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Heavy Ion Laboratory

Annual Report

2009

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Annual Report of the
Heavy Ion Laboratory, University of Warsaw
ul. Pasteura 5a, 02-093 Warszawa, Poland
phone (+48)22-8222123, (+48)22-5546000
fax (+48)22-6592714
`http://www.slcj.uw.edu.pl`

Editors:
Marcin Palacz, Magda Zielińska
e-mail: palacz@slcj.uw.edu.pl, magda@slcj.uw.edu.pl
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Introduction

Heavy Ion Laboratory (HIL) is a part of the University of Warsaw, the largest university in Poland. It is the largest experimental nuclear physics laboratory in the country, equipped with a K=160 cyclotron. The first beam was extracted in 1993 and since that time HIL is an effective "user facility", serving up to the present time over 350 scientists from Poland and abroad and becoming a recognised element of the European Research Area.

The research programme comprises nuclear and atomic physics, materials science, radiochemistry, biology and particle detector development. HIL is currently in a transition period and will shortly become an accelerator centre, operating two cyclotrons. Installation of a commercial proton-deuteron cyclotron ($E_p = 16.5$ MeV) is under way in the HIL building. This accelerator will be used for the production of and research on radiopharmaceuticals for the Positron Emission Tomography (PET). Production of long-lived radiopharmaceuticals for other medical and life-science applications is also foreseen.

HIL is located at the University Ochota Campus, together with Faculties of Biology, Geology, Chemistry and Mathematics. In the next few years the Faculty of Physics will also move from its present location at Hoża Street to the Ochota Campus and we are hoping for a much closer collaboration between HIL and the Faculty of Physics in the future. The Ochota Campus is located close to the main campus of the Medical University and its clinic. This opened a possibility for a very close collaboration, established a few years ago, between HIL and the Department of Nuclear Medicine of the Medical University.

An especially important achievement at HIL in 2009 was the commissioning of the EAGLE spectrometer in May, followed by the experimental campaign. EAGLE is an array of gamma-ray detectors designed as a multi-configuration detector setup adjustable to the needs of several research groups. In the present configuration it is equipped with 12 anti-Compton shielded HPGe detectors. It can be coupled to ancillary particle detectors such as SiBall, conversion electron spectrometer and Coulex scattering chamber. The spectrometer will be upgraded during the coming years — up to 30 HPGe detectors will be installed.

The year 2009 was a year of a hope for change. The main problem of a large experimental laboratory is always related to the available funds. So far HIL has been financially supported mainly by the University of Warsaw (about 75 percent of the total budget) and by the grants of the Polish Ministry of Science and Higher Education (MNiSW). The grants were allocated on a yearly basis. This support has not been enough to maintain properly the existing infrastructure. In September 2009 MNiSW decided to create a "Road Map of National Research Infrastructure", for the first time in Poland, in order to improve funding of the national research institutes. This is a very good news for us, we are crossing our fingers and hoping that our financial situation will at last become more normal.

Prof. Krzysztof Rusek, Director of HIL

Part A

Laboratory overview

A.1 Operation of the cyclotron during 2009

J. Choiński, M. Wolińska-Cichocka, W. Kalisiewicz, M. Kopka, J. Kurzyński, J. Miszczak, B. Paprzycki, O. Steczkiewicz, J. Sura, A. Bednarek

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Altogether 1993 hours of beam time were successfully delivered to various experimental arrangements during the last year, which is a number comparable to what was reached in 2007 and 2008. Figure 1 shows usage of cyclotron beams over the last eleven years. After the maximum number of over 3000 beam hours delivered in 2004, the total numbers of beam time per year started decreasing, which was mostly due to severe problems with the water cooling system of the machine. In spite of repairs and modifications, the system was not efficient enough to allow normal operation during the hot summer months, and every year since 2005 the Laboratory was forced to curtail some of the experiments due to overheating.

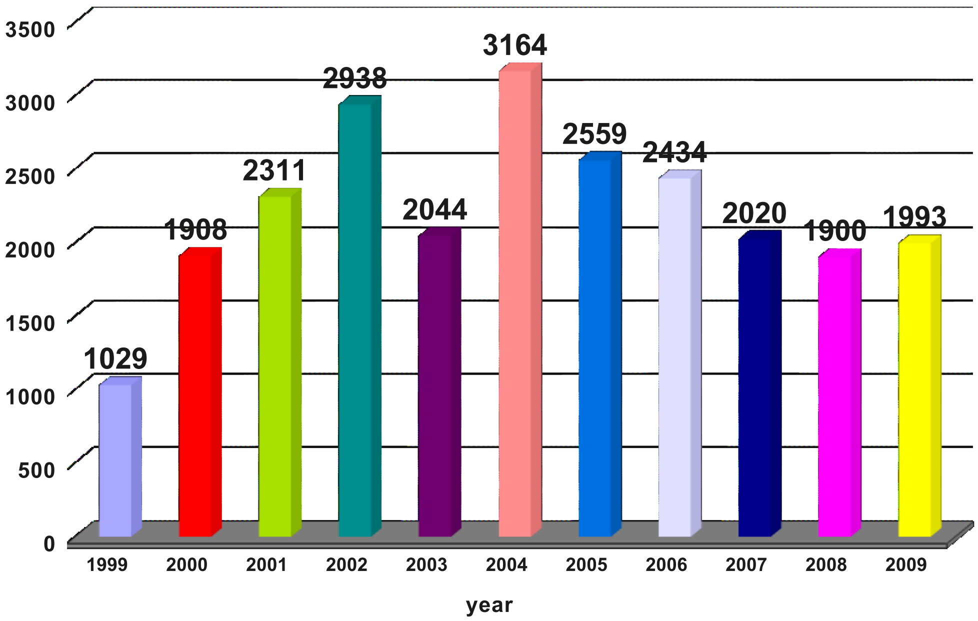

Figure 1: Total cyclotron beam time in years 1999 to 2009.

Following the complete replacement of the water heat exchange system, since 2008 the cyclotron has been fully operational regardless outside temperatures. This is illustrated by Fig. 2, showing the monthly distribution of the beam time during 2009. After the traditional summer vacation in July and August, machine development and conservation works were undertaken, including modifications of the cyclotron vacuum chamber and the re-alignment of the duants as well as construction works in the basement of the cyclotron vault, required for the installation of a new ECR ion source.

The new horizontal part of the injection line was installed by Pantechnik and HIL teams in December. This operation caused the shutdown of the cyclotron. As a result we have gained possibility to operate in future both ion sources, the new and the old one. The new ECR ion source was installed and commissioned in May 2010 (see Sec. A.2 of this Report).

The most important difficulty in the daily operation in 2009 was the vacuum system. This system includes out-dated pumps and control units, in some cases almost 30 years

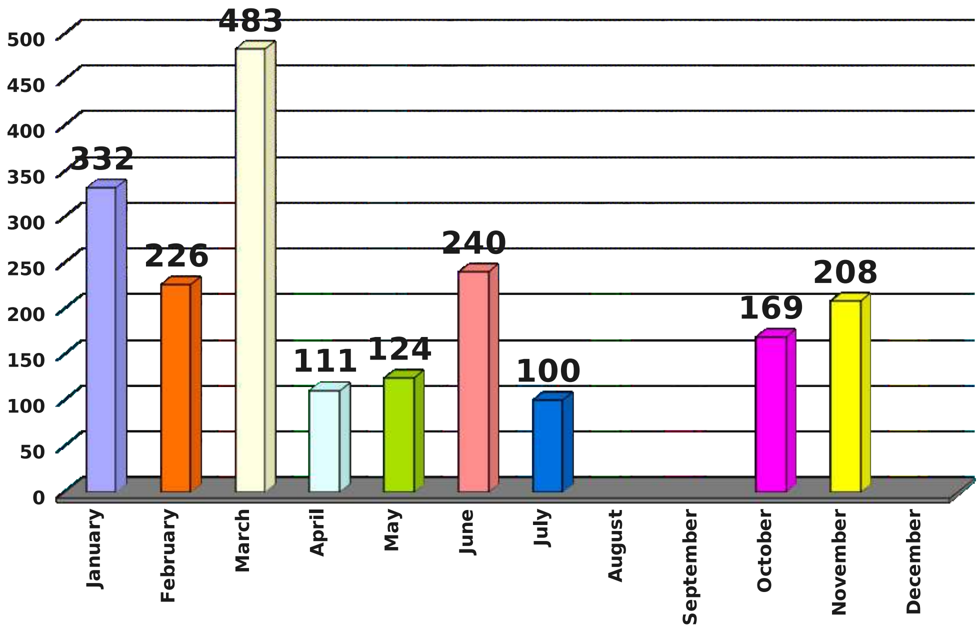

Figure 2: Monthly beam time distribution (hours) in 2009.

old, which often fail. Due to vacuum problems, in the first quarter of 2009 we were forced to switch off beam line B. Modernisation of the vacuum system is urgently required, unfortunately our attempts to acquire funds for this purpose have not been successful so far. A new grant application was submitted for the next year.

Participation of undergraduate and graduate students in the experimental campaigns strongly reinforces the experimental teams currently working at HIL and helps them maintaining the research momentum. The involvement of young researchers is illustrated by Fig. 3, which shows the number of HIL beam users for each of the research projects performed in 2009. Detailed description of experimental set-ups can be found at the Heavy Ion Laboratory website. Despite the fact that basic nuclear physics research consumed most of the beam time, a fair share of it was allocated to other areas: the program of radiobiological studies using heavy-ion beams was continued and traditionally a week of beam time was allocated to the student workshop.

More detailed data concerning developments of the apparatus for research projects can be found in articles describing the on-going activities, published further in this section of the Annual Report. The first experimental campaign of the EAGLE multi-detector array, installed on the reconstructed beam line C2, is especially worth mentioning. A histogram showing the number of hours used for different projects in 2009 is presented in Fig. 4.

Table 1 summarises all the experiments performed in 2009. Acronyms of the following institution names are used in the table:

- Institute of Biology, Jan Kochanowski University, Kielce (IB JKU Kielce),
- Holycross Cancer Centre, Kielce (HCC, Kielce),
- Institute of Experimental Physics, University of Warsaw, Warsaw (IEP UW),
- The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków (INP Kraków),
- The Andrzej Sołtan Institute for Nuclear Studies, Łódź (SINS Łódź),
- The Andrzej Sołtan Institute for Nuclear Studies, Świerk (SINS Świerk),
- Institut de Physique Nucléaire, Orsay, France (IPN Orsay),
- National University, Kharkiv, Ukraine (NU Kharkiv),
- University of Silesia, Katowice (US Katowice),

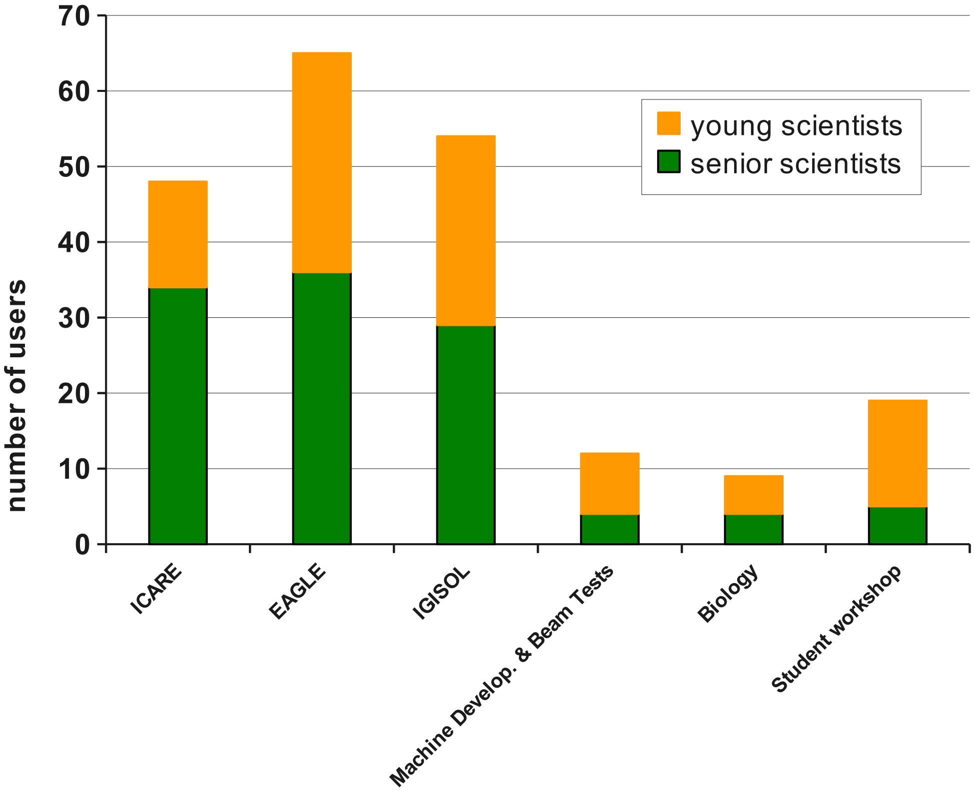

Figure 3: Users of the Warsaw Cyclotron beams in 2009.

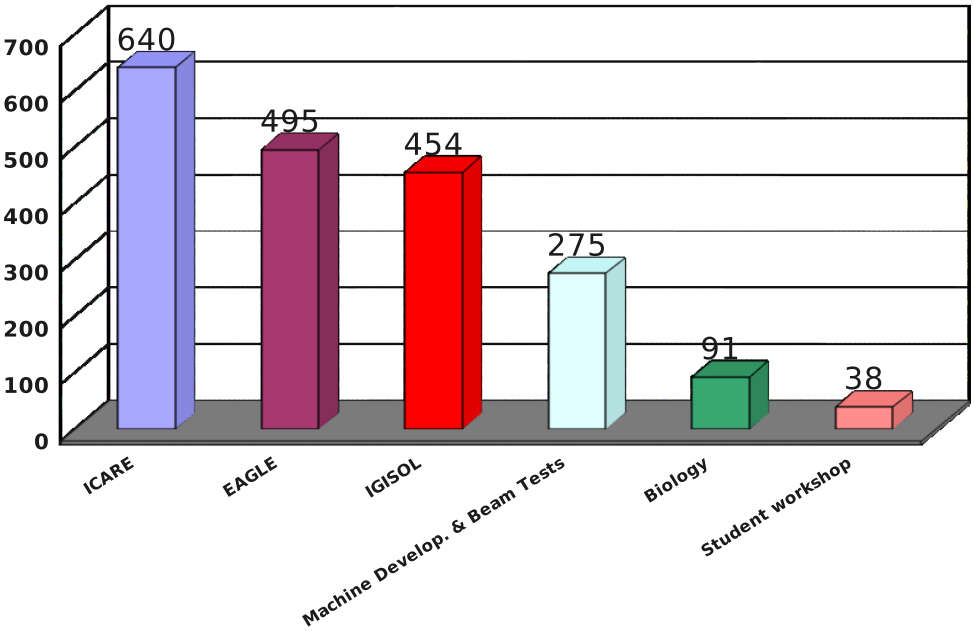

Figure 4: Distribution of beam time (in hours) among different experiments in 2009.

- Nicolaus Copernicus University, Toruń (NCU Toruń),
- Adam Mickiewicz University, Poznań (AMU Poznań),
- Maria Curie-Skłodowska University, Lublin (MCSU Lublin).

Table 1: Experiments from 06.01.2009 to 29.12.2009

Dates	Ion	Experiment	Leading institution	Collaborating institutions
06.01–07.01 13.01–14.01	$^{20}Ne^{+4}$	ICARE	HIL	SINS Świerk, NU Kharkiv, US Katowice, INP Kraków
19.01–23.01	$^{14}N^{+3}$	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź, US Katowice
26.01–30.02	$^{20}Ne^{+4}$	ICARE	HIL	SINS Świerk, NU Kharkiv, US Katowice, INP Kraków
02.02–06.02	$^{12}C^{+2}$	Biology	IEP UW, IB JKU Kielce	HIL, HCC Kielce, SINS Świerk, NCU Toruń
09.02–13.02	$^{14}N^{+3}$	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź, US Katowice, IPN Orsay
17.02–18.02	$^{14}N^{+3}$	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź, US Katowice, IPN Orsay
02.03–06.03	$^{18}O^{+4}$	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź, US Katowice
09.03–23.03	$^{20}Ne^{+4}$	ICARE	HIL	SINS Świerk, NU Kharkiv, US Katowice, INP Kraków
26.03	$^{20}Ne^{+4}$	Test of buncher	HIL	
30.03–03.04	$^{18}O^{+4}$	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź, US Katowice
20.04–22.04	$^{20}Ne^{+4}$	Students' workshop	HIL	
13.05–14.05	$^{20}Ne^{+3}$	ICARE	HIL	AMU Poznań, MCSU Lublin
25.05–29.05	$^{18}O^{+4}$	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź
08.06–09.06	$^{20}Ne^{+5}$	Cyclotron beam test	HIL	
15.06–19.06	$^{20}Ne^{+5}$	EAGLE	IEP UW	HIL, SINS Świerk
22.06–26.06	$^{20}Ne^{+4}$	ICARE	HIL	SINS Świerk, NU Kharkiv, US Katowice, INP Kraków
29.06–03.07	$^{20}Ne^{+5}$	EAGLE	IEP UW	HIL, SINS Świerk
06.07– 08.07	$^{20}Ne^{+5}$	EAGLE	HIL	SINS Świerk, NU Kharkiv, US Katowice, INP Kraków
13.10–16.10	$^{20}Ne^{+5}$	EAGLE	IEP UW	HIL, SINS Świerk
26.10–30.10	$^{14}N^{+3}$	EAGLE	IEP UW	HIL, SINS Świerk
16.11–20.11	$^{10}B^{+2}$	EAGLE	IEP UW	HIL, SINS Świerk
23.11–27.11	$^{14}N^{+3}$	EAGLE	HIL	IEP UW, SINS Świerk
29.12	$^{14}N^{+3}$	Test of upgraded injection beam line	HIL	

A.2 New ECR ion source and injection line

O. Steczkiewicz, J. Jastrzębski, L. Pieńkowski, J. Choiński, P. Napiorkowski, J. Sura, M. Wolińska-Cichocka, R. Tańczyk

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Work on the installation of the new ECR ion source and the injection line at the Heavy Ion Laboratory was continued [1]. Following signing in October 2008 the second contract between the Heavy Ion Laboratory, University of Warsaw and PANTECHNIK S.A, Factory Acceptance Tests (FAT) were carried out in France in June 2009. The adaptation of rooms at HIL for the new equipment was done during the summer vacation period. Support stands for the ion tubes, magnetic elements and the tubes themselves were manufactured in the HIL mechanical workshop. First elements of the injection line reached Warsaw in December 2009. The analysing dipole magnet (T type) was installed (Fig. 1), and this makes possible to deliver beams from both ECR sources (the old and the new one) to the cyclotron. A new quadrupole magnet was also installed at the vertical beam line. Another set of quadrupole doublets and the analysing chamber (Fig. 1) were placed in final positions, but without cabling. In March 2010 the lacking elements of the injection line and the complete ECR ion source were delivered to HIL. In-site installation of all the equipment, followed by the commissioning and training was done in April and May 2010.

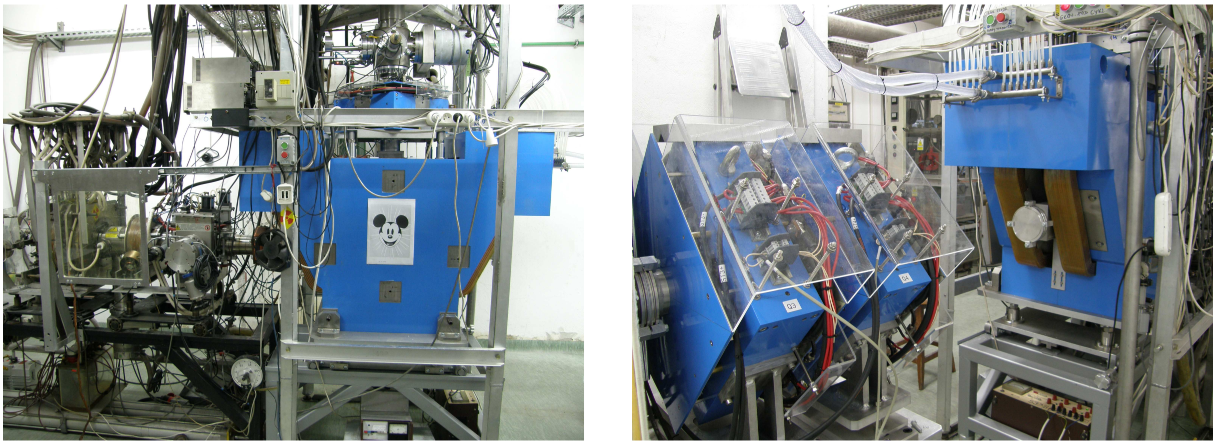

Figure 1: Left picture: the existing ECR ion source with the new T-dipole and quadrupole magnets (blue coloured). Right: the beginning of the new injection line — the T-dipole and the first quadrupole doublet.

Bibliography

[1] O. Steczkiewicz *et al.*, HIL Annual Report 2008, page 11

A.3 Activity report of the ECR group

A. Górecki, B. Filipiak, R. Tańczyk

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

In 2009 the ECR ion source worked without failure and delivered the following ions to the cyclotron:

ion	$^{12}C^{+2}$	$^{14}N^{+3}$	$^{18}O^{+4}$	$^{20}Ne^{+4}$	$^{20}Ne^{+5}$
Current at the inflector [eμA]	140	100	95	116	63

The ion source was periodically surveyed and cleaned. In December 2009 the new analysing T-type magnet was installed and put into operation, ready to be connected to the new ion-source, see also Ref. [1].

