Design and Status of the Super Separator Spectrometer for the GANIL SPIRAL2 Project

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Abstract: $S^3$ Design and Status

The Super Separator Spectrometer ($S^3$) is a device designed for experiments with the very high intensity stable heavy ion beams of the superconducting linear accelerator of the SPIRAL2 Project at GANIL. $S^3$ is designed to combine high acceptance, a high degree of primary beam rejection, and high mass resolving power to enable new opportunities in several physics domains, e.g. super-heavy and very-heavy nuclei, spectroscopy at and beyond the drip-line, isomers and ground state properties, multi-nucleon transfer and deep-inelastic reactions. The spectrometer comprises 8 large aperture multipole triplets (7 superconducting and 1 open-sided room temperature), 3 magnetic dipoles, and 1 electrostatic dipole arranged as a momentum achromat followed by a mass separator. A summary of the beam-optical simulations and the status of the main spectrometer components will be presented with special emphasis on the design of the superconducting multipole triplets.
Outline of this talk

- The GANIL SPIRAL2 Project
  - Overview talk this afternoon by E. Petit
- Physics with heavy ion beams at SPIRAL2
- Requirements/goals for the new spectrometer
- Optics configuration
- Technical components
- The superconducting multipole triplets
- The electric dipole
In order to define the spectrometer specifications, we selected several specific experiments, as a model for the physics at S3, and simulate their kinematical characteristics:

1. Direct kinematics fusion reaction: $^{48}\text{Ca} + ^{248}\text{Cm} \rightarrow ^{292}\text{116} + 4n$
2. Inverse kinematics fusion reaction: $^{208}\text{Pb} + ^{48}\text{Ca} \rightarrow ^{254}\text{No} + 2n$
3. Fusion of symmetric systems: $^{58}\text{Ni} + ^{46}\text{Ti} \rightarrow ^{100}\text{Sn} + 4n$
4. Inverse kinematics fusion reaction (light system): $^{58}\text{Ni} + ^{12}\text{C} \rightarrow ^{68}\text{Se} + 2n$
5. Multi-nucleon transfer reaction (study of Neutron Rich Nuclei):
   - Light nuclei: $^{12}\text{C} + ^{13}\text{C} \rightarrow ^{11}\text{Be} + 2p$
   - Medium nuclei: $^{68}\text{Se} + ^{238}\text{U} \rightarrow ^{80}\text{Zn} + X$
   - Heavy nuclei: $^{238}\text{U} + ^{248}\text{Cm} \rightarrow ^{262}\text{No} + X$
SPIRAL2 under construction

Phase 1: High intensity stable beams in 2014 + Experimental rooms ($S^3 + NFS$)
Phase 2: High intensity Radioactive Ion Beams (RIB)
Benchmark reactions

SHE / VHE - Fusion-evaporation in direct kinematics

<table>
<thead>
<tr>
<th>SHE / VHE</th>
<th>Synthesis and delayed spectroscopy</th>
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<tbody>
<tr>
<td>(^{48}\text{Ca} + ^{248}\text{Cm} \rightarrow ^{292}\text{116} + 4n)</td>
<td>Chemistry</td>
</tr>
<tr>
<td></td>
<td>Ground state properties (half-lives, masses, spectroscopy)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>E [MeV/n]</th>
<th>(&lt;B_\rho&gt;) [Tm]</th>
<th>(&lt;E_\rho&gt;) [MV]</th>
<th>(&lt;Q&gt;)</th>
<th>(&lt;V&gt;_V&gt;) [cm/ns]</th>
<th>(\Delta \theta (\pm 2\sigma)) [mrad]</th>
<th>dQ</th>
<th>dp/p [%]</th>
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</thead>
<tbody>
<tr>
<td>Beam parameters (^{48}\text{Ca})</td>
<td>4.92</td>
<td>0.88</td>
<td>27</td>
<td>+17</td>
<td>3.0</td>
<td>± 8</td>
<td>±0.2</td>
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<tr>
<td>Recoil parameters (^{292}\text{116})</td>
<td>0.131</td>
<td>0.58</td>
<td>3</td>
<td>+25</td>
<td>0.5</td>
<td>± 40</td>
<td>± 2</td>
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The \(^{100}\text{Sn}\) factory

<table>
<thead>
<tr>
<th>N = Z</th>
<th>Ground state properties (half-lives, masses, spectroscopy)</th>
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<td>(^{58}\text{Ni} + ^{46}\text{Ti} \rightarrow ^{100}\text{Sn} + 4n)</td>
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<th>dp/p(±2σ) [%]</th>
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<tbody>
<tr>
<td>Beam parameters (^{58}\text{Ni})</td>
<td>2.94</td>
<td>0.660</td>
<td>15.6</td>
<td>21.68</td>
<td>2.37</td>
<td>±8.6</td>
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<tr>
<td>Recoil parameters (^{100}\text{Sn})</td>
<td>0.882</td>
<td>0.559</td>
<td>7.27</td>
<td>24.17</td>
<td>1.30</td>
<td>±50</td>
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Summary of Technical Challenges

