The RAID experiment for the investigation of negative ion physics for fusion applications

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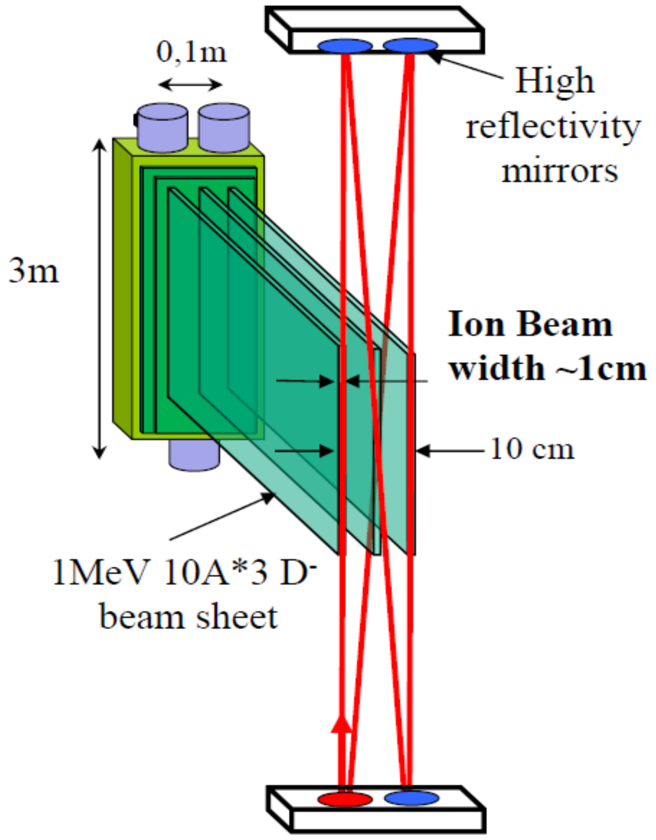
Which negative ion source for DEMO?

	DEMO[1]
Species	D^-
Beam Energy [keV]	800
Current [A]	34
Filling pressure [Pa]	0.2
Beam on time [s]	7200
Extracted e-/D- fraction	<1
Neutralization efficiency	>0.65

[1] P. Sonato et al., *Conceptual design of the beam source for the DEMO NBI*, submitted NJP



Neutral beam concept for DEMO developed at Cybele
(Talk of A. Simonin)

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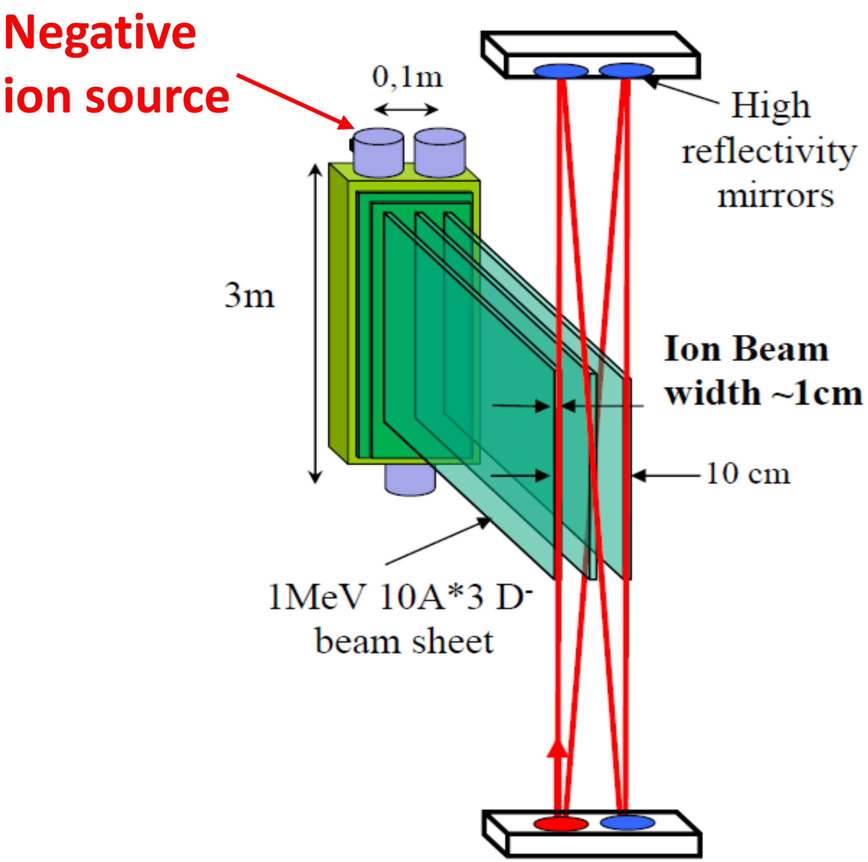

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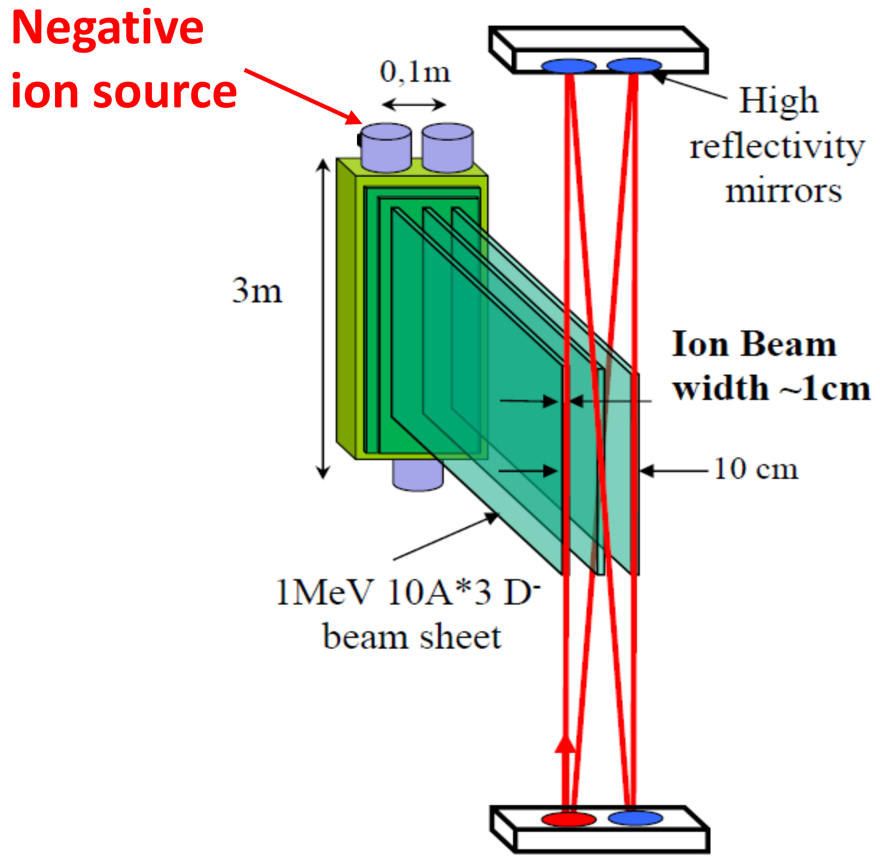
Can helicon sources be an option?

- Physics and technology challenge



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Outline

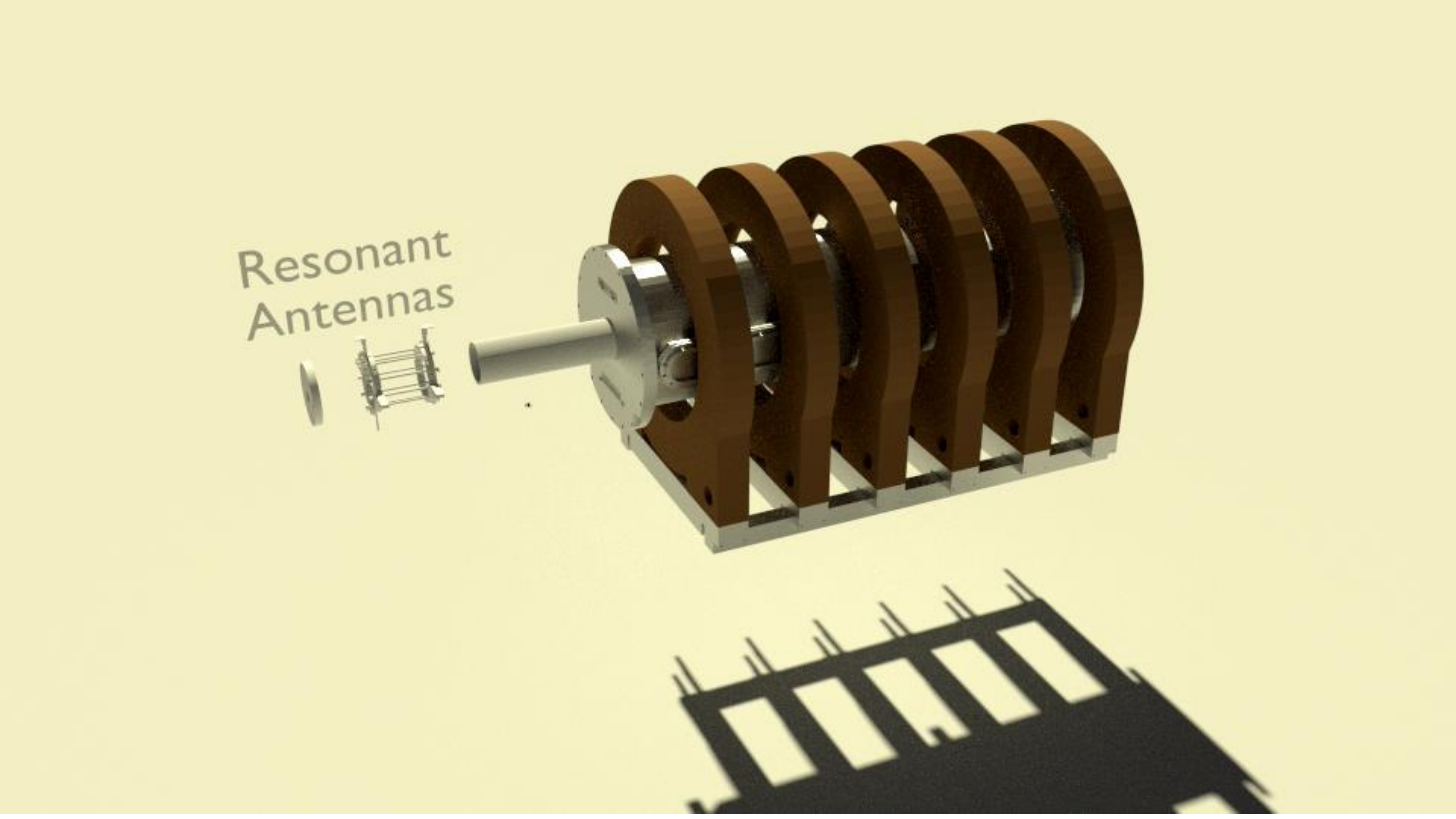
1) The Resonant Antenna Ion Device (RAID) at the SPC

