# SIMULATION OF BEAM FORMATION IN THE CERN NEGATIVE ION SOURCE FOR THE LINAC4 ACCELERATOR


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## Abstract

Linac4 is the negative hydrogen ion ($H^-$) injector of the CERN accelerator complex. Modelling of the beam formation is essential for optimizing the current and emittance of the $H^-$ ion source. We exploited the 3D PIC-Monte Carlo ONIX (Orsay Negative Ion eXtraction) code for studying $H^-$ beam formation processes in caesiated negative ion sources [1]. The various geometries of the IS03 prototypes have been implemented into ONIX [2]. The code, designed for neutral injector multi-aperture sources for fusion has been adapted to match the single-aperture extraction region of the Linac4 $H^-$ source [3]. A plasma electrode designed to ensure radial metallic boundary conditions was produced and tested. The simulation results of the beam formation region at low plasma density to validate the functionality of the modified ONIX version are presented.


## Introduction

The Radio Frequency Inductively Coupled Plasma (RF-ICP) $H^-$ source prototype (IS03b) is being operated on CERN's Linac4 [4]. This cesiated molybdenum-surface plasma source produces $H^-$ through the volume and surface production mechanisms.

**AIM:**

Modelling the beam phase space around the meniscus region (positions and velocities of each ion and electron).

**MOTIVATION OF RESEARCH:**

To simulate IS03b Linac4 ion source and at a later stage, to benchmark its input to detailed Optical Emission Spectroscopy (OES) measurements of the plasma and to compare its output to Beam Emission Spectroscopy (BES), beam profiles and emittances.

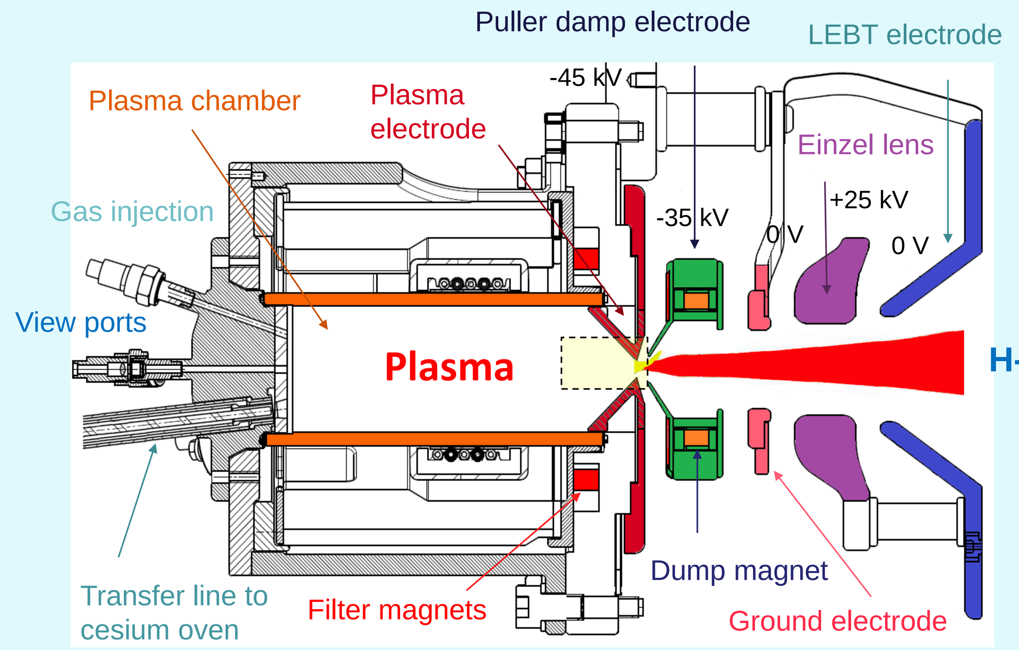


***Figure. 1**. Layout of the IS03 Linac4 $H^-$ ion source (H- current = 40 - 80 mA) and extraction system.*

## Simulation model

- ONIX has been modified and adapted to match extraction region of the Linac4 H− source.
- Boundary conditions of the simulation volume in directions orthogonal to the beam axis were set to **non-periodic.**
- The various geometries of the IS03 prototypes have been implemented into ONIX:
  - standard plasma electrode (**PE45**);
  - dedicated prototype (**PE75**) to provide simple metallic radial boundary conditions at the periphery of the beam formation region of the ONIX simulation region.

