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SIMULATIONS OF LOW FIELD HELICON DISCHARGES

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AGENDA

- Motivation
- Plasma Modeling - Hybrid Plasma Equipment Model (HPEM)
- Description of Model for Wave Heated Discharges
- Helicon Behavior in a Solenoidal Field
- Trikon Helicon Simulations
- Conclusions

MOTIVATION FOR USING HELICON DISCHARGES

- Due to their high ionization efficiency, high flux density and their ability to deposit power within the volume of the plasma, helicon reactors are being developed for downstream etching and deposition.

- The power coupling of the antenna radiation to the plasma is of concern due to issues related to process uniformity.

- Operation of helicon discharges at low magnetic fields (< 100 G) is not only economically attractive, but lower fields provide greater ion flux uniformity to the substrate.

- To investigate these issues, we have improved the electromagnetics module of the HPEM to resolve the helicon structure of a m = 0 mode.

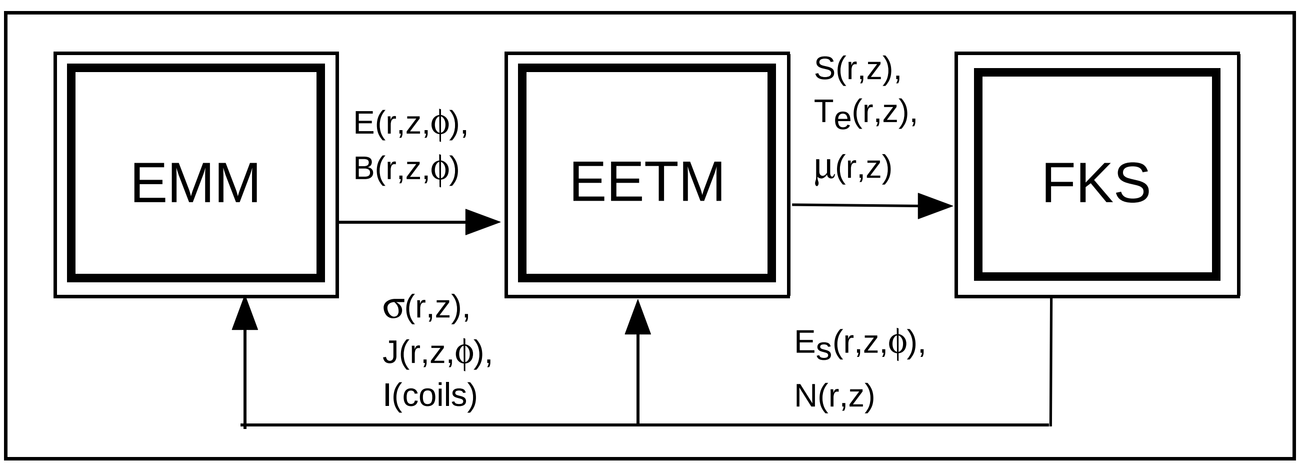
- Results for process relevant gas mixtures are examined and the dependence on magnetic field strength, field configuration, and power are discussed.

HYBRID PLASMA EQUIPMENT MODEL

- The base two-dimensional HPEM consists of an electromagnetics module (EMM), an electron energy transport module (EETM), and a fluid kinetics simulation (FKS).

- Particle transport:
  - Ions: Continuity, Momentum, Energy
  - Electrons: Drift Diffusion, Energy

- Potentials:
  - Early Iterations: Ambipolar
  - Late Iterations: Poisson



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COLD PLASMA CONDUCTIVITY TENSOR

- Algorithms were developed to investigate helicon plasma tools using HPEM-2D. A full tensor conductivity was added to the EMM to calculate 3-d components of the inductively coupled electric field based on 2-d applied magnetostatic fields.

$$-\nabla \cdot \left(\frac{1}{\mu} \nabla \overline{E} \right) = -\, i\omega \overline{\overline{\sigma}} \cdot \overline{E} - i\omega \overline{J}_{ext} + \omega^2 \varepsilon \overline{E}$$

- The plasma current in the wave equation is addressed by a cold plasma tensor conductivity.

$$\overline{\overline{\sigma}} = \sigma_o \frac{m_e \nu_m}{q\alpha} \left(\frac{1}{\alpha^2 + B^2} \right) \begin{pmatrix} \alpha^2 + B_r^2 & \alpha B_z + B_r B_\theta & -\alpha B_\theta + B_r B_z \\ -\alpha B_z + B_r B_\theta & \alpha^2 + B_\theta^2 & \alpha B_r + B_\theta B_z \\ \alpha B_\theta + B_r B_z & -\alpha B_r + B_\theta B_z & \alpha^2 + B_z^2 \end{pmatrix}$$

where, $\sigma_o = \dfrac{q^2 n_e}{m_e \nu_m}$ and, $\alpha = \dfrac{m_e}{q} (\nu_m + i\omega)$

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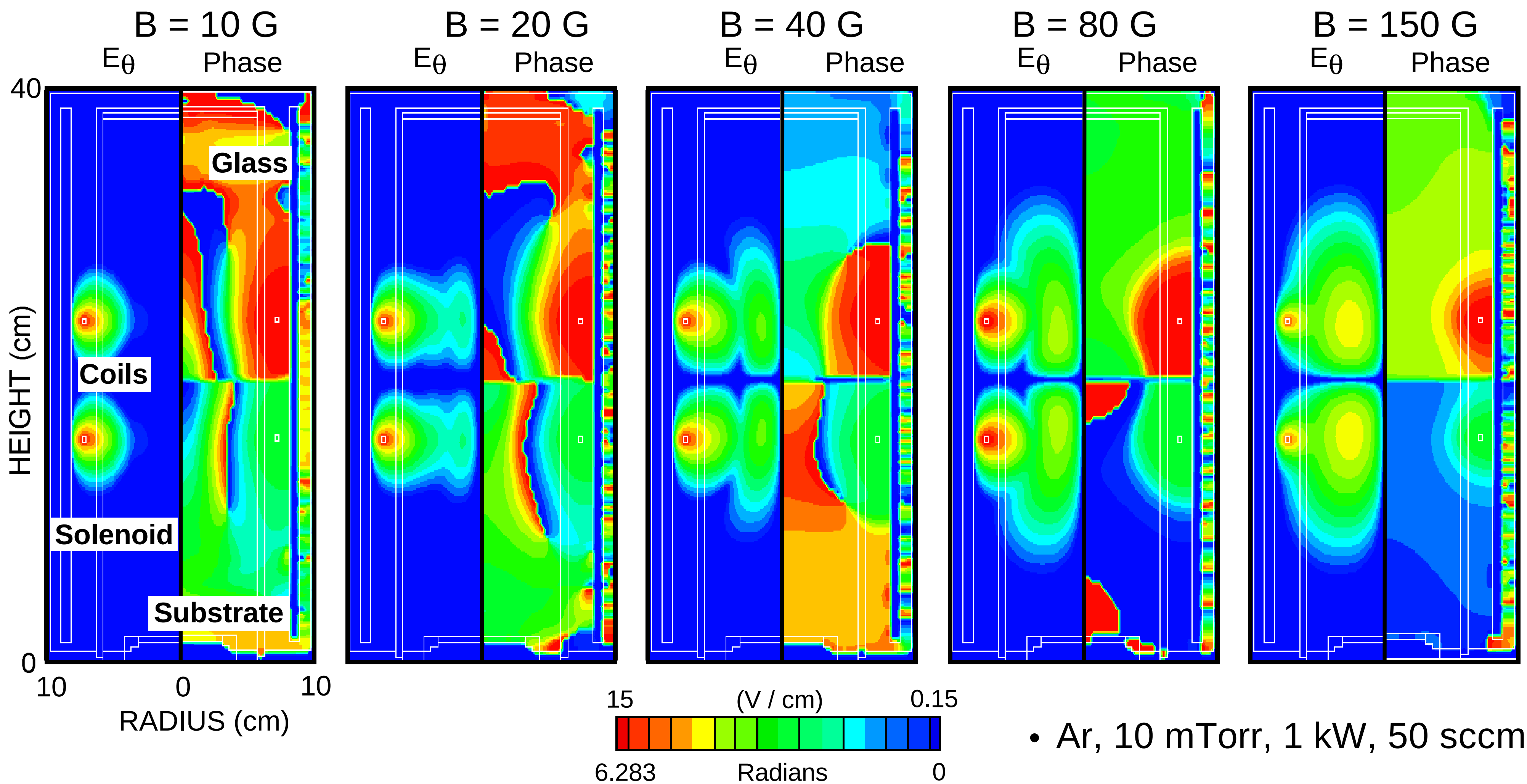
HELICON TRANSITION - AZIMUTHAL ELECTRIC FIELD (E_θ)