Bibliography

[1] O. Steczkiewicz *et al.*, this Annual Report, page 13

A.4 The Warsaw PET Project — Radiopharmaceuticals Production and Research Centre at HIL

J. Choiński[1]*, J. Jastrzębski*[1]*, D. Hechner*[1]*, K. Kilian*[1]*, I. Mazur*[1]*, P.J. Napiorkowski*[1]*, A. Pękal*[1,2]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Faculty of Chemistry, University of Warsaw, Warszawa, Poland

Information on the Warsaw Consortium for PET Collaboration (WCPC), the Warsaw PET Project and its Radiopharmaceuticals Production and Research Centre (RPRC) has been already presented in previous HIL Annual Reports [1–4] The realisation of the project during 2009 was substantially delayed due to the Contractor (GE Medical Systems) problems with his main subcontractor Block-Zalup. Till the end of 2009 the excavation works around the Centre building were executed and the concrete works were started. In December 2009 the state of completion of the construction works was estimated at the level of 30–35%.

At the beginning of 2010 the Contractor started negotiations with the prospective new subcontractor for the building execution.

Bibliography

[1] J. Jastrzębski *et al.*, HIL Annual Report 2006, page 42

[2] J. Choiński *et al.*, HIL Annual Report 2007, page 14

[3] J. Jastrzębski *et al.*, HIL Annual Report 2008, page 15

[4] `http://www.slcj.uw.edu.pl/PET`

A.5 Laboratory of ^{11}C and ^{15}O

K. Kilian, J. Choiński, J. Jastrzębski

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

The project aims are to purchase, install and commission equipment for the synthesis of radiopharmaceuticals, based on labelling with nuclides ^{11}C and ^{15}O, allowing to conduct multidisciplinary research in oncology, neurology and cardiology.

The new production centre of radiopharmaceuticals will participate in interdisciplinary research on applications of positron emission tomography (PET) in biology and medicine. Radiopharmaceuticals for medical diagnosis and clinical research will be produced on regular basis. Synthesis of active substances will be carried on to support other CePT [1] teams and external customers, in compliance with Good Manufacturing Practice. Work on methods for labelling molecules of potential drugs is also foreseen, to investigate the biological activity and to develop innovative methods of synthesis.

Bibliography

[1] Centre of Pre-clinical Research and Technology, `http://cept.wum.edu.pl`

A.6 Central European Array for Gamma Level Evaluation (EAGLE) in-beam of the Warsaw Cyclotron at HIL UW — a status report

A. Jakubowski[1]*, H. Mierzejewski*[2] *for the EAGLE collaboration*[3]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Faculty of Production Engineering, Warsaw University of Technology, Warszawa, Poland

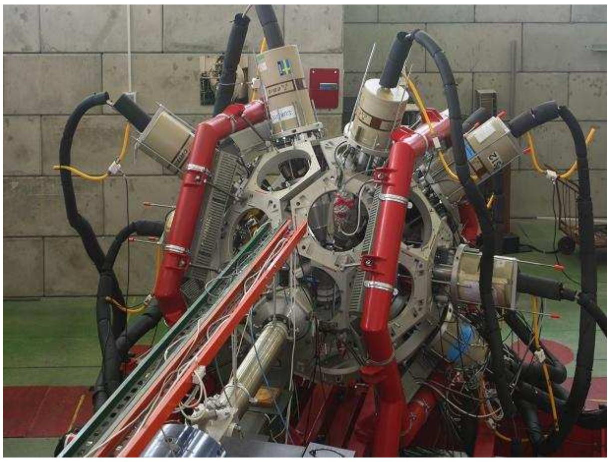

Figure 1: The EAGLE gamma spectrometer at the experimental hall of HIL.

The EAGLE array (central European Array for Gamma Level Evaluations) is designed as a multi-configuration detector setup adjustable to the needs of several research groups, dealing with different branches of nuclear physics, gathered around the Heavy Ion Laboratory, University of Warsaw. In the present configuration (EAGLE Phase I) the array is equipped with 12 anti-Compton shielded HPGe detectors of 20-35% efficiency and, depending on the type of measurements performed, coupled to ancillary detectors such as SiBall [1], conversion electron spectrometer [2] and Coulex scattering chamber [3]. Currently the data acquisition and LN_2 filling systems from the previous gamma ray spectrometer at HIL (OSIRIS II) are used.

In May 2009 the EAGLE array was installed on the dedicated beam line at the experimental hall of the Heavy Ion Laboratory. Since then the following experiments have been performed using EAGLE Phase I:

- Charged particles as a tool for reaction mechanism investigation [1]
- Efficiency calibration of the $LaBr_3$ detectors for gamma energy range up to 8 MeV using heavy-ion reaction products [4]
- In-beam study of the $LaBr_3$(Ce) detector response [4]
- DSAM lifetime measurements in ^{124}Cs (test run)
- Multiplicity determination of gamma-ray transitions from the decay of the $K=8^-$ isomer in ^{130}Ba by an internal conversion coefficients measurement (test run)

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[3] EAGLE collaboration includes more than 50 scientists from 9 Polish institutions as well as from ATOMKI Debrecen, CEA Saclay, GANIL, Lund and Sofia Universities. For the full list, see the EAGLE web site `http://www.slcj.uw.edu.pl/eagle`

The present EAGLE equipment will be soon complemented by 20 Phase-I HPGe detectors loaned by the European GammaPool. In order to optimise the use of GammaPool resources, the previous schedule of experimental campaigns [5] has been modified: EAGLE will obtain the detectors in June 2011, one year later than previously agreed, but will benefit from a full two-year running period instead of a single year.

To upgrade the EAGLE array to its Phase-II stage (including 30 HPGe detectors) new data acquisition and LN_2 filling systems are required. Both projects have received the necessary funding and are progressing. The installation of the new LN_2 filling system is scheduled for autumn 2010.

In 2010 two experimental campaigns are planned. The first one will begin in January and last until the end of March, the second one is scheduled from the beginning of June until November.

The EAGLE Consortium was founded in May 2009 by eight Polish institutions pursuing experimental and theoretical studies in the field of nuclear physics. The Consortium members are:

- Heavy Ion Laboratory, University of Warsaw,
- Nuclear Physics Division, Institute of Experimental Physics, University of Warsaw,
- Nuclear Structure Theory Division, Institute of Theoretical Physics, University of Warsaw,
- The Andrzej Sołtan Institute for Nuclear Studies, Otwock-Świerk,
- Division of Nuclear Physics, University of Łódź,
- The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków,
- Department of Theoretical Physics, Institute of Physics, M. Curie-Skłodowska University, Lublin
- Faculty of Physics, Warsaw University of Technology.

The project submitted by the EAGLE consortium “Nuclear symmetries and their spontaneous breaking – experiments on beams of the HIL cyclotron” received the full requested funding from the Ministry of Science and Higher Education.

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[2] J. Perkowski *et al.*, this Annual Report, page 45

[3] K. Wrzosek *et al.*, Acta Phys. Pol. **B**39 (2008) 513

[4] K. Hadyńska-Klęk *et al.*, this Annual Report, page 47

[5] J. Srebrny *et al.*, HIL Annual Report 2008, page 13

A.7 Activity report of the electrical support group

M. Kopka, V. Khrabrov, P. Krysiak, K. Łabęda-Dyszy, Z. Morozowicz, K. Pietrzak

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

The electrical group in 2009 designed and implemented several projects:

1. Modernisation of the street lighting in the cyclotron building area — replacement of sodium lamps with ignitors by blended ones.
2. Modernisation of the wall lighting at the experimental hall and its basement — installation of energy–saving lamps.
3. Modernisation of the UZ 3 power supply using transistors with better parameters than those of the ones previously installed.
4. Regulation of thyristor controllers in the UZ 1, UZ 2, UZ 3 power supplies.
5. Contribution to the construction of the EAGLE stand and beam line:
    - Two low voltage switchboards (RTE, RTB types) were installed to connect the tract equipment.
    - The switch for quadrupole magnets was reconstructed — new power supplies with related power and protection cables were installed.
    - The switch for deflecting magnets was reconstructed — the power supply with related power and protection cables for the new magnet M5 was added.
    - The manual switch for the steering magnets were constructed to enable switching of power supplies between the EAGLE and ICARE tracts.
    - The universal switchboard at the experimental hall was moved to a different location.
    - Additional lighting for the experimental set-up and related electronics was installed.
    - Two steering electromagnets were constructed.
    - The unused RG58 cabling, connecting the acquisition hall and the C2 and C3 stands at the experimental hall, was dismounted.
6. The temperature monitoring system with the related software was developed for the external cooling system of the cyclotron.
7. Design study of the stabilised power supply DC/DC, 0-10 A, 30 V. The proposed solution was described in an internal report under the same title, see Sec. D.3.3.
8. Contribution to the installation of the new ECR ion source:
    - Preparation of the documentation necessary for projects of the electrical installation and the ventilation system.

  - Construction of the power supply and the control unit for the pump raising the pressure in the cooling system.
  - Installation of the dewatering pump with a new type of water level monitoring system.
  - Installation of cable channels for the ECR equipment.

9. A new dewatering pump was installed in room 013. The existing power supply and control unit were adapted.
10. The main earth electrode of the HIL building was modernised. Currently it is labelled "Uziom 1" with the ZK 1 monitoring connection.
11. An additional earth electrode (labelled "Uziom 2,3") with ZK 2 and ZK 3 monitoring connections were installed.
12. Two additional earth electrodes made of I-beams remaining from the PET Centre construction were installed and labelled as "Uziom 4" and "Uziom 5". The monitoring connections are labelled as ZK 4 and ZK 5, respectively.
13. Paper-based documentation of existing electrical installation was replaced by the electronic one and updated.

The following routine measurements and maintenance procedures were performed:

1. Capacitance measurements of the main power supply of the cyclotron magnet.
2. Temperature measurements in the coil winding of the magnetic quadrupole DK 13.
3. Measurements of the magnetic field, coil resistance and temperature and cooling water flow of the deflecting magnet M5 in the EAGLE tract.
4. Coil resistance and magnetic field measurements of the quadrupole triplet in the ICARE tract.
5. Measurements and maintenance of the electrical installation, including lighting inside and outside the building.
6. Measurements and maintenance of power supplies, electromagnets and wiring of the laboratory equipment.

Results of the measurements listed above in items 1–6 were published as internal reports, see Sec. D.3.3.

In addition, five members of the electrical group performed regular cyclotron operator duties according to the experimental schedule and participated in the science popularisation and teaching activities at HIL (guided tours of the facility, Polish Workshop of Acceleration and Applications of Heavy Ions).

A.8 Unix computers and computer network at HIL

R. Tarnowski, M. Palacz, J. Miszczak, A. Trzcińska, M. Zielińska

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

In 2009 modernisation and unification of all Unix computer systems used at HIL has been started. It was decided that all Unix hosts should run under the same version of the operating system, and Ubuntu (desktop or server version) was selected as the Linux distribution of choice. The Unix personal workstations and laptops are gradually converted from other or older Linux versions to Ubuntu version 9.10. Along the same line, hardware for creating new servers of all basic services (user home directories, authentication, name server, WWW) has been acquired and configured. The new servers were commissioned and made available in spring 2010. Care is taken of regular (weekly) updates of all the newly installed systems, and their upgrades to the next version of the operating system will be performed once a year — upgrade to Ubuntu 10.10 is scheduled for October 2010.

A new e-mail server, equipped with efficient spam and virus filters has been configured by an external contractor, and made available for users in autumn 2009, after a two month period of extensive tests of all its functionalities. The installation of the new server reduced amount of illegitimate e-mail reaching user mail-boxes to almost zero, and contributed significantly to the security of all the computers in the Laboratory. The new server is accessible via secure IMAP protocol both from the local network as well as from outside HIL. The POP3 protocol access is also temporarily maintained, for the convenience of users who have been so far accessing their e-mail using the Novell based POP3 server. A secure WWW interface to the new e-mail server is also available.

A so called version control system has been installed on one of the HIL servers, using the Subversion software. Being originally a computer programmer tool, a version control system is a suite of programs, which automates handling of different versions of all kinds of projects, kept in the form of computer files. It can be used for example in software development, writing text articles or maintaining documentation, and is especially suitable when a group of people is working on the same files. The system at HIL is at present used for the documentation relevant to the HIL computer network administration, administrative scripts, handling parts of source codes written by HIL employees, and for keeping two personal logbooks. A more widespread use of the version control system is anticipated in 2010 and the following years. Access to this system is available on request.

Collaborative SPIRAL2 Preparatory Phase web site has been modified. Access rights scheme for the whole site has been redesigned and restricted areas have been added. Groups of privileged users that have rights to view/modify content of the restricted areas have been created. A new domain, spiral2pp.eu has been acquired and associated with the HIL SPIRAL2PP web server. Modifications of the SPIRAL2 Preparatory Phase web site will be continued in 2010.

The HIL web server is since 2009 also serving the site of the International Nuclear Target Development Society, `http://www.intds.org`.

A.9 Modification of the Software for the Cyclotron's Distributed Control System

R. Tarnowski

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Changes in number and ordering of magnets in both C4 and D beam lines forced modification of the software for cyclotron's distributed control system. The system consists of the main host located in the cyclotron's control room (remote control) and five local stations. Local stations are responsible for direct control of the following parts of cyclotron's infrastructure: steering magnets power supplies, additional steering magnets power supplies (at C and D beam lines), trim coils power supplies, RF generator, beam measurements. All computers run under control of the QNX 4.25 operating system [1]. Communication between the main host and local stations is based on Qnet — the network protocol delivered with QNX OS. The whole software for cyclotron's distributed control system is written in the C++ programming language.

Programs running at the main host and two local stations have been modified. The following modules have been changed: user interface, communication layer, hardware drivers. The new version of software was successfully tested and released in September 2009. All changes have been introduced accordingly to subsets of MISRA-C: 2004 [2] and MISRA C++: 2008 [3] standards (MISRA stands for The Motor Industry Software Reliability Association). Both standards include guidelines covering the use of C and C++ programming languages in safety critical applications and have been developed and published by the professional body promoting the safest possible use of the mentioned above programming languages. The guidelines directly address the safety of applications where electronic systems are being designed to control vital operations. Accordance with standards has been tested by using dedicated software for source code static analysis (PC-lint [4], C++ test [5]). As for now only modifications released in September 2009 follow MISRA requirements; factorisation of the rest of source code is planned for 2010.

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A.10 Educational and science popularisation activities at HIL

K. Hadyńska-Klęk[1,2]*, G. Jaworski*[1,3]*, K. Kilian*[1]*, J. Mierzejewski*[1,2]*,*
P.J. Napiorkowski[1]*, M. Palacz*[1]*, L. Pieńkowski*[1]*, J. Srebrny*[1]*, O. Steczkiewicz*[1]*,*
A. Trzcińska[1]*, K. Wrzosek-Lipska*[1,2]*, M. Wolińska-Cichocka*[1]*, M. Zielińska*[1]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
3) Faculty of Physics, Warsaw University of Technology, Warszawa, Poland

For many years the Laboratory has been strongly involved in education and science popularisation. Guided tours at HIL have become our regular activity. These "live" lessons on the cyclotron and nuclear physics continue to enjoy popularity in high schools, including ones from outside Warsaw. During the guided tour visitors can see the control room and the cyclotron, get acquainted with facilities installed in the Laboratory and experiments performed here. Short lectures providing basic introduction to the nuclear physics and principles of the cyclotron operation are also offered, especially to high school students. Tours are free of charge.

The number of visitors per year has stabilised at the level of about 40 organised groups, which amounts to more than 1000 people. High-school classes were the largest category of our visitors in 2009, but we also welcomed students from various faculties of the University of Warsaw, including Physics, Chemistry and Biology, as well as postgraduate students of the Sołtan Institute for Nuclear Studies. Finalists of the Interschool Competition in Physics and Chemistry "EUREKA", participants of the Summer School of Physics and several groups of physics teachers were also among our visitors.

In 2009 for the 13th time HIL participated in the annual Festival of Science. We opened the door for general public on 19 September, when more than 100 people visited the Laboratory. Guests were invited to participate in guided tours of the cyclotron and other experimental facilities. A wide offer of introductory lectures on nuclear physics and its applications was proposed (see Sec. D.2.4 for the full list of lectures). During the preceding week we also organised so-called Festival Lessons for secondary school classes. These simple lectures, addressed to youths of age 14-15, attracted large attention.

As a part of the pan-European event “Researchers’ Night”, we prepared a more informal presentation of our Laboratory in the evening of 25 September. We demonstrated various equipment from a nuclear physicist toolbox, starting from very simple and old to modern and sophisticated ones. Every guest was invited to bring a potentially radioactive substance (e.g. soil, drinking water, building materials, food — any everyday use product) and the most active one has been chosen by open competition. Our visitors had an opportunity to talk to physicists and ask them all kind of questions, concerning not only the science, but also their motivations of choosing this career path.

The Fifth Polish Workshop on Acceleration and Applications of Heavy Ions was organised at HIL in April 2009 (see Sec. A.11 of this Report). HIL staff members are also engaged in supervising MSc and PhD theses — see Sec. D.1. In summer a four-week training was organised for several students from the Warsaw University of Technology and the University of Łódź.

A.11 Polish Workshop on Acceleration and Applications of Heavy Ions

P.J. Napiorkowski[1], *A. Trzcińska*[1], *K. Hadyńska-Klęk*[1,2], *G. Jaworski*[1,3], *K. Kilian*[1], *A. Kordyasz*[1], *M. Kowalczyk*[1,2], *J. Kownacki*[1], *M. Palacz*[1], *J. Srebrny*[1], *O. Steczkiewicz*[1], *A. Stolarz*[1], *I. Strojek*[4], *M. Wolińska-Cichocka*[1], *K. Wrzosek-Lipska*[1,2], *M. Zielińska*[1]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
3) Faculty of Physics, Warsaw University of Technology, Warszawa, Poland
4) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland

Polish Workshop on Acceleration and Applications of Heavy Ions is organised at HIL every spring since 2005. It is intended for third year physics students interested in nuclear physics, and offers them a unique opportunity to gain experience in methods of data acquisition and analysis, in operating the cyclotron including the beam diagnostics measurements and in charged particle and gamma-ray detection techniques.

The number of participants has been increasing every year, reaching nineteen in 2008. After success of the first editions, we usually receive over two times more applications than the number of places available. It should be also noted that almost every year new institutions join the list of universities interested in sending their students to the Workshop. The participants are often willing to continue the collaboration with HIL in a form of a summer internship or at the MSc stage. Three MSc theses prepared at HIL by former Workshop participants have been defended: one in 2008 at the Adam Mickiewicz University in Poznań and two in 2009 at the University of Silesia in Katowice.

Due to a temporary decrease of the capacity of our guesthouse, we could accept only 14 students in 2009, and finally 13 of them attended the Workshop (3 from the University of Łódź, 3 from the University of Silesia, 3 from the Adam Mickiewicz University in Poznań, 2 from the Maria Curie-Skłodowska University in Lublin and 2 from the University of Szczecin). During the Workshop they attended a series of lectures on subjects related to heavy ion physics. The experimental tasks allowed them to get acquainted with HIL infrastructure by performing measurements using dedicated apparatus available in the Laboratory. The Workshop was concluded by student presentations — each group prepared a 20 minute talk on their measurements and results.

In 2009, the programme of the lectures was the following:

- Radioprotection at HIL (R. Tańczyk),
- Introduction to heavy ion acceleration and elements of ion optics (M. Wolińska-Cichocka),
- Detection of gamma radiation, charged particles and neutrons (M. Palacz),
- X-ray fluorescence spectroscopy (J. Kownacki)
- In-beam gamma spectroscopy (M. Zielińska),
- Targets for nuclear physics (A. Stolarz),
- Radiopharmaceuticals for Positron Emission Tomography (K. Kilian).

Students took part in the following experimental tasks:

- Beam focusing in heavy ion acceleration,
- Beam energy measurements based on the Rutherford scattering,
- Determination of cross section in the Rutherford scattering,
- Elemental analysis using X-ray fluorescence,
- Measurements of ^{137}Cs activity in environmental samples,
- Identification of reaction products based on the pulse shape analysis.

The first international edition of the Workshop on Acceleration and Applications of Heavy Ions will take place at HIL in March 2011. A two weeks course for 15–20 participants will be organised jointly by HIL, University of Huelva (Spain) and University of Sofia (Bulgaria) in the framework of the ERASMUS Intensive Programme.

Part B

Experiments at HIL

B.1 Nuclear deformation of ^{20}Ne from ^{20}Ne(105, 115 MeV) + ^{208}Pb scattering

I. Strojek[1], W. Czarnacki[1], W. Gawlikowicz[2], N. Keeley[1], M. Kisieliński[1,2],
S. Kliczewski[3], A. Kordyasz[2], E. Koshchiy[4], M. Kowalczyk[2,5], E. Piasecki[1,2],
A. Piórkowska[6], K. Rusek[1,2], R. Siudak[3], A. Staudt[6], A. Trzcińska[2]

1) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
2) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
3) The Henryk Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
4) Kharkiv University, Kharkiv, Ukraine
5) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
6) Institute of Physics, University of Silesia, Katowice, Poland

The ^{20}Ne nucleus is highly deformed; its hexadecapole deformation is one of the highest known in nature. In our previous experiment performed at University of Jyväskylä the quasielastic events from ^{20}Ne + ^{208}Pb scattering were detected at a few backward angles at energies in the vicinity of the Coulomb barrier (Fig. 1). From this data, a set of the barrier distribution (a probability that the barrier height is equal to a certain energy) was derived. This distribution was found to be in disagreement with the predictions obtained by means of the coupled-channel (CC) calculations. This could be due to either insufficient knowledge of the ^{20}Ne structure (deformation of ^{20}Ne ground state), or its incorrect implementation in the calculations. The charge distribution of ^{20}Ne ground state is well known from the proton and electron scattering experiments [3, 4] and the model-independent Coulomb matrix elements could be directly included in the CC calculations. Thus, the disagreement could be caused by the nuclear deformation that is described by a model-dependent "deformation length" δ. The values of this parameter derived from different scattering experiments are not consistent and range from 1.29 fm [5, 6] to 1.47 fm [7]. In order to solve this puzzle we performed a series of experiments aimed at precise measurements of the angular distributions of ^{20}Ne + ^{208}Pb quasielastic scattering (elastic plus inelastic, leading to the first excited state of the projectile) close to the Coulomb barrier. Consistent analysis of these data sets together with the scattering data measured previously at higher energies [2] should help in the extraction of the of ^{20}Ne nuclear deformation length.