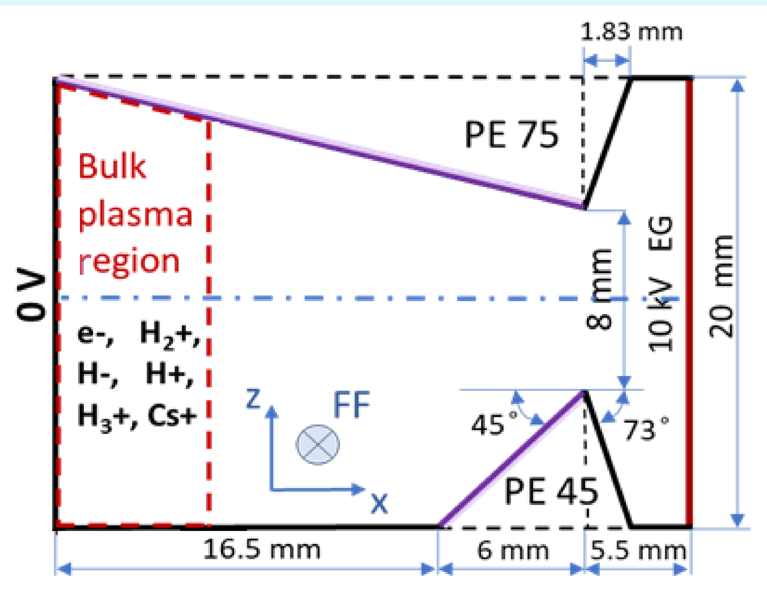


***Figure 2**. Schematic view of the simulation domains for modelling beam formation of IS03b PE45 bottom and PE75 top.*

**Parameters used in the simulation:**

- bulk plasma density of $10^{16}$ $m^{-3}$
- plasma composition and energy distributions:

  50% $H^-$ (0.8eV), 50% e (1eV), 70% $H^+$ (0.8eV), 20% $H_2^+$ (0.1eV), 10% $H_3^+$ (0.1eV)
- $H^-$ emission rate: 550 $Am^{-2}$
- Extraction potential: 10 kV
- Magnetic field: 11 mT

- The simulation has been performed on a CERN cluster using 20 CPUs (360 cores). The cell size is $6.5\times10^{-5}$ m, slightly larger than the Debye length ($\lambda_D \approx 4.1 \times 10^{-5}$ m).

## Simulation of PE45

- The system evolves towards a **quasi-steady state** after 0.7 μs.
- The value of co-extracted electrons and $H^-$ currents is about **9 mA**. The $H^-$ current includes volume and surface production modes.
- The plasma density drastically drops close to the PE aperture and Debye length condition is fulfilled in the **plasma sheath** region including the meniscus.