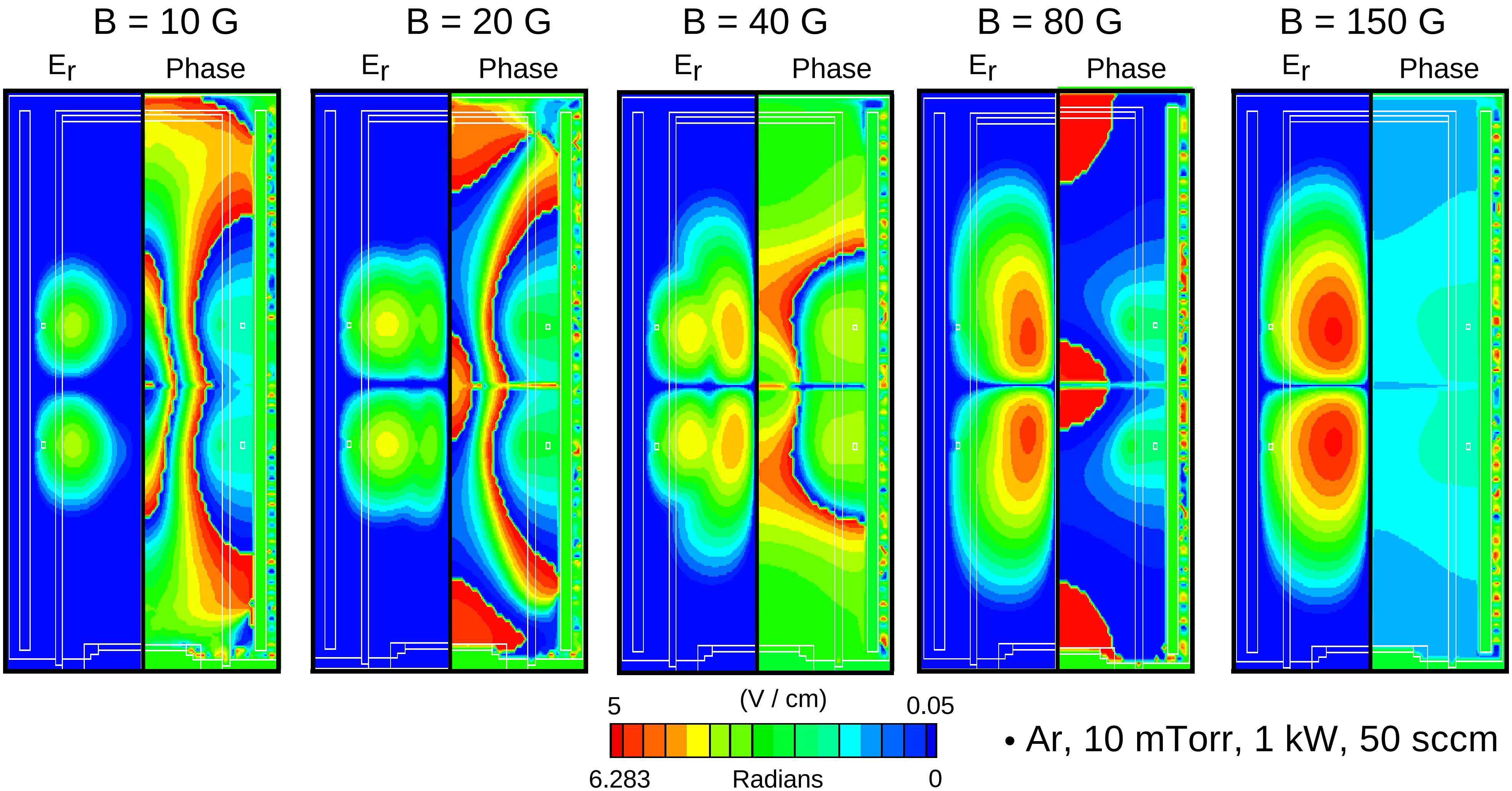


- Ar, 10 mTorr, 1 kW, 50 sccm

- At a critically low magnetic field, the azimuthal electric field remains inductively coupled and a radially propagating wave dominates.

- As magnetic fields are increased, standing wave patterns arise in radial direction and the electric field begins to propagate in the axial direction.

