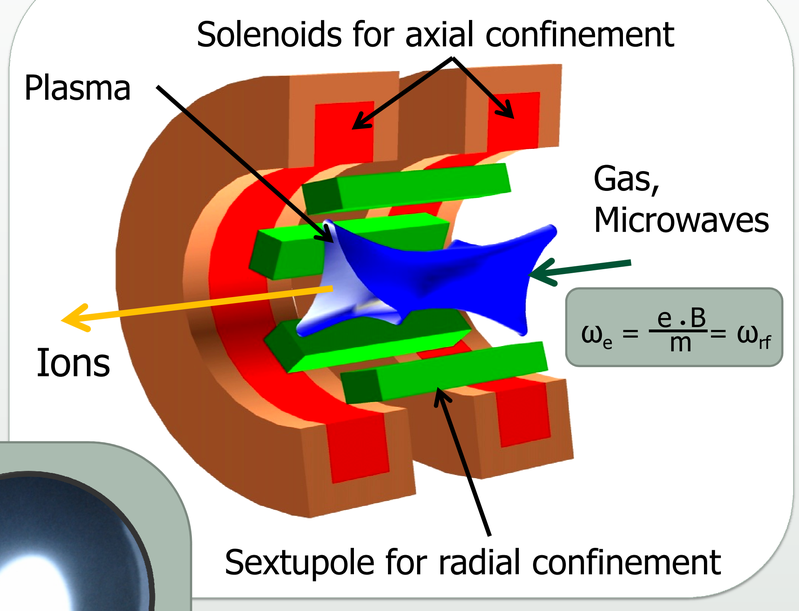
ECRIS extraction and LEBT simulations with the PIC code WARP

Daniel Winklehner, Daniela Leitner,
LBNL, Berkeley, CA, USA and NSCL-MSU, East Lansing, MI, USA

Introduction

The versatility of ECR (Electron Cyclotron Resonance) ion sources makes them the injector of choice for many heavy ion accelerators. However, the design of the LEBT (Low Energy Beam Transport) systems for these devices is challenging. This work aims to provide a design tool for future ECRIS extraction and LEBT systems.

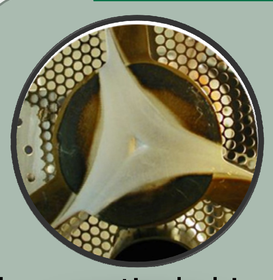
ECRIS Cartoon



Challenges

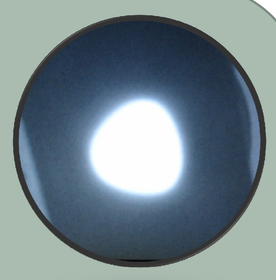
- Multi species extraction
- Sextupole confinement → beam profile exhibits no radial symmetry
- Extraction takes place at a high magnetic field → adds to emittance and rotation
- Different focal properties of the beam species due to different magnetic rigidity
- Changing space charge through the magnet
- Include 3D Fringe fields of the analyzing magnet
- Beam Neutralization

Initial Conditions



The negatively biased disk at the injection side of the source shows distinct sputter marks, especially a small triangle etched deeply into the disk.

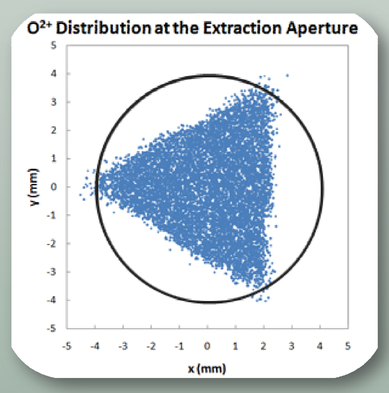
The extraction aperture shows sputter marks similar to the biased disk. Field lines coming from the small triangle at the other disk all pass through the aperture forming, again, a triangle.



A Tantalum viewing screen after extraction shows a triangular beam.

Initial Conditions 2

Sputter marks on the biased disk are used to obtain initial conditions for a WARP extraction simulation by collisionless tracking of ions through the source's magnetic field (10,000 ions per species, 28 species).



