transition from liquid to hadron gas has been established by studying fragmentation processes. At even higher energies, available at SPS and RHIC, a new form of the nuclear matter, Quark Gluon Plasma has been sought. At highest available on the earth energies of LHC this new state of the nuclear matter will be investigated by means of ALICE and also ATLAS detectors. However, detailed knowledge of the nuclear matter phase diagram is still far from being complete and needs more detailed investigations, as for example planned at lower energy by second generation experiments as CBM at FAIR or Na49 at SPS.

Table 1 shows contribution of Polish experimental groups to the three topics discussed above. Middle column presents main collaborations, experimental and accelerator facilities where the projects are performed. Only experiments with a significant contribution from the Polish groups have been selected. One should emphasize that in all listed cases dedicated detector systems were developed, constructed and installed to large extend by the Polish groups. Furthermore, contribution to physics analysis resulted in many important results. Similar situation is expected for the future projects which are presented by italic.

In the next three chapters I will shortly present selected scientific highlights obtained so far and will discuss perspectives for the upcoming experiments

INTERACTIONS AND STRUCTURE OF HADRONS

The interaction of hadrons is caused by the strong color forces acting between constituent quarks and gluons. At low energies, regime of non-perturbative QCD, the interaction is commonly described by meson exchange but it is also often discussed in context of the underlying quark-gluon structure. Here the most difficult is the study of the low energy interactions between the flavour-neutral mesons like η, η', ω, ϕ and nucleons and between the nucleons and e.g. hyperons, as for example Σ. The short life time of these particles makes impossible direct scattering experiments and allows to investigate final state interactions. Hence, the experiments are based on the production of a meson or a hyperon in the nucleon-nucleon collisions close to the kinematical threshold (exclusive reactions) or in the kinematics regions where the outgoing particles possess small relative velocities and remain in the distance of few femtometers, long enough to experience the strong interaction. The strength of the interaction between particles depends on their relative momenta. Therefore, the mutual interaction among the outgoing particles manifests itself in the modification of the distributions of differential cross sections as well as in the magnitude and energy dependence of the total reaction rate [1,2,3].

Physics	Experiments	Polish Groups[1]
Interactions and structure of hadrons	**COSY**: COSY11,GEM, PISA, *WASA@COSY* **SATURN**: DISTO **CELSIUS**: WASA **GSI** : *PANDA*	JU, US *JU, ,INS, US* JU INS,UW *JU, INS,US*
Hadron properties in nuclear matter	**GSI:** KAOS,FOPI,HADES	JU, UW
Properties of hadronic matter under extreme conditions	**GSI/SIS**:FOPI, *CBM* **CERN/SPS**: Na49(+) **RHIC:** PHOBOS, BRAMS **LHC**: *ALICE, ATLAS*	UW, *UW, JU, US, INS* UW, IPSA, INP INP, JU *INP, WIT*

Table 1. *Contribution of Polish groups to second generation experiments.*

From the experimental point of view, measurement of the energy dependence of the total cross section for the production of mesons or hyperons close to the kinematical threshold is rather challenging. This is because the studied cross sections are by orders of magnitude smaller as compared to the total yield of the nucleon-nucleon reactions, and also because they vary by a few orders of magnitude in a few MeV range of the excess energy. This is visualized in Figure 1 (top) on example of the total cross sections for the η and η' meson production in proton-proton collisions conducted during the last decade at the CELSIUS, COSY and SATURNE laboratories [4]. Comparing the data to the arbitrarily normalized phase space integrals (dashed lines) reveals that the interaction among involved hadrons enhances the total cross section by more than an order of magnitude for low excess energies. In the case of the η' meson the data are described very well assuming that the square of the proton-proton scattering amplitude exclusively determines the phase space population. This indicates that the proton-η' interaction is too small to manifest itself in the excitation function within the achieved statistical accuracy. In contrary in the case of the η meson the interaction between outgoing nucleons is not sufficient to describe the shape of the excitation function. This is even more obvious when one looks into distribution of the $pp \rightarrow pp\eta$ events in the Dalitz representation, shown in Figure 1 (bottom), at an excess energy of Q=15.5 MeV. In this figure one recognizes a steep

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[1] **INP** - Institute of Nuclear Physics (Kraków),
IPSA - Institute of Physics Świetokrzyska Academy (Kielce),
INS - Institute of Nuclear Studies (Warszawa),
JU - Jagiellonian University (Kraków),
WIT - Warsaw Instiue of Technology (Warszawa)
US - University of Silesia (Katowice),
UW- Warsaw University (Warszawa)

growth of the population density at the region where the protons have small relative momenta (black area) and the rather homogenous distribution outside this area. However, when taking the proton-proton finite state interaction into account a gradual decrease of the abundance is expected towards the large values of the proton-proton invariant masses in contrast to the experimental data. Such discrepancy between the empirical distributions and predictions based on the assumption that the phase space abundance is due to the proton-proton interaction only, indicates that the observed enhancement is due to the proton-η interaction.

The precise data on η and η' mesons production in proton-proton collisions collected over last years allowed to settle the general features of the production processes and revealed the sensitivity of discussed observables to the proton-meson interaction. A quantitative derivation of the proton-η and proton-η' interaction requires, however, a development of the sophisticated theoretical approach based on the three-body formalism including the complex meson-baryon hadronic potential. The observed large difference in the total cross sections between the η and η' meson production shows that these mesons are created via different mechanisms, since comparable coupling constants are expected for both of them at least in the SU(3)-flavour limit. The different production mechanisms reflect differences in the structure of these mesons. Due to the large momentum transfer needed for the production at threshold the reaction occurs at the distances of about 0.3 fm. This might suggests that the quark-gluon degrees of freedom play a significant role in the production dynamics. In particular, the η' meson can be efficiently created from the glue excited in the interaction region and a subsequent hadronization of gluons to the η' meson via its gluonic or flavour-singlet quark component [5]. The creation through the colour-singlet object is isospin independent and hence should lead to the same production amplitudes for the pp→ ppη' and pn → pnη' reactions. At the CELSIUS laboratory it was determined that the η meson is by more than an order of magnitude enhanced if the total isospin of colliding nucleons is equal to zero (pn). Corresponding investigations of the isospin dependence for the η'meson production are presently conducted at COSY.

Another example of the experiments sensitive to the quark degrees of freedom are studies of the flavour symmtery breaking processes. The isospin symmetry breaking via π^0-η mixing in pd→^{3}Heπ^+/π^0 reactions close to the η production threshold was studied by the GEM collaboration [6]. In the lowest order chiral perturbation theory the π^0- η mixing angle depends on the u,d quark mass difference which breaks isospin symmetry [7]. Study of the isospin symmetry breaking in the η' decays (i.e via $\pi^+\pi^-\pi^0$) is also one of the main parts of the WASA programme at COSY which is just coming into operation [8]. In this experiment also the flavour conserving $\eta\to\pi^+\pi^- e^+e^-$ decays will be studied to test CP symmetry conservation where Standard Model predictions are very small.

The production cross section ratio of the ϕ/ω mesons in NN reactions have been proposed as a sensitive observable for strangeness content of the nucleon. In the SU(3) flavour nonet the ϕ meson consists almost entirely of strange and the ω meson of light quarks. As a results ϕ meson production is expected to be suppressed relative to the ω in NN reactions (OZI rules). Interesting results on ϕ/ω cross section ratio in NN reactions have been obtained by ANKE at COSY and DISTO at SATURNE. Significant (~7-10) enhancement over the OZI rule predictions have been established in the p-p and p-n reactions close the production threshold [9,10]. It may indicate important, not yet understood, role of the strangeness in the nucleon which was proposed some time ago in order to explain large ϕ/ω enhancement measured in proton-antiproton annihilation at rest.

Hadron spectroscopy will be extended on charmed mesons with the PANDA detector at future FAIR facility. Antiproton beams of momentum 1.4-15 GeV/c from High Energy Storage Ring will be used to study structure of hadrons up to masses of 5.5 GeV/c^2 [11]. In particular charmed mesons consisting of light (u,d) and heavy (c) quarks are ideally suited for studies of basic QCD properties like confinement and chiral symmtery breaking and its role in the hadron mass generation.

HADRON PROPERTIES IN NUCLEAR MATTER

It is commonly accepted that only a small part of the nucleon mass is furnished by the rest mass of it constituents. Indeed, taking an average current mass of the u,d quarks of 10 MeV/c^2 one arrives to conclusion that ~97% of the nucleon mass is dynamically created by the strong interaction. The main mechanism responsible for this spectacular phenomenon is related to the spontaneous chiral symmtery breaking, a basic feature of the vacuum structure of QCD, signaled by appearance of quark and gluon condensates. Formation of the condensates is a non-pertubative QCD phenomenon and its studies are very difficult and possible only via lattice QCD or

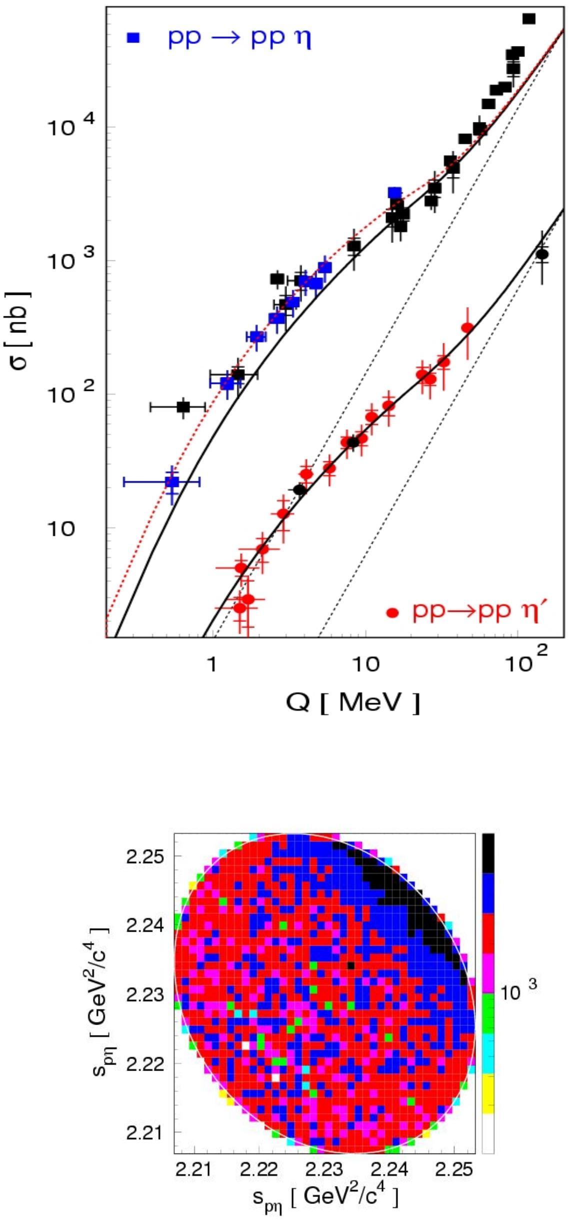

Figure 1: *<u>Top:</u> Total cross section as a function of the excess energy Q for the reactions pp→ppη (squares) and pp→ppη' (circles). The dotted lines indicate a 3-body phase space integral normalized arbitrarily. The solid lines show the phase space distribution with inclusion of the proton-proton final state interaction. The result of calculations taking into account additionally the interaction between the η meson and the proton is presented by the red dotted line <u>Bottom:</u> Dalitz plot distribution for the pp→ppη reaction determined at the excess energy of Q = 15.5 MeV. It shows enhancement due to strong pp final state interactions (black) and due to p-η interactions [4]*

models based on effective field theories. As an example of such calculations [12] Figure 2 shows light quark constituent mass as a function of four momentum transfer, which can be related to distance probed for example by photon in electron-nucleon scattering experiment. As one can see at distance of ~ 1 fm quark mass obtains its constituent mass of ~350 MeV/c².

QCD inspired models predict decrease of the quark condensate in a function of temperature and/or baryon density of the nuclear matter. Although the quark and gluon condensates are not an experimental observable QCD sum rules relate their expectation values to the integral over hadronic spectral functions and therefore open a possibility (though not direct) to study their behavior in the nuclear matter. Brown and Rho suggested scaling low which relates dropping of the quark condensate with hadron masses as a function of the nuclear density. This suggestion has triggered widespread theoretical [13] and experimental activities with spectacular results. Enhanced low mass (M < 1 AGeV/c²) dilepton (e^+e^- and $\mu^+\mu^-$) pair production in nucleus-nucleus collisions at the CERN Super-Proton-Synchrotron (SPS) were reported by CERES [14] and NA60 collaborations [15]. These findings have been successfully explained by theoretical models assuming substantial broadening of the in-medium ρ-meson spectral function. At lower beam energies of 1-2 AGeV similar enhancements were measured by the DLS and HADES at GSI [16], but, in contrast to the SPS energies, they are still lacking full theoretical explanation. Figure 3 shows dielectron invariant mass distribution measured by HADES in C+C collisions at 2 AGeV together with expected contributions from hadron decays at chemical freeze-out (line A). A strong enhancement (shown in the bottom figure) over these sources is seen for the invariant masses M>0.15 GeV/c² (π^0 mass). It can only partially be explained by additional dielectron decays from short lived resonances (Δ and ρ) populated in the early collision phase (dashed line B) assuming vacuum spectral functions. This observation suggests significant in-medium effects due to collision dynamics and/or in-medium spectral function modification. Follow-up experiments with heavy collision systems (from Ar+KCl to Au+Au) will provide in next 2-3 years more information on the nature of the enhancement. Furthermore, precise measurements of the ω and ρ meson spectral functions in nucleus will be

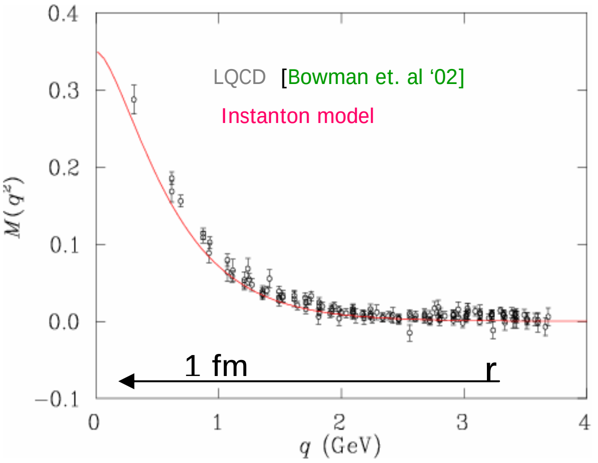

Figure 2. *Mass of light quark as function of four momentum transfer obtained from lattice QCD.*

measured by HADES collaboration and will provide complementary data on in-medium spectral function at T=0 and normal nuclear matter density.

Studies of charged Kaon production in heavy ion collisions at beam energies close to production threshold in NN reactions provide another, though not direct, possibility to study in-medium hadron properties. Multi-step processes of the type $NN \rightarrow NN\pi$ $N\pi \rightarrow KY$ (Y denotes hyperon) are driving production reactions and are confined to a high density phase of a fireball. Consequently, K^+/K^- production ratio appears very sensitive to in-medium potential of kaons which is predicted to be slightly repulsive for K^+ and attractive for K^-. This feature leads to the lowering of K^- production threshold in nuclear matter and to the increase of the K^-/K^+ ratio over the value known from NN reactions.

This phenomenon was for the first time measured by the KAOS collaboration [17] and confirmed by independent measurement by the FOPI experiment at GSI [18]. Moreover, Kaon production at this energy also appears very sensitive to nuclear matter compressibility and is related to the nuclear matter Equation Of State (EOS). In particular excitation function of the K^+ production in Au+Au collisions when compared to the measured for lighter C+C system allows to discriminate between two distinct EOS: soft and hard, favoring the first one as shown in the bottom part of [19]. Further measurements of in-medium kaon properties are planned with the upgraded FOPI detector with the main aim to measure flow of K^- mesons in heavy ion collisions to pin down details of the in-medium kaon potential.

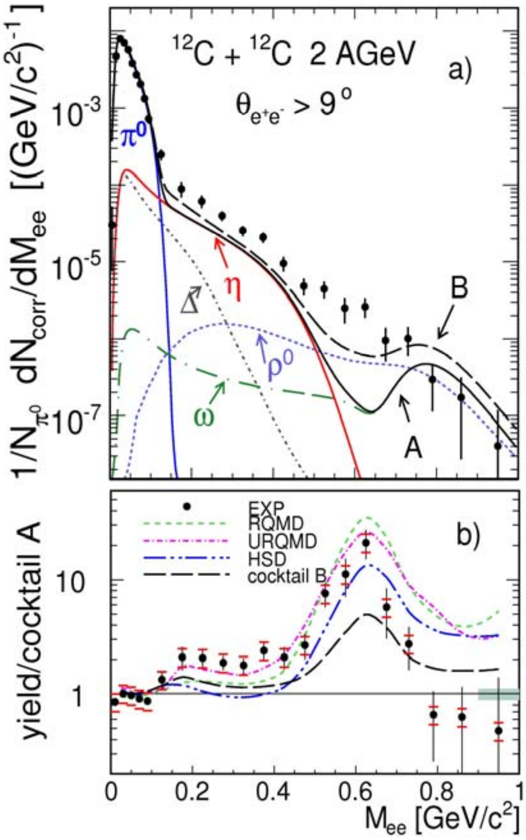

Figure 3. *<u>Top</u>: Invariant e+e- mass distribution measured in C+C collisions at 2 AGeV by HADES collaboration compared to contributions expected from decays of: (i) long lived hadrons after chemical freeze-out (coctail A) and (ii) short lived resonances (ρ,Δ) (coctail B). <u>Bottom:</u> Ratio of data and coctail A, and coctail A and B (dashed line). The latter shows contribution from ρ,Δ decays inside fireball.*

Kaon production will also be continued with new Compressed Barionic Matter (CBM) experiment at FAIR at higher beam energies (8-40 AGeV) [20]. Main emphasis in studies of hadron properties in nuclear matter, however, will be placed on D and J/ψ mesons, for a first time in the same experiment. Production of $D^\pm$ mesons, which consist of light (u,d) quarks and heavy c quark, is predicted to exhibit in-medium mass splitting of the order of 50 MeV/c^2 and hence can be probed experimentally. In-medium properties of charmed mesons and charmonium states will also be probed at normal nuclear matter by antiproton-nucleus collisions by the PANDA experiment at High Energy Storage Ring at future FAIR.

NUCLEAR MATTER UNDER EXTREME CONDITIONS

Heavy ion collisions give unique opportunity to investigate nuclear matter under extreme temperatures and/or densities in earth-bound laboratories. The main goal is to search for and explore nuclear matter phase transition from hadron gas to Quark Gluon Plasma (QGP), a state of nuclear matter which existed ~1√s after the Big Bang. Nuclear matter phase diagram is shown in Figure 4 (top) together with exploration regions covered by SIS/ Bevelac ($\sqrt{s}$<2.7 AGeV), AGS ($\sqrt{s}$=4.5 AGeV), SPS ($\sqrt{s}$=17 AGeV), RHIC ($\sqrt{s}$=200 AGeV) and upcoming LHC ($\sqrt{s}$=5500 AGeV). The chemical freeze-out, a stage where hot nuclear matter which is undergoing fast expansion after primary compression phase reaches its final hadronic composition, is indicated by solid line with points derived from measured particle ratios. The line also corresponds to roughly constant energy of 1 GeV/hadron which is close to the critical energy of first order transition to QGP obtained by lattice QCD calculations (shown by shaded area). This energy density can be compared to the energy obtained in the most energetic HI collisions reached so far at RHIC and estimated to be in the order of 5 GeV/fm^{3,} assuming 1fm/c medium formation time[21,22], therefore clearly above the critical value [23]. The central question which arises is

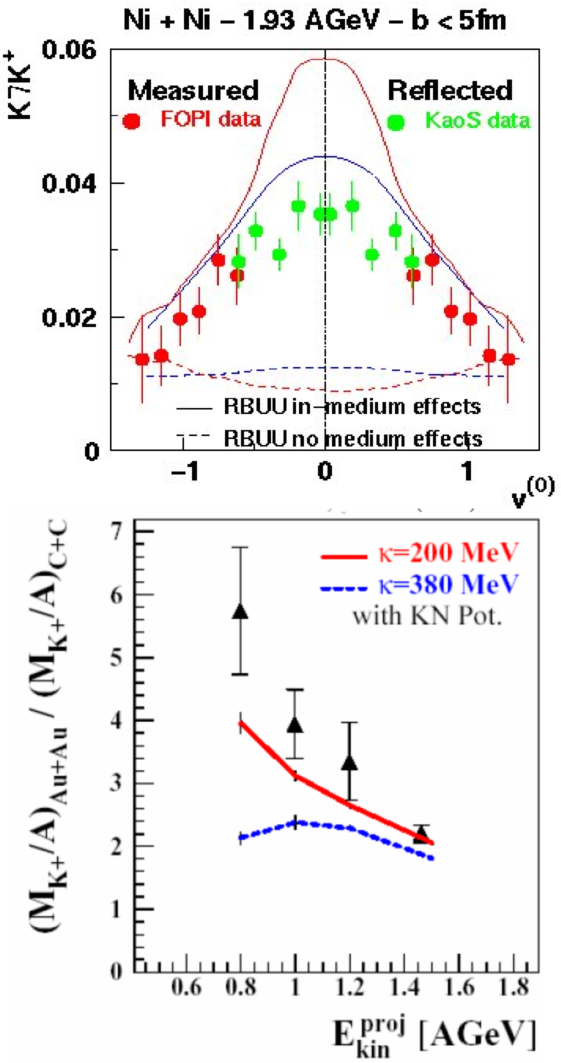

Figure 5. *Top: K^-/K^+ ratio in Ni+Ni collisions as function of normalized rapidity in nucleus-nucleus C M frame: $y^0= (y/Y_{cm}-1)$ compared to model predictions with (solid line) and without (dashed line) in-medium kaon mass modification: $-K^+$ mass increase, K^- mass decrease. Bottom: Ratio of K^+ multiplicity in Au+Au and C+C collisions as function of beam energy compared to predictions based on soft (red) and hard(blue) nuclear matter equation of state.*

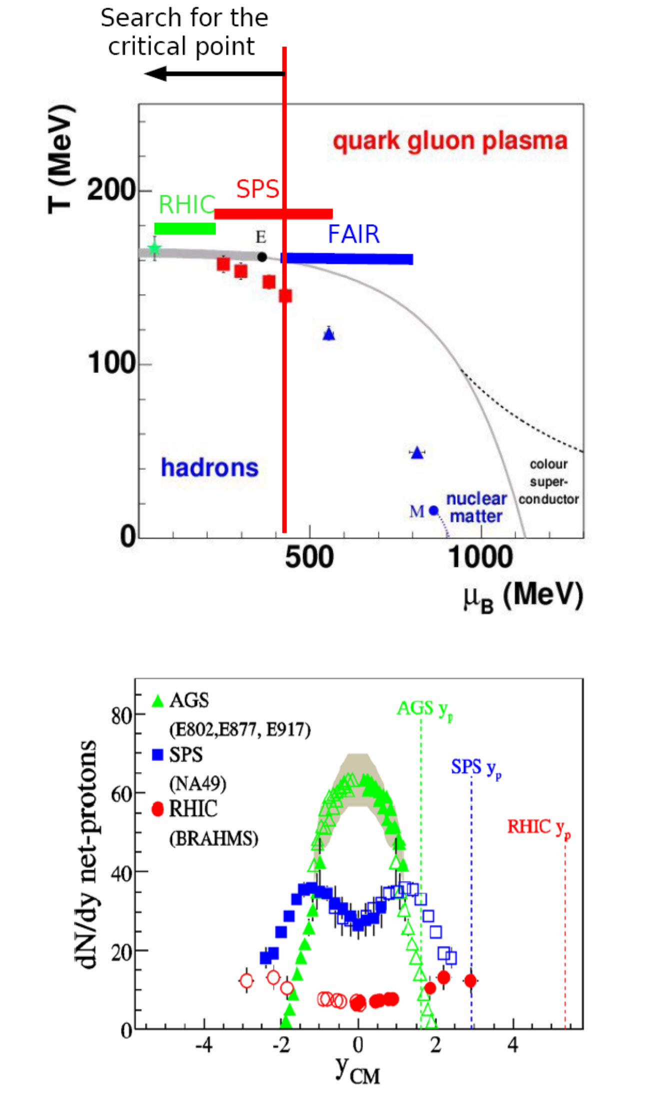

Figure 4. *Top: Nuclear matter phase diagram (temperature vs baryonic chemicl potential). Solid line indicates temperature of chemical freeze-out determined from particle ratios measured in heavy ion collisions at various accelerators indicated in upper panel). Shaded area presents predicted phase border between hadronic and Quark Gluon Plasma and critical point (E). Bottom: Net proton (proton-antiproton) rapidity distributions measured at top AGS, SPS and RHIC energies. Beam rapidities are indicated by dotted lines.*

what are then the properties of the nuclear matter in such extreme conditions? Have we established a new form of nuclear matter in our laboratories?

First striking feature observed by the BRAHMS collaboration at RHIC is that the net proton rapidity distributions around central region (y_{cm}~0) are significantly smaller, as compared to AGS and SPS, what indicated larger matter transparency (see Figure 4 and note that beam rapidity at the RHIC top energy is around 5.4). BRAHMS estimated the average rapidity loss to be equal 2.0±0.4. This value is significantly lower than predicted by the empirical linear scaling from lower AGS and SPS energies [24]. Nevertheless, the absolute energy loss increases appreciably from SPS to RHIC reaching the value of about 72 GeV per participanting nucleon [25]. Furthermore, at mid-rapidity the anti-proton to proton ratio is on the level of 0.75 which indicates that there is still a significant contribution from participant baryons over the entire rapidity range [26]. On the other hand, the anti-particle to particle ratios for mesons, that dominate the produced matter, are consistent with unity.

The above observations clearly show that studies of high energy nucleus-nucleus collisions have moved to a qualitatively new physics domain characterized by a high degree of reaction transparency leading to the formation of a near baryon free central region with approximate balance between matter and anti-matter.

Several observables have been proposed for RHIC and SPS energies as possible signals for the formation of QGP. One of the most important ones is a jet suppression quenching seen directly as a suppression of high transverse momentum hadrons ($p_\perp > 2$ GeV/c) produced in HI collisions as compared to nucleon-nucleon reactions. This effect can be quantified by the nuclear modification factor R_{AA} [27]. It is displayed in Figure 4 for 2 pseudo-rapidity regions (η) and various centrality selections (central and semi-peripheral) for the BRAHMS data. The apparent high $p_\perp$ suppression in central collisions has been interpreted as a consequence of bremsstrahlung losses of high $p_\perp$ partons traversing deconfined medium created in HI collisions. According to QCD colored objects may lose energy by radiating gluons as bremsstrahlung [28]. Due to the color charge of the gluons, the energy loss is proportional to the square of the length of color medium traversed. Such a mechanism would strongly degrade the energy of leading partons resulting in a reduced transverse momentum of leading particles in the jets and the effect is expected to increase with increasing collision energy, system size and centrality, as observed in the experiments [29].

Unique feature of the BRAHMS and PHOBOS spectrometers are a large acceptance at forward η regions accompanied by excellent particle identification. Surprisingly large R_{AA} suppression at forward η region is observed both for Au+Au and d+Au colliding systems (see also Figure 6). For Au+Au this observation led to a suggestion that suppressing medium extends also in the longitudinal direction, however, for d+Au the suppression has been attributed to the initial conditions of the colliding Au nucleus, in particular, to the possible existence of the Color Glass Condensate (CGC)- another new form of nuclear matter [30].

Anisotropy of emitted hadrons with respect to the reaction plane (flow) is an important observable which characterizes the gradient of pressure build in the reaction zone at early stage of the collision. Figure 6 shows anisotropies measured for 200 AGeV central Au+Au collisions obtained by the PHOBOS collaboration [31]. Solid line shows result of hydrodynamical calculation which assumes ideal fluid nature (no viscosity) of the matter and which for first time reproduces anisotropy strength measured at RHIC energies. This surprising result indicates that in contrast to former predictions nuclear matter created in these collisions is not consistent with a model of weakly interacting gas of partons but rather strongly interacting fluid.

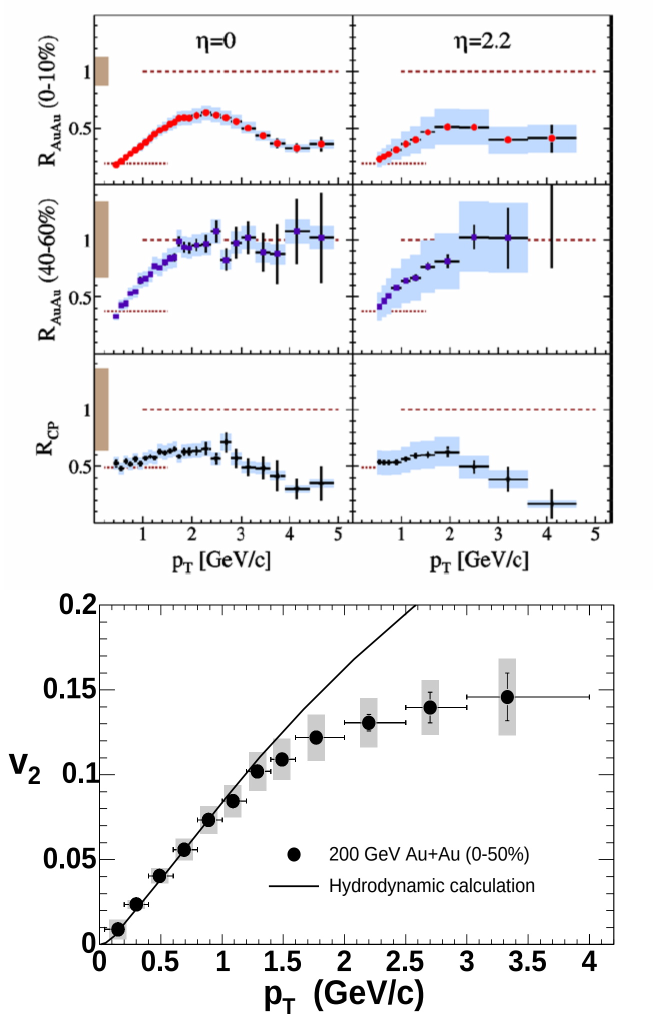

Figure 6. *Top: Nuclear modification factor (R_{AA}) in function of transverse momentum for 2 pseudo-rapidity bins and reaction classes (central and semi-peripheral) measured by BRAHMS in 200 AGeV Au+Au collisions. Lower row shows ratio of R_{AA} central to semi-peripheral collsions. Bottom: Eliptic flow (v_2) for same collisions measured by PHOBOS*

Further measurements are certainly necessary to understand nature of the matter created in these collisions. The programme will be continued at upcoming LHC by the dedicated heavy ion experiment ALICE and also ATLAS, which was designed to study pp interactions. At LHC energy densities will increase to 15-40 GeV/fm^3 and estimated life time of the QGP will be in the order of 5-10 fm (by the volume size of the fireball at the freeze-out of 2000 fm^3 !).

At lower energies (30-40 AGeV) upgrade of the Na49 experiment is planned to search for the onset of the deconfinment and critical point of the nuclear matter. The indications of the first one has been proposed by the Na49 experiment as the explanation for the pronounced peak in kaon/pion ratio observed in HI collisions, but not in pp, at SPS energies [32].

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[1] C. Hanhart , Phys. Rep. **397** (2004) 155

[2] G. Faldt, T. Johansson, C. Wilkin, Phys. Scripta **T99** (2002) 146

[3] P. Moskal, M. Wolke, A. Khoukaz, W.Oelert, Prog. Part. Nucl. Phys. **49** (2002) 1.

[4] P. Moskal et al., hep-ph/0408162, Phys. Rev. **C 69** (2004) 025203

[5] S. D. Bass, Phys. Lett. **B 463** (1999) 286

[6] M. Abdel-Mary et al., PRC68 (2003) 021603

[7] H. Machner, Prog. Part. Nucl. Phys.**50**(2003) 605

[8] WASA-at-COSY collaboration, H. H. Adam nucl-ex/0411038

[9] F. Balestra *et al.*, Phys. Rev. **C 63** (2001) 024004.

[10] M. Hartmann et al., Phys. Rev. Lett. **96** (2006) 242301

[11] K. Peters, Nucl. Phys. Proc. Suppl (2006)154, J. Smyrski, Int. J. Mod. Phys. **A20**(2005)564

[12] P. O. Bowman et. al., hep-lat/0203001

[13] R. Rapp and J. Wambach, Adv. Nucl. Phys. **25**, (2000) 1

[14] G. Agakichiev et al., Eur. Phys. J. **C 41**, (2005) 475

[15] R. Arnaldi et al., Phys. Rev. Lett. **96**, (2006) 162302

[16] G. Agakichiev et al. Phys. Rev. Lett. **98** (2007) 052302

[17] F. Laue et al. , Phys. Rev. Lett. **82**(1999)

[18] K. Wisniewski et al., Eur. Phys. J. **A9** (2000) 515

[19] C.Sturm et al., Phys. Rev. Lett. **86** (2001) 39 , C. Fuchs et al., Phys. Rev. Lett. 86 (2001) 1974

[20] P. Senger, Acta Phys. Polon. **B37** (2006) 115

[21] P. Staszel et al. Int. J. Mod. Phys. **A20**, (2005) 4369.

[22] I. G. Bearden et al. Phys. Rev. Lett. **94** (2005) 162301.

[23] F. Karsch, Nucl. Phys. A698 (2002) 199.

[24] F. Vedebaek and O. Hansen, Phys. Rev. **C 52** (1995) 2684.

[25] I.G. Bearden et al. Phys. Rev. Lett. **93**, (2004) 102301.

[26] I.G. Bearden et al. Phys. Rev. Lett. **90** (2003) 102301.

[27] I. Arsene et al. Phys. Rev. Lett. **91** (2003) 072305.

[28] M. Gyulassy, P. Levai, I. Vitev, Nucl. Phys. **B594** (2001) 371.

[29] T.M. Larsen et al., Nucl. Phys. **A774** (2006) 541.

[30] I. Arsene et al., Phys. Rev. Lett. **93** (2004) 242303. D. Kharzeev, E. Levin and L. McLerran, Phys. Lett. **B 561** (2003) 93.

[31] B. B Back et al., Nucl.Phys.**A757**(2005)28.

[32] Na49: Proposal SPSC-P-264

NUCLEAR* THEORY IN POLAND

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The goal of this short overview is to present a snapshot of Polish scientists' activity in theory of nuclear structure, nuclear astrophysics, and nuclear reactions. In short, this domain of physics will be below called nuclear*. The time span I am going to cover is limited to exactly five years, between 2001 and 2005.

The definition of boundaries of this domain of physics is, as always, a difficult task. There are certainly numerous connections, by which this branch of science extends towards atomic or condensed matter physics on one side, and towards particle and high energy physics on the other. For the sake of adopting a precise and well defined methodology, I am going to look at publications that appeared in specific journals or specific sections of these journals. The selection I have made is supposed to cover the mainstream scientific journals, in which papers in this domain of physics are published, although the complete list would certainly be longer and probably more desirable.

By this token, the numbers of reported papers undoubtedly constitute a lower limit; the total number of papers is significantly higher. Nevertheless, by looking at lists of authors of these papers, I was able to identify Polish physicists who actively contribute to the scientific research in this domain of physics.

The analysis presented below is based on publications that appeared in:

- European Physical Journal A
- Nuclear Physics A
- Physical Review Letters, section Nuclear Structure, page numbers xx25xx.
- Physical Review C, sections Nucleon-Nucleon Interaction, Few-Body Systems (S=0), Nuclear Structure (S=3), Nuclear Reactions (S=6), Nuclear Astrophysics (S=8), page numbers xxxSxx.
- Physics Letters B

An automated search of electronic databases, performed for the above five journals and sections, revealed **838** papers with co-affiliations from Poland. In case of Physics Letters B, papers are not divided into sections, which excludes a possibility of simple identification of whether they belong to the class of nuclear* physics. Therefore **327** papers published in this journal were manually scanned, and **24** of them were attributed to nuclear* physics.

Moreover, in case of European Physical Journal A, only the information on the affiliation of the so-called corresponding author is available in electronic databases, which strongly limits the number of papers from Poland found in this journal.

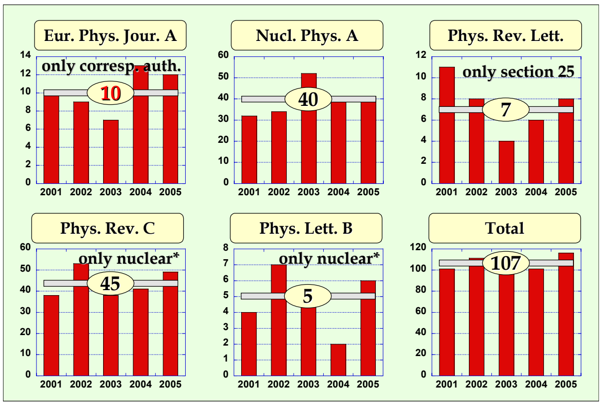

Fig. 1. *Numbers of papers from Poland published in theoretical and experimental nuclear* physics in five major journals.*

All in all, during 2001-2005, **535** papers have been published, both in theory and experiment. Within the above methodology, results of searches are presented in Fig 1, where numbers of papers are shown as functions of the publication year. Numbers in ovals and horizontal bars indicate the average numbers of papers per year. The first striking observation, which is revealed by the present analysis, is a great stability in time of contribution of Polish physicists to this domain of physics, with at least 100 papers per year.

Similarly, Fig. 2 shows the percent fractions of papers coming from Poland, as compared to the total numbers of papers published[2]. It turns out that about every 20th paper published world-wide was coauthored by a scientist from Poland. It is particularly gratifying to see that about every 10th paper published in Physical Review Letters was coauthored by a Polish author.

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[2] For Physics Letters B, percentage of all papers from Poland (not only nuclear*) is shown in the Figure.

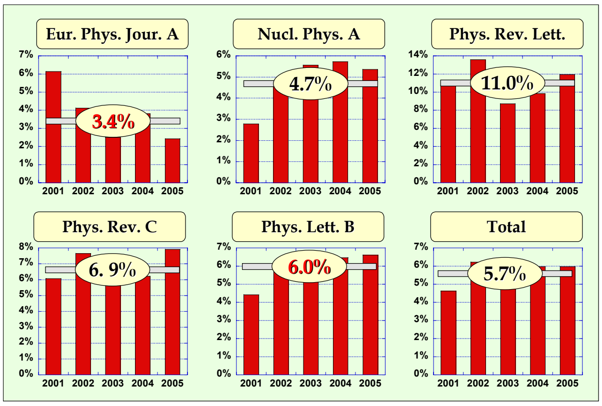

Fig. 2. Percent fractions of papers published with Polish co-affiliations in theoretical and experi-mental nuclear physics in five major journals.*

In order to put the above numbers in perspective, the analogous analysis, within the same methodology, was repeated for papers originating from France, the country, which by all means can be considered a scientific superpower in the research worldwide. Fig. 3 presents the distributions of papers with Polish (**535**) and French (**1016**) co-affiliations, published in the five major journals.

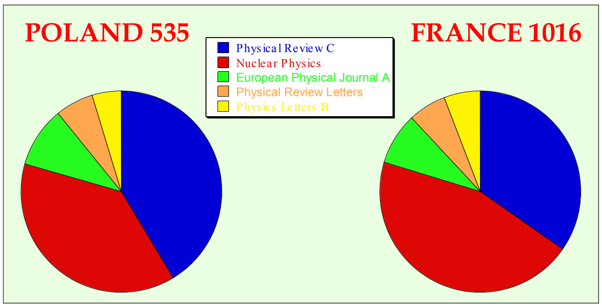

Fig. 3. Numbers of papers published with Polish and French co-affiliations in theoretical and experi-mental nuclear physics in five major journals.*

Although due to restrictions of the adopted methodology both total numbers of papers are probably strongly underestimated, nonetheless their relative values illustrate important strength of the Polish community in the domain of nuclear* physics. It is important to add at this point that the scientific collaboration between Poland and France is particularly **strong**, and hence a great deal of scientific papers are coauthored by Polish and French scientists, thus counting towards figures of merit of both countries.

The next step of the analysis requires identifying papers that can be qualified as theoretical. This could not have been done otherwise but by scanning all the **535** papers one by one, and taking decisions in each of the individual cases. The task was not easy, because very many papers result from close and fruitful collaborations between theorists and experimentalists. With all the reservations such a qualification may carry, **158** theoretical papers were selected for further analysis.

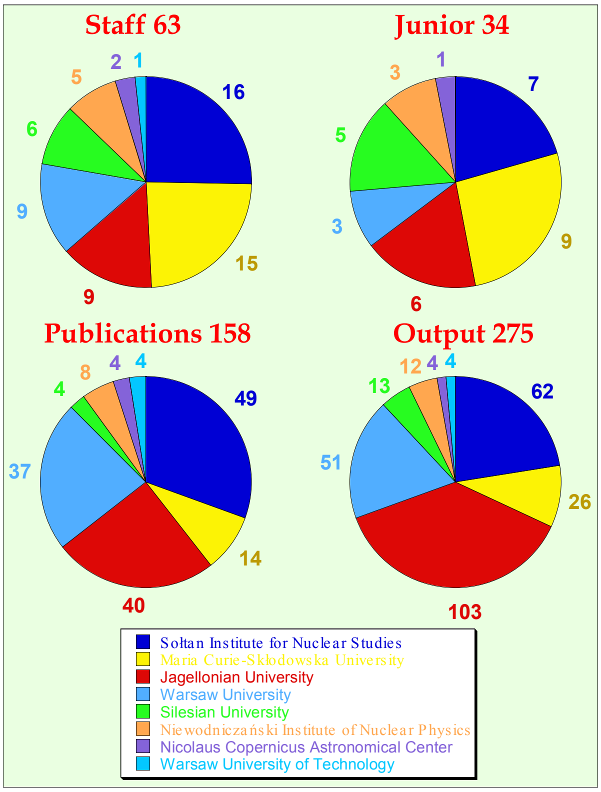

Fig. 4. Distributions of authors (upper left), junior authors (upper right), papers (lower left), and output (lower right) among eight Polish scientific institutions in nuclear theory.*

As shown in Fig, 4, among authors of the above set of papers, I could identify **63** Polish theorists affiliated with **8** scientific institutions. It is very important to see that **34** of them, i.e. more than a half, are young scientists (prior to their D.Sc. degree). At this point, the largest uncertainty comes from the fact that it is often difficult to label a given author as a 'theorist' or 'experimentalist'. And again, the numbers shown in the Figure certainly do not exhaust the entire list of Polish nuclear* theorists. However, those who have published during five years at least one paper in one of the five journals considered, probably belong to the class of the most active ones.

Distribution of papers among the 8 institutions shows that 4 of them provide the majority of publications. It is interesting to see that the sum of numbers of publications in this distribution is equal to 160. This means that papers are coauthored by researchers working at **different** institutions. This seems to be a typical situation in Polish science, where very intense collaborations exist between Polish and foreign physicists, but very few inside Poland.

Another important observation is revealed by the output index shown in Fig. 4. The output index is constructed by adding numbers of papers of each author affiliated with a given institution. Therefore, it illustrates the degree of internal collaboration and strength of research groups at various institutions. It turns out that, on average, between 1.2 and 3 authors working at **the same** institution cosign scientific papers in this domain of physics.

Within the analyzed set of publications, six authors have published ten or more papers. It turns out that these six authors provide more than one half of the output index defined above. This allows to identify **three** most active research groups in nuclear* theory in Poland. Since their research is in more details described in other parts of the Report, here I only give a very brief account of their activity, and cite their flagship publications and results.

The group of K. Rusek (Sołtan Institute for Nuclear Studies) with collaborators has published in years 2001–2005 over 20 papers in the domain of nucleus-nucleus reactions, especially those involving exotic species. Their very interesting result concerns the dipole polarizability of ^{6}He [1], where the reduction of the ^{6}He+^{208}Pb elastic scattering cross section at forward angles was shown to be caused by long-range dipole Coulomb polarizability of the projectile.

The group of H. Witała, J. Golak, and R. Skibiński (M. Smoluchowski Institute of Physics, Jagiellonian University) with collaborators has published in years 2001–2005 over 35 papers in the domain of structure and reactions of few-body systems. Their pioneering study of the polarization transfer in d(p,p)d and d(p,d)p reactions [2], performed with modern nuclear forces, including the NNLO interactions obtained within the chiral perturbation theory, reveals important role of three-body interactions.

The group of J. Dobaczewski, W. Nazarewicz, and W. Satuła (Institute of Theoretical Physics, Warsaw University) with collaborators has published in years 2001–2005 over 30 papers in the domain of nuclear structure studied with energy-density-functional methods. In their study of deformation effects in nuclei near the neutron drip line [3] they point out new possible shape-coexistence effects that may extend nuclear binding due to the hindrance of neutron emission between states having different deformations.

In summary, a brief inspection of Polish contribution to theoretical studies in nuclear* physics (nuclear structure, nuclear astrophysics and nuclear reactions) shows the strength and importance of this domain of research in Poland. This research is carried out in 4 leading scientific institutions, involves more than 60 physicists, and brings over 30 publications in major journals per year. In spite of a weak collaboration between Polish institutions, strong and dynamic groups carry out world-class research on several subjects that are internationally recognized as Polish trademarks.

[1] **K. Rusek,** N. Keeley, K.W. Kemper, and R. Raabe, Phys. Rev. **C67**, 041604 (2003).

[2] **H. Witała, J. Golak, R. Skibiński,** W. Glöckle, A. Nogga, E. Epelbaum, H. Kamada, A. Kievsky, and M. Viviani, Phys. Rev. C73, 044004 (2006).

[3] M.V. Stoitsov, **J. Dobaczewski, W. Nazarewicz**, S. Pittel, D.J. Dean, Phys. Rev. **C68**, 054312 (2003)

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* Structure, Astrophysics, and Reactions

NUCLEAR PHYSICS IN POLAND – APPLICATIONS AND INTERDISCIPLINARY RESEARCH

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The general public frequently associates nuclear physics with the development of nuclear weapons or with the Chernobyl nuclear power plant reactor accident. Less recognized are the numerous beneficial applications of nuclear physics and techniques which serve mankind in technology, health care and environmental protection. In this short review, medical and radiation protection aspects of applied nuclear research in Poland, mainly based on accelerators, will be outlined.

***Table I**. The statistical data on the number of employees, scientists, Ph.D. students and annual budget of some Polish institutions involved in applied nuclear research. The acronyms of the institutions are explained in the text.*

	Employees	Scientists	Ph.D. students	Annual budget (M€)
ICHTJ	**270**	**84**	**21**	**4.5**
IFJ PAN	**450**	**200**	**55**	**7.0**
ŚLCJ	**60**	**18**	**3**	**1.1**

Historically, Warszawa and Kraków were the first Polish centers where systematic research in nuclear physics began at the beginning of the 50-ties of last century. The current list is much longer and includes universities and technical schools in Katowice, Lublin, Łódź, Poznań, Wrocław and several other Polish cities. The scale of these activities should be viewed from the perspective of the budget available to universities and research institutes. As can be seen from data shown in Table 1, the average budget of three major Polish institutes involved in nuclear research in 2004 ranged between 15 and 24 kEuro/year/ per employee. This is clearly inadequate, being at least an order of magnitude below that available at most of scientific institutions in developed European countries.

The Heavy Ion Laboratory (Polish acronym SLCJ) of the Warsaw University is a "User Facility" which operates an isochronous K_{max}=160 cyclotron which delivers heavy ion beams ranging from B to Ar with energies between 2 and 10 MeV/nucleon. In 2008 a second commercial proton – deuteron cyclotron (E_p = 16.5 MeV) will be installed there for production and research on radiopharmaceuticals for Positron Emission Tomography (PET) – see Fig. 1. Production of long – lived radiopharmaceuticals for other medical and life – science applications is also foreseen. The SLCJ coordinates the work of the Warsaw Consortium for PET Collaboration (cf. Fig. 2), aimed at delivering fluorodeoxyglucose (FDG) for many clinics in Warsaw, using this new cyclotron. At present, some 20 institutions in Warsaw region expressed their interest in receiving PET isotopes for diagnostics and research. This could improve the critically underdeveloped nuclear medicine facilities, where only a few hundred PET procedures per year are performed to serve the 38 million population of Poland.

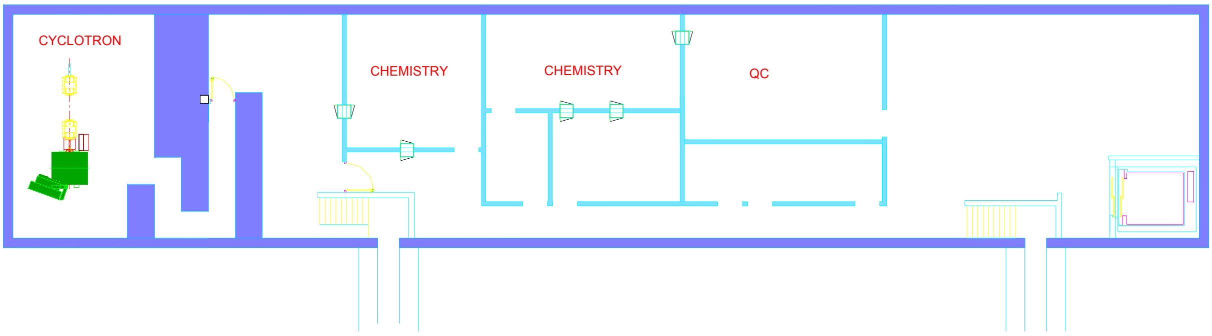
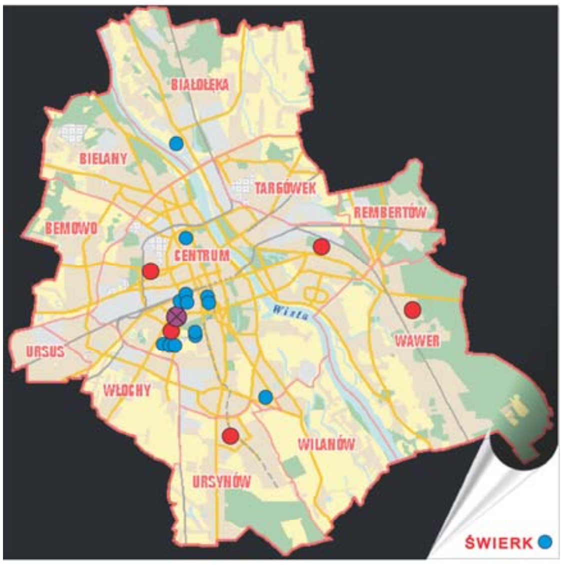


***Fig. 1.** The preliminary layout of the new proton/deuteron cyclotron and chemistry units in Heavy Ion Laboratory of the Warsaw University.*

Warsaw Consortium for PET Collaboration



⊗ Radiopharmaceuticals Production Center - HIL

● PET Diagnostic Centers

● Research Units

Fig. 2. *Distribution of the Warsaw Consortium for PET Collaboration on the city map.*

A. Sołtan Institute of Nuclear Studies in Warsaw – Świerk (Polish acronym IPJ) is a state owned Laboratory, which carries out basic research on subatomic physics, i.e. elementary particle and nuclear physics, hot plasma physics and related fields. IPJ is well known as the developer and producer of specialized equipment for various applications in medicine and environmental radiation protection. The Establishment for Nuclear Equipment (Polish acronym ZdAJ) is IPJ's production unit which has designed and is manufacturing linear electron accelerators for clinical radiotherapy (delivering photon and electron beams up to 15 MeV), for industrial radiography and for food preservation. 22 radiotherapy units have been installed in Polish clinics in the last 10 years and 8 units were exported. An interesting development of IPJ is a miniature X-ray irradiator, called the "X-ray needle", which can be used for local tumor irradiation Fig.3.

Fig. 3. *The prototype of X-ray needle, developed at the Andrzej A. Sołtan Institute of Nuclear Studies in Warsaw – Świerk.*

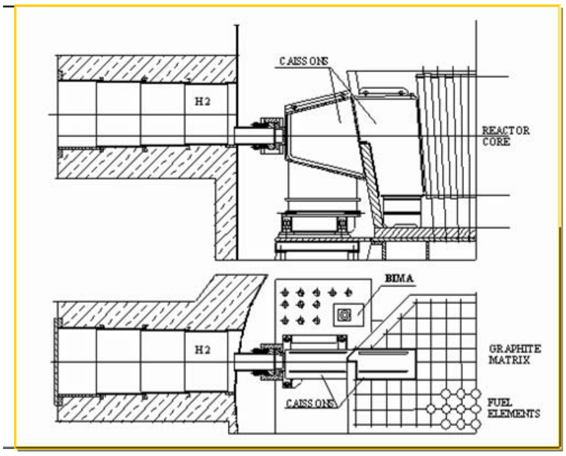


Fig. 4. *The schematic view of the plans of the neutron beam delivery system for BNCT facility at the MARIA reactor at IEA Świerk. The construction of the facility starts in 2008.*

The advantage of the system, as compared to radioactive sources, is that radiation dose is delivered locally, dose rate and beam energy can be optimized, and that the source can be "turned off", so it is safe for the personnel. Another unique experimental setup available at the IPJ is the JET counter, developed at IPJ to investigate the track structure of ionizing radiation. Data provided by the JET counter, is essential in understanding the action of radiation at the molecular level. Single ionization events produced by charged particles passing through the tissue-equivalent gas expanding at a pressure of 10-20 Torr, can be detected and used to reconstruct the track structure in microscopic volumes representing the DNA scale.

The Institute of Nuclear Energy (Polish acronym IEA) at Świerk-Otwock operates the MARIA research nuclear reactor, the only one in Poland. This 30 MW unit is used to produce radioisotopes, applied in studies of radiation modification of materials and in research using neutron beams with a maximum fluence rate of $4\ 10^{14}$ n $cm^{-2}s^{-1}$. One of the planned applications of this reactor in the field of medicine is Boron Neutron Capture Therapy, BNCT. Feasibility studies, performed a few years ago by a consortium of several Polish institutions, have demonstrated that a BNCT facility could be constructed at the MARIA reactor. A neutron beam delivery system has been proposed, basing on results of Monte Carlo modeling of radiation transport (Fig.4). Construction of the BNCT facility is to begin in 2008, supported by Structural

Funds of the European Union foreseen for Poland in 2007-2013. Another interesting application is neutron radiography, developed mainly for materials science. Thermal neutrons are scattered very effectively by ordinary liquids, which opens the way to study at greater detail the migration of liquids in many inorganic porous materials by means of neutron radiography. Propagation of water in bricks used for housing construction has been investigated by exploring the difference between neutron scattering cross sections.

The Henryk Niewodniczański Institute of Nuclear Physics (Polish acronym IFJ) with 450 employees and 70 Ph.D. students is the largest institute of the Polish Academy of Science. Several accelerators at IFJ are applied in projects related to medicine and protection of the environment. The AIC-144 isochronous cyclotron, in-house designed and built, is the only accelerator in Poland able to accelerate a beam of protons to energies of about 60 MeV. This cyclotron was used to produce a palette of radioisotopes and since 2006 it is being adapted to develop the first Polish facility for proton radiotherapy of eye cancer. The facility will be completed in 2007 (see Fig.5) and after commissioning in 2008, the first patients will be treated. The Kraków Proton Microprobe, based on a Van der Graaff unit which accelerates protons to an energy of up to 3 MeV, is an important tool in life sciences and biomedical applications. Survival of mammalian cells after a controlled number of proton "hits" has been studied to gain more information on the "by-stander effect" in radiobiology. Another major installation at the IFJ is the Dual Beam Ion Implanter where complex biocompatible coating layers with excellent adhesion and low internal stresses can be created, e.g. for use in medical implants. The radiation hazard in space has been studied on board of the International Space Station within the ESA Matroshka project. Over 3000 thermoluminescent detectors, developed and produced at the IFJ, were installed in a humanoid phantom and exposed in open space to investigate space radiation doses to various human organs.

The Institute of Nuclear Chemistry and Technology (ICHTJ), established in Warsaw-Żerań in 1983, is involved in research in the field of radiation chemistry and technology, application of nuclear methods in material engineering and process engineering, design and production of instruments based on nuclear and radioanalytical techniques, and in environmental research A considerable achievement of the ICHTJ was the successful installation of an industrial electron beam to treat gaseous effluents of the Pomorzany Electric Power Station (EPS) near Szczecin, one of the first such industrial installations in Europe. The process involves fast oxidation of SO_2 and NO_x, acid formation and gaseous ammonia neutralization of acids to a solid aerosol form which is collected on-site at the EPS and later used as a high-quality fertilizer in agriculture. The ICHTJ also produces a number of specialized instruments for use in industry, medicine and environmental protection. The dose-rate activity gauge MAD-2000 measures the dose rate and activity of ^{106}Ru and ^{125}I brachytherapy applicators for eye cancer radiotherapy (Fig. 6). The AMIZ2000 airborne monitor gauge is designed to measure airborne dust concentration. These instruments can work either as individual dust pollution monitors or be interconnected within a

Fig. 5. *Elements of the eye proton therapy installation for eye irradiation at the Institute of Nuclear Physics, Kraków.*

Fig. 6. *The dose-rate activity gauge MAD-2000 for measurements of the dose rate and activity of ^{106}Ru and ^{125}I brachytherapy applicators for eye cancer radiotherapy, developed at ICHTJ.*

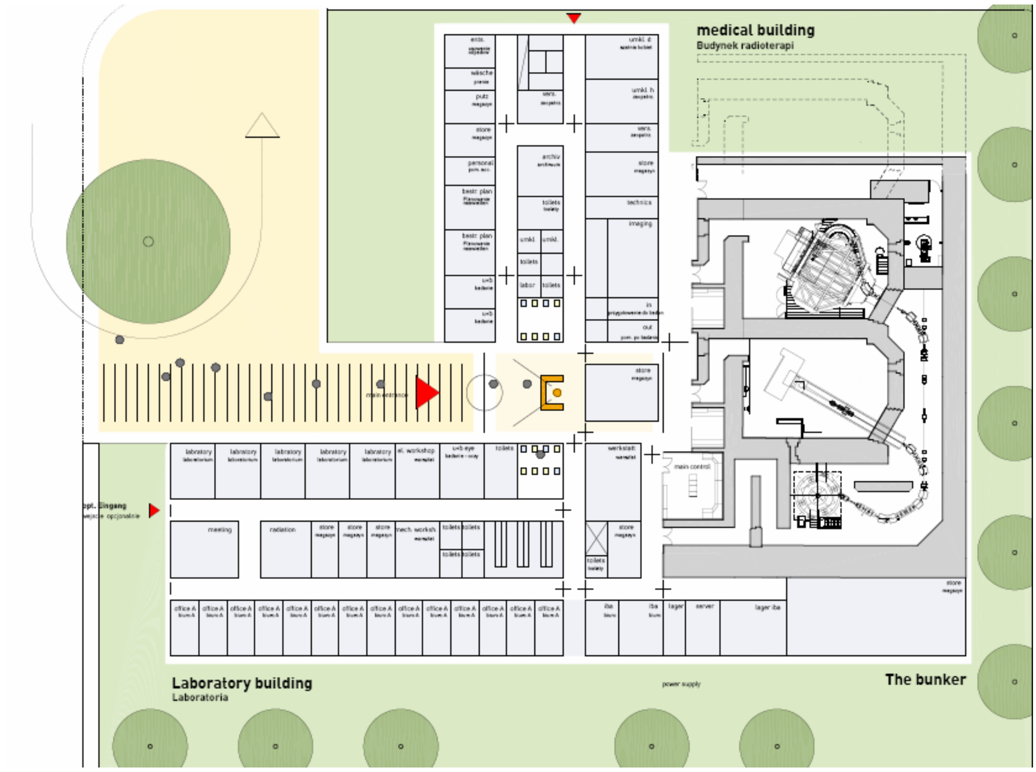


Fig. 7. The schematic view of the proton radiotherapy facility planned in frame of National Centre of Hadron Radiotherapy, phase I at IFJ PAN Kraków. The centre will be operational at the beginning of 2013.

monitoring network. The RGR-40 mining radiometer is an explosion proof gauge for rapid measurements of the concentration of radon decay products in coal or metal ore mines, or in chemical raw material mines. Radiometers produced at ICHTJ are widely used in Polish coal mines to monitor radon gas concentration.

Poland joined the European Union on May 1st, 2004. This historical event not only provided Polish scientists with the opportunity to participate in European Framework Programs but also gave Poland access to massive EU Structural Funds. Of about 60 billion Euro (€) foreseen for Poland in 2007-2013, 1.2 billion € will be spent in reconstructing our scientific infrastructure. This stream of money is probably the largest support for research facilities in the recent history of Poland. In September 2006 several major scientific institutions based in Katowice, Kielce, Kraków and Warszawa singed an agreement to form the National Consortium of Hadron Radiotherapy, NCRH. The goal of this consortium is to consolidate national research in the field of ion radiotherapy and to build a facility to provide this type of treatment for Polish patients.

The NCRH project will be performed in two stages. In the first stage (Fig. 7), the IFJ Kraków cyclotron facility will be upgraded with a 235-250 MeV proton cyclotron, eye therapy room and possibly a radiotherapy gantry. In cooperation with the Kraków Centre of Oncology and the Department of Ophthalmology and Ophthalmic Oncology of the Jagiellonian University, a few hundred cancer patients per year will be treated. The proton beam will be also used for research purposes in the field of nuclear physics, radiobiology and material engineering. In the second stage of the NCRH project, a dedicated clinical ion radiotherapy center will be built in Warszawa. The centre will be equipped with an accelerator, producing 250 MeV protons and 400 MeV/amu carbon ions, two proton gantries and a therapy room with a horizontal carbon ion beam. 1500 new cancer patients per year, directed from all over the Poland, will be treated in this facility.

Despite severe budgetary constraints over the last decades, nuclear physicists in Poland have managed to significantly contribute to progress in applied physics and interdisciplinary research. Poland's membership in the European Union and availability of EU structural funds in the years 2007-2013 offer new perspectives of radically modernizing and upgrading her national research infrastructure.

POSSIBLE LOCATION FOR THE UNDERGROUND LABORATORY IN POLAND

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First measurements of neutrinos from the Sun in 1964 and from the supernova explosion in 1987, and recent discoveries of the oscillations of atmospheric and solar neutrinos caused that the physics of natural neutrinos became the important field of studies and that the neutrino astronomy was born. It is clear that neutrinos are important messengers from stars. Another big but still open question concerns the proton decay, predicted by Grand Unification Theories aiming at the unification of fundamental forces in Nature. Achieving significant progress in both studies requires huge detectors on the 100 – 1000 ktons scale, i.e. by one to two orders of magnitude larger than the existing ones [1].

At present there is no single infrastructure in the world which could host such detectors. The LAGUNA project [2] aims at looking for the possible localization in Europe, in agreement with the ApPEC roadmap. Although studies of the low energy neutrinos from astrophysical sources and searches for proton decay are of the primary interest, the localization should take into account the possibility of neutrino studies with accelerator neutrino beams. One of the possible locations of the new infrastructure is in Poland.

The pre-feasibility study of the localization of a big underground laboratory in the Polkowice-Sieroszowice mine in Poland has been performed in the years 2004-2006. The Polkowice-Sieroszowice mine belongs to the KGHM holding of copper mines in west-southern Poland. The site is placed about 80 km from the airport in Wrocław and 40 km from the motor way A4 crossing southern Poland in the west-east direction (see Figure 1). Its distance from CERN is about 950 km.

Fig.1. *Map showing the localization of the Polkowice-Sieroszowice site (marked with a red star).*

Apart from copper ores the local geological structure contains a layer of NaCl, which is about 70 meters thick and located at a depth of 900-1000 meters below the surface. Anhydrite layers, placed directly above and below the salt layer, are of comparable thickness. This salt has not been yet massively exploited but in the Polkowice-Sieroszowice mine a few big salt caverns were excavated in the nineties. One of them, almost 100 m long, 15 m wide and 15 m high, placed at a depth of 950 m below the surface, is shown in Figure 2. It is being used for measurement purposes. The movements of the salt walls have been monitored there since 1997 in order to understand better the viscous creep of salt at big depths. The temperature in this cavern is about 35^{0}C and the humidity is about 20%.

The pre-feasibility study contained two elements: measurements of the background due to natural radioactivity and initial geo-mechanical simulations of the excavation of a huge salt cavern.

Fig.2. *Photo of the existing big salt cavern; inset shows an element of the measuring system used for the long term monitoring of wall movements due to salt viscous creep.*

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[1] Contributions: W. Pytel (KGHM Cuprum, Wrocław), K. Urbanczyk, J. Slizowski (Mineral and Energy Economy Research Institute PAS, Kraków), J. Dorda, J. Kisiel, A. Konefal (University of Silesia, Katowice), M. Budzanowski, S. Grabowska, K. Kozak, J. Mazur, J.W. Mietelski, M. Puchalska, A. Szelc, E. Tomankiewicz, A. Zalewska (H.Niewodniczanski Institute of Nuclear Physics PAN, Kraków)

The measurements of natural radioactivity have been performed mostly in the existing chamber. They consisted of alpha and gamma spectrometric measurements of salt and anhydrite samples, long term integrated dose measurements with thermo-luminescent detectors and radon content measurements of air in the cavern. The results show that the level of natural radioactivity in the cavern is very low. In particular, the U and Th contents in salt are at the level of 0.01-0.02 Bq/kg. Although the content of the radioactive K^{40} is higher, equal to 4±0.9 Bq/kg, this level is also much lower than a typical level in other mines.

The measurements of the dose, integrated over eight months and performed with 11 sets of thermo-luminescent detectors placed on walls of the cavern, gave the very low value of 1.9 nGy per hour; for comparison, the dose measured one meter under the surface in Kraków is 65 nGy/hour. The radon content was between 10 Bq/m^3 and 38 Bq/m^3. This was due to the pumping of external air through the mine ventilation system. The measurements of anhydrite samples gave the U and Th contents of 0.8 – 1.3 Bq/kg.

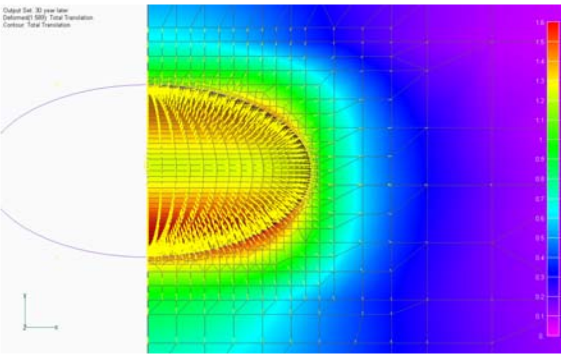


Fig. 3. *Salt cavern movement, 30 years after mining (from [4]).*

The geo-mechanical simulations concerned the possibility of excavating a salt cavern big enough to place there the GLACIER detector filled with 100 ktons of Liquid Argon [3]. Two independent preliminary analyses have been performed in the framework of this study. In both analyses a 30 year period of the cavern exploitation was simulated.

The first simulation [4] assumed an ellipsoidal shape of the cavern with the lengths of half-axes equal to 45.5 m for the horizontal one and 24 m for the vertical one and with the centre placed 889 m below the surface. According to the preliminary conclusions this cavern should be stable and should not destabilize the waterproof anhydrite layers. After 30 years of exploitation, a horizontal squeezing by up to 1.5 m, due to the salt viscous creep, is foreseen. This is illustrated in Figure 3.

The second simulation [5] assumed two different cavern geometries (see Fig. 4), seven depths under the surface (400, 500, 600, 700, 800, 900 and 1000 meters) and two different variants of the coefficients in the Norton's creep law (corresponding to the extreme conditions of salt). Four combinations of the cavern geometry and the creep law were considered (for geometry 1,models 1 and 2; for geometry 2, models 3 and 4). The evaluation of salt massive ability to resist the long-lasting loads is one of least-studied problems in the geomechanics of salt deposits. Thus, four different criteria, three based on the stress of the rock massive, and one based on the combination of the stress and strain, were applied in the estimates of the long-term stability of caverns.

According to preliminary results, the cavern stability depends relatively weakly on the cavern geometry and on the model of viscous creep while the dependence on the cavern depth is strong. This is illustrated in Figures 5 and 6 showing the time dependence at the cavern roof of the maximum effective stress and of the maximum strain rate. One can also see that a big instantaneous change follows the excavation and that after about 15 years the speed of change stabilizes.

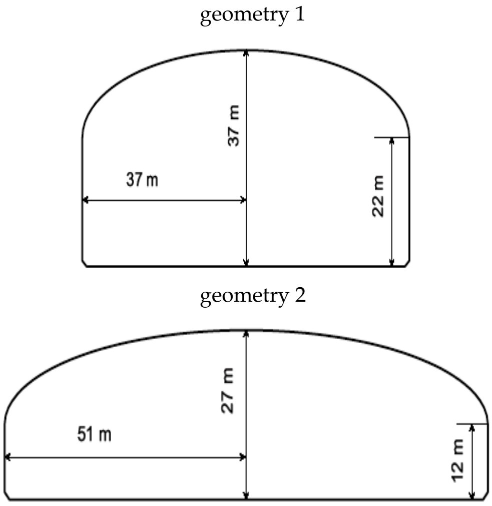


Fig. 4. *Shapes of the salt caverns in the second geo-mechanical analysis [5].*

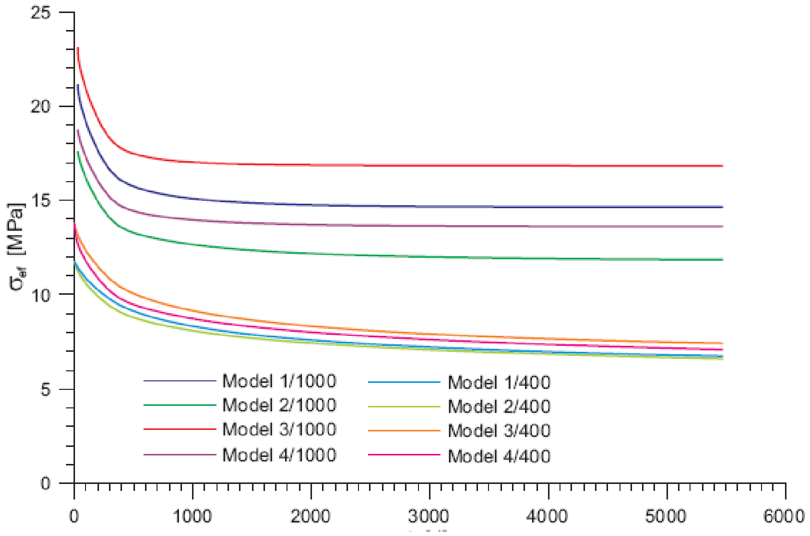


Fig. 5. Time dependence of maximum effective stress at the chamber roof for all the four models and for depths under the surface: 400 and 1000 m (from [5]).

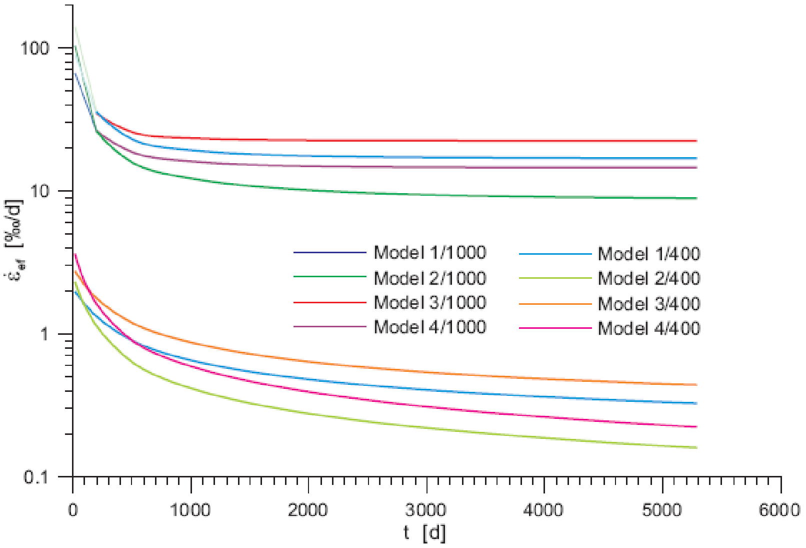
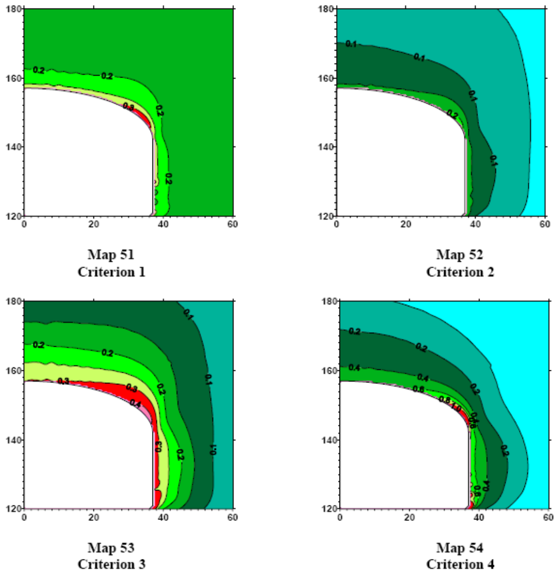


Fig. 6. Time dependence of maximum strain rate at the chamber roof for all the four models and for depths under the surface: 400 and 1000 m (from [5]).

The cavern simulations at different depths show that the stable cavern of geometry 1 can be constructed down to 700 m below the surface. At the depth of 950 m the cavern instability cannot be excluded. The results of the simulations at 700 m are given in Fig.7. The discrepancy between the two geo-mechanical studies of the cavern stability at 900-950 m implies that a thorough feasibility study should be performed to give a conclusive answer. This will be done in the framework of the LAGUNA project [5]. One should stress the availability of a detailed knowledge of the geological structure in the Sieroszowice region which makes a selection of the place with the best quality of the salt rock possible. Future simulations should take this into account. Another plan for the near future is to adapt the existing cavern to host an initial small laboratory. The proposed name for this laboratory is SUNLAB (Sieroszowice UNderground LABoratory).


Map 51
Criterion 1

Map 52
Criterion 2

Map 53
Criterion 3

Map 54
Criterion 4

Fig. 7. Distributions of the rock effort coefficient for the chamber of geometry 1 at the depth of 700 m after 30 years of its exploitation (from [5]).

Bibliography

[1] D. Autiero et al.: *Large undeground, liquid based detectors for astro-particle physics in Europe: Scientific case and prospects"*, e-Print: arXiv:0705.0116 [hep-ph], wysłane do druku w Journal of Cosmology and Astroparticle Physics.

[2] LAGUNA – *Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics*, FP7–Infrastructures–2007–1, proposal ref. Number FP7-212343, May 2007

[3] A.Rubbia: *Experiments for CP violation: A giant liquid argon scintillation, Cerenkov and charge imaging experiment?,* hep-ph/0402110

[4] W. Pytel: *Salt cavern stability analysis – preliminary study,* KGHM CUPRUM, Wrocław, 2004

[5] J. Slizowski, K. Urbanczyk: *Influence of depth on rock salt effort around the single chamber,* IGSMiE PAN, Kraków, 2004

CONTRIBUTIONS

GLOBAL PROPERTIES OF NUCLEI

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The potential energy of β-stable nuclei was calculated within Hartree-Fock procedure with the Relativistic Mean Field Theory (RMFT+NL3) , the Gogny force (D1S), Skyrme interaction and macroscopic-microscopic method with the Woods-Saxon and Nilsson single particle potentials [1].

The proton and neutron radii were calculated and their isospin dependence analysed for exotic nuclei using RMFT [2,3], D1S [4] and macroscopic-microscopic method with Woods-Saxon potential [5]. The radii of K isomers [6] and neutron halo in heavy nuclei with D1S force were also calculated [7].

In Fig. 1 the shell corrections are presented, extracted from the single particle levels of self-consistent mean fields of Gogny D1S [8,9,10,11] and RMFT+NL3 [12,13,14] by the Strutinsky method smoothing the energy in the energy space (NL3, D1S) or in nucleon number space (NL3N, D1SN). The smooth part of potential energy was compared to various liquid drop models [15,16]. The shell and pairing energies were obtained by folding in nucleon number space [17,18]. The average pairing energy is also analysed within n-folding [19] giving double value for scission point in fission isomers.

The new way of evaluating the shell corrections [21] by folding in nucleon number space conserves the particle number exactly and gives similar results as the traditional Strutinsky folding in single particle energy space for large deformed nuclei, while for spherical isotopes the new shell corrections become deeper. This effect is connected with the zero point vibrations, which should be taken into account [22], but were neglected previously (Nucl. Phys. A95, 420 (1967)). The whole macroscopic-microscopic method should be modified by the new macroscopic – Lublin Strasbourg Drop [23] part, Yukawa folded mean field, new shell corrections [21] and the n-folded average pairing [18] term. All the parameters should be fitted to the actually available data. Then the macroscopic-microscopic method can compete with selfconsistent models, which are much more calculation time consuming.

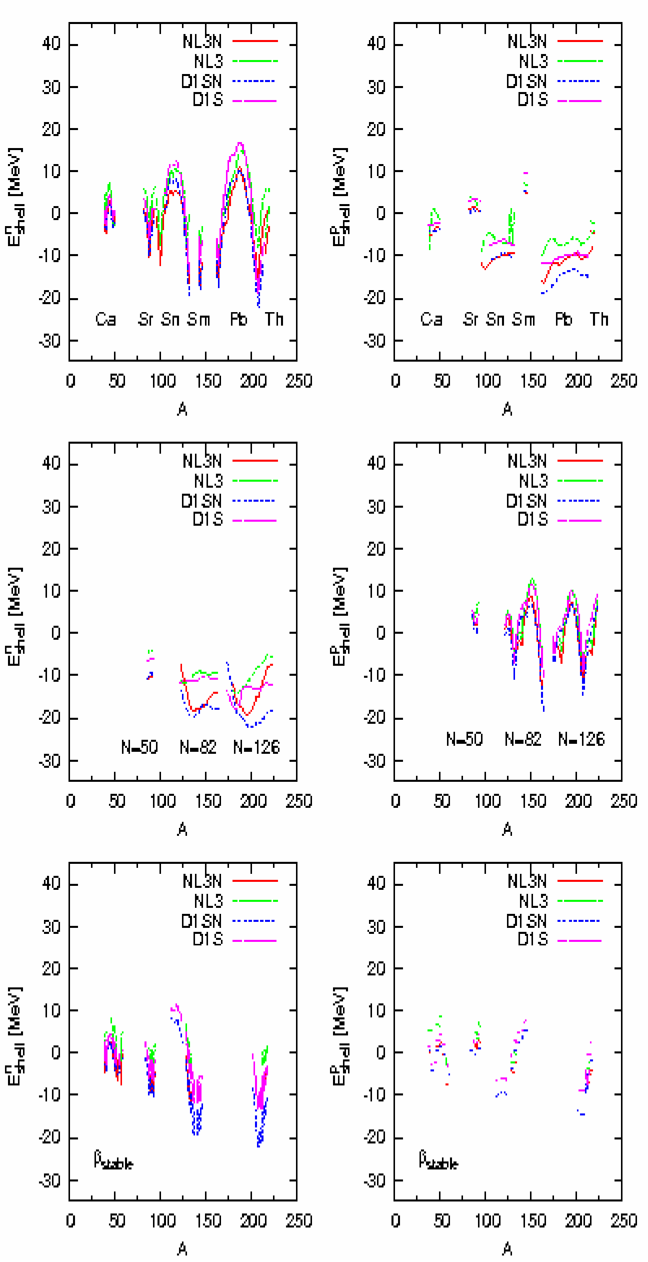

Fig. 1. The shell corrections of neutrons (left) and protons (right) for isotopes (upper panels), isotones (middle panels) and β-stable nuclei (lowest panel).

[1] **K. Pomorski, B. Nerlo-Pomorska,** P. Ring, G. A. Lalazissis**, A. Baran. Z. Łojewski, B. Nerlo-Pomorska, M. Warda,** Nucl. Phys.**A 624,** 349 (1997)

[2] **M. Warda, B. Nerlo-Pomorska, K. Pomorski,** Nucl. Phys. A**635,** 484 (1998)

[3] **M. Warda. B. Nerlo-Pomorska, K. Pomorski,** Acta Phys. Polon. **B 30**, 755 (1999)

[4] **B. Nerlo-Pomorska, K. Pomorski,** J. F. Berger**,** Acta Phys. Polon. **B 32**, 925 (2001)

[5] **Z. Łojewski, B. Nerlo-Pomorska,** J. Dudek**,** Acta Phys. Polon. **B 32**, 2981 (2001)

[6] **K. Mazurek, B. Nerlo-Pomorska,** Acta Phys. Polon. **B 32**, 783 (2001)

[7] **B. Nerlo-Pomorska, K. Pomorski,** J. F. Berger**,** Eur. Phys. Jour. **A 8**, 19 (2000)

[8] **M. Kleban, B. Nerlo-Pomorska, K. Pomorski,** J. F. Berger**,** J. Decharge**,** Acta Phys. Polon. **B 32**, 1119 (2001)

[9] **M. Kleban, B. Nerlo-Pomorska,** .Annales UMCS, Sect. AAA, **LV/LVI,** 1 (2001)

[10] **M. Kleban, B. Nerlo-Pomorska,** J. Berger**,** J. Decharge**,** J. Girod**,** S. Hilaire**,** Phys. Rev. **C 65,** 024309, 1 (2002)

[11] **M. Kleban, B. Nerlo-Pomorska, K. Pomorski,** J F. Berger**,** J. Decharge**,** Acta Phys. Polon. **B 33**, 383 (2002)

[12] **B. Nerlo-Pomorska, K. Mazurek,** Phys. Rev. **C 66,** 064305, 1 (2002)

[13] **B. Nerlo-Pomorska, K. Mazurek, M. Kleban,** Acta Phys. Polon. **B 34,** 1777, 1 (2003)

[14] **B. Nerlo-Pomorska, J. Sykut,** Acta Phys. Polon. **B 35,** 1299, 1 (2004)

[15] **B. Nerlo-Pomorska,** Physica Scripta **T 125,** 26 (2006)

[16] **B. Nerlo-Pomorska, K. Pomorski, M. Zwierzchowska,** Int. Journ. of Modern Phys. **E 16,** 276 (2007)

[17] **K. Pomorski, B. Nerlo-Pomorska,** Physica Scripta **T 125**, 21 (2006)

[18] **B. Nerlo-Pomorska, K. Pomorski,** Int. Journ. of Modern Phys. **E 16**, 130 (2007)

[19] **B. Nerlo-Pomorska, K. Pomorski,** Int. Journ. of Modern Phys. **E 15,** 471 (2006)

[20] **B. Nerlo-Pomorska, K. Pomorski,** Int. Journ. of Modern Phys. **E 16,** 276 (2007)

[21] **K. Pomorski,** Phys. Rev. **C** 70, 044306 (2004)

[22] H. Molique**, J. Dudek, K. Pomorski,** Int. Journ. of Modern Phys. **E 14,** 499 (2005)

[23] **K. Pomorski, J. Dudek,** Phys. Rev. **C 67,** 044316 (2003)

MASSES AND FISSION BARRIERS OF ATOMIC NUCLEI

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Theoretical estimates of the masses of nuclei which are not far from stability agree well with the measured data. Nevertheless the progress made in experimental nuclear physics over the last years, like discovery of superheavy nuclei or isotopes close to the proton or neutron drip-lines, demands for a more careful checking of the theoretical model predictions and may lead to some revision of its parameters.

The recently developped Lublin-Strasbourg Drop (LSD) [1] model together with the Moeller microscopic corrections [At. Data Nucl. Data Tab. 59, 185 (1995)] is very successful in describing many features of nuclei. In addition to the classical liquid drop model the LSD contains the curvature term proportional to the A^1/3. Its parameters were adjusted to the bindings energies of presently known 2766 [Isotope chart of M. Antony, Strasbourg 2002] with proton and neutron numbers larger or equal to 8. The r.m.s. deviation of the experimental binding energies versus those predicted by the LSD model, equal to 0.698 MeV, is smaller than the ones given by other more elaborated theories like the finite-range droplet, the Thomas-Fermi model or old liquid drop model of Myers and Swiatecki [Nucl. Phys. A601, 141 (1996); Ark. Phys. 36, 343 (1967)].

The LSD estimates of binding energies of nuclei which are far from the beta stability differ significantly from the data predicted by the other macroscopic-microscopic or selfconsistent models [2-4]. There is a hope that new experiments with the radioactive beams will bring suffcient sample of data in order to decide which model describes better the position of the proton and neutron drip lines.

It turns out that the liquid drop model which in addition to the volume, surface and Coulomb energies contains just the first order curvature term gives not only a very good description of the masses but also a rather satisfactory prediction of the fission barrier heights. It is worth emphasizing that all the parameters of the LSD model were fitted to the nuclear masses only and thus the correct reproduction of the barrier heights can be seen as an additional sign of the intrinsic consistency of the model. The mean square deviation of the barrier heights from experiment is 3.56 MeV, but it decreases to only 0.88 MeV when the four lightest nuclei are disregarded i.e. when only the nuclei with Z>70 are considered.

In addition it was found in Ref. [5] that taking into account the deformation dependence of the congruence energy significantly approaches the theoretical LSD-model barrier-heights to the experimental data in the case of the light isotopes while the fission barriers for heavy nuclei remain nearly unchanged and agree well with experiment.

Another important effect which influences the fission barrier heights is the assumtion, made in all type microscopic-macroscopic calculations, that the proton and neutron distributions have the same deformations. It was shown in Ref. [6] on basis of selfconsistent HFB calculations with the Gogny force that such an effect can change the barrier height estimates even by 1 MeV. A generalization of the macroscopic model was proposed in Ref. [7], where the term corresponding to the response of the system on the change of the relative proton to neutron deformation was derived using the ETF approximation to the HF hamiltonian with the Skyrme force. Similar estimates made in the Yukawa folded model were performed in Refs. [8,9] where the effect of the proton and neutron deformation difference on the fission barrier heights was studied.

Recently developped in Ref. [10] new shell correction method obtained by averaging in the particle number space (not by smoothing the single energies as in the traditional Strutinsky prescription) predicts deeper minima for sperical nuclei what can also change the estimates of the barrier height of such isotopes.

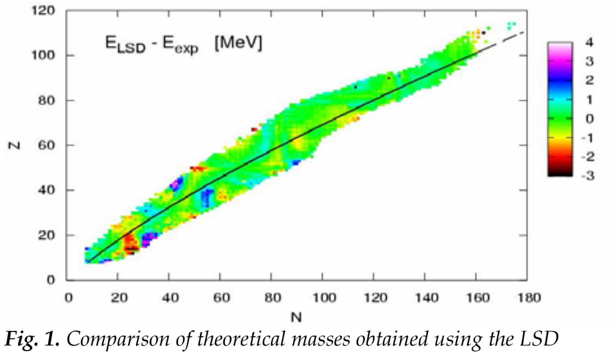

Fig. 1. *Comparison of theoretical masses obtained using the LSD model with the experimental data for known isotopes.*

[1] **K. Pomorski** and J. Dudek**,** Phys. Rev. **C 67**, 044316 (2003)

[2] **M. Warda, B. Nerlo-Pomorska, and K. Pomorski,** Acta Phys. Polon. **B30**, 755 (1999)

[3] **B. Nerlo-Pomorska** and J. Sykut, Acta Phys. Polon. **B35,** 1299 (2004)

[4] J. Dudek, **K. Mazurek,** and **B. Nerlo-Pomorska,** Acta. Phys. Polon. **B 35**, 1263 (2004)

[5] **K. Pomorski** and J. Dudek**,** Int. Journ. Mod. Phys. **E13**, 107 (2004)

[6] J.F. Berger and **K. Pomorski,** Phys. Rev. Lett. **85**, 30 (2000)

[7] **A. Dobrowolski, K. Pomorski,** and J. Bartel, Phys. Rev. **C65**, 041306(R) (2002)

[8] **A. Dobrowolski,** J. Bartel, and **K. Pomorski,** Int. Journ. Mod. Phys. **E14** , 457 (2005)

[9] **A. Dobrowolski,** J. Bartel, and **K. Pomorski,** Physica Scripta **T125**, 188 (2006)

[10] **K. Pomorski,** Phys. Rev. **C70**, 044306 (2004)

ANTIPROTONIC ATOMS

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Experimental facility: Low Energy Antiproton Ring (LEAR) at CERN

The antiproton-nucleon interaction is very strong. Therefore antiprotons interacting with atomic nuclei are absorbed and annihilate already at the nuclear periphery, where the nucleon density is significantly smaller than the central nuclear density. For sufficiently slow antiprotons the annihilation takes place after the antiprotonic atom has been formed. In this case the spatial distribution of the antiproton wave function is well determined and one can imagine that the annihilation "signals" (whatever they are) could perhaps be used to test the extent and the composition of the nuclear surface.

Beginning more than ten years ago we have performed an experimental study of the medium-heavy antiprotonic atoms using the slow antiproton beam from Low Energy Antiproton Ring (LEAR) at CERN. The main objective of our program was to obtain information on the neutron distributions at the nuclear periphery and to provide data useful in deducing the antiproton-nucleus optical potential parameters.

Two experimental methods were employed. First, using the so called "radiochemical method" we have investigated [1-4] the ratios of peripheral neutron to proton densities at distances around 2.5 fm larger than the nuclear charge half-density radius [5]. The method consisted in measuring the yield of radioactive nuclei having one proton or one neutron less than the target nucleus, produced after antiproton capture, cascade and annihilation in the target antiprotonic atom. The experiment yielded 19 density ratios (determining the so called "halo factors", see Ref. [1] for definition) subsequently employed to deduced the shape of the peripheral neutron distribution.

The second method consisted in measurements of the antiprotonic atom level widths and shifts due to the strong antiproton-nucleus interaction. These observables are sensitive to the interaction potential which contains, in its simplest form, a term depending on the sum of the neutron and proton densities. The level widths and in a number of cases also the level shifts were measured for 34 antiprotonic atoms (in some cases for different isotopes of the same element).