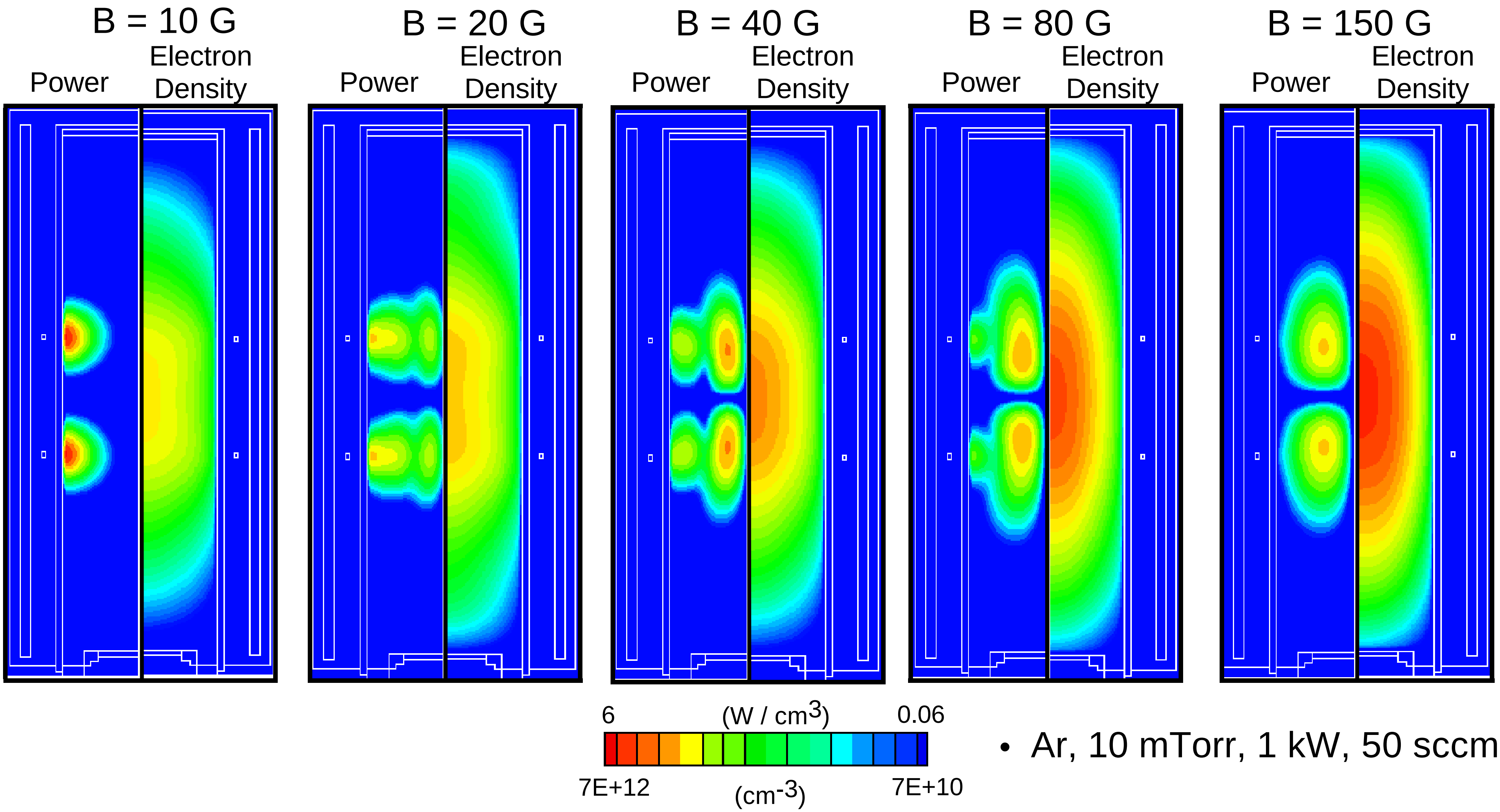
HELICON TRANSITION - RADIAL ELECTRIC FIELD (E_r)



• Ar, 10 mTorr, 1 kW, 50 sccm

- The propagation of radial electric field E_r is similar to azimuthal electric field E_θ.
- Initially propagation is dominantly in the the radial direction, with a highly damped wave.

HELICON TRANSITION - POWER AND ELECTRON DENSITY



- Ar, 10 mTorr, 1 kW, 50 sccm

- At low magnetic fields power deposition is inductively coupled and occurs near the coils

- As nodal structure develops in the azimuthal and radial fields, the skin depth of the power deposition is increased to within the volume of the plasma.

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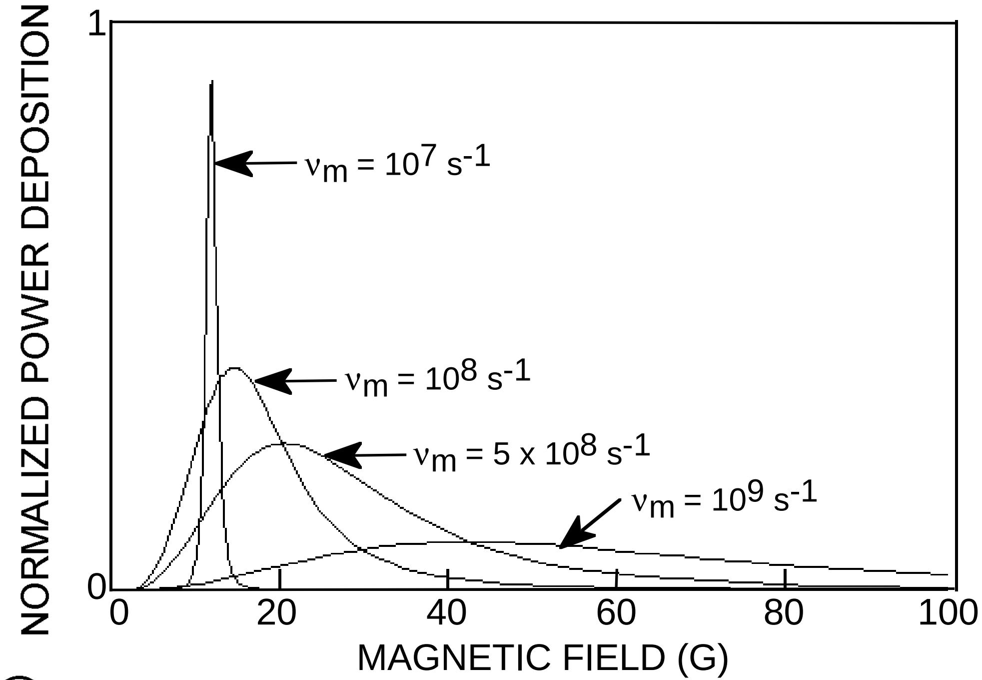
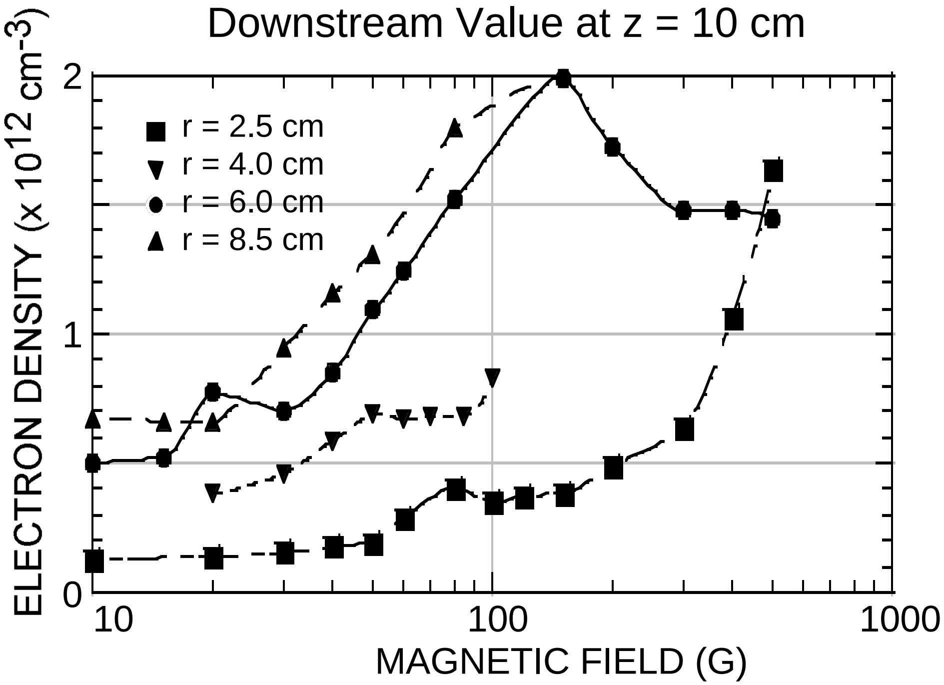
LOW FIELD DOWNSTREAM DENSITY PEAK

