EBIS Charge Breeder for CARIBU

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• Motivation for EBIS charge breeder and choice of breeder type
• Design features and parameters of CARIBU EBIS charge breeder
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• Summary
CARIBU - Californium Rare Ion Breeder Upgrade

Main components of CARIBU

- "ion source" is $^{252}\text{Cf}$ source inside gas catcher / RFQ cooler
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam
- Isobar separator
  - Purifies beam
- Charge breeder
  - Increases charge state for post-acceleration
- Post-accelerator
  - ATLAS with energy upgrade

CARIBU was commissioned in 2010

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CARIBU Isotope Yield at Low Energy (50 kV)

- 1 Ci $^{252}$Cf source
- about 20% of total activity extracted as ions
- works for all species
- complementary to uranium fission
Choice of Charge Breeder for CARIBU

**EBIS vs ECR:**
- Higher breeding efficiency (about factor 2)
- Better purity of beams (several orders)
- Shorter breeding time (factor 5-10)

**Choice for CARIBU:**
- "Classical" EBIS
  - Proven technology (REXE GIS, CERN)
  - Higher acceptance (larger electron beam size) than in case of EBIT
- BNL RHIC and Test EBISes are prototypes (the most advanced EBIS technology nowadays)
EBIS Charge Breeder - Principle of Operation

- 1+ ions are accumulated in the RFQ cooler-buncher
- Injection time ~10 μs
- Breeding time ~33 ms
- Extraction time ~10 μs can be adjusted if necessary
- Repeat with the rate of 30 Hz
- Transverse confinement is achieved by electron beam space charge
- Longitudinal confinement is provided by drift tube potentials

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Main Parameters of CARIBU EBIS Charge Breeder

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low current e-gun</th>
<th>High current e-gun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superconducting solenoid: length/field</td>
<td>1 m/6 T</td>
<td>1 m/6 T</td>
</tr>
<tr>
<td>Diameter of the IrCe thermocathode</td>
<td>1.6 mm</td>
<td>4 mm</td>
</tr>
<tr>
<td>Electron beam current</td>
<td>0.2 A</td>
<td>2 A</td>
</tr>
<tr>
<td>Electron beam energy</td>
<td>~2 keV</td>
<td>~5 keV</td>
</tr>
<tr>
<td>Electron beam diameter in the trap</td>
<td>~230 µm</td>
<td>~580 µm</td>
</tr>
<tr>
<td>Electron beam current density in the trap</td>
<td>~480 A/cm²</td>
<td>~750 A/cm²</td>
</tr>
<tr>
<td>Ion trap length</td>
<td>0.5 m</td>
<td>0.5 m</td>
</tr>
<tr>
<td>Trap capacity (in elementary charges)</td>
<td>~4 x 10¹⁰</td>
<td>~2 x 10¹¹</td>
</tr>
</tbody>
</table>

Required q/A of charge bred ions > 1/7

CBSIM code (Xe)

Low current e-gun will be used to study efficiency gain at shell closures

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Off-line Commissioning Configuration

1 – e-gun with RT coil, 2 – ion trap chambers, 3 – 6 T SC solenoid, 4 – electron collector, 5 – 2nd Einzel lens & steerers, 6 – 75 kV acceleration tube, 7 – diagnostics chambers, 8 – 1st Einzel lens & steerers, 9 – electrostatic switchyard, 10 – steerers, 11 – quad lens, 12 – 60 kV ceramic break, 13 – Cs$^+$ ion source, 14 – 70° bending magnet, 15 - FC

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Injection-Extraction Line & Electrostatic Switchyard

TRACK, EM Studio and Particle studio were used to optimize elements of injection-extraction line:

- Diagonally split cylindrical steerers
- Steerers are incorporated into Einzel lenses
- Steerers and lenses with large aperture (110 mm) to minimize emittance growth
- 15° diagonally split cylindrical switchyard
**Drift Tube Structure**

- **Potential leads (SS, 3 mm)**
- **Openings for pumping**
- **Openings for potential leads**
- **NEG coating**
- **Supporting tube (scaffold)**
- **Screws for centering and holding (3 on each end)**

- NEG coating instead of NEG strips due to restricted space and highest pumping speed (largest NEG surface)
- Alignment – by high accuracy of ceramic stand-off length ($\pm$ 25 $\mu$m) vertically and by insertion of tube into structure horizontally