The experiment was performed at the Heavy Ion Laboratory in Warsaw, Poland. The intensity of the ^{20}Ne beam delivered by the $K = 160$ cyclotron was of about 6×10^8 ions per second. The target thickness was 100 μg/cm^2. We have used the multipurpose scattering chamber ICARE and the set of five telescopes to detect and to identify charged particles (Fig. 2). Each of the telescopes was composed of the gas (isobutane) ionisation chamber and a thick (300 μg/cm^2) silicon detector. The angular positions of the telescopes were in the range from 52° to 160° in the laboratory system. Four silicon detectors situated at forward angles monitored the beam by means of Rutherford scattering. Data were collected at two beam energies: 105 and 115 MeV. The analysis is in progress.

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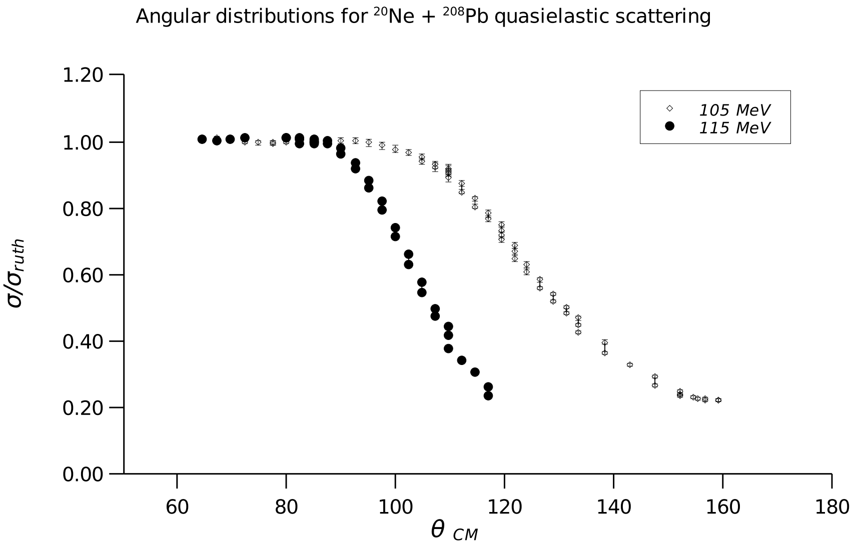

Figure 1: Angular distributions for ^{20}Ne + ^{208}Pb quasielastic scattering at 105 and 115 MeV

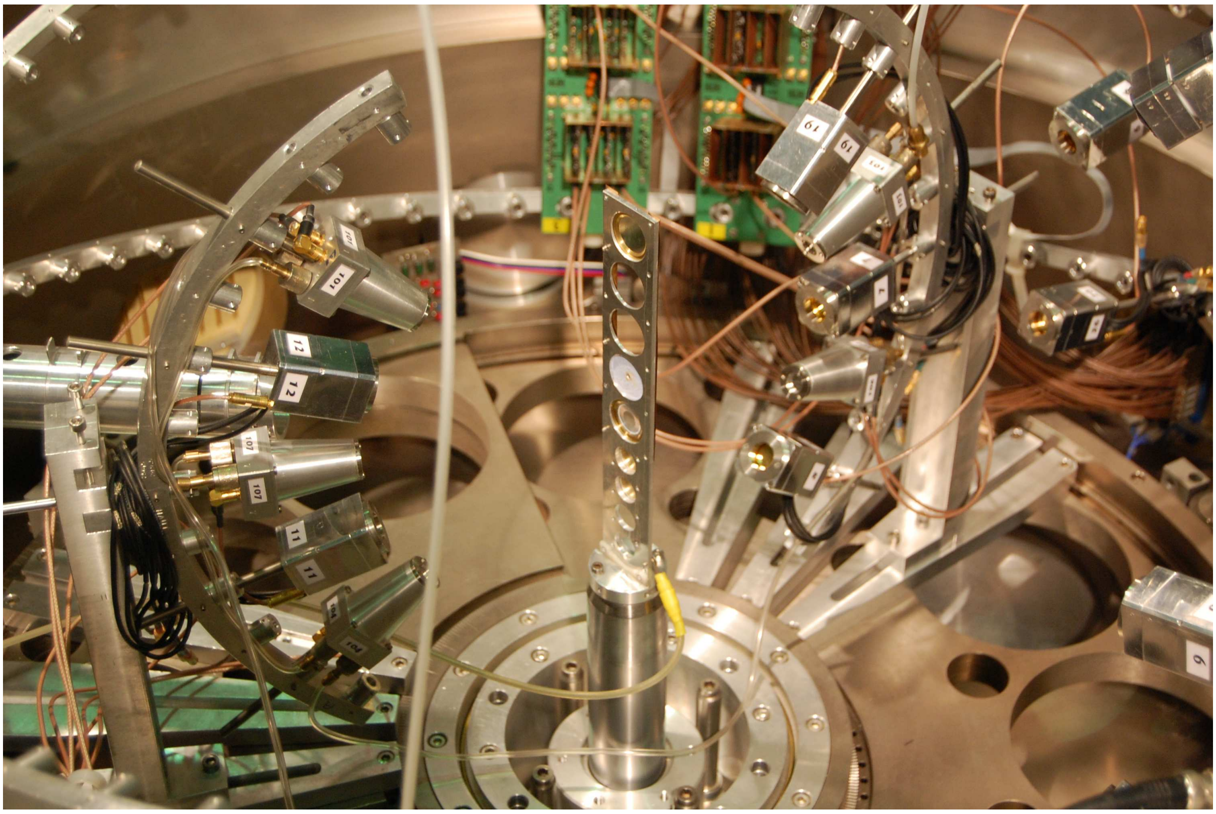

Figure 2: Inside of the ICARE chamber with the target holder and the telescopes

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B.2 New detector system for the super-heavy elements (SHE) detection

A. Wieloch[1], Z. Sosin[1], P. Bańka[1], A. Gonciarz[1], J. Péter[2], A. Drouart[3], R. Dayras[3], K. Łojek[1], Ch. Stodel[4], M. Adamczyk[1], B. Avez[3], P. Lasko[1], Ł. Zosiak[1], T. Kozik[1], N. Alamanos[3], A. Gillibert[3], S. Grévy[4], F. Hanappe[5], F. Hannachi[6], R. Hue[4], A. Khouaja[4], A. Lopez-Martens[7], L. Manduci[2], F. de Oliveira Santos[4], G. Politi[8], M.G. Saint-Laurent[4], L. Stuttgé[9], Ch. Vandamme[2], J.P. Wieleczko[4], E. Piasecki[10], A. Trzcińska[10], W. Gawlikowicz[10], M. Kisieliński[10], M. Kowalczyk[10], A. Kordyasz[10], L. Pieńkowski[10], J. Błocki[11]

1) M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland
2) LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, France
3) CEA Saclay, IRFU/SPhN, Gif-sur-Yvette, France
4) GANIL, Caen, France
5) PNTPM, Université Libre de Bruxelles, Belgium
6) CENBG, Bordeaux-Gradignan, France
7) CSNSM, Orsay, France
8) Istituto Fisica dell'Universitá, Catania, Italy
9) IPHC, Strasbourg, France
10) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
11) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland

The synthesis of SHE elements via complete fusion reactions has been an important and successful sub-field of nuclear physics research [1, 2]. In this report we describe the Scintillation Ionization Detector (SID), designed to detect super-heavy nuclei and currently proposed to be used as a part of the new experimental setup at the Heavy Ion Laboratory. This detector has been successfully tested at GANIL during the E533 experiment [3]. The advantage of the new detection line at HIL is the small length of the fusion product separator. This feature allows for investigation of super-heavy nuclei with a very short life time — about 100 ns.

The current version of SID is dedicated to study properties of very heavy nuclei and SHE nuclei that decay via spontaneous fission. The detection line is described below, using as an example the reaction $^{40}\mathrm{Ar}+^{208}\mathrm{Pb}$, which produces $^{248}\mathrm{Fm}$ in the fusion process. The beam energy is optimised to create compound nuclei (Fm) with a low excitation energy. In this case, the fermium nucleus emits only 1–3 neutrons during deexcitation in the target. Non-interacting beam ions are deflected by the Solid (neodymium) Magnetic Separator (SMS) to a certain angle and then absorbed in the beam stopper (see Fig. 1).

The fusion products $^{247-245}\mathrm{Fm}$, which have smaller magnetic rigidity than the Ar ions, enter the SMS and are deflected to larger angles as compared to the argon nuclei. At this point they can be detected by SID, as it is schematically illustrated in Fig. 1. The detector is filled with the CF_4 gas and consists of two parts (for a scheme of SID see Fig. 1 of Ref. [4]). The first part provides a fast scintillation pulse, which can be used in time of flight (ToF) measurements. The amplitude of the pulse is proportional to the atomic number (Z) of the detected element, so it can be useful in the fast Z discrimination. After passing the scintillation section, the ion is stopped in the ionisation part, which is composed of two wire planes with a stopping mylar foil (or a stopping silicon detector) placed in the centre. The pressure of the gas inside the detector is chosen in such a way that the fusion products — Fm ions — are stopped in the foil. The fermium ions undergo

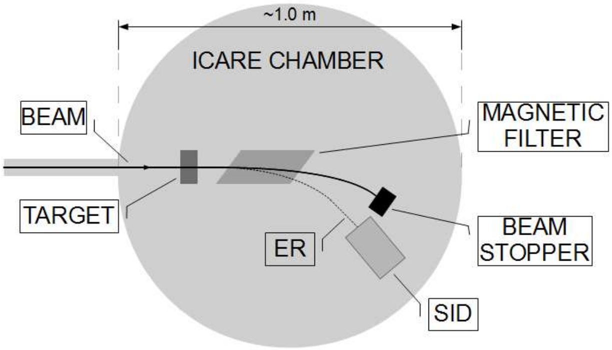

Figure 1: Proposed detection line at HIL. Evaporation residues (ER) are strongly deflected by the magnetic field.

the spontaneous fission with the decay time depending on the created Fm isotope (3.3 ms to 30 s). Fission fragments originating from the spontaneous decay of the Fm nucleus implanted in the foil are emitted back to back and detected by the wire planes. The properties of SID were investigated in the test run (summer 2009) in the ICARE chamber installed at HIL.

As it was shown in the paper of Ref. [4], signal amplitudes from the scintillation and ionisation parts are well correlated for fission fragments from the Cf source of kinetic energy around 1 MeV·A. In the normal kinematics, the kinetic energy of fusion products is much lower (in our case, for the Ar beam of energy 5 MeV·A, by a factor of about seven: 0.13 MeV·A). For this reason, the possibility of discrimination between ions of different Z at a very low gas pressure was investigated during the last test at HIL. Two reactions were used: ^{20}Ne + ^{120}Sn and ^{20}Ne + ^{197}Au, both at the beam energy of 8 MeV·A. In the first reaction, with the detector placed at 50°, it was possible to detect mainly projectile-like fragments, see Fig. 2a. Due to a grazing angle target-like fragments were not observed. In the second reaction both projectile-like and heavy fragments produced in fission process of the compound nucleus system (Z=89) were measured, see Fig. 2b. As one can see from both panels of Figure 2, it is easy to distinguish between Ne-like and fission fragments. More details on the measurements can be found in the work of Ref. [5].

In conclusion, the detector presented in the current report possesses valuable features, helpful in the SHE detection. Pulses from the scintillation part of the SID (light output) have a very short rise-time (ca. 1 ns) and are proportional to the Z number of the detected particle. That, in consequence, allows for a considerable background reduction. Signals from the proportional counter (charge output) can be used in measurements of the angular distribution of fission fragments. Such possibility has not yet been offered by standard detection setups for the SHE production, at least not with a granulation sufficient for an angle measurement. The foil used to stop the residues can be replaced by a thin position-sensitive silicon detector in order to increase the precision of the trajectory determination. It is worth noting that in order to use the beam time in a more efficient way, future experiments are planned in a GANIL-HIL collaboration.

We appreciate the help given to us by the Heavy Ion Laboratory management and the technical staff during test measurements in this Laboratory.

This work was supported in part by the Polish Ministry of Science and Higher Education, Grant no. PB 3336/H03/2007/32, and by the IN2P3-Poland agreement, collaboration no. 08-128.

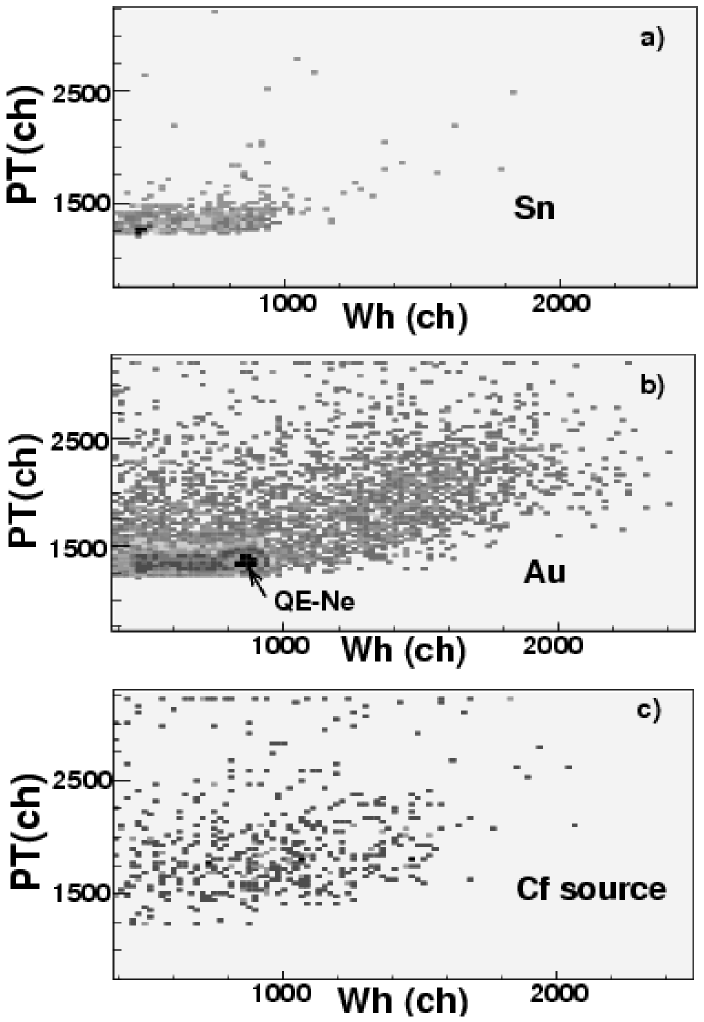

Figure 2: Data from the SID detector. Amplitude of pulses from the phototube (PT) vs. amplitude of pulses from the wires of the horizontal plane (Wh) of the ionisation part is presented in all three panels. The reactions used were ^{20}Ne+^{120}Sn (a) and ^{20}Ne+^{197}Au (b). For reference, panel (c) represents measured fission fragments from the Cf source, visible in the same region as the events corresponding to heavy ions produced in the reaction Ne+Au (panel b).

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B.3 Partner bands of ^{126}Cs — first observation of chiral electromagnetic selection rules

E. Grodner[1], I. Sankowska[1,2], T. Morek[1], Ch. Droste[1], S.G. Rohoziński[3], J. Srebrny[4], A.A. Pasternak[5], M. Kisieliński[4,6], M. Kowalczyk[1,4], J. Kownacki[4], J. Mierzejewski[1,4], A. Król[7], K. Wrzosek-Lipska[1,4]

1) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
2) Institute of Electron Technology, Warszawa, Poland
3) Institute of Theoretical Physics, University of Warsaw, Warszawa, Poland
4) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
5) A.F. Ioffe Physical Technical Institute, St. Petersburg, Russia
6) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
7) Institute of Physics, University of Łódź, Łódź, Poland

The rotational states of ^{126}Cs were populated in the ^{120}Sn(^{10}B,4n)^{126}Cs reaction. The ^{10}B beam of 55 MeV energy was provided by the U200P cyclotron of the Heavy Ion Laboratory, University of Warsaw. About 10^9 $\gamma-\gamma$ coincidences were collected by 12 ACS HPGe spectrometers of the OSIRIS II array placed at angles 25°, ±38°, 63°, ±90°, 117°, ±142°, 155° with respect to the beam direction. Lifetimes of excited levels were measured using the Doppler Shift Attenuation method. The ^{120}Sn target 40 mg/cm^2 thick played simultaneously the role of a stopper. Doppler broadened line-shapes of the γ transitions were analysed by the methods described in detail in Ref. [1].

The problem of the side feeding cannot be completely circumvented in the DSA technique, therefore the applied method for gamma line-shape analysis is based on a complex side feeding study with detailed side-feeding pattern as a byproduct. At the beginning of the line-shape analysis process, distribution of entry states is calculated where kinetic energy loss of the projectile moving in the target is accounted for. The feeding times due to unobserved transitions from entry states to known levels were described by the side-feeding model whose parameters were experimentally determined from the analysis of the highest energy levels and intensity distribution in the ^{132}La, ^{128}Cs and ^{126}Cs nuclei. The feeding times due to observed transitions are automatically taken into account since all experimental branching ratios are given as input parameters for line-shape analysis. When the level scheme is well established and the intensity is large enough, the best way of proceeding is the step-by-step extraction of lifetimes, starting from the upper levels and taking into account all feeding cascades. Two spectra were used for extraction of lifetimes: the forward one, being the sum of the spectra from the detectors placed at angles 25°, ±38°; and the backward one, being the sum of spectra from 155°, ±142° detectors. Comparison of the total intensities of γ transitions observed in the yrast band of ^{126}Cs and calculated in terms of the side feeding model, together with examples of Doppler broadened line-shapes, are shown in Fig. 1. The stopping power of Cs recoils moving in the Sn target was measured in additional experiments with help of the semi-thick target method (see Ref. [2]). The lifetimes of the rotational states belonging to chiral partner bands built on the $\pi h_{11/2} \otimes \nu^{-1} h_{11/2}$ configuration measured in the present experiment are in the range: 0.42-1.24 ps. The lifetime data, together with the gamma line intensities, were used to obtain experimental B(M1) and B(E2) reduced transition probabilities. The $\Delta I = 1$ transitions are assumed to be pure M1 type according to Ref. [3]. In Fig.3 the experimental B(M1; I→I-1) and B(E2; I→I-2) reduced transition probabilities of the ^{126}Cs

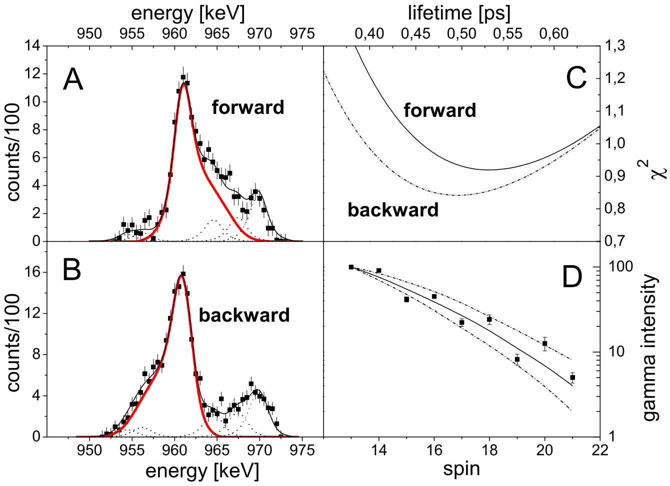

Figure 1: Panel A and B: DSA line-shape analysis of the $18^+ \rightarrow 16^+$ E2 transition in the yrast band. Red solid line shows the peak of interest. Black solid line shows a fit to the fragment of the spectrum. Dotted lines show background peaks. Panel C: Value of χ^2 found from the DSA line-shape analysis performed for the forward (solid line) and the backward (dotted line) spectrum. Panel D: total γ-ray intensity depopulating a given level in the yrast band. Solid line — intensities calculated in terms of the side-feeding model. Dotted lines present the uncertainty of the γ-ray intensities given by the side-feeding model that are taken into account in the final lifetime uncertainties.

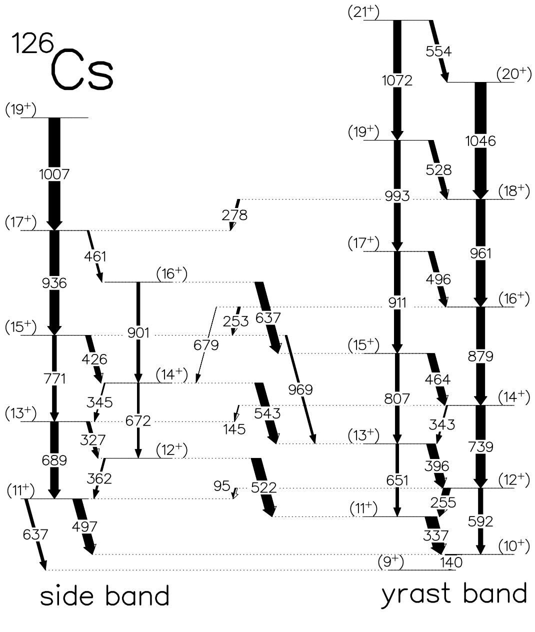

Figure 2: Partner bands of ^{126}Cs built on the $\pi h_{11/2} \otimes \nu^{-1} h_{11/2}$ configuration observed in the present experiment. The arrow widths are proportional to corresponding branching ratios.

