H⁻ BEAM FORMATION SIMULATION IN NEGATIVE ION SOURCE FOR CERN'S LINAC4 ACCELERATOR

A. Vnuchenko [1]*, J. Lettry[1], S. Mochalskyy[2], M. Lindqvist[2], D. Wünderlich[2], U. Fantz[2], A. Revel[3], T. Minea[3]

[1] CERN, Esplanade des Particules 1, P.O. Box, 1211 Geneva 23, Switzerland
[2] Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, D-85748 Garching, Germany
[3] Laboratoire de Physique des Gaz et des Plasmas, UMR 8578 CNRS, Université Paris-Saclay, Bat. 210, rue Henri Becquerel, 91405 Orsay, France

Abstract

The caesiated surface negative ion source is the first element of CERN's LINAC4 linear injector designed to accelerate negative hydrogen ions (H^-) to 160 MeV. The **IS03** ion source, used during Run 3, is operated at **35 mA** beam intensity. The 3D PIC-Monte Carlo **ONIX** code written to study H- beam formation processes in neutral injectors for fusion has been adapted to match the conditions of the beam formation and extraction regions of the **Linac4 H^- source**. A set of plasma parameters and surface emission were chosen to match the specific volume and surface production modes. Simulated results of the extraction regions are presented and benchmarked with experimental results obtained at the Linac4 test stand.

Introduction

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

PROJECT GOAL:

Investigate the H^- **beam formation processes** and their impact on **beam properties of L4-IS03b ion source**.

AIM OF THE RESEARCH:

Simulation of the beam formation region of Linac4 ion source and comparison at a later stage to Beam Emission Spectroscopy (BES), beam profiles and emittances measurements.

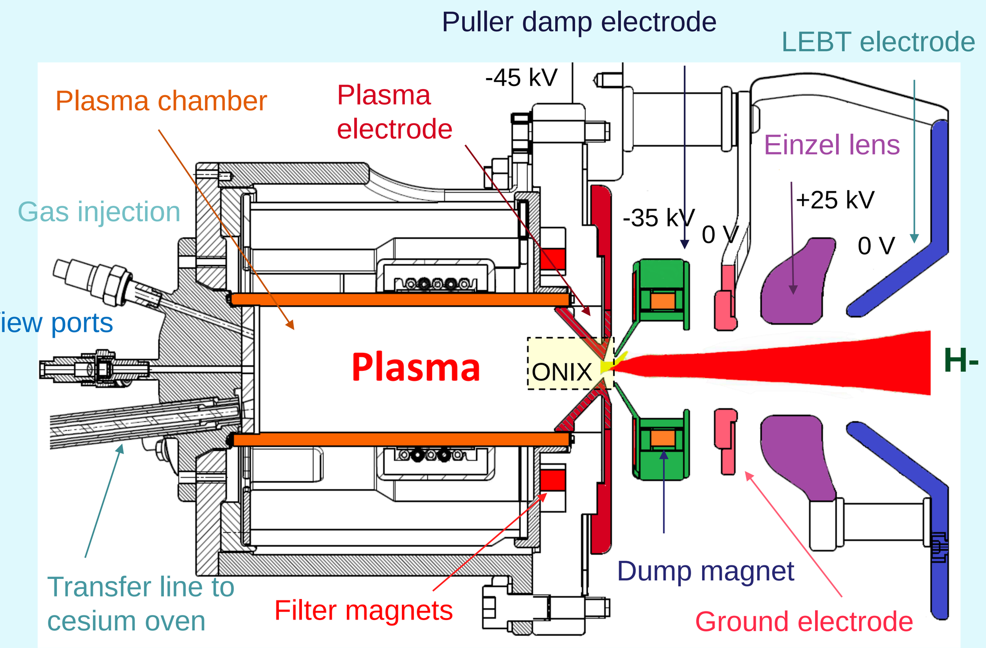


Figure. 1. Layout of the IS03 Linac4 H^- ion source (H- current = 40 - 80 mA) and extraction system.

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 are set to **non-periodic.**
- **The mirror boundary** is applied to the left side of the simulation domain: particles hitting the right wall are reflected into the bulk plasma.
- The cell size is 6.5×10^{-5} m, slightly larger than the Debye length ($\lambda_D \approx 4.1 \times 10^{-5}$ m).
- ONIX simulations performed for various initial parameters.

