A novel helicon plasma source for negative ion beams for fusion

Ivo Furno[1]

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Requirements for DEMO neutral beam are challenging and R&D is required

	DEMO[1]
Species	D^-
Beam Energy [keV]	800
Current [A]	34
Filling pressure [Pa]	0.2
Beam on time	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

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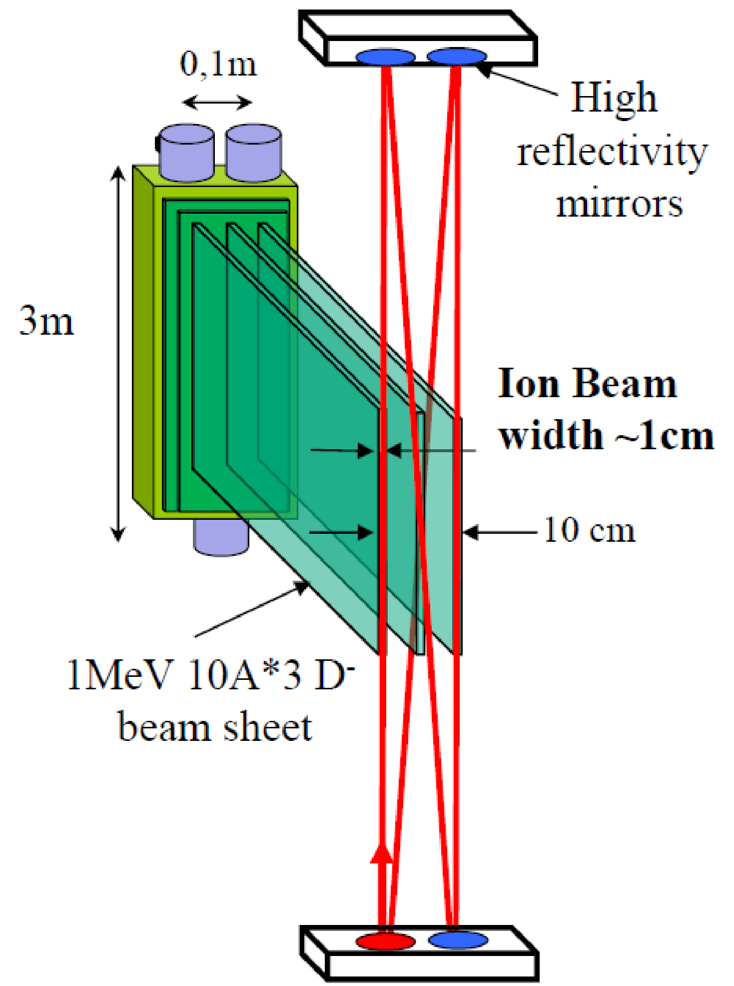
Photoneutralization concept on Cybele



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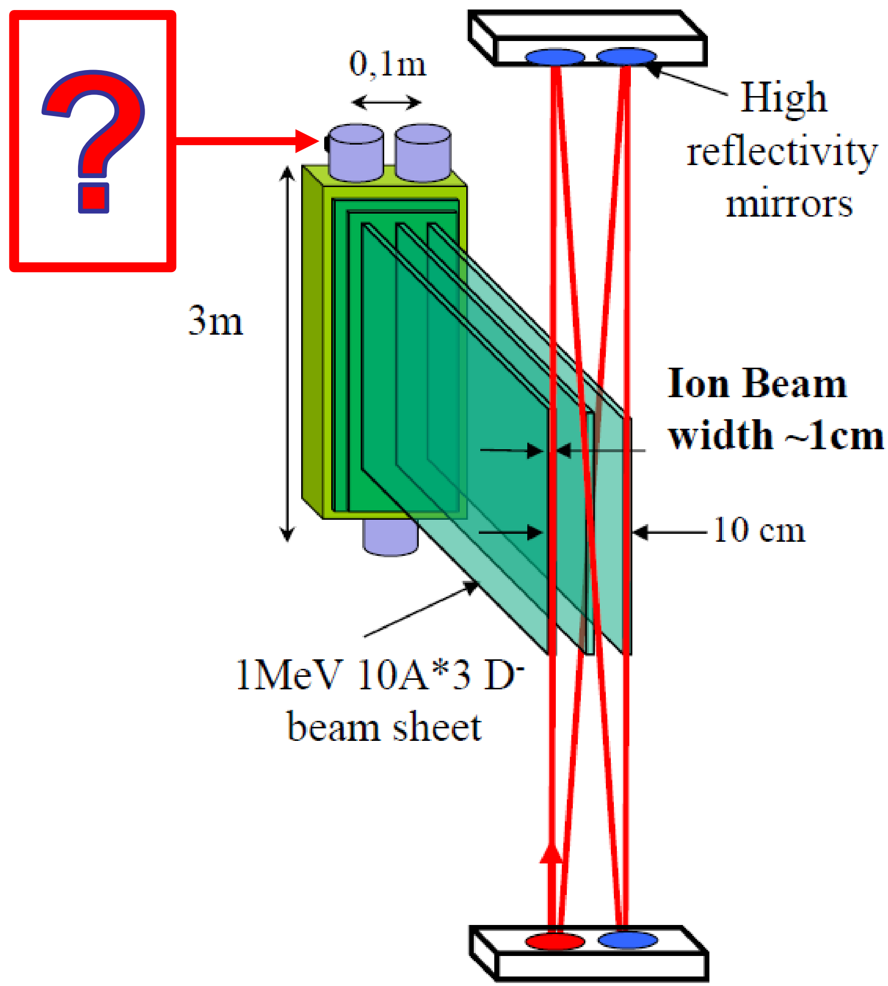

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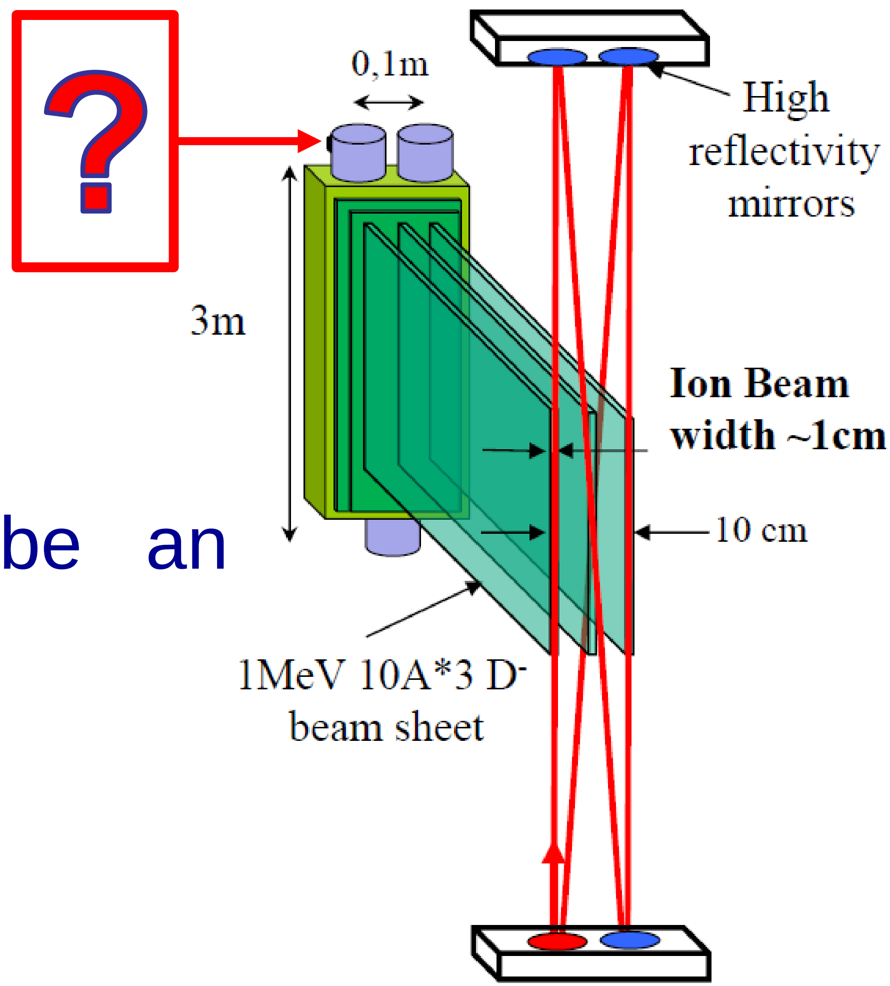


- Can helicon sources be an option?
  - Physics
  - Technology

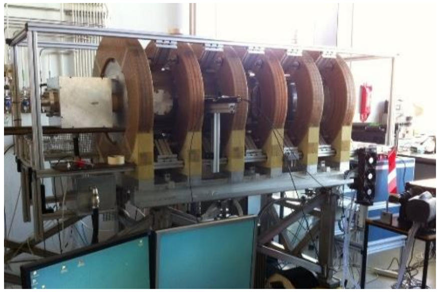
Outline

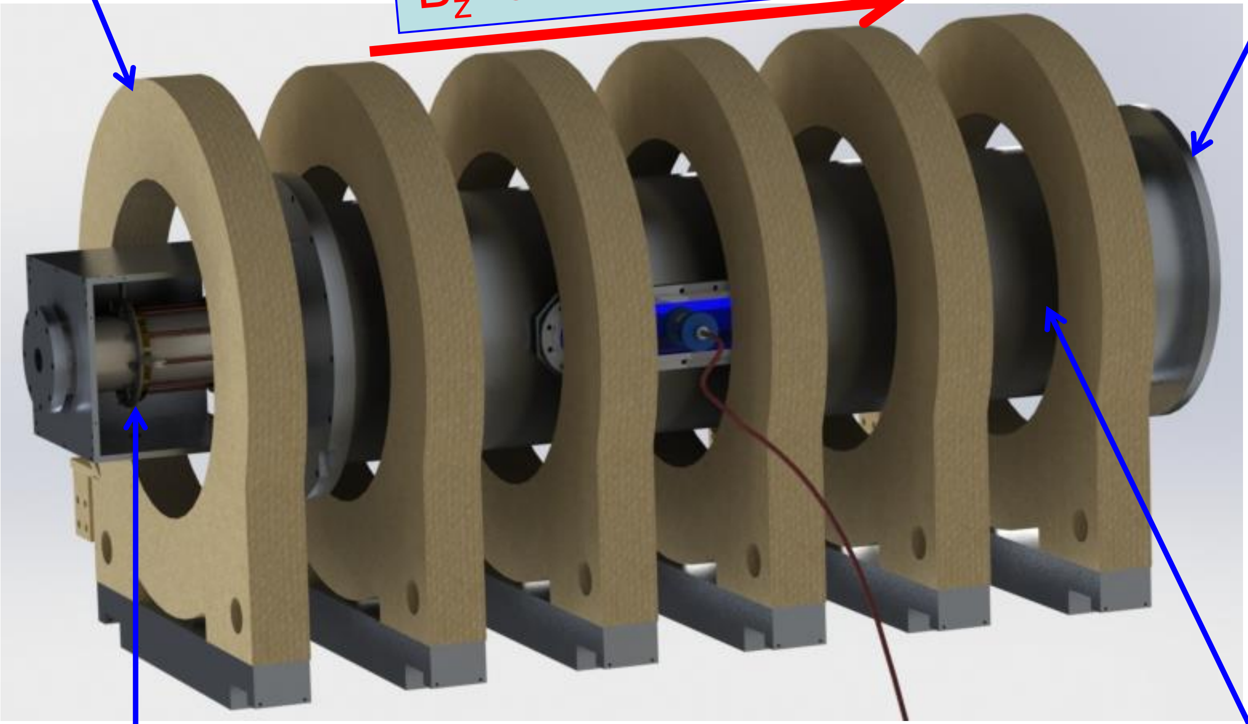
- The Resonant Antenna Ion device RAID at SPC
  - the birdcage resonant antenna

