A compact ECR plasma source for large area H^- ion production

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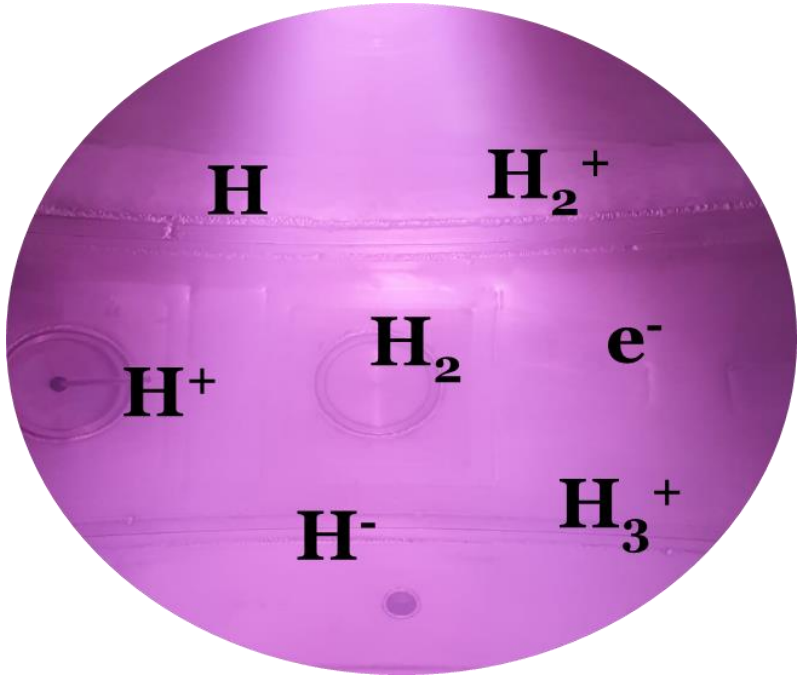
Outline

- Introduction & Motivation
- Experimental Setup
- Optimization of Magnetic Field Configuration (& Source)
- Results with optimized source
- Conclusion

Introduction & Motivation



Most noteworthy being the "Fusion Plasma Heating" by injection of neutral beams

Generated by Extraction, Acceleration & Neutralisation of ions

H^+ ion

H^- ion → Particle of choice by ITER

Production Processes

Surface Production
(Utilizes H & H_x^+ Species)

Volume Production
(Utilizes $H_2(\upsilon)$)

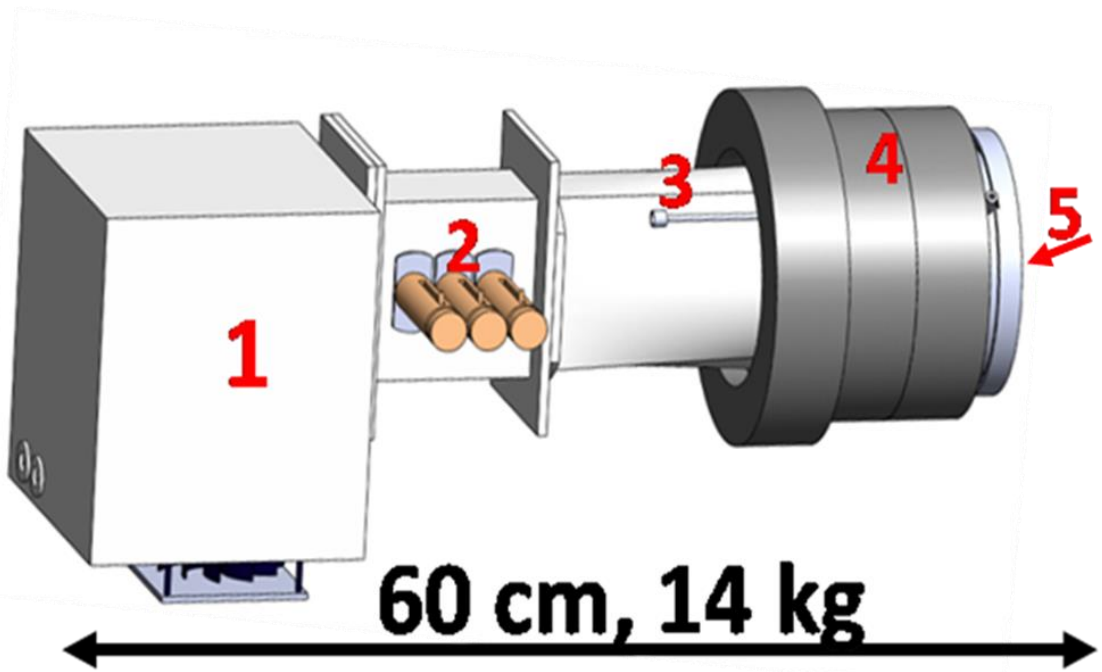
NBI Application requisites:

- ❑ Uniform Plasma over a large area (~ 100 cm^2)
- ❑ High Density ($5x10^{11}$-10^{12} /cm^3)
- ❑ Low electron temperature (~ 1 - 2eV)

Mode of plasma production :

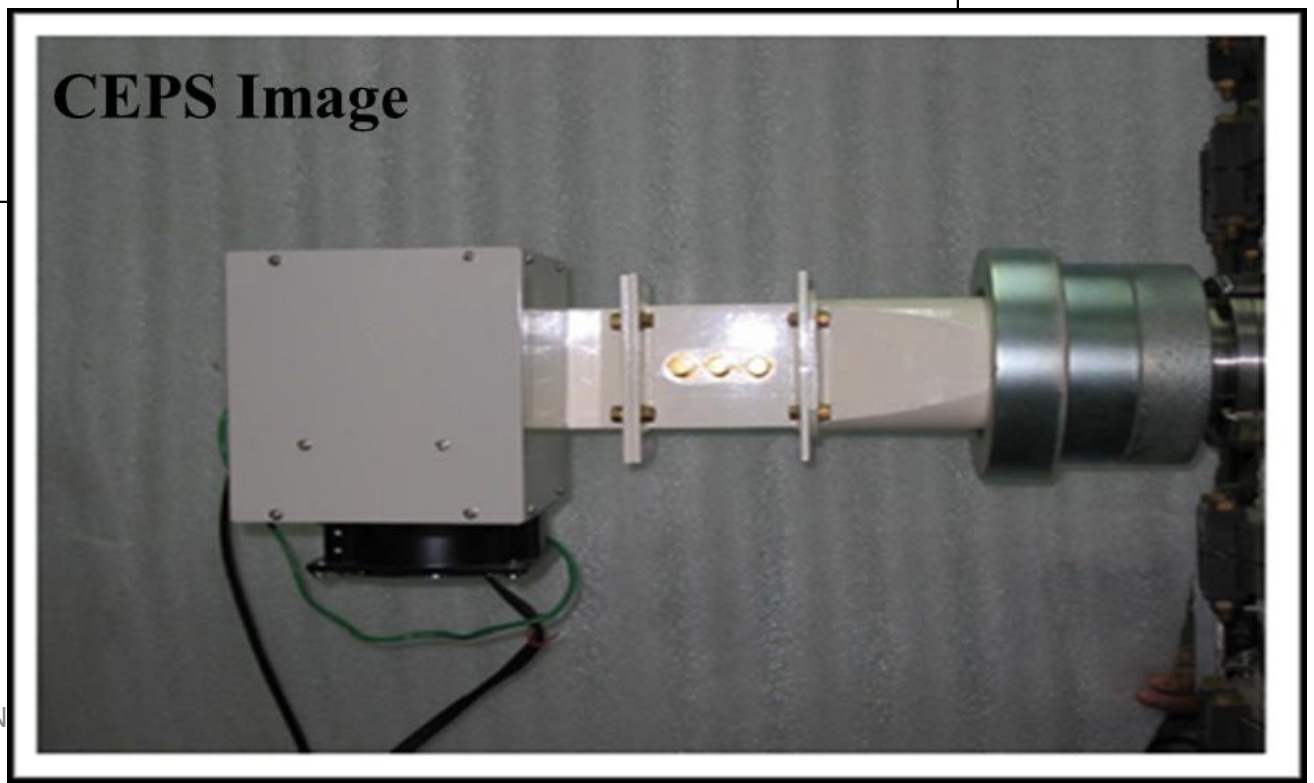
- ❑ Low gas pressure operation
- ❑ Moderate power usage
- ❑ Must be contamination / maintenance free

CEPS : Compact ECR Plasma Source



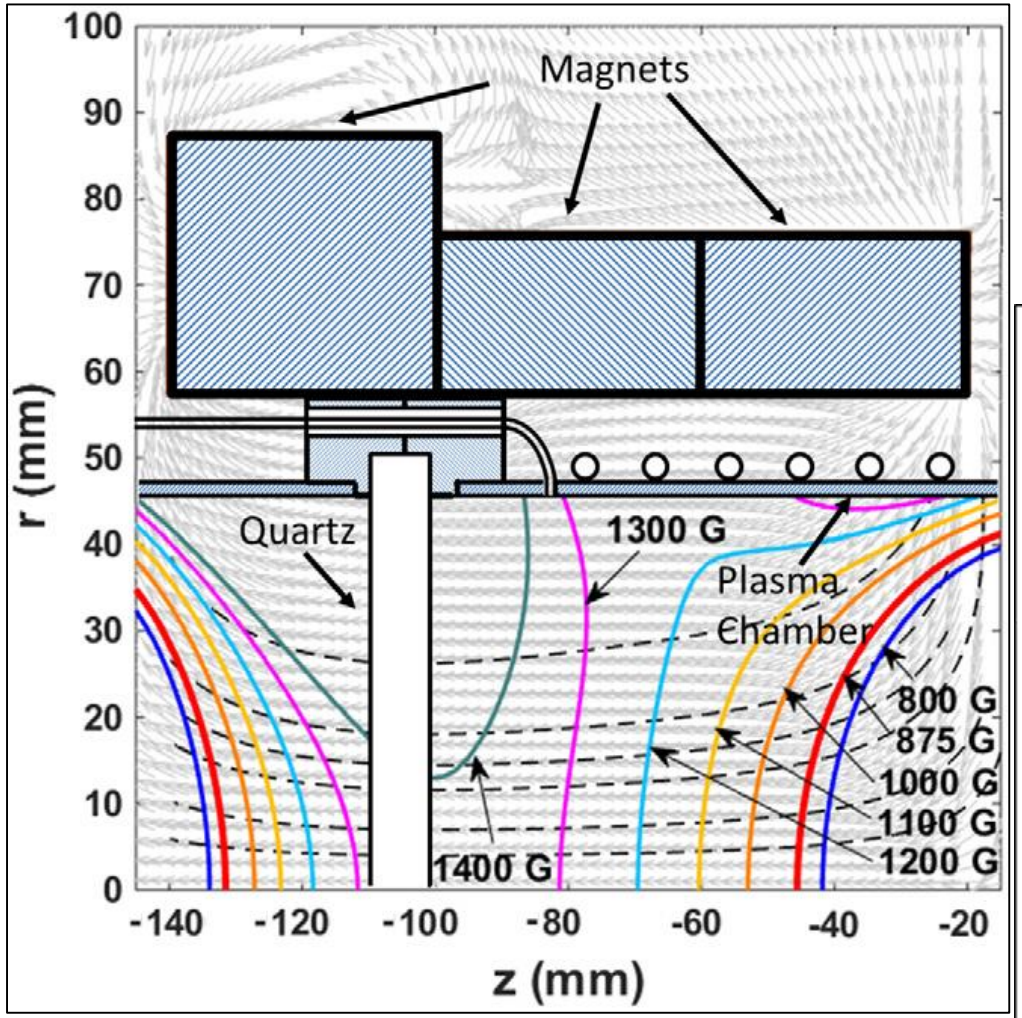
1. Microwave generator
2. Stub Tuner
3. Waveguide converter
4. Magnet
5. Plasma source section