**High Beam intensity**
- High power target: $10\,\mu$A ($= 6.10^{14}$pps) or more
- Rejection of the beam: >$10^{13}$

**Low Energy** (fusion-evaporation residues)
- Large angular acceptance: +/- 50 mrad X and Y
- Large Charge state acceptance: B$p$ acceptance: +/- 10%

**Many reaction channels** (evaporation channels)
- M/q selection: 1/350 resolution
- Identification when possible

**Transfer/Deep inelastic Reactions (non 0°)**
- Beam Sweeper for incident beam at 10°
- Specific Target chamber and beam dump
S3 conceptual layout: Momentum Achromat, Mass Separator (MAMS)

Proposed Solution: Two-stage selection (Bp and m/q) that will achieve very good rejection of both the beam and adjacent mass channels of reaction products.
S3 conceptual layout: Momentum Achromat, Mass Separator (MAMS)

Proposed Solution: Two-stage selection (Bρ and m/q) that will achieve very good rejection of both the beam and adjacent mass channels of reaction products
Histogram at mass focal Plane

Overall transmission of fusion reactions
~50-60% for direct and symmetric kinematics

m/q resolution
~300-400 for 5 charge states

Optics team from GANIL, Saclay, Bucknell, Argonne & Strasbourg

Plot showing position of mass lines, 5 charge states, 3 masses
Open-sided RT magnets with sextupoles
MSU/NSCL SC Cold-iron Triplet for fragment separator
Argonne concept of SC multipoles

- High quality and cost-effective multipole designs using SC magnets are being developed
Winding with Pure $\sin m\phi$ Symmetry and its Shape Function - nearly perfect multipole fields

Peter Walstrom, NIM A519 (2004) 216
Harmonics for Quadrupole Magnet using Walstrom-type coils

All allowed harmonics are near zero

Air-core 3D fields calculated within COSY ∞ by S. Manikonda
Preliminary model of a SC multipole triplet for $S^3$
Overall layout and concept of SMT

Fig. 4.1.1: Schematic view of the S3 layout showing the position of the 7 SMT

Fig. 4.1.2: Overview of the SMT assembly
Summary of multiplet requirements for S3

- 8 triplets are required (quadruplet design changed to triplets to add space at target and focal planes while still fitting in the room)
- Can use 7 “closed” style with 1 “open-sided” for beam dump region
- SC multiplets: cost-effective, excellent field quality, shorter overall system
- Each “closed” singlet can have quadrupole, sextupole, & octupole coils, with 30-cm warm bore diameter & 40-cm effective length
- Fields required at 15-cm radius for 2 T-m rigidity (higher rigidity is easy):
  - Quadrupole: ~1.0 T
  - Sextupole: ~0.4 T
  - Octupole: ~0.2 T
- Cryogenics:
  - Warm iron used to speed up cool down
  - Small centralized cryo-system, ~100 W helium refrigeration with a small cold box (in the S3 vault)
  - Liquid helium bath for magnet coils
  - LN2-cooled shields
  - HTS and N2 gas-cooled leads
  - Operating current 200-400 amps (3 lead pairs per singlet)
Detailed beam dump concept being developed currently at Saclay
Beam Dump sketch

Safety related studies by Irfu/SENAC
E-dipole: +/- 300 kV, 20-cm gap

Preliminary Opera 3D model

Argonne/IPN-Orsay collaboration
Summary

- The $S^3$ separator is being designed and is to be built and used at SPIRAL2 by a large international collaboration: SPIRAL2 phase 1 research by 2015
- This instrument will use the intense stable heavy ion beams of SPIRAL2 phase 1
  - Important physics goals include studies of $N\sim Z$ nuclei around $^{100}$Sn, as well as, nuclear structure, chemistry, and synthesis studies of very- and super-heavy elements
- There are active collaborations proceeding with R&D and studies of all $S^3$ major subsystems – e.g. optics, magnets, E-dipole, targets, detectors, low energy branch
- Advanced optical simulations with a variety of magnet types are in progress
  - Simulations already show that SC multipoles with up to octupole corrections are required in the mass separator section
- RT and SC magnet design studies are in progress (mostly for “open-sided”)
- Safety studies are continuing and include detailed studies of the target and beam dump areas
- The electric dipole of $S^3$ is a limiting element for some beams and reactions
  - The ILL/LOHENGRIN E-dipole may be the best “model” for the S3 E-dipole