- OES and LP measurements
  - highly dissociated H_2 and D_2 plasmas
  - presence of negative ions

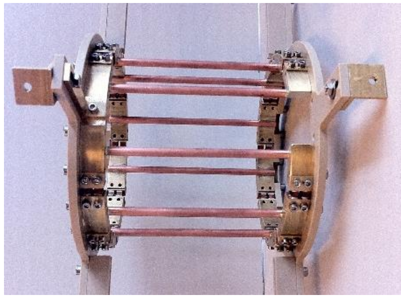
- Summary and outlook

The Resonant Antenna Ion Device (RAID) at SPC





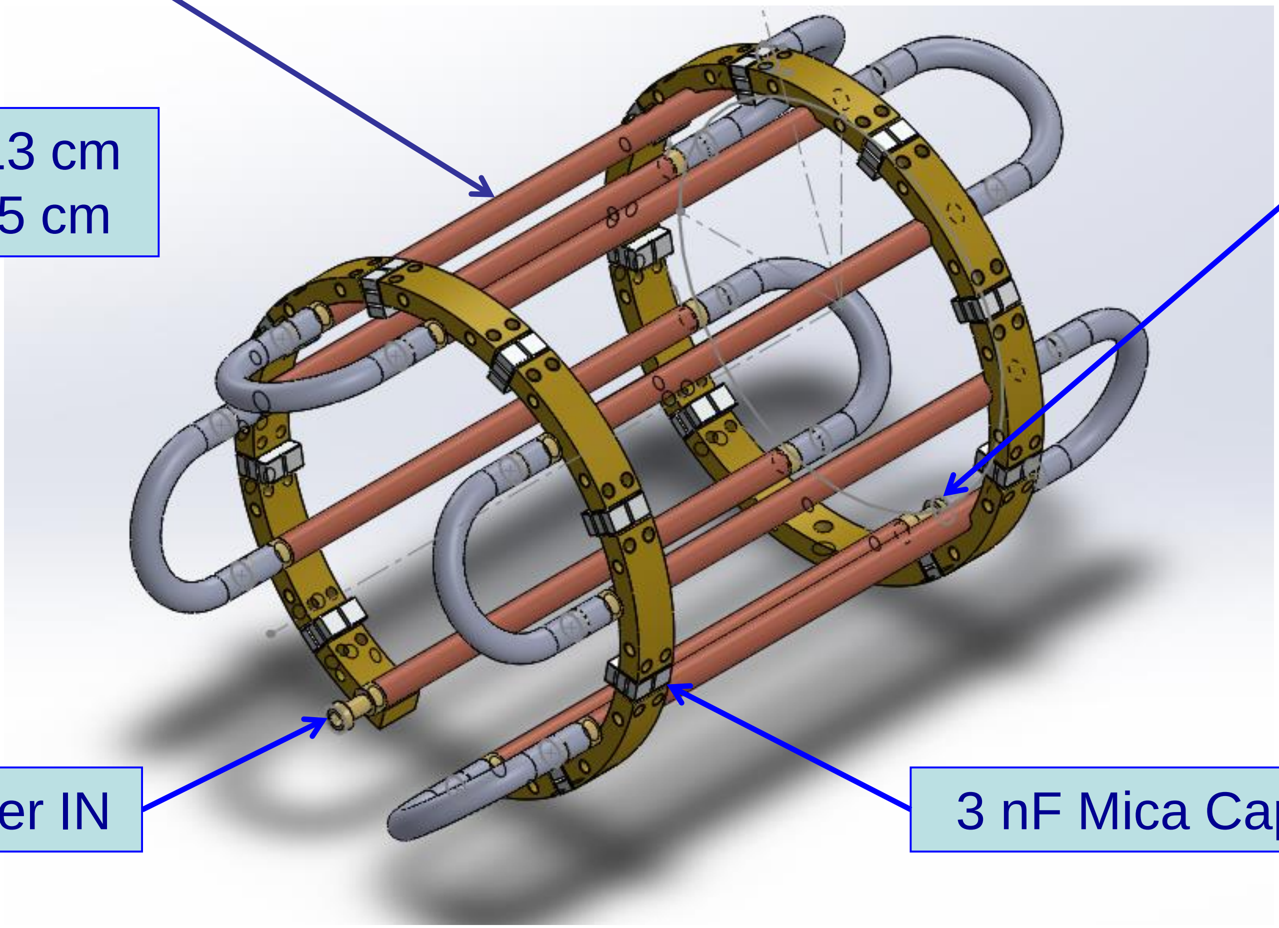
10kW birdcage resonant antenna



9 water-cooled copper legs

D_{int}=13 cm
L = 15 cm

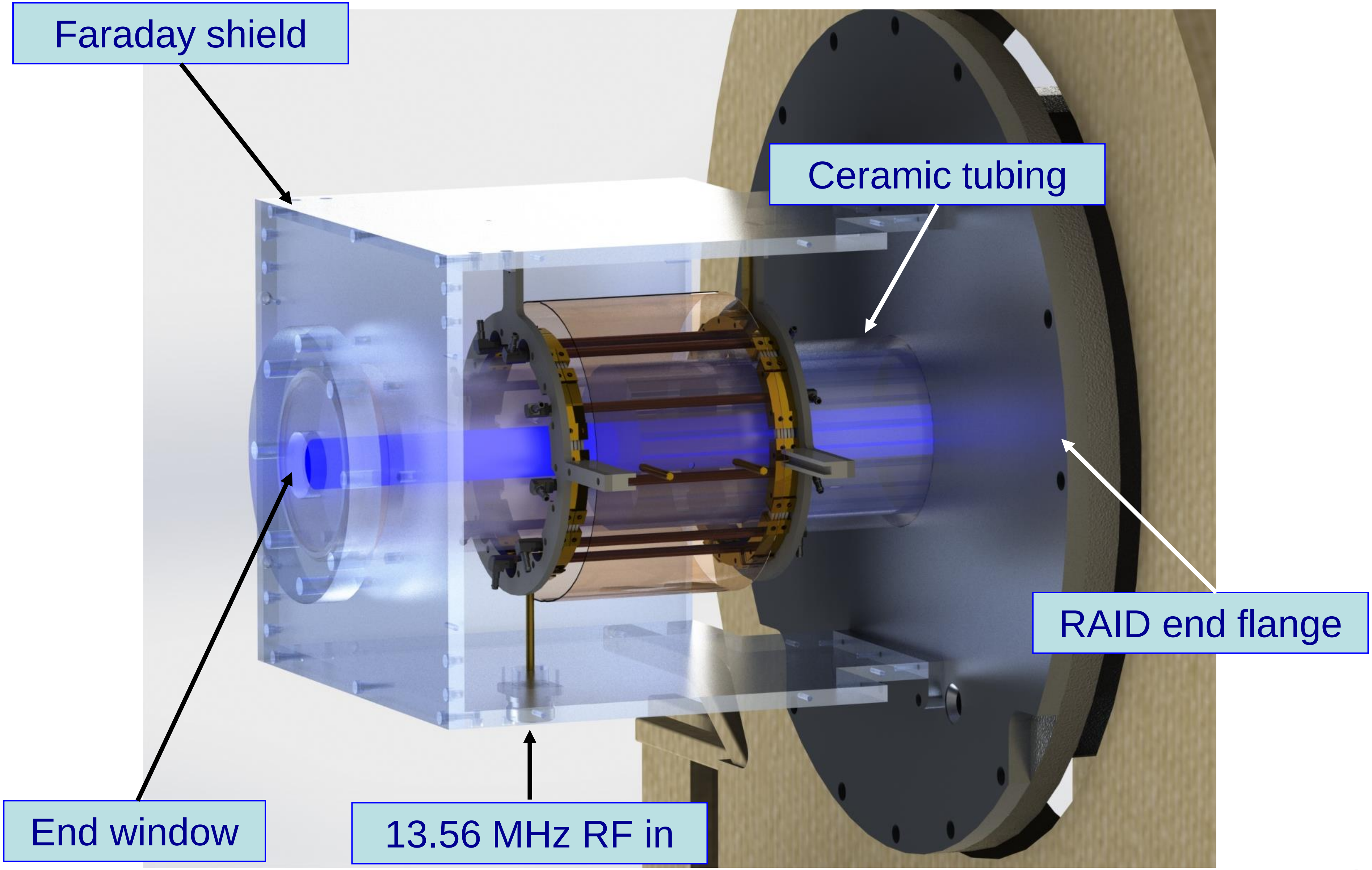
Water IN



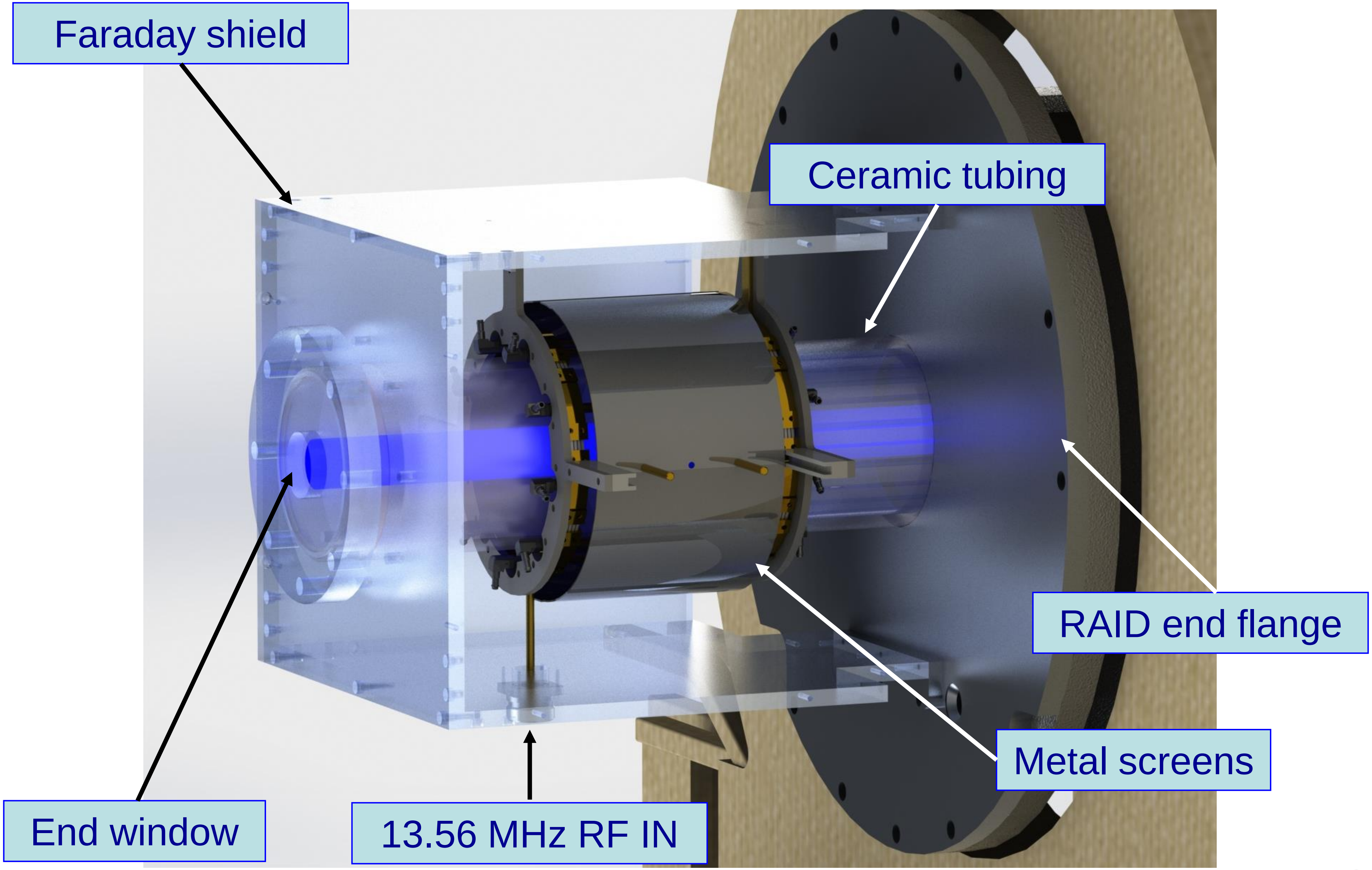
Water IN

3 nF Mica Capacitors