MW is coupled through a QW making it an electrodeless configuration

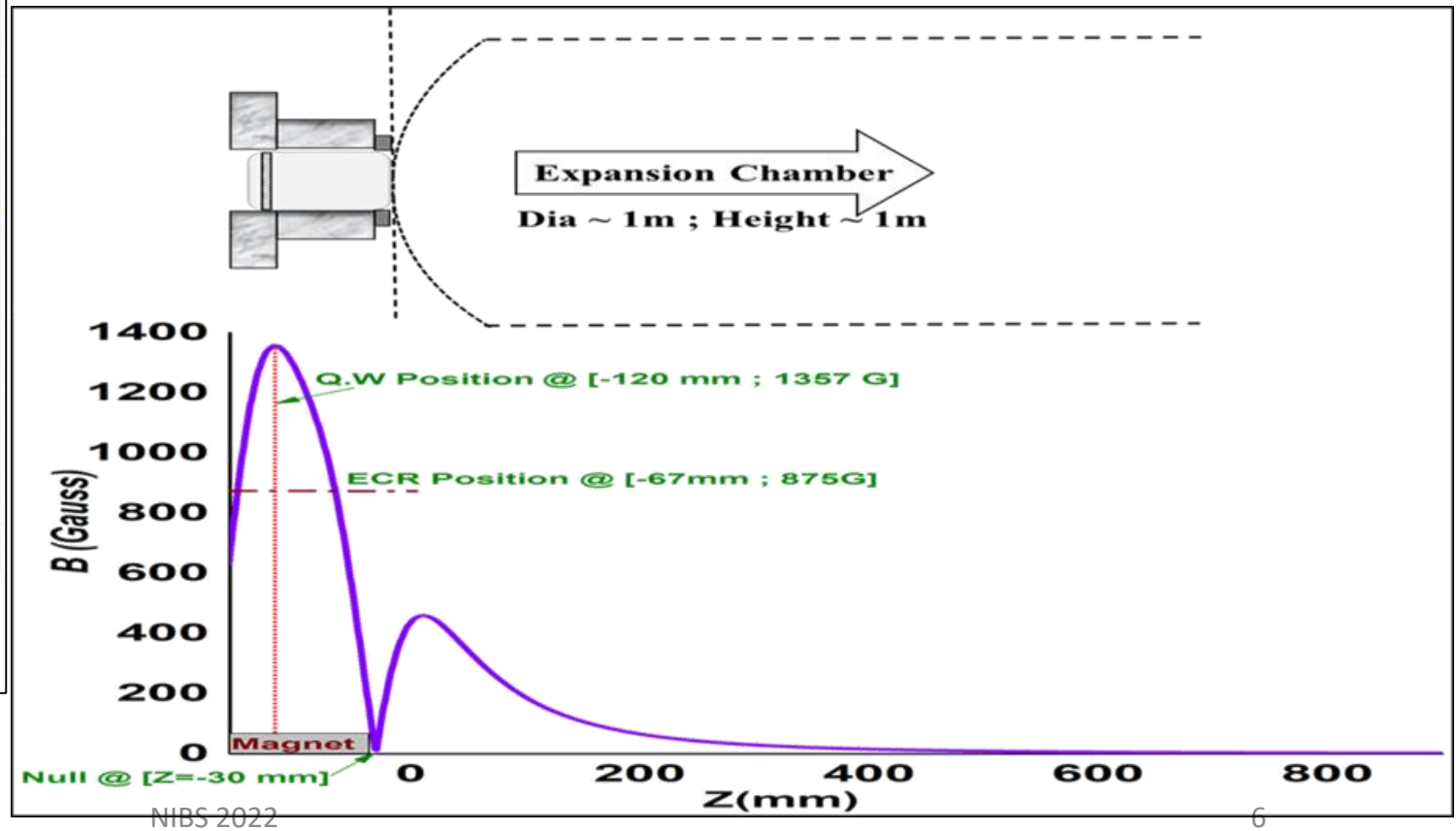


1. Ganguli, A., *et. al*. 2016 Plasma Sources Sci. Technol., 25.2: 025026.
2. Ganguli, A. and Tarey, R.D., 2006 Indian Patent # 301583 Patentee: IIT Delhi
3. Tarey, R. D., *et. al* 2017 Plasma Sources Sci. Technol., 26.1
4. Ganguli, A. *et. al* 2019 Plasma Sources Sci. Technol., 28 035014
5. Verma, Anshu, *et. al* 2020 Plasma Sources Sci. Technol., 29 085007
6. Verma, Anshu, *et. al* 2019 Plasma Res. Express 1 035012
7. Ganguli, A.," 2013 19th IEEE Pulsed Power Conf.

Detailed Magnetic Field Configuration Inside CEPS.



Axial Magnetic Field Profile



Experimental Setup :

Schematic of large volume Chamber

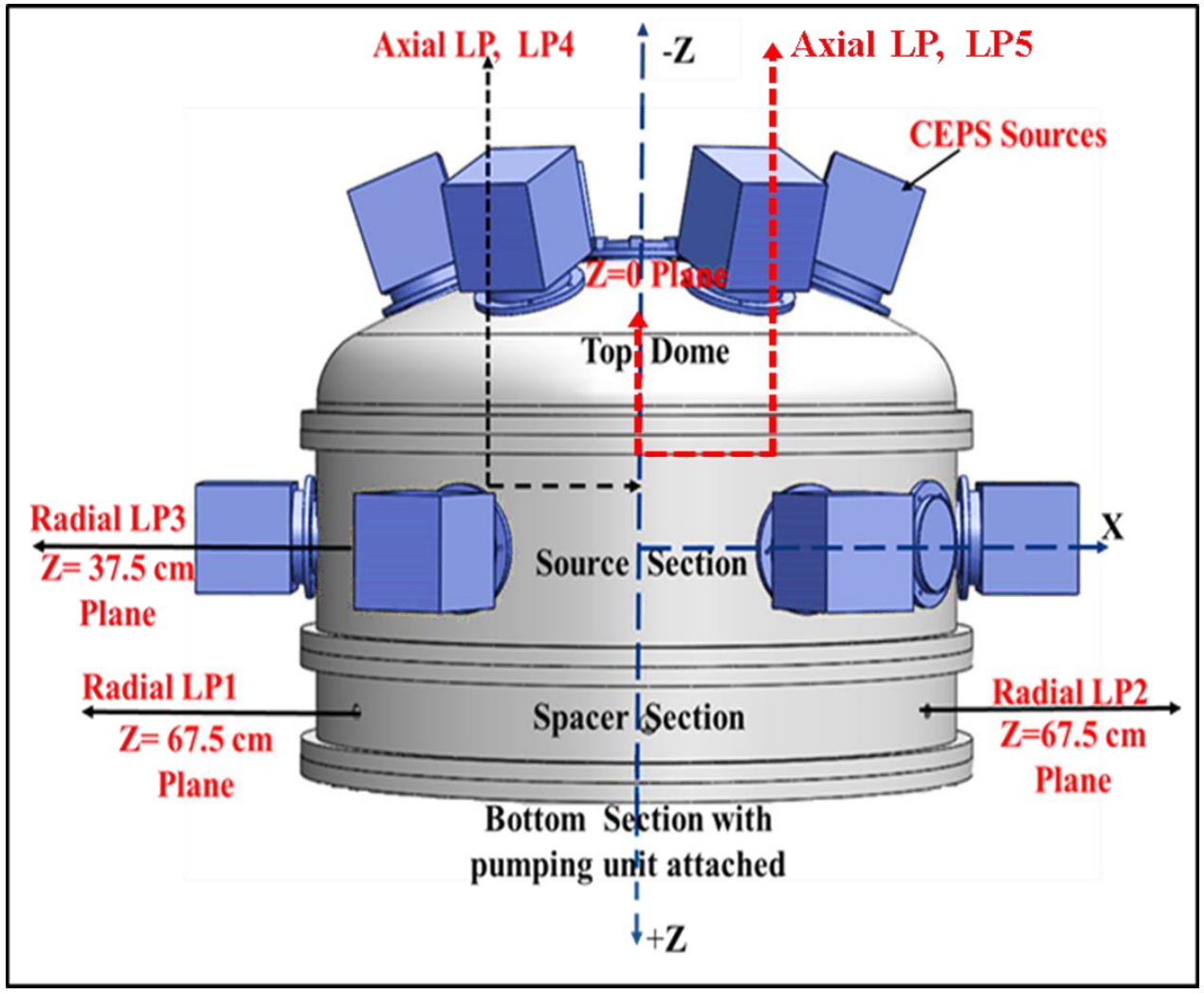
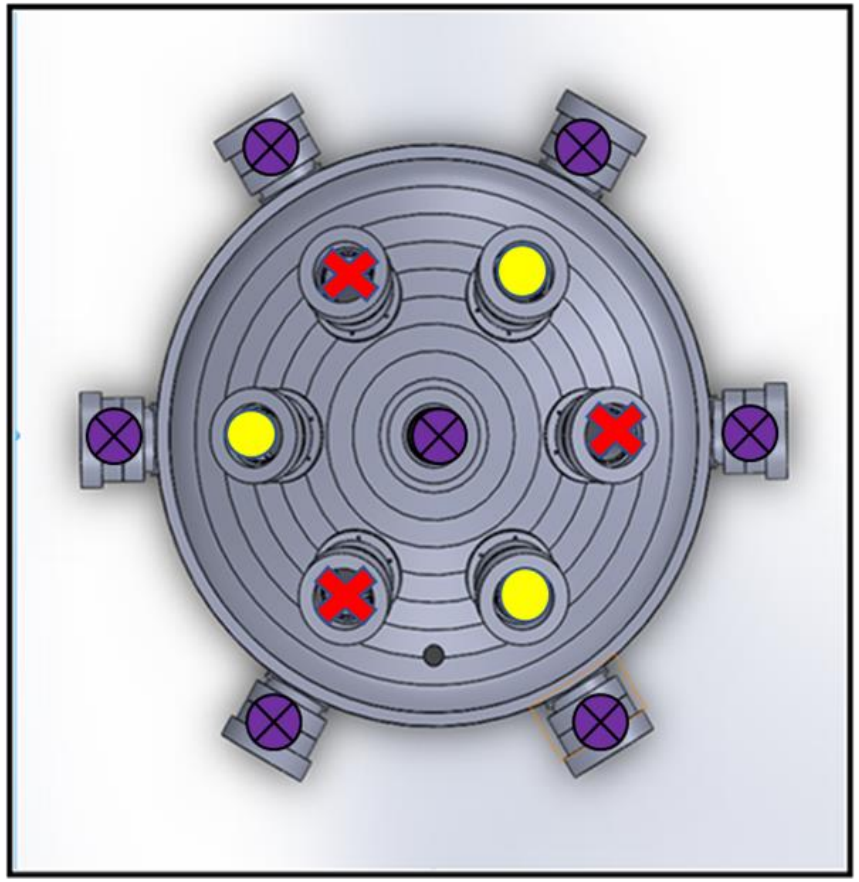