The rich harvest of the two employed methods, sensitive to the neutron and proton density ratio and the sum of these densities has allowed to derive a number of systematic conclusions on the neutron distributions in nuclei [6-10]. Moreover, our data [11-18] were used to determine the antiproton-nucleus optical model parameters through global fits of $\bar{p}$ X-rays and halo factors with a substantially larger and more precise database than employed in previous approaches (see Nucl. Phys. **A761**, 283 (2005) and Ref. [10]).

Figure 1 presents the deduced neutron-proton rms radii difference obtained from the analysis of the antiprotonic atom data.

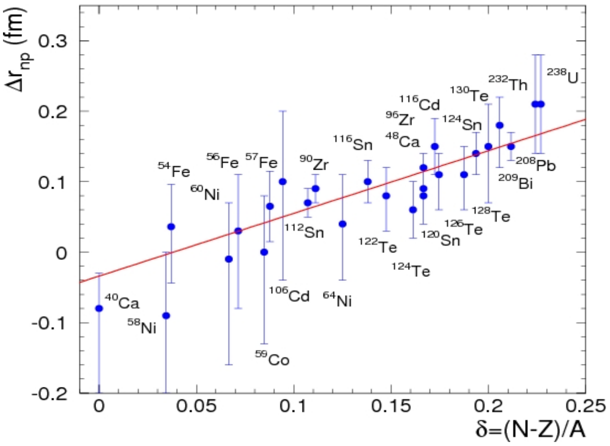

Fig. 1. *Difference Δr_{np} between the rms radii of the neutron and proton distributions as deduced from the antiprotonic atom X-ray data, as a function of δ=(N-Z)/A.*

[1] **J. Jastrzębski**, H. Daniel, T. von Egidy, **A. Grabowska**, Y.S. Kim, **W. Kurcewicz, P. Lubiński**, G. Riepe, W. Schmid, **A. Stolarz**, **S. Wycech**, Nucl. Phys. **A558**, 405c (1993).

[2] **P. Lubiński**, **J Jastrzębski**, **A. Trzcińska**, **W. Kurcewicz**, F.J. Hartmann, W. Schmid, T. von Egidy, **R. Smolańczuk**, **S. Wycech**, Phys. Rev. Lett. **57**, 3199 (1994).

[3] **P. Lubiński**, **J. Jastrzębski**, **A. Trzcińska**, **W. Kurcewicz**, F.J. Hartmann, W. Schmid, T. von Egidy, **R. Smolańczuk**, **S. Wycech**, Phys. Rev. C **57**, 2962 (1998).

[4] R. Schmidt, F.J. Hartmann, B. Ketzer, T. von Egidy, **T. Czosnyka**, **J. Jastrzębski**, **M. Ksieliński**, **P. Lubiński**, **P. Napiorkowski**, **L. Pieńkowski**, **A. Trzcińska**, **B. Kłos**, **R. Smolańczuk**, **S. Wycech**, W. Poschl, **K. Gulda**, **W. Kurcewicz**, E. Wiedmann, Phys. Rev. C **60**, 054309 (1999).

[5] **S. Wycech**, **J. Skalski**, **R. Smolańczuk**, **J. Dobaczewski**, J. Rook, Phys. Rev. C 54, 1832 (1996).

[6] **A. Trzcińska**, **J. Jastrzębski**, **T. Czosnyka**, T. von. Egidy, **K. Gulda**, F.J. Hartmann, **J. Iwanicki**, B. Ketzer, **M. Kisieliński**, **B. Kłos**, **W. Kurcewicz,** **P. Lubiński**, **P. Napiorkowski**, **L. Pieńkowski**, R. Schmidt, E. Widmann, Nucl. Phys. **A692**, 176c (2001).

[7] **A. Trzcińska**, **J. Jastrzębski**, **P. Lubiński**, F.J. Hartmann, R. Schmidt, T. von Egidy, **B. Kłos**, Phys. Rev. Lett. **87**, 082501 (2004).

[8] **J. Jastrzębski**, **A. Trzcińska**, **P. Lubiński**, **B. Kłos**, F.J. Hartmann, T. von Egidy, **S. Wycech**, Int. J. Mod. Phys. **13,** 343 (2004).

[9] **A. Trzcińska**, **J. Jastrzębski**, **P. Lubiński**, F.J. Hartmann, R. Schmidt, T. von Egidy, **B. Kłos**, Nucl. Instr. Methods B **214,** 157 (2004).

[10] **S. Wycech**, **F.J. Hartmann, J. Jastrzębski, B. Kłos, A. Trzcińska, T. von Egidy,** Phys. Rev. C **76**, 034316 (2007).

[11] **J. Jastrzębski**, **P. Lubiński**, **A. Trzcińska**, Acta Phys. Polonica **26**, 527 (1995).

[12] R. Schmidt, F.J. Hartmann, T. von Egidy, **T. Czosnyka**, **J. Iwanicki**, **J. Jastrzębski**, **M. Kisieliński**, **P. Lubiński**, **P. Napiorkowski**, **L. Pieńkowski**, **A. Trzcińska**, **J. Kulpa**. **R. Smolańczuk**, **S. Wycech**, **B. Kłos**, **K. Gulda**, **W. Kurcewicz**, E. Widmann, Phys. Rev. C **58**, 3195 (1998).

[13] F.J. Hartmann, R. Schmidt, B. Ketzer, T. von Egidy, **S. Wycech**, **R. Smolańczuk**, **T. Czosnyka**, **J. Jastrzębski**, **M. Kisieliński**, **P. Lubiński**, **P. Napiorkowski**, **L. Pieńkowski,** **A. Trzcińska**, **B. Kłos**, **K. Gulda**, **W. Kurcewicz**, E. Widmann, Phys. Rev. C **65**, 014306 (2001).

[14] **A. Trzcińska**, **J. Jastrzębski**, **T. Czosnyka**, T. von Egidy, **K. Gulda,** F.J. Hartmann, **J. Iwanicki**, B. Ketzer, **M. Kisieliński**, **B. Kłos**, **W. Kurcewicz,** **P. Lubiński**, **P. Napiorkowski**, **L. Pieńkowski**, R. Schmidt, E. Widmann, Nucl. Phys. **A692**, 176 (2001)

[15] R. Schmidt, **A. Trzcińska**, **T. Czosnyka**, T. von Egidy, **K. Gulda**, F.J. Hartmann, **J. Jastrzębski**, B. Ketzer, **M. Kisieliński**, **B. Kłos**, **W. Kurcewicz**, **P. Lubiński**, P. Napiorkowski, **L. Pieńkowski**, **R. Smolańczuk**, E. Widmann, **S. Wycech**, Phys. Rev. C **67**, 044308 (2003).

[16] **B. Kłos**, **S. Wycech**, **A. Trzcińska**, **J. Jastrzębski**, **T. Czosnyka**, **M. Kisieliński**, **P. Lubiński**, **P. Napiorkowski**, **L. Pieńkowski**, F.J. Hartmann, B. Ketzer, R. Schmidt, T. von Egidy, J. Cugnon, **K. Gulda**, **W. Kurcewicz**, E. Widmann, Phys. Rev. C **69**, 044311 (2004).

[17] W.J. Świątecki, **A. Trzcińska**, **J. Jastrzębski**, Phys. Rev. C **71**, 047301 (2005).

[18] **B. Kłos**, **A. Trzcińska**, **J. Jastrzębski**, **T. Czosnyka**, **M. Kisieliński**, **P. Lubiński**, **P. Napiorkowski**, **L. Pieńkowski**, F.J. Hartmann, B. Ketzer, P. Ring, R. Schmidt, T. von Egidy, **R. Smolańczuk, S. Wycech,.** **K Gulda**, **W. Kurcewicz**, E. Widmann, B.A. Brown, Phys. Rev. C **76**, 014311 (2007)

NUCLEAR SYMMETRY ENERGY AND NEUTRON SKINS DERIVED FROM PYGMY DIPOLE RESONANCES IN ^{130,132}Sn ISOTOPES

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Experimental facility: LAND-FRS setup at GSI, Darmstadt

The pygmy dipole resonance (PDR) manifests itself as a concentration of dipole strength near the neutron separation threshold below the giant dipole resonance (GDR) domain. It is related to structural changes in nuclei with a large neutron excess giving rise to a neutron skin. According to theoretical calculations, a very precise measurement of the neutron skin thickness in heavy doubly magic nuclei like ^{208}Pb or ^{132}Sn would help in constraining the neutron matter equation of state (Nucl.Phys.**A706,** (2002) 85). At present, the neutron matter radius in nuclei as a fundamental ground-state property cannot be approached experimentally in a straightforward way and its extraction from experimental data involves a certain model dependence. Existing results on the neutron skin thickness are limited to stable nuclei. As suggested in Phys.Rev.C **73**(2006)044325, the PDR strength provides insight into the skin thickness as both quantities are strongly correlated with the symmetry energy.

Low-lying E1 strength was observed in exotic ^{130,132}Sn isotopes in a kinematically complete measurement performed at the LAND facility based on the relativistic Coulomb excitation in inverse kinematics [1]. It was the first attempt of dipole strength investigation in unstable neutron-rich nuclei with such high mass numbers. Previous experiments were focused on much lighter unstable oxygen [2,3] and carbon isotopes [4]. Dipole strength distributions were deduced from the measured energy-differential cross sections obtained in an invariant-mass analysis applied to decay products and covered excitation energies ranging from the one-neutron separation threshold up to 25 MeV, including thus the GDR. The dipole response emerging below the GDR is characterized by exhausting 7(3)% and 4(3)% of the Thomas-Reiche-Kuhn sum rule for ^{130}Sn and ^{132}Sn, respectively.

Observed dipole strength in Sn isotopes is useful in constraining parameters describing the symmetry energy and carries information on the neutron skin thickness in ^{130,132}Sn. In order to extract this information a series of fully self-consistent relativistic Hartree-Bogoliubov (RHB) plus relativistic quasiparticle random phase approximation (RQRPA) calculations of ground-state properties and dipole strength distributions has been carried out (Phys.Lett.**B606**(2005)288). A set of differently parametrized nucleon-nucleon interactions, corresponding to a softer or stiffer neutron matter equation of state by varying the a_4 parameter (i.e. the symmetry energy at equilibrium density) has been used. In each case the parameter set was calibrated to accurately reproduce the ground-state properties, like binding energies or charge radii, for a standard set of stable nuclei. An almost linear correlation between the ratio of the non-energy weighted strength absorbed by the PDR to that of GDR and the neutron skin thickness has been found. By comparing the experimental values of this ratio with that from the RQRPA, the parameters of the symmetry energy were fixed. An average values a_4=32.0±1.8 MeV and the slope of the symmetry energy p_o=2.2±0.8 MeV/fm^3 have been obtained. Using this result subsequently the neutron skin thicknesses of $\Delta R_{np}(^{130}\mathrm{Sn})=0.23\pm0.04$ and $\Delta R_{np}(^{132}\mathrm{Sn})=0.24\pm0.04$ fm were derived, following a trend established by a measurement in stable Sn isotopes (Phys.Rev.Lett. **82**(1999) 3216), see Fig.1.

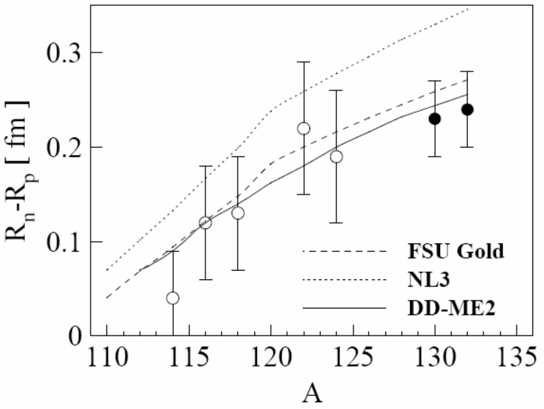

Fig. 1. *Evolution of the neutron skin in Sn isotopes. The data for stable Sn isotopes (open circles) extracted from Phys.Rev.Lett. 82(1999) 3216 are compared to our values (filled circles) for unstable ones. Theoretical predictions are shown as well.*

[1] **P.Adrich, A.Klimkiewicz,** M. Fallot, K. Boretzky, T.Aumann, D. Cortina-Gil, U. Datta Pramanik, Th.W. Elze, H. Emling, H. Geissel, M. Hellstroem, K.L. Jones, J.V. Kratz, **R. Kulessa**, Y. Leifels, C. Nociforo, R. Palit, H. Simon, **G. Surówka**, K. Sümmerer and **W. Waluś**, Phys. Rev. Lett. **95,** 132501 (2005)

[2] A. Leistenschneider, T. Aumann, K. Boretzky, D. Cortina, J. Cub, U. Datta Pramanik, W. Dostal, Th.W. Elze, H. Emling, H. Geissel, A. Grünschloß, M. Hellstroem, S. Ilievski, N. Iwasa, M. Kaspar, A. Kleinboehl, J.V. Kratz, **R. Kulessa**, Y. Leifels, E. Lubkiewicz, G. Münzenberg, P. Reiter, M. Rejmund, C. Scheidenberger, C. Schlegel, H. Simon, J. Stroth, K. Sümmerer**, E. Wajda, W. Waluś**, S. Wan, Phys. Rev. Lett. **86**, 5442 (2002)

[3] C. Nociforo, K.L. Jones, L.H. Khiem, **P. Adrich**, T. Aumann, B.V. Carlson, D. Cortina-Gil, U. Datta Pramanik, Th.W. Elze, H. Emling, H. Geissel, M. Hellstroem, J.V. Kratz, **R. Kulessa**, T. Lange, Y. Leifels, H. Lenske, **E. Lubkiewicz**, G. Münzenberg, R. Palit, H. Scheit, H. Simon, K. Sümmerer, S. Typel, **E. Wajda, W. Waluś** and H. Weick, Phys. Lett. **B 605**, 79 (2005)

[4] U. Datta Pramanik, T. Aumann, K. Boretzky, B.V. Carlson, D. Cortina, Th.W. Elze, H. Emling, H. Geissel, A. Grünschloß, M. Hellstroem, S. Ilievski, J.V. Kratz, **R. Kulessa**, Y. Leifels, A. Leistenschneider, **E. Lubkiewicz**, G. Münzenberg, P. Reiter, H. Simon, K. Sümmerer, **E. Wajda** and **W. Waluś**, Phys. Lett. **B 551**, 63 (2003)

NUCLEAR STRUCTURE NEAR THE DRIP LINES

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The study of nuclei far from stability is an increasingly important part of a nuclear physics portfolio [19]. As radioactive beams gradually expand the borders of the nuclear landscape, theoretical modeling of the nucleus is changing in significant ways. The crucial question for the field, namely "What binds protons and neutrons into stable nuclei and rare isotopes?", nicely underlines this point: indeed, the data on rare isotopes with the large neutron-to-proton imbalance indicate that there are many gaps in our present understanding.

Short-lived exotic nuclei offer unique tests of those aspects of the nuclear theory that depend on neutron excess [6]. The major challenge is to predict or describe in detail exotic new properties of nuclei far from the stability valley, and to explain the origins of these properties. New ideas and progress in computer technology have allowed nuclear theorists to understand bits and pieces of nuclear structure quantitatively.

The new experimental developments inevitably require safe and reliable theoretical predictions of nuclear properties throughout the whole nuclear chart in two main directions: (i) along the isospin axis, i.e., going outwards from the beta stability line to the neutron and proton drip lines, and (ii) towards the uncharted territory of super-heavy elements at the limit of mass and charge. The tool of choice is the nuclear density functional theory (DFT) based on the self-consistent Hartree-Fock-Bogoliubov (HFB) method. The key component is the universal energy density functional, which will be able to describe properties of finite nuclei as well as extended asymmetric nucleonic matter. The development of such a universal functional, including dynamical effects and symmetry restoration, is one of the main goals of the field.

By employing various criteria (agreement with measured masses, radii, low-lying excited states, giant vibrations, rotational properties, and other global nuclear characteristics), one aims at adjusting the coupling constants of the functional. By finding correlations between parameters, one hopes to reduce their number and to understand physical reasons why different parameterizations yield similar results. One may also want to expand the parameterizations to cover aspects dictated by physics arguments and/or motivations coming from the effective field theory and QCD. The main challenges in this quest can be nicely summarized through five questions:

- What is the form of the nuclear energy density functional?
- What are the constraints on the nuclear energy density functional?
- What is the form of the pairing functional?
- How to account for quantum correlations and symmetry-breaking effects?
- How to optimize computational techniques and error analysis?

Due to a concerted effort of many researchers working in this domain of physics, numerous theoretical tools have already been developed. In particular, mean-field description of pairing, deformation, and weak-binding effects is now possible within the HFB method solved on the transformed-harmonic-oscillator basis for axial symmetry [9,14,16,20]. This developments set the stage for further microscopic studies of drip-line nuclei.

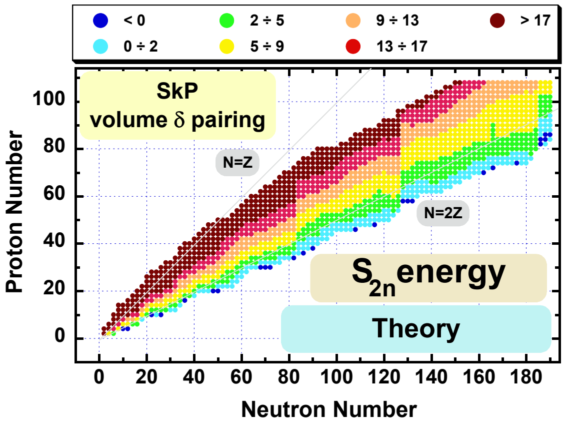

Fig. 1. *Two-neutron separation energies S_{2n} calculated within the self-consistent HFB theory with the SkP Skyrme interaction, zero-range pairing force, and approximate particle-number projection employing the Lipkin-Nogami method [14].*

[4] **J. Dobaczewski, W. Nazarewicz, T.R. Werner,** Z. Phys. **A354**, 27 (1996)

[5] **W. Nazarewicz, J. Dobaczewski, T.R. Werner**, J.A. Maruhn, P.-G. Reinhard, K. Rutz, C.R. Chinn, A.S. Umar, M.R. Strayer, Phys. Rev. **C53**, 740 (1996)

[6] **J. Dobaczewski, W. Nazarewicz, T.R. Werner**, J.F. Berger, C.R. Chinn, J. Dechargé, Phys. Rev. **C53**, 2809 (1996)

[7] **T.R. Werner**, J. A. Sheikh, M. Misu, **W. Nazarewicz**, J. Rikovska, K. Heeger, A. S. Umar, M. R. Strayer, Nucl. Phys. **A597**, 327 (1996)

[8] **T.R. Werner, J. Dobaczewski, W. Nazarewicz**, Z. Phys. **A358**, 169 (1997)

[9] **J. Dobaczewski, W. Nazarewicz**, Phil. Trans. R. Soc. Lond. **A356**, 2007 (1998)

[10] K. Bennaceur, **J. Dobaczewski**, M. Płoszajczak, Phys. Rev. **C60**, 034308 (1999)

[11] **J. Dobaczewski**, Acta Phys. Pol. **B30**, 1647 (1999)

[12] M.V. Stoitsov, **J. Dobaczewski**, P. Ring, S. Pittel, Phys. Rev. **C61**, 034311 (2000)

[13] S. Mizutori**, J. Dobaczewski**, G.A. Lalazissis, **W. Nazarewicz**, P.-G. Reinhard, Phys. Rev. **C61**, 044326 (2000)

[14] K. Bennaceur, **J. Dobaczewski**, M. Płoszajczak, Phys. Lett. **B496**, 154 (2000)

[15] **J. Dobaczewski, W. Nazarewicz**, P.-G. Reinhard, Nucl. Phys. **A693**, 361 (2001)

[16] **J. Dobaczewski, W. Nazarewicz**, Prog. Theor. Phys. **146**, 70 (2002)

[17] M.V. Stoitsov, **J. Dobaczewski, W. Nazarewicz**, S. Pittel, D.J. Dean, Phys. Rev. **C68**, 054312 (2003)

[18] K. Amos, S. Karataglidis, **J. Dobaczewski**, Phys. Rev. **C70**, 024607 (2004)

[19] M.V. Stoitsov, **J. Dobaczewski, W. Nazarewicz**, P. Ring, Comput. Phys. Comm. **167**, 43 (2005)

[20] J. Terasaki, J. Engel, M. Bender, **J. Dobaczewski, W. Nazarewicz**, M.V. Stoitsov, Phys. Rev. **C71**, 034310 (2005)

[21] K. Bennaceur, **J. Dobaczewski**, Comput. Phys. Comm. **168**, 96 (2005)

[22] M.V. Stoitsov, **J. Dobaczewski, W. Nazarewicz**, P. Borycki, Int. J. Mass. Spec. **251**, 243 (2006)

[23] M.V. Stoitsov, **J. Dobaczewski**, R. Kirchner, **W. Nazarewicz**, J. Terasaki, submitted to Physical Review C, nucl-th/0610061

[24] **J. Dobaczewski**, N. Michel, **W. Nazarewicz**, M. Płoszajczak, J. Rotureau, Progress in Particle and Nuclear Physics, in press, nucl-th/0701047

SUPERHEAVY NUCLEI

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The objective of this paper is to review studies of superhevy nuclei (SHN) done in Poland in a wide international cooperation. More precisely, we concentrate here on theoretical research of the structure and properties of heaviest nuclei. Theoretical studies of the problem of synthesis of these nuclei are described in separate articles by K. Siwek-Wilczyńska and J. Wilczyński, and by R. Smolańczuk. Experimental studies are analysed by A. Wieloch. One should also mention chemical studies of superheavy elements (SHE), done in Poland (A. Bilewicz, S. Siekierski, Z. Szeglowski and coworkers), not discussed in this issue, which importantly contributed to our knowledge on SHE and SHN.

Theoretical studies of SHN in Poland started very early, immediately after raising the problem of SHN by W.D. Myers and W.J. Świątecki in 1966. They started from the prediction [1] of the proton and neutron magic numbers (Z=114 and N=184) next to the largest experimentally known (Z=82 and N=126), done commonly with theoreticians from Dubna. Then, the investigations were followed by extensive studies (e.g., [2-4]) of the properties of spherical SHN, situated around the doubly magic nucleus $^{298}114$. They were done in a close cooperation with theoreticians of Lund, Los Alamos and Berkeley. Rather crude estimations of half-lives of SHN, done at that time, were quite optimistic, indicating for a chance to find these nuclei in nature. This gave a motivation for searching for them in nature (cf. e.g., G. Herrmann, Nature 280 (1979) 543; G.N. Flerov and G.M. Ter-Akopian, Rep. Prog. Phys. 46 (1983) 817).

In the last decade, on which this issue is concentrated, main attention was given to deformed SHN (DSHN), predicted to be localized around the doubly magic DSHN $^{270}108$ [5]. Calculations of shell correction [6], masses, α- and spontaneous-fission half-lives [7,8] have confirmed that the largest shell effects may be really expected at the proton, Z=108, and neutron, N=162, numbers, and that the half-lives may be long enough for observation of nuclei localized around the nucleus $^{270}108$. The idea of DSHN was important for experimental studies as these nuclei are situated much closer to nuclei, which were experimentally known at that time, than the predicted spherical nuclei, and, thus, much easier to be synthesized.

Besides half-lives, much attention has been also given to the analysis of rotational properties (e.g., [9]), masses (e.g., [10,11]), α-decay energies (e.g., [5,12]), fission-barrier heights (e.g., [13-15]), single-particle spectra (e.g., [16-19]), shape coexistence in SHN (e.g., [20]). Improvements in macro-micro methods have been proposed [21,22].

Figure 1 illustrates, as an example, the quality of description of measured masses of heaviest nuclei obtained within a macro-micro approach.

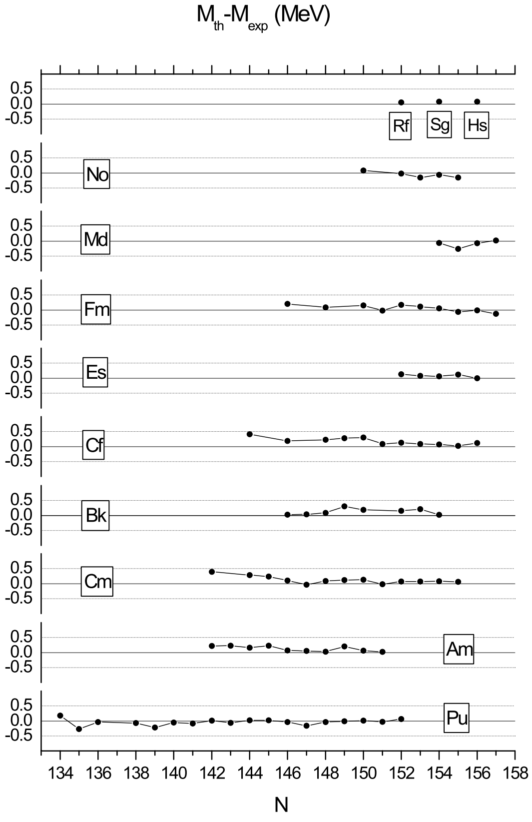

Fig. 1. Difference between calculated, M_{th} , and measured, M_{exp} , masses of nuclei with proton number Z=94-108 [10].

Besides macro-micro, also pure microscopic self-consistent methods have been used (e.g., [23-25]). A wide comparison between results obtained with macro-micro methods and self-consistent ones were done in [26]. Many details of the theoretical studies of the properties of SHN may be found in a recent review [27].

[1] **A. Sobiczewski**, F.A. Gareev, B.N. Kalinkin, Phys. Lett. **22** (1966) 500.

[2] S.G. Nilsson, J.R. Nix, **A. Sobiczewski**, **Z.Szymański**, **S. Wycech**, C. Gustafson, P. Möller, Nucl. Phys. A**115** (1968) 545.

[3] S.G. Nilsson, C.F. Tsang, **A. Sobiczewski**, **Z. Szymański**, **S. Wycech**, C. Gustafson, I.L. Lamm, B. Nilsson, Nucl. Phys. A**131** (1969) 1.

[4] J. Randrup, S.E. Larsson, P.Möller, S.G. Nilsson, **K. Pomorski**, **A. Sobiczewski**, Phys. Rev. **C 13** (1976) 229.

[5] **Z. Patyk**, **A. Sobiczewski**, Nucl. Phys. A**533** (1991) 132.

[6] **R. Smolańczuk**, **A. Sobiczewski**, Proc. XV Nucl. Phys. Conf.: *Low Energy Nuclear Dynamics*, St. Petersburg (Russia) 1995, eds. Yu.Ts. Oganessian et al. (World Scientific, Singapore, 1995) p. 313.

[7] **R. Smolańczuk**, **J. Skalski**, **A. Sobiczewski**, Phys. Rev. **C 52** (1995) 1871.

[8] **R. Smolańczuk**, Phys. Rev. **C 56** (1997) 812.

[9] **A. Sobiczewski**, I. Muntian, **Z. Patyk**, Phys. Rev. **C 63** (2001) 034306.

[10] I. Muntian, **Z. Patyk**, **A. Sobiczewski**, Yad. Fiz. **66** (2003) 1051; Phys. At. Nucl. 66 (2003) 1015.

[11] **A. Baran**, **Z.Łojewski**, **K. Sieja**, **M. Kowal**, Phys. Rev. **C 72** (2005) 044310.

[12] **I. Muntian**, S. Hofmann, **Z. Patyk**, **A. Sobiczewski**, Acta Phys. Pol. **B 34** (2003) 2073.

[13] **S. Ćwiok**, V.V. Pashkevich, **J. Dudek**, **W. Nazarewicz**, Nucl. Phys. A**410** (1983) 254.

[14] **S. Ćwiok**, **A. Sobiczewski**, Z. Phys. **A 342** (1992) 203.

[15] **I. Muntian**, **Z. Patyk**, **A. Sobiczewski**, Acta Phys. Pol. **B 34** (2003) 2141.

[16] **S. Ćwiok**, **S. Hofmann**, **W. Nazarewicz**, Nucl. Phys. A**573** (1994) 356.

[17] **S. Ćwiok**, **W. Nazarewicz**, P.H. Heenen, Phys. Rev. Lett. **83** (1999) 1108.

[18] O. Parkhomenko, **A. Sobiczewski**, Acta Phys. Pol. **B 35** (2004) 2447.

[19] A. Parkhomenko, **A. Sobiczewski**, Acta Phys. Pol. **B 36** (2005) 3115.

[20] **S. Ćwiok**,P.H. Heenen, **W. Nazarewicz**, Nature **433** (2005) 705.

[21] **K Pomorski**, **J. Dudek**, Phys. Rev. **C 67** (2003) 044316.

[22] **K. Pomorski**, Phys. Rev. **C 70** (2004) 044306.

[23] **S. Ćwiok**, **J. Dobaczewski**, P.-H. Heenen, **P. Magierski**, **W. Nazarewicz**, Nucl. Phys. A**611** (1996) 211.

[24] **M. Warda**, J. L. Egido, L. M. Robledo, **K. Pomorski**, Phys. Rev. **C 66** (2002) 014310.

[25] **A. Staszczak**, **J. Dobaczewski**, **W. Nazarewicz**, Int. J. Mod. Phys. **E 14** (2005) 395.

[26] **Z. Patyk**, **A. Baran**, J. F. Berger, J. Decharge, **J. Dobaczewski**, P. Ring, **A. Sobiczewski**, Phys. Rev. **C 59** (1999) 704.

[27] **A. Sobiczewski**, **K. Pomorski**, Prog. Part. Nucl. Phys. **58** (2007) 292.

THEORETICAL INVESTIGATIONS OF PROPERTIES AND SYNTHESIS OF SUPERHEAVY NUCLEI

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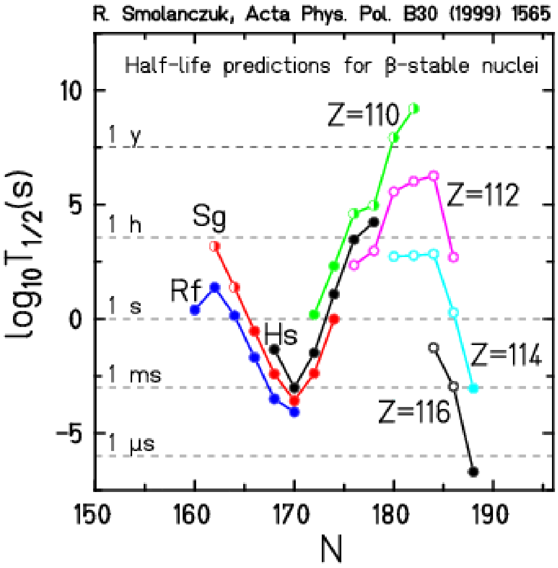
We were investigating very heavy nuclei with atomic numbers Z>103. Masses (binding energies), deformations, fission barriers, spontaneous-fission half-lives, as well as alpha-decay energies and half-lives have been calculated [1,2]. The nuclear binding energy has been calculated as a sum of the macroscopic and microscopic energies. The Yukawa-plus-exponential potential has been used as the macroscopic energy. The microscopic energy, originating from the structure of the single-particle energy levels of a nucleus, has been calculated by means of the Strutinsky method. Fission barrier has been found as binding energy versus position on the fission trajectory in the four-dimensional deformation space that describes axially and reflection symmetric nuclear shapes. The fission trajectory and, consequently, the spontaneous-fission half-live, has been obtained by minimizing the action integral that describes penetration of a nucleus through a potential-energy barrier. Alpha-decay half-live has been calculated by using the Viola and Seaborg formula with the parameters adjusted to heavy even-even nuclei.

The half-live systematics for beta-stable superheavy nuclei is shown in Fig.1. The alpha-decay half-lives are indicated by empty symbols whereas the spontaneous-fission half-lives by filled ones. Half-filled symbols indicate nuclei for which both decay modes have been predicted. It is clearly seen that the half-lives cover 16 orders of magnitude. The obtained half-lives are too small to find the superheavy nuclei in nature. They are, however, large enough in order to accumulate some of the superheavy nuclei if they were synthesized.

The possibilities of the production in the laboratory of spherical superheavy nuclei have been investigated theoretically in ref.[3]. The fusion reactions with the emission of one neutron have been considered. We have proposed a model for calculating the cross sections for these reactions. In the model the fusion cross section is calculated as a product of the probability of the formation of the compound nucleus (an intermediate state of fusion consisted of all nucleons of the colliding nuclei) and the probability of the emission of a neutron from the compound nucleus. The probability of the formation of the compound nucleus has been calculated as the probability of tunneling through an effective fusion barrier with the height dependent on the product of atomic numbers of the colliding nuclei. The probability of the emission of a neutron from the compound nucleus has been calculated by means of the modified statistical model formula. The modification takes into account an influence of shell effects on this probability. The most advantageous fusion cross sections have been obtained for some nuclei with atomic numbers Z=118-121 that could be synthesized in the reactions based on lead and bismuth target nuclei [3]. Decay chains for these nuclei with atomic numbers Z=118-120 have also been obtained [4,5].



R. Smolanczuk, Acta Phys. Pol. B30 (1999) 1565

Fig.1. *Calculated logarithm of half-live versus neutron number N for beta-stable even-even nuclei with atomic numbers Z=104-116.*

[1] **R. Smolańczuk**, Phys. Rev. C **56**, 812 (1997).

[2] **R. Smolańczuk**, Acta Phys. Pol. **B30**, 1565 (1999).

[3] **R. Smolańczuk**, Phys. Rev. C **63**, 044607 (2001).

[4] **R. Smolańczuk**, Phys. Rev. C **60**, 021301(R) (1999).

[5] **R. Smolańczuk**, Phys. Lett. **B509**, 227 (2001).

REACTION MECHANISM AND CROSS SECTIONS FOR PRODUCTION OF HEAVY AND SUPER-HEAVY NUCLEI

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Synthesis of super-heavy nuclei (of atomic numbers well beyond Z=100) focuses attention of nuclear physicists since many years. The non-existing in nature very heavy nuclei can be produced only with extremely low cross sections by fusing two lighter nuclei. However, the dynamics of these fusion reactions is very complex. It is essential to be able to predict the very small production cross sections and thus to choose optimal combinations of the two reacting nuclei and the optimal bombarding energies in experimental attempts to synthesize new super-heavy elements.

To some approximation, one can assume that the cross section to form a given super-heavy nucleus in its ground state, σ(form.) can be factorized in the form [1]:

$$\sigma(\text{form.}) = \sigma(\text{capture}) \cdot P(\text{fusion}) \cdot P(\text{surv.}), \qquad (1)$$

where σ(capture) is the cross section of overcoming the interaction barrier (the capture cross section), P(fusion) is the probability that the combined system will eventually fuse avoiding reseparation on the way from the contact configuration to the equilibrium shape, and P(surv.) is the probability for the compound nucleus to decay to the ground state of the final residual nucleus via evaporation of light particles and γ rays thus surviving fission which is the dominating decay mode of very heavy nuclei.

Our knowledge regarding the physics governing each of the mentioned above factors was rather limited and each of these factors required separate studies.

Following some early studies of the energy thresholds for fusion of very heavy systems [2], the existing data on capture cross sections were extensively studied [3,4] on medium and moderately heavy systems for which the overcoming the potential energy barrier automatically leads to fusion of the colliding nuclei and formation of the compound nucleus. All existing data on near-barrier fusion excitation functions have been analyzed using a simple "diffused-barrier formula" [1,3,4] derived assuming the Gaussian shape of the barrier height distributions. The obtained mean values of the barrier height have been used then for determination of the parameters of the empirical nucleus-nucleus potential [4]. A reliable systematics for determination of the capture cross sections [4] was obtained in such a way.

The fact that fusion cross sections for synthesis of super-heavy nuclei may be hindered by several orders of magnitude was known since many years. The existing theoretical models are not yet sufficiently developed to make reliable predictions of P(fusion) for a wide range of the compound nucleus Z, mass asymmetry of the fusing system and excitation energy. In [1,5,6] a simple model for calculating P(fusion), based on the Smoluchowski diffusion equation was proposed. It is assumed that after overcoming the Coulomb barrier (the "capture" stage) a rapid growth of the neck between the colliding nuclei brings the system to the injection point in the asymmetric fission valley that extends outside the saddle configuration. Starting from the injection point, the system may diffuse uphill and overcome the saddle due to thermal shape fluctuations. A closed formula for the probability of this process has been derived [1,5,6]

Great effort was made to construct and test [7-11] a reliable Monte Carlo program for calculating survival probabilities for heavy compound nuclei for which evaporation channels are dominated by fission decay mode. Shell-effect dependent level densities for both evaporation and fission channels were used in these calculations. Various assumptions regarding predictions of the ground state and saddle point energies [12] of nuclei in the unexplored region of super-heavy nuclei were tested.

In the present stage, the "Capture-Diffusion-Survival" model that is based on the factorization scheme of Eq. (1) can successfully explain [6] existing data on so called "cold fusion" (1n) reactions in which all super-heavy nuclei up to Z=113 had been synthesized. Attempts to make predictions for both symmetric [13] and asymmetric systems (used for synthesis of Z=114-118 nuclei in hot fusion reactions) are under way.

[1] W.J. Świątecki, **K. Siwek-Wilczyńska, J. Wilczyński**, Acta Phys. Pol. **B34**, 2049 (2003).

[2] **K. Siwek-Wilczyńska, J. Wilczyński**, Phys. Rev. **C64**, 024611 (2001).

[3] **K. Siwek-Wilczyńska, I. Skwira, J. Wilczyński**, Acta Phys. Pol. **B34**, 1867 (2003).

[4] **K. Siwek-Wilczyńska, J. Wilczyński**, Phys. Rev. **C69**, 024611 (2004).

[5] W.J. Świątecki, **K. Siwek-Wilczyńska, J. Wilczyński**, Int. J. Mod. Phys. **E13**, 261 (2004).

[6] W.J. Świątecki, **K. Siwek-Wilczyńska, J. Wilczyński**, Phys. Rev. **C71**, 014602 (2005).

[7] **K. Siwek-Wilczyńska, I. Skwira, J. Wilczyński**, Phys. Rev. **C72**, 034605 (2005).

[8] I**. Skwira, K. Siwek-Wilczyńska, J. Wilczyński**, Acta. Phys. Pol. **B36**, 1191 (2005).

[9] **K. Siwek-Wilczyńska, I. Skwira, J. Wilczyński**, Int. J. Mod. Phys**. E14**, 333 (2005).

[10] **K. Siwek-Wilczyńska, I. Skwira-Chalot, J. Wilczyński**, Int. J. Mod. Phys. **E15**, 405 (2006).

[11] **K. Siwek-Wilczyńska, I. Skwira, J. Wilczyński**, AIP Conf. Proc. **853**, 265 (2006).

[12] J. Świątecki, **K. Siwek-Wilczyńska, J. Wilczyński**, Acta Phys. Pol. B, in press.

[13] **K. Siwek-Wilczyńska, I. Skwira, J. Wilczyński**, Int. J. Mod. Phys. **E16**, 483 (2007).

EXPERIMENTAL SEARCH FOR SUPER HEAVY ELEMENTS (SHE)

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Experimental facility: Heavy ion cyclotron & LISE3, GANIL, France; Superconducting cyclotron & BIGSOL, Cyclotron Institute, Texas A&M University, USA.

One of the most important question in low energy nuclear physics, concerns the limit of nuclear stability and the existence, due to the shell effects, of stable island of super heavy nuclei centered at Z=114 (proton number) and N=184 (neutron number). Discoveries announced by Dubna group in years 1998-2002, especially synthesis of element Z=114 in reaction ^{48}Ca+^{242,244}Pu, seem to confirm existance of the island of stable SHE.

The main experimental method for the production of new SHE elements are fusion reactions of heavy ions at low incident energies. Disadvantage of the method is very low production cross section for the SHE, 1 pbarn for Z=112 element.

Our group actively participates in experimantal search for the SHE nuclei since year 1999. This activity concentrates on two different approaches to the subject. The first approach (I) is based on the standard, cold fusion (excititation energy of a compound nucleus is 10-20 MeV) reaction techniques, and experiments are conducted at the GANIL facility in the frame of FULIS collaboration. Here we use the velocity Wien filter LISE3. The second approach (II) uses a new concept to search for super and hyper heavy elements and experiments are accomplished at the super conducting cyclotron at the Cyclotron Institute of Texas A&M University in collaboration with groups from Italy and Texas A&M. One of the main tool is a superconducting solenoid BIGSOL.

In the case of the approach (II), in order to synthesize elements in the region of Z=116-128, a fissile target nuclei such as U or Th are bombarded by heavy ions e.g. Au nuclei. The Au nucleus induces the fission of the target nucleus and one of the fission fragments is transferred to the projectile. As a results a new very heavy nucleus is created. If the fission fragment is neutron-rich it enhances the creation and survival probability of the super heavy nucleus.

Using method (I) several experiments were conducted: ^{86}Kr+^{208}Pb →^{294}118, at the beam energy E=5.270 MeV/u, ^{54}Cr+^{208}Pb→^{262}106, E=4.70 and 4.76 MeV/u, and in the fall of 2003 ^{58}Fe+^{208}Pb→^{266}108, E=4.92, 4.87 and 4.82 MeV/u and ^{76}Ge+^{208}Pb→^{284}114, E=4.90 MeV/u. In the first mentioned experiment no fusion events were observed. In the measurements aimed at synthesis of elements 106 (Sg) and 108 (Hs) we have found 12 and 7 events correspondingly, which confirms the production of those nuclei. For the isotope of the element Z=108 this gives around 10% of all documented events so far. In the reaction with Ge beam, attempt to make synthesis of Z=114, we did not find any case of the synthesis, only estimate of the production cross section for Z=114, $\sigma<0.5$ pbarn, was received. Results of these experiments are presented in papers [1-5].

In case of method (II) two experiments were conducted. One in 2004, when we have studied reactions with the following projectiles - targets combinations: ^{172}Yb (E=15, 10 and 7.5 MeV/u), ^{197}Au (E=7.5 MeV/u), ^{136}Xe (E=7.5 MeV/u) and ^{84}Kr(E=25, 15 and 7.5 MeV/u) on a ^{232}Th target and with ^{238}U (E=7.5 MeV/u) projectiles on ^{nat}Ti, ^{64}Zn, ^{90}Zr and ^{232}Th targets[6]. Analysis of experimental data allowed to select some conadidates, see figure below, for super heavy elements as well as the most promising reaction for the next experiment searching for the SHE. It is ^{197}Au + ^{232}Th at E=7.5 MeV/u. In August 2006 this reaction was studied. It is important to notice that the method gives a hope that the formation cross section for the SHE nuclei can be much higher here then in the case of fusion reactions.

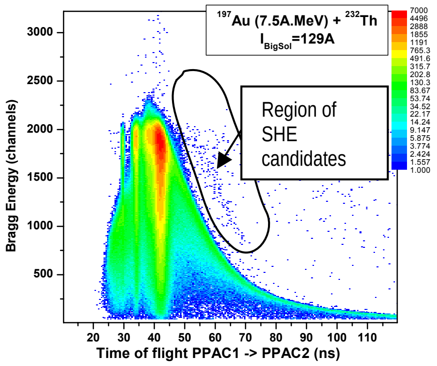

Fig. 1. *Energy signal from Bragg detector as a function of time of flight for heavy ion products of the reaction Au+Th. Products are selected by the BIGSOL.*

[1] J. Peter, N. Alamanos, N. Amar, J.C. Angelique, R. Anne, G. Auger, F. Becker, R. Dayras, A. Drouart, J.M. Fontbonne, A. Gillibert, S. Grevy, D. Guerreau, F. Hanappe, R. Hue, R. Lalleman, N. Lecesne, T. Legou, M. Lewitowicz, R. Lichtenthaler, E. Lienard, W. Mittig, F. De Oliveira, N. Orr, G. Politi, **Z. Sosin**, M.G. Saint-Laurent, J.C. Steckmeyer, C. Stodel, J. Tillier, R. De Tourreil, A.C.C. Villari, J.P. Wieleczko, **A. Wieloch**, Proc. Int. Symp. on Exotic Nuclei, EXON, Baikal, eds. Yu. Penionzhkievich and E. Cherepanov, World Scientific, (2001), p.41.

[2] S. Grevy, N. Alamanos, N. Amar, J.C. Angelique, R. Anne, G. Auger, F. Becker, R. Dayras, A. Drouart, J.M. Fontbonne, A. Gillibert, D. Guerreau, F. Hanappe, R. Hue, A.S. Lalleman, T. Legou, R. Lichtenthaler, E. Lienard, W. Mittig, F. De Oliveira, N. Orr, G. Politi, **Z. Sosin**, M.G. Saint-Laurent, J.C. Steckmeyer, C. Stodel, J. Tillier, R. de Tourreil, A.C.C. Villari, J.P. Wieleczko, **A. Wieloch**, Jour. Nucl. Rad. Sci., vol. **3**, no.1, (2002), p.9.

[3] J. Peter , N. Alamanos, N. Amar, J.C. Angelique, R. Anne, G. Auger, F. Becker, R. Dayras, A. Drouart, J.M. Fontbonne, A. Gillibert, S. Grevy, D. Guerreau, F. Hanappe, R. Hue, R. Lalleman, N. Lecesne, T. Legou, M. Lewitowicz, R. Lichtenthaler, E. Lienard, W. Mittig, F. De Oliveira, N. Orr, G. Politi, **Z. Sosin**, M.G. Saint-Laurent, J.C. Steckmeyer, C. Stodel, J. Tillier, R. De Tourreil, A.C.C. Villari, J.P. Wieleczko, **A. Wieloch**, Nuclear Physics et Border Lines, May 21-24, Lipari (Italy), eds. G. Fazio, G. Giardina, F. Hanappe, G. Imme and N. Rowley, World Scientific, (2002), p.257.

[4] **A. Wieloch**, **Z. Sosin**, J. Peter, **K. Łojek**, N. Alamanos, N. Amar, R. Anne, J.C. Angelique, G. Auger, R. Dayras, A. Drouart, J.M. Fontbonne, A. Gillibert, S. Grevy, F. Hanappe, F. Hannachi, R. Hue, A. Khouaja, T. Legou, A. Lopez-Martens, E. Lienard, L. Manduci, F. de Oliveira Santos, N. Orr, G. Politi, M.G. Saint-Laurent, C. Stodel, L. Stuttg, J. Tillier, R. de Tourreil, A.C.C. Villari, J.P. Wieleczko, Nucl. Inst. Meth., **A517**, (2004), p.364.

[5] Ch. Stodel, R. Anne, G. Auger, B. Bouriquet, J.M. Casandjian, R. Cee, G. De France, F. de Oliveira Santos, R. De Tourreil, A. Khouaja, A. Peghaire, M.G. Saint-Laurent, A.C.C. Villari, J.P. Wieleczko, N. Amar, S. Grevy, J. Peter, R. Dayras, A. Drouart, A. Gillibert, Ch. Theisen, A. Chatillon, E. Clement, **K. Łojek**, **Z. Sosin**, **A. Wieloch**, K. Hauschild, F. Hannachi, A. Lopez-Martens, L. Stuttge, F.P. Hessberger, S. Hofmann, R. Lichtenthaler, F. Hanappe, Proc. Int. Symp. on Exotic Nuclei, EXON2004,5-12 July, 2004, eds. Yu. Penionzhkievich and E. Cherepanov, World Scientific, (2005), p.180.

[6] T. Materna, **S. Kowalski**, K. Hagel, R. Murthy, J. Natowitz, L. Qin, G. Souliotis, R. Wada, J. Wang, D. Fabris, M. Lunardon, M. Morando, S. Moretto, G. Nebbia, S. Pesente, V. Rizzi, G. Viesti, V. Bocci, M. Barbui, A. Andrighetto, M. Cinausero, G. Prete, **Z. Majka**, **A. Wieloch**,
Progress in Research April 1, 2004-March 31, Cyclotron Institute, Texas A&M University, (2005), p.II-8.

NUCLEAR STRUCTURE STUDIES WITH DEEP-INELASTIC HEAVY ION REACTIONS

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Experimental facilities: Tandem and ALPI Linac with the GASP, EUROBALL and PRISMA-CLARA spectrometer at the INFN LNL Legnaro, ATLAS accelerator with the Gammasphere multi-detector array at the Argonne NL

In contrast to the neutron-deficient nuclei which are easily produced in fusion evaporation reactions, the nuclei located at and beyond the neutron-rich side of the beta stability valley could not be accessed for spectroscopic investigation and until recently for most of them only limited information from beta-decay studies was available. This difficulty severely restricted the range for the exploration of nuclear structure evolution with the isospin composition of nuclei.

We pioneered the spectroscopic study of these unknown and hard-to-reach nuclei by exploiting deep-inelastic heavy-ion reactions in thick target gamma-coincidence experiments. The details of the experimental method and techniques used in the data analysis were recently reviewed [1] along with the summary of many spectroscopic results obtained in various regions of the nuclides chart. The research program included investigation of the reaction mechanism details [9,l] that are particularly important for spectroscopic application of binary heavy-ion reactions. The nuclear structure spectroscopic study was concentrated on the neutron-rich Sn and Te isotopes, exotic nuclei in the sdf "island of inversion" region as well as neutron-rich Ni, Cu, Fe and Zn isotopes, which included the discovery of the N=40 subshell closure in ^{68}Ni isotope. Spectacular results demonstrating the power of the method was the study of hitherto completely inaccessible high-spin state structures in nuclei from the doubly magic ^{208}Pb region.

In the last decade the investigation was focused mainly on neutron-rich nuclei located in two regions of shell model nuclei, namely close to the doubly magic ^{48}Ca and ^{208}Pb. In nuclei from the ^{208}Pb region extensive high-spin level structures were established, reaching record I=30 spin values and including many new isomeric states, as e.g. the simple $\pi h_{11/2}^{-2}$ 10^+ isomer in ^{206}Hg, which yielded the proton $h_{11/2}$ hole effective charge [7]. In this region the fine tuning of shell model input parameters allows to improve the theoretical description and confront it with experiment up to high-spin and excitation energy ranges. The obtained results included also interesting phenomena that could not be studied earlier e.g. the coupling of the octupole vibrations with various multi-particle configuration states.

In the ^{48}Ca region the newly identified structures provided experimental input to improve and test the shell model description which still suffers from rather incomplete knowledge of two-body interactions. In these light nuclei the evolution of nuclear structure with increasing neutron excess displays dramatic dynamics involving reordering of single particle energies and appearance of subshell closures. As an example, summarizes results confirming the existence of the N=32 closure and the absence of a similar effect at the N=34 which was anticipated in some theoretical calculations. In the most recent extension of this research line the PRISMA-CLARA spectrometer at the INFN LNL Legnaro is used to reach even more exotic neutron-rich nuclei of the ^{48}Ca region. Within the reported period the obtained results were communicated in 47 publications (14 examples are listed below).

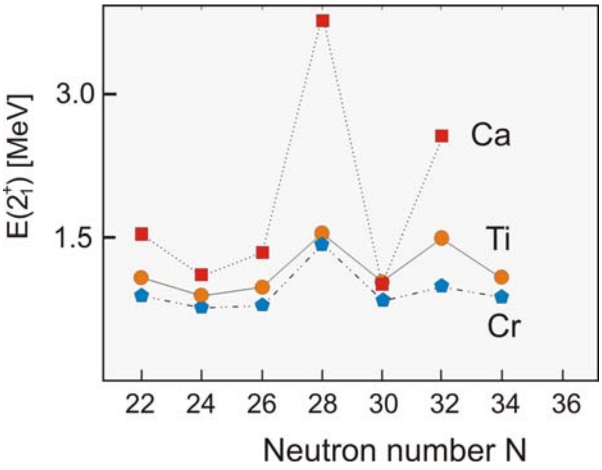

Fig. 1. *Systematics of first 2$^+$ states in neutron-rich Ca, Ti and Cr isotopes.*

[1] **R. Broda**, J. Phys. (London) **G32**, R151 (2006).

[2] **B. Fornal, R. Broda, W. Królas, T. Pawłat, J. Wrzesiński,** D. Bazzacco, D. Fabris, S. Lunardi, C. Rossi Alvarez, G. Viesti, G. de Angelis, M. Cinausero, D.R. Napoli, Z.W. Grabowski, Phys. Rev. **C55**, 762 (1997).

[3] M. Rejmund, K.H. Maier, **R. Broda, B. Fornal, M. Lach, J. Wrzesiński**, J. Blomqvist, A. Gadea, J. Gerl, M. Gorska, H. Grawe, M. Kaspar, H. Schaffner, C. Schlegel, R. Schubart, H.J. Wollersheim, Eur. Phys. J. **A1**, 261 (1998).

[4] **R. Broda, B. Fornal**, P.J. Daly, C.T. Zhang, P. Bhattacharyya, Z.W. Grabowski, J.F.C. Cocks, P.A. Butler, P.T. Greenlees, G.D. Jones, P.M. Jones, R. Julin, I.Y. Lee, A.O. Macchiavelli, J. Blomqvist, Phys. Rev. **C59**, 3071 (1999).

[5] **B. Fornal, R. Broda, W. Królas, T. Pawłat, J. Wrzesiński**, D. Bazzacco, S. Lunardi, C. Rossi Alvarez, G. Viesti, G. de Angelis, M. Cinausero, D. Napoli, J. Gerl, E. Caurier, F. Nowacki, Eur. Phys. J. **A7**, 147 (2000).

[6] **J. Wrzesiński,** K.H. Maier, **B. Fornal, R. Broda, W. Królas, T. Pawłat,** D. Bazzacco, S. Lunardi, C. Rossi Alvarez, G. de Angelis, A. Gadea, J. Gerl, M. Rejmund, Eur. Phys. J. **A10**, 259 (2001).

[7] **B. Fornal, R. Broda,** K.H. Maier, **J. Wrzesiński** G.J. Lane, M. Cromaz, A.O. Macchiavelli, R.M. Clark, K. Vetter, A.P. Byrne, G.D. Dracoulis, M.P. Carpenter, R.V.F. Janssens, I. Wiedenhoever, M. Rejmund, J. Blomqvist, Phys. Rev. Lett. **87**, 212501 (2001).

[8] R.V.F. Janssens, **B. Fornal,** P.F. Mantica, B.A. Brown, **R. Broda,** P. Bhattacharyya, M.P. Carpenter, M. Cinausero, P.J. Daly, A.D. Davies, T. Glasmacher, Z.W. Grabowski, D.E. Groh, M. Honma, F.G. Kondev, **W. Królas,** T. Lauritsen, S.N. Liddick, S. Lunardi, N. Marginean, T. Mizusaki, D.J. Morrissey, A.C. Morton, W.F. Mueller, T. Otsuka, **T. Pawłat,** D. Seweryniak, H. Schatz, A. Stolz, S.L. Tabor, C.A. Ur, G. Viesti, I. Wiedenhover, **J. Wrzesiński,** Phys. Lett. **546B,** 55 (2002).

[9] **W. Królas, R. Broda, B. Fornal, T. Pawłat,** H. Grawe, K.H. Maier, M. Schramm, R. Schubart, Nucl. Phys. **A724**, 289 (2003).

[10] S.N. Liddick, P.F. Mantica, R.V.F. Janssens, **R. Broda,** B.A. Brown, M.P. Carpenter, **B. Fornal,** M. Honma, T. Mizusaki, A.C. Morton, W.F. Mueller, T. Otsuka, J. Pavan, A. Stolz, S.L. Tabor, B.E. Tomlin, Phys. Rev. Lett. **92**, 072502 (2004).

[11] **R. Broda, B. Fornal, W. Królas, T. Pawłat, J. Wrzesiński**, D. Bazzacco, G. de Angelis, S. Lunardi, C. Rossi Alvarez, Eur. Phys. J. **A20**, 145 (2004).

[12] **B. Fornal,** S. Zhu, R.V.F. Janssens, M. Honma, **R. Broda,** P.F. Mantica, B.A. Brown, M.P. Carpenter, P.J. Daly, S.J. Freeman, Z.W. Grabowski, N.J. Hammond, F.G. Kondev, **W. Królas,** T. Lauritsen, S.N. Liddick, C.J. Lister, E.F. Moore, T. Otsuka, **T. Pawłat,** D. Seweryniak, B.E. Tomlin, **J. Wrzesiński**, Phys. Rev. **C70**, 064304 (2004).

[13] **B. Fornal,** S. Zhu, R.V.F. Janssens, M. Honma, **R. Broda,** B. A. Brown, M.P. Carpenter, S.J. Freeman, N.J. Hammond, F.G. Kondev, **W. Królas,** T. Lauritsen, S.N. Liddick, C.J. Lister, S. Lunardi, P.F. Mantica, N. Marginenan, T. Mizusaki, E.F. Moore, T. Otsuka, **T. Pawłat,** D. Seweryniak, B.E. Tomlin, C.A. Ur, I. Wiedenhover, **J. Wrzesiński**, Phys. Rev. **C72**, 044315 (2005).

[14] **R. Broda, B. Fornal, W. Królas, T. Pawłat, J. Wrzesiński,** D. Bazzacco, S. Lunardi, G. de Angelis, A. Gadea, C. Ur, N. Marginean, R.V.F. Janssens, M.P. Carpenter, S.J. Freeman, N. Hammond, T. Lauritsen, C.J. Lister, F. Moore, D. Seweryniak, P.J. Daly, Z.W. Grabowski, B.A. Brown, M. Honma, Acta Phys. Pol. **B36**, 1343 (2005).

SINGLE-PARTICLE AND STRONGLY DEFORMED STRUCTURES IN $f_{7/2}$ SHELL NUCLEI

J. Styczeń, P. Bednarczyk, M. Brekiesz, J. Grębosz, M. Kmiecik, M. Lach, A. Maj, W. Męczyński, M. Ziębliński, K. Zuber,
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The interplay of the shell model and deformed structures is more pronounced and easier to study in light nuclei due to relatively low numbers of protons and neutrons. Those numbers in the $f_{7/2}$ nuclei are not prohibitively large for the new generation shell-model calculations, and at the same time, are large enough to create substantial collectivity. Some time already [1], the presence of collective modes of excitations linked with intruder states in those nuclei was observed. Recently, we have studied in detail the nature of high-spin positive parity (intruder) states in the $f_{7/2}$ nuclei. Several investigations were performed [2-5] applying the 4π γ-ray spectrometer GASP and also the Recoil Mass Spectrometer (RMS) at INFN, Legnaro. The lifetimes, *B(M1)* and *B(E2)* values indicated a significant defor-mation of the positive parity intruder band in ^{45}Sc. The band is predicted by the mean-field approach accounting for cross-shell *p-h* excitations. The large scale spherical shell-model calculations reproduce observed excitation energies and transition rates for both spherical and deformed structures [4]. New generation of the γ-ray detecting array such as EUROBALL IV (EB) and application of the efficient Recoil Filter Detector (RFD) [6] - with its high ability for Doppler correction, allowed for further studies of the $f_{7/2}$ nuclei and for reaching very high spin states at and beyond 'band terminating states' [7,8], (Fig.1). The systematics of the observed *B(E2)* and *B(M1)* probabilities indicate a decrease of collectivity when approaching band termination in ^{45}Sc (Fig. 2). Detailed investigations of single-particle and collective bands in several other nuclei [9-10], were also performed with the precise gamma-recoil coincidence, and measurements of DCO ratios and polarization of γ-rays. Moreover, the EB+RFD combination allowed for lifetime determination of very short lived excited states. In ^{42}Ca, we observed a non-*yrast* positive-parity band reaching (12^{+}) state at 11405 keV. The enhancement of the *B(E2)* values for the in-band *E2* transitions confirmed the highly collective (deformed) character of the band. It is very likely built on the 0^{+} state at 1837 keV, of the 6*p*-4*h* configuration which was known both from transfer reactions and theory to have strongly deformed structure. Moreover, further studies of the GDR in the decay of the ^{46}Ti compound nucleus have revealed splitting of the GDR into two components and a direct feeding of that band by the low energy component. This effect is interpreted as an evidence for the Jacobi shape transition which occurs in the very hot fast rotating ^{46}Ti nucleus [12-14]. To further confirm high deformation of the ^{46}Ti* nucleus, *a*-particle spectra were investigated with the use of the charged-particle multi-detector array ICARE and a large volume BGO detector [15,16], applying the same reaction as in the previous GDR decay studies. The experimental data give strong signatures of very large deformations of the ^{46}Ti compound nucleus in the Jacobi transition region at the highest-spins

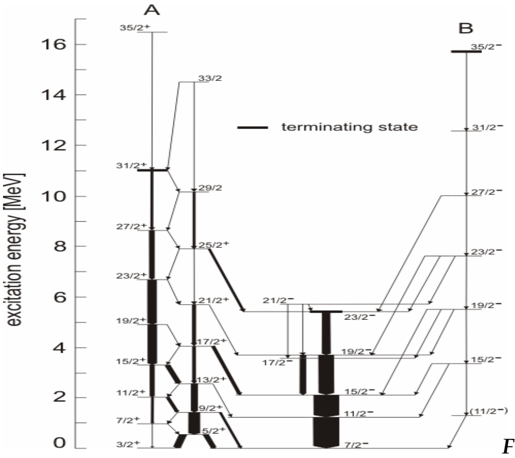

Fig. 1.

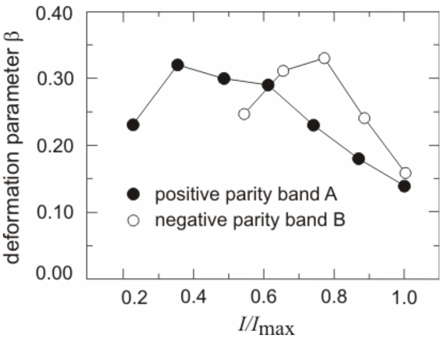

Fig. 2.

.

1. **J. Styczeń**, J. Chevallier, B. Haas, N. Schulz, P. Taras, M. Toulemonde, Nucl. Phys. **A262**, 317 (1976);
2. **P. Bednarczyk, J. Styczeń, R. Broda, M. Lach, W. Męczyński**, D. Bazzacco, F. Brandolini, G. de Angelis, S. Lunardi, L. Müller, N. Medina, C. Petrache, C. Rossi-Alvarez, F. Scarlassara, G.F. Segato, C. Signorini, F. Soramel, Nucl. Phys. **A583**, 227 (1995);
3. **P. Bednarczyk, R. Broda, M. Lach, W. Męczyński, J. Styczeń,** D. Bazzacco, F. Brandolini, G. de Angelis, S. Lunardi, L. Müller, N. Medina, C. Petrache, C. Rossi-Alvarez, F. Scarlassara, G.F. Segato, C. Signorini, F. Soramel, W. Nazarewicz, E. Ormand, Acta Phys. Pol. **B27**, 145 (1996);
4. **P. Bednarczyk, J. Styczeń, R. Broda, M. Lach, W. Męczyński, W. Nazarewicz,** W.E. Ormand, **W. Satuła,** D. Bazzacco, F. Brandolini, G. de Angelis, S. Lunardi, L. Müller, N.H. Medina, C.M. Petrache, C. Rossi Alvarez, F. Scarlassara, G.F. Segato, C. Signorini,F. Soramel, Phys. Lett. **B393**, 285 (1997);
5. **P. Bednarczyk, J. Styczeń, R. Broda, M. Lach, W. Męczyński**, D. Bazzacco, F. Brandolini, G. de Angelis, S. Lunardi, L. Müller, N.H. Medina, D.R. Napoli, C.M. Petrache, C. Rossi Alvarez, F. Scarlassara, G.F. Segato, C. Signorini,F. Soramel, Eur. Phys. J. **A2**, 157 (1998);
6. **W. Męczyński, P. Bednarczyk, J. Grębosz**, J. Heese, M. Janicki, K.H. Maier, J.C. Merdinger, K.M. Spohr, **M Ziębliński, J. Styczeń**, Nucl. Instr. Methods, **A580**, 1310 (2007);
7. **P. Bednarczyk, W. Męczyński, J. Styczeń, J. Grębosz, M. Lach, A. Maj, M. Ziębliński,** N. Kintz, J.C. Merdinger, N. schulz, J.P. Vivien, A. Bracco, J.L. Pedroza, M.B. Smith, K.M. Spohr, Acta Phys. Pol. **B32**, 747 (2001);
8. **P. Bednarczyk, J. Styczeń,** A. Bracco, D. Curien, **J. Grębosz, M. Lach, A. Maj**, J.C. Merdinger, **W. Męczyński**, F. Nowacki, M.B. Smith, K. Spohr, J.P. Vivien, **M. Ziębliński,** Eur. Phys. J. **A20,** 45 (2004);
9. **M. Lach, P. Bednarczyk,** A. Bracco, **J. Grębosz, M. Kadłuczka,** N. Kintz, A. Maj, J.C. Merdinger, **W. Męczyński,** J.L. Pedroza, N. Schulz, M.B. Smith, K.M. Spohr, J.P. Vivien, **M. Ziębliński, J. Styczeń**, Eur. Phys. J. **A12**, 381 (2001);
10. **M. Lach, J. Styczeń, W. Męczyński, P. Bednarczyk**, A. Bracco, J. Grębosz, A. Maj, J.C. Merdinger, N. Schulz, M.B. Smith, K.M. Spohr, J.P. Vivien, M. Ziębliński, Eur. Phys. J. **A16,** 309 (2003);
11. **M. Lach, J. Styczeń, W. Męczyński, P. Bednarczyk**, A. Bracco, J. Grębosz, **A. Maj**, J.C. Merdinger, N. Schulz, M.B. Smith, K.M. Spohr, **M. Ziębliński**, Eur. Phys. J. **A25**, 1 (2005);
12. **A. Maj, M. Kmiecik, W. Królas, J. Styczeń**,A. Bracco, F. Camera, B. Million, J.J. Gaardhoeje, B. Herskind, **M. Kicińska-Habior, J. Kownacki**, W.E. Ormand, Acta Phys. Pol. **B32**, 2433 (2001);
13. **A. Maj, M. Kmiecik**, A. Bracco, F. Camera, **P. Bednarczyk**, B. Herskind, S. Brambilla, G. Benzoni, M. Brekiesz, D. Curien, G. De Angelis, E. Farnea, **J. Grębosz, M. Kicińska-Habior**, S. Leoni, **W. Męczyński**, B. Million, D.R. Napoli, J. Nyberg, C.M. Petrache, **J. Styczeń**, O. Wieland, **M. Ziębliński**, **K. Zuber,** N. Dubray, **J. Dudek, K. Pomorski**, Nucl. Phys. **A731**, 319 (2004);
14. **A. Maj** *et al., this Report;*
15. **M. Brekiesz, P. Papka, A. Maj, M. Kmiecik, F. Beck, P. Bednarczyk, J. Grębosz**, F. Haas, **W. Męczyński**, V. Rauch, M. Rousseau, A. Sanchez, I. Zafra, **J. Styczeń**, S. Thummerer, **M. Ziębliński**, **K. Zuber**, Acta Phys. Pol. **B36**, 1175 (2005);
16. **M. Brekiesz, A. Maj, M. Kmiecik, K. Mazurek, W, Męczyński, J. Styczeń, K. Zuber, P. Papka**, C. Beck, F. Haas, V. Rauch, M. Rousseau, I. Zafra, **J. Dudek**, N. Schunck, Nucl. Phys. **A788**, 224C-230C (2007).

QUEST OF CHIRAL SYMMETRY BREAKING IN ATOMIC NUCLEI

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Experimental facility: OSIRIS II, U200P cyclotron at the Heavy Ion Laboratory

Chirality phenomenon is well known in chemistry and biology from the times of Pasteur who discovered that certain molecules exist in left- and right- handed forms. Recent theoretical and experimental works attracted attention to chirality in atomic nuclei. In these works the spontaneous breaking of chiral symmetry in the body-fixed frame has been predicted. In the laboratory reference frame it manifests itself as the presence of chiral partner collective bands, which should exist if three angular momenta vectors – of valence proton, valence neutron and of the even-even core – are mutually perpendicular forming left- or right- handed coordinate frames (Fig. 1).

Recently the candidates for the chiral bands have been found in several nuclei, namely in the odd-odd nuclei from the region of A~ 130 (nuclei in the vicinity of ^{128}Cs) and region of A~104 (nuclei around ^{104}Rh). In the majority of publications on the nuclear chirality only the level schemes are presented. Therefore, the lifetime measurements of the excited states belonging to the partner bands have been undertaken [1-6] since such experimental data are very sensitive to nuclear structure.

The ^{132}La and ^{128}Cs isotopes have been studied. High spin states of ^{128}Cs and ^{132}La nuclei were populated in the ^{122}Sn(^{10}B,4n)^{128}Cs and ^{122}Sn(^{14}N,4n)^{132}La reactions at the beam energy of 55 and 70 MeV, respectively. The beam was provided by the Warsaw U-200P cyclotron placed at the Heavy Ion Laboratory (Warsaw University). About 10^8 gamma-gamma coincident events were collected in each experiment by the OSIRIS II multidetector array consisting of 10 Compton-suppressed HPGe detectors. The lifetimes of the excited levels were determined by the Doppler shift attenuation method with the use of the procedure and computer code developed by A.A. Pasternak [5].

The lifetime results have shown that the ^{132}La and ^{128}Cs nuclei, in spite of their similar level schemes, have essentially different electromagnetic properties [6]. The reduced transition probabilities for ^{132}La are not consistent with the symmetry requirements imposed by chirality attained in the intrinsic system (Phys. Rev. Lett **93**, 172502 (2004)) The properties of the partner bands of ^{128}Cs exhibit the main features expected for chiral partner bands. It is the first case of such a good agreement of comprehensive experimental data with the chiral interpretation.

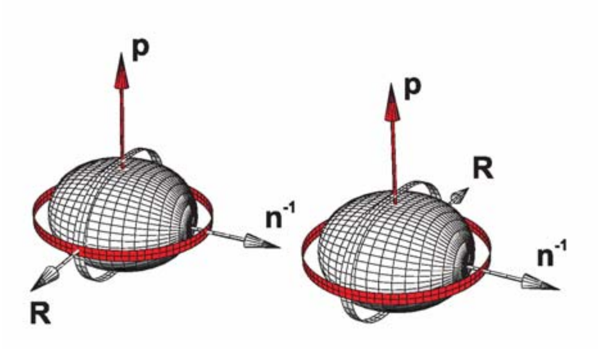

Fig. 1. *Three mutually perpendicular angular momenta vectors is odd-odd triaxial nucleus forming right-handed and left-handed states.*

[1] **E. Grodner**, **J. Srebrny**, **Ch. Droste**, **T. Morek**, A. A. Pasternak, **J. Kownacki**
International Journal of Modern Physics **E13**, 243-246 (2004)

[2] **E. Grodner**, **I. Zalewska**, **T. Morek**, **J. Srebrny**, **Ch. Droste**, **M. Kowalczyk**, **J. Mierzejewski**, **M. Sałata**, A. A. Pasternak, **J. Kownacki**, **M. Kisieliński**, **A. Kordyasz**, **P. Napiorkowski**, **M. Wolińska**, **S. G. Rohoziński**, **R. Kaczarowski**, **W. Płóciennik**, **E. Ruchowska**, **A. Wasilewski**, **J. Perkowski**
International Journal of Modern Physics **E14**, 347 (2005)

[3] **J. Srebrny**, **E. Grodner**, **T. Morek**, **I. Zalewska**, **Ch. Droste**, **J. Mierzejewski**, **J. Kownacki**, **J. Perkowski** Acta Physica Polonica **B36**, 1063-1069 (2005)

[4] **E. Grodner**, **J. Srebrny**, **I. Zalewska**, **T. Morek**, **Ch. Droste**, **M. Kowalczyk**, **J. Mierzejewski**, A.A. Pasternak, **J. Kownacki**, **M. Kisieliński** International Journal of Modern Physics **E15**, 548 (2006)

[5] **E. Grodner**, A.A. Pasternak, **Ch. Droste**, **T. Morek**, **J. Srebrny**, **J. Kownacki**, **W. Płóciennik**, **Wasilewski**, **M. Kowalczyk**, **M. Kisieliński**, **R. Kaczarowski**, **E. Ruchowska**, **A.Kordyasz** **and M.Wolińska** Eur. Phys. J. **A27**, 325-340 (2006)

[6] **E.Grodner**,**J. Srebrny**,A.A. Pasternak,**I. Zalewska**,**T. Morek**,**Ch. Droste**,**J. Mierzejewski**,**M. Kowalczyk**,**J. Kownacki**,**M. Kisieliński**,**S.G. Rohoziński**,T. Koike,K. Starosta,**A. Kordyasz**,**P.J. Napiorkowski**,**M. Wolińska-Cichocka**,**E. Ruchowska**,**W. Płóciennik**,**J. Perkowski**
Phys. Rev. Lett. **97**, 172501 (2006)

NUCLEAR STRUCTURE CLOSE TO N=Z=50

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Experimental facility: GSI on-line mass separator, TAS spectrometer, EUROBALL detector

Studies of nuclei in the ^{100}Sn region offer the possibility to test nuclear models describing properties of nuclei in which protons and neutrons occupy identical orbitals near a double shell closure. A variety of phenomena are predicted to occur in such systems. Nuclei with N≈Z are expected to show enhanced neutron-proton correlations giving rise e.g. to a new pairing mode, high-spin isomers or enhanced α-decay probability.

An insight into the role of the proton-neutron interaction and/or core excitation in the shell model structure of N=Z nuclei close to ^{100}Sn can be gained, e.g. in studies of decay properties of their ground and isomeric states, as well as by γ-ray spectroscopy investigations of excited near-yrast states populated in heavy ions induced fusion-evaporation reactions.

Beta decay of nuclei in the ^{100}Sn region proceeds mainly via the Gamow-Teller (GT) transformation of a $g_{9/2}$ proton into a $g_{7/2}$ neutron. Since the N=Z=50 shell closure occurs far from the beta stability line, isotopes in this region have relatively large Q_{EC} values and the GT strength can be investigated and confronted with theoretical predictions over a broad range of excitation energies. Recently, decays of several nuclei in the ^{100}Sn region have been studied using the total absorption spectroscopy technique. These measurements provided reliable information on the GT strength distribution in the decays of close neighbours of ^{100}Sn e.g. ^{100,102}In and ^{102,103}Sn [1-4]. The same nuclei were also in focus of numerous in-beam γ-ray investigations, which gradually overcome technical difficulties of populating excited states of more and more close neighbours of ^{100}Sn. A significant example of such studies was first identification of excited states in ^{103}Sn, which lead to the determination of single-particle energy spacing between neutron $g_{7/2}$ and $f_{5/2}$ orbitals (110±40 keV) [5].

Slightly more distant neighbours of ^{100}Sn, like ^{99}Ag, ^{101}Ag, ^{106}Sb were investigated in-beam, up to the highest spin which can be generated by the respective valence particle (hole) configurations with the rigid N=Z=50 core [6,7]. Investigation of prompt γ-ray radiation emitted from excited states of ^{102}In led in turn to the identification of states related to the neutron excitations across the N=50 shell gap [8].

Several high-spin isomers are predicted to occur in nuclei close to ^{100}Sn as a result of the attractive interaction of $pg_{9/2}$-$ng_{9/2}$ holes in the upper part of the $g_{9/2}$ sub-shell, which lowers the energy of stretched configurations and creates spin gaps. Studies of spin-gap isomers characterized by very specific configurations provide a valuable test of residual interactions and truncation schemes in the shell model calculations. One of the most spectacular discoveries of the recent years was the observation of the decay of ^{94m}Ag(21$^+$) isomer resulting from the stretched coupling of the $(g_{9/2}^{-3})_{21/2}$ proton and neutron configurations. This state shows unprecedented variety of disintegration modes such as β-decay and delayed proton emission, proton decay and even two proton emission to the high spin states of the final nuclei [9-10]. Another important result is the observation of the core-excited E4 isomer in ^{98}Cd, from which the size of the ^{100}Sn shell gap of 6.46(15) MeV was inferred [11].

One of the consequences of the N, Z=50 shell closure is the occurrence of an island of α-emitters in the trans-tin region. Moreover, strong binding of nuclei close to the ^{100}Sn opens a possibility of cluster emission – a very exotic decay mode observed so far only in the ^{208}Pb region. In the ^{100}Sn region, ^{114}Ba is predicted to be the most promising candidate for the observation of ^{12}C cluster emission. Measurements of the energies in the $^{114}\text{Ba} \rightarrow {}^{110}\text{Xe} \rightarrow {}^{106}\text{Te}$ α-decay chain provided precise information on the Q-value for the ^{12}C emission from ^{114}Ba and allowed verification of the theoretical models [12].

[1] C.Plettner, L.Batist, J.Doring, A.Blazhev, H.Grawe, V.Belleguic, C.R.Bingham, R.Borcea, **M.Gierlik**, M.Górska, N.Harrington, **Z.Janas**, **M.Karny**, R.Kirchner, C.Mazzocchi, P.Munro, E.Roeckl, K.Schmidt, R.Schwengner, Phys. Rev. **C66**, 044319 (2002).

[2] M.Gierlik, **A.Płochocki**, **M.Karny**, **W.Urban**, **Z.Janas**, L.Batist, F.Moroz, R.Collatz, M.Gorska, H.Grawe, M.Hellstrom, Z.Hu, R.Kirchner, W.Liu, M.Rejmund, E.Roeckl, M.Shibata, J.Agramunt, A.AlGóra, A.Gadea, B.Rubio, J.L.Tain, D.Cano-Ott, S.Harissopulos, Nucl. Phys. **A724**, 313 (2003).

[3] **M.Karny**, L.Batist, A.Banu, F.Becker, A.Blazhev, B.A.Brown, W.Bruchle, J.Doring, T.Faestermann, M.Gorska, H.Grawe, **Z.Janas**, A.Jungclaus, M.Kavatsyuk, O.Kavatsyuk, R.Kirchner, M.La Commara, S.Mandal, C.Mazzocchi, K.Miernik, I.Mukha, S.Muralithar, C.Plettner, **A.Plochocki**, E.Roeckl, M.Romoli, K.Rykaczewski, M.Schadel, K.Schmidt, R.Schwengner, **J.Żylicz**, Eur. Phys. J. **A27**, 129 (2006).

[4] O.Kavatsyuk, M.Kavatsyuk, L.Batist, A.Banu, F.Becker, A.Blazhev, W.Bruchle, J.Doring, T.Faestermann, M.Górska, H.Grawe, **Z.Janas**, A.Jungclaus, **M.Karny**, R.Kirchner, M.La Commara, S.Mandal, C.Mazzocchi, I.Mukha, S.Muralithar, C.Plettner, A.Płochocki, E.Roeckl, M.Romoli, M.Schadel, R.Schwengner, **J.Żylicz**, Eur.Phys. J. **A25**, 211 (2005)

[5] C.Fahlander, **M.Palacz**, D.Rudolph, D.Sohler, J.Blomqvist, **J.Kownacki**, K.Lagergren, L.O.Norlin, J.Nyberg, A.AlGóra, C.Andreoiu, G.de Angelis, A.Atac, D.Bazzacco, L.Berglund, T.Back, J.Cederkall, B.Cederwall, Zs.Dombradi, B.Fant, E.Farnea, A.Gadea, M.Gorska, H.Grawe, N.Hashimoto-Saitoh, A.Johnson, A.Kerek, W.Klamra, S.M.Lenzi, A.Likar, M.Lipoglavsek, **M.Moszynski**, D.R.Napoli, C.Rossi-Alvarez, H.A.Roth, T.Saitoh, D.Seweryniak, O.Skeppstedt, M.Weiszflog, **M.Wolinska**, Phys. Rev. **C63**, 021307 (2001).

[6] D.Sohler, Zs.Dombradi, J.Blomqvist, J.Cederkall, J.Huijnen, M.Lipoglavsek, **M.Palacz**, A.Atac, C.Fahlander, H.Grawe, A.Johnson, A.Kerek, W.Klamra, **J.Kownacki**, A.Likar, L.-O.Norlin, J.Nyberg, J.Persson, D.Seweryniak, G.de Angelis, P.Bednarczyk, D.Foltescu, D.Jerrestam, S.Juutinen, E.Makela, M.dePoli, H.A.Roth, T.Shizuma, O.Skeppstedt, G.Sletten, J.Timar, S.Tormanen, M.Weiszflog, Eur. Phys.J. **A16**, 171 (2003).

[7] D.Sohler, **M.Palacz**, Zs.Dombradi, M.Hjorth-Jensen, C.Fahlander, L.-O.Norlin, J.Nyberg, T.Back, K.Lagergren, D.Rudolph, A.AlGóra, C.Andreoiu, G.de Angelis, A.Atac, D.Bazzacco, J.Cederkall, B.Cederwall, B.Fant, E.Farnea, A.Gadea, M.Gorska, H.Grawe, N.Hashimoto-Saitoh, A.Johnson, A.Kerek, W.Klamra, **J.Kownacki**, S.M.Lenzi, A.Likar, M.Lipoglavsek, **M.Moszynski**, D.R.Napoli, C.Rossi-Alvarez, H.A.Roth, T.Saitoh, D.Seweryniak, O.Skeppstedt, J.Timar, M.Weiszflog, **M.Wolinska**, Nucl. Phys. **A753**, 251 (2005).

[8] D.Sohler, **M.Palacz**, Zs.Dombradi, J.Blomqvist, C.Fahlander, L.-O.Norlin, J.Nyberg, T.Back, K.Lagergren, D.Rudolph, A.AlGóra, C.Andreoiu, G.de Angelis, A.Atac, D.Bazzacco, J.Cederkall, B.Cederwall, B.Fant, E.Farnea, A.Gadea, M.Gorska, H.Grawe, N.Hashimoto-Saitoh, A.Johnson, A.Kerek, W.Klamra, **J.Kownacki**, S.M.Lenzi, A.Likar, M.Lipoglavsek, **M.Moszynski**, D.R.Napoli, C.Rossi-Alvarez, H.A.Roth, T.Saitoh, D.Seweryniak, O.Skeppstedt, J.Timar, M.Weiszflog, **M.Wolinska**, Nucl. Phys. **A708**, 181 (2002).

[9] I.Mukha, E.Roeckl, J.Doring, L.Batist, A.Blazhev, H.Grawe, C.R.Hoffman, M.Huyse, **Z.Janas**, R.Kirchner, M.La Commara, C.Mazzocchi, C.Plettner, S.L.Tabor, P.Van Duppen, M.Wiedeking
Phys. Rev. Lett. **95**, 022501 (2005).

[10] I.Mukha, E.Roeckl, L.Batist, A.Blazhev, J.Doring, H.Grawe, L.Grigorenko, M.Huyse, **Z.Janas**, R.Kirchner, M.La Commara, C.Mazzocchi, S.L.Tabor, P.Van Duppen, Nature **439**, 298 (2006).

[11] A.Blazhev, M.Górska, H.Grawe, J.Nyberg, **M.Palacz**, E.Caurier, O.Dorvaux, A.Gadea, F.Nowacki, C.Andreoiu, G.de Angelis, D.Balabanski, Ch.Beck, B.Cederwall, D.Curien, J.Doring, J.Ekman, C.Fahlander, K.Lagergren, J.Ljungvall, **M.Moszynski**, L.-O.Norlin, C.Plettner, D.Rudolph, D.Sohler, K.M.Spohr, O.Thelen, M.Weiszflog, M.Wisell, **M.Wolinska**, **D.Wolski**, Phys. Rev. **C69**, 064304 (2004).

[12] C.Mazzocchi, **Z.Janas**, L.Batist, V.Belleguic, J.Doring, **M.Gierlik**, M.Kapica, R.Kirchner, G.A.Lalazissis, H.Mahmud, E.Roeckl, P.Ring, K.Schmidt, P.J.Woods, **J.Żylicz** Phys. Lett. **532B**, 29 (2002).

OCTUPOLE DEFORMATION IN THE ACTINIDE AND LANTHANIDE REGIONS

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Experimental facilities: Isotope Separator On Line ISOLDE at CERN, OSIRIS at Studsvik

Numerous experimental and theoretical studies were performed in the 80's providing evidence of reflection asymmetric octupole deformation in the actinide nuclei around A=225. The octupole deformed nuclei exhibit features familiar to molecular physics. One signature of such shape in the ground state of even-even nuclei is the presence of particularly low K, $J^{\pi}=0,1^-$ states, and in odd-A nuclei a characteristic feature is the existence of a parity-doublet band with levels connected by strong electric dipole (E1) transitions. In the reflection-symmetric nuclei the expectation value of E1 moment, D_0, is zero, thus a large static E1 moment may arise only in the intrinsic frame of reflection asymmetric system. Many of these nuclei have been studied at ISOLDE/CERN in the beta decay experiments (see [1] and references quoted therein) using advanced fast timing and γ-ray techniques. The lifetimes of the excited states have been measured using the time-delayed βγγ(t) method. Two-fold γ–coincidences were recorded in the Tardis multidetector array. It represents the first use of these complex techniques at ISOLDE. In particular the spectroscopic properties of the transitional nuclei ^{225,227}Fr, ^{227,228,229,231}Ra and ^{229,231}Th were studied [2-9]. Recent results provide the first information on the absolute values of B(E1) in the octupole transitional Fr, Ra and Th nuclei. In the theoretical part of this study the quasiparticle-plus-phonon model (QPPM) with inclusion of the Coriolis coupling was introduced to interpret the results, and particularly the transition rates, for octupole transitional nuclei. The model calculations reproduce remarkably well the general enhancement (and occasional quenching) of the E1 intra-doublet transitions. It was the first time that this model had been used for the interpretation of the transition rates in the actinide region.

The presence of pronounced octupole effects in the heavy lanthanides region around N=88 and Z=56 was predicted by Nazarewicz et al., Nucl.Phys.A429(1984) 269. In fact, this region is the second one besides the heavy Ra-Th region, where these correlations are exceptionally strong, although they are somewhat weaker than in the Ra-Th nuclei. Some of these features were studied using γ -ray multidetector arrays such as EUROGAM2 or GAMMASPHERE and spontaneously fissioning ^{248}Cm and ^{252}Cf sources (see review [10]). The experimental data allowed to establish the extent of the enhanced octupole correlation region, the low-Z and high-Z at 54 and 63, respectively. The low-N limit has been found at N=85, while high-N limit is at present not known (see e.g.[11-13]).

Systematic studies of octupole collectivity in the Ba-Nd region were undertaken by the Warsaw-Uppsala-Świerk collaboration, and were complementary to the investigation of octupole collective nuclei in the heavy actinide region. Recent advance in research on the odd-A nuclei from A=147 and A=149 provide for the first time an opportunity to establish structure systematics of these nuclei, from the region near the line of stability to the most exotic one [14,15].The results from the beta decay work obtained recently at OSIRIS were crucial in order to correct the level scheme proposed in the prompt-fission studies on ^{149}Ce, the most exotic A=149 nucleus on which there is detailed spectroscopy information.

[1] **W. Kurcewicz**, Hyperfine Interactions 129, 175 (2000).

[2] A.J. Aas, H. Mach, M.J.G. Borge, B. Fogelberg, I.S. Grant, **K. Gulda**, E. Hagebo, **W. Kurcewicz**, J. Kvasil, A. Lindroth, T. Martinez, D. Nosek, B. Rubio, J.F. Smith, K. Steffensen, J.L. Tain, O. Tengblad, T.F.Thorsteinsen, Nucl. Phys. **A611**, **281** (1996).

[3] **W.Kurcewicz**, I.S. Grant, **K. Gulda**, A.J. Aas, J. Billowes, M.J.G. Borge, D.G. Burke, P.S. Butler, J.F.C. Cocks, B. Fogelberg, S.J. Freeman, G.D. Jones, E. Hagebo, P. Hoff, J. Honsi, A. Lindroth, G. Lovhoiden, H. Mach, T. Martinez, R.A. Naumann, K. Nybo, G. Nyman, H. Ravn, B. Rubio, J. Simpson, A.G. Smith, J.F. Smith, K. Steffensen, J.L. Tain, O. Tengblad, T.F. Thorsteinsen, and the ISOLDE Collaboration, Nucl. Phys. **A621**, **827** (1997).

[4] D.G.Burke,**W. Kurcewicz**, G. Lovhoiden, M.J.G. Borge, M. Cronqvist, H. Gabelmann, H. Gietz, P. Hill, N. Kaffrell, S. Mattson, R.A. Naumann, K. Nybo, G. Nyman, J. Rogowski, G.L. Struble, T.F. Thorsteinsen, Nucl. Phys. **A612**, **91** (1997).

[5] **K.Gulda**, H. Mach, A.J. Aas, M.J.G. Borge, D.G. Burke, B. Fogelberg, H. Gietz, I.S. Grant, E. Hagebo, P. Hill, P. Hoff, N. Kaffrell, **W. Kurcewicz**, A. Lindroth, G. Lovhoiden, T. Martinez, S. Mattson, R.A. Naumann, K. Nybo, G. Nyman, B. Rubio, M. Sanchez-Vega, J.L.Tain, R.B.E. Taylor, O. Tengblad, T.F. Thorsteinsen, Nucl. Phys. **A636**, **28** (1998).

[6] A.J.Aas, H. Mach, J. Kvasil, M.J.G. Borge, B. Fogelberg, I.S. Grant, **K. Gulda**, E. Hagebo, P. Hoff, **W. Kurcewicz**, A. Lindroth, G. Lovhoiden, A. Mackova, T. Martinez, B. Rubio, M. Sanchez-Vega, J.F. Smith, J.L. Tain, R.B.E. Taylor, O. Tengblad, T.F. Thorsteinsen, Nucl. Phys. **A654**, **499** (1999).

[7] L.M. Fraile, M.J.G.Borge, H. Mach, R. Boutami, A.J. Aas, B Fogelberg, L.M. Garcia-Reffi, I.S. Grant, **K. Gulda**, E. Hagebo, **W. Kurcewicz**, J. Kvasil, M.J. Lopez, G. Lovhoiden, T. Martinez, B. Rubio, J.L. Tain, O. Tengblad, Nucl.Phys. **A686**, **71** (2001).

[8] M.J.G. Borge, L.M. Fraile, **W. Kurcewicz**, H. Mach, Nucl. Phys. **A690**, **227c** (2001).