The birdcage antenna on RAID



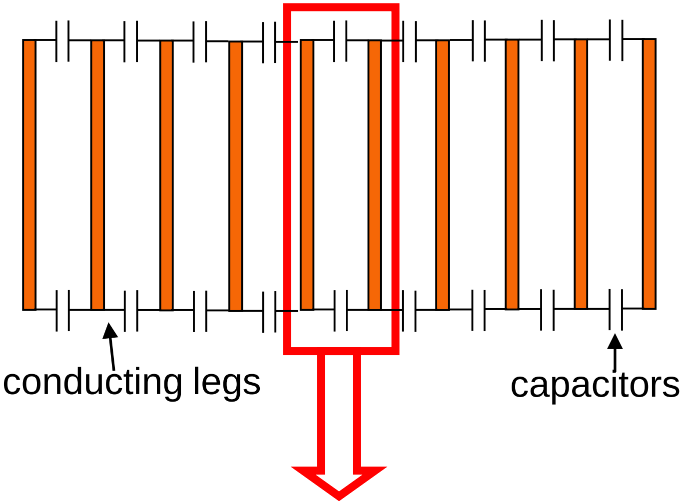
The birdcage antenna on RAID



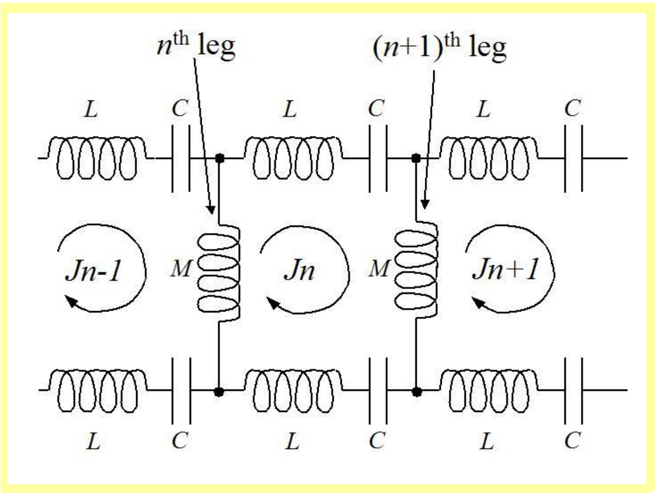
The birdcage antenna in a nutshell

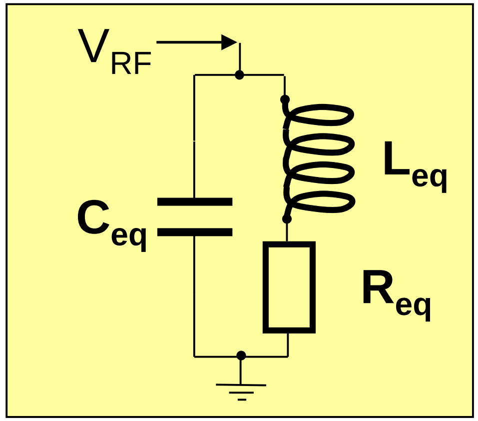
RF : 1-100 MHz

Balanced, high-pass, passive filter ladder network



Antenna equivalent circuit (lumped elements)





Each resonant frequency

Real impedance

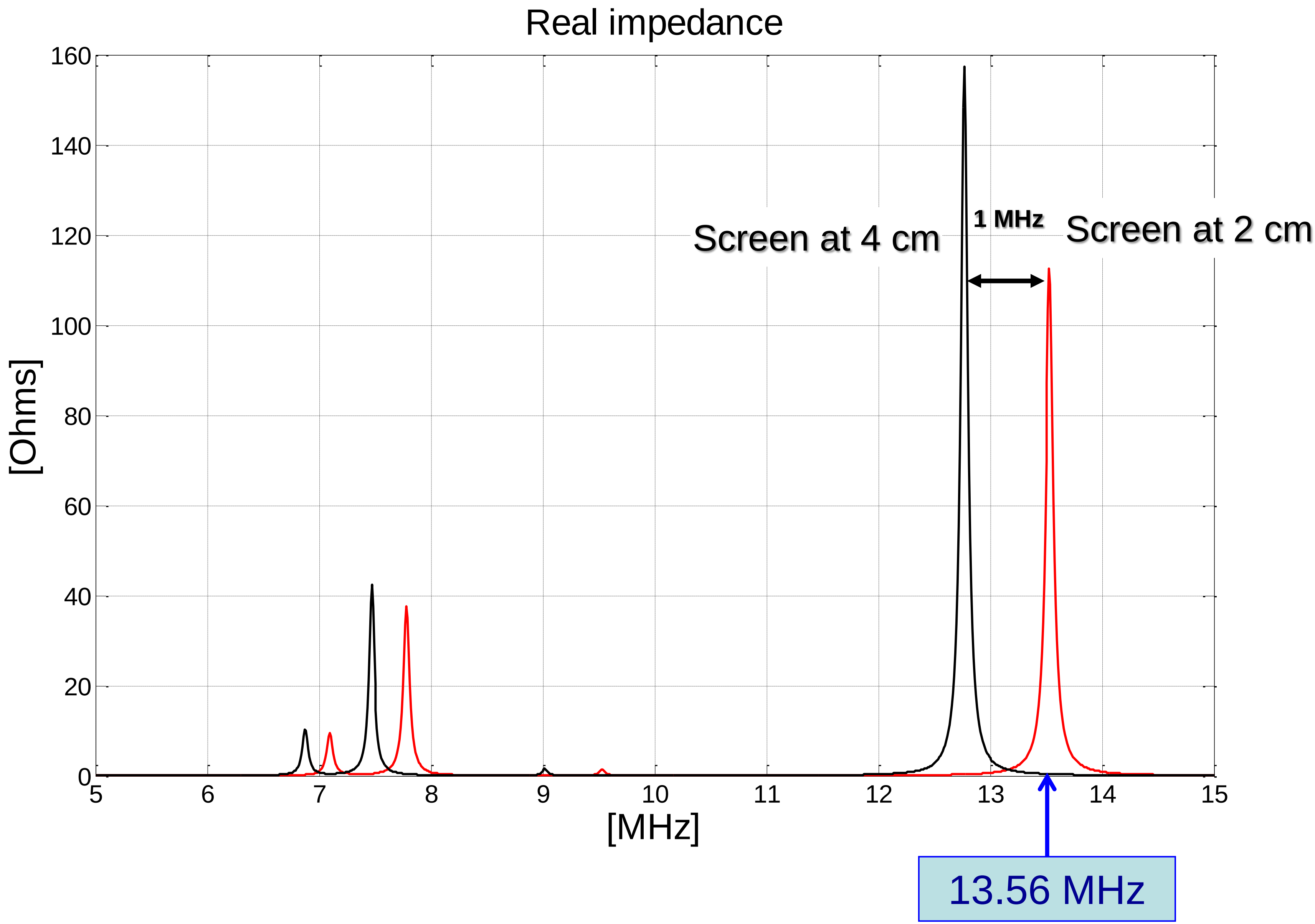
$$\omega_m \approx \frac{1}{\sqrt{L_{eq} C_{eq}}}$$