Image of fully assembled experimental setup

Optimization of Magnetic Field Configuration

1. Cusp Configuration :

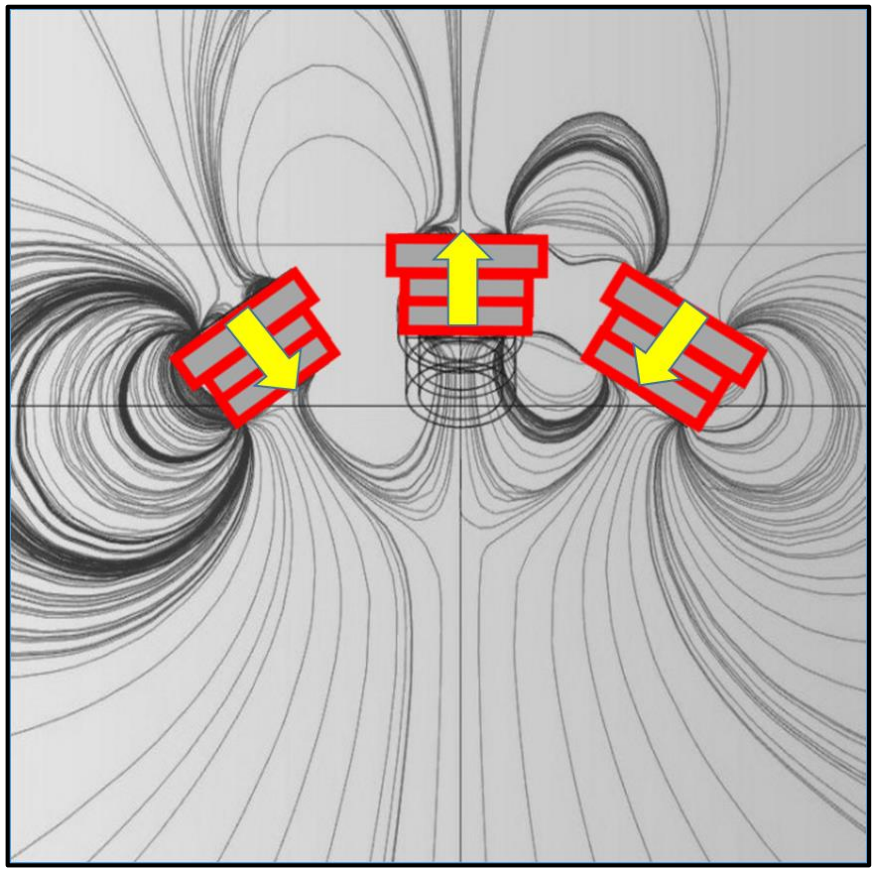


Top view of chamber depicting placement of Sources

✖: CEPS Source with field lines going inside

●: CEPS Source with field lines coming outside

⊗: No CEPS Source placed



Simulated M.F. lines emanating from multiple CEPS Magnet using Comsol Multiphysics

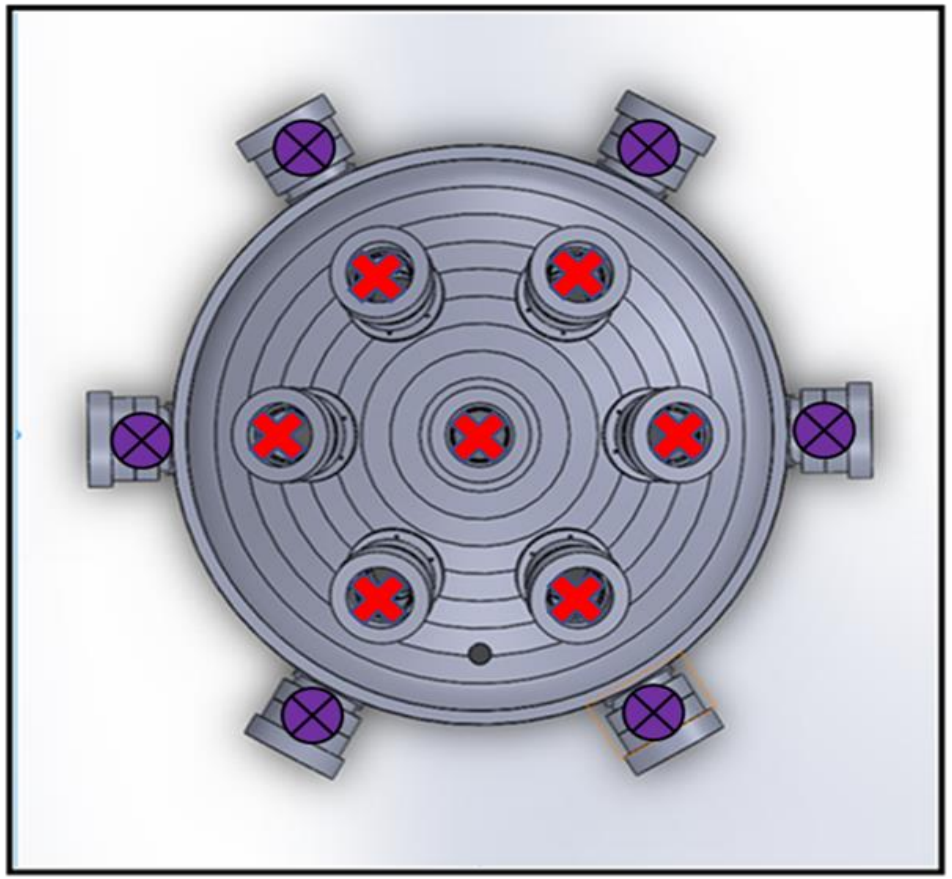
Cusp Configuration (contd..)

Plasma inside the chamber showing cusp configuration

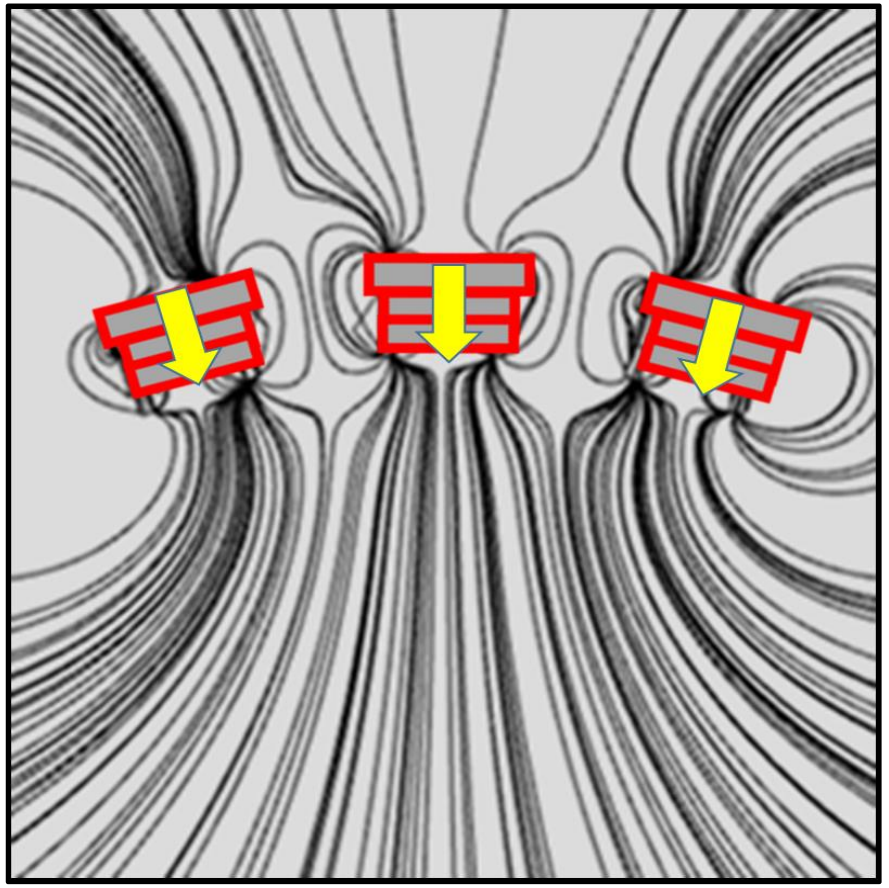
Cross-Talk between the plasma sources led to Fluctuating reflected power and Unstable Plasma Formation was observed