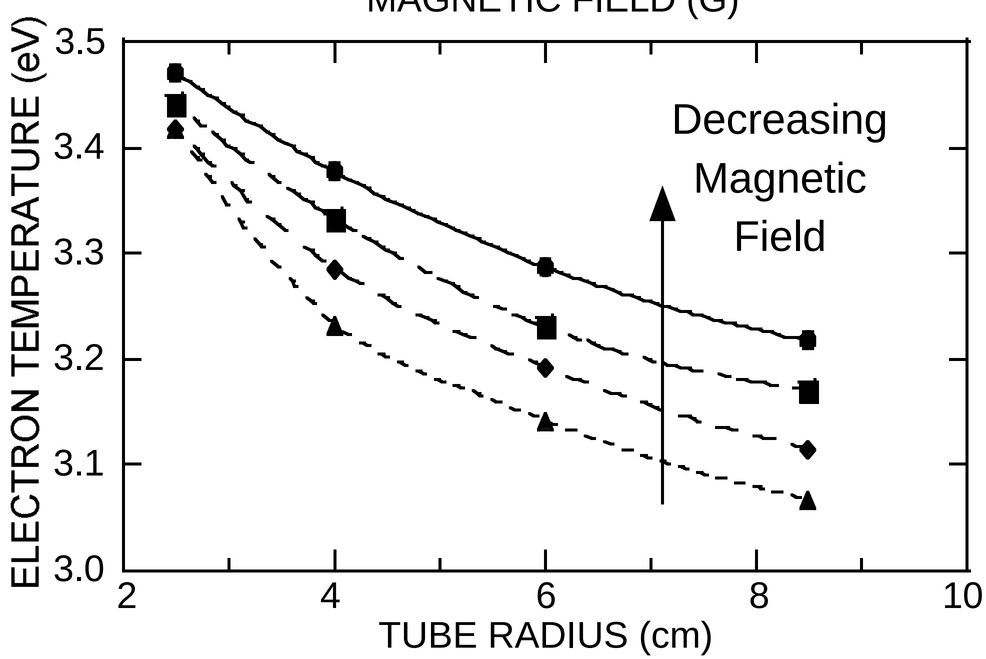
- Previous experiments using a Nagoya Type III antenna (Chen and Chevalier) show a small peak in the electron density in the downstream region in low magnetic field (20-60 G) regime.

- Ar, 5 mTorr, 1 kW, 50 sccm



Downstream Value at z = 10 cm





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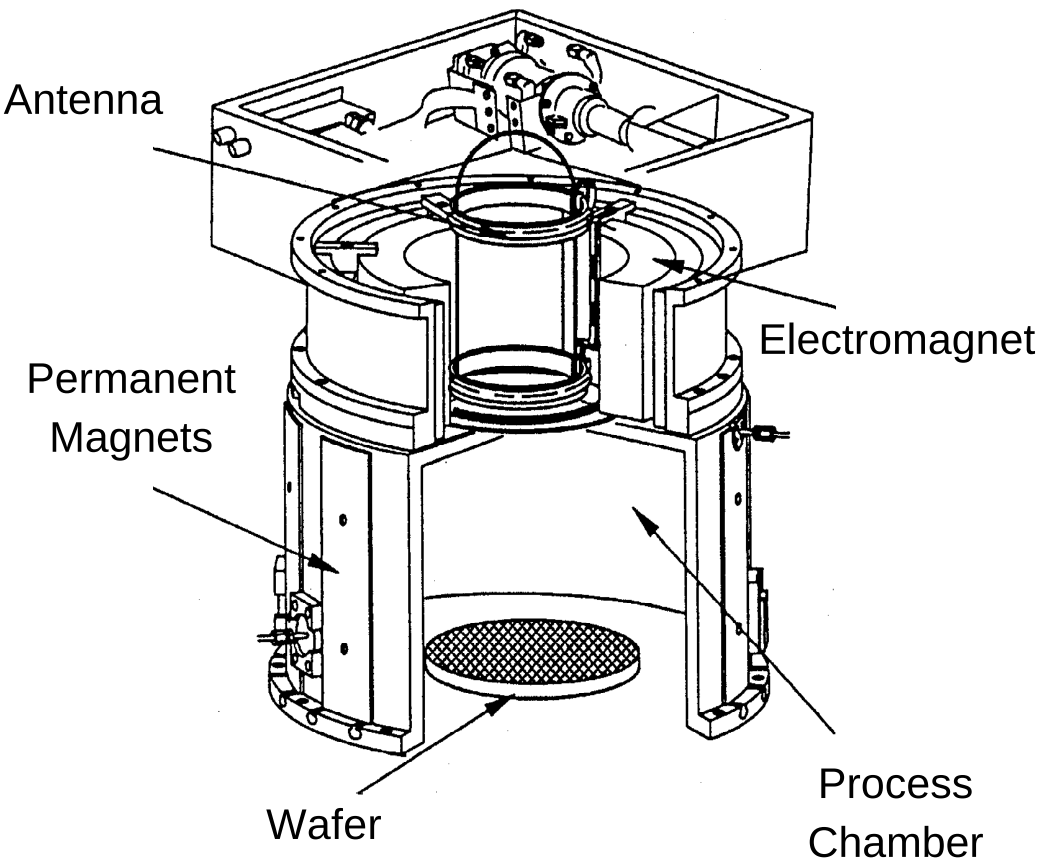
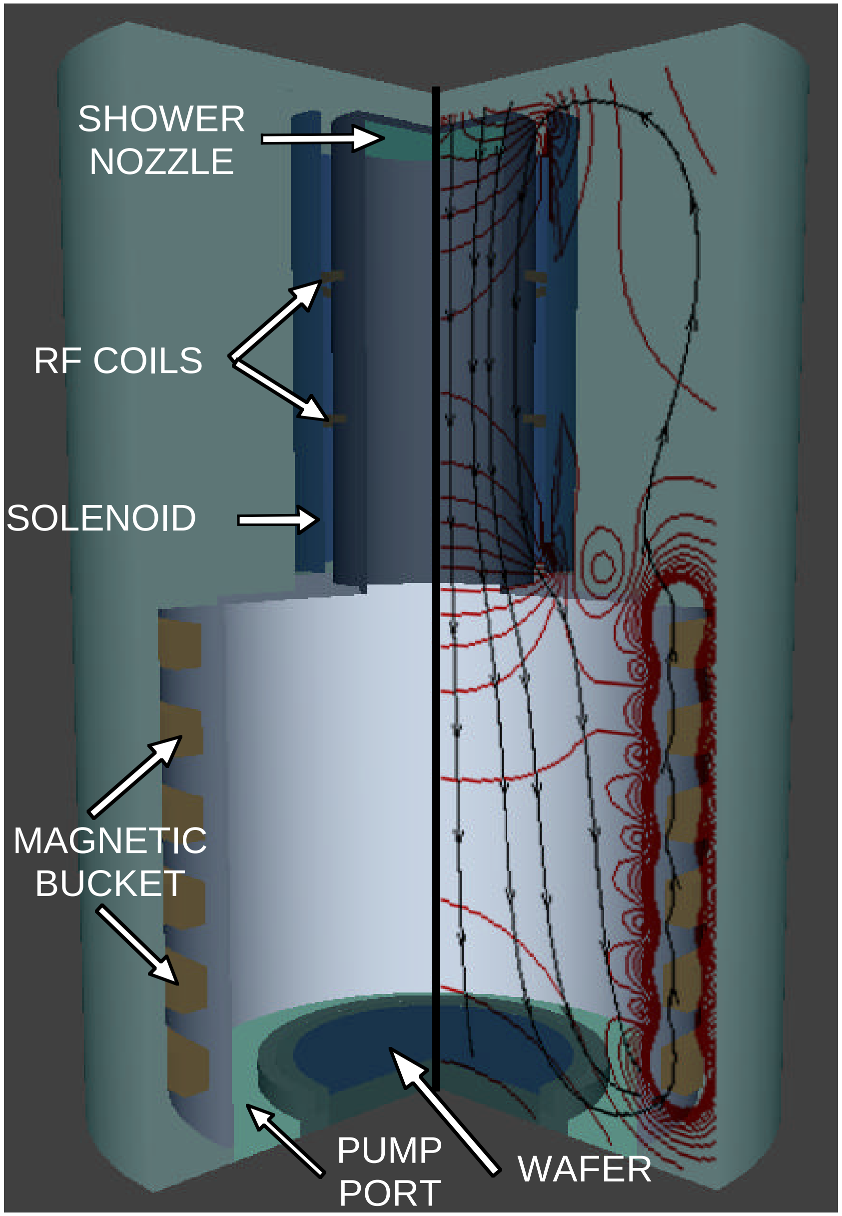
TRIKON MORI™ 200 HELICON PLASMA SOURCE

