From FRS to Super-FRS

Martin Winkler
Artic FIDIPRO-EFES Workshop, April 20-24, 2009, Saariselkä, Finland

- From GSI to FAIR (Facility of Antiproton and Ion Research)
- The FRagment Separator FRS @ GSI
- The Super-FRS (Layout, Features, Challenges) @ FAIR
- The Experimental Branches of the Super-FRS
- Summary
GSI and FAIR

GSI today

UNILAC

SIS 18

FRS

ESR
**GSI and FAIR**

**FAIR in the future**

$L_{SIS100/300} = 1.1 \text{ km}$

**Super-FRS**
**GSI**

Linac: UNILAC  
Synchrotron: SIS-18  
Storage Ring: ESR  
Secondary Beams:  
  RIB (FRS)  
  Pion  

**FAIR**

2 Linac's  
  Proton  
  Electron  

8 Rings  
(Synchrotron, Storage/Cooling)  
  SIS-100, SIS -300  
  CR, RESR,NESR  
  e⁻ (\(\bar{p}\)) - Ring (collider)  
  HESR (\(\bar{p}\))  
  FLAIR  

Secondary Beams:  
  RIB (Super-FRS)  
  Anti-Proton (\(\bar{p}\))
Beams now:
Z = 1 – 92
(protons to uranium)
up to 2 GeV/nucleon
Some beam cooling

Future Beams:
Intensity: primary 100 fold
secondary 10000 fold
Species: Z = -1 – 92
(anti-protons to uranium)
Energies: ions up to 35 - 45 GeV/u
antiprotons 0 -15 GeV/c
Precision: full beam cooling
Secondary Nuclear Beam Facility at GSI

FRS: In-flight Separator & High-Resolution Spectrometer

1. Decay Spectroscopy, High-resolution spectrometer, range bunching
2. Masses, Lifetimes, Direct Reactions, Isomeric Beams
3. Reactions Studies (Complete Kinematics)

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B_\rho - \Delta E - B_\rho  Separation Method

Production Target

\[^{86}\text{Kr} \quad 500 \text{ A} \cdot \text{MeV}\]

\[\Delta E \propto \frac{Z^2}{m}\]

First Selection

First and Second Selection

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Standard FRS equipments

- **Target**
- **TPC - x,y position** @ S2,S4
- **Plastic scintillator (TOF)** @ TA, S1, S2, S3, S4, S8
- **Beam profile** @TA,S1,S2 S3,S5,S6

**Full isotope identification**

\[ B\rho = \frac{mv}{q}; \quad q = Z \]

\[ \begin{align*}
ToF &\rightarrow v \\
\Delta E &\rightarrow Z \\
B\rho &
\end{align*} \]

\[ \implies \frac{A}{Z} El \]

- **NEW:** Isomer tagger @ S4

- **SEETRAM Intensity monitor** (primary beams) @TA
- Schottky probes, Degrader, etc.
Tracking detectors at the FRS

High-resolution momentum measurements ($\sim 1.5 \cdot 10^{-4}$) in knockout reactions

$$^{33}\text{Mg} + \text{C} \rightarrow ^{32}\text{Mg} + (\gamma)$$

Interaction cross-section measurements in the Island of Inversion @ 1GeV/u

- S1 total rate: $4 \cdot 10^4$/s
- $^{33}\text{Mg}$ rate at S2: $\sim 40$/s
- max. trigger rate: $10^3$/s
  (low Z rejection)

Rate limitation due to pile-up in the Music at S2
(pile-up rejection by trigger selection)

48Ca intensity: $\sim 2 \cdot 10^9$/spill
- spill (1-8) sec
- multi-injection mode (SIS18)
Landmarks from FRS Experiments

- New Fission Studies
- New Mass Measurements
- Pionic Atoms
- New Fission Fragments
- Shells far off Stability
- Skin Nuclei
- Halo Nuclei
- $^8\text{B}$
- $^{11}\text{Li}$
- $^{100}\text{Sn}$
- $^{78}\text{Ni}$

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The Present Rare Isotope Facility at GSI

Limitations

- 'Low' primary beam intensity (e.g. $10^9$ $^{238}$U/s)
- 'Low' transmission for projectile fission fragments (4-10% at the FRS)
- 'Low' transmission for fragments into the storage ring and to the exp. area #3 (beam-line magnets are not designed for fragment beams)
- Limited space at focal planes and the experimental areas
Goal: Larger Acceptance

- Elements p - U
- Energy up to 1.5 GeV/u
- Intensity up to $10^{12}$/s
  (depending on element)
- DC or pulsed operation

Design Parameters:
- $\varepsilon_x = \varepsilon_y = 40 \pi \text{ mm mrad}$
- $\Phi_x = \pm 40 \text{ mrad}$
- $\Phi_y = \pm 20 \text{ mrad}$
- $\Delta P/P = \pm 2.5 \%$

- $B_p = 2 - 20 \text{ Tm}$
- $R_n = 750 / 1500$
  (first / second stage)

- Spot size on target:
  - $\sigma_x = 1.0 \text{ mm}$
  - $\sigma_y = 2.0 \text{ mm}$

Features:
- 2 Separator-stages in achromatic mode
- Separation by $B_p-\Delta E-B_p$ method
  (variable degrader)
- Multi-branch system
- Large acceptance utilizing sc magnets
- Handling concept for high- radiation area

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Comparison of FRS with Super-FRS, intensity gain

