Suppression of drift wave turbulence and zonal flow formation by changing axial boundary conditions in a linear magnetized plasma device

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Take Home Points

- Flow of currents in a linear plasma device, can be altered simply by changing the end boundaries from insulating to conducting.

- Changing the boundary has significant effects on the fluctuation characteristics.

Theoretical background

Drift Waves have $\nabla \cdot \mathcal{J} = 0 \Rightarrow \nabla_{//} \mathcal{J}_{//} = -\nabla_{\perp} \mathcal{J}_{\perp}$

Parallel Current from electron motion along field lines:

$$\tilde{J}_{\|} = -\eta \nabla_{\|} \tilde{\phi}$$

Perpendicular Current from Ion Polarization Drift:

$$\mathcal{J}_{\perp} = -\frac{1}{\Omega_{C_i} B} \left(\partial_t + \left(v_{ExB} \cdot \nabla \right) \nabla \phi \right)$$

This perpendicular current can be thought of as giving a torque to the plasma => Reynolds Stress

*P. H. Diamond and Y-B. Kim, Phys. Fuilds B **3**, 1626 (1991)

Simple pictorial description

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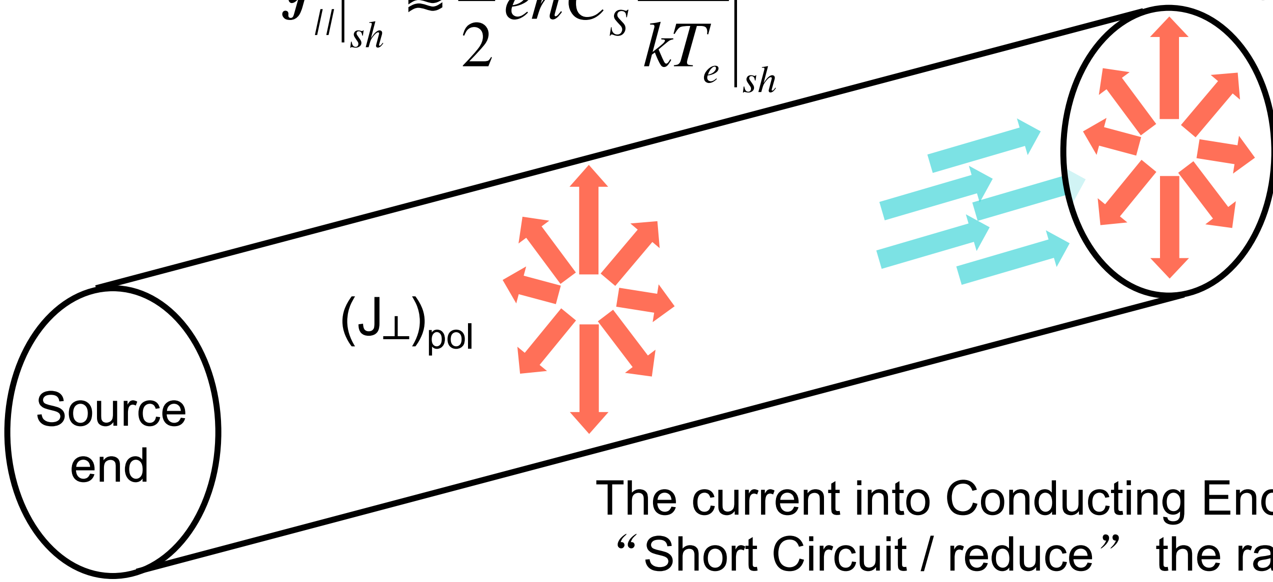
$$^{*}\; \left. j_{//}\right|_{sh} \approx \frac{1}{2} e n C_S \left. \frac{e\phi}{kT_e}\right|_{sh}$$

$J_{\parallel} \Rightarrow (J_{\perp})_{\text{End plates}}$



The current into Conducting End Plates can effectively "Short Circuit / reduce" the radial polarization current.

