3D simulations of the CAPRICE ECRIS extraction system

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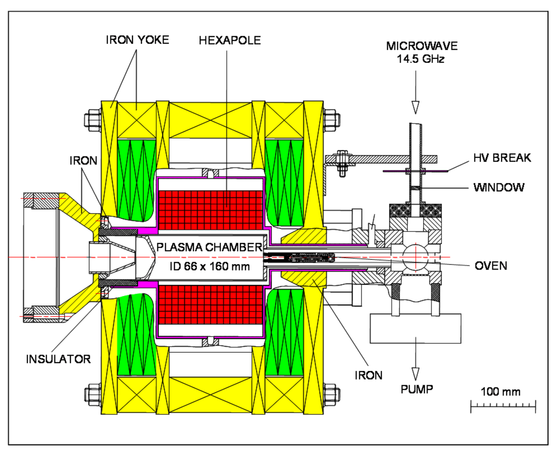
Abstract

The simulation of the ion extraction from the Electron Cyclotron Resonance Ion Sources (ECRISs) is necessary for the optimization and development of the performance of ion sources. Due to the magnetic field configuration of the ECRISs the calculations need to be performed in 3D. Therefore simulation programs based i.e. on C++ libraries like IBSimu [1] were developed. In this work a physical model was implemented in IBSimu generating detailed 3D simulations of ion extraction from a CAPRICE-type ECRIS. Simulations of multi-species Argon ion beam including Helium contribution as support gas extracted from CAPRICE are carried out. The simulation results were compared to experimental findings, i.e. ion beam intensities and beam profiles measured with viewing screens.

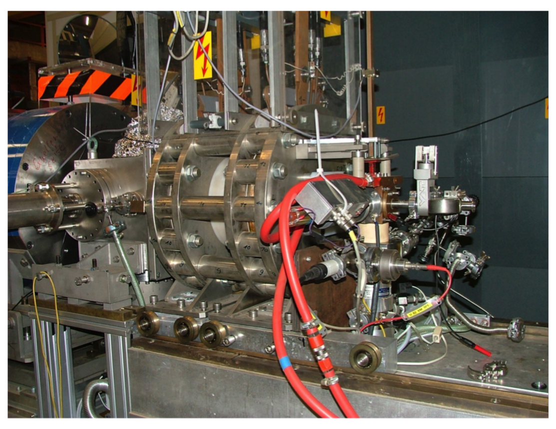
CAPRICE ECRIS



(a) Structure of the CAPRICE-ECRIS

Hexapole field	1 ... 1,2 T
Solenoid field	0,8 ... 1,5 T
microwave-power	10 ... 800 W (CW)
microwave-frequency	14,5 GHz
Ion species	Gas and Metal

(b) CAPRICE-ECRIS main parameters



(c) Picture of the CAPRICE-ECRIS

Figure 1. Experimental setup of the CAPRICE-ECRIS. (a) illustrates the schematic layout of the ion source, (b) presents the key parameters of the ion source, and (c) provides a photograph of the experimental setup.

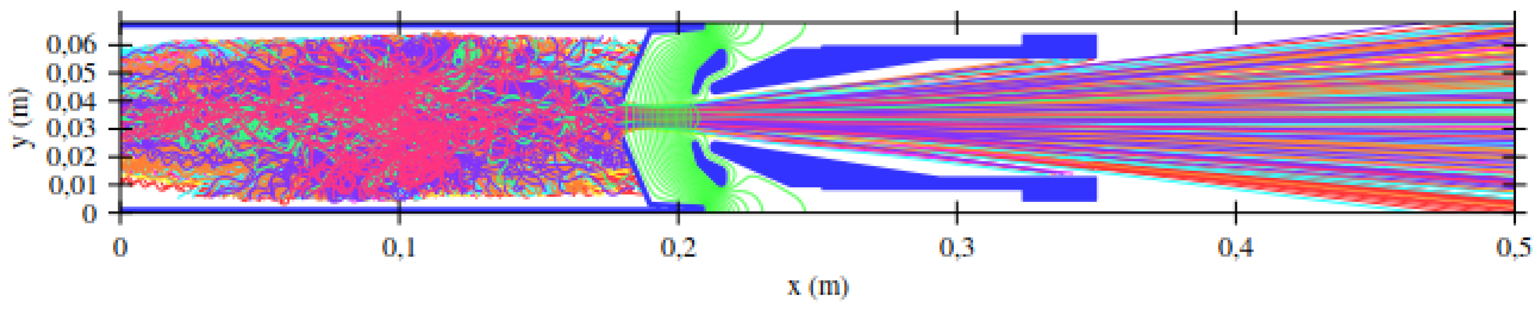
Simulations

To ensure a comparable simulation, the program was modeled as closely as possible to the experimental setup. However, some parameters crucial to the proper functioning of the simulation could not be measured or set during the experiment. As a result, certain assumptions had to be made. The following table and figures present the simulation parameters and results that most accurately reflected the experimental outcomes.

