

Production of negative hydrogen ions in a magnetized plasma column

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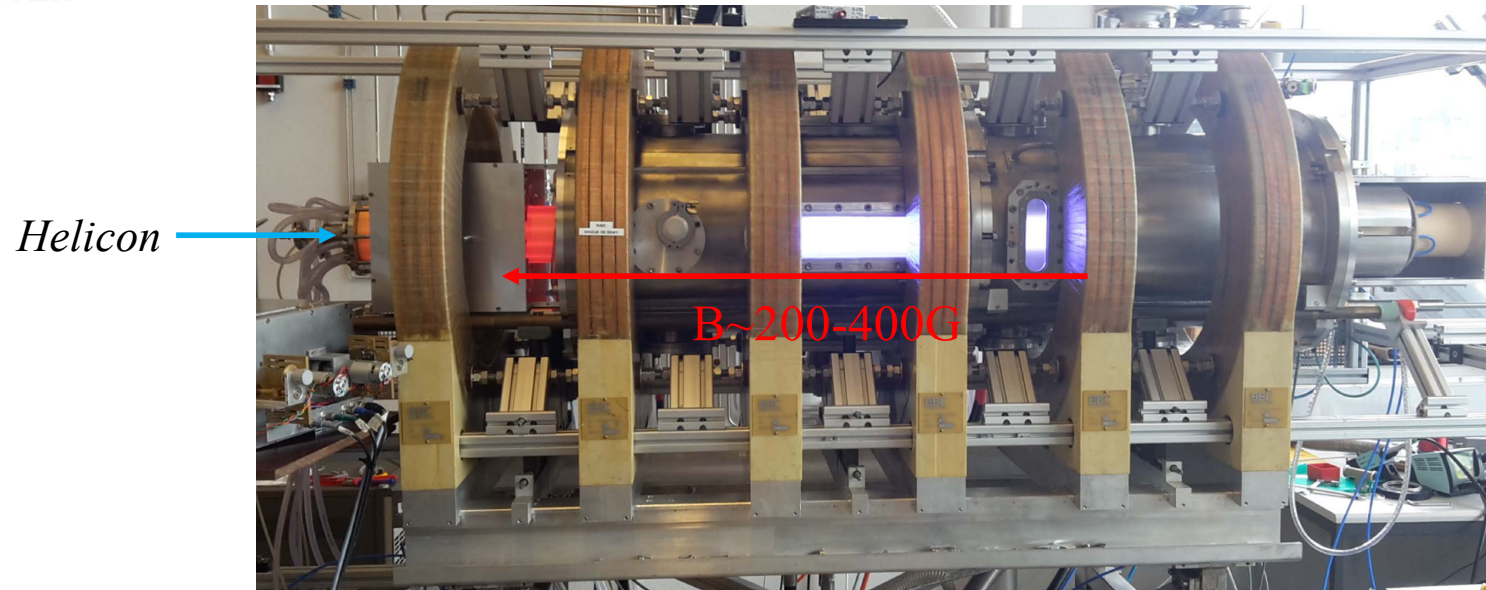
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EUROfusion

Context: production of negative hydrogen ions in a magnetized plasma column

SWISS PLASMA
CENTER



- Scope is to produce negative ions in the plasma volume via a dissociative attachment process
 - $e + H_2(v>4) \rightarrow e + H^- + H$
- Electrons are well confined by the axial magnetic field (drift motion is closed)
- Device flexibility allows exploring various experimental knobs (ex. controlling end-plate bias to finely tune plasma potential profile)

EUROfusion Enabling Research grant (6 research labs involved)



- A. Simonin, V. Lamaison and E. Delmas



- I. Furno, A. Howling, R. Agnello (*PhD*) and M. Fadone (*post-doctoral position*)