x

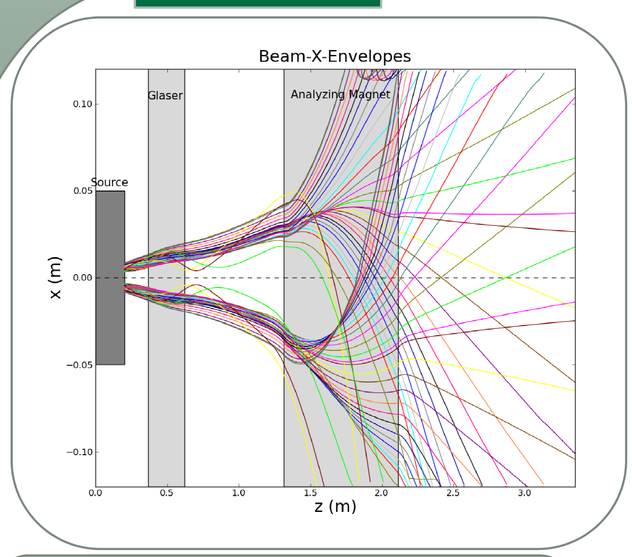
+

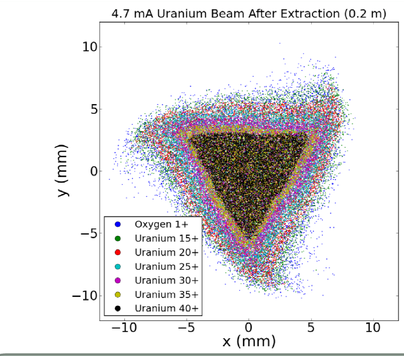
Parameter	Value	
Total extracted current	**1.6 emA**	**4.6 emA**
Ion mean Temperature	2 eV	2 eV
Uranium E_{kin} (longitudinal)	~3 eV	~3 eV
Electron Temp. (in sheath)	5 eV	5 eV
Source Voltage	20 kV	22 kV
Puller Voltage	-2 kV	-3 kV
B_{max} at extraction	2.1 T	2.1 T
Extraction Aperture ↔Puller	31.5 mm	21.6 mm

Simulation 1 - Extraction

- RZ – Symmetry Mode: Axially symmetric beam with the same initial parameters as the triangular beam is extracted using a 2D plasma sheath extraction model. The beam is tracked through the simulation several times, until steady state (relaxation) at the plasma surface has been reached.
- The potential is stored and used as an applied field in a single 3D Simulation.

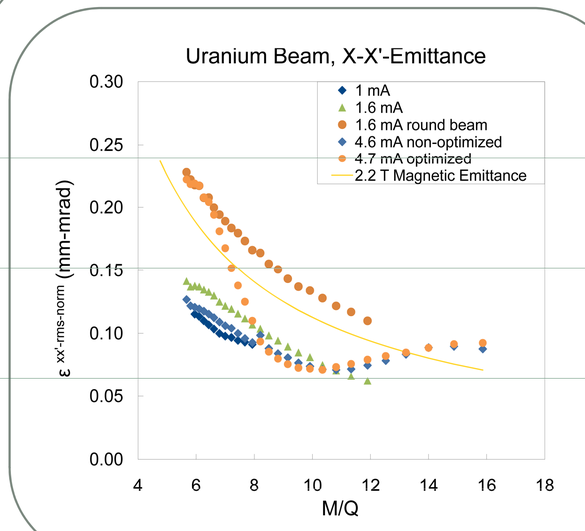
First Results

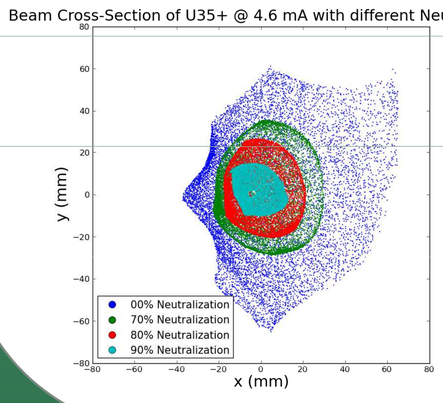




Above: Selected beam cross-sections 20 cm after extraction, note different focusing and rotation.
Below: Comparison of horizontal emittances 3.3 m after extraction.

Above: Horizontal beam envelopes from 0.2 m to 3.3 m
Coordinates inside the 90 degree bend are transformed ('warped') so the selected species seems to go straight.





Left: Beam cross-sections at 3.3 m for different neutralization levels of a 4.6 mA beam.

Simulation 2 – Beam Transport

A two dimensional (xy) Poisson-solver is used to simulate the beam line transport in slice mode, neglecting the longitudinal self-fields which have little effect for longitudinal beam velocities much higher than transversal beam velocities. The two beam optics elements in this simulation are a solenoid focusing magnet and a dipole analyzing magnet.

Conclusion

WARP Simulations for ECR Ion sources are a work in progress.

Achieved so far:

- Multispecies Injection inside the plasma with non-uniform particle distributions
- Effects like hollowing of the beam and multi-component beams are seen in simulation
- Emittances are in reasonable agreement with measurement

Requires further analysis:

- Changing radial distribution for each species (are higher charge states bound more tightly to the axis?)
- Systematic studies of ion and electron temperatures and influence on outcome of simulation
- Neutralisation (Beamline, Solenoid, Dipole)

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