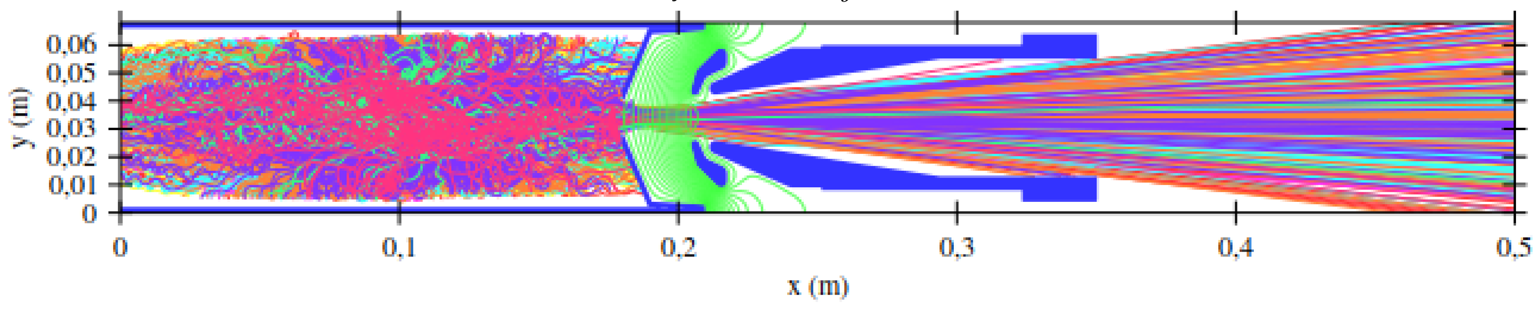
parallel ion temperature T_p	0.1 eV	plasma electrode voltage	15 kV
transversal ion temperature T_t	0.15 eV	screening electrode voltage	-2 kV
start energy of the ions E_i	0.8 eV	ground electrode voltage	0 V
electron temperature T_e	5 eV	number of ions N	100000
location of ion creation	$x = 0.1$ m	(middle of the plasma chamber)	

Table 1. Simulation parameters

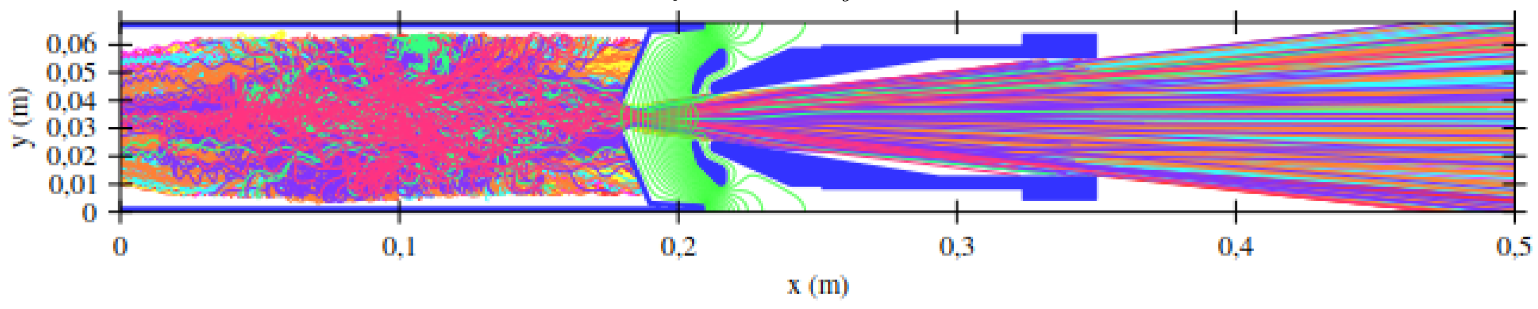
The simulations were conducted for various charge states of argon (Ar^{3+} to Ar^{10+}) together with helium (He^{+} and He^{2+}) and hydrogen (H^{+}) ions. The magnetic field parameters and electrode geometry (STL files) utilized in the simulation were based on the results of simulations previously performed. [2]