Consiglio Nazionale
delle Ricerche

- F. Taccogna and P. Minelli



- I. Turner, R. McAdams and A. Holmes

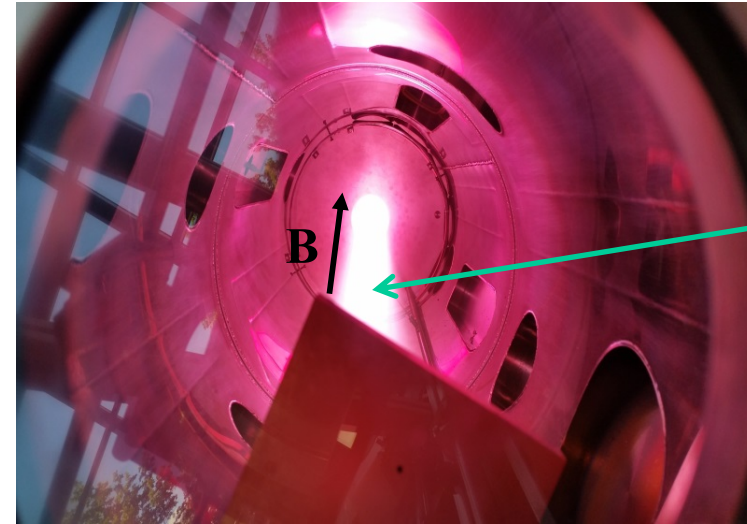
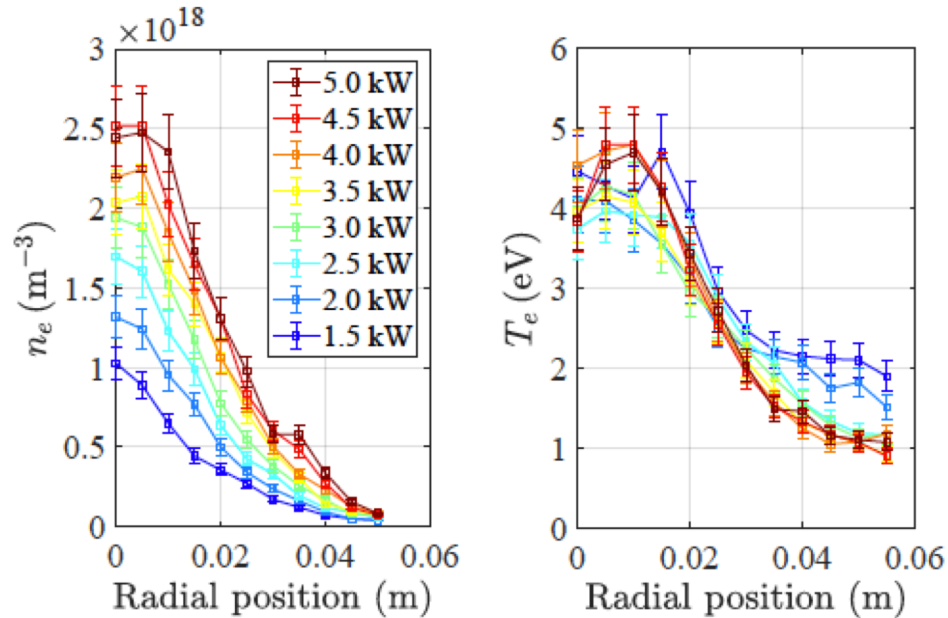


- S. Bechu

- G. Fubiani (PI), G. Hagelaar, L. Garrigues, J.P. Boeuf and B. Reman (*post-doctoral position*)

The main goal for the ion source concept is optimizing the production and extraction of negative ions

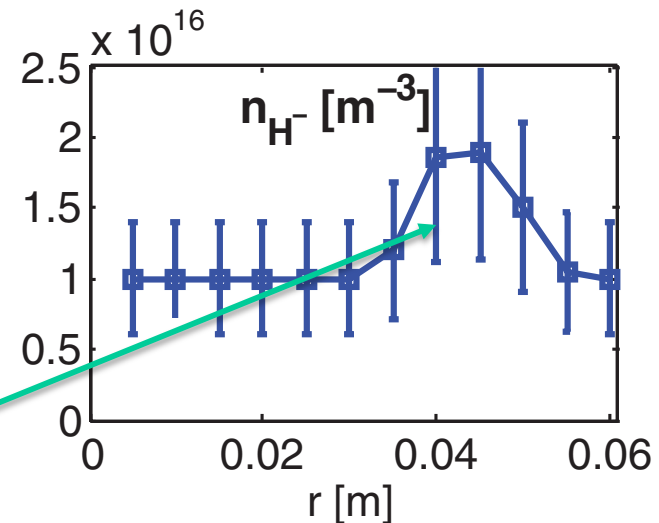
Magnetized plasma column (SPC, EPFL)