Not Investigated Further

2. Unipolar Configuration



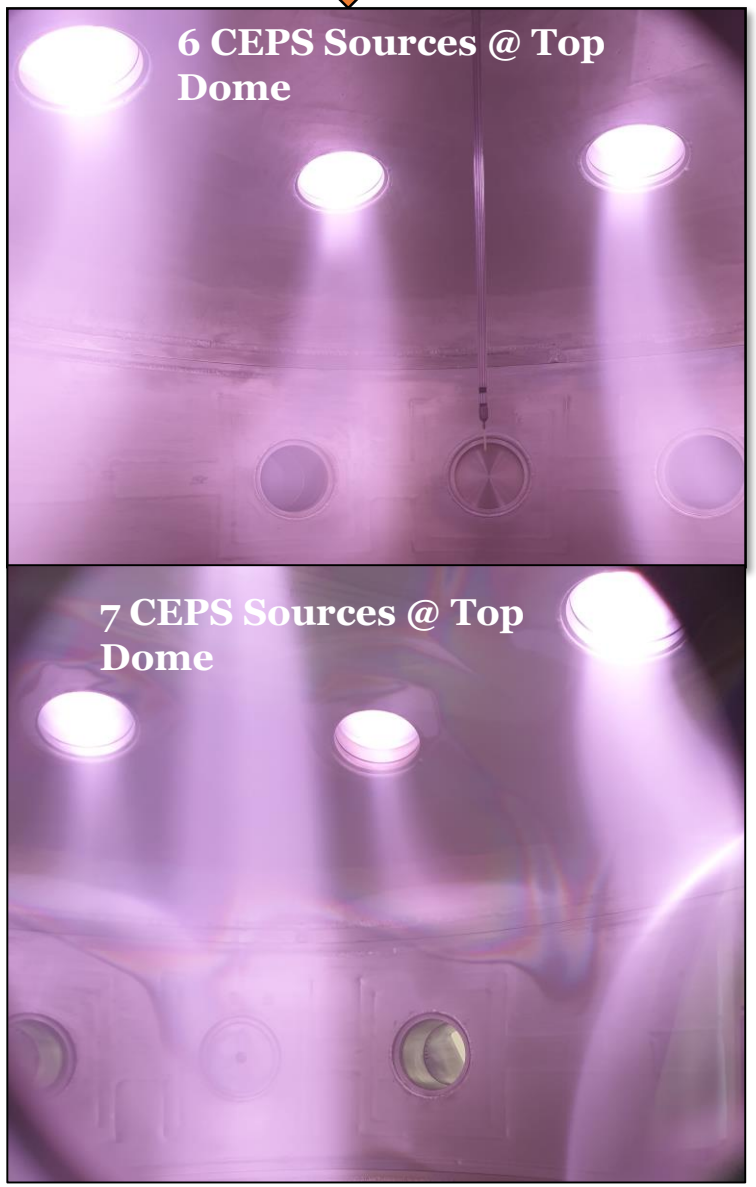
Top view of chamber depicting placement of magnets
: CEPS Source with field lines going inside
: No CEPS Source placed



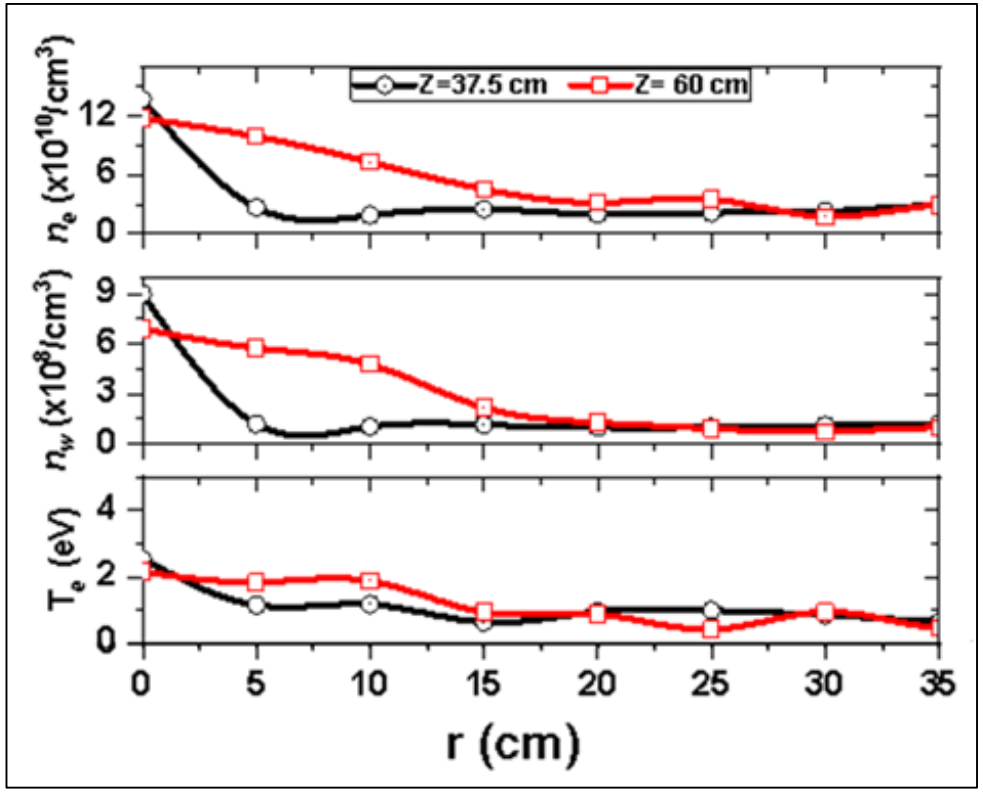
Simulated M.F. lines emanating from
CEPS magnet
(using Comsol Multiphysics)

Unipolar Configuration (cntd..)

Plasma inside the chamber showing Unipolar configuration @ 400W, 2mTorr



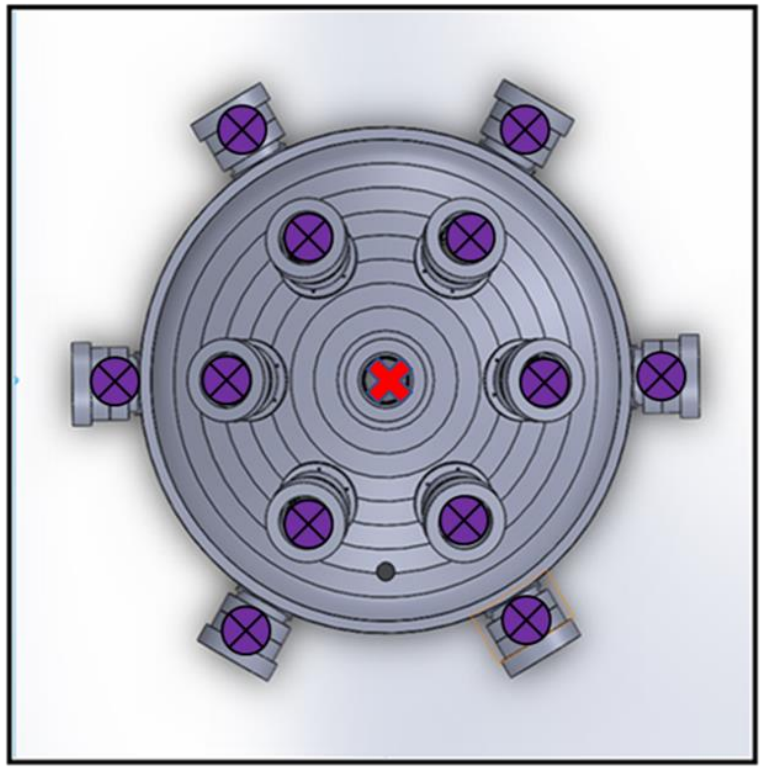
Plasma Profiles @ 400W; 2mTorr with Radial Probe LP 1 & LP 3



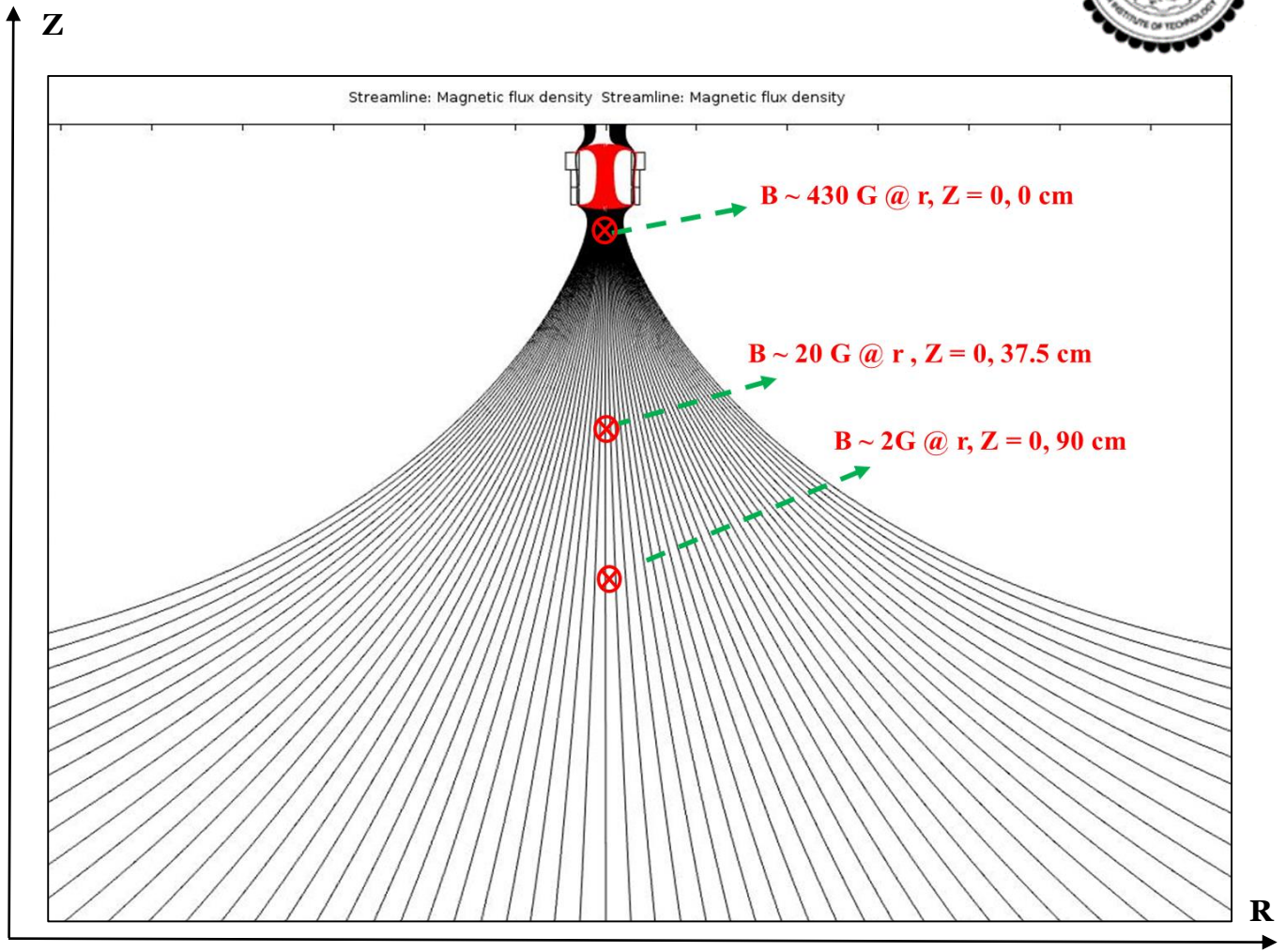
Plasma from the sources flow into the chamber as distinct columns without merging and remains so downstream

Hence giving rise to non-uniform plasma.