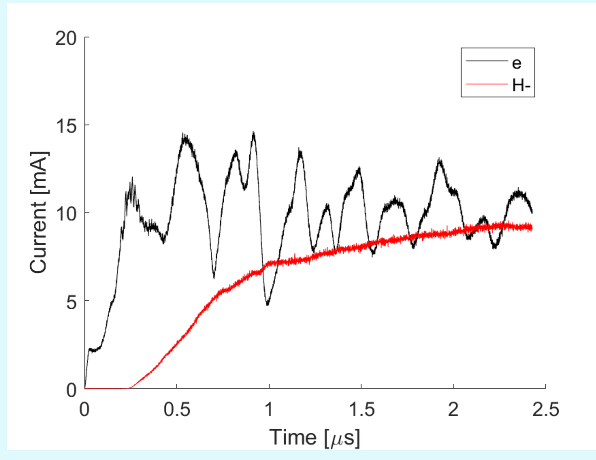


***Figure 3**. Time evolution of the extracted H− current and co-extracted electron.*

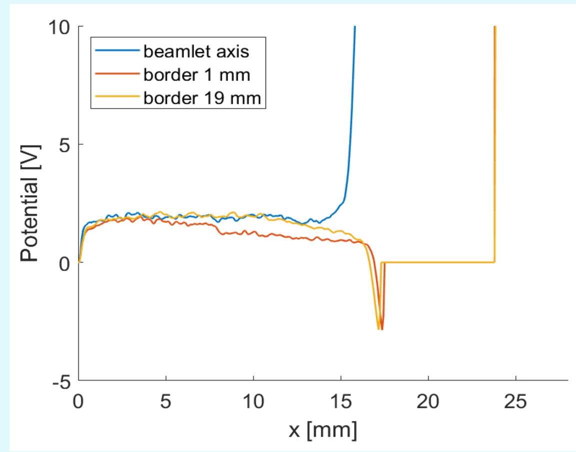


***Figure 4**. Potential profile at beamlet axis and near the borders.*

- A different H- density distribution is observed in the (x-y) and (x-z) planes since the filter field is predominant in the y direction and limits the electron flow, that influence the distribution of the positive charged species.
- The influence of the magnetic field strength on the extracted current was considered. The co-extracted electron current increases with reducing of magnetic field, while the value of the proton yield remains unchanged.

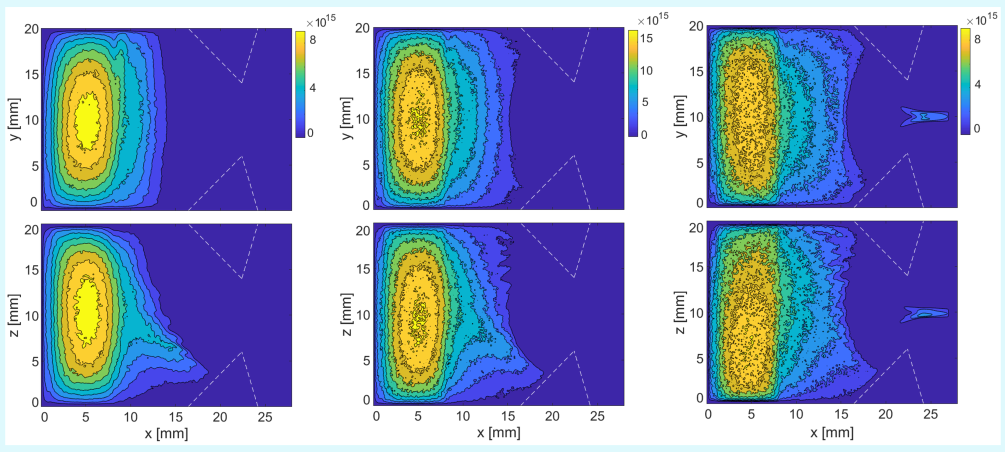

***Figure. 5**. Density maps of electrons (left), positively charged particles (H+, H2+, H3+) (center) and H− (right) in the (x-y) (top) and (x-z) (bottom) plane.*