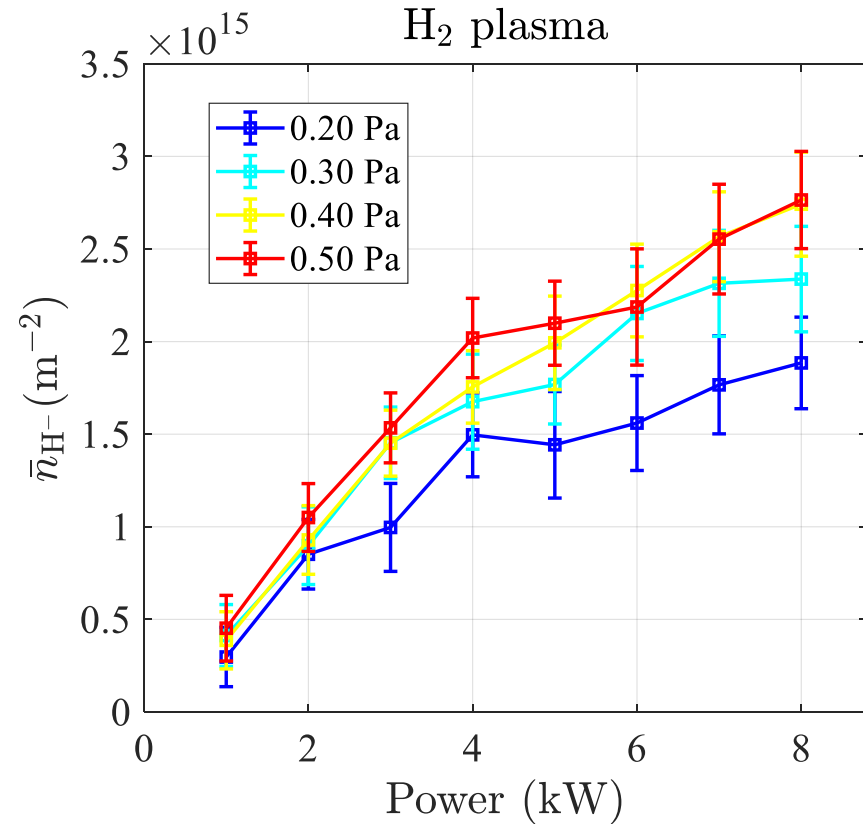
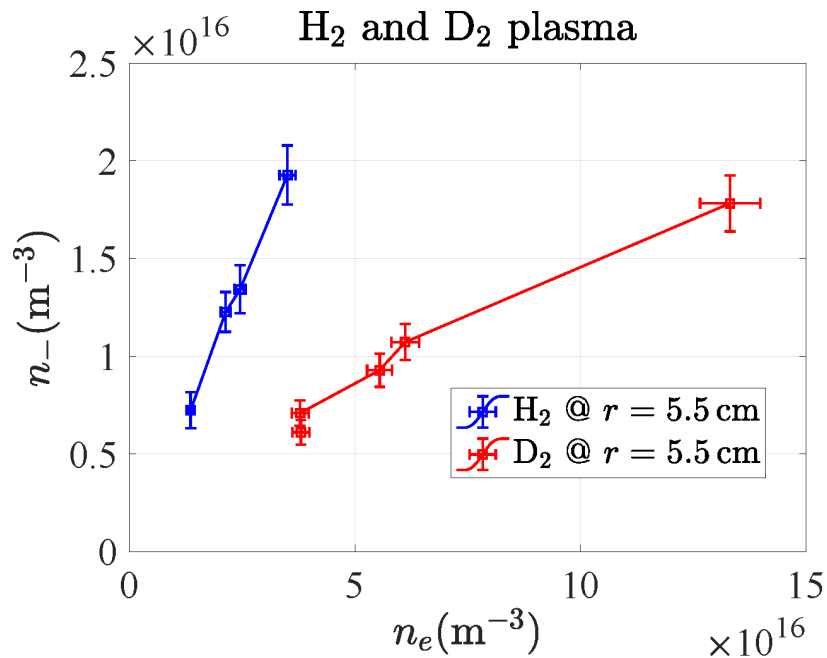
