The Super-FRS Project at GSI

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for the Super-FRS working group
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- FRS facility
- The concept of the new facility
- The Super-FRS and its branches
- Summary
Projectile Fragmentation and Projectile Fission

Projectile Fragmentation

\[ V_f = V_p \]

Nucleon-Nucleon-Collisions (Abrasion Ablation)

Projectile Fission

\[ V_f = V_p + V_{fusion} \]

Coulomb Excitation in Peripheral Collisions

K. Sümmerer
Kinematics of Exotic Nuclei produced in Projectile Fragmentation and Projectile Fission

![Graphs showing kinematics of exotic nuclei](image-url)

- $^{238}\text{U} + ^{12}\text{C} \rightarrow ^{78}\text{Ni}$ - (Fission)
- $^{238}\text{U} + ^{12}\text{C} \rightarrow ^{132}\text{Sn}$ - (Fission)
- $^{124}\text{Xe} + ^{12}\text{C} \rightarrow ^{100}\text{Sn}$ - (Fragmentation)
Bρ-ΔE-Bρ Separation Method

Production Target

αKr 500 A·MeV

Degrader

First Selection

First and Second Selection

Neutron Number N

Proton Number Z

24 26 28 30
46 48 50 52 54

20,000 m
Experiments with the FRS

• **Nuclear structure and reactions**
  Explore the properties of dripline nuclei, search for new structures and shells, study hadronic atoms

• **Nuclear astrophysics and applications**
  Exotic nuclei are the key to understand the formation of elements in the universe

• **Atomic interactions of heavy ions with matter**
  Basic atomic collision studies and applications
  PET, isotope separation, stopping of fragments in a gas cell
Limitations of the facility:

- Low primary beam intensity (e.g. $10^9 \ ^{238}\text{U} / \text{s}$)
- Low transmission for projectile fission fragments (4-10% at the FRS)
- Low transmission for fragments into the storage ring and to the experimental areas
- Limited maximum magnetic rigidity
The Energy-Z Operating Domain for In-Flight Separation
Comparison of the FRS and the Super-FRS

<table>
<thead>
<tr>
<th></th>
<th>$B_{\rho_{\text{max}}}$</th>
<th>$\Delta p/p$</th>
<th>$\Delta \Phi_x$</th>
<th>$\Delta \Phi_y$</th>
<th>Resolving Power</th>
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<tbody>
<tr>
<td>FRS</td>
<td>18 Tm</td>
<td>1.0 %</td>
<td>$\pm 13$ mrad</td>
<td>$\pm 13$ mrad</td>
<td>1500</td>
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<tr>
<td>Super-FRS</td>
<td>20 Tm</td>
<td>2.5 %</td>
<td>$\pm 40$ mrad</td>
<td>$\pm 20$ mrad</td>
<td>1500</td>
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Transmission Gain for Fission Products

![Graph showing transmission gain for Super-FRS and FRS as a function of Z.](image-url)
Rates for Exotic Nuclei at the Super-FRS
Ion-Optical Design of the Super-FRS

<table>
<thead>
<tr>
<th></th>
<th>at F1</th>
<th>at F2</th>
<th>at F4</th>
<th>at F6</th>
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<tbody>
<tr>
<td>(x,x)</td>
<td>-3.28</td>
<td>2.00</td>
<td>1.46</td>
<td>1.60</td>
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<tr>
<td>(x,a)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>(x,p)</td>
<td>5.05</td>
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<td>(a,x)</td>
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<td>(a,p)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>(y,y)</td>
<td>-2.55</td>
<td>1.90</td>
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<td>0</td>
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<tr>
<td>(b,y)</td>
<td>0.12</td>
<td>-0.21</td>
<td>-0.36</td>
<td>-0.67</td>
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Separation performance using two degrader stages

Features of two degrader stages
• Reduction of contaminants from fragments produced in the degrader
• Optimization of the fragment rate on detectors in the main-separator
• Introduction of another separation cut in the A-Z plane
• Possible usage of pre- and main-separator for secondary reaction studies
Separation Characteristics for $^{100}$Sn with 1 and 2 Degrader Stages
The Super-FRS and it’s Facility

- SIS-18
- Production Target
- Pre-Separator
- Main-Separator
- Super-FRS
- Energy Buncher
- Low-Energy Branch
- High-Energy Branch
- CR
- NESR
- eA-collider
The High-Energy Branch

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<thead>
<tr>
<th>Reaction</th>
<th>Physics goals</th>
<th>Ions/s</th>
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<td>Knockout</td>
<td>Unbound states, properties beyond the driplines</td>
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<td>Electromagnetic</td>
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<td>Excitation</td>
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<td>Giant dipole resonance</td>
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<td>Giant quadrupole strength</td>
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<td>B(E2), evolution of shell structure</td>
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<td>Astrophysics, rp-process, $(p,\gamma)$ S-factor</td>
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<td>Fission</td>
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<td>Fragmentation</td>
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<td>Multifragmentation</td>
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<td>$(p,n)$</td>
<td>Spin-dipole exc., neutron skin, GT strength</td>
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<td>Quasi-free scattering</td>
<td>Single particle structure</td>
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<td>Spallation</td>
<td>Reaction theory (applications, e.g. hybrid reactors)</td>
<td>$10^4$</td>
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Instrumentation of the Low-Energy Branch

**Extraction** RFQ

**Cooler trap**

**Precision trap**

**Detector**

**LASER spectroscopy**

**Decay spectroscopy**

**γ-ray spectroscopy**

**Trap system**

Exotic nuclei from SUPER-FRS with different momenta

\[ +\delta p, p, -\delta p \]

Monoenergetic ion beam

Energy-dispersed ion beam

Monoenergetic ion beam

\[ +\delta p \rightarrow p \]

\[ p \rightarrow p \]

\[ -\delta p \rightarrow p \]

Monoenergetic degrader

**Si-Detectors**

**NaI-Crystals**

**Super-Clover Ge-Detector**

**AGATA**
Instrumentation for Experiments with Stored Beams
Summary

• Large momentum and angular acceptance
• Super-FRS consists of three branches feeding caves for different types of experiments
• High secondary-beam transmission to all experimental areas and into the CR/NESR
• Increase of secondary beam intensities of more than 10000 compared to now
• Super-FRS needs more than one separation stage to provide sufficient background reduction
• Unambiguous fragment identification (q=Z)
  ➢ Higher separation quality
  ➢ Higher sensitivity and selectivity
  ➢ Physics with single exotic atoms
Intensity distribution in the preseparator of Super-FRS

First quadrupoles: up to 30%

In the first dipole most of the fragments will drop out, everything with dp/p > 3%

Target: up to 25% of primary beam
dump of primary beam 60%

remaining intensity 1% of primary beam

Degrader: further fragmentation of up to 40% of the fragments.

90% of fragments stopped in slit remaining intensity 0.1% of primary beam

beam lost or target

all intensities in percent of the primary beam intensity in particles per sec.
The GSI Upgrade