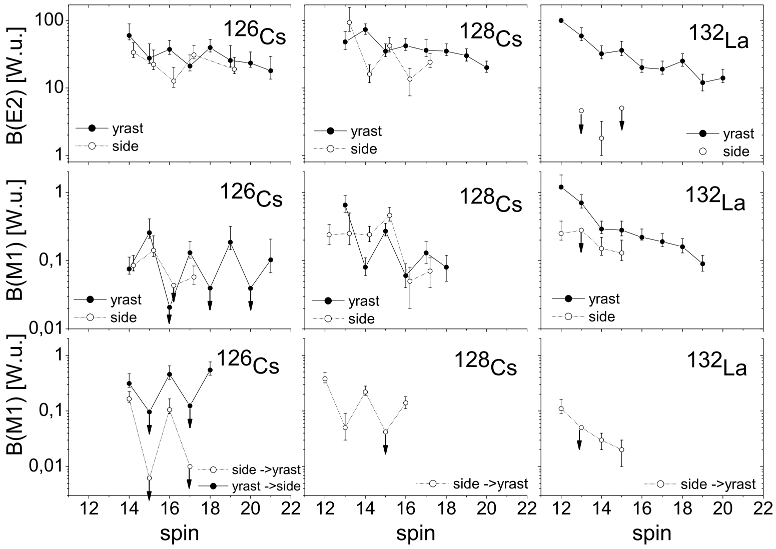

Figure 3: Comparison of γ transition probabilities in the partner bands of ^{126}Cs (left column), of ^{128}Cs (middle), and of ^{132}La (right column). Upper and middle row: B(E2) and B(M1) values for in-band transitions, respectively; bottom row: B(M1) values for inter-band transitions.

nucleus are compared with similar data measured in the ^{128}Cs and ^{132}La nuclei [4]. One can see that for ^{126}Cs the electromagnetic properties of both partner bands are similar. The B(M1) staggering for in-band transitions is clearly observed up to higher spins as compared with the ^{128}Cs case. For the first time the inter-band B(M1) staggering is observed for side → yrast and yrast → side γ transitions and has an opposite phase to the in-band one. This means that if an in-band transition is strong then the corresponding inter-band transition is weak or even absent and vice-versa. The complete set of chiral electromagnetic selection rules predicted in Ref. [5] is thus experimentally confirmed.

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B.4 Charged particles as a tool for reaction mechanism investigation

J. Mierzejewski[1,2]*, M. Antczak*[1]*, Ch. Droste*[2]*, E. Grodner*[2]*, K. Hadyńska-Klęk*[1]*,*
A. Jakubowski[1]*, P. Jasiński*[1]*, G. Jaworski*[1,5]*, M. Kisieliński*[1,3]*, M. Komorowska*[1,2]*,*
A. Kordyasz[1]*, M. Kowalczyk*[1,2]*, J. Kownacki*[1]*, T. Morek*[2]*, P.J. Napiorkowski*[1]*,*
J. Ogrodnik[1,5]*, J. Perkowski*[4]*, W. Perkowski*[1]*, A. Pietrzak*[1]*, J. Skalski*[3]*, J. Srebrny*[1]*,*
A. Stolarz[1]*, K. Wrzosek-Lipska*[1]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
3) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
4) Institute of Physics, University of Łódź, Łódź, Poland
5) Faculty of Physics, Warsaw University of Technology, Warszawa, Poland

Incomplete fusion mechanism (ICF) was first described in late 70's [1, 2]. Excitation functions for ICF were determined by α-γ coincidence measurements and interpreted in terms of the Generalised Critical Angular Momentum concept. Later this ground was deeply investigated. In the work of reference [3] correlations of charged-particle energies and angles with γ-ray multiplicities were measured. Authors showed clearly that angular momentum transferred in the capture of a projectile fragment by a target increases linearly with captured mass.

In Ref. [5] the Sum Rule Model based on the Generalised Critical Angular Momentum Model was proposed. It describes well cross sections for the complete (CF) and incomplete (ICF) fusion mechanisms. Later it was slightly modified [6] by adding some dissipation effects in preequilibrium stage.

In recent years some cross sections for ICF were measured [7, 8] by off-line γ spectrometry. Cross section were much bigger than expected taking into account only the CF mechanism. The ICF influence on high spin states population was also shown [9]. Nevertheless, there is no model describing exactly the dynamics of the process. In this work we present preliminary results of the experiment where proton-γ and α-γ coincidences were measured, to provide necessary data for developing a new model describing creation of the compound and kinematics of the escaping fragment in the ICF mechanism.

Measurements were performed using the EAGLE setup [10] equipped with 12 HPGe detectors and Si-ball [11] consisting of 30 thin (100 μm) Si detectors in 4π geometry. ^{20}Ne beam of energy 141 MeV and 150 MeV was bombarding a 5.4 mg/cm^2 ^{122}Sn target. The target was mounted in an aluminium tube [12] of 70 μm thickness to protect Si detectors from the scattered beam. We focused on the ^{122}Sn(^{20}Ne,$\alpha 6n$)^{132}Ce reaction channel. For each energy not only particle-γ coincidences were measured but also single γ spectra [13] to determine relative yields for the production of the most intensive channels. Difference between single and particle-γ coincidence mode is shown in Fig. 1a, where the 325.4 keV ($2^+ \rightarrow 0^+$ in ^{132}Ce) line is shown for both modes. As expected particle coincidences clear the background well.

In Fig. 1b two particle spectra measured at 141 MeV by Si detectors covering θ angles from 52° to 85° are shown. The green spectrum results from summing up gates on ^{132}Ce transitions: 325 keV ($2^+ \rightarrow 0^+$), 533 keV ($4^+ \rightarrow 2^+$), 682 keV ($6^+ \rightarrow 4^+$) and 788 keV ($8^+ \rightarrow 6^+$). The blue one was obtained by the standard Compton background subtraction. Spectra are easy to interpret — proton and α particles are well separated. Most of the background events are proton-γ coincidences. After background removal the total amount of proton-γ coincidences decreased 5.2 times, while α-γ events only 2.3 times.

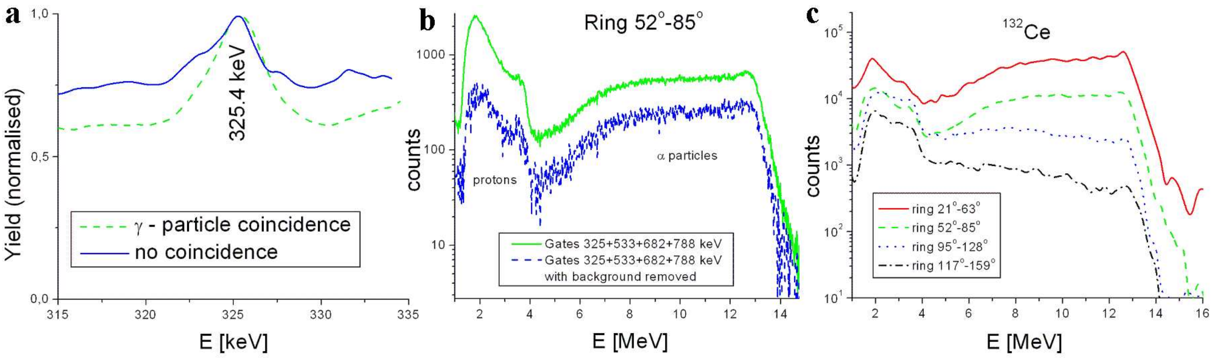

Figure 1: a) Fragments of γ spectra: single (blue solid line), and particle-γ coincidence (green dashed). b) Particle spectra corresponding to ^{132}Ce, observed in the 52°-85° ring, with (blue dashed) and without (green solid) background subtraction. c) Comparison of ^{132}Ce particle spectra in rings covering θ angles 21°-159°.

In Fig. 1c. preliminary results for ^{132}Ce from all rings are shown. Further analysis will focus on simulations of α-particle spectra. We believe that in forward detectors (rings 21°-63°) we see α particles from both the CF and ICF mechanisms. On the other hand, in rings covering θ angles from 63° to 169°, only evaporated α particles from the CF mechanisms should be observed. Since CF is well known and theory describing evaporation from the compound nucleus is well established, we can use the data from the 63° to 169° rings to check if we are able to correctly simulate evaporation spectra. If so, it will be possible to extract the ICF contribution from the spectra collected by the forward detectors, and in consequence investigate the reaction mechanism more in detail. Data analysis is in progress.

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B.5 Relative cross sections for selected channels in the ^{122}Sn+^{20}Ne reaction at 151 MeV beam energy

M. Komorowska[1,2], *J. Mierzejewski*[1,2], *J. Srebrny*[1], *T. Morek*[2]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland

As described in paper [1], the mechanism of the ^{122}Sn+^{20}Ne reaction was investigated through charged particle-gamma coincidences measured in-beam at HIL, with 30 Si detectors of Si-ball and the EAGLE spectrometer, consisting of 12 BGO Compton-suppressed HPGe detectors. Relative cross sections for the production of several different nuclei were also evaluated, using single γ rays registered during the experiment. Cross sections were determined from the intensity of selected γ-ray lines [2], which correspond to the feeding of the ground states.

For the following nuclei, it was possible to use single g.s. feeding transition: ^{132}Ce — line 325 keV, ^{134}Pr — line 307 keV, ^{134}Nd — line 294 keV, ^{136}Nd — line 373 keV. In some other cases such a dominating line did not exist and not all the fragmented g.s. feedings could be identified. The list below shows nuclei and γ-ray lines which were used to determine the cross sections in such cases, with proper normalisation based on the γ-ray intensities known from similar reactions [2], so that the total ground state feeding intensity could be estimated. The following lines were used:

- ^{131}Ce, line 162 keV;
- ^{133}Ce, line 170 keV;
- ^{135}Pr, line 204 keV;
- ^{135}Nd, line 199 keV.

Preliminary evaluated relative cross sections for the ^{122}Sn+^{20}Ne reaction channels at 150 MeV beam are shown in Figure 1.

The spectra collected in the experiment contained contribution originating from long-lived radioactivity, which should be taken into account in the determination of the cross sections. For this purpose the time macro-structure of beams provided by the Warsaw Cyclotron was used — data were sorted with time condition corresponding to in-beam and off-beam time windows, 2 and 3 ms gates, respectively. In this way it was possible to subtract 1 ms and longer activity. Different dead time of the date acquisition system for the two time conditions was taken into account as well as the influence of the time width of both gates. The result of this procedure is shown in Figure 2.

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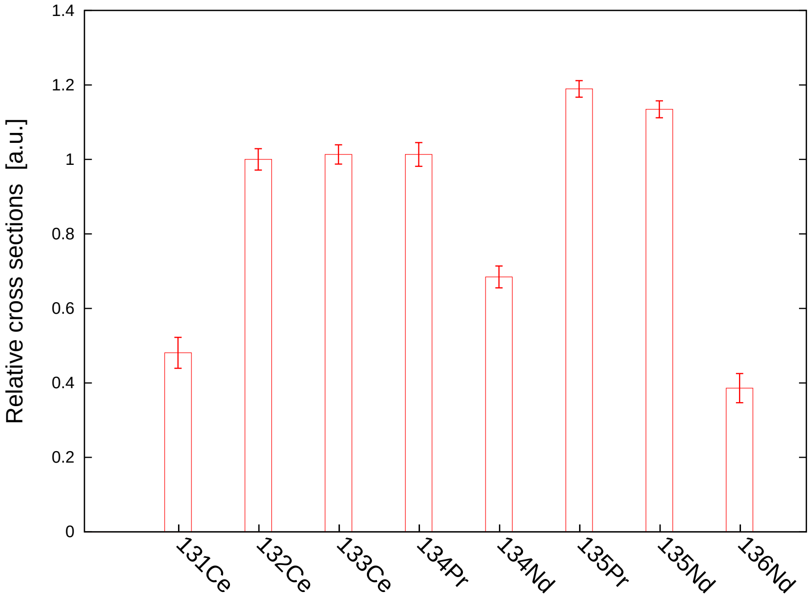

Figure 1: Relative cross sections of different reaction channels of the ^{122}Sn+^{20}Ne reaction, at 150 MeV ^{20}Ne beam energy. Statistical and efficiency calibration uncertainties were included in the error bars, as well as uncertainties originating from the spectra subtraction procedure.

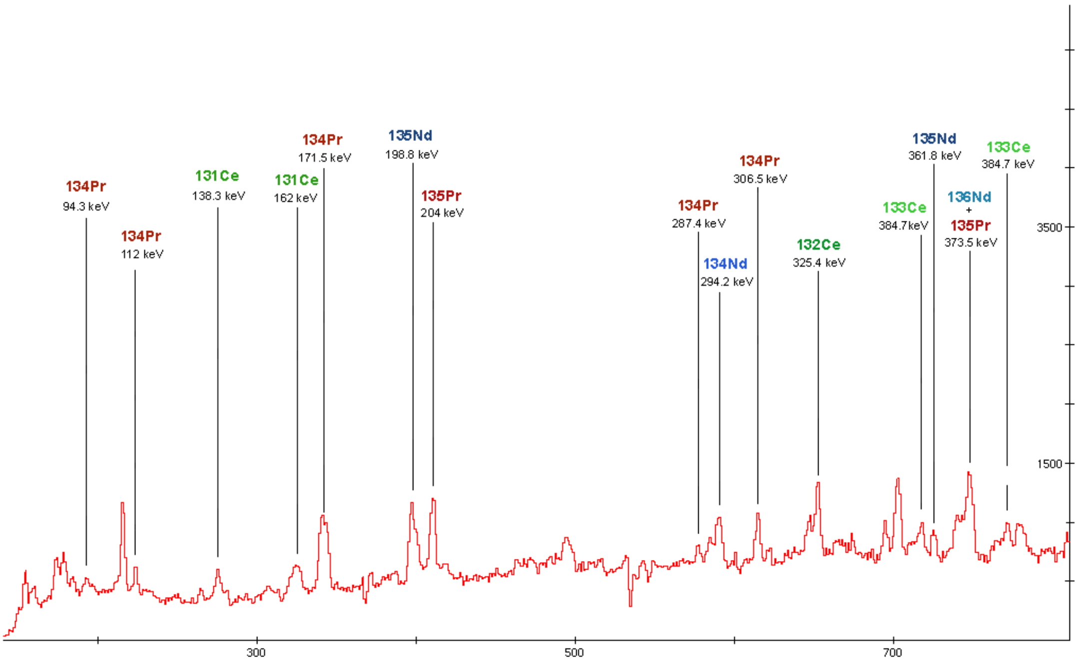

Figure 2: Part of the measured γ spectrum, relevant to the evaluation of the cross sections. The dead time and beam macro-structure, as well as the efficiency of the detectors were taken into account.

B.6 Coulomb excitation of ^{100}Mo — determination of the E3 strength

K. Hadyńska-Klęk[1,2]*, K. Wrzosek-Lipska*[1,2]*, J. Iwanicki*[1]*, M. Kisieliński*[1,3]*,*
A. Kordyasz[1]*, M. Kowalczyk*[1,2]*, J. Kownacki*[1]*, S. Lalkovski*[4]*, P.J. Napiorkowski*[1]*,*
D.A. Piętak[1,5]*, J. Srebrny*[1]*, M. Zielińska*[1]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
3) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
4) Sofia University "St. Kliment Ohridski", Sofia, Bulgaria
5) Institute of Radioelectronics, Warsaw University of Technology, Warszawa, Poland

A Coulomb excitation experiment of ^{100}Mo was performed in 2007 using the 81 MeV ^{32}S beam from the Warsaw Cyclotron. Experimental set-up consisted of the OSIRIS-II spectrometer coupled to the array of PiN diodes placed inside the so-called "Munich chamber".

The OSIRIS-II was a multi-detector array designed for γ-ray spectroscopy with heavy ion beams at the Heavy Ion Laboratory in Warsaw, consisting of 12 HPGe detectors equipped with anti-Compton BGO shields. At present the OSIRIS-II array is replaced by the larger γ-ray spectrometer EAGLE.

Scattered projectiles were detected by 45 silicon PiN diodes, placed inside a spherical chamber of 5 cm radius [1]. The active area of a single PiN-diode is 0.5×0.5 cm^2 . The diodes covered the angular range from 112° to 152° with respect to the beam direction.

Two types of measurements were carried on. During the first part of the experiment γ rays were detected in coincidence with back-scattered ions. The second part of the experiment was performed in the non-coincidence mode, which means that all scattering angles, including forward ones, were possible. The excitation could also take place in any moment during the beam stopping in the target, so the incident energies ranged from zero to the total beam energy (81 MeV). Since excitation strength strongly depends on the scattering angle, the excitation patterns obtained in these two types of measurements are different, and bring complementary information on matrix elements involved.

The GOSIA code [2] was used to simulate yields of gamma transitions depopulating the Coulomb excited 3^- state. Two different ways to populate the state in question have been taken into account: one step ($0^+_1 \rightarrow 3^-$) and two step excitation (($0^+_1 \rightarrow 2^+_1) \otimes (2^+_1 \rightarrow 3^-$)). The simulation was carried out for two different ranges of the incident energy, corresponding to the coincidence and non-coincidence mode measurement, and for the full range of scattering angles. Fig. 1 presents the dependence on scattering angle of the $3^- \rightarrow 0^+_1$ yield normalised to the $2^+_1 \rightarrow 0^+_1$ one. The vertical lines mark the angular coverage of the particle detectors used in the coincidence mode experiment. The average theta angle for this experiment is 140°, whereas in the non-coincidence mode measurement it was equal 65°. One can observe that the contribution from the two-step excitation in the non-coincidence mode measurement is negligible, therefore this type of measurement allows to extract the B(E3; $0^+_1 \rightarrow 3^-$) value in an unambiguous way. On the other hand, simulations performed for the coincidence mode measurement show important contribution of the two-step excitation process. The B(E3; $0^+_1 \rightarrow 3^-$) determined from the non-coincidence mode experiment can be used when analysing the coincidence mode data. With the B(E3; $0^+_1 \rightarrow 3^-$) value known from the non-coincidence data, the only unknown is B(E3; $2^+_1 \rightarrow 3^-$), which can be precisely determined from the coincidence mode data analysis.

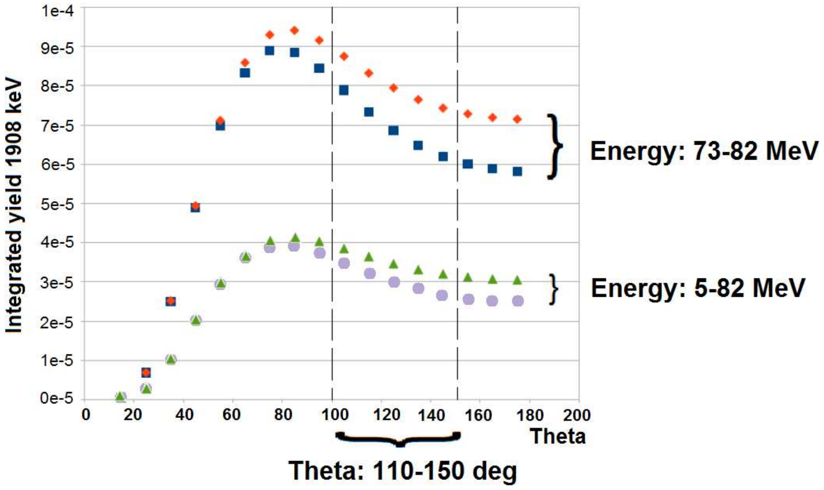

Figure 1: Dependence of the $3^- \rightarrow 0^+_1$ yield on the scattering angle. Two upper curves correspond to the conditions of the coincidence mode measurement — the $3^- \rightarrow 0^+_1$ yield is integrated over the narrow energy range (73-82 MeV). The excitation strength is simulated for the one step excitation ($0^+_1 \rightarrow 3^-$ — navy-blue squares) and for the two-step process (($0^+_1 \rightarrow 2^+_1) \otimes (2^+_1 \rightarrow 3^-$)) — red diamonds). Two lower curves are calculated for the conditions of the non-coincidence mode measurement, i.e. the $3^- \rightarrow 0^+_1$ yield is integrated over the wide energy range (5-82 MeV). The excitation strength simulated for the one step excitation is denoted by purple circles, and for the two-step process by green triangles.

It was possible to determine the matrix element in a model-independent way from the non-coincidence data, using the GOSIA code. In the low-energy Coulex, the only way to populate the 3^- state in ^{100}Mo is via an E3 transition. On the other hand, the depopulation of this state proceeds predominantly via the E1 decay. The B(E3; $0^+_1 \rightarrow 3^-$) value could be determined independently of the 3^- lifetime thanks to the fact that observed E1 yields of the $3^- \rightarrow 2^+_2$ and $3^- \rightarrow 2^+_1$ transitions are the direct measure of the 3^- state population.

In the non-coincidence data analysis, the B(E3;$0^+_1 \rightarrow 3^-$) value equal 0.52(2) eb$^{3/2}$ was obtained, while earlier measurements gave the values of 0.48(8) [3] and 0.132(17) [4] eb$^{3/2}$. The on-going data analysis aims at determining the B(E3) value for the second possible path of the 3^- state excitation, namely via the $2^+_1 \rightarrow 3^-$ transition.

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B.7 Quadrupole moment of the 2_1^+ state in ^{100}Mo

K. Wrzosek-Lipska[1,2], *K. Hadyńska-Klęk*[1,2], *J. Iwanicki*[1], *M. Kisieliński*[1,3], *A. Kordyasz*[1], *M. Kowalczyk*[1,2], *J. Kownacki*[1], *S. Lalkovski*[4], *P.J. Napiorkowski*[1], *D. A. Piętak*[1,5], *L. Pieńkowski*[1], *J. Srebrny*[1], *M. Zielińska*[1]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
3) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
4) Sofia University "St. Kliment Ohridski", Sofia, Bulgaria
5) Institute of Radioelectronics, Warsaw University of Technology, Warszawa, Poland

Choosing the right strategy to subdivide the Coulomb excitation data is quite an important issue during the data analysis. A subdivision based on the projectile scattering angle makes it possible to disentangle contributions from various excitation paths. On the other hand, subdividing the data according to the relative angle between γ-ray and particle trajectories enables the observation of the γ-ray angular distribution, thus increasing the sensitivity to the M1 matrix elements.

In order to extract the triaxiality parameters for the ^{100}Mo nucleus in its ground and excited 0^+ states, it is crucial to precisely determine not only the transitional E2 matrix elements coupling the low-lying 0^+ and 2^+ states, but also the diagonal ones, especially for the first excited state 2_1^+.