3. Flaring Field Configuration With Single CEPS

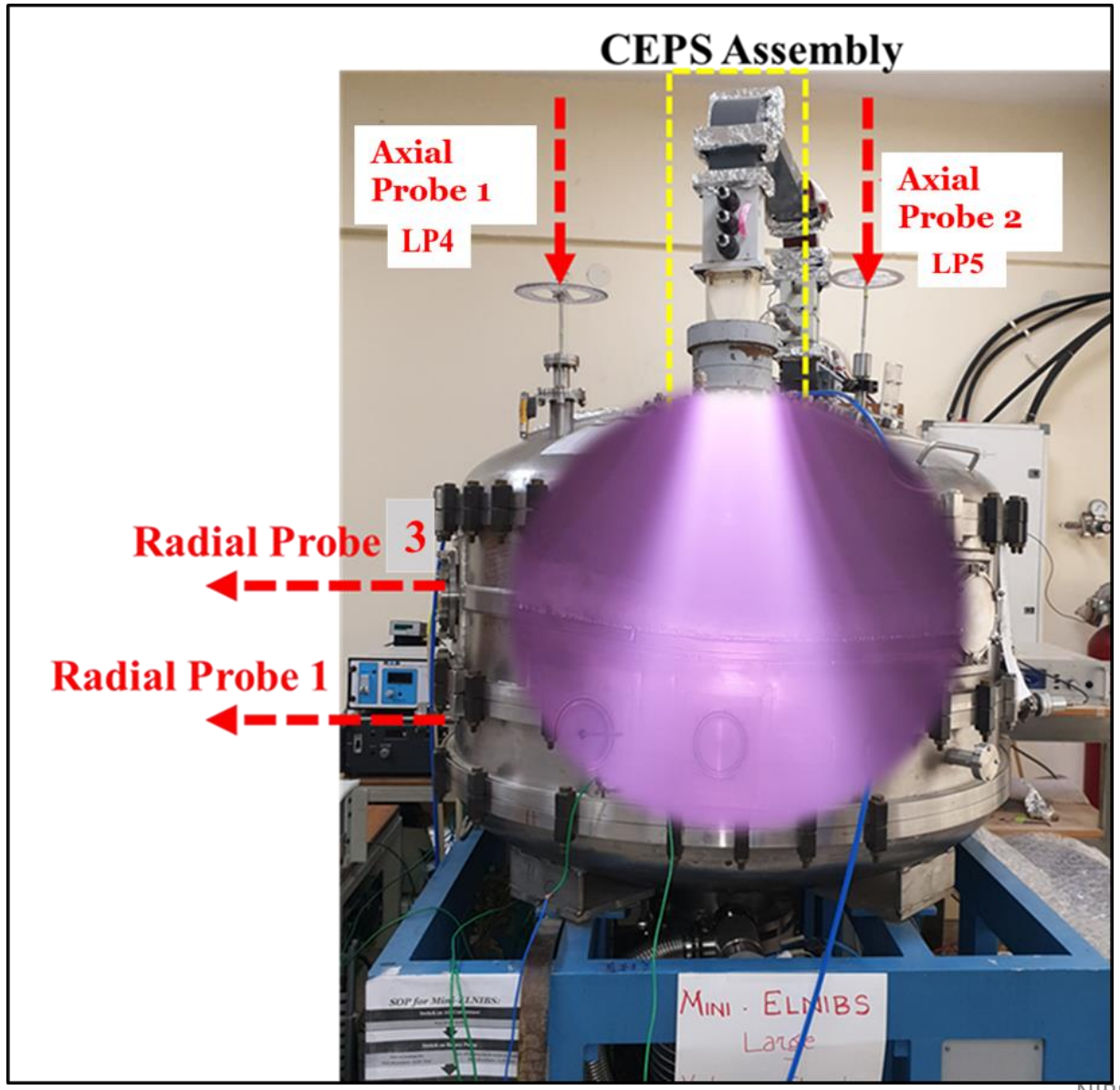


Top view of chamber depicting placement of sources
⊗ ; CEPS Source with field lines going inside
⊗ ; No CEPS Source placed

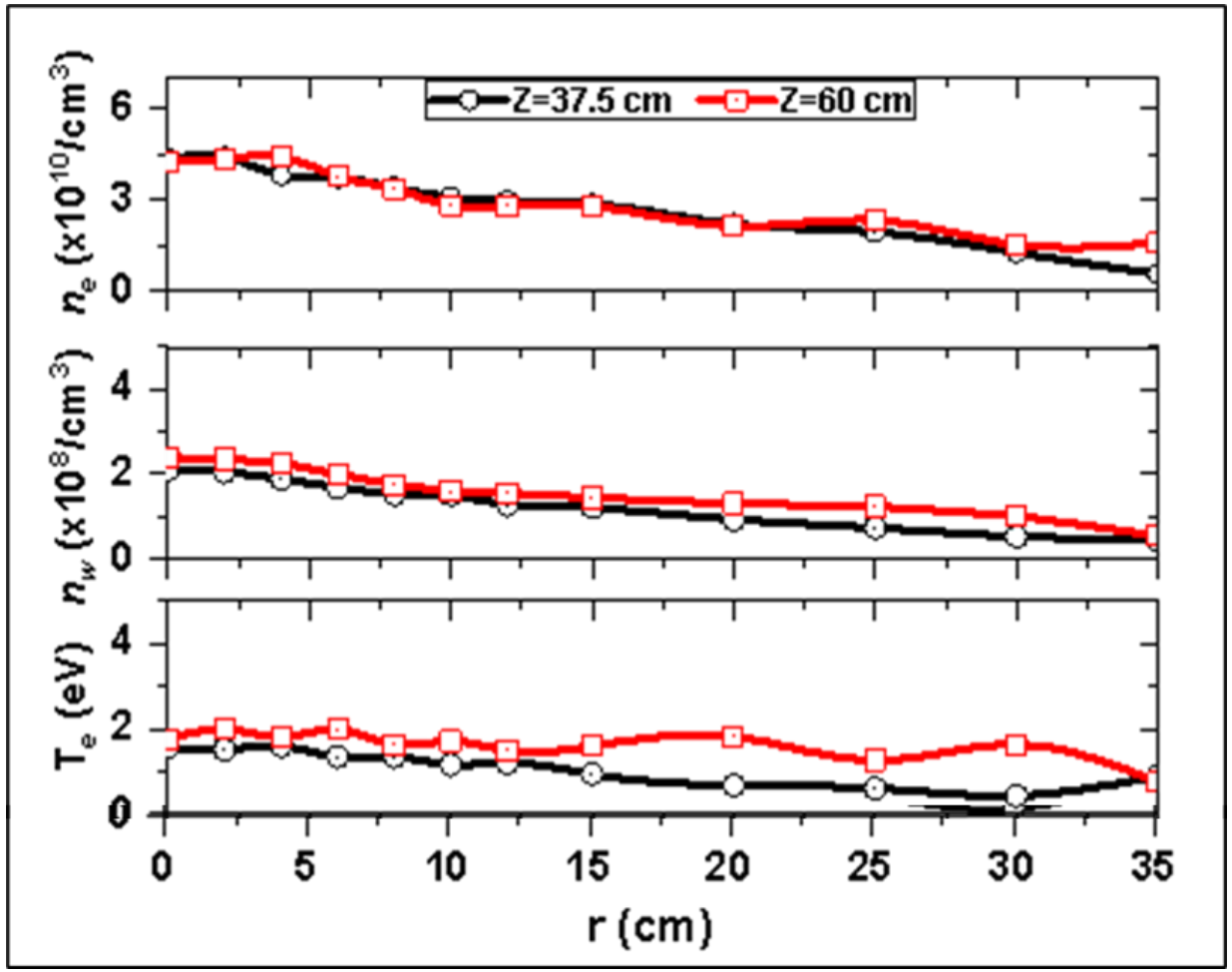


Simulated M.F. lines emanating from single CEPS magnet using Comsol Multiphysics

RESULTS:



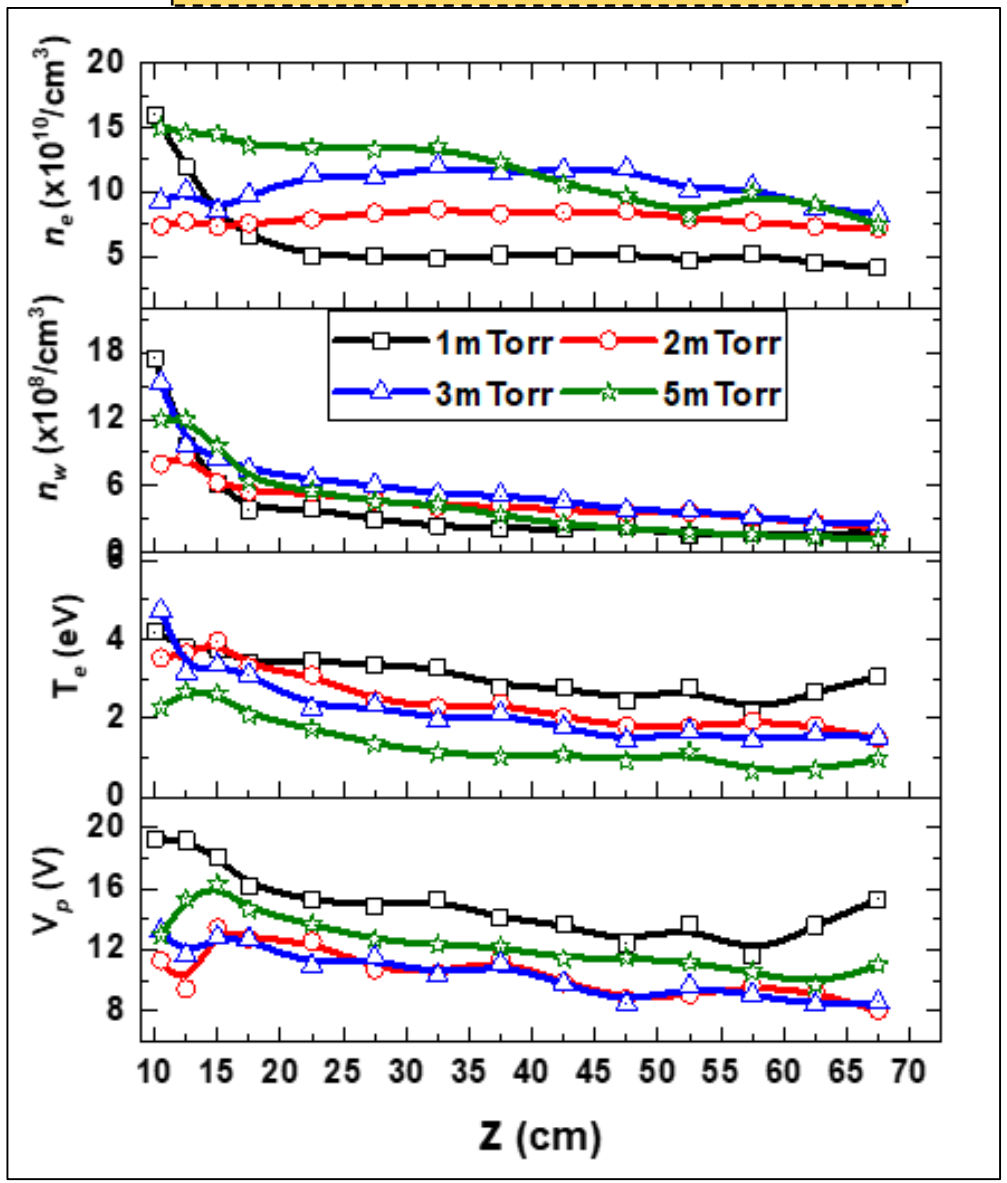
Plasma Profiles @ 400W; 2mTorr with Radial Probe LP 1 & LP 3



