Development of H⁻ Ion Source for JYFL Pelletron Accelerator

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Presentation outline

- Short introduction to JYFL Accelerator Laboratory
- Background to ion source development
- Design of filament-driven H⁻ ion source
- Measurements
- Future plans for ion source development
JYFL: Personnel of 190, including 85 Ph.D. students

Main research areas:

- Nuclear and accelerator based physics:
- Material physics
- High-energy physics
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In Accelerator Laboratory:
- Accelerator technology
- Rare isotope beam science (IGISOL)
- Nuclear structure at the limits (RITU, MARA, JUROGAM)
- Nuclear reactions
- Accelerator based material physics (PELLETRON)
- Industrial applications (RADEF)
- Nuclear theory
One of the leading stable-ion beam facilities

NuPECC Long Range plan 2010

- Accelerator Laboratory is an integral part of the Department of Physics
- K130: over 6000 beam time hours a year
- EU Access Laboratory in FP4, FP5, FP6 and FP7
- International infrastructure in Finland
  - over 200 users a year, foreign investments of 10 M€
- Accredited European Space Agency (ESA) test facility
Accelerator Laboratory layout

- Ion sources
- Applications
- MARA
- RITU
- Test beamlines
- Pelletron
- RADEF
- IGISOL4
- K=130 MeV
- K=30 MeV
Motivation

The JYFL 1.7 MV Pelletron accelerator is primarily used for ion beam analysis and ion beam lithography.

More about the Pelletron facility after the coffee in a talk by M. Laitinen.
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The applications would benefit from high brightness proton beams, that the existing Alphatross and SNICS ion sources couldn’t produce.
Production of $H^-$ with existing ion sources

Alphatross RF source

- Produces typically up to 250 nA of $H^-$, too low intensity
- Unconvenient to change between He and H, different size Ta channel needed
Production of H\(^-\) with existing ion sources

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**SNICS**
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- Poor beam stability in \(\sim\) hour timescale
- Changing of cathodes
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It would be convenient to have a dedicated H\(^-\) ion source.
We have the space, experience, know-how and workshop at JYFL for designing, engineering and building a filament driven volume production H⁻ ion source. Also by making it in-house, the costs could be kept low.
H⁻ ion source for Pelletron

So we started a development project for the Pelletron Light Ion Source, PELLIS.
H⁻ ion source for Pelletron

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PELLIS

Pellis (finnish), Bellis Perennis, English Daisy
Volume source operation principle

\[ \text{H}_2 \to \text{H}^- \] (fast)

\[ \text{H}_2(\nu) \to \text{H}^- \] (slow)

Extraction
PELLIS design

16 pole NdFeB-42 multicusp and back plate cusp

1.5 mm Ta filament with 70-80 A heating current and up to 8 A arc current at 100-120 V

2 mm diameter plasma electrode aperture
PELLIS design

Magnetic filter field for volume H-production formed by electric magnets

Permanent magnet dipole-antidipole electron dump integrated in puller electrode

SS430 plasma electrode insert for separating the magnetic fields
PELLIS magnetic filter

- Electric magnets with $3 \times 70$ rounds of $\varnothing 0.95$ mm copper winding each
- Magnet placed within the ion source front plate immersed in cooling water
PELLIS magnetic filter

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PELLIS extraction simulations

The plasma extraction and low energy beam transport were designed with IBSIMU code.

Nominal beam parameters used in simulations were 100 \( \mu \text{A} \) H\(^-\) and 3.5 mA e\(^-\) with \( T_i = 1.0 \) eV (upper limit).
PELLIS extraction simulations

The beam rms emittance from the source/extraction according to the simulations was between $0.017$ and $0.020$ mm mrad depending on the input parameters.