The performed particle-γ coincidence experiment has been described in contribution of Ref. [1]. A simulation was performed using the GOSIA code to estimate the impact of various methods of Coulex data subdivision on the accuracy of the resulting diagonal E2 matrix element of the 2_1^+ state. The calculations were made for the same geometry as the measurement [2]. To perform such a simulation, using the GOSIA code, a set of matrix elements needs to be assumed, therefore the resulting values rather indicate a trend than should be treated as absolute numbers. The obtained accuracy of the $\langle 2_1^+\|E2\|2_1^+\rangle$ matrix element for each method of data subdivision is obviously related to the γ yield used in the calculation. The intensity of the strongest transition ($2_1^+ \rightarrow 0_1^+$) in each γ-ray spectrum collected by an individual Ge detector in coincidence with a single PIN diode was assumed to be known within 1% statistical uncertainty. Systematic errors of 5% related to efficiency calibration were assessed to all simulated gamma yields. The accuracy of the $\langle 2_1^+\|E2\|2_1^+\rangle$ matrix element was determined for four different strategies of the data analysis:

1. *PIN and Ge*: subdivision of the data based on the particle scattering angle and γ detection angle (576 individual γ-ray spectra): accuracy of 4%;

2. *PIN*: data from all Ge detectors summed together, but subdivided according to the particle scattering angle (48 individual γ-ray spectra): accuracy of 11%

3. *Ge*: data from all particle detectors summed together, but subdivided according to the γ detection angle (12 individual γ-ray spectra): accuracy of 25%

4. *no subdivision*: one γ-ray spectrum resulting from summing of all data, accuracy of 56%.

The simulations show that the highest accuracy of the 2_1^+ diagonal matrix element results from the possibly highest subdivision of data, based both on the angles of the projectile scattering and the γ-ray emission. However, the level of statistics obtained in a typical Coulex experiment is usually too low to analyse individual PiN-Ge spectra.

Since summing of data from some detectors cannot be avoided, the best strategy is to sum over all Ge detectors while keeping the division according to the projectile scattering angle. While the summing over all particle detectors increases the number of counts in the analysed γ-ray spectra, it also smoothes out the effects, which allow determination of the contribution of concurrent excitation paths.

To demonstrate how the relative population of a state changes as a function of the scattering angle, the example of the 0^+_2 state in ^{100}Mo is shown in Fig. 1. The performed analysis indicates that 0^+_2 state can be populated only via two-step Coulomb excitation. The calculations were carried out for various values of the $\langle 2^+_1 \| E2 \| 2^+_1 \rangle$ matrix element. The probability of the two-step process with respect to the one-step excitation of the 2^+_1 state in ^{100}Mo increases with the projectile scattering angle. In addition it is clearly visible that population of the 0^+_2 state, excited via two step Coulomb excitation: $(0^+_1 \rightarrow 2^+_1) \otimes (2^+_1 \rightarrow 0^+_2)$ is sensitive to the quadrupole moment of the intermediate 2^+_1 state.

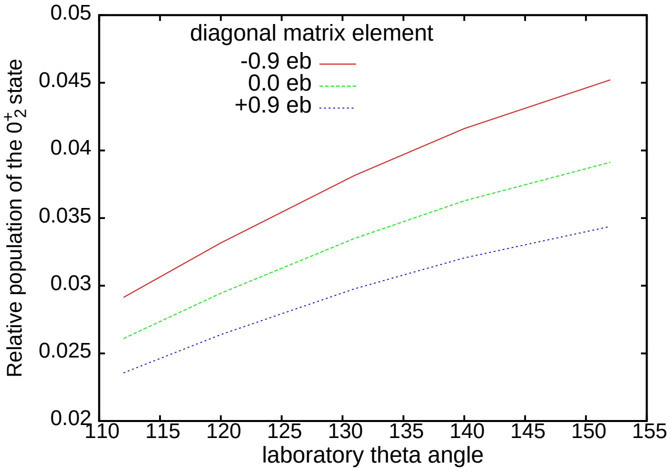

Figure 1: Relative population of the 0^+_2 state (normalised to the population of the first excited state 2^+_1) as a function of the projectile scattering angle, calculated for three values of the 2^+_1 diagonal matrix element: -0.9 eb (red curve), 0.9 eb (blue), 0.0 eb (green).

When analysing the data from the Coulomb excitation experiment of ^{100}Mo with the ^{32}S beam, it was decided to sum the spectra from individual Ge detectors, thus increasing the number of counts in observed γ lines to a level sufficient to subdivide the data according to the projectile scattering angle. Three ranges of the ^{32}S scattering angle were used: 112° - 124°, 127° - 131°, 135° - 152°.

As a result of the data analysis, the diagonal E2 matrix element of the 2^+_1 state in ^{100}Mo was determined. The value obtained is -0.33(10) eb, which corresponds to the spectroscopic quadrupole moment of -0.25(7) eb. The obtained magnitude of the quadrupole moment is smaller compared to the one resulting from the measurement with the ^{4}He and ^{16}O beams, 0.39(8) eb [3], but both values agree within the error bars.

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B.8 Spin and parity assignment for long-lived isomers in odd-odd N=81 nuclei ^{146}Tb and ^{148}Ho

J. Kownacki[1], *Ch. Droste*[2], *T. Morek*[2], *E. Ruchowska*[3], *M. Kisieliński*[1,3], *M. Kowalczyk*[1,2], *R.M. Lieder*[4], *J. Perkowski*[5], *P.J. Napiorkowski*[1], *K. Wrzosek-Lipska*[1,2], *M. Zielińska*[1], *A. Kordyasz*[1], *A. Korman*[3], *W. Czarnacki*[3], *K. Hadyńska-Klęk*[1,2], *E. Grodner*[2], *J. Srebrny*[1], *J. Mierzejewski*[1,2], *J. Andrzejewski*[5], *A. Król*[5]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
3) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
4) Institut für Kernphysik Forschungszentrum Jülich, Germany
5) Institute of Physics, University of Łódź, Łódź, Poland

In the reported experiment 11 HPGe detectors of the OSIRIS-II array were assembled together with an electron spectrometer chamber. Measurements of conversion electrons in the off-beam mode were performed in order to deduce multipolarity assignments for specific transitions in the decay path of the 10^+ isomers observed [1] in the ^{146}Tb and ^{148}Ho N=81 isotones (Fig. 1).

The electrons were detected with 6 Si(Li) detectors located inside the chamber, in which the combination of two magnetic fields has been generated to separate e^+ from e^- and then to transport electrons from the target area to the detectors [2]. Electron spectra for the 373 keV line, gated on the 180 and 321 keV γ rays, and for the 321 keV line gated on the 373 keV γ-ray in ^{148}Ho are shown in Fig. 1. The obtained conversion coefficients K_α, which are given in Table 1, indicate that the 373 keV transition in ^{148}Ho is of the E3 character — in agreement with the former [1, 3] assumption based on the α_{tot} value estimated from the intensity balance. Formerly [4], basing on the decay characteristics, a spin/parity assignment of (6^-) was proposed for the 9.59 s isomeric state in ^{148}Ho. In refs. [1, 3] an M1 nature for the 321 keV transition from (7^-) level to this state was suggested. However, our conversion electron results (Fig. [1] and Table 1) firmly indicate the E2 nature for this transition. Based on this results spin and parity of 5^- can be assigned to the 0+x keV, 9.59 s isomer state (supported also by the shell model calculation). However, looking at the β^+/EC data [4–7] for the ^{148}Ho → ^{148}Dy decay the spin and parity of 6^- can not be excluded. Feeding the 8^+ state in ^{148}Dy with log ft=6.97 ($I_{EC+\beta+} = 0.35$) would be in conflict with the 5^- assignment.

There is, however, a possibility that this feeding is due to existence of not observed weak γ rays populating the 2833 keV level in ^{148}Dy. The log ft values [5–7] indicate that β transitions from the 9.59 s isomer to the ^{148}Dy excited states are mainly allowed ($\delta I = 0, 1$; no parity change), and in few cases first forbidden ($\delta J = 0, 1, 2$ parity changed). The 9.59 s isomer is suggested [3] to be of $[\pi h_{11/2}, \nu s^{-}_{11/2}]$ configuration, thus the 321 keV, E2 transition can proceed from $[\pi h_{11/2}, \nu d^{-1}_{15/2}\ ]\ 7^-$ to $[\pi h_{11/2}, \nu s^{-1}_{11/2}]\ 5^-$ state. Since the $[\pi h_{11/2}, \nu h^{-1}_{11/2}]10^+ \rightarrow [\pi h_{11/2}, \nu d^{-1}_{3/2}]7^-$ E3 transition is configuration forbidden [1, 3] one can guess that this transition proceeds to admixtures ($\pi h_{11/2}$, $\nu d^{-1}_{5/2}$) in the 7^- state, and consequently the 321 keV, E2 transition has to proceed via $\nu d^{-1}_{5/2} \rightarrow \nu s^{-1}_{1/2}$ admixed configurations. The 180, 141 and 108 keV transitions in ^{148}Ho remain of M1 character.

In a similar way the present conversion electron results show (Table 1 and Fig. 1) the E3 nature for the 417 keV transition in the ^{146}Tb nucleus, in agreement with Refs. [1, 3], while the E2 nature is observed for the 343 keV transition. This observation does not change the spin and parity — it remains $I^\pi = 5^-$, as it was determined in Refs. [6, 8].

However, the E2 nature of the 343 keV transition suggests the decay from $[\pi h_{11/2}, \nu d^{-1}_{5/2}]7^-$ to $[\pi h_{11/2}, \nu s{-}1_{1/2}]5^-$ state placed 19 keV above 0+x keV, 23 s isomer. Similarities in the decay of the 10^+ isomers in ^{146}Tb$_{81}$ and ^{148}Ho$_{81}$ nuclei confirm our 5^- assignment to 9.59 s isomer in ^{148}Ho$_{81}$. From the observation of spin and parity 5^- for the long lived isomers in ^{146}Tb$_{81}$ and ^{148}Ho$_{81}$ nuclei one can also expect that the ground state spin of ^{150}Tm$_{81}$ (assumed in Refs. [1, 3] to be 6^-) can be 5^- as well.

Table 1: Properties of the conversion lines assigned to ^{146}Tb and ^{148}Ho.

Nucleus	E_γ (keV)	α_k^{exp}	α_k^{theo}	Multipolarity
^{146}Tb	343	0.040(8)	0.0322	E2
	417	0.049(6)	0.0516	E3
^{148}Ho	321	0.043(8)	0.0410	E2
	372	0.065(10)	0.0760	E3

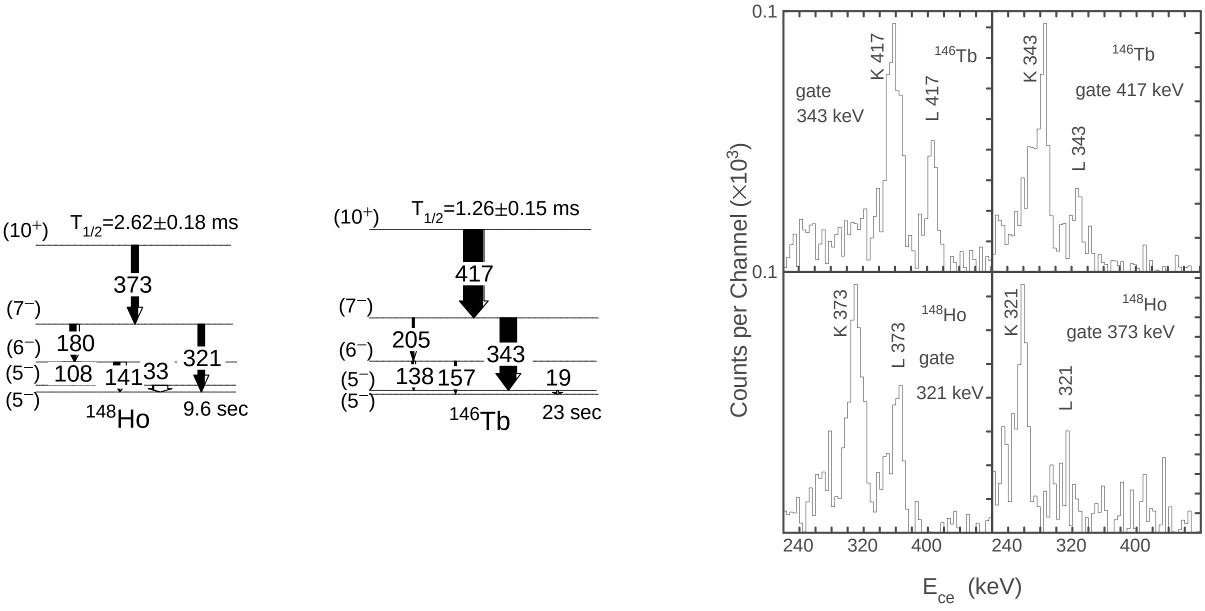

Figure 1: Isomer decay paths in ^{148}Ho and ^{146}Tb (left) and off-beam background corrected e$^-$ spectra gated by γ rays (right).

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B.9 Upgrade of the internal conversion electron spectrometer

J. Andrzejewski[1]*, J. Perkowski*[1]*, J. Samorajczyk*[1]*, Ł. Janiak*[1]*, J. Kownacki*[2]*,*
J. Srebrny[2]*, W. Czarnacki*[3]*, A. Korman*[3]

1) Institute of Physics, University of Łódź, Łódź, Poland
2) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
3) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland

The Internal Conversion Spectrometer (ICE) designed and constructed at the University of Łódź was used in several successful measurements at beams of the Warsaw Cyclotron. A detailed description of the spectrometer is presented in the publication [1] and results achieved in experiments using the device together with the OSIRIS II germanium detector array were published in papers of Refs. [1–3].

Further modification of the ICE spectrometer was highly desired, with the goals of increasing its efficiency and improving energy resolution of the Si(Li) detectors. The gathered experience led to the idea of a segmented silicon detector, with 12 independent parts, see Figure 1. The new detector was manufactured by W. Czarnecki and collaborators at the A. Sołtan Institute for Nuclear Studies in Świerk, and it was ready for testing in the middle of 2009. The active total area of the new detector is 4 times bigger than of the previously used one [1]. The detector is segmented at the back side.

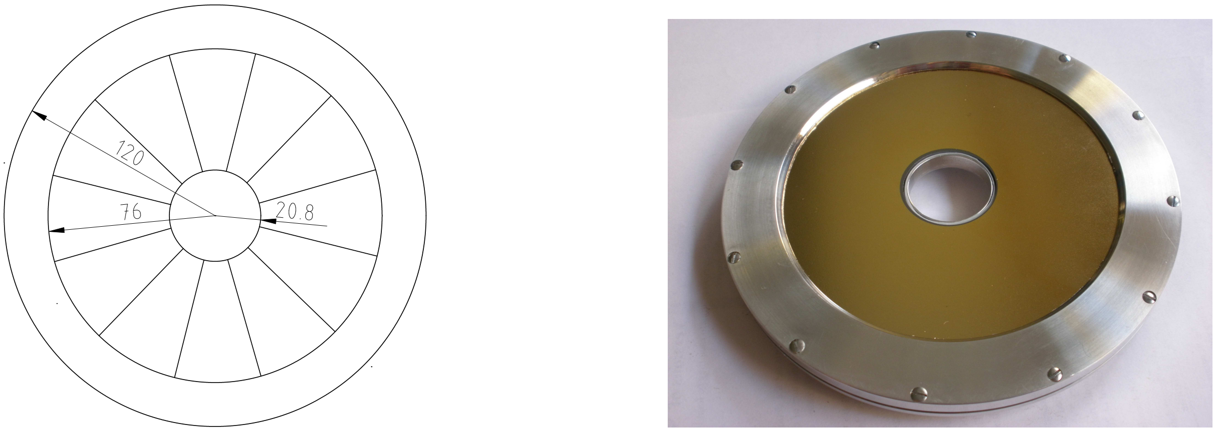

Figure 1: Schematic drawing of the new segmented silicon detector (left) and a picture of the detector manufactured in the A. Sołtan Institute for Nuclear Studies in Świerk (right).

Only six silicon detectors (3 PIPS and 3 Si(Li)) were installed in the previous version of the ICE spectrometer, so the electronics system had to be modified. Six new electronics tracks with preamplifiers were mounted. In order to achieve good energy resolution, the detectors must be cooled down. Originally, the cooling system consisted of two independently supplied electric circuits for three Peltier modules. Currently, the thermal energy is transferred from the detector in two cooling steps through the copper conveyor to the outer radiator. The first cooling step, located between the base of the heat conveyor and the cover of the spectrometer housing, is now composed of 5 Peltier modules, with 69 W power each, connected in series. The second step is placed directly under the copper plate with the detector, and it consists of 6 Peltier modules, 21 W each. These changes enable cooling of the detector down to −30°C, which is optimal for the energy resolution of Si(Li) detectors [4].

Internal conversion electron spectra measured with the ^{207}Bi calibration source are presented in Figure 2. The two spectra were collected by a single segment of the new detector in room temperature, and at −30°C, and they are marked with red and black lines, respectively. The FWHM for the 975 keV electron line is 9.8 keV.

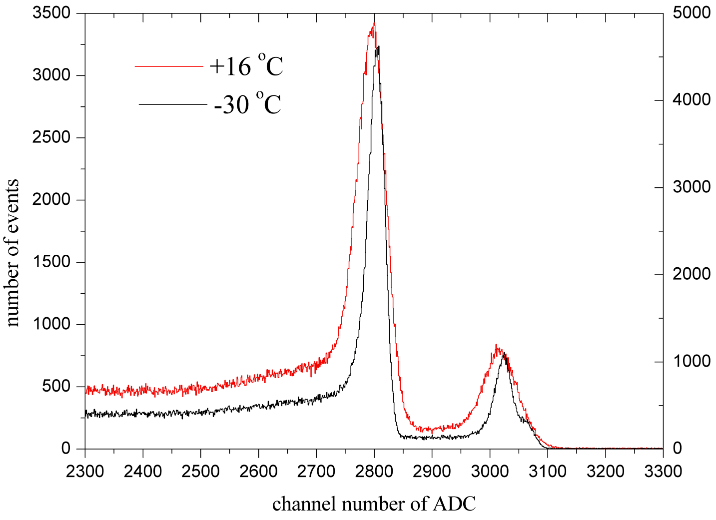

Figure 2: The internal conversion electron K, L and M lines of the 1064 keV transition ^{207}Bi, measured by a single segment of the new Si(Li) detector. The spectrum was collected for two different temperatures of the silicon.

The efficiency of the ICE spectrometer was determined by the measurement of internal conversion electrons emitted by two calibration sources: ^{207}Bi and ^{133}Ba. Absolute efficiency of the spectrometer for the previous set-up and for the new segmented one, for the same geometrical set of magnetic fields, is presented in Figure 3. One can clearly notice that the efficiency of the new set-up in the most interesting energy range of electrons (300–1000 keV) is 3 to 4 times higher than of the old one.

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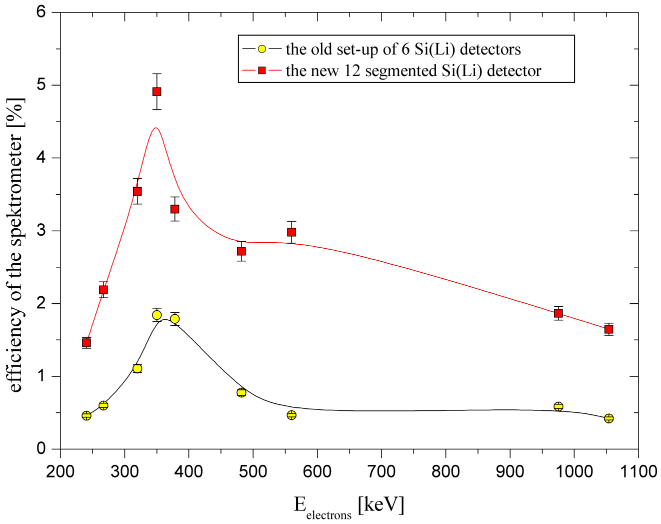

Figure 3: Absolute efficiency of the ICE spectrometer for the earlier set-up of detectors (yellow circles) and for the new segmented device (red squares), obtained by using calibration sources ^{207}Bi and ^{133}Ba.

B.10 The LaBr$_3$ detector non-linearity problem

K. Hadyńska-Klęk[1,2], *M. Ciemała*[3], *M. Kisieliński*[1,4], *S. Kisyov*[5], *M. Kmiecik*[3], *M. Kowalczyk*[1,3], *A. Maj*[3], *W. Męczyński*[3], *M. Moszyński*[4], *P.J. Napiorkowski*[1], *J. Srebrny*[1], *Ł. Świderski*[4], *D. Wolski*[4], *M. Ziębliński*[3]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
3) The Henryk Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
4) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
5) Sofia University "St. Kliment Ohridski", Sofia, Bulgaria

Lanthanum bromide LaBr$_3$ is a promising new scintillator for high energy γ rays. The excellent energy resolution (3% for the 662 keV γ line in ^{137}Cs) and timing response (time resolution of about 250 ps [1]) make this material very attractive for high resolution and high energy γ ray spectroscopy.

Properties of a lanthanum bromide 2 inch cubic detector were investigated using long-lived γ sources. Tests were performed at HIL, at the Andrzej Sołtan Institute for Nuclear Studies in Świerk and at the Institute of Nuclear Physics of the Polish Academy of Sciences in Kraków.

The detector setup consisted of the LaBr$_3$ crystal, the photomultiplier tube (Photonis model XP 3292B) and a voltage divider. Two voltage dividers were used: the Photonis model VD282K [2] and a device constructed in the Andrzej Sołtan Institute for Nuclear Studies in Świerk with a goal to improve the linearity of the energy response of the detector. The main difference between these two voltage dividers is the total resistivity.

Each step of the dynode cascade in the Świerk voltage divider has a significantly lower resistance compared to the VD282K model. This results in the smaller influence of the incoming pulse on the charge distribution inside the voltage divider.

Two γ sources were used for the energy calibration and energy linearity measurements: ^{60}Co (1173.2 keV, 1332.5 keV and the sum peak 2505 keV) and a high-energy mono-energetic source ^{244}Cm + ^{13}C (6129 keV). The ^{244}Cm + ^{13}C source emits the 6129 keV γ-ray following the $^{13}\mathrm{C}(\alpha, n\gamma)^{16}\mathrm{O}$ reaction, where the α particles are produced by the decay of ^{244}Cm. In addition, a background line from the ^{40}K decay (1460 keV) was visible and used for calibration.

Results of the linear fit to the experimental data are presented in Fig. 1 for the set-up with the VD282K voltage divider (left panel) and with the new device (right panel).