***N*-1 resonant frequencies**

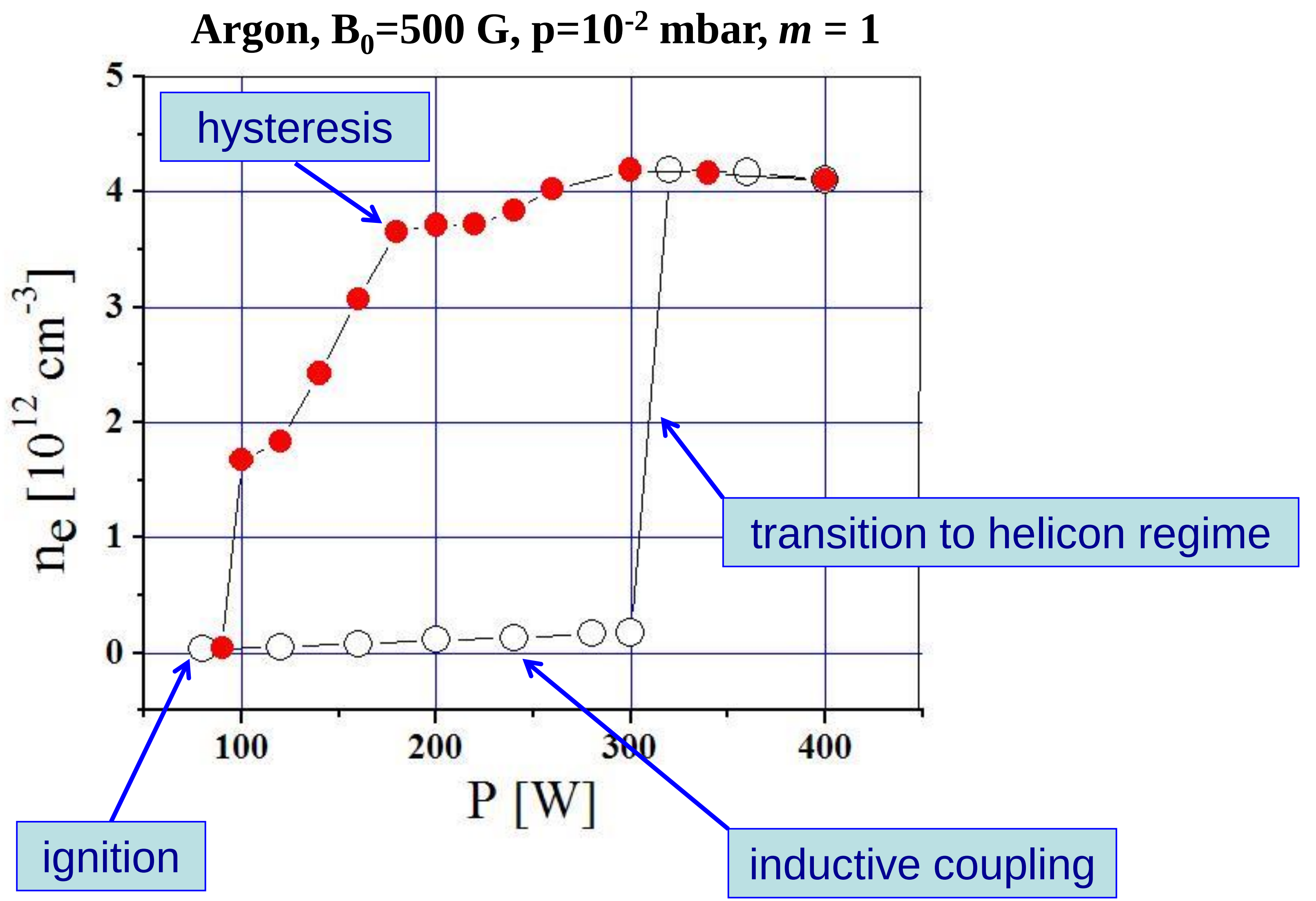
$$\omega_m = \frac{1}{\sqrt{C\left(M + 2L\sin^2\left\{\frac{m\pi}{2N}\right\}\right)}}$$

***m*=1, 2,…, *N*-1**

RAID antenna impedance

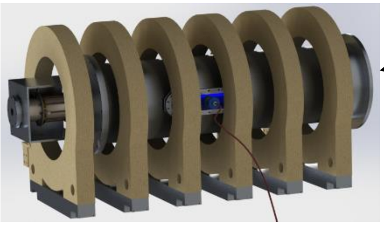


Birdcage antennas efficiently produce helicon plasmas

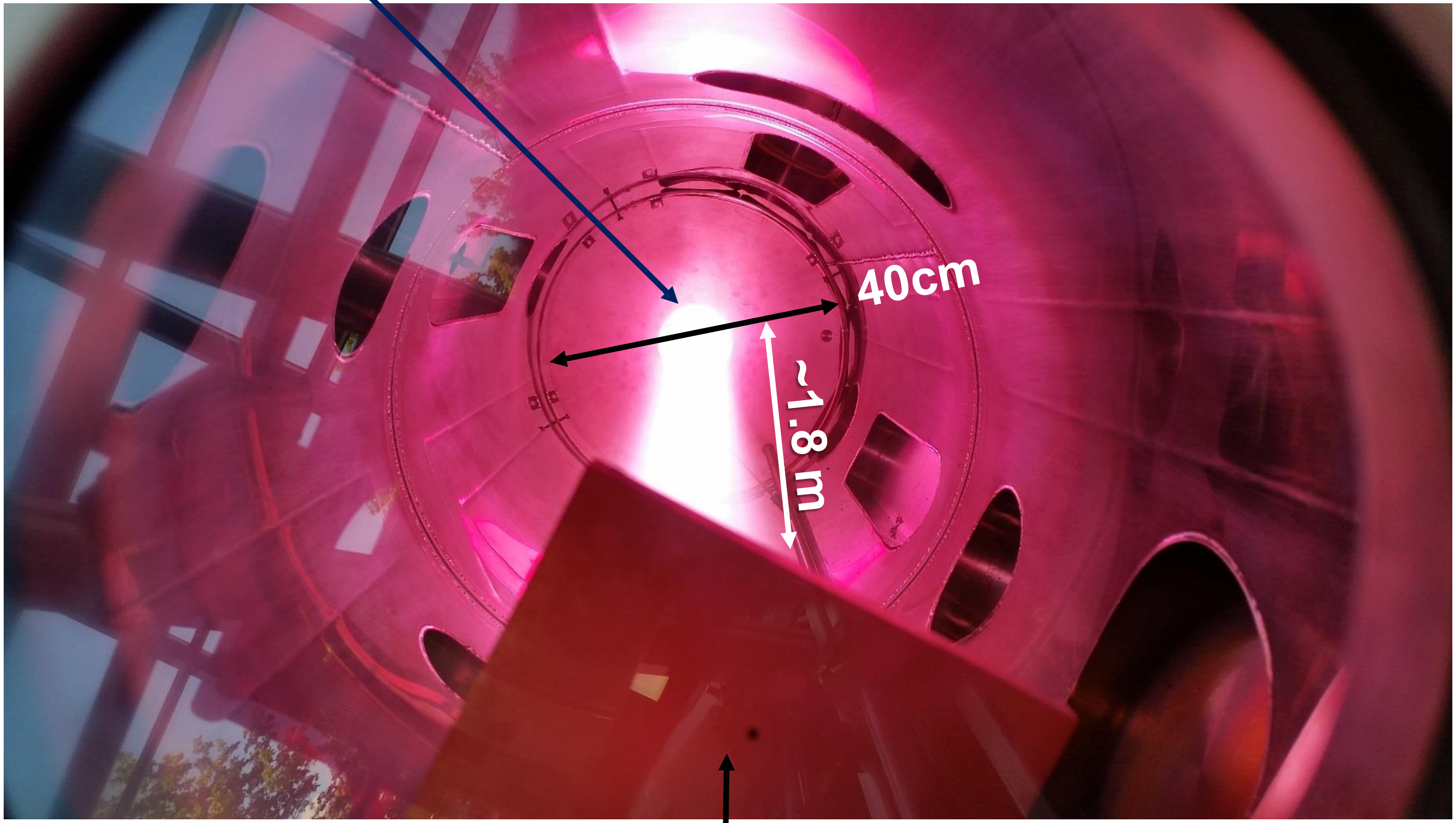


Ph. Guittienne et al., *J. Appl. Phys.* **98,** 083304 (2005)