[9] **E.Ruchowska**, **W.A.Płóciennik**, **J.Żylicz**, H.Mach, J.Kvasil, A.AlGóra, N.Amzal, T.Back, M.G.Borge, R.Boutami, P.A.Butler, J.Cederkall, B.Cederwall, B.Fogelberg, L.M.Fraile, H.O.U.Fynbo, E.Hagebo, P.Hoff, H.Gausemel, A.Jungclaus, **R.Kaczarowski**, A.Kerek, **W.Kurcewicz**, K.Lagergren, E.Nacher, B.Rubio, **A.Syntfeld**, O.Tengblad, **A.A.Wasilewski**, L.Weissman, Phys.Rev. **C73**, 044326 (2006).

[10] **W.Urban**, "Experimental Studies of Octupole Correlations in Lanthanide Nuclei", Habilitation, Warsaw University, Warszawa 2001.

[11]**W.Urban, A.Korgul, T.Rząca-Urban**, N.Schulz, M.Bentaleb, E.Lubkiewicz, J.L.Durell, M.J.Leddy, M.A.Jones, W.R.Phyllips, A.G.Smith, B.J.Varley, I.Ahmad, L.R.Morss, Phys.Rev. **C61**, 041301 (2000).

[12] **W.Urban**, W.R.Phillips, I.Ahmad, **J.Rękawek, A.Korgul, T.Rząca-Urban**, J.L.Durell, M.J.Leddy, A.G.Smith, B.J.Varley, N.Schulz, L.R.Morss, Phys.Rev. **C66**, 044302 (2002).

[13] **W.Urban, T.Rząca-Urban**, J.L.Durell, W.R.Phillips, A.G.Smith, B.J.Varley, N.Schulz, I.Ahmad, Phys.Rev. **C69**, 017305 (2004).

[14]**A.Syntfeld**, H.Mach, **W.Kurcewicz**, B.Fogelberg, **W.Płóciennik, E.Ruchowska**, Phys.Rev. **C68**, 024304 (2003).

[15]**A.Syntfeld**, H.Mach, **W.Kurcewicz**, B.Fogelberg, N.Amzal, J.Galy, **K.Gulda, A.Korgul**, A.Lindroth, **W.A.Płóciennik**, M.Sanchez-Vega, **W.Urban**, Eur. Phys. J. **A23**, **481** (2005).

NUCLEAR SHAPE COEXISTENCE STUDIED BY COULOMB EXCITATION

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Experimental facility: Warsaw Cyclotron, REX-ISOLDE (CERN), GANIL, JYFL Jyvaskyla, GSI Darmstadt, JAEA Tokai, NBI Copenhagen, NSRL Rochester, LBL Berkeley

Low-energy multiple Coulomb excitation provides a wealth of information on electromagnetic structure of atomic nuclei. This powerful experimental method allows in particular to infer nuclear shapes, which makes it ideally suited to investigate the cases of predicted shape coexistence. The present renaissance of modern Coulex can be associated with evolution of accelerator facilities, delivering large variety of both stable and radioactive beams as well as with development of sophisticated software such as Warsaw-Rochester Coulomb excitation least square code GOSIA.

One of the indications of shape coexistence in even-even nuclei is an observation of a low-lying 0^+ state, which in some rare cases, such as ^{72}Ge or ^{98}Mo, can be the first excited state. These two nuclei, together with neighboring isotopes, were subjects of an extensive Coulomb excitation study. The second 0^+ excited state in ^{72,74,76}Ge isotopes, as well as in ^{96}Mo, was found to be of spherical shape [1,2], while for ^{70}Ge and ^{98}Mo both 0^+ states were deformed, differing either by magnitude of deformation (^{70}Ge, [1]) or by triaxiality (^{98}Mo, [3]). A complicated interplay of collective and single-particle effects, which is characteristic for the nuclei in the transitional region, makes a full and consistent explanation of observed phenomena a real challange.

A series of experiments performed on beams of the Warsaw Cyclotron allowed to determine the deformation parameters of the two gamma bands in ^{165}Ho, differing by the projection of K quantum number [4]. Unexpectedly, the deformations proved to be different, showing the influence of the K spin projection on the internal structure of the nucleus.

For the radioactive odd-A ^{231}Pa nucleus Coulomb excitation studies [5] allowed for determination of 78 matrix elements of E1, M1, E2, E3, E4 multipolarities. It is the richest set of electromagnetic matrix elements ever known for an odd-A nucleus.

The rich and precise experimental data obtained using Coulomb excitation method provide a stringent test for theoretical models, stimulating the mutual cooperation between experimentalists and theorists[8]. Another example are the experimental results on even-even Mo isotopes [2,3] indicated the significance of neutron-proton pairing, which was by then considered as negligible for $N \neq Z$ nuclei.

Recently new interest in Coulex is drawn by availability of radioactive beams allowing to perform Coulomb excitation of short-lived unstable nuclei. For the neutron-deficient ^{74,76}Kr isotopes studied at the SPIRAL facility of GANIL, states up to 8^+ were excited, and large sets of matrix elements, including diagonal ones, were determined [6], which provided new arguments in the discussion of shape coexistence in this mass region. The recent measurement of quadrupole moment of the first excited state in ^{70}Se [7]. suggested a prolate shape of this nucleus, in contrary to the theoretical predictions.

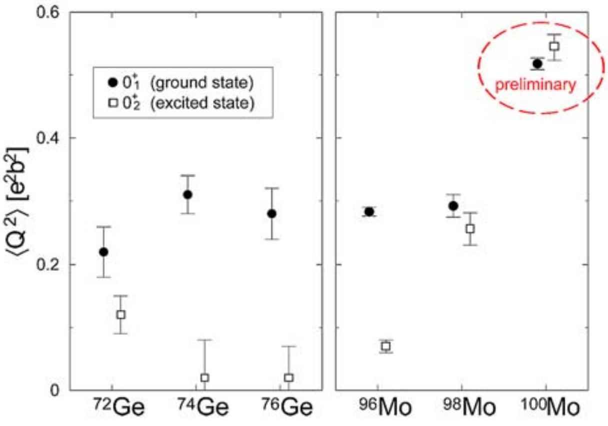

Fig1. *Quadrupole deformation parameters of Mo and Ge isotopes determined using Coulomb excitation method [1,2,3].*

[1] M. Sugawara, Y. Toh, **T.Czosnyka**, M. Oshima, T. Hayakawa, H. Kusakari, Y. Hatsukawa, J. Katakura, N. Shinohara, M. Matsuda, T. Morikawa, A. Seki, F. Sakata, Eur. Phys. J **A16**, 409 (2003).

[2] **K. Wrzosek**, **M. Zielińska**, **J. Choiński**, **T. Czosnyka**, Y. Hatsukawa, **J. Iwanicki**, J. Katakura, M. Kisieliński, M. Koizumi, M. Kowalczyk, H. Kusakari, M. Matsuda, T. Morikawa, **P. J. Napiorkowski**, A. Osa, M. Oshima, L. Reissig, T. Shizuma, **J. Srebrny**, M. Sugawara, Y. Toh, Y. Utsuno, **K. Zając**, Int. J. Mod. Phys. **E15**, 374 (2006).

[3] **M. Zielińska**, **T. Czosnyka**, **J. Choiński**, **J. Iwanicki**, **P. J. Napiorkowski**, **J. Srebrny**, Y. Toh, M. Oshima, A. Osa, Y. Utsuno, Y. Hatsukawa, J. Katakura, M. Koizumi, M. Matsuda, T. Shizuma, M. Sugawara, T. Morikawa, H. Kusakari, A. D. Efimov, V. M. Mikhajlov, Nucl. Phys. **A712**, 3 (2002).

[4] **J. Iwanicki**, **M. Zielińska**, **T. Czosnyka**, **J. Choiński**, **P. J. Napiorkowski**, M. Loewe, M. Wurkner, **J. Srebrny**, Journal of Physics G-Nuclear and Particle Physics Vol **29**, 743 (2003).

[5] M. Wurkner, J. de Boer, A. I. Levon, M. Loewe, J. Kvasil, **J. Srebrny**, **P. J. Napiorkowski**, **J. Iwanicki**, **T. Czosnyka**, Nucl. Phys. **A725**, 3 (2003).

[6] W. Korten, E. Bouchez, E. Clement, A. Chatillon, A. Gorgen, Y. Le Coz, C. Theisen, J. Wilson, J. M. Casandjian, G. de France, G. Sletten, **T. Czosnyka**, **J. Iwanicki, M. Zielińska**, C. Andreoiu, P. Butler, R. D. Herzberge, D. Jenkins, G. Jones, F. Becker, J. Gerl, W. Catford, C. Timis, Nucl. Phys. **A746**, 90c (2004).

[7] A. Hurst, P. Butler, D. Jenkins, P. Delahaye, F. Wenander, F. Ames, C. Barton, T. Behrens, A. Burger, J. Cederkall, E. Clement, T. Czosnyka, T. Davinson, G. de Angelis, J. Eberth, A. Ekstrom, S. Franchoo, G. Georgiev, A. Gorgen, R.-D. Herzberg, M. Huyse, O. Ivanov, **J. Iwanicki**, G. Jones, P. Kent, U. Koster, T. Kroll, R. Krucken, A. Larsen, M. Nespolo, M. Pantea, E. Paul, M. Petri, H. Scheit, T. Sieber, S. Siem, J. Smith, A. Steer, I. Stefanescu, N. Syed, J. Van de Walle, P. Van Duppen, R. Wadsworth, N. Warr, D. Weisshaar, **M. Zielinska**, Phys. Rev. Lett. **98**, 072501 (2007).

[8] **J. Srebrny**, **T. Czosnyka**, **C. Droste**, **S. G. Rohoziński**, **L. Próchniak**, **K. Zając**, **K. Pomorski**, D. Cline, C. Y. Wu, A. Backlin, L. Hesselgren, R. M. Diamond, D. Habs, H. J. Korner, F. S. Stephens, C. Baktash, R. P. Kostecki, Nucl. Phys. **A766**, 25 (2006).

[9] N. Amzal, P. A. Butler, D. Hawcroft, N. J. Hammond, R. D. herzberge, G. D. Jones, C. Scholey, O. Stezowski, **T. Czosnyka, J. Iwanicki, P. J. Napiorkowski**, R. Julin, H. Mach, J. Cederkall, L. M. Fraile, H. O. U. Fynbo, Nucl. Phys. **A734**, 465 (2004).

[12] F. Becker, A. Petrovici, **J. Iwanicki**, N. Amzal, W. Korten, K. Hauschild, A. Hurstel, Ch. Theisen, P.A. Butler, R.A. Cunningham, **T. Czosnyka**, G. de France, J. Gerl, P. Greenlees, K. Helariutta, R.-D. Herzberg, P. Jones, R. Julin, S. Juutinen, H. Kankaanpaa, M. Muikku, P. Nieminen, O. Radu, P. Rahkila, Ch. Schlegel, Nucl.Phys. **A770**, 107 (2006).

A STUDY OF THE VIOLATION OF K – SELECTION RULES

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Experimental facility: NBI Tandem accelerator & NORDBALL, Risø, Denmark,
Tandem Accelerator in Garching, Germany ATLAS & GAMMASPHERE & CHICO,
Argonne, USA, Warsaw Cyclotron & OSIRIS II, Warszawa

The projection *K* of the total angular momentum *I* on the symmetry axis of a deformed nucleus appears to be conserved, as evidenced by the existence of "*K* isomers," nuclear states that are metastable despite the availability of allowed decay paths. In axially symmetric nuclei *K* is expected to be a good quantum number, so that an electromagnetic (EM) transition must obey the selection rule $|\Delta K| \leq \lambda$, where λ is the multipolarity of the electromagnetic transition. However, *K*-forbidden γ decays are known to be merely hindered, rather than truly forbidden.

Coulomb excitation of high-*K* bands has been observed, showing an apparent violation of the *K* selection rule, but the mechanism remained a mystery. Coriolis mixing or breaking of axial symmetry can result in EM transitions, such as direct excitation of a high-*K* isomer band from the GSB, that are forbidden between pure-*K* bands. Alternatively, if there is a multi-step path available, consisting of successive allowed or low-forbiddenness transitions, then multiple Coulomb excitations can populate high-*K* bands.

The first case, investigated using COULEX technique, was a study of K-isomer in ^{180}Ta. Two types of Coulomb excitation experiments were performed to find a fast depopulation path from the $K^{\pi}=9^-$ extremely long-lived excited state to $K^{\pi}=1^+$ GSB. Regular in-beam studies allowed to identify γ-vibrational bands with typical bandhead E2 excitation strengths. A complementary measurement using Coulomb activation technique was performed with ^{36}S and ^{64}Ni projectiles and thin Ta targets. The excitation functions and the ^{180}Ta recoil angular distributions favor a $K^{\pi} = 7^+$ octupole vibration at Ex = 1155(40) keV as intermediate state in the population of the ground state [1,2,3].

Coulomb excitation of ^{178}Hf target with a 650 MeV ^{136}Xe beam has revealed three distinctly different mechanisms to populate the $K^{\pi}=6^+$ ($T_{1/2}$=77 ns), 16^+ (31 yr) and 8^+ (4 s) high spin states in the ^{178}Hf isomer bands. The bands in question were populated in a Coulex measurement, although a direct excitation of high-*K* bands is strongly *K*-forbidden. A rapid increase in *K*-mixing with increasing spin in the isomer bands was observed, as well as an onset and saturation of *K*-mixing in low-*K* bands, whereas the mixing was negligible in the high-*K* bands [4,5,6,7].

The decay of the 9.3 ms $K^{\pi}=8^-$ isomer in ^{132}Ce was investigated by using the ^{136}Xe(^{16}O,4n) ^{132}Ce reaction. A band mixing mechanism involving the ground state and s bands is responsible for hindrance factors of E1 transitions for N=74 isotones. The newly discovered transition to 5_γ^+ state can result from a K-mixing due to the large degree of nonaxiality [8].

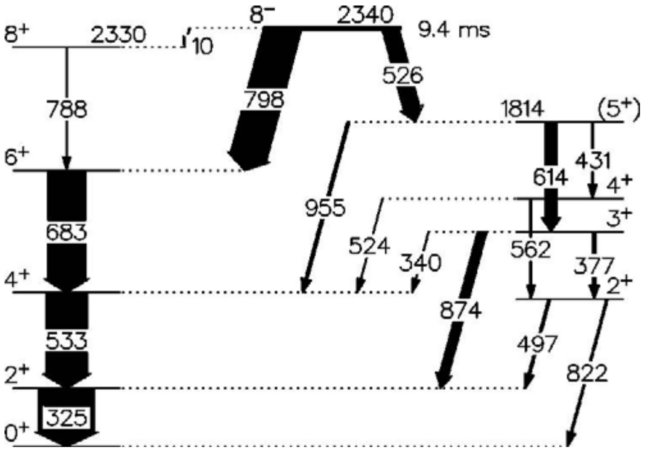

***Fig.1.** The decay scheme of the $K^{\pi}=8^-$ isomer in ^{132}Ce established on beam of Warsaw Cyclotron. The K-forbidden E1 ($8^- \rightarrow 8^+$) and E3 ($8^- \rightarrow 5^+$) decays of the isomer were newly found[8].*

[1] M.Loewe, J.de Boer, H.J.Maier, M.Wurkner, **P.Olbratowski, J.Srebrny, J.Choinski, T.Czosnyka, J.Iwanicki, P.J.Napiorkowski,** G.Hagemann, G.Sletten, S.A.Karamian, P.von Neumann-Cosel, A.Richter, C.Schlegel, H.J.Wollersheim, Z.Phys. **A356**, 9 (1996)

[2] Ch.Schlegel, P.von Neumann-Cosel, J.de Boer, J.Gerl, M.Kaspar, I.Kozhoukharov, M.Loewe, H.J.Maier, **P.J.Napiorkowski**, I.Peter, M.Rejmund, A.Richter, H.Schaffner, **J.Srebrny**, M.Wurkner, H.J.Wollersheim, and the EBGSI96-Collaboration, Eur.Phys.J. **A 10**, 135 (2001)

[3] M.Loewe, P.Alexa, **T.Czosnyka,** J.de Boer, **J.Iwanicki,** A.I.Levon, H.J.Maier, **P.J.Napiorkowski,** P.von Neumann-Cosel, A.Richter, C.Schlegel, G.Sletten, **J.Srebrny**, M.Wurkner, Phys.Lett. **551B**, 71 (2003)

[4] **P.J. Napiorkowski, J. Srebrny, T. Czosnyka**, J. Gerl, Ch. Schlegel, H-J. Wollersheim, D. Cline, C.Y. Wu, R. Teng, K. Vetter, A. Macchiavelli, M. Devlin, J. deBoer, **J. Iwanicki, J. Kownacki,** M. Loewe, M. Wuerkner Acta Phys. Pol. **B 32**, 861(2001)

[5] A.B.Hayes, D.Cline, C.Y.Wu, M.W.Simon, R.Teng, J.Gerl, C.Schlegel, H.J.Wollersheim, A.O.Macchiavelli, K.Vetter, **P.Napiorkowski, J.Srebrny**, Phys.Rev.Lett. **89**, 242501 (2002)

[6] A.B.Hayes, D.Cline, C.Y.Wu, J.Ai, H.Amro, C.Beausang, R.F.Casten, J.Gerl, A.A.Hecht, A.Heinz, R.Hughes, R.V.F.Janssens, C.J.Lister, A.O.Macchiavelli, D.A.Meyer, E.F.Moore, **P.Napiorkowski**, R.C.Pardo, Ch.Schlegel, D.Seweryniak, M.W.Simon, **J.Srebrny**, R.Teng, K.Vetter, H.J.Wollersheim, Phys.Rev.Lett. **96**, 042505 (2006)

[7] A.B.Hayes, D.Cline, C.Y.Wu, H.Ai, H.Amro, C.Beausang, R.F.Casten, J.Gerl, A.A.Hecht, A.Heinz, H.Hua, R.Hughes, R.V.F.Janssens, C.J.Lister, A.O.Macchiavelli, D.A.Meyer, E.F.Moore, **P.Napiorkowski**, R.C.Pardo, Ch.Schlegel, D.Seweryniak, M.W.Simon, **J.Srebrny**, R.Teng, K.Vetter, H.J.Wollersheim, Phys.Rev. **C 75**, 034308 (2007)

[8] **T.Morek, J.Srebrny, Ch.Droste, M.Kowalczyk, T.Rzaca-Urban**, K.Starosta, **W.Urban, R.Kaczarowski, E.Ruchowska, M.Kisielinski, A.Kordyasz, J.Kownacki, M.Palacz, E.Wesolowski**, W.Gast, R.M.Lieder, **P.Bednarczyk, W.Meczynski, J.Styczen**, Phys.Rev. **C63**, 034302 (2001).

POLARIZATIONAL-DIRECTIONAL CORRELATION FROM ORIENTED NUCLEI

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Experimental facility: EUROGAM II and EUROBALL III

Experimental determination of the spin and parity of excited states is crucial for nuclear structure study. To determine these quantities in the "in-beam" spectroscopy, one should combine results of the DCO analysis (giving information about spins) with linear polarization of γ-transitions (giving information about parities). In modern multidetector γ-spectrometers (e.g. EUROBALL, RISING, EXOGAM) segmented Ge detectors are frequently used. In future such detectors will be employed in the AGATA and GRETA γ-tracking arrays. Such highly segmented detectors can work as sensitive Compton polarimeters. Nowadays, the large total efficiency of arrays allows us to carry out coincidence measurements between γ-ray polarimeters and the remaining Ge-detectors.

In the typical situation of nuclei excited during a heavy ion reaction, γ-rays are emitted in the cascade from an aligned nucleus. In the standard procedure aimed at the parity determination, the polarization of γ-quantum is measured at $\theta_1 \approx 90^o$ (see Fig. 1) in coincidence with γ-rays registered in the remaining detectors. Often, the final results for the spin and parity assignment are not unique. It was the reason that we have proposed to measure new additional observables, namely:

1. the correlation between linear polarization of one γ-ray quantum and direction of emission of another γ-quantum (being in coincidence with the former one). This polarizational-directional correlation from oriented nuclei is named PDCO. Two different modes are considered, namely POL-DIR (correlation between polarization of γ_1 and direction of emission of γ_2 - see inset in Fig. 1) and DIR-POL (correlation between direction of γ_1 and polarization of γ_2.
2. the correlation between linear polarization of γ_1 and polarization of γ_2, both γ's being in the cascade. In this case a standard detector located at θ_2 (Fig. 1) should be replaced by the second polarimeter e.g. CLOVER. This polarization-polarization correlation from oriented nuclei is named PPCO.

A general formula for both types of correlations was derived [1,2] and appropriate observables were proposed. The formula and a computer program (available for request) give an opportunity for measuring new observables sensitive for γ-multipolarity, spins and parities of investigated levels. Some important symmetries, [2] very helpful for planning the PDCO or PPCO experiments, result from our formula. The abilities of the PDCO and PPCO methods were checked experimentally [3,4] by using data from the EUROGAM II experiments. The general formula describes also the cases well known from the literature e.g. the standard case when polarization of γ_1 is measured and information is integrated over all the possible emission direction of γ_2 ("4π integrated PDCO").

We suggest the following strategy [4] when polarization is measured by means of multidetector arrays: use the "4π integrated PDCO" method [2,3], but if results turn out to be not unique then use the PDCO [3] and PPCO [4] methods. The linear polarization sensitivities of the CLOVER and CLUSTER detectors following from our experiments are given in [3] and [5], respectively.

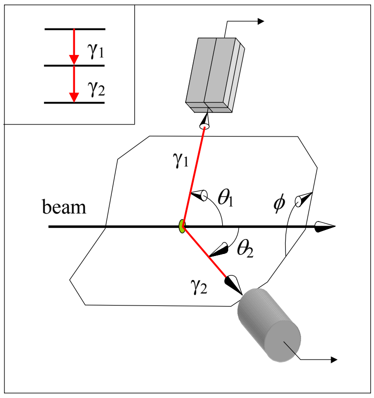

Fig. 1. *Geometry of an in-beam experiment in which polarization and direction of γ_1 and direction of γ_2 are measured.*

[1] **S.G. Rohoziński**, **K. Starosta**, **Ch. Droste**, **T. Morek**, **J. Srebrny**, **P. Magierski,** Acta Phys. Polonica **B27** (1996) 499

[2] **Ch. Droste**, **S.G. Rohoziński**, **K. Starosta**, **T. Morek**, **J. Srebrny**, **P. Magierski,** Nucl. Instr. and Meth. **A378** (1996) 518

[3] **K. Starosta**, **T. Morek**, **Ch. Droste**, **S.G. Rohoziński**, **J. Srebrny**, **A. Wierzchucka**, M. Bergstrom, B. Herskind, E. Melby, **T. Czosnyka**, **P.J. Napiorkowski**, Nucl. Instr. and Meth. **A423** (1999) 16

[4] **Ch. Droste**, **K. Starosta**, **A. Wierzchucka**, **T. Morek**, **S.G. Rohoziński**, **J. Srebrny**, M. Bergstrom, B. Herskind, **E. Wesołowski,** Nucl. Instr. and Meth. **A430** (1999) 260

[5] **Ch. Droste**, **B. Czajkowska**, **Z. Marcinkowska**, R.M. Lieder, **T. Morek**, **T. Rząca-Urban**, W. Gast, Nucl. Instr. and Meth. **A556** (2006) 182

LEVEL DENSITY PARAMETER

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The level density parameter “a”, necessary to calculate the single-particle level densities from the experimental data, was obtained within the selfconsistent models. Using the mean field potential obtained by Hartree-type procedure with the relativistic mean field theory (NL3) [1-5], Skyrme interaction (Skm*) [6] and Yukawa folded (YF) [7, 8] potential we have smoothed the single particle level schemes with temperature using the Strutinsky shell correction method by and folding the free energy in energy or nucleon number space [9]. The calculation was done for even-even spherical nuclei. The level density parameters “a”, where fitted to the liquid drop like formula and compared to the experimental data:T. von Egidy, H. H. Schmidt, A. N. Behkam, Nucl. Phys. A481, 189 (1988), J. Töke, W. J, Świątecki, Nucl. Phys. A**372,** 141 (1981),N. Dilg, W. Schantl, H. Vonach, M. Uhl, Nucl. Phys. **A 217,** 269 (1973) in Fig. 1. The best agreement was obtained for the YF potential with the formula of von Egidy (Egidy). The Thomas Fermi estimate (TF) is larger than all other microscopic predictions. The NL3 and Skm* results lie near the predictions of Dijg obtained within the back shifted Fermi gas model (Dilg). The results are displayed for different nuclei (upper panel), isotones (second panel) and β-stable elements (third panel). The number $n = A/a$ is presented in the lowest panel.

The deformation dependence of level density parameter “a” was investigated for a few nuclei with the Yukawa folded potential and the common formula for “a” for spherical and deformed nuclei was found in [7]:

$$\frac{a^{YF}}{1/\mathrm{MeV}} = 0.92A + 0.036\,A^{23} B_{\mathrm{surf}}(\mathrm{def}\,) + $$
$$+\,0.275\,A^{13} B_{\mathrm{curv}}(\mathrm{def}\,) - 0.001\,Z^2 / A^{13} B_{\mathrm{Coul}}(\mathrm{def}\,),$$

where B_{surf}(def), B_{curv}(def) *and* B_{Coul}(def) are the ratios of surface, curvature and Coulomb energy of deformed nucleus to the spherical one. The Yukawa folded mean field gives the levels densities closest to the experimental data of von Egidy while the selfconsistent mean fields provide the lower densities of Dilg.

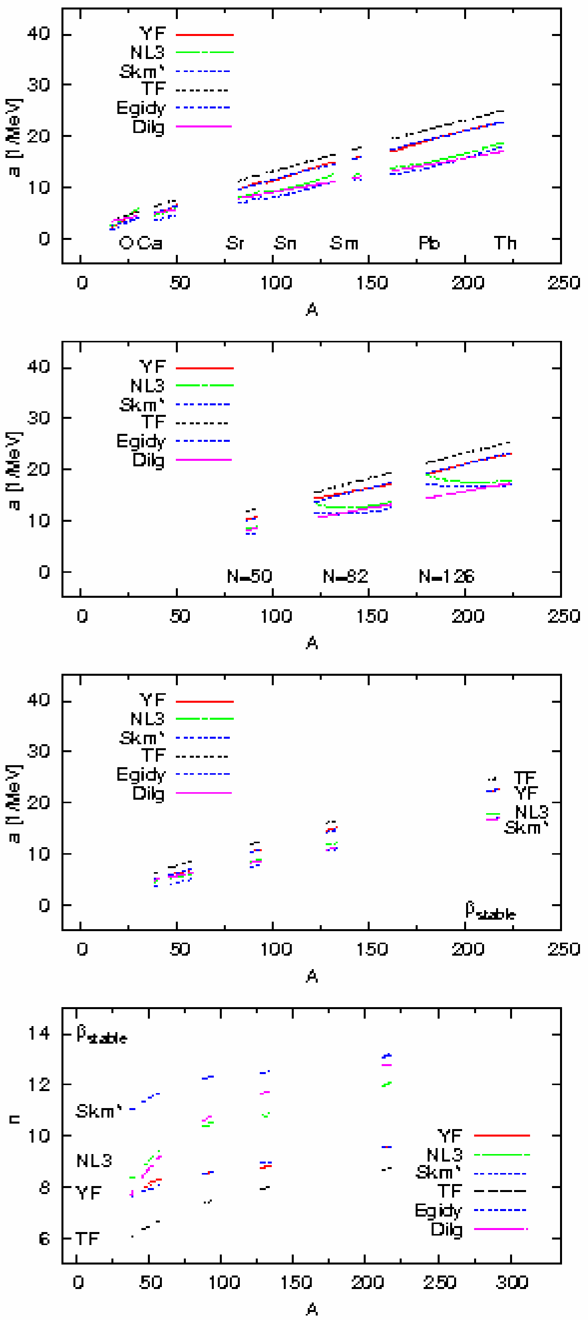

Fig. 1. Nuclear levels density parameters as functions of mass number A for different isotopes (upper panel), isotones (second panel) and β-stable nuclei (third panel). Lowest panel shows n number for β-stable nuclei.

[1] **B. Nerlo-Pomorska, K. Pomorski, J. Bartel,** Phys. Rev. **C 66,** 0516302 (2002)

[2] **B. Nerlo-Pomorska, K. Pomorski, J. Sykut, J. Bartel,** Int. Journ. of Modern Phys. **E 13**, 75 (2004)

[3] **B. Nerlo-Pomorska, J. Sykut,** Int. Journ. of Modern Phys. **E 13**, 117 (2004)

[4] **B. Nerlo-Pomorska, J. Sykut, J. Bartel,** Acta Phys. Polon. **B 36**, 1377 (2005)

[5] **B. Nerlo-Pomorska, K. Pomorski, J. Sykut, J. Bartel,** Int. Journ. Mod. Phys. **E 14,** 505 (2005)

[6] **J. Bartel, K. Pomorski, B. Nerlo-Pomorska,** Int. Journ. Mod. Phys. **E 15,** 478 (2006)

[7] **B. Nerlo-Pomorska, K. Pomorski, J. Bartel,** Phys. Rev. **C 74,** 034327 (2006)

[8] **K. Pomorski, B. Nerlo-Pomorska, J. Bartel,** Int. Journ. Mod. Phys. **E 16,** 368 (2007)

[9] **K. Pomorski,** Phys. Rev. **C 70,** 044306 (2004)

THE „QUADRUPOLE PLUS PAIRING" COLLECTIVE MODEL

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The lowest-lying excited levels in even-even nuclei are interpreted as the quadrupole excitations of nuclear surface. The description of them within the collective model works qualitatively excellently. A fair quantitative agreement between the model and the experimental data can be achieved by fitting parameters of the collective Hamiltonian. However, when we have determined the Hamiltonian from a microscopic many-body theory, we have obtained excitation energies of the collective states out of scale when compared to the experimental energy spectra (cf. e.g. Nucl. Phys. **A292,** 66 (1977)). Such a disagreement between the theory and experiment seems to occur independently of the range of nuclei investigated, the version of microscopic approach and the method of calculation of the collective Hamiltonian. This led us to conclusion that the collective space should contain not only the five quadrupole degrees of freedom but also the four collective pairing variables, namely the proton and neutron energy gaps and gauge angles.

The collective model which we call "the quadrupole plus pairing collective model" is formulated in [1,2,3]. It describes, apart from the quadrupole excitations, also the proton and the neutron pairing vibrations, and the transfer of the like nucleon pairs, that is the rotations in the proton and neutron gauge spaces.

As the lowest excitations have mainly the quadrupole character, to describe them we solve the model in the Born-Oppenheimer approximation [1,4] assuming that the pairing vibrations have energies high enough. First, for a given deformations β and γ we separate from the collective Hamiltonian the proton and the neutron pairing Hamiltonians, and find the proton and neutron zero-point energies $E_p(\beta,\gamma)$, $E_n(\beta,\gamma)$, and the most probable energy gaps $\Delta_p(\beta,\gamma)$, $\Delta_n(\beta,\gamma)$. This is shown in Fig. 1. Secondly, the effective Bohr Hamiltonian for the quadrupole excitations is obtained through substituting the pairing terms, previously separated in the collective Hamiltonian, by the sum of zero-point energies and inserting the most probable values of energy gaps. Finally, we diagonalize the effective Bohr Hamiltonian [1].

The collective Hamiltonian has been determined from the microscopic many-body theory which has treated the nucleus as a system of Z protons and N neutrons in the deformed Nilsson mean fields interacting via the standard pairing forces [1]. The deformation potential has been calculated using the microscopic-macroscopic method. The cranking method has been used to calculate the inertial functions [4]. The pairing correlations have been treated within the BCS approximation and the Generator Coordinate Method[1]. No parameter has been fitted to data.

The present approach has been applied to the description of the quadrupole collective states in nuclei from different regions. A prominent example is the ^{104}Ru nucleus, for which rich data from COULEX [5] are available. We reproduced these data with an unexpected accuracy [3,6]. A fairly good agreement of the theory with experimental data was achieved for other neutron-rich[6,7], rare-earth [8] and neutron-deficient nuclei [1].

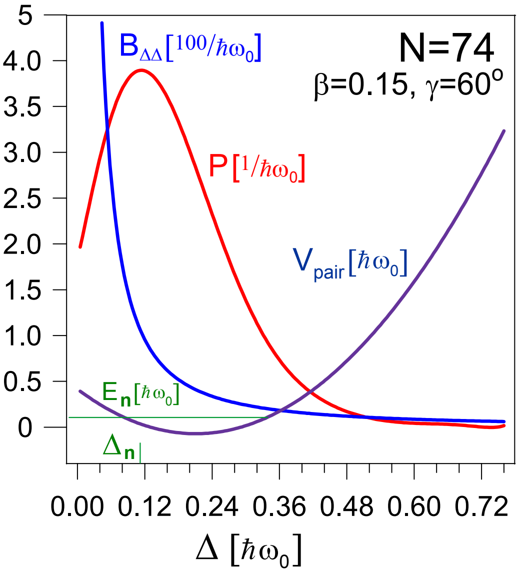

Fig. 1. *The zero-point pairing vibration in the system of N=74 neutrons. Blue lines: inertial function* $B_{\Delta\Delta}$ *and pairing potential* V_{pair} *. Red line: the probability distribution P of Δ's at zero-point vibration. Zero-point energy* E_n *and the most probable energy gap* Δ_n *(the abscissa of maximum of P) are marked in green.*

[1] **L.Próchniak, K.Zając, K.Pomorski, S.G. Rohoziński, J.Srebrny,** Nucl. Phys. **A648,** 181 (1999).

[2] **S.G. Rohoziński, K. Zając, L. Próchniak, K. Pomorski, J. Srebrny,** Particles and Nuclei, **31,** part 7B, 237 (2000).

[3] **S.G. Rohoziński, K. Pomorski, L. Próchniak, K. Zając, Ch. Droste, J.Srebrny,** Yadernaya Fizika **64,** 1081 (2001).

[4] **K.Pomorski, L. Próchniak, K. Zając, S.G. Rohoziński, J. Srebrny,** Physica Scripta **T88**, 111 (2000).

[5] **J. Srebrny, T. Czosnyka, Ch. Droste, S.G. Rohoziński, L. Próchniak, K. Zając, K. Pomorski,** D. Cline, C. Y. Wu, A. Bäcklin, L. Hasselgren, R. M. Diamond, D. Habs, H. J. Körner, F. S. Stephens, C. Baktash, **R. P. Kostecki,** Nucl. Phys. **A766,** 25 (2006).

[6] **K.Zając, L.Próchniak, K.Pomorski, S.G. Rohoziński , J.Srebrny,** Nucl. Phys. **A653,** 71 (1999).

[7] **K. Zając, L.Próchniak, K.Pomorski, S.G. Rohoziński , J.Srebrny,** Acta Phys. Polon. **B30,** 765 (1999).

[8] **K. Zając, L. Próchniak, K. Pomorski, S.G. Rohoziński ,J. Srebrny,** Acta Phys. Polon. **B31**, 459 (2000).

EXOTIC NUCLEAR SYMMETRIES

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Believed to be spherical after their discovery in 1909, then found elongated in the 50s, the atomic nuclei are now known to exhibit a variety of shapes and symmetries. The interest in the last decade went towards phenomena like the magnetic and chiral rotations or the tetrahedral and octahedral deformations.

We investigate these effects theoretically by using the Skyrme energy density functional. We developed one of the first computer codes [1,2] which impose no limitations on the symmetry of the density, and are thus applicable here.

The peculiarity of the magnetic rotation is that it occurs in nuclei with almost spherical mass distribution, which cannot rotate as a quantum object. The total spin is generated by the individual angular momenta of high-*j* valence particles and holes, which take perpendicular directions and then align toward each other like a pair of shears. In ^{142}Gd, we performed the first Hartree-Fock calculations for magnetic rotation [3]. They confirm the important role of the shears mechanism, although the collective rotation seems to dominate, possibly because the pairing correlations were not taken into account.

In a triaxially deformed nucleus, the high-*j* valence particles and holes align their angular momenta with the short and long axes, respectively, while the collective rotation takes place about the medium axis. Thus, the vectors of the particle, hole, and collective spins are approximately perpendicular, and can form a left or right-handed set. Such a configuration is called chiral and gives rise to characteristic pairs of rotational bands.

We argued that the chiral system can be modeled by two gyroscopes stiffly attached along the short and long axes of a classical rigid body. Such a model leads to an important conclusion that chiral rotation can occur only above a certain critical angular frequency [4].

Taking ^{132}La as a sample nucleus, we obtained the first self-consistent chiral solutions [5]. The results agree surprisingly well with the predictions of our classical model. The calculated value of the critical frequency lies in half the frequency range covered by the experimental bands, suggesting that they actually represent a transition from non-chiral to chiral rotation.

Quantum systems are most bound when large energy gaps between single-particle levels exist at the Fermi surface. Gaps are most likely to appear if the levels themselves are strongly degenerate. Degeneracy in turn results from conservation of symmetries. It has been suggested that the symmetries of the regular tetrahedron and octahedron, which give four-fold degeneracies, may lead to stable shapes like that in Fig. 1.

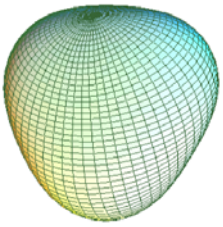

Fig. 1. *The tetrahedral deformation.*

Indeed, we found tetrahedral Hartree-Fock-Bogolyubov solutions in Zr, Ba, Sm, Gd, Yb, and Th [6,7]. The Skyrme forces differ as to the values of excitation energies of the tetrahedral minima, sometimes predicting them even as ground states. The depths of those minima can be significantly reduced by the pairing correlations. We also used the Generator-Coordinate Method for the case of Zr isotopes [8,9], and found that tetrahedral vibrations about the spherical shape are more likely than a static deformation. Moreover, such vibrations are mixed with those related to the pear-like shape. First attempts to consider rotations of tetrahedrally deformed nuclei [10] showed that regular bands are difficult to develop because the moment of inertia is very small and multiple level crossings occur.

On the other hand, we indicated that the observed E1 and lacking E2 transitions, as well as the alignment properties of some bands in the Gd region may result from zero-point quadrupole vibrations about the tetrahedral shape [11]. Apparently, the role of the tetrahedral symmetry still remains a puzzle, which encourages us to undertake further efforts.

[1] **J. Dobaczewski**, J. Dudek, Comp. Phys. Comm. **102**, 166 (1997); **102**, 183 (1997); **131**, 164 (2000).

[2] **J. Dobaczewski**, **P. Olbratowski**, Comp. Phys. Comm. **158**, 158 (2004); **167**, 214 (2005).

[3] **P. Olbratowski**, **J. Dobaczewski**, J. Dudek, **T. Rząca-Urban**, **Z. Marcinkowska**, R.M. Lieder, Acta Phys. Pol. **B33**, 389 (2002).

[4] **P. Olbratowski**, **J. Dobaczewski**, J. Dudek, **W. Płóciennik**, Phys. Rev. Lett. **93**, 052501 (2004).

[5] **P. Olbratowski**, **J. Dobaczewski**, J. Dudek, Phys. Rev. **C73**, 054308 (2006).

[6] **P. Olbratowski**, **J. Dobaczewski**, P. Powałowski, M. Sadziak, **K. Zberecki**, Int. J. of Mod. Phys. **E15**, 333 (2006).

[7] J. Dudek, **J. Dobaczewski**, N. Dubray, **A. Góźdź**, V. Pangon, N. Schunck, Int. J. Mod. Phys. **E16**, 516 (2007).

[8] **K. Zberecki**, **P. Magierski**, P.-H. Heenen, N. Schunck, Phys.Rev. **C74**, 051302 (2006).

[9] **K. Zberecki**, **P. Magierski**, P.-H. Heenen, N. Schunck, Int. J. Mod. Phys. **E16**, 533 (2007).

[10] N. Schunck, **P. Olbratowski**, J. Dudek, **J. Dobaczewski**, Int. J. of Mod. Phys. **E15**, 490 (2006).

[11] J. Dudek, D. Curien, N. Dubray, **J. Dobaczewski**, V. Pangon, **P. Olbratowski**, N. Schunck, Phys. Rev. Lett. **97**, 072501 (2006).

HIGH SPIN STATES OF STRONGLY DEFORMED CONFIGURATIONS IN MEDIUM-MASS NUCLEI

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Magic and doubly magic nuclei and their nearby neighbors play a special role in our quest for understanding nuclear structure. Information obtained for these nuclei, both experimental and theoretical, is intensively used for determination of single-particle energies needed, e.g., for large-scale calculations within the shell model; it also provides estimates of two-body matrix elements of the residual interactions which enter this kind of calculations. Properties of these nuclei have always been used in procedures of fitting parameters in various theoretical models, like, e.g., simple independent particle models of Nilsson or Woods-Saxon type or more involved mean-field approaches like those based on Hartree-Fock (HF) or Hartree-Fock-Bogoliubov (HFB) equations, Relativistic Mean Field (RMF) methods, Monte Carlo shell models, etc. [1,2].

The region around doubly magic ^{56}Ni nucleus is of particular interest. Nuclei in this region (Fe, Co, Ni, Cu, Zn) have intermediate masses which are large enough to induce pronounced collective phenomena, but still sufficiently small to make these nuclei amenable to "low-level" microscopic theoretical treatment. Since proton and neutron numbers are similar ($Z \approx N$), valence nucleons can occupy the same subshells and, as the mass is still not too large, their spatial distributions can also be very close: this can lead to manifestations of T=0 channel of pairing interactions. In addition, neutron and proton shell effects can act coherently, what results in particularly reach pattern of shape coexistence and shape transitions — these shapes range from spherical to triaxial and superdeformed (with deformation up to $\beta_2 \approx$ 0.5) and can be alternatively described by various theoretical models: particle-hole excitations within shell model, minima in the total Routhian surfaces in Strutinsky-Woods-Saxon cranking calculations, special configurations of alpha clusters, etc. Peculiarities of this region of nuclei makes it particularly well suited for analyzing the interplay between T=0 and T=1 channels of the pairing interactions; while the T=1 component is quickly quenched by high frequency rotation, the T=0 component should survive longer [5,8].

In our studies we used mainly the Skyrme-Hartree-Fock (and/or HFB) cranking approach, as well as independent particle model of Woods-Saxon type (with cranking and shell and pairing corrections taken into account) [2-8]. In these models (as well as in the shell model), high spin states of low-isospin nuclei in the $A \approx 60$ region can be described as multi-particle-multi-hole configurations involving $f_{7/2}$ hole and $g_{9/2}$ particle orbitals (i.e., excitations across $N = Z = 28$ shell gap). Dynamic moments of inertia, alignments, branching ratios and other observable quantities are highly sensitive to assumed physical scenarios and details of models used for interpreting the experimental findings; this gives us a possibility to "fine tune" our models and to understand better the physics behind phenomena observed in experiments.

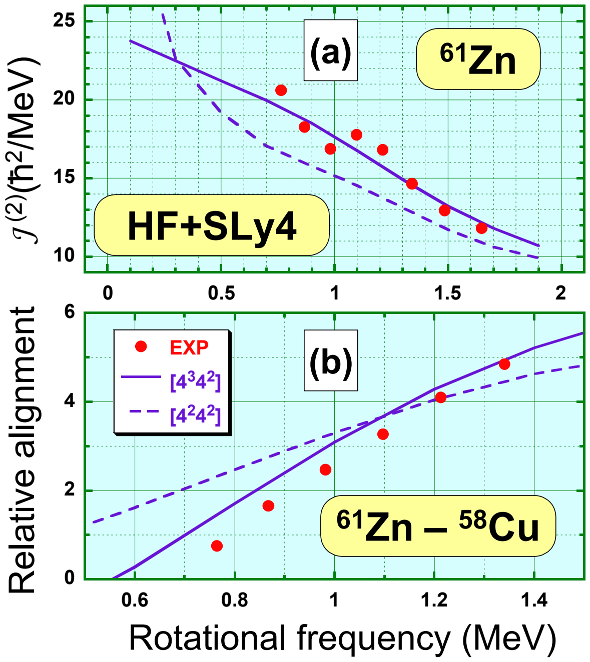

Fig. *Dynamic moments of inertia, $\mathcal{J}^{(2)}$, of the super-deformed band in ^{61}Zn (a) and its relative alignment with respect to SD bands in ^{58}Cu (b). Two different configurations are compared with experimental results. From Ref. [5].*

[1] **W. Nazarewicz**, **J. Dobaczewski**, **T.R. Werner**, J.A. Maruhn, P.- G. Reinhard, K. Rutz, C.R. Chinn, A.S. Umar, M.R. Strayer, Phys. Rev. **C53**, 740 (1996).

[2] D. Rudolph, C Baktash, **W. Satuła**, **J. Dobaczewski**, **W. Nazarewicz**, M.J. Brinkman, M. Devlin, H.-Q. Jin, D.R. LaFosse, L.L. Riedinger, D.G. Sarantites, C.-H. Yu, Nucl. Phys. **A630**, 417c (1998).

[3] D. Rudolph, C Baktash, **J. Dobaczewski**, **W. Nazarewicz**, **W. Satuła**, M.J. Brinkman, M. Devlin, H.-Q. Jin, D.R. LaFosse, L.L. Riedinger, D.G. Sarantites, C.-H. Yu, Phys. Rev. Lett. **80**, 3018 (1998).

[4] D. Rudolph, C Baktash, M.J. Brinkman, E. Caurier, D.J. Dean, M. Devlin, **J. Dobaczewski**, P.-H. Heenen, H.-Q. Jin, D.R. LaFosse, **W. Nazarewicz**, F. Nowacki, A. Poves, L.L. Riedinger, D.G. Sarantites, **W. Satuła**, C.-H. Yu, Phys. Rev. Lett. **82**, 3763 (1999).

[5] C.-H. Yu, C Baktash, **J. Dobaczewski**, J.A. Cameron, C. Chitu, M. Devlin, J. Eberth, A. Galindo-Uribari, D.S. Haslip, D.R. LaFosse, T.J. Lampman, I.-Y. Lee, F. Lerma, A.O. Macchiavelli, S.D. Paul, D.C. Radford, D. Rudolph, D.G. Sarantites, C.E. Svensson, J.C. Waddington, J.N. Wilson, Phys. Rev. **C60**, 031305 (1999).

[6] **W. Nazarewicz**, **J. Dobaczewski**, M. Matev, M. Mizutori, **W. Satuła**, Acta Phys. Pol. **B32**, 2349 (2001).

[7] W. Reviol, D.G. Sarantites, R.J. Charity, V. Tomov, **J. Dobaczewski**, D. Rudolph, R.M. Clark, M. Cromaz, P. Fallon, A.O. Macchiavelli, M.P. Carpenter, D. Seweryniak, Phys. Rev. **C65**, 034309 (2002).

[8] **J. Dobaczewski**, J. Dudek, R. Wyss, Phys. Rev. **C67**, 034308 (2003).

SELF-CONSISTENT TREATMENT OF QUADRUPOLE EXCITATIONS

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Modern nuclear mean field theories offer detailed, uniform description of large range of properties of both β-stable and exotic nuclei. Self-consistent potentials in such models are obtained from effective nucleon-nucleon interaction (of Skyrme or Gogny type) or from the relativistic approach with a nucleon interaction mediated by several types of bosons. The interaction in the particle-particle channel is approximated by various forms of short-range, pairing type force. The mean field theory as based on the variational principle is aimed at description of a ground state; however it can be extended to cover also excited states, including collective ones. There are two methods used to study large scale collective motion, as e.g. connected with changes of nuclear deformation, namely the Generating Coordinate Method and the Adiabatic Time Dependent HFB theory. In case of quadrupole collective excitations the collective space is 5 dimensional (as it includes rotational and vibrational degrees of freedom) so the GCM is hardly applicable and the ATDHFB method remains the main theoretical tool (see Phys. Rev. C60, 054301 (1999), Phys. Rev. C70, 054321 (2004) and [2]).

Collective variables used in the mean field approach are components of the quadrupole mass distribution tensor, and hence they have clear, model independent meaning. After transformation to the principal axis frame they can be expressed through Euler angles and deformation variables β, γ. The ATDHFB expressions for potential energy and mass parameters lead in case of quadrupole variables to the general collective Bohr Hamiltonian. Eigenvalues of the Bohr Hamiltonian are directly interpreted as energies of collective states while its eigenfunctions allow us to calculate B(E2) transition probabilities and values of invariants e.g. β^2, $\beta^3\cos 3\gamma$ which give a synthetic measure of a nuclear shape. It is worth to note that presented method does not introduce any new additional parameters besides the ones defining the interaction.

In the papers [1,2,3] we presented results of calculations for several medium heavy nuclei (from Mo-Ru and Xe-Ba region) using the model with Skyrme interaction. The B(E2) probabilities are reproduced very well but energy spectra are somewhat stretched. This effect weakly depends on the variant of used Skyrme force and the type of the pairing interaction (seniority, δ-force or surface δ-force). The Relativistic Mean Field model was used for some nuclei from the same region in [4, 5] leading to conclusions similar to mentioned previously. An example of calculated potential energy and comparison of theoretical and experimental levels for the ^{104}Ru nucleus is presented in Fig. 1. The effect of stretching of the spectra which is a consequence of too small values of the mass parameters can indicate a need for an extension of the collective space by including pairing degrees of freedom and/or for consideration of so called Thouless-Valatin corrections, see [4, 5]. The approach presented here, based on a sound foundation of the mean field theory and employing well defined collective variables, is well suited also for interpretation of shape coexistence phenomena and for a critical discussion of various phenomenological models, such as e.g. using recently proposed dynamical symmetry E(5) and X(5) [3,7].

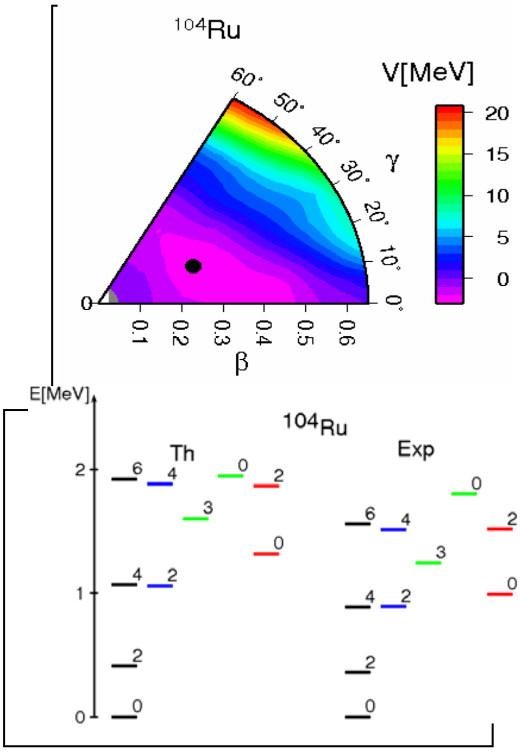

Fig. 1. Calculated potential energy and comparison of theoretical and experimental levels of the ^{104}Ru nucleus (see also text).

[1] **L. Próchniak**, P. Quentin, D. Samsoen, and J. Libert, Acta Phys. Pol. **B 34**, 2461 (2003).

[2] **L. Próchniak**, P. Quentin, D. Samsoen, and J. Libert, Nucl. Phys. A**730**, 59 (2004).

[3] **L. Próchniak**, Acta. Phys. Pol. B, (2007), in press.

[4] **L. Próchniak** and P. Ring, Int. J. Mod. Phys. E **13**, 217, (2004).

[5] **L. Próchniak**, Int. J. Mod. Phys. E **15,** 379 (2006).

[6] **L. Próchniak**, Int. J. Mod. Phys. E (2007), in press.

[7] **L. Próchniak**, to be published.

THE ISOSCALAR BOSONS IN NUCLEAR COLLECTIVE EXCITATIONS

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Proton-neutron pairing forces are hard to investigate because of their almost negligible influence on nuclear ground-state properties. But the observed [Nucl.Phys.A712(2002)79] features of the excited 0^+ state of ^{98}Mo (i.e. the lowering of excitation energies and the change of nuclear shape) suggest the affection of isoscalar pairing interaction on the behaviour of some excited N≠Z nuclei. Especially in A=98 region the energy needed to create a proton-neutron „deuteron-like" pair could be found so small that the recombination of two-nucleon cluster structure could compete with such collective movements as vibrations or even rotations [1]. In order to consider such an assumption (or just to point out possible origins of observed symmetries) the special version of the IBM-4 approximation [J. Phys. G14, 869 (1988)] was adopted.

The isoscslar–isovector boson scheme can be applied to even nuclei which valence protons and valence neutrons occupy shell-model levels with the same orbital angular momentum. The low-lying 0^+ and 1^+ states of such a nucleus are described in terms of a system of N interacting bosons of two types [1]: „deuteron-like" isoscalar L=0, S=1, T=0 and isovector L=0, S=0, T=1 bosons representing nucleon pairs coupled to the same angular momentum L, spin S and isospin T values. The analysis [Acta Phys. Pol.B20,815 (1989)] of possible dynamical symmetries of the group chain $U(6) \supset SO_S(3) \otimes SO_T(3)$ allows us to approximate excitation energies of the boson system – and, as follows, of a nucleus – in the simple form :

$$E(N,n,S.T)= E_0 + \xi n + \sigma S(S+1) +\tau T(T+1),$$

where n=N, N-1, …,0(1) is the number of isoscalar bosons while S=n, n-2, …,0(1) and T=N-n, N-n-2, …,1(0) mean the spin and the isospin of the boson system. Free parameters E_0, ξ, σ and τ should be fitted separately for each group of isobars.

Calculations were done for all neighbours of ^{98}Mo that is A=94, A=96, A=98, A=100 nuclei with valence nucleons occupying g-levels of the shell model ($g_{7/2}$ and $g_{9/2}$) [1,2]. The corresponding number of bosons changes from N=12 for A=94 to N=16 for A=100 isobars and it counts nucleon pairs outside the Z_c=28, A_c=68 core (the same for all considered nuclei). In Fig.1 some exemplary results are presented in comparison to experimental data [NNDC On-line Data Service]. Theoretical values were obtained [1] with ξ=0.37 MeV, σ=1.433 MeV, τ=0,483 MeV and the scale parameter E_0=-88.966 MeV.

The 0^+ and 1^+ binding energies of A=96 and A=100 isobars were reproduced [2] with the similar accuracy. Discrepancies are unexpectedly small especially if one takes into account the absence of rotational and vibrational modes in the proposed description. Of course, the scheme should be confirmed by further studies on properties of interpreted states including β decay and Gamow-Teller transitions [3]. But it is quite clear that the 0^+ and 1^+ binding energies of considered isotopes follow the scheme which comes out of an essential symmetry including the proton-neutron interaction. It seems that the region of nuclei surrounding ^{98}Mo could be promising in investigating the role and features of isoscalar pairing forces.

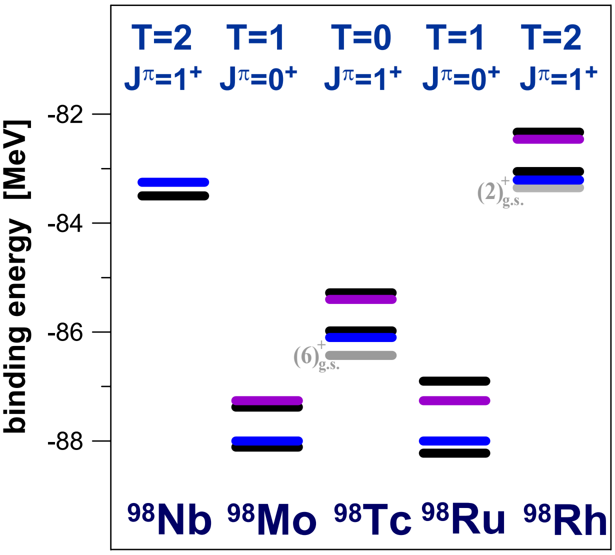

Fig.1. Comparison between measured (black) and calculated 0^+ and 1^+ binding energies in ^{98}Mo region. T means the isospin of the corresponding boson system, blue lines mark n=0 or 1 while the violet ones are for one extra isoscalar boson in the system.

[1] **K. Zając,** Acta Phys. Pol. **B34**, 2241 (2003).

[2] **K. Zając,** Int. J. Mod. Phys. **13**, 103 (2004).

[3] **K. Zając,** Int. J. Mod. Phys. **15**, 515 (2006).

QUADRUPOLE EXCITATIONS OF TRANSACTINIDE NUCLEI

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The noticeable progress in spectroscopy of transactinide isotopes (especially interesting with regard to their nearness to the super-heavy mass region) allows us to discuss their collective properties in reference to experimental data. Because of the axial symmetry some ground-state features of transactinides could be interpreted in the frame of rotational model. However, the proper description of excited states can be only achieved when one adds at least the coupling of the rotational motion with quadrupole shape vibrations. As a suitable approximation we adopted the model [1] developed on the basis of earlier ideas [2].

Allowing only for the zero-point pairing vibrations [1] we obtain the modified quadrupole-plus-pairing Hamiltonian

$$\hat{\mathcal{H}}_{\mathrm{CQP}} \approx \hat{\mathcal{H}}_{\mathrm{CQ}}(\beta,\gamma,\Omega;\, \Delta^{p}_{max},\Delta^{n}_{max}) = \hat{\mathcal{H}}_{\mathrm{vib}} + \hat{\mathcal{H}}_{\mathrm{rot}} + \mathcal{V}_{\mathrm{coll}},$$

which describes the motion of an even-even nucleus in terms of the intrinsic Bohr deformation variables β and γ, Euler angles Ω and the most probable values of pairing gap energies for protons and neutrons Δ^{p}_{max} and Δ^{n}_{max} determined for each deformation point. In this way [1] we can approximately include into description of quadrupole nuclear modes the main effect of coupling with the pairing collective degrees of freedom.

The $\hat{\mathcal{H}}_{\mathrm{CQP}}$ does not contain any free parameters but its form is determined by the parameters of adopted single-particle potential and the strengths of the pairing interaction. For very heavy transuranium nuclei we just extrapolate the known [Nucl.PhysA131(1969)] Nilsson single-particle potential and we calculate inertial functions for a given isotope within Strutinsky microscopic - macroscopic method with recently obtained [2] LSD parameters. In order to solve the problem of pairing vibrations and to get the most probable gap values we use the estimations of pairing strengths obtained for heavy isotopes from the appropriate mass formulas [Z. Phys. A332, 259 (1989)].

Thus, solving the eigenproblem of $\hat{\mathcal{H}}_{\mathrm{CQP}}$ we were able to reproduce observed excitation energies and E2 transition probabilities for all even-even U, Pu, Cm, Fm and No isotopes with number of neutrons N=146-156 [3-5]. The detailed comparison with known experimental data (i.e.[4]) shows that our approach reproduces successfully both, low-lying excitation energies and electromagnetic transition probabilities. It should be noticed that we get a dynamical picture – we are able to immanently indicate pure rotational modes as well as deviations from the axial symmetry.

Of course, the description is restricted to quadrupole deformations, but obtained results confirm that it takes into account the main features of collective excitations even in the extreme mass region. Thus we expect that some predictions provided by our model (see Fig.1) for g.s.-bands and γ-bands could be quite reliable even if higher multipolarities are not included.

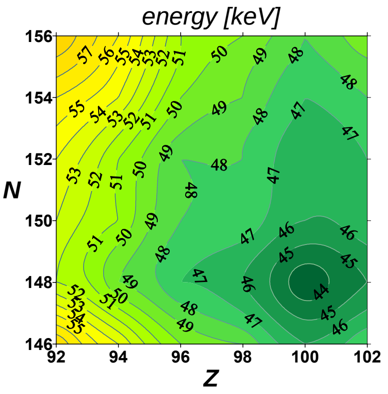
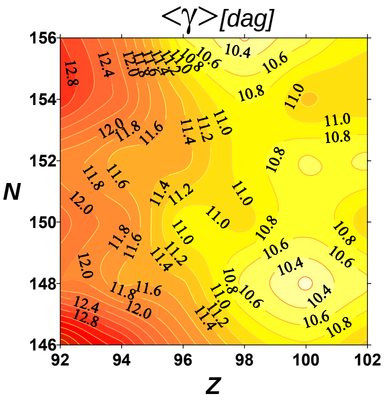


Fig. 1. Properties of the first 2^+ excited state as a function of proton Z and neutron N numbers. Above: the contour plot of the energy; below: map of the average triaxial parameter γ .



[1] **L. Próchniak**, **K. Zając**, **K. Pomorski**, **S.G. Rohoziński**, **J.Srebrny**, Nucl. Phys. **A648**, 181 (1999).

[2] **K. Pomorski**, J. Dudek, Phys. Rev. **C7,** (2003) 044316.

[3] **K. Zając**, **L. Próchniak**, **K. Pomorski**, **S.G. Rohoziński**, **J.Srebrny**, Acta Phys. Pol. **B32**, 691 (2001).

[4] **L. Próchniak**, **K. Zając**, **K. Pomorski**, **S.G. Rohoziński**, **J.Srebrny**, Acta Phys. Pol. **B33**, 405 (2002).

[5] **K. Zając**, **L. Próchniak**, **K. Pomorski**, **S.G. Rohoziński**, **J.Srebrny**, Acta Phys. Pol. **B34**,1789 (2003).

GIANT DIPOLE RESONANCE AS A PROBE OF SHAPES OF HOT ROTATING ATOMIC NUCLEI

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Experimental facilities: LNL Legnaro (Italy), IRES Strasbourg (France)

During the last decade the field of the giant dipole resonance in hot nuclei has progressively expanded, due to new exclusive experimental techniques [1-3]. Among the structure and reaction effects explored with the GDR there are, for example, the coupling to low lying states and to quadrupole deformation [4-7], damping due to collisions and thermal shape fluctuations [8-11], fission time scales [12], entrance channel effects and pre-equilibrium giant dipole vibrations [13-15] and, especially the determination of the nuclear shape [16-21]. This paper focuses on the latter problem, and more specifically, on the search for the *Jacobi shape transitions* in hot rotating ^{46}Ti nuclei. The results were achieved in the experiments at Large Scale Facilities, such as LNL Legnaro and IRES Strasbourg, performed in large international collaborations.

The shape of hot atomic nuclei is predicted, in the liquid drop models, to change under stress of rotation and the shape evolution pattern depends among others on the mass. Heavy nuclei with A>160 change their equilibrium shape from spherical to oblate, the size of the oblate deformation increases with angular momentum and at certain value the nucleus undergoes the fission process. Lighter nuclei, with A<<160, besides this standard evolution, are expected to exhibit more exotic behavior – the Jacobi shape transition: at certain critical value of spin, an abrupt change of shape can be expected, with the nucleus following a series of triaxial, more and more elongated shapes, and finally by fission (Fig. 1a).

The high energy X-rays from the GDR decay in ^{46}Ti were measured in the HECTOR array in coincidence with known, well-resolved, low-energy X-ray transitions of ^{42}Ca detected in EUROBALL [17]. This gating condition, together with the highly selective master trigger condition, allowed for enhancement of high energy γ-rays coming from nuclei with the highest spins, but free from fission and direct reaction contaminations. The extracted experimental GDR line shape is shown in Fig. 1b, together with the theoretical predictions (Fig. 1b,c). As can be seen, both the experimental line shape and the calculated one for the Jacobi regime agree with each other remarkably well. This proves that beyond I=26ħ, the hot ^{46}Ti nucleus undergoes a Jacobi shape transition and additionally shows the importance of Coriolis effects upon the GDR line shape. In this context it is worth mentioning that very large deformations of ^{46}Ti at high angular momentum were also suggested by the spectra of emitted ħ-particles measured in the ICARE array [18,19]. The low energy, 10 MeV, component of the GDR strength function, resulting from the very large deformation of the *hot* compound nucleus, was found to feed preferentially the highly-deformed band in the *cold* ^{42}Ca evaporation residue [19, 21]. This suggests that the very deformed shape of the hot compound nucleus, resulting from the Jacobi shape transition, persists along the entire decay process.

Experiments of this type will become even more attractive with the availability in the near future of intense radioactive beams (e.g. SPIRAL2, FAIR), with which the very neutron-rich nuclei can be produced at extremely high spins, or very exotic collective modes will be excited .

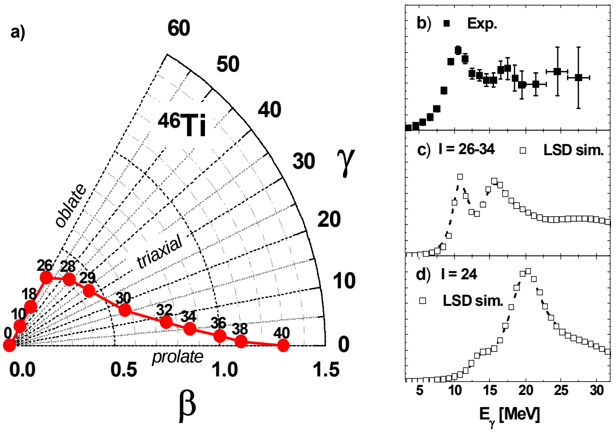

Fig. 1. a) Spin evolution of the equilibrium shape of ^{46}Ti; b) Experimental GDR line shape for ^{46}Ti at high angular momentum; c) Liquid Drop Model prediction on the GDR line shape for spin region 26-34η, where Jacobi regime is expected; d) Same as c), but for I=24η, where oblate regime is expected.

[1] **A.Maj, M.Kmiecik**, F.Camera, B.Herskind, J.J.Gaardhøje, A.Bracco, A.Ataç, R.A.Bark, I.G.Bearden, P.Bosetti, S.Leoni, M.Mattiuzzi, T.S.Tveter, **Z. Żelazny**, *Acta Phys. Pol.* **B27,** 541 (1996).
[2] B.Million, A.Bracco, F.Camera, S.Brambilla, A.Gadea, D.Giugni, B.Herskind, **M.Kmiecik,** R. Isocrate, S. Leoni, **A. Maj,** F.Prelz, O.Wieland, *Nucl. Instr. Meth. in Phys. Res.* **A452,** 422 (2000).
[3] **A.Maj**, *Acta Phys.Pol.* **B32**, 793 (2001).
[4] F.Camera, A. Bracco, **A. Maj**, B. Herskind, A. Ataç, P. Bosetti, R. Bark, I.G. Bearden, J.J. Gaardhøje, **M. Kmiecik,** S. Leoni, M. Mattiuzzi, G. Turri, *European Physical Journal* **A2** (1998) 1.
[5] G.Benzoni, A.Bracco, F.Camera, S.Leoni, B.Million, **A.Maj**, A.AlGóra, A.Axelsson, M.Bergstrom, N.Blasi, M.Castoldi, S.Frattini, A.Gadea, B.Herskind, **M.Kmiecik**, G.Lo Bianco, J.Nyberg, M.Pignanelli, **J.Styczen**, O.Wieland, **M.Zieblinski**, A.Zucchiatti, *Phys.Lett.* **540B**, 199 (2002).
[6] B.Herskind, G.Benzoni, J.N.Wilson, T.Dossing, G.B.Hagemann, G.Sletten, C.R.Hansen, D.R.Jensen, A.Bracco, F.Camera, S.Leoni, P.Mason, O.Wieland, **A.Maj, M.Brekiesz, M.Kmiecik**, H.Hubel, P.Bringel, A.Neusser, A.K.Singh, R.M.Diamond, R.M.Clark, M.Cromaz, P.Fallon, A.Gorgen, I.Y.Lee, A.O.Macchiavelli, D.Ward, F.Hannachi, A.Korichi, A.Lopez-Martens, T.Byrski, D.Curien, **P.Bednarczyk**, J.Dudek, H.Amro, W.C.Ma, J.Lisle, S.Odegard, C.Petrache, D.Petrache, T.Steinhardt, O.Thelen, *Acta Phys.Pol.* **B34**, 2467 (2003).
[7] **M.Kmiecik, A.Maj, J. Styczeń, P.Bednarczyk, M.Brekiesz, J.Grębosz, M.Lach, W.Męczyński, M.Ziębliński, K.Zuber,** A.Bracco, F.Camera, G.Benzoni, B.Million, S.Leoni, O.Wieland, B.Herskind, D.Curien, N.Dubray, J.Dudek, N.Schunck, **K.Mazurek**, *Acta Phys. Pol.* **B36**, 1169 (2005).
[8] M.Mattiuzzi, A.Bracco, F.Camera, W.E.Ormand, J.J.Gaardhøje, **A.Maj**, B.Million, M.Pignanelli, T.Tveter, *Nucl. Phys.* **A612,** 262 (1997).
[9] F.Camera, A.Bracco, S.Leoni, B.Million, M.Mattiuzzi, M.Pignanelli, **A.Maj, M.Kmiecik**, R.Bark, J.Bearden, J.J.Gaardhoje, W.E.Ormand, T.Lonnroth, R.Osterbacka, *Phys. Rev.* **C60,** 014306 (1999).
[10] **M.Kmiecik, A.Maj,** A.Bracco, F.Camera, M.Casanova, S.Leoni, B.Million, B.Herskind, R.A.Bark, W.E.Ormand, *Nucl. Phys.* **A674,** 29 (2000).
[11] **M.Kmiecik, A.Maj,** B.Million, **M.Brekiesz, W.Królas, W.Męczyński, J.Styczen, M.Ziębliński**, A.Bracco, F.Camera, G.Benzoni, S.Leoni, O.Wieland, S.Brambilla, B.Herskind, **M.Kicinska-Habior**, N.Dubray, J.Dudek and N.Schunck, *Phys. Rev.* **C70**, 064317 (2004).
[12] T.S.Tveter, J.J.Gaardhøje, **A.Maj**, T.Ramsøy, A.Ataç, J.Bacelar, A.Bracco, A.Buda, F.Camera, B.Herskind, W.Korten, **W.Królas**, A.Menthe, B.Million, H.Nifenecker, M.Pignanelli, J.A.Pinston, H.v.d.Ploeg, F.Schussler, G.Sletten, *Phys. Rev. Lett* **76,** 1035 (1996).
[13] **M.Kmiecik, A.Maj**, B.Herskind, A.Bracco, R.Bark, M.Bergström, F.Camera, G.Hagemann, N.Hashimoto, A.Holm, S.Leoni, T.Saitoh, T.S.Tveter, *European Physical Journal* **A1,** 11 (1998).
[14] **A.Maj, M.Kmiecik**, B.Herskind, A.Bracco, F.Camera, G.Hagemann, P.Varmette, *Nucl. Phys.* **A649,** 137 (1999).
[15] **O.Wieland**, A.Bracco, F.Camera, G.Benzoni, N.Blasi, S.Brambilla, F.Crespi, A.Giussani, S.Leoni, B.Million, A.Moroni, S.Barlini, V.L.Kravchuk, F.Gramegna, A.Lanchais, P.Mastinu, **A.Maj, M.Brekiesz, M.Kmiecik**, M.Bruno, E.Geraci, G.Vannini, G.Casini, M.Chiari, A.Nannini, A.Ordine, E.Ormand, *Phys. Rev. Lett.* **97**, 012501 (2006).
[16] **A.Maj, M.Kmiecik, W.Królas, W.Męczyński, J.Styczeń, M.Ziębliński**, B.Million, A.Bracco, F.Camera, S.Leoni, O.Wieland, B.Herskind, **M.Kicińska-Habior**, *Nucl. Phys.* **A687,** 192 (2001).
[17]**A.Maj, M.Kmiecik**, A.Bracco, F.Camera, **P.Bednarczyk**, B.Herskind, S.Brambilla, G.Benzoni, **M.Brekiesz**, D.Curien, G.De Angelis, E.Farnea, **J.Grębosz**, **M.Kicińska-Habior**, S.Leoni, **W.Męczyński**, B.Million, D.R.Napoli, J.Nyberg, C.M.Petrache, **J.Styczeń**, O.Wieland, **M.Ziębliński**, **K.Zuber**, N.Dubray, J.Dudek, **K.Pomorski**, *Nucl.Phys.* **A731**, 319 (2004).
[18] **M.Brekiesz**, **A.Maj**, **M.Kmiecik. K.Mazurek**, **W.Męczyński**, **J.Styczeń**, **K.Zuber**, P.Papka, C.Beck, F.Haas, V.Rauch, M.Rousseau, A.Sànchez i Zafra, J.Dudek and N.Schunck., *Nucl. Phys.* **A788**, 224c (2007**).**
[19] **M.Kmiecik, A.Maj, M.Brekiesz, K.Mazurek, P.Bednarczyk, J.Grębosz, W.Męczyński, J.Styczeń, M.Ziębliński, K.Zuber**, P.Papka, C.Beck, D.Curien, F.Haas, V.Rauch, M.Rousseau, J.Dudek, N.Schunck, A.Bracco, F.Camera, G.Benzoni, O.Wieland, B.Herskind, E.Farnea, G. De Angelis, *Acta Phys. Pol.* **B38**, 1437 (2007).
[20] **K.Mazurek, M.Kmiecik, A.Maj**, J.Dudek, N.Schunck., *Acta Phys. Pol.* **B38**, 1455 (2007).
[21]**J.Styczeń, P.Bednarczyk, M.Brekiesz, J.Grębosz, M.Kmiecik, M.Lach, A.Maj, W.Męczyński, M.Ziębliński, K. Zuber**, *this Report.*

GIANT DIPOLE RESONANCE AS A PROBE OF ISOSPIN MIXING IN HOT NUCLEI

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Experimental facility: Warsaw Cyclotron at HIL, and Superconducting Linear Accelerator at the University of Washington, Seattle

Experimental and theoretical studies of the Giant Dipole Resonance (GDR) built on highly excited states in compound nuclei formed in heavy-ion collisions proved already in the 1990-ties that the γ-decay of the GDR is an important tool for learning about the nuclear properties at high temperatures and angular momenta [1-3]. Thus, shortly after heavy-ion beams started to be available from the Warsaw Cyclotron, an experimental set-up JANOSIK suitable to measure high-energy γ-rays was built at the Heavy Ion Laboratory of Warsaw University [4]. Several projects were from then performed at HIL but some were still done in collaboration with the Seattle group at the University of Washington.

In all our experiments high-energy γ-rays have been measured in the large NaI spectrometer positioned at several angles with respect to the beam axis. The multiplicity of low-energy γ-rays has been measured by using the small multiplicity filter. The n-γ discrimination has been achieved by the standard time-of-flight technique [4, 5].

Character of the high-energy (E_γ = 10-50 MeV) γ-ray radiation emitted in heavy-ion collisions at projectile energies 3-11 MeV/u depends strongly on a projectile energy. At projectile energies up to 6 MeV/u the main source of high-energy γ-rays is the decay of the GDR excited in a compound nucleus formed by complete fusion reactions. At such beam energies we have performed shape evolution [1-2, 5-6], and isospin mixing [7-11] studies in hot nuclei. One of the results was the observation of the Jacobi shape transition in the ^{45}Sc nuclei [1, 2] measured in Seattle.

Pure isovector character of the GDR provided possibilities to study isospin symmetry in hot nuclei. In order to extract the isospin mixing probability and investigate its dependence on the atomic number Z of highly excited self-conjugate nuclei, four nuclei: ^{32}S, ^{36}Ar, ^{44}Ti and ^{60}Zn, with Z increasing from 16 to 30, were formed at excitation energies around 50 MeV by the entrance channels with the isospin T = 0. The reactions populating neighbouring compound nuclei: ^{31}P, ^{37}Ar, ^{45}Ti, and ^{61}Zn at similar excitation energy, but with the $T \neq 0$ were also measured. All experiments were performed with the use of the beams from the Warsaw Cyclotron. Experimental method was based on the rule that the E1 decays from T = 0 to T = 0 states are isospin forbidden due to the isovector nature of the electric dipole radiation. The GDR parameters, Coulomb spreading widths, and the isospin mixing probabilities and their dependence on the atomic number Z were extracted [7-11]. It was shown for the first time that the isospin mixing probability for highly excited states increases with the Z number of the self-conjugate nuclei [11].

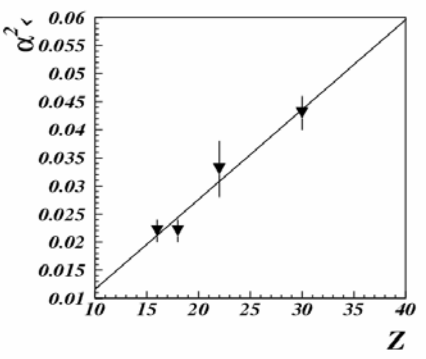

Fig. 1. *Isospin mixing α^2 as deduced from the GDR studies, as a function of the atomic number Z.*

At projectile energies above 6 MeV/u additional sources of γ-rays may occur in the heavy-ion collision. Statistical decay of the GDR may follow formation of the compound nucleus by the complete, as well as incomplete, fusion. Also bremsstrahlung emission may take place. In order to study these effects the ^{12}C + $^{24, 26}$Mg, ^{12}C + ^{58,64}Ni and ^{20}Ne+^{12}C reactions have been studied [5-6,12-15]. It was found that simultaneous analysis of γ-ray spectra and angular distributions allows to differentiate between statistical decay and bremsstrahlung [12-15]. It was also shown that the GDR parameters, especially the width, are strongly influenced by the presence of incomplete fusion in the analysis [15].

[1] **M.Kicińska-Habior**, K.A.Snover, J.A.Behr, C.A.Gossett, Y.Alhassid and N.Whelan, Phys. Lett. **B 308**, 225 (1993) .

[2] **M.Kicińska-Habior**, K.A.Snover, J.A.Behr, C.A.Gossett, J.H.Gundlach, Z.M.Drebi, M.S.Kaplan, D.P.Wells, Nucl. Phys. **A569**, 17c (1994).

[3] **M.Kicińska-Habior, A.Maj, Z.Sujkowski**, Acta Phys. Pol. **B27**, 285 (1996).

[4] **M.Kicińska-Habior, Z.Trznadel, M.Kisieliński, J.Kownacki, M.Kowalczyk, Z.Żelazny, T.Matulewicz, D.Chmielewska, A.Maj, Z.Sujkowski, J. Dworski, M.Augsburg, A. Kordyasz, A. Krzyczkowska, J. Kwieciński, J.Romanowski,** Acta Phys. Pol. **B28**, 219 (1997) .

[5] **M.Kicińska-Habior**, Acta Phys. Pol. **B30**, 1353 (1999).

[6] **M. Kicińska-Habior, Z. Trznadel, O. Kijewska, E. Wójcik**, Acta Phys. Pol. B33, 949 (2002).

[7] **M. Kicińska-Habior, E. Wójcik, O. Kijewska, M. Kisieliński, M. Kowalczyk, J. Choiński**, Nucl. Phys. **A 731c**, 138 (2004).

[8] **M. Kicińska-Habior**, Acta Phys. Pol. **B36**, 1133 (2005).

[9] **O. Kijewska, M. Kicińska-Habior, E. Wójcik, M. Kisieliński, M. Kowalczyk, J. Choiński, W. Czarnacki,** Acta Phys. Pol. **B36**, 1185 (2005).

[10] **E. Wójcik, M. Kicińska-Habior, O. Kijewska, M. Kowalczyk, M. Kisieliński, J. Choiński**, Acta Phys. Pol. **B37**, 207 (2006).

[11] **E. Wójcik, M. Kicińska-Habior, O. Kijewska, M. Kowalczyk, M. Kisieliński, J. Choiński**, Acta Phys. Pol. **B38**, 1469 (2007).

[12] **M.Kicińska-Habior**, **Z. Trznadel**, K.A.Snover, **A.Maj**, M.Kelly, Acta Phys. Pol. **B28**, 189 (1997).

[13] **M.Kicińska-Habior, Z. Trznadel, A. Maj,** M.P. Kelly, J.P.S. van Schagen, K.A. Snover, Nucl. Phys. **A649**, 130 (1999).

[14] **M.Kicińska-Habior, Z. Trznadel**, Acta Phys. Pol. **B30**, 535 (1999).

[15] **Z. Trznadel, M.Kicińska-Habior**, M.P. Kelly, J.P.S. van Schagen, K.A. Snover, Nucl. Phys. **A687,** 199c (2001) .

LOW-LYING DIPOLE STRENGTH AND PYGMY RESONANCE IN UNSTABLE NEUTRON-RICH ISOTOPES IN THE MASS REGION OF DOUBLY-MAGIC ^{132}Sn NUCLEUS

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Experimental facility: LAND-FRS setup at GSI, Darmstadt

Exotic neutron-rich nuclei display unique structural phenomena as a consequence of strong neutron-proton asymmetry. Large neutron excess leads to formation of regions with very diffuse neutron densities. Heavy nuclei develop neutron skin, an outer coat of neutron-rich matter that surrounds the isospin saturated core. Modifications of effective nuclear potential, evolution of the shell structure and regrouping of energy levels can be observed as well, having impact on the multipole response of nuclei. Theoretical calculations predict appearance of a new collective mode in medium and heavy neutron-rich nuclei at excitation energies below the giant dipole resonance (GDR), near one-neutron separation threshold. This so-called "pygmy" dipole resonance (PDR) is pictured as an oscillation of the neutron skin against the nuclear core. Experimental evidence for PDR is rather scarce.

This report presents results from a measurement performed at GSI facility, whose main aim was investigation of dipole response in unstable nuclei around doubly-magic ^{132}Sn, with special emphasis placed on the low-energy components [1]. The secondary, radioactive beam was produced via in-flight fission of a primary ^{238}U beam at 550 MeV/u. Isotopes with similar A/Z ratio, including $^{129-132}$Sn and ^{133,134}Sb, were selected with the fragment separator FRS, identified on an event-by-event basis and transported to the experimental area hosting the LAND setup (detailed description of the setup can be found in [2,3,4]). Projectiles then passed through a Pb target where a dominant reaction process are electromagnetic dipole excitations to states of relatively high excitation energies which subsequently decay by neutron and γ-ray emission. The excitation energy of projectiles was reconstructed in an invariant-mass analysis applied to all decay products. Dipole strength distributions were obtained from measured energy-differential Coulomb cross sections.

In order to gain insight into the low-lying strength in isotopes of interest, contribution from the GDR and associated instrumental effects had to be subtracted first. GDR parameterization, common for all isotopes, was chosen as a Lorentzian distribution with resonance energy E_o=15.5 MeV, width Γ=4.75 MeV and photo-absorption cross section (integrated up to 25 MeV) σ_γ=2150±140 mb MeV, being in good agreement with systematics known from photo-absorption measurements in stable nuclei. The remaining low-lying strength is shown in Fig.1. It appears in all isotopes studied. Distributions for isotopes with odd-neutron number seem to extend towards lower excitation energies. It should be noted, however, that the experimental data cover excitation energies only above the one-neutron separation threshold, which is significantly higher in case of even neutron numbers. Strength components in ^{130}Sn and ^{132}Sn isotopes exhaust 7(3)% and 4(3)% of the Thomas-Reiche-Kuhn energy-weighted sum rule [1]. Such an amount of strength appears too large to be interpreted in terms of a single-particle excitation and suggests a coherent motion of part of nucleons. The experimental findings are rather close to results of calculations within the (Q)RPA-phonon-coupling (Phys. Lett. **B601** (2004) 27) and the relativistic RPA approach (Phys. Rev. C**67** (2003) 34312). It should be noted, however, that any decisive conclusion on the collectivity degree of the observed low-lying strength cannot be made.

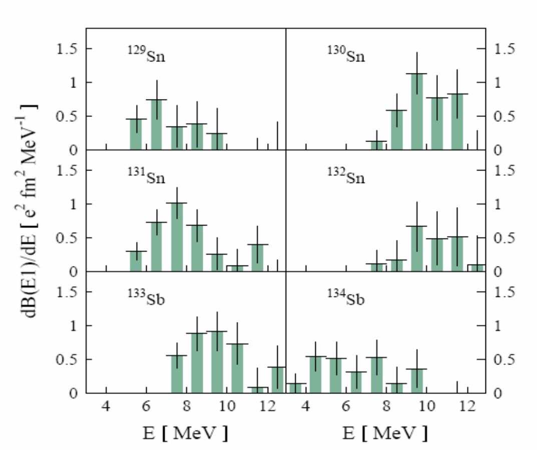

Fig. 1. Low-lying dipole strength distributions obtained for unstable Sn and Sb isotopes.

[1] **P.Adrich, A.Klimkiewicz,** M. Fallot, K. Boretzky, T.Aumann, D. Cortina-Gil, U. Datta Pramanik, Th.W. Elze, H. Emling, H. Geissel, M. Hellstroem, K.L. Jones, J.V. Kratz, **R. Kulessa**, Y. Leifels, C. Nociforo, R. Palit, H. Simon, **G. Surówka**, K. Sümmerer and **W. Waluś**, Phys. Rev. Lett. **95,** 132501 (2005)

[2] K. Boretzky, A. Grünschloß, S. Ilievski, **P.Adrich**, T.Aumann, C.A. Bertulani, J. Cub, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, M. Fallot, J.Holeczek, R. Holzmann, C. Kozhuharov, J.V. Kratz, **R. Kulessa**, Y. Leifels, A. Leistenschneider, **E. Lubkiewicz**, S. Mordechai, T. Ohtsuki, P.Reiter, H. Simon, K. Stelzer, J.Stroth, K. Sümmerer, A. Surowiec, **E. Wajda** and **W. Waluś**, Phys. Rev. C**68**, 024317 (2003)

[3] Th. Blaich, Th.W. Elze, H.Emling, H. Freiesleben, K. Grimm, W. Henning, R. Holzmann, G. Ickert, J.G. Keller, H. Klingler, W. Kneissl, R. Koenig, **R. Kulessa**, J.V. Kratz, D. Lambrecht, J.S. Lange, Y. Leifels, **E. Lubkiewicz**, M. Proft, **W. Prokopowicz**, C. Schütter, R. Schmidt, H. Spies, H. Stelzer, J.Stroth, **E. Wajda**, **W.Waluś,** H.J. Wollersheim, M. Zinser and E. Zude, Nucl. Instr. Methods A**314**, 136 (1992)

[4] J. Cub, G. Stengel, A. Grünschloß, K. Boretkzy, T. Aumann, W. Dostal, B. Eberlein, Th.W. Elze, H. Emling, G. Ickert, J. Holeczek, R. Holzmann, J.V. Kratz, **R. Kulessa**, Y. Leifels, H. Simon, H. Stelzer, J. Stroth, A. Surowiec and **E. Wajda**, Nucl. Instr. Methods A**402**, 67 (1998)

ISOSPIN MIXING IN DEUTERON-INDUCED REACTIONS AT VERY LOW ENERGIES

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Experimental facility: electrostatic accelerator at the Technical University of Berlin,Germany

Nuclear reactions at very low energies are usually of astrophysical interest. The deuteron-induced reactions on light nuclei are especially important for the creation and destruction of chemical elements in the early universe in terms of the inhomogeneous Big-Bang model. Moreover, the primordial abundance of ^{2}H provides very sharp limits for the cosmological baryon-to-photon ratio, strictly related to the baryon density of the universe. On the other hand, the nuclear reactions on the odd-odd self-conjugated nuclei ^{2}H, ^{6}Li and ^{10}B reported here possess many exceptional features making them interesting for fundamental nuclear physics. Since both projectile and target nuclei have in the ground state isospin T=0, only compound-nucleus states with T=0 can be excited. Thus, any isospin impurity of the compound states can then be easily studied by means of the branching ratio between the neutron and proton exit channels [1]. The isospin mixing effects were observed in all of the studied systems.

The investigations performed on ^{6}Li and ^{10}B nuclei could solve some long-standing problems concerning the reaction mechanisms at very low deuteron energies. In the case of ^{6}Li it was shown that an isospin-mixed subthreshold-resonance consisting of the 2^+ isospin-doublet explains the branching ratio between the neutron and proton channels for the ground and first excited states of the final mirror nuclei ^{7}Li and ^{7}Be [1,2] (see Fig.1). It was also pointed out that the constructive interference between this resonance and the direct reaction amplitude correctly describes the experimentally observed angular distribution of the ^{6}Li(d,α)^{4}He reaction [3-5].

The isospin-mixing mechanism also plays an important role in deuteron-induced reactions on ^{10}B. Here, it was indicated that only an excitation of the giant dipole resonance as a doorway-state at projectile energies as low as 300 keV can explain the experimental data (Fig.2). Similarly to ^{6}Li, an isospin impurity of the giant dipole resonance and its coherent contribution to the reaction amplitude had to be included [5,6]. The theoretical calculations could also describe observed angular distributions for the ^{10}B(d,p)^{11}B reaction to the excited states as well as for the ^{10}B(d,α)^{8}Be reaction [6,7].

At very low projectile energies the screening of the nuclear charges by surrounding electrons enhances the experimental cross sections. This effect, important for astrophysical plasmas, could be studied for the mirror reactions ^{2}H(d,p)^{3}H and ^{2}H(d,n)^{3}He [8]. The neutron-proton branching ratio of about 1 observed for gas targets results from two 1^- isospin mixed states in the compound nucleus ^{4}He. For deuteron energies smaller than 20 keV, we observed [9] a quenching of the neutron channel by about 20 % and increasing of anisotropy of the angular distribution when the reactions preceded in metallic Sr or Li environments. The effect could be explained by a partial polarization of deuterons in the crystal lattice.