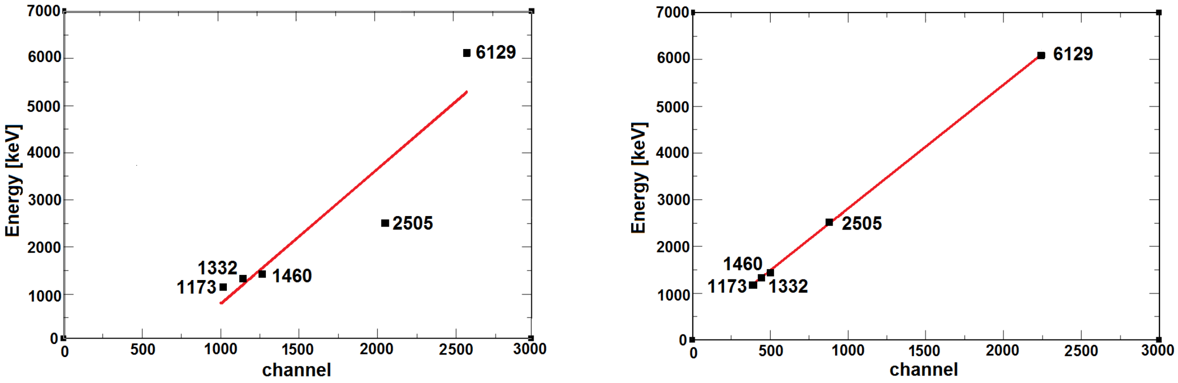

Figure 1: Linear fit to the experimental energy calibration points of the $\mathrm{LaBr_3}$ detector with the Photonis voltage divider model VD282K (left panel) and with the new voltage divider (right panel).

The energy calibration is highly non-linear in the set-up with the original voltage divider VD282K. The problem was caused by a bad match between the voltage divider and the preamplifier. After replacing the original voltage divider by the one better adapted to the specific preamplifier, a much better linearity was achieved.

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B.11 In-beam investigations of the properties of $LaBr_3$ detectors

K. Hadyńska-Klęk[1,5], *D. Balabanski*[2], *M. Ciemała*[3], *E. Clément*[4], *A. Dijon*[4],
A.K. Gourishetty[3], *M. Kicińska-Habior*[5], *M. Kisieliński*[1,6], *S. Kisyov*[2], *M. Kmiecik*[3],
M. Kowalczyk[1,5], *S. Lalkovski*[2], *A. Maj*[3], *W. Męczyński*[3], *M. Moszyński*[6],
P.J. Napiorkowski[1], *D.A. Piętak*[1,7], *J. Srebrny*[1], *Ł. Świderski*[3], *D. Wolski*[3],
K. Wrzosek-Lipska[1,5], *M. Zielińska*[1], *M. Ziębliński*[2]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Sofia University "St. Kliment Ohridski", Sofia, Bulgaria
3) The Henryk Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
4) GANIL, Caen, France
5) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
6) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
7) Institute of Radioelectronics, Warsaw University of Technology, Warszawa, Poland

In-beam investigations of the $LaBr_3$ detectors efficiency and timing properties were performed using gamma radiation from fusion-evaporation reactions induced by beams of the HIL cyclotron. Two one-week long experiments were performed in autumn 2009.

Experimental set-up for both measurements consisted of:

- one two-inch $LaBr_3$ detector from the Institute of Nuclear Physics in Kraków,
- two one-inch cylindrical $LaBr_3$ detectors from the University of Sofia "St. Kliment Ohridski"
- six HPGe detectors in anti-Compton shields (part of the EAGLE spectrometer, HIL, University of Warsaw)

In both experiments the same nuclear reaction was used: ^{14}N beam, with the incident energy of 75 and 86 MeV, and intensity of 1 pnA was bombarding the ^{12}C thick target ($>$50 mg/cm^2). The measurements were focused on the following nuclear reaction channels:

- $^{12}\mathrm{C}(^{14}\mathrm{N}, np)^{24}\mathrm{Mg}$ (stable) with the calculated cross section of 1000 mb
- $^{12}\mathrm{C}(^{14}\mathrm{N}, 2p)^{24}\mathrm{Na}$ ($T_{1/2} = 15$ h) with the calculated cross section of 7.8 mb
- $^{12}\mathrm{C}(^{14}\mathrm{N}, 2n)^{24}\mathrm{Al}$ ($T_{1/2} = 2$ s) with the calculated cross section of 0.2 mb.

1. Efficiency calibration of the $LaBr_3$ detector

The main goal of this experiment was to test a new method of in-beam efficiency calibration and to determine the energy calibration of the $LaBr_3$ detector for gamma energy up to 8 MeV, using heavy ion induced reaction products. The most interesting reaction channel was $^{12}\mathrm{C}(^{14}\mathrm{N}, 2n)^{24}\mathrm{Al}$. The reaction product, ^{24}Al, decays via the β^+ process to the excited ^{24}Mg, with the lifetime of 2.05 s. The strongest gamma lines, expected to be observed following the de-excitation in ^{24}Mg, were: 1368, 2754, 4316 and 7059 keV. Experimental spectra were collected in the 6 ms pause between the beam pulses — for this measurement, the beam macro-structure was 4 ms in-beam, followed by 6 ms off-beam.

Comparison of the experimental spectra from the 2-inch cubic $LaBr_3$ detector (blue) and from the HPGe detector (red) for the low energy region is shown in the Fig. 1. Besides

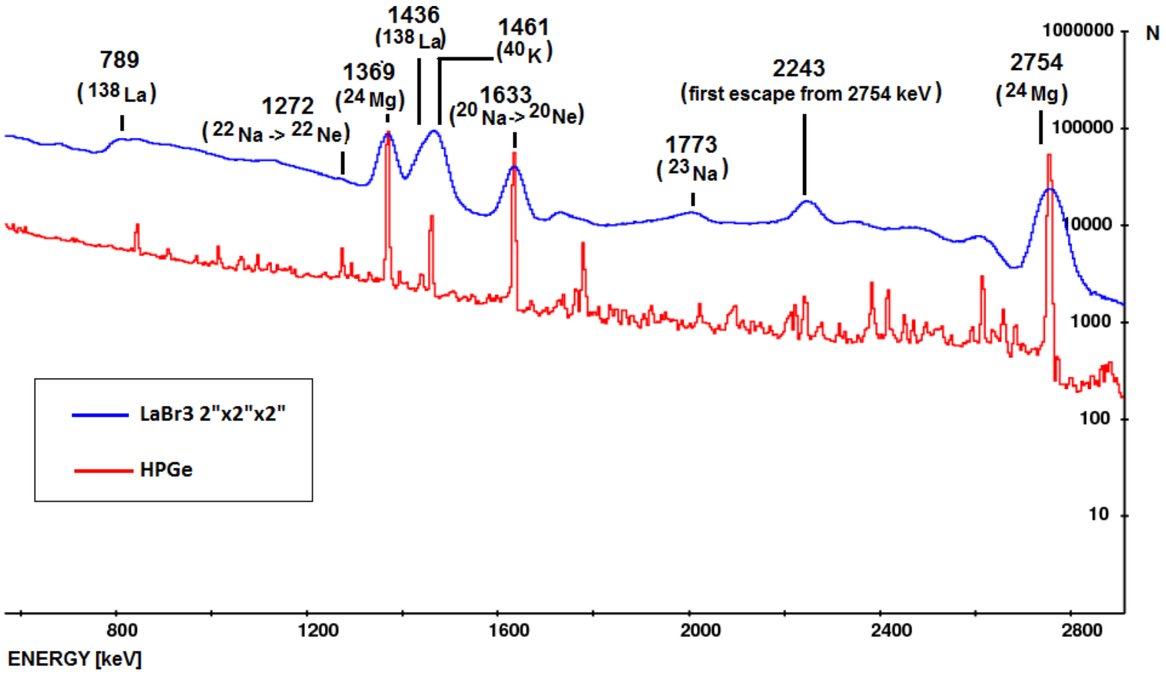

Figure 1: Comparison of the spectra from the 2-inch cubic $LaBr_3$ detector (blue) and from the HPGe detector (red) for the low energy region.

gamma lines from ^{24}Mg, single lines from many reaction channels, including ^{24,25}Mg, ^{23,24}Na, ^{20,21,22}Ne, ^{16}O, were clearly visible.

On-going data analysis will give an answer if the proposed nuclear reaction is the best and shortest procedure for the in-beam efficiency calibration.

2. In-beam study of $LaBr_3$ detectors response

The aim of the experiment was to measure the time resolution of two 1-inch cylindrical $LaBr_3$ detectors.

The most interesting reaction channel was $^{12}\mathrm{C}(^{14}\mathrm{N}, 2p)^{24}\mathrm{Na}$. The beta decay from the ^{24}Na ground state ($T_{1/2} = 15$ h) leads to the 4122 keV state in ^{24}Mg, which de-excites by the 2754 keV gamma transition, feeding the 1386 keV state. This simple decay scheme enabled determination of the $LaBr_3$ detector time resolution.

Two $LaBr_3$ detectors were used in coincidence — one detector gave the START and the second one provided the STOP signal. The time signals from the detector's photomultiplier were sent to the constant fraction discriminator ORTEC QUAD 935, and after shaping were analysed by the ORTEC TAC 566 converter. On-going data analysis will provide information about timing properties of small cylindrical $LaBr_3$ detectors.

B.12 Search for alpha-decaying isomers in trans-lead isotopes using the IGISOL device

A. Wojtasiewicz[1], W. Czarnacki[2], M. Kasztelan[3], M. Kisieliński[2,4], A. Korgul[1], J. Kurcewicz[5], W. Kurcewicz[1], S. Lewandowski[1], S. Mianowski[1], A. Płochocki[1], B. Roussiére[6], O. Steczkiewicz[4], P. Szaflik[7], A. Wilczek[7]

1) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
2) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
3) The A. Sołtan Institute for Nuclear Studies, Łódź, Poland
4) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
5) Gesellschaft für Schwerionenforschung, Darmstadt, Germany
6) Institut de Physique Nucléaire, Orsay, France
7) Institute of Physics, University of Silesia, Katowice, Poland

Experiments performed using the IGISOL device at HIL are focused on the search for isomeric states in nuclei beyond lead. Our former studies have determined the α-decay energy and half-life of the (9^-) state in ^{216}Fr for the first time [1]. Identification of the (9^-) isomer provides a basis for the assignment of level energies of alternating parity band, which is interpreted as indicating reflection asymmetry. The present investigations of the α-decay chain $^{224}\mathrm{Pa} \rightarrow {}^{220}\mathrm{Ac} \rightarrow {}^{216}\mathrm{Fr} \rightarrow {}^{212}\mathrm{At}$ are aiming at the identification of the 9^- isomer in the ^{220}Ac nucleus fed in the (5^-) ground state α decay of ^{224}Pa.

The ^{224}Pa activity was produced in the $^{209}\mathrm{Bi}(^{18}\mathrm{O}, 3n)$ reaction [2]. The bismuth target was placed inside the helium gas cell of the IGISOL device. The A=224 α activity implanted into a thin carbon foil was viewed by four silicon detectors with the solid angle of about 52%. Digital signal processing was applied to obtain data on α-time correlations.

In 2009 several technical improvements have been introduced to the IGISOL system. The detector chamber at the line end of the IGISOL device [3] has been reconstructed. A flange with a thick capton window and a Ge detector with efficiency of 40% were installed, and the test experiment (reaction $^{14}\mathrm{N}+^{209}\mathrm{Bi}$, radioactivity of the A=220 chain) was performed to check the possibility of simultaneous measurements of α and γ activities.

An ion beam deflecting system has been constructed and installed on the 40 keV radioactive beam of the mass separator. It permits to determine half-lives of the isomeric states from the measured decay curves. The system was tested using the $^{14}\mathrm{N}+^{209}\mathrm{Bi}$ reaction and deflection time of 75 msec for the ^{220}Ac alpha activity. The time stability of the IGISOL device in the presence of 40 kV high voltage and the heavy ion beam from the cyclotron was improved by the installation of high fidelity elements in the main power supply system.

These works were partially performed in the framework of the University of Warsaw — IN2P3 (France) collaboration (No. 04-112) and have been supported in part by the Polish Ministry of Science and Higher Education (Grant No. N202 017 032/0696).

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B.13 Target set-up for study of incomplete fusion reaction

A.Kordyasz[1], *A.Stolarz*[1], *J.Mierzejewski*[1,2]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland

A silicon ball made of ΔE silicon detectors [1, 2] is used at HIL as a light charged particle (α, proton) counter for in-beam γ-ray spectroscopy experiments and studies of incomplete fusion reactions. It is well known that Si layer degrades easily due to the bombardment by scattered beam projectiles or heavy products of the reaction, and this can significantly shorten the detector life time. Such damages can be avoided, or significantly decreased, and thus the life time of detectors extended, if suitable protective foils are used, which stop heavy nuclei from reaching the detectors. The optimum thickness of the shielding material varies depending on beam projectiles and reaction products.

In case of big silicon balls with sufficient inner space and relatively easy access to the detectors, the shielding can be designed as foils, placed directly in front of each detector. For a small array, in which access to the inside is very limited (see Figure 1 in the paper of reference [2]) and which cannot be disassembled, such way of protecting the silicon detectors would practically be impossible. In this situation, instead of installing foils in front of the detector wafers, the shielding may become a part of the target set-up.

The target is placed between two tubes acting as shields, made of the appropriate material (aluminium, lead, etc), thick enough to stop the heavy projectiles. One end of each tube is fixed to ring-frames. The target itself is placed between these rings and both rings are screwed together using mini screws (ϕ 1 mm) (Fig. 1).

The complete set-up of the target and shielding is then installed at the beam line. Such set-up can be easily inserted into/taken out from the silicon ball and in a relatively short time the shielding can be modified if needed. The presented configuration of the shielding is not only easy and quick to assemble, but also offers the opportunity of using the same Si-ball in various measurements without dismounting it for modification of the detector protection.

The target-shielding configuration described here was used in the measurement of charged particle angular distributions, performed to study the mechanism of incomplete fusion reaction [3]. The target-shielding set-up was composed of the ^{122}Sn target and tubes made of 70 μm aluminium foil. During this experiment, for a test purpose, it was necessary to modify the shielding, by adding a thick (about 1 mm) Pb absorber. The procedure of changing the shields took less than 1 hour.

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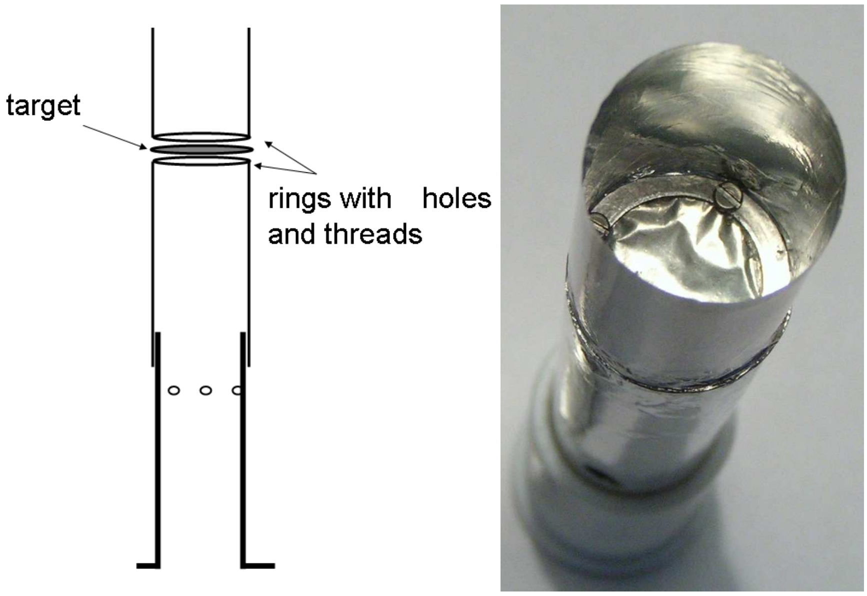

Figure 1: Sectional view of the target-shielding set-up and its photo.

Part C

Experiments using outside facilities

C.1 Coulomb excitation of ^{109}Ag

M. Zielińska[1,2], A. Görgen[2], A. Bürger[3], W. Catford[4], E. Clément[2,5], C. Dossat[2], J. Iwanicki[1], W. Korten[2], J. Ljungvall[2], P.J. Napiorkowski[1], D. Piętak[1,6], G. Sletten[7], J. Srebrny[1], Ch. Theisen[2], K. Wrzosek-Lipska[1]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) CEA Saclay, IRFU/SPhN, Gif-sur-Yvette, France
3) HISKP, University of Bonn, Germany
4) Department of Physics, University of Surrey, Guildford, UK
5) GANIL, Caen, France
6) Institute of Radioelectronics, Warsaw University of Technology, Warszawa, Poland
7) NBI, University of Copenhagen, Danmark

A Coulomb excitation experiment to study the electromagnetic structure of the exotic ^{44}Ar beam was performed at the SPIRAL facility at GANIL. Radioactive ^{44}Ar ions were produced by fragmentation of the intense ^{48}Ca beam, post-accelerated with the CIME cyclotron, and Coulomb excited on ^{208}Pb and ^{109}Ag targets of 1 mg/cm^2 thickness, at beam energies of 3.7 MeV/A and 2.7 MeV/A, respectively. The average beam intensity was 2×10^5 pps at the secondary target position.

Gamma rays from the Coulomb excited states were detected in the EXOGAM array, comprising 10 large segmented Compton-suppressed germanium clover detectors. The scattered projectiles and the recoiling target nuclei were detected in an annular highly segmented silicon detector, divided into 16 concentric rings and 96 azimuthal sectors. The active surface of the detector had inner and outer radii of 9 and 41 mm, respectively, and it was placed 25 mm behind the target. It covered scattering angles between 25° and 56° in the laboratory frame, which corresponds to a range between 30° and 130° for the ^{208}Pb target and between 35° and 130° for the ^{109}Ag target in the centre-of-mass frame.

The experiment yielded several E2 matrix elements connecting the low-lying states of ^{44}Ar, including the quadrupole moment of the first excited 2^+_1 state [1]. As a byproduct, a large data set concerning the ^{109}Ag isotope was collected. Eleven gamma transitions between eight low-lying states in ^{109}Ag were observed (see Fig. 1). The statistics accumulated during ~50 hours of data taking with the ^{109}Ag target allowed subdividing the data into eight sub-sets corresponding to different ranges of scattering angles (four for recoil detection and another four for scattered projectile detection).

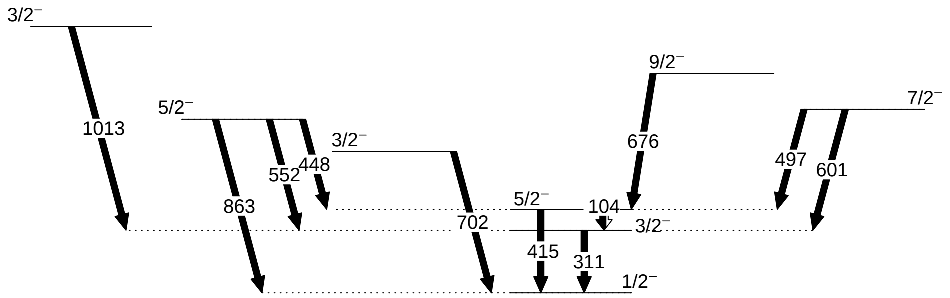

Figure 1: Low-energy part of the level scheme for ^{109}Ag showing γ-ray transitions observed in the present Coulomb excitation experiment.

A rich set of E2 and M1 matrix elements in ^{109}Ag was obtained as a result of the analysis using the standard Coulomb excitation code GOSIA [2]. Among these, the quadrupole moment of the first excited state is especially worth mentioning. As the ^{109}Ag isotope is nowadays a common target material in radioactive beam Coulex experiments, the reduced transition probabilities of exotic nuclei are often determined using normalisation to the excitation of the two lowest states in ^{109}Ag. The results obviously depend on quadrupole moments of these states, especially for high scattering angles.

New values of the E2 and M1 matrix elements in ^{109}Ag determined from the present analysis are listed in Tables 1 and 2. These were normalised to the B(E2) values of the most prominent transitions in ^{109}Ag, namely: 311 keV, $3/2^- \rightarrow$ g.s., and 415 keV, $5/2^- \rightarrow$ g.s., for which B(E2)'s of 0.075(7) and 0.104(5) eb, respectively, are known [3].

Table 1: E2 matrix elements in ^{109}Ag.

I_i	I_f	$\langle I_f \| E2 \| I_i \rangle$[eb]	I_i	I_f	$\langle I_f \| E2 \| I_i \rangle$[eb]
$1/2^-_1$	$3/2^-_2$	$-0.098^{+0.006}_{-0.015}$	$3/2^-_1$	$7/2^-_1$	$1.16^{+0.09}_{-0.10}$
$1/2^-_1$	$5/2^-_2$	$0.175^{+0.005}_{-0.015}$	$5/2^-_1$	$3/2^-_2$	$-0.17^{+0.08}_{-0.08}$
$3/2^-_1$	$3/2^-_1$	$-1.3^{+0.3}_{-0.4}$	$5/2^-_1$	$9/2^-_1$	$1.64^{+0.05}_{-0.07}$
$3/2^-_1$	$3/2^-_2$	$0.27^{+0.04}_{-0.03}$	$5/2^-_1$	$5/2^-_2$	$-0.38^{+0.16}_{-0.17}$
$3/2^-_1$	$5/2^-_2$	$0.36^{+0.09}_{-0.09}$			

Table 2: M1 matrix elements in ^{109}Ag.

I_i	I_f	$\langle I_f \| M1 \| I_i \rangle[\mu_N]$	I_i	I_f	$\langle I_f \| M1 \| I_i \rangle[\mu_N]$
$1/2^-_1$	$3/2^-_1$	$0.92^{+0.11}_{-0.08}$	$3/2^-_1$	$5/2^-_2$	$0.60^{+0.04}_{-0.04}$
$1/2^-_1$	$5/2^-_1$	$0.12^{+0.02}_{-0.02}$	$5/2^-_1$	$3/2^-_2$	$-1.4^{+0.3}_{-0.4}$
$1/2^-_1$	$3/2^-_2$	$-0.74^{+0.11}_{-0.18}$	$5/2^-_1$	$5/2^-_2$	$-0.91^{+0.07}_{-0.07}$
$3/2^-_1$	$3/2^-_2$	$0.37^{+0.06}_{-0.04}$			

This work was partly supported by the European Community FP6 - Structuring the ERA - Integrated Infrastructure Initiative - Contract EURONS No. RII3-CT-2004-506065.

