Status of the HIE-ISOLDE linac

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on behalf of the HIE-ISOLDE teams

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• Project Phases
• Status of the HIE-ISOLDE linac technical systems
  • General infrastructure
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  • Alignment and Monitoring
  • Beam Instrumentation
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• Summary
NC linac for post acceleration of ISOLDE RIBs up to 3 MeV/u

Started in 2001: 72 different beams already used of > 700 available at ISOLDE
Physics program @ REX

Coulomb excitation with Miniball: collective versus individual nucleon behaviour

WE NEED MORE ENERGY!
HIE-ISOLDE phases

HIE-ISOLDE LINAC: STAGE 1

HIE-ISOLDE LINAC: STAGE 2a

HIE-ISOLDE LINAC: STAGE 2b
Physics scope at HIE-ISOLDE

- May 2010: 34 LoI submitted
- 1 Nov 2012: INTC endorsed the increase of 2 GeV-proton energy for ISOLDE
- 27 experiments already approved
- 600 shifts already allocated for physics

Number of institutes (82) per country involved in HIE-ISOLDE
Proposals submitted in October 2012
HIE ISOLDE installation progress

- Compressor building 198
- Water station B197
- Cold Box building 199
- HIE SC linac
- Equipment platform
- High Energy Beam Transfer lines HEBT
- ISOLDE target zone
- ISOLDE Low Energy
Compressor building 198

- Demineralized water station
- Chilled water station
- Compressors skid
RF, cryogenics, solenoid racks, and CV systems installed.
Linac Hall

Linac shielding

HEBT magnet supports and piping
Cryo Module 2 installation: Shutdown 2015/16: Jan – March 2016
Scenario: 2nd commissioning at 5.5Mev/u with 2 CM’s as of May 2016
High beta cryomodules (phase II)
High beta QWR

### HIE ISOLDE

<table>
<thead>
<tr>
<th></th>
<th>Baseline†</th>
<th>New*</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$ at 4.5K [MHz]</td>
<td>101.28</td>
<td>101.28</td>
</tr>
<tr>
<td>$\beta_{opt}$ [%]</td>
<td>10.86</td>
<td>10.88</td>
</tr>
<tr>
<td>TTF at $\beta_{opt}$</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>$R/Q$ [Ω] (incl. TTF)</td>
<td>554</td>
<td>556</td>
</tr>
<tr>
<td>$E_p/E_{acc}$</td>
<td>5.5</td>
<td>5.0</td>
</tr>
<tr>
<td>$H_p/E_{acc}$ [G/(MV/m)]</td>
<td>95.4</td>
<td>95.3</td>
</tr>
<tr>
<td>$U/E_{acc}^2$ [mJ/(MV/m)^2]</td>
<td>208</td>
<td>207</td>
</tr>
<tr>
<td>$G=R_s Q$ [Ω]</td>
<td>30.7</td>
<td>30.8</td>
</tr>
<tr>
<td>$P_{diss}$ @ 6 MV/m [W]</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>$P_{diss}$ on bottom plate [W]</td>
<td>0.0035</td>
<td>0.0018</td>
</tr>
</tbody>
</table>

†Original tuning plate  *Simplified tuning plate

Ref. Proceedings of SRF2009, p. 609
Bias diode sputtering system at CERN

Schematics

System assembly in clean room

Thermocouples positions:
- Inner conductor
- Ext. top
- Ext. middle (regulator)
- Ext. bottom

CAVITY
CATHODE
IR-Lamps
GRIDS
DC -1000V
Bias -80V
Surface quality of the inner conductor tip

Central electrode: 20 mm diameter, at earth potential

No counter electrode
Cavity Tuning

<table>
<thead>
<tr>
<th>influence variables</th>
<th>frequency shift (kHz)</th>
</tr>
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<tr>
<td>295 K to 4.5 K and air to vacuum</td>
<td>+371 +/- 5</td>
</tr>
<tr>
<td>chemical etching 40'</td>
<td>-27 +/- 3</td>
</tr>
<tr>
<td>Nb coating</td>
<td>-7 +/- 5</td>
</tr>
</tbody>
</table>

Measured $f_0$: 101.156 MHz, $\Delta f$ by mechanical error: kHz
Suggested tg: 80.35 mm, suggested trimming: 27.1 mm
Surface resistance vs. thermal gradient across $T_c$.