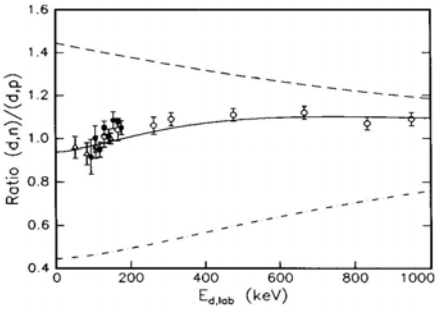

Fig.1. *Branching ratio ^{6}Li(d,n_1)/^{6}Li(d,p_1). The dashed lines represent theoretical calculations performed within DWBA. The solid line include the resonant reaction amplitude additionally.*

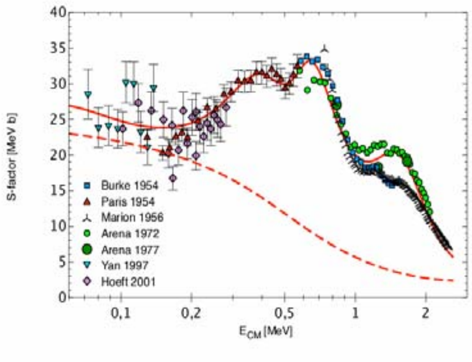

Fig..2. *S-factor and angular distribution coefficients of the ^{10}B(d,p_0)^{11}B reaction. The dashed lines represent the direct reaction component only, the solid lines correspond to the coherent superposition of direct and resonant (GDR) components.*

[1] **K. Czerski**, H. Bucka, P. Heide and T. Makubire, Phys. Lett. **B 307** (1993) 20

[2] **K. Czerski**, H. Bucka, P. Heide and G. Ruprecht, Nucl. Phys. **A621** (1997) 119

[3] **K. Czerski**, A. Huke, H. Bucka, P. Heide, G. Ruprecht and B. Unrau, Phys. Rev. **C 55** (1995) 1517

[4] G. Ruprecht, D. Bemmerer, **K. Czerski**, P. Heide and M. Hoeft, Nucl. Phys. **A688** (2001) 521c

[5] G. Ruprecht, **K. Czerski**, D. Bemmerer, M. Hoeft, P. Heide, Phys. Rev. **C 70** (2004) 025803

[6] G. Ruprecht, **K. Czerski**, D. Bemmerer, M. Hoeft, P. Heide, Nucl. Phys. **A758** (2005) 170

[7] M. Hoeft, **K. Czerski**, P. Heide and M. Lang, Nucl. Phys. **A688** (2001) 524c

[8] **K. Czerski**, A. Huke, A. Biller, P. Heide, M. Hoeft and G. Ruprecht, Europhys. Lett. **54** (2001) 449

[9] A. Huke, **K. Czerski**, T. Dorsch, A. Biller, P. Heide, G. Ruprecht, Eur. Phys. J. **A 27** (2006) 187

PROTON EMISSION

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Experimental facility: Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, USA.

Discovery of proton emitting isomer 53mCo (1970) and, about ten years later, ground-state proton emitters ^{151}Lu and ^{147}Tm marked the beginning of the proton radioactivity studies. Today more than forty proton emitting ground- and isomeric states are known in over thirty proton-emitting nuclei, many of them discovered with a substantial Polish contribution.

Simple experimental observables like proton energy and a partial half-life confronted with theoretical modeling allow us to deduce an angular momentum of the emitted proton and the component of the wave function active in the decay process. For odd-Z even-N nuclei, an observation of the proton emission to the first excited 2^+ state yields the deformation of the tunneled potential as well as unveils more components of the wave function of these very exotic unbound nuclei.

We perform our studies at the HRIBF at Oak Ridge, USA. Since 1998, 6 new proton emitting states, ^{150m}Lu, ^{151m}Lu, ^{144,145}Tm, ^{140}Ho, ^{141m}Ho were found, and three (^{145}Tm, ^{141}Ho, ^{141m}Ho) out of 4 known odd-even proton radioactivities exhibiting fine structure in proton emission were discovered there (by Karny et al.).

At HRIBF, fusion-evaporation products are mass-over-charge selected and implanted into the Double-sided Silicon Strip Detector where energy and time are measured for implanted ion and emitted proton. The main experimental improvement, which allowed the studies of µs-emitters, was a development of digital signal processing. Spectroscopy with programmable digital modules (DGFs) allows us to efficiently select and count rare decays, at µs lifetimes and nano-barn cross section level. Exotic ^{144}Tm has the shortest half-life ($T_{1/2}=1.9^{+1.2}_{-0.5}$(µs) observed to date for proton radioactivity, while proton transition from ^{141m}Ho to 2^+ state in ^{140}Dy has the estimated cross section of 4 nb.

Figure 1 presents the results on ^{145}Tm having second shortest half-life observed ($T_{1/2}$=3.1(3) µs) in proton emission. The $h_{11/2}$ component coupled to the 0^+ core configuration is responsible for the proton emission to the 0^+ ground state, while $f_{7/2}\otimes 0^+$ component governs proton emission to the 2^+ state in the transitional (β_2=0.18) ^{144}Er.

Our latest discovery of the fine structure in proton emission from ^{141m}Ho and ^{141gs}Ho created a challenge for theoretical models. Observed four proton energies, two half-lives, two $2^+/0^+$ branching ratios and experimentally determined β_2 deformation turned out to be hard to reproduce within one nuclear structure model.

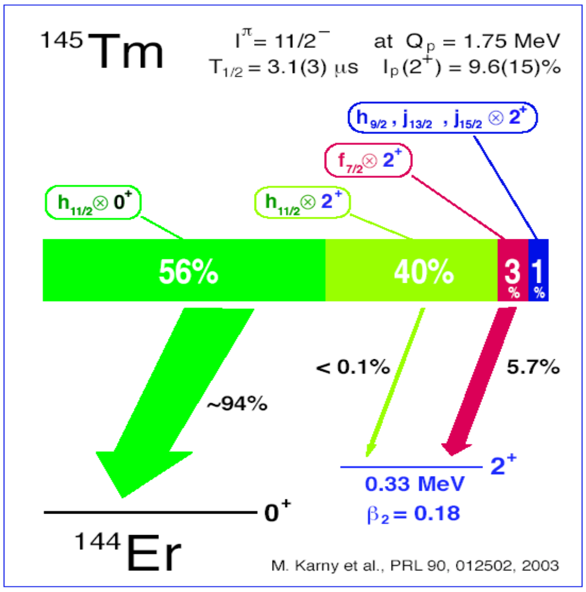

Fig. 1. *^{145}Tm wave function components calculated on the basis of the observation of the proton emission to the ground 0^+ state as well as to the first 2^+ excited state.*

[1] C.R Bingham, M.N. Tantawy, J.C. Batchelder, M. Danchev, T.N. Ginter, C.J. Gross, D.J. Fong, **R. Grzywacz**, K. Hagino K, J.H. Hamilton, **M. Karny**, **W. Królas**, C. Mazzocchi, A. Piechaczek, A. Ramayya, **K. Rykaczewski**, A. Stolz, J.A. Winger, C-H. Yu, E.F. Zganjar, Nucl. Instr. Methods **B241**, 185 (2005)

[2] **R. Grzywacz**, **M. Karny**, **K.P Rykaczewski** , J.C. Batchelder, C.R. Bingham, D. Fong, C.J. Gross, **W. Królas**, C. Mazzocchi, A.Piechaczek, M.N. Tantawy, J.A Winger, E.F.Zganjar. Eur.Phys. J. **A25**, 145 (2005)

[3] J.C. Batchelder, Tantawy M, C.R. Bingham, Danchev M, D. Fong, T.N. Ginter, C.J. Gross, **R. Grzywacz**, Hagino K, J.H. Hamilton, **M. Karny**, **W. Królas**, C. Mazzocchi, A.Piechaczek, A. Ramayya, K.P. Rykaczewski, A. Stolz, J.A Winger, C.H. Yu, E.F.Zganjar. Eur.Phys. J. **A25**, 149 (2005)

[4] T.N. Ginter, J.C. Batchelder, C.R. Bingham, C.J. Gross, **R. Grzywacz**, J.H. Hamilton, **Janas Z**, **M. Karny**, A.Piechaczek, A. RamayyaV, **K.P. Rykaczewski**, Walters WB, E.F.Zganjar. Phys. Rev. **C68**, 034330 (2003),

[5] **M. Karny**, **R. Grzywacz**, J.C. Batchelder, C.R. Bingham, C.J. Gross, K. Hagino, J.H. Hamilton, **Z. Janas**, W.D. Kulp, J.W. McConnell, M. Momayezi, A.Piechaczek, **K.P. Rykaczewski**, P.A. Semmes, M.N. Tantawy, J.A Winger, C.H. Yu, E.F.Zganjar. Phys.Rev.Lett **90**, 012502 (2003)

[6] **K. Rykaczewski**, J.W. McConnell, C.R. Bingham, **R. Grzywacz**, **M. Karny**, J.C. Batchelder, C.J. Gross, **Z. Janas**, M. Momayezi, Wahl J, A.Piechaczek, Zganjar ER, T.N. Ginter, J.H. Hamilton, W.B. Walters, W.D. Kulp, J.A Winger. Nucl.Phys. **A701**, 179c (2002)

[7]**W. Krolas**, **R. Grzywacz**, **K.P. Rykaczewski**, J.C. Batchelder, C.R. Bingham, C.J.Gross, D. Fong, J.H. Hamilton, D.J. Hartley, J.K. Hwang, Y. Larochelle, T.A. Lewis, K.H. Maier, J.W. McConnell, A.Piechaczek, A.V. Ramayya, K. Rykaczewski, D. Shapira, M. N.Tantawy, J.A. Winger, C.-H. Yu, E.F. Zganjar, A.T. Kruppa, W.Nazarewicz, T.Vertse, Phys.Rev. **C65,** 031303R (2002)

[8] **K.P. Rykaczewski**, J.C. Batchelder, C.R. Bingham, T.N. Ginter, C.J. Gross, **R. Grzywacz**, J.H. Hamilton, D.J. Hartley, **Z. Janas** , **M. Karny**, W.D. Kulp, M. Lipoglavsek, J.W. McConnell, M. Momayezi, A.Piechaczek, M.N. Tantawy, J. Wahl, W.B. Walters, J.A Winger, E.F.Zganjar. Acta Phys. Pol. **B32** ,971 (2001)

[9] **K.P. Rykaczewski**, **R. Grzywacz**, **M. Karny**, J.W. McConnell, M. Momayezi, Wahl J, **Z. Janas**, J.C. Batchelder, C.R. Bingham, D. Hartley, M.N. Tantawy, C.J. Gross, T.N. Ginter, J.H. Hamilton, W.D. Kulp, M. Lipoglavsek, A.Piechaczek, E.F.Zganjar, W.B. Walters, J.A Winger. Nucl. Phys. **A682**, 270c (2001)

[10] T.N. Ginter, J.C. Batchelder, C.R. Bingham, C.J. Gross, **R. Grzywacz**, J.H. Hamilton, **Z. Janas**, **M. Karny**, S.H. Kim SH,J.F. Mas, J.W. McConnell, A.Piechaczek, A. Ramayya, **K. Rykaczewski** , P.B. Semmes , J.Szerypo, K.S. Toth, R. Wadsworth, C.H. Yu, E.F.Zganjar. Phys.Rev. **C61**, 014308 (2000)

[11] **K. Rykaczewski**, J.C. Batchelder, C.R. Bingham, Davinson T, T.N. Ginter, C.J. Gross, **R. Grzywacz**, **M. Karny**, MacDonald BD, Mas JF, J.W. McConnell, A.Piechaczek, Slinger RC, K.S. Toth, Walters WB, Woods PJ, E.F.Zganjar, B. Barmore, L.G. Ixaru, A.T Kruppa, W. Nazarewicz, M. Rizea, T. Vertse . Phys. Rev. **C60**, 011301 (1999)

[12] C.R. Bingham, J.C. Batchelder, **K Rykaczewski**, K.S. Toth, C.H. Yu, T.N. Ginter, C.J. Gross, **R. Grzywacz**, **M. Karny**, Kim SH, MacDonald BD, Mas J, J.W. McConnell, Semmes PB, J.Szerypo, Weintraub W, E.F.Zganjar. Phys. Rev. **C59** (R2984 (1999)

[13] **K. Rykaczewski** , J.C. Batchelder, C.R. Bingham, Davinson T, T.N. Ginter, C.J. Gross, **R. Grzywacz**, **Z. Janas**, **M. Karny**, MacDonald BD, Mas JF, J.W. McConnell, A.Piechaczek, Slinger RC, J.Szerypo, K.S. Toth, Walters WB, Woods PJ, E.F.Zganjar, Nazarewicz W, Semmes PB. Acta Phys. Pol. **B30**, 565 (1999)

[14]C. R. Bingham, J. C. Batchelder, **K. Rykaczewski**, K. S. Toth, C. -H. Yu, T. N. Ginter, C. J. Gross, **R. Grzywacz**, **M. Karny**, S. H. Kim, B. D. MacDonald, J. Mas, J. W. McConnell, P. B. Semmes, J.Szerypo, W.Weintraub, E. F. Zganjar Phys. Rev. **C59**, R2984 (1999)

[15]J.C Batchelder, C. R. Bingham, **K. Rykaczewski**, K. S. Toth, T.Davinson, J.A.McKenzie, P.J.Woods, T.N.Ginter, C. J. Gross, J.W.McConnell, E.F.Zganjar,J.H Hamilton, W.B.Walters, C.Baktash,J.Greene, J. Mas, W.T. Milner, S.D. Paul, D.Shapira, X.J.Xu, C. -H. Yu, Phys. Rev. **C57**, R1042, (1998).

[16] C.H. Yu, J.C. Batchelder, C.R. Bingham, **R. Grzywacz**, **Rykaczewski K**, K.S. Toth, Akovali Y, Baktash C, Galindo-Uribarri A, T.N. Ginter, C.J. Gross, **M. Karny**, S.H. Kim, B.D. MacDonald, S.D. Paul, D.C. Radford, J.Szerypo, W. Weintraub. Phys. Rev. **C58**, R3042 (1998)

TWO-PROTON RADIOACTIVITY

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Two-proton (2p) radioactivity is a process, predicted already in 1960 for medium-mass, even-Z, extremely neutron deficient nuclei, in which two protons are ejected simultaneously by a nucleus in a ground state. Theoretical predictions identified a few nuclides like ^{45}Fe, ^{48}Ni, and ^{54}Zn as the best candidates for this new decay mode. For many years, however, these systems could not be reached experimentally. Only the development of methods based on projectile fragmentation and in-flight identification of selected reaction products allowed for a breakthrough in this field.

The road to the discovery of the 2p radioactivity was opened when 3 atoms of ^{45}Fe were identified for the first time at GSI Darmstadt among the fragmentation products of relativistic ^{58}Ni beam [1]. Later, at GANIL Caen, also ^{48}Ni was sythesized using the same production method with lower beam energy [2], and a step towards production of ^{54}Zn was made [3]. In these pioneering experiments, however, no information on decay properties of 2p candidates could be obtained. In order to investigate decays of selected and identified ions, detection systems based on silicon detectors were developed. Ions of interest were implanted into a stack of such detectors where their decays could be recorded [4].

The first information on the decay of ^{45}Fe has been obtained in a GSI experiment using the implantation method. Ions of interest, produced by the fragmentation of ^{58}Ni beam at 650 MeV/u, selected by the FRS separator and indentified in-flight, were stopped into a stack of 8 silicon detectors, each 300 μm thick. A special care has been taken to provide sensitivity of the set-up to a broad range of lifetime values ranging from microseconds to milliseconds [5]. Fast-reset preamplifiers, specially developed for this purpose, and the data acquisition system based on digital electronic modules were used [5]. Decays of five ions of ^{45}Fe were recorded [6]. Four of them were interpreted as the first evidence of the 2p radioactivity. One event was consistent with the β^+ decay of ^{45}Fe followed by a beta-delayed high-energy proton emission. The 2p decay energy was estimated to be 1.1 ± 0.1 MeV and the deduced half-life of ^{45}Fe was $3.2^{+2.6}_{-1.0}$ ms [6].

Similar results were obtained in a independent experiment performed at GANIL, where the ^{58}Ni beam at 75 MeV/u and the LISE spectrometer were used to produce and separate ions of ^{45}Fe which were implanted into a double-sided silicon strip detector of 300 μm thickness [7]. Out of 22 identified events of ^{45}Fe, for eight of them a single decay energy of 1.14 ± 0.04 MeV was observed in agreement with the 2p decay scenario. The branching ratio for the 2p decay channel was deduced to be 70% - 80% and the half-life was measured to be $4.7^{+3.4}_{-1.4}$ ms [7].

In both experiments only the total decay energy and decay time were recorded, so the 2p decay interpretation had to be based on theoretical arguments [8,9]. A crutial next step in the study of 2p radioactivity will be a direct observation of this process by recording both proton independently. Even more important would be the determination of angular and energy correlations between protons. Only these observables may shed light on the mechanism of the 2p radioactivity [10].

To achieve this goal, a novel type of a detector – the gaseous time projection chamber with optical readout is being developed at Institute of Experimental Physics, Warsaw University [11]. The combination of imaging by means of a digital camera with the dift-time profile of ionisation electrons will allow the reconstruction of the charged particles tracks in three dimensions [12].

[1] B. Blank, S. Czajkowski, F. Davi, R. Del Moral, J.P. Dufour, A. Fleury, C. Marchand, M.S. Pravikoff, J. Benlliure, F. Boue, R. Collatz, A. Heiz, M. Hellstroem, Z. Hu, E. Roeckl, M. Shibata, K. Suemmerer, **Z. Janas, M. Karny, M. Pfützner**, M. Lewitowicz
Phys. Rev. Lett. **77**, 2893-2896 (1996).

[2] B. Blank, M. Chartier, S. Czajkowski, J. Giovinazzo, M.S. Pravikoff, J.-C. Thomas, G. de France, F. de Oliveira Santos, M. Lewitowicz, C. Borcea, **R. Grzywacz, Z. Janas, M. Pfützner**
Phys. Rev. Lett. **84**, 1116 (2000)

[3] J. Giovinazzo, B. Blank, C. Borcea, M. Chartier, S. Czajkowski, G. de France, **R. Grzywacz, Z. Janas**, M. Lewitowicz, F. de Oliveira Santos, **M. Pfützner**, M.S. Pravikoff, J.C. Thomas
First Observation of ^{55,56}*Zn*
Eur. Phys. J. A**11** (2001) 247

[4] J. Giovinazzo, B. Blank, C. Borcea, M. Chartier, S. Czajkowski, G. de France, **R. Grzywacz, Z. Janas**, M. Lewitowicz, F. de Oliveira Santos, **M. Pfützner**, M.S. Pravikoff, J.C. Thomas
*Eur. Phys. J. A***10** (2001) 73

[5] **M. Pfützner**, E. Badura, **R. Grzywacz**, **Z. Janas**, M. Momayezi, C. Bingham, B. Blank, M. Chartier, H. Geissel, J. Giovinazzo, M. Hellström, **J. Kurcewicz**, A.S. Lalleman, C. Mazzocchi, I. Mukha, C. Plettner, E. Roeckl, **K.P. Rykaczewski**, K. Schmidt, R.S. Simon, M. Stanoiu, J.-C. Thomas
Nucl. Instr. Meth. A **493**, 155 (2002)

[6] **M. Pfützner**, E. Badura, C. Bingham, B. Blank, M. Chartier, H. Geissel, J. Giovinazzo, L.V. Grigorenko, **R. Grzywacz**, M. Hellström, **Z. Janas, J. Kurcewicz**, A.S. Lalleman, C. Mazzocchi, I. Mukha, G. Münzenberg, C. Plettner, E. Roeckl, **K.P. Rykaczewski**, K. Schmidt, R.S. Simon, M. Stanoiu, and J.-C.Thomas
Eur. Phys. J. A **14**, 279 (2002)

[7] J. Giovinazzo, B. Blank, M. Chartier, S. Czajkowski, A. Fleury, M.J. Lopez Jimenez, M.S. Pravikoff, J.-C. Thomas, F. de Oliveira Santos, M. Lewitowicz, V. Maslov, M. Stanoiu, **R. Grzywacz**, **M. Pfützner**, C. Borcea, B.A. Brown
Phys. Rev. Lett. **89**, 102501 (2002)

[8] **M. Pfützner**, B. Blank, J. Giovinazzo, E. Badura, C. Bingham, C. Borcea, B.A. Brown, M. Chartier, S. Czajkowski, F. de Oliveira Santos, A. Fleury, H. Geissel, L.V. Grigirenko, R. Grzywacz, M. Hellström, **Z. Janas**, **J. Kurcewicz**, A.S. Lalleman, M. Lewitowicz, M.J. Lopez Jimenez, V. Maslov, C. Mazzocchi, I. Mukha, G. Münzenberg, C. Plettner, M.S. Pravikoff, E. Roeckl, **K.P. Rykaczewski**, K. Schmidt, R.S. Simon, M. Stanoiu, J.-C. Thomas
Acta Phys. Pol. B **34**, 2363 (2003)

[9] B. Blank, J. Giovinazzo, **M. Pfützner,** *C. R. Physique* **4**, 521 (2003)

[10] **M. Pfützner,** *Nucl. Phys. A***738**, 101 (2004)

[11] **M. Pfützner,** *Eur. Phys. J. A* **25**, Supplement 1, 165 (2005)

[12] **M. Ćwiok, W. Dominik, Z. Janas, A. Korgul, K. Miernik, M. Pfützner, M. Sawicka, A. Wasilewski,** *IEEE Trans. On Nucl. Science* 52, 2895 (2005)

NUCLEAR OPEN QUANTUM SYSTEM MANY-BODY PROBLEM

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Many-body nuclear Hamiltonian does not describe just one nucleus (N, Z), but all nuclei that can exist. In this sense, a nucleus is never isolated (closed) but `communicates' with other systems through decays and captures. If the continuum space is not considered, this communication is not allowed: the system is closed.

The nuclear shell model (SM) is the cornerstone of our understanding of nuclei. SM, in its standard realization, assumes than the many-nucleon sys-tem is perfectly isolated from an external environment of scattering states and decay channels. That is, within the standard SM the nucleus is viewed as a closed quantum system (CQS). However, weakly bound or unbound nuclear states obviously cannot be treated in a CQS framework. The theoretical description of strongly correlated open quantum systems (OQS) requires the rigorous treatment of both: many-body correlations, and the continuum of positive energy states and decay channels. Solution of this challenging nuclear OQS many-body problem has been advanced recently through a new-generation continuum SM approaches, including shell model embedded in the continuum (SMEC) (Hilbert space formulation) and Gamow shell model (GSM) (the rigged Hilbert space formulation).

Properties of unbound states lying above the particle (or cluster) threshold directly impact the continuum structure. Coupling to the particle continuum is also important for weakly bound states, such as `halos'. The generic mechanism of alignment of bound and unbound near-threshold states with the decay channel explains the appearance of cluster structures close to their cluster decay thresholds. A unified description of nuclear structure and nuclear reaction aspects became possible only recently in the framework of the SMEC [1-3]. The SMEC has been applied for the description of spectra and reactions involving one particle in the scattering continuum, like the (p, p') reaction, the nucleon radiative capture reactions [1-5], the Coulomb dissociation reaction [6], or the first forbidden β-decay [7]. Further applications of the SMEC with one-particle continuum involved the study of binding systematics of neutron-rich nuclei in *sd* shell [8], and the statistical aspects of the continuum coupling for states in ^{24}Mg [9]. The generalization of SMEC to the two-particle continuum allowed to formulate a microscopic theory of the two-proton decay [10-11].

The GSM [12-15] is the first multi-configurational SM approach for OQS with no restriction on number of particles in the continuum. In the roots of GSM lies the Berggren one body completeness relation [Nucl. Phys. **A109**, 265 (1968)] that provides mathematical foundation for unifying bound and unbound states. The fundamental difference between GSM and a real-energy SM is that the many-body resonant states of the GSM are embedded in the background of scattering eigenstates. The principal limitation of GSM applications is the explosive growth in the number of configurations because for each resonant single particle state in the Berggren ensemble one should include a large set of discrete non-resonant continuum states. All these states become new active shells in the many-body framework of GSM and, because of their presence, the dimension of the many-body Fock space grows extremely fast. This crucial problem for GSM has been solved recently by generalizing the density-matrix renormalization group method for OQSs [16].

The GSM has been applied for the description of spectra of weakly-bound or unbound nuclei in p and *sd* shells [12-15]. These studies have demonstrated that nucleon-nucleon correlations in weakly bound or unbound states, as probed by spectroscopic factors, can be significantly different from SM predictions (CQS description) and may even exhibit a non-analytical behavior at the particle threshold [17]. This phenomenon, resembling a quantum phase transition, shares many features of the near-threshold behavior of scattering cross sections, first noted by Wigner [Phys. Rev. **73**, 1002 (1948)]. The GSM provides first explanation of the Wigner cusp phenomenon and multi-channel coupling effects in the vicinity of particle emission threshold(s) within a microscopic many-body approach based on many-fermion interaction.

[1] K. Bennaceur, F. Nowacki, **J. Okołowicz**, M. Płoszajczak, J. Phys. G: Nucl. Part. Phys. **24,** 1631 (1998)

[2] K. Bennaceur, F. Nowacki, **J. Okołowicz**, M. Płoszajczak, Nucl. Phys. **A651,** 289 (1999)

[3] **J. Okołowicz**, M. Płoszajczak, I. Rotter, Phys. Rep. **374,** 271 (2003)

[4] K. Bennaceur, F. Nowacki, N. Michel, **J. Okołowicz**, M. Płoszajczak, Phys. Lett. **488B,** 75 (2000)

[5] K. Bennaceur, F. Nowacki, **J. Okołowicz**, M. Płoszajczak, Nucl. Phys. **A671,** 203 (2000)

[6] R. Shyam, K. Bennaceur, **J. Okołowicz**, M. Płoszajczak, Nucl. Phys. **A669,** 65 (2000)

[7] N. Michel, **J. Okołowicz**, F. Nowacki, M. Płoszajczak, Nucl. Phys. **A703,** 202 (2002)

[8] Y. Luo, **J. Okołowicz**, M. Płoszajczak, N. Michel, arXiv:nucl-th/0201073; N. Michel, **W. Nazarewicz**, **J. Okołowicz**, M. Płoszajczak, *Proc. Int. Symposium on Frontiers of Collective Motion* (CM2002) H. Sagawa and H. Iwasaki eds., World Scientific (2003) p. 157

[9] **S. Drożdż**, **J. Okołowicz**, M. Płoszajczak, I. Rotter, Phys. Rev. C **62,** 024313 (2000)

[10] J. Rotureau, **J. Okołowicz**, M. Płoszajczak, Phys. Rev. Lett. **95,** 042503 (2005)

[11] J. Rotureau, **J. Okołowicz**, M. Płoszajczak, Nucl. Phys. **A767,** 13 (2006)

[12] N. Michel, **W. Nazarewicz**, M. Płoszajczak, K. Bennacur, Phys. Rev. Lett. **89,** 042502 (2002)

[13] N. Michel, **W. Nazarewicz**, M. Płoszajczak, **J. Okołowicz**, Phys. Rev. C **67,** 054311 (2003)

[14] N. Michel, **W. Nazarewicz**, M. Płoszajczak, Phys. Rev. C **70,** 054311 (2004)

[15] N. Michel, **W. Nazarewicz**, M. Płoszajczak, J. Rotureau, Phys. Rev. C **74,** 054305 (2006)

[16] J. Rotureau, N. Michel, **W. Nazarewicz**, M. Płoszajczak, J. Dukelsky, Phys. Rev. Lett. **97,** 110603 (2006)

[17] N. Michel, **W. Nazarewicz**, M. Płoszajczak, Phys. Rev. C **75,** 031301 (2007)

THREE-NUCLEON FORCE EFFECTS IN NUCLEON-DEUTERON REACTIONS

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The 3N system is the first nontrivial case to test the nucleonic Hamiltonian. Traditionally it is taken in a nonrelativistic form with realistic NN forces, which are adjusted to the NN data. We use the most modern NN forces AV18, CD Bonn, and Nijmegen I and II, which are very well tuned to the NN data base up to about 350 MeV. In general such a Hamiltonian gives a quite good description for 3N scattering observables and the predictions show stability against exchanges of modern NN forces [1]. In the calculations with the TM three-nucleon force (3NF) we adjust the form factor parameter in that force together with each of the NN forces to the triton binding energy. These Hamiltonians are then used to provide estimates for 3NF effects in the 3N continuum.

A complete overview of our results and their comparison to many data is shown in [2-4]. For the total nd cross section up to about E_n=100 MeV there is a nice agreement of the pure 2N force predictions and the data [5,6]. A discrepancy develops at higher energies and calculations underestimate the data by about 11% at 300 MeV. The effect of the TM 3NF enhances the total nd cross section at the higher energies only by about 4%. The elastic Nd scattering is quite well described with NN forces only at lower energies but there develops a strong discrepancy, starting at about 30 MeV, in the minimum of angular distribution. It is very probably caused by 3NF effects, which fill this minimum [7]. This expectation is supported by recent precise data [8,9] (see Fig.1). The nucleon analyzing power A_y in low energy elastic Nd scattering poses a still unsolved puzzle [10]. There are, however, still doubts whether the ^3P_J NN force components, on which A_y is extremely sensitive, have been constrained sufficiently well by the NN data basis [10]. Present day 3N forces have insignificant effects at those low energies. If a 3NF would be responsible for the low energy A_y puzzle it must be of different structure than the TM 3NF. It may turn out that 3NF derived in the framework of chiral perturbation theory will provide solution to that puzzle [11-13].

New precise pd polarization data taken at higher energies opened recently a new region to test the 3N Hamiltonian and the properties of a 3NF. At those energies large 3NF effects, as given by the 2π-exchange TM model, are predicted for some observables. For some of them a discrepancies between pure NN force predictions and data have been found. Adding the 3NF leads to a better description of data for deuteron vector analyzing power and some spin correlation coefficients [14]. However, for the proton analyzing power the effects predicted by the TM 3NF are too large indicating a failure of the TM 3NF [15]. Also for polarization observables in the breakup process at higher energy large 3NF effects are predicted in some kinematical configurations. Tests of them require a precise data basis. Recently a rich data set was provided which allows to draw first conclusions on importance of 3NF in breakup reaction [16].

We started to apply two- and many-nucleon forces derived in the chiral effective field theory approach [17-19]. This will allow to analyze 3N continuum reactions with consistent nucleonic Hamiltonian a good knowledge and a well founded understanding of which is the prerequisite to theoretical analysis of electroweak processes with three participating nucleons.

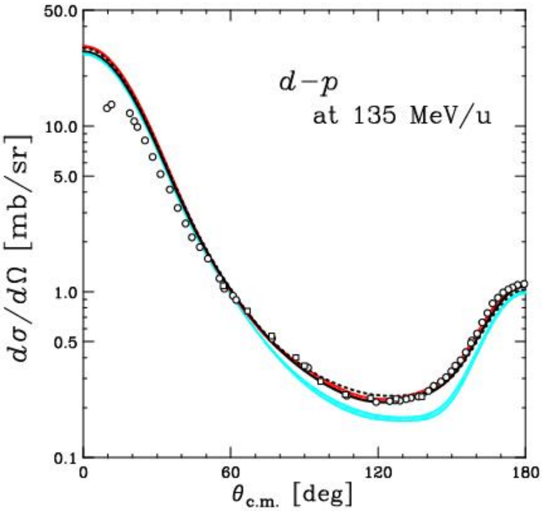

Fig.1. *The Nd elastic scattering cross section at E_d=270 MeV. The data (circles) are from [9]. The curves and bands, described in [9], show results of calculations with different dynamical models.*

[1] W. Glöckle, **H.Witała**, D.Hüber, H.Kamada, **J.Golak,** Phys. Rep. **274**, 107 (1996)

[2] **H.Witała**, W.Glöckle, **J.Golak,** A. Nogga, H. Kamada,**R. Skibiński,** and **J. Kuroś-Żołnierczuk,** Phys. Rev. **C63**, 024007 (2001).

[3] **J. Kuroś-Żołnierczuk**, **H.Witała**, **J.Golak,** H. Kamada, A. Nogga, **R. Skibiński,** W. Glöckle, Phys. Rev. **C66**, 024003(2002).

[4] **J. Kuroś-Żołnierczuk, H.Witała**, **J.Golak,** H. Kamada, A. Nogga, **R. Skibiński,** W. Glöckle, Phys. Rev. **C66**, 024004(2002).

[5] W.P.Abfalterer, F.B.Bateman, F.S.Dietrich, Ch.Elster, R.W.Finlay,W.Glöckle, **J.Golak,** R.C.Haight, D.Hüber, G.L.Morgan, **H.Witała**, Phys. Rev. Lett. **81**, 57 (1998).

[6] **H.Witała**, H. Kamada, A. Nogga, W.Glöckle, Ch. Elster, D.Hüber, Phys. Rev. **C59**, 3035 (1999).

[7] **H.Witała**, W.Glöckle, D.Hüber, **J.Golak,** H.Kamada, Phys. Rev. Lett. **81**, 1183 (1998).

[8] H. Sakai, K. Sekiguchi, **H.Witała**, W.Glöckle, M. Hatano, H. Kamada, H. Kato, Y. Maeda, A. Nogga, T. Ohmishi, H. Okamura, N. Sakamoto, S. Sakoda, Y. Satou, K. Suda, A. Tamii, T. Uesaka, T. Wakasa, and K. Yako, Phys. Rev. Lett. **84**, 5288 (2000).

[9] K. Sekiguchi, H. Sakai, **H.Witała,** W.Glöckle, **J.Golak,** K. Hatanaka, M. Hatano, K. Itoh, H. Kamada, H. Kuboki, Y. Maeda, A. Nogga, H. Okamura, T. Saito, N. Sakamoto, Y. Sakemi, M. Sasano, Y. Shimizu, K. Suda, A. Tamii, T. Uesaka, T. Wakasa, and K. Yako, Phys. Rev. Lett. **95**, 162301 (2005).

[10] W.Tornow, **H.Witała**, Nucl. Phys., **A637**, 280 (1998).

[11] E.Epelbaum, H.Kamada, A.Nogga, **H.Witała**, W.Glöckle, Ulf-G. Meissner, Phys. Rev. Lett. **86**, 4787 (2001).

[12] E. Epelbaum, A. Nogga, W. Glöckle, H. Kamada, Ulf-G. Meissner, **H.Witała**, Phys. Rev. **C66**, 064001(2002).

[13] D.R. Entem, R. Machleidt, **H.Witała**, Phys. Rev. **C65**, 064005 (2002).

[14] R.V. Cadman, J. Brack, W.J. Cummings, J.A. Fedchak, B.D. Fox, H. Gao, W. Glöckle, **J.Golak,** C. Grosshauser, R.J. Holt, C.E. Jones, H. Kamada, E.R. Kinney, M.A. Miller, W. Nagengast, A. Nogga, B.R. Owen, K. Rith, F.Schmidt, E.C. Schulte, J.Sowinski, F.Sperisen, E.L. Thorsland, R.Tobey, J.Wilbert, **H.Witała**, Phys. Rev. Lett. **86**, 967 (2001).

[15] K. Ermisch, A.M. van den Berg, R. Bieber, W.Glöckle, **J.Golak,** M. Hagemann, V.M. Hannen, M.N. Harakeh, M.A. de Huu, N. Kalantar-Nayestanaki, H. Kamada, M. Kis, **J. Kuroś-Żołnierczuk**, M. Mahjour-Shafiei, **A. Micherdzińska,** A. Nogga, **R. Skibiński, H.Witała**, H.J. Wörtche, Phys. Rev. Lett. **86**, 5862 (2001).

[16] **St. Kistryn, E. Stephan, A. Biegun, K. Bodek,** A. Deltuva, E. Epelbaum, K. Ermisch, W. Glöckle, **J.Golak,** N. Kalantar-Nayestanaki, H. Kamada, M. Kis, **B. Kłos, A. Kozela, J. Kuroś-Żołnierczuk**, M. Mahjour-Shafiei, U.-G. Meissner, **A. Micherdzińska,** A. Nogga, P.U. Sauer, **R. Skibiński**, **R. Sworst, H.Witała**, **J. Zejma,** and **W. Zipper,** Phys. Rev. **C72**, 044006 (2005).

[17] **H.Witała**, **J.Golak, R. Skibiński**, W. Glöckle, A. Nogga, E. Epelbaum, H. Kamada, A. Kievsky, M. Viviani, Phys. Rev. **C73**, 044004 (2006).

[18] **H.Witała**, **R. Skibiński**, **J.Golak,** W. Glöckle, A. Nogga, and H. Kamada, Eur. Phys. J. **A29**, 141 (2006).

[19] **D.Rozpędzik**, **J.Golak, R. Skibiński**, **H.Witała**, W. Glöckle, E. Epelbaum, A. Nogga, H. Kamada, Acta Phys. Polon. **B37**, 2889 (2006).

RELATIVISTIC EFFECTS IN THREE-NUCLEON CONTINUUM

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The high precision nucleon-nucleon (NN) potentials which describe very well the NN data set up to about 350 MeV, like e.g. AV18 and CD Bonn form a very firm basis for a study of three-nucleon (3N) reactions. With increasing amount of precise 3N elastic scattering data it turned out, that nonrelativistic description based on pairwise forces only is insufficient to explain the data at higher energies of the 3N system. Moreover, the inclusion of three nucleon forces (3NF) only partially removes discrepancy between data and theoretical predictions. This can be to some extent attributed to missing structures in modern models of 3NF's but relativistic effects may be also important.

To study the latter we introduced [1] the Hamiltonian scheme in equal time formulation and applied it to elastic nucleon-deuteron (Nd) scattering [2-4] as well as to deuteron breakup [5,6], taking as a starting point the Lorentz boosted NN potential which generates the NN t-matrix in a moving frame via a modified Lippmann-Schwinger equation. The NN potential in an arbitrary moving frame is based on the interaction in the two-nucleon c.m. system, which enters a relativistic NN Schrödinger or Lippmann-Schwinger equation. We constructed the relativistic two nucleon (2N) potential by performing an analytical scale transformation of momenta, which relates NN potentials in the nonrelativistic and relativistic Schrödinger equations in such a way, that exactly the same NN phase shifts are obtained by both equations. In our study [2] we also looked for changes in elastic Nd scattering observables when the nonrelativistic form of the kinetic energy was replaced by the relativistic one and a proper treatment of boost effects and Wigner rotations of spin states was included. It turned out, that the effects of spin rotations in the studied energy range up to 250 MeV were practically negligible for elastic scattering cross sections and analyzing powers. The relativistic effects for the elastic scattering cross section were significant only at higher energies and restricted to the very backward angles, where relativity increased the nonrelativistic cross section. The decisive role was played by the boost effects which reduced the transition matrix elements at higher energies and led, in spite of the increased elastic scattering relativistic phase-space factor as compared to the nonrelativistic one, to rather small effects in the cross section [3].

Investigation of polarized observables in elastic Nd scattering shows that existing discrepancies between data and nonrelativistic predictions based on NN+3NF interactions cannot be removed by adding relativistic effects coming from kinematics and boost corrections to the employed NN ineraction [2,4].

For exclusive deuteron breakup at incoming nucleon lab. energy 65 MeV and 200 MeV we performed [6] a search for magnitudes and signs of relativistic effects on the breakup cross sections over the relevant parts of the breakup phase-space. We found, that depending on the phase-space region relativity can decrease as well as increase the nonrelativistic cross section. The magnitude of the effects rises with the incoming nucleon energy. While at 65 MeV the effects are rather moderate (up to 20%), at 200 MeV they can change the nonrelativistic cross section even by a factor of 2. Comparison to existing data (see Fig.1) seems to support this finding. At 65 MeV the inclusion of relativity can explain some discrepancies found in the past between theory and data.

Summarizing, our formalism allows us to estimate relativistic effects on the observables for 3N processes. Since higher energies seem to be more favorable to study properties of 3N forces, inclusion of relativistic effects is an important step in studies of that force component.

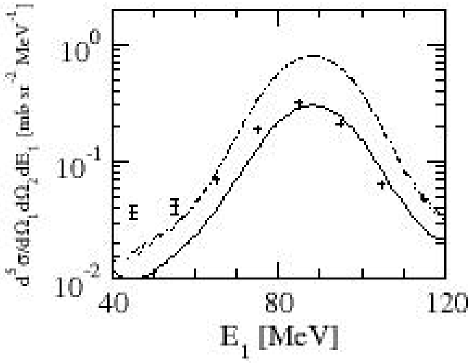

Fig. 1. The symbols show experimental five-fold cross section for the d(n,np)n reaction at E_n=200 MeV for configuration given in [6]. The solid line is for relativistic predictions and dotted and dashed lines are for nonrelativistic ones without and with 3NF, respectively [6] .

[1] H.Kamada, W.Glöckle, **J.Golak**, and Ch.Elster, Phys. Rev. C **66**, 044010 (2002).

[2] **H.Witała, J.Golak**, W.Glöckle, H.Kamada, Phys. Rev. C **71**, 054001 (2005).

[3] K.Sekiguchi, H.Sakai, **H.Witała**, W.Glöckle, **J.Golak**, K.Hatanaka, M.Hatano, K.Itoh, H.Kamada, H.Kuboki, Y.Maeda, A.Nogga, H.Okamura, T.Saito, N.Sakamoto, Y.Sakemi, M.Sasano, Y.Shimizu, K.Suda, A.Tamii, T.Uesaka, T.Wakasa, and K.Yako, Phys. Rev. Lett. **95**, 162301 (2005).

[4] **H.Witała, R.Skibiński, J.Golak**, W.Glöckle, A.Nogga, and H.Kamada, Eur. Phys. J. A **29**, 141(2006).

[5] **H.Witała, J.Golak**, and **R.Skibiński**, Phys. Lett. B **634**, 374 (2006).

[6] **R.Skibiński, H.Witała, J.Golak**, Eur. Phys. J. A **30**, 369 (2006).

ELECTRON AND PHOTON SCATTERING ON THREE-NUCLEON BOUND STATES

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The interaction of photons with charged particles is relatively weak and can be treated perturbatively. This opens the possibility to probe the complicated dynamics of the nuclear systems. Electron and photon facilities, like the Thomas Jefferson National Accelerator Facility (JLab), the Mainz Microtron (MAMI) or The High Intensity Gamma-Ray Source (HIGS) are used to investigate nuclei and nucleons themselves.

Few-nucleon studies are a central part in the physics program of these facilities because the lightest nuclei and reactions with few nucleons can be treated rigorously. Especially three-ucleon (3N) systems are an excellent test ground for our understanding of nuclear forces. Exact nonrelativistic calculations are available both for the ground states of ^{3}He and ^{3}H (see Phys. Rev. C**67**, 034004 (2003)) and the 3N continuum [1]. In the Faddeev framework a few modern high-precision nucleon-nucleon (NN) realistic potentials have been employed. Also calculations combining different NN and 3N force models have been recently performed [1-4]. Although further investigations in the pure 3N system are necessary to establish the final form of the 3N Hamiltonian, it is mandatory to use already now the existing formalism and study electromagnetic processes with three nucleons.

In electron scattering on ^{3}He which we study below the pion production threshold, one can fix the spin orientations of the electron and of the ^{3}He nucleus in the initial state before the reaction takes place, which leads to the so-called spin-dependent electron helicity asymmetries. These observables are useful for studying the neutron structure because the ground state of polarized ^{3}He is dominated by a spatially symmetric configuration in which the proton spins cancel and the spin of the ^{3}He nucleus is carried by the unpaired neutron.Thus electron scattering on polarized ^{3}He is very similar to electron scattering on a polarized neutron. This is of great importance because of the lack of free neutron targets. Until recently, most data on the neutron electromagnetic form factors had been deduced from elastic and quasi-elastic electron-deuteron scattering. Our theoretical contribution made it possible to extract equivalent information about the magnetic and electric neutron form factors through inclusive or semi-inclusive electron scattering on ^{3}He [5-7]. We could quite independently verify the data on fundamental neutron properties.

Within our theoretical framework it is also possible to ask very detailed questions about the properties of light nuclei. We have investigated for example nucleon-nucleon correlations [8], spin dependent momentum distributions [9] and proton polarizations in polarized ^{3}He [10]. Our results show that final state interactions among the three outgoing nucleons, meson exchange currents and three-nucleon forces play generally an important role and that previously used approximations are not justified. Similar conclusions can also be drawn from our theoretical description of photon scattering on ^{3}He and ^{3}H. We have studied the total photoabsorption cross sections [11] as well as two- and three-body exclusive and semi-exclusive disintegration reactions [12-14]. Nucleon-deuteron capture, closely related (via time reversal) to two-body disintegration of ^{3}H has been recently studied with potentials derived within the framework of chiral effective field theory [15]. Detailed information about electron and photon scattering on ^{3}He and ^{3}H can be found in our recent review paper [16].

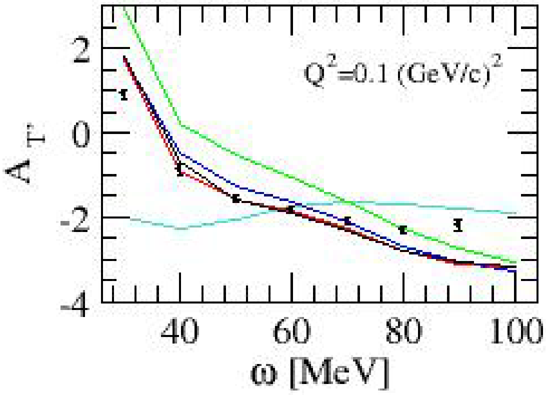

Fig. 1. *The parallel asymmetry $A_{T'}$ as a function of the energy transfer ω. The data are from [5]. The curves, described in [16], show results of calculations with different dynamical models.*

[1] W. Glöckle, H. Witała, D. Hüber, H. Kamada, **J. Golak**, Phys. Rept. **274**, 107 (1996).

[2] **H. Witała**, W. Glöckle, **J. Golak**, A. Nogga, H. Kamada, **R. Skibiński**, and **J. Kuroś-Żołnierczuk**, Phys. Rev. C**63**, 024007 (2001).

[3] **J. Kuroś-Żołnierczuk, H. Witała, J. Golak**, H. Kamada, A. Nogga, **R. Skibiński**, W. Glöckle, Phys. Rev. C**66**, 024003 (2002).

[4] **J. Kuroś-Żołnierczuk, H. Witała, J. Golak**, H. Kamada, A. Nogga**, R. Skibiński**, W. Glöckle, Phys. Rev. C**66**, 024004 (2002).

[5] W. Xu, D. Dutta, F. Xiong, B. Anderson, L. Auberbach, T. Averett, W. Bertozzi, T. Black, J. Calarco, L. Cardman, G. D. Cates, Z. W. Chai, J. P. Chen, S. Choi, E. Chudakov, S. Churchwell, G. S. Corrado, C. Crawford, D. Dale, A. Deur, P. Djawotho, B. W. Filippone,J. M. Finn, H. Gao, R. Gilman, A. V. Glamazdin, C. Glashausser, W. Glockle, **J. Golak**, J. Gomez, V. G. Gorbenko, J.-O. Hansen, F. W. Hersman, D. W. Higinbotham, R. Holmes, C. R. Howell, E. Hughes, B. Humensky, S. Incerti, C. W. de Jager, J. S. Jensen, X. Jiang, C. E. Jones, M. Jones, R. Kahl, H. Kamada, A. Kievsky, I. Kominis, W. Korsch, K. Kramer, G. Kumbartzki, M. Kuss, E. Lakuriqi, M. Liang, N. Liyanage, J. LeRose, S. Malov, D. J. Margaziotis, J. W. Martin, K. McCormick, R. D. McKeown, K. McIlhany, Z.-E. Meziani, R. Michaels, G. W. Miller, E. Pace, T. Pavlin, G. G. Petratos, R. I. Pomatsalyuk, D. Pripstein, D. Prout, R. D. Ransome, Y. Roblin, M. Rvachev, A. Saha, G. Salmè, M. Schnee, T. Shin, K. Slifer, P. A. Souder, S. Strauch, R. Suleiman, M. Sutter, B. Tipton, L. Todor, M. Viviani, B. Vlahovic, J. Watson, C. F. Williamson, **H. Witała**, B. Wojtsekhowski, J. Yeh, and P. Zolnierczuk, Phys. Rev. Lett. **85**, 2900 (2000).

[6] **J. Golak**, G. Ziemer, H. Kamada, **H. Witała**, W.Glöckle, Phys. Rev. C**63**, 034006 (2001).

[7] **J. Golak**, W. Glöckle, H. Kamada, **H. Witała**, **R. Skibiński**, A. Nogga, Phys. Rev. C**66**, 024008 (2002).

[8] W. Glöckle, H. Kamada, **J. Golak**, A. Nogga, **H. Witała**, **R. Skibiński**, and **J. Kuroś-Żołnierczuk**, Acta Phys. Polon. **B32**, 3053 (2001).

[9] **J. Golak**, W. Glöckle, H. Kamada, **H. Witała, R. Skibiński**, A. Nogga, Phys. Rev. C**65**, 064004 (2002).

[10] **J. Golak, R. Skibiński, H. Witała**, W. Glöckle, A. Nogga, H. Kamada, Phys. Rev. C**72**, 054005 (2005).

[11] **J. Golak, R. Skibiński**, W. Glöckle, H. Kamada, A. Nogga, **H. Witała**, V. D. Efros, W. Leidemann, G. Orlandini, E.L. Tomusiak, Nucl.Phys. **A707**, 365 (2002).

[12] **R. Skibiński, J. Golak**, H. Kamada, **H. Witała**, W.Glöckle, A. Nogga, Phys.Rev. C**67**, 054001 (2003).

[13] **R.Skibiński, J.Golak, H.Witała**, W.Glöckle, H.Kamada, A.Nogga, Phys. Rev. C**67**, 054002 (2003).

[14] **R.Skibiński, J.Golak, H.Witała**, W.Glöckle, A.Nogga, H.Kamada, Phys.Rev. C**72**, 044002 (2005).

[15] **R.Skibiński, J.Golak, H.Witała**, W.Glöckle, A.Nogga, E.Epelbaum, Acta Phys. Polon. **B37**, 2905 (2006).

[16] **J. Golak, R. Skibiński, H. Witała**, W. Glöckle, A. Nogga, H. Kamada, Phys. Rept. **415**, 89 (2005).

EXPERIMENTAL STUDIES OF THREE-NUCLEON SYSTEM IN VARIOUS KINEMATICAL CONDITIONS

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Experimental facility: PSI, Villigen, Switzerland; KVI Groningen, The Netherlands

Few nucleon systems are fundamental laboratories to study nuclear interaction. Among them, the systems composed of three nucleons (3N) are the simplest non-trivial environment to explore details of the nucleon-nucleon (NN) interaction models and to study effects of additional dynamics, the so-called three nucleon force (3NF). The deuteron-proton breakup process, with its continuum of the 3N final states, provides very rich testing ground for modern theoretical predictions, obtained via exact solutions of the Faddeev equations. Physical input to the predictions are e.g. the realistic NN potentials combined with model 3NF, the 2- and 3-nucleon interactions obtained by an explicit treatment of the Δ–isobar excitation within the coupled-channel framework or forces obtained via Chiral Perturbation Theory methods.

Precise measurements of the breakup process are experimentally very demanding. Usually, like in our early studies performed at PSI at 65 MeV proton beam energy, the experiments provided data confined to just a few specific kinematical configurations. Our new approach to the breakup research assumed simultaneous measurement over a large part of the phase space by using high acceptance position-sensitive detection system. Measurements of the $^1H(d,pp)n$ reaction were carried out at KVI at 130 MeV beam energy. With the use of polarized deuteron beam cross sections, vector and tensor analyzing powers were measured in a wide range of proton angles. Data collected simultaneously for the elastic scattering were used for normalization and determination of the beam polarization.

Cross section values were extracted for about 80 kinematical configurations, defined by polar angles of the two outgoing protons, θ_1, θ_2, and their relative azimuthal angle $\phi_{12.}$, and presented as functions of the arc-length variable S, giving in total over 1700 experimental points. These results allowed to conclude on importance of the 3NF effects for the breakup reaction – only inclusion of this additional dynamics in the calculations leads generally to a better description of the cross sections (see figure 1, left panel).

In the kinematical region of small proton polar angles significant discrepancies between the measured and predicted cross sections were observed. This has been attributed to the fact that at a small relative energy of the two protons Coulomb interaction plays an important role, while the calculations are valid for nd system. Only recently Coulomb force was successfully included in the coupled-channel calculations. Importance of this progress for a correct description of the breakup reaction is demonstrated in figure 1, right panel. The studies on few-nucleon system dynamics are continued on both, experimental and theoretical, frontiers.

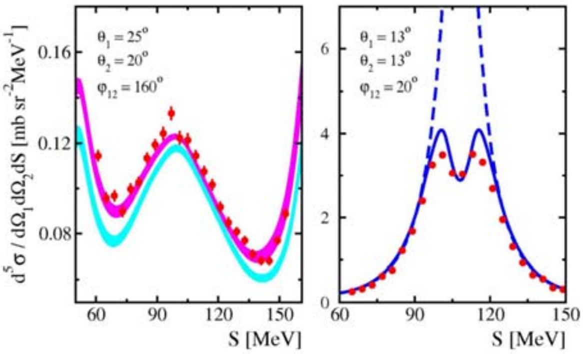

Fig. 1. *Breakup cross sections for two kinematical configurations, specified in the panels. Left: Data compared to predictions based on realistic NN potentials only (blue band) and on the same forces combined with a 3NF model (magenta band). Righ: Data compared to the coupled channel calculations without (dashed line) and with (solid line) Coulomb force.*

[1] **J. Zejma**, M. Allet, **K. Bodek**, J. Lang, R. Müller, S. Navert, O. Naviliat-Cuncic, **J. Sromicki**, **E. Stephan**, **L. Jarczyk**, **St. Kistryn**, **J. Smyrski**, **A. Strzałkowski**, W. Glöckle, **J. Golak**, D. Hüber, **H. Witała**, P. Schmelzbach, Phys. Rev. **C55**, 42 (1997).

[2] **K. Bodek**, W. Glöckle, **J. Golak**, **L. Jarczyk**, **St. Kistryn**, **B. Kozłowska**, J. Lang, **A. Micherdzińska**, O. Naviliat-Cuncic, **J. Smyrski**, **M. Sokołowski**, **J. Sromicki**, **A. Strzałkowski**, **H. Witała**, **J. Zejma**, **W. Zipper**, Nucl. Phys. **A631**, 687c (1998).

[3] R. Bieber, **K. Bodek**, K. Ermisch, W. Glöckle, **J. Golak**, M.N. Harakeh, N. Kalantar-Nayestanaki, **St. Kistryn**, **J. Kuroś-Żołnierczuk**, J. Lang, **A. Micherdzińska**, **R. Skibiński**, **M. Sokołowski**, **J. Sromicki**, **E. Stephan**, **A. Strzałkowski**, M. Volkerts, **H. Witała**, **J. Zejma**, **W. Zipper**, Nucl. Phys. **A684**, 536c (2001).

[4] **K. Bodek**, **J. Golak**, **L. Jarczyk**, **St. Kistryn**, **J. Kuroś-Żołnierczuk**, J. Lang, **A. Micherdzińska**, **R. Skibiński**, **J. Smyrski**, **M. Sokołowski**, **J. Sromicki**, **A. Strzałkowski**, **H. Witała**, **J. Zejma**, **W. Zipper**, Few-Body Systems **30**, 65 (2001).

[5] **St. Kistryn**, R. Bieber, **K. Bodek**, K. Ermisch, W. Glöckle, **J. Golak**, M.N. Harakeh, N. Kalantar-Nayestanaki, **J. Kuroś-Żołnierczuk**, H. Kamada, **A. Micherdzińska**, A. Nogga, **R. Skibiński**, **M. Sokołowski**, **E. Stephan**, **A. Strzałkowski**, **H. Witała**, **J. Zejma**, **W. Zipper**, Nucl. Phys. **A689**, 345c (2001).

[6] **A. Micherdzińska**, PhD Thesis, University of Silesia, Katowice, 2003.

[7] **St. Kistryn**, R. Bieber, **A. Biegun**, **K. Bodek**, K. Ermisch, W. Glöckle, **J. Golak**, M.N. Harake, N. Kalantar-Nayestanaki, H. Kamada, **J. Kuroś-Żołnierczuk**, M. Kis, **A. Micherdzińska**, A. Nogga, M. Shafiei, **R. Skibiński**, **E. Stephan**, **H. Witała**, **J. Zejma**, **W. Zipper**, Few-Body Systems Suppl. **14**, 141 (2003).

[8] **St. Kistryn**, **A. Micherdzińska**, R. Bieber, **A. Biegun**, **K. Bodek**, K. Ermisch, W. Glöckle, **J. Golak**, N. Kalantar-Nayestanaki, H. Kamada, M. Kiš, **A. Kozela**, **J. Kuroś-Żołnierczuk**, A. Nogga, M. Mahjour-Shafiei, **R. Skibiński**, **E. Stephan**, **H. Witała**, **J. Zejma**, **W. Zipper**, Phys. Rev. **C 68**, 054004 (2003).

[9] **St. Kistryn**, **A. Micherdzińska**, R. Bieber, **A. Biegun**, **K. Bodek**, K. Ermisch, W. Glöckle, **J. Golak**, M.N. Harakeh, N. Kalantar-Nayestanaki, H. Kamada, **J. Kuroś-Żołnierczuk**, M. Kiš, A. Nogga, M. Mahjour-Shafiei, **R. Skibiński**, **E. Stephan**, **H. Witała**, **J. Zejma**, **W. Zipper**, Nucl. Phys. **A737**, S58 (2004).

[10] **St. Kistryn**, Habilitation Thesis, published by DjaF, ISBN 83-86774-42-8, Kraków, 2005.

[11] **St. Kistryn**, **E. Stephan**, **A. Biegun**, **K. Bodek**, A. Deltuva, E. Epelbaum, K. Ermisch, W. Glöckle, **J. Golak**, N. Kalantar-Nayestanaki, H. Kamada, M. Kiš, **B. Kłos**, **A. Kozela**, **J. Kuroś-Żołnierczuk**, M. Mahjour-Shafiei, U.-G. Meissner, **A. Micherdzińska**, A. Nogga, P.U. Sauer, **R. Skibiński**, **R. Sworst**, **H. Witała**, **J. Zejma**, **W. Zipper**, Phys. Rev. **C 72**, 044006 (2005).

[12] **A. Biegun**, PhD Thesis, University of Silesia, Katowice, 2005.

[13] **A. Biegun**, **E. Stephan**, **St. Kistryn**, **K. Bodek**, **I. Ciepał**, A. Deltuva, E. Epelbaum, W. Glöckle, **J. Golak**, N. Kalantar-Nayestanaki, H. Kamada, M. Kiš, **B. Kłos**, **A. Kozela**, **J. Kuroś-Żołnierczuk**, M. Mahjour-Shafiei, U.-G. Meissner, **A. Micherdzińska**, A. Nogga, P.U. Sauer, **R. Skibiński**, **R. Sworst**, **H. Witała**, **J. Zejma**, **W. Zipper**, Acta Phys. Pol. **B 37**, 213 (2006).

[14] **St. Kistryn**, **E. Stephan**, **B. Kłos**, **A. Biegun**, **K. Bodek**, A. Deltuva, **I. Ciepał**, A.C. Fonseca, N. Kalantar-Nayestanaki, M. Kiš, **A. Kozela**, M. Mahjour-Shafiei, **A. Micherdzińska**, P.U. Sauer, **R. Sworst**, **J. Zejma**, **W. Zipper**, Phys. Lett. **B 641, 23** (2006).

A SEARCH FOR MAJORANA NEUTRINO

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Experimental facility: β – Beam project at CERN

The recent discovery of neutrino oscillations implies that there is a non-vanishing difference between masses of neutrinos of different kind. This means that at least one of the neutrinos has a finite rest mass and thus it is not fully left-handed. The right helicity component is expected to be of the m_ν/E_ν order. A related challenge is to determine this mass value and here the nuclear physics may be of use. Another challenge comes from the old idea of Majorana that neutrino is identical to its charge conjugate. This assumption

requires violation of the lepton number. As the weak currents are predominantly left handed the experiments which could detect Majorana type neutrinos are hindered by small $(m_\nu/ E_\nu)^2$ factor. At present, the perspective experiment of this type is the neutrino-less double beta decay, $0\nu\beta\beta$. Neutrino produced in a nuclear decay of one neutron may be absorbed in the decay of another neutron. The nucleus thus undergoes the $0\nu\beta^-\beta^-$ transformation

$$(A,Z) \rightarrow (A,Z+2) + e^- + e^-$$

There have been several attempts at observing the $0\nu\beta^-\beta^-$. They resulted in the limiting values of the life-times of the potential emitters. These in turn can be interpreted in terms of the upper limits of m_{ν_e}. The interpretation requires the knowledge of the nuclear matrix elements. It is also model dependent, as it requires, e.g., some assumptions about the right handed current. Still, even with these constraints, the $0\nu\beta\beta$ decay provides at present the most sensitive measure of the electron neutrino mass more so than the measurement of the end point of the β^- spectrum from tritium decay .

As an alternative it was proposed to study the inverse process [1], the radiative neutrino-less double electron capture $0\nu 2EC\gamma$. The associated monoenergetic photon provides a convenient experimental signature. Other advantages are the favourable ratio of the $0\nu 2EC\gamma$ to the basic $2\nu 2$ $EC\gamma$ capture rates as oposed to that of $0\nu\beta^-\beta^-$,$2\nu\beta^-\beta^-$ and, very importantly, the existence of the coincidence trigger to suppress the random background. These advantages partly offset the expected longer lifetimes of the 0 2ECγ process. Chances for this process were calculated and high Z atoms are strongly favored. Several available targets offer the capture rates of the order of 10^{-28}/year [2,3].

A resonance enhancement of the capture rates is predicted at small energy release ΔE comparable to the 2P-1S atomic level difference. Away from the resonance the rates depend only slowly on ΔE in strong contrast with the $0\nu\beta\beta$ decays. This makes studies of decays to excited states in final nuclei feasible, enhancing chances of locating the resonances. Candidates for such studies were found. The experimental feasibility is estimated and found highly encouraging [3]. In some cases the resonant conditions may be met to the precision of 1 KeV. Those cases require very precise atomic mass measurements to be performed [4]. These pose also an interesting atomic problem related to the time structure of the process and the relaxation time for the final two hole atomic states. In some targets the capture rates rise to 10^{-25}/year. All together the double neutrino-less electron capture may become a viable alternative to the neutrino-less double beta decay. The stage of experimenting is expected to be materialized when the possibilities of $0\nu\beta\beta$ process are exploited and put under control.

New experimental facilities producing fast neutrino emitters are planned at CERN – the beta beams. Chances to produce and detect Majorana neutrino were calculated [5]. Such a chance is of the order $(m_\nu/ E_\nu)^2$ in the system where the emitter is at rest . It may be much higher in the laboratory frame if the emitter is very fast. That is due to the effect of helicity flip generated by the Lorentz transformation. It is found to be very strong for the neutrino emission in the backward direction with respect to the beam. Chances for a real experiment are evaluated [5,6] and the best emitters are looked after [7]. These should be long lived and, if possible, produce neutrinos of small E_ν.

[1] **Z. Sujkowski and S. Wycech ,** Acta Phys. Pol. **B33** (2002) 471

[2] **Z. Sujkowski and S. Wycech ,** Acta. Phys.Pol. **B35**(2004)1223

[3] **Z. Sujkowski and S. Wycech ,** Phys. Rev.**C70**(2004)052501(R)

[4] **Z.Sujkowski and S. Wycech ,** Nucl.Instr.Meth. **B235**(2005)81

[5] **L. Łukaszuk, Z. Sujkowski and S. Wycech ,** Eur.Phys. Journ. **A27**(2006) 63

[6] **L. Łukaszuk, Z. Sujkowski and S. Wycech ,** Acta Phys. Pol. **B33** (2007)

[7] **L. Łukaszuk, Z. Sujkowski and S. Wycech ,** To be published

DOUBLE BETA DECAY MATRIX ELEMENTS IN THE RPA APPROACH

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The Random Phase Approximation (RPA), since its origin in the late fifties and early sixties, has become a very powerful tool for studying the nuclear structure. In particular, the quasiparticle version of the theory (the Quasiparticle Random Phase Approximation -- QRPA) has been successfully applied to the nuclei far from the closed shells, and consequently extended as the proton--neutron QRPA (pnQRPA) to the description of charge-changing transitions in nuclei. Among those transitions, the double-beta decay draws very much attention, since its proper description at the nuclear level allows (and is necessary) to understand such phenomena as the origin and value of the neutrino mass, the existence of right-handed gauge bosons and other fundamentals of the Standard Model.

The main drawback in the formulation of the QRPA theory, however, is the violation of the Pauli exclusion principle, connected with the usage of bosonic commutation relations for the QRPA phonon operators, that are in fact collective pairs of fermions. To overcome this shortcoming of the QRPA framework, the renormalization technique has been proposed and extended to include proton--neutron pairing. This approach has been based on the early works by Rowe, Hara, Ikeda, and Schuck and Ethofer in the context of RPA and QRPA. The main goal of the method, called in the literature the renormalized QRPA (RQRPA), is to take into account additional one-quasiparticle scattering terms in the commutation relations by a self-iteration of the QRPA equation.

Recently, we have developed and presented an extension to the RQRPA formalism [1-13], that tries to solve the problem of non-vanishing quasi-particle content of the ground state that in turn introduces some inconsistency between RQRPA and the BCS approach. Our method, called the self-consistent RQRPA (SRQRPA), is based on the reformulation of the BCS equations and further reiteration of the BCS+RQRPA calculation scheme. This formalism has been successfully applied to the two-neutrino double-beta decay of medium-heavy nuclei ($100<A\leq150$) [1,4-11, 14,15,16], as well as to the neutrinoless mode for the following emitters: ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{150}Nd [12-14,16].

The comparison between the QRPA, the RQRPA, and the SRQRPA results shows the main features of the extended versions of the theory: the inclusion of the ground-state correlations beyond QRPA is not only improving the agreement between theoretical calculations and experimental data but also causes the stabilization of the dependence of the two-neutrino decay matrix element $M^{2\nu}_{GT}$ as a function of the particle-particle strength g_{pp}. Moreover, the iteration procedure for quasiparticle densities, which causes the treating of RQRPA and BCS on the same footing, stabilizes the results even further. This behaviour can be explained by the suppression of ground-state correlations in the RQRPA and the SRQRPA methods. As a summary, in the Fig. 1 we compare the range of results, that can be obtained from all three approaches and the available experimental data. Our studies show as well, that both QRPA and the SRQRPA reproduce the experimental data quite nicely for $g_{pp}\approx1.0$, whereas the RQRPA fails and needs much higher (and rather unphysical) value of this parameter to get close to the experiment. This effect is probably due to lack of internal consistency in the RQRPA approach.

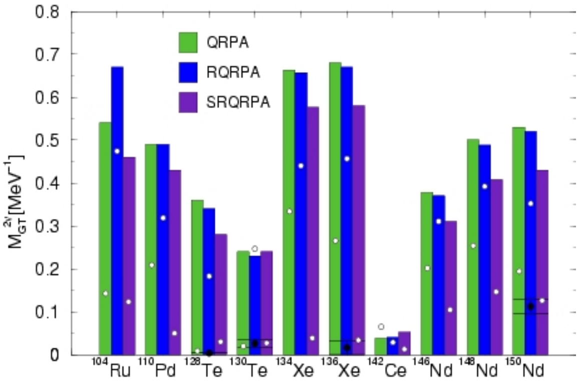

Fig. 1. *Range of the Gamow-Teller matrix elements values, calculated using three different QRPA approaches (vertical bars) and compared with the available experimental data (points with error bars). The open symbols show the calculated values for* $g_{ph}=g_{pp}=1.0$ *(from Ref. [15]).*

[1] J. Schwieger, F. Simkovic, A. Faessler, **W. A. Kamiński**,
Journal of Physics (Nuclear and Particle Physics) **G23** (1997) 1647—1653

[2] **A. Bobyk, W. A. Kamiński, P. Zaręba**, A. Faessler, Acta Physica Polonica **29** (1998) 470—474

[3] **A. Bobyk, W. A. Kamiński, P. Zaręba**, A. Faessler, Acta Physica Polonica **29** (1998) 799—808

[4] J. Schwieger, F. Simkovic, A. Faessler, **W. A. Kamiński**, Physical Review **C57** (1998) 1738

[5] **W.A. Kamiński, A. Gozdz, P. Zaręba**, Czechoslovak Journal of Physics **48** (1998), 191—195

[6] A. A. Raduta, C. M. Raduta, A. Faessler, **W. A. Kamiński**, Nuclear Physics **A634** (1998), 497

[7] **W.A. Kamiński, P. Zareba**, Izvestya of Russian Academy of Science **11** (1998) 2147-2152

[8] **A. Bobyk, W. A. Kamiński, P. Zaręba**, European Physics Journal **A5**, 385 (1999).

[9] **A. Bobyk, W. A. Kamiński**, I. Borzov, Acta Physica Polonica. **B31** (2000) 953—963

[10] **A. Bobyk, W. A. Kamiński, P. Zaręba**, Czechoslovak Journal of Physics **50** (2000) 463—469

[11] **A. Bobyk, W. A. Kamiński, P. Zaręba**, Nuclear Physics **A669**, 221 (2000).

[12] **A. Bobyk, W. A. Kamiński**, F. Šimkovic, Physical Review **C63**, 051301(R) (2001).

[13] F. Simkovic, **M. Nowak, W. A. Kamiński**, A. A. Raduta, Amand Faessler,
Physical Review **C64** (2001) 035501

[14] **A. Bobyk, W. A. Kamiński, M. Góźdź, P. Zaręba**, F. Šimkovic,
Czechoslovak Journal of Physics **52** (2002) 615

[15] **A. Bobyk, M. Góźdź, W. A. Kamiński, P. Zaręba**, A. Faessler, European Physics Journal **A19**, 327 (2004).

[16] P. Beneš, **A. Bobyk, W. A. Kamiński**, A. Faessler, F. Šimkovic, Acta Physica Polonica **B37**, 1927 (2006).

NEUTRINOLESS DOUBLE BETA DECAY IN SUPERSYMMETRIC MODELS

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Recent experimental evidence of neutrino oscillations, thus non-zero mass of these particles, gave strong backup for building extensions of the Standard Model. One of the most promising candidate is the Minimal Supersymmetric Standard Model (MSSM) in which all the gauge couplings unify at some scale $m_{GUT}\approx 10^{16}$ GeV. As is well known, extrapolations of data from the LEP measurements suggest such behavior. However, supersymmetric (SUSY) particles have not been observed in experiments, so supersymmetry has to be broken in the low-energy regime. The issue how this breaking is realized is the least understood question of the theory. The most widely studied version of SUSY accidentally conserves the so-called *R* parity defined as $R = (-1)^{2S+3B+L}$, where *B* and *L* are the baryon and lepton numbers, and *S* is the spin of corresponding particle. Considering, however, the more general case, in which *R* parity is broken, processes which do violate lepton or baryon number are expected - among them, the sought in many experiments neutrinoless mode of the double beta decay (0νββ).

One of the most popular models discussed in literature is the supergravity mediated SUSY breaking (SUGRA MSSM models). The soft breaking terms are generated in these models at m_{GUT}, or even the Planck scale, and then transmitted to the low-energy sector by gravitational interactions. However, there is a problem related to the flavor symmetry, which, due to high energies and radiative corrections, is permanently broken. It is therefore desirable to lower the scale of SUSY breaking. It is achieved in the so-called gauge mediated supersymmetry breaking (GMSB), which has recently attracted a great deal of attention. In GMSB models supersymmetry breaking is transmitted to the superpartners of quarks, leptons, and gauge bosons via the usual $SU(3)\times SU(2)\times U(1)$ gauge interactions and occurs at the scale $m_{SUSY}\approx 10^5$ GeV, so there is no problem with the flavor symmetry.

Neither SUSY nor 0νββ decay has been observed, but extensive experimental search of the latter resulted in lower bounds on the half-life of this exotic process for different nuclei. The description of 0νββ decay within non-standard models involve many uknown parameters, like mass scales, masses of new particles, and coupling constants of exotic interactions. The experimental bounds can be used to formulate constraints on these parameters. Such investigation has been done in the framework of the MSSM model with broken *R* parity, with SUSY breaking realized through the SUGRA [1,2,4,6,11] and GMSB [3,5,8] mechanisms. An example of upper bounds on a non-standard coupling constant λ'_{111} is presented in Fig. 1.

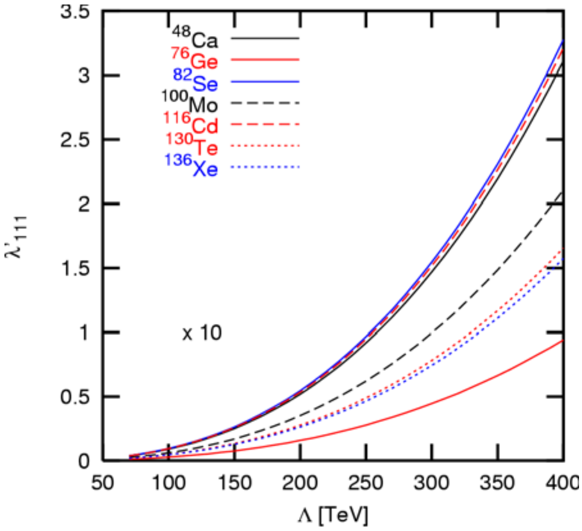

Fig. 1. *Limits on the coupling constant λ'_{111} as the function of the GMSB scale Λ, coming from experimental lower bounds on the half-life of 0νββ decay in different nuclei. The corresponding nuclear matrix elements have been calculated using pn-RQRPA method and the bag model (from Ref. [8]).*

[1] **Andrzej Wodecki, Wiesław A. Kamiński**, Slavomir Pagerka, Physics Letters **B413** (1997) 342

[2] **Andrzej Wodecki, Wiesław A. Kamiński**, Slavomir Pagerka, Progress in Particle and Nuclear Physics **40** (1998) 333

[3] **A. Wodecki, W. A. Kamiński, Phys**. Rev. **C59** (1999) R1232

[4] **A. Wodecki, W. A. Kamiński**, F. Šimkovic, Physical Review **D60** (1999) 115007

[5] **Wiesław A. Kamiński, A. Wodecki**, F. Simkovic, Czechoslovak Journal of Physics **50** (2000) 489

[6] **A. Wodecki, W. A. Kamiński**, International Journal of Modern Physics, **A15** (2000) 2447

[7] **Marek Góźdź, Wieslaw A. Kaminski**, Physical Review **D68** (2003) 057901

[8] **M.Góźdź, W. A. Kamiński**, Physical Review **D69**, 076005 (2004).

[9] **M.Góźdź, W. A. Kamiński, A. Wodecki**, Physical Review **C69** (2004) 025501

[10] **Marek Góźdź, Wieslaw A. Kaminski**, International Journal of Modern Physics **E13** (2004) 367

[11] **Marek Góźdź, Wieslaw A. Kaminski**, Fedor Simkovic, Physical Review **D70** (2004) 095005

[12] **Marek Góźdź, Wieslaw A. Kaminski**, Amand Faessler, Physical Review **D71** (2005) 096005

FUSION BARRIER DISTRIBUTIONS

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Experimental facility: Warsaw Cyclotron

Nuclear reactions at sub-barrier energies play extremely important role in Nature, being responsible for the very existence of the stars, their evolution and many aspects of the origin of elements. One of the most important classes of sub-barrier reactions is fusion. It turns out that connection between nuclear reaction mechanism and structure of the interacting nuclei exists and manifests itself in strong enhancement of fusion cross-sections at sub-barrier energies. It can be understood as the result of couplings between various reaction channels: elastic and inelastic scattering, transfer reactions, break-up and fusion. Experiments point to the presence of the barriers of various heights in the same projectile– target system, giving rise to the barrier height distributions.

It was demonstrated that the barrier distributions could be extracted from the sum of the cross-sections of all quasielastic reactions (elastic and inelastic scattering and the transfer reactions) using the cyclotron beams [1]. Since 5 years we are using this method for studying interaction of ^{20,22}Ne with various targets (^{nat}Ni, ^{90,92}Zr, ^{112,116,118}Sn, ^{208}Pb).

The ^{20}Ne nucleus was chosen for these studies because of its remarkable properties: its β_2 and β_4 ground state deformations are enormous, namely 0.46 and 0.27. Due to this, calculations performed by means of the coupled channels method predict in the ^{20}Ne + Sn case the strongly structured barrier distribution. However, the experimental distribution turned out [2,3] to be completely smooth, of the Gaussian-like shape (fig.1, upper left panel). Suspicions, that smoothing of the barrier distribution was caused by the strong α particle transfer and break-up channels (due to the strongly clustered ^{20}Ne nucleus) were falsified [4] by replacing the projectile by ^{22}Ne. This replacement resulted in considerable (by the factor of 6) decreasing of the α transfer probability without, however, significant changing of the barrier distribution (the lower left panel of Fig. 1). On the other hand, using the same experimental method, the clear structure was observed for the ^{20}Ne projectile, when the Sn target was replaced by the ^{nat}Ni one (right panels) [5]. The structure has been observed also for the ^{90}Zr target, while it was lacking in the case of ^{92}Zr [6].

It seems that the reason of structure smoothing, observed in the case of Ne + Sn, ^{92}Zr systems, is due to the strong neutron transfer channels. This would point to the limits of the present version of the Coupled Channels method, consisting in assuming that only the collective channels have to be taken explicitly into account in the calculations. Usually the other reaction channels, being considered as the "weak" ones, are treated by including them into the imaginary Optical Model Potential. The hypothesis is presently undergoing experimental and theoretical testing.

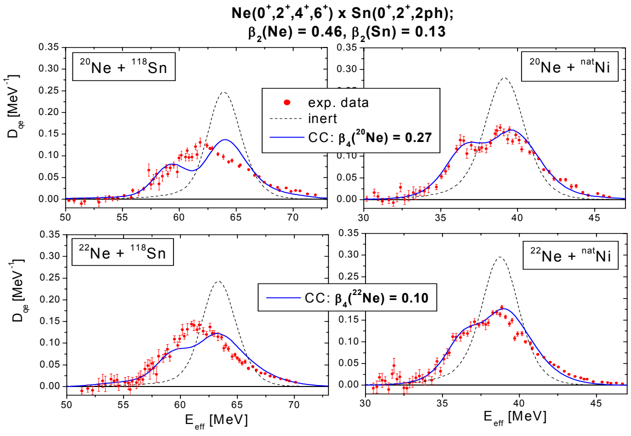

Fig.1. *Comparison of calculated and experimental quasi-elastic barrier distributions. The dashed curves were calculated without taking into account any couplings. The blue lines show calculated results assuming the coupling parameters taken from the literature.*

[1] **E. Piasecki, M. Kowalczyk, K. Piasecki, Ł. Świderski, J. Srebrny, M. Witeck**i, F. Carstoiu, **W. Czarnacki, K. Rusek, J. Iwanicki, J. Jastrzębski, M. Kisieliński, A. Kordyasz, A. Stolarz, J. Tys, T.Krogulski**, N.Rowley, Phys. Rev. **C 65,** 054611 (2002)

[2] **E.Piasecki, Ł. Świderski, M. Witecki**, Acta Phys. Pol. **33**, 397 (2002)

[3] **Ł.Świderski, P. Czosnyka, M. Kowalczyk, E. Piasecki, K. Piasecki, M. Witecki, J. Jastrzębski, A. Kordyasz, M. Kisieliński, T. Krogulski**, N. Rowley, C. Marchetta, A. Pagano, M. Mutterer, W. H. Trzaska, K. Hagino, Int. Journ. of Modern Phys. E, **13**, 315 (2004)

[4] **E. Piasecki, Ł.Świderski, P. Czosnyka, M. Kowalczyk, K. Piasecki, M. Witecki, T. Czosnyka, J. Jastrzębski, A. Kordyasz, M. Kisieliński, T Krogulski**, M. Mutterer, S. Khlebnikov, W.H. Trzaska, K. Hagino, N.Rowley, Phys. Lett. **B 615** (2005) 55

[5] **Ł. Świderski, E. Piasecki, P. Czosnyka, T. Krogulsk**i and N. Rowley, Intl. Journ. Mod. Phys. E **14,** 341 (2005)

[6] **E.Piasecki, Ł. Świderski, K.Rusek, M.Kisieliński, J.Jastrzębski, A.Kordyasz, M.Kowalczyk**, M.Mutterer, **T.Krogulski, K.Piasecki**, P.Russotto, A.M.Stefanini, N.Rowley, Intl. Journ. Mod. Phys. **16** (2007) 502

NUCLEAR OPTICAL POTENTIAL FROM LIGHT-PARTICLE TRANSFER REACTIONS

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Experimental facility: Warsaw Cyclotron

Interaction of the two colliding nuclei can be reduced to the Optical Model (OM) potential, which is complex and energy dependent. The dependence of this OM potential on energy is especially strong in the vicinity of the Coulomb barrier. It is related to the fact that in this energy region many reactions channels are opened, so the absorptive imaginary part of the OM potential, responsible for the removal of the scattered nuclei from the elastic channel, changes from value negligibly smaller than the Coulomb barrier to some tens of MeV above it. Like in optics, the refraction and absorption are related, and change of the imaginary part generates a sudden increase of the real part of OM potential at the barrier.

All models of the direct nuclear reactions are based on Optical Model. Thus, in order to describe different nuclear reactions one has to know rather precisely the OM potential for the pair of interacting nuclei. This knowledge is especially important in modern nuclear physics that is oriented for investigations of weakly bound, radioactive, nuclei as they have to be produced in different nuclear processes.

In the recent years we have performed many experiments with stable nuclei looking at the reactions that lead to exotic nuclei in the exit channel. Changing the energy, we could investigate the energy dependence of the OM potential in this channel [1-3,5,7-8]. An example is shown in Fig. 1. The unbound nuclei ^{8}Be were produced in the α- and triton-transfer recations induced by ^{11}B beam on ^{12}C target. The beam was delivered by Warsaw Cyclotron and the reaction products were measured by charged particles telescopes consisting of gas-filled ionization counters and silicon detectors, mounted in the scattering chamber "Syrena". The data were analysed by means of coupled-reaction-channel model, with the OM potential in the entrance ^{11}Be + ^{12}C channel adopted from our previous studies. The values of ^{8}Be+^{15}N OM potential, extracted from the analysis, are compared with the potential for ^{8}Be+^{13}C found by us previously (Fig.1).

We have also studied the effect of coupling between different nuclear processes. In particular we have investigated excitation of ^{14}C to a few low-lying states and its effect on ^{11}B + ^{14}C elastic scattering as well as single-particle and collective nature of those excited states [4,6]. One of the interesting findings was the large radius of the wave function of the 1^{-}, 6.094 MeV excited state, suggesting its neutron- halo nature.

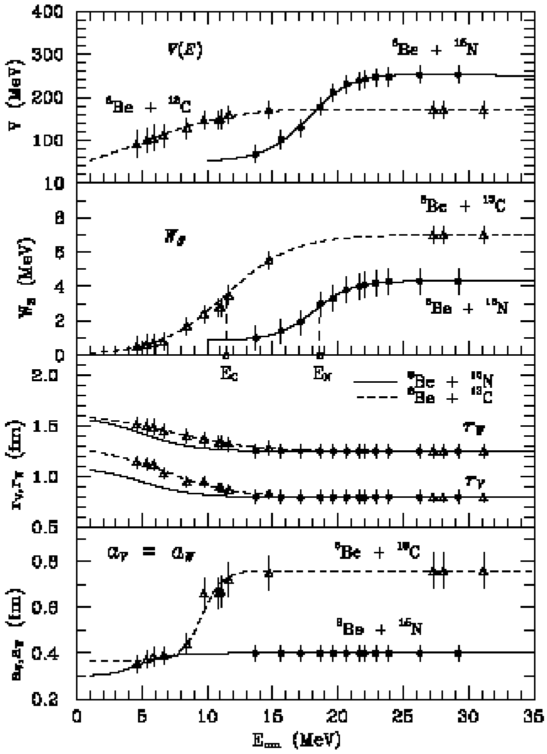

Fig. 1. *Energy dependence of the OM potential parameters for the ^{8}Be+^{13}C (open triangles and dashed curves) and for ^{8}Be+^{15}N (filled circles and solid curves), ref. [7].*

[1] A.T. Rudchik, **A. Budzanowski**, V.K. Chernievsky**, B. Czech, L. Głowacka, S. Kliczewski**, A.V. Mokhnach, O.A. Momotyuk, S.E. Omelchuk, Val.M. Pirnak, **K. Rusek, R. Siudak, I. Skwirczyńska, A.Szczurek, L. Zemło,** Nucl. Phys. A**695,** 51 (2001).

[2] A.T. Rudchik, V.M. Kyryanchyk, **A. Budzanowski**, V.K. Chernievsky, **B. Czech, T. Czosnyka, L. Głowacka, S. Kliczewski**, E.I. Koshchy, S.Yu. Mezhevych, A.V. Mokhnach**, K. Rusek**, S.B. Sakuta, R. Siudak, **I. Skwirczyńska, , L. Zemło** , Nucl. Phys. A**714**, 391 (2003).

[3] V.M. Kyryanchyk, A.T. Rudchik, **A. Budzanowski**, V.K. Chernievsky**, T. Czosnyka, B. Czech, L. Głowacka, S. Kliczewski**, E.I. Koshchy, S.Yu. Mezhevych, A.V. Mokhnach**, K. Rusek**, S.B. Sakuta, **R. Siudak, I. Skwirczyńska, A. Szczurek, L. Zemło**, Nucl. Phys. A**726**, 231 (2003).

[4] S.Yu. Mezhevych and **K. Rusek,** Acta Phys. Pol. B **34**, 2415 (2003).

[5] S.Yu. Mezhevych, **K. Rusek**, A.T. Rudchik, A. Budzanowski, V.K. Chernievsky, **B. Czech, J. Choiński, L. Głowacka, S. Kliczewski**, E.I. Koshchy, V. M. Kiryanchuk, A.V. Mokhnach, A.A. Rudchik, S.B. Sakuta, **R. Siudak, I. Skwirczynska, A. Szczurek, L. Zemło**, Nucl. Phys. A**724**, 29 (2003) .

[6] S. Yu. Mezhevych, A.T. Rudchik, **K. Rusek, A. Budzanowski, B. Czech, J. Choiński, L. Głowacka, S. Kliczewski**, E.I. Koshchy, V.M. Kyryanchuk, A.V. Mokhnach, A.A. Rudchik, S.B. Sakuta, **R. Siudak, I. Skwirczyńska, A. Szczurek**, Nucl. Phys. A**753**, 13 (2005).

[7] A.A. Rudchik, A.T. Rudchik, **A. Budzanowski**, **A.Szczurek**, **B. Czech, T. Czosnyka, J. Choiński, L. Głowacka, S. Kliczewski**, E.I. Koshchy, S.Yu. Mezhevych, A.V. Mokhnach, O.A. Momotyuk, Val.M. Pirnak, **R. Siudak, I. Skwirczyńska,** Eur. Phys. J. A **23,** 445 (2005).

[8] A.A. Rudchik, A.T. Rudchik, M. Kozeratska, O.A. Ponkratenko, E.I. Koshchy, **A. Budzanowski**, **B. Czech, S. Kliczewski**, **R. Siudak, I. Skwirczyńska, A.Szczurek**, S.Yu. Mezhevych, K.W. Kemper, **J. Choiński, T. Czosnyka, L. Głowacka,** Phys. Rev. C **72**, 034608 (2005).

REACTIONS WITH LOOSELY BOUND PROJECTILES

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Physics of weakly bound nuclei shows how strongly nuclear reactions are related with nuclear structure studies. A small energy separation between the ground state and the unbound states from the continuum makes the couplings between them very probable. Thus, even such a simple process like elastic scattering can be strongly affected by virtual excitations of a weakly bound nucleus to its resonant and nonresonant unbound states.

From the experiments with polarized and unpolarized ^{6,7}Li beams we have learnt that the properties of these weakly bound nuclei, like deformation of the ground state, energy of the breakup threshold or the structure of the bound and unbound states, have an influence on induced nuclear reactions [1-7,14-16,22]. These properties can be also directly related to some of the observables, like the analysing powers of different rank.

Presently, one can profit from the experience gained with stable beams, studing the properties of exotic radioactive nuclei by means of nuclear reactions. For example, the dipole polarizability of neutron-rich helium isotope, ^{6}He (dipole couplings between the ground state and the states from the continuum) can by studied by means of elastic scattering of this nucleus from a heavy target [8-11,13,19,21]. At energies close to the Coulomb barrier the dipole couplings generate a long range absorption that suppresses the Coulomb rainbow in the elastic scattering angular distribution (Fig. 1).

From the comparison of the model calculations with experimental data one can also draw some conclusions about the cluster structure of ^{6}He. The calculations presented in Fig. 1 by the solid blue curves were performed assuming a simple two-body dineutron (α+2n) model of this nucleus. Good agreement of the calculated curves and experimental data suggests that the most relevant internal degree of freedom is the coordinate between the alpha particle and the centre of mass of the two neutrons. The dineutron model takes into account explicitly the excitation of this degree of freedom that occurs during the collision of ^{6}He with the target nucleus. This aspect of the internal structure of ^{6}He seems sufficient to obtain satisfactory description of the elastic scattering data.

Our studies have also shown that apart of the couplings with the continuum, neutron transfer reactions play an important role in the interaction of exotic, neutron-rich nuclei [17,20]. It was shown that the large fission yield observed for ^{6}He + ^{238}U below the Coulomb barrier is due to two-neutron transfer reaction rather than fusion of these nuclei [18]. A large number of alpha-particles detected at backward scattering angles for ^{6}He + ^{208}Pb could also be attributed to the two-neutron transfer reaction to unbound states of the final nucleus.