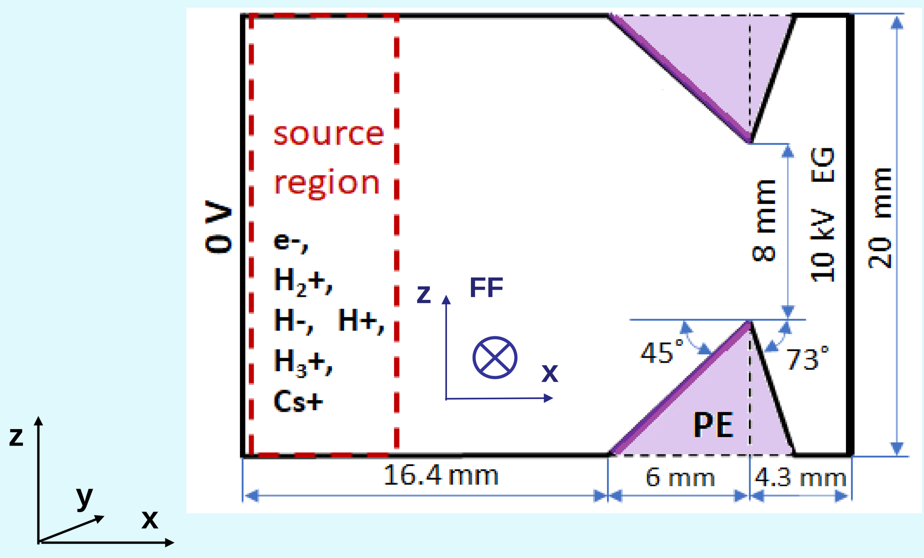


Figure 2. Schematic view of the simulation domains for modelling beam formation of IS03b.

- **Parameters** set in ONIX simulation:
  - Bulk plasma density of 10^{17} m^{-3};
  - Extraction potential of **10 kV**,
  - Magnetic field of **11 mT** at PE aperture.
  - E(e) bulk plasma = 2 eV
- **Simulations** performed at **HPC** clusters:
  - **CERN** cloud: 36 CPUs (2304 cores);
  - **CSCS**, Cray XC50-Hybrid: 120 CPUs (2400 cores);
  - **CINECA** ICEI system G100: 64 CPUs (3072 cores).

Simulation result

- ONIX simulations performed for H^- surf. emission rates of **10 Am⁻²** and **80 Am⁻²**, and bulk Plasma densities of 10^{17} m^{-3} (e:H⁻)= 1:1).