A 3 kW, 0.3 Pa, H_2 plasma

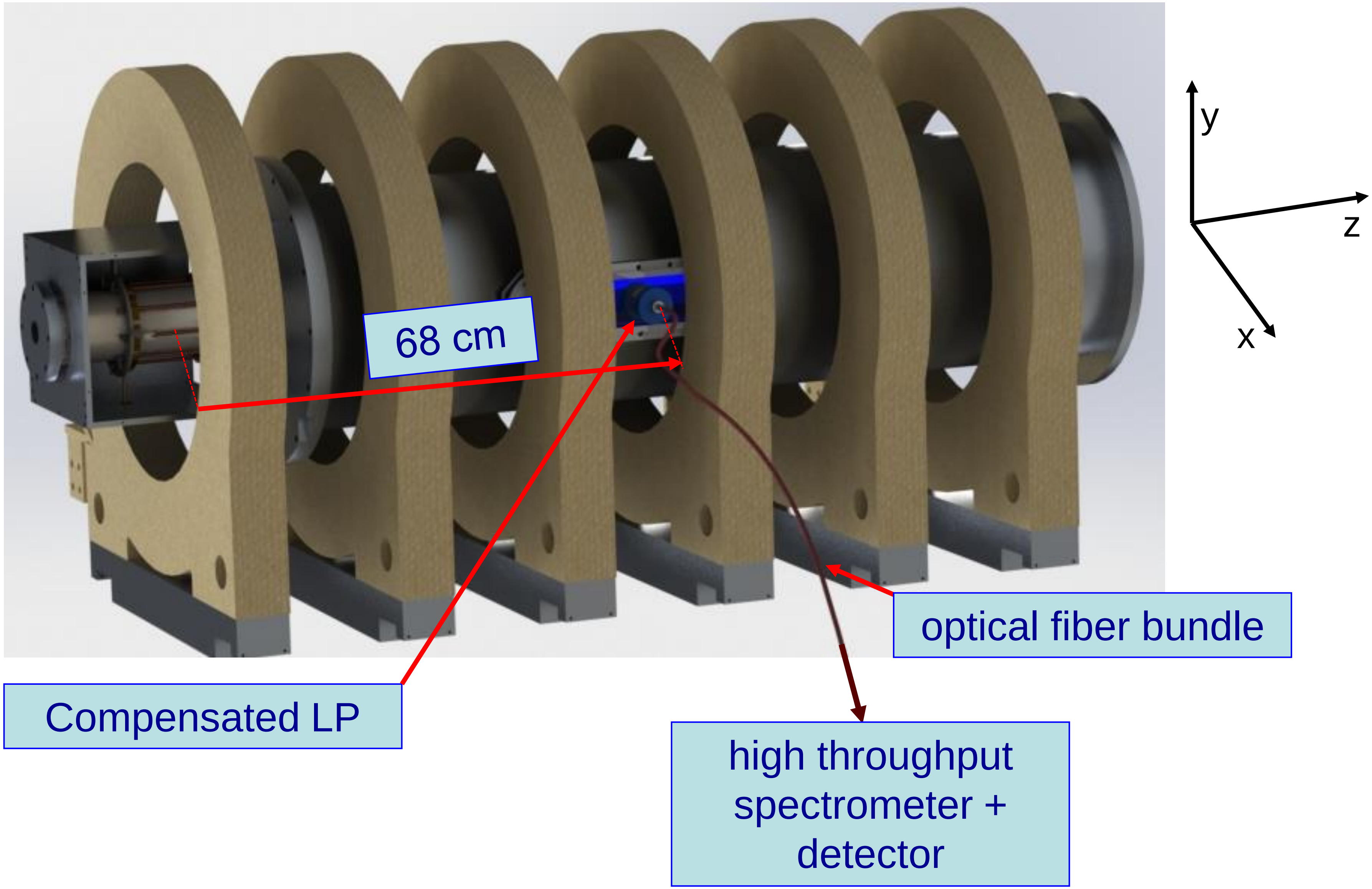


Birdcage antenna

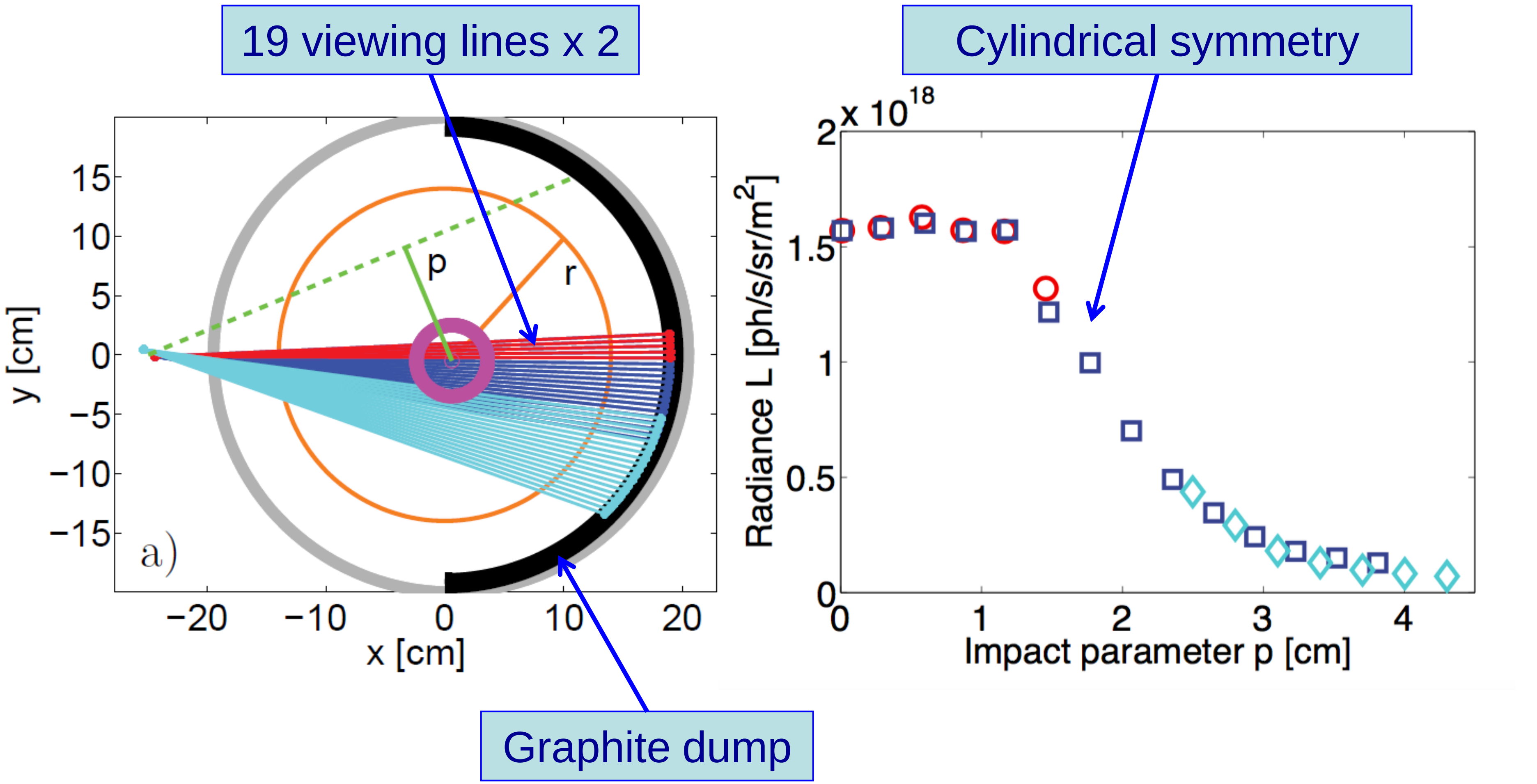


water-cooled end plate

Diagnostics: Langmuir probe, OES

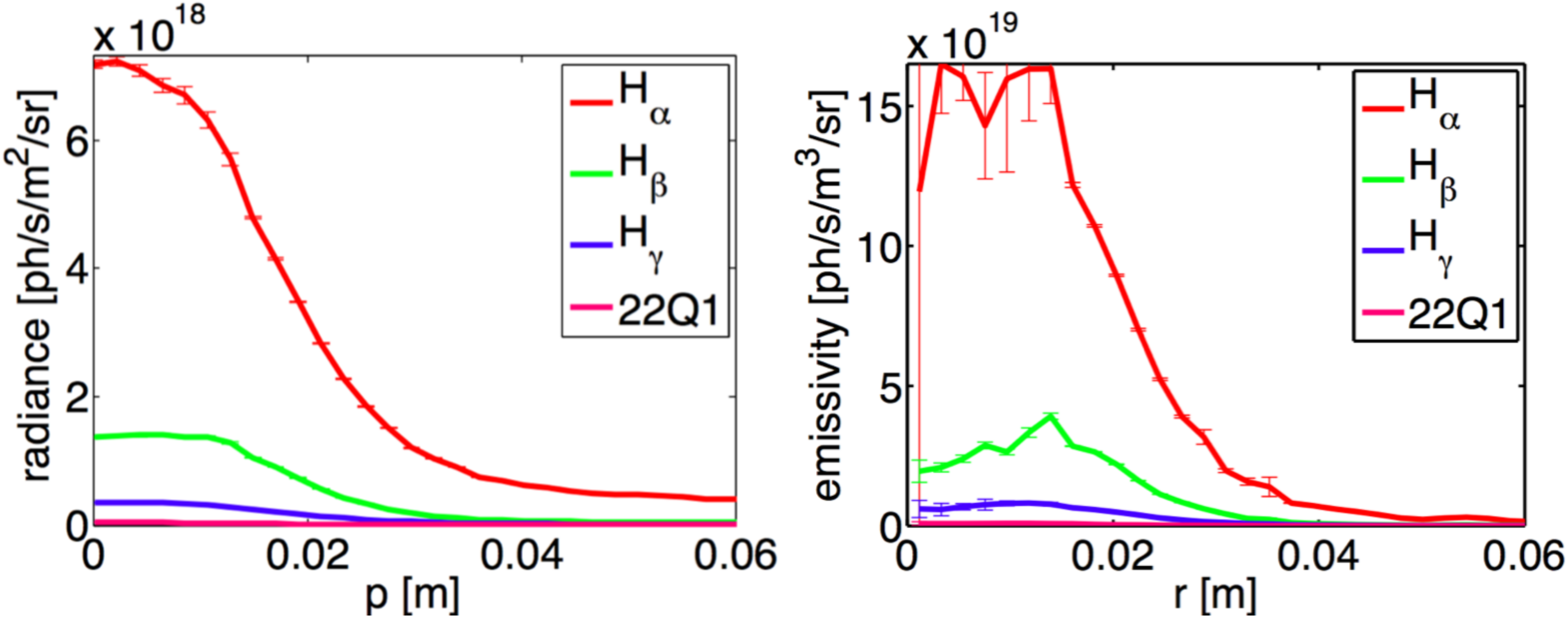


Absolute OES in multi-chord geometry

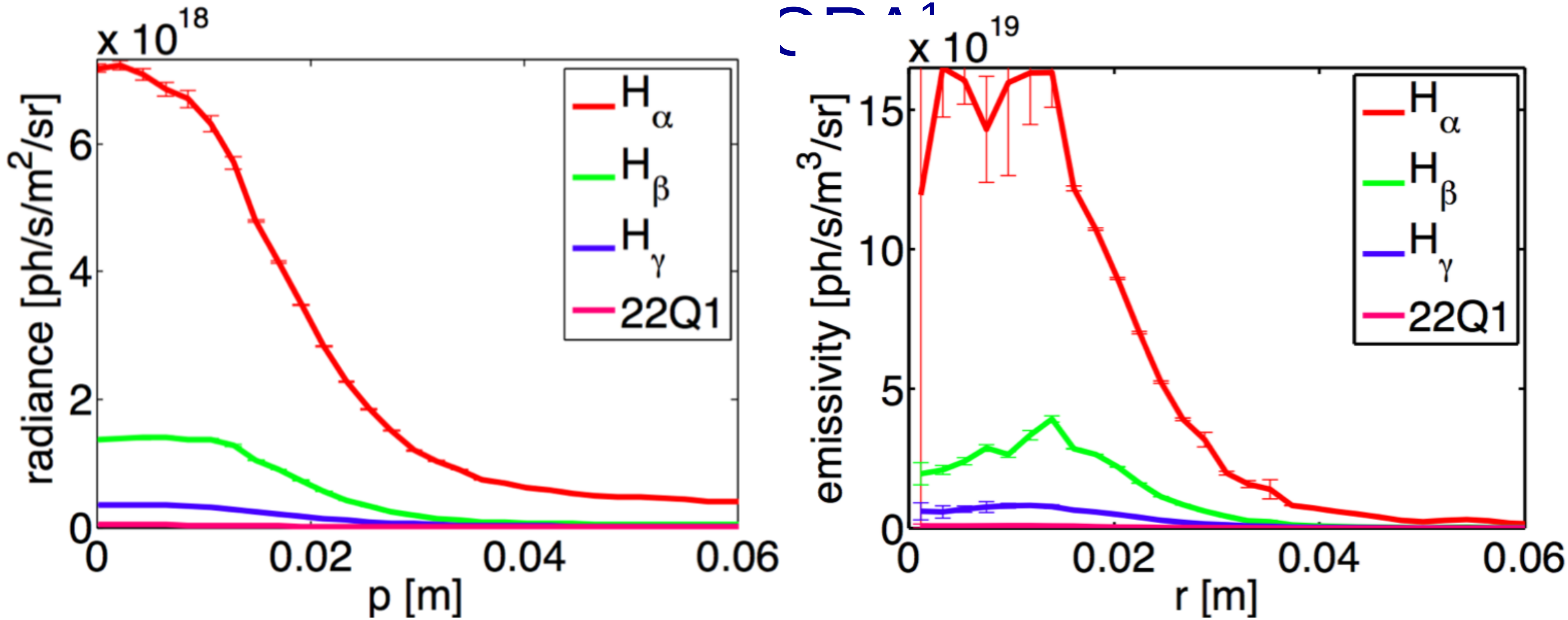


C. Marini et al., *Spectroscopic characterization of H_2 and D_2 helicon plasmas generated by a resonant antenna for neutral beam applications in fusion*, in preparation for NF