Thermal gradient: $\Delta T = T_2 - T_1$
Cavity production workflow

Start: Cavity reception

Cavity tuning → Surface treatment → Rinsing cleanroom assembly

6 weeks production process

Niobium coating

Ultrapure water rinsing (dust free)

End: Cavity storage

RF test → Test cryostat preparation → Cavity closure

Quality Factor vs Eacc(MV/m)
Prototype cavities performance

Quality Factor vs. $E_{acc}(\text{MV/m})$
Performance of the first 4 series cavities

The graph shows the quality factor as a function of the accelerating electric field strength $E_{\text{acc}}$ (MV/m). The data is categorized by different power levels (10 W, 7 W) and specifications (HIE-ISOLDE with final plate, QP2.1, QP3.2, QS1.1, QS2.1). The graph illustrates the performance improvement with increasing $E_{\text{acc}}$ and power levels, adhering to specific specifications for each category.
Series cavities stored
RF systems (Power and LLRF)

- Low microphonics; sensitivity to He pressure $\sim 0.01$ Hz/mbar, no beam loading $\rightarrow$ high $Q_L$ in operation
- $\rightarrow$ Eased design for the input coupler
- $\rightarrow$ 700 W solid state RF amplifiers

- State of the art digital LLRF system
  - Direct RF sampling
  - Digital quadrature demodulation
  - Direct RF generation by DAC
  - VME form factor, 1 LLRF controller card per cavity

- LLRF system installed in 14 shielded racks

- Reference RF phase distributed over the length of linac to allow automatic cavity phasing for different species

Paper TUPP031
High beta cryomodules

Nb-Ti
SC solenoid
SC solenoid
Qualification test results solenoid1

Training performance

Magnetic field measurements
Cryo-module assembly
Cryo-module elements
Cryo-module reception and logistics area
Cryo-module assembly area
Integration of Cryo-module cold test stand
Beam Transport and beam instrumentation
NC magnets

Pre-series dipole yoke stacking

Series Quad #2

Pre-series steerer delivered June 2014

Series Quad #3
Diagnostic box prototype validated
Short Faraday cup qualification tests

HIE linac FC

![Diagram of Faraday cup with repeller and collector](image)

![Graph showing the fluctuation on I_{beam}](image)

- E/A = 5.50 MeV/u ($^4$He$^+$)
- E/A = 1.53 MeV/u ($^{20}$Ne$^{5+}$)
- E/A = 2.63 MeV/u ($^{20}$Ne$^{5+}$)
- E/A = 5.43 MeV/u ($^{20}$Ne$^{5+}$)
MATHILDE (Monitoring and Alignment Tracking for Hie IsoLDE)

Requirements:
- 0.3mm (Cavities) and 0.15mm (Solenoids) at 1σ with respect to the nominal beam line

H-BCAM cameras and electronics
- Manufactured
- Calibrated
- Delivered at CERN

High-index glass ball targets:
- Tested precision: 10 micro-rad at 1σ
- Tested in vacuum and at 5 K
- Targets under price inquiry

Viewports with 5 deg. tilt:
- Effects on measurement studied and verified
- Quantity for 2 CM delivered at CERN
  → Under Reception Tests

Metrologic plate toward final design

Software development on-going
Safety
Cryogenic Hazard

Safety pressure device on insulation vacuum routed outside

Safety pressure device on LHe tank routed outside

Port for instrumentation re-assigned to rupture disk

Access to the tunnel possible while cryo-modules are cold
Radioprotection (I)

