Radioactive Ion Beam Post-Acceleration at CERN-ISOLDE

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for the HIE-ISOLDE Project Team
Outline

- **Introduction**
  - CERN-ISOLDE Facility
  - HIE-ISOLDE Upgrade
- **HIE-ISOLDE Phase 1**
  - Commissioning and operation in 2016
- **HIE-ISOLDE Phase 2**
  - Installation and commissioning activities
  - 2017 Operations
- **Summary & Outlook**
ISOLDE Facility

- ISOLDE is the CERN radioactive ion beam facility
- Oldest experiment at CERN (approved > 50 y ago)
- Provides low energy and post-accelerated beams
- Run by an international collaboration since 1965

- > 500 Users from 100 Institutions, 50 experiments / year
- Decay spectroscopy (IDS, TAS,..)
- Coulomb excitation (MINIBALL)
- Transfer reactions (T-REX, Scattering)
- Electromagnetic Properties (COLLAPS, CRIS, NICOLE)
- Polarized Beta-NMR (VITO, COLLAPS)
- Masses (ISOLTRAP)
- Fundamental Interactions (WITCH)
- Applications:
  - Solide state (Collections)
  - Life Science (collections & VITO)
HIE-ISOLDE Cryomodule # 1

Late August 2014: Assembly start

Assembly time of CM1: 30 weeks
Baseline: 27 weeks

1 May 2015: Assembly completed

Mid-June 2015: Successfully cooled to 4.5K
2015 Commissioning Campaign

The 2015 Commissioning campaign achieved its goals

CM design choices validated

SC cavities performance were confirmed with beam

RF coupler problem identified (overheating)

Physics run started on 19th October, on schedule
2015 Operations

- SRF limited to running ~ 6 - 8 hours per working day due to heating problem in couplers
- Typically: SRF on during the day, REX energy during the evenings and nights
- Approximately 2.5 days needed for a non-scalable new A/Q set-up of the machine

![Diagram showing operation hours and set-up times for various isotopes from 22-Oct to 12-Nov, with a note indicating a 6-8 hours limit for SRF set-up time.]
RF Coupler Heating

RF short preventing further cavity loading

RF cable insulation melt and polymerized
RF Coupler Heating

RF short prevents further cavity loading.

RF cable insulation melt and polymerized.
Phase 1: Commissioning & Operation (2016)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Isotope</th>
<th>HEBT</th>
<th>Destination</th>
<th>Energy [MeV/u]</th>
<th>Shifts</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS-562</td>
<td>$^{110}$Sn</td>
<td>XT01</td>
<td>Miniball Spectrometer</td>
<td>4.5</td>
<td>12</td>
</tr>
<tr>
<td>IS-562</td>
<td>$^{108}$Sn</td>
<td>XT01</td>
<td>Miniball Spectrometer</td>
<td>4.5</td>
<td>12</td>
</tr>
<tr>
<td>IS-548</td>
<td>$^{142}$Xe</td>
<td>XT01</td>
<td>Miniball Spectrometer</td>
<td>4.5</td>
<td>30</td>
</tr>
<tr>
<td>IS-557</td>
<td>$^{80}$Zn</td>
<td>XT01</td>
<td>Miniball Spectrometer</td>
<td>4.0</td>
<td>12</td>
</tr>
<tr>
<td>IS-557</td>
<td>$^{78}$Zn</td>
<td>XT01</td>
<td>Miniball Spectrometer</td>
<td>4.0</td>
<td>12</td>
</tr>
<tr>
<td>IS-551</td>
<td>$^{132}$Sn</td>
<td>XT01</td>
<td>Miniball Spectrometer</td>
<td>5.5</td>
<td>18</td>
</tr>
<tr>
<td>IS-561</td>
<td>$^9$Li</td>
<td>XT02</td>
<td>Scattering Chamber</td>
<td>6.9 (7.2 req.)</td>
<td>15</td>
</tr>
<tr>
<td>IS-559</td>
<td>$^{68}$Ni</td>
<td>XT01</td>
<td>Miniball Spectrometer</td>
<td>5.5</td>
<td>24</td>
</tr>
</tbody>
</table>

Energy Gain for $^{12}$C$^{3+}$: 5.42 MeV/u
Commissioning and operation : 2016

- Cool down and commissioning of CM1+CM2 hardly performed during summer 2016
- Major issues identified: CP flow limitation, bad LHe “quality” supply, and strong oscillations in the 4.5K return line (-> indications of high heat load estimated to 3 x the expected figure)
- Operational conditions found by increasing by-pass valve opening in the Return Box and by powering heaters in each CM