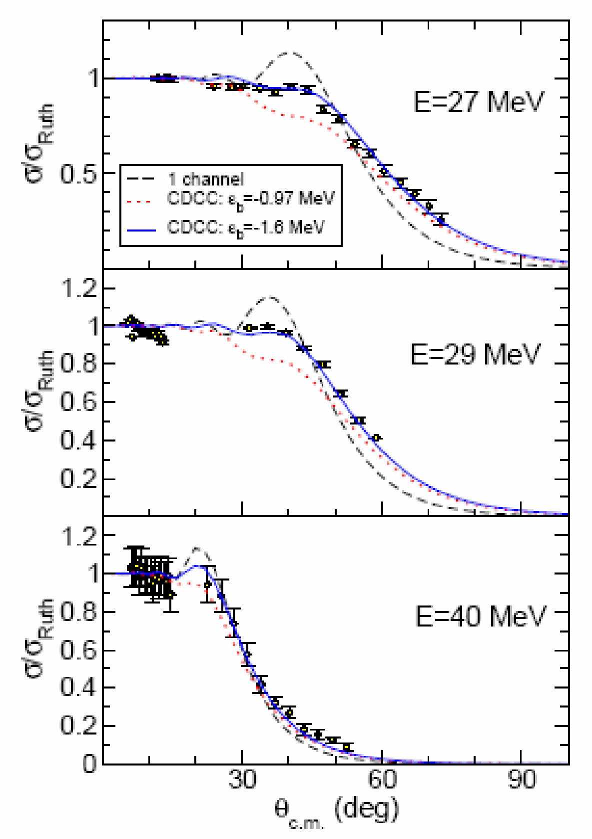

Fig. 1. *Effect of couplings to the α+2n continuum on the ^{6}He + ^{197}Au elastic scattering at the three energies, in the vicinity of the Coulomb barrier. The dashed curves show optical model calculations (no couplings) while the solid blue curves the results of coupled-channel calculations with these couplings included[21].*

[1] N. Keeley, **K.Rusek**, Phys. Let. B **375**,9 (1996).

[2] **K.Rusek**, P.V.Green, P.L.Kerr and K.W.Kemper, Phys. Rev. C **56**, 1895 (1997).

[3] N.Keeley and **K.Rusek**, Phys. Rev. C **56**, 3421 (1997).

[4] N.Keeley and **K.Rusek**, Phys. Let. B **427**, 1 (1998).

[5] **K.Rusek** and K.W.Kemper, Phys. Rev. C **61**, 634808 (2000).

[6] Dhruba Gupta, C.Samanta, A.Chatterjee, **K.Rusek**, Y.Hirabayashi, J. of Phys. G **26**, L81 (2000).

[7] N. Keeley, K.W. Kemper and **K. Rusek**, Phys. Rev. C **64**, 031602(R) (2001).

[8] **K.Rusek**, K.W. Kemper and **R. Wolski**, Phys. Rev. C **64**, 044602 (2001).

[9] N. Keeley, K.W. Kemper and **K. Rusek**, Phys. Rev. C **65**, 014601 (2002).

[10] N. Keeley, K.W. Kemper, **K.Rusek**, Phys. Rev. C **66**, 044605 (2002).

[11] R.S. Mackintosh, **K. Rusek**, Phys. Rev. C **67**, 034607 (2003).

[12] **K. Rusek**, P.D. Cathers, E.E. Bartosz, N. Keeley, K.W. Kemper, F. Marechal, Phys. Rev. C **67**, 014608 (2003).

[13] **K. Rusek**, N. Keeley, K.W. Kemper, R.Raabe, Phys. Rev. C **67**, 041604(R) (2003).

[14] A.Pakou, N. Alamanos, A. Gillibert, M. Kokkoris, S. Kossionides, A. Lagoyannis, N.G. Nicolis, C. Papachristodoulou, D. Patitir, D. Pierroutsakou, E.C. Pollaco, **K. Rusek**, Phys. Rev. Lett. **90**, 202701 (2003).

[15] N. Keeley, J.M. Cook, K.W. Kemper, B.T. Roeder, D. Weintraub, F. Marechal, **K.Rusek**, Phys. Rev. C **68**, 054601 (2003).

[16] A. Pakou and **K. Rusek**, Phys. Rev. C **69**, 057602 (2004).

[17] **K. Rusek**, N. Alamanos, N. Keeley, V. Lapoux, A. Pakou, Phys. Rev. C **70**, 014603 (2004).

[18] R. Raabe, J.L. Sida, J.L. Charvet, N. Alamanos, C. Angulo, J.M. Casandijan, S. Courtin, A. Drouart, D.J. C. Durand, P. Figuera, A. Gillibert, S. Heinrich, C. Jouanne, V. Lapoux, A. Lepine-Szily, A. Musumarra, L. Nalpas, D. Pierroutsakou, M. Romoli, **K. Rusek** and M. Trotta, Nature **431**, 823 (2004).

[19] A. M. Sanchez-Benitez, D. Escrig, M.A.G. Alvarez, M.V. Andres, C. Angulo, M.J.G. Borge, J. Cabrera, S. Cherubini, J.M. Espino, P. Figuera, M. Freer, J.E. Garcia-Ramos, J. Gomez-Camacho, M. Gulino, O.R. Kakuee, I. Martel, C. Metelco, A.M. Moro, J. Rahigi, **K. Rusek**, D. Smirnov, O. Tengblad, P. Van Duppen, V. Ziman, J. of Phys. G **31**, S1953 (2005).

[20] L. Giot, P. Roussel-Chomaz, C.E. Demonchy, W. Mittig, H. Savajols, N. Alamanos, F. Auger, A. Gillibert, C. Jouanne, V. Lapoux, L. Nalpas, E.C. Polacco, J.L. Sida, F. Skaza, M.D. Cortina-Gil, J. Fernandez-Vasquez, R.S. Mackintosh, A. Pakou, S. Pita, **K. Rusek**, I. Thompson, R. Wolski, Phys. Rev. C **71**, 064311 (2005).

[21] **K. Rusek**, I. Martel, J. Gomez-Camacho, A.M. Moro, R. Raabe, Phys. Rev. C **72**, 037603 (2005).

[22] A. Pakou, N. Alamanos, N.M. Clarke, N.J. Davis, G. Doukelis, G. Kalyva, M. Kokkoris, A. Lagoyannis, T.J. Mertzimekis, A. Musumarra, N.G. Nicolis, C. Papachristodoulou, N. Patronis, G. Perdikakis, D. Pierroutsakou, D. Roubos, **K. Rusek**, A. Spirou, Ch. Zakardas, Phys. Let. B **633**, 691 (2006).

NEUTRON-INDUCED REACTIONS

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During last years we performed some experimental study of neutron-induced reactions as well as theoretical calculations of neutron resonance parameters of interest to basic nuclear physics, nuclear astrophysics and nuclear technology applications.

The main goal of our study the (n, α) reactions was the essential improvement in determination of rates for reactions involving alpha particles inside the stars. The first measurements of the ^{147}Sm (n, α) and ^{143}Nd (n, α) cross section in wide neutron energy interval, to better define the α + nucleus optical potential, were carried out at ORELA neutron spectrometer in Oak Ridge [1 - 3]. For resonance neutrons the Q-values for (n, α) reactions are such that the relative energy between the α particle and residual nucleus are in the astrophysically interesting range, so no extrapolation is necessary. To match different optical potential in statistical model of nuclear reactions and to compare calculated cross sections with obtained experimentally one can define optimal potential. Its value permit to calculate with better accuracy reaction rates for the reactions involving alpha particles such as (γ, α) and (α, p), important in p-process nucleosynthesis.

Two of us as the members of n_TOF Collaboration participated in experiments performed in CERN. The n_TOF spallation neutron source is based on proton beam of the CERN-PS. The collaboration has successfully collected some of the world wide best measurements of neutron capture and fission cross sections of actinides, long lived fission fragments and other isotopes relevant for nuclear technology and/or nuclear astrophysics [4 - 7]. For example, the result obtained for $<\sigma^{151}\mathrm{Sm}(n, \gamma)>$ is much larger than previous estimates, all based on model calculations. The firm estimate of capture rate for the first time based on an experimental value allowed to reach two important conclusions with respect to the s-process nucleosynthesis in this mass region: a) the classical model, based on a phenomenological study of the s-process fails to produce consistent results of branching at ^{151}Sm and ^{147}Pm, b) the p-process contribution to the production of ^{152}Gd can amount up to 30 % of the solar-system observed abundance [4].

The effect of parity violation in lead was measured on pulse neutron source IBR-2 in JINR, Dubna by means of multidetector COCOS device. This effect can be explained by presence of a strong negative p-resonance near the thermal point (below the neutron threshold). Energy dependence of the ^{204}Pb(n,γ) and ^{207}Pb(n,γ) reaction cross section was observed by means of the registration of gamma-quanta, which came from the decay of the excited states of a compound nucleus. The deviation in the "1/v law" led to the conclusion that, in vicinity of the neutron binding energy, there is a strong p-wave resonance in ^{207}Pb isotope (the negative neutron resonance) [8].

Several computational works devoted to the subject of level density of s-wave neutron resonances were done basing on semi-classical description. The problem was considered in three different ways. The systematics of the experimental and calculated neutron resonance level density has been presented as the function of neutron number N for more than 220 nuclei. Comparison of the calculated results obtained under consideration the energy gap near Fermi level is in good agreement with experimental data [9-11].

We have participated in the international collaboration with researchers from FLNP JINR, Dubna, Peking University and Tsinghua University, Beijing, China. This joint research group has carried out the study of ^{39}K(n,α)^{36}Cl, ^{40}Ca(n,α)^{37}Ar, ^{64}Zn(n,α)^{61}Ni reactions at 4.0 ÷ 7.0 MeV neutron energy region [12] using grided ionization chamber (GIC). Because of multiple benefits of such detector i.e. simple construction, high efficiency, a good energy resolution and angular information of particles ejected simultaneously, good energy resolution, radiation stability in neutron field, GIC overcame the limitations of the semiconductor telescope detector [13].

[1] Yu.M Gledenov,. P.E. Koehler**, J. Andrzejewski**, K.H. Guber and T. Rauscher, Phys. Rev. **C 62** Rapid Communication (2000) 801

[2] P. E. Koehler, Yu. M. Gledenov, **J. Andrzejewski**, K. H. Guber, S. Raman and T. Rauscher, Nucl. Phys. **A688** (2001) 86c

[3] Yu.M Gledenov,. P.E. Koehler, **J. Andrzejewski**, Yu.P. Popov, R.Yu. Gledenov, Journal of Nuclear Science and Technology, Supplement 2 (2002) 358

[4] U.Abbondanno, ... **J.Andrzejewski, J.Marganiec** + n_TOF Collaboration, Phys. Rev. Letters, **93**, 161103 (2004)

[5] S. Marrone, ... **J. Andrzejewski, J. Marganiec** + n_TOF Collaboration, Phys. Rev. **C 73**, 034604 (2006)

[6] G. Aerts, ... **J. Andrzejewski, J. Marganiec** + n_TOF Collaboration, Phys. Rev. **C 73**, 054610 (2006)

[7] C. Domingo-Pardo, ... **J. Andrzejewski, J. Marganiec** + n_TOF Collaboration, Phys. Rev. **C74**, 025807 (2006)

[8] **J. Andrzejewski**, N.A. Gundorin, I.L. Karpikhin**, L. Łason,** G.A. Lobov, D.V. Matveev, L.B. Pikelner, Physics of Atomic Nuclei, **v. 67, no.7,** (2004) 1233, translated from Yadernaya Fizika **67** (2004) 1257

[9] **M.Kaczmarczyk,** J.Phys. **G26** (2000) 253

[10] **M.Kaczmarczyk,** J.Phys. **G31** (2005) 669

[11] **M.Kaczmarczyk** and **L.Łasoń,** J.Phys. **G32** (2006) 417

[12] Yu.M.Gledenov, M.V.Sedysheva, P.V.Sedyshev, A.Oprea, G.Khuukhenkhuu, Z.Chen, Y.Chen, Z.Yuan, G.Tang, G.Zhang, **J.Andrzejewski**, **P.J.Szalanski**, Izvestiya Akademii Nauk**,** Seriya Fizicheskaya, **67** No 5 (2003) 689

[13] Yu.M. Gledenov, R. Machrafi, V.I. Salatski, P.V. Sedyshev, **J. Andrzejewski**, **P.J. Szalanski**, Nucl.Instrum.Meth.Phys.Res., **A431** (1999) 201

n_TOF Collaboration: U. Abbondanno, G. Aerts, H. Álvarez, F. Alvarez-Velarde, S. Andriamonje, J. Andrzejewski, P. Assimakopoulos, L. Audouin, G. Badurek, P. Baumann, F. Bečvář , E.Berthoumieux, F. Calviño, D. Cano-Ott, R. Capote, A. Carrillo de Albornoz, P. Cennini, V. Chepel, E. Chiaveri, N. Colonna, G. Cortes, A. Couture, J. Cox, M. Dahlfors, S. David, I. Dillmann, R. Dolfini, C. Domingo-Pardo, W. Dridi, I. Duran, C. Eleftheriadis, M. Embid-Segura, L. Ferrant, A. Ferrari, R. Ferreira-Marques, L. Fitzpatrick, H. Frais-Koelbl, K. Fujii, W. Furman, C. Guerrero, I. Goncalves, R. Gallino, E. Gonzalez-Romero, A. Goverdovski, F. Gramegna, E. Griesmayer, F. Gunsing, B. Haas, R. Haight, M. Heil, A. Herrera-Martinez, M. Igashira, S. Isaev, E. Jericha, Y. Kadi, F. Käppeler, D. Karamanis, D.Karadimos, M. Kerveno, V. Ketlerov, P. Koehler, V. Konovalov, E. Kossionides, M. Krtička, C. Lamboudis, H. Leeb, A. Lindote, I. Lopes, M. Lozano, S. Lukic, L. Marques, J. Marganiec, S. Marrone, P. Mastinu, A.Mengoni, P.M. Milazzo, C. Moreau, M. Mosconi, F. Neves, H. Oberhummer, S. O'Brien, M. Oshima, J. Pancin, C. Papachristodoulou, C. Papadopoulos, C. Paradela, N. Patronis, A. Pavlik, P. Pavlopoulos, L. Perrot, R. Plag, A. Plompen, A. Plukis, A. Poch, C. Pretel, J. Quesada, T. Rauscher, R. Reifarth, M. Rosetti, C. Rubbia, G. Rudolf, P. Rullhusen, J. Salgado, L. Sarchiapone, I. Savvidis, C. Stephan, G. Tagliente, J.L. Tain, L. Tassan-Got, L. Tavora, R. Terlizzi, G. Vannini, P. Vaz, A. Ventura, D. Villamarin, M.C. Vincente, V. Vlachoudis, R. Vlastou, F. Voss, S. Walter, H. Wendler, M. Wiescher, and K.Wisshak

NUCLEAR FUSION AND FISSION IN MEAN-FIELD MODELS

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Although fusion and fission are elementary nuclear processes, even after many years of development of the nuclear science our ability to predict fusion probabilities or fission half-lives is not very impressive. This results from two important reasons: complicated interactions and difficulties in solving many-body problems. The mean-field method of the Hartree-Fock type with effective, density dependent interactions is probably the most advanced approach to the description of fusion and fission. The interest in these processes is stimulated by the efforts and successes in the creation of superheavy elements.

In our studies we concentrate on two topics: (i) calculations of fusion and fission barriers and (ii) the instanton approach to finding fission half-lives.

The proper calculation of fission or fusion barriers requires a correct energy evaluation for nuclear shapes with constriction. It seems that the existing calculations overestimate energies of nuclear configurations close to scission by including a spurious contribution of kinetic energy of the fragments' relative motion. When this spurious energy is eliminated, one can obtain fission barriers in relatively light A=70-100 systems much closer to the experimental values than in the standard calculations [1].

The same correction is important for fusion barriers, but, in contrast to the fission studies, it was usually included. The calculations of adiabatic fusion barriers [2,3] show that, perhaps, one needs to refine the correction and remove a proper fraction of the relative kinetic energy, depending on whether the fragments are more or less divided. The same calculations show that the static fusion barriers obtained with the Skyrme forces SkM* and Sly6 quite well agree with the experimental fusion barriers for relatively light systems. For the heavier systems, the barriers are slightly underestimated. Beside the barriers, the second ingredient in typical calculations of fission half-lives [4] is the mass tensor, necessary for the evaluation of WKB-like action. None of these is well defined and they introduce the arbitrariness to the theory. On the other hand, the time-dependent Hartree-Fock equations in imaginary time have solutions that provide the optimal fission paths without additional assumptions. One only has to find these solutions, called instantons.

Nuclear fission problem leads to instantons with many single particle wave functions and specific orthogonality relations that must be fulfilled [5]. We are working on the practical reformulation of the problem in terms of the functional minimization. For simpler systems, described by the one wave function, like a Bose-Einstein condensate, such variational solutions may be obtained [6]. The work towards obtaining solutions that give the fission half-lives of heavy nuclei is in progress.

[1] **J. Skalski,** Phys. Rev. **C 74,** 051601 (2006)

[2] **J. Skalski**, Int. Journ. of Modern Phys. E **13**, 315 (2004)

[3] **J. Skalski,** submitted

[4] **R. Smolańczuk, J. Skalski and A. Sobiczewski,** Phys. Rev. **C 52,** 1871 (1995)

[5] **J. Skalski,** in Proc. Int. Workshop on „New Developments in Nuclear Self-Consistent Mean-Field Theories", Yukawa Institute for Theoretical Physics report series (2005), http://wwwnucl.ph.tsukuba.ac.jp/MF05/proceedings.html

[6] **J. Skalski,** Phys. Rev. **A 65,** 033626 (2002)

FISSION AND FUSION OF NUCLEI WITHIN THE SKYRME-HARTREE-FOCK THEORY

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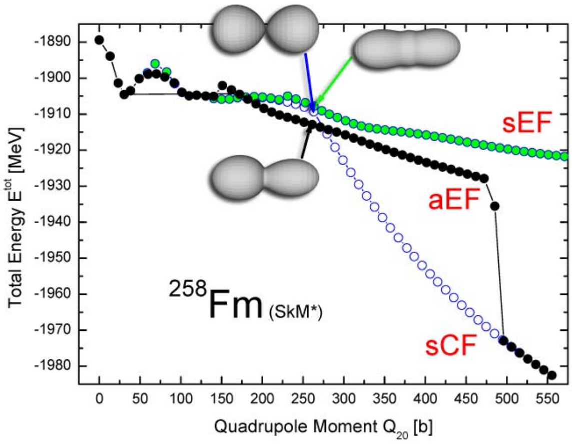
As has been illustrated many times in all fields of science, with an improved understanding of microworld come applications that benefit society. Fusion and fission are excellent examples. Our description of these fundamental nuclear processes is still very schematic, yet, nuclear fission powers reactors that produce energy for the nation, and fusion, which is responsible for energy production in stars, has the promise to provide a clean alternative source of energy. Our group carries out a programmatic study of the fission process in nuclei, based on self-consistent density functional theory (DFT). We attack the problem of spontaneous fission using modern theoretical methods and state-of-the-art computational tools.

Fission is a fundamental many-body phenomenon that possess the ultimate challenge for theory. Microscopically, this phenomenon can be viewed as a many-body tunneling. Studies of fission barriers are important for, e.g., the determination of the stability of the heaviest nuclei and for understanding of nucleosynthesis in stars. A number of theoretical calculations of fission barriers of the heavy nuclei have been carried out. These include calculations based on the microscopic-macroscopic method and the self-consistent approach with the Gogny and Skyrme forces, and relativistic mean-field model.

Our calculations have been performed within the self-consistent constrained Skyrme-Hartree-Fock+BCS (SHF+BCS) framework. We have used the code HFODD [1, 2] that solves self-consistent HF equations by using the Cartesian harmonic oscillator finite basis. This code makes it possible to break all self-consistent symmetries of the nuclear mean field at the same time, including the axial and reflection symmetry.

In Refs. [3-5] the Skyrme energy density functional with the SLy4 parameterization has been applied to study static fission barriers of even-even SHE with $100 \leq Z \leq 110$ and even-even spherical isotones with $N = 184$. The effects of reflection-asymmetric and triaxial degrees of freedom on the fission barriers have been discussed. The sensitivity of static fission barriers in $N = 184$ isotones to the choice of paring interaction has been studied in Ref. [6]. In the particle-particle channel of SHF+BCS model we have applied the seniority paring force and three variants of δ-interaction (DI, DDDI, or MIX). The collective inertia tensor and zero-point quadrupole energy correction have been calculated in Ref. [7].

A phenomenon of bimodal fission has been studied in Ref. [8]. Figure below displays the predicted static fission paths of ^{258}Fm along a mass quadrupole moment Q_{20}. Beyond the region of the first fission barrier, at $Q_{20} \approx 150$ b, a reflection-asymmetric path corresponding to elongated fragments (aEF) branches away from the symmetric valley. At $Q_{20} \approx 225$ b, a reflection-symmetric path splits into two branches: one corresponding to a division into nearly spherical fragments (sCF) and the second corresponding to elongated fragments (sEF). The sCF and sEF paths can be associated with the higher- and lower-TKE modes of the bimodal fission, respectively. Moreover, the less favorable aEF path may yield a small asymmetric contribution to the mass distribution of events with lower TKEs.



[1] **J. Dobaczewski,** J. Dudek, Comput. Phys. Commun. **102**, 166 (1997); *ibid.* **102**, 183 (1997); *ibid.* **131**, 164 (2000).

[2] **J. Dobaczewski, P. Olbratowski,** Comput. Phys. Commun. **158**, 158 (2004); *ibid.* **167**, 214 (2005); **J. Dobaczewski *et al.***, to be published in Comput. Phys. Commun.; HFODD home page http://www.fuw.edu.pl/~dobaczew/hfodd/hfodd.html.

[3] **A. Staszczak, J. Dobaczewski, W. Nazarewicz**, Int. J. Mod. Phys. **E14,** 395 (2005).

[4] **A. Staszczak, J. Dobaczewski, W. Nazarewicz**, Proceed. of the 3rd International Workshop on Nuclear Fission and Fission-Product Spectroscopy, Cadarache, France 11-14 May 2005, ed. H. Goutte, H. Faust, G. Fioni, D. Goutte, AIP Conference Proceedings **798,** 93 (2005).

[5] **A. Staszczak, J. Dobaczewski, W. Nazarewicz**, Int. J. Mod. Phys. **E15,** 302 (2006).

[6] **A. Staszczak, J. Dobaczewski, W. Nazarewicz**, accepted for publication in Int. J. Mod. Phys. **E16** (2007); nucl-th/0611076.

[7] **A. Baran, A. Staszczak, J. Dobaczewski, W. Nazarewicz**, accepted for publication in Int. J. Mod. Phys. **E16** (2007); nucl-th/0610092.

[8] **A. Staszczak, J. Dobaczewski, W. Nazarewicz**, accepted for publication in Acta Phys. Polonica **B,** (2007);
nucl-th/0612017.

ENHANCED ELECTRON SCREENING IN DEUTERON FUSION REACTIONS

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Experimental facility: accelerators at the Technical University of Berlin, Humboldt University of Berlin, Hahn Meitner Institute Berlin, University of Porto Alegre, Brasil

Nuclear reactions in dense astrophysical plasmas preceding at low energies, far below the Coulomb barrier are very sensitive to the electronic properties of the medium. The electrons surrounding the reacting nuclei shield the Coulomb barrier leading to an increase of the tunneling probability and a characteristic exponential-like enhancement of reaction cross sections for lowering energies. The electron screening effect is especially important for strongly coupled plasmas where the kinetic energy of constituents is smaller than the mean Coulomb repulsion energy. In such a case nuclear reaction rates can be increased by many orders of magnitude, which is probably realized in White and Brown Dwarfs or Giant Planets.

In terrestrial laboratories, the effect of the enhanced electron screening was observed for the first time [1] in the $^{2}H(d,p)^{3}H$ and $^{2}H(d,n)^{3}He$ reactions taking place in deuterized metallic targets that are good models for strongly coupled plasmas. The experimentally determined reduction of the Coulomb barrier by means of the screening energy U_e (see Fig.1) was found to be dependent of the target material and reaches values of about 300 eV for heavier metals (Fig.2), by a factor of ten larger than for gas targets and insulating materials. From the theoretical point of view, a charge point impurity embedded in a metallic environment leads to a polarization of surrounding degenerate valence and bound electrons causing a cut off of screened Coulomb field at a characteristic distance of the inverse of the Fermi wave number. The theoretical calculations [2-4] based on the self-consistent dielectric function theory can qualitatively explain the target material dependence of the screening energies, however, the absolute theoretical values are underestimated by a factor of two. The reason for this discrepancy is still unknown. Careful experimental and theoretical studies of the effect [5-7] could exclude any other significant contributions resulting from the solid-state phenomenology. The first measurement of the screening effect performed under ultra-high vacuum conditions [8] pointed even to much larger experimental screening energies.

Recently, some new experiments have been carried out to investigate the influence of electronic dynamics on channeling conditions [9] and stopping power values [10] in a hot dense plasma. Hereby, ion tracks produced in metals by swift heavy ions have been applied.

Since the Coulomb interaction also plays an important role in beta and alpha radioactive decays, the enhanced electron screening observed for the deuteron fusion reactions might modify corresponding transition probabilities in different metallic environments. Unfortunately, theoretical calculations and first experiments suggest that the effects are rather small [11-13].

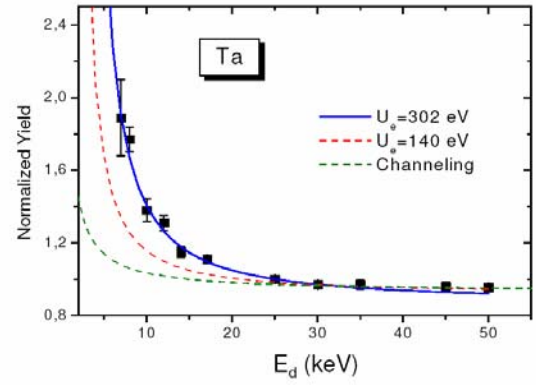

Fig.1. *Experimental yield for the $^{2}H(d,p)^{3}H$ reaction in the Ta environment normalized to the cross section for bare nuclei. The exponential-like increase for lowering energies is due to electron screening. Theoretical curves correspond to different screening energies and a channeling contribution.*

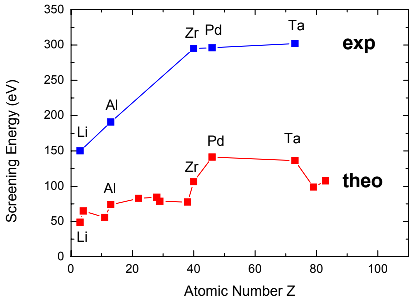

Fig.2. *Experimental screening energies and theoretical values obtained within the improved dielectric function theory.*

[1] **K. Czerski**, A. Huke, A. Biller, P. Heide, M. Hoeft, G. Ruprecht, Europhys Letters **54** (2001) 449

[2] **K. Czerski**, A. Huke, P. Heide, Nuclear Physics. **A 719** (2003) 52

[3] **K. Czerski**, A. Huke, P. Heide, G. Ruprecht, Europhys. Lett. **68** (2004) 363

[4] **K. Czerski**, A. Huke, P. Heide, G. Ruprecht, Eur. Phys. J. **A 27** (2006) 83

[5] **K. Czerski**, A. Huke, P. Heide and G. Schiwietz, Instr. Meth. **B 193** (2002) 183

[6] A. Huke, **K. Czerski**, P. Heine, Nucl. Phys. **A 719** (2003) 279c

[7] A. Huke, **K. Czerski**, P. Heine, Nucl. Instr. Meth. **B 256** (2007) 599

[8] **K Czerski**, A Huke, L Martin, **N Targosz**, D Blauth, **A Górska**, P Heide and H Winter, J. Phys. **G 35** (2008) 014012

[9] R.C. Fadanelli., P.L. Grande, M. Behar, J.F. Dias, **K. Czerski**, G. Schiwietz, Phys. Rev. **B 73** (2006) 245336

[10] G. Schiwietz, M. Roth, **K. Czerski**, F. Staufenbiel, P. L. Grande, Phys. Rev. Lett. **99** (2007) 197602

[11] **K. Czerski**, P. Heide, A. Huke, L. Martin, G. Ruprecht, PoS (NIC-IX 2006) 044

[12] G. Ruprecht, L. Buchman, D. Hutcheon, D. Ottewell, C. Ruiz, P. Walden, C. Vockenhuber, **K. Czerski,** PoS (NIC-IX 2006) 171

[13] G Ruprecht, C Vockenhuber, C Ruiz, L Buchmann, J Pearson, D Ottewell, **K Czerski**, A Huke J. Phys. G 35 (2008) 014017

EXPERIMENTAL APPROACHES TO HEAVY ION REACTIONS AT INTERMEDIATE ENERGIES

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Experimental facility: Cyclotron Institute Texas A&M University, USA

One of the main purpose of the study heavy ion reactions is to explore the properties of nuclear matter at various densities and temperatures. During nuclear reactions at intermediate energies it is expected that the composite system of projectile and target nuclei is compressed and excited in the early stage of the reactions, and than the hot-dense nuclear system expand and breaks up by multifragmetatins process. Additionally, the light particle emissions occurs during such violent collisions and carries essential information on the early dynamics and on the degree of equilibrium at each stage of the reactions.

The various reactions systems were experimentally studied by using the K-500 superconducting cyclotron facility at Texas A&M University and NIMROD (Neutron Ion Multidetector for Reactions Oriented Dynamics) detections system [1]. NIMROD is 4π detector which consists of a charge particle array inside a 4π neutron calorimeter. The charge particle detector array of NIMROD includes 166 individual CsI detectors arranged in 12 rings, each forward ring included two "super-telescopes" composed of two Si detectors and seven Si-CsI telescopes to identity intermediate mass fragments (IMF).

A detailed analysis of the central collision events revealed that multifragmentation with cold fragment emission is a common feature predicted for all reactions studied reactions. A possible multifragmentation scenario is presented; after the preequilibrium emission ceases in the composite system, cold light fragments are formed in a hotter gas of nucleons and stay cold until the composite system underdoes multifragmentation [1].

The kinetic-energy variation of emitted light clusters has been employed as a clock to explore the time evolution of the temperature for thermalizing composite systems produced in the measured reactions systems. For each system investigated, the double-isotope ratio temperature curve exhibits a high maximum apparent temperature, which value increase with increasing projectile energy and decrease with increasing target mass [2-4].

Experimental analyses of moderate temperature nuclear gases reveal a large degree of alpha particle clustering at low densities. For these gases, temperature and density dependent symmetry energy coefficients have been derived from isoscaling analyses [5].

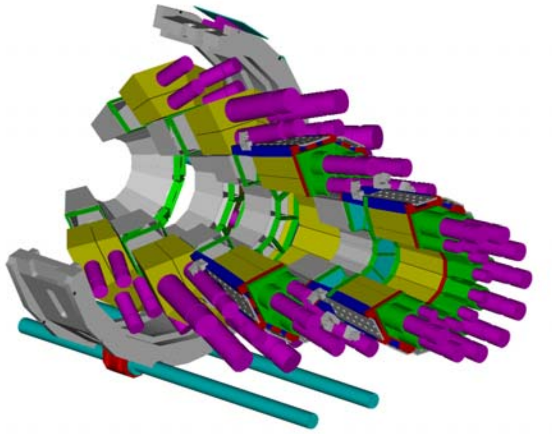

Fig. 1. *NIMROD - Three dimensional schematic plot.*

[1] R. Wada, T. Keutgen, K. Hagel, Y. G. Ma, J. Wang, M. Murray, L. Qin, P. Smith, J. B. Natowitz, R. Alfarro, **J. Cibor**, M. Cinausero, Y. El Masri, D. Fabris, E. Fioretto, A. Keksis, **S. Kowalski**, M. Lunardon, A. Makeev, N. Marie, E. Martin, **Z. Majka**, A. Martinez-Davalos, A. Menchaca-Rocha, G. Nebbia, G. Prete, V. Rizzi, A. Ruangma, D. V. Shetty, G. Souliotis, **P. Staszel**, M. Veselsky, G. Viesti, E. M. Winchester, S. J. Yennello, **W. Zipper**, and A. Ono, Phys. Rev. **C 69**, 044610 (2004)

[2] J. Wang, T. Keutgen, R. Wada, K. Hagel, Y. G. Ma, M. Murray, L. Qin, P. Smith, J. B. Natowitz, R. Alfaro, **J. Cibor**, A. Botvina, M. Cinausero, Y. El Masri, D. Fabris, A. Keksis, **S. Kowalski**, M. Lunardon, A. Makeev, N. Marie, E. Martin, **Z. Majka**, A. Martinez-Davalos, A. Menchaca-Rocha, G. Nebbia, S. Moretto, G. Prete, V. Rizzi, A. Ruangma, D. V. Shetty, G. Souliotis, **P. Staszel**, M. Veselsky, G. Viesti, E. M. Winchester, S. J. Yennello and **W. Zipper,** Phys. Rev. **C 71**, 054608 (2005)

[3] J. Wang, R. Wada, T. Keutgen, K. Hagel, Y. G. Ma, M. Murray, L. Qin, A. Botvina, **S. Kowalski**, T. Materna, J. B. Natowitz, R. Alfarro, **J. Cibor**, M. Cinausero, Y. El Masri, D. Fabris, E. Fioretto, A. Keksis, M. Lunardon, A. Makeev, N. Marie, E. Martin, **Z. Majka**, A. Martinez-Davalos, A. Menchaca-Rocha, G. Nebbia, G. Prete, V. Rizzi, A. Ruangma, D. V. Shetty, G. Souliotis, **P. Staszel**, M. Veselsky, G. Viesti, E. M. Winchester, S. J. Yennello, and **W. Zipper**, Phys. Rev. **C 72**, 024603 (2005)

[4] J. Wang, T. Keutgen, R. Wada, K. Hagel, **S. Kowalski**, T. Materna, L. Qin, Z. Chen, J. B. Natowitz, Y. G. Ma, M. Murray, A. Keksis, E. Martin, A. Ruangma, D. V. Shetty, G. Souliotis, M. Veselsky, E. M. Winchester, S. J. Yennello, D. Fabris, M. Lunardon, S. Moretto, G. Nebbia, S. Pesente, V. Rizzi, G. Viesti, M. Cinausero, G. Prete, **J. Cibor, W. Zipper, Z. Majka, P. Staszel**, Y. El Masri, R. Alfarro, A. Martinez-Davalos, A. Menchaca-Rocha, A. Ono, Phys. Rev. **C 75**, 014601 (2007)

[5] **S. Kowalski**, J. B. Natowitz, S. Shlomo, R. Wada, K. Hagel, J. Wang, T. Materna, Z. Chen, Y. G. Ma, L. Qin, A. S. Botvina, D. Fabris, M. Lunardon, S. Moretto, G. Nebbia, S. Pesente, V. Rizzi, G. Viesti, M. Cinausero, G. Prete, T. Keutgen, Y. El Masri, **Z. Majka**, A. Ono, Phys. Rev. **C 75**, 014604 (2007)

HEAVY ION EXPERIMENTS AT LNS CATANIA WITH 4π CHIMERA MULTIDETECTOR

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Experimental facility: CHIMERA detector at INFN-LNS Catania, Italy

Analysis of isotopic characteristics of products for the inclusive data measured in heavy ion collisions at intermediate energies is one of the most interesting jobs in the study of the nuclei under extreme conditions of density and temperature.

The aim is to explore the behavior of the basic properties of the nuclear matter equation of state (EOS) New international collaboration CHIMERA-REVERSE-ISOSPIN was established at INFN-LSN Catania in 1997. The CHIMERA (Charged Heavy Ion Mass and Energy Resolving Array) 4π detector was build for heavy ion studies in the intermediate regime.

The CHIMERA device is made of 1192 individual two-step telescopes arranged in cylindrical geometry around the beam axis in 35 rings. The detector is divide in the two parts: "forward part" covering the angular range (1o-30o) and consist 688 telescopes arranged in 18 rings, "sphere" with 504 telescopes covering the angular range 30o-170o. The Fig. 1 shows an schematic view of the detector. Each single telescope is composed of silicon (300um) planer detector followed by a CsI scintillator with thickens ranging from 3cm to 12cm. depending on the detection angle. Three different identifications techniques are simultaneously used: πE-E for charge identifications of heavy ion, the πE-TOF (Time of Flight) for velocity measurements and PSD (Pulse Shape Discrimination) method for identifications of light charge particles stopped in the CsI.

At LNS Catania two campaigns were performed with the CHIMERA detector: REVERSE year 2000 and REVERSE / ISOSPIN year 2003. The scientific program of the campaigns followed three different studied: isospin degree of freedom, cluster production and dynamical fission [1-14].

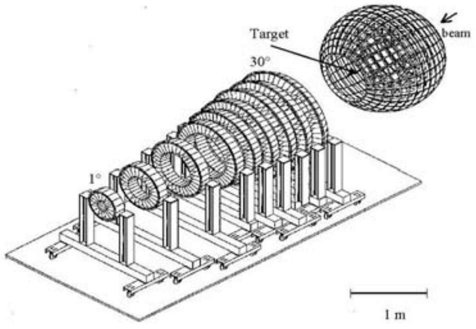

Fig. 1. *The CHIMERA detector.*

Reverse/Isospin collaboration. Within the reported period the obtained results were communicated in 21 publications (6 examples are listed below)

[1] F. Porto, S. Aiello, A. Anzalone, C. Cali, G. Cardella, Sl. Cavallaro, E. De Filippo, S. Femino, E. Geraci, F. Giustolisi, **A. Grzeszczuk,** P. Guazzoni, C. M.Iacono--Manno, **S. Kowalski**, G. Lanzano, G. Lanzalone, S. LoNigro, D. Mahboub, D. Nicotra, **T. Paduszynski,** A. Pagano, M. Papa, S. Pirrone, G. Politi, C. Rapicavoli, F. Rizzo, S. Sambataro, M.L. Sperduto, C.M. Sutera, S. Urso, L. Zetta, **W. Zipper** Acta Physica Polonica, vol. **31** (2000) 1489

[2] Le Neindre, N.; Alderighi, M.; Anzalone, A.; Barnà, R.; Bartolucci, M.; Berceanu, I.; Borderie, B.; Bougault, R.; Bruno, M.; Cardella, G.; Cavallaro, S.; D'Agostino, M.; Dayras, R.; De Filippo, E.; De Pasquale, D.; Geraci, E.; Giustolisi, F.; **Grzeszczuk, A**.; Guazzoni, P.; Guinet, D.; Iacono-Manno, M.; Italiano, A.; **Kowalski, S**.; Lanchais, A.; Lanzanó, G.; Lanzalone, G.; Li, S.; Lo Nigro, S.; Maiolino, C.; Manfredi, G.; Moisa, D.; Pagano, A.; Papa, M.; **Paduszynski, T**.; Petrovici, M.; **Piasecki, E**.; Pirrone, S.; Politi, G.; Pop, A.; Porto, F.; Rivet, M. F.; Rosato, E.; Russo, S.; Sambataro, S.; Sechi, G.; Simion, V.; Sperduto, M. L.; Steckmeyer, J. C.; Sutera, C.; Trifirò, A.; Tassan-Got, L.; Trimarchi, M.; Vannini, G.; Vigilante, M.; Wilczynski, J.; Wu, H.; Xiao, Z.; Zetta, L.; Zipper, W. Nucl. Instr. and Meth. **A490** (2002) 251-262

[3] A. Pagano, M. Alderighi, A. Anzalone, L. Auditore, V. Baran, R. Barnà, M. Bartolucci, I. Berceanu, **J. Blicharska,** A. Bonasera, B. Borderie, R. Bougault, **J. Brzychczyk,** M. Bruno, G. Cardella, S. Cavallaro, M.B. Chatterje. A. Chbihi, **J. Cibor**, M. Colonna, M. D Agostino, R. Dayra, E. De Filippo, D. De Pasquale, M. Di Toro, **W. Gawlikowicz,** E. Geraci, F. Giustolisi, **A. Grzeszczuk,** P. Guazzoni, D. Guinet, M. Iacono-Manno, A. Italiano, **S. Kowalski**, E. La Guidara, G. Lanzalone, G. Lanzano, N. LeNeindre, S. Li , S. Lo Nigro, C. Maiolino, Z. Majka, G. Manfredi, **T. Paduszynski,** M. Papa, M. Petrovici, **E. Piasecki**, S. Pirrone, G. Politi, A. Pop, F. Porto, M.F. Rivet, E. Rosato, S. Russo, P. Russotto, G. Sechi, V. Simion, M. L. Sperduto, J. C. Steckmeyer, A. Trifirò, M. Trimarchi, G. Vannini, M. Vigilante, J.P. Wieleczko, **J. Wilczynski**, H. Wu, Z. Xiao, L. Zetta, **W. Zipper** Nucl..Phys. **A 732** (2004) 173-201

[4] E. De Filippo, A. Pagano, **J. Wilczyñski,** F. Amorini, A. Anzalone, L. Auditore, V. Baran, I. Berceanu, **J. Blicharska, J. Brzychczyk,** A. Bonasera, B. Borderie, R. Bougault, M. Bruno, G. Cardella, S. Cavallaro, M. B. Chatterjee, A. Chbihi, **J. Cibor**, M. Colonna, M. D'Agostino, R. Dayras, M. Di Toro, J. Frankland, E. Galichet, **W. Gawlikowicz**, E. Geraci, F. Giustolisi, **A. Grzeszczuk**, P. Guazzoni, D. Guinet, M. Iacono-Manno, **S. Kowalski**, E. La Guidara, G. Lanzan`o, G. Lanzalone, N. Le Neindre, S. Li, C. Maiolino, Z. Majka, M. Papa, M. Petrovici, **E. Piasecki**, S. Pirrone, **R. Płaneta**, G. Politi, A. Pop, F. Porto, M. F. Rivet, E. Rosato, F. Rizzo, S. Russo,P. Russotto, M. Sassi, **K. Schmidt, K. Siwek-Wilczyñska, I. Skwira,** M. L. Sperduto, Ł. ´Swiderski, A. Trifir`o, M. Trimarchi, G. Vannini, M. Vigilante, J. P. Wieleczko, H. Wu, Z. Xiao, L. Zetta, and **W. Zipper** Phys. Rev. **C 71** 044602 (2005)

[5] **J. Wilczyński,** E. De Filippo, A. Pagano, F. Amorini, A. Anzalone, L. Auditore, V. Baran, I. Berceanu, **J. Blicharska, J. Brzychczyk,** A. Bonasera, B. Borderie, R. Bogault, M. Bruno, G. Gardella, S. Cavallaro, M.B. Chatterjee, A. Chbihi, **J. Cibor,** M. Colonna, M. D,Agostino, R. Dayras, M. Di Toro, J. Frankland, E. Galichet, **W. Gawlikowicz,** E. Geraci, F. Giustolisi, **A. Grzeszczuk,** P. Guazzoni, D. Guinet, M. Iacono - Manno, **S. Kowalski**, E. La Guidara, G. Lanzano, N. Le Neindre, S. Li, C. Maiolino, **Z. Majka,** M. Papa, M. Petrovici, E. Piasecki, S. Pirrone, R. Planeta, G. Politi, A. Pop, F. Porto, M.F.Rivet, E. Rosato, F.Rizzo, S. Russo, P. Russotto, M. Sassi, **K. Schmidt, K. Siwek - Wilczyńska, I. Skwira,** M.L. Sperduto, Ł. Świderski, A. Trifiro, M. Trimarchi, G. Vannini, M. Vigilante, J.P. Wileczko, H. Wu, Z. Xiao, L. Zetta and **W. Zipper**, Int. J. of Mod. Phys. **E 14** (2005) 353

[6] **R. Planeta,** F. Amorini, A. Anzalone, L. Auditore, V. Baran, I. Berceanu, **J. Blicharska, J. Brzychczyk,** B. Borderie, R. Bougault, M. Bruno, G. Cardella, S. Cavallaro, M.B. Chatterjee, A. Chbihi, M. Colonna, M. D,Agostino, E. DeFilippo, R. Dayras, M. Di Toro, J. Frankland, E. Galichet, **W. Gawlikowicz,** E. Geraci, F. Giustolisi, **A. Grzeszczuk**, P. Guazzoni, D. Guinet, M. Iacono-Manno, **S. Kowalski**, E. La Guidara, G. Lanzano, G. Lanzalone, **J. Lukasik**, C. Maiolino, **Z. Majka,** N. Le Neindre, N.G. Nicolis, A. Pagano, M. Papa, M. Petrovici, **E. Piasecki,** S. Pirrone, G. Politi, A. Pop, F. Porto, M.F. Rivet, E. Rosato, F. Rizzo, S. Russo, P. Russotto, M. Sassi, **K. Schmidt, K. Siwek-Wilczynska, I. Skwira-Chalot, A. Sochocka,** M.L. Sperduto, L. Swiderski, A. Trifiro, M. Trimarchi, G. Vannini, G. Verde, M. Vigilante, J.P. Wieleczko, **J. Wilczynski,** L. Zetta, **W. Zipper,** Acta Phys. Pol. **B37** (2006) 199

HEAVY ION REACTION MECHANISMS AT FERMI ENERGY DOMAIN

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Experimental facility: AMPHORA 4π detector GRENOBLE; INDRA 4π detector GANIL

The Grenoble–Kraków–Lyon Cooperation was devoted to some problems of the mechanism of the intermediate energy heavy ion reactions including their statistical (thermodynamic) properties. The ^{40}Ca + ^{40}Ca,^{197}Au reactions were studied using the Grenoble AMPHORA 4π detector additionally equipped in two rings of 30 gas ionization chambers constructed in Kraków [1]. Measurements were done at E_{lab} = 35 MeV/nucleon.

The idea of our research was to study possible departures from the binary reaction scenario demonstrated in multiplicities of different charge (mass) particles, their energy and angular distributions [14].

Multiplicity as well as event shape filters were used to distinguish nearly central from peripheral collisions. For a significant portion of events, in coincidence with projectile-like and with target-like fragments, the intermediate mass fragments, IMF's, were observed with velocities close to zero in the CM reference frame. Such intermediate velocity source could be seen in the simple BNV calculations, but not in the modified by us binary reaction Cole model. [2-7]

For both ^{40}Ca + ^{40}Ca,^{197}Au reactions the shape of the velocity distributions of charged particles projected on the beam direction could be explained if emissions from the hot projectile-like and target-like fragments were supplemented by an emission from an intermediate velocity source, IVS, located between them. Such conclusion was also suggested by a Monte Carlo code describing a heavy-ion collision as a two step process [10]. Some of the nucleons which are identified as participants in the first step are transferred in the second step to these final states, which correspond on average to the maximum value of entropy. The model allows for competition between mean-field effects and nucleon-nucleon interactions in the overlap zone of the interacting nuclei.

The creation of the hot Ca-like fragments was investigated in both ^{40}Ca + ^{40}Ca,^{197}Au reactions. Here the primary projectile-like fragment was reconstructed and its properties (mass, charge, excitation energy, and angular distribution) determined. Both primary and secondary distributions were compared with the predictions of the mentioned above Monte Carlo code. The data and analysis suggest a thermalized source picture of the decay of the projectile-like fragment. [8-10,12]

It was found that in the investigated reactions the yield of particles emitted from the IVS decreases with the increasing value of the particle Z. Most of these are light particles. In the more peripheral collisions deuterons, tritons, and to lesser extend helium 3 particles are preferentially emitted from the IVS. [9,11]

As continuation of the above program the ^{58}Ni + ^{197}Au and ^{107}Ag + ^{58}Ni, 52 MeV/nucleon, reactions are investigated in cooperation with LPC and GANIL, Caen. Analysis of data is concentrated on the reconstruction of the projectile-like fragment and in particular on the spin production process. For this purpose influence of the fragment-fragment interaction potential in the Monte Carlo code has been investigated in a separate paper [13]. This modified version of the code has been successfully used in the PhD thesis of Mrs A.Buta and in papers prepared for publication.

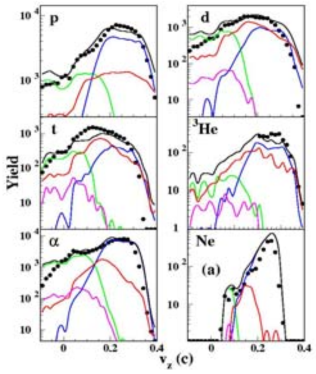

Fig. *Velocity distributions (LAB) for the ^{40}Ca+^{197}Au system projected on a direction parallel to the beam; black dots: experimental data. Model predictions for IVS, PLF, and TLF sources: red, blue, and green lines, respectively. Black line: total emission.*

[1] **T. Barczyk**, **J.Brzychczyk**, **P. Burzyński**, **W. Gawilikowicz**, **K.Grotowski**, **S.Micek**, **P. Pawłowski**, **R. Płaneta**, A.J.Cole, A.Chabane, P.Desesquelles, A.Giorni, D.Heuer, A.Lleres, J.B.Viano, D.Benchekroun, B.Cheynis, A.Demeyer, E.Gerlic, D.Guinet, P.Lautesse, L.Lebreton, E.Bisquer, M.Stern, L.Vagneron. M.Charvet, Nucl. Instr. Meth. **A364**, 311 (1995).

[2] **Z. Sosin**, **K. Grotowski**, **A. Wieloch** and H.W. Wilschut, Acta Phys. Pol. **B** 25 (1994).

[3] **P. Pawłowski**, **J. Brzychczyk**, P. Burzyński, D. Benchekroun, A. Chabane, M. Charvet, B. Cheynis, A.J. Cole, A. Demeyer, P. Desesquelles, **W. Gawlikowicz**, E. Gerlic, A. Giorni, **K. Grotowski**, D. Guinet, D. Heuer, P. Lautesse, L. Lebreton, A. Lleres, **S. Micek**, **R. Płaneta**, **Z. Sosin**, M. Stern, L. Vagneron, J.B. Viano, **A. Wieloch**, Phys.Rev. **C54**, R10 (1996).

[4] **P.Pawłowski**, D.Benchekroun, **J.Brzychczyk**, A.Chabane, M.Charvet, B.Cheynis, A.J.Cole, A.Demeyer, P.Desesquelles, **W.Gawlikowicz**, E.Gerlic, A.Giorni, **K.Grotowski**, D.Guinet, D.Heuer, P.Lautesse, L.Lebreton, A.Lleres, **S.Micek**, **R.Płaneta**, **Z.Sosin**, M.Stern, L.Vagneron, J.B.Viano, **A.Wieloch**, Z.Phys. **A357**, 387 (1997).

[5] **P.Pawłowski**, **J.Brzychczyk**, A.J.Cole, P.Desesquelles, **W.Gawlikowicz**, **K.Grotowski**, **P.Hachaj**, **S.Micek**, **R.Płaneta**, **Z.Sosin**, **A.Wieloch**, D.Benchekroun, E.Bisquer, A.Chabane, M.Charvet, B.Cheynis, A.Demeyer, E.Gerlic, A.Giorni, D.Guinet, D.Heuer, P.Lautesse, L.Lebreton, A.Lleres, M.Stern, L.Vagneron, J.B.Viano, Phys.Rev. **C57,** 1771 (1998).

[6] **P.S. Hachaj**, **J.Brzychczyk**, A.J.Cole, P.Desesquelles, **W.Gawlikowicz**, **K.Grotowski**, **S.Micek**, **P.Pawłowski**, **Z.Sosin**, **A.Wieloch**, D.Benchekroun, E.Bisquer, A.Chabane, M.Charvet, B.Cheynis, A.Demeyer, E.Gerlic, A.Giorni, D.Guinet, D.Heuer, P.Lautesse, L.Lebreton, A.Lleres, M.Stern, L.Vagneron, J.B.Viano, Acta Phys. Pol. **B29**, 369 (1998).

[7] **R.Płaneta**, **W.Gawlikowicz**, **K.Grotowski**, **J.Brzychczyk**, **T.Ciszek**, A.J.Cole,P.Desesquelles, **S.Micek**, **P.Pawłowski, Z.Sosin**, D.Benchekroun, **A.Wieloch**, E.Bisquer, A.Chabane, E.Gerlic, A.Giorni, D.Guinet, D.Heuer, L. Lebreton, A.Lleres, M.Stern, L.Vagneron, J.B.Viano, Acta Phys. Pol. **B31**, 1479 (2000).

[8] **R.Płaneta**, **W. Gawlikowicz**, **A. Wieloch**, **J. Brzychczyk**, **T.Ciszek**, A.J. Cole, P. Desesquelles, **K. Grotowski**, **P. Hachaj**, **S. Micek**, **P. Pawłowski**, **Z. Sosin**, D. Benchekroun, E. Bisquer, A. Chabane, M.Charvet, B. Cheynis, A. Demeyer, E. Gerlic, A. Giorni, D. Heuer, P. Lautesse, L. Lebreton, A. Lleres, M. Stern, L. Vagneron, and J.B. Viano, European Physical Jounal **A11**, 297 (2001).

[9] **Z. Sosin**, **R. Płaneta**, **T. Ciszek**, **J. Brzychczyk**, **W. Gawlikowicz**, **K. Grotowski**, **S. Micek**, **P. Pawłowski**, **A. Wieloch**, A.J. Cole, D. Benchekroun, E. Bisquer, A. Chabane, M. Charvet, B. Cheynis, A. Demeyer, P. Desesquelles, E. Gerlic, A. Giorni, D. Heuer, P.Lautesse, L. Lebreton, A. Lleres, M. Stern, L. Vagneron, and J.B. Viano European Physical Jounal **A11**, 305 (2001).

[10] **Z. Sosin**, European Physical Jounal **A11**, 311 (2001).

[11] **R.Płaneta**, **Z. Sosin**, **T. Ciszek**, **P. Hachaj**, **W.Gawlikowicz**, **K.Grotowski**, **S.Micek**, **P.Pawłowski**, A.J.Cole, P.Desesquelles, D.Benchekroun, **A.Wieloch**, E.Bisquer, A.Chabane, E.Gerlic, A.Giorni, D.Guinet, D.Heuer, L. Lebreton, A.Lleres, M.Stern, L.Vagneron, J.B.Viano, Acta Phys. Pol. **B32**, 3079 (2001).

[12] **W.Gawlikowicz**, **R.Płaneta**, **K. Grotowski**, **J. Brzychczyk**, **P. Hachaj**, **S. Micek**, **P. Pawłowski**, **Z. Sosin**, **A. Wieloch**, P. Desesquelles, A.J. Chabane, M.Charvet, A. Giorni, D. Heuer, A. Lleres, J.B. Viano, D. Benchekroun, E. Bisquer, B.Cheynis, A. Demeyer, E. Gerlic, D. Guinet, P. Lautesse, L. Lebreton, M. Stern, L. Vagneron, Nuclear Physics **A681**, 295 (2001)

[13] **Z. Sosin**, Acta Physica Polonica **B37**, 2859 (2006).

[14] **R. Płaneta**, Int. J. of Mod. Phys. **E15**, 937 (2006).

HARD PHOTONS FROM NUCLEUS-NUCLEUS AND PROTON-NUCLEUS COLLISIONS

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The properties of the hot and dense zone formed in (central) nucleus-nucleus collisions can be best studied with the probes which do not suffer from strong final state interactions. Bremsstrahlung photons can provide relatively undistorted insight into the physical conditions of the hot zone, but their usage is restricted at low energies (below ~20*A* MeV) by dramatically low production cross section, and at higher energies (above 100*A* MeV), by photons stemming from electromagnetic decays of produced hadrons like π^0 and η mesons. The total spectrum of photons (Fig. 1) consists of the low energy part (below ~10 MeV) originating from statistical decays of excited fragments, photons from the deexcitation of the Giant Dipole Resonance (around 15 to 20 MeV) and hard photons (above 30 MeV). Hard photons come predominantly from the bremsstrahlung process in proton-neutron interactions and they can witness the early phase of the collision. Studies of the photon spectra were done for nucleus-nucleus collisions in the energy range from 40*A* to 100*A* MeV using the TAPS spectrometer. TAPS consists of approx. 400 BaF_2 scintillator modules, which can be arranged in various experiment-specific configurations. Excellent time resolution and pulse-shape analysis allows for unambiguous photon identification and spectroscopy.

Detailed analysis of the shape of the photon energy spectrum above the region influenced by the Giant Dipole resonance revealed the presence of a second, softer, component. According to the transport model calculations, these photons are emitted at a later stage of the collision, when the excited zone approaches the thermal equilibration. The extracted source temperature agrees quite well with the caloric curve. Also, the thermalization time can be evaluated.

At the high-end of the spectrum, even the fully constructive superposition of the Fermi motion with the beam momentum does not allow to explain the origin of most energetic photons. According to the transport model, photons above the Fermi-motion related kinematical limit (190 MeV for 60*A* MeV beam) are predominantly produced by a two-step process: a pion produced in nucleon-nucleon interaction subsequently undergoes photoabsorption on another nucleon, what releases also the pion rest mass and creates photons of extreme energies.

The measurements realized for 180A MeV Ar+Ca system showed a significant enhancement of the hard photon cross section with respect to the extrapolations based on lower energy data.

The second-order quantum interference effect, known as Hanbury-Brown and Twiss (HBT) effect or intensity interferometry, allows to extract the source size on the basis of the analysis of two-body correlation function. Pairs of bremsstrahlung photons (E>25 MeV) have been measured. While the initial experiments of limited statistics indicated the oscillatory character of the correlation function (suggesting secondary recompression of the nuclear matter during the collision), higher statistics data show a flat correlation function. This shape can be understood only as a peculiar interference between photons from first-chance collisions and photons from target or projectile-like fragments. Only in the case of central collisions (selected via charged particles multiplicity) the indications for the standard HBT effect can be found.

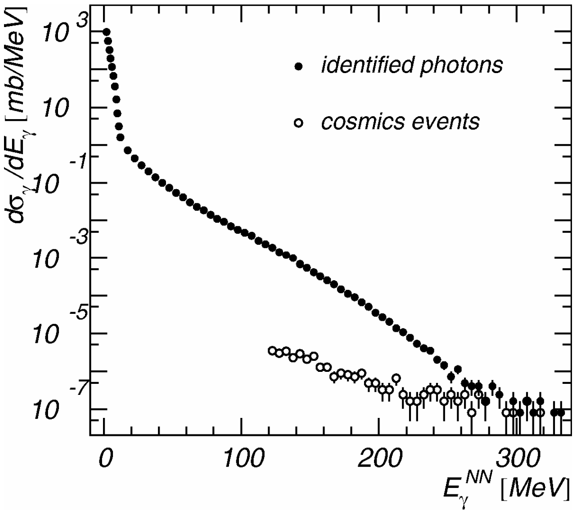

Fig. 1: *Photon energy spectrum measured with TAPS for the Kr+Ni collisions at 60A MeV.*

[1] J.H.G.van Pol, H.W.Wilschut, H.Löhner, R.H.Siemssen, P.Lautridou, F.Lefévre, F.M.Marqués, **T.Matulewicz**, W.Mittig, R.W.Ostendorf, P.Roussel-Chomaz, Y.Schutz, S.Hlavác, R.Holzmann, A.Schubert, R.S.Simon, V.Wagner, M.Franke, W.Kühn, M.Notheisen, R.Novotny, F.Ballester, J.Díaz, A.Marín, G.Martínez, A.Kugler
Physical Review Letters **76**(1996)1425

[2] K.K.Gudima, **T.Matulewicz**, H.Delagrange, F.M.Marqués, G.Martínez, R.W.Ostendorf, M.Ploszajczak, Y.Schutz, V.D.Toneev, **P.Bożek**, S.Hlavác, R.Holzmann, A.Schubert, R.S.Simon, V.Wagner, H.Löhner, J.H.G.van Pol, R.H.Siemssen, H.W.Wilschut, J.Díaz, A.Marín
Physical Review Letters **76**(1996)2412

[3] F.M.Marqués, G.Martínez, **T.Matulewicz**, R.W.Ostendorf, Y.Schutz
Physical Review **C 54**(1996)2783

[4] F.M.Marqués, G.Martínez, **T.Matulewicz**, R.W.Ostendorf, Y.Schutz
Physics Letters **B394**(1997)37

[5] F.M.Marqués, G.Martínez, **T.Matulewicz**, R.W.Ostendorf, Y.Schutz
Physics Reports **284**(1997)91

[6] G.Martínez, L.Aphecetche, Y.Charbonnier, H.Delagrange, **T.Matulewicz**, Y.Schutz
Nuclear Instruments and Methods **A391**(1997)435

[7] Y.Schutz, G.Martínez, F.M.Marqués, A.Marín, **T.Matulewicz**, R.W.Ostendorf, **P.Bozek**, H.Delagrange, J.Díaz, M.Franke, K.K.Gudima, S.Hlavác, R.Holzmann, P.Lautridou, F.Lefèvre, H.Löhner, W.Mittig, M.Ploszajczak, J.H.G.van~Pol, J.Québert, P.Roussel-Chomaz, A.Schubert, R.H.Siemssen, R.S.Simon, **Z.Sujkowski**, V.D.Toneev, V.Wagner, H.W.Wilschut, Gy.Wolf
Nuclear Physics **A622**(1997)404

[8] G.Martínez, L.Aphecetche, Y.Charbonnier, H.Delagrange, D.d'Enterria, **T.Matulewicz**, Y.Schutz, R.Turrisi, M.Appenheimer, V.Metag, R.Novotny, H.Ströher, A.R.Wolf, M.Wolf, J.Weiss, R.Averbeck, S.Hlavác, R.Holzmann, F.Lefèvre, R.S.Simon, R.Stratmann, F.Wissmann, M.Hoefman, M.J.van Goethem, H.Löhner, R.W.Ostendorf, R.H.Siemssen, P.Vogt, H.W.Wilschut, J.Díaz, A.Marín, A.Kugler, P.Tlusty, V.Wagner, A.Döppenschmidt
Physics Letters **B 461** (1999) 28

[9] L. Aphecetche, J. Bacelar, H. Delagrange, D. d'Enterria, M. Hoefman, H. Huisman, N. Kalantar-Nayestanaki, H. Löhner, G.Martínez, **T. Matulewicz**, J. Messchendorp, M.-J. Mora, R. Ostendorf, S. Schadmand, Y. Schutz, M. Seip, A. Taranenko, R. Turrisi, M.-J.Van Goethem, M. Volkerts, V. Wagner, H.W. Wilschut
Physics Letters **B519** (2001) 8

[10] **K. Piasecki**, **T. Matulewicz**
Acta Physica Polonica **B37** (2006) 175

[11] R. Ortega, D. d'Enterria, G.Martínez, D. Baiborodin, H. Delagrange, J.Díaz, F. Fernandez, H. Löhner, **T. Matulewicz** , R.W. Ostendorf, S. Schadmand, Y. Schutz, P. Tlusty, R. Turrisi, V. Wagner, H.W. Wilschut, N. Yahlali
European Physical Journal **A28** (2006) 161

NEUTRAL MESON PRODUCTION AND BARYONIC RESONANCE EXCITATION IN SUBTHRESHOLD NUCLEUS-NUCLEUS COLLISIONS

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Particles produced at subthreshold energies (i.e. beam energy per nucleon below the free nucleon-nucleon threshold) witness the early phase of the nucleus-nucleus collisions, where the energy density reaches maximum values. Subsequent dissipation of the relative motion strongly reduces the production yield in the later stages of the collision. Experiments have been carried out with the TAPS spectrometer consisting of approx. 400 BaF_2 scintillator modules, which were arranged in various experiment-specific configurations. Good position determination and excellent time resolution supplemented by pulse-shape analysis allowed for unambigous photon identification. The two-photon decays of neutral mesons π^0 and η were observed in the invariant mass spectrum.

The angular distribution of π^0 mesons, already from the first studies of the process in the eighties, is known to show evidences of significant pion reabsorption process on the side of the heavier collision partner. Systematic studies of the shape of the angular distribution have been carried out at 2 beam energies at several target nuclei from carbon to gold. Reasonable description of the data was obtained within a geometrical model of the collision, which also takes into account momentum-dependent pion absorption length [R. Mehrem *et al.*, Phys. Rev. C30(1984)301]. We observed, that the angular distribution of primordial pions does not show any significant energy or mass dependence and can be described as $\sim 1+A_2P_2(\cos\theta)$, where θ denotes the emission angle in the nucleon-nucleon center of mass. From the global fit to the data we obtained the value of $A_2=0.33\pm0.05$.

The production of particles at deep subthreshold energies is very important for the studies of particular concentration in one hadronic channel of the energy available in the nucleus-nucleus collision. The η meson production was studied at the ^{40}Ar beam energy of 180*A* MeV, that is 14% of the free threshold energy of 1255 MeV. The measured η yield was significantly below that expected from the general scaling based on the ratio of beam energy per nucleon to the threshold energy. However, the data were nicely reproduced with the transverse mass $m_t=(m^2+p_t^2)^{1/2}$ scaling used previously at much higher beam energies.

Transport model calculations show, that the $\Delta(1232)$ resonance plays an important role as an intermediate step in pion production process during nucleus-nucleus collisions. Experimental evidence of the $\Delta^+(1232)$ resonance excitation in nuclei was provided by the study of correlated emission of protons and π^0 mesons (see Figure 1) in 180*A* MeV Ar+Ca collisions. The coincident events show a clear excess above the mixed-events background, indicating the excitation of the low energy tail of the $\Delta(1232)$ resonance (due to the low beam energy, only the low energy tail might be effectively populated). Simultaneous detection of $\Delta(1232)$ resonance and π^0 mesons allowed to determine the ratio of the number of $\Delta(1232)$ resonances to the number of pions. Assuming isospin symmetry, this ratio was found to be equal to $0.79\pm0.30(\mathrm{stat})\pm0.2(\mathrm{syst})$. It indicates, that most (if not all) produced π mesons originate from the decay of $\Delta(1232)$ resonances.

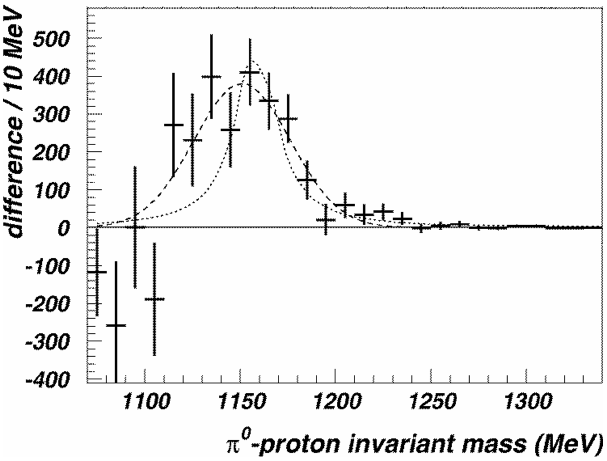

Fig. 1. *The excess of counts in the invariant mass spectrum of proton and neutral pion pairs above the combinatorial background. The data are from 180A MeV Ar+Ca collisions.*

[1] R.Holzmann, A.Schubert, S.Hlavác, R.Kulessa, W.Niebur, R.S.Simon, P.Lautridou, F.Lefèvre, F.M.Marqués, **T.Matulewicz**, W.Mittig, R.W.Ostendorf, P.Roussel-Chomaz, Y.Schutz, H.Löhner, J.H.G.van Pol, R.H.Siemssen, H.W.Wilschut, F.Ballester, J.Díaz, A.Marín, G.Martínez, V.Metag, R.Novotny, V.Wagner, J.Québert,
Physics Letters **B366**(1996)63

[2] **T.Matulewicz**, L.Aphecetche, Y.Charbonnier, H.Delagrange, F.M.Marqués, G.Martínez, Y.Schutz, Nuclear Instruments and Methods **A378**(1996)179

[3] **T.Matulewicz,** Acta Physica Polonica **B27**(1996)3055

[4] R.Holzmann, M.Appenheimer, R.Averbeck, Y.Charbonnier, H.Delagrange, J.Díaz, A.Döppenschmidt, V.Hejny, S.Hlavác, A.Kugler, F.Lefèvre, H.Löhner, A.Marín, G.Martínez, **T.Matulewicz**, V.Metag, R.Novotny, R.W.Ostendorf, R.Pleskac, Y.Schutz, R.H.Siemssen, R.S.Simon, H.Ströher, P.Tlusty, P.H.Vogt, V.Wagner, J.Weiss, H.W.Wilschut, F.Wissmann, A.R.Wolf, M.Wolf Physical Review **C 56**(1997)2920

[5] **T.Matulewicz**, Acta Physica Polonica **B 29** (1998) 419

[6] G.Martínez, Y.Charbonnier, L.Aphecetche, H.Delagrange, K.K.Gudima, **T.Matulewicz**, M.Płoszajczak, Y.Schutz, V.Toneev, R.Turrisi, M.Appenheimer, V.Metag, R.Novotny, H.Ströher, A.R.Wolf, M.Wolf, J.Weiss, R.Averbeck, S.Hlavác, R.Holzmann, F.Lefèvre, R.S.Simon, R.Stratmann, F.Wissmann, M.Hoefman, M.J.van Goethem, H.Löhner, R.W.Ostendorf, R.H.Siemssen, P.Vogt, H.W.Wilschut, J.Díaz, A.Marín, A.Kugler, P.Tlusty, V.Wagner, A.Döppenschmidt, Physical Review Letters **83** (1999) 1538

[7] **K.Korzecka**, **T.Matulewicz**, Nuclear Instruments and Methods **A453** (2000) 606

[8] **T.Matulewicz**, L.Aphecetche, Y.Charbonnier, H.Delagrange, K.K.Gudima, G.Martínez, M.Płoszajczak, Y.Schutz, V.D.Toneev, M.Appenheimer, R.Averbeck, J.Díaz, A.Döppenschmidt, M.J.van Goethem, S.Hlavác, M.Hoefman, R.Holzmann, F.Lefèvre, A.Kugler, H.Löhner, A.Marín, V.Metag, R.Novotny, R.W.Ostendorf, R.H.Siemssen, R.S.Simon, R.Stratmann, H.Ströher, P.Tlusty, P.Vogt, V.Wagner, J.Weiss, H.W.Wilschut, F.Wissmann, A.R.Wolf, M.Wolf, European Physical Journal **A9** (2000) 69

[9] **K. Piasecki**, **K. Tymińska**, **T. Matulewicz**, D. d'Enterria, Acta Physica Polonica **B33** (2002) 973

[10] **K. Tymińska**, **T. Matulewicz**, **K. Piasecki** , Acta Physica Polonica **B33** (2002) 981

[11] **K. Tymińska**, **T. Matulewicz**, **K. Piasecki**, Acta Physica Polonica **B37** (2006) 161

CORRELATIONS AND FLUCTUATIONS IN HEAVY ION REACTIONS AT ENERGIES BETWEEN 100 AND 2000 AMeV

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The study of correlation and fluctuation effects has been the subject of ongoing research by the Warsaw branch of the FOPI Collaboration. The importance of such studies has grown recently with the establishment of modern experiments. The methods applied in those studies were developed for the analysis of high multiplicity, high statistics, long running, high-energy (from about 10AGeV upwards) experiments of heavy-ion and particle physics. Our results are in some cases the first attempt to use those methods in the intermediate energy range, where particle multiplicities are much lower and drawing the conclusions is much harder. In addition to the physics results, correlation/fluctuation studies of FOPI data provide us with the experience to conduct such analyses for the new generation of experiments, like the planned CBM experiment.

There are two main goals of correlations and fluctuations studies: the first is to establish whether the state of thermodynamic equilibrium is reached during the nuclear collision; the second is to probe if a phase transition occurred during the collision. The results of such studies can also be used for testing, whether certain statistical and quantum aspects of the reaction are properly taken into account in the theoretical codes describing nuclear collisions.

Two main methods were used in our study: the so-called Φ variable and the normalized, scaled factorial moments (NSFMs) where the intermittency effect was looked for. In addition we also attempted to use two other methods: the Ma and "JKRW" methods.

INTERMITTENCY ANALYSIS

The idea of this research was proposed by Białas and Peshanski in 1986 and was applied by us in ref. [1],[2],[5], and [6]. Factorial moments of a distribution of a certain variable split into equal-size bins are calculated on an event-by-event basis for a set of bin sizes. The intermittency signal is found if there is a power-law dependence of NSFMs on the bin size, and the character of this dependence may allow to draw conclusions about the reaction process. This method was applied to the FOPI data on heavy symmetric system (Au+Au) at the energy range between 100 and 800AMeV, and a clear intermittency signal was seen for the polar emission angle (φ) of forward-emitted Z=1 reaction products. It could be described by two intermittency exponents, for small and for the large bin sizes. The second one was attributed to the anisotropy in particle emission with respect to the reaction plane ("bounce-off") and it was reproduced with the models.

Φ ANALYSIS

The Φ variable was proposed by Mrówczyński and Gaździcki as an equilibration measure in 1992. It can be used to distinguish between two scenarios of nuclear reaction: superposition of single, first nucleon-nucleon collisions or full thermodynamic equilibrium achieved during reaction. We applied this method to the data obtained by the FOPI collaboration, for the medium-sized symmetric system (Ru+Ru) at beam energy of 1.7AGeV, the first reported case of using Φ variable in such a low energy range. We found a higher degree of equilibration in central events compared to peripheral ones [3]. It should be noted, that our attempt is the first known case of using Φ variable in such a low energy range.

OTHER ANALYSES

The Ma method, proposed by Białas and Czyż, following the ideas of Ma, allows to test, whether the thermal equilibrium is achieved in the nuclear reaction. The feasibility of this method for the SIS energy range and FOPI statistics was tested [4].

The JKRW method, proposed by Jeon, Koch, Redlich and Wang to study the hypothesis of chemical equilibration was applied to the K^+ data obtained in Ni+Ni collisions at 1.9AGeV. The low statistics did not allow us to draw any firm conclusions so far.

As a side result of this analysis it was proven, that scaled factorial moments are not influenced by the acceptance of the detector [7].

[1] **K.Wiśniewski, B.Sikora, K.Siwek-Wilczynska, M.Kirejczyk** Acta Physica Polonica **B 27** (1996) 505

[2] **M.M.Smolarkiewicz, M.Kirejczyk, B.Sikora, K.Siwek-Wilczynska, K.Wisniewski** Acta Physica Polonica **B 31** (2000) 385

[3] **I.J.Soliwoda, M.Kirejczyk, B.Sikora, K.Siwek-Wilczynska** Acta Physica Polonica **B 31** (2000) 389

[4] **M. Kirejczyk** Acta Physica Polonica **B 33** (2002) 377

[5] **M.M. Smolarkiewicz, M. Kirejczyk, B. Sikora, K. Siwek-Wilczynska, I.J. Soliwoda** Acta Physica Polonica **B 33** (2002) 457

[6] **M.M.Smolarkiewicz, M. Kirejczyk, B. Sikora, K. Siwek-Wilczynska, I.J. Soliwoda-Poddany** Acta Physica Polonica **B 35** (2004) 1151

[7] **M.Kirejczyk** Acta Physica Polonica **B 35** (2004) 225

MASS AND ISOTOPIC EFFECTS IN NUCLEAR MULTIFRAGMENTATION

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Challenging motivations for isotopic studies in nuclear multifragmentation are derived from the importance of the density dependence of the symmetry-energy term of the nuclear equation of state for astrophysical applications and for effects linked to the manifestation of the nuclear liquid-gas phase transition. A systematic study of isotopic effects in the break-up of projectile spectators at relativistic energies has been performed at the GSI laboratory within the ALADiN 2000 collaboration [1]. In the S254 experiment fragments have been detected in reactions with beams of ^{197}Au, ^{124}La, ^{124}Sn, and ^{107}Sn at the energy of 600 AMeV. The experimental setup, which includes the ALADiN spectrometer with the TP-MUSIC IV drift chamber, a time of flight detector (TOF-wall) and the LAND neutron detector, allowed measurement of the fragment charge and momentum vector for $Z > 1$ fragments, identification of isotopes for $Z < 12$, and the momentum and multiplicity of neutrons. Unique experimental data were obtained for nuclei located far from the stability line, which are characterized by a wide range of fragment identification.

The experimental study of fragment production with isotopic resolution has led to the identification of isoscaling, observed by comparing product yields from reactions which differ in the isotopic composition of the projectiles [2]. Of particular interest is a connection of the isoscaling parameters with the symmetry-energy term of the nuclear equation of state, $E_{sym} = \gamma(A-2Z)^2/A$. Preliminary results indicate that the coefficient γ is close to its normal-density value of ~25 MeV for peripheral collisions but drop to lower values at the more central impact parameters. Temperature measurements using the double-isotope thermometer are currently being investigated in order to quantitatively establish the evolution of the symmetry term.

Neutrons emitted in directions close to $\theta_{lab} = 0^o$ were detected with the Large-Area Neutron Detector (LAND) which covers about one half of the solid angle required for neutrons from the spectator decay. An analysis of the invariant multiplicity distributions of neutrons has led to the identification of the spectator sources of neutrons. They are characterized by temperatures up to about 4 MeV possibly caused by large contributions from evaporation. Neutrons will be important for establishing the mass and energy balance, in particular for calorimetry. Neutron analysis could allow to investigate the symmetry-energy term dependence on the excitation energy of the system, in a similar way as with the isoscaling analysis.

The experimental data contain unique information on the size of the largest fragment expected to play the role of the order parameter, which is of particular interest in phase transition studies. We have studied the order parameter fluctuations in the framework of a percolation model to construct and verify procedures tracing critical behavior in fragmenting systems [3]. Dimensionless cumulant ratios measuring the fluctuations exhibit distinct features near the critical and pseudocritical points, providing a method for their identification. The method is remarkably insensitive to finite-size effects and may be applied even for very small systems. The possibility of using various measurable quantities for sorting events makes the procedure useful in fragmentation studies. The method was applied for the Au + Au data showing the percolation pattern of the fluctuations. Characteristics of the pseudocritical and critical points have been determined. The analysis will be extended to other investigated systems to establish dependence of the critical parameters on the system isospin.

[1] C. Sfienti, P. Adrich, T. Aumann, C.O. Bacri, **T. Barczyk**, R. Bassini, C. Boiano, A.S. Botvina, A. Boudard, **J. Brzychczyk**, A. Chbihi, **J. Cibor**, **B. Czech**, M. De Napoli, J.E. Ducret, H. Emling, J. Frankland, M. Hellstrom, D. Henzlova, K. Kezzar, G. Imme, I. Iori, H. Johansson, A. Lafriakh, A. Le Fevre, E. Le Gentil, Y. Leifels, W.G. Lynch, J. Luhning, **J. Łukasik**, U. Lynen, **Z. Majka**, M. Mocko, W.F.J. Muller, A. Mykulyak, H. Orth, A.N. Otte, R. Palit, A. Pullia, G. Raciti, E. Rapisarda, H. Sann, C. Schwarz, H. Simon, A. Sokolov, K. Summerer, W. Trautmann, M.B. Tsang, G. Verde, C. Volant, M. Wallace, H. Weick, J. Wiechula, **A. Wieloch**, **B. Zwięgliński**, Nucl. Phys. **A749**, 83c (2005).

[2] C. Sfienti, P. Adrich, T. Aumann, C.O. Bacri, **T. Barczyk**, R. Bassini, C. Boiano, A.S. Botvina, A. Boudard, **J. Brzychczyk**, A. Chbihi, **J. Cibor**, **B. Czech**, M. De Napoli, J.-E. Ducret, H. Emling, J. Frankland, M. Hellstrom, D. Henzlova, K. Kezzar, G. Imme, I. Iori, H. Johansson, A. Lafriakh, A. Le Fevre, E. Le Gentil, Y. Leifels, W.G. Lynch, J. Luhning, **J. Łukasik**, U. Lynen, **Z. Majka**, M. Mocko, W.F.J. Muller, A. Mykulyak, H. Orth, A.N. Otte, R. Palit, **P. Pawłowski**, A. Pullia, G. Raciti, E. Rapisarda, H. Sann, C. Schwarz, H. Simon, K. Summerer, W. Trautmann, M.B. Tsang, C. Volant, M. Wallace, H. Weick, J. Wiechula, **A. Wieloch**, **B. Zwięgliński**, Acta Phys. Polonica **B 37**, 193 (2006).

[3] **J. Brzychczyk**, Phys. Rev. C **73**, 024601 (2006).

NUCLEAR MATTER AT THE LIQUID-GAS PHASE TRANSITION ENERGY DOMAIN

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Experimental facility: Cyclotron Institute of Texas A&M University, USA

The nuclear liquid-gas phase transition is one of the most intriguing phenomena currently being investigated by experimentalists. The thermodynamic properties of hot nuclei are often presented in the excitation energy – temperature diagram. The shape of this curve for a nuclear system is predicted to have similarities to the well-known caloric curve of H_2O and the temperature as a function of the excitation energy curve is also called the caloric curve for the nuclear system.

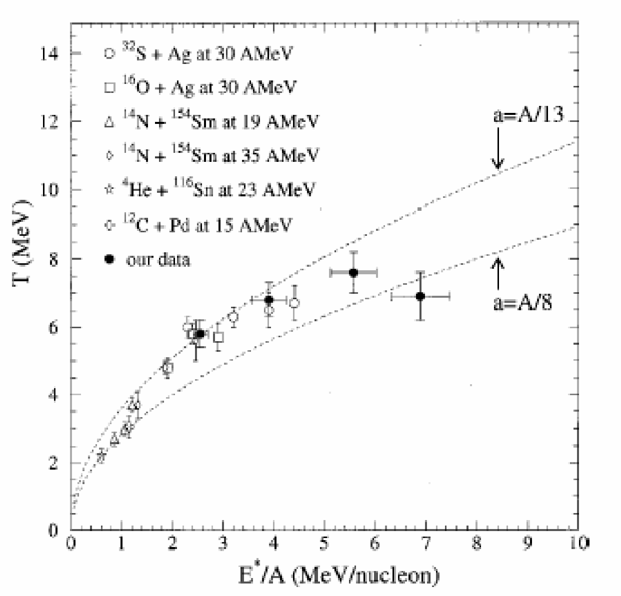

Fig. *Caloric curve for nuclei with A~110, see [6].*

Intermediate energy nucleus-nucleus collisions provide opportunities for studying properties of nuclear matter at densities and temperatures far different from those encountered in nuclei in their ground state. This provides an opportunity to probe the physics contained in the equation of state for infinite nuclear matter. In order to approach this fundamental problem, two crucial questions concerning the formation and decay of hot nuclear systems produced in nuclear collisions have been investigated: i.e., what is the maximum excitation energy which can be deposited in a nuclear system before complete disintegration, and what are the dominant mechanisms responsible for decay of the excited nuclear system.

In order to pursue this problems, several experiments with dedicated detection systems (e.g. 4π charged particle/neutron array set) were performed. Since late 80's our group is actively involved in this research by the construction of detection systems and participating in the international experimental projects. Recent ten years were very fruitful in achieving several interesting results in our collaboration with Cyclotron Institute of Texas A&M University, USA. Among them are:

[1]. Study of quantum statistical thermodynamics of hot finite nuclear systems - temperatures and isotopic yield ratios.

[2].Study of time scale of the fission process in the reaction 50A MeV Ne + Ho as a function of mass asymmetry.

[3,4]. Experimental determination of fragment excitation energies in multifragmentation events.

[5]. Study of dynamic evolution and the caloric curve for medium mass nuclei.

[6-7]. Coalescence model analyses - probing dynamic evolution of heavy ion collisions.

[8,9].Multi-fragmentation in Fermi energy heavy ion reactions

[10-12] Critical behavior in the disassembly of nuclei.

[1]. **Z. Majka, P. Staszel, J. Cibor,** J. B. Natowitz, K. Hagel, J. Li, N. Mdeiwayeh, R. Wada and Y. Zhao, Phys. Rev. **C55** (1997) 2971.

[2] N. Mdeiwayeh, R. Wada, K. Hagel, J. Li, Y. Lou, R. Tezkratt, D. Utley, B. Xiao, J. B. Natowitz, **J. Cibor, Z. Majka**, Nucl. Phys. **A627** (1997) 137 .

[3]. N. Marie, A. Chbihi, J. B. Natowitz, A. Le Fevre, S. Salou, J. P. Wieleczko, L. Gingras, M. Assenard, G. Auger, Ch. O. Bacri, F. Bocage, B. Borderie. R. Bougault, R. Brou, P. Buchet, J. L. Charvet, **J. Cibor,** J. Colin, D. Cussol, R. Dayras, A. Demeyer, D. Dore, D. Durand, P. Eudes, J. D. Frankland, E. Galichet, E. Genouin-Duhamel, E. Gerlic, M. Germain, D. Gourio, D. Guinet, K. Hagel, P. Lautesse, J. L. Laville, J. F. Lecolley, T. Lefort, R. Legrain, N. Le Neindre, O. Lopez, M. Louvel, **Z. Majka,** A. M. Maskay, L. Nalpas, A. D. Nguyen, M. Parlog, J. Peter, E. Plagnol, A. Rahmani, T. Reposeur, M. F. Rivet, E. Rosato, F. Saint-Laurent, J. C. Steckmeyer, M. Stern, G. Tabacaru, B. Tamain, O. Tirel, E. Vient, C. Volant, R. Wada, Phys. Rev. **C58** (1998) 256.

[4] **P.Staszel, Z.Majka,** L.G.Sobotka, D.G.Sarantites, R.J.Charity, D.W.Stracener, **J.Cibor,** K.Hagel, N.Marie, J.B.Natowitz, R.Wada, D.W.Stracener, G.Auger, Y.Schutz, J.P.Wieleczko, R.Dayras, E.Plagnol, J.Baretto, E.Norbeck , Phys. Rev. **C63** (2001) 064610.

[5]. **J. Cibor**, R. Wada, K. Hagel, M. Lunardon, N. Marie, R. Alfaro, W. Shen, B. Xiao, Y. Zhao, J. Li, B. A. Li, M. Murray, J. B. Natowitz, **Z. Majka, P. Staszel**, Phys. Lett. **B473** (2000) 29.

[6]. K.Hagel, R.Wada, **J.Cibor**, M.Lunardon, N.Marie, R.Alfaro, W.Shen, B.Xiao, Y.Zzhao, **Z.Majka, P.Staszel**, J.Li, B.A.Li, M.Murray, T.Keutgen, A.Bonasera, J.B.Natowitz, Phys. Rev. **C62** (2000) 034607.

[7]. L.B.Natowitz, **J.Cibor**, A.Bonasera, K.Hagel, R.Wada, M.Murray, T.Keutgen, M.Lunardon, N.Marie, R.Alfaro, W.Shen, **Z.Majka and P.Staszel,** Acta Phys. Pol. **B31** (2000) 1449.

[8].R.Wada, T. Keutgen, K.Hagel, Y.G. Ma, J.Wang, M. Murray, L. Qin, P. Smith, J.B. Natowitz, R. Alfaro, **J. Cibor**, M. Cinausero, Y.El. Masri, D. Fabris, E. Fioretto, A. Keksis, M. Lunardon, A. Mekeev, N. Marie, E. Martin, A. Martinez – Davalos, A. Menchaca – Rocha, G. Nebbia, G. Prete, V. Rizzi, A. Ruangma, D.V. Shetty, G. Souliotis, **P. Staszel,** M. Veselsky, G. Viesti, E.M. Winchester, S.J. Yennello, **Z. Majka**, A. Ono, Phys. Rev. **C69**, 044610, (2004).

[9].D.V.Shetty, A.Keksis, E.Martin, A.Raungma, G.A.Souliotis, M.Veselsky, E.M.Winchester, S.J.Yennello, K.Hagel, Y.G.Ma, A.Makeev, N.Marie, M.Murray, J.B.Natowitz, L.Qin, P.Smith, R.Wada, J.Wang, M.Cinausero, E.Fioretto, G.Prete, D.Fabris, M.Lunardon, G.Nebbia, V.Rizzi, G.Viesti, **J.Cibor, Z.Majka, P.Staszel,** R.Alfaro, A.Martinez-Davalos, A.Menchaca-Rocha, Y.El Masri, T.Keitgen, Nucl. Phys. **A734** (2004) E100.

[10].Y. G. Ma, R.Wada, K.Hagel, J.Wang, T. Keutgen, **Z. Majka**, M. Murray, L. Qin, P. Smith, J.B. Natowitz, R. Alfaro, **J. Cibor,** M. Cinausero, Y.El. Masri, D. Fabris, E. Fioretto, A. Keksis, M. Lunardon, A. Mekeev, N. Marie, A. Martinez – Davalos, A. Menchaca – Rocha, G. Nebbia, G. Prete, V. Rizzi, A. Ruangma, D.V. Shetty, G. Souliotis, **P. Staszel**, M. Veselsky, G. Viesti, E.M. Winchester, S.J. Yennello, Phys. Rev. **C69** (2004) 031604.

[11].Y. G. Ma, J.B. Natowitz, R.Wada, K.Hagel, J.Wang, T. Keutgen, **Z. Majka**, M. Murray, L. Qin, P. Smith, R. Alfaro, **J. Cibor,** M. Cinausero, Y.El. Masri, D. Fabris, E. Fioretto, A. Keksis, M. Lunardon, A. Mekeev, N. Marie, E. Martin, A. Martinez – Davalos, A. Menchaca – Rocha, G. Nebbia, G. Prete, V. Rizzi, A. Ruangma, D.V. Shetty, G. Souliotis, **P. Staszel**, M. Veselsky, G. Viesti, E.M. Winchester, S.J. Yennello, Nucl. Phys. **A749** (2005) 106c.

[12].Y. G. Ma, J.B. Natowitz, R.Wada, K.Hagel, J.Wang, T. Keutgen, **Z. Majka**, M. Murray, L. Qin, P. Smith, R. Alfaro, **J. Cibor**, M. Cinausero, Y.El. Masri, D. Fabris, E. Fioretto, A. Keksis, M. Lunardon, A. Mekeev, N. Marie, E. Martin, A. Martinez – Davalos, A. Menchaca – Rocha, G. Nebbia, G. Prete, V. Rizzi, A. Ruangma, D.V. Shetty, G. Souliotis, **P. Staszel**, M. Veselsky, G. Viesti, E.M. Winchester, S.J. Yennello, Phys. Rev. **C71** (2005) 054606.

HEAVY-ION COLLISIONS: GEOMETRY AND DYNAMICS

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Experimental Facility: STAR Experiment at RHIC, Brookhaven National Laboratory and ALICE experiment at LHC, CERN

The main objective of the heavy-ion program at the Relativistic Heavy-Ion Collider is to discover and study the properties of the Quark-Gluon Plasma (QGP), expected to be formed at extreme temperatures and nuclear matter densities obtained in the AuAu 200 GeV/nucleon collisions. From the wealth of results produced by the RHIC experiments a surprising picture emerged – the QGP is not, as initially thought, a weakly bound plasma of quarks and gluons. Instead it is a strongly bound system (sQGP), behaving like a fluid with a small viscosity.