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6 T Superconducting Solenoid

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Field</td>
<td>6.0 T</td>
<td>6.05 T @ 82.66 A</td>
</tr>
<tr>
<td>Maximum Field</td>
<td>6.6 T</td>
<td>6.6 T @ 90.17 A</td>
</tr>
<tr>
<td>Charge Time to 6 T</td>
<td>70 min</td>
<td>70 min</td>
</tr>
<tr>
<td>Field Homogeneity</td>
<td>± 0.4% over ± 30 cm on axis</td>
<td>± 0.2% over ± 30 cm on axis</td>
</tr>
<tr>
<td>Coil Inductance</td>
<td>195 H</td>
<td>193 H</td>
</tr>
<tr>
<td>Field Decay Rate</td>
<td>&lt; 1 ppm/hour</td>
<td>&lt; 0.01 ppm/hour</td>
</tr>
</tbody>
</table>
**Electron Guns**

Supplier: BINP (Novosibirsk, Russia)

G. I. Kuznetsov

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CARIBU (high current)</th>
<th>CARIBU (low current)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Up to 2 A</td>
<td>Up to 0.2 A</td>
</tr>
<tr>
<td>Current density at the cathode</td>
<td>10–15 A/cm²</td>
<td>10–15 A/cm²</td>
</tr>
<tr>
<td>Magnetic field at the cathode</td>
<td>~ 0.15 T</td>
<td>~ 0.15 T</td>
</tr>
<tr>
<td>surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cathode material</td>
<td>IrCe</td>
<td>IrCe</td>
</tr>
<tr>
<td>Cathode diameter</td>
<td>4 mm</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>Radius of cathode convex surface</td>
<td>6.6 mm</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>Expected cathode lifetime</td>
<td>~ 20000 hours</td>
<td>~ 20000 hours</td>
</tr>
</tbody>
</table>

- IrCe thermionic cathodes demonstrated the longest life time

- 2 A and 0.2 A e-guns are exchangeable by exchanging cathode units

**Perveance is about $2 \cdot 10^{-6} \text{ A/V}^{3/2}$**
Electron Collector

Collector is capable to dissipate up to 25 kW power of DC electron beam

- Input Flange (stainless steel)
- Water Channels
- Outer Cup (oxygen free copper)
- Magnetic Shield (steel)
- 4 Inlet and 4 Outlet Water Pipes (copper)
- Output Flange (stainless steel)
- Collector Body (oxygen free copper)

Brazing of all collector parts using gold based alloy at 1000 °C

ANSYS simulations
- Water flow – 5 gpm
- Max temperature rise of collector – 67°C
- Water pressure drop – about 35 psi
- Water temperature rise – about 14°C
Vacuum Testing of Ion Trap

- Turbo pumps (480 l/s N₂)
- NEG pumps (5000 l/s H₂, 2250 l/s N₂)
- Cryo pumps (4000 l/s H₂O)

In situ baking for 72 hours:
- 450 °C – trap middle
- 300 °C – trap ends

Achieved residual gas pressure - 1.5·10⁻¹⁰ Torr

Better vacuum is expected with NEG coated scaffold

1 – e-gun, 2 and 6 – gate valves, 3 and 5 – ion gauges, 4 - 6 T superconducting solenoid, 7 - 25 kW electron collector
Assembly for Electron Beam Commissioning

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Electron Beam Commissioning

Transport of 2 A/400 μs electron beam from e-gun cathode to collector was optimized by tuning of 8 pairs of magnetic steering coils and room temperature collector coil.

- Close to 100 % transmission from e-gun to collector
- Electron beam losses at 10 mm collimator (collector entrance) below 1 mA
- Current of secondary electrons streaming back from collector at 11 mm collimator below 1 mA

Next step – transport of DC electron beam with total losses on drift tubes and collimators about 50 μA
Summary

• EBIS charge breeder is an excellent choice for acceleration of CARIBU rare isotope beams by ATLAS
• Design of EBIS charge breeder was completed
• Different EBIS charge breeder sub-systems were recently commissioned and met specified parameters
• EBIS charge breeder was assembled in final configuration
• Commissioning of 2 A electron beam was successfully performed in pulsed mode