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C.2 First modification of silicon wafer resistivity distribution by the Selective Neutron Transmutation Doping

A.J. Kordyasz[1], M. Kowalczyk[1], E. Bednarek[1], L. Bardelli[2], R. Bougault[3], L. Lavergne[4], J. Sarnecki[5], M. Kisieliński[6], W. Czarnacki[6], T. Kozik[7], A. Brzozowski[5], K. Pytel[8], M. Tarchalski[8], J. Tarasiuk[9], P. Grabiec[10], A. Panas[10]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) University of Florence, I.N.F.N. Sezione di Firenze, Italy
3) LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, France
4) Institute de Physique Nucléaire, CNRS/IN2P3 Université Paris-Sud 11, France
5) Institute of Electronic Materials Technology, Warszawa, Poland
6) The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
7) M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland
8) Institute of Atomic Energy POLATOM, Otwock-Świerk, Poland
9) Institute of Experimental Physics, University of Warsaw, Warszawa, Poland
10) Institute of Electron Technology, Warszawa, Poland

Uniform resistivity of silicon wafers is very important for silicon detector technology, especially for heavy ion identification by pulse shape analysis [1]. A new method, named Selective neutron Transmutation Doping (SnTD), was proposed [2]. for the correction of silicon wafer resisitivity distribution In this process the silicon wafer resistivity is locally modificated by phosphorus donors, produced by the neutron transmutation doping (nTD), using the thermal neutron induced capture reaction $^{30}\mathrm{Si}(n,\gamma)^{31}\mathrm{Si} \rightarrow {}^{31}\mathrm{P} + \beta^-$. The local silicon resistivity modification was achieved by change of the thermal neutron flux distribution using dedicated neutron filters. For preliminary test of the SnTD, we have used the four inch n-n$^+$ epitaxial structure produced in the Institute of Electronic Materials Technology, Warsaw, Poland, of thickness about 118 μm, with an average resistivity 3.9 kΩ·cm, determined by the C-V method [3]. The tested SnTD process was performed by covering this structure by a 1 mm thick Cd mask with empty holes and an empty cross. Geometry of the mask is illustrated in Fig. 1.

The mask with the n-n$^+$ structure was then inserted into the thermal neutron flux of about $1.7{\cdot}10^{12}$n/cm^{2}s to accumulate neutron fluence $6{\cdot}10^{16}$n/cm^2. The irradiation was performed using the virtual vertical neutron beam channel of the reactor Maria at The Sołtan Institute for Nuclear Studies in Świerk [4]. After irradiation by thermal neutrons, the regions of silicon not covered by the Cd mask have reduced their resistivity from 3.9 kΩ·cm to about 220 Ω·cm, see Fig. 2 .

It was additionally observed that the weak neutron irradiation of the silicon through the 1 mm thick Cd mask leads to the reduction of wafer resistivity from about 3.9 kΩ·cm to approximately 900 Ω·cm. This process depends on the Cd cross section for neutron capture, which is effective for neutrons with energy less than 6 eV. To obtain more effective absorption of thermal neutrons, the mask should be made from the boron material, which has a high neutron capture cross section in the broad neutron energy range.

Acknowledgements: We would like thank very much to Magda Zielińska, Krzysztof Rusek, Wojtek Gawlikowicz, Ludwik Pieńkowski, G. Poggi and Daniel Tomaszewski for fruitful discussions and comments.

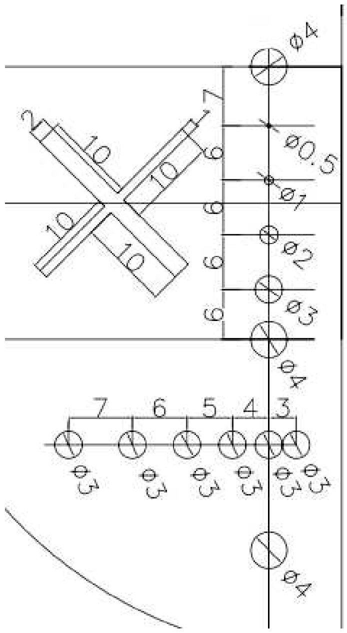

Figure 1: Pattern of Cd mask with empty holes and the empty cross. All dimensions are in mm.

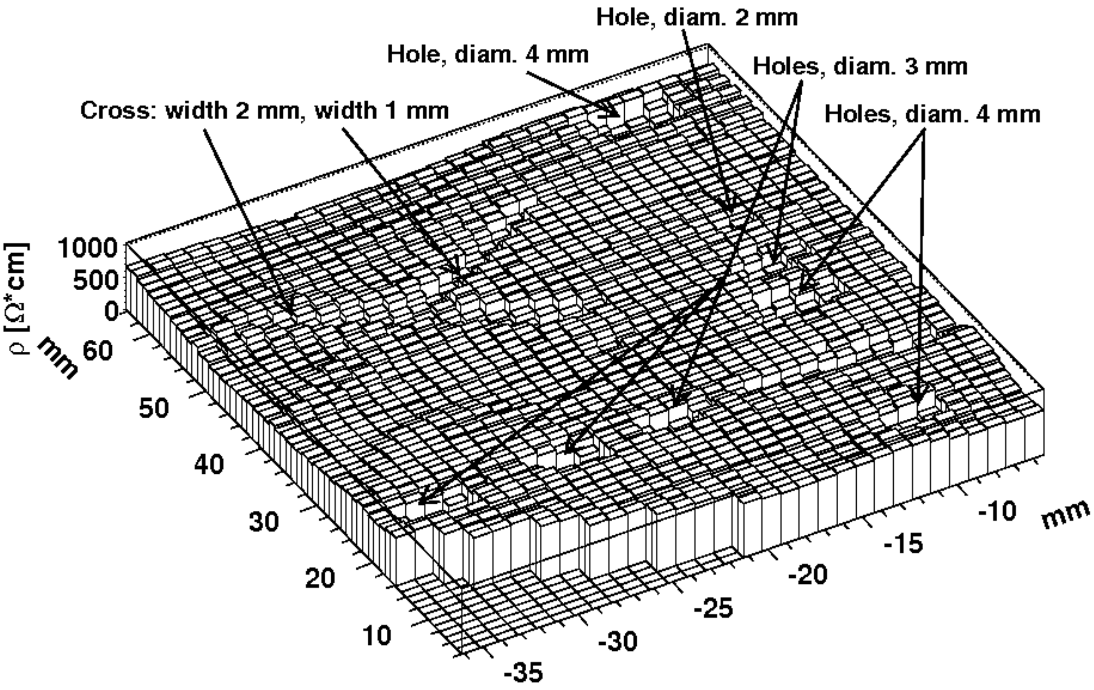

Figure 2: Resistivity distribution of the silicon wafer epitaxial n-n$^+$ structure, after irradiation by the thermal neutron flux with fluence $6{\cdot}10^{16}$n/cm^2 through the Cd mask shown in Fig. 1. Resistivity distribution was measured by the C-V method [3].

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C.3 Silicon vertex detector for super-heavy elements identification

A. Kordyasz

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

A silicon vertex detector for identification of super-heavy elements has been designed. The detector is shown in Fig. 1. The setup will consist of 9 silicon strip detectors with the thickness about 5 μm produced by the PPPP process [1], and an additional 300 μm thick strip detector for stopping α particles from the decay of forward moving super-heavy elements and their daughters. The energy loss of α particles in 5 μm thick detectors is about 0.5 MeV, which is sufficient to determine their trajectories. For α particles which are emitted in backward directions, a system of 300 μm thick detectors with a hole for a super-heavy beam is proposed (shown in red in Fig. 1). Almost all α particles, except those moving in the direction parallel to the beam line, are stopped by this system. The proposed vertex detector measures energies of super-heavy elements as well as their products (α particles and fission fragments) in the solid angle close to 4π. Additionally, it provides trajectories of all registered particles, which considerably improves identification of super-heavy elements.

Acknowledgements: My sincere thanks to M. Zielińska, K. Rusek, J. Błocki, W. Gawlikowicz, L. Pieńkowski, Z. Sosin, A. Wieloch, T. Kozik, A. Trzcińska, M. Palacz, for fruitful discussions and comments.

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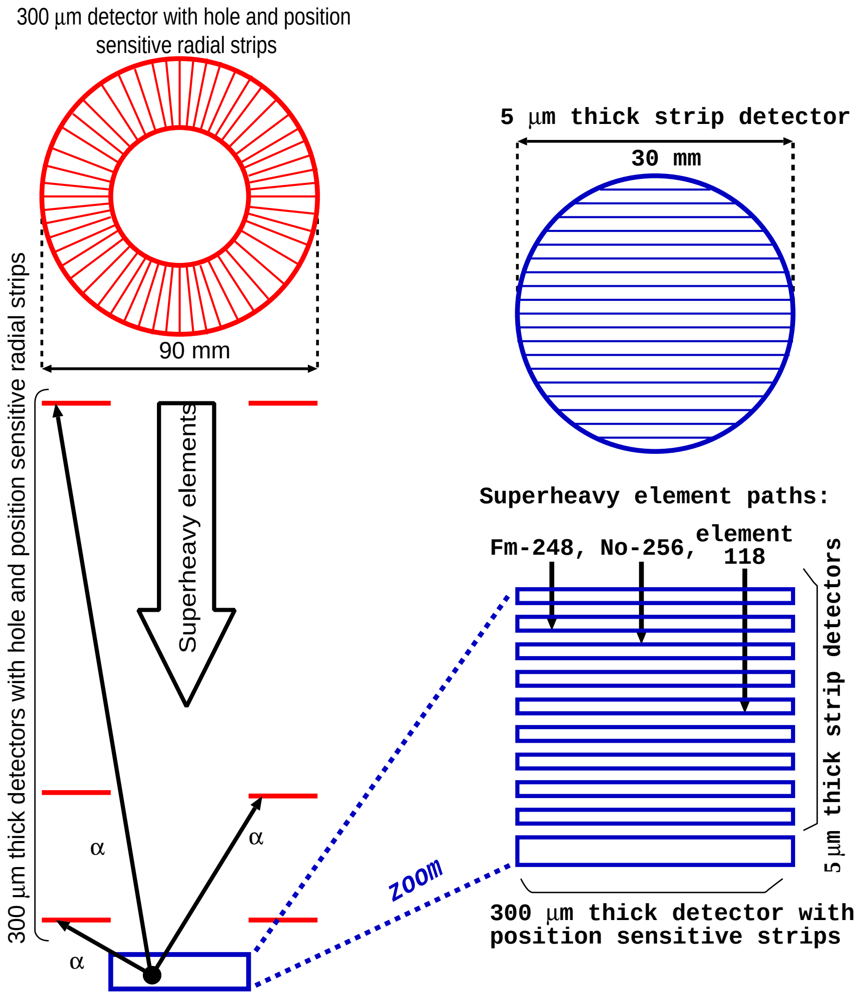

Figure 1: The silicon vertex detector.

C.4 NEDA simulations

G. Jaworski[1,2], *M. Palacz*[1], *T. Hüyük*[3], *A. Gottardo*[4], *J. Nyberg*[5], *B. Roeder*[6], *J.J. Valiente Dobon*[4]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Faculty of Physics, Warsaw University of Technology, Warszawa, Poland
3) Instituto de Física Corpuscular, Valencia, Spain
4) Laboratori Nationali di Legnaro, Legnaro, Italy
5) Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
6) Cyclotron Institute, Texas A&M University, Collage Station, USA

Work on the design of the new neutron detection array NEDA is continued (see [1]) and Monte Carlo simulations are in progress, with the aim to evaluate properties of scintillators used to register neutrons, as well as to establish optimum geometry of the array.

The simulations are performed using the Geant4 package version 4.9.2.p02, employing also the Agata Simulation Code (ASC) [2]. The ASC package is used as a convenient tool for handling simulation input and output data, as well various detector geometries.

Neutrons deposit energy in the detector by interaction with nuclei of the scintillator medium. Two different scintillators are considered: standard BC501A and deuterated BC537, with the approximate chemical composition C_8H_{10} (xylene) and C_6D_6 (benzene), respectively. The following interactions of neutrons are possible:

- elastic scattering (on p, d and ^{12}C);
- endothermic ^{12}C(n,α)^{9}Be (Q=-5.701 MeV);
- exothermic neutron capture on p, d and ^{12}C, followed by emission of a γ-ray;
- similar reactions on rare isotopes contained in the scintillators: ^{13}C and deuteron in case of BC501A (natural isotopic abundance of hydrogen and carbon is assumed for the scintillator material), as well as on ^{13}C and contaminating protons in case of BC537.

The products of these reactions (or secondary particles produced in subsequent interactions) deposit energy in the scintillator and this energy is converted to light using parametrisation of reference [3]. Light may by produced by protons, deuterons, ^{9}Be and ^{12}C nuclei, α particles, as well as by electrons and γ rays.

Significant deficiencies of neutron interaction model contained in Geant4 versions earlier than 4.9.2 are known. The present Geant4 version was validated by analysing the physical processes activated in Geant4 when neutrons interact in organic scintillators, and by comparing the results to the available experimental cross section data, as well as to the results given by the MCNP-X code. It was concluded that for the neutron energy range of approximately 0 to 10 MeV Geant4 produces reliable results. Note that inelastic interactions were not fully validated. Problems with such interactions could actually still be identified — like missing reaction ^{12}C(n,n')3α or wrong kinematics of the ^{12}C(n,α)^{9}Be process. The remaining deficiencies cannot be significant for NEDA as these processes are not important in the neutron energy of interest.

A systematic study was performed in order to establish optimum size of a single detector, which would maximise efficiency of the neutron detection, minimise probability that one neutron interacts in two or more detectors, and provide good time resolution. It was concluded that NEDA detectors should be about 20 cm long (dimension along the neutron impact direction) and transverse size of a single detector is actually limited by the diameter of largest photomultiplier tubes available, which is 5 inches.

Size of the entire NEDA detector array is limited by the space constraints in the experimental hall, one of which is the height above the floor level of the SPIRAL2 beam line (1.75 m), but also by the maximum flight time of neutrons to the detectors, which should not be larger than the distance between pulses of beams used in the experiments. Taking both space and time-of-flight constraints into account, we concluded that the largest practical inner radius of the NEDA detector setup is about 1 m, and in such configuration the majority of neutron interactions will happen within 100 ns window, starting from the time when beam hits the target. Such an array will consist of more than 200 individual detectors.

Details of the NEDA simulations performed so far can be found in the progress report [4]. Further work concentrates now on evaluating properties of different possible NEDA geometries.

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Part D

General information on HIL activities

D.1 PhD and MSc theses completed in 2009 or in progress

D.1.1 PhD theses of students affiliated at HIL and of HIL staff members

Katarzyna Wrzosek-Lipska
Badanie struktury elektromagnetycznej niskospinowych stanów wzbudzonych jądra ^{100}Mo metodą wzbudzeń kulombowskich
Electromagnetic structure of low-spin excited states in ^{100}Mo using the Coulomb excitation method
Supervisor: dr hab. L. Pieńkowski. Expected completion time: 2010

Jan Mierzejewski
Mechanizm niekompletnej fuzji badany z wykorzystaniem EAGLE i SiBall
Mechanism of incomplete fusion studied with EAGLE and SiBall
Supervisor: prof. dr hab. T. Matulewicz. Expected completion time: 2011

Grzegorz Jaworski, Faculty of Physics, Warsaw University of Technology
Supervisor: prof. dr hab. J. Kownacki. Expected completion time: 2011

Katarzyna Hadyńska-Klęk
Supervisor: prof. dr hab. M. Kicińska-Habior. Expected completion time: 2012

Daniel Piętak, Institute of Radioelectronics, Warsaw University of Technology
Supervisor: prof. dr hab. J. Wojciechowski. Expected completion time: 2012

D.1.2 PhD theses based on experiments performed at HIL

Volodymyr O. Romanyshyn, Institute for Nuclear Research,
Ukrainian Academy of Sciences
Nuclear processes in the collision of the ^{7}Li + ^{10}B nuclei
Supervisor: prof. A.T. Rudchik. Thesis defended in 2010

Joanna Czub, Faculty of Physics, Jan Kochanowski University, Kielce
Biologiczne działanie promieniowania o wysokim LET
Biological effects of radiation with high LET value
Supervisor: prof. dr hab. J. Braziewicz. Expected completion time: 2010

Izabela Strojek, The Andrzej Sołtan Institute for Nuclear Studies, Świerk
Wpływ struktury jądra ^{20}Ne na reakcje z jego udziałem
Influence of the ^{20}Ne structure on reactions with this nucleus
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2011

Urszula Kaźmierczak, Faculty of Physics, University of Warsaw
Supervisor: dr hab. Z. Szefliński. Expected completion time: 2014

D.1.3 MSc theses supervised by HIL staff members

Łukasz Czernik, Faculty of Physics, Warsaw University of Technology
Kalibracje spektrometru scyntylacyjnego promieniowania γ z wykorzystaniem krótkożyciowych produktów reakcji jądrowych
Calibration of a scintillator γ-ray spectrometer using short-lived nuclear reaction products
Supervisor: dr J. Srebrny. Thesis defended in 2009

Alicja Staudt, Department of Physics, University of Silesia
Badanie własności zespołu detektorów układu ICARE
Characteristics of the ICARE detection set-up
Supervisors: prof. dr hab. W. Zipper, dr hab. E. Piasecki. Thesis defended in 2009

Anna Piórkowska, Department of Physics, University of Silesia
Zastosowanie wielodetektorowego układu ICARE do pomiaru rozkładu kątowego rozpraszania ^{20}Ne + ^{208}Pb przy energiach 105 MeV i 115 MeV
Angular distributions of ^{20}Ne + ^{208}Pb scattering at 105 and 115 MeV beam energy measured with the ICARE multidetector set-up
Supervisors: prof. dr hab. W. Zipper, dr hab. E. Piasecki. Thesis defended in 2009

Grzegorz Mentrak, Faculty of Physics, Warsaw University of Technology
Opracowanie układu cyfrowo-analogowego sterowania zasilaczami prądu stałego do magnesów odchylających w Warszawskim Cyklotronie
A digital/analog control system for DC power supplies for bending magnets of the Warsaw Cyclotron
Supervisor: dr J. Choiński. Expected completion time: 2010

Michalina Komorowska, Faculty of Physics, University of Warsaw
Supervisors: prof. M. Kicińska-Habior, dr J. Srebrny. Expected completion time: 2011

D.1.4 Other MSc theses based on experiments performed at HIL

Jan Dyczewski, Faculty of Physics, University of Warsaw
Opracowanie metodyki uzyskania jednorodnej wiązki jonów z Cyklotronu Warszawskiego
A method to obtain homogeneous beams from the Warsaw Cyclotron
Supervisor: dr hab. Z. Szefliński. Thesis defended in 2009

Urszula Górak, Faculty of Physics, University of Warsaw
Współczynniki skuteczności biologicznej dla komórek CHO-K1, naświetlanych jonami węgla ^{12}C
Relative biological effectiveness for CHO-K1 cells irradiated with ^{12}C ions
Supervisor: dr hab. Z. Szefliński. Thesis defended in 2009

Łukasz Kaźmierczak, Faculty of Physics, University of Warsaw
Symulacje numeryczne skuteczności radiobiologicznej jonów węgla w naświetlaniu komórek CHO-K1
Numerical simulations of the radiobiological effectiveness of carbon ions irradiating CHO-K1 cells
Supervisor: dr hab. Z. Szefliński. Thesis defended in 2009

Grzegorz Knor, Faculty of Physics, University of Warsaw
Symulacje oddziaływania ciężkich jonów z materiałem komórkowym
Simulations of the heavy-ion interaction in the cellular material
Supervisor: dr hab. Z. Szefliński. Thesis defended in 2009

Damian Karpiński, Faculty of Physics, University of Warsaw
Badanie korelacji kątowych kwantów gamma na wiązce ciężkich jonów jako źródło informacji spektroskopowych
Angular correlations of in-beam measured gamma rays: a source of spectroscopic information
Supervisor: dr E. Grodner. Expected completion time: 2010

Łukasz Janiak, University of Łódź
Wyznaczenie multipolowości przejść elektromagnetycznych na podstawie pomiarów koincydencyjnych elektron-gamma
Determination of multipolarities of electromagnetic transitions from electron-gamma coincidence measurements
Supervisor: dr J. Perkowski. Expected completion time: 2010

D.1.5 BSc theses supervised by HIL staff members

Jakub Ogrodnik, Faculty of Physics, Warsaw University of Technology
Dobór optymalnych warunków pracy osłony antykomptonowskiej spektrometru germanowego
Optimum working conditions of an anti-Compton shield of the germanium spectrometer
Supervisor: dr J. Srebrny. Expected completion time: 2010

D.2 Seminars

D.2.1 Seminars at HIL

J. Jastrzębski (HIL) 5 March
Sprawozdanie z działalności Laboratorium w roku 2008
Report from the HIL director for the year 2008

K. Rusek (HIL) 5 March
ŚLCJ — jak je widzę
My vision of HIL

J. Srebrny (HIL) 14 May
EAGLE — nowy etap spektroskopii na wiązce U200P
EAGLE — new stage in the in-beam spectroscopy at the U200P cyclotron

E. Kajfasz (CPPM Marseille, France) 13 July
How we study the two infinities at CPPM

L. Grigorenko (JINR Dubna, Russia) 23 November
Fragment separator ACCULINNA-2 project

J. Jastrzębski (HIL) 26 November
Terapia hadronowa — impresje z Kongresu PTCOG 48, Heidelberg 1-3 października 2009
Hadron therapy — impressions from the 48th Particle Therapy Co-Operative Group Meeting, Heidelberg, 1-3 October 2009

