Program to improve the JYFL ion beam transport efficiency for K130 cyclotron

Contents:
- Present beam transport and possible reasons for the behavior
- Program/steps towards the better beam transport
- Beam instabilities/plasma research
- New RF-driven H⁻ ion source
Low energy beam line: 14 GHz ECRIS – K130 cyclotron

The main problem: Cyclotron requires injection voltage of about 10 kV
Present extraction geometry:

- Extraction electrode
- Puller electrode
- Decel-electrode
- Asymmetric Einzel lens (negative)
- Grounded holder
The efficiency decreases when the total beam intensity from the ECRIS increases! Why?

Total beam intensity of about 1 mA seems to be a critical limit.
Effect of solenoid:

A beam profile of the Ar\(^{9+}\) ion beam (110 µA) obtained downstream from the DJ1 analysing magnet when a high focusing power is used. A hollow beam structure is present: corresponds to maximum intensity measured after the dipole!

Indications/questions:
- Hollow beam caused by the solenoid focusing?
- Space charge problem: Yes
- Space charge compensation?

A beam profile of the Ar\(^{9+}\) ion beam (33 µA) obtained downstream from the DJ1 analysing magnet (DJ1) after the JYFL 14 GHz ECRIS when a low focusing power is used. Beam is cut some where?
Effect of decel-voltage

Decel-voltage = 0
- 64 µA of Ar$^8+$ beam
- Fairly good beam profile

Decel-voltage = 4 kV
- 100 µA of Ar$^8+$ beam
- Hollow beam structure
- Remarkable increase of emittance!

Indications: we should not use decelerating electrodes!
- Slows down the beam (which is already slow)
- Affects probably the space charge compensation
Lets try to change the space charge compensation:
A) By adding electrons into the beam line (gas feeding)
B) By decreasing the electrons (positive grid)
Effects of adding electrons
Electron production with neutral gas injection via ionization processes

Beam quality improves → transmission improved
Charge exchange and ionization processes → beam losses

→ only a modest increase in accelerated beam
Effect of removing electrons – beam current
Positive grid used to remove electrons from the beam

Unpublished results: measurements by V. Toivanen (spring 2011)

Our typical operation voltage: amount of compensating electrons is of critical importance!
Effect of removing electrons – beam emittance (quality)

Between ECRIS and dipole

After dipole

Even a small disturbance in space charge compensation (before mass separation) destroys the beam quality!
Beam formation simulations with IBSimu

New code developed by: Taneli Kalvas

Originally developed for H⁻ ion beams
Can be used now also for positive ion beams!

New comprehensive simulations for our present extraction geometry
by: Ville Toivanen
At 10 kV extraction voltage

Plasma meniscus

0.38 mA

1.11 mA

1.75 mA

<table>
<thead>
<tr>
<th>$I_{\text{ext}}$ (mA)</th>
<th>$I_{\text{out}}$ (mA)</th>
<th>Transmission (%)</th>
<th>Beam shape</th>
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</thead>
<tbody>
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<td>98.8</td>
<td>not hollow</td>
</tr>
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</table>

Maximum usable total beam intensity!

This is the behavior we have observed!!

→ Bad emittance → low transmission efficiency!
How to solve the transport problem?
1) New extraction capable of handling more beam (work in progress!)
2) ECRIS closer to dipole: no focal point (space charge effect reduced)
3) First section of the beam line on high voltage (higher velocity of ion beam)
4) New high quality dipole
5) Future R&D concerning further space charge compensation, etc...
6) New ECRIS?
New extraction design: no decelerating electrodes

1.5 mA, 100 % transmission

$\approx - 25 \text{ kV}$

2.2 mA, 100 % transmission

2.9 mA, 100 % transmission