(a) Ion trajectories for $j = 5$ A/m^2

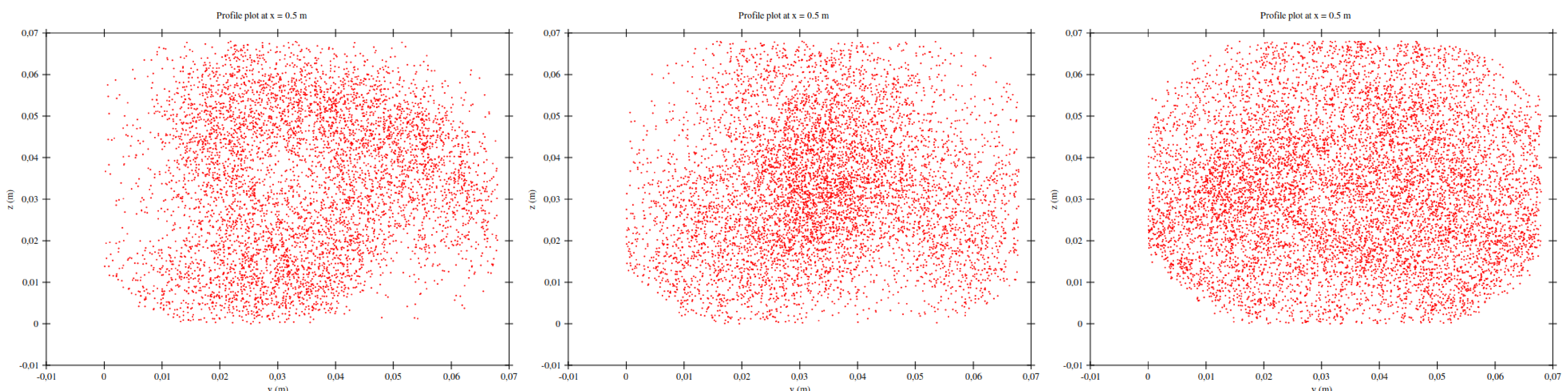


(b) Ion trajectories for $j = 3$ A/m^2

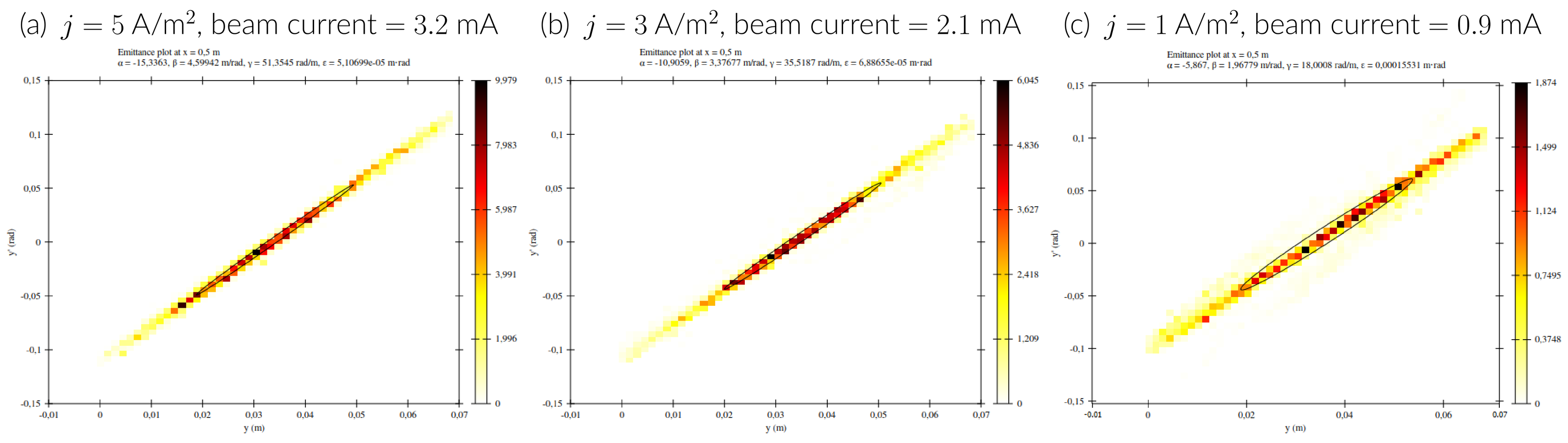


(c) Ion trajectories for $j = 1$ A/m^2

Figure 2. Simulated beam with Ar, He and H ions. Distance between plasma electrode and screening electrode $\Delta x = 24$ mm. (a), (b) and (c) are showing the trajectories of the ions for different current densities j at the start point $x = 0.1$. The different colours represent the different ion species while the green lines represent the electric potential lines.



