Mini-recoil spectrometer

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October 17th-21th, 2022
Physics opportunities

The ISRS allows an application of several reaction mechanisms to produce exotic nuclei in the energy levels of interest, decays of which can be observed by detecting particles or photons with the existing and planned detection systems.

**Reaction mechanisms**

- Deep inelastic reactions
- Coulomb dissociation
- Transfer reactions in inverse kinematics
- Multinucleon transfer reactions
- Fusion evaporation reactions in inverse kinematics
- Transfer, breakup and fusion reactions
- Resonant elastic scattering
ISOLDE Recoil Separator ISRS

Conceptual design
I. Martel. 84th ICC meeting.
CERN, March 2019.

- Remove only primary beam

Combined function SC magnets

Based on superconductor combined function magnets
dipolar and quadrupolar components
Maximum magnetic field ~ 6 T

3D G4beamline model
(20 multifunction magnets)

First optimization
(10 multifunction magnets)
C. Bontoiu et al., NIMA 969 (2020) 164048

C=4.7 m

C=3.56 m

Ejected A+

All isotopes

Storrd A_t, A_k

Target

Extracting RF system

Focal plane detector

Ring concept
Superconducting combined magnets

Summary of magnet parameters for operation mode with light isotopes (e.g. $^{11}\text{Li}$) and heavy isotopes (e.g. $^{118}\text{Ag}$ and $^{226,234}\text{Ra}$ nuclides).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$^{11}\text{Li}$</th>
<th>$^{118}\text{Ag}$</th>
<th>$^{226}\text{Ra}$</th>
<th>$^{234}\text{Ra}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective charge $q_{eff}$</td>
<td>2.999</td>
<td>35.457</td>
<td>52.883</td>
<td>52.879</td>
</tr>
<tr>
<td>Rrigidity $B_\rho$ [T m]</td>
<td>1.67</td>
<td>1.52</td>
<td>1.94</td>
<td>2.02</td>
</tr>
<tr>
<td>Deflection angle [deg]</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Dipolar magnetic field $B_y$ [T]</td>
<td>5.26</td>
<td>4.77</td>
<td>6.13</td>
<td>6.35</td>
</tr>
<tr>
<td>Quadrupolar strength $KL$ [m$^{-1}$]</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Quadrupolar gradient $G$ [T/m]</td>
<td>41.86</td>
<td>37.98</td>
<td>48.77</td>
<td>50.5</td>
</tr>
</tbody>
</table>

Magnets originally designed for a SC gantry for hadrontherapy

C. Bontoiu et al., IPAC2015, TUPW1014
C. Bontoiu et al., IPAC2015, WEPMN051
C. Bontoiu et al., NIMA 969 (2020) 164048

Fixed field alternating gradient (FFAG) focus
Canted Cosine Theta (CCT)

Two superimposed coils, oppositely skewed

pure cosine-theta field
No axial field.

test bench at CERN
Dipole field

![Graph showing dipole field versus beam radius of curvature in meters for different ions: Ra234, Ra226, Ag118, Li11.]

**Magnetic rigidity**

\[ B\rho [\text{T m}] = \left( \frac{3.3356}{q_{\text{eff}}} \right) \cdot A \cdot P [\text{GeV/c}] \]

Example for different ions at 10 MeV/u kinetic energy

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</tr>
<tr>
<td>(B\rho) [T m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Multifunction and high order aberrations with CCT

Dipole

Quadrupole

G. Kirby
Ion optics

Fixed field alternating gradient (FFAG) focus
Significantly reducing the size with respect to standard recoil separator configurations
Angular and momentum acceptance – Resolving power

Tracking of Ra226 for 300 turns

Max\( (x', y') \approx (115, 160) \) mrad

Momentum acceptance

\[
\delta = 10\% \rightarrow \text{Beampipe radius} \approx 100 \text{ mm}
\]

C=3.56 m

Mass resolving power

\(^2\text{H}(^{233}\text{Ra}, ^{234}\text{Ra})\text{H}\)

The detected intensity peaks of both Ra233 and Ra234 separate longitudinally as the number of turns increases.