Profiles are Abel inverted



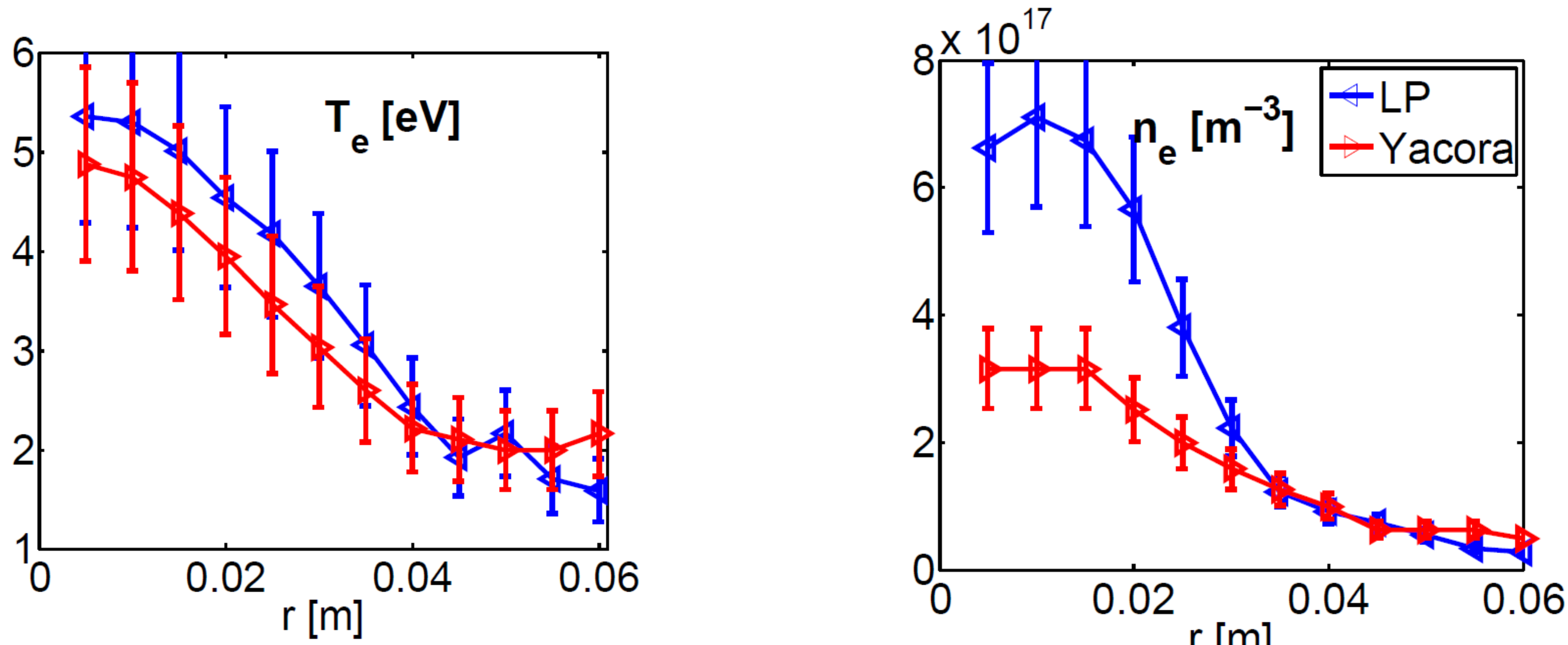
Profiles are Abel inverted and analyzed with the collisional radiative code YACORA[1]



YACORA ➔ profiles of H, H^-, H_2 , H_2^+ , H_3^+, n_e, T_e

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

Peaked T_e and N_e profiles are observed in good agreement between OES and LP measurements



A. Simonin et al., *Negative ion source development for a photoneutralization based neutral beam system for future fusion reactors*, to appear in NJP

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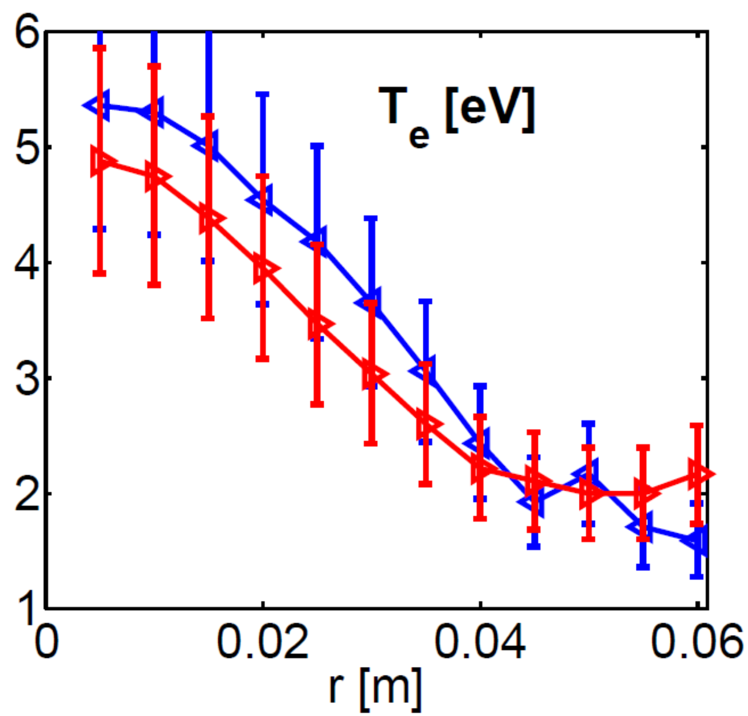
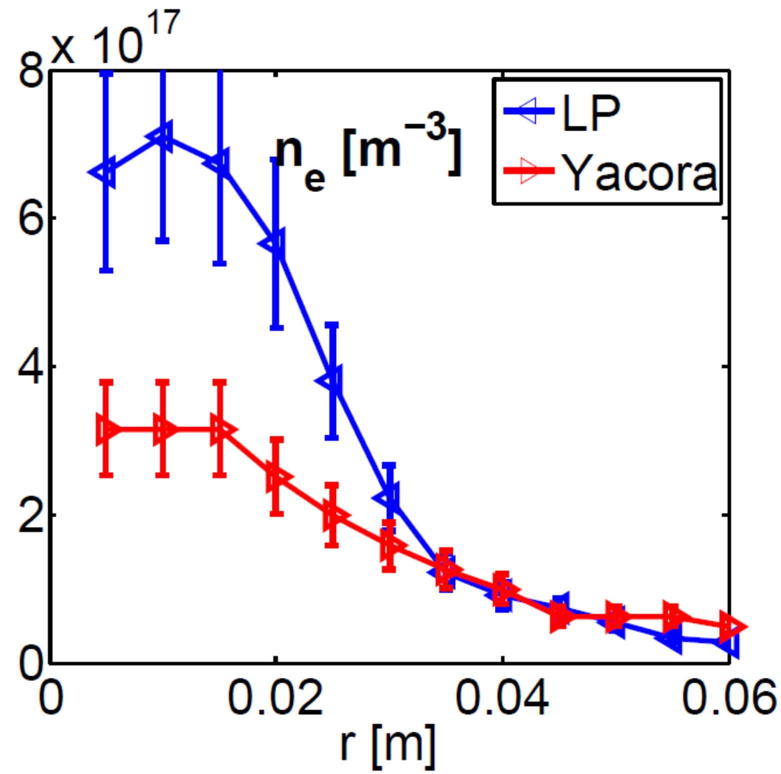


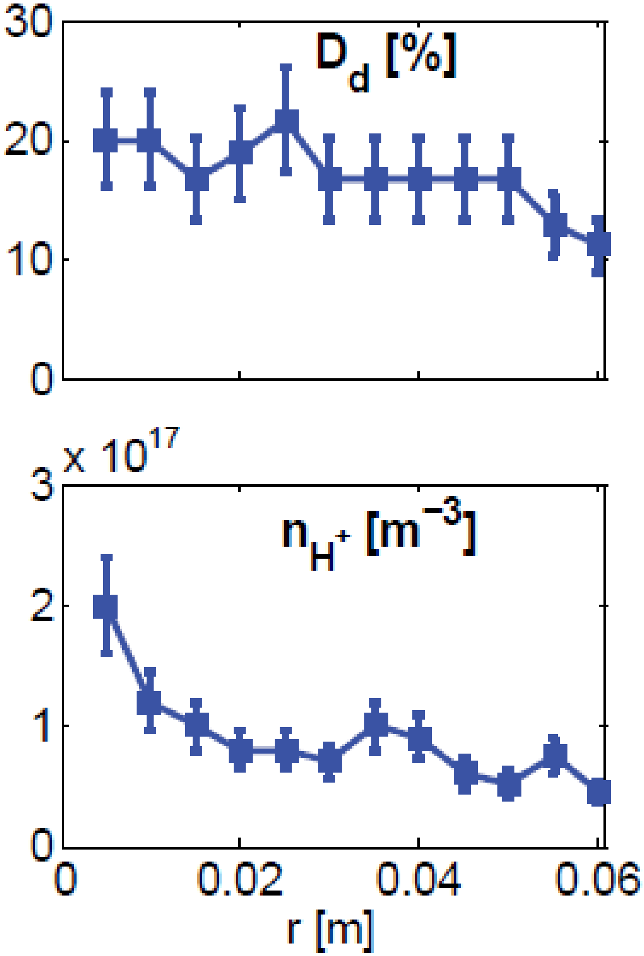


Favorable for negative ion production by dissociative attachment

$$H_2(v) + e \rightarrow H^- + H^+$$

A. Simonin et al., *Negative ion source development for a photoneutralization based neutral beam system for future fusion reactors*, to appear in NJP