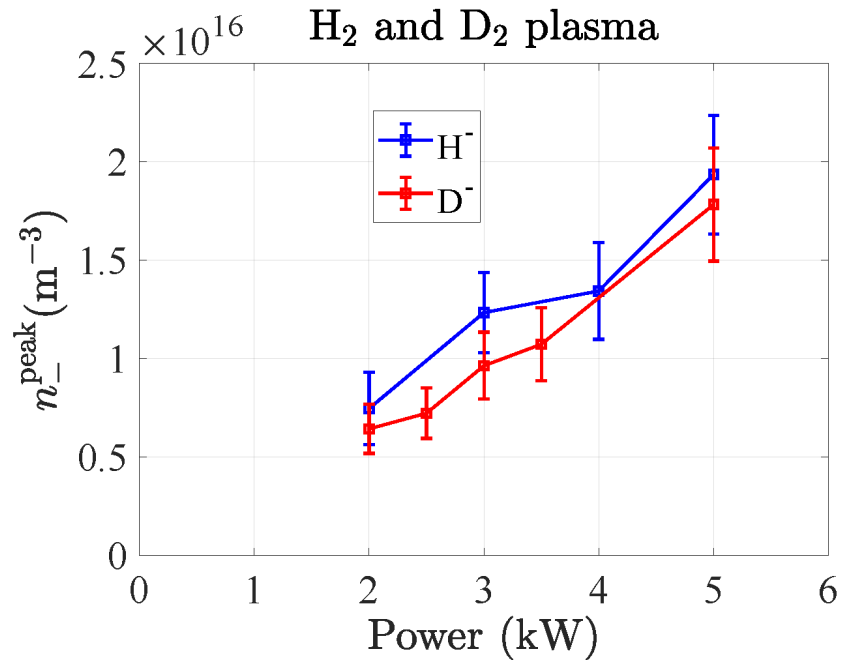
Plasma jet
1.5 m long