C. Bontoiu et al., NIMA 969 (2020) 164048

Teresa Kurtukian-Nieto

GANIL Community Meeting, October 17\textsuperscript{th} - 21\textsuperscript{th} 2022
High momentum acceptance designing

- FDF optics for non-scaling FFAG
- Lattice with sbend magnets. BMAD code

<table>
<thead>
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<th>Beam</th>
<th>$^{234}$Ra</th>
</tr>
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<tr>
<td>Kinetic energy</td>
<td>10 MeV/u</td>
</tr>
<tr>
<td>Rigidity, $B\rho$ [T m]</td>
<td>2</td>
</tr>
<tr>
<td>Maximum beta functions, $\beta_{x,y}$ [m]</td>
<td>7.8, 13.5</td>
</tr>
<tr>
<td>Maximum dispersion, $D_x$ [m]</td>
<td>0.32</td>
</tr>
</tbody>
</table>

**$^F$ magnet**

| Effective length [m]     | 0.497 |
| Dipole field [T]         | 2.0   |
| Quadrupole gradient [T/m] | 12.3  |

**$^D$ magnet**

| Effective length [m]     | 0.55  |
| Dipole field [T]         | 2.11  |
| Quadrupole gradient [T/m] | -13.1 |

Expected max. momentum acceptance: $\Delta p/p = \pm 31.25 \%$
A conceptual design of the ISRS ring showing the main subsystems

Energy-saving and lightweight helium circulating system that re-liquefies all the evaporating helium gas and consumes far less power than conventional systems.
Injection/extraction systems

SuShi (for superconducting shield) septum using a canted cosine theta-like (CCT) magnet being developed for the HiLumi LHC phase

Isochronous mode

Revolution period deviation

\[
\frac{dT}{T} = -\frac{df}{f} = \frac{1}{\gamma_t^2} \frac{d(m/q)}{m/q} - \left(1 - \frac{\gamma}{\gamma_t^2}\right) \frac{dv}{v}
\]

The revolution frequency becomes velocity independent if

\[\gamma \rightarrow \gamma_t\]

By placing a small RF cavity at the isochronous focus, it is possible to deflect the recoils according to their m/q ratio, independent of their energy and scattering angle.

By carefully choosing the harmonic and phase used in the cavity, several charge states of the same isotope can be aligned to have the same deflection and be focused at the same location.
$^{50}\text{Cr}^{(56}\text{Ni},\alpha 2n)^{100}\text{Sn}$ at about 3.7 MeV/u, where the $^{100}\text{Sn}$ ions are produced with charge states ranging from 22+ to 26+.

Isochronous mode

- DFD optics for non-scaling FFAG
- Matching with two additional quads. (Q). BMAD

\[ \alpha_c = 0.98 \quad \gamma_t = 1.0102 \]
\[ \gamma = 1.0107 \quad (^{234}\text{Ra at 10 MeV/u}) \]

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<td>2</td>
</tr>
<tr>
<td>Maximum beta functions, $\beta_x, \beta_y$ [m]</td>
<td>2.85, 2.72</td>
</tr>
<tr>
<td>Maximum dispersion, $D_z$ [m]</td>
<td>1.8</td>
</tr>
</tbody>
</table>

**F magnet**

- Effective length [m] | 0.55 |
- Dipole field [T] | 2.45 |
- Quadrupole gradient [T/m] | 2.531 |

**D magnet**

- Effective length [m] | 0.497 |
- Dipole field [T] | 2.133 |
- Quadrupole gradient [T/m] | -2.967 |

**Additional quads. Q**

- Quadrupole gradient [T/m] | 0.423 |

Expected max. momentum acceptance: $\Delta p/p = +/-5.5\%$
Maybe at GANIL?
Momentum acceptance $\Delta p/p \sim 30\%$ for 10 MeV/u

To be studied for other energy ranges

At LISE?
**FFAG-SCMR advantages**

- State-of-the-art iron-based magnetic systems are heavy energy-consuming. Currents up to 200 A with **20 KW energy consumption per coil are typical**, requiring cooling systems to remove the heat dissipated by ohmic losses.

- Magnet operation suffers from **nonlinearities, hysteresis, and remnant magnetization** of the iron yokes.

- The use of **SC magnets** avoids energy losses of equivalent conventional warm magnets down to **a few watts**, reaching **30 times higher fields with 10 times smaller size and 1000 times reduced weight**.

- The equivalent system of an FFAG-SCMR with similar functionalities, would be at least **twenty times larger and three orders of magnitude heavier and energy-consuming**.

- **The advances in iron-free SC coils**, together with cryostat optimization, make **cryocoolers** a good option that eliminates the need for important and expensive infrastructures to produce and distribute liquid helium and all the associated safety and maintenance constraints. 10 €/litter...

- Adding **acceleration cavities** to the layout, the FFAG-SCMR will become a very **compact lightweight particle synchrotron accelerator**.

- **Recirculating target**
ISRS Collaboration

72 members of 30 Institutions from 13 countries

Spain
UK
France
Italy
Switzerland
Poland
Sweden
Hungary
Denmark
Finland
Romania
Mexico
Saudi Arabia

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That's all folks