X-Ray doses: Locally hundreds of $\mu$Sv/h on the roof during He processing

BASELINE : NO ACCESS TO THE ROOF
Radioprotection (III)

```
<table>
<thead>
<tr>
<th>A</th>
<th>Z</th>
<th>q</th>
<th>A/q</th>
<th>Stage1 MeV/u</th>
<th>Stage2 MeV/u</th>
<th>Stage3 MeV/u</th>
<th>Stage1 Sw/ht at 1 m</th>
<th>Stage2 Sw/ht at 1 m</th>
<th>Stage3 Sw/ht at 1 m</th>
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<tbody>
<tr>
<td>He</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>10.19</td>
<td>16.90</td>
<td>20.05</td>
<td>1.6E-06</td>
<td>6.6E-06</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>6.47</td>
<td>10.20</td>
<td>11.45</td>
<td>1.3E-07</td>
<td>1.1E-06</td>
</tr>
<tr>
<td>N</td>
<td>14</td>
<td>7</td>
<td>4</td>
<td>3.5</td>
<td>8.09</td>
<td>13.19</td>
<td>15.37</td>
<td>2.3E-07</td>
<td>1.5E-06</td>
</tr>
<tr>
<td>O</td>
<td>16</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>8.36</td>
<td>13.67</td>
<td>15.98</td>
<td>3.5E-07</td>
<td>1.7E-06</td>
</tr>
<tr>
<td>Ne</td>
<td>20</td>
<td>10</td>
<td>6</td>
<td>3.333333333</td>
<td>7.23</td>
<td>11.62</td>
<td>13.33</td>
<td>9.6E-08</td>
<td>8.2E-07</td>
</tr>
<tr>
<td>Ar</td>
<td>40</td>
<td>18</td>
<td>9</td>
<td>4.444444444</td>
<td>6.08</td>
<td>9.47</td>
<td>10.46</td>
<td>7.7E-08</td>
<td>6.6E-07</td>
</tr>
</tbody>
</table>
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HIE simplified planning

Timeline:

- **Start Isolde shutdown**: 17 Dec 2012
- **End LS1: Start Low E physics**: July 2014
- **We are here**: September 2014
- **HIE physics at 4.2 MeV/u**: October 2015

**Civil eng.**
- **Civil eng. hall & tunnel**
- **Main services**
- **SRF cavities R/D**

**Cabling**

**RF**

**HEBT**

**Cryo**

**CM 1**

**CM 2**

**Beam commissioning**: 7 weeks

**HIE installations and tests** (Isolde normal operations)

**Machine Check-Out** (Isolde normal operations)

**Beam Commissioning** (Isolde normal operations)
To be Commissioned in 2015

- Re-commissioning of REX nc linac
- 1 cryomodule / cavities (including cryo plant and infrastructure)
- 2 experimental beam lines
Status summary

HIE-ISOLDE is much awaited for by the nuclear physics community.

We are aiming at delivering the first beams at the end of 2015, with one cryomodule, physics programme was adjusted accordingly:

- General infrastructure progressing well
- Cavity workflow at CERN optimized, throughput ~ 1 cavity/month
- 3 cavities accepted, fourth cavity on hold
- Copper substrates non conformities being handled
- SC solenoids: first conforming item being delivered at CERN
- Cryomodule assembly infrastructure in place
- Cryomodule elements being received from industry, also with strong engagement of the CERN workshops
- Cryomodule assembly in clean room starting
- Beam instrumentation, alignment and monitoring equipment validated and being procured
- Safety issues addressed, safety file to be approved by end 2014
- Staggered dry runs of the installed equipment, software and controls starting at the end of this year.
Acknowledgments

CERN technical staff
All the HIE ISOLDE Working Groups at CERN
Belgian Big Science program of the FWO (Research Foundation Flanders) and the Research Council K.U. Leuven.
CATHI Marie Curie Initial Training Network: EU-FP7-PEOPLE-2010-ITN Project number 264330.
The HIE ISOLDE International Advisory Panel
CERN management
Thanks for the attention....

... backup slides
Operation with one cryomodule

Between October 2015 and 2015/16 shutdown, only one cryomodule (5 cavities) will be available. Can we run with a missing cryomodule?

- The beam blows up but remains well inside +/- 20 mm aperture
- The beam can be matched into the transport channel with the matching quadruplet without losses

±20 mm
Series substrates “teething” problems

Not visible anymore after SUBU

Defect appeared close to the weld after SUBU
Frequency monitoring in metrology

<table>
<thead>
<tr>
<th></th>
<th>Initial freq. (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QS1</td>
<td>101.207 ± 0.002</td>
</tr>
<tr>
<td>QS2</td>
<td>101.206 ± 0.002</td>
</tr>
<tr>
<td>QS3</td>
<td>101.209 ± 0.002</td>
</tr>
</tbody>
</table>

![Graph showing frequency changes over time with corresponding temperature and humidity values.](image)
**Thermal cycle (B→, B↓, B↑)**

<table>
<thead>
<tr>
<th></th>
<th>1&lt;sup&gt;st&lt;/sup&gt; TC(norm)</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt; TC(norm)</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; TC(reduced)</th>
<th>4&lt;sup&gt;th&lt;/sup&gt; TC(enhanced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max T reached (K)</td>
<td>16.8</td>
<td>17.4</td>
<td>17.0</td>
<td>18.8</td>
</tr>
<tr>
<td>ΔT during transition(K)</td>
<td>0.21 ± 0.06</td>
<td>0.11 ± 0.05</td>
<td>0.15 ± 0.05</td>
<td>0.18 ± 0.03</td>
</tr>
<tr>
<td>P&lt;sub&gt;cav&lt;/sub&gt;@6MV/m</td>
<td>10.8 W</td>
<td>11.5 W</td>
<td>10.4 W</td>
<td>12.5 W</td>
</tr>
</tbody>
</table>

**QP3.2 after rinsing with new plate**

![Graph showing Q0 vs. Eacc (MV/m)]
Rs vs. B-field

Rs0

\[ y = 0.0011x + 15.968 \]
\[ R^2 = 0.9876 \]

Rs1

\[ y = 0.0013x + 4.9354 \]
\[ R^2 = 0.992 \]
Low-Level RF system

• A block diagram of the HIE-Isolede LLRF system
Low-Level RF system

- Example of a cavity start up at $Q_0$

1) Start at low power, measure cavity parameters (BW)
2) Inject nominal power
3) Mechanical tuner action
4) Switch over to generator driven mode, lock the loops
Beam current measurements: Faraday Cup (stable beams)

Faraday cups work in a regime where the loss of electrons is negligible (plateau), with $V_{\text{rep}} \sim -60$ V.
Radioprotection (II)

Neutrons production: can become significant at HIE energies (outside shielding)

Full beam loss of 1 ppA (profile)

He 19.8 MeV/amu

Acknowledgment: J. Vollaire DGS/RP

“Draw up a clear table of operational modes and ions species with intensities and energies required and evaluate the resulting dose rates…”