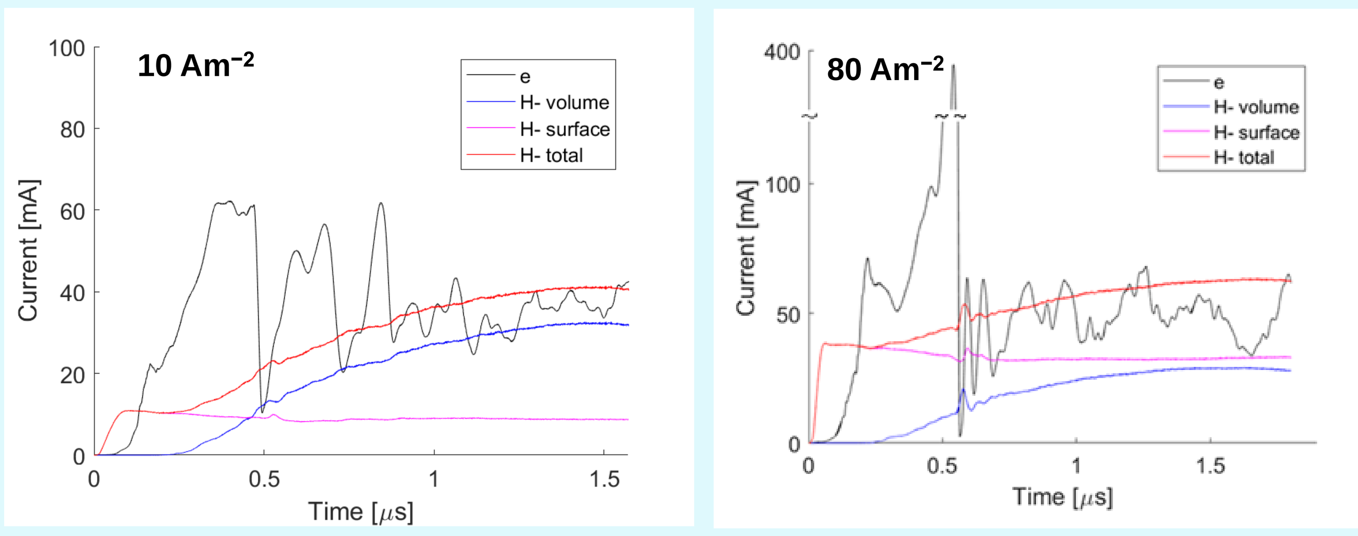


Figure 3. Time evolution of the extracted H− current and co-extracted electron simulated with different emission rate.

Emission rate:	10 Am⁻²	80 Am⁻²
H⁻ total [mA]	**41**	**63.5**
H⁻ volume [mA]	**32.5**	**28.5**
H⁻ surface [mA]	**8.5**	**35**
e [mA]	37	50
e/H⁻ total	0.9	0.8
H- bulk density [m⁻³]	**1.8 10¹⁷**	**1.8 10¹⁷**

- ✓ **80 Am⁻² Surface** H^- current reduced **volume** contribution by **12%**.

- The production of H^- from the PE **surface** is **influenced** by the **B-field** in the extraction area.
- Asymmetry of the density profiles of ONIX simulation was compared with BES measurement performed at L4IS test stand (see oral presentation of J.Lettry: Correlation H- beam properties to Cs-coverage)

- Density profile of H^- according to their origin (surf., vol. mode) illustrates their contribution to the beam profile **asymmetry**.

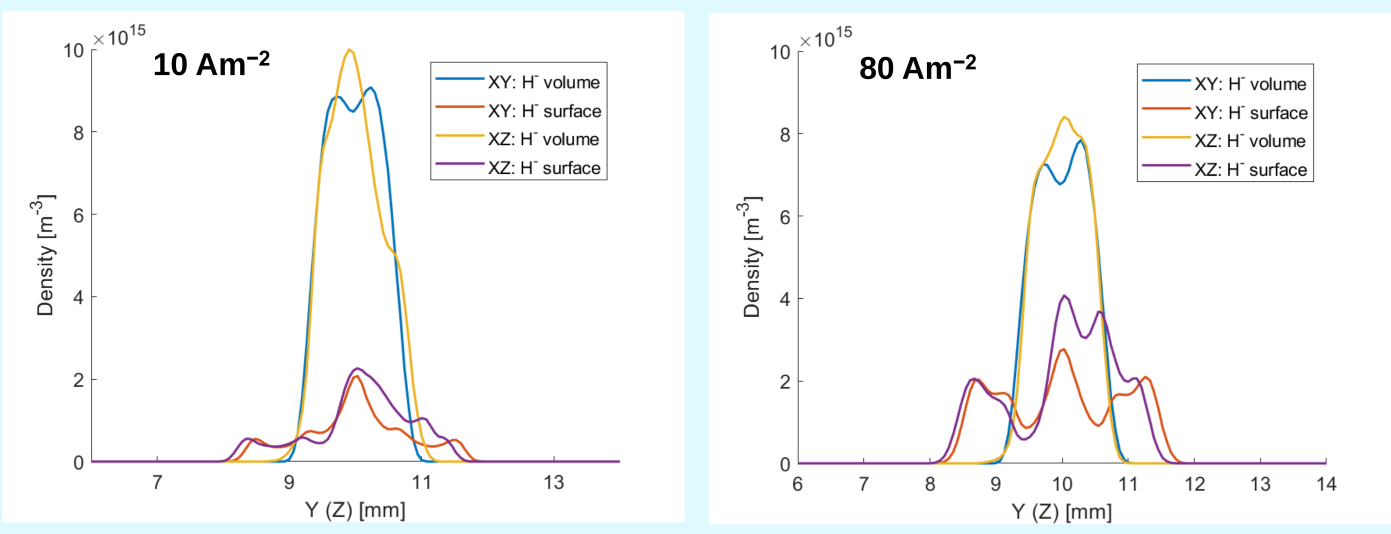


Figure 4. Density profile of H− according to their origin (volume and surface production) in the extraction area (for x = 26 mm).

