HIE-ISOLDE
The technical options

Mats Lindroos and Matteo Pasini, the ISOLDE technical team and the ISOLDE collaboration
(Yacine Kadi)
HIE-ISOLDE: Next step with three objectives

✓ ENERGY: REX energy upgrade and increase of current capacity (Matteo Pasini)
  • Energy upgrade in 3 stages: 8 MeV and 10 MeV/u and lower energy capacity

✓ QUALITY: ISOLDE radioactive ion beam quality - more than half already financed through the ISOLDE collaboration
  • Smaller longitudinal and transverse emittance
    • Done
  • RILIS upgrade and LARIS construction
    • Done
  • Charge breeder upgrade
  • Better mass resolution
  • Continued target and ion source developments
    • On-going and absolutely essential!

✓ INTENSITY: ISOLDE proton driver beam intensity upgrade - strongly linked to PS Booster improvements including linac4 (INTENSITY WP, Richard Catherall)
  • Faster cycling of the booster
  • New target stations for ISOLDE
  • New target design
  • New target handling system
HIE-ISOLDE project

• **HIE-ISOLDE 1**
  - Energy upgrade up to 8-10 MeV/u with a superconducting linac, beam quality improvements and the design study of the intensity upgrade
    • R&D activity for LINAC funded

• **HIE-ISOLDE 2**
  - Intensity upgrade for 30 kW on target
    • Linac 4 beam via PSB and Light SPL beam to ISOLDE
  - Super-HRS
Existing REX-ISOLDE linac – a world leading RIB facility
HIE-ISOLDE LINAC - layout

3 stages installation

1.2 MeV/u

3 MeV/u

5.5 MeV/u

8 MeV/u

10 MeV/u
HIE-ISOLDE SC-linac

• SC-linac between 1.2 and 10 MeV/u
• Energy fully variable; energy spread and bunch length are tunable. Average synchronous phase \( \phi_s = -20 \) deg
• \( 2.5<A/q<4.5 \) limited by the room temperature cavity
• 16.02 m length (without matching section)
• No ad-hoc longitudinal matching section (incorporated in the lattice)
Final Beam Energies

N.B! With ECR technology:
- $A/q=6 \quad 7.9 \text{ MeV/u}$
- $A/q=9 \quad 5.4 \text{ MeV/u}$
Cavity prototype
Cryomodule design

Each cryomodule can be isolated and taken out in case of failure.

Common vacuum concept to minimize the inter-cryomodule distance.

This concept foresees the possibility to align the solenoid when cold from the outside (beam alignment).
HIE-ISOLDE SC linac
DOE proposal - Comparison EBIS/ECR/1+

<table>
<thead>
<tr>
<th>Efficiency for single charge-state re-acceleration</th>
<th>Proposed high-intensity EBIS/T breeder</th>
<th>Next-generation ECR breeder</th>
<th>1+ scheme with stripping</th>
<th>Gain EBIS/T vs ECR</th>
<th>Gain EBIS/T vs 1+</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε (A&lt;40)</td>
<td>&gt; 60 %</td>
<td>&lt; 20 %</td>
<td>&lt;40%</td>
<td>&gt;3</td>
<td>&gt;1.5</td>
</tr>
<tr>
<td>ε (A=100)</td>
<td>&gt; 50 %</td>
<td>&lt; 20 %</td>
<td>&lt;10%</td>
<td>&gt;2.5</td>
<td>&gt;5</td>
</tr>
<tr>
<td>ε (A=200)</td>
<td>&gt; 40 %</td>
<td>&lt; 20 %</td>
<td>&lt;5%</td>
<td>&gt;2</td>
<td>&gt;8</td>
</tr>
<tr>
<td>Chance of reaching breeding performance</td>
<td>Present performance 25-50% of values</td>
<td>Present performance 20-40% of values</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breeding (trapping) time</td>
<td>&lt;20 ms</td>
<td>&gt;100 ms</td>
<td>NA</td>
<td>&gt;5</td>
<td>NA</td>
</tr>
<tr>
<td>Beam rate limit</td>
<td>&gt;10^9/s</td>
<td>&gt;&gt;10^11/s</td>
<td>No limit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chance of reaching beam rate capability</td>
<td>RHIC test EBIS: 10^9 ions/pulse</td>
<td>No risk</td>
<td>No risk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam purity - stable beam current intensities</td>
<td>pA</td>
<td>&gt;&gt; μA</td>
<td>NA</td>
<td>&gt;&gt;1000</td>
<td>NA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proposed High-Intensity EBIT</th>
<th>MSU EBIT</th>
<th>TITAN EBIT</th>
<th>BNL test EBIS</th>
<th>REX-EBIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron beam energy (keV)</td>
<td>&lt; 60</td>
<td>&lt; 30</td>
<td>&lt; 60</td>
<td>&lt;30</td>
</tr>
<tr>
<td>Electron beam current (A)</td>
<td>&lt; 10</td>
<td>&lt; 5</td>
<td>&lt;5</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Central current density (A/cm^2)</td>
<td>&lt;10^5</td>
<td>&lt;10^4</td>
<td>&lt;10^4</td>
<td>&lt;600</td>
</tr>
<tr>
<td>Magnet design</td>
<td>Helmholtz coil + Solenoid</td>
<td>Helmholtz coil + Solenoid</td>
<td>Helmholtz coil</td>
<td>Solenoid</td>
</tr>
<tr>
<td>Maximum magnetic field (T)</td>
<td>9</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Trap length (m)</td>
<td>1 m</td>
<td>0.5 m</td>
<td>0.1 m</td>
<td>0.7 m</td>
</tr>
</tbody>
</table>