Ref: C. Marini et al., Nucl. Fusion 57 (2017), 036024

Maximum of negative ion density measured outside the plasma jet

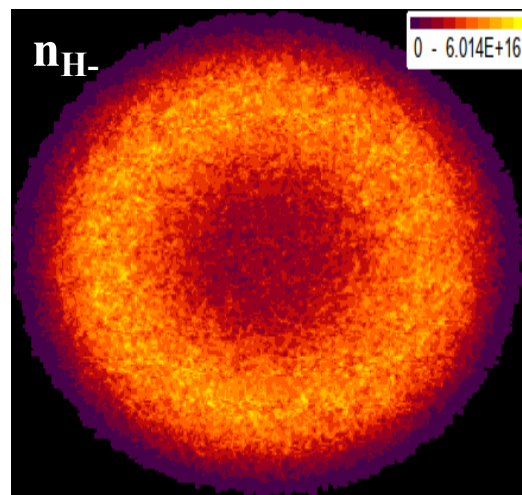
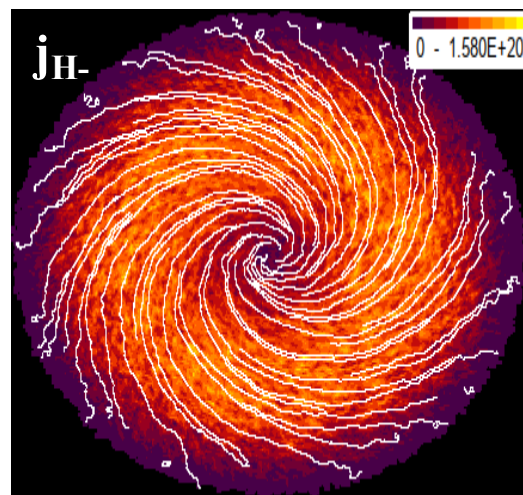
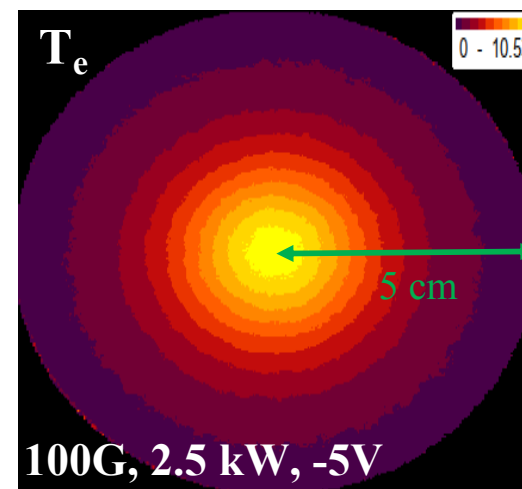
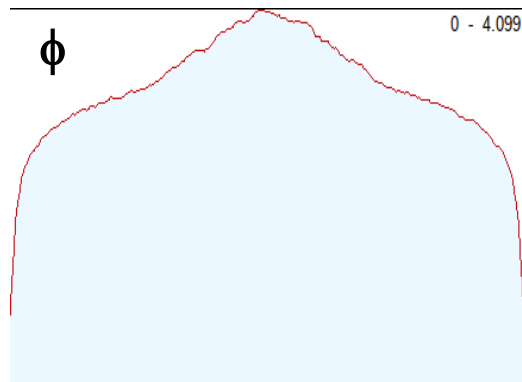
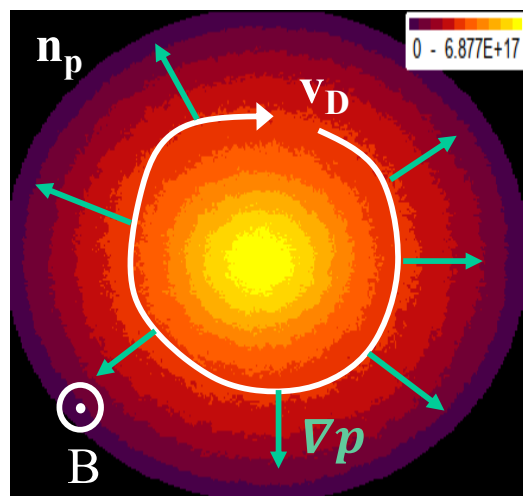


CRDS confirms the presence of negative ions



**Favorable scaling with helicon power
but large e⁻ fraction in D₂**

2D Particle-in-Cell (PIC) modeling perpendicular to the magnetic field + losses along field lines estimated analytically