H_2 plasmas are characterized by high dissociation degree

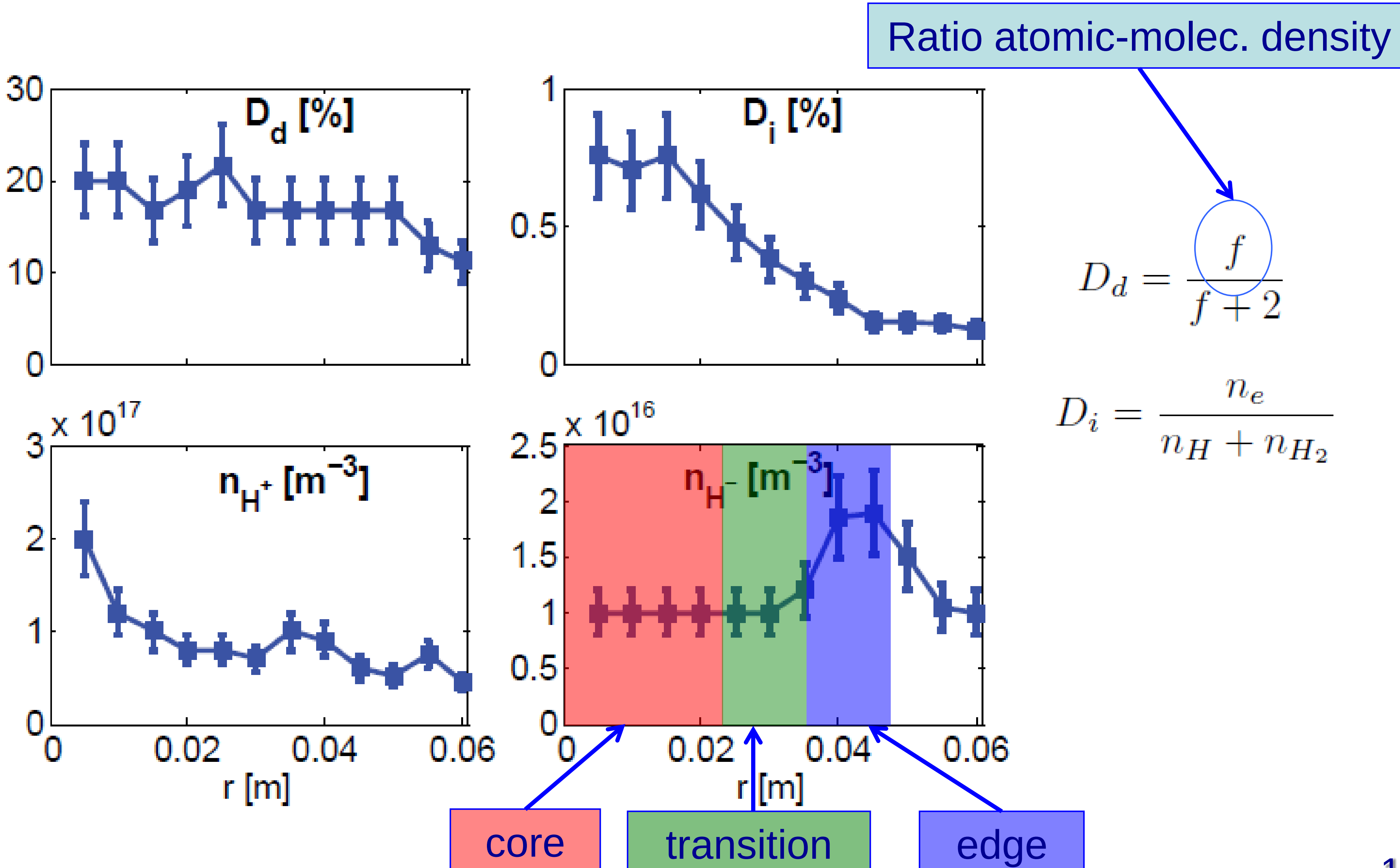


Ratio atomic-molec. density

$$D_d = \frac{f}{f+2}$$

$$D_i = \frac{n_e}{n_H + n_{H_2}}$$

H_2 plasmas are characterized by high dissociation degree and negative ions



$$D_d = \frac{f}{f+2}$$

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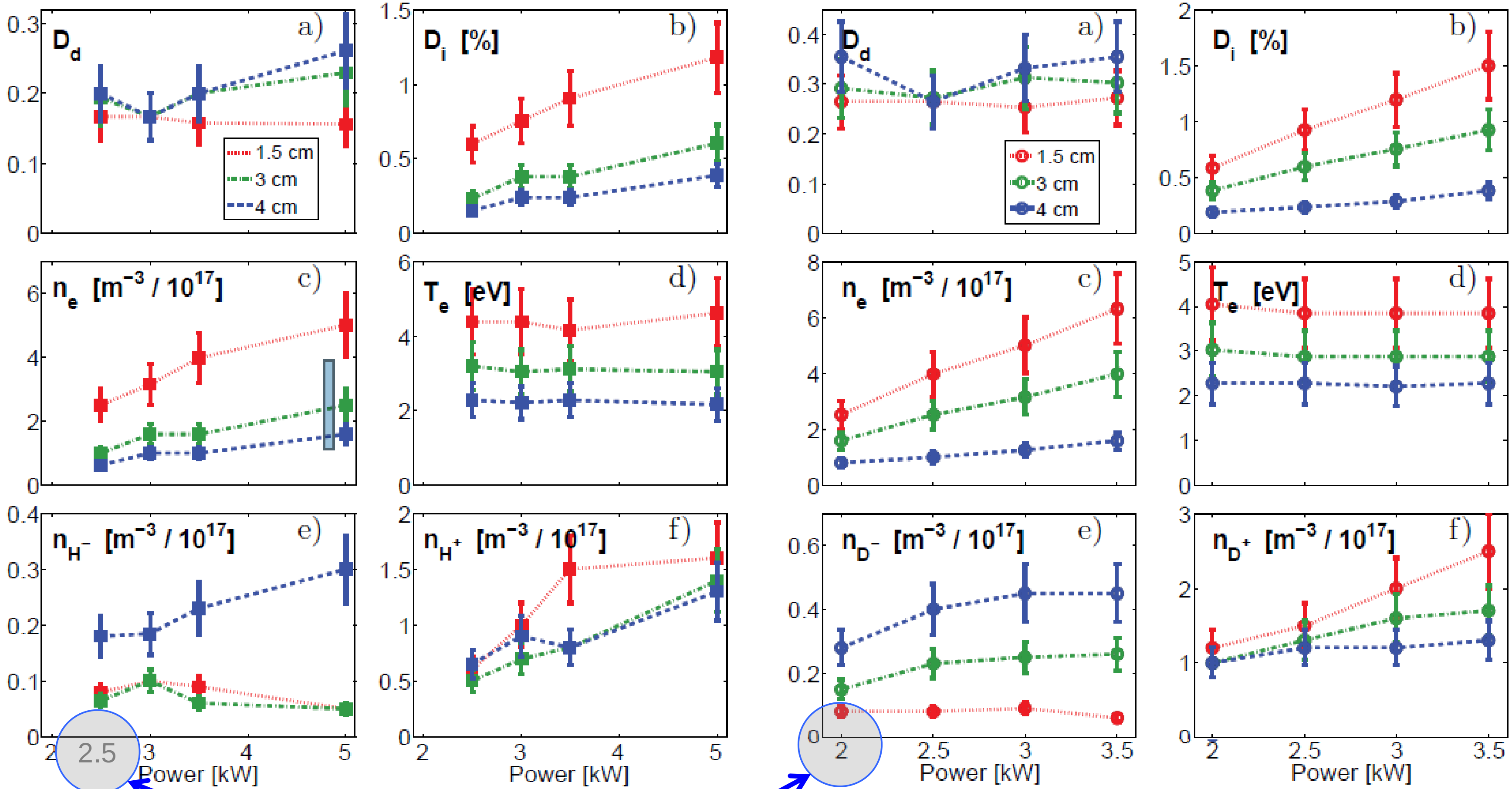
Both H_2 and D_2 plasmas are efficiently produced at different RF powers