D.2.2 External seminars given by the HIL staff

L. Pieńkowski 20 January
Synergia węglowo-jądrowa perspektywą technologiczną dla wielkiej syntezy chemicznej w Polsce
Nuclear-coal synergy — a technology perspective for the great chemical synthesis in Poland
Seminar of the Faculty of Chemistry, Warsaw University of Technology, Warszawa, Poland

J. Choiński 13 February
Heavy Ion Laboratory and the Radiopharmaceuticals Production Centre
Seminar of the JINR Dubna, Russia

L. Pieńkowski 17 March
European demonstration of process heat application with nuclear reactors. Towards nuclear-coal synergy
presentation at the National Economy Committee meeting, the Senate of the Republic of Poland, Warszawa, Poland

J. Jastrzębski 19 March
Tomografia pozytonowa w Polsce
Positron tomography in Poland
Seminar of the Faculty of Physics, Adam Mickiewicz University, Poznań, Poland

L. Pieńkowski 23 March
Synergia węglowo-jądrowa, duży europejski projekt demonstrujący wykorzystania reaktorów wysokotemperaturowych w Polsce
Nuclear-coal synergy, a large European project showing applications of high-temperature reactors in Poland
Open lecture at the Polish Physics Society meeting, Szczecin, Poland

M. Palacz 31 March
Simulation of ancillary detectors
8th Agata Week, Köln, Germany

L. Pieloreńkowski 23 April
European demonstration of process heat application with nuclear reactors
Presentation at the European Parliament, Strasbourg, France

E. Piasecki 5 May
Fuzzy barrier distributions
Conference “Nuclear Structure and Dynamics”, Dubrovnik, Croatia

L. Pieńkowski 27 May
Skąd wziąć fachowców dla energetyki jądrowej w Polsce?
Where to find the qualified staff for nuclear energy in Poland?
“A but maybe H? — prospects for nuclear energy in Poland in light of European experiences”, Warszawa, Poland

D. Piętak 1 June
Application of Genetic Algorithm with Real Representation to COULEX Data Analysis
XII Conference “Evolutionary Computation and Global Optimization” Zawoja, Poland

G. Jaworski 18 June
Is it a good idea to deuterize the Neutron Wall?
SPIRAL2 PP Task 5.8 collaboration meeting “NEDA — New Neutron Detector for SPIRAL 2”, Istanbul, Turkey

M. Palacz 18 June
Validation of neutron interactions in Geant4
SPIRAL2 PP Task 5.8 collaboration meeting “NEDA — New Neutron Detector for SPIRAL 2”, Istanbul, Turkey

G. Jaworski 10 July
Modelowanie eksperymentów z udziałem RFD
Simulating RFD experiments
Presentation at the Henryk Niewodniczański Institute of Nuclear Physics,
Polish Academy of Sciences, Kraków, Poland

A. Trzcińska 31 August
Antiprotonic atoms as a tool to study the nuclear periphery
XXXI Mazurian Lakes Conference on Physics, Piaski, Poland

M. Zielińska 8 September
Coulomb excitation of neutron-rich ^{44}Ar at SPIRAL:
determination of nuclear static moments using post-accelerated exotic beams
XVI Colloque GANIL, Giens, France

K. Rusek 25 September
Probing the nuclear potential with reactions
16th Nuclear Physics Workshop “Marie & Pierre Curie”, Kazimierz Dolny, Poland

K.Wrzosek-Lipska 25 September
EAGLE — a new experimental tool for gamma spectroscopy on beams of the Warsaw cyclotron
16th Nuclear Physics Workshop “Marie & Pierre Curie”, Kazimierz Dolny, Poland

A. Kordyasz 1 October
Determination of Si wafer resistivity distributions by C-V measurements
RD09 — 9th International Conference on Large Scale Applications
and Radiation Hardness of Semiconductor Detectors, Florence, Italy

K. Hadyńska-Klęk 15 October
Tests of cubic 2×2×2 $LaBr_3$ in Kraków and Warsaw
PARIS Collaboration Meeting, Kraków, Poland

K. Rusek 23 October
Potencjał optyczny z dala od ścieżki stabilności
Optical potential far from the stability line
Seminar of the Nuclear Physics Department, Faculty of Physics, University of Warsaw,
Warszawa, Poland

A. Kordyasz 24 October
Resistivity distribution of Si wafer by C-V measurement with gravitationally pressed mercury drop
FAZIA Meeting, Kraków, Poland

W. Gawlikowicz 30 October
Dynamiczna i statystyczna emisja fragmentów w zderzeniach ciężkojonowych przy pośrednich energiach
Dynamical and statistical fragment emission in heavy ion collision at intermediate energies
Seminar of the Nuclear Physics Department, Faculty of Physics, University of Warsaw, Warszawa, Poland

J. Jastrzębski 8 November
Snapshots on long going — competition — collaboration — friendship
Jan Styczeń Anniversary Colloquium, Kraków, Poland

M. Zielińska 14 November
Collectivity in the vicinity of N=50 shell closure
HRIBF Users Workshop: HRIBF, Upgrade for the FRIB Era, Oak Ridge, USA

L. Pieńkowski 19 November
Concept of the nuclear-coal synergy
Nuclear Power Technology, Investor, Financing International Conference, Warszawa, Poland

K. Rusek 16 December
EAGLE — present status and the nearest future
DREB2009: Direct Reactions with Exotic Beams, Tallahassee, Florida, USA

D.2.3 Poster presentations

K. Hadyńska-Klęk
Coulomb excitation of ^{100}Mo — determination of the E3 strength
Euroschool on Exotic Beams, Leuven, Belgium, 4-11 September 2009

M. Zielińska
EAGLE (central European Array for Gamma Levels Evaluation) campaign at the Heavy Ion Laboratory, University of Warsaw
XVI Colloque GANIL, Giens, France, 6-11 September 2009

J. Jastrzębski
Radiopharmaceuticals Production and Research Centre at the University of Warsaw
5th International Conference on Imaging Technologies in Biomedical Sciences (ITBS 2009), 13-16 September 2009, Milos Island, Greece

M. Wolińska-Cichocka
Heavy Ion Laboratory at the University of Warsaw
XXVII European Cyclotron Progress Meeting, Groningen, The Netherlands, 28-31 October 2009

K. Kilian
Radiofarmaceutyki do diagnostyki chorób układu nerwowego
Radiopharmaceuticals for diagnosing nervous system diseases
II CePT Scientific Conference, Warszawa, Poland, 4 November 2009

D.2.4 Science popularisation lectures

K. Kilian 28 April
Diagnostyka medyczna z wykorzystaniem najnowszych osiągnięć fizyki jądrowej
Medical diagnostics based on modern achievements of nuclear physics
Third Age University of the Shalom Foundation, Warszawa, Poland

K. Kilian 19 May
O myśleniu w doświadczeniu
On thinking behind the experiment
Lecture closing the "EUREKA" competition for secondary schools, Warszawa, Poland

L. Pieńkowski 19 September
Energetyka jądrowa w Polsce — dobry początek
Nuclear energy in Poland — good starting point
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

P. Napiorkowski 19 September
Broń jądrowa w walce z fałszerzami win
Nuclear weapons against wine fraudsters
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

J. Kownacki 19 September
Przegląd akceleratorów i ich zastosowania
Overview of accelerators and their applications
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

A. Kordyasz 19 September
Naturalna promieniotwórczość wokół nas — pomiar radioaktywności radonu i jego pochodnych w środowisku naturalnym
Natural radioactivity around us — measurement of the activity of radon and its daughters in the natural environment
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

K. Kilian 19 September
Radiofarmaceutyki do pozytronowej tomografii emisyjnej (PET). Nowe możliwości dla nauki, ochrony zdrowia i przemysłu
Radiopharmaceuticals for Positron Emission Tomography (PET). New perspectives for science, health care and industry
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

P. Napiorkowski 21 September
Fizyka dla bramkarzy
Physics for goalkeepers
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

M. Zielińska 25 September
Jak zobaczyć jądro atomowe?
How to see an atomic nucleus?
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

L. Pieńkowski 25 September
Czym polecieć na Marsa?
How to reach Mars?
XIII Festival of Science, 19-25 September 2009, Warszawa, Poland

M. Zielińska 18 November
Jak zobaczyć jądro atomowe?
How to see an atomic nucleus?
Open Day of the University of Warsaw, Warszawa, Poland

D.2.5 Lectures for students

L. Pieńkowski 29 September
Energetyka jądrowa w Polsce
Nuclear energy in Poland
Postgraduate Studies in Physics and Astronomy (II year), University of Warsaw, Warszawa, Poland

M. Zielińska 29 September
Środowiskowe Laboratorium Ciężkich Jonów
Presentation of the Heavy Ion Laboratory
Postgraduate Studies in Physics and Astronomy (II year), University of Warsaw, Warszawa, Poland

K. Kilian 29 November
Radiofarmaceutyki PET
PET radiopharmaceuticals
Faculty of Biology (II year), University of Warsaw, Warszawa, Poland

D.2.6 Involvement of the HIL staff in organisation of conferences and workshops

Polish Workshop on Acceleration and Applications of Heavy Ions
20-25 April 2009, HIL, Warszawa, Poland
Local Organising Committee: P. Napiorkowski, A. Trzcińska

XXXI Mazurian Lakes Conference on Physics
"Nuclear Physics and the Road to FAIR"
30 August – 6 September 2009, Piaski, Poland
Member of the Local Organising Committee: M. Wolińska-Cichocka

XIII Festival of Science, 19-25 September 2009, Warszawa, Poland
Local Coordinator: K. Wrzosek-Lipska

Researchers' Night, 25 September 2009, Warszawa, Poland
Local Coordinator: K. Hadyńska-Klęk

D.3 Publications

D.3.1 ISI listed publications

Publications resulting from work performed with HIL facilities

J. Czub, D. Banaś, A. Błaszczyk, J. Braziewicz, I. Buraczewska, J. Choiński, U. Górak, M. Jaskóła, A. Korman, A. Lankoff, H. Lisowska, A. Łukaszek, Z. Szefliński, A. Wójcik,
Cell survival and chromosomal aberrations in CHO-K1 cells irradiated by carbon ions,
Applied Radiation and Isotopes 67 (2009) 447.

J. Jastrzębski,
Nuclear Physics at the Warsaw Cyclotron,
Acta Phys. Pol. **B40** (2009) 839.

E. Piasecki, Ł. Świderski, W. Gawlikowicz, J. Jastrzębski, N. Keeley, M. Kisieliński, S. Kliczewski, A. Kordyasz, M. Kowalczyk, S. Khlebnikov, E. Koshchiy, E. Kozulin, T. Krogulski, T. Loktev, M. Mutterer, K. Piasecki, A. Piórkowska, K. Rusek, A. Staudt, M. Sillanpää, S. Smirnov, I. Strojek, G. Tiourin, W.H. Trzaska, A. Trzcińska, K. Hagino, N. Rowley,
Effects of weakly coupled channels on quasielastic barrier distributions,
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E. Piasecki, A. Trzcińska, W. Gawlikowicz, J. Jastrzębski, N. Keeley, M. Kisieliński, S. Kliczewski, A. Kordyasz, M. Kowalczyk, S. Khlebnikov, E. Koshchiy, E. Kozulin, T. Krogulski, T. Lotkiev, M. Mutterer, K. Piasecki, A. Piórkowska, K. Rusek, A. Staudt, I. Strojek, W.H. Trzaska, M. Sillanpää, S. Smirnov, G. Tiourin, K. Hagino, N. Rowley,
Are the weak channels really weak?,
Acta Phys. Pol. **B40** (2009) 849.

S. Kliczewski, A.A. Rudchik, A.T. Rudchik, O.A. Ponkratenko, E.I. Koshchy, V.M. Kyryanchuk, Val.M. Pirnak, O.A. Momotyuk, A. Budzanowski, B. Czech, R. Siudak, I. Skwirczyńska, A. Szczurek, S.Yu. Mezhevych, K. Rusek, S.B. Sakuta, E. Piasecki, J. Choiński, L. Głowacka,
Study of light exotic and stable nuclei with heavy ion reactions,
Acta Phys. Pol. **B40** (2009) 893.

A.T. Rudchik, Y.M. Stepanenko, K.W. Kemper, A.A. Rudchik, O.A. Ponkratenko, E.I. Koshchy, S. Kliczewski, K. Rusek, A. Budzanowski, S.Y. Mezhevych, V.M. Pirnak, I. Skwirczyńska, R. Siudak, B. Czech, A. Szczurek, V.V. Uleshchenko, J. Choiński, L. Głowacka,
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D.4 Laboratory staff

Directors: Jerzy Jastrzębski[1], Krzysztof Rusek[2]
Deputy directors: Jarosław Choiński, Ludwik Pieńkowski[1], Magdalena Zielińska[3]
Financial executive: Paweł Napiorkowski

Senior scientists:

Jerzy Jastrzębski, Jan Kownacki[4], Andrzej Kordyasz, Ernest Piasecki[4], Ludwik Pieńkowski, Krzysztof Rusek, Józef Sura

Scientific staff and engineers:

Andrzej Bednarek, Izabela Cydzik[5], Jarosław Choiński, Bohdan Filipiak, Wojciech Gawlikowicz, Dorota Hechner, Jędrzej Iwanicki[5], Andrzej Jakubowski, Viatcheslav Khrabrov, Krzysztof Kilian, Maciej Kisieliński[4], Marian Kopka, Michał Kowalczyk[4], Janusz Kurzyński[4], Ireneusz Mazur, Jan Miszczak, Paweł Napiorkowski, Marcin Palacz, Anna Pękal[4], Daniel Piętak[4], Mateusz Sobolewski, Olga Steczkiewicz, Anna Stolarz, Julian Srebrny[4], Roman Tańczyk, Radosław Tarnowski, Agnieszka Trzcińska, Jan Tys[4], Marzena Wolińska-Cichocka, Magdalena Zielińska

Doctoral candidates:

Jan Mierzejewski[6], Katarzyna Wrzosek-Lipska[6], Katarzyna Hadyńska-Klęk[6], Grzegorz Jaworski[7]

Technicians:

Mariusz Antczak, Tomasz Bracha, Marek Figat, Andrzej Górecki, Piotr Jasiński, Wiesław Kalisiewicz, Zbigniew Kruszyński, Piotr Krysiak, Krzysztof Łabęda-Dyszy, Zygmunt Morozowicz, Bogusław Paprzycki, Wiesław Perkowski[4], Andrzej Pietrzak, Krzysztof Pietrzak, Ryszard Pozorek, Irena Skrzeczanowska, Krzysztof Sosnowski

Administration and support:

Edyta Czerwonka[8], Agnieszka Maciejewska, Iwona Tomaszewska, Ewa Sobańska, Krystyna Szczepaniak, Joanna Wasilewska, Wanda Wesoły, Andrzej Wiechowski

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[1] till 28 February 2009
[2] from 1 March 2009
[3] from 1 October 2009
[4] part time
[5] on long term leave
[6] PhD student at the Institute of Experimental Physics, University of Warsaw
[7] PhD student at the Faculty of Physics, Warsaw University of Technology
[8] part time, till 31 January 2009

D.5 Laboratory Council

1. Prof. UŁ dr hab. Józef Andrzejewski
Nuclear Physics Division,
University of Łódź
90-236 Łódź, ul. Pomorska 149/153

2. Prof. dr hab. Janusz Braziewicz
Institute of Physics,
Jan Kochanowski University
25-406 Kielce, ul. Świętokrzyska 15

3. Prof. dr hab. inż. Andrzej Chmielewski
Institute of Nuclear Chemistry
and Technology
03-195 Warszawa, ul. Dorodna 16

4. Prof. dr hab. Anna Grabowska
The Nencki Institute of Experimental
Biology
02-093 Warszawa, ul. Pasteura 3

5. Prof. dr hab. inż. Jacek Jagielski
Institute of Electronic Materials
and Technology
01-919 Warszawa, ul. Wólczyńska 133

6. Prof. dr hab. Jerzy Jastrzębski
Heavy Ion Laboratory,
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

7. Prof. dr hab. Marta Kicińska-Habior
University of Warsaw
00-681 Warszawa, ul. Hoża 69

8. inż. Marian Kopka
(representative of the HIL staff)
Heavy Ion Laboratory,
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

9. Prof. dr hab. Paweł Kulesza
Faculty of Chemistry,
University of Warsaw
02-093 Warszawa, ul. Pasteura 1

10. Prof. PW dr hab. inż. Tadeusz Kulik
Warsaw University of Technology
00-661 Warszawa, pl. Politechniki 1

11. Prof. dr hab. Adam Maj
The Henryk Niewodniczański
Institute of Nuclear Physics,
Polish Academy of Sciences
31-342 Kraków, ul. Radzikowskiego 152

12. Dr hab. Sławomir Nazarewski
Medical University of Warsaw
02-091 Warszawa, ul. Żwirki i Wigury 61

13. Prof. dr hab. Paweł Olko
The Henryk Niewodniczański
Institute of Nuclear Physics,
Polish Academy of Sciences
31-342 Kraków, ul. Radzikowskiego 152

14. Prof. UW dr hab. Marek Pfutzner
Faculty of Physics, University of Warsaw
00-681 Warszawa, ul. Hoża 69

15. Prof. dr hab. Ernest Piasecki
Heavy Ion Laboratory,
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

16. Dr hab. Ludwik Pieńkowski
(Chairman of the Council)
Heavy Ion Laboratory,
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

17. Prof. dr hab. Krzysztof Pomorski
Maria Curie-Skłodowska University
20-031 Lublin, ul. Radziszewskiego 10

18. Prof. dr hab. Krzysztof Rusek
(Director of HIL)
Heavy Ion Laboratory,
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

19. Prof. dr hab. Teresa Rząca-Urban
Faculty of Physics, University of Warsaw
00-681 Warszawa, ul. Hoża 69

20. Prof. dr hab. Adam Sobiczewski
The Andrzej Sołtan Institute
for Nuclear Studies
00-681 Warszawa, ul. Hoża 69

21. Prof. dr hab. Henryk Szymczak
Institute of Physics,
Polish Academy of Sciences
02-668 Warszawa, Al. Lotników 32/46

22. Prof. dr hab. Grzegorz Wrochna
The Andrzej Sołtan Institute
for Nuclear Studies
05-400 Świerk k/Warszawy

23. Prof. dr hab. Wiktor Zipper
A. Chełkowski Institute of Physics
University of Silesia
40-007 Katowice, ul. Uniwersytecka 4

D.6 Program Advisory Committee

PAC members (until 8 December 2009)

- Brunon Sikora, Chairman (Faculty of Physics, University of Warsaw)
- Bogdan Fornal (Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków)
- Jerzy Jastrzębski (HIL, University of Warsaw)
- Reinhard Kulessa (Marian Smoluchowski Institute of Physics, Jagiellonian University, Kraków)
- Andrzej Marcinkowski (The A. Sołtan Institute for Nuclear Studies, Warszawa/Świerk)
- Adam Sobiczewski (The A. Sołtan Institute for Nuclear Studies, Warszawa/Świerk)
- Władysław Trzaska (University of Jyväskylä, Finland)
- Andrzej Turos (The A. Sołtan Institute for Nuclear Studies, Warszawa/Świerk; Institute of Electronic Materials Technology, Warszawa)
- Teresa Rząca-Urban (Faculty of Physics, University of Warsaw)
- Jan Żylicz (Faculty of Physics, University of Warsaw)

PAC members (since 8 December 2009)

- Dimiter Balabanski (University of Sofia, Bulgaria)
- Konrad Czerski (Institute of Physics, University of Szczecin; Physics Department, Technical University of Berlin)
- Bogdan Fornal (Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków)
- Gilles de France (GANIL, Caen, France)
- Andres Gadea (University of Valenzia, Spain)
- Zenon Janas (Faculty of Physics, University of Warsaw)
- Nicholas Keeley (The A. Sołtan Institute for Nuclear Studies, Warszawa)
- Rainer Lieder (University of Bonn, Germany)
- Piotr Magierski (Faculty of Physics, Warsaw University of Technology)
- Leszek Próchniak (Maria Curie-Skłodowska University, Lublin)
- Brunon Sikora (Faculty of Physics, University of Warsaw)
- Władysław Trzaska (University of Jyväskylä, Finland)

The international Program Advisory Committee of the Heavy Ion Laboratory meets usually twice a year, in spring and in autumn. Deadline for submitting proposals is three weeks before a PAC meeting. Due to a large backlog of approved experiments, there was no PAC meetings in 2009. PAC approved experiments are scheduled at the meetings of the Users' Committee, which is also serving as a link between the cyclotron users and the Laboratory. The Users' Committee is chaired by Julian Srebrny (HIL UW).

D.7 Laboratory Guests

Participants of HIL experiments from outside-Warsaw laboratories

M. Adamczyk	Jagiellonian University, Kraków, Poland
D. Banaś	Holycross Cancer Centre, Kielce, Poland
J. Braziewicz	Jan Kochanowski University, Kielce, Poland
M. Ciemała	The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
E. Clément	GANIL, Caen, France
J. Czub	Jan Kochanowski University, Kielce, Poland
A. Dijon	GANIL, Caen, France
A.K. Gourishetty	The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
M. Kasztelan	The Andrzej Sołtan Institute for Nuclear Studies, Łódź, Poland
S. Kisyov	University of Sofia, Bulgaria
S. Kliczewski	The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
M. Kmiecik	The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
E. Koshchiy	Kharkiv University, Ukraine
S. Lalkovski	University of Sofia, Bulgaria
J. Perkowski	University of Łódź, Poland
A. Piórkowska	University of Silesia, Katowice, Poland
B. Roussière	Institut de Physique Nucléaire, Orsay, France
R. Siudak	The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
Z. Sosin	Jagiellonian University, Kraków, Poland
A. Staudt	University of Silesia, Katowice, Poland
P. Szaflik	University of Silesia, Katowice, Poland
A. Wieloch	Jagiellonian University, Kraków, Poland
A. Wilczek	University of Silesia, Katowice, Poland

Other short-time visitors

V. Buzmakov	Joint Insitute for Nuclear Research, Dubna, Russia
G. de France	GANIL, Caen, France
I. Ivanenko	Joint Insitute for Nuclear Research, Dubna, Russia
I. Martel	University of Huelva, Spain
A. Pakou	University of Ioannina, Greece

Long-time visitors

S. Kisyov	University of Sofia, Bulgaria (5 months)