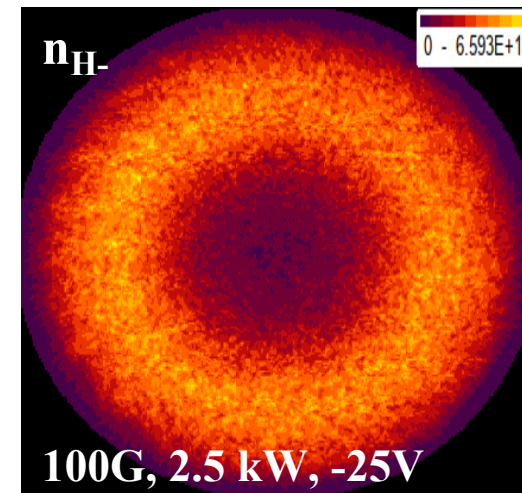
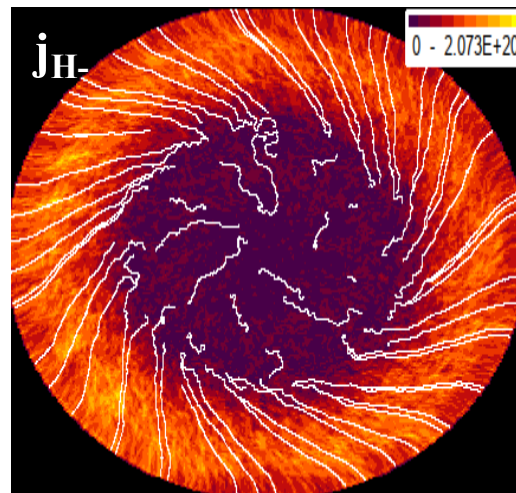
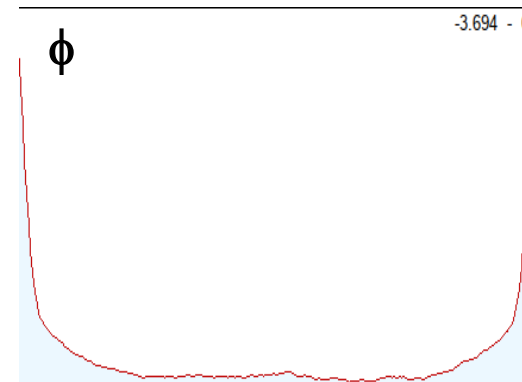
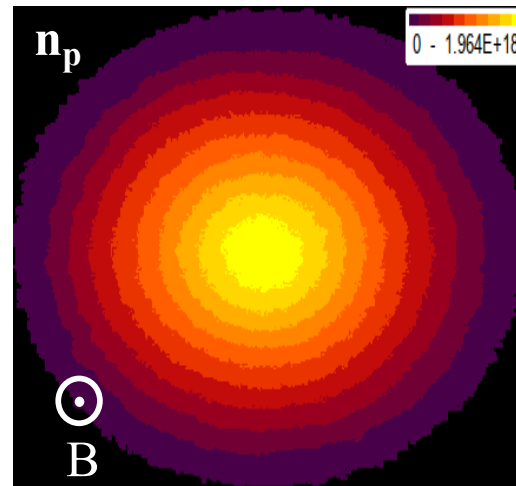
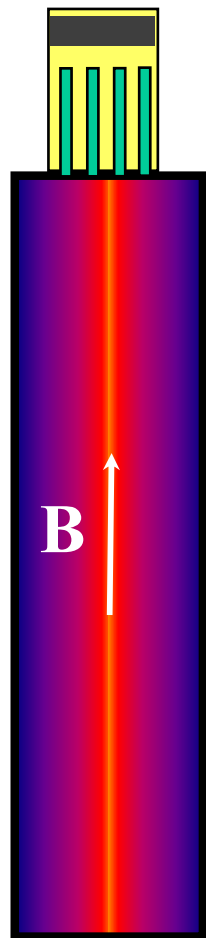


- Power absorption profile is Gaussian: $3\sigma = 4$ cm
- EEDF is Maxwellian
- Gas: H_2 , $P_g = 0.4$ Pa
- -5V on the end-plates

- Donut-like density profile for the negative ions, similar to the experiments
- Assumptions: **1.5%** of H_2 capable of producing H^- in the model ($\nu \geq 4$)
- One may raise the negative ion density by increasing confinement of electrons