- A different H- density distribution is observed in the (x-y) and (x-z) planes.

  The **filter field** the **y orientation** impacts the electron flow and influences the distribution of the positive charged species.

Parameters	BES	ONIX simulations			
	Total	Total	Total	Volume	Surface
Current [mA]	**50**	**41**	**63.5**		
H^-_{volume} [mA]	33	33	28.5		
$H^-_{surface}$ [mA]	17	8	35		
e/H⁻	**2-3**	**0.9**	**0.8**		
Up, %	101	98	100	99.5	101
Down, %	99	102	100	100.5	99
Left., %	88	101	95	100	88
Right, %	112	99	105.3	100	112

- ✓ **BES** measurements and **simulations** demonstrate good agreement between the results

  The difference in asymmetry cannot be compared directly since the beam profiles are made at different distances from the plasma electrode.

- The **H⁻ yield** depends on the energy of the incoming **flux** and the **surface work function** resulting from the surface coverage of Cs on the Mo-PE surface. As coverage gradients were measured, H^- flux distribution gradients were simulated.

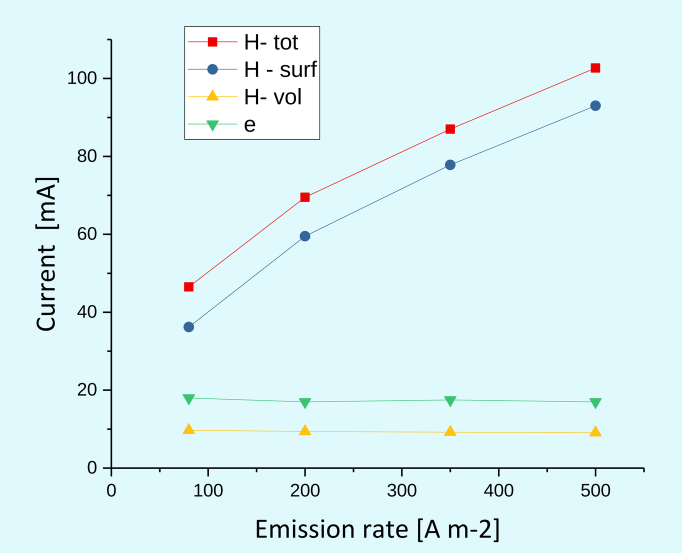
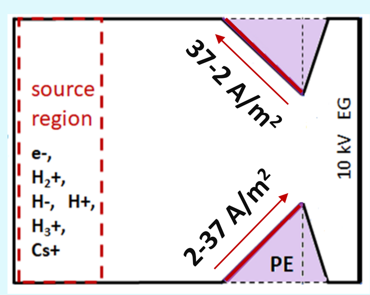


Figure 5. Current densities for extracted electrons and H-.

Emission rate [Am⁻²]	20	2 - 37	37 - 2
H⁻ total [mA]	**21**	**25.5**	**13.6**
H⁻ volume [mA]	5.6	5.4	5.9
H⁻ surface [mA]	**15.5**	**20**	**7.6**
e [mA]	5	7	7
e/H⁻ total	0.24	0.27	0.5

20 A/m² - average emission rate from Sc-Mo surface



Simulation performed for plasma density of 10^{16} m^{-3}

- Emission rate distribution along PE impact the total H^- yield.
- **Surface emission rate** from the PE surface increases **H- beam** but also impacts the beam phase space.
- The increase in emission rate from PE tips was confirmed by measurement of Cs-monolayers on the Mo-PE surface at ISL4 test stend.

Conclusion outlook

- A **modified** version of ONIX with a **single extraction aperture and non-periodic boundary conditions** was implemented and used to model the beam formation region of the Linac4 ion source.
- ONIX simulations were performed for various sets of initial parameters.
- The **beam** extracted from the peripheral region are influenced by the **vertical magnetic filter field**.
- **Asymmetry** of beam profile is confirmed by BES measurements.
- Production rate and Cs-coverage gradient has significant impact on properties of the beam of the IS03 H^- source.