2) First characterization of helicon plasma in RAID
   - Microwave interferometry
   - Langmuir Probe

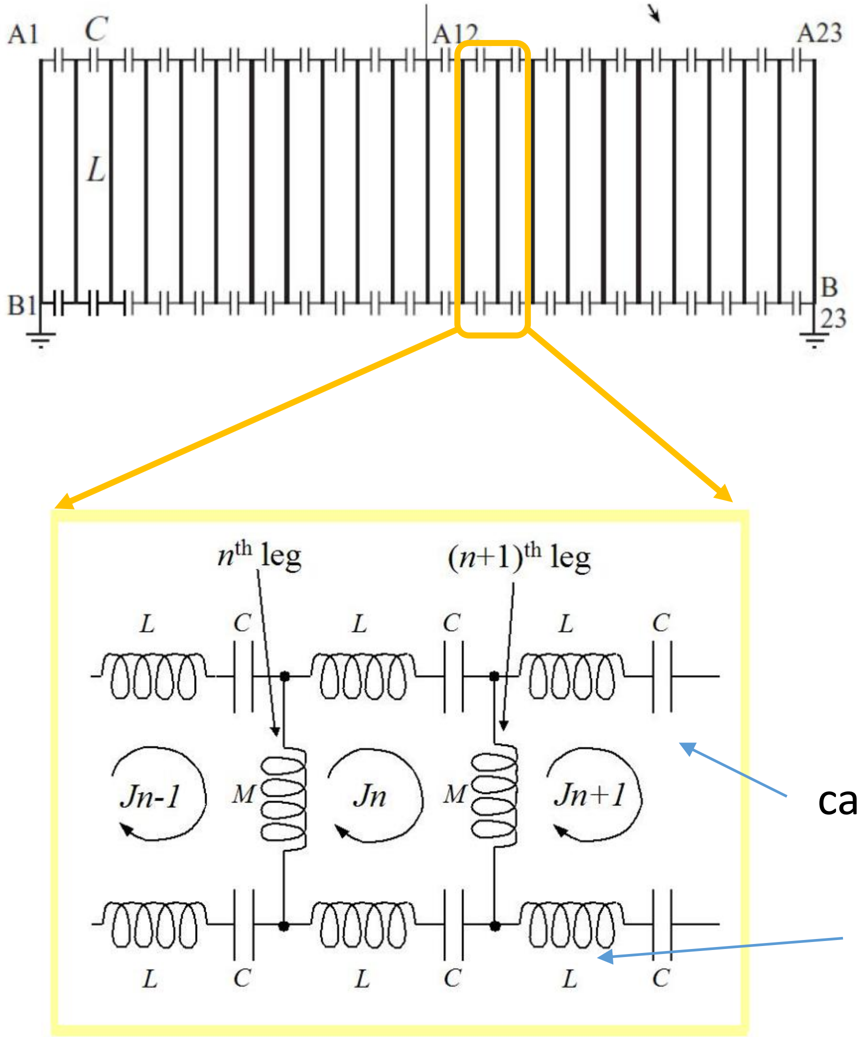
   Production of a dense and homogeneous plasma column

   - Optical Emission Spectroscopy → *Volume production of H^- and D^- and scale law with power*
   - Cavity Ring-Down Spectroscopy → *Preliminary direct measurement of D^- density*

3) Summary and Outlook

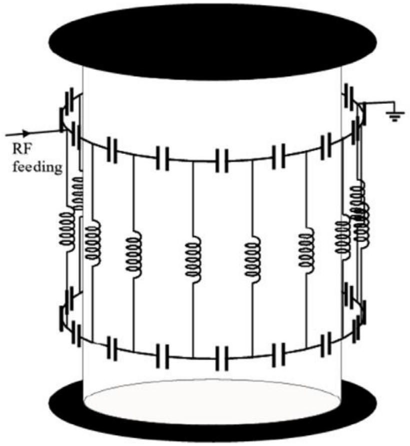

Resonant
Antennas

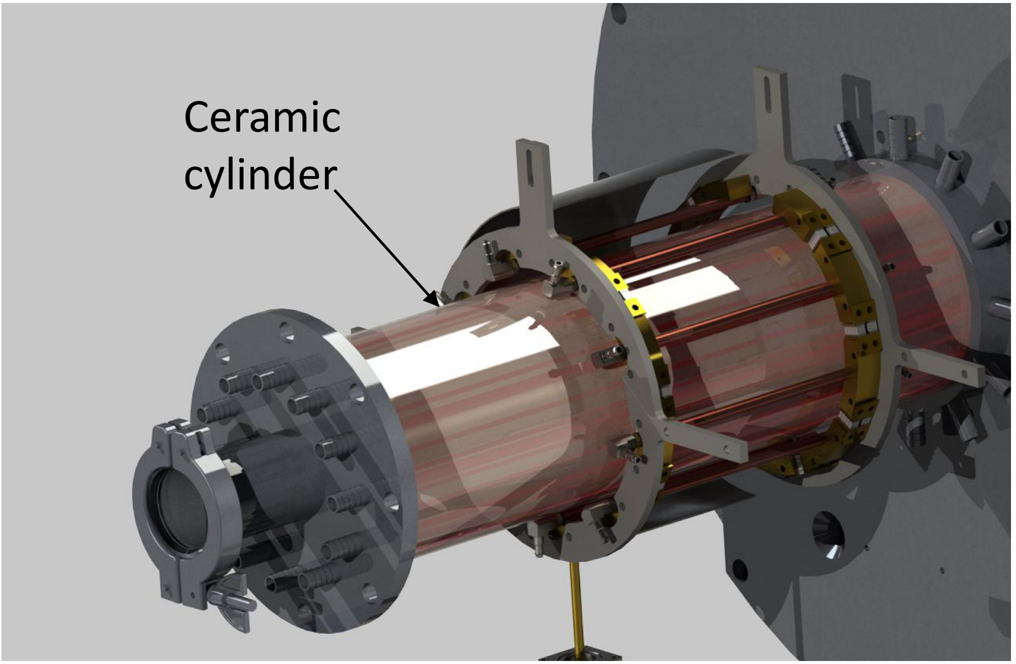
The birdcage antenna



capacitors

conductive legs





Resonance frequencies:

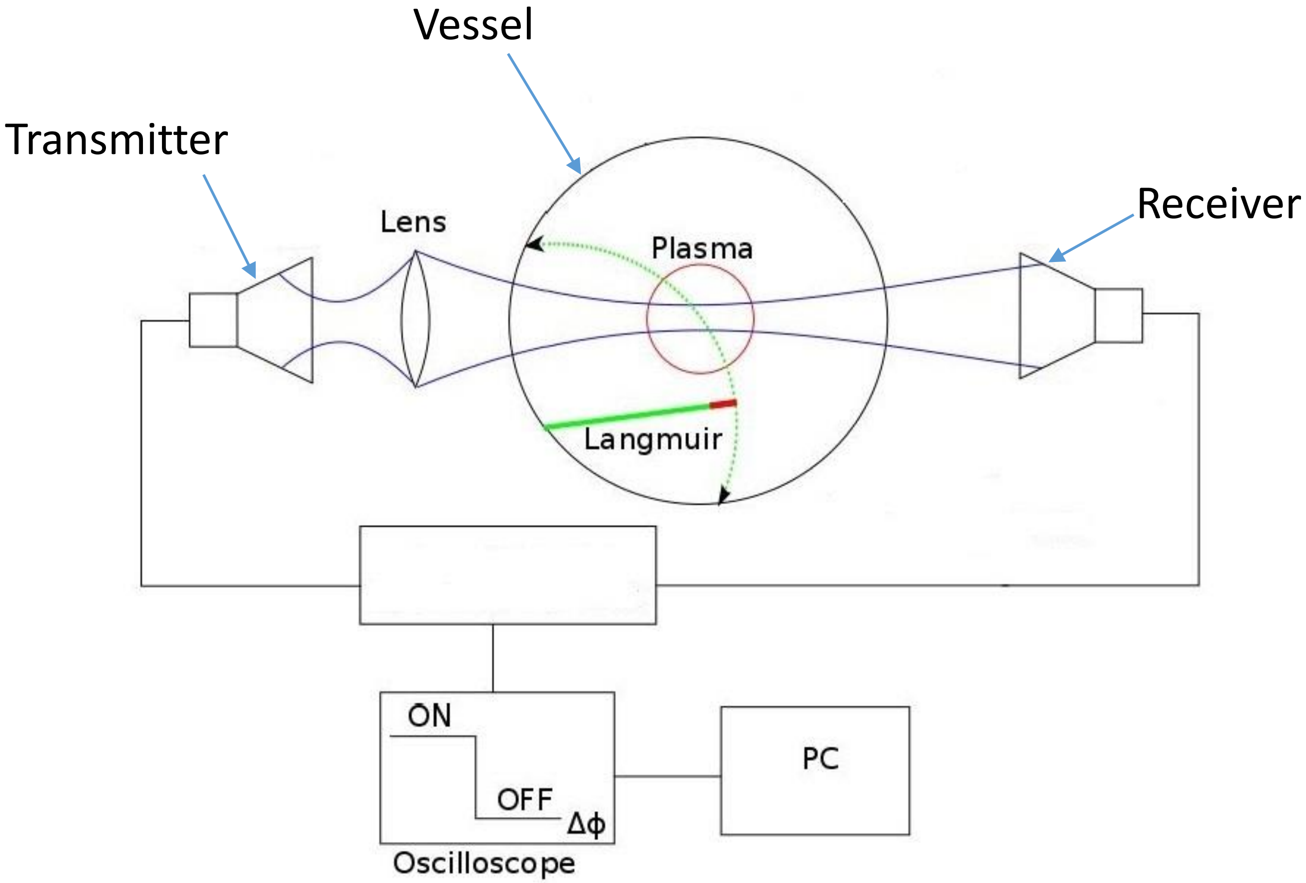
$$\omega_m = \frac{1}{\sqrt{C\left(M + 2L\sin^2\left\{\frac{m\pi}{2N}\right\}\right)}}$$

