Super-FRS the Next-Generation Facility for Physics with Exotic Nuclei

Hans Geissel
Polish-German Meeting, Warsaw, November 24, 2003

- Introduction
- The Superconducting FRagment Separator
- The Experimental Branches
Polish Contributions to Nuclear Structure Physics

Maria Skłodowska
* 7.11.1867 in Warsaw
Discovery of Polonium

The discovery of the two-proton radioactivity

Marek Pfützner
Institute of Experimental Physics
Warsaw University
Polish Collaborations in Nuclear Structure Research at GSI

- At the UNILAC (SHIP, Online Separator)
  Theory and experimental groups for super-heavy element research, spectroscopy of fusion products near the proton dripline and gamma spectroscopy (Coulomb excitation).

- At the SIS18 (FRS, LAND-ALADIN, ESR)
  From MUSIC to the discovery of 2p radioactivity
  Mass measurements
  Halo and skin nuclei
  Gamma spectroscopy (RISING)

- At the Super-FRS
  Low-Energy Branch: Spectroscopy (α, β, γ, p, 2p, ...)
  Ring Branch: Stored isomeric beams
Physics with Exotic Nuclei

Fundamental Symmetries and Interactions

Parity Violation and Time Reversal in Atoms

Test of the Standard Model CKM-Matrix

Superheavy Elements

r-Process and Supernovae

r-process, Novae and X-ray Bursts

Structure & Dynamics of Exotic Nuclei

New Shells
New Shapes

Halo, Skin, Molecule Nuclei

New Decay Mode 2 p-Emission

Applications

Nuclear Astrophysics
High Energies RIB →
Discovery of the Proton Halo

1500 MeV/u

W. Schwab et al.,

H. Lenske,
Prog. Part. Nucl. Phys. 46 (2001)
Landmarks from FRS Experiments

- New Fission Studies
- New Mass Measurements
- 2-p Radioactivity
- Halo Nuclei
- $^{8}$B
- $^{100}$Sn
- $^{78}$Ni
- $^{11}$Li
- Shell far off Stability
- Skin Nuclei
- Bound-state $\beta^-$-decay
- Pionic Atoms
- New Fission Fragments
- $B_p=0$
- $B_n=0$
- $B_F=4\text{MeV}$
- r-process
Limitations of the Present Facility

- Low primary beam intensity (e.g. $10^8$ $^{238}$U ions /s)
- Low transmission for projectile fission fragments (4-10%)
- Low transmission for fragments to the experimental areas (cave B,C) and into the storage ring ESR (a few %)
- Limited maximum magnetic rigidity
  @ FRS: for U-like fragments
  @ ESR: cooler performance and magnets
  @ALADIN, to deflect break-up fragments
Solutions
SIS-100/300, Super-FRS, CR, NESR

- SIS-100/300 \( ^{238}\text{U} \) ions \( 10^{12} / \text{s} \)

- Large Acceptance Superconducting FRagment Separator (Super-FRS)

- Ion-optical Parameters:
  \[ \varepsilon_x = \varepsilon_y = 40 \pi \text{ mm mrad} \]
  \[ \varphi_x = \pm 40 \text{ mrad} \]
  \[ \varphi_y = \pm 20 \text{ mrad} \]
  \[ \frac{\Delta p}{p} = \pm 2.5 \% \]
  \[ B\rho_{\text{max}} = 20 \text{ Tm} \]
  \[ R_{\text{ion}} = 1500 \]
Comparison of FRS and Super-FRS

FRS

Super-FRS

Degrader

Degrader 1

Degrader 2

H. Geissel et al. NIM B 204 (2003) 71
The Super-FRS is ideal for Studies of r-Process Nuclei

K.-H. Schmidt
The International Accelerator Facility for Beams of Ions and Antiprotons
The Super-FRS and its Branches

see talk by Magda Górska
The Super-FRS and its Branches

Diagram showing the flow from SIS-100 through Pre-Separator, Main-Separator, High-Energy Cave, and NESR, with branches to CR complex and eA-Collider.
Reactions with Relativistic Radioactive Beams

Experiments in the High Energy Branch of the Super-FRS

T. Aumann, H. Emling, B. Jonson

**Experiments**
- knockout and quasi-free scattering
- electromagnetic excitation
- charge-exchange reactions
- fission
- spallation
- fragmentation

**Physics Goals**
- single-particle occupancies, spectral functions, correlations, clusters, resonances beyond the drip lines
- single-particle occupancies, astrophysical reactions (S factor), soft coherent modes, giant resonance strength, B(E2)
- Gamov-Teller strength, spin-dipole resonance, neutron skins
- shell structure, dynamical properties
- reaction mechanism, applications (waste transmutation, ...)
- $\gamma$-ray spectroscopy, isospin-dependence in multifragmentation
The High Energy Experimental Setup

