Initial Tests of the Recoil Mass Spectrometer EMMA

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EMMA: The ISAC-II Recoil Spectrometer

- EMMA: recoil mass spectrometer spatially separates heavy products of nuclear reactions from beam & disperses according to mass/charge ratios
- 4 magnetic quadrupole lenses, 1 dipole magnet, 2 electrostatic deflectors, 3 slit systems, target chamber with integral Faraday cup, and modular focal plane detection system w/ PGAC, ionization chamber, and Si detectors
- Magnets and deflectors from contractor, other components TRIUMF-built
Quadrupole Tests at Manufacturer

- Various properties of 4 quadrupole magnets measured by manufacturer:
  - Field Gradient
  - Effective Length
  - Effective Field Boundary Locations
  - Higher Harmonic Content
  - Deviation of Mechanical and Magnetic Axes
Quadrupole Tests at TRIUMF

- Field gradients of all 4 quadrupoles measured as a function of current using Hall effect magnetometer, which was calibrated using an NMR system and the uniform field of our dipole magnet
- Field is measured at all times using a reference probe, which was calibrated simultaneously
<table>
<thead>
<tr>
<th>Magnetic Lenses</th>
<th>Quadrupole 1</th>
<th>Quadrupoles 2 &amp; 3</th>
<th>Quadrupole 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore Diameter</td>
<td>7 cm</td>
<td>15 cm</td>
<td>20 cm</td>
</tr>
<tr>
<td>Specified Effective Length</td>
<td>14 cm</td>
<td>30 cm</td>
<td>40 cm</td>
</tr>
<tr>
<td>Achieved Effective Length</td>
<td>13.98 cm</td>
<td>29.98 cm/29.88 cm</td>
<td>40.18 cm</td>
</tr>
<tr>
<td>Specified Maximum Pole Tip Field</td>
<td>1.21 T</td>
<td>0.87 T</td>
<td>0.81 T</td>
</tr>
<tr>
<td>Achieved Maximum Pole Tip Field</td>
<td>1.21 T</td>
<td>0.84 T</td>
<td>0.80 T</td>
</tr>
<tr>
<td>Achieved Field Gradient</td>
<td>34.6 T m(^{-1})</td>
<td>11.3 T m(^{-1})</td>
<td>8.4 T m(^{-1})</td>
</tr>
</tbody>
</table>
Dipole Tests at Manufacturer

- 40 degree dipole magnet’s field mapped at manufacturer
- Removable pole shims had to be machined three times before acceptance
Dipole Field Map Analysis

- Homogeneity and field boundary shape at 4 different currents analyzed at TRIUMF; magnet remapped at TRIUMF
- Maximum deviation from required effective length found at bending radius of 800 mm to be just under 0.3%; on average better than 0.1%
TRIUMF-Built HV Supplies

- Built 3 positive and 3 negative
- All have been tested to $|V| \geq 325 \text{ kV}$
- Housed in re-entrant ceramic vessel
- Pressurized with 3 bar $\text{SF}_6$
Complete ED2 Electrode Assembly
## EMMA Dipoles

<table>
<thead>
<tr>
<th>Dipoles</th>
<th>Magnetic</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius of Curvature</td>
<td>1 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Specified Deflection Angle</td>
<td>40.00°</td>
<td>20°</td>
</tr>
<tr>
<td>Achieved Deflection Angle</td>
<td>40.11°</td>
<td>20.05°</td>
</tr>
<tr>
<td>Specified Effective Field Boundary Inclination Angle</td>
<td>8.3°</td>
<td>0</td>
</tr>
<tr>
<td>Achieved Effective Field Boundary Inclination Angle</td>
<td>7.93° and 8.67°</td>
<td></td>
</tr>
<tr>
<td>Effective Field Boundary Radii</td>
<td>3.472 m</td>
<td>-</td>
</tr>
<tr>
<td>Maximum Field</td>
<td>1 T</td>
<td>40 kV cm⁻¹</td>
</tr>
</tbody>
</table>
Vacuum Systems