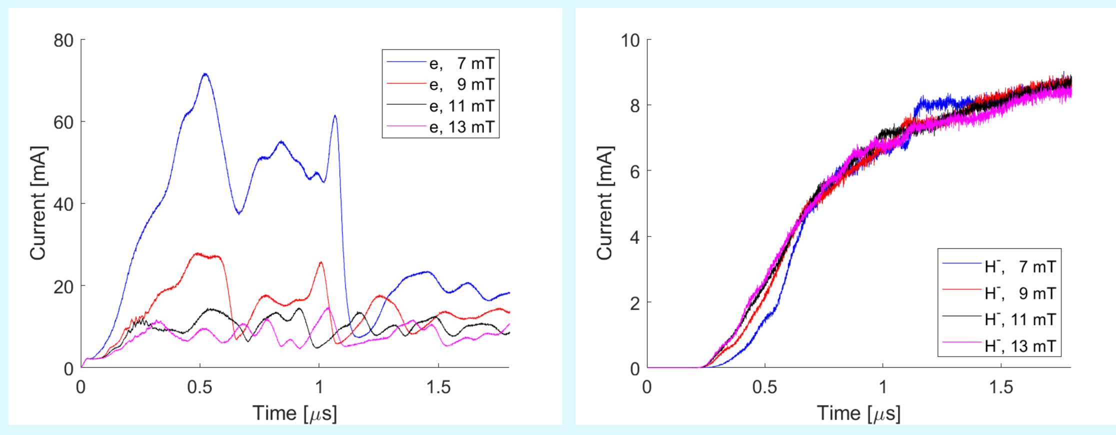


***Figure. 6**. Time evolution of co-extracted electron and the extracted H− current simulated with different magnetic field.*

- The **majority** of extracted $H^-$ are created at the **conical part** of the PE and the production of $H^-$ from the surface of PE is uniform, while the particles from the bulk plasma region are strongly influenced by the magnetic field.

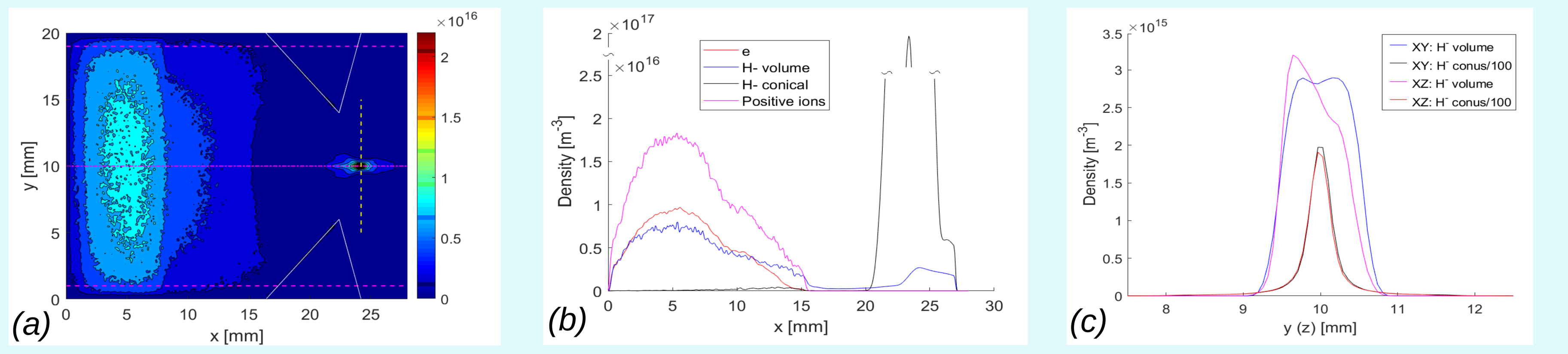


***Figure 7**. Density map of $H^-$ in the (x-y) plane (a). Density profile of electrons, negative and positive ions along a beamline (b) and $H^-$ profile at extraction aperture (c).*

## Simulation of PE75

- Similar simulations were carried out for the PE75 with the same settings.
- A significant decrease in $H^-$ current was observed. The value of $H^-$ current is about **4.5 mA**, that is two times lower than for PE45 geometry. The e/H current ratio is below 1.
- Comparative analysis of density of positive and negative charged particles was performed with and without an applied extraction potential.