m=1,2,…N-1

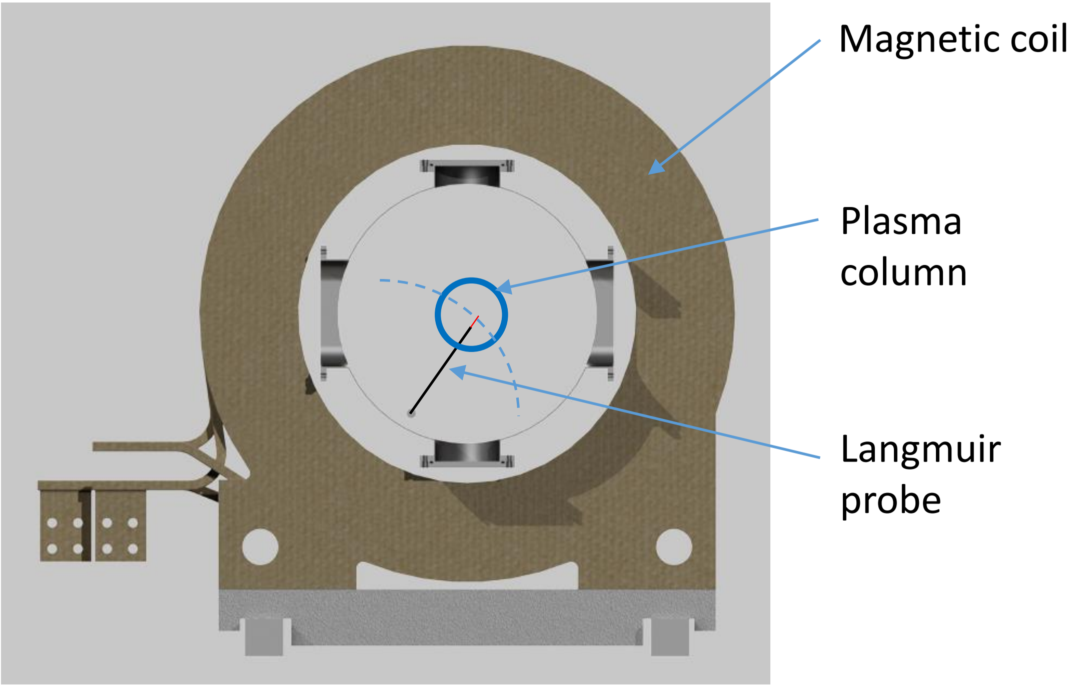
Frequency: **13.56 MHz**

Ph. Guittienne et al., *J. Appl. Phys.* **98,** 083304 (2005)

Plasma density is obtained by microwave interferometry and Langmuir probe

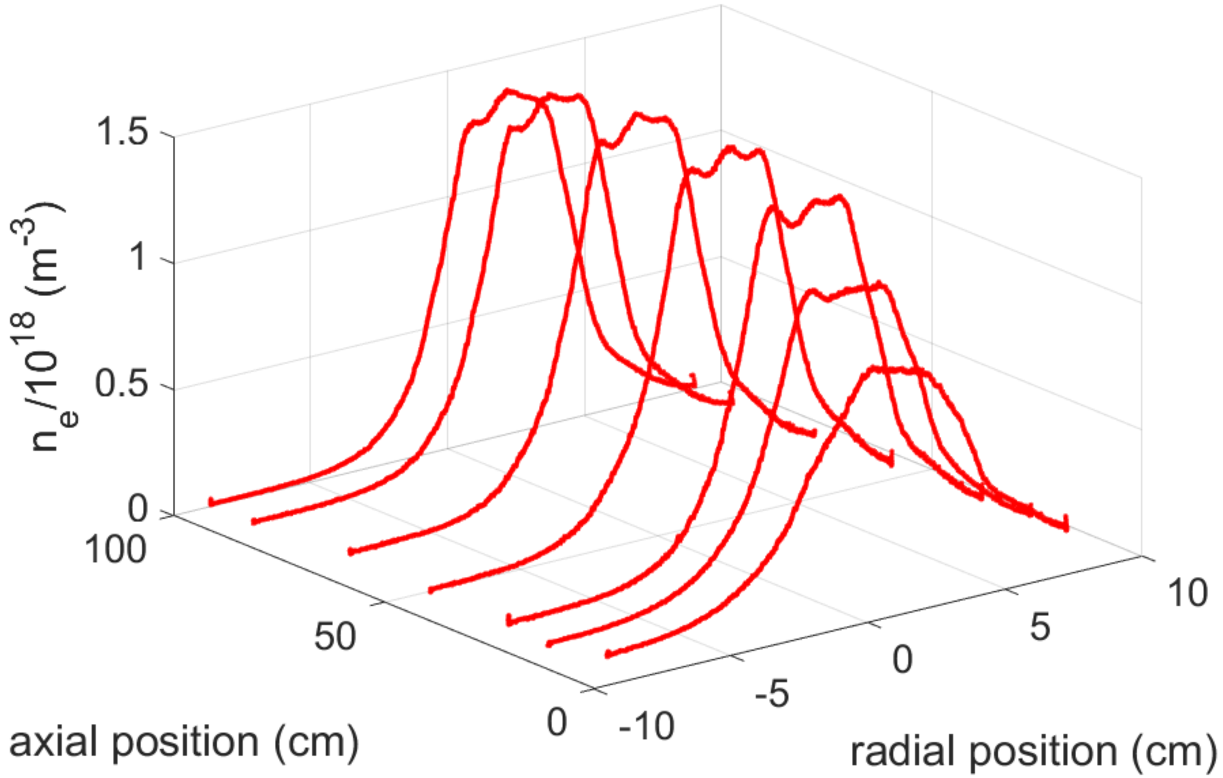


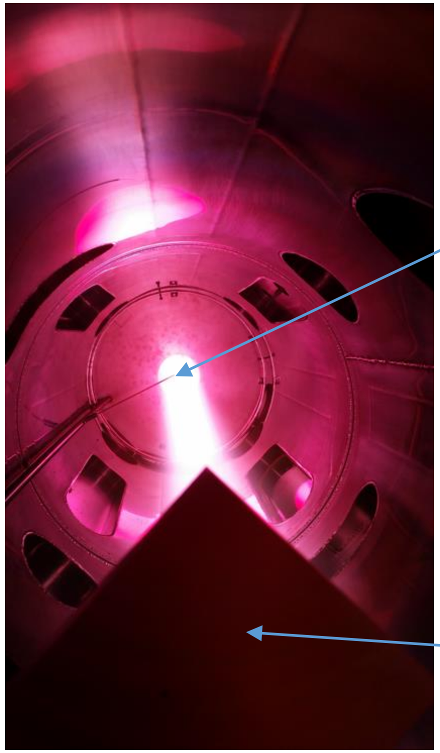
The 100 GHz heterodyne interferometer scheme