One of the major arguments for such conclusion was the observation of the prominent collective behavior of matter – flows, that were successfully described by hydrodynamics. In this framework the momentum part of the phase-space was adequate and self-consistent. However the same models had significant difficulties describing the space-time part.

Heavy-ion collision is a femtoscopic process – it happens on the scale of 1fm=10^{-15}m and 1fm/c =10^{-23}s. Such distances cannot be measured directly. Instead the technique of femtoscopy (also referred to as "HBT") is applied, which relies on the interaction between two particles with close velocity. It produces a two-particle correlation function that can be analyzed to infer the size of the emitting system. By systematically analyzing the sizes as a function of the collision centrality, type of the colliding nuclei, pair momentum, particle species etc. ones is also able to draw conclusions about the dynamics, or the correlation between space-time and momentum characteristics of the emission process.

Femtoscopy is traditionally done with identical particles to exploit the two-particle correlations coming mainly from quantum statistics. For non-identical particles the effect comes from Coulomb and strong final state interactions only. However it enables to access the new observable – the difference in the mean emission points of various particle species. Hydrodynamics predicts such difference and shows that it is a necessary consequence of the collective behavior of the system. Observation of such asymmetry is a key pieces of evidence, necessary for the claim of the discovery of the QGP.

In the STAR experiment we have observed such asymmetry shown in Fig. 1. The departure of the so-called double ratio in the outwards direction (along the direction of the pair momentum) is a direct experimental proof that pions are emitted closer to the center of the system and/or later than kaons, exactly as expected in the case of the collective behavior of matter called radial flow

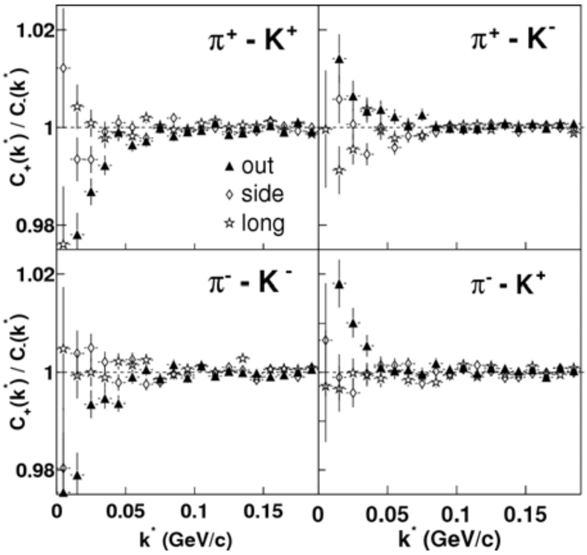

Fig. 1. *The out "double ratios" deviating from unity are evidence of asymmetry between pions and kaons.*

[1] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. **87** (2001) 082301

[2] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. **91** (2003) 262301

[3] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. 91 262302 (2003)

[4] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. **93** (2004) 012301

[5] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. C **71** (2005) 044906

[6] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. C **74** (2006) 064906

[7] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. C **74** (2006) 054902

[8] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. **86** (2001) 402

[9] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. **87** (2001) 182301

[10] **A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. **89** (2002) 132301

[11**] A. Kisiel, T.Pawlak, W.Peryt, J.Pluta,** et al. (STAR Collaboration)*) Phys. Rev. Lett. **92** (2004) 052302

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MULTIFRAGMENTATION IN HEAVY-ION COLLISIONS AT RELATIVISTIC ENERGIES – THE SOURCE OF INFORMATION ON THERMODYNAMICS OF NUCLEAR MATTER

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Experimental facility: ALADiN spectrometer at GSI-Darmstadt

Nucleus-nucleus collisions at relativistic energies present an opportunity to study a transition from the state of a Fermi liquid, which is the state of nuclei close to their ground state to the state of nuclear vapor, in which nuclear droplets (fragments with $Z \geq 3$) are immersed in nucleon gas (light particles with $Z \leq 2$). The unique feature of these multifragmentation reactions is a nearly instantaneous injection of fast nucleons from the region of overlap of the colliding nuclei into the spectators which causes their heating in the course of a nucleon-nucleon cascade.

The ALADiN Collaboration at GSI-Darmstadt studies this transient state with the aid of **A LA**rge **Di**pole mag**N**et equipped with a sophisticated detection system, permitting to identify simultaneously all fragmentation products in Z and A and measure their momenta. The past experimental activities had several stages highlighted with the following discoveries:

1) "The rise and fall of multifragmentation" as a function of the decreasing impact parameter in Au+Au collisions at 600 MeV/u [1]. The intial rise in the multiplicity of intermediade-mass fragments is interpreted as due to increasing excitation energy in the multifragmenting residue, while the fall is an effect of the decreasing residue size and its conversion into "gas" of nucleons and light particles with further increase of the excitation energy. An independence of this pattern of the target size (other nuclei besides Au have also been used) indicated a high degree of equilibration and applicability of thermodynamic concepts to the decay of highly excited Au projectile residues.

2) "The optimum energy for multi-fragmentation" in central collisions of heavy nuclei [2] at intermediate energies. In these collisions a system consisting of ~400 nucleons is formed, whose excitation energy increases with the increasing bombarding energy. In the case of central collisions the initial compres-sional energy is converted into thermal one in relaxation mediated by nucleon-nucleon collisions. The maximum number of about 10 intermediate-mass fragments is observed in central Au+Au collisions at ~100MeV/nucleon.

3) Establishing that the nuclear liquid-gas phase transition is probably of first order by measuring the nuclear "caloric-curve" [3]. The "caloric-curve" is temperature vs. the excitation energy dependence, demonstrating a sort of plateau at T~5 MeV, which might be considered the boiling temperature of nucleon liquid. This result excited a widespread debate.

4) The process of fragment formation is an illustration of the concept of "self-organization" as applied to a femtoscopic system, the atomic nucleus [4,5]. The concept has been initially formulated by the 1977 Nobel price winner in Chemistry Ilya Prigogine for classical complex systems [*G. Nicolis and I. Prigogine, Self-organization in Nonequilibrium Systems, from Dissipative Structures to Order through Fluctuations, Wiley, New York, 1977*]. Later on it has been cast into a formalism able to interprete e.g. the action of a laser [*H. Haken, Advanced Synergetics; Instability Hierarchies of Self-Organizing Systems and Devices, Springer, Berlin, 1983*] as a phase transition in the system of atoms and field in a cavity. A similar formalism for the nuclear liquid-gas phase transitions still awaits formulation.

5) Establishing that the coefficient of symmetry energy in the Bethe-Weizsaecker binding energy formula is a decreasing function of the nuclear excitation energy [6, 7]. This has non-trivial consequences for astrophysical applications, e.g. supernova simulations or neutron star models.

6) The recent experiments (see e.g. [8]) have been performed with the INDRA multidetector, demonstrating some universal features of fluctuations in the multifragmen-tation observables. These may be interpreted, using microcanonical thermostatics, as an independent proof of a phase-transition occuring in nuclei in the investigated energy range. A systematic study of directed and elliptic flow [9] in Au+Au collisions at intermediate energies is another important result of the INDRA experiment at GSI.

[1] C. Ogilvie, J.C. Adloff, M. Begemann-Blaich, P. Bouissou, J. Hubele, G. Imme, I. Iori, G.J. Kunde, P. Kreutz, S. Leray, V. Lindenstruth, Z. Liu, U. Lynen, R.J. Meijer, U. Milkau, A. Moroni, W.F.J. Müller, C. Ngo, J. Pochodzalla, G. Raciti, G. Rudolf, H. Sann, A. Schüttauf, W. Seidel, L. Stuttge, W. Trautmann, **A. Tucholski**, Phys. Rev. Lett. **67**, 1214 (1991).

[2] M.B. Tsang, W.C. Hsi, W.G. Lynch, D.R. Bowman, C.K. Gelbke, M.A. Lisa, G.F. Peaslee, G.J. Kunde, M.L. Begemann-Blaich, T. Hoffman, J. Hubele, J. Kempter, P. Kreutz, W.D. Kunze, V. Lindenstruth, U. Lynen, M. Mang, W.F.J. Müller, M. Neumann, B. Ocker, C. Ogilvie, J. Pochodzalla, F. Rosenberger, H. Sann, A. Schüttauf, V. Serfling, J. Stroth, W. Trautmann, **A. Tucholski**, A. Wörner, E. Zude, **B. Zwieglinski**, S. Aiello, G. Imme, V. Pappalardo, G. Raciti, R.J. Charity, L.G. Sobotka, I. Iori, A. Moroni, R. Scardoni, A. Ferrero, W. Seidel, Th. Blaich, L. Stuttge, A. Cosmo, W.A. Friedman, G. Peilert, Phys. Rev. Lett. **71**, 1502 (1993).

[3] J. Pochodzalla, T. Möhlenkamp, T. Rubehn, A. Schüttauf, A. Wörner, E. Zude, M.L. Begemann-Blaich, Th. Blaich, C. Gross, H. Emling, A. Ferrero, G. Imme, I. Iori, G.J. Kunde, W.D. Kunze, V. Lindenstruth, U. Lynen, A. Moroni, W.F.J. Müller, B. Ocker, G. Raciti, H. Sann, C. Schwarz, W. Seidel, V. Serfling, J. Stroth, W. Trautmann, **A. Trzciński**, **A. Tucholski**, G. Verde, **B. Zwieglinski**, Phys. Rev. Lett. **75**, 1040 (1995).

[4] **B. Zwieglinski** for the ALADIN Collaboration, Nucl. Phys. **A681**, 275c (2001).

[5] **B. Zwieglinski** for the ALADIN Collaboration, Acta Phys. Pol. **B33**, 141 (2002).

[6] A. LeFevre, G. Auger, M.L. Begemann-Blaich, N. Bellaize, R. Bittiger, F. Bocage, B. Borderie, R. Bougault, B. Bouriquet, J.L. Charvet, A. Chbihi, R, Dayras, D. Durand, J.D. Frankland, E. Galichet, D. Gourio, D. Guinet, S. Hudan, G. Imme, P. Lautesse, F. Lavaud, R. Legrain, O. Lopez, **J. Lukasik**, U. Lynen, W.F.J. Mueller, L. Nalpas, H. Orth, E. Plagnol, G. Raciti, E. Rosato, A. Saija, C. Schwarz, W. Seidel, C. Sfienti, B. Tamain, W. Trautmann, **A. Trzciński**, K. Turzo, E. Vient, M. Vigilante, C. Volant, **B. Zwieglinski**, A. Botvina, Phys. Rev. Lett. **94**, 162701 (2005).

[7] C.Sfienti, J. Lühning, U. Lynen, W.F.J. Müller, **A.Mykulyak**, T. Barczyk, J. Brzychczyk, R. Bassini, C. Boiano, J. Cibor, A. Le Fevre, K. Kezzar, G. Imme, I. Iori, **J. Lukasik**, H. Orth, N. Otte, A. Pullia, G. Raciti, C. Schwarz, A. Sokolov, W. Trautmann, K. Turzo , **B. Zwieglinski** , Nucl. Phys. **A749**, 83 (2005)

[8] **A. Trzciński, J. Lukasik**, W.F.J. Müller, W. Trautmann, **B. Zwieglinski**, G. Auger, Ch.O. Bacri, M.L. Begemann-Blaich, N. Bellaize, R. Bittiger, F. Bocage, B. Borderie, R. Bougault, B. Bouriquet, Ph. Buchet, J.L. Charvet, A. Chbihi, R, Dayras, D. Dore, D. Durand, J.D. Frankland, E. Galichet, D. Gourio, D. Guinet, S. Hudan, B. Hurst, P. Lautesse, F. Lavaud, J.L. Laville, C. Leduc, A. Le Fevre, R. Legrain, O. Lopez, U. Lynen, L. Nalpas, H. Orth, E. Plagnol, E. Rosato, A. Saija, C. Schwarz, C. Sfienti, J.C. Steckmeyer, G. Tabacaru, B. Tamain, K. Turzo, E. Vient, M. Vigilante, C. Volant, Nucl. Instr. and Meth. **A501**, 367 (2003).

[9] **J. Lukasik**, G. Auger, M.L. Begemann-Blaich, N. Bellaize, R. Bittiger, F. Bocage, B. Borderie, R. Bougault, B. Bouriquet, J.L. Charvet, A. Chbihi, R, Dayras, D. Durand, J.D. Frankland, E. Galichet, D. Gourio, D. Guinet, S. Hudan, P. Lautesse, F. Lavaud, A. Le Fevre, R. Legrain, O. Lopez, U. Lynen, W.F.J. Müller, L. Nalpas, H. Orth, E. Plagnol, E. Rosato, A. Saija, C. Schwarz, C. Sfienti, B. Tamain, W. Trautmann, **A. Trzciński**, K. Turzo, E. Vient, M. Vigilante, C. Volant, **B. Zwieglinski**, Phys. Lett. **B608**, 223 (2005)

ULTRA-RELATIVISTIC REACTIONS BETWEEN HEAVY IONS AND NUCLEONS

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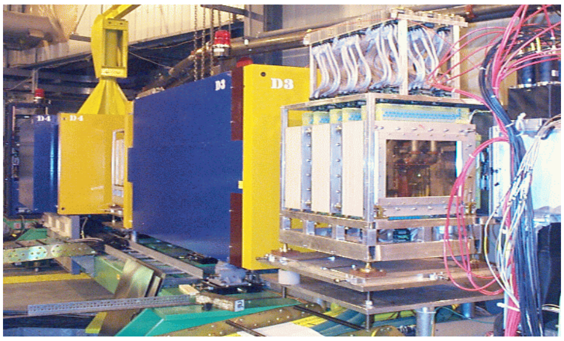
Experimental facility: Brookhaven National Laboratory, USA

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory [1] is designed to extend frontiers of modern physics, providing access to the new form of matter called Quark-Gluon Plasma (QGP) composed of primordial elements – quarks and gluons. By colliding the atomic nuclei with the energy of 200 GeV per pair of nucleons, RHIC produces hot and dense matter at the initial energy density well above the value of the critical energy density for QGP formation that is predicted by the lattice quantum chromo-dynamical (QCD) calculations [2,3]. RHIC provides the first chance for a rigorous test of the most basic predictions of what is thought to be understood about the structure of QCD matter at high energy, namely the color glass condensate (CGC). CGC is considered as an universal form of QCD matter which describes high energy strongly interacting particles and nuclei. While QGP is the incoherent thermal limit of QCD matter at high temperature, CGC is the coherent limit of QCD matter at high energies.

The Jagiellonian University group has been participating in BRAHMS project since 1995. Our initial task within the collaboration was to design and construct a set of three drift chambers for the BRAHMS experiment. Figure displays one of them installed on the BRAHMS Back Forward Spectrometer platform [4]. The BRAHMS collaboration began it's research program in 2000 and within the period of 6 years has collected large data sets on four reacting systems (p+p, Au+Au, d+Au, Cu+Cu) at two collision energies: $\sqrt{s_{NN}}$ = 200 GeV and 62.4 GeV. First striking feature observed by BRAHMS is that the net-baryon rapidity distributions around central region (y_{cm}~0) are significantly smaller, as compared to AGS and SPS. We estimated the average rapidity loss to be equal 2.0±0.4. This value is well below prediction from the empirical linear scaling of lower AGS and SPS energy results. Nevertheless, the absolute energy loss increases appreciably from SPS to RHIC reaching the value of about 72 GeV per participant [5]. Several observables has been proposed for RHIC and SPS energies as possible signals for the formation of QGP. One of most important is a jet quenching seen directly as a suppression of high transverse momentum hadrons (p_T > 2 GeV/c) produced in heavy ion collisions as compared to nucleon-nucleon reactions. This effect can be quantified by the nuclear modification factor R_{AA} [7]. The apparent high p_T suppression observed in central collisions has been interpreted as a consequence of bremsstrahlung losses of high p_T partons traversing deconfined medium created in heavy ion collisions [8]. The effect is expected to increase with increasing collision energy and centrality, as observed in the experiment [9]. Unique feature of the BRAHMS spectrometer is a large acceptance at forward regions accompanied by excellent particle identification. Surprisingly, large R_{AA} suppression at forward region is observed both for Au+Au and d+Au colliding systems [10]. For Au+Au the forward suppression reveals the same scheme for baryons and mesons as this observed at mid-rapidity [11] which led to suggestion that the suppressing medium extends also in the longitudinal direction [12]. However, for d+Au the suppression has been attributed to the initial conditions of the colliding Au nucleus, in particular, to the possible existence of CGC - a new form of nuclear matter [13].



[1] http://www.bnl.gov/RHIC

[2] **P. Staszel, R.Karabowicz, T. Kozik, Z. Majka, P. Płaneta,** [BRAHMS collaboration], Int. Journ. of Modern. Phys. A **20,** 4369 (2005)

[3] F. Karsh, Nucl. Phys. A**698**, 199 (2002)

[4] **M. Adamczyk, J. Brzychczyk, J.Cibor, L. Dutka, K. Grotowski, E. Kotula, T. Kozik, Z. Majka, P. Płaneta Z. Sosin**, **P. Staszel, A. Wieloch,** [BRAHMS collaboration], Nucl. Instr. Meth. **A499**, 437 (2003).

[5] I. G. Bearden**J. Cibor, R.Karabowicz, T. Kozik, Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Phys. Rev. Lett. **93**, 102301.

[6] I.G. Bearden **J. Cibor, R.Karabowicz, T. Kozik, Z. Majka, P. Płaneta, P. Staszel, A. Wieloch,** [BRAHMS collaboration], Phys. Rev. Lett. **90**, 102301 (2003).

[7] I. Arsene **J. Cibor, R.Karabowicz, T. Kozik, Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Phys. Rev. Lett. 91, 072305 (2003).

[8] M. Gyulassy, P. Levai, I. Vitev, Nucl. Phys. **B594** (2001) 371.

[9] T.M. Larsen **R.Karabowicz, Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Nucl. Phys. **A774**, 541 (2006) .

[10] I. Arsene **J. Cibor, R.Karabowicz, T. Kozik Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration] Phys. Rev. Lett. 93 (2004) 242303.

[11] **R. Karabowicz** , **Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Nucl. Phys. **A774**, 477 (2006) **P. Staszel R.Karabowicz, Z. Majka, P. Płaneta,** [BRAHMS collaboration], Nucl. Phys. **A774**, 77 (2006) .

[12] G. G. Barnaföldi, P. Lévai, G. Papp, and G. Fai, hep-ph/0609023, and references therein.

[13] D. Kharzeev, E. Levin and L. McLerran, Phys. Lett. **B 561** (2003) 93.

[14] I. Arsene **J. Cibor, R.Karabowicz, T. Kozik Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Nucl. Phys. **A757**, 1 (2005) .

[15] I. Arsene **J. Cibor, R.Karabowicz, T. Kozik Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Phys. Rev. **C 72**, 014908 (2005).

[16] I. Arsene **J. Cibor, R.Karabowicz, T. Kozik Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Phys. Rev. Lett. **94**, 162301 (2005).

[17] I. G. Bearden **J. Cibor, R.Karabowicz, T. Kozik Z. Majka, P. Płaneta, P. Staszel, A. Wieloch,** [BRAHMS collaboration], Phys. Lett. **B 607**, 42 (2005).

[18] I. Arsene **J. Cibor, R.Karabowicz, T. Kozik Z. Majka, P. Płaneta, P. Staszel,** [BRAHMS collaboration], Phys. Rev. Lett. **94**, 032301 (2005).

[19] I. G. Bearden **J. Cibor, R.Karabowicz, T. Kozik Z. Majka, P. Płaneta, P. Staszel, A. Wieloch** [BRAHMS collaboration], Phys. Rev. Lett. **88**, 202301 (2002).

[20] I. G. Bearden **J. Brzychczyk, J. Cibor, K. Grotowski, T. Kozik Z. Majka, P. Płaneta, Z. Sosin, P. Staszel, A. Wieloch** [BRAHMS collaboration], Phys. Lett. **B 523**, 237 (2001).

[21] I. G. Bearden **J. Brzychczyk, J. Cibor, K. Grotowski, T. Kozik Z. Majka, P. Płaneta, Z. Sosin, P. Staszel, A. Wieloch** [BRAHMS collaboration], Phys. Rev. Lett. **87**, 112305 (2001).

BRAHMS Collaboration

I. Arsene, I.G. Bearden, D. Beavis, S. Bekele, C. Besliu, Y. Blyakhman, J.Brzychczyk, B. Budick, H. Bøggild, C. Chasman, C. H. Christensen, P. Christiansen, J.Cibor, R.Debbe, J. J. Gaardhøje, M. Germinario, K. Grotowski, K. Hagel, O. Hansen, A.K. Holme, H. Ito, E. Jacobsen, A. Jipa, J. I. Jordre, F. Jundt, C. E. Jørgensen, T. Keutgen, R. Karabowicz, N. Katryńska, E. J. Kim, T. Kozik, T.M.Larsen, J. H. Lee, Y. K.Lee, S. Lindahl, G. Løvhøjden, Z. Majka, A. Makeev, B. McBreen, M. Murray, J. Natowitz, B.S.Nielsen, K. Olchanski, D. Ouerdane, R.Planeta, F. Rami, D. Roehrich, B. H. Samset, S. J. Sanders, I. S. Sgura, R.A.Sheetz, Z.Sosin, P. Staszel, T.S. Tveter, F.Videbæk, R. Wada, A.Wieloch, H. Yang, Z. Yin, I.S. Zgura.

INVESTIGATION OF HADRON PROPERTIES IN NUCLEAR MATTER WITH PROTON-NUCLEUS, ANTIPROTON-NUCLEUS AND NUCLEUS-NUCLEUS REACTIONS

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Experimental facility: accelerator SIS18, GSI Darmstadt

HADES (High Acceptance Di-Electron Spectrometer) [1] installed at SIS18 (GSI Darmstadt), has been designed to measure invariant mass of di-electrons with a high mass resolution (~1%) in pp, πp, pA, πA and AA collisions at 1-2 AGeV. The spectrometer consists of 6 sectors, covering full azimuthal angle, polar angles from 18° to 85° and rapidity $0 < y < 2$ (acceptance for e^+e^- pair from a direct vector meson decay ~35%). Each sector works independently and contains a set of fast particle detectors (RICH, TOF/TOFino, Pre-SHOWER) and a tracking system (MDC I-IV and magnet). The detector went into operational in 2002 and collected data from $^{12}C+^{12}C$ collisions at 2 AGeV (2002) and 1 AGeV (2004), $^{40}Ar+KCl$ at 1.757 AGeV (2005) and proton-proton reactions at 2.2 GeV (2004) and 1.25 GeV (2006).

The invariant-mass spectrum of e^+e^- pairs produced in $^{12}C+^{12}C$ collisions at an incident energy of 2 GeV per nucleon (see Fig) has been measured for the first time [2]. At low masses, i.e. $M_{ee}<0.15$ GeV/c², the pair yield is in agreement with the known π^0 production and decay probabilities. For 0.15 GeV/c² $<M_{ee}<0.5$ GeV/c² it exceeds expectations

based on the known production and decay rates of the η meson by 2.07 ± 0.21(stat) ± 0.38 (sys). This pair yield excess is consistent with that measured by DLS at 1.04 GeV if its energy scaling is similar to that of pion production. Additional sources associated with the radiation from the early collision phase (Delta$^{0(+)}$, ρ) are not sufficient to account for the excess observed for M>0.15 GeV/c². Transport calculations based on vacuum spectral functions only also

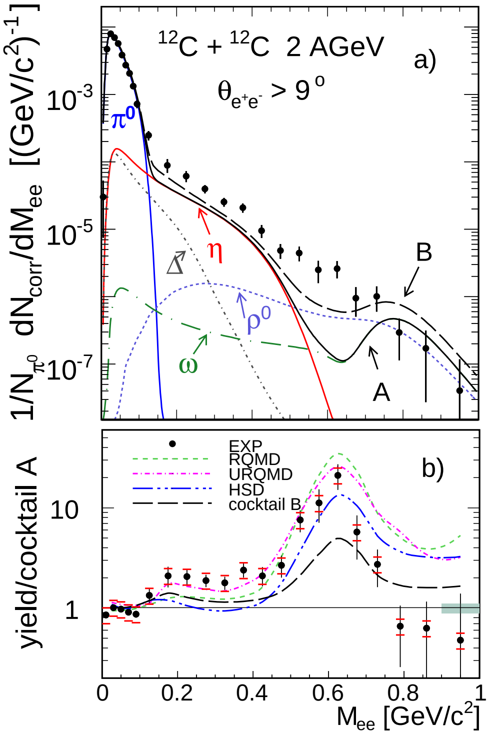
fail to quantitatively describe the excess yield in the full invariant-mass range. Further investigations with other collision are expected to shed more light on origin of the excess.

Figure shows:

(a) Efficiency- and background-corrected e^+e^- invariant-mass distribution for $\theta_{e+e-}>9°$ (symbols) compared to a thermal dielectron cocktail of free π^0, η and ω decays (cocktail A, solid line), as well as including ρ and Δ resonance decays (cocktail B, long-dashed line). Only statistical errors are shown.

(b) Ratio of data and cocktail A (dots), compared to ratios of various model calculations and cocktail A. All calculations have been filtered and folded with the HADES acceptance and mass resolution. Statistical and systematic errors of the measurement are shown as vertical and horizontal lines, respectively.

The overall normalization error of 11% is depicted by the shaded area.



[1] **P. Salabura** *et al*., (HADES Collaboration), Nucl. Phys. **A749** 150c (2005);
P. Salabura *et al*., (HADES Collaboration), Acta Phys. Pol. B Vol.**35** 1119 (2004)
W. Przygoda et al., HADES collaboration Nuclear Physics **A783** (2007)583c
S.Spataro et al., (HADES collaboration) International Journal of Modern Physics A vol. **22** (2007)533
J.Pietraszko et al., (HADES collaboration) International Journal of Modern Physics A vol. **22** (2007)38
T.Christ et al., (HADES collaboration) International Journal of Modern Physics A vol. **22** (2007)600

[2] G. Agakichiev *et al*. (HADES Collaboration), Phys. Rev. Lett. **98** (2007) 052302

list of HADES collaboration authors is available at *www.hades.gsi.de*

SPALLATION AND FRAGMENTATION OF ATOMIC NUCLEI WITH PROTONS

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Experimental facility: Cooler Synchrotron COSY, Forschungszentrum Juelich

Knowledge of the reaction mechanism of medium energy protons interacting with atomic nuclei is of importance by itself, having simultaneously very broad range of applications from *e.g.* model calculations of the production of cosmogenic nuclides in extraterrestrial matter by solar and galactic cosmic ray protons, medicine (radionuclide production, radiation therapy), accelerator technology (activation of detectors, radiation protection, on-line mass separation) to accelerator-based nuclear waste transmutation and energy amplification.

In the last years we have performed measurements of double differential cross sections ($d^2\sigma/dEd\Omega$) with isotopic identification of the light charged reaction products from proton induced reactions on several target nuclei (Al, Ni, Ag, and Au) at various energies (0.175, 1.2, 1.9 and 2.5 GeV). The experiments were performed at the internal beam of COSY accelerator using thin, self supporting targets (of about 300 $\mu g/cm^2$ thickness) what resulted in negligible distortion of the reaction product spectra by interaction of the emitted particles with the target. Using of the internal beam enabled to obtain, due to multiple passing of the beam through the target, statistics of spectra comparable with that which can be reached only with very intense external beams. The particles were detected using nine independent detection arms comprising various kinds of detectors. Two of these arms (placed at 15^0 and 120^0 with respect to the beam direction) were equipped with the Bragg curve detectors (BCD), which permitted the Z-identification of the reaction products and determination of their kinetic energies with low energy threshold (of about 1 MeV / nucleon). The telescopes consisted of silicon detectors supplied with additional scintillating (CsI) detectors, 7.5 cm thick, were used to measure broad energy range spectra of the light charged particles (p,d,t,^{3}He, and ^{4}He). The silicon detector telescopes enabled us also to measure spectra of intermediate mass fragments (from Li to B) with isotopic identification and heavier fragments (from C to Al) with elemental identification. It was found that the spectra cannot be reproduced assuming the most popular scenario of the reaction mechanism, i.e. intranuclear nucleon-nucleon cascade plus evaporation of fragments from the equilibrated remnant of the cascade. For all identified ejectiles a high energy tail of the spectra, varying quickly with the scattering angle was observed besides the evaporation spectrum.. This high energy part of the spectra may be reproduced assuming isotropic emission from the source moving in forward direction, i.e. parallel to the beam direction, with velocity larger than that of proton-target nucleus center of mass.

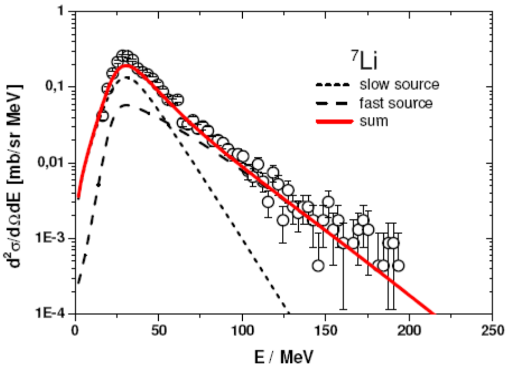

Fig.1. *Symbols present the data obtained at 35^0 lab for Au(p, ^{7}Li) reaction at T_p=2.5 GeV , dotted line presents evaporation contribution, dashed line - the contribution from the fast moving source, solid line – the sum of both contributions.*

[1] **A. Bubak**, **B. Kamys**, **M. Kistryn**, and **B. Piskor-Ignatowicz**, Nucl. Instr. and Meth. in Phys. Research **B 204**, 507 (2004)

[2] R. Barna, V. Bollini, **A. Bubak**, **A. Budzanowski**, D. D. Pasquale, D. Filges, S. V. Foertsch, F. Goldenbaum, **A. Heczko**, H. Hodde, A. Italiano, **L. Jarczyk**, **B. Kamys**, **J. Kisiel**, **M. Kistryn** , **St. Kistryn**, **St. Kliczewsk**i, **A. Kowalczyk**, **P. Kulessa**, H. Machner, **A. Magiera**, **J.Majewski**, **W. Migdał,** H. Ohm, N. Paul, **B. Piskor-Ignatowicz**, **K. Pysz**, **Z. Rudy**, H. Schaal, **R. Siudak**, **E. Stephan**, G.F. S teyn, **R. Sworst**, T. Thovhogi, **M.Wojciechowski**, **W. Zipper**, Nucl. Instr. Meth. in Phys. Research **A 519**, 610 (2004).

[3] **A.Bubak**, PhD-thesis Katowice (2004)

[4] V. Bollini, **A. Bubak**, **A. Budzanowski**, J. Cugnon, D.Filges, F. Goldenbaum, **A. Heczko**, H. Hodde, **L. Jarczyk**, **B. Kamys**, **M. Kistryn**, **St. Kistryn**, **St. Kliczewski**, **A. Kowalczyk**, **P. Kulessa**, H. Machner, **A. Magiera**, **W. Migdał**, K. Nuenighoff, N. Paul, **B. Piskor-Ignatowicz**, **K. Pysz**, **Z. Rudy**, **R. Siudak**, **M. Wojciechowski, E.Kozik**, Nucl. Instr. Meth. in Phys. Research **A 562**, 73 (2006)

[5] **A. Bubak**, **A. Budzanowski**, D. Filges, F. Goldenbaum, **A. Heczko**, H. Hodde, **L. Jarczyk**, **B. Kamys**, **M. Kistryn**, **St. Kistryn**, **St. Kliczewski**, **A. Kowalczyk**, **E.Kozik**, **P. Kulessa**, H. Machner, **A. Magiera**, **W. Migdał**, N. Paul, **B. Piskor-Ignatowicz**, **M. Puchał**a, **K. Pysz**, **Z. Rudy**, **R. Siudak**, **M. Wojciechowski**, and P. Wuestner, sent for publication in Physical Review C (2006)

STRANGE-PARTICLE PRODUCTION IN NUCLEUS-NUCLEUS AND PION-NUCLEUS COLLISIONS AT NEAR-THRESHOLD ENERGIES

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Experimental facility: SIS18 at GSI-Darmstadt

At beam energies below 2 GeV per nucleon, particles that carry strangeness are produced in early stages of nucleus-nucleus collisions. The production rate of $s\bar{s}$-quark pairs in such collisions is primarily determined by the available energy density and, therefore, reflects the properties of the equation of state of the nuclear matter. It may also be affected by the anticipated in-medium changes of hadrons' properties, which, furthermore, should influence the subsequent propagation of strange particles in the nuclear medium as well. In order to learn more about these phenomena, the FOPI collaboration has measured production of K- and Φ-mesons as well as strange hyperons in collisions of medium- and heavy-nuclei at beam energies between 1.5 and 1.9 GeV per nucleon.

The FOPI spectrometer is a modular system used for fixed-target experiments on the SIS beam-line in GSI. It allows for simultaneous measurements of a large fraction of charged reaction products in the close-to-4π geometry. Depending on the emission angle, the identification of particles is accomplished by measuring the specific energy loss, the curvature of particle's trajectory in the magnetic field or the time of flight of a particle. In addition, short-living neutral reaction products are identified via their decays into charged hadrons and the invariant mass reconstruction.

The K^-/K^+ yields ratios (Fig. 1) as well as the K^+ sidewards flow were measured in Ru+Ru collisions at 1.7 AGeV beam energy and in Ni+Ni collisions at 1.9 AGeV beam energy. Comparison of the experimental results to predictions of BUU transport-model calculations revealed additional repulsion of the K^+-nucleon potential and additional attraction of the K^--nucleon potential with respect to the corresponding interactions in vacuum.

In Ni+Ni collisions at 1.9 AGeV beam energy, the production probability of Φ-mesons was measured, and the Φ/K^- yields ratio was determined. It showed that the substantial fraction of the measured K^- mesons yield steams from Φ mesons decays, and that both processes need to be studied simultaneously.

In nucleus-nucleus collisions a large number of K mesons are produced in two step processes, in which in the first step the necessary energy is temporarily accumulated in a pion or in a delta-resonance. However, the cross-sections of $\pi N \rightarrow KY$ reactions (Y stands for the appropriate hyperon), in which the strangeness should be actually produced, are not known at nuclear densities. First experiments with a π^- beam of 1.15 GeV/c momentum on various light-, medium- and heavy-targets, showed a surface-like scaling of the K^0 and Λ production with the mass of the target and suggested that in π^--nucleus collisions the cross-sections of the underlying elementary processes are modified with respect to the reactions in vacuum.

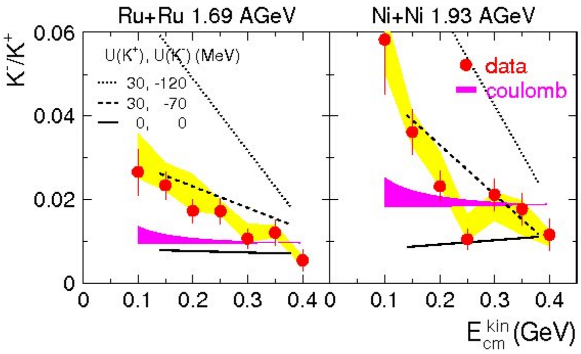

Fig. 1. *The K^-/K^+ yields ratio as a function of E^{kin}_{cm} in the Ru+Ru (left) and Ni+Ni (right) experiments. The data are extracted in the polar-angle range $150^o < \Theta_{cm} < 165^o$. The light-grey (yellow) shaded areas correspond to the estimate of systematic errors. The lines depict predictions of the RBUU transport model with different strength $U(\rho=\rho_0)$ of the in-medium (anti)kaon potentials at normal nuclear matter density. Statistical uncertainties of the predictions are similar to those of the experimental data. The horizontal dark-grey (magenta) shaded areas show the results of numerical simulations carried out in order to estimate the influence of the Coulomb potential on the K^-/K^+ yields ratio.*

[1] D. Best, N. Herrmann, B. Hong, **M. Kirejczyk**, J. Ritman, **K. Wisniewski**, A. Zhilin, A. Gobbi, K.D. Hildenbrand, Y. Leifels, C. Pinkenburg, W. Reisdorf, D. Schull, U. Sodan, G.S. Wang, T. Wienold, J.P. Alard, V. Amouroux, N. Bastid, I. Belyaev, G. Berek, J. Biegansky, R. Cherbachev, J.P. Coffin, P. Crochet, P. Dupieux, Z. Fodor, A. Genoux-Lubain, G. Goebels, G. Guillaume, E. Hafele, F. Jundt, J. Kecskemeti, Y. Korchagin, R. Kotte, C. Kuhn, A. Lebedev, A. Lebedev, I. Legrand, C. Maazouzi, V. Manko, J. Mosner, S. Mohren, D. Moisa, W. Neubert, D. Pelte, M. Petrovici, P. Pras, F. Rami, C. Roy, Z. Seres, **B. Sikora**, V. Simion, **K. Siwek-Wilczynska**, V. Smolyankin, A. Somov, L. Tizniti, M. Trzaska, M.A. Vasilev, P. Wagner, D. Wohlfarth, I. Yushmanov, Nucl. Phys. **A625**, 307 (1997).

[2] **K. Wisniewski,** Acta Phys. Polon. **B31**, 399 (2000).

[3] P. Crochet, N. Herrmann, **K. Wisniewski**, Y. Leifels, A. Andronic, R. Averbeck, A. Devismes, C. Finck, A. Gobbi, O. Hartmann, K.D. Hildenbrand, P. Koczon, T. Kress, R. Kutsche, W. Reisdorf, D. Schull, J.P. Alard, V. Barret, Z. Basrak, N. Bastid, I. Belyaev, A. Bendarag, G. Berek, R. Caplar, N. Cindro, P. Dupieux, M. Dzelalija, M. Eskef, Z. Fodor, Y. Grishkin, B. Hong, J. Kecskemeti, Y.J. Kim, **M. Kirejczyk**, M. Korolija, R. Kotte, M. Kowalczyk, A. Lebedev, K.S. Lee, V. Manko, H. Merlitz, S. Mohren, D. Moisa, W. Neubert, A. Nianine, D. Pelte, M. Petrovici, C. Plettner, F. Rami, B. de Schauenburg, Z. Seres, **B. Sikora**, K.S. Sim, V. Simion, **K. Siwek-Wilczynska**, V. Smolyankin, A. Somov, M. Stockmeier, G. Stoicea, M. Vasiliev, P. Wagner, D. Wohlfarth, J.T. Yang, I. Yushmanov, A. Zhilin, Phys. Lett. **B486**, 6 (2000).

[4] **K. Wisniewski**, P. Crochet, N. Herrmann, A. Andronic, R. Averbeck, A. Devismes, C. Finck, A. Gobbi, O. Hartmann, K.D. Hildenbrand, P. Koczon, T. Kress, R. Kutsche, Y. Leifels, W. Reisdorf, D. Schull, J.P. Alard, V. Barret, Z. Basrak, N. Bastid, I. Belyaev, A. Bendarag, G. Berek, R. Caplar, N. Cindro, P. Dupieux, M. Dzelalija, M. Eskef, Z. Fodor, Y. Grishkin, B. Hong, J. Kecskemeti, Y.J. Kim, **M. Kirejczyk**, M. Korolija, R. Kotte, M. Kowalczyk, A. Lebedev, K.S. Lee, V. Manko, H. Merlitz, S. Mohren, D. Moisa, W. Neubert, A. Nianine, D. Pelte, M. Petrovici, C. Plettner, F. Rami, B. de Schauenburg, Z. Seres, **B. Sikora**, K.S. Sim, V. Simion, **K. Siwek-Wilczynska**, V. Smolyankin, A. Somov, M. Stockmeier, G. Stoicea, M. Vasilev, P. Wagner, D. Wohlfarth, J.T. Yang, I. Yushmanov, A. Zhilin, Eur. Phys. J. **A9**, 515 (2000).

[5] A. Mangiarotti, N. Herrmann, P.R. Maurenzig, A. Gobbi, R. Kotte, J. Kecskemeti, Y. Leifels, J.P. Alard, A. Andronic, R. Averbeck, V. Barret, Z. Basrak, N. Bastid, I. Belyaev, A. Bendarag, G. Berek, R. Caplar, P. Crochet, A. Devismes, P. Dupieux, M. Dzelalija, C. Finck, Z. Fodor, Yu. Grishkin, O. Hartmann, K.D. Hildenbrand, B. Hong, Y.J. Kim, **M. Kirejczyk**, P. Koczon, M. Korolija, T. Kress, R. Kutsche, A. Lebedev, V. Manko, M. Merschmeyer, D. Moisa, A. Nianine, W. Neubert, D. Pelte, M. Petrovici, C. Plettner, F. Rami, W. Reisdorf, B. de Schauenburg, D. Schull, Z. Seres, **B. Sikora**, K.S. Sim, V. Simion, **K. Siwek-Wilczynska**, V. Smolyankin, M. Stockmeier, G. Stoicea, M. Vasilev, P. Wagner, **K. Wisniewski**, D. Wohlfarth, I. Yushmanov, A. Zhilin, Nucl. Phys. **A714**, 89 (2003).

[6] N. Herrmann, **K. Wisniewski**, Acta Phys. Polon. **B35**, 1091 (2004).

PHASE TRANSITIONS IN HIGHLY EXCITED NUCLEAR MATTER

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Introduction

States of nuclear matter in the Universe after the Big Bang are subject to different phase transitions from gas to liquid drops. It is impossible to create in the laboratory conditions to study this processes directly in a slow non explosive way. So we are left with the problem of a reversed study of the liquid to gas phase processes. The availability of various charged particles beams allows us to create nuclei at various excitation energies, spins, izospins, compressions and shape deformations. There is a great challenge to theorists to disentangle all these quantities and to find clear evidence of the phase transition and its order.

Microcanonical ensembles

The nucleus is an inhomogeneous non-extensive object composed of a limited number of nucleons not exceeding 300. Non-extensive means that $S \neq S_1 + S_2$ and $E \neq E_1 + E_2$ where S and E indicate the total entropy and total energy of the nucleus and S_1, S_2, E_1 and E_2 are entropies and energies of its parts. Forces between the constituent particles are of comparable or longer (Coulomb potential) range than the size of the object. Good examples are the following objects: nuclei, stars, charged liquid droplets. Therefore, the microcanonical thermodynamics seems to be the proper one to describe nuclei.

Multifragmentation of highly excited nuclei.

At the excitation energies of 3-10 AMeV a copious emission of intermediate mass fragments i.e. light nuclei with $2<Z<20$ is observed . This emission may be a sign of a liquid to gas phase transition and can be treated in terms of the microcanonical thermodynamics. The main characteristics of this process are listed below:

a. It occurs nearly simultaneously, within short time interval from 50fm/c to 100 fm/c.

Fragments are accelerated by the Coulomb field from what is called freeze-out radius.

b. Fragments are emitted symmetrically in the coordinate system related to the source.

c. Flattening of the caloric curve is observed.

d. Fluctuation $\sigma^2_K = \langle K^2 \rangle - \langle K \rangle^2$ of the measured kinetic energy release K is observed from event to event.

e. Negative specific heat capacity indicates a phase transition of the first order.

Pure thermally excited nucleus.

Pure thermal excitation of the heavy nucleus has been proposed by Karnaukhov et al. [1]. The principle of this method is as follows. Relativistic light projectile passes through the heavy nucleus starting an intranuclear cascade. The recoiled nucleons, produced clusters and particles are ejected out of the nucleus. A substantial fraction of particles can still be emitted as preequilibrium ejectiles. The final energy left in the target nucleus has a form of pure thermal energy. After the time of a few tens of fm/c the excited nucleus expands and subsequently explodes into preformed IMF's at the so called freeze-out radius. For the analysis we have used the microcanonical model of Bondorf et al. (Phys.Rep. **257,** 433 (1995).) called SMM (Statistical Multifragmentation Model). Results were published in a series of papers [2], in which the transition volume sometimes called multisaddle point V_t, freeze-out volume V_f, and critical temperature were determined . In addition parameters of the spinodal instability configuration (density and temperature) were conjectured.

Proposals for future experiments.

It is proposed to extend the measurements to non thermal excitations. This would require the reconstruction of the multi telescope system of the FASA detector in Dubna or construction of the new system close to the light heavy ion beam accelerator (including proton beams of the energy range 1-30 GeV. New results are expected with the use of antiproton beams from the future FAIR facility at GSI Darmstadt.

Finally let me mention the main difference between the thermally excited nucleus and possible quark-gluon plasma. From our measurements [2-5] in case of gold nucleus thermally excited $V_t/V_o = 2.6 \pm 0.3$, $V_f/V_o = 5 \pm 1$, whereas from the analysis of the RHIC data on gold - gold collisions at 200 GeV per nucleon pair the possible plasma volume is hardly greater then 2 volumes of gold nuclei in CM (W. Broniowski and W. Florkowski, Phys.Rev.Lett **87,** 272302(2001). C. Adler et al. STAR Collaboration, Phys. Rev. Lett.**87,** 082301 (2001).). This is due to the fact that the attractive forces between partons are very strongly increasing with the distance between them.

[1] V.A. Karnaukhov, S.P. Avdeyev, W.D. Kuznetsov, L.A. Petrov, V.K. Rodionov, A.S. Zubkevich, H. Oeschler, O.V. Bochkarev, L.V. Chulkov, E.A. Kuzmin, **A. Budzanowski, W. Karcz, M. Janicki,** E. Norbeck, A.S. Botvina. Yad. Fizika ,No.2, **62,** 272 (1999). Phys. At. Nucl. **62,** 237 (1999).

[2] V.A. Karnaukhov, H. Oeschler, S.P. Avdeyev, E.V. Duginova, V.K. Rodionov, **A.Budzanowski**, **W. Karcz**, O.V. Bochkarev, L.V. Chulkov, E.A. Kuzmin, E. Norbeck, A.S.Botvina, Phys. Rev., **C67,** 0011601(R)1 (2003).

[3] V.A. Karnaukhov, H. Oeschler, S.P. Avdeyev, V.K. Rodionov, **A.Budzanowski**, **W. Karcz**, **I. Skwirczyńska**, O.V. Bochkarev, L.V. Chulkov, E.A. Kuzmin, E. Norbeck, A.S.Botvina. Nucl.Phys. **A734,** 520(2004).

[4] V.A. Karnaukhov, H. Oeschler, S.P. Avdeyev, V.K. Rodionov, **A.Budzanowski**, **W. Karcz**, **I.Skwirczyńska**, O.V. Bochkarev, L.V. Chulkov, E.A. Kuzmin, E. Norbeck, A.S.Botvina. Phys. Rev.**C70,** 041601(R) (2004).

[5] **Budzanowski**, V.A. Karnaukhov , H. Oeschler, S.P. Avdeyev,V.K. Rodionov, V.V. Kirakosyan, A.V. Simonenko, P.A. Rukoyatkin, **W. Karcz**, **I. Skwirczyńska**, E.A. Kuzmin, L.V. Chulkov, E. Norbeck and A.S. Botvina, Acta Phys. Polon. **B36,** 1203 (2005).

NUCLEAR SINGLE PARTICLE SUM RULES IN THE EMC EFFECT

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The nuclear EMC effect, quite strong as witnessed by Fig. 1 (where it is shown for mass number A = 56), is reflection of the influence which nuclear field exerts on the partonic structure of nucleons.

Using the extended Relativistic Mean Field model (RMF) [1] we have investigated this effect and calculated parton distributions in nuclei (Phys. Lett**. B 432**, 402 (1998)) for Bjorken variable 0<x<A. It turned out that in this region the crucial factor is the change of the nuclear virtual pion cloud (connected with the existence of exchanged mesons originated from the nuclear forces) . In order to reproduce the observed behavior of experimental data in that region we had to adjust accordingly the value of parameter determining the relative number of intermediate pions [2] . In deep inelastic scattering in the nuclear medium, part of nuclear pions contribute to the sea quark part of the nucleon structure function, but for small values of x (x < 0.01) the uncertainty in the life time of intermediate photon-quark state becomes comparable (or larger) then the mean distance between nucleons and this results in the shadowing of single nucleon contributions. We argue therefore that experimental results on deep inelastic *e-A* scatterings show partial deconfinement [3] of nucleons inside the nuclear matter (NM) enhancing therefore the role played by the partonic degrees of freedom. In particular, as we have shown, the magnitude of the nuclear Fermi motion is sensitive to the residual interactions between partons, influencing both the nucleon structure functions and the value of the nucleon mass in the NM [4]. Our model for parton distribution in nuclei is based on the assumption that nuclear Fermi motion fully accounts for the collective motion of partons in nuclear medium. The sea parton distributions are described by allowing for some additional virtual pions in hadron in the quantity which reproduces both the nuclear lepton pair production data and saturates the energy-momentum sum rule. Good agreement with the experimental data has been obtained [5], see Figs.1 and 2**.**

These medium effects, namely the changes in the nucleon rest energy and the enhancement of the sea quark contribution (simulated by "nuclear pions") modify the transverse parton momentum distribution inside the (NM). Some predictions for future experiments on heavy ion collisions are given in [6]. The influence of these modifications on the equation of state (EoS) in the NM was discussed in [7]. We have also investigated the density dependent corrections to the nucleon structure function in the frame of nuclear RMF models.

Concluding, the new sea parton distributions described by the modified cloud of virtual pions and the change of the nucleon mass as a function of x (due to the final state interaction) obtained in our model satisfy the nuclear single particle momentum sum rule and are in good agreement with experimental data, namely with the EMC effect for x>0.1 and with nuclear lepton pair production data. This agreement has been obtained essentialy without free parameters (Fig.1,2). The influence of these medium modifications on the value of quark condensate inside nucleus (Phys. Rev. **C51**, 2188 (1995)) and determination of EoS in RMF models of NM is under investigations .

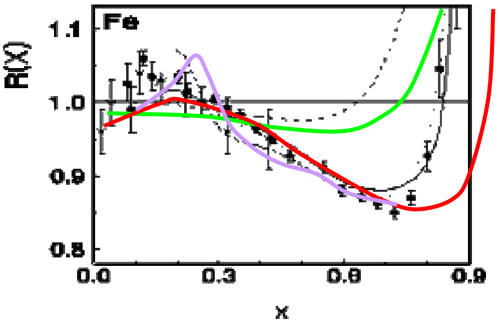

Fig. 1. *$R(x)=F_2^{56}(x)/F_2(x)$ The nuclear to nucleon structure function ratio as a function of x. Green line – Fermi motion without medium modification, pink without final state interaction, red line - full results.*

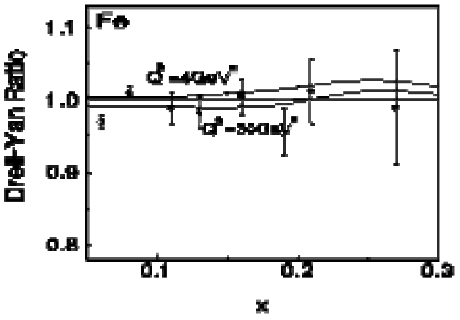

Fig.2. *Nuclear Drell -Yan ratio (the same iron target) for two values of the foton momentum transfer square Q^2.*

[1] **J. Rożynek**, Int. J. Phys. **E 9,** 195 (2000).

[2] **J. Rożynek, G.Wilk**, Phys. Lett. **B473**, 167 (2000).

[3] **J. Rożynek, G.Wilk**, Acta Phys. Pol. **B35**, 2303 (2004).

[4] **J. Rożynek**, Nucl. Phys. **A755**, 357c (2004).

[5] **J. Rożynek, G.Wilk,** Phys. Rev. **C 71**, 068202 (2005).

[6] **J. Rożynek**, Acta Phys. Pol. **B37**, 95 (2006).

[7] **J. Rożynek**, Int. J. Phys. **E 16,** 608 (2007).

FLUCTUATIONS AND SEARCH FOR THE CRITICAL POINT AT SPS ENERGIES

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Experimental facility: NA49 experiment at CERN SPS

One of the main objectives of studying heavy ion collisions at relativistic energies is to understand the properties of quark-gluon plasma (QGP) – a new state of matter that is expected to appear when the system is sufficiently hot and dense [Phys. Rev. Lett. **34**, 1353 (1975)]. If the energy density is much higher than a typical energy density inside a nucleus, the matter can form a gas of subhadronic degrees of freedom. The quarks and gluons are not confined inside hadrons but they can move freely in the whole volume of QGP. It is also believed that QGP was created during the evolution of the early Universe [Phys. Rept. **201**, 335 (1991)].

The theoretical predictions within the Statistical Model of the Early Stage suggested that the energy threshold for deconfinement is localized between AGS and top SPS energies [1]. Indeed, the latest NA49 results [2, 3, 4] on dependencies of various quantities on the collision energy seem to confirm that the onset of deconfinement sets in at lower SPS energies.

The phase diagram of strongly interacting matter is most often presented as a (T, μ_B) plot, where T is the temperature and μ_B is a baryochemical potential. For large values of μ_B one expects the first order phase transition between hadron gas and QGP, which terminates in a critical point, and for smaller values of μ_B turns into a so-called crossover. The recent lattice QCD calculations suggest that the end-point of the first-order phase transition is a critical point of the second-order and may be located at a baryochemical potential characteristic of the CERN SPS energy range [JHEP **0404**, 050 (2004)].

Dynamical (non-statistical) fluctuations are considered to be important observables in the study of the phase diagram of strongly interacting matter. Significant transverse momentum and multiplicity fluctuations are expected for systems that hadronize from QGP near the second-order critical QCD end-point [Phys. Rev. **D60**, 114028 (1999)]. The phase diagram can be scanned by varying both the energy and size of the colliding nuclei and an observed enhancement of dynamical (p_T and multiplicity) fluctuations may provide evidence for the QCD critical end-point.

The NA49 experiment used the Φ_{p_T} measure [5] to quantify dynamical event-by-event p_T fluctuations. Fig.1 shows a significant non-monotonic evolution with the system size of Φ_{p_T} for all charged particles registered in the forward rapidity region in A+A collisions at top SPS energy (158*A* GeV) – see [6] for details. Moreover, an increase of multiplicity fluctuations for peripheral Pb+Pb interactions (when compared to p+p and central Pb+Pb collisions) was measured by NA49 [7]. Both observations might be the first indication of the critical point.

The above results provided powerful arguments for a new experiment at CERN – NA61 [8, 9], which plans to study collisions of light and intermediate mass nuclei in order to cover a broad range of the (T, μ_B) plane. The results may help to confirm, discover or rule out the existence of the critical point in the SPS domain.

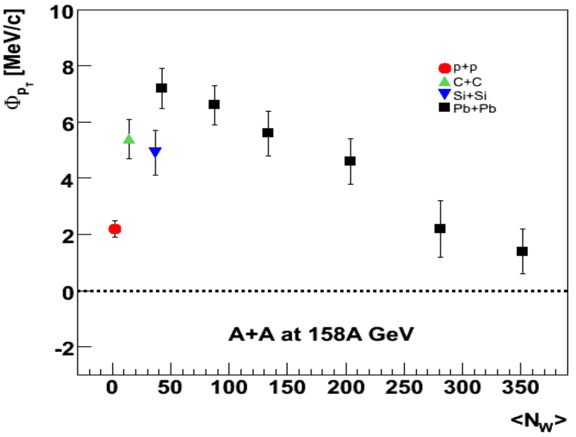

Fig. 1. *Event-by-event transverse momentum fluctuations versus number of wounded nucleons (measure of the system size) obtained for all charged particles produced in A+A collisions at top SPS energy.*

[1] **M. Gaździcki** and M. I. Gorenstein, Acta Phys. Polon. **B30**, 2705 (1999).

[2] M. Mitrovski, **M. Gaździcki, K. Grebieszkow, S. Mrówczyński, P. Seyboth, E. Skrzypczak** et al. [NA49 Coll.], J. Phys. **G32,** S43 (2006).

[3] **P. Seyboth, M. Gaździcki, K. Grebieszkow, S. Mrówczyński, E. Skrzypczak** et al. [NA49 Coll.], Acta Phys. Polon. **B36,** 565 (2005).

[4] S. V. Avanasiev, **M. Gaździcki, K. Grebieszkow (Perl), P. Seyboth, E. Skrzypczak** et al. [NA49 Coll.], Phys. Rev. **C66**, 054902 (2002).

[5] **M. Gaździcki, S. Mrówczyński,** Z. Phys. **C54**, 127 (1992).

[6] T. Anticic, **M. Gaździcki, K. Grebieszkow, S. Mrówczyński, P. Seyboth, E. Skrzypczak** et al. [NA49 Coll.], Phys. Rev. **C70**, 034902 (2004).

[7] C. Alt, **M. Gaździcki, K. Grebieszkow, S. Mrówczyński, M. Rybczyński, P. Seyboth, E. Skrzypczak** et al. [NA49 Coll.], Phys. Rev. **C75**, 064904 (2007).

[8] **M. Gaździcki,** nucl-ex/0512034, published in Jalta 2005, New trends in high-energy physics 131-138

[9] N. Antoniou, **M. Gaździcki, K. Grebieszkow, S. Mrówczyński, P. Seyboth, E. Skrzypczak** et al. [NA49-future Coll.], CERN-SPSC-2006-001 and SPSC-P-329 (2006).

NA49 Collaboration (III.2007):

C. Alt, T. Anticic, B. Baatar, D. Barna, **J. Bartke**, L. Betev, **H. Białkowska**, C. Blume, **B. Boimska**, M. Botje, J. Bracinik, R. Bramm, P. Buncic, V. Cerny, P. Christakoglou, P. Chung, O. Chvala, J.G. Cramer, P. Csató, P. Dinkelaker, V. Eckardt, D. Flierl, Z. Fodor, P. Foka, V. Friese, J. Gál, **M. Gaździcki**, V. Genchev, G. Georgopoulos, **E. Gładysz**, **K. Grebieszkow**, S. Hegyi, C. Höhne, K. Kadija, A. Karev, **D. Kikoła**, M. Kliemant, S. Kniege, V.I. Kolesnikov, **E. Kornaś**, **R. Korus**, **M. Kowalski**, I. Kraus, M. Kreps, A. Laszlo, R. Lacey, M. van Leeuwen, P. Lévai, L. Litov, B. Lungwitz, M. Makariev, A.I. Malakhov, M. Mateev, G.L. Melkumov, A. Mischke, M. Mitrovski, J. Molnár, **St. Mrówczyński**, V. Nicolic, G. Pálla, A.D. Panagiotou, D. Panayotov, A. Petridis, **W. Peryt**, M. Pikna, **J. Pluta**, D. Prindle, F. Pühlhofer, R. Renfordt, C. Roland, G. Roland, **M. Rybczyński**, **A. Rybicki**, A. Sandoval, N. Schmitz, T. Schuster, **P. Seyboth**, F. Siklér, B. Sitar, **E. Skrzypczak**, **M. Słodkowski**, G. Stefanek, R. Stock, C. Strabel, H. Ströbele, T. Susa, I. Szentpétery, J. Sziklai, **M. Szuba**, **P. Szymański**, **V. Trubnikov**, D. Varga, M. Vassiliou, G.I. Veres, G. Vesztergombi, D. Vranic, A. Wetzler, **Z. Włodarczyk**, **A. Wojtaszek**, I.K. Yoo, J. Zimányi

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N. Antoniou, P. Christakoglou, F. Diakonos, A. D. Panagiotou, A. Petridis, M. Vassiliou, F. Cafagna, M. G. Catanesi, T. Montaruli, E. Radicioni, D. Röhrich, L. Boldizsar, Z. Fodor, A. Laszlo, G. Palla, I. Szentpetery, G. Vesztergombi, J. Cleymans, **J. Brzychczyk, N. Katryńska, R. Karabowicz, Z. Majka R. Planeta, P. Staszel,** B. Baatar, V. I. Kolesnikov, A. I. Malakhov, G. L. Melkumov, A. N. Sissakian, A. S. Sorin, W. Rauch, M. Gaździcki, B. Lungwitz, M. Mitrovski, R. Renfordt, T. Schuster, C. Strabel, H. Stroebele, A. Blondel, A. Bravar, M. Di Marco, J. Blumer, R. Engel, A. Haungs, C. Meurer, M. Roth, **M. Gaździcki, R. Korus, St. Mrówczyński, M. Rybczyński, P. Seyboth, G. Stefanek, Z. Włodarczyk, A. Wojtaszek,** F. Guber, A. Kurepin, A. Ivashkin, A. Maevskaya, B. Andrieu, J. Dumarchez, K.-U. Choi, J.-H. Kim, J.-G. Yi, I.-K. Yoo, D. Kolev, R. Tsenov, A. G. Asryan, D. A. Derkach, G. A. Feofilov, S. Igolkin, A. S. Ivanov, R. S. Kolevatov, V. P. Kondratiev, P. A. Naumenko, V. V. Vechernin, P. Chung, R. Lacey, A. Taranenko, T. Kobayashi, T. Nakadaira, K. Sakashita, T. Sekiguchi, **K. Grebieszkow, D. Kikoła, W. Peryt, J. Pluta, M. Słodkowski, M. Szuba,** T. Anticic, K. Kadija, V. Nikolic, T. Susa

BETWEEN NUCLEAR AND ELEMENTARY INTERACTIONS: RELATIVISTIC ION COLLISIONS

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Experimental facility: SPS accelerator at CERN, RHIC accelerator at BNL

The last decade has witnessed an unprecedented development of a new branch of high energy and nuclear physics - the physics of relativistic ion collisions, RI. The main motivation beyond large experimental and theoretical effort is the search for a hypothetical transition to a new state of matter, the quark-gluon plasma, QGP. This state is predicted by the Quantum Chromodynamics - the theory of strong interactions. Several polish groups have joined experiments on RI.

At CERN the NA49 experiment has studied charged hadron production in hadron-hadron, hadron - nucleus and nucleus - nucleus collisions in a wide energy range (from 20 to 158 GeV/N) and for several nuclear beams, up to lead. The data taking stopped in 2002, but the analysis continues.

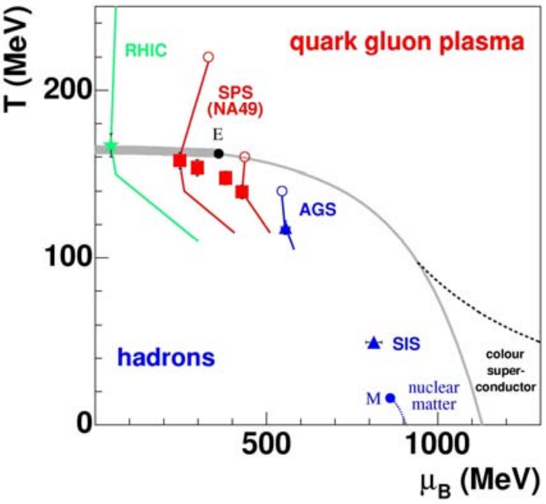

Fig.1. The phase diagram of strongly interacting matter. The points are the chemical freeze-out points derived from a fit with a statistical hadron gas model.

The main physics results on nuclear collisions are summarized in several review papers, recent - [1], [2]. At top SPS energy strongly interacting matter of high energy density is created in central Pb-Pb collisions and the hadrochemical freezeout occurs close to the predicted phase boundary, as illustrated in Fig.1 (from [1]). An extensive study of particle production in elementary collisions, measured within unprecedented phase space coverage [3] at 158 GeV/c offers a necessary background for all nuclear collisions at this energy range.

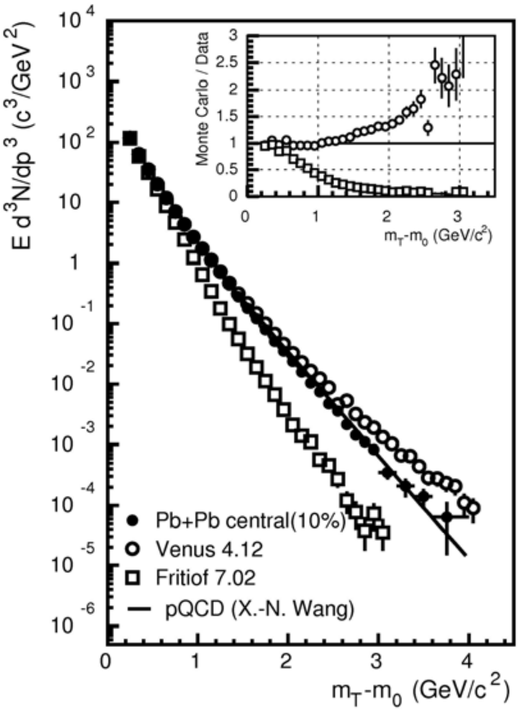

Fig.2. Transverse mass spectra of neutral pions in central PbPb collisions at 158 GeV/c/N.

The WA98 experiment, also studying Pb Pb collisions at 158 GeV/N, specialized in the neutral pion production measurements. Of the many important results, Fig.2 (from [4]) illustrates the transverse mass spectra of neutral pions, measured over several orders of magnitude of cross section, compared with model predictions.

Several polish physicists actively participate in 3 (out of 4) large RHIC experiments on nuclear collisions at 200 GeV/N (in a collider mode). A comprehensive summary is given by all experiments in a so called White Papers [5](BRAHMS experiment), [6] (PHOBOS), [7] (STAR).

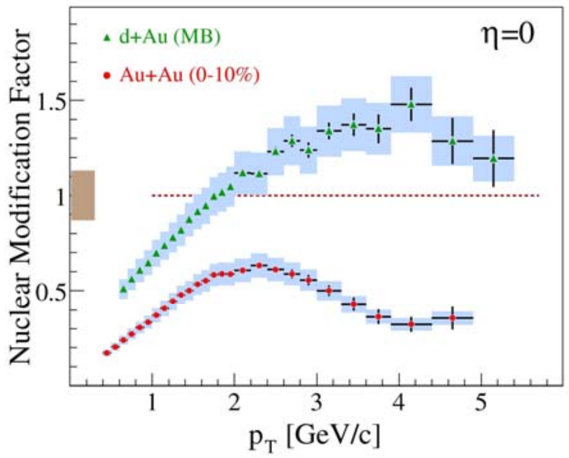

Fig.3. *Nuclear modification factors for central Au Au collisions and minimum bias d Au collisions at sqrt(s) 200GeV, evidencing the high p_t suppression in central Au Au.*

The most important findings of the RHIC experiments concern the properties of the hot and dense matter created in central collisions of high energy heavy nuclei. Contrary to previous expectations, this matter does not resemble a gas of free quarks and gluons, but shows the characteristics of a near perfect fluid. These conclusions follow from the observation of the so called jet quenching, or the suppression of high transverse momentum particles in Au-Au collisions (in comparison to the production of such particles in d-Au collisions), and the behaviour of the flow of all particles produced. The effect of jet quenching is illustrated in Fig.3 (from [5]).

This behaviour is supposedly due to high density of gluons in the matter created after the collision, slowing down or `quenching' the jets, from which high transverse momentum particles originate. Such effects notwithstanding, the bulk of global particle characteristics is - to a surprising detail - governed by the geometry of colliding objects. The PHOBOS experiment (with a substantial contribution from polish participants) has demonstrated, that from low (19.6 GeV/N) to high energy 200 GeV/N (these are the center of mass energies) and for several centralities (measured by the number of participating nucleons) the total charged particle multiplicity, per participating nucleon -scales with the mumber of participants. This is illustrated in Fig.4 (from [6]).

Polish experimental groups are now preparing for the exciting perspective of heavy ions from the LHC accelerator. The dedicated ALICE experiment, and the sub-groups from other, ATLAS and CMS experiments, hope to see the first ion beams in 2009.

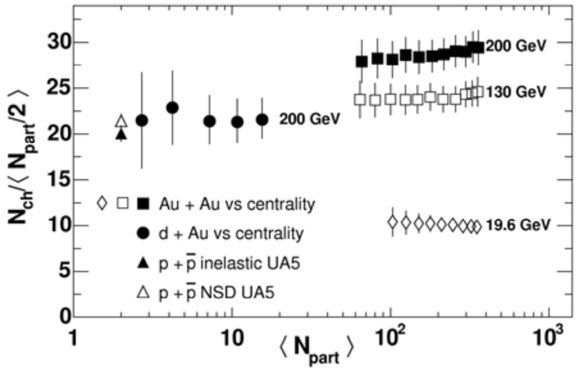

Fig.4. *Total charged particle multiplicity per participant pair as a function of number of participant.*

[1] C.Blume et al., (**J.Bartke, H.Białkowska, B.Boimska, E.Gładysz, K.Grebieszkow, E.Kornas, R.Korus, M.Kowalski, S.Mrówczynski, M.Rybczyński, A.Rybicki, E.Skrzypczak,G.Stefanek, P.Szymański, V.Trubnikov, Z.Włodarczyk**) J.Phys.**G31**:S685-S692,2005.

[2] C. Hohne et al, (**J.Bartke, H.Białkowska, B.Boimska, E.Gładysz, K.Grebieszkow, E.Kornas, R.Korus, M.Kowalski, S.Mrówczynski, M.Rybczyński, A.Rybicki, E.Skrzypczak,G.Stefanek, P.Szymański, V.Trubnikov, Z.Włodarczyk**) Nucl. Phys. **A774**:35,2006.

[3] C. Alt et al., (**J.Bartke, H.Białkowska, B.Boimska, E.Gładysz, K.Grebieszkow, E.Kornas, R.Korus, M.Kowalski, S.Mrówczynski, M.Rybczyński, A.Rybicki, E.Skrzypczak,G.Stefanek, P.Szymański, V.Trubnikov, Z.Włodarczyk**) Eur. Phys. J. **C45**,343,2006.

[4] M.Aggarval et al., (**K.Karpio, T.Siemiarczuk, G.Stefanek, L.Tykarski**) Phys.Rev.Letters 81, 4087, 1998.

[5] I.Arsene et al., (**R.Karabowicz, T.Kozik, Z.Majka, R.Planeta**) Nucl.Phys.**A757**, 1, 2005

[6] B.B.Back et al., (**A.Budzanowski, T.Gburek, R.Holyński, A.Olszewski, P.Sawicki, A.Trzupek, B.Wosiek, K.Woźniak**) Nucl.Phys.**A757**, 28, 2005

[7] J.Adams et al., (**M.Jedynak, A.Kisiel, T.Pawlak, W.Peryt, J.Pluta**) Nucl.Phys.**A757**, 102, 2005

INVESTIGATION OF CHARGE AND ISOSPIN SYMMETRY BREAKING

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Experimental facility: Cooler Synchrotron (COSY) at Forschungszentrum Jülich

Soon after the discovery of proton and neutron it was realized that they behave very much alike. Those observed experimentally symmetries led Heisenberg to introduce isospin, a new quantum number, which allows treating neutron and proton as two charge states of one particle – the nucleon. Direct consequences of this concept are the isospin symmetry (IS) and charge symmetry (CS). Since the masses and interactions of different nucleons are not the same, the IS and CS are not exact and until discovery of quarks were considered as accidental. On the quark level these symmetries are broken due to up and down quark mass difference and to their electromagnetic interaction. Since the quark masses cannot be measured directly the observation of isospin or/and charge symmetry violation for hadrons opens a unique window to study the quark mass term of the Quantum Chromo Dynamics.

We have conducted a study of the isospin and charge symmetry violation in low energy pion production reactions [1]. The expected symmetry breaking effects are very small. Therefore it was necessary to apply specially developed detection methods and techniques, which allowed for a strong suppression of systematic uncertainties [2,3].

In the first stage of our investigations the ratio of cross sections for $pd\to{}^3H\pi^+/{}^3He\pi^0$ reactions was measured at the beam momenta close to the excitation of a Δ resonance in the intermediate state [4-6]. The measured cross section dependence on the four momentum transfer consists of two components. For the large momentum transfer component the slope is independent on the beam momentum but is different for ${}^3H\pi^+$ and ${}^3He\pi^0$ channels, what violates isospin symmetry. The small momentum transfer component, which is almost isotropic, is in agreement with IS.

More detailed studies of the above processes were performed at the beam momenta close to the threshold for the $pd\to{}^3He\eta$ reaction [7-10]. It was expected that in this region the isospin symmetry breaking should be large due to so called π^0-η meson mixing. The experimental results shown in figure 1 reveal the expected variation of the cross section ratio. The detailed, quite tedious, theoretical analysis of extracting the π^0-η meson mixing angle is in progress.

We proposed also measurements of the charge symmetry forbidden reactions. The expected cross sections are of the order of picobarns. Therefore up to now the measurements were not possible. The new detection system WASA installed at COSY accelerator opens possibilities to perform such studies. Within WASA collaboration the investigations will address charge symmetry forbidden reactions $dd\to{}^4He\pi^0$ and $dd\to dd\pi^0$, together with the CS allowed channels ($dd\to{}^3Hen\pi^0$, $dd\to{}^3Hp\pi^0$, …), necessary for the theoretical interpretation. The use of polarized deuteron beam enables us also to study charge symmetry breaking in the deuteron break-up reaction $dd\to dpn$. Such a complete set of data, analyzed on the basis of the Chiral Perturbation Theory, would allow to conclude on the mass difference of up and down quarks.

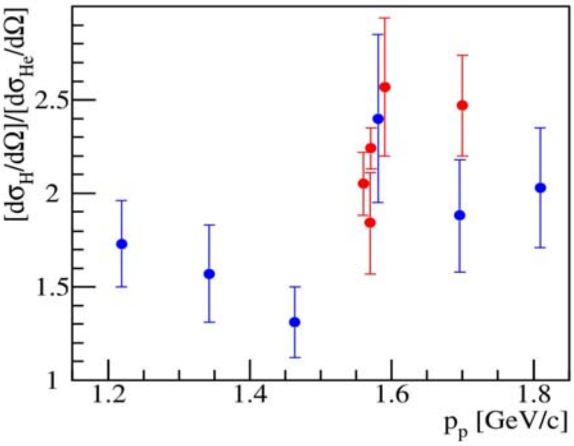

Fig. 1. *Beam momentum dependence of the differential cross section ratio for $pd\to{}^3H\pi^+$ and $pd\to{}^3He\pi^0$ reactions. Blue points represent the values calculated using results of previous measurements. Red points show the results of our experiment, in which both reactions channels were measured simultaneously.*

[1] **A. Magiera**, H. Machner, Nucl. Phys. **A674**, 515 (2000).

[2] M. Betigeri, **E. Białkowski**, H. Bojowald, **A. Budzanowski**, A. Chatterjee, M. Drochner, J. Ernst, S. Förtsch, **L. Freindl**, D. Frekers, W. Garske, K. Grewer, A. Hamacher, S. Igel, J. Ilieva, **L. Jarczyk**, M. Jochmann, G. Kemmerling, K. Kilian, **S. Kliczewski**, **W. Klimala**, D. Kolev, T. Kutsarova, J. Lieb, G. Lippert, H. Machner, **A. Magiera**, H. Nann, E. Pentchev, H.S. Plendl, D. Protic, B. Razen, P. von Rossen, B.J. Roy, **R. Siudak**, **J. Smyrski**, R.V. Srikantiah, **A. Strzałkowski**, R. Tsenov, **P.A. Żołnierczuk**, K. Zwoll, Nucl. Inst. Methods A **421**, 447 (1999).

[3] J. Bojowald, **A. Budzanowski**, A. Chatterjee, J. Ernst, **L. Freindl**, D. Frekers, **P. Hawranek**, J. Ilieva, **L. Jarczyk**, K. Kilian, **S. Kistryn**, **S. Kliczewski**, **W. Klimala**, D. Kolev, M. Kravcikova, T. Kutsarova, J. Lieb, H. Machner, **A. Magiera**, G. Martinska, L. Pentchev, D. Protic, B. Razen, P. von Rossen, B.J. Roy, **R. Siudak**, **J. Smyrski**, **A. Strzałkowski**, R. Tsenov, M. Ulicny, J. Urban, **A. Wrońska**, Nucl. Inst. Methods A **487**, 314 (2002).

[4] M.G. Betigeri, J. Bojowald, **A. Budzanowski**, A. Chatterjee, I. Ilieva, **L. Jarczyk**, K. Kilian, **S. Kliczewski**, **W. Klimala**, D. Kolev, T. Kutsarova, B.J. Lieb, H. Machner, **A. Magiera**, H. Nann, E. Pentchev, H.S. Plendl, D. Protic, B. Razen, P. von Rossen, B.J. Roy, **R. Siudak**, **A. Strzałkowski**, R. Tsenov, K. Zwoll, Nucl. Phys. **A663&664**, 963c (2000).

[5] M. Betigeri, J. Bojowald, **A. Budzanowski**, A. Chatterjee, J. Ernst, L. Freindl, D. Frekers, W. Garske, K. Grewer, A. Hamacher, J. Ilieva, **L. Jarczyk**, K. Kilian, **S. Kliczewski**, **W. Klimala**, D. Kolev, T. Kutsarova, J. Lieb, H. Machner, **A. Magiera**, H. Nann, L. Pentchev, H.S. Plendl, D. Protic, B. Razen, P. von Rossen, B.J. Roy, **R. Siudak**, **A. Strzałkowski**, R. Tsenov, K. Zwoll, Nucl. Phys. **A690**, 473 (2001).

[6] S. Abdel-Samad, J. Bojowald, **A. Budzanowski**, A. Chatterjee, J. Ernst, D. Frekers, **P. Hawranek**, J. Ilieva, **L. Jarczyk**, K. Kilian, **S. Kliczewski**, **W. Klimala**, D. Kolev, M. Kravcikova, T. Kutsarova, J. Lieb, H. Machner, **A. Magiera**, G. Martinska, H. Nann, L. Pentchev, D. Protic, P. von Rossen, B.J. Roy, **R. Siudak**, **A. Strzałkowski**, R. Tsenov, M. Ulicny, J. Urban, K. Zwoll, Phys. Lett. B **553**, 31 (2003).

[7] M. Abdel-Bary, **P. Hawranek**, J. Ilieva, K. Kilian, D. Kirilov, **St. Kistryn**, **S. Kliczewski**, **W. Klimala**, D. Kolev, M. Kravcikova, T. Kutsarova, J. Lieb, H. Machner, **A. Magiera**, G. Martinska, L. Pentchev, N. Piskunov, P. von Rossen, B.J. Roy, I. Sitnik, **R. Siudak**, **J. Smyrski**, R. Tsenov, M. Ulicny, J. Urban, **A. Wrońska**, Phys. Rev. C **68**, 021603 (2003).

[8] H. Machner, S. Abdel-Samad, J. Bojowald, **A. Budzanowski**, A. Chatterjee, J. Ernst, D. Frekers, W. Garske, **P. Hawranek**, J. Ilieva, R. Jahn, **L. Jarczyk**, K. Kilian, D. Kirillov, **S. Kliczewski**, **W. Klimala**, D. Kolev, M. Kravcikova, T. Kutsarova, J. Lieb, **A. Magiera**, G. Martinska, H. Nann, L. Pentchev, N. Piskunov, D. Protic, P. von Rossen, B.J. Roy, I. Sitnik, **R. Siudak**, M. Ulicny, **A. Strzałkowski**, R. Tsenov, J. Urban, K. Zwoll, Prog. Part. Nucl. Phys. **50**, 605 (2003).

[9] J. Bojowald, **A. Budzanowski**, A. Chatterjee, J. Ernst, **L. Freindl**, D. Frekers, **P. Hawranek**, J. Ilieva, **L. Jarczyk**, V. Jha, K. Kilian, D. Kirilov, **S. Kliczewski**, **W. Klimala**, D. Kolev, M. Kravcikova, T. Kutsarova, J. Lieb, H. Machner, **A. Magiera**, G. Martinska, H. Nann, L. Penchev, N. Piskunov, D. Protic, P. von Rossen, B.J. Roy, I. Sitnik, **R. Siudak**, **A. Strzałkowski**, R. Tsenov, M. Ulicny, J. Urban, **A. Wrońska**, Few-Body Systems Supplement **15**, 61 (2003).

[10] S. Abdel-Samad, J. Bojowald, **A. Budzanowski**, A. Chatterjee, J. Ernst, D. Frekers, **P. Hawranek**, J. Ilieva, **L. Jarczyk**, K. Kilian, **S. Kliczewski**, **W. Klimala**, D. Kolev, M. Kravcikova, T. Kutsarova, J. Lieb, H. Machner, **A. Magiera**, G. Martinska, H. Nann, L. Pentchev, D. Protic, P. von Rossen, B.J. Roy, **R. Siudak**, **A. Strzałkowski**, R. Tsenov, M. Ulicny, J. Urban, K. Zwoll, Eur. Phys. J. **A18**, 367 (2003).

NUCLEAR STATES OF η, K MESONS, Σ HYPERONS & ANTIPROTONS

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Experimental facilities: CELSIUS (Uppsala), COSY(Juelich)

The search for nuclear states of exotic hadrons follow the polish tradition of hypernuclear studies. However, the physics of these new states is different in two aspects: the states are short-lived and the mechanisms of nuclear attraction is apparently not related to the standard forces due to meson exchange. In the cases of K and η mesons the mechanism of the binding is due to internal excitations of nucleons. Thus η mesons excite N*(1535) which is an external state to the N η system and is composed of quarks. The K mesons excite Λ(1405) which may be a KN bound state mixed with a quark state. Thus the interest in this field is motivated by studies of these resonances and the way their properties are affected by the nuclear medium.

The N η state is coupled strongly to N π state and such systems may be described by a real reaction matrix Ķ. Since there are no η meson beams, matrix Ķ at low energies is not well determined by the experimental meson-nucleon scattering data. Final state interactions of η in few nucleon system yield additional valuable data. The figure indicates strong attraction of η and deuteron at low energies [1]. The peak at threshold reflects existence of a quasi-bound or a virtual state in the η-d system. A similar behavior was found in η-He systems in Saclay and Uppsala [2]. Strong interactions are also found in the N-N-η systems at low energies [3,4] but these are more difficult to interpret. Experiments were performed to discover η bound to heavier nuclei but none was successful, apparently due to high background and/or large widths of those states.

These interactions have been studied by theorists in our institute. A phenomenological Ķ matrix for N-η system was elaborated [5] and applied to studies of η-d [6] and η-He final state interactions [7]. A system of full three body equations was used to find the η-d scattering length [8] and a formalism was given to discuss the final three body ηNN states [9]. One conclusion is that the in deuteron and in ^{3}He η meson forms a virtual state but in ^{4}He the state is bound but unstable. While the main decay mode is due to the pion decay channel the two nucleon capture is also sizable [10].

The idea that K meson may be bound in nuclei existed for a long time, and one expectation was that this binding may be strong enough to make such states long-lived [11]. Discoveries of such states in KNNN and KNN systems were reported by Japanese and Italian groups, but these leave some uncertainty in the interpretation. The binding mechanism may be due to excitation of nucleon to Λ(1405) but also to Σ(1385) [12].

The nuclear potential for Σ hyperon, is known from Σ atoms [13] to be attractive at the nuclear surface. Inside nuclei this potential was calculated with the Nijmegen models of the baryon-baryon interaction. The analysis of the $(K^-,\pi^\pm)$ and (π^-,K^+) reactions suggest that V_Σ is repulsive inside nuclei [14,15]. This makes the existence of large Σ hypernuclei unlikely.

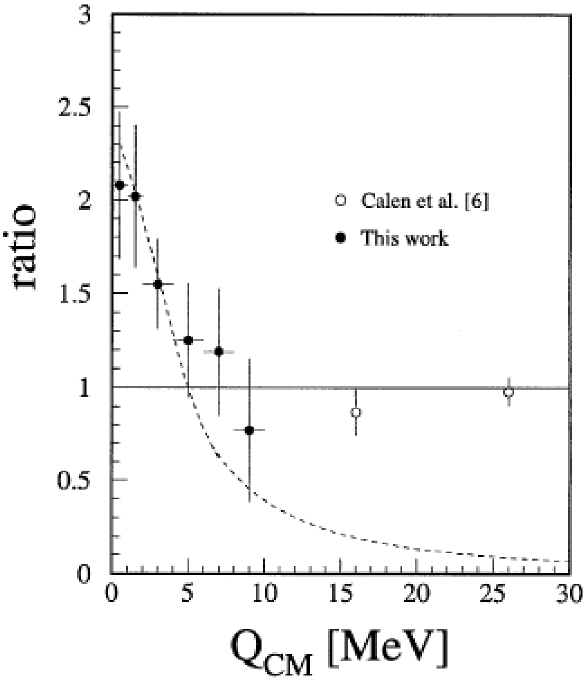

Fig. 1. The cross section for pp→dη divided by phase space. Q – energy excess.

[1] H. Calén, J. Dyring, K. Fransson, L. Gustafsson, S. Häggström, B. Höistad, J. Johanson, A. Johansson, T. Johansson, A. Khoukaz, S. Kullander, R. J. M. Y. Ruber, and J. Złomańczuk B. Morosov, A. Povtorejko, A. Sukhanov, and A. Zernov, **A.Kupść, P.Marciniewski, J. Stepaniak,** R. Bilger, W. Brodowski, H. Clement, and G. J. Wagner ,C. Ekström **, J.Zabierowski,** A. Bondar, A. Kuzmin, B. Shwartz, V. Sidorov, and A. Sukhanov , **A.Turowiecki ,Z.Wilhelmi,** K. Kilian, W. Oelert, and T. Sefzick V. Sopov and V. Tchernychev Phys.Rev.Lett.**80**(1998) 2069

[2].R. Bilger, W. Brodowski, H. Calén, H. Clement, C. Ekström, G. Fäldt, K. Fransson, L. Gustafsson, B. Höistad, A. Johansson, T. Johansson, K. Kilian, S. Kullander, **A.Kupść** , G. Kurz, P. Marciniewski, B. Morosov, A. Mörtsell, W. Oelert, V. Renken, R. J. M. Y. Ruber, B. Shwartz, **J. Stepaniak**, A. Sukhanov, P. Thörngren-Engblom, A. Turowiecki, G. J. Wagner, **Z.Wilhelmi**, C. Wilkin, **J.Zabierowski**, and J. Złomańczuk, Phys.Rev.**C65**(2002)044608

[3] M. Abdel-Bary, S. Abdel-Samad, R. Bilger, K.-Th. Brinkmann, H. Clement, S. Dshemuchadse, E. Dorochkevitch, H. Dutz, W. Eyrich, A. Erhardt, D. Filges, A. Filippi, H. Freiesleben, M. Fritsch, R. Geyer, A. Gillitzer, D. Hesselbarth, B. Jakob, L. Karsch, K. Kilian, H. Koch, J. Kreß, E. Kuhlmann, S. Marcello, S. Marwinski, S. Mauro, W. Meyer, P. Michel, K. Möller, H. P. Morsch, L. Naumann, N. Paul, M. Richter, E. Roderburg, M. Rogge, A. Schamlott, M. Schmitz, P. Schönmeier, M. Schulte-Wisserman, W. Schroeder, T. Sefzick, F. Stinzing, G.Y. Sun, G.J. Wagner, M. Wagner, A. Wilms, P. Wintz, S. Wirth and , **P.Żuprański** , Eur. Phys.Journ. **A16**(2003)127

[4] H. Calén, J. Dyring, K. Fransson, L. Gustafsson, S. Häggström, B. Höistad, A. Johansson, T.Johansson, S.Kullander, A. Mörtsell, R. Ruber, U. Schuberth, J. Złomańczuk ,C. Ekström K. Kilian, W. Oelert, T. Sefzick ,R. Bilger, W. Brodowski, H. Clement, G. J. Wagner ,A. Bondar, A. Kuzmin, B. Shwartz, V. Sidorov, A. Sukhanov, **A.Kupść, P.Marciniewski, J. Stepaniak,** V. Dunin, B. Morosov, A. Povtorejko, A. Sukhanov, A. Zernov , **J.Zabierowski, A.Turowiecki , Z.Wilhelmi ,** Phys.Rev.**C58**(1998)2667.

[5] A.M.Green and **S. Wycech,** Phys. Rev.C 71 (2005)014001, Phys.Rev. **C 55** (1997) 2167R

[6] **S. Wycech** A.M.Green, Phys.Rev. **C 64** (2001) 045206.

[7] A.M.Green and **S. Wycech** , Phys. Rev.**C 69** (2003)

[8] **A.Deloff** , Phys. Rev. **C61** (2000) 024004

[9] **A.Deloff** , Phys. Rev. **C69** (2004) 035206

[10] **J.Kulpa S. Wycech,** Acta.Phys.Pol. **71** (2005)014001

[11] **S. Wycech,** Nucl.Phys. **A450** (1986)399c

[12] A.M.Green and **S. Wycech,** Int.Journ.Mod.Phys. (2007).

[13] **J.Dąbrowski, J.Rożynek,** G.S.Anagnostatos, Eur.Phys.Journ.A **14**, 125 (2002).

[14] **J.Dąbrowski, J.Rożynek**, Int.Journ.Mod.Phys.E **16**, 603 (2007).

[15] **J.Dąbrowski**, Phys.Rev.C **60**, 025205 (1999}

HYPERON RESONANCES PRODUCED IN PROTON-PROTON COLLISIONS

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Experimental facility: ANKE at COSY, IKP, Forschungszentrum Jülich, Germany

The question of how hadrons arise from QCD is central to a fundamental understanding of hadronic multiquark and gluon systems. New experimental data may pave the way to achieve this understanding in conjunction with lattice QCD, which is poised to provide the theoretical insight into strong QCD.

The production of hyperons and their decay properties have been a focus of experimental investigations ever since their discovery, mostly in hadron-induced reactions. In comparison to the excitation spectrum of the nucleon resonances (N, Δ), the excited states of hyperons (Λ, Σ) are still much less well known. Of particular interest is the Λ(1405) where quark models have difficulties to explain its low mass, and which alternatively has been interpreted as a $\overline{K}N$ bound state or it may even be of exotic type. On the other hand, the Σ(1480) hyperon is far from being an established resonance. Our program is thus focused on the investigation of production and decay of hyperons produced in pp collisions.