- Measurements from a commercial Trikon Technologies, Inc., Pinnacle 8000 helicon source was used to validate model.





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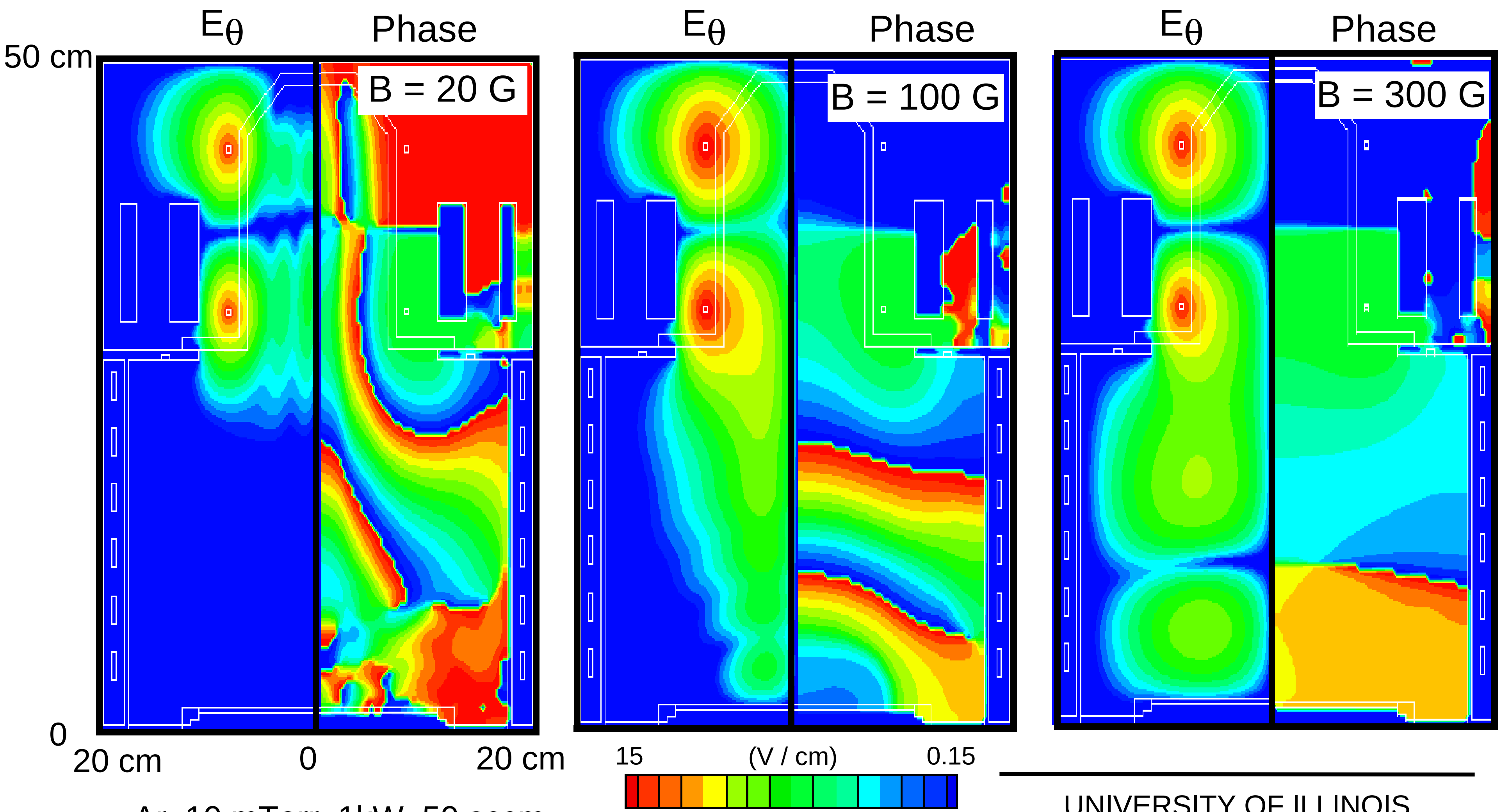
ANALYSIS OF TRIKON HELICON TOOL : E_θ

- At low fields, the electromagnetic propagation is mainly radial, producing standing wave pattern in the radial direction.

- However as the field increases, propagation dominates in the axial direction, shifting standing wave patterns in the direction of propagation.