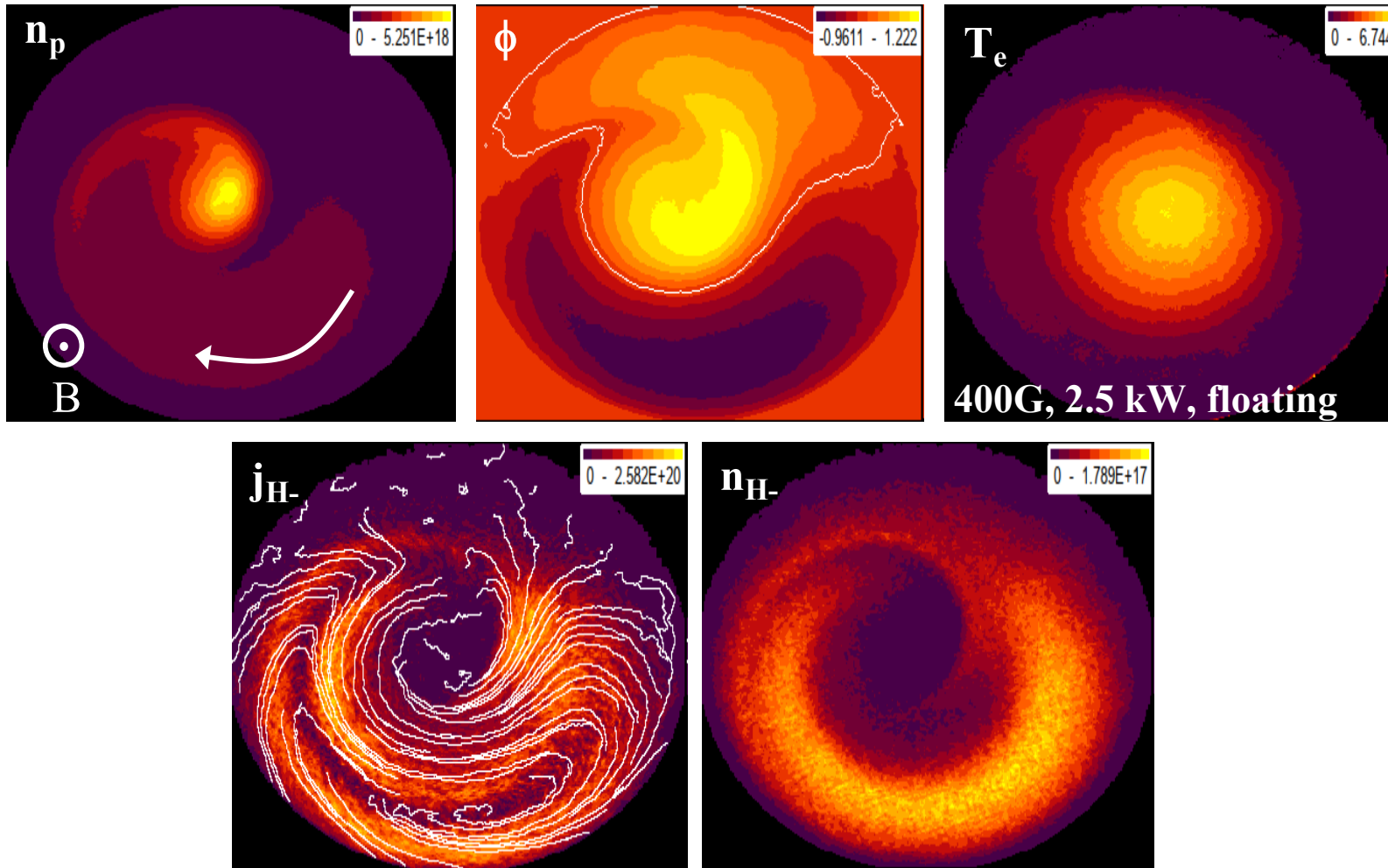


One may reverse the shape of the plasma potential in the model by biasing the end-plates



