Comparison of extraction and beam transport simulations with emittance measurements from the ECR ion source VENUS

D. Winklehner[1,3,#], D. Todd[1], D. Grote[2], D. Leitner[1], J. Benitez[1], M. Strohmeier[1], F. Aumayr[3]
[1]LBNL, Berkeley, CA 94704, USA, [2]LLNL, Livermore, CA 94551, USA,
[3]Vienna University of Technology, Vienna, Austria
[#]email: dwinklehner@lbl.gov

VENUS

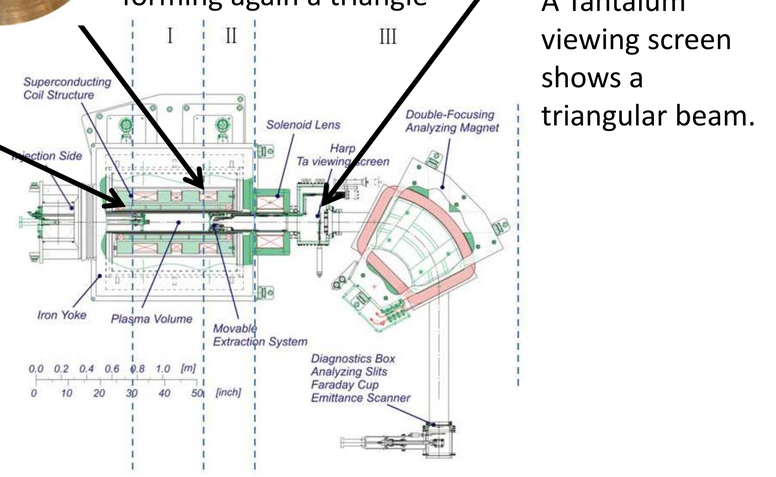
Abstract

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, because it has to be matched for a wide variety of ions. In addition, due to the magnetic confinement fields, the ion density distribution across the extraction aperture is inhomogeneous and charge state dependent. In addition, the ion beam is extracted from a region of high axial magnetic field, which adds a rotational component to the beam. In this paper the development of a simulation model (in particular the initial conditions at the extraction aperture) for ECR ion source beams is described. Extraction from the plasma and transport through the beam line are then simulated with the particle-in-cell code WARP. Simulations of the multispecies beam containing Uranium ions of charge state 18+ to 42+ and oxygen ions extracted from the VENUS ECR ion source are presented and compared to experimentally obtained emittance values

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.

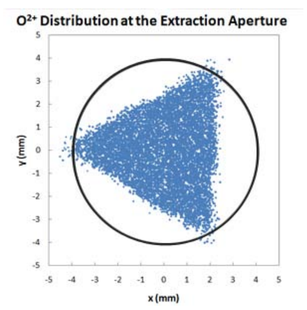
The extraction aperture shows sputter marks similar to the biased disk. Field lines coming from the small triangle at the other disk all pass through the aperture forming again a triangle



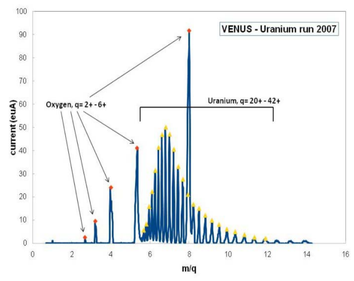
A Tantalum viewing screen shows a triangular beam.

- From emittance data that suggests a decreasing beam diameter at extraction with increasing charge state and beam images taken with a Tantalum viewing screen that show a triangular beam shortly after extraction it is concluded that the beam at the extraction aperture of the ECR ion source VENUS is smaller than the aperture and has triangular shape.
- Sputter marks on the biased disk are used to obtain initial conditions for a WARP extraction simulation by tracking ions through the source's magnetic field.

Simulations



Ion distributions in the plasma shortly before extraction…



…for each species in a spectrum of a Uranium beam of VENUS…

Parameter	Value
Ion mean Temperature	2 eV
Uranium E_{kin} (longitudinal)	~3 eV
Electron Temperature (in sheath)	5 eV
Source Voltage	20 kV
Puller Voltage	-2 kV
Total drain current	1 mA
Max. mag. flux density at extraction	2.1 T

…together with initial parameters of the source, form the input values of the simulations.