- Typical pressures in 3/4 vacuum sections of $4 \times 10^{-9}$ Torr; 1000 l/s turbos and 1500 l/s cryos
- Focal plane box has a single 1000 l/s turbo; pressure in low $10^{-6}$ Torr range
Target Chamber

- Integral Faraday cup with 1 mm entrance aperture coincides spatially with target position
- Target wheel with 3 positions
- Pumped by SEBT3B 500 l/s turbo; pressure in low $10^{-7}$ Torr range
• Plate slit systems upstream and downstream of dipole magnet
• More complex focal plane slit system has 2 plates and 2 rotatable fingers, allowing for 3 openings of variable width and position
Focal Plane Detectors

Detector 1 Y vs. X, Calibrated

Position resolution 1 mm
Timing resolution 660 ps
Ionisation chamber tested with alpha and fission sources on bench
December 2016 Test

- There was no time to commission with an alpha source prior to December 16th beam time.
- Bombarded thick Au foil with 80 MeV $^{36}$Ar beam.
- Tuned for multiply scattered beam with very large angular spread.

![Predicted Angular Distribution of Scattered $^{36}$Ar]
December 2016 Test

- Si-detector measured residual energy spread of 40% FWHM
- Consistent with filling nominal energy acceptance of +25%, -17%
Measured Focal Plane Position Spectrum of Scattered $^{36}$Ar

Focal Plane Position Spectrum

EMMA’s First M/Q Spectrum
December 2016 Test

Measured mass/charge dispersion & resolving power consistent with ion optical calculations

Measured Focal Plane Position Spectrum of Scattered $^{36}\text{Ar}$

FWHM = 5.6 mm
M/Q Resolving Power = 170
December 2016 Test

- Si-detector measured residual energy spread of 111% FWHM
- Consistent with filling energy acceptance + energy loss straggling in PGAC windows

![Residual Energy vs Counts Graph](Run 112 Au Data)
Measured Focal Plane Position Spectrum of Scattered $^{197}$Au

Set for $^{197}$Au$^{9+}$, observed single mass peak, no background in hour-long run with $10^9$ ions/s on target implying hardware beam suppression $> 10^{12}$
Approved Experiments

- Typically EMMA will be required to detect heavy products of fusion and transfer reactions.
- Two approved experiments, both of which require TIGRESS to be installed around EMMA target position.
  - Stable beam experiment: $^6$Li($^{17}$O,d)$^{21}$Ne to infer $^{17}$O(α,γ)$^{21}$Ne reaction cross section for the $s$ process; also requires SHARC.
  - RIB experiment: direct measurement of p($^{83}$Rb,γ)$^{84}$Sr reaction cross section at $p$ process energies.
Experiments to be Proposed

- With SHARC: $p^{(21}\text{Na},\alpha)^{18}\text{Ne}$ to infer $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ reaction cross section for Type I X-ray bursts
- With TIGRESS: direct measurements of $p^{(78}\text{Kr},\gamma)^{79}\text{Rb}$ and $p^{(79}\text{Br},\gamma)^{80}\text{Kr}$ reaction cross sections at $\rho$ process energies
Future Plans

• Continue HV conditioning
  • Both anodes conditioned to 250 kV with <100 nA load current
  • ED2 cathode conditioned to -250 kV with <200 nA load current
  • ED1 cathode drew excessive load current at low voltages, likely due to field emission from dust on cathode and/or field clamp; cleaning underway
  • ED2 reached $\Delta V = 340$ kV this weekend
• Alpha source tests this summer
• Elastic scattering and fusion evaporation reaction with stable beam starting Sep. 23, to complete commissioning
• Standalone experiments possible in fall schedule
• TIGRESS move to EMMA target position during shutdown 2017-2018
Core Personnel

- Martin Alcorta, ISAC Target & Detector Physicist
- Nicholas Esker, Postdoctoral Researcher
- Kevan Hudson, MSc Student
- Naimat Khan, Project Engineer
- Peter Machule, Expert Technician
- Matt Williams, PhD Student