Beam exits the extraction with a 5 mrad angle. Can be corrected by electrostatic deflectors and/or dipole magnet of the injection beam line.
PELLIS schematic

- Source bias -10 kV/10 mA
- Einzel #1 -10 kV/10 mA
- Einzel #2 -10 kV/100 uA

Turbo-molecular pump

Switching magnet

230 VAC INPUT

Isolation transformer

3 kW, 20 kV

H₂

Arc 150 V/11.2 A

Filament 12 V/140 A

Filter magnet 20 V/20 A

Puller 10 kV/10 mA

HV break

FC position
PELLIS installed

The ion source was installed in February 2012 and characterized with current and emittance measurements.
PELLIS performance

The $\text{H}^-$ current to the first FC and electron current to electron dump with 0.5 Pa gas pressure and filter magnet current for maximal $\text{H}^-$ current.

![Graph showing the relationship between arc current (A) and $\text{H}^-$ current (µA) and electron current (mA). The graph indicates the $e^-/\text{H}^-$ ratio between 30 and 120.]
PELLIS performance

- Iarc 0.58 A, H- current
- Iarc 0.58 A, electron current
- Iarc 2.37 A, H- current
- Iarc 2.37 A, electron current
- Iarc 5.60 A, H- current
- Iarc 5.60 A, electron current
Emittances were measured with Allison-scanner at 169 mm from plasma electrode. Data was filtered with thresholding to contain 95% of beam.
PELLIS emittance

Emittances were measured with Allison-scanner at 169 mm from plasma electrode. Data was filtered with thresholding to contain 95% of beam.

![Graph showing emittance vs. current for different gap voltages](image)

Extraction was designed for 100 µA current. Puller-plasma gap should be increased and/or plasma electrode aperture made smaller to reach optimum at typical current levels.
It is known that there is an optimal operation point at certain current. The minimum emittance value and location of optimum depends on plasma parameters, which are difficult to estimate ⇒ optimum has to be searched experimentally. Extraction is on threaded rods!
Beam through the accelerator
Applied Kilovolts MS0.2MZZ065 6 channel ±200 V power supply was acquired for driving the deflector plates in the injection.

- Provides $\sim 10\%$ increase in accelerated beams from other ion sources
- $\sim 50\%$ increase from PELLIS.
Beam through the accelerator

Transmission measurement at 1 MV

Transmission ($I_{ext}/I_{inj}$)

Injection current (µA)

1.7 µA highest accelerated H⁺ produced so far.
Beam through the accelerator

Transmission measurement at 1 MV

Optimal stripper gas pressure dominates transmission
Cost of ion source
## Cost of ion source

<table>
<thead>
<tr>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament and arc power supplies</td>
<td>4200 €</td>
</tr>
<tr>
<td>Filter magnet power supply</td>
<td>1000 €</td>
</tr>
<tr>
<td>High voltage power supplies</td>
<td>3700 €</td>
</tr>
<tr>
<td>Isolation transformer</td>
<td>1700 €</td>
</tr>
<tr>
<td>Magnets</td>
<td>500 €</td>
</tr>
<tr>
<td>Gas line, regulator, needle valve, etc.</td>
<td>1200 €</td>
</tr>
<tr>
<td>O-rings, water and vacuum fittings, etc.</td>
<td>1200 €</td>
</tr>
<tr>
<td>Materials</td>
<td>2500 €</td>
</tr>
<tr>
<td>Workshop hours</td>
<td>15000 €</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>31000 €</td>
</tr>
</tbody>
</table>

Designing, engineering?
Future plans for ion sources

In addition to improving the PELLIS beam brightness with extraction adjustment, two other improvements are underway.

1. Replacement of the existing SNICS ion source with 40 MC-SNICS

Second hand ion source from GNS, New Zealand is ready to be installed.
Future plans for ion sources

2. Improvement of NEC RF-Alphatross performance

Main problems are:

- Production of the $\text{He}^+$ in the RF ion source
- Highly sensitive alignment of the source

He$^+$ drilling through Tantalum
Future plans for ion sources

Planned improvements:

- Improving the power efficiency of plasma generation with inductive or Helicon-mode RF coupling.
- Change of solenoid magnet and/or magnet power supply for higher B-field.
- Studying He\(^+\) beam formation, possibly changing to traditional plasma electrode - puller electrode extraction for better control of alignment.
Thank you for your attention!