- Investigations of Cryogenic Distribution System (CDS) in situ did not show evidence of problem (cold spots, vacuum issue)
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### IS557: Coulomb excitation $^{74}\text{Zn} - ^{80}\text{Zn}$ (N=50): probing the validity of shell-model descriptions around $^{78}\text{Ni}$

<table>
<thead>
<tr>
<th>RF structure</th>
<th>REX</th>
<th>HIE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7GP1</td>
<td>7GP2</td>
</tr>
<tr>
<td># Trips</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Downtime [mins]</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Downtime [%]</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

#### Beam transmission/efficiency (approx.)

<table>
<thead>
<tr>
<th>Low energy</th>
<th>REX-TRAP + EBIS</th>
<th>REX/HIE linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>88 %</td>
<td>13 %</td>
<td>68 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment #</th>
<th>IS557</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIB (A/q)</td>
<td>$^{78}\text{Zn}^{20+}$ (3.9)</td>
</tr>
<tr>
<td>Energy [MeV/u]</td>
<td>4.3</td>
</tr>
<tr>
<td>Target</td>
<td>GPS</td>
</tr>
<tr>
<td>Exp. Station</td>
<td>Miniball Spect.</td>
</tr>
<tr>
<td>Start date</td>
<td>Oct. 10$^{th}$ (18:00)</td>
</tr>
<tr>
<td>End date</td>
<td>Oct. 17$^{th}$ (04:30)</td>
</tr>
<tr>
<td>Length [hours]</td>
<td>130</td>
</tr>
<tr>
<td>Pilot beam (A/q)</td>
<td>$^{39}\text{K}^{10+}$ (3.9)</td>
</tr>
<tr>
<td>Target type</td>
<td>UC2</td>
</tr>
<tr>
<td>EBIS breeding time [ms]</td>
<td>75</td>
</tr>
</tbody>
</table>
**IS551: Coulomb excitation of doubly magic $^{132}\text{Sn}$ with MINIBALL at HIE-ISOLDE**

<table>
<thead>
<tr>
<th>RF structure</th>
<th>REX</th>
<th>HIE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7GP1</td>
<td>7GP3</td>
</tr>
<tr>
<td># Trips</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>Downtime [mins]</td>
<td>450</td>
<td>135</td>
</tr>
<tr>
<td>Downtime [%]</td>
<td>5.8%</td>
<td>1.7%</td>
</tr>
</tbody>
</table>

**Beam transmission/efficiency (approx.)**

<table>
<thead>
<tr>
<th>Low energy</th>
<th>REX-TRAP + EBIS</th>
<th>REX/HIE linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>10.5 %</td>
<td>68 %</td>
</tr>
</tbody>
</table>

**Experiment #** | IS551
---|---
**RIB (A/q)** | $^{132}\text{Sn}^{31+}$ (4.26)
**Energy [MeV/u]** | 5.5
**Target** | HRS
**Exp. Station** | Miniball Spect.
**Start date** | Oct. 19th (19:50)
**End date** | Oct. 26th (08:20)
**Length [hours]** | 130
**Pilot beam (A/q)** | $^{39}\text{K}^{9+}$ (4.33)
**Target type** | UC2
**EBIS breeding time [ms]** | 194
2016 Physics Campaign

IS561: Transfer reactions at the neutron dripline with triton target

<table>
<thead>
<tr>
<th>RF structure</th>
<th>REX</th>
<th>HIE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7GP1</td>
<td>7GP3</td>
</tr>
<tr>
<td># Trips</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Downtime [mins]</td>
<td>210</td>
<td>45</td>
</tr>
<tr>
<td>Downtime [%]</td>
<td>4.7%</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

Beam transmission/efficiency (approx.)