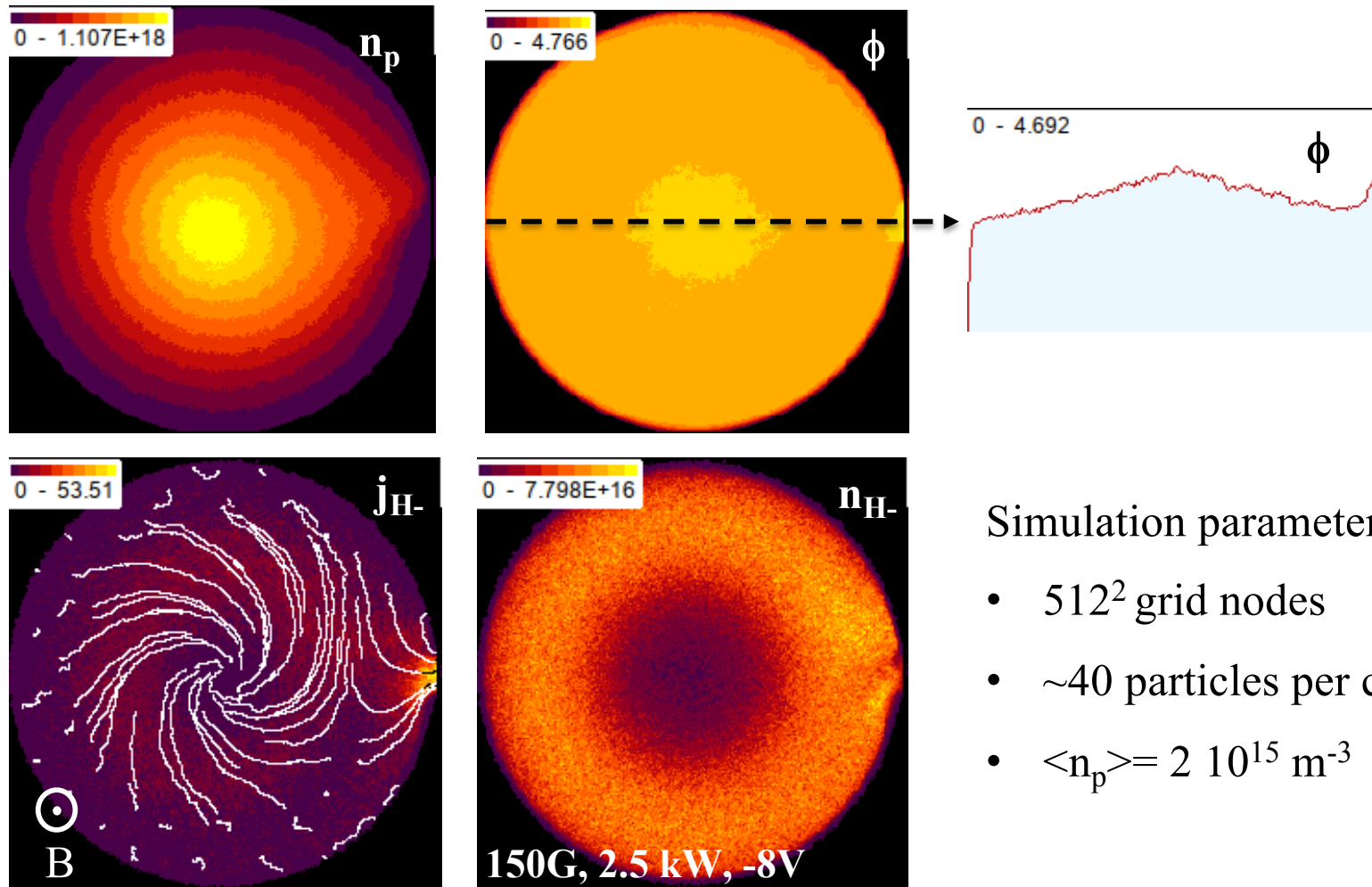
- -25V on the end-plates: **about half of negative ion current is impacting the side walls**
- Simulation parameters: 256^2 grid nodes, ~ 100 particles per cell, $\langle n_p \rangle = 6.2 \cdot 10^{13} \text{ m}^{-3}$
- Numerical convergence was checked (up to 1024^2 grid nodes)

Instabilities are observed for larger magnetic fields
(when the ions become somewhat magnetized)



Floating end-plates (about -15V)

Can we extract efficiently negative ions through a slit aperture in the model ?



Simulation parameters:

- 512^2 grid nodes
- ~ 40 particles per cell
- $\langle n_p \rangle = 2 \cdot 10^{15} \text{ m}^{-3}$

- Slit of 1 cm diameter (5V bias). Column with a diameter of 10 cm.
- Less than 10% of negative ion current is extracted (in the model) which is rather poor...

- Helicon powered magnetized plasma columns show promising results for H⁻ production
- A peak in negative ion density is observed at the edges of the plasma jet
- Negative ion production yield can be enhanced in the Particle-In-Cell model by:
 - Confining the electrons electrostatically
 - May be achieved with a negative bias voltage at the end of magnetic field lines
- Negative ion current ratio extracted through a slit aperture is low in the model (<10%)
 - Need to control the shape of the plasma potential
 - This will be tested experimentally on RAID

Design for a negative ion extractor