Reactions with Relativistic Radioactive Beams R3B

A versatile setup for kinematical complete measurements

Large-acceptance measurements

The setup includes:
- High-resolution momentum measurement
- Large-acceptance measurements
- Exotic beam from Super-FRS

Equation: $B_\rho = m_\gamma \nu / Z$

T. Aumann
The Super-FRS and its Branches
Predictive Power of Mass Models

![Graph showing the predictive power of mass models for measured masses and r-process isotopes. The graph compares different models against experimental data, highlighting the accuracy of the mass predictions.]
New Isospin Dependence of Pairing

Yu. Litvinov

2. Pairing-Gap energy, deduced from 5-point binding difference

\[
\Delta_{n5}(Z,N) = \frac{1}{8} \left( m(Z, N + 2) - 4(Z, N + 1) + 6m(Z, N) - 4m(Z, N - 1) + m(Z, N - 2) \right) c^2
\]

\[
\Delta_{p5}(Z,N) = \frac{1}{8} \left( m(Z + 2, N) - 4(Z + 1, N) + 6m(Z, N) - 4m(Z - 1, N) + m(Z - 2, N) \right) c^2
\]
Lifetime Measurements of Short-lived Nuclei
Applying Stochastic and Electronic Cooling

D. Boutin
Observation of the Short-Lived Isomer $^{207m}$Tl with Stochastic Cooling

$T_{1/2} = \frac{T_{1/2}^{lab}}{\gamma} = \frac{\ln 2}{\gamma \lambda_{lab}} = 1.48 \pm 0.12 \text{ s}$

$\lambda_{lab} = 0.328 \pm 0.026 \text{ s}^{-1}$

$\gamma = 1.4305$

D. Boutin, F. Nolden
Advantage and Opportunities of eA Experiments

PRL 85 (2000) 2913

H. Simon, H. Weick

Coincidence with recoils

H. Simon, H. Weick

GSi
International Collaborations at the Super-FRS

★ NUSTAR, 73 Council Members, 23 Countries

★ Super-FRS: D(JLU), F(GANIL), JPN(Riken), USA(ANL, MSU),

★ Low-Energy Branch: B, D, E, PL, SF, UK,

★ High-Energy Branch: D, E, NL, S, (R3B)

★ Ring Branch: D, JPN, NL, PL, S, USA
Studies of exotic atoms and exotic nuclei will contribute significantly to the basic knowledge of matter.

Precision experiments with stored exotic nuclei open up a new field for nuclear structure physics and astrophysics.

The next-generation facility will present unique conditions for research and education.

There are many technical challenges inviting especially also the next-generation scientists.
Electron Scattering

Conventional

- Point like particle
- Pure electromagnetic probe ⇒ formfactors $F(q)$
- $F(q)$ transition formfactors ⇒ high selectivity to certain multipolarities

eA collider

- Unstable nuclei
- Large recoil velocities ⇒ full identification $(Z,A)$
- Kinematics ⇒ $4\pi$ - geometry, small angles complete kinematics
- Bare ions ⇒ no atomic background
Main task: fast cooling
Bunch rotation
Adiabatic debunching
Stochastic Precooling
Isochronous mass measurements

Circumference: 189.27m
Horizontal tune: 3.63/3.42/2.36
Vertical tune: 2.62/2.62/3.36
Transition energy: 4.3/2.9/1.84

Lattice designed by A. Dolinskii
Layout of the NESR Lattice

**Tasks**
- In-ring-experiments at
  - Gas-jet-target
  - Electron target
  - Electron ring
  - Deceleration to energies < 100 MeV/u
## The Electron Ring

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Luminosity [cm⁻² s⁻¹]</td>
<td>( \sim 1 \times 10^{28} )</td>
</tr>
<tr>
<td>Vertical tune</td>
<td>2.8</td>
</tr>
<tr>
<td>Horizontal tune</td>
<td>3.8</td>
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<tr>
<td>Momentum spread [%]</td>
<td>( \pm 0.018 )</td>
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<tr>
<td>Horizontal/vertical emittance [mm mrad]</td>
<td>0.05</td>
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<tr>
<td>Circumference [m]</td>
<td>45.22</td>
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<tr>
<td>e⁻-energy [MeV]</td>
<td>200 - 500</td>
</tr>
<tr>
<td>Interaction point magnet free space [m]</td>
<td>1 - 4</td>
</tr>
</tbody>
</table>