The 2 axis Langmuir probe inside the RAID vessel

Uniform density along the axis is measured





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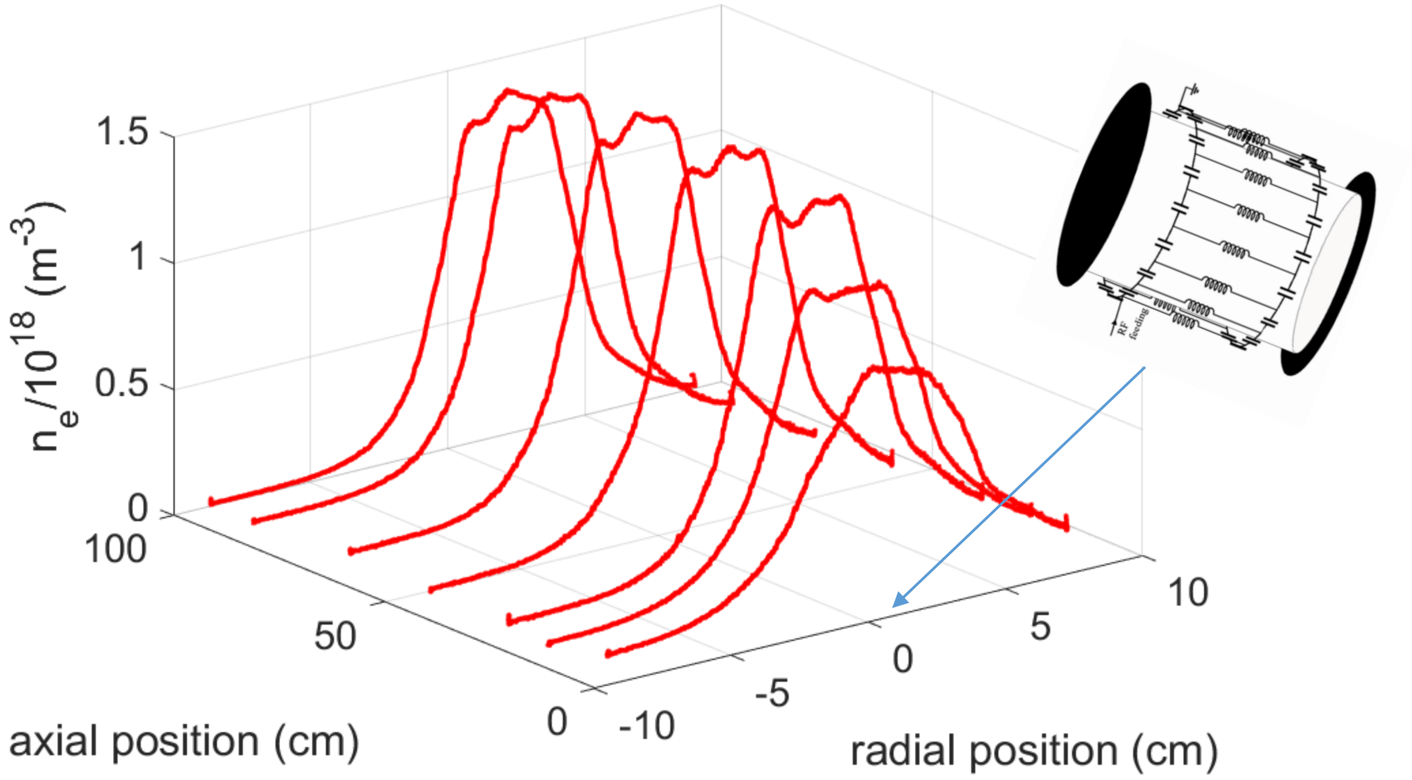
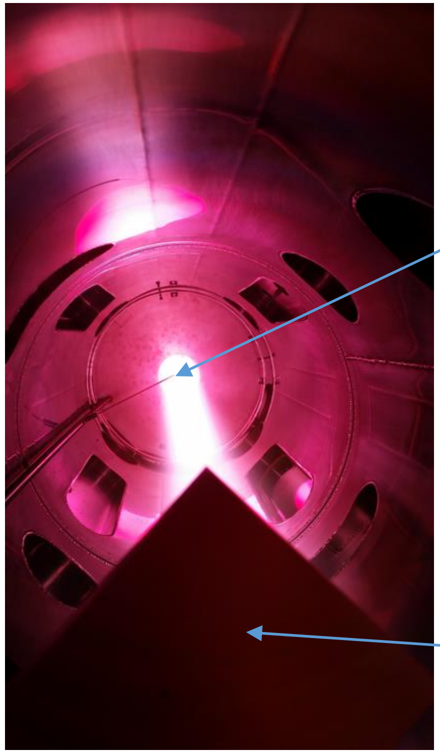
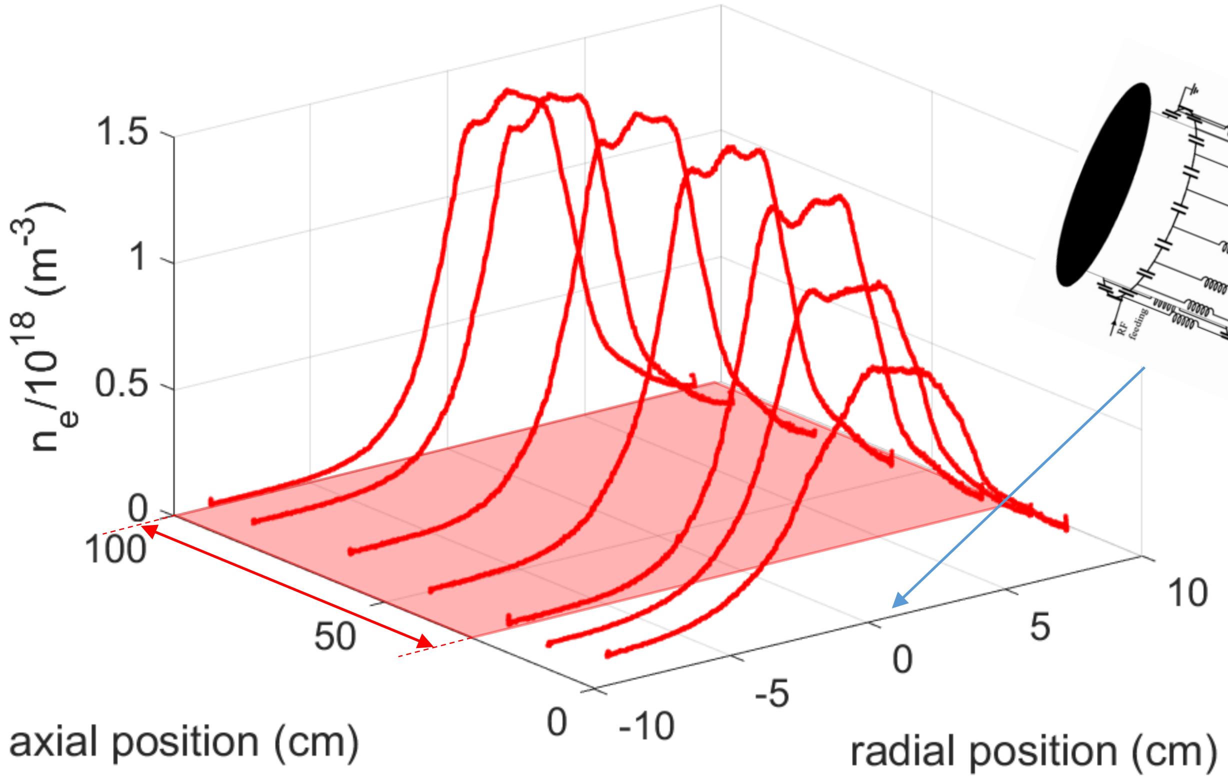


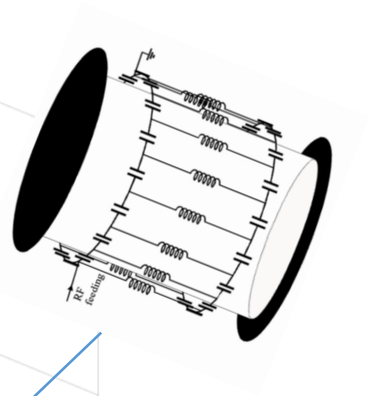


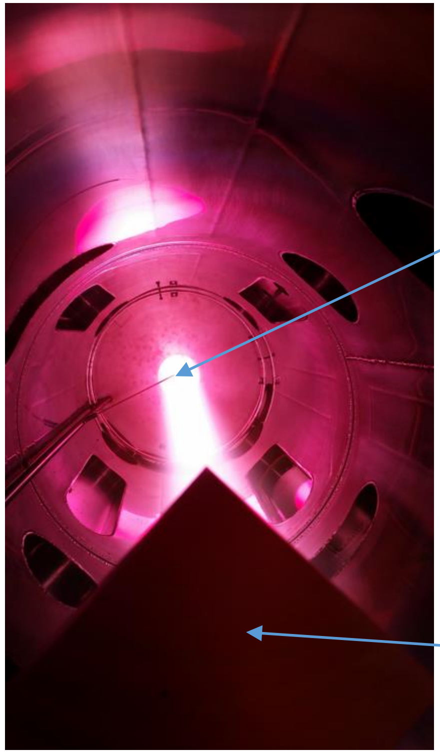
Langmuir Probe

Water cooled end-plate

Uniform density along the axis is measured





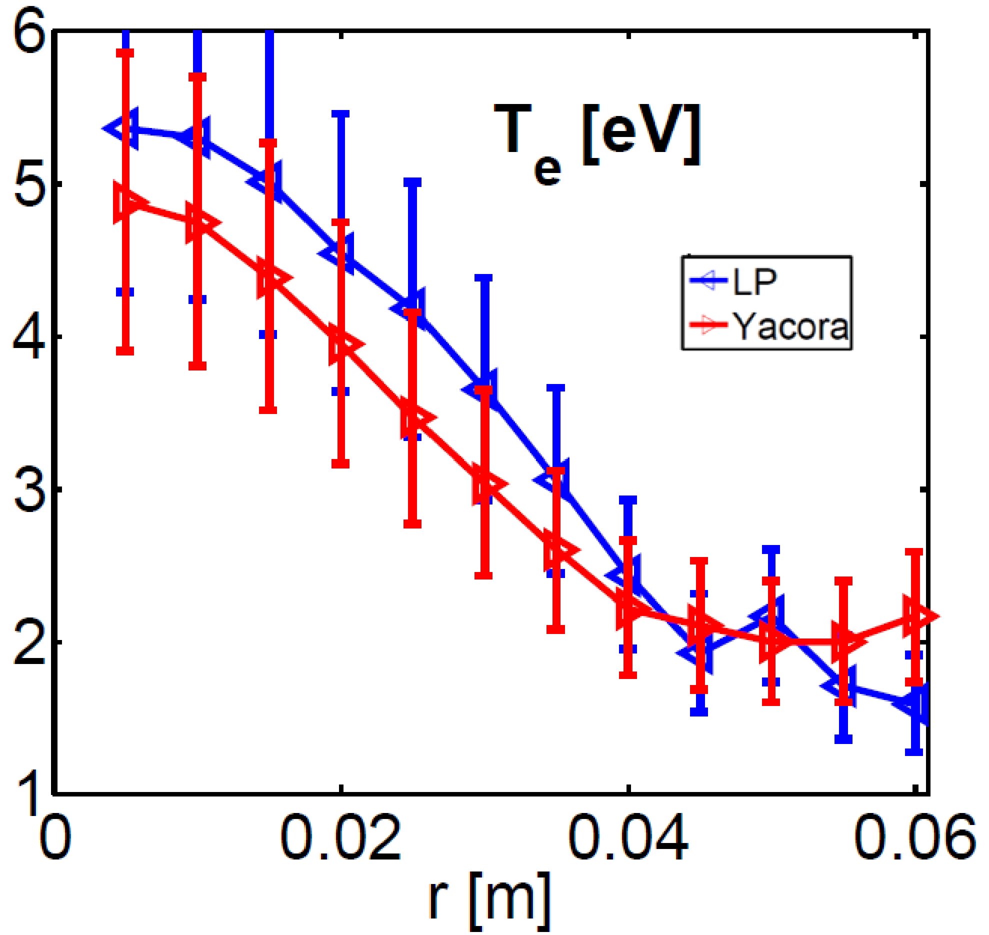


Plasma density profiles for hydrogen plasma at 2kW: uniform density along 80 cm → favorable for production of negative ions