- Ar, 10 mTorr, 1kW, 50 sccm

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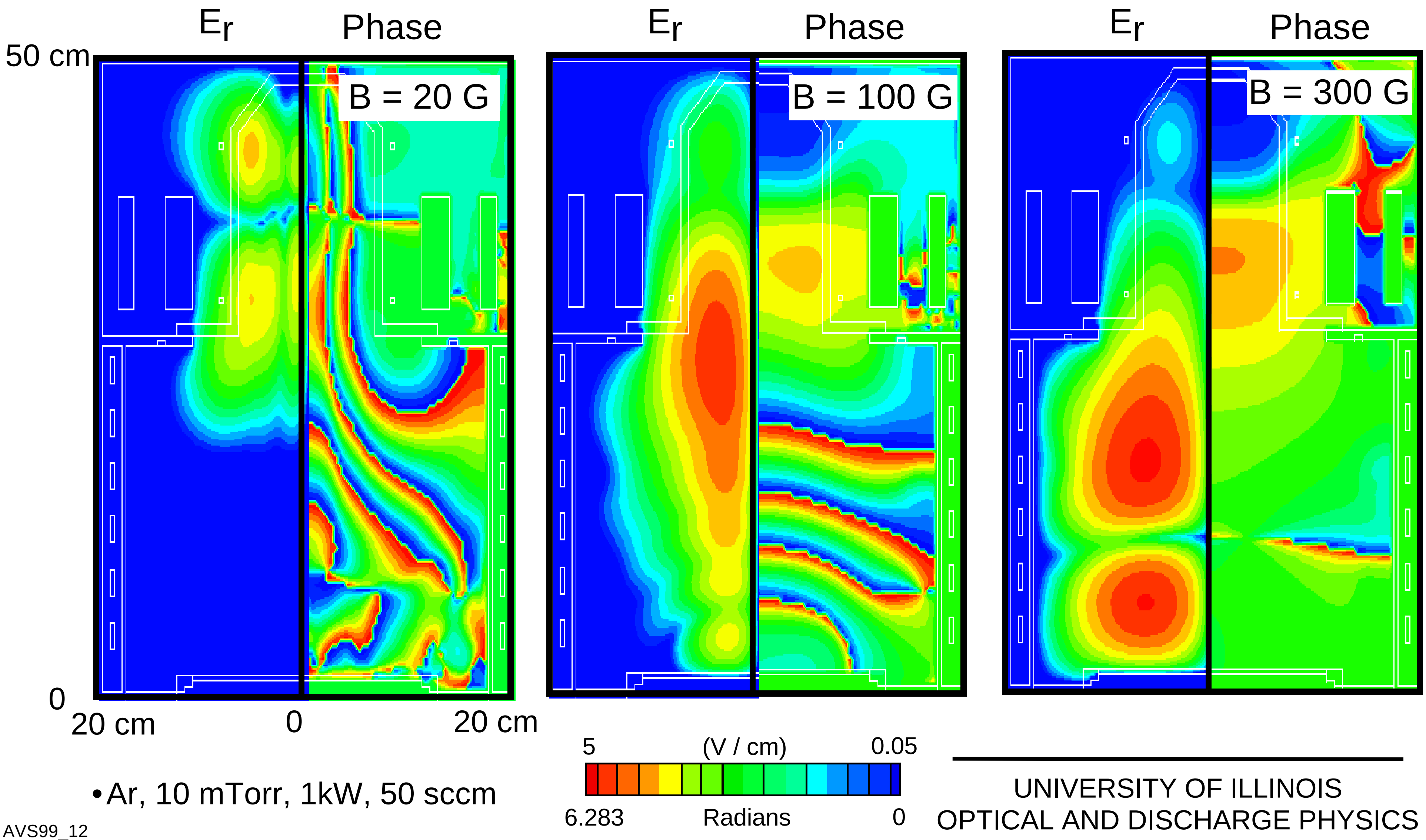
ANALYSIS OF TRIKON HELICON TOOL : E_r

- Similar effects can be seen in the radial electric field profile and propagation.
- Antenna coupling seems to have a significant effect at higher magnetic fields.



- Ar, 10 mTorr, 1kW, 50 sccm

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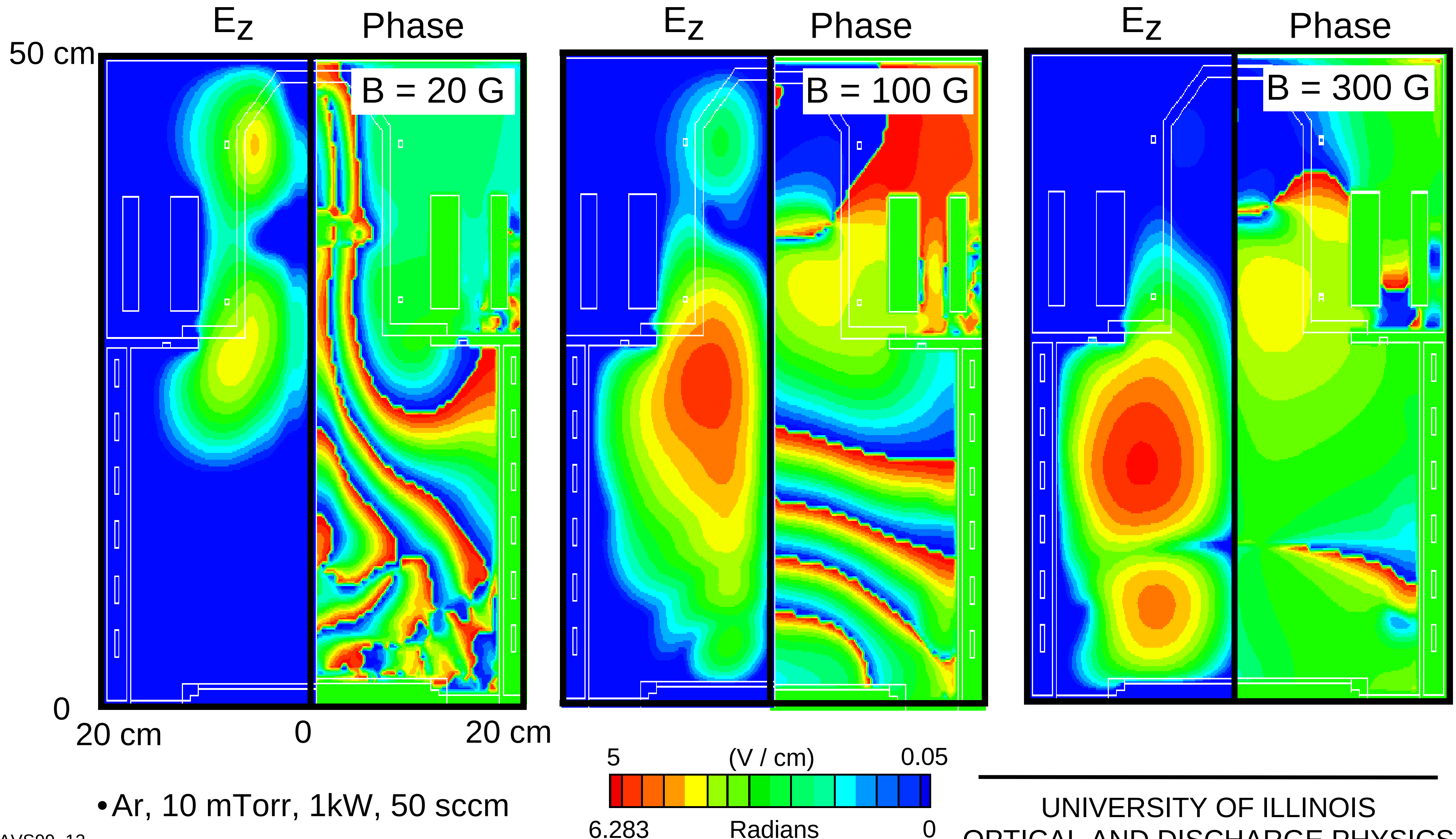
ANALYSIS OF TRIKON HELICON TOOL : E_Z

- Axial electric field propagation and wave pattern resembles radial electric fields.