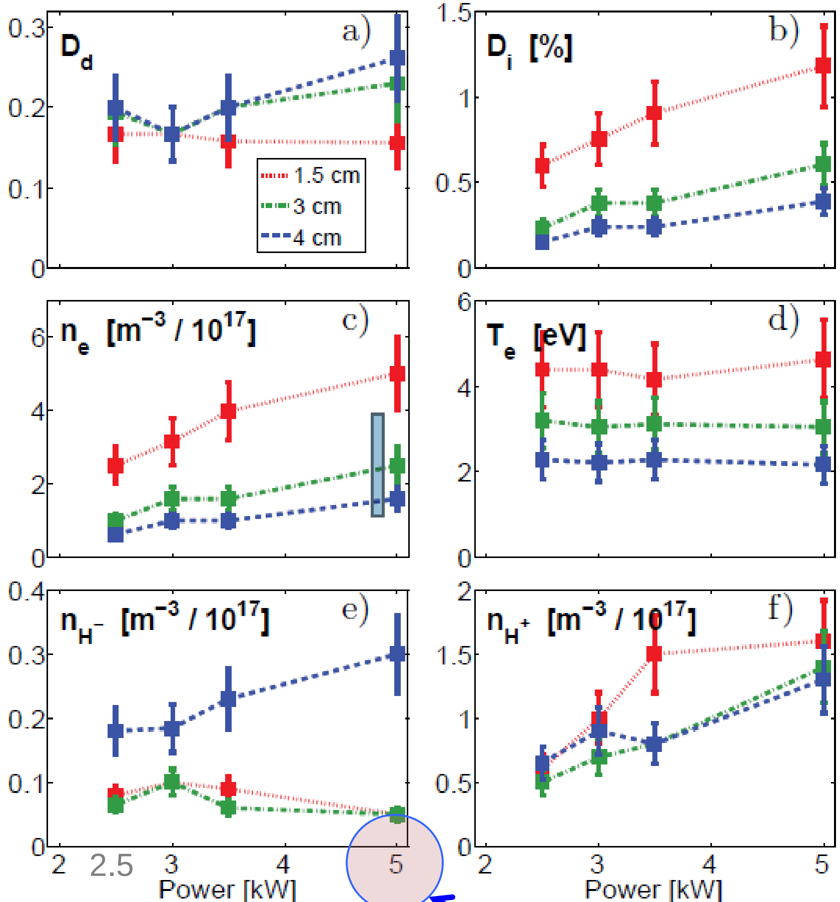
Hydrogen | Deuterium



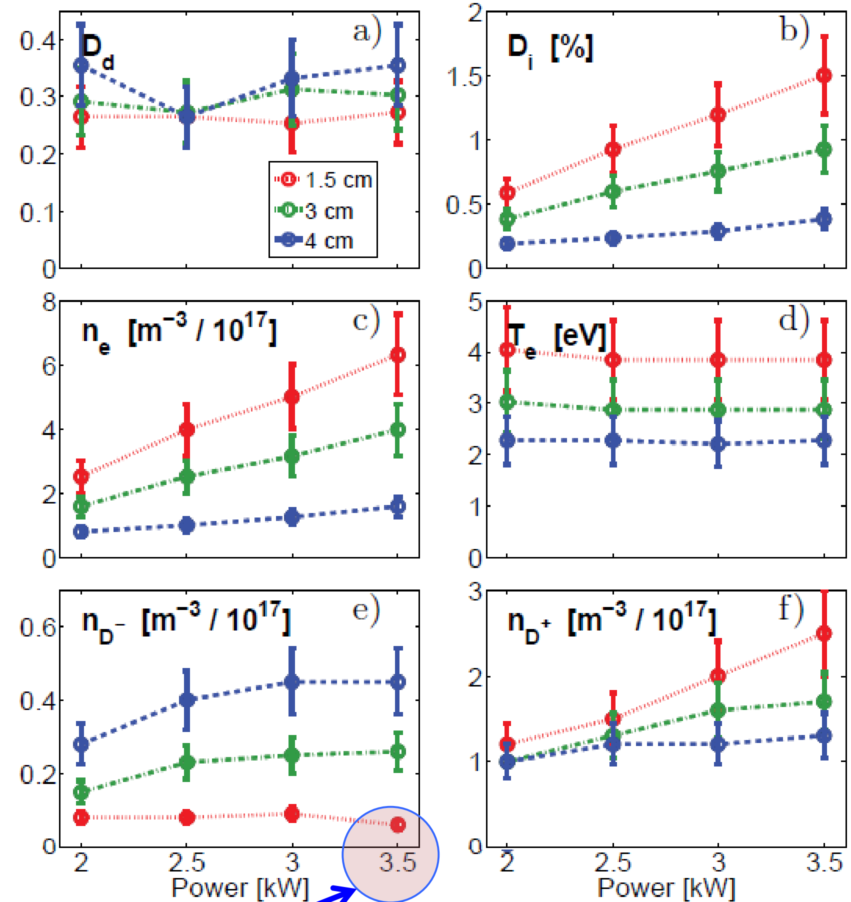
minimum power

Both H_2 and D_2 plasmas are efficiently produced at different RF powers

Hydrogen



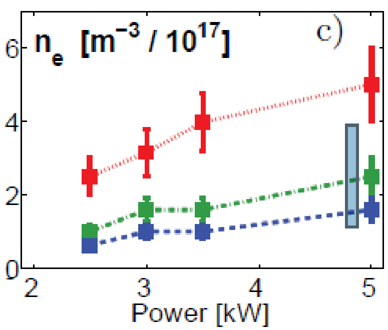
Deuterium

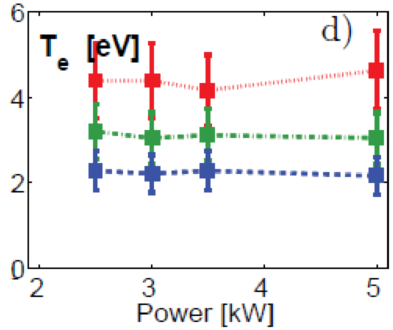


maximum power

n_e increases with RF power while T_e is almost constant

Hydrogen





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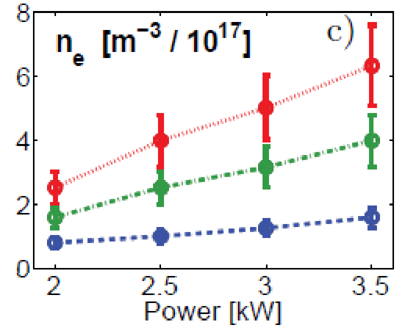
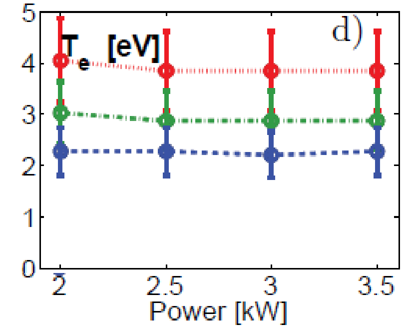
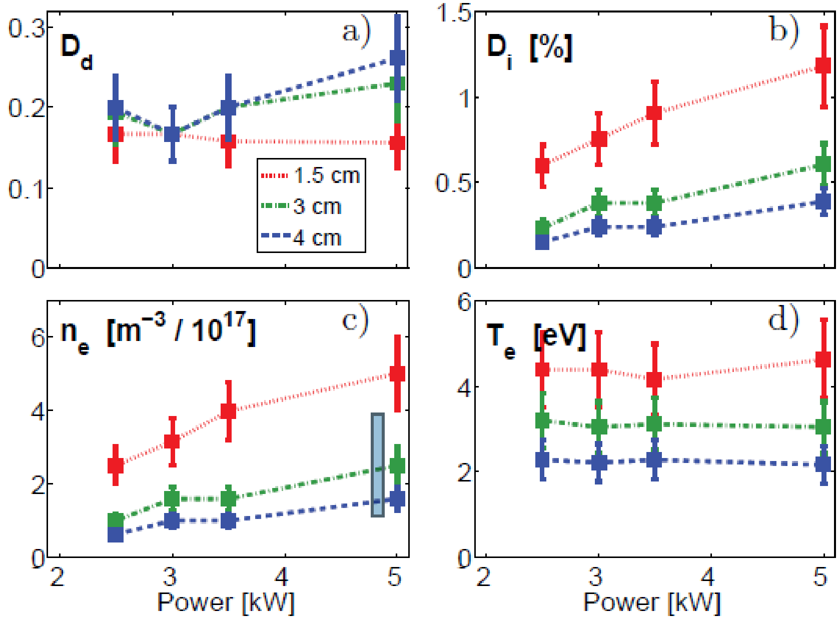




Isotopic effect: D_2 has higher dissociation and ionization degrees than H_2 increasing with RF power

Hydrogen



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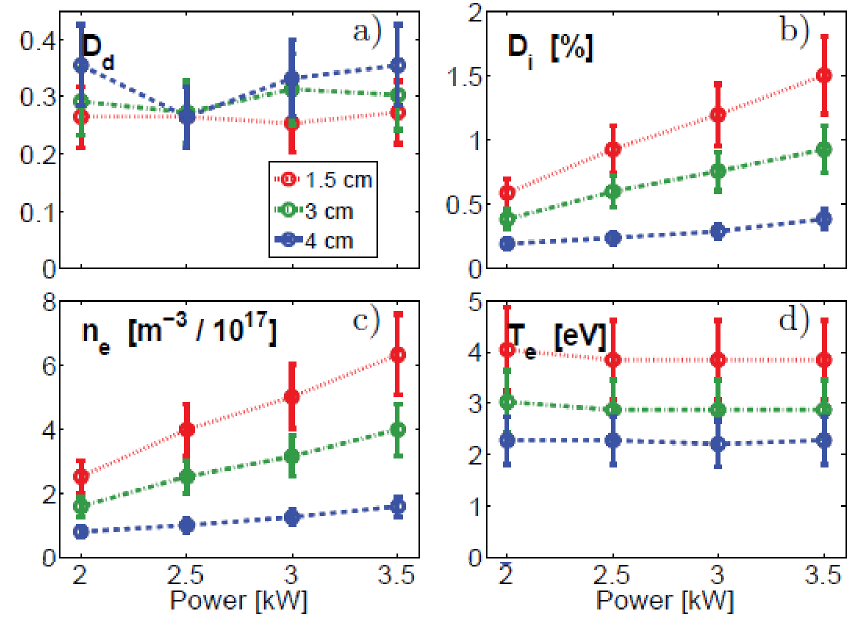
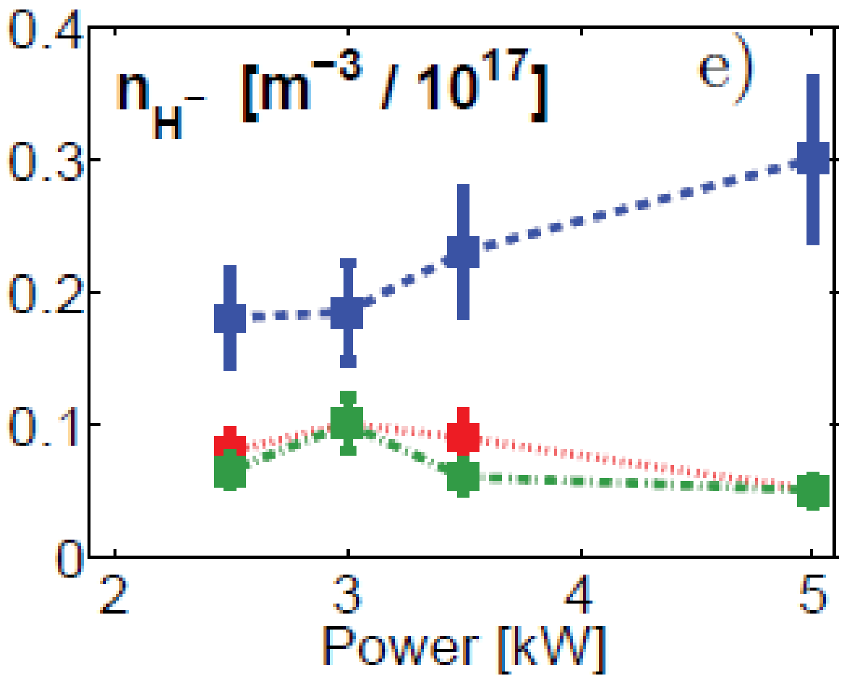
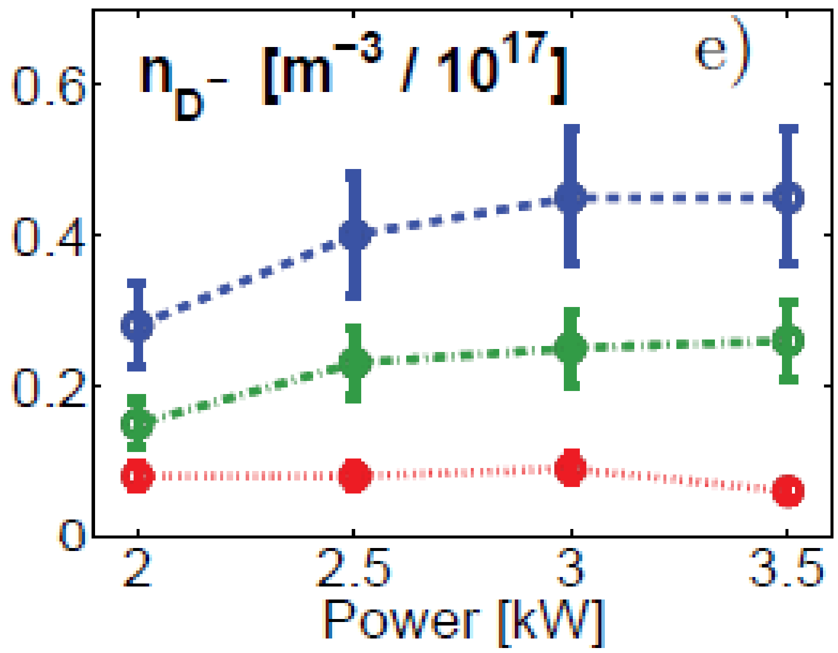


The negative ion population increases with RF power

Hydrogen



Deuterium



Summary

- The RAID facility recently came online at SPC to study the physics of resonant helicon antennas for negative ion production
- We demonstrated plasma production in H_2 and D_2 at different RF power and low magnetic field
- OES and LP measurements show the presence of peaked n_e and T_e profiles together with high dissociation degree and negative ion population
- Low pressure operation, high dissociation rate, favorable scaling with power are encouraging for applications of the resonant helicon antenna as negative ion source for fusion in a Cybele-like geometry
- What about other magnetic geometries?

Outlook

- Open physics questions
  - helicon wave physics ➔ source optimization
- Upgraded and new diagnostics
  - Microwave interferometer
  - Laser photo-detachment ➔ comparison with OES
  - Laser induced fluorescence(LIF)
  - 3D Langmuir probes
  - Magnetic probes ➔ helicon waves physics
- A new water-cooled ceramic tubing allows for larger power up to 10kW
- Installation of the resonant antenna on the Cybele to test negative ions extraction.