Peaked T_e is observed from OES and LP measurements

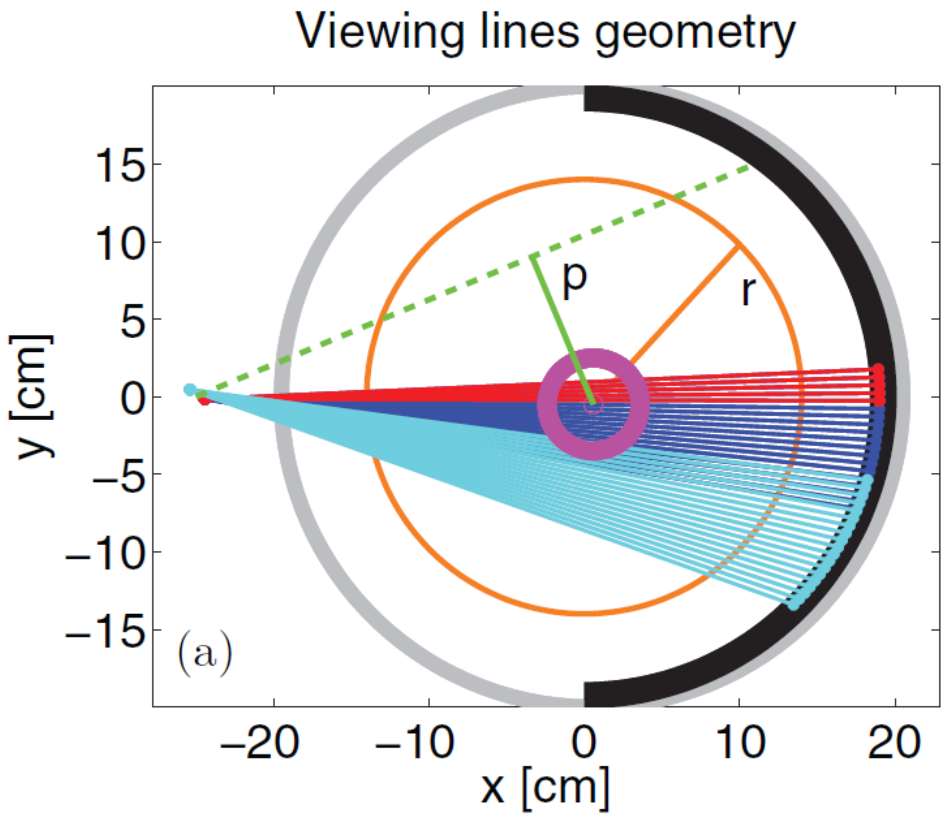
$$H_2^* + e\,(< 1\,eV) \rightarrow H^- + H$$

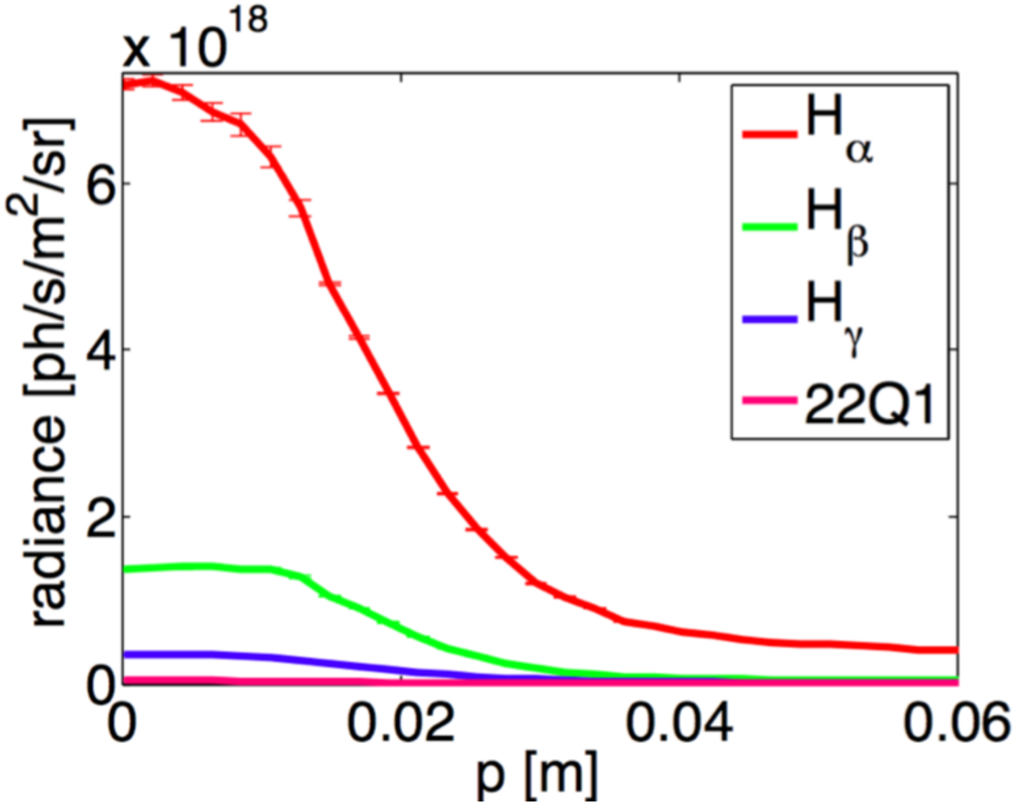
*Temperature profile favorable for negative ion production by **dissociative attachment** (volume production)*



Comparison of the temperature profile with LP and OES

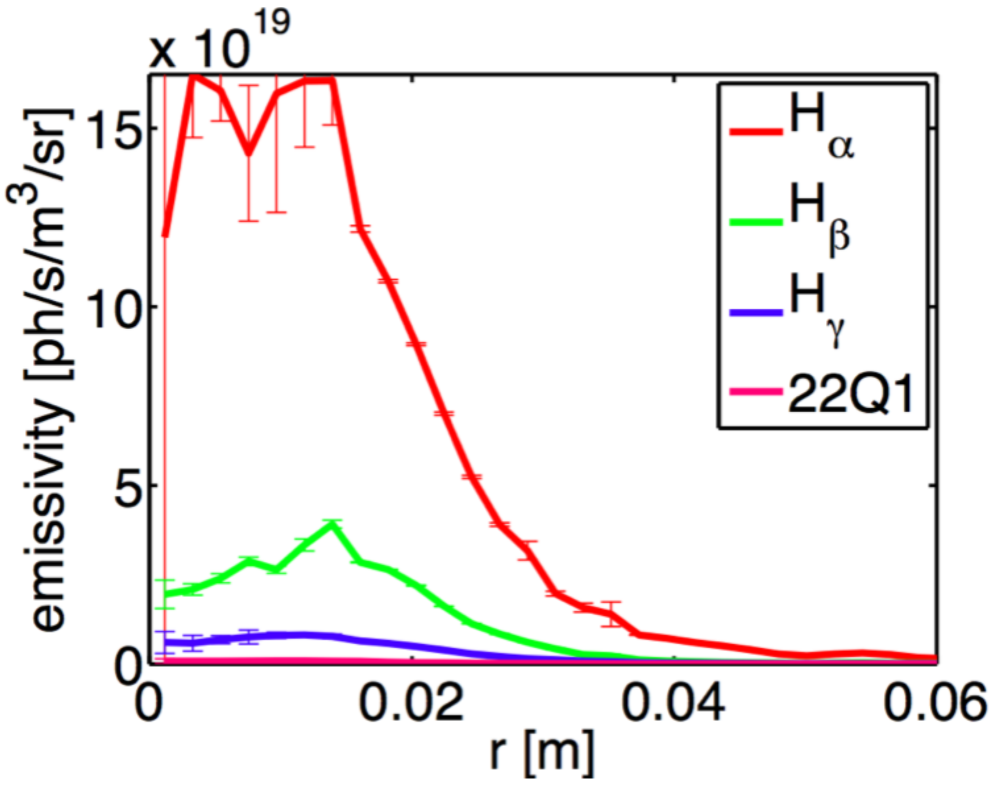
Optical emission spectroscopy in multi-chord geometry allows measurements of radiance profiles



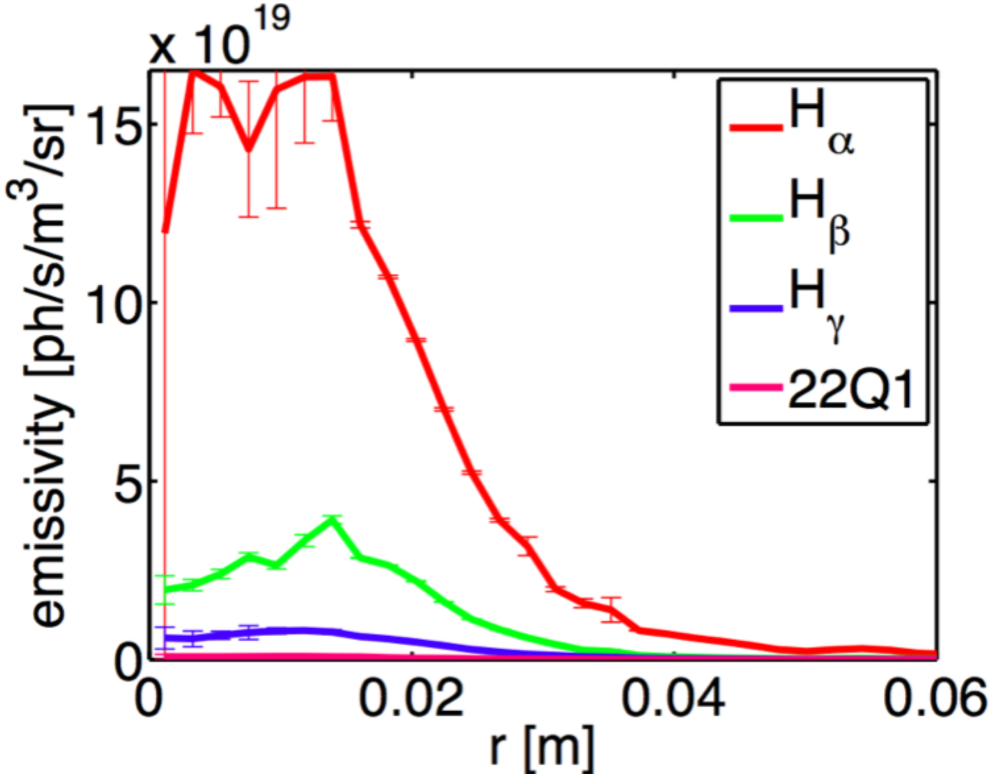


C. Marini et al., *Spectroscopic characterization of H_2 and D_2 helicon plasmas generated by a resonant antenna for neutral beam applications in fusion*, Nuclear Fusion, **57**, 036024 (2017).