O. Kester et al.
RFQ cooler “ISCOOL” - DONE
EPSCR grant (Manchester, Birmingham)

Emittance meter

RFQ cooler

Alkali ion source

Continuous mode

\(~5\pi \cdot \text{mm} \cdot \text{mrad} \)

90% emittance

\(~30\pi \cdot \text{mm} \cdot \text{mrad} \)

90% emittance as input

<table>
<thead>
<tr>
<th>Ion</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li⁺</td>
<td>17%</td>
</tr>
<tr>
<td>Na⁺</td>
<td>27%</td>
</tr>
<tr>
<td>K⁺</td>
<td>60%</td>
</tr>
<tr>
<td>Cs⁺</td>
<td>70%</td>
</tr>
</tbody>
</table>
The Resonance Ionization Laser Ion Source

RILIS beams of 28 elements are available so far:

<table>
<thead>
<tr>
<th>Elements Available at ISOLDE LIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-step: (1 resonance)</td>
</tr>
<tr>
<td>3-step: (2 resonance)</td>
</tr>
</tbody>
</table>

4 types of ionization scheme:

2-step: (1 resonance)  
(2 resonance)  
3-step: (2 resonance)  
(3 resonance)
New Nd:YAG lasers at ISOLDE RILIS - DONE

Diode Pumped Solid State Nd:YAG Lasers as replacement of Copper Vapor Lasers:

**CVL**
- 15 ns @ 11 kHz
- Green Beams: 45 W @ 511 nm
- Yellow Beams: 35 W @ 578 nm

**SSL**
- 8 ns @ 10 kHz
- Green Beams: 90 - 100 W @ 532 nm
- UV Beam: 18 W @ 355 nm
- IR Beam: 35 W @ 1064 nm

**Improvement of Ga ionization efficiency by SSL:**
- Two dye lasers were applied at 1st step of excitation - x 2
- More power could be delivered to HRS target at the 2nd step of excitation
- Better power stability

Knut and Alice Wallenberg foundation grant
Road map of RILIS upgrade

- Installation of solid state lasers for dye laser pumping. Keeping CVL lasers at RILIS as backup until reliable SSL performance is reached.

- Upgrade of dye lasers: purchasing and installation of commercial dye lasers

- Installation of solid-state tunable lasers with own pump laser in addition to the dye laser system

- Duo-RILIS: two laser systems available for operation with a possibility of quick switch from one element to another

Knut and Alice Wallenberg foundation grant
LARIS results – A new RILIS scheme for Manganese - DONE

- Replacement of current scheme which uses the CVL green beam.

**Outcome of RIS study of Mn at LARIS:**

Many new auto-ionizing states found

Various promising Nd:YAG based schemes tested and ready for efficiency measurement at RILIS

Knut and Alice Wallenberg foundation grant
ISOLDE target area - The 3D Laser Scan

Cloud of point in the CERN coordinate system

Reference Points

May, 2008

J. Sarret, L. Bruno
Manipulator concept design

- 6-DOF Manipulator mounted on ceiling monorails
- Equipped with tool changer for mounting different tools
- Recoverable by decoupling (remotely) rail gear drive
- High lifting capacity (FFE)
- Target & electrode accurate / sensitive operations
Overall layout of the new injectors (1/2)
Analysis

- **SPL block diagram**

```
Linac4  β=0.65  β=1  β=1  β=1
```

Extraction to ISOLDE

- **Main impact of faster cycling rate: klystron modulators (SPL + Linac4)**

Limited $P_{\text{average}}$ + technology limited cycling rate ($\sim 15$ Hz)

$P_{\text{average}} \propto \text{Modulator pulse length} \times \text{Rep. rate}$

$P_{\text{average}} \propto (\text{Modulator rise} + \text{Cavity fill} + \text{Beam pulse}) \times \text{Rep. rate}$

- **Other consequences of faster cycling rate:**
  - Magnets power supplies
  - Beam instrumentation
  - Controls…

$\beta = 0.65$  $732 \text{ MeV}$  $1.4 \text{ GeV}$

$160 \text{ MeV}$  $(560 \text{ MeV})$  $(1 \text{ GeV})$  $2.5 \text{ GeV}$  $4-5 \text{ GeV}$

$E_{\text{acc}} = 200 \mu s$

$\propto E_{\text{acc}}^2$
# Minimum cost options

⇒ LP-SPL type modulators ($P_{\text{nominal}} \equiv 0.35$ % duty cycle)

* Basic period : 600 ms – PS2 cycling time: 2.4 s

<table>
<thead>
<tr>
<th>Beam energy (GeV)</th>
<th>Max. pulse duration (ms)</th>
<th>Max. current during pulse (mA)</th>
<th>Cycling rate* (Hz)</th>
<th>Max. protons /pulse ($\times 10^{13}$)</th>
<th>Max. beam power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>0.9</td>
<td>20</td>
<td>1.25 (3 out of 4 pulses)</td>
<td>11</td>
<td>31</td>
</tr>
<tr>
<td>0.35</td>
<td>28</td>
<td>2.92 (7 out of 8 pulses)</td>
<td></td>
<td>6.1</td>
<td>29</td>
</tr>
</tbody>
</table>

Baseline solution

Need for wide range high power RF phase shifters… ⇒ Cost!
Summary

• Planning for a staged implementation project

• HIE-ISOLDE 1
  - HIE LINAC R&D within the EUCARD I3 and with Belgium grant is making good progress
  - Test of the first cavity for the SC linac are expected in June/July at TRIUMF in Vancouver
  - On-going beam quality development e.g. RFQ cooler and RILIS
  - Construction of linac and design study of new target area

• HIE-ISOLDE 2
  - Construction of new target area and Super-HRS
  - Linac 4 (10 kW) and LP-SPL (30 kW)