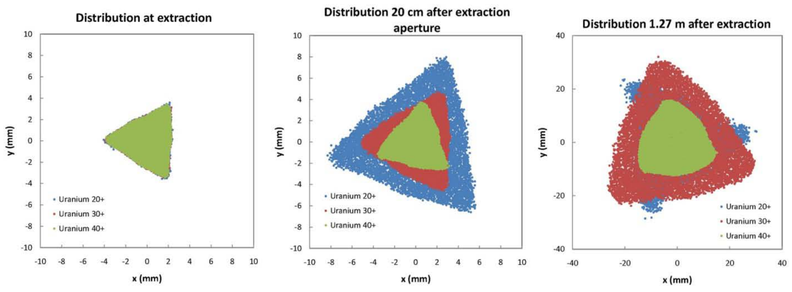
<u>Simulations are then done with the particle-in-cell code WARP in a three step process:</u>

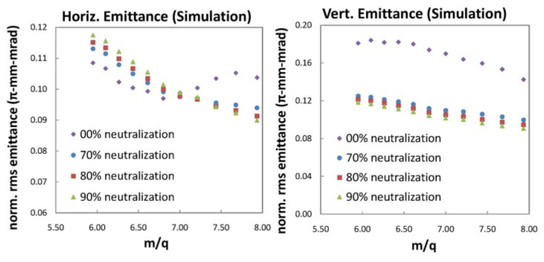
- An axially symmetric beam with the same species parameters, currents and energies as the triangular beam is extracted using a two-dimensional (rz) plasma sheath extraction model. The beam is tracked through the simulation several times, until a relaxation of the combined potential of applied fields and self-fields has been reached.
- The obtained potential is stored and used as an applied field in the second step, where the beam is initialized with the obtained triangular particle distributions and the simulation is run in three-dimensional mode.
- 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.

Simulation Results

Spatial distributions of U^{20+}, U^{30+} and U^{40+} :
- in the plasma,
- 20cm after extraction
- 127cm after extraction

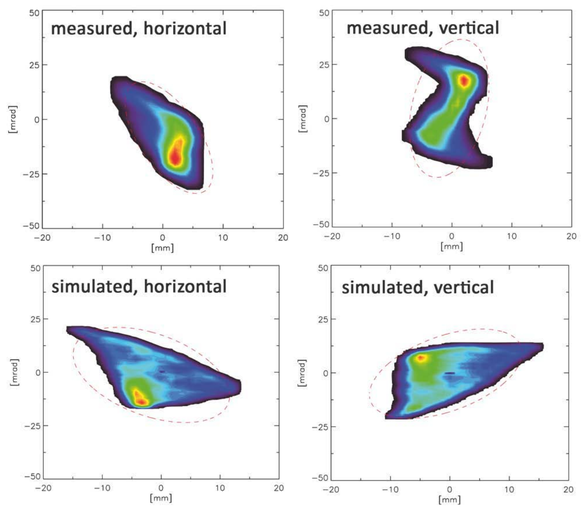
A noticeable difference in rotation and focusing is seen for different species.



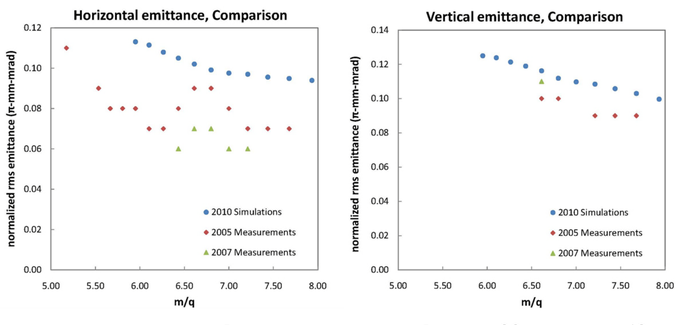


Comparison of horizontal and vertical emittances for U^{20+} to U^{40+} for different neutralization factors. As expected, a decrease is seen in vertical emittance with increasing neutralization, the horizontal emittance, however, shows additional structures which can't be explained at the moment and will be further investigated.

Comparison to Experiment



Comparison of U^{36+} phase space plots 3.3 m after extraction (position of the diagnostics box after the analyzing magnet). The simulation was done with 70% neutralization and optimal focusing for U^{36+}. Though there is no 1:1 resemblance, certain features (like the region of maximum beam current seem to be in good agreement.



Comparison of emittances for U^{30+} to U^{43+} obtained by simulations and by experiment. An unusual trend of increasing emittance with decreasing m/q of the experimental results is also seen in the simulations.

Conclusion

A new method of obtaining initial conditions on the plasma side of the extraction simulation has been tested and a simulation of a 28 species Uranium beam has been run. The first results look promising and further investigation of the influence of:
- Initial ion and electron temperature
- Initial radial ion density profile
- Beam neutralization in the beam line

on the results of the presented simulation model seems feasible.

Acknowledgements

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