Profiles are Abel inverted



Profiles are Abel inverted and interpreted with the collisional radiative code YACORA



YACORA code → profiles of $H, H_2, H^-, H^+, H_2^+, n_e, T_e$

D. Wunderlich et al., J. Quant. Spectros. Radia. Transfer **110**, 62-71 (2009)

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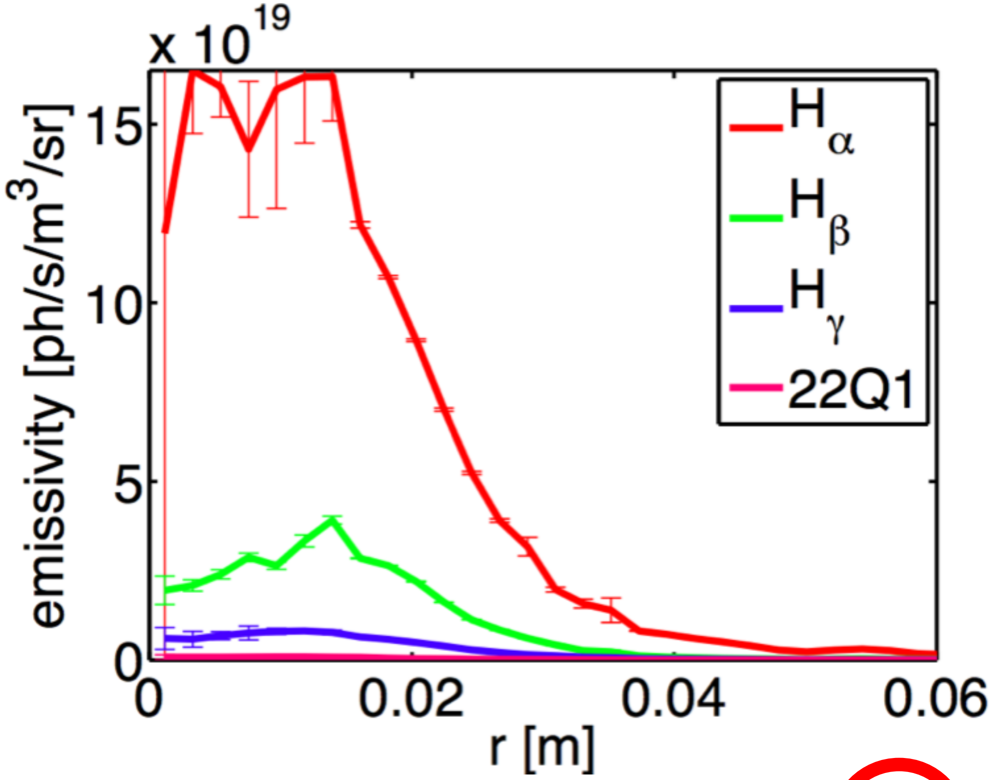

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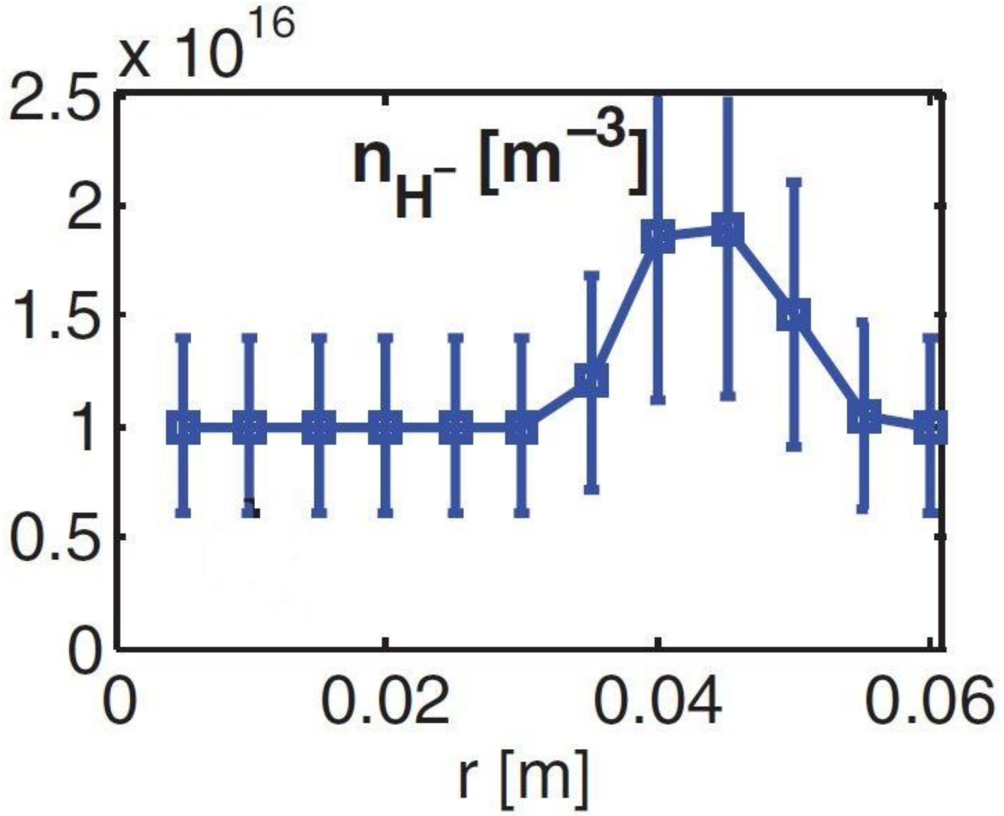
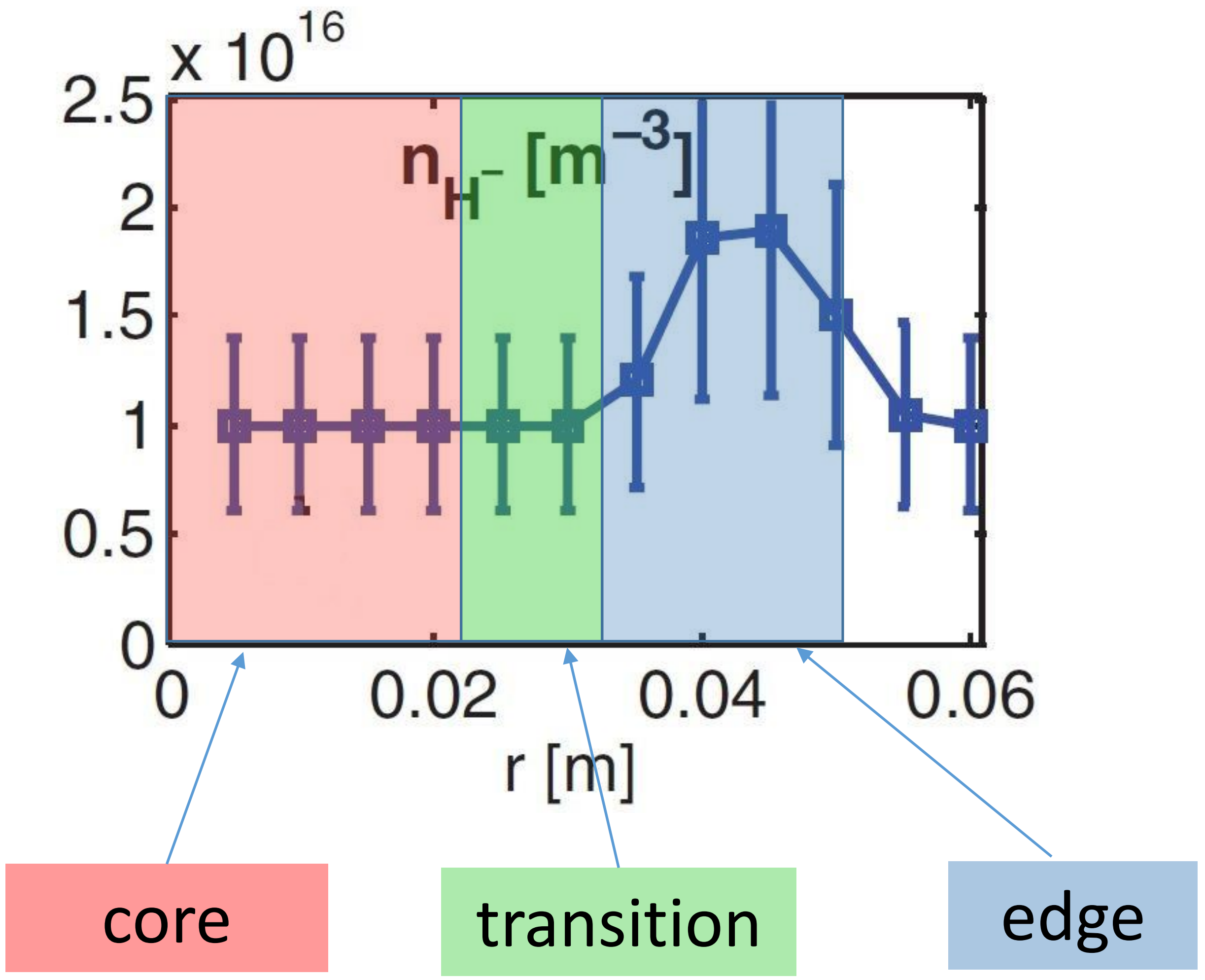
Negative ion density is peaked off-axis