- As magnetic fields are increased, overall electric field propagation in the axial direction dominates.



- Ar, 10 mTorr, 1kW, 50 sccm

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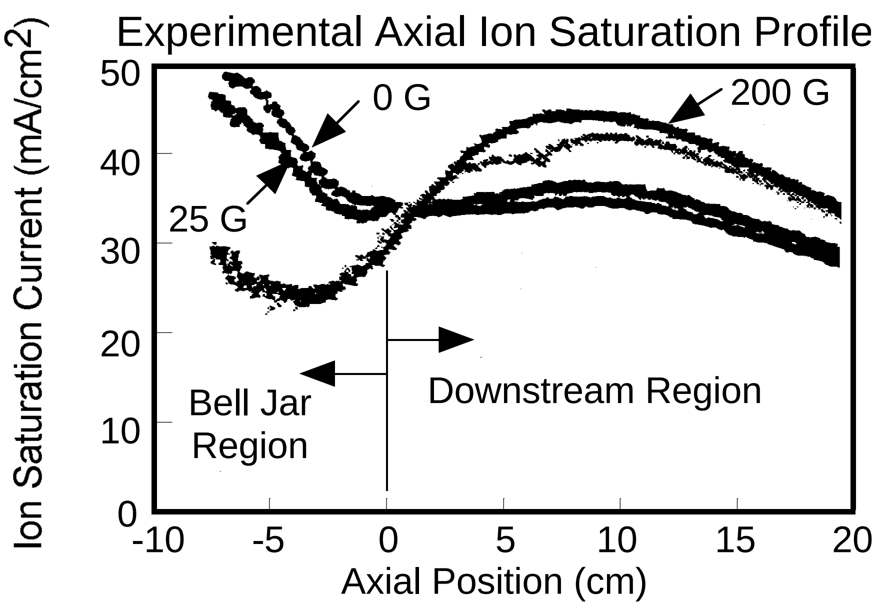
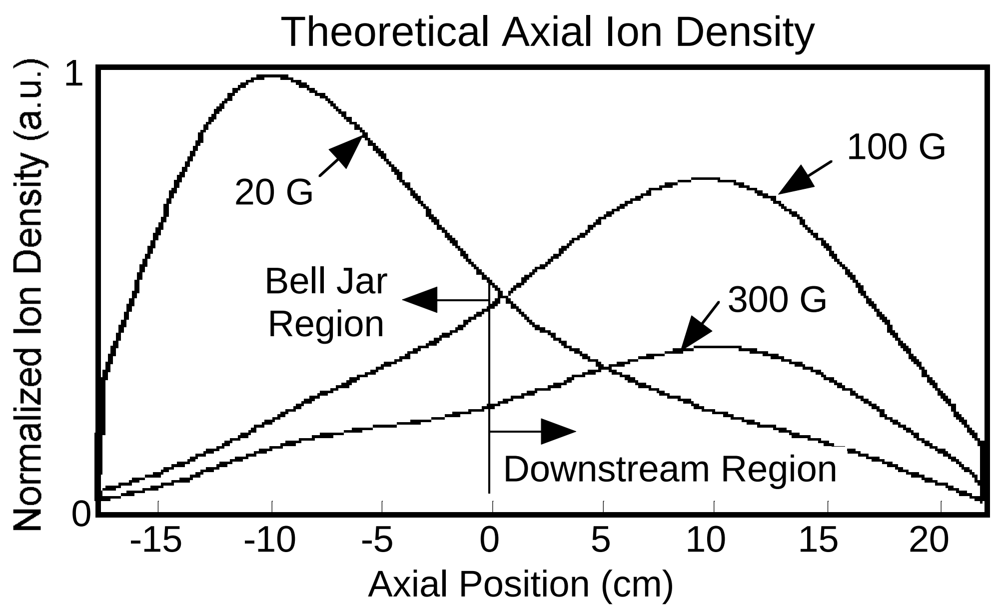
ANALYSIS OF TRIKON HELICON TOOL : VALIDATION

- As static magnetic field increases, ion saturation current peaks further downstream. Simulations show a similar trend for the ion saturation profile.

- For simulations at constant power, downstream peak decreases with increasing static magnetic fields since plasma peaks at larger radius (i.e. larger plasma volume).



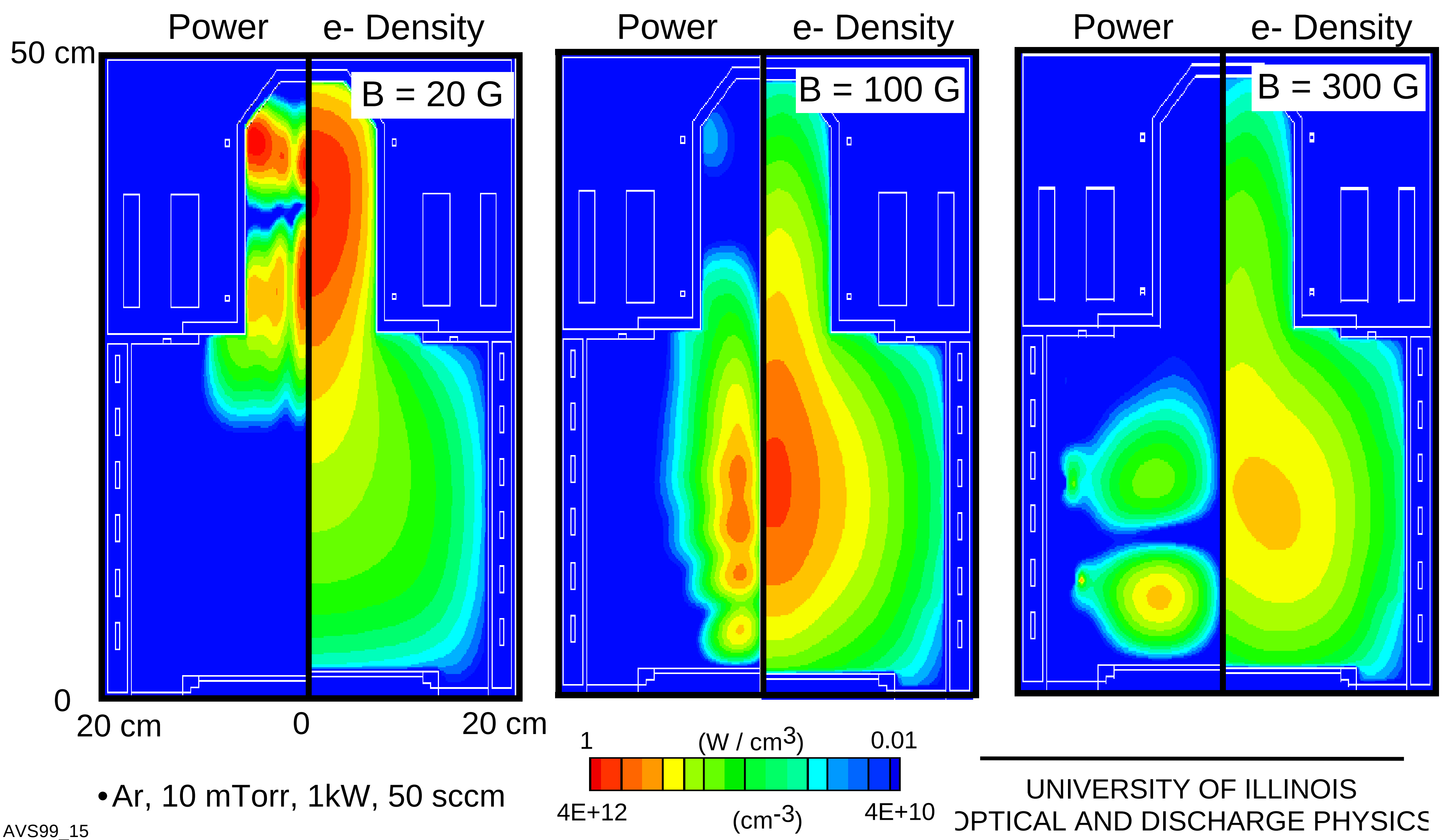
- Ar, 2.3 mTorr, 1kW (Trikon Technologies, Inc.)