At the COoler SYnchrotron COSY at the IKP-Forschungszentrum Jülich hyperons Y^0 with masses up to 1540 MeV/c² are produced directly in $pp \to pK^+Y^0$ reactions at a proton beam momentum of up to 3.65 GeV/c. The detection systems of the magnetic spectrometer ANKE, placed at one internal target position of COSY, simultaneously register particles of either charge and measure their momenta [1-5]. Indications for the production of a neutral excited hyperon have been found in reactions induced by protons incident on a hydrogen cluster-jet target by detecting charged pions from the heavy hyperon decays (like $\Sigma^0(1480) \to \Sigma^{\pm}\pi^{\mp}$) in coincidence with K^+p pairs. Consistent results were obtained for both final states providing an evidence for the production of a neutral excited hyperon with a mass of (1480±15) MeV/c² and a width of (60±15) MeV/c². The production cross section is of the order of few hundred nanobarns. Since the isospin of the Y^{0*} has not been determined here, it could either be an observation of the Σ⁰(1480) or alternatively of the Λ(1480) hyperon. Relativistic quark models for the baryon spectrum do not predict any excited hyperon in this mass range and so the Y^{0*} may be of exotic nature [6].

In addition, in the $pp \to K^+pY^0$ reaction we have been investigating the decay of Y^{0*} hyperons via $\Sigma^0\pi^0$. Such a decay mode allows to separate Λ(1405) from the lighter but overlapping hyperon Σ^0(1385) and thus gives the line shape of the Λ(1405). Preliminary cross section for the production of Λ(1405) in the reaction at 3.65 GeV/c beam is estimated to be of the order of few microbarns.

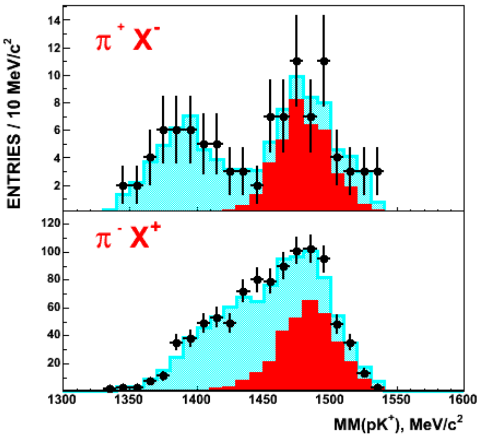

Fig. 1. *Missing-mass MM(pK⁺) spectra for the reaction $pp \to pK^+\pi^+X^-$ (upper part) and $pp \to pK^+\pi^-X^+$ (lower). Experimental points with statistical errors are compared to the fitted overall Monte Carlo simulations (shaded histogram, blue). The contribution from the Y^{0*} resonance with a mass of (1480±15) MeV/c² and a width of (60±15) MeV/c² is shown as a solid histogram (red).*

[1] S. Barsov, U. Bechstedt, W. Bothe, N. Bongers, G. Borchert, W. Borgs, W. Brautigam, M. Buescher, W. Cassing, V. Chernyshev, B. Chiladze, J. Dietrich, M. Drochner, S. Dymov, W. Erven, R. Esser, A. Franzen, E.S. Golubeva, D. Gotta, T. Grande, D. Grzonka, A. Hardt, M. Hartmann, V. Hejny, L.v.Horn, **L. Jarczyk**, H. Junghans, A. Kacharava, **B. Kamys**, A. Khoukaz, T. Kirchner, F. Klehr, W. Klein, H.R. Koch, V.I. Komarov, L. Kondratyuk, V. Koptev, S. Kopyto, R. Krause, P. Kravtsov, V. Kruglov, **P. Kulessa**, A. Kulikov, N. Lang, N. Langenhagen, A. Lepges, J. Ley, R. Maier, S. Martin, G. Macharashvili, S. Merzlyakov, K. Meyer, S. Mikirtychyants, H. Muller, P. Munhofen, A. Mussgiller, M. Nekipelov, V. Nelyubin, M. Nioradze, H. Ohm, A. Petrus, D. Prasuhn, B. Prietzschk, H.J. Probst, **K. Pysz**, F. Rathmann, B. Rimarzig, Z. Rudy, R. Santo, H. Paetz gen.Schieck, R. Schleichert, A. Schneider, C. Schneider, H. Schneider, U. Schwarz, H. Seyfarth, A. Sibirtsev, U. Sieling, K. Sistemich, A. Selikov, H. Stechemesser, H.J. Stein, **A. Strzalkowski**, K.H. Watzlawik, P. Wustner, S. Yashchenko, B. Zalikhanov, N. Zhuravlev, K. Zwoll, **I.. Zychor**, O.W.B. Schult, H. Ströher, Nucl.Instrum. Meth. **A462**, 364 (2001)

[2] V. Koptev, M. Buescher, H. Junghans, M. Nekipelov, K. Sistemich, H. Ströher, V. Abaev, H.-H. Adam, R. Baldauf, S. Barsov, U. Bechstedt, N. Bongers, G. Borchert, W. Borgs, W. Braeutigam, W. Cassing, V. Chernyshev, B. Chiladze, M. Debowski, J. Dietrich, M. Drochner, S. Dymov, J. Ernst, W. Erwen, R. Esser, P. Fedorets, A. Franzen, D. Gotta, T. Grande, D. Grzonka, G. Hansen, M. Hartmann, V. Hejny, L.v.Horn, **L. Jarczyk**, A. Kacharava, **B. Kamys**, A. Khoukaz, T. Kirchner, F. Klehr, H.R. Koch, V.I. Komarov, S. Kopyto, R. Krause, P. Kravtsov, V. Kruglov, **P. Kulessa**, A. Kulikov, V. Kurbatov, N. Lang, N. Langenhagen, I. Lehmann, A. Lepges, J. Ley, B. Lorentz, G. Macharashvili, R. Maier, S. Martin, S. Merzliakov, K. Meyer, S. Mikirtychyants, H. Mueller, P. Munhofen, A. Mussgiller, V. Nelubin, M. Nioradze, H. Ohm, A. Petrus, D. Prasuhn, B. Prietzschk, H.J. Probst, D. Protic, K. Pysz, F. Rathmann, B. Rimarzik, Z. Rudy, R. Santo, H. Paetz gen. Schieck, R. Schleichert, A. Schneider, Chr. Schneider, H. Schneider, G. Schug, O.W.B.Schult, H. Seyfarth, A. Sibirtsev, H. Stechemesser, H.J. Stein, **A. Strzalkowski**, K.H. Watzlawik, C. Wilkin, P. Wuestner, S. Yashenko, B. Zalikhanov, N. Zhuravlev, **P. Zolnierczuk**, K. Zwoll, **I. Zychor**, Phys. Rev. Lett. **87**, 022301 (2001)

[3] M. Buescher, H. Junghans, V. Koptev, M. Nekipelov, K. Sistemich, H. Ströher, S. Barsov, G. Borchert, W. Borgs, **M. Debowski**, W. Erven, R. Esser, P. Fedorets, D. Gotta, M. Hartmann, V. Hejny, A. Kacharava, H.R. Koch, V. Komarov, **P. Kulessa**, A. Kulikov, G. Macharashvili, S. Merzlyakov, S. Mikirtychyants, H. Muller, A. Mussgiller, R. Nellen, M. Nioradze, H. Ohm, A. Petrus, F. Rathmann, **Z. Rudy**, R. Schleichert, C. Schneider, O.W.B. Schult, H.J. Stein, **I. Zychor**, Nucl. Instrum. Meth. **A481**, 378 (2002)

[4] **I.Zychor**, Acta Phys. Polon. **B33,** 521 (2002)

[5] V. Kleber, M. Buescher, V. Chernyshev, S. Dymov, P. Fedorets, V. Grishina, C. Hanhart, M. Hartmann, V. Hejny, A. Khoukaz, H.R. Koch, V. Komarov, L. Kondratyuk, V. Koptev, N. Lang, S. Merzliakov, S. Mikirtychyants, M. Nekipelov, H. Ohm, A. Petrus, D. Prasuhn, R. Schleichert, A. Sibirtsev, H.J. Stein, H. Ströher, K.H. Watzlawik, P. Wustner, S. Yaschenko, B. Zalikhanov, **I. Zychor**, Phys. Rev. Lett. **91**, 172304 (2003)

[6] **I. Zychor**, V. Koptev, M. Buescher, A. Dzyuba, I. Keshelashvili, V. Kleber, H.R. Koch, S. Krewald, Y. Maeda, S. Mikirtychyants, M. Nekipelov, H. Ströher, C. Wilkin, Phys. Rev. Lett. **96**, 012002 (2006)

NONMESONIC DECAY OF Λ - HYPERON IN HEAVY HYPERNUCLEI

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Experimental facility: Cooler Synchrotron COSY, Forschungszentrum Juelich

The nonmesonic Λ-decay $\Lambda+N \rightarrow N+N$ represents an example for the nonleptonic weak interaction of baryons with a change of strangeness ($\Delta S = 1$) and isospin ($\Delta I = 1/2$ or $3/2$). The study of the nonmesonic decay, which proceeds via a weak interaction only (the Coulomb and strong interactions preserve the strangeness) allows to study both parity violating and parity conserving amplitudes in contrast to *e.g.* the nucleon-nucleon weak interaction, where the latter amplitudes are completely masked by strong and Coulomb forces. The only possibility to study nonmesonic decay of Λ-hyperon is investigation of hypernuclei since at present neither beams nor targets of hyperons are available. Heavy hypernuclei are favorized for this purpose, because another mode of the Λ-hyperon decay, *i.e.* $\Lambda \rightarrow \pi+N$, which dominates decay of free hyperons is strongly Pauli blocked for all but the lightest hypernuclei. We report here on the investigations of production and decay of heavy hypernuclei in proton interaction with Au, Bi, and U targets [1-9]. The experiments have been performed on the internal beam of COSY accelerator in Forschungszentrum Juelich using proton beams of two energies: 1 GeV, which is below the threshold for Λ-hyperon production, and 1.5 or 1.9 GeV at which hyperons can be produced. The thin targets of Au, Bi or U (thickness of order of 30 μg/cm^2) with thin carbon backing [5] , placed in the circulating beam of COSY accelerator were bombarded with 1 GeV and 1.5 (1.9) GeV protons in the subsequent acceleration cycles. This allowed for background measurement (at 1 GeV) and hypernucleus production (at higher energies) under identical target conditions. The recoil shadow metod has been applied for measurement of lifetime of heavy hypernuclei produced in p+Bi [4], p+Au [7] and p+U [8] reactions. Details of the experimental setup and procedure are described in Ref. [5] whereas properties of the produced hypernuclei and the probability of their production and decay were subject of theoretical estimations in Refs. [1,2]. The following lifetimes of the Λ-hyperon have been obtained in the reported investigations: 130±20 ps (Au target), 161±16 ps (Bi target) and 138±18 ps (U target) giving the average value of the lifetime of Λ-hyperon in heavy hypernuclei 145±11 ps, in excellent agreement with results of studies performed with antiprotons on Bi and U targets (Phys.Rev. **C47,** 1957 (1993)) , i.e. 143±36 ps, however, much more accurate. The lifetimes obtained from electron induced production of heavy hypernuclei on Bi and U targets (Sov. J. Nucl. Phys **43**, 856 (1986); **46**, 769 (1987)) are order of magnitude larger. Our experiments can give estimation on cross section of such long living hypernuclei to be smaller than 80 nanobarns whereas cross section for production of hypernuclei with lifetime of about 145 ps was found to be ~ 350 microbarns.

In summary, the performed experiments have lead to the most precise value of the lifetime of Λ - hyperons in very heavy nuclei known up to now.

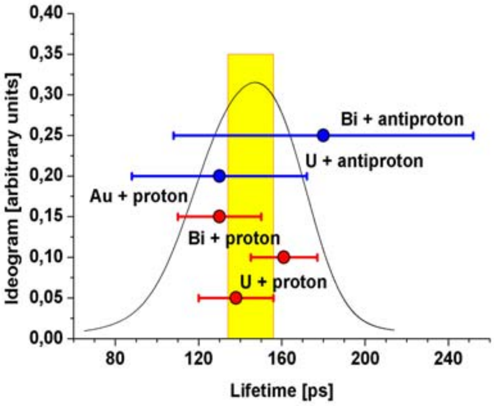

Fig.1. *The lifetimes of proton- and antiproton-produced hypernuclei on Au, Bi and U targets. The horizontal bars present the statistical and systematic errors added in quadrature. The position and width of the yellow vertical bar display the overall average value for the lifetime and its error, respectively. The smooth curve was evaluated adding Gaussian curves representing results from individual experiments.*

[1] **Z. Rudy**, **T.Demski**, **L. Jarczyk**, **B. Kamys**, **P. Kulessa**, **A. Strzałkowski**, W. Cassing, O.W.B. Schult, Z. Phys. **A351**, 217 (1995).

[2] **Z. Rudy**, W.Cassing, **L. Jarczyk**, **B. Kamys**, **P. Kulessa**, O.W.B. Schult, **A. Strzałkowski**, Z. Phys. **A354**, 445 (1996)

[3] H. Ohm, T. Hermes, W. Borgs, H.R. Koch, R. Maier, D. Prasuhn, H.J. Stein, O.W.B. Schult, **K. Pysz**, **Z. Rudy**, **L. Jarczyk**, **B. Kamys**, **P. Kulessa**, **A. Strzałkowski**, W. Cassing, Y. Uozumi, **I. Zychor**, Phys. Rev. **C55**, 3062 (1997)

[4] **P. Kulessa**, **Z. Rudy**, M. Hartmann, **K. Pysz**, **B. Kamys**, **I. Zychor**, H. Ohm, **L. Jarczyk**, **A. Strzałkowski**, W.Cassing, H. Hodde, W. Borgs, H.R. Koch, R. Maier, D. Prasuhn, M. Matoba, **Z. Rudy**, Phys. Lett. **B427**, 403 (1998)

[5] **K. Pysz**, **I. Zychor**, T. Hermes, M. Hartmann, H. Ohm, **P. Kulessa**, W. Borgs, H.R. Koch, R. Maier, D. Prasuhn, **Z. Rudy**, **B. Kamys**, W. Cassing, J. Pfeiffer, Y. Uozumi, **L. Jarczyk**, **A. Strzałkowski**, O.W.B. Schulz, Nucl. Inst. Meth. **A420**, 356 (1999)

[6] W. Cassing, **L. Jarczyk**, **B. Kamys**, **P. Kulessa**, **Z. Rudy**, **Z. Rudy**, **A. Strzałkowski**, Eur. Phys. J. **A5**, 127 (2001)

[7] **B. Kamys**, **P. Kulessa**, H. Ohm, **K. Pysz**, **Z. Rudy**, H. Stroeher, Eur. Phys. J. **A11**, 1 (2001)

[8] **P. Kulessa**, W. Cassing, **L. Jarczyk**, **B. Kamys**, H. Ohm, **K. Pysz**, **Z. Rudy**, H. Stroeher, Acta Phys. Polon. **B33**, 603 (2002)

[9] W. Cassing, **L. Jarczyk**, **B. Kamys**, **P. Kulessa**, H. Ohm, **K. Pysz**, **Z. Rudy**, O.W.B. Schult, H. Stroeher, Eur. Phys. J. **A16,** 549 (2003)

INTERACTION OF THE η AND η' MESONS WITH NUCLEONS

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Experimental facility: COSY-11 facility at the Cooler Synchrotron COSY, Jülich, Germany

In the low energy regime where the interaction between quarks and gluons cannot be treated perturbatively, there exists no clear understanding of the processes governed by the strong forces. The phenomena in this regime are not calculable using the particles and fields of the Standard Model. Here hadrons become the relevant degrees of freedom and the knowledge of their interactions is of the basic importance. In this report we give account of the studies of the interactions between the η and η' mesons with nucleons. It is rather challenging to conduct such research because these mesons decay within a distance of tens of femtometers rendering their direct detection impossible. It is also completely unfeasible to accomplish out of them a beam or a target. Therefore, we have produced these mesons in the collisions of protons close to the kinematical threshold where the outgoing particles possess low relative velocities and remain in the distance of few femtometers long enough to experience the strong interaction which may manifest itself in a measurable manner.

Using the stochastically cooled proton beam of the cooler synchrotron COSY and the COSY-11 facility we have conducted measurements of the pp→ppη and pp→ppη' reactions close to the kinematical threshold. The remarkable difference between the shape of the excitation functions of the pp→ppη and pp→ppη' reactions allowed to conclude that the interaction between the η' meson and the proton is significantly weaker than the analogous η-proton interaction. This is the first ever empirical appraisal of this hitherto entirely unknown force. As far as the production dynamics is concerned, the observed large difference of the total cross sections for the creation of the η and η' mesons indicates that they are produced via different mechanisms. The large cross section for the η meson implies that it is created via baryonic resonance.

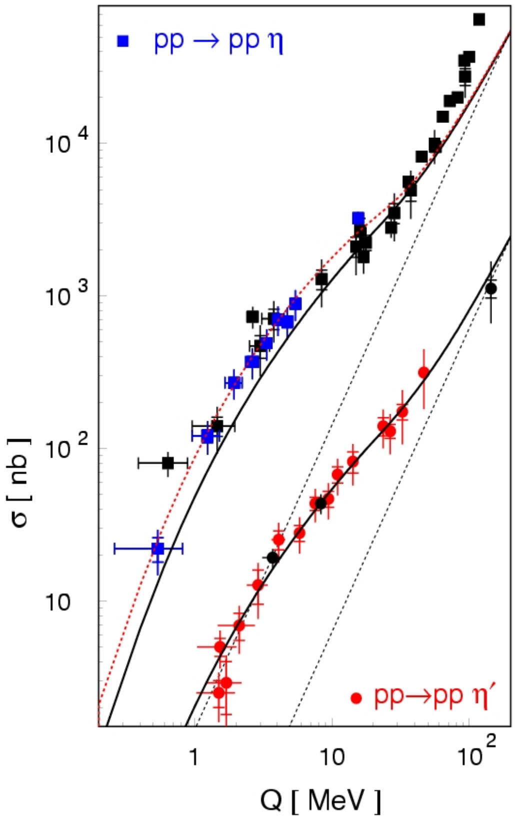

Fig. 1. *Total cross section as a function of the excess energy Q for the reactions pp→ppη (squares) and pp→ppη' (circles). The results determined using the COSY-11 setup and the synchrotron COSY (red and blue) are shown together with the data from the CELSIUS and SATURNE facilities (black). The dashed lines indicate a phase space integral normalized arbitrarily. The solid lines show the phase space distribution with inclusion of the proton-proton strong and Coulomb interaction. The result of calculations taking into account additionally the interaction between the η meson and the proton is presented by the red dotted line.*

[1] **P. Moskal, J.T. Balewski, A. Budzanowski,** H. Dombrowski, C. Goodman, D. Grzonka, J. Haidenbauer, C. Hanhart, **L. Jarczyk**, M. Jochmann, A. Khoukaz, K. Kilian, M. Köhler, **A. Kozela,** T. Lister,U.G. Meissner, N. Nikolaev, W. Oelert, C. Quentmeier, R. Santo, G. Schepers, U. Seddik, T. Sefzick, **J. Smyrski, M. Sokołowski, A. Strzałkowski,** C. Thomas, M. Wolke, P. Wüstner, **D. Wyrwa,** Phys. Rev. Lett. **80** (1998) 3202

[2] V. Baru, J. Haidenbauer, C. Hanhart, A. Kudryavtsev, **P. Moskal,** J. Speth, Eur. Phys. J. **A6** (1999) 445

[3] **J. Smyrski,** P. Wüstner, **J.T. Balewski, A. Budzanowski,** H. Dombrowski, D. Grzonka, **L. Jarczyk**, M. Jochmann, A. Khoukaz, K. Kilian, **P. Kowina**, M. Köhler, T. Lister, **P. Moskal,** W. Oelert, C. Quentmeier, R. Santo, G. Schepers, U. Seddik, T. Sefzick, S. Sewerin, **A. Strzałkowski,** C. Thomas,M. Wolke, Phys. Lett. **B 474** (2000) 182

[4] **P. Moskal,** H.H. Adam, **J.T. Balewski,** V. Baru, **A. Budzanowski,** D. Grzonka, J. Haidenbauer, **L. Jarczyk**, A. Khoukaz, K. Kilian, M. Köhler, **P. Kowina,** A. Kudryavtsev, N. Lang, T. Lister, W. Oelert, C. Quentmeier, R. Santo, G. Schepers, T. Sefzick, S. Sewerin, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** M. Wolke, P. Wüstner, **W. Zipper,** Phys. Lett. **B 474** (2000) 416

[5] **P. Moskal,** H.H. Adam, **J.T. Balewski, A. Budzanowski,** J. Budziński, D. Grzonka, **L. Jarczyk,** A. Khoukaz, K. Kilian, **P. Kowina,** N. Lang, T. Lister, W. Oelert, C. Quentmeier, R. Santo, G. Schepers, T. Sefzick, S. Sewerin, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** M. Wolke, P. Wüstner, **W. Zipper,** Phys. Lett. **B 482** (2000) 356

[6] P. Winter, H.H. Adam, F. Bauer, **A. Budzanowski, R. Czyżykiewicz,** T. Götz, D. Grzonka, **L. Jarczyk**, A. Khoukaz, K. Kilian, C. Kolf, **P. Kowina,** N. Lang, T. Lister, **P. Moskal,** W. Oelert, C. Quentmeier, **T. Rozek,** R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski,** S. Steltenkamp, **A. Strzałkowski,** M. Wolke, P. Wüstner, **W. Zipser,** Phys. Lett. **B 544** (2002) 251

[7] **P. Moskal,** M. Wolke, A. Khoukaz, W. Oelert, Prog. Part. Nucl. Phys. **49** (2002) 1

[8] A. Khoukaz, I. Geck, C. Quentmeier, H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **L. Jarczyk**, K. Kilian, **P. Kowina,** N. Lang, T. Lister, **P. Moskal,** W. Oelert, **C. Piskor-Ignatowicz, T. Rożek,** R. Santo, G. Schepers, T. Sefzick, S. Sewerin, **M. Siemaszko, J. Smyrski,** S. Steltenkamp,**A. Strzałkowski,** P. Winter, M. Wolke, P. Wüstner, **W. Zipper,** Eur. Phys. J. **A 22** (2004) 293

[9] **P. Moskal,** H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Kowina,** K. Nakayama, W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa, T. Rożek,** R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski,** S. Steltenkamp, A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper,** Phys. Rev. **C 69** (2004) 025203

[10] **P. Klaja, P. Moskal,** H.H. Adam, **A. Budzanowski, E. Czerwiński, R. Czyżykiewicz, D. Gil,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **J. Majewski, W. Migdał,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** J. Ritman, **T. Rożek,** R. Santo, T. Sefzick, **M. Siemaszko, J. Smyrski,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, Z. Zhang, **W. Zipper,** Acta Phys. Slov. **56** (2006) 251

[11] **R. Czyżykiewicz, P. Moskal,** H.H. Adam, **A. Budzanowski, E. Czerwiński, D. Gil,** D. Grzonka,**M Hodana, M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Klaja,** B. Lorentz, W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa, B. Rejdych,** J. Ritman, T. Sefzick, **M. Siemaszko, J. Smyrski,** A. Täschner, K. Ulbrich, P. Winter, M. Wolke, P. Wüstner, **W. Zipper,** Phys. Rev. Lett**. 98** (2007) 122003

INVESTIGATION OF THE HYPERON-NUCLEON INTERACTION

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Experimental facility: COSY-11 facility at the Cooler Synchrotron COSY, Jülich, Germany

The existence of light hypernuclei, such as $^3He_{\Lambda}$, shows the low energy Λ-p interaction to be strongly attractive, though not sufficient to bind the hyper-deuteron. The hyperon-nucleon interaction is of special interest since it is influenced by the strange quark content of the hyperon. However, in contrast to the nucleon-nucleon case, due to the short lifetime of hyperons, the direct measurements of low-energy hyperon-nucleon scattering are sparse and the resulting parameters are rather poorly known.

Using the COSY-11 detection setup and the cooler synchrotron COSY we have determined the excitation functions of the $pp \to pK^+\Lambda$, $pp \to pK^+\Sigma^0$, and $pp \to nK^+\Sigma^+$ reactions in the near threshold energy range. The reactions have been identified by the registration of the outgoing nucleon and the K^+ meson, and the usage of the missing mass technique for the determination of hyperons.

Surprisingly, the total cross section for the production of the hyperon Λ was found to be by a factor of thirty larger than this for Σ^0. It is in drastic contrast to the results of the cross section ratio $\sigma(pp \to pK^+\Lambda)/\sigma(pp \to pK^+\Sigma^0)$ determined at higher energies, where it was found to be equal to three as expected from the isospin relations. This observation raised an interesting question whether the drastic increase of the cross section ratio near threshold is a mere effect of the Λ-p interaction or whether it is due to the reaction mechanism. To explain this unexpected increase, different models have been proposed based on the coherent exchange of the π and K mesons or on the excitation of the intermediating resonances. All these models, failed however to predict the value of the total cross section for the $pp \to nK^+\Sigma^+$ reaction. To understand the hyperon-nucleon interaction further thorough theoretical investigations are needed. They can be confronted with the empirical base delivered during the last decade by the COSY-11 group.

Figure 1 presents the data together with expectations derived under the assumption of the homogenously populated phase space and the phase-space modified by the hyperon-nucleon interaction. The comparison of the calculations and the data suggests much weaker final-state interaction in the p-Σ^0 channel than in the case of the p-Λ. Interestingly the parameters derived for the n- Σ^+ potential are comparable to those for the p-Λ system. This may indicate a strong n- Σ^+ interaction but due to the present large systematic uncertainties the data are also consistent with a pure phase space distribution.

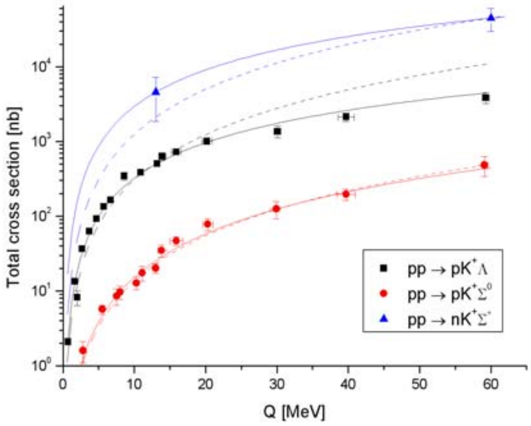

Fig. 1. *Total cross section as a function of the excess energy Q for the near threshold production of the hyperons Λ, Σ^0 and Σ^+ via the $pp \to pK^+\Lambda$, $pp \to pK^+\Sigma^0$, and $pp \to nK^+\Sigma^+$ reactions, respectively. The dashed lines show excitation functions calculated for non-interacting particles. The solid lines indicate results after the inclusion of the hyperon-nucleon interaction which was fitted to conform the data. All superimposed lines were normalized in amplitude to the data.*

[1] **J.T. Balewski. A. Budzanowski,** H. Dombrowski, C. Goodman, D. Grzonka, J. Haidenbauer, C. Hanhart, **L. Jarczyk,** M. Jochmann, A. Khoukaz, K. Kilian, M. Köhler, **A. Kozela,** T. Lister, R. Maier, **P. Moskal,** W. Oelert, D. Prasuhn, C. Quentmeier, R. Santo, G. Schepers, U. Seddik, T. Sefzick, **J. Smyrski, M. Sokołowski, A. Strzałkowski,** M. Wolke, P. Wüstner, Phys. Lett. **B 388** (1996) 859

[2] **J.T. Balewski.** R. Bilger, **A. Budzanowski,** H. Clement, K.H. Diart, H. Dombrowski, K. Foehl, C. Goodman, D. Grzonka, H. Gutschmidt, K. Heitlinger, **L. Jarczyk,** M. Jochmann, M. Karnadi, A. Khoukaz, K. Kilian, M. Köhler, **A. Kozela,** T. Lister, **P. Moskal,** R. Nellen, W. Oelert, C. Quentmeier, R. Santo, D. Schapler, G. Schepers, U. Seddik, T. Sefzick, **J. Smyrski, M. Sokołowski, A. Strzałkowski,** M. Wolke, G.J. Wagner, K.H. Watzlawik, P. Wüstner, K. Zwoll, Acta Phys. Polon. **B 27** (1996) 2911

[3] **J.T. Balewski. A. Budzanowski,** H. Dombrowski, E. Eyrich, C. Goodman, D. Grzonka, J. Haidenbauer, C. Hanhart, J. Hauffe, **L. Jarczyk,** M. Jochmann, A. Khoukaz, K. Kilian, M. Köhler, **A. Kozela,** T. Lister, A. Metzger, **P. Moskal,** W. Oelert, C. Quentmeier, R. Santo, G. Schepers, U. Seddik, T. Sefzick, **J. Smyrski, M. Sokołowski,** F. Stinzing, **A. Strzałkowski,** C. Thomas, S. Wirth, M. Wolke, R. Woodward, P. Wüstner, **D. Wyrwa,** Phys. Lett. **B 420** (1998) 211

[4] **J.T. Balewski. A. Budzanowski,** C. Goodman, D. Grzonka, M. Hofmann, **L. Jarczyk,** A. Khoukaz, K. Kilian, T. Lister, **P. Moskal,** W. Oelert, I.A. Pellmann, C. Quentmeier, R. Santo, G. Schepers, T. Sefzick, S. Sewerin, **J. Smyrski, A. Strzałkowski,** C. Thomas, C. Wilkin, M. Wolke, P. Wüstner, **D. Wyrwa,** Eur. Phys. J. **A 2** (1998) 99

[5] S. Sewerin, G. Schepers, **J.T. Balewski. A. Budzanowski,** W. Eyrich, M. Fritsch, C. Goodman, Grzonka, J. Haidenbauer, C. Hanhart, M. Hofmann, **L. Jarczyk,** M. Jochmann, A. Khoukaz, K. Kilian, M. Köhler, T. Lister, **P. Moskal,** W. Oelert, I. Pellmann, C. Quentmeier, R. Santo, U. Seddik, T. Sefzick, **J. Smyrski,** F. Stinzing, **A. Strzałkowski,** C. Wilkin, M. Wolke, P. Wüstner, **D. Wyrwa,** Phys. Rev. Lett. **83** (1999) 682

[6] **P. Moskal,** H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, C. Kolf, **L. Jarczyk,** A. Khoukaz, K. Kilian, **P. Kowina,** N. Lang, A. Lister, W. Oelert, C. Quentmeier, R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** P. Winter, M. Wolke, P. Wüstner, **W. Zipper,** J. Phys. **G 28** (2002) 1777

[7] **P. Kowina,** M. Wolke, H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, T. Lister, **P. Moskal,** W. Oelert, T. Rozek, R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski,** S. Steltenkamp, **A. Strzałkowski,** P. Winter, P. Wüstner, **W. Zipper,** Eur. Phys. J. **A 18** (2003) 351

[8] **P. Kowina,** M. Wolke, H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, J. Haidenbauer, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Moskal,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** C. Quentmeier, **T. Rożek,** R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski,** S. Steltenkamp, **A. Strzałkowski,** A. Täschner, P. Winter, P. Wüstner, **W. Zipper,** Eur. Phys. J. **A 22** (2004) 293

[9] **T. Rożek,** D. Grzonka, K. Kilian, P. Kowina, W. Oelert, T. Sefzick, P. Winter, M. Wolke, P. Wüstner, **M. Siemaszko, W. Zipper, R. Czyżykiewicz, M. Janusz, L. Jarczyk, B. Kamys, P. Klaja, P. Moskal, C. Piskor-Ignatowicz, J. Przerwa, J. Smyrski,** H.H. Adam, A. Khoukaz, R. Santo, A. Täschner, **A. Budzanowski,** Int. J. Mod. Phys. **A 20** (2005) 680

[10] **T. Rożek,** D. Grzonka, H.H. Adam, **A. Budzanowski, R. Czyżykiewicz, M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Klaja, P. Kowina, P. Moskal,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** J. Ritman, T. Sefzick, **M. Siemaszko, J. Smyrski,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper,** Phys. Lett. **B 643** (2006) 251

η AND η′ MESONS PRODUCTION IN D-P COLLISIONS

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Experimental facility: COSY-11 facility at the Cooler Synchrotron COSY, Jülich, Germany

One of the basic questions of the η meson physics concerns existence of η-nucleus bound states postulated by Haider and Liu (Phys. Lett. **B172**, (1986) 257). Recent data from MAMI show some indications for photoproduction of η-mesic ^{3}He. The ^{3}He-η interaction can be investigated in experiments both above and below the η production threshold. In the first case, low energy ^{3}He-η scattering parameters can be determined on the basis of the final state interaction effects. In measurements below threshold one can search for resonance like structures in excitation curves originating from decays of ^{3}He-η bound state in various possible reaction channels like ^{3}He- π^0 or $ppp\,\pi^-$.

We performed studies of the ^{3}He-η production and interaction using the internal deuteron beam of the COSY-Jülich accelerator scattered on a proton target of the cluster jet type and the COSY-11 facility detecting the charged reaction products. The nominal momentum of the deuteron beam was varied continuously within each acceleration cycle in the range from 41 MeV/c below to 39 MeV/c above threshold momentum equal to 3.140 GeV/c, allowing to reduce most of the systematic errors associated with relative normalization of points measured at different beam momenta. In the missing mass spectra to the registered ^{3}He ions determined as a function of the beam momentum (see Figure 1) clear signals from the η meson production as well as from the single π^0 production are visible. Our results on the forward-backward asymmetries of the differential cross sections for the $dp\to{}^3\mathrm{He}\eta$ reaction deviate clearly from zero for the center-of-mass momenta above 50 MeV/c indicating the presence of higher partial waves in the final state. Below 50 MeV/c center-of-mass momenta a fit of the final state enhancement factor to the data of the $dp\to{}^3\mathrm{He}\eta$ total cross section results in the ^{3}He-η scattering length of $a=|2.9|+i\cdot 3.2$ fm. The excitation curve for pion production in the reaction $dp\to{}^3\mathrm{He}\pi^0$ shows no structure originating from decays of possible ^{3}He-η bound state.

We use also the p+d collisions for studies of the structure of the η' mesons which due to their flavour-singlet nature can mix with purely gluonic states. Therefore, additionally to the mechanisms associated with the meson exchanges it is possible that the η' meson is created from excited glue in the interaction region of the colliding nucleons. We expect that comparison of the cross sections which we determined for the $pp\to pp\eta'$ reaction with the cross sections which we have recently measured for the isospin related $pn\to pn\eta'$ process, should provide insight into the flavour-singlet (perhaps also gluonium) content of the η' meson and the relevance of quark-gluon or hadronic degrees of freedom in the creation process. Data analysis of measurements of the quasi–free $pn\to pn\eta'$ reaction is in progress.

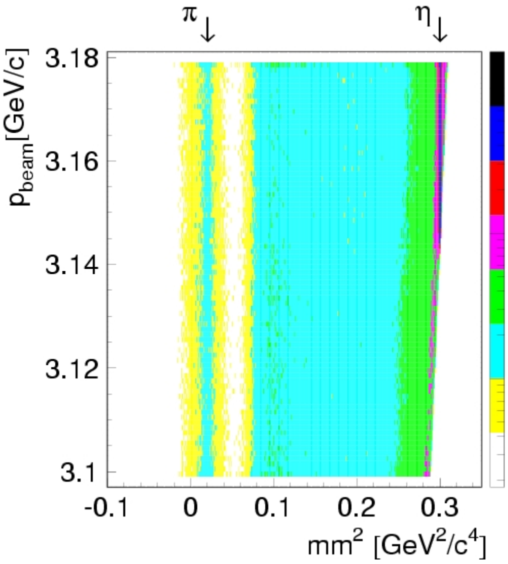

Fig. 1. *Missing mass to the $dp\to{}^3\mathrm{He}X$ reaction (x-axis) as a function of beam momentum (y-axis).*

[1] **P. Moskal,** H.H. Adam, **A. Budzanowski,** T. Götz, D. Grzonka, **L. Jarczyk,** A. Khoukaz, K. Kilian, C. Kolf, **P. Kowina,** N. Lang, T. Lister, W. Oelert, C. Quentmeier, R. Santo, G. Schepers, T. Sefzick **M. Siemaszko, J. Smyrski,** S. Steltenkamp, **A. Strzałkowski,** P. Winter, M. Wolke, P. Wüstner, **W. Zipper,** Phys. Lett. **B 517** (2001) 295

[2] **P. Moskal,** H.H. Adam, **A. Budzanowski,** D. Grzonka, **L. Jarczyk,** A. Khoukaz, K. Kilian, **P. Kowina,** N. Lang, T. Lister, W. Oelert, C. Quentmeier, R. Santo, G. Schepers, T. Sefzick, S. Sewerin, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** M. Wolke, P. Wüstner, **W. Zipper** Nucl. Inst. & Meth. **A 466** (2001) 448

[3] **P. Moskal,** H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M. Janusz, L. Jarczyk,** T. Johansson, **B. Kamys,** A. Khoukaz, K. Kilian, **P. Kowina,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa, T. Rożek,** R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper** AIP Conf. Proc. **717** (2004) 907.

[4] **J. Przerwa,** H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Klaja,** N. Lang, **P. Moskal,** , W. Oelert, **C. Piskor-Ignatowicz, T. Rożek,** R. Santo, T. Sefzick, **M. Siemaszko, J. Smyrski,** A. Tächner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper** Int. J. Mod. Phys. **A 20** (2005) 625

[5] H.H. Adam, A. Khoukaz, N. Lang, T. Lister, R. Santo, S. Steltenkamp, **R. Czyżykiewicz, M. Janusz, L. Jarczyk, B. Kamys, P. Moskal, C. Piskor-Ignatowicz, J. Przerwa, J. Smyrski,** D. Grzonka, K. Kilian, W. Oelert, T. Sefzick, P. Winter, M. Wolke, P. Wüstner, **A. Budzanowski, T. Rożek, M. Siemaszko, W. Zipper** Int. J. Mod. Phys. **A 20** (2005) 643

[6] **P. Moskal,** H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M. Janusz, L. Jarczyk,** T. Johansson, **B. Kamys,** A. Khoukaz, K. Kilian, **P. Klaja, J. Majewski,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** J. Ritman, **T. Rożek,** T. Sefzick, **M. Siemaszko, J. Smyrski,** A. Täschner, J. Wessels, P. Winter, M. Wolke, P. Wüstner, Z. Zhang, **W. Zipper,** J. Phys. **G 32** (2006) 629

[7] **J. Smyrski,** H.H. Adam, **A. Budzanowski, E. Czerwiński, R. Czyżykiewicz, D. Gil,** D. Grzonka, **A. Heczko, M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Klaja, J. Majewski, P. Moskal,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** J. Ritman, **T. Rożek,** R. Santo, T. Sefzick, **M. Siemaszko,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, Z. Zhang, **W. Zipper**, Acta Phys. Slov. **56** (2006) 387

[8] H.H. Adam, I. Geck, A. Khoukaz, T. Lister, R. Santo, S. Steltenkamp, A. Täschner, **E. Czerwiński, R. Czyżykiewicz, M. Janusz, L. Jarczyk, B. Kamys, P. Klaja, P. Moskal, C. Piskor-Ignatowicz, J. Przerwa, J. Smyrski,** D.Grzonka, K. Kilian, W. Oelert, T. Sefzick, P. Winter, M. Wolke, P. Wüstner, **A. Budzanowski, T. Rożek, M. Siemaszko, W. Zipper**, Phys. Rev. **C 75** (2007) 014004

[9] **C. Piskor-Ignatowicz, J. Smyrski, P. Moskal,** H.H. Adam, **A. Budzanowski, E. Czerwiński, R. Czyżykiewicz, D. Gil,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, **P. Klaja, J. Majewski, P. Moskal,** W. Oelert, **J. Przerwa,** J. Ritman, **T. Rożek,** T. Sefzick, **M. Siemaszko,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper.** Int. J. Mod. Phys **A 22** (2007) 528

[10] **J. Smyrski,** H.H. Adam, **A. Budzanowski, E. Czerwiński, R. Czyżykiewicz, D. Gil,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, **P. Klaja, P. Moskal,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** J. Ritman, **T. Rożek,** T. Sefzick, **M. Siemaszko,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper**. Nucl. Phys. A(2007), in print

[11] **J. Smyrski,** H.H. Adam, **A. Budzanowski, E. Czerwiński, R. Czyżykiewicz, D. Gil,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, **P. Klaja,** T. Mersmann, **P. Moskal,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa, B. Rejdych,** J. Ritman, **T. Rożek,** T. Sefzick, **M. Siemaszko,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper**. Phys. Lett. **B** (2007) , submitted

K+ PRODUCTION IN PROTON-NUCLEUS REACTIONS

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The production of mesons heavier than pions in p+A collisions at bombarding energies far below and close to the free nucleon-nucleon threshold is of specific interest, as one hopes either to learn about cooperative nuclear phenomena and/or about high-momentum components of the nuclear many body wave function that arise from nucleon-nucleon correlations. Especially K^+ mesons have been considered as promising hadronic probes, due to the moderate final state interaction, which is a consequence of strangeness conservation and fact that there are no barion resonances with antistrange quarks in nuclei. Antihyperons, futhermore, have a much larger production threshold and annihilate very fast in nuclei. On the other hand, the kaon properties might change in the nuclear medium, thus, the conclusions on cooperative nuclear phenomena require a precise understanding of the kaon potentials at finite nuclear density. Experiments on K^+ production from nucleus-nucleus collisions at SIS energies of 1-2 A GeV have shown that in-medium properties of the kaons are seen in the collective flow pattern of K^+ mesons, both in-plane and out of plane , as well as in the abundancy of antikaons. Thus in-medium modifications of the mesons have become a topic of substantial interest triggered in part by the suggestion of Brown and Rho that the modification of hadron masses should scale with the scalar quark condensate <qqbar> at finite baryon density. In the series of papers we have published results of studies on the production of K+ mesons in proton-nucleus collisions from 1.0 to 2.5 GeV with respect to one-step nucleon-nucleon and two step Δ-nucleon or pion-nucleon production channels on the basis of a coupled channel transport approach (CBUU) including differential transition probabilities from πN reactions that have been calculated within the folding model. We have included the kaon final-state interactions, which are important for heavy targets like Pb or Au and we explored the effects of momentum-dependent potentials for the nucleon, hyperon and kaon in the nucleus. A comparison of the calculations to the experimental K+ spectra taken at LBL Berkeley, SATURNE, CELSIUS, GSI and COSY-Juelich has shown that the different data sets are not compatible with each other. Thus no clear signal on in-medium potentials could be extracted from our analysis in comparison to experimental spectra. However, the detailed calculations demonstrate that precise and complete spectra show a substantial sensitivity to the potentials and their momentum dependence. At low bombarding energies of ~1.0 GeV the net attractive potentials for the nucleon and the Λ hyperon in the final state lead to a relative enhancement of the K^+ spectra while at higher bombarding energies (~2 GeV) the baryon potentials are repulsive and thus they suppress K^+ production relative to the free case. The phenomenon is to be observed in the excitation function of the K^+ cross section when varying T_{LAB} from 1.0 to 2.5 GeV. Furthermore, the shape of the spectrum for low K^+ momenta in the laboratory is very sensitive to both Coulomb U_{Coul} and nuclear kaon U_K potentials, since the kaons are accelerated by both forces when leaving the nuclear environment and propagating to continuum. The relative strength of this momentum shift in the forward K^+ spectra is proportional to the square root of the sum of both potentials, i.e. $\Delta p=\sqrt{2M_K(U_{Coul}+U_K)}$. Thus the K^+ spectral shape at low momenta (or kaon kinetic energies T_K) allows to determine the strength of the K^+ potential from experimental data in an almost model-independent way especially when comparing kaon spectra from light and heavy targets at the same bombarding energy as a function of T_K. A systematic study of K^+ production in p + A reactions down to outgoing momenta of 150 MeV/c in the laboratory or $T_K \approx 23$ MeV, performed on ANKE detector at COSY accelerator site (FZJ Juelich) has given value of 20 ± 5 MeV for strength of the kaon repulsion at normal density.

[1] W.Cassing, **T.Demski**, **L.Jarczyk**, **B.Kamys**, **Z.Rudy**, O.W.B.Schult, **A.Strzalkowski**, Z.Phys. **A349**, 77 (1994)

[2] S. Barsov, U.Bechstedt, W.Bothe, N.Bongers, G.Borchert, W.Borgs, W.Bräutigam, M.Büscher, W Cassing, V.Chernyshev, B.Chiladze, J.Dietrich, M.Drochner, S.Dymov, W.Erven, R.Esser, A.Franzen, Ye.Golubeva, D.Gotta, T.Grande, D.Grzonka, A.Hardt, M.Hartmann, V.Hejny, L.v.Horn, **L.Jarczyk**, H.Junghans, A.Kacharava, **B.Kamys**, A.Khoukaz, T.Kirchner, F.Klehr, W.Klein, H.R.Koch, V.I.Komarov, L.Kondratyuk, V.Koptev, S.Kopyto, R.Krause, P.Kravtsov, V.Kruglov, **P.Kulessa**, A.Kulikov, N.Lang, N.Langenhagen, A.Lepges, J.Ley, R.Maier, S.Martin, G.Macharashvili, S.Merzliakov, K.Meyer, S.Mikirtychiants, H.Müller, P.Munhofen, A.Mussgiller, M.Nekipelov, V.Nelyubin, M.Nioradze, H.Ohm, A.Petrus, D.Prasuhn, B.Prietzschk, H.J.Probst, **K.Pysz**, F.Rathmann, B.Rimarzig, **Z.Rudy**, R.Santo, H.Paetz gen.Schieck, R.Schleichert, A.Schneider, Chr.Schneider, H.Schneider, U.Schwartz, H.Seyfarth, A.Sibirtsev, U.Sieling, K.Sistemich, A.Selikov, H.Stechemesser, H.J.Stein, **A.Strzalkowski**, K.-H.Watzlawik, P.Wüstner, S.Yashenko, B.Zalikhanov, N.Zhuravlev, K.Zwoll, I.Zychor, O.W.B.Schult, H.Ströher, Nucl. Instrum. Methods Phys.Res. **A 462**, 364 (2001),

[3] V.Koptev, M.Buscher, H.Junghans, M.Nekipelov, K.Sistemich, H.Stroher, V.Abaev, H.-H.Adam, R.Baldauf, S.Barsov, U.Bechstedt, N.Bongers, G.Borchert, W.Borgs, W.Brautigam, W.Cassing, V.Chernyshev, B.Chiladze, **M.Debowski**, J.Dietrich, M.Drochner, S.Dymov, J.Ernst, W.Erven, R.Esser, P.Fedorets, A.Franzen, D.Gotta, T.Grande, D.Grzonka, G.Hansen, M.Hartmann, V.Hejny, L.von Horn, **L.Jarczyk**, A.Kacharava, **B.Kamys**, A.Khoukaz, T.Kirchner, S.Kistryn, F.Klehr, H.R.Koch, V.Komarov, S.Kopyto, R.Krause, P.Kravtsov, V.Kruglov, **P.Kulessa**, A.Kulikov, V.Kurbatov, N.Lang, N.Langenhagen, I.Lehmann, A.Lepges, J.Ley, B.Lorentz, G.Macharashvili, R.Maier, S.Martin, S.Merzliakov, K.Meyer, S.Mikirtychyants, H.Muller, P.Munhofen, A.Mussgiller, V.Nelyubin, M.Nioradze, H.Ohm, A.Petrus, D.Prasuhn, B.Prietzschk, H.J.Probst, D.Protic, **K.Pysz**, F.Rathmann, B.Rimarzig, **Z.Rudy**, R.Santo, H.Paetz gen.Schieck, R.Schleichert, A.Schneider, Chr.Schneider, H.Schneider, G.Schug, O.W.B.Schult, H.Seyfarth, A.Sibirtsev, **J.Smyrski**, H.Stechemesser, E.Steffens, H.J.Stein, **A.Strzalkowski**, K.-H.Watzlawik, C.Wilkin, P.Wustner, S.Yashenko, B.Zalikhanov, N.Zhuravlev, **P.Zolnierczuk**, K.Zwoll, **I.Zychor**, Phys.Rev.Lett. **87**, 022301 (2001)

[4] **Z.Rudy**, W.Cassing, **L.Jarczyk**, **B.Kamys**, **P.Kulessa**, Eur. Phys. J. **A 15**, 303 (2002)

[5] M.Nekipelov, M.Buscher, W.Cassing, M.Hartmann, V.Hejny, V.Kleber, H.R.Koch, V.Koptev, Y.Maeda, R.Maier, S.Merzliakov, S.Mikirtychiants, H.Ohm, A.Petrus, D.Prasuhn, F.Rathmann, **Z.Rudy**, R.Schleichert, H.Schneider, K.Sistemich, H.J.Stein, H.Stroher, K.-H.Watzlawik, C.Wilkin,
Phys.Lett. **540B**, 207 (2002),

[6] M.Buscher, H.Junghans, V.Koptev, M.Nekipelov, K.Sistemich, H.Stroher, S.Barsov, G.Borchert, W.Borgs, **M.Debowski**, W.Erven, R.Esser, P.Fedorets, D.Gotta, M.Hartmann, V.Hejny, A.Kacharava, H.R.Koch, V.Komarov, **P.Kulessa**, A.Kulikov, G.Macharashvili, S.Merzliakov, S.Mikirtychiants, H.Muller, A.Mussgiller, R.Nellen, M.Nioradze, H.Ohm, A.Petrus, F.Rathmann, **Z.Rudy**, R.Schleichert, Chr. Schneider, O.W.B.Schult, H.J.Stein, I.Zychor, Nucl.Instrum.Methods Phys.Res. **A481**, 378 (2002)

[7] V.Koptev, M.Nekipelov, M.Buscher, S.Dymov, M.Hartmann, V.Hejny, H.R.Koch, N.Lang, S.Mikirtichyants, H.Ohm, A.Petrus, **Z.Rudy**, R.Schleichert, A.Sibirtsev, K.Sistemich, H.Stroher, K.-H.Watzlawik, Eur.Phys.J. **A 17**, 235 (2003)

[8] M.Buscher, V.Koptev, M.Nekipelov, **Z.Rudy**, H.Stroher, Yu.Valdau, S.Barsov, M.Hartmann, V.Hejny, V.Kleber, N.Lang, I.Lehmann, S.Mikirtychiants, H.Ohm, Eur.Phys.J. **A 22**, 301 (2004)

[9] **Z.Rudy**, W.Cassing, **L.Jarczyk**, **B.Kamys**, **A.Kowalczyk**, **P.Kulessa**,
Eur. Phys. J. A 23, 379 (2005); Erratum Eur.Phys.J. **A 24**, 159 (2005)

INTERACTION OF K^+K^- MESONS

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Experimental facility: COSY-11 facility at the Cooler Synchrotron COSY, Jülich, Germany

Over the last several years, near-threshold production of mesons in elementary nucleon-nucleon scattering has become an important field of studies of medium-energy physics. A specific feature of near-threshold measurements is connected with the fact that due to the proximity of bound or quasi-bound states of some of the reaction products, interaction between them can be very strong thus influencing the measured cross sections essentially. This creates an opportunity to investigate interaction between particles which cannot be accessed in direct elastic scattering experiments. For example, measurements of the reaction $pp \to ppK^+K^-$ allow one to investigate the kaon-antikaon interaction. Such measurements can help us to understand the nature of the scalar mesons $f_0(980)$ and $a_0(980)$ which have masses very close to the mass of a kaon pair. The nature of these mesons has been a long-standing problem of meson physics. The standard quark model has difficulties with interpreting these mesons as quark-antiquark pairs. In response to these difficulties, various non q-qbar descriptions have been proposed including a four-quark system, a glueball and a kaon-antikaon molecule. Especially for the formation of the molecule, the strength of the kaon-antikaon interaction is of a crucial importance.

For study of this interaction we performed measurements of the $pp \to ppK^+K^-$ reaction using the internal detection facility COSY-11 at the COoler SYnchrotron COSY in Jülich. The measurements were done for four beam momenta above K^+K^- production threshold but below the $\phi(1020)$ meson production threshold. They were based on kinematically complete reconstruction of positively charged ejectiles while the negative kaon was identified via the missing mass. Our results for the total cross section in the reaction $pp \to ppK^+K^-$ are clearly showing that towards the lower values of the excess energy Q the data are exceeding any expectations both from pure phase space with and without the pp final state interaction (FSI) enhancement factor (see Figure 1). The observed difference might originate from the pK and/or KK FSI. We investigated the effect of the interaction between particles in the final state using the distributions of invariant masses of pK^+, pK^- and K^+K^- pairs. Within the limited statistics the distribution for the pK^- pairs shows an enhancement towards lower masses which could at least be partially connected to the influence of the $\Lambda(1405)$ resonance. The K^+K^- system is rather constant for different invariant masses which agrees with a pure phase space distribution. For a strict description of the final state, calculations based on application of the four-body formalism are required. Further experimental study of the $pp \to ppK^+K^-$ reaction with a high acceptance and a high statistics is planned at the newly commissioned WASA-at-COSY detector.

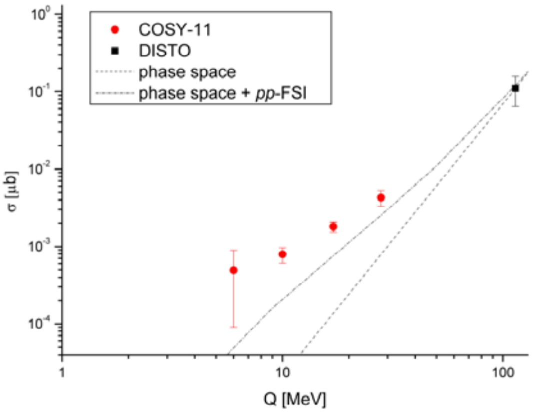

Fig. 1. *Total cross section for the reaction $pp \to ppK^+K^-$ as a function of the excess energy Q. Our data points lie significantly above the expectations indicated by the different lines that are all normalized to the data point measured by the DISTO collaboration at Q=114 MeV.*

[1] S. Brauksiepe, D. Grzonka, K. Kilian, W. Oelert, E. Roderburg, M. Rook, T. Sefzick, P. Turek, M. Wolke, U. Bechstedt, J. Dietrich, R. Maier, S. Martin, D. Prasuhn, A. Schnase, H. Schneider, H. Stockhorst, Raimund Toelle, M. Karnadi, R. Nellen, K.H. Watzlawik, K.H. Diart, H. Gutschmidt, M. Jochmann, M. Koehler, R. Reinartz, P. Wuestner, K. Zwoll, F. Klehr, H. Stechemesser, H. Dombrowski, W. Hamsink, A. Khoukaz, Tim A. Lister, C. Quentmeier, R. Santo, G. Schepers, **L. Jarczyk, A. Kozela, J. Majewski, A. Misiak, P. Moskal, J. Smyrski, M. Sokołowski, A. Strzałkowski, J. Balewski, A. Budzanowski, S.** Bowes, A. Hardt, C. Goodman, U.Seddik, M. Ziolkowski, Nucl. Instr. Meth. **A 376** (1996) 397

[2] M. Wolke, H.H. Adam, **J.T. Balewski, A. Budzanowski,** C. Goodman, D. Grzonka, **L. Jarczyk,** M. Jochmann, Khoukaz, K. Kilian, M. Köhler, **P. Kowina,** N. Lang, T. Lister, **P. Moskal,** W. Oelert, C. Quentmeier, R. Santo, G. Schepers, U. Seddik, T. Sefzick, S. Sewerin, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** P. Wüstner, **W. Zipper,** AIP Conf. Proc. **512** (2000) 143

[3] **P. Moskal,** H.H. Adam, **A. Budzanowski,** D. Grzonka, **L. Jarczyk,** Khoukaz, K. Kilian, M. Köhler, **P. Kowina,** N. Lang, T. Lister, W. Oelert, C. Quentmeier, R. Santo, G. Schepers, T. Sefzick, S. Sewerin, **M. Siemaszko, J. Smyrski, M. Sokołowski, A. Strzałkowski,** M. Wolke, P. Wüstner, **W. Zipper,** Acta. Phys. Polon. **B 31** (2000) 2277

[4] C. Quentmeier, H.H. Adam, **J.T. Balewski, Budzanowski,** D. Grzonka, **L. Jarczyk,** A. Khoukaz, K. Kilian, **P. Kowina,** N. Lang. T. Lister, **P. Moskal,** W. Oelert, R. Santo, G. Schepers, T. Sefzick, S. Sewerin, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** M. Wolke, P. Wüstner, **W. Zipper,** Phys. Lett. **B 515** (2001) 276

[5] M. Wolke, H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Kowina,** T. Lister, **P. Moskal,** W. Oelert, **T. Rożek,** R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski,** S. Steltenkamp, **A. Strzałkowski,** P. Winter, P. Wüstner, **W. Zipper,** Nucl. Phys. A**721** (2003) 683

[6] **P. Moskal,** H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, C. Kolf, **P. Kowina,** T. Lister, Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** C. Quentmeier, **T. Rożek,** R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko, J. Smyrski, A. Strzałkowski,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipper,** J. Phys. **G 29** (2003) 2235

[7] **J. Smyrski,** Ch. Kolf, H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **A. Heczko, M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Kowina, A. Misiak, P. Moskal,** W. Oelert, **C. Piskor-Ignatowicz, J. Przerwa,** C. Quentmeier, **T. Rożek,** R. Santo, G. Schepers, T. Sefzick, **M. Siemaszko,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipser,** Nucl. Instr. & Meth. **A 541** (2005) 574

[8] P. Winter, M. Wolke, H.H. Adam, **A. Budzanowski, R. Czyżykiewicz,** D. Grzonka, **M, Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, K. Kilian, **P. Klaja, P. Moskal,** W. Oelert, C. **Piskor-Ignatowicz, J. Przerwa,** J. Ritman, T. **Rożek,** T. Sefzick, **M. Siemaszko, J. Smyrski,** A. Täschner, P. Wüstner, Z. Zhang, **W. Zipser,** Phys. Lett. **B 635** (2006) 23

[9] W. Oelert, H.H. Adam, **A. Budzanowski, E. Czerwiński, R. Czyżykiewicz, D. Gil,** D. Grzonka, **M. Janusz, L. Jarczyk, B. Kamys,** A. Khoukaz, **P. Klaja, P. Moskal, C. Piskor-Ignatowicz, J. Przerwa, T. Rożek,** R. Santo, T. Sefzick, **M. Siemaszko, J. Smyrski,** A. Täschner, P. Winter, M. Wolke, P. Wüstner, **W. Zipser,** Int. J. Mod. Phys. **A 22** (2007) 305

PRODUCTION OF K+ AND K- MESONS IN HEAVY-ION COLLISIONS

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Experimental facility: SIS, KaoS at GSI Darmstadt

The production of charged kaons in heavy- ion collisions at incident energies from 0.6A to 2.0A GeV has been measured with Kaon Spectrometer(KaoS) at GSI by KAOS Collaboration[1-16]. This subject has been systematically studied by analyzing total production cross section, energy distributions, and polar angle distribution as the function of size of the collision system, the incident energy, and the collision centrality. The key observations can be summarised as follows[Phys. Rev. C**75,** 024906(2007)] :

(i) The multiplicities of both K^+ and K^- mesons, per mass number A of the collisions system, are higher in heavy collision systems than in light systems. This difference increase with decreasing beam energy.

(ii) The multiplicities per number of participating nucleons A_{part} of K^+ and K^- mesons within the same collision system rise stronge than linearly with A_{part}, whereas the pion multiplicity is proportional to A_{part}. Moreorver, the rise is rather similar for K^+ and K^-, although the respective NN thresholds for their production are significantly different.

(iii) The K^-/K^+ ratio is almost constant as the function of the collision centrality. At 1.5A GeV this ratio is the same for Au + Au and Ni + Ni collisions.

(iv) The inverse slop parameters of the energy distributions of K^+ and K^- mesons are higher in heavy than in light collision systems.

(v) The inverse slop parameters of the energy distributions of K^+ mesons are about 15 to 25 MeV higher than those of the K^- distributions. This is observed for all collision system and for all centralities.

(vi) The polar angle distributions exhibit a forward-backward rise which is more pronounced for K^+ than K^- mesons. K^- mesons produced in central collisions are emitted almost isotropically.

From the systematics of these experimental results and from comparisons with transport-model calculations, the folloving conclusions on the properties of dense nuclear matter as created in heavy-ion collisions and on the production mechanisms of K^+ and K^- mesons can be drawn:

(i) The K^- and the K^+ yields are coupled by strangeness exchange: Despite their significantly different thresholds in binary NN collisions, the multiplicicities of K^+ and K^- mesons show the same dependence on the collision centrality. They are even similar for different collision systems. This can be explained by the K^- being predominantly produced via strageness exchange from hyperons which on the other hand are created together with the K^+ mesons. Strageness exchange is predicted to be the main contribution to K^- production in heavy-ion collisions at SIS energies by transport-model calculations as well.

(ii) K^+ and K^- mesons exhibit different freeze-out conditions: Transport model calculations predict different emissions times for K^+ and K^- mesons as consequence of the strageness-exchange reaction. The K^- are continouously produced and reabsorbed and finally leavy the reaction zone much later than K^+ mesons. This and the kinematics of the strageness-exchange process are manifest in an isotropic emission of the K^- in central collisions and in systematically lower inverse slope parameters of the K^- energy distributions compered with those for K^+.

(iii) The nuclear equation of state is soft: The increase of $M(K^+)/A$ with the size of the collision system A points toward a dependence of the K^+ production on the density reached in the collision. The ratio of the K^+ multiplicities in in Au + Au and C + C as a function of the incident energy allows the extraction of the compression modulus K_N of nuclear matter by comparing the data with transport-model calculations. Only calculations using a soft nuclear EoS ($K_N \approx$ 200 MeV) can describe the data. This conclusion is rather insensitive to the various input parameters of such calculations. A soft nuclear E0S is further supported by comparing the centrality dependence of the K^+ multiplicities in Au + Au collisions with transport-model calculations.

KAOS Collaboration results demonstrate the importance of the strageness-exchange reaction for production and propagation of negatively charged kaons in heavy-ion collisions at incident energies from 0.6A to 2A GeV, on the one hand coupling their yield to the K^+ production, and on the other hand causing a rather late emission of K^-. The production of positively charged kaons itself is strongly linked to the high-density phase of a heavy-ion collision, allowing for the conclusion that the equation of state of nuclear matter is soft within the density regime explored by heavy-ion collisions between 0.6A and 2.0A GeV.

[1] W.Ahner, C. Bormann, R. Barth, P. Beckerle, D. Brill, **M. Cieslak, M. Debowski,** E. Grosse, W. Henning, P. Koczon, B. Kohlmeyer, D. Miskowiec, C. Müntz, H. Oeschler, F. Pühlhofer, E. Schwab, R. Schicker, P. Senger, Y. Shin, J. Speer, R. Stock, H. Ströbele, C.Sturm, K. Völkel, A. Wagner, **W. Walus,** Phys. Lett. **B 393**, 31 (1997)

[2] R.Barth, P. Senger, W.Ahner, P. Beckerle, C. Bormann, D. Brill, **M. Cieslak, M. Debowski,** E. Grosse, P. Koczon, B. Kohlmeyer, **D. Miskowiec,** C. Müntz, H. Oeschler, F. Pühlhofer, E. Schwab, R. Schicker, Y. Shin, J. Speer, H. Ströbele, C.Sturm, K. Völkel, A. Wagner, **W. Walus,** Phys. Rev. Lett. **78**, 4007 (1997)

[3] **M. Debowski,** P. Senger, M. Boivin, Y. Le Bornec, P. Courtat, R. Gacougnolle, E. Grosse, S. Kabana, T. Kirchner, P. Koczon, M. Mang, E. Schwab, B. Tatischeff, A. Wagner, **W. Walus,** N. Willis, G. Wolf, R. Wurzinger. J. Yonnet, Phys. Lett. **B 413,** 8 (1997)

[4] A. Wagner, C. Müntz, H. Oeschler, C. Sturm, R. Barth, **M. Cieslak, M. Debowski,** E. Grosse, P. Koczon, M. Mang, **D. Miskowiec,** R. Schicker, E. Schwab, P. Senger, P. Beckerle, D. Brill, Y. Shin, H. Ströbele, **W. Walus,** B. Kohlmeyer, F. Pühlhofer, J. Speer, K. Völke, Phys. Lett. **B 420**, 20 (1998)

[5] Y. Shin, W. Ahner, R.Barth, P. Beckerle, D. Brill, **M. Cieslak**, **M. Debowski**, E. Grosse, P. Koczon, B. Kohlmeyer, M. Mang, **D. Miskowiec**, C. Müntz, H. Oeschler, F. Pühlhofer, E. Schwab, R. Schicker, P. Senger, J. Speer, H. Ströbele, C. Sturm, K. Völkel, A. Wagner and **W. Walus,** Phys. Rev. Lett. **81**, 1576(1998)

[6] P. Senger, P. Koczon, F. Laue, **G. Surowka**, A. Wagner, A. Förster, H. Oeschler, C. Sturm, F. Uhlig, E. Schwab, Y. Shin, H. Ströbele, I. Böttcher, B. Kohlmeyer, M. Menzel, F. Pühlhofer, **M. Debowski**, **W. Walus**, F. Dohrmann, E. Grosse, L. Naumann, W. Scheinast, Prog. Part. Nucl. Phys. **42**, 209 (1999)

[7] F. Laue, C. Sturm, I. Böttcher, **M. Debowski**, A. Förster, E. Grosse, P. Koczon, B. Kohlmeyer, M. Mang, L. Naumann, H. Oeschler, F. Pühlhofer, E.Schwab, P. Senger, Y. Shin, J. Speer, H. Ströbele, **G. Surowka**, F. Uhlig, A. Wagner, **W. Walus,** Phys. Rev. Lett. **82**, 1640 (1999)

[8] N. Iwasa, F. Boue, **G. Surowka**, K. Sümmerer, T. Baumann, B. Blank, S. Czajkowski, A. Forster, M. Gai, H. Geissel, E. Grosse, M. Hellstrom, P. Koczon, B. Kohlmeyer, **R. Kulessa** R., F. Laue, C. Marchand, T. Motobayashi, H. Oeschler, A. Ozawa, M. S. Pravikoff, E. Schwab, W. Schwab, P. Senger, J. Speer, C. Sturm, A. Surowiec, T. Teranishi, F. Uhlig, A. Wagner, **W. Walus**, C. A. Bertulani, Phys. Rev. Lett. **83,** 2910 (1999)

[9] A. Wagner, C. Müntz, H. Oeschler, C. Sturm, R. Barth, **M. Cieslak, M. Debowski**, E. Grosse, P. Koczon, F. Laue, M. Mang, **D. Miskowiec**, E. Schwab, P. Senger, P. Beckerle, D. Brill, Y. Shin, H. Ströbele, **W. Walus**, B. Kohlmeyer, F. Pühlhofer, J. Speer, I.K. Yoo, Phys. Rev. Lett. **85,** 18 (2000)

[10] M. Menzel, I. Böttcher, **M. Debowski**, A. Förster, E. Grosse, P. Koczon, B. Kohlmeyer, F. Laue, L. Naumann, H. Oeschler, F. Pühlhofer, E.Schwab, P. Senger, Y. Shin, H. Ströbele, C. Sturm, **G. Surowka**, F. Uhlig, A. Wagner, **W. Walus,** Physics Letters B, Vol. **495** (1-2), 26(2000)

[11] C. Sturm, I. Böttcher, **M. Debowski**, A. Förster, E. Grosse, P. Koczon, B. Kohlmeyer, F. Laue, M. Mang, L. Naumann, H. Oeschler, F. Pühlhofer, E.Schwab, P. Senger, Y. Shin, J. Speer, H. Ströbele, G. Surowka, F. Uhlig, A. Wagner, **W. Walus,** Phys. Rev. Lett. **86**, 39 (2001)

[12] A. Förster, F. Uhlig, I. Böttcher, **M. Dębowski**, F. Dormann, E. Grosse, P. Koczoń, B. Kohlmeyer, F. Laue, M. Menzel, L. Naumann, H. Oeschler, W. Scheinast, E. Schwab, P. Senger, Y. Shin, H. Ströbele, C. Sturm, **G. Surówka**, A. Wagner, and **W. Waluś**, Phys. Rev. Lett. **91**, 152301 (2003)

[13] F. Uhlig, A. Förster, I. Böttcher, **M. Dębowski**, F. Dohrmann, E. Grosse, P. Koczoń, B. Kohlmeyer, F. Laue, M. Menzel, L. Naumann, H. Oeschler, W. Scheinast, E. Schwab, P. Senger, Y. Shin, H. Ströbele, C. Sturm, **G. Surówka**, A. Wagner, and **W. Waluś**, Phys. Rev. Lett. **95**, 012301(2005)

[14] A. Schmah, S. Lang, I. Böttcher, F. Dohrmann, A. Förster, E. Grosse, P. Koczoń, B. Kohlmeyer, F. Laue, M. Menzel, L. Naumann, H. Oeschler, W. Scheinast, T. Schuck, E. Schwab, P. Senger, Y. Shin, H. Ströbele, C. Sturm, **G. Surówka**, F. Uhlig, A. Wagner, and **W. Waluś,** Phys. Rev. C**71**, 64907(2005)

[15] W. Scheinast, I. Böttcher, **M. Dębowski**, F. Dohrmann, A. Förster, E. Grosse, P. Koczoń, B. Kohlmeyer, F. Laue, M. Menzel, L. Naumann, E. Schwab, P. Senger, Y. Shin, H. Ströbele, C. Sturm, **G. Surówka**, F. Uhlig, A. Wagner, **W. Waluś**, B. Kämpfer and H.W. Barz, Phys. Rev. Letters **96,** 072301(2006)

[16] A. Förster, F. Uhlig, I. Böttcher, D. Brill, **M. Dębowski**, F. Dohrmann, E. Grosse, P. Koczoń, B. Kohlmeyer, S. Lang, F. Laue, M. Mang, M. Menzel, L. Naumann, H. Oeschler, **M. Płoskoń**, W. Scheinast, A. Schmah, T.J. Schuck, E. Schwab, P. Senger, Y. Shin, J. Speer, H. Ströbele, C. Sturm, **G. Surówka**, A. Wagner and **W. Waluś**, Phys. Rev. C**75**, 024906(2007)

AT THE BORDER BETWEEN ATOMIC AND NUCLEAR PHYSICS

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We report on studies performed in the years 1996-2006, mainly in Warsaw, on selected phenomena that belong to both the atomic and nuclear phy-sics: (i) the radiative electron capture (REC), (ii) nuclear structure effects in atomic energy levels, and (iii) the hyperfine interaction in a hydrogen-like $^{229}Th^{89+}$ ion.

REC is the beta decay via capture of an orbital electron, in which the emission of a neutrino is accompanied by radiation of a photon. It is a higher order effect with a probability of a few orders of magnitude lower than that of the non-radiative decay. Experiments performed during the last decade in Warsaw (in collaboration with the Aarhus University) were focused on first-forbidden-unique (1u) decays: $^{204}Tl \rightarrow {}^{204}Hg$ [1] and $^{81}Kr \rightarrow {}^{81}Br$ (still in progress). The original aim of these studies was to test the theory of REC provided by Zon and Rapaport for the 1u transitions. This was a continuation of our earlier studies on the $^{41}Ca \rightarrow {}^{41}K$ 1u decay. In that case, the measured photon intensity per non-radiative decay was found to be essentially higher than the theory predicts. An agreement with experiment was achieved after an account for the γ/β and β/γ detour transitions (see papers quoted in ref. 2). However, the same approach applied to the ^{204}Tl data failed. Recently, Pachucki et al. [3] developed a new and remarkably simple approach with the use of length gauge for the emitted photon, which suppresses significantly the nuclear contribution and shows an excellent agreement with the experimental results for all three cases under consideration.

Atomic energy levels depend on the nuclear size and this effect is proportional to the square of the charge radius. For different isotopes this charge radius is different and thus contributes to the isotope shift. From precise measurement of the isotope shift in lithium isotopes, performed at GSI, and from our calculations of finite nuclear mass effects we have obtained nuclear charge radii for various isotopes of lithium [4], including the most interesting halo nucleus ^{11}Li. Moreover, we have studied polarizability effect, the excitation of a nucleus by the atomic electron and we have found a significant measurable contribution for ^{11}Li. This investigation is continued with A. Moro and several interesting results for helium isotopes have recently been obtained in [5].

It was indirectly shown by Helmer and Reich (1994) that the first excited $3/2^+$ nuclear state of ^{229}Th is expected at about 3.5 eV above the $5/2^+$ ground state. Thus, ^{229}Th offers a unique chance to study coupling of the atomic and nuclear degrees of freedom. Moreover, it has been suggested (Flambaum 2006) that a study of the ultraviolet transition between the two ^{229}Th states may shed light on the question of temporal variation of the fine structure constant. In this context, there is a need for a direct observation of this transition and a much better determination of its energy. A hope is to achieve this goal via studies of hydrogen-like $^{229}Th^{89+}$ ions with the ESR facility at GSI Darmstadt. We have performed theoretical studies (partly, in collaboration with the St. Petersburg physicists) on hyperfine structure in $^{229}Th^{89+}$ [6,7]. In paticular we have investigated nuclear-spin mixing oscillations following a formation of a hydrogen-like ^{229}Th ion in a fast collision process. We have discussed possible methods of experimental verifications of these phenomena.

[1] **J. Kurcewicz, M. Pfützner**, P. Hornshoj, H.L. Nielsen and **B. Szweryn,** Nuclear Physics A **728** (2003) 3.

[2] **J.L. Żylicz, M. Pfützner, S.G. Rohoziński** and B.A. Brown Physical Review C **53** (1996) 1593

[3] **K. Pachucki**, U.D. Jentschura and **M. Pfützner** submitted to Physical Review C.

[4] **M. Puchalski**, A. Moro and **K. Pachucki**, Phys. Rev. Lett. **97**, 133001 (2006)

[5] **K. Pachucki** and A. Moro, Phys. Rev. A (in print).

[6] E.F. Karpeshin, **S. Wycech**, I.M. Band, M.B. Trzhaskovskaya, **M. Pfützner and J. Żylicz**, Physical Review C **57** (1998) 3085

[7] **K. Pachucki, S. Wycech, J. Żylicz and M. Pfützner,** Physical Review C **64** (2001) 64301

ATOMIC PHYSICS IN HEAVY ION – ATOM COLLISIONS

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Experimental Facility: Accelerator Facility at GSI, Darmstadt, Germany

Production of cooled intense beams of heavy ions at GSI, Darmstadt provides a powerful tool for precise spectroscopy measurements. Electric field of high-Z ions gives an opportunity to test QED in regime where an ordinary perturbation treatment of QED, with $Z\alpha$ as the expansion parameter, is no longer applicable. In such systems high order QED corrections can be tested, for example by Lamb shift measurements.

In recent years a number of experiments [1, 2] were performed at the ESR gas target or electron cooler in order to obtain precision of the measured Lamb shift in the H-like uranium comparable to theoretical calculations (i.e. 0.5 eV). Many techniques, such as beam deceleration and cooling, have been used in order to improve the results, mainly to reduce Doppler broadening of the observed X-ray lines. Additionally, crystal spectrometer (FOCAL) [3] and microstrip Ge-detectors, dedicated to the Lamb shift measurements, were constructed. Experimental results obtained in recent 15 years are presented in Fig. 1.

Precise spectroscopy allows observations of many electrons contributions to the ground-state energy. This kind of experiment was performed for the simplest many electron system – He-like uranium. Here, energy of K-RR line for radiative recombination to H- and He-like U-ions was observed. The energy difference between those two lines was obtained with an accuracy on the level of two-electron contribution [2].

Another process which was investigated is the Radiative Electron Capture (REC) in relativistic collisions. Such systems reveal completely new effects, which go beyond the dipole approximation. Experiments, in accordance with theory, show that even at moderately relativistic collision velocities (up to about 1 GeV/u) total K-REC cross sections are still well described by a simple non-relativistic dipole approximation [4, 5]. This is mostly due to an accidental cancellation among the various manifestations of relativistic, retardation, and multipole effects. Strong deviation from this behavior, predicted by theory, was only observed in the highly relativistic collision regime.

More detailed information on REC was obtained from differential cross sections. In particular, studies of the angular distribution of the REC radiation revealed importance of spin-flip transitions caused by the magnetic interaction. This interaction produces a forward-backward asymmetry of the REC emission pattern in the laboratory frame, manifested by the enhanced photon emission at 0° [6, 7, 8].

Also angular distribution of the Ly-α1 line, following radiative electron capture from a gas target into the $2p_{3/2}$ level of H-like uranium was measured, which allows us to obtain magnetic-substrate sensitive information on the REC process. First experiments performed in relativistic collisions of high-Z ions with light target atoms show a strong emission anisotropy [9].

Recently, polarization of photons produced due to radiative electron capture has attracted particular interest [9]. By means of segmented germanium detectors polarization measurements can be performed by exploiting the relation between the differential Compton scattering cross-section and the linear polarization of the primary photon as predicted by the Klein-Nishina formula.

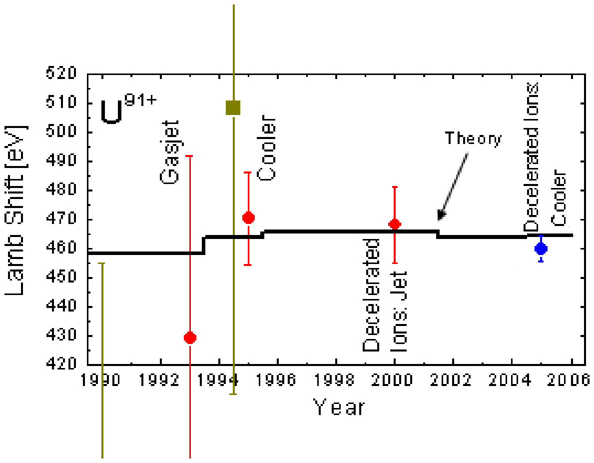

Fig. 1. *Progress in precision of the Lamb shift measurement in ESR experiments.*

[1] Th.Stöhlker, P.H.Mokler, F.Bosch, R.W.Dunford, F.Franzke, O.Klepper, C.Kozhuharov, **T.Ludziejewski**, F.Nolden, H.Reich, **P.Rymuza**, **Z.Stachura**, M.Steck, **P.Świat**, **A.Warczak**, Phys. Rev. Lett. **85** (2000) 3109

[2] A.Gumberidze, Th.Stöhlker, **D.Banaś**, K.Beckert, P.Beller, H.F.Beyer, F.Bosch, X.Cai, S.Hagmann, C.Kozhuharov, D.Liesen, F.Nolden, X.Ma, P.H.Mokler, A.Orsic-Muthig, M.Steck, **D.Sierpowski**, S.Tashenov, **A.Warczak** ,Y.Zou, Phys. Rev. Lett. **92** (2004) 203004

[3] S.Chatterjee, H.F.Beyer, D.Liesen, ThStöhlker, A.Gumberidze, C.Kozhuharov, **D.Banaś**, D.Protic, K.Beckert, P.Beller, Th.Krings, F.Bosch, B.Franzke, S.Hagmann, **J.Hoszowska**, P.Indelicato, H.-J.Kluge, X.Ma, B.Manil, I.Mohos, F.Nolden, U.Popp, A.Simionovici, **D.Sierpowski**, M.Steck, U.Spillmann, C.Brandau, E.Förster, Z.Stachura, S.Tashenov, M.Trassinelli, **A.Warczak**, O.Wehrhan, E.Ziegler, S.Trotsenko, R.Reuschl, Nucl. Instr. Meth. B245 (2006) 67

[4] **A.Warczak**, Nucl. Instr. Meth. **B205** (2003) 36-46

[5] Th.Stohlker, C.Kozhuharov, P.Mokler, **A.Warczak**, F.Bosch, H.Geissel, R. Moshammer, C.Schneidenberger, J.Eichler, A.Ichihara, T.Schirai, **Z.Stachura**, **P.Rymuza**, Phys. Rev. **A 51** (1995) 2089

[6] Th.Stöhlker, **T.Ludziejewski**, F.Bosch, R.W.Dunford, C.Kozhuharov, P.H.Mokler, H.F.Beyer, O.Brinzanescu, B.Franzke, J.Eichler, A.Griegal, S.Hagmann, A.Ichihara, A.Krämer, **J.Lekki**, D.Liesen, F.Nolden, H.Reich, **P.Rymuza**, **Z.Stachura**, M.Steck, **P.Świat**, **A.Warczak**, Phys. Rev. **A 82** (1999) 3232

[7] Th.Stöhlker, **D.Banaś**, S.Fritzsche, A.Gumberidze, C.Kozhuharov, X.Ma, A.Orsic-Muthig, U.Spillmann, **D.Sierpowski**, A.Surzhykov, S.Tachenov, **A.Warczak**, Phys. Scr T **110** (2004) 384

[8] Th.Stöhlker, P.Mokler, C.Kozhuharov, **A.Warczak**, Comm. At. Mol. Phys. **33** (1997) 271

[9] Th.Stöhlker, F.Bosch, A.Gallus, C.Kozhuharov, G.Menzel, P.H.Mokler, H.T.Prinz, J.Eichler, A.Ichihara, T.Shirai, R. W.Dunford, **T.Ludziejewski**, **P.Rymuza**, **Z.Stachura**, **P.Świat**, and **A.Warczak,** Phys. Rev. Lett. **79** (1997) 3270

[10] Th.Stöhlker, X.Ma, **T.Ludziejewski**, H.F.Beyer, F.Bosch, O.Brinzanescu, R.W.Dunford, J.Eichler, S.Hagmann, A.Ichihara, C.Kozhuharov, A.Kraemer, D.Liesen, P.H.Mokler, **Z.Stachura**, **P.Świat**, **A.Warczak**, Phys. Rev. Lett. **86** (2001) 983

PRECISION TESTS OF THE STANDARD MODEL IN THE DECAY OF POLARIZED MUONS

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Experimental facility: Paul Scherrer Institute, Villigen, Switzerland

The universality of the charged week interaction allows to describe on the same basis such a wide range of phenomena as nuclear beta decay, muon decay, and semileptonic decays of hadrons and is incorporated in the Standard Model characterized by lefthanded fermions (V-A) and by the universal coupling constant G_F. It was a selected set of μ decay experiments (including inverse μ decay) for which it was possible to show the V-A structure of the week interaction. Moreover, it is also exclusively μ decay from which G_F was derived.

Although the *e*+ are polarized mainly longitudinally (P_L = 0.998 ± 0.045), the experimental limit ΔP_L still allows for sizeable transverse components $\mathbf{P}_{T1} = P_{T1}\cdot\mathbf{x}_1$, $\mathbf{P}_{T2} = P_{T2}\cdot\mathbf{x}_2$, where

$$\mathbf{x}_2 = \left(\mathbf{k}_e \times \mathbf{P}_\mu\right) / \left|\mathbf{k}_e \times \mathbf{P}_\mu\right|, \qquad \mathbf{x}_1 = \mathbf{x}_2 \times \mathbf{k}_e / \left|\mathbf{k}_e\right|.$$

The experiment was performed at the μE1 beam-line at Paul Scherrer Institute, Villigen, Switzerland. A longitudinally polarized μ^+ beam ($P_\mu \approx 0.91$) enters a beryllium stop target with bunches every 19.75 ns and a burst width of 3.9 ns (FWHM). The polarization $\mathbf{P}_\mu(t)$ of the stopped muons precesses in a homogeneous magnetic field (B = 373.6 ± 0.4 mT) with the same angular frequency as the accelerator RF. This ensures a high stopped muon polarization $P_\mu = 0.91 \pm 0.02$. A system of drift chambers and two thin plastic scintillator counters selects decay e^+ emitted at ≈90° with respect to $\mathbf{P}_\mu$. A 1 mm thick magnetized Vacoflux 50™ foil with its polarized e^- ($P_{e-} = 0.07$) serves as polarization analyzer. The two γ's from e^+ annihilation-in-flight with the polarized e^- are selected by an array of 127 BGO crystals with veto counters in front of them (Fig. 1).

The precession of $\mathbf{P}_\mu(t)$ implies precession of $\mathbf{P}_T(t)$ while $\mathbf{P}_{e^-}$ remains constant in time. The rate of detected γγ coincidences for a given BGO crystal pair can be expressed as

$$R(t) = 1 + a\cos\omega t + b\sin\omega t = N_{\text{res}}(t)\cdot N_{\mu\text{SR}}(t)\cdot N_{\gamma\gamma}(t),$$

where N_{res} represents residual effects like the differential nonlinearity of the TDC, $N_{\mu\text{SR}}$ is due to small remnant decay asymmetry and $N_{\gamma\gamma}$ is the annihilation rate which traces the transverse muon polarization.

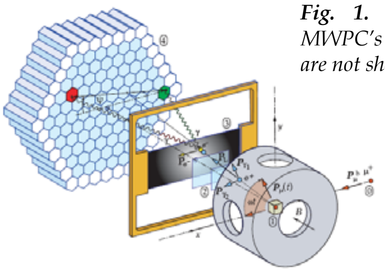

Fig. 1. *Experimental setup. MWPC's and veto scintillators are not shown.*

The Fourier analysis of the collected data led to the energy dependent transverse polarization components as shown in Fig. 2. Table I summarizes the results of the general and of the restricted analysis based on the 4-fermion contact interaction.

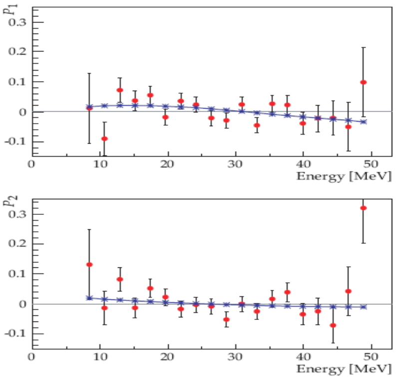

Fig. 2. *Transverse positron polariza-tion components P_{T1} and P_{T2} as a function of the e^+ energy at the moment of annihilation. The curves are fit to the data.*

Table I. *V-A values and experimental results (in units of 10^{-3}). The errors are statistical and systematic.*

	$V\!-\!A$	General analysis	Restricted analys
η	0	$71 \pm 37 \pm 5$	$-2.1 \pm 7.0 \pm 1.0$
η"	0	$105 \pm 52 \pm 6$	$\equiv -\eta$
α'/A	0	$-3.4 \pm 21.3 \pm 4.9$	$\equiv 0$
β'/A	0	$-0.5 \pm 7.8 \pm 1.8$	$-1.3 \pm 3.5 \pm 0.6$
$\rho_{\eta\eta"}$		946	–
$\rho_{\alpha'\beta'}$		-893	–
$\mathrm{Re}(g^S_{RR})$	0	–	$-4.2 \pm 14.0 \pm 2.$
$\mathrm{Im}(g^S_{RR})$	0	–	$5.2 \pm 14.0 \pm 2.4$
$\langle P_{\mathrm{T1}}\rangle$	-3	$6.3 \pm 7.7 \pm 3.4$	
$\langle P_{\mathrm{T2}}\rangle$	0	$-3.7 \pm 7.7 \pm 3.4$	

[1] N. Danneberg, W. Fetscher, K.-U. Köhler, J. Lang, T. Schweizer, A. von Allmen, **K. Bodek**, **L. Jarczyk**, **S. Kistryn**, **J. Smyrski**, **A. Strzałkowski**, **J. Zejma**, K. Kirch, **A. Kozela**, and **E. Stephan**, Phys. Rev. Lett. **94**, 021802 (2005).

[2] W. Fetscher, **K. Bodek**, **A. Budzanowski**, N. Danneberg, C. Hilbes, **L. Jarczyk**, K. Kirch, **S. Kistryn**, J. Klement, K. Köhler, **A. Kozela**, J. Lang, X. Morelle, T. Schweizer, **J. Smyrski**, J. Sromicki, **E. Stephan**, **A. Strzałkowski**, **J. Zejma**, Nucl. Phys. **A721** (2003) 457c.

[3] W. Fetscher, **K. Bodek**, **A. Budzanowski**, N. Danneberg, C. Hilbes, **L. Jarczyk**, K. Kirch, **S. Kistryn**, J. Klement, K. Köhler, **A. Kozela**, J. Lang, G. Llosá-Llácer, T.Schweizer, **J. Smyrski**, J. Sromicki, **E. Stephan**, **A. Strzałkowski**, **J. Zejma**, J. Phys. G: Nucl. Part. Phys. **A 29** (2003) 2017.

[4] I.C. Barnett, C. Bee, **K. Bodek**, **A. Budzanowski**, N. Danneberg, P. Eberhardt, W. Fetscher, C. Hilbes, M. Janousch, **L. Jarczyk**, K. Kirch, **S. Kistryn**, J. Klement, K. Koehler, **A. Kozela**, J. Lang, G. Liosa, M. Markiewicz, X. Morelle, O. Naviliat, T. Schweizer, **J. Smyrski**, J. Sromicki, **E. Stephan**, **A. Strzałkowski**, K. Szeker, **J. Zejma**, Nucl. Instr. Meth **A 455** (2000) 329.

[4] **K. Bodek**, **A. Budzanowski**, N. Danneberg, W, Fetscher, C. Hilbes, M. Janousch, **L. Jarczyk**, K. Kirch, **S. Kistryn**, J. Klement, K. Koehler, **A. Kozela**, J. Lang, G. Liosa Llacer, M. Markiewicz, X. Morelle, T. Schweizer, **J. Smyrski**, J. Sromicki, **E. Stephan**, **A. Strzałkowski**, **J. Zejma**, Nucl. Phys. **A663-664** (2000) 907.

SEARCH FOR TIME REVERSAL VIOLATION EFFECTS IN BETA-DECAY OF NUCLEI AND NEUTRONS

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Experimental facility: Paul Scherrer Institute, Villigen, Switzerland

All the CP violation effects observed so far could be accommodated within the Standard Model (SM) through CKM mixing of the quark states. The amplitude of CP violation due to mixing of the quark states is by several orders of magnitude too small to explain the matter-antimatter asymmetry of the Universe. If the only source of CP-violation would be the one offered by the SM, effects in *β*-decay would be vanishingly small. Thus any observation of time reversal violation in such a process would be the first unambiguous signal of *new physics* beyond the SM. In renormalizable gauge-theories, at the tree level, the candidate models for scalar contributions are charged Higgs, slepton and leptoquark exchange while for tensor coupling the only candidate is the exchange of a spin-0-leptoquark.