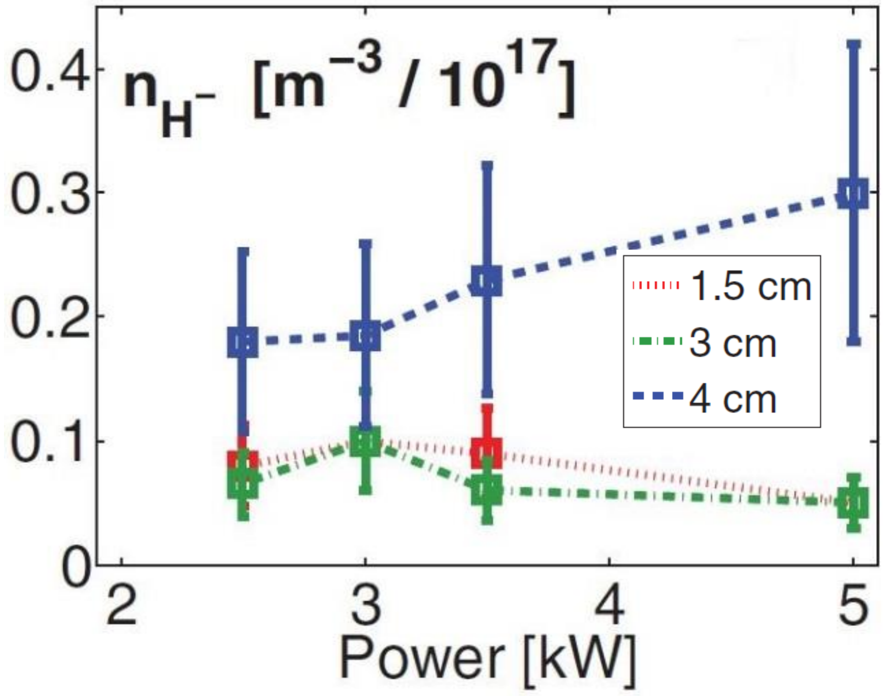


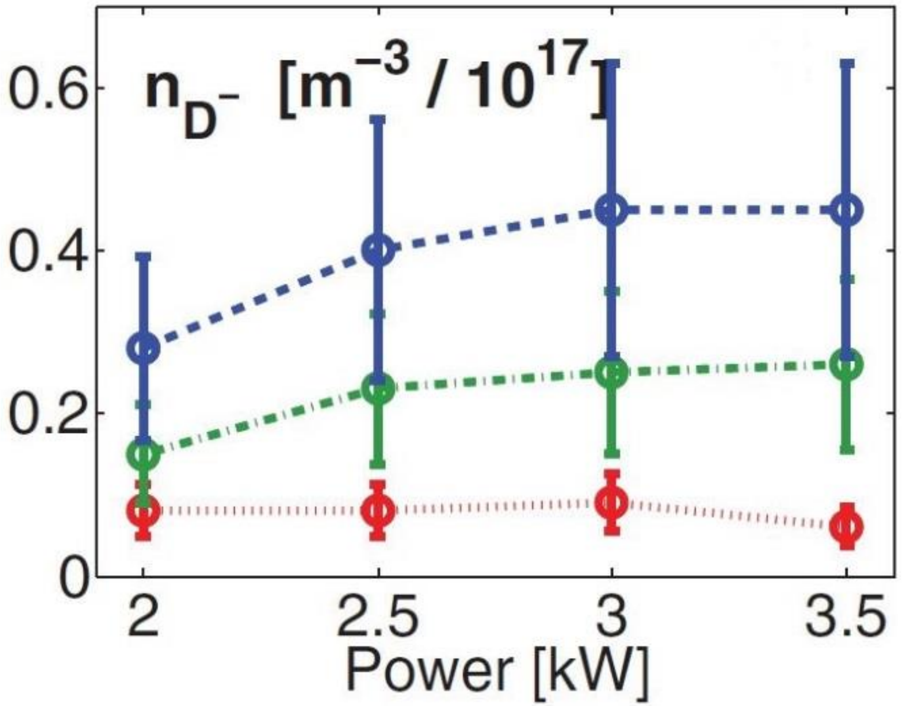
H^- density estimated by YACORA for an input power of 3 kW in hydrogen

Negative ion density is peaked off-axis



Negative ion population increases with power

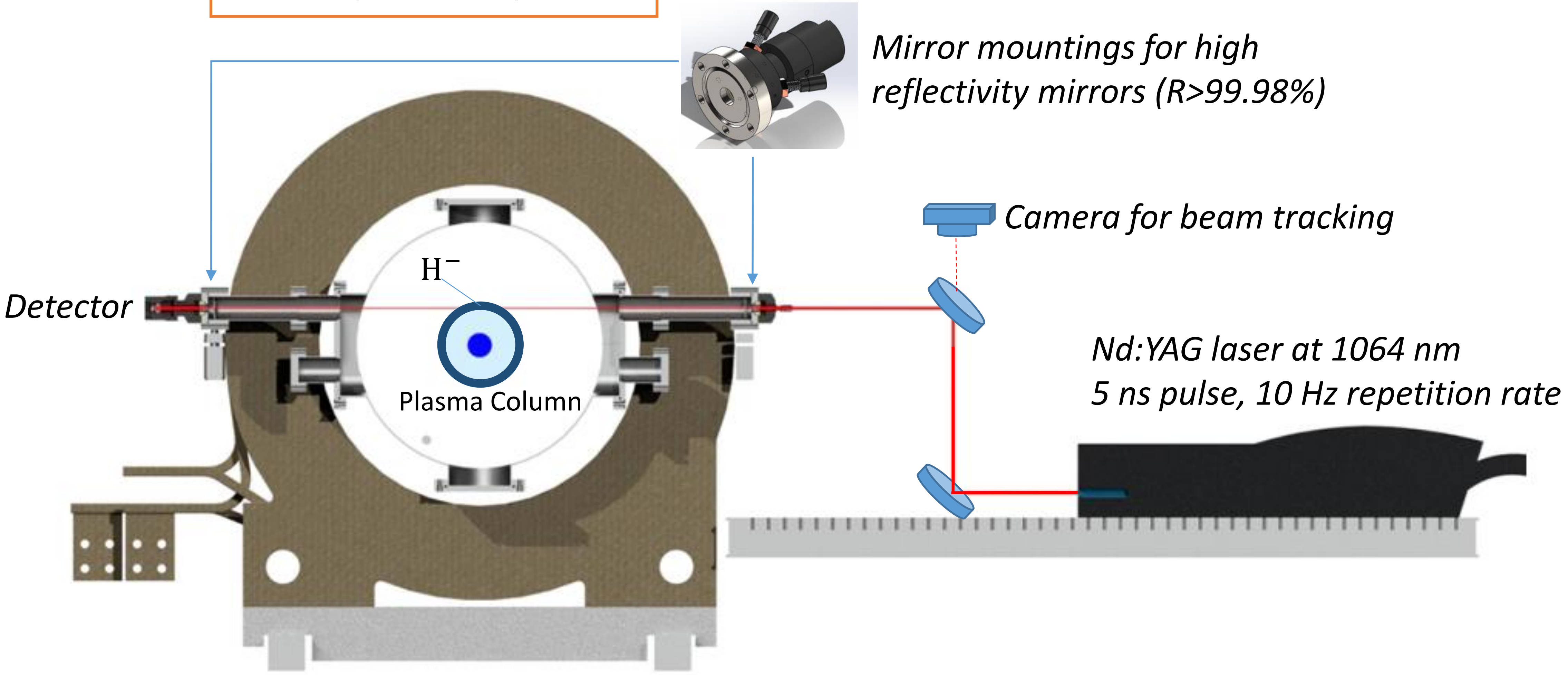




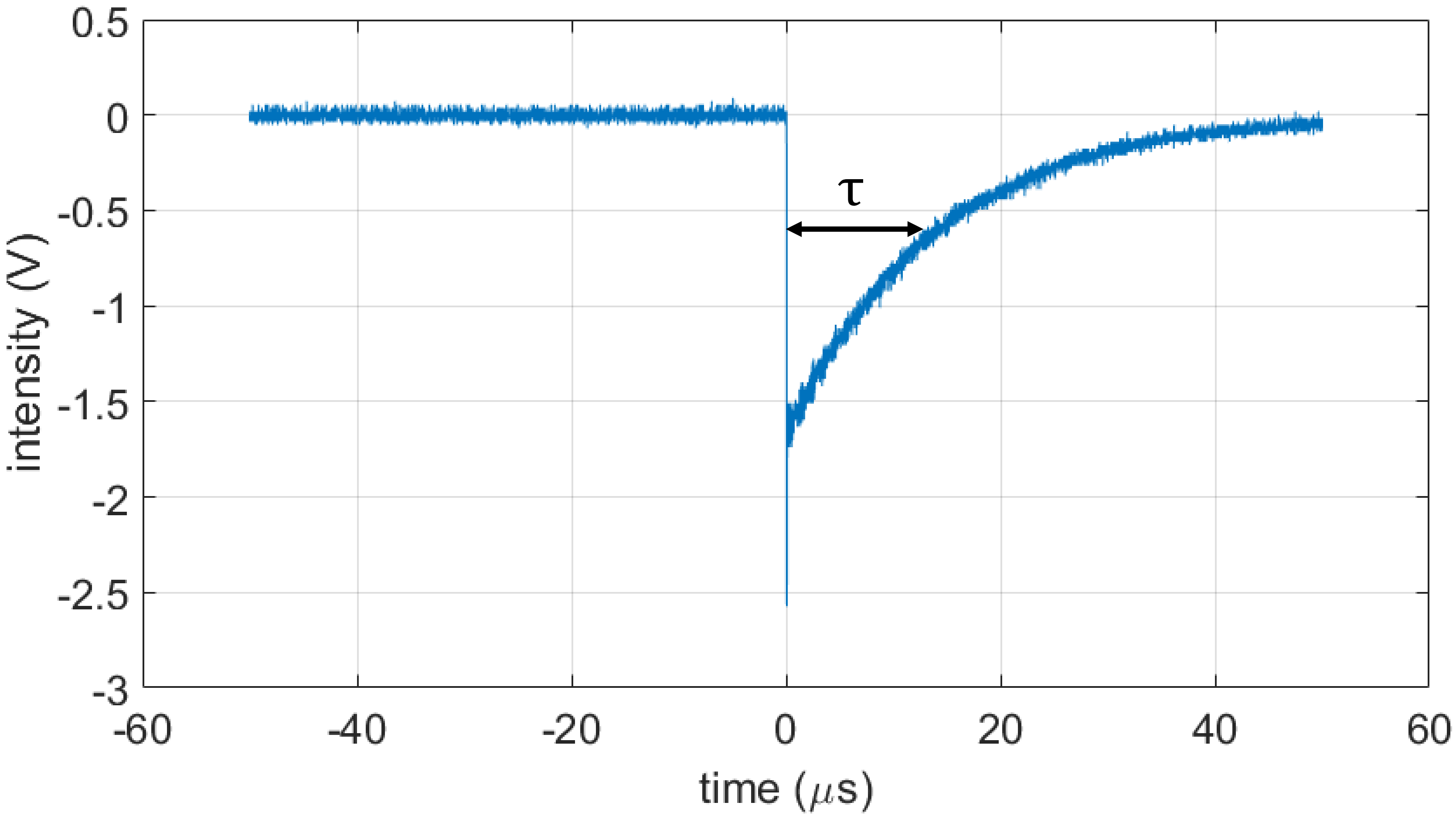
A favorable scaling with the power in the edge is observed