<table>
<thead>
<tr>
<th></th>
<th>$B_{p_{\text{max}}}$</th>
<th>$\Delta p/p$</th>
<th>$\Delta \Phi_x$, $\Delta \Phi_y$</th>
<th>resolving power</th>
<th>gain factor $^{18}\text{C}$</th>
<th>gain factor $^{132}\text{Sn}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRS</td>
<td>18 Tm</td>
<td>1.0 %</td>
<td>$\pm 13$, $\pm 13$ mrad</td>
<td>1500</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Super-FRS</td>
<td>20 Tm</td>
<td>2.5 %</td>
<td>$\pm 40$, $\pm 20$ mrad</td>
<td>1500</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

including primary rate: 250 20 000

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Production Rates for Exotic Nuclei at FAIR

K.-H. Schmidt
Separation Performance of the Super-FRS

1.1 A GeV $^{238}$U on 4 g/cm$^2$ C target, two Al degraders d/R=0.3, d/R=0.7

Features of two degrader stages

- Introduction of another separation cut in the A-Z plane
- Reduction of contaminants from fragments produced in the degrader
- Optimization of the fragment rate on detectors in the Main-Separator
- Possible usage of Pre- and Main-Separator for secondary reaction studies
Technical Challenges

Remote Handling

Target & Beam Catcher

Cryogenics

SC Multiplets

Effective length (quads) 0.8 / 1.2 m
Aperture (warm) ± 150 mm
Pole radius 240 mm
Field gradient 1.0 – 10.0 Tm

Main-Separator

Degrader 1

Degrader 2

SC Dipoles

Radiation Reistant Magnets

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Shielding and Handling Concept in the Target Area (vertical plug system)

Promt Dose Rates 1.5 GeV/u $10^{12}/s$ $^{238}$U
(top view, beam level)

Target building (schematic)
Graphite Wheel Target

- Cooling only by radiation
- $R_{out} = 22.5$ cm

Solid graphite
SGL Carbon R 6400P
**5 steps, 1 – 8 g/cm$^2$**
each step 16 mm wide

Spokes from INCONEL 600

$\text{Si}_3\text{N}_4$ ball bearings
Ag-coated cages
$\text{MoS}_2$ lubrication
$T_{\text{limit}} = 150^\circ\text{C}$
Prototype Target
to be used at FRS with SIS18 beams

- Prototype target ready
- Off-line tests started
- Preparation of induction heating (20 kW generator)
Beam Catcher
(in Collaboration with VECC Calcutta, India)

The relative difference in magnetic rigidity ($Bp$) determines where the beam after passing the target is going to be dumped.

- **Front part:** graphite (20cm+), absorb strong pressure waves, water cool
- **Back part:** iron (60cm) to absorb protons and neutrons.

Remote Handling of Beam Catcher
Pole gap height: 180 mm
Length / width / height (m): 3.2 / 3.0 / 2.1
Total weight: 100 t
Integrated field quality $\pm 3 \cdot 10^{-4}$
### Superferric Dipoles for the Main Separator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of main dipoles</td>
<td>21</td>
</tr>
<tr>
<td>Dipole field</td>
<td>0.15-1.6T</td>
</tr>
<tr>
<td>Bending angle</td>
<td>9.75°</td>
</tr>
<tr>
<td>Curvature radius, R</td>
<td>12.5 m</td>
</tr>
<tr>
<td>Effective straight length, $L_{\text{eff}}$</td>
<td>2127 mm</td>
</tr>
<tr>
<td>Good field region</td>
<td>±190±35 mm</td>
</tr>
<tr>
<td>Pole gap height</td>
<td>170 mm</td>
</tr>
<tr>
<td>Integral field quality (relative)</td>
<td>±3×10⁻⁴</td>
</tr>
</tbody>
</table>

- H-Type, warm bore, warm iron
- Sector shape
- Total weight: ~50 t

![Pre-Separator to Main-Separator diagram](image)

- Case welding (LHe vessel)
- Prototype ready for mapping
The NUSTAR Facility at FAIR
(The 3 Branches of the Super-FRS)

Super-FRS

NUSTAR = Nuclear Structure, Astrophysics and Reactions

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NUSTAR LOI's (667 authors)

8 approved LOI by NUSTAR-PAC → presented as Technical Proposals in spring 2006

1.) Low Energy Branch (LEB)
- High-resolution In-Flight Spectroscopy (HISPEC)/
- Decay Spectroscopy with Implanted Ion Beams (DESPEC)
- Precision Measurements of very short-lived Nuclei using an
- Advanced Trapping System for highly-charged Ions (MATS)
- LASER Spectroscopy for the Study of Nuclear Properties (LASPEC)
- Neutron Capture Measurements (NCAP)
- Antiprotonic Radioactive Nuclides (Exo+pbar)

2.) High Energy Branch (R3B)
- A Universal Setup for Kinematical Complete Measurements of
  Reactions with Relativistic Radioactive Beams (R3B)

3.) Ring Branch (STORIB)
- Study of Isomeric Beams, Lifetimes and Masses (ILIMA)
- Exotic Nuclei Studied in Light-Ion Induced Reactions
  at the NESR Storage Ring (EXL)
- Electron-Ion Scattering in a Storage Ring (e-A Collider) (ELISe)
- Antiproton-Ion Collider: A Tool for the Measurement of Neutron and
  Proton rms radii of Stable and Radioactive Nuclei (AIC)

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Summary

- Super-FRS based on experiences with FRS
- Large-acceptance device using large-aperture SC magnets
- Two separator stages, multi-branch system
- R&D for major components as well as civil construction under progress
- Super-FRS as part of FAIR

→ Construction together with FAIR member states

Thank You!