The terms in the allowed *β*-decay rate function which are relevant for the discussed experiments are:

$$W \propto \left(1 + A\frac{\mathbf{J}\cdot\mathbf{p}_e}{E_e} + R\frac{\mathbf{J}\cdot(\mathbf{p}_e\times\boldsymbol{\sigma}_e)}{E_e} + N\mathbf{J}\cdot\boldsymbol{\sigma}_e + \dots\right).$$

The essential physics is contained in the parity violating decay asymmetry parameter A, in the parity and time reversal violating parameter *R* and in the parity and time reversal conserving parameter *N*. **J** describes the initial nucleus (or neutron) polarization, whereas $\mathbf{p}_e$, E_e and $\boldsymbol{\sigma}_e$ correspond to the momentum, energy and spin of the electron, respectively.

The first experiment, performed at the Paul Scherrer Institute, Villigen, Switzerland, measured the *R*-correlation coefficient in the decay of ^{8}Li nuclei produced via the polarization transfer reaction ^{7}Li(d,p)^{8}Li induced by 10 MeV vector polarized deuterons. The sketch of the apparatus is shown in Fig. 1. The final value of the *R*-coefficient for 8Li decay is

$$R_{^8\mathrm{Li}} = (0.9 \pm 2.2)\times 10^{-3}.$$

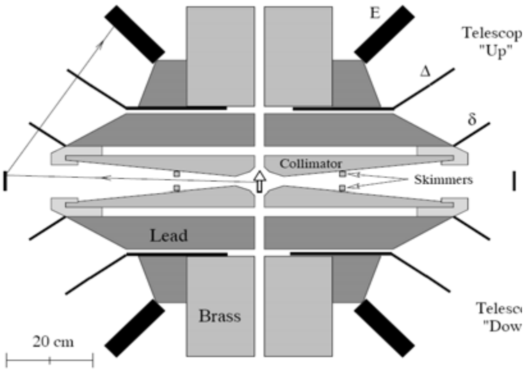

Fig. 1. *Vertical cross section through the Mott polarimeter. The direction of the incident polarized deuteron beam is perpendicular to the figure.*

The result is consistent with the time reversal invariance.

The distinct advantage of the ^{8}Li → ^{9}Be(2.9 MeV) transition is that the Fermi matrix element vanishes and the *R*-parameter depends only on the tensor interaction which gives:

$$\left|\mathrm{Im}\left(a^T_{RL}\right)\right| \le 0.029, \quad \left|a^T_{RL}\right| < 0.0044 \quad (90\%\ \mathrm{C.L.})$$

and

$$\frac{m_{LQ}}{\left|h_L h_R^*\right|^{1/2}} = \left|\frac{\sqrt{2}}{8G_F a^T_{LR}}\right|^{1/2} \ge 1.8\ \mathrm{GeV} \quad (90\%\ \mathrm{C.L.}).$$

h_L and h_R are the (unknown) coupling constants of the leptoquarks and G_F is the Fermi coupling constant. Assuming the "canonical" values for $h_{L,R}=\sqrt{(4\pi\alpha_{\mathrm{elm}})} \approx 0.3$ we get $m_{LQ} \ge 560$ GeV/c^2.

The advantage of the neutron beta decay is its mixed F–GT character and precisely known matrix elements leading to

$$R_n = 0.28\cdot\mathrm{Im}\left(\frac{C_S + C_S'}{C_A}\right) + 0.33\cdot\mathrm{Im}\left(\frac{C_T + C_T'}{C_A}\right).$$

The experiment measuring both components of the electron transverse polarization is being carried out on the polarized cold neutron facility FUNSPIN at the spallation source SINQ at the Paul Scherrer Institute, Villigen, Switzerland. Present values of the *N*- and *R*-coefficient are:

$$N_n = 0.059 \pm 0.015 \quad R_n = 0.026 \pm 0.024.$$

The achieved limits on imaginary parts of the scalar and tensor couplings are shown in Fig. 2.

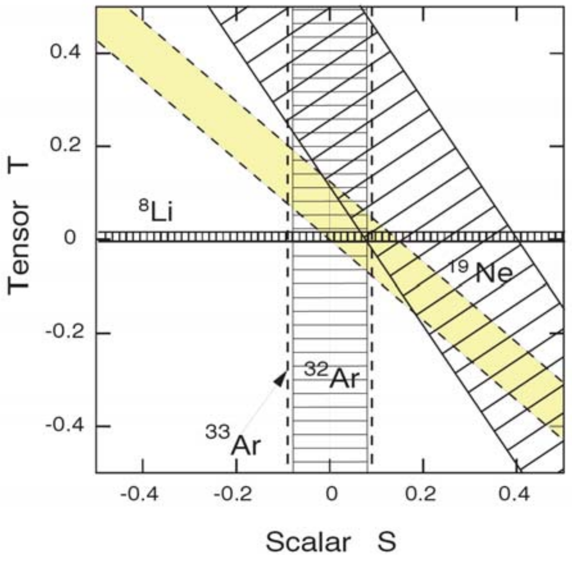

Fig. 2. *±σ constraints ob-tained from β-decay experiments on* $S=Im\{(C_S+C'_S)/C_A\}$ *and* $T=Im\{(C_T+C'_T)/C_A\}$*. Yellow band indicates the preliminary result obtained from neutron decay.*

[1] R. Huber, J. Lang, S. Navert, J. Sromicki, **K. Bodek**, **St. Kistryn**, **J. Zejma**, O. Naviliat-Cuncic, **E. Stephan**, W. Haeberli, Phys. Rev. Lett. **90** (2003) 202301.

[2] N. Severijns, M. Allet, **K. Bodek**, B.A. Brown, J. Camps, P. De Moor, J. Deutsch, M. Ferro-Luzzi, F. Gimeno-Nogues, J. Govaerts, B.R. Holstein, R. Kirchner, J. Lang, R. Mueller, S. Navert, O. Naviliat-Cuncic, T. Otto, I. Pepe, R. Prieels, P.A. Quin, P. Schuurmans, J. Sromicki, **E. Stephan**, E. Thomas, A. Van Geert, B. Vereecke, L. Vanneste, **J. Zejma**, Nucl. Phys. **A629** (1998) 423c-432c.

[3] J. Sromicki, **K. Bodek**, D. Conti, **St. Kistryn**, J. Lang, S. Navert, O. Naviliat-Cuncic, **E. Stephan**, C. Sys, **J. Zejma**, W. Haeberli, E. Reichert, N. Steigerwald, Phys. Rev. Lett. **82** (1999) 57.

[4] **K. Bodek**, P. Boeni, Ch. Hilbes, J. Lang, M. Lasakov, M. Luethy, **St. Kistryn**, M. Markiewicz, E. Medvedev, V. Pusenkov, A. Schebetov, A. Serebrov, J. Sromicki, A. Vassiljev, Neutron News **11** (2000) 29.

[5] J. Sromicki, M. Allet, **K. Bodek**, W. Hajdas, J. Lang, R. Müller, S. Navert, O. Naviliat-Cuncic, **J. Zejma**, W. Haeberli, Phys. Rev. **C 53** (1996) 932.

[6] G. Ban, M. Beck, **A. Białek**, **K. Bodek**, P. Gorel, K. Kirch, **St. Kistryn**, **A. Kozela**, **M. Kuźniak**, A. Lindroth, O. Naviliat-Cuncic, **J. Pulut**, N. Severijns, **E. Stephan**, **J. Zejma**, Nucl. Instr. Meth. in Phys. Res. **A 565** (2006) 622.

[7] **J. Zejma**, G. Ban, M. Beck, **A. Białek**, **K. Bodek**, G. Frei, Ch. Hilbes, G. Kuehne, P. Gorel, K. Kirch, **St. Kistryn**, **A. Kozela**, **M. Kuźniak**, A. Linroth, O. Naviliat, **J. Pulut**, N. Severijns, **E. Stephan**, Nucl. Instr. Meth. **A 539** (2005) 622-639.

[8] **K. Bodek**, T. Boehm, D. Conti, N. Danneberg, W. Fetscher, C. Hilbes, M. Janousch, **S. Kistryn**, K. Köhler, J. Lang, M. Markiewicz, J. Sromicki, **J. Zejma**, Nucl. Instr. Meth. Phys. Res. **A 473** (2001) 326-334

HIGH INTENSITY ULTRA-COLD NEUTRON SOURCE FOR FUNDAMENTAL PHYSICS

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Ultra cold neutrons (UCN) are neutrons with energy of less than about 300 neV. Such slow neutrons are totally reflected by some material surfaces. Due to their magnetic moment, one spin state is also reflected by conventionally achievable magnetic fields (1 T corresponds to 60 neV). UCN are also affected by gravity. It is possible to confine UCN for times comparable to the neutron lifetime. Very often the neutron itself is an object of interest. Prominent examples include precision measurements of the neutron lifetime, the neutron electric dipole moment or the angular correlations among the decay products. The accuracy of such experiments is often limited by the UCN flux or densities available. Currently, the only UCN source operating as a user facility is located at the ILL Grenoble, France. It delivers a few tenth of UCN per cm^3. with an increase in UCN intensity, a whole class of investigations, e.g. neutron-antineutron conversion, phase-space transformer or surface analysis experiments would become feasible.

Among the world wide efforts to build the high intensity UCN sources, the project of the Paul Sherrer Institute, Villigen, Switzerland, is the most advanced. The essential elements of the PSI UCN source are a pulsed proton beam with highest intensity (≥ 2 mA) and a low duty cycle (~ 1%), a heavy element spallation target, a large moderator and converter system. The moderator consists of about 4 m^3 of heavy water at room temperature where the spallation neutrons are thermalized. These are then down-scattered into the UCN regime in a converter made of 30 dm^3 of solid Deuterium (sD$_2$) at low temperature (~ 6 K). A storage volume of about 2 m^3 serves as UCN reservoir and allows for quasi continuous operation. It is connected to the experiments with via horizontal neutron guide pipes equipped with mechanical shutters.

Operating the UCN source in a pulsed mode makes it possible to hold the sD2 at low temperatures in the vicinity of the spallation target despite the large power deposition during the beam pulse of a few seconds. Moreover, the pulsed regime is typical for UCN experiments which need the beam only for a few seconds to feed the apparatus and then use a long (a few min.) observation time. The layout of the UCN source tank is shown in Fig. 1.

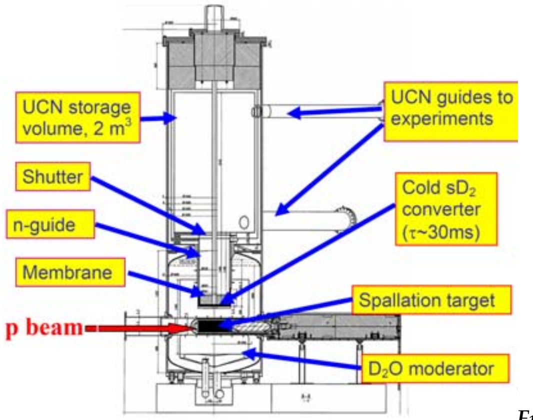

Fig. 1.

The layout of the UCN source tank.

The design of the PSI pulsed UCN source has been accompanied by a series of dedicated R&D activities and special experiments proving the feasibility of applied solutions. Much attention was put the properties of the sD$_2$ converter. The behavior of solid deuterium exposed to frequent temperature cycling was studied with atomic spectroscopy methods and using cold, very-cold and ultra-cold neutrons. Also cooling and maintaining 30 dm^3 sD$_2$ crystal in a UCN "friendly" manner is challenging enterprise for itself.

Another issue, critical for the project is the spallation target which must sustain up to 2 MW peak power and be robust against numerous cycling of physical conditions and heavy radiation damage. Also the preparation of surfaces with the highest possible UCN reflection potential and minimum losses is a challenging task. DLC coatings will be used in both large area (storage tank) and small area (UCN shutters, construction details, etc.)

The expected UCN density in the storage volume is about 3'000 per cm^3. Start of regular operation is planned for 2008.

[1] F. Atchison, **T. Bryś**, M. Daum, P.Fierlinger, A. Fomin, R. Henneck, K. Kirch, **M. Kuźniak**, A. Pichlmaier, Nucl. Instr. Meth. in Phys. Res. **A 552** (2005) 513.

[2] F. Atchison, P. Baumann, **T. Bryś**, M. Daum, A. Egorov, P. Fierlinger, P. Fuchs, R. Henneck, St. Joray, R. Keil, K. Kirch, R. Krutova, G. Kuehne, V.T. Lebedev, H. Obermeier, D.N. Orlova, Ch. Perret, A. Pichlmeier, Ph. Richard, A. Serebrov, S. Thies, Nucl. Instr. Meth. in Phys. Res. **A 539** (2005) 646.

[3] **T. Bryś**, M. Daum, P. Fierlinger, A. Foelske, M. Gupta, R. Henneck, S. Heule, M. Kasprzak, K. Kirch, **M. Kuźniak**, T. Lippert, M. Meier, A. Pichlmeier, U. Straumann, Diamond & Related Materials **15** (2006) 928.

[4] F. Atchison, B. van den Brandt, **T. Bryś**, M. Daum, P. Fierlinger, P. Hautle, R. Henneck, K. Kirch, J. Kohlbrecher, G. Kuehne, J.A. Konter, A. Pichlmeier, A. Wokaun, **K. Bodek**, **M. Kasprzak**, **M. Kuźniak**, P. Geltenbort, M. Giersch, J. Zmeskal, M. Hino, M. Utsuro, Phys. Rev. Lett. **94**, 212502 (2005).

[5] F. Atchison, B. van den Brandt, **T. Bryś**, M. Daum, P. Fierlinger, P. Hautle, R. Henneck, S. Heule, M. Kasprzak, K. Kirch, J.A. Konter, A. Michels, A. Pichlmeier, M. Wohlmuther, A. Wokaun, **K. Bodek**, **U. Szerer**, P. Geltenbort, J. Zmeskal, Y. Pokotilovskiy, Phys. Rev. **C 71** 054601 (2005).

[6] F. Atchison, P. Beaud, **T. Bryś**, M. Daum, P. Fierlinger, R. Henneck, T. Hofmann, K. Kirch, G. Kuehne, G. Knopp, A. Pichlmeier, A. Serebrov, H. Spitzer, J. Wambach, J. Wimmer, A. Wokaun, **K. Bodek**, P. Geltenbort, M. Giersch, J. Zmeskal, K. Mishima, Phys. Rev. **B 68** 094114 (2003).

[7] F. Atchison, B. Blau, M. Daum, P. Fierlinger, P. Geltenbort, R. Henneck, S. Heule, M. Kasprzak, K. Kirch, K. Kohlik, **M. Kuźniak**, M. Meier, C.-F. Meyer, A. Pichlmeier, C. Plonka, P. Schmidt-Wellenburg, B. Schultrich, Th. Stucky, V. Weihnacht, O. Zimmer, Phys. Rev. **C 74** 055501 (2006).

[8] **T. Bryś**, **S. Czekaj**, M. Daum, P. Fierlinger, D. Georgie, R. Henneck, **M. Kasprzak**, K. Kirch, **M. Kuźniak**, G. Kuehne, A. Pichlmeier, **A. Siódmok**, **A. Szelc**, L. Tanner, C. Assman, S. Bechstein, D. Drung, Th. Schurig, C. Ciofi, B. Neri, Nucl. Instr. Meth. in Phys. Res. **A 554** (2005) 527.

[9] **K. Bodek**, K. van den Brandt, **T. Bryś**, M. Daum, P. Fierlinger, P. Geltenbort, M. Giersch, P. Hautle, R. Henneck, M. Kasprzak, K. Kirch, J.A. Konter, G. Kuehne, **M. Kuźniak**, K. Mishima, A. Pichlmeier, D. Raetz, A. Serebrov, J. Zmeskal, Nucl. Instr. Meth. in Phys. Res. **A 533** (2004) 491.

[10] **T. Bryś**, M. Daum, P. Fierlinger, A. Fomin, P. Geltenbort, R. Henneck, K. Kirch, A. Kharitonov, I. Krasnoshekova, **M. Kuźniak**, M. Lasakov, A. Pichlmeier, F. Raimondi, R. Schelldorfer, A. Serebrov, E. Siber, R. Tald’aev, V. Varlamov, A. Vasiliev, J. Wambach, O. Zherebtsov, Nucl. Instr. Meth. in Phys. Res. **A 551** (2005) 429.

[11] F. Atchison, **T. Bryś**, M. Daum, P. Fierlinger, P. Geltenbort, R. Henneck, S. Heule, M. Kasprzak, K. Kirch, A. Pichlmeier, C. Plonka, U. Straumann, C. Wermelinger, Phys. Lett. **B 625**(2005) 19.

[12] **T. Bryś**, M. Daum, P. Fierlinger, P. Geltenbort, D. Geurge, M. Gupta, R. Henneck, S. Heule, M. Horvat, M. Kasprzak, K. Kirch, K. Kohlik, M. Negrazus, A. Pichlmeier, U. Straumann, V. Vrankovic, C. Wermelinger, Nucl. Instr. Meth. in Phys. Res. **A 550** (2005) 637.

NUCLEAR PHYSICS WITH ULTRACOLD ATOMIC GASES

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In the last couple of years we have witnessed a tremendous progress in the field of cold fermionic atoms. Ultra cold atomic gases provide a remarkable opportunity to investigate strongly correlated Fermi systems. They are dilute and their interactions can be precisely controlled over an enormous range. In particular, they form unique laboratories where the crossover between the Bose-Einstein condensate and the BCS superfluid can be explored. In this limit, often referred to as unitary regime, which is relevant for the dilute neutron matter, the scattering length greatly exceeds the average inter-particle separations. Consequently, the system is believed to be strongly paired and the size of Cooper pairs is comparable with the Fermi wavelength.

The experimental investigation of the unitary Fermi gas (UFG) began with its realization in atomic traps by the Duke group [1]. At unitarity (often referred to as ``at resonance"), when scattering length tends to infinity, the properties of such a system are governed by deceptively simple laws. In particular, the ground state energy per particle is given by $E/N=3\varepsilon_F\xi/5$, where $\varepsilon_F=\hbar^2k_F^2/2m$ is the Fermi energy of a noninteracting Fermi gas with the same number density $n=n/V=k_F^3/3\pi^2$. The determination of the dimentionless constant ξ is theoretically very demanding as it requires the non-perturbative methods. The best current accepted value was determined through restricted/fixed node Monte Carlo (MC) calculation as $\xi=0.42(1)$. This value was confirmed by the zero temperature extrapolation of unrestricted MC calculations of Ref. [2], where $\xi=0.44(3)$ was obtained. Theoretically, it was also found that this system is superfluid at low temperatures and the value of the pairing gap was estimated at zero temperature to be $\Delta = 0.504(24)\,\varepsilon_F$. A number of finite temperature thermodynamic properties of the homogeneous phase were determined as well [2-6]. In particular it was shown [2,3] that at low temperatures the thermodynamic behavior appears as a rather surprising and unexpected melange of fermionic and bosonic features, which defies a straightforward classification as any known superfluid. Namely, the temperature dependence is characteristic of an ideal Bose gas, which is superfluid at the same time.

On the experimental side there is a quite wide spread in values of the dimensionless parameter ξ determined in various experiments. However, the latest experiments seem to converge, possibly guided by the existence of firm theoretical results, to the expected value [7,8].

The measurements of the pairing gap are still in their infancy. Although it has been conclusively demonstrated that a UFG is superfluid at sufficiently low temperatures [9] the value of the pairing gap has only been determined so far in one experiment [10]. Moreover, the extracted value is significantly smaller than the theoretical value.

One of the most interesting recent achievements was the first model-independent comparison of measurements of the entropy and of the critical temperature for the supefluid-to-normal phase transition of a unitary Fermi gas, performed by the Duke group [11], with the most complete results currently available from finite temperature Monte Carlo calculations [12]. The measurement of the critical temperature in a cold fermionic atomic cloud is consistent with a value $T_C=0.23(2)\varepsilon_F$ in the bulk, as predicted in Ref. [2].

[1] K.M. O'Hara, et al., Science, **298**, 2179 (2002).

[2] A. Bulgac,J.E. Drut, **P. Magierski**., Phys. Rev. Lett. **96**, 090404 (2006);

[3] A. Bulgac,J.E. Drut, **P. Magierski.**, Int. J. Mod. Phys. **B20**, 5165 (2006)

[4] E. Burovski, et al., Phys. Rev. Lett. 96, 160402 (2006); ibidem 97, 239902(E) (2006); New J. Phys. **8**, 153 (2006).

[5] D. Lee and T. Shäffer, Phys. Rev. **C 73**, 015202 (2006); D. Lee, Phys. Rev. **B 73**, 115112 (2006).

[6] V.K. Akkineni, et al., cond-mat/0608154.

[7] J.T. Stewart, et al., Phys. Rev. Lett. **97**, 220406 (2006).

[8] L. Tarruell, et al., cond-mat/0701181.

[9] M.W. Zwierlein, et al., Nature, **435**, 1047 (2005).

[10]C. Chin, et al., Science **305**, 1128 (2004).

[11] L. Luo et al., cond-mat/0611566

[12] A. Bulgac,J.E. Drut, **P. Magierski**., cond-mat/07017786

FORWARD SPECTROMETER FOR PANDA

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Experimental facility: future Facility for Antiproton and Ion Research (FAIR), Darmstadt

PANDA (**P**roton **AN**tiproton **D**etector **A**ssembly) is a general purpose detector which was proposed for studies of reactions induced by antiproton beams on hydrogen as well as on nuclear targets at the Facility for Antiproton and Ion Research (FAIR) at GSI-Darmstadt (www-panda.gsi.de). PANDA will be installed at the internal target of the High Energy Storage Ring (HESR) at FAIR which can store up to 10^{11} antiprotons and accelerate them in the momentum range 1.5-15 GeV/c. Application of electron cooling will guarantee unprecedented quality of the antiproton beam. This will enable performance of high-precision experiments in the field of: charmonium spectroscopy, establishment of the QCD-predicted qluonic excitations (charmed hybrids, glueballs), search for modifications of properties of mesons with open and hidden-charm in nuclear medium, spectroscopy and study of rare decays of D and D_s mesons, measurements of the proton electric and magnetic form factors in the time-like region up to $Q^2 \approx 25$ GeV^2/c^2.

Our Kraków group is a member of the international collaboration working at present on the design and prototyping of the PANDA detector. We are responsible for the Forward Spectrometer (FS) which, besides the Target Spectrometer (TS), is the key component of the PANDA setup. Our studies involve a "3-D" modeling of the FS detectors including drift chambers, TOF scintillation wall, RICH detector, electromagnetic calorimeter and muon counters. We participate also in development of simulation and data analysis software which we exploit for optimization of the FS detector setup. In order to study performance of drift chambers in the high rate environment expected at PANDA we constructed a prototype drift chamber which is shown in Figure 1. The chamber is equipped with the read-out electronics also developed in Kraków. It comprises preamplifier-discriminator cards based on the CARIOCA chips and the TDC boards based on the HPTDC chips. Currently we are testing the chamber in various ways including irradiation with proton beam from the COSY-Juelich accelerator. Last but not least we contribute to development of the data acquisition system (DAQ) for PANDA. We proposed a novel architecture of triggerless DAQ based on data buffers and processing nodes interconnected with a high speed network, allowing for a very high flexibility in the event selection. Results of studies of this architecture, performed with the use of the SYSTEM-C framework, are very promising.

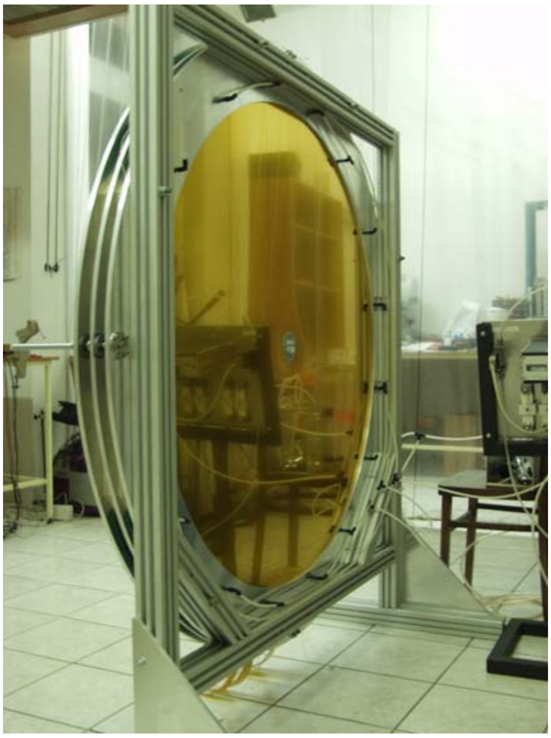

Fig. 1. *Prototype drift chamber for PANDA. The chamber contains four detection planes with square 1cm x 1cm cells. The central opening is foreseen for the beam pipe.*

[1] C. Schwarz, T. Barnes, D. Bettoni, R. Calabrese, W. Cassing, M. Duren, S. Ganzhur, A. Gillitzer, O. Hartmann, V. Hejny, P. Kienle, H. Koch, W. Kuhn, U. Lynen, R. Meier, V. Metag, **P. Moskal**, H. Orth, S. Paul, K. Peters, J. Pochodzalla, J. Ritman, M. Sapozhnikov, L. Schmitt, K. Seth, A. Sokolov, N. Vlassov, W. Weise, U. Wiedner, Phys. Scripta **T104**, 147 (2003).

[2] **J. Smyrski**, Int. J. Mod. Phys. **A20**, 564 (2005).

[3] **J. Smyrski,** "PANDA: a detector for research with antiprotons", Proceedings of the 9th ICATPP Conference on Astroparticle, Particle, Space Physics, Detectors and Medical Physics Application, Como, 17-21 October 2005.

[4] **P. Hawranek**, Int. J. Mod. Phys. **A22**, 574 (2007).

DESIGN STUDIES OF CHARMONIUM DETECTION VIA J/$\psi \rightarrow 2\mu$ DECAYS IN CBM

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The Compressed Baryonic Matter (CBM) experiment at the new major accelerator facility named FAIR in Darmstadt aims at the investigation of strongly interacting matter at very high baryon densities. Joining the international CBM Collaboration, we participated in the planing of research and consequently in the designing of apparatus – an universal detection system dedicated to fully exploit the physics potential of nucleus-nucleus collisions at FAIR. The Warsaw group contributed to the shaping of the basic initial setup of the CBM [1], particularly the geometry of transition radiation detector (TRD) planes and of the time-of-flight (TOF) detector.

The research program comprises the study of the structure and the equation of state of baryonic matter. This includes the search for the phase boundary between hadronic and partonic matter, the critical endpoint and the search for signatures for the onset of chiral symmetry restoration.

Among the various probes that should allow to gain insight into the properties of hot and dense nuclear matter, important are pairs of leptons e^+e^- and $\mu^+\mu^-$. They originate from and can be used to detect the decays of the hidden charm meson J/ψ and of the low short-lived strange low-mass vector mesons (LMVM) ρ and ω as well as of the hidden strangeness meson ϕ. These leptons do not interact strongly and thus penetrate quasi freely the hot and dense zone of collisions.

The CBM experiment is designed to operate at interaction rates up to 10^7 reactions per second with multiplicities of up to ~1000 charged particles per collision. Such parameters require unprecedented detector performance in terms of readout. The search for rare events requires in addition an appropriate trigger concept and efficient fast particle identification algorithms.

Simulations of J/ψ identification via the measurement of di-muon pairs as an alternative to the di-electron pairs have been peformed. In this case the background is caused by muons from weak decays of charged pions and kaons. One of the possible locations of the muon detector is behind the basic CBM setup consisting of: silicon tracking system STS in a magnetic dipole, ring imaging Cerenkov detector RICH, TRD, TOF and electromagnetic calorimeter ECAL [1]. The other location considered is in the space occupied in the basic setup by RICH, with the consequence of resigning from the detection of di-electron pairs. As a part of comparative studies of these options a search was performed for the optimum geometry of a muon detector at the former position in CBM .

The distant location implies large dimensions and requires optimizing the geometry, compromising between efficiency, acceptable signal/background ratio (S/B) and size. The results favour the choice of a two-arm structure – a consequence of the emission of the muon pair into opposite hemispheres. Moreover a vertical arrangement of the arms, i.e. out of the bending plane of the magnetic dipole, results in increasing S/B. With two optimized rectangular arms of total area 25 m^2 located at a distance 15 m from the target the detection efficiency of 5% could be achieved for J/ψ's produced in 25A GeV Au+Au collisions.

The rare production of J/ψ mesons ($2 \cdot 10^5$ per such collision) with 6% decaying into the $\mu^+\mu^-$ channel has to be measured in presence of a strong combinatorial background of muons from decays of several hundreds of pions. The suppression of this background could be achieved by measuring the kink angle between the trajectory of meson and its decay daughter. This method requires the optimization of the set of parameters used to distinguish between deviations of trajectories due to decay kinks and trivial multiple scattering [2]. Realistic estimates of tracking precision based on the resolution of STS (1% momentum uncertainty) and TRD (3 stations with 3 planes of 250 μm spatial resolution) result in the reduction of background and yield S/B ~ 2 in a 100 MeV wide nvariant mass window centered at the mass of J/ψ . The muon identifying algorithm [2] has been improved and optimized to allow for fast particle tagging required to take trigger decisions.

Further simulations are carried out in search for possible alternative and complementary configurations of the CBM detector aiming at simultaneous detection of J/ψ and LMVM via their di-muon decays.

[1] CBM Experiment, Technical Status Report, GSI, Darmstadt, 2005, p.14

[2] CBM Experiment, Technical Status Report, GSI, Darmstadt, 2005, p.367

ONLINE EVENT SELECTION IN THE CBM EXPERIMENT

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The CBM experiments is a dedicated to investigate the properties of highly compressed baryonic matter as it is produced in nucleus-nucleus (e.g. Au+Au) collisions from 15 to 45 AGeV. The scientific goal of the research program is to explore the QCD phase diagram of strongly interacting matter in the region of highest baryon densities and thus measurements of hadronic, leptonic and photonic observables at interaction rates up to 10MHz. To make it feasible the dedicated detectors will be designed. The current layout consist of high-resolution silicon tracking system (STS) placed in the field of a superconducting dipole magnet. Outside of the magnetic field, a RICH detector and several stations of transition radiation detectors (TRD) will identify electrons in the momentum ranges relevant for low-mass vector meson and charmonium measurements. Hadron identification will be achieved by the time-of-flight measurement in an array of resistive plate chambers (TOF). The setup is completed by an electromagnetic calorimeter (ECAL) for identification of photons, electrons and muons. The experiment will operate at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.

The major experimental challenge is posed by extremely high reaction rates of up to 10^7 event/second. A typical central Au+Au collision in the CBM experiment will produce up to 700 tracks in the TRD detector. It produces a huge amount of data which currently can not be transmitted and stored for further slow off-line analysis. Therefore the standalone TRD tracking algorithm has been developed having the low-level online event selection in mind. It has been created to reduce the amount of data that do not contain interesting signal, i.e. detected electrons and positrons from the J/ψ decay. This particle is particularly interesting because is one of the predicted signal and experimental evidence of the formation of the quark-gluon plasma. The J/ψ meson, called also "charmonium", is produced in Au(25 AGeV)+Au reaction with multiplicity $1.5 \cdot 10^5$. If will be taken into consideration planned beam intensity, number of interaction, charmonium rate, fraction ($J/\psi \rightarrow e^+e^-$) and detector acceptance, only 0.17/s charmonium will be meausered. Thus, the huge bulk of background data should be efficiently suppressed to make it possible to pass remaining information to the mass storage system. This required high-speed, efficient and reliable data acquisition and an online event selection and backgrund suppression methods. The standalone TRD tracking procedure, based on cellular automaton algorithm, is just a part of wider online background suppression issue.

In the present shape the algorithm gives promising results with regard to speed and efficiency. As testing environment the particles produced from Au+Au central collision at 25GeV were taken. After processing 1000 events produced by UrQMD particle generator, on average 550 tracks per event were reconstructed. Efficiency of correctly reconstructed tracks is about 86% and 91% for particles with momentum below and above 1 GeV/c respectively. On average processing time per event is about 0.8 seconds. The procedure was tested using the standard PC computer with 2 multithreads, 3GHz processors and 1GB RAM.

Reconstructing the tracks of electron and positron from discussed decay and calculating each particle's momentum vector leads to the reconstruction of J/ψ mass, which is equal 3.1 GeV/c^2. Hence, if the algorithm finds a value of invariant mass similar to the J/ψ, it accepts the entire event and sends it to the data acquisition system. For production event with e^+e^- pairs from J/ψ decay was used the Pluto generator (a monte carlo simulation tool for hadronic physics).

[1] CBM Collaboration, Technical Status Report, Compressed Baryonic Experiment,GSI 2005.

[2] CBM Collaboration, Scientific Report 2005, GSI Report 2006-1.

DEVELOPMENT OF A FAST DATA READOUT SYSTEM FOR MEDIUM SIZE EXPERIMENTS

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In numerous nuclear/particle physics experiments detection systems comprise up to few thousands of analog data sources. High precision studies require accumulation of large data samples and therefore the readout system must work reliably at trigger rates reaching a few tens of thousands events (with multiplicities below about a hundred) per second, *without* any significant dead-time. To meet such requirements it is necessary to utilize a fast bus and/or protocol for the data transmission. In contrast to the present generation of HEP experiments, here the usage of complicated multiplexing schemes with specially developed chips and boards as well as many-level triggering and event-building techniques is rather disadvantageous.

As a response to the needs of moderate-size experiments we have developed a readout system based on the standard FERA (trademark of the LeCroy Corporation) configuration and an additional custom CAMAC module, whose use permits to avoid the limitations inherent in the original FERA system. Use of the custom FERA Extender/Tagger module allows us to divide the readout system into sections matching the detector configuration, and to drive each section by a separate (differing in width or shifted in time) gate signal. In each sub-system the data are

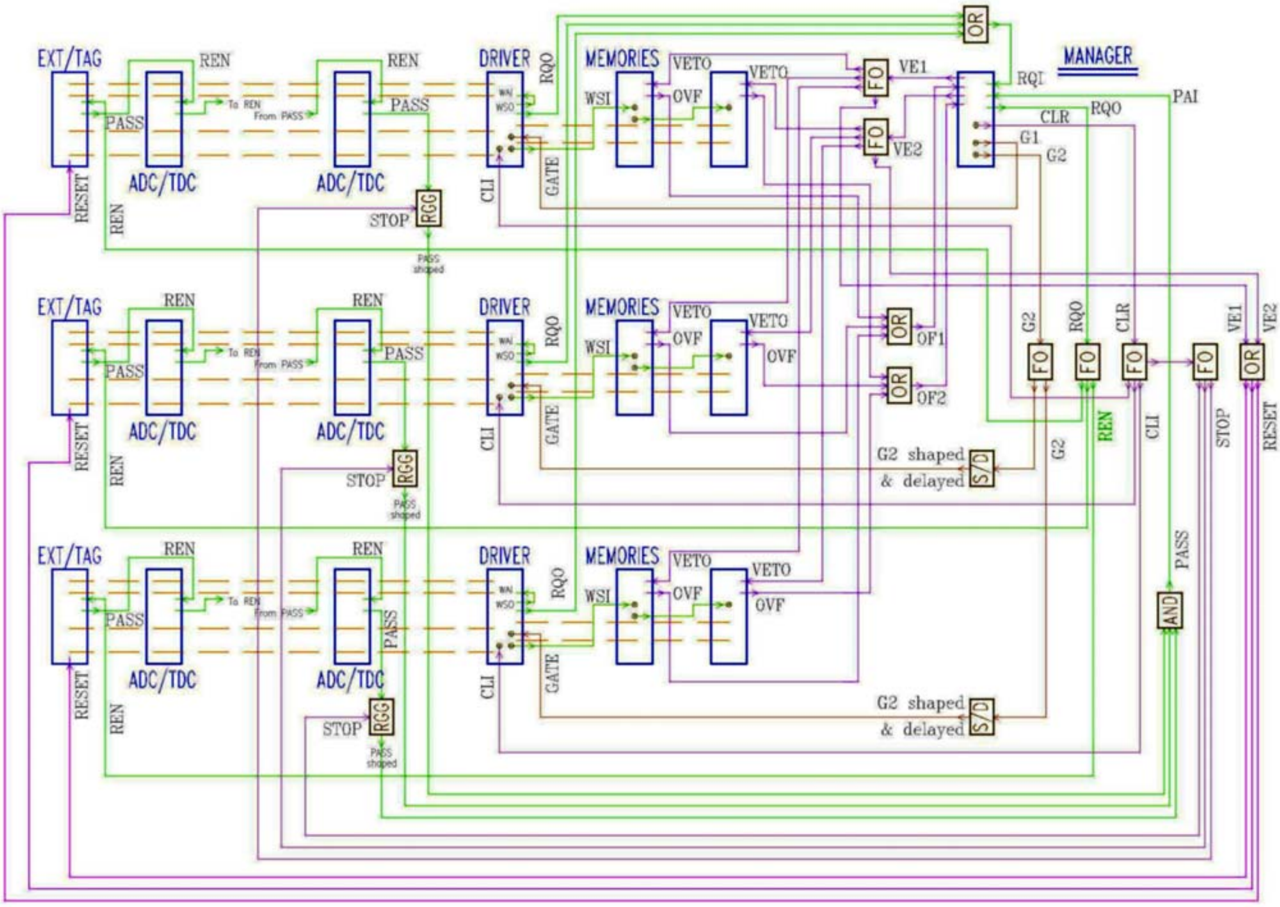

Fig. 1. *Block diagram of the full FERA readout system composed of three branches containing the Extender/Tagger modules, and controlled by a single Manager module equipped with auxiliary logic.*

sent over a dedicated bus (at the speed of 100 ns per data word) to a pair of alternatively active buffering memories. The coordination of the full system (controlling the event cycle, switching the memories, issuing DAQ requests) is performed by a single FERA Manager, which is equipped with a logic system for distributing and multiplexing of the synchronization signals – see figure 1. The sub-events are uniquely marked by the Extender/Tagger module (synchronously in all branches), what allows to recombine them into full events by the processor controlling the acquisition.

Rate capability of the full FERA system depends clearly on a particular experimental implementation. For three sub-systems with a total of 2000 readout channels and a typical event size of 80 words, one obtains a conservative estimation for the event cycle duration of around 25 μs. It follows, that an event rate of about $3 \cdot 10^4$ per second can be processed by the system with dead-time losses of 3% only. A limitation on the rate capability could arise due to the memories emptying time, a slow procedure on the CAMAC DATAWAY. Even then the acceptable event rate is about $3 \cdot 10^3$ s^{-1}. This restriction on the data throughput could be easily removed by replacing the CAMAC memory modules by their VME versions. In such a hybrid system the full rate capability can be restored, allowing for the data rates of about 5 MB/s (i.e. some 30000 moderate-length events per second). The described system has been, in various versions, successfully used in several fundamental research projects and proved its stable and reliable performance.

[1] **St. Kistryn**, C.P. Bee, P. Eberhardt, Proc. of the 6-th Int. Conf. on Electronics for Particle Physics, LeCroy Corporation, Chestnut Ridge New York, May 28-29, 1997, ed. G.J. Blanar, R.L. Sumner, New York 1997, p. 193.

[2] I.C. Barnett, C.P. Bee, **St. Kistryn**, Proc. of the 6-th Electronics New Zealand Conference, ed. G.E.J. Bold, University of Auckland, 1999.

[3] I.C. Barnett, C. Bee, **K. Bodek**, **A. Budzanowski**, N. Danneberg, P. Eberhardt, W. Fetscher, C. Hilbes, M. Janousch, **L. Jarczyk**, K. Kirch, **S. Kistryn**, J. Klement, K. Köhler, **A. Kozela**, J. Lang, G. Llosa, **M. Markiewicz**, X. Morelle, O. Naviliat, T. Schweizer, **J. Smyrski**, **J. Sromicki**, **E. Stephan**, **A. Strzałkowski**, K. Szeker, **J. Zejma**, Nucl. Instr. Meth. **A455**, 329 (2000).

[4] **K. Bodek**, T. Boehm, D. Conti, N. Danneberg, W. Fetscher, C. Hilbes, M. Janousch, **S. Kistryn**, K. Köhler, J. Lang, **M. Markiewicz**, **J. Sromicki**, **J. Zejma**, Nucl. Instr. Meth. **A473**, 326 (2001).

[5] G. Ban, M. Beck, **A. Białek**, **K. Bodek**, P. Gorel, K. Kirch, **St. Kistryn**, **A. Kozela**, **M. Kuźniak**, A. Lindroth, O. Naviliat-Cuncic, **J. Pulut**, N. Severijns, **E. Stephan**, **J. Zejma**, Nucl. Instr. Meth. **A565**, 711 (2006).

NEW TECHNOLOGIES OF SILICON DETECTORS

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Experimental facility: Warsaw Cyclotron

Identification of low-energy light charged particles and heavy ions requires application of E-ΔE telescopes with very thin transmission ΔE detectors. The new technology elaborated for production of thin strip ΔE detectors is named *Planar Process Partially Performed on Thin Silicon Membrane (PPPP process)* [1,2]. Using this technology the 52 and 22 μm thick strip detectors (of diameter 3 in) were elaborated, see Fig. 1.

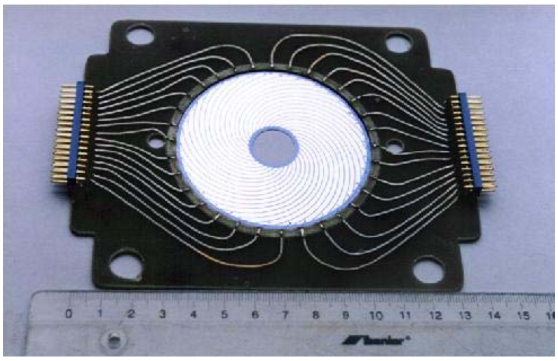

Fig. 1. *Thin srtip detector with spral strips.*

Combinning it with thicker silicon E detector, the E-ΔE telescopes are formed. The result of heavy ions measurements with this telescopes is presented in Fig. 2.

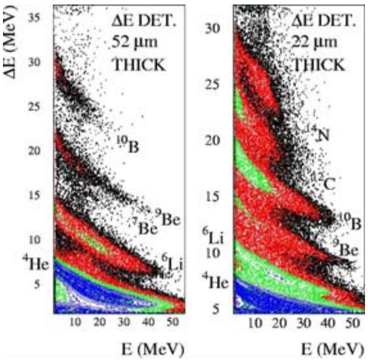

Fig. 2. *E-ΔE spectra measured by telescopes.*

For construction of silicon monolithic E-ΔE telescopes (pair of silicon detectors created on single silicon wafer) we have elaborated a new technological process named *Quasi-Selective Epitaxy (QSE)* [3,4,5] As a result of the QSE process, we have the silicon mesa epitaxially grown in the place of the SiO_2 windows.

Tests of monolithic E-ΔE telescopes with heavy ions are illustrated by Fig. 3:

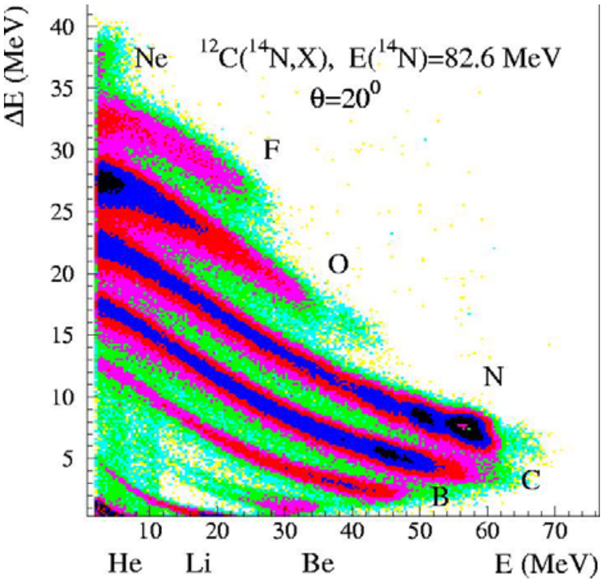

Fig. 3. *E-ΔE spectrum measured by a monolithic E-ΔE telescope.*

PPPP proces and QSE can be applied to the new generation Si-balls as front detectors for light charged particles and heavy ion identification.

Proces QSE can be applied to microelectronics for production transistors and ASIC's.

[1]**A.J.Kordyasz, E.Nossarzewska-Orłowska, J.Wojtkowska, M.Kisieliński, E.Kulczycka, L.Reissig, J.Kownacki, A.Wojtasiewicz, J.Sarnecki, J.Iwanicki,** Nucl. Instr. and Meth. **A 539** (2005) 262

[2]**A.J.Kordyasz, M. Kowalczyk, E.Nossarzewska-Orłowska, M.Kisieliński, E.Kulczycka, J.Sarnecki, J.Iwanicki,** Nucl. Instr. and Meth. **A 570** (2007) 336

[3]**A.J.Kordyasz, E.Nossarzewska-Orłowska, E.Piasecki, D.Lipiński, A.Brzozowski, J.Kownacki, M.Kowalczyk, Ł.Świderski, A.Syntfeld, L.Reissig, A.Pietrzak, A.Jakubowski, R.Pozorek, R.Gąsiorowski,** Nucl. Instr. and Meth. **A 530** (2004) 87

[4]**A.J.Kordyasz, E.Nossarzewska-Orłowska, E.Piasecki, D.Lipiński, A.Brzozowski, J.Kownacki, M.Kowalczyk, Ł.Świderski, A.Syntfeld, L.Reissig, A.Pietrzak, A.Jakubowski, R.Pozorek, R.Gąsiorowski,** Nucl. Instr. and Meth. **A 528** (2004) 721

[5]**A.J.Kordyasz, J.Iwanicki, M.Kowalczyk, E.Kulczycka, E.Nossarzewska-Orłowska, D.Lipiński, A.Brzozowski,** Nucl. Instr. and Meth. **A 568** (2006) 778

NUCLEAR REACTIONS IN THE ACCELERATION THERAPY BY THE HIGH-ENERGY X-RAYS AND ELECTRONS

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The high-energy photons and electrons of the therapeutic beams used in the accelerator therapy induce the photonuclear (γ,n) and electronuclear (e,e'n) reactions mainly inside the primary beam. The direct consequence of these reactions is a production of undesirable neutrons and radioisotopes. In the vicinity of the accelerator head the contaminant-neutrons have a broad energy spectrum with the high-energy end of more than 10 MeV (Fig.1). The thermal and epithermal neutron radiation level is particularly important because of the simply capture reaction (n,γ) occurring at thermal and epithermal energies for most of isotopes. In this reaction, various radioisotopes can be produced, like in the photo- and electronuclear reactions. The radioisotope production induced by the neutrons is not limited to the primary beam but it takes place in the whole accelerator bunker (in the walls, floor and ceiling and in all objects inside the treatment room and in the maze etc.) because the neutron flux does not decrease significantly as the distance from the accelerator head increases. The originated radioisotopes can emit the penetrative gamma rays with energies of even several MeV during the disintegration of excited states of nuclei. Particularly unfavorable radioisotopes are those with metastable states since they cause radioactivity of accelerator components (Fig.1), accessories, air, walls and other objects in the bunker. This radioactivity can be accumulated and remain on measurable level even for several days after the last beam emission. It is the main factor of the dose to personnel operating the accelerator. The originated neutrons appear only when the beam is on because the single neutron life time in air is about several μs. However, the neutrons are source of the additional undesired total body dose to patients. This neutron dose is not calculated by the treatment planning system, thus the supplementary precise investigations are required.

Our investigations started in 1999 have aimed at determination of distribution and energy spectrum of the neutrons and at identification of major radioactive sources inside the accelerator bunker. The study were and are carried out in cooperation with Department of Medical Physics of Centre of Oncology in Gliwice and with Radiotherapy Department of the Hospital-Memorial St. Leszczyński in Katowice, for two widely used type of medical linacs: Primus Siemens and Varian Clinac-2300. Experimental methods as well as computer simulations were applied in the investigations. The spectral measurements of gammas were performed with the use of an high-purity germanium detector connected to a multichannel analyzer installed in a PC computer (system for a field spectrometry). The thermal and epithermal neutrons were measured applying the induce activity method whereas the neutron spectra and doses were determined by the mean of the computer simulations based on the GEANT4 libraries – one of the newest simulation software for the use in nuclear physics. In future we plan to apply out investigation for hadrontherapy.

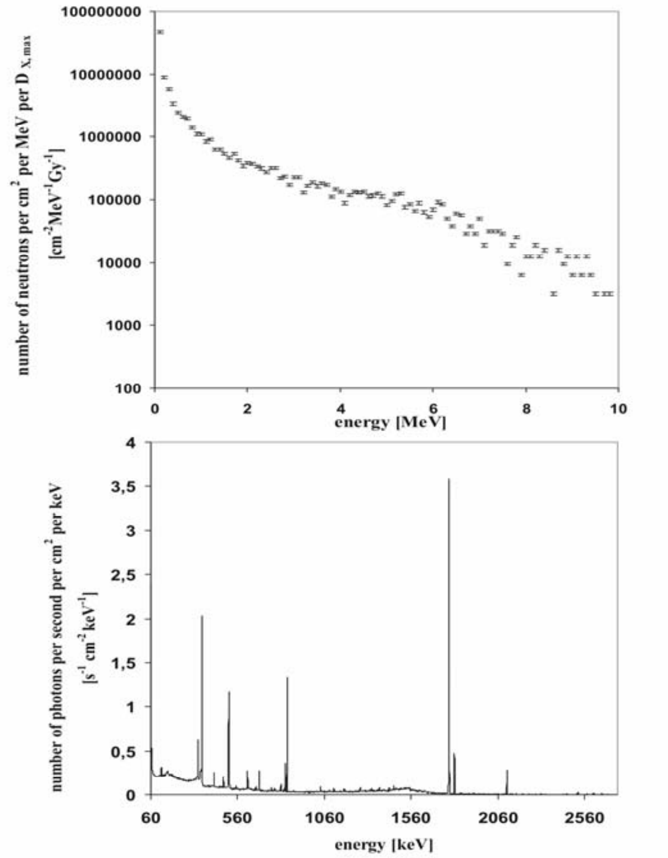

Fig. 1. *The neutron spectrum in the plane the treatment couch, calculated for the 20 MV X-rays from Varian Clinac-2300 linac (highly) and the gamma spectrum measured under the Primus Siemens head after the short lasting emission of the 15 MV X-rays (low).*

[1] **A. Konefał**, A. Orlef, **W. Zipper**, **J. Dorda**, W. Łobodziec, Polish Journal of Medical Physics and Engineering **7**(2), 95-108 (2001)

[2] **A. Konefał**, A. Orlef, **W. Zipper**, Z.Maniakowski, Physica Medica,Vol. XX, Suplement **1**, p. 165-167 (2004)

[3] **A. Konefał**, M. Dybek, **W. Zipper**, W. Łobodziec, K. Szczucka, Nuleonika Vol. **50**, No. 2 p. 73-81 (2005)

[4] **A. Konefał**, Postępy Fizyki, **57**(6), 242-251 (2006)

[5] **A. Konefał**, **K. Polaczek-Grelik**, A. Orlef, Z. Maniakowski, **W. Zipper**, Polish Journal of Environmental Studies vol. **15**, No. 4A, 176-180 (2006)

[6] **K. Polaczek-Grelik**, **A. Konefał**, A. Orlef, **W. Zipper**, Polish Journal of Environmental Studies vol. **15**, No. 4A, 195-197 (2006)

NATURAL RADIOACTIVITY STUDIES IN SOIL, WATER AND AIR

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Experimental facility: Laboratory of Low Activities, University of Silesia

Natural radionuclides are present in air, water, soil, plants and animals and in consequence in the human diet. In groundwater, their presence is determined by their activity concentration in soil and bedrock. Groundwater reacts with the surrounding rocks and releases elements which can be dissolved in it. Presence of radionuclides from uranium and thorium series in soil and rocks may also result in increased radon and thoron activity concentration in air, soil air and water. Radionuclides of natural decay chains enter the human body through ingestion and inhalation.

Investigations carried out in the Laboratory of Low Activities concern the distribution and migration of naturally occurring radionuclides, i.e. ^{234,236}U, ^{226,228}Ra, ^{222}Rn in soil, water and air using nuclear spectrometry techniques. Naturally occurring uranium contains three alpha emitting radionuclides ^{238}U, ^{235}U and ^{234}U, each with a different half-life and mass abundance. Uranium ^{234}U is a decay product of the ^{238}U series and after a sufficient time the ^{234}U isotope approaches a secular equilibrium with the ^{238}U activity. Radiological risk arising from uranium ingestion is small in comparison with its chemical toxicity. Uranium is deposited on the bones surfaces together with calcium but about 90% is removed from the body within 24 h with urine. In nature there are four radium isotopes ^{223}Ra, ^{224}Ra, ^{226}Ra, ^{228}Ra. The longest half-life equal to 1620 years has ^{226}Ra so this isotope is the most important from the radiological point of view. Ingestion of both uranium and radium into humans may be toxic and dangerous. Similar behavior of radium as calcium may cause this element to incorporate in bones. In natural radioactivity studies one cannot omit radon ^{222}Rn measurements. Radon is a noble gas present in soil air, air and also soluble in water. Radon itself is not harmful but its decay products are toxic heavy metals not neutral for human health.

Laboratory of Low Activities carries environmental studies with the use of modern α,β,γ – spectrometry systems. The measurement of γ – radioactivity is performed with the use of γ – spectrometry systems with HPGe semiconductor detectors, both in the laboratory and directly in the field (In Situ Spectroscopy). Studies of γ – radioactive isotopes in environmental and non-environmental condensed and liquid samples are carried out. Alpha and beta-radioactive isotopes (^{222}Rn and ^{226,228}Ra) are studied using WinSpectral 1414 α/β liquid scintillation counter (LSC) from Wallac. Alpha radioactive isotopes of uranium are investigated with the use of alpha spectrometer 7401VR from Canberra – Packard with semiconductor detector from Ortec. Radon measurements are also carried out with portable detektor RAD7 from Durridge company.

Laboratory of Low Activities carries not only research but also didactics.
Liquid Scintillation Counter 1414 α/β from Wallac is presented at the figure below.

Fig. 1. *Liquid Scintillation Counter 1414 α/β from Wallac at the Laboratory of Low Activities.*

[1] **B. Kozłowska, A. Hetman, W. Zipper** , Appl. Rad. Isotopes **51** (1999) 475-480

[2] **B. Kozłowska, J. Dorda, A. Hetman, W. Zipper**, Proc. of the XXXIV Zakopane School of Physics, Condensed Matter Studies by Nuclear Methods edited by E. Gorlich, A. Pędziwiatr (1999) **226**.

[3] **B. Kozłowska, A. Hetman, J. Dorda, W. Zipper** , Radiation Physics and Chemistry **61** (2001) 677-678

[4] T. Przylibski**, B. Kozłowska, J. Dorda**, B. Kiełczawa, Journal of Radioanal. Nucl. Chem. 253 (2002) **11**.

[5] Przylibski T.A., **J. Dorda, B. Kozłowska**, Nukleonika **47** No 2 (2002) 59-64.

[6] Przylibski T. A., Staśko S., Szczepanowski S., Modelska M., **Dorda J., Kozłowska B.**, Przegląd Geologiczny **50** No. 5, (2002) 436-440 (in Polish).

[7] **B. Kozłowska, M. Kordiak**, M. Wysocka, Proceedings of the 4th European Conference on Protection against Radon at Home and Work, Praga (2004).

[8] T. A. Przylibski, K. Mamont-Cieśla, M. Kusyk**, J. Dorda, B. Kozłowska,** J. of Environmental Radioactivity **75** (2004) 193.

[9] **A. Walencik, B. Kozłowska**, Proceedings of the 2005 LSC Conference. Edts: Chalupnik, Schonhofer, Noakes. Radiocarbon (2005) 229.

[10] **B. Kozłowska, J. Dorda, B. Kłos** and T. A. Przylibski, Radioactivity in the environment, ISBN 82-90362-21-8, (2005) 99-102.

[11] **A. Walencik, B. Kozłowska, Ł. Wojtecki**, Polish Journal of Environmental Studies, **15** (4A), 210-213 (2006).

APPLICATION OF THE MÖSSBAUER SPECTROSCOPY ON INVESTIGATION OF IRON MINERALS

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Mössbauer spectroscopy is an examination technique based on the resonant emission and absorption of gamma radiation. Thanks to high scopes of resolution, the Mössbauer spectroscopy is beginning to be used in variety of research concerning the examination of physical and chemical properties of solid state. The Laboratory of Mössbauer Spectroscopy at the Institute of Physics, University of Silesia, possesses three Mössbauer spectrometers and one cryostat, which enable us to test samples of materials in temperatures ranging from 10 to 500 K. The laboratory is also equipment with a heat treatment furnace that is capable of testing samples in temperatures up to 1470 K. Due to the fact that we possess sources of radioactivity and detection equipment, the laboratory is a place where research based on the isotope of iron ^{57}Fe is conducted. High presence of iron in the nature allows us to examine a wide spectrum of materials, both natural and artificial.

For the past few years, the Laboratory of Mössbauer Spectroscopy has been doing research on the examination of minerals and rocks so as to determine which iron compounds are present in them and specify what kinds of changes these compounds undergo during different technological or geological processes. For instance, several examinations were done in the Laboratory, the aim of which was to identify iron compounds in hard coal obtained from different coal deposits and to specify what changes these compounds would undergo in such technological processes as: pyrolysis, hydropyrolysis and coal liquefaction [1, 2].

The scope of analyses conducted in the Laboratory also includes determining the presence and composition of minerals that contain iron in various geological formations. Iron-manganese concretions, granites and basalt's were examined. Currently we are doing research the purpose of which is to examine changes of ferriferous minerals during heat treatment (Fig. 1) and other processes such as weathering and secondary mineralization [3-8].

The Mössbauer Spectroscopy makes it possible to obtain accurate information concerning the crystalochemical features of iron atom and the influence of immediate neighbours within a crystalline network on properties of the entire alloy. The Mössbauer measurements allow us to specify the proportions of iron atoms in crystalline networks. They also make it possible for us to determine the influence of particular components of the alloy on crystallographical location. For many years, the Laboratory of Mössbauer Spectroscopy has been working on the examination of magnetic properties of there-component alloys that contain lanthanides and transient metals, e.g. $Sm_2Fe_{17-x}Si_x$ $(0<x<4)$. The purpose of these examinations is to determine the influence of particular components and their proportions on magnetic properties of the alloy [9-12].

The investigations are conducted in cooperation with the Department of Solid State Physics, University of Silesia and Institute of Applied Geology, University of Silesia of Technology.

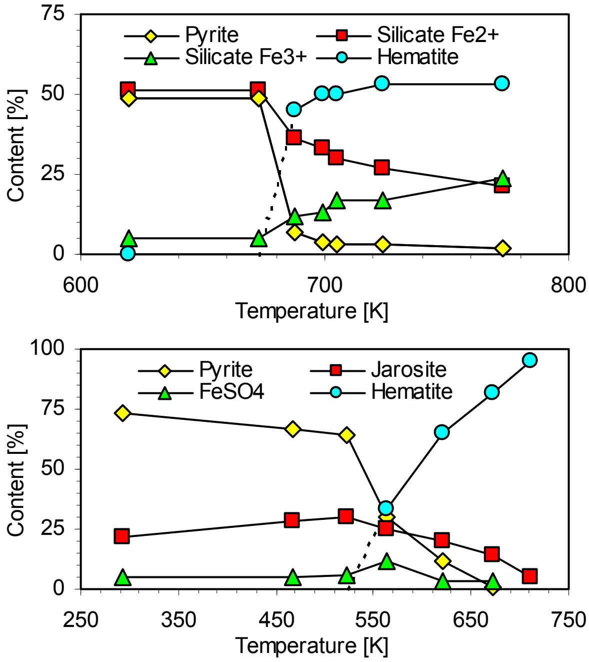

Fig. 1. *Relative contents of iron compounds as function of the temperature of annealing of the mineral (a) and coal (b) pyrite.*

[1] **J.L. Komraus; E.S. Popiel,** Hyperfine Interactions, **90** 383-388 (1994).

[2] **S. Pusz; A. Krztoń; J.L. Komraus;** M.R. Martinez-Tarazona; A. Martinez-Alonso; J.M.D. Tascón, International Journal of Coal Geology, **33** 369-386 (1997)

[3] **Z. Adamczyk, J. Komraus,** Molecular Physics Reports, Vol. **30**, p. 9-14, (2000).

[4] **Ludwig A. Zarek W. Popiel E. Winiarski A.,** Mol. Phys. Rep., vol. **30**, (2000) 86-93.

[5] **Z. Adamczyk, J. Komraus,** Materials and Manufacturing Processes, Vol. **16**, No. 4, p. 577-587, (2001)

[6] **J. L. Komraus, Z. Adamczyk,** Hyperfine Interactions **163**, str 57-72 (2005) Springer 2006.

[7] **E. Talik, W. Zarek, M. Kruczek,** S. Ganschow**, D. Skrzypek, E. Popiel,** Crystal Research and Technology **41**, 979-987 (2006).

[8] **M. Tuszyński, J. L. Komraus,** Polish J. of Environ. Stud. Vol. **15** No. 4A 109-111 (2006).

[9] **Brząkalik K. Popiel E. Zarek W.,** Mol. Phys. Rep., vol. **30**, (2000) 21-6

[10] **E.Popiel, W. Zarek, Z. Kapuśniak, M. Tuszyński,** Nukleonika **48**, 65-70 (2003)

[11] **E.S. Popiel, W. Zarek, M. Tuszyński,** Nukleonika **49** (Suplement 3) (2004) 49 – 52

[12] **W.Zarek, E.Popiel, M.Tuszyński, E.Teper,** Nukleonika **49** (Supplement 3), S59-S62 (2004)

POSITRON ANNIHILATION LIFETIME SPECTROSCOPY STUDIES PERFORMED FOR POLYMERIC SYSTEMS

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Positron annihilation lifetime spectroscopy (PALS) is widely used for investigations of different aspects of polymer properties. The thermalized positron can annihilate with an electron from the absorber (annihilation of free positrons) or it may form, with the electron, a bound system - positronium (Ps) and then annihilation from the bound state takes place. The ground state of Ps atom consists of two substates: para-Ps (total spin of the particles is zero) and ortho-Ps (total spin of the particles is one). In vacuum a para-Ps lifetime is equal 125 ps and ortho-Ps lifetime is equal 140 ns. In condensed matter this long, ortho-Ps lifetime may be considerably reduced. In amorphous regions of a polymer substance free volumes exist where ortho-Ps may live for several nanoseconds. Positron lifetimes in polymer matter may be perturbated by different factors, for instance: changes in degree of crystallinity, blending of polymers, plasticization of polymers, aging of polymers, temperature, pressure and so on. The results of the positron lifetime measurements in polymers might be resolved into three or four exponentially decaying components. The shortest component (the mean lifetime equal to 125 ps), τ_1 , is usually attributed to para-Ps annihilation. The intermediate component, τ_2 , describes the annihilation of the free positrons. The third component, τ_3, is interpreted as the pick-off annihilation (annihilation of the positron, forming the ortho-Ps atom, with an electron from the surrounding polymer matter) of ortho-Ps in the crystalline regions of the polymer. Finally, the longest lived component, τ_4 , is attributed to the pick-off annihilation of ortho-Ps in the amorphous regions of the polymer. According to a model proposed by Tao (J.Chem. Phys. **56**, 5499(1972)) and Eldrup et al. (Chem. Phys. **63**, 51 (1981)) , the longest lived component of the positron lifetime spectrum may be correlated with the mean radius of the free volume cavity in the polymer matter. They derived an equation:

$$\tau_{\mathrm{l.lived}} = 0.5\left[l - \frac{R}{R+0.1656} + \frac{l}{2\pi}\sin\left(\frac{2\pi R}{R+0.1656}\right)\right]^{-1}$$

where $\tau_{l.lived}$ is the o-Ps lifetime expressed in nanoseconds, R is the mean radius of the spherical well expressed in nm, and 0.1656 nm is an empirical constant.

A conventional slow-fast coincidence spectrometer with two cylindrical plastic scintillators is used in the laboratory.The time resolution of the spectrometer, approximated by two Gaussian curves, is determined by analysing the positron lifetimes in Kapton foils. Typical values of the full widths at half of the maximum ($FWHM_i$) are : $FWHM_1$ - 258.4 ps, (I_1 - 73.58%); $FWHM_2$ - 365.9 ps. A positron source (^{22}Na, about 0.2 MBq) is sealed between two Kapton foils. The source correction is taken into account during numerical evaluations.

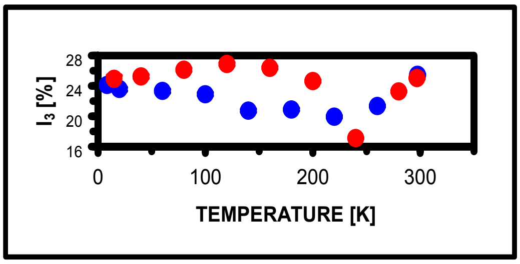

Fig 1. The I_3 values vs. temperature.
● - cooling cycle, ● - heating cycle

In Fig 1. the change of the longest lived component I_3 is presented, as a function of the temperature in polyethylene.

[1] **J. Borek, W. Osoba**, Polymer, **vol. 42**, 2901, (2001).

[2] **J. Borek, W. Osoba**, Mat.Sci.Forum, **vols. 363-365**, 334, (2001).

[3] **W. Osoba**, Acta Phys.Polonica A, **vol. 99, no. 3-4**, 447,(2001).

[4] **A. Danch, W. Osoba**, Journal of Thermal Analysis and Calorimetry, **vol. 72**, 641, (2003).

[5] **A. Danch, W. Osoba**, Fibres and Textiles in Eastern Europe, **vol. 11, no. 5**, 126, (2003).

[6] **A. Danch, W. Osoba,** and F.Stelzer: European Polymer Journal, **vol. 39**, 2051, (2003).

[7] **A. Danch, W. Osoba,** Radiation Phys.Chem., **vol. 68**, 445, (2003).

[8] **A. Danch, W. Osoba**, Desalination, **vol. 163**, 143, (2004).

[9] **M. Kozak, A. Danch, W. Osoba, L. Domka**, F.Stelzer and **S.Jurga,** Polymers&Polymer Composites, **vol. 12, no. 5**, 409, (2004).

[10] **A. Danch, W. Osoba**, Journal of Thermal Analysis and Calorimetry, **vol.78**, 923, (2004).

[11] **A. Danch, W. Osoba**, Journal of Materials Processing Technology, **vol. 155-156**, 1428-1434, (2004).

[12] **W. Osoba**, Recent Res.Devel. Polymer Science, **vol. 8**, 87-104, (2004), Transworld Research Network

[13] **A. Danch** and **W. Osoba**, Acta Physica Polonica A, **vol. 107,** no. **5**, 811-816, (2005).

[14] **A. Danch, W. Osoba**, Proceedings of the 7th Mediterranean Conference on Calorimetry and Thermal Analysis , 2-6 July 2005, Thesaloniki, Greece, p.45-49.

[15] **A. Danch, W. Osoba**, Journal of Thermal Analysis and Calorimetry, **vol. 84(1)**, 79-83, (2006).

[16] **A. Danch, W. Osoba**, Journal of Thermal Analysis and Calorimetry, **vol.84 (2)**, 311-337, (2006).

VALIDATION OF NUCLEAR DATA AND MODELS FOR THE SPALLATION TARGET CALCULATIONS

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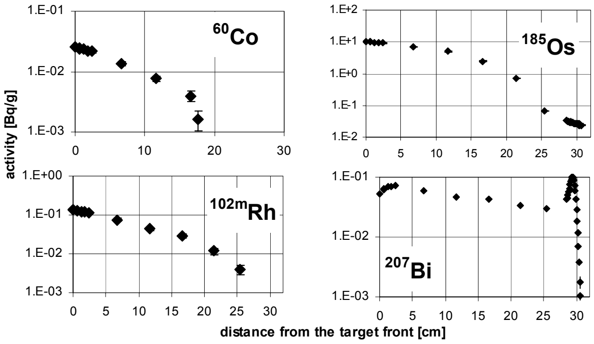
Experimental facility: Fazotron – 660 MeV proton accelerator at the Dzhelepov Laboratory of Nuclear Problems in JINR, Dubna, Russia

The experiments are a part of the verification of calculations used in the designing of accelerator driven systems (ADS), mainly for prediction of transmutations in construction materials and the resulting radioactivity. Samples of materials as well as models of spallation target were exposed to 660 MeV protons. Using γ-spectrometry, a number of radionuclides were identified and absolute activities determined. The experiments were also simulated with the MCNPX code. Comparison of the measured and computed activities was used for the validation of models of nuclear interactions in the MCNPX code. The models: CEM, Bertini-Dresner, Bertini-ABLA, Isabel-Dresner, Isabel-ABLA and INCL4-ABLA were evaluated

The experimentally determined cross sections for production of 17 radionuclides in (p,x) reactions on natural iron were compared with the computed ones and the conclusions were drawn: 1) The best agreement, for all applied physical models, is observed for ^{54}Mn ($\Delta = 0.054 \pm 0.023$) and slightly worse for ^{44}Sc ($\Delta = 0.084 \pm 0.013$). $\Delta = 1 - C/E$ (calculation/experiment). 2) All model options strongly underestimate values for ^{24}Na and overestimate for ^{56}Co. 3) For even-even nuclides (^{44}Ti, ^{48}Cr, ^{52}Fe) and near ones (^{43}Sc, ^{51}Mn, ^{52}Mn) there is remarkable difference between the ABLA (2 - 3 fold overestimation) and Dresner (2 - 3 fold underestimation) evaporation codes. 4) Values for ^{41}Ar, ^{42}K, ^{43}K, ^{46}Sc (except CEM) and for ^{47}Sc (except Bertini and Isabel with Dresner option) are underestimated.

In another example the axial distributions of activity inside the Pb target were measured and compared with calculations [2]. Three types of the residual nuclides distribution shapes were distinguished: 1) of Bi isotopes, 2) of medium nuclides 3) of heavier ones. Examples are presented in the Figure. Some general regularities were found:
1) Underestimated in calculations are values for fission fragments. 2) Better agreement is observed for heavier nuclides (A > 170). 3) At the worst, the comparison shows the discrepancy within one order of magnitude. 4) Almost always the C/E ratio remains between 3 and 1/3. 4) For the whole target activity differences as low as 10% are observed. In particular for the atomic mass differing by ~ 10 - 30 u from the original. 5) However, one cannot point out a single code and/or model yielding good results for all examined nuclides. 6) The model of Cugnon-Schmidt gives the best agreement with our experimental values - about 70 % of results remain within 30 % difference.

Fig. 1. *Typical axial distributions of the specific activity of radionuclides along the Pb target.*



[1] **J. Janczyszyn, W. Pohorecki, G. Domańska, L. Loska, S. Taczanowski,** V. Shvetsov, Annals of Nuclear Energy **33** 633 (2006)

[2] **W. Pohorecki, T. Horwacik, J. Janczyszyn, S. Taczanowski,** V. P. Bamblevski, S. A. Gustov, I. V. Mirokhin, A. G. Molokanov, A. Polanski, Radiation Protection Dosimetry **115** 630 (2005)

[3] **J. Janczyszyn, S. Taczanowski, G. Domańska, W. Pohorecki,** Working Material, Research Coordination Meeting of the Coordinated Research Project on "Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems", IAEA-RC-1003.1 TWG-FR/127, pp. 140-154, Reproduced by IAEA, 2006

[4] **W. Pohorecki, J. Janczyszyn, S. Taczanowski,** I.V. Mirokhin,. A.G. Molokanov, **G. Domańska, T. Horwacik,** Nuclear Inst. and Methods in Physics Research, **A 562** 750 (2006)

LOOK TO THE FUTURE: NUCLEAR PHYSICS LONG RANGE PLAN

LONG-RANGE PLAN OF POLISH NUCLEAR PHYSICS FOR THE YEARS 2008 – 2016

Nuclear Physics Committee of the National Atomic Energy Agency[1]

Polish nuclear physicists are involved **in fundamental research,** development of which is of great importance for future applications and for education of young generations of scientists that in the course of time will take the lead in the field of nuclear technologies in our country. Nuclear physicists in Poland have always recognized the need for contributing to nuclear physics applications.

On the global scale, Polish nuclear physicists participate in many large, European projects, which grant the highest standards of scientific investigations. Very often they play leading role in these collaborations - this can be certified by a large number of citations of articles published in well-known international journals. Polish theoretical nuclear physicists, supporting experimentalists continuously stream into new research directions and play also the leading role in Europe.

Nowadays the most important experiments are performed at the SIS accelerator at GSI (*Gesellschaft für Schwerionenforschung*) in Darmstadt, at COSY in Jülich, at the GANIL (*Grand Accelerateur National d'Ions Lourds*) laboratory in Caen (France), at the ALPI accelerator in Legnaro (Italy), at JYFL in Jyväskylä (Finland) and at ZIBJ in Dubna (Russia).

Experiments in the field of nuclear physics are in part performed using the **HEAVY ION CYCLOTRON** at Heavy Ion Laboratory, Warsaw University (Polish acronym ŚLCJ). However, this cyclotron to deliver a large spectrum of heavy ion beams needs improvement - it is necessary to equip it with the new generation ion source (ECR, installation in progress), as well as to perform progressive modernization of the intensively used all accelerator facilities.

For Polish scientists, one of the most interesting European project is the **FAIR** project – *Facility for Antiproton and Ion Research* – at GSI in Darmstadt. Considering scientific and technical reasons, the FAIR project is one of the most ambitious global programs. Its full cost is planned for 950 million Euros – 80% of the sum will be covered by the German government. The scientific studies at FAIR will be carried out in five main areas of physics:

1) nuclear structure physics and nuclear astrophysics with the use of radioactive beams;
2) hadron physics with antiproton beams;
3) hadron matter of high density;
4) plasma physics of high pressure and temperature;
5) atomic physics and its applications.

In the FAIR project, the most advanced technology will be employed - it should allow for parallel running of several experiments. The universal character of FAIR will make GSI the main scientific center of European nuclear physics for the next decades.

Second ambitious project, involving a coniderable group of Polish physicists, is the **SPIRAL 2** project (*Systeme de Production d'Ions Radioactifs Acceleres en Ligne* 2) at GANIL in Caen. SPIRAL 2 is a French initiative (financed by French government in amount of 135 million Euros) of global range. For the production of radioactive beams, a linear low energy accelerator will be used. The SPIRAL 2 project should be started in 2011 and will provide radioactive beams basing on the ISOL method (*Isotope Separation On-Line*). The beams will be used for nuclear structure and nuclear astrophysics investigations, as well as for the studies of new symmetries. This project has a strong support of European community because it is a predecessor for EURISOL – a large European project – planned after the year 2016.

In the context of the FAIR and SPIRAL 2 projects, the **AGATA** (***A****dvanced* ***GA****mma* ***T****racking* ***A****rray*), a 4π array of highly segmented Ge detectors for γ-ray detection - new European device - attracts a considerable Polish involvement. It will be used in future experiments with the radioactive beams at both FAIR and SPIRAL 2 sites.

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In the nearest future, other possibilities for the Polish nuclear physics at relativistic energies will be offered by the large hadron collider LHC at CERN. It will be done mainly by using the **ALICE, CMS** and **ATLAS** detectors, built with the contribution of Polish institutes. One of the objectives will be investigation of quark-gluon plasma produced in relativistic heavy ion collisions in the TeV energy range. Nowadays, similar works, but at much lower energies than planned at LHC, are conducted on **RHIC** accelerator (USA).

Among nuclear physics experiments which do not require accelerated beams, we have to mention the search for neutrino-less double beta decay. This kind of measurements, which are performed in the underground laboratories with low natural background, may give the information on basic properties of neutrinos. The interest of Polish nuclear physicists concentrates on the participation in the construction of SuperNEMO (Frejus) and GERDA (Gran Sasso) detectors. We plan also to start the Polish project of the low natural background laboratory. This would be done with the use of chambers with unique physico-chemical properties in the old copper mine in Sieroszowice-Polkowice.

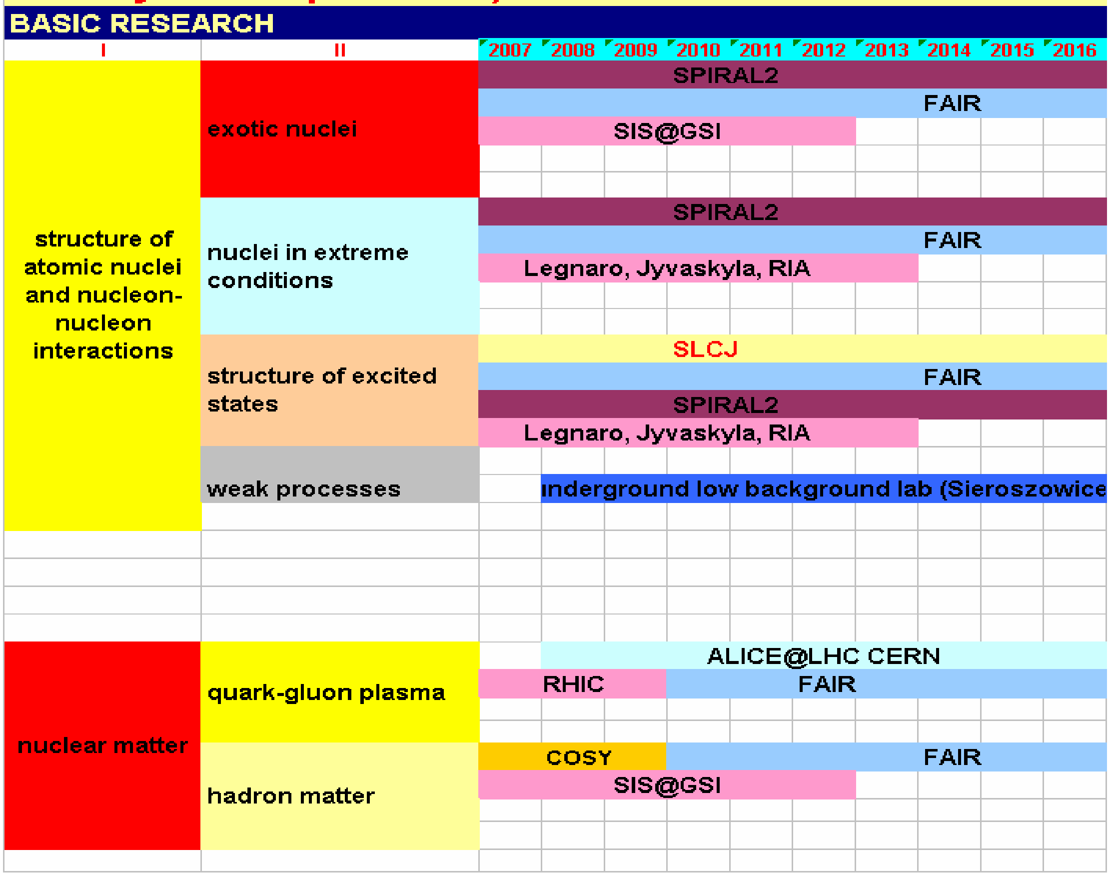
The theoretical investigations on nuclear physics are distributed among many academic centers, similarly as it is organized in other countries. On the European scale, the Polish theoreticians play a very important role in the activity of the European Center for Theoretical Studies (ECT*) in Nuclear Physics in Trento.

Radioactive isotopes, high-energy proton beams and heavy ions play vital role in medicine - in diagnostic and treatment of various diseases, particularly oncological. Consequently, the support for research projects aiming at **applications of nuclear methods** in medicine and the increase of funds for those projects should be of primary importance. A significant project is the Proton Therapy Center in Kraków. At this center, located at the Institute of Nuclear Physics PAN (IFJ PAN), the development of proton radiotherapy of the eye melanoma is already advanced. Also, the construction of the Center of Positron Tomography at ŚLCJ in Warsaw is of great importance. Those centers are vital both for the development of new medical diagnostic methods and for carrying out research in large scale of "life sciences".

It is inevitable that in the nearest future Poland, taking care of its energy self-dependence and of ecology, will have to introduce nuclear energy on the large scale. Recent events proved that Poland cannot be secure with respect to energy self-dependence. Therefore, to improve the safety, the construction of nuclear power plants is necessary. Polish science – particularly nuclear physics – may support the decision process by preparing various expert reports, education of high-qualified specialists and education of the society. Nowadays, we have to think about future technologies, which assume among other issues the construction of IV generation high-temperature reactors. Preliminary studies on the above-mentioned reactors have been started at the Faculty of Physics and Applied Computer Science AGH and at the Heavy Ion Laboratory (ŚLCJ) in the Warsaw University, and several other institutions. The aim of the research program is the construction of the appropriate installations in Poland, about the year of 2015. Deeper investigations on the thermo-nuclear reactors have been undertaken. The Institute of Nuclear Studies and the Institute of Plasma Physics and Laser Micro-synthesis actively participate in the project of the European ITER reactor – it is done in the frame of the EURATOM program.

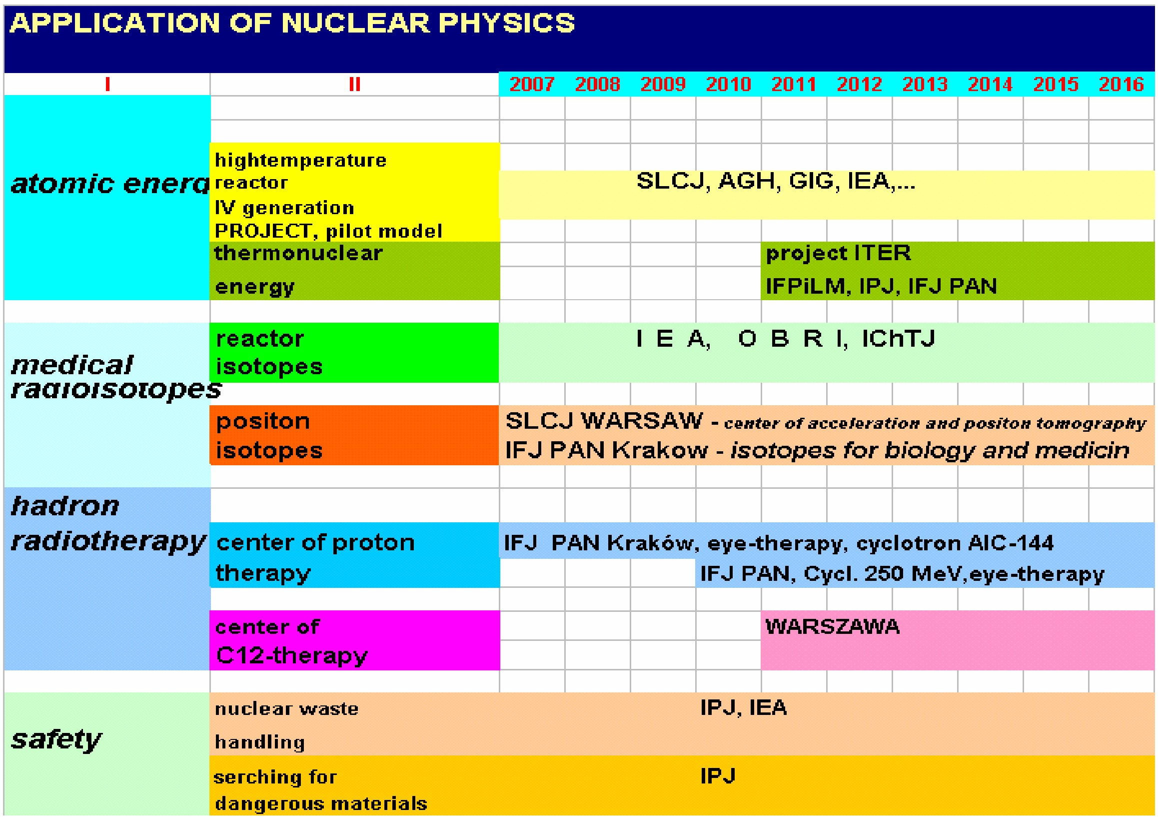
A long-range plan of the development of Polish nuclear physics and the engagement of Polish physicists in the large, European research projects for the years 2007-2016 is presented below. Included are also large projects associated with the use of nuclear physics technologies in medicine, biology and interdisciplinary investigations, and in the studies on nuclear energy and environment.

STRATEGICAL REASEARCH PLAN
POLISH NUCLEAR PHYSICS (2007-2016)
Theory and experiment)



BASIC RESEARCH

I	II	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
structure of atomic nuclei and nucleon-nucleon interactions	exotic nuclei	SPIRAL2									
		FAIR									
		SIS@GSI									
	nuclei in extreme conditions	SPIRAL2									
		FAIR									
		Legnaro, Jyvaskyla, RIA									
	structure of excited states	SLCJ									
		FAIR									
		SPIRAL2									
		Legnaro, Jyvaskyla, RIA									
	weak processes		nderground low background lab (Sieroszowice								
nuclear matter	quark-gluon plasma		ALICE@LHC CERN								
		RHIC			FAIR						
	hadron matter	COSY			FAIR						
		SIS@GSI									



APPLICATION OF NUCLEAR PHYSICS

I	II	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
atomic energ	hightemperature reactor IV generation PROJECT, pilot model	SLCJ, AGH, GIG, IEA,...									
	thermonuclear energy					project ITER IFPiLM, IPJ, IFJ PAN					
medical radioisotopes	reactor isotopes	I E A, O B R I, IChTJ									
	positon isotopes	SLCJ WARSAW - *center of acceleration and positon tomography* IFJ PAN Krakow - *isotopes for biology and medicin*									
hadron radiotherapy	center of proton therapy	IFJ PAN Kraków, eye-therapy, cyclotron AIC-144									
					IFJ PAN, Cycl. 250 MeV,eye-therapy						
	center of C12-therapy					WARSZAWA					
safety	nuclear waste handling	IPJ, IEA									
	serching for dangerous materials	IPJ									

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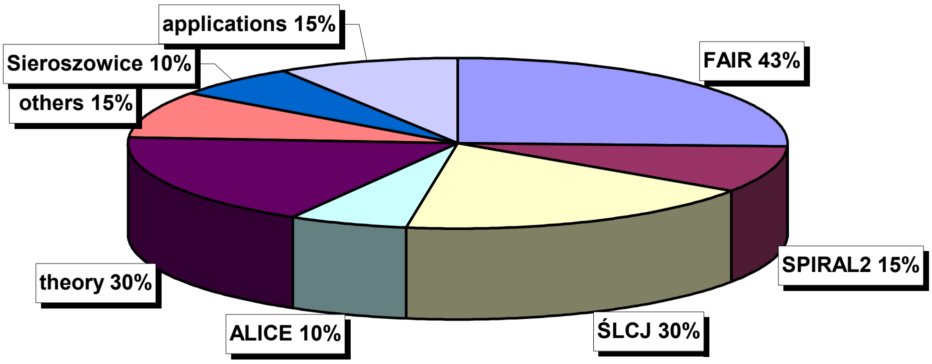
IFJ PAN – H. Niewodniczański Institute of Nuclear Physics PAN, Kraków
IPJ – A. Sołtan Institute of Nuclear Studies, Świerk-Warszawa
AGH – AGH University of Science and Technology
GIG – Central Mining Institute, Katowice
IEA – Institute of Atomic Energy, Świerk
IFPiLM – Institute of Plasma Physics and Laser Microfusion, Warszawa
OBRI - Research and Development IAE Radioisotope Centre POLATOM, Świerk
IChTJ – Institute of Chemistry and Nuclear Technology

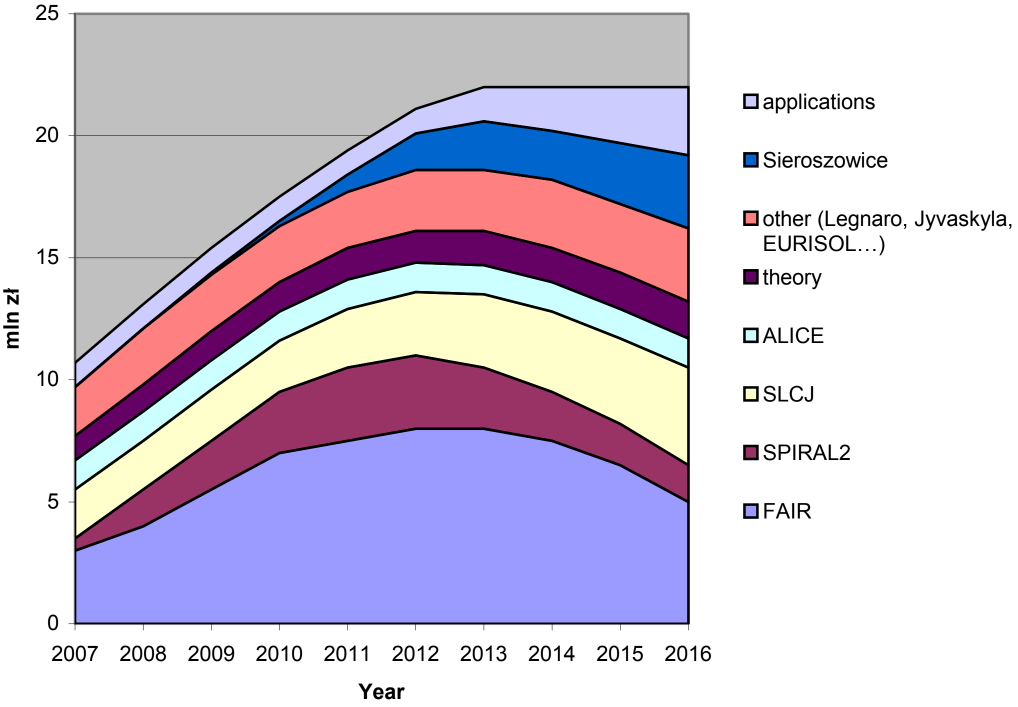
PLANNED AVERAGE STAFF INVOLVEMENT

Number of scientists involved in particular projects – full time employees



THE OUTLINE OF BUDGET EXPENDITURES

The necessary research expenditures of particular projects (not including yearly operation costs of the laboratories).



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