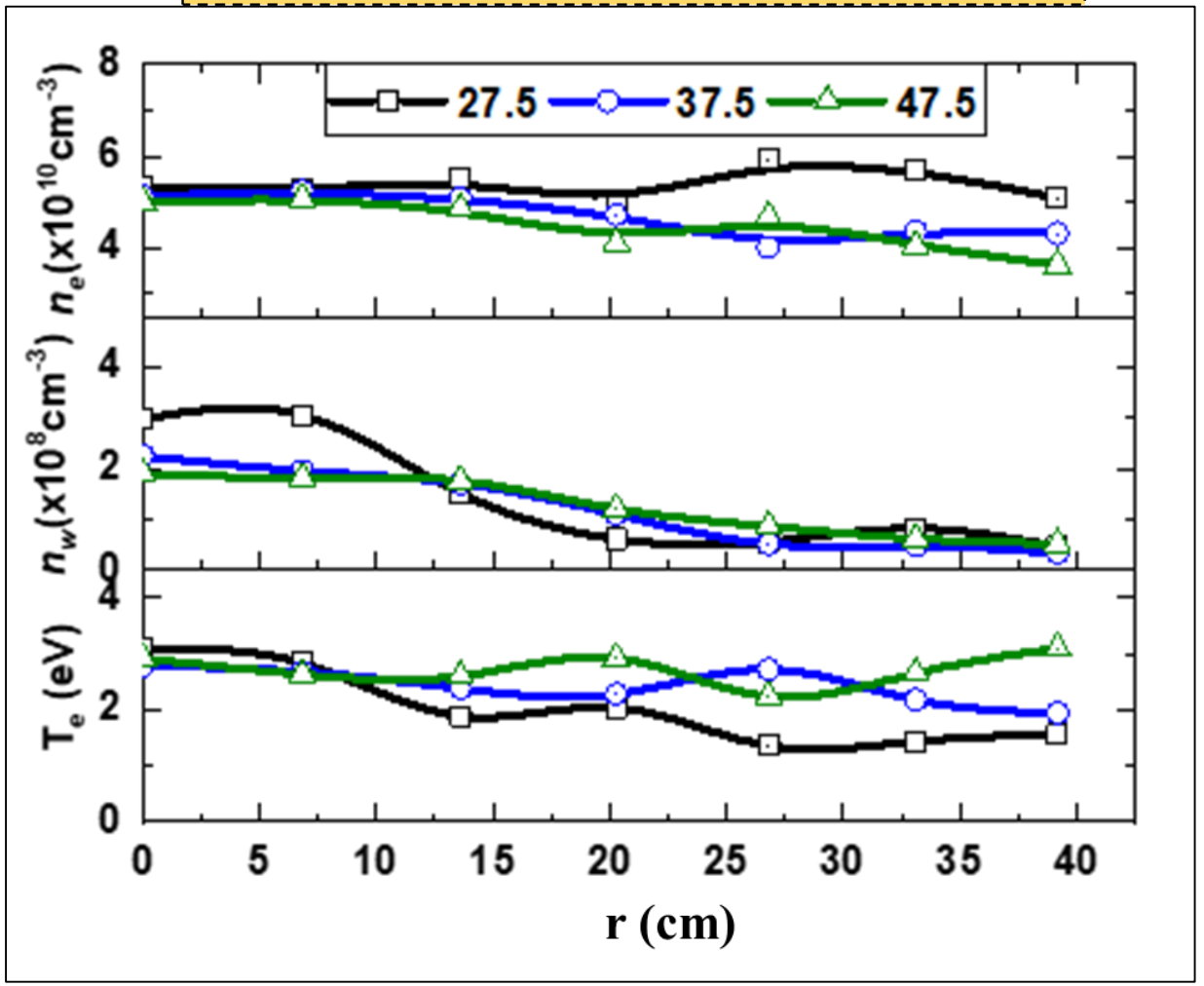
Detailed characterization of chamber with single CEPS configuration