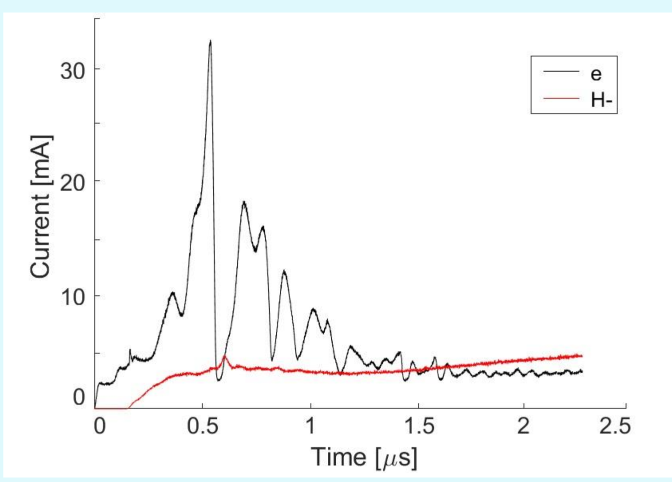


***Figure 8.** Time evolution of the extracted $H^-$ current and co-extracted electron current.*

- The non-uniform density profiles of positive and negative ion are observed with significant impact of magnetic field on the meniscus.

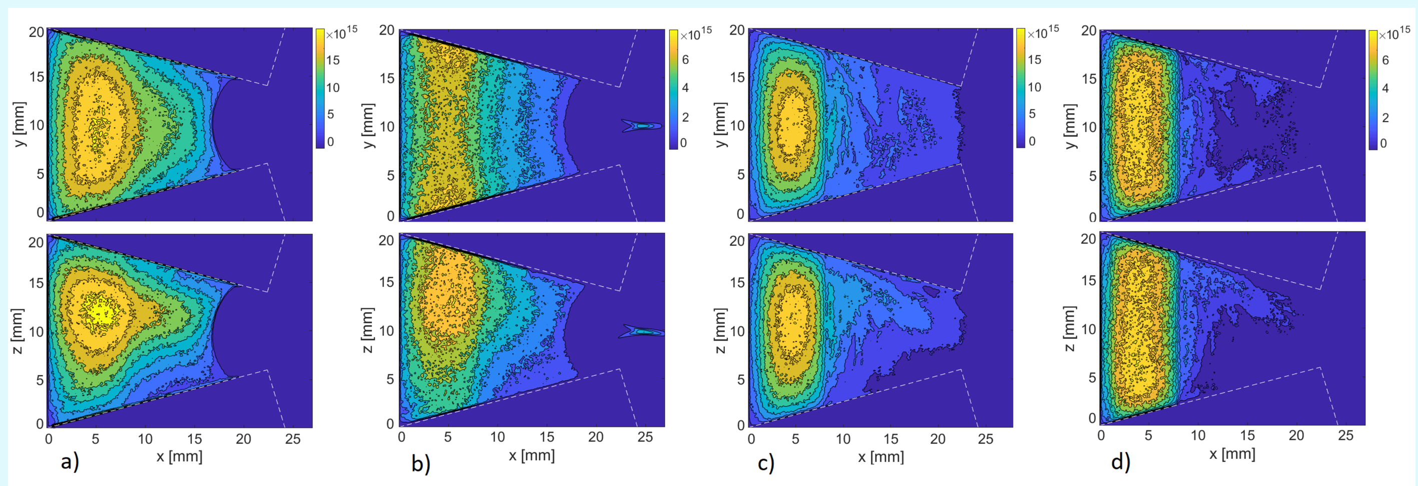


***Figure 9.** Density maps of positively charged particles ($H^+$, $H_2^+$, $H_3^+$) and $H^-$ using an extraction voltage of 10 kV (a – b) and 0 V (c – d) in the (x-y) (top) plane and (x-z) (bottom)*

## Conclusion outlook

- A **modified** version of ONIX with a **single extraction aperture and non-periodic boundary conditions** to model the beam formation region of the Linac4 ion source was successfully tested using **low plasma density**.
- Different **configuration of plasma electrode** was simulated. A **meniscus shape** and the **beam** extracted from the peripheral region were observed strongly influenced by the **magnetic field**.
- Simulation of **higher plasma densities** are planned to be performed with initial conditions refinements base on analysis from OES system installed around the plasma generator at the Linac4 ion source test stand [5].

## References


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