The Cavity Ring-Down Spectroscopy (CRDS) in RAID

Photodetachment process
$$\mathrm{H}^- + h\nu \rightarrow \mathrm{H} + e^-$$



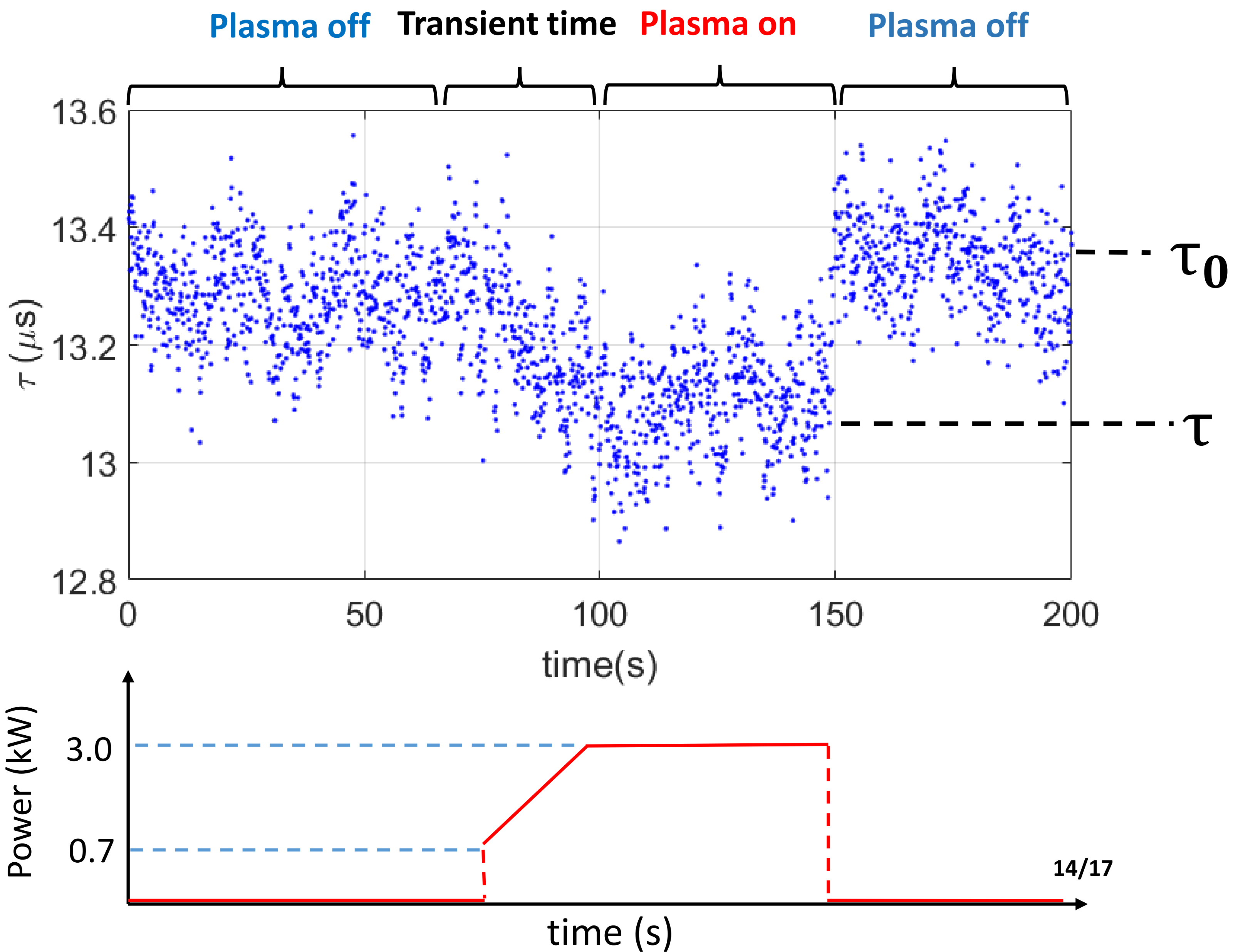
The transmitted YAG signal exhibits an exponential decay with a typical decay time τ



The presence of D⁻ is confirmed by the variation of τ in time

Transient time
time needed for impedance matching to have a stable plasma

- gas pressure = 0.3 Pa
- magnetic field = 200 G



First CRDS measurements agree with OES

τ_0 is averaged before and after the plasma

τ is averaged during plasma on (stable plasma)

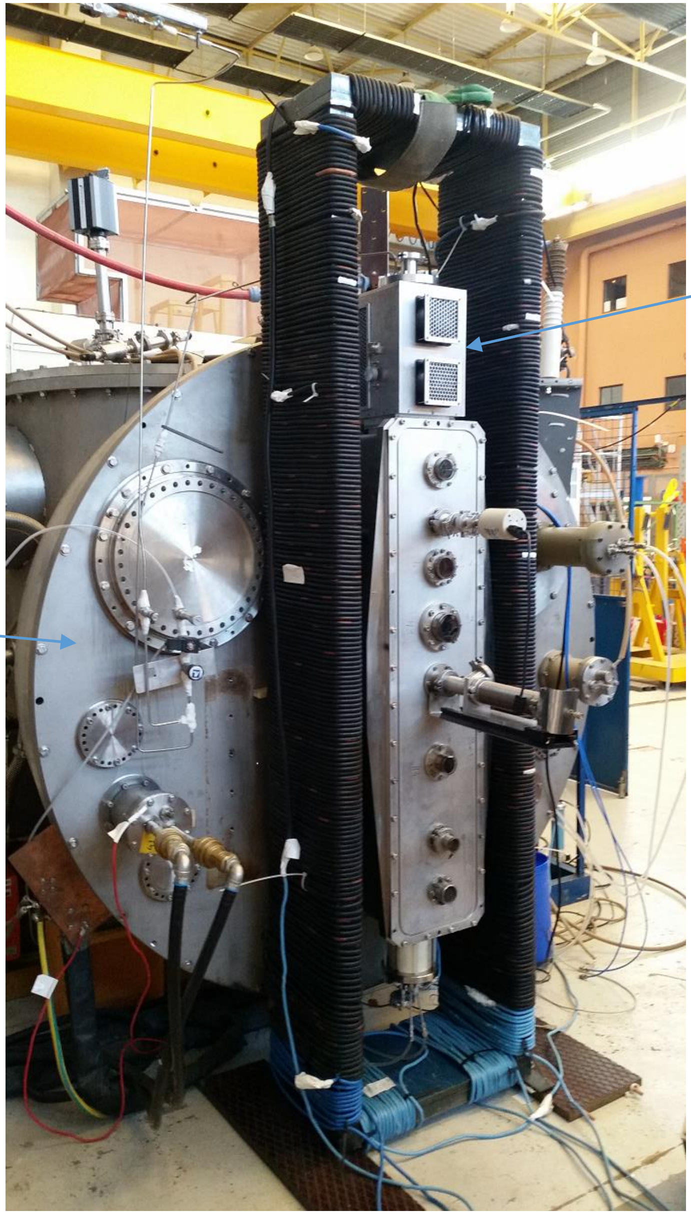
$$n(D^-) = \frac{L}{c\sigma d}\left(\frac{1}{\tau} - \frac{1}{\tau_0}\right)$$

L = 91 cm (HR mirror to HR mirror distance)
d = 5 cm (estimation of integration length)
$\sigma = 3.5 \times 10^{-21}\ m^{-2}$ (photo-detachment cross section)

	τ_0 (µs)	τ (µs)	$\bar{n}\ (m^{-3})$
1st test	13.313 ± 0.002	13.107 ± 0.004	$(\mathbf{2.04} \pm \mathbf{0.05}) \times \mathbf{10^{16}}$
2nd test	13.712 ± 0.003	13.476 ± 0.004	$(\mathbf{2.21} \pm \mathbf{0.05}) \times \mathbf{10^{16}}$

Similar Resonant Antenna installed on Cybele

Chamber of extraction of negative ions



Resonant antenna

Summary

- The production of dense magnetized $\mathrm{H}_2/\mathrm{D}_2$ plasma columns up to 5kW has been demonstrated
- OES shows a negative ion population and a scaling with power
- We have performed a direct measurement of D^- by means of CRDS and we found an agreement with OES predictions

Outlook

- An extensive study of $\mathrm{H}^-/\ \mathrm{D}^-$ and helicon wave physics
    - ➢ Effect of the magnetic field, end plates, plasma rotation
    - ➢ Helicon wave absorption