Pressure Variation from 1-5 mTorr @ 400W Using Axial probe LP4

Axial Variation @ P ~ 400W



Radial Variation @ 1 mTorr ; 400W Z= 27.5 cm ; Z= 37.5 cm ; Z =47.5

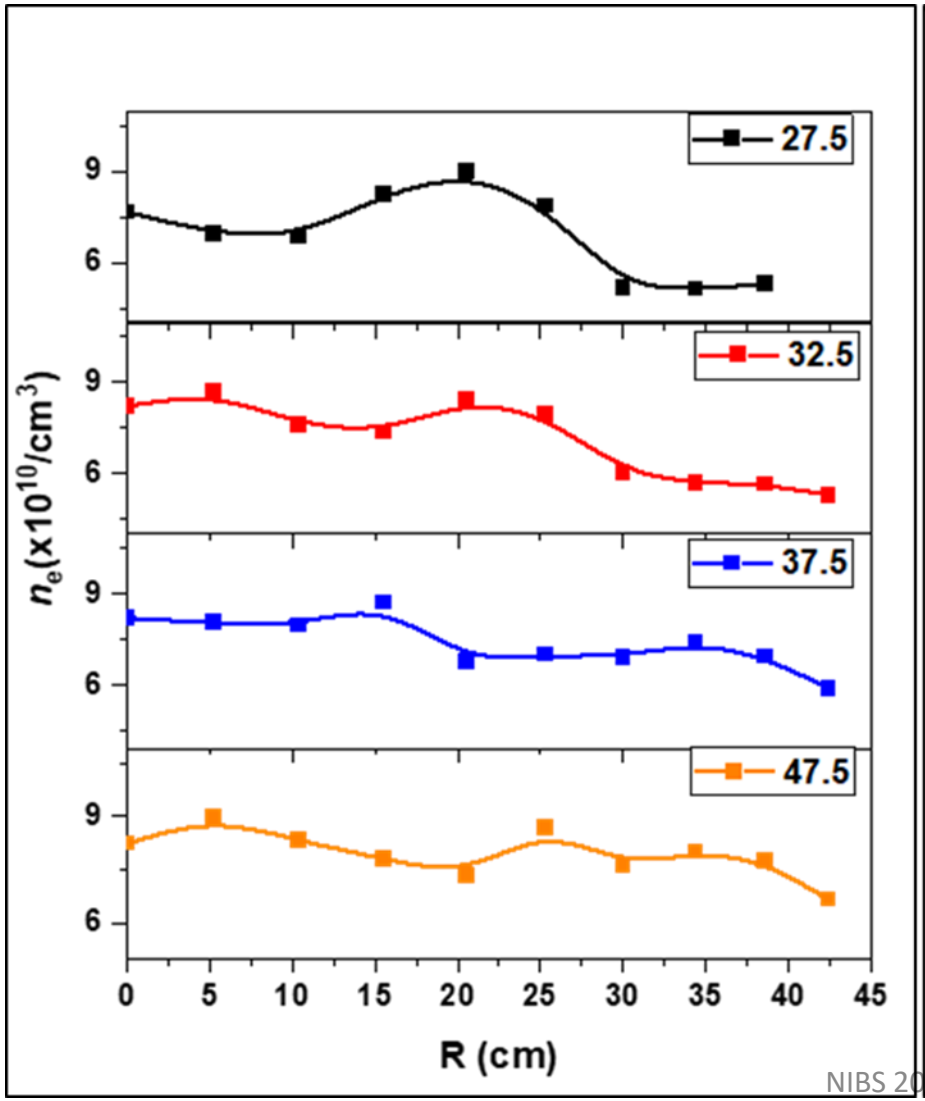


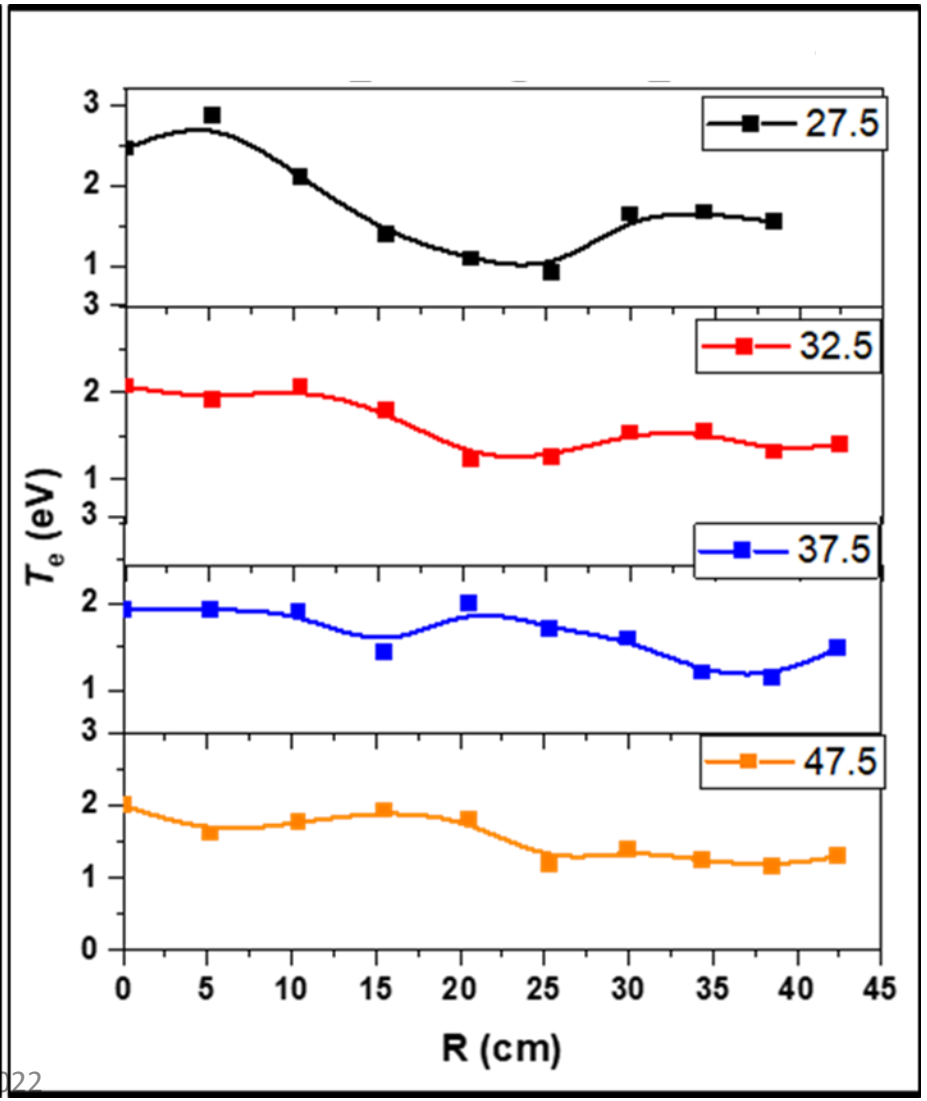
Radial Variations @ Various Planes :

Plasma Density & Electron Temperature :

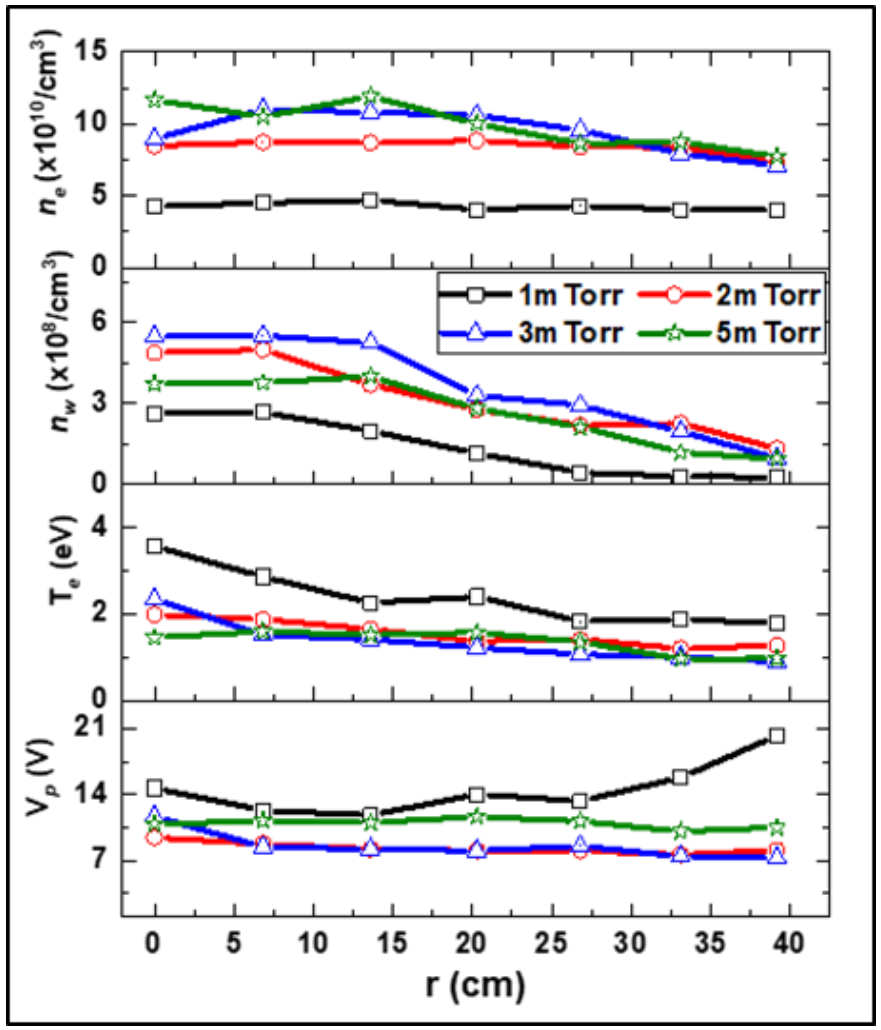
@ 400W

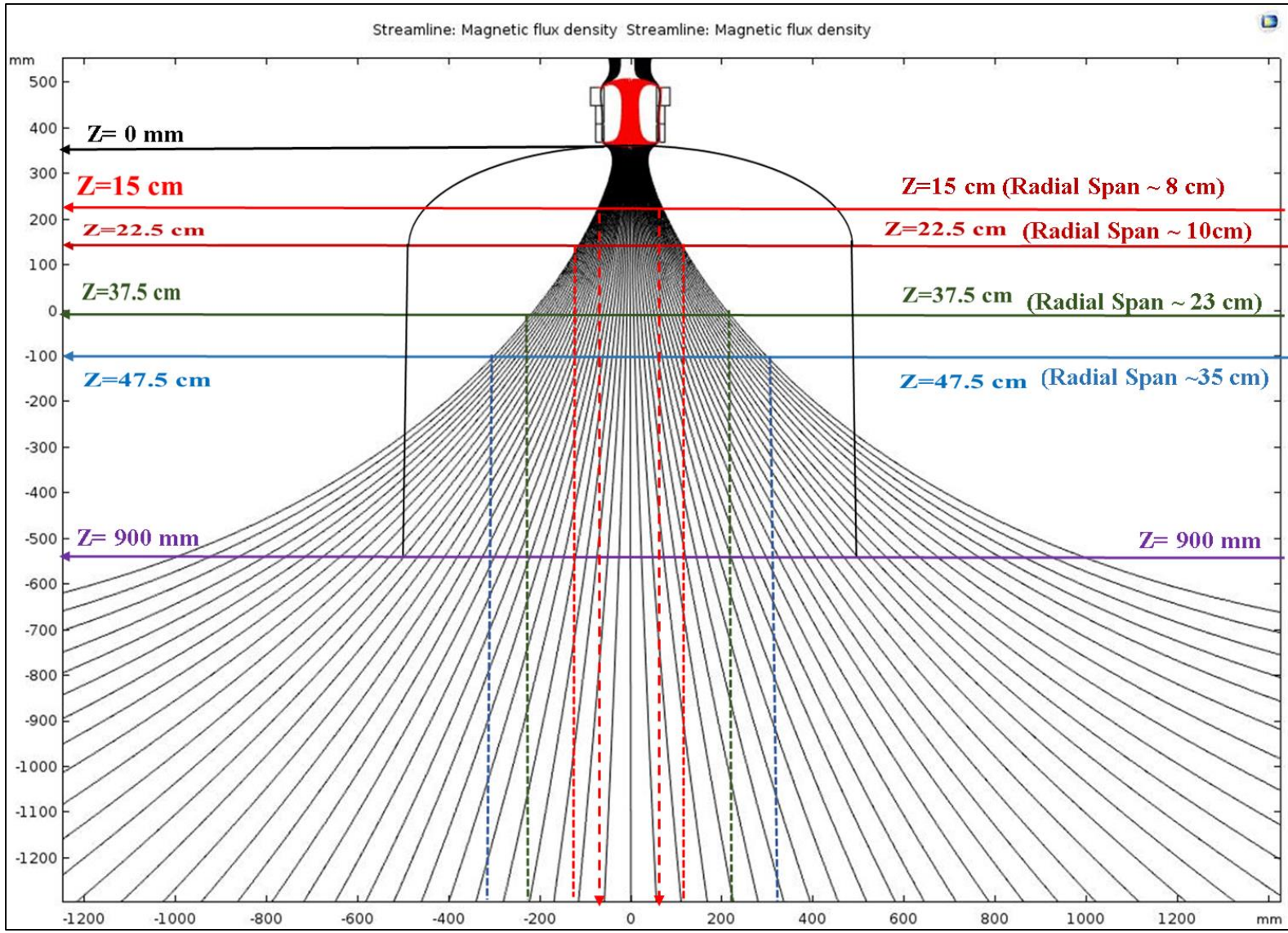
2mTorr





Pressure Variation in radial direction @ 400W_ Z = 37.5cm





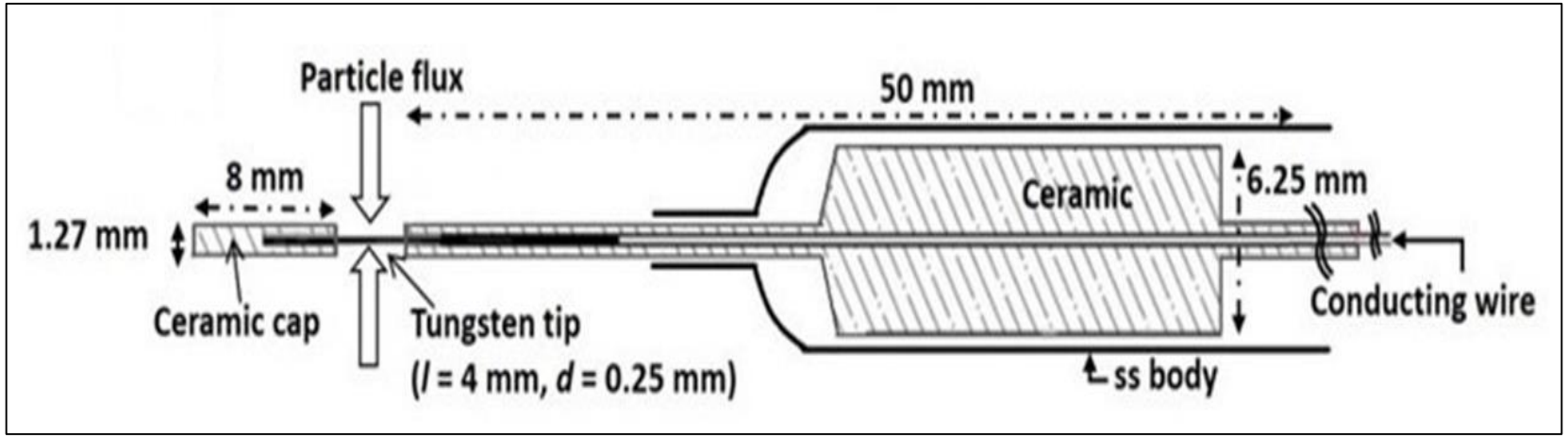
Streamline plot of magnetic flux density of single CEPS magnet:

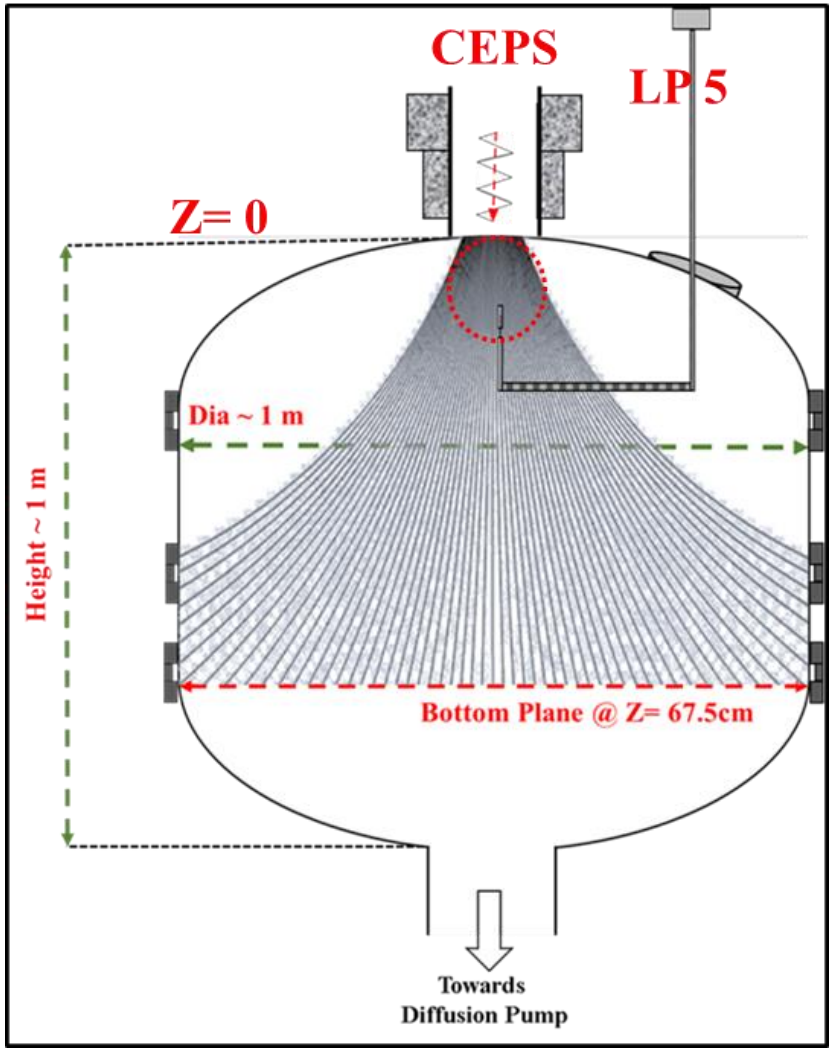
The image shows 3 planes of chamber based on the distance away from the CEPS magnet namely 22.5cm, 37.5cm & 47.5cm and the span of magnetic field lines covered in the respective planes.

**Z=0 has been assigned to top dome inner surface

Exploring Plasma Parameters close to CEPS mouth

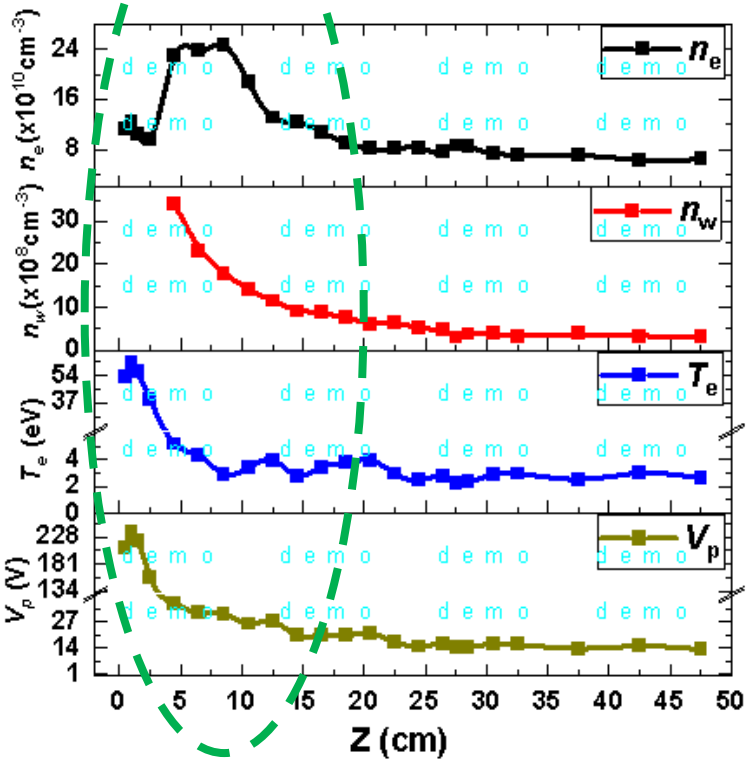
Specially designed capped Langmuir Probe
used to safeguard the probe from harsh plasma environment

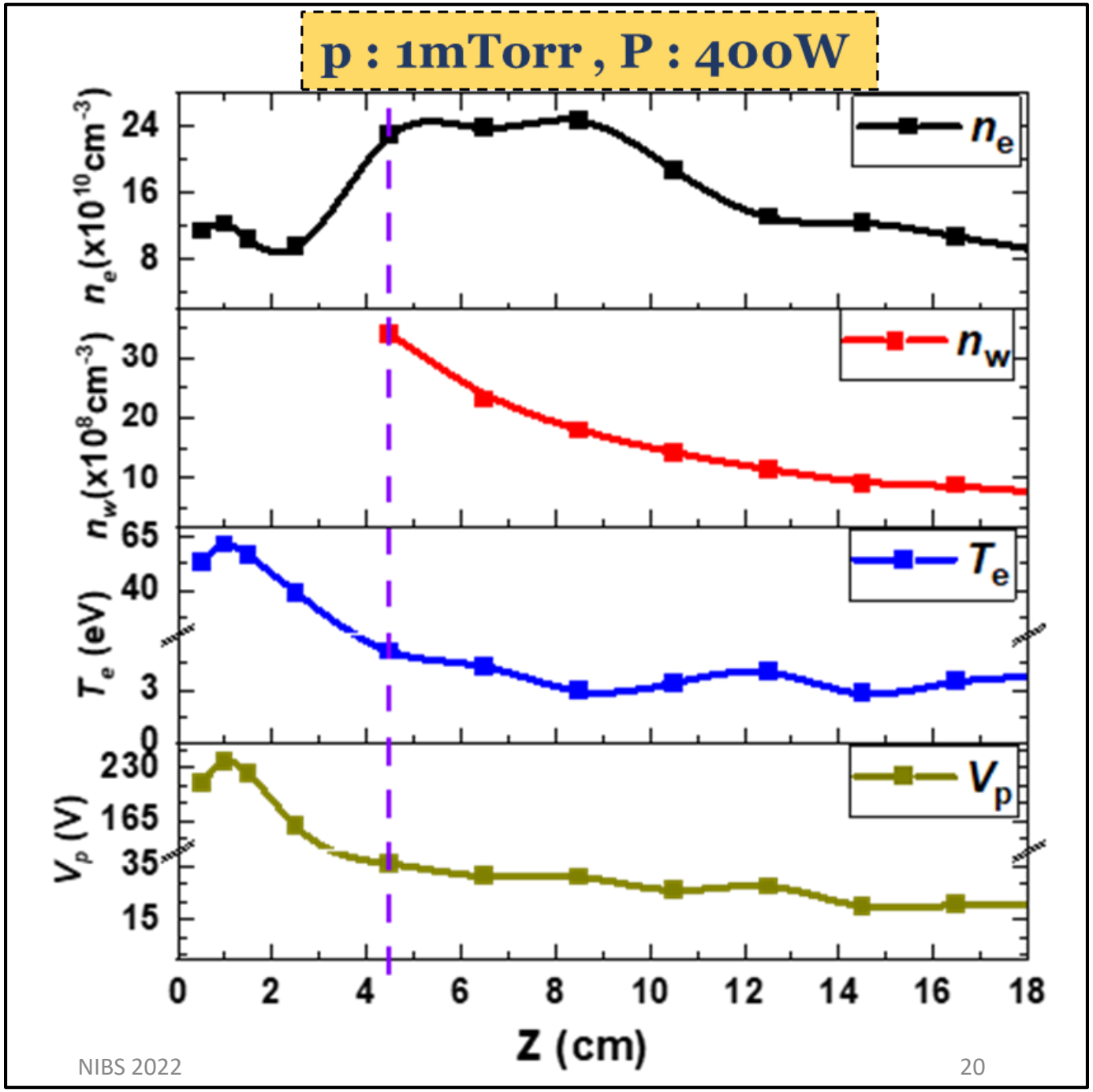




Axial Characterisation using LP5

Enlarged view





Observations (near to the source)

- Existence of Single population observed near to the source.
- Single population switches to double population, as plasma moves ahead in expansion chamber.
- High temperature electron population observed near to the source, which later drops down to low values of ~ 2eV.
- This existence of dual population at 2 different planes can encourage production of H- ions (via Volumetric process).
- More insight towards production processes can be looked upon by theoretical models.

Summary & Future Scope

- ***Hydrogen plasma's distinct behavior*** w.r.t magnetic field was observed.
- ***Optimization*** of number of source/ magnetic field configuration was done.

✓ **Moderately Dense plasma** ~ 8-10 x $10^{10}/cm^3$ (@ 37.5cm away from source with input power of **400W**)

✓ **Uniform plasma** over 35 cm

✓ **Low electron temperature** (1-2 eV).

- This ***CEPS source can be utilized for production*** of H^- ion source in both modes : surface or volume.

Next in Line:

- More deeper diagnosis of plasma parameters will be done via OES, RFEA etc.
- Power scaling to study changes in plasma parameters : specifically n_e & T_e.
- H^- ion density model will be studied to look into the role of existence of double population onto the H^- density.

Regards to

My utmost regards to all the contributors Specifically my guides Prof. Debaprasad Sahu & Prof. Satyananda Kar.
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Thank You !!!!!