(a) $j = 5$ A/m^2, beam current $= 3.2$ mA (b) $j = 3$ A/m^2, beam current $= 2.1$ mA (c) $j = 1$ A/m^2, beam current $= 0.9$ mA



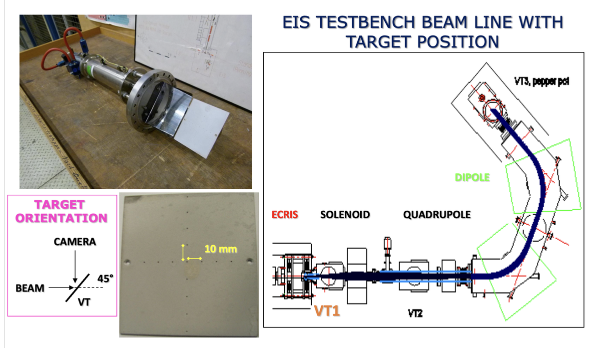
(d) Emittance for $j = 5$ A/m^2 (e) Emittance for $j = 3$ A/m^2 (f) Emittance for $j = 1$ A/m^2

Figure 3. (a), (b) and (c) are showing the beam profile and current at the position $x = 0.5$ m for the different current densities j at the start point. (d), (e) and (f) are showing the emittance at the position $x = 0.5$ m for the different j.

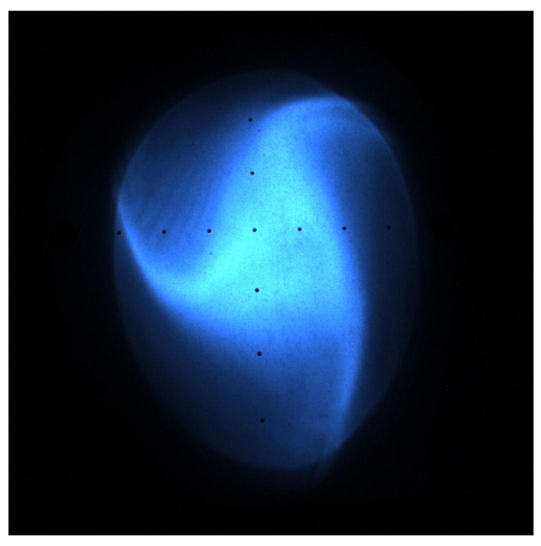
Measurements

extraction voltage	15 kV
screening electrode	-2 kV
beam current	1.63 mA
pressure	$1.75 * 10^{-6}$ mbar
microwave power	400 W

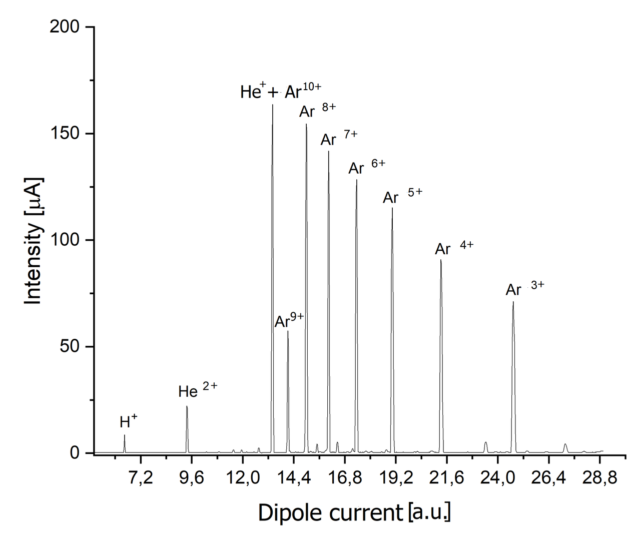
(a) Parameters for the measurment



(b) Experimental setup



(c) Picture of screen/Beam profile



(d) Charged state distribution

Figure 4. (a) shows the parameters used for the experiment, (b) shows the experimental setup and the used screen. The screen was coated with KBr. (c) shows the picture of a beam profile of an ion beam generated using argon as working gas together with helium as auxiliary gas. The picture was taken at the first viewing Target (VT1 in (b), approximately 32 cm away from the plasma electrode). Figure (d) presents the spectrum of the previously mentioned ion beam profile.

Conclusion & Outlook

As of now the simulation appears to provide a reasonable approximation of the beam profile for the CAPRICE-ECRIS.

Further work will be dedicated to refining the current simulation in order to enhance its accuracy in representing real-world condition. A key focus will be on determining precise values for the unknown but necessary parameters for the function of the program. Once these parameters have been adequately calibrated, the simulation framework will be extended to explore various different plasma electrode apertures.

References

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