- Ar, 10 mTorr, 1kW, 50 sccm

ANALYSIS OF TRIKON HELICON TOOL : POWER AND ELECTRON DENSITY

- As the magnetic fields increase, axial propagation dominates depositing power in the downstream region. An increase in ion current to the substrate comes at the loss of flux uniformity.



- Ar, 10 mTorr, 1kW, 50 sccm

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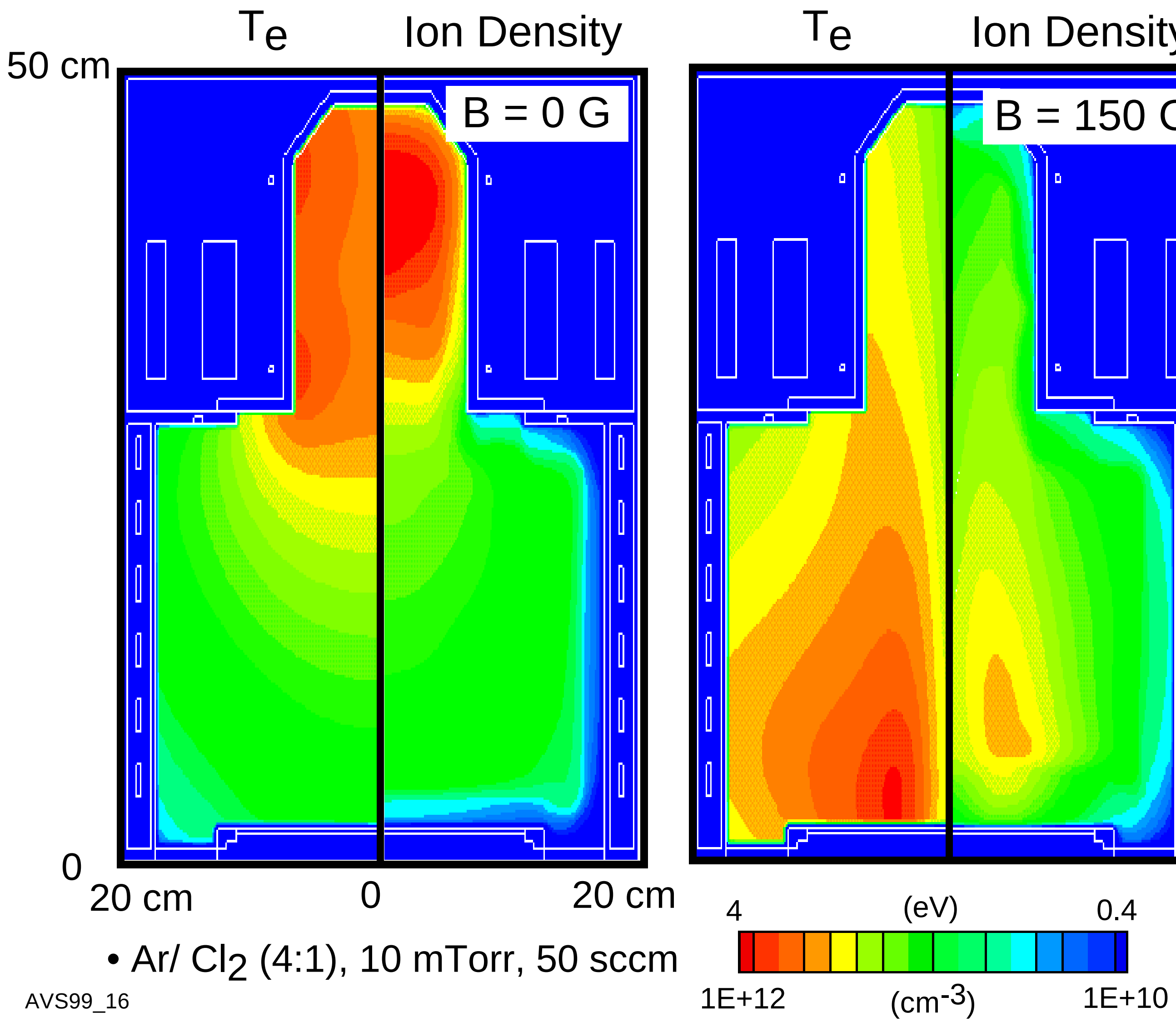
ANALYSIS OF TRIKON HELICON TOOL : Ar/Cl_2

- As the magnetic fields increase, axial propagation dominates depositing power in the downstream region.

- However, for specific mixtures, at high enough magnetic fields the electric field wavelength is larger than the reactor size, resembling ICP behavior.



- Ar/Cl_2 (4:1), 10 mTorr, 50 sccm

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CONCLUDING REMARKS

- Parametric studies using low magnetic fields show nodal behavior in the electric field structure, thereby increasing the skin depth of the power deposition to within the volume of the plasma.

- As the magnetic field increases, axial propagation of electromagnetic fields dominates with an increase in wavelength.

- The transition from inductive coupling to helicon mode appears to occur when the fraction of power deposited through the radial and axial fields dominates.

- Simulations of the Trikon helicon source showed significant power deposition downstream in the higher magnetic field regime, thereby shifting the location of peak plasma density.

- As static magnetic fields become large enough, the wavelength of the electric fields is increased and power deposition resembles ICP.