- Low energy: 81%
- REX-TRAP + EBIS: 4%
- REX/HIE linac: 75%

Experiment # | IS561
RIB (A/q)    | $^9\text{Li}^3+$ (3.0)
Energy [MeV/u] | 6.8 (7.2 req.)
Target        | GPS
Exp. Station  | Scattering Chamber
Start date    | Oct. 28th (22:20)
End date      | Nov. 1st (8:30)
Length [hours] | 70
Pilot beam (A/q) | $^{12}\text{C}^4+$ (3.0)
Target type   | UC
EBIS breeding time [ms] | 21
2016 Beam Commissioning

- Beam transverse profiles were measured at different locations
- Comparison w.r.t. optics model were postponed to 2017 => could not optimize beam transmission
2016 Beam Commissioning

The energy of the beam was measured using three independent methods:

- Calibration of the RF systems ($W_{RF}$)
- First dipole of the XT01 HEBT line ($W_{B}$)
- TOF between silicon detectors in XT00 ($W_{TOF}$)

<table>
<thead>
<tr>
<th>#</th>
<th>$E_{SRF08}$ [MV/m]</th>
<th>$W_{RF}$ [MeV/u]</th>
<th>$W_{RF} - W_{TOF}$</th>
<th>$W_{B}$ [MeV/u]</th>
<th>$W_{B} - W_{TOF}$</th>
<th>$W_{TOF}$ [MeV/u]</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>5.455</td>
<td>4.908</td>
<td>4.866</td>
<td>4.810</td>
<td>4.777</td>
<td></td>
</tr>
<tr>
<td>E2</td>
<td>4.455</td>
<td>4.846</td>
<td>4.745</td>
<td>4.740</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E3</td>
<td>3.455</td>
<td>4.784</td>
<td>4.677</td>
<td>4.670</td>
<td></td>
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</tr>
<tr>
<td>E4</td>
<td>2.455</td>
<td>4.722</td>
<td>4.631</td>
<td>4.621</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E5</td>
<td>1.455</td>
<td>4.659</td>
<td>4.572</td>
<td>4.574</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E6</td>
<td>0.455</td>
<td>4.597</td>
<td>--</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E7</td>
<td>0.000</td>
<td>4.569</td>
<td>--</td>
<td>--</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Phase 2: Installation & Commissioning (2017)
Phase 2: Installation & Commissioning (2017)
2017 Cryogenic Maintenance and Repairs

- Preventive and corrective maintenance (10’000 h): charcoal, filters, gearbox, safety valves, calibration check of whole instrumentation, valves, vacuum syst, ...

- Update of CP logic -> allow full CP performance and ease restarts;

- Update of refrigerator process control -> more robust process with automatisms allowing reconnection of cryomodules in all cool down situations

- **endoscopic investigations of the inner parts of the cryogenic distribution line:** Obvious contact of LHe and GHe lines (headers C & D) with the shield in the TL interconnecting the Jumper Box (JBs)
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Cool down of 3 CMs

LHe filling of cryomodules achieved much quicker wrt 2016 and via the frame circuit only ⇒ proof of better LHe «quality»

<table>
<thead>
<tr>
<th>Phases</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>300K → 5K</td>
<td>15 days</td>
<td>9 days</td>
</tr>
<tr>
<td>LHe Filling (stable)</td>
<td>5 days</td>
<td>4h for CM1&amp;2 + 4h for CM3</td>
</tr>
</tbody>
</table>
Cavity performance on line in 2017

- MP conditioning and RF measurements at cold done on all 15 cavities
- Performance gain on line due to smaller temperature gradients across $T_c$
Frequency perturbation

- Reminder: the cause of sudden cavity trips last year
- The frequency shift has positive correlation to LHe pressure and valve
- Slow (10-20 min) and “small” (~10Hz) can be easily followed by the tuner moved by stepping motor.
Summary & Outlook

• Phase 1 has been completed
• Quite successful Physics Run in 2016
• Schedule for 2016/2017 Shutdown:
  ✓ Installation of CM3 completed
  ✓ Installation of 3rd beam line + ISS magnet on XT02 completed
  ✓ Cryogenics maintenance & consolidation completed
• HW commissioning work on track, due to finish at end of May:
  ✓ Overall RF performance of SC cavities is very good
  ➢ Only 2 cavities suffer from field emission
  ✓ Frequency perturbation is much less severe, still worth improving
  ✓ LLRF setting up (ongoing), solenoids powering, cold alignment
• Physics Run to start early July 2017:
  ✓ Only 13/27 requested beams in 2017 could be scheduled (235 shifts)
  ✓ typical acceleration is 4.4 – 5.5 MeV/u (exceptions: 9Li and 11Be)
THANK YOU
ACKNOWLEDGEMENTS

- The ISOLDE Collaboration

- The HIE-ISOLDE project team and in particular all the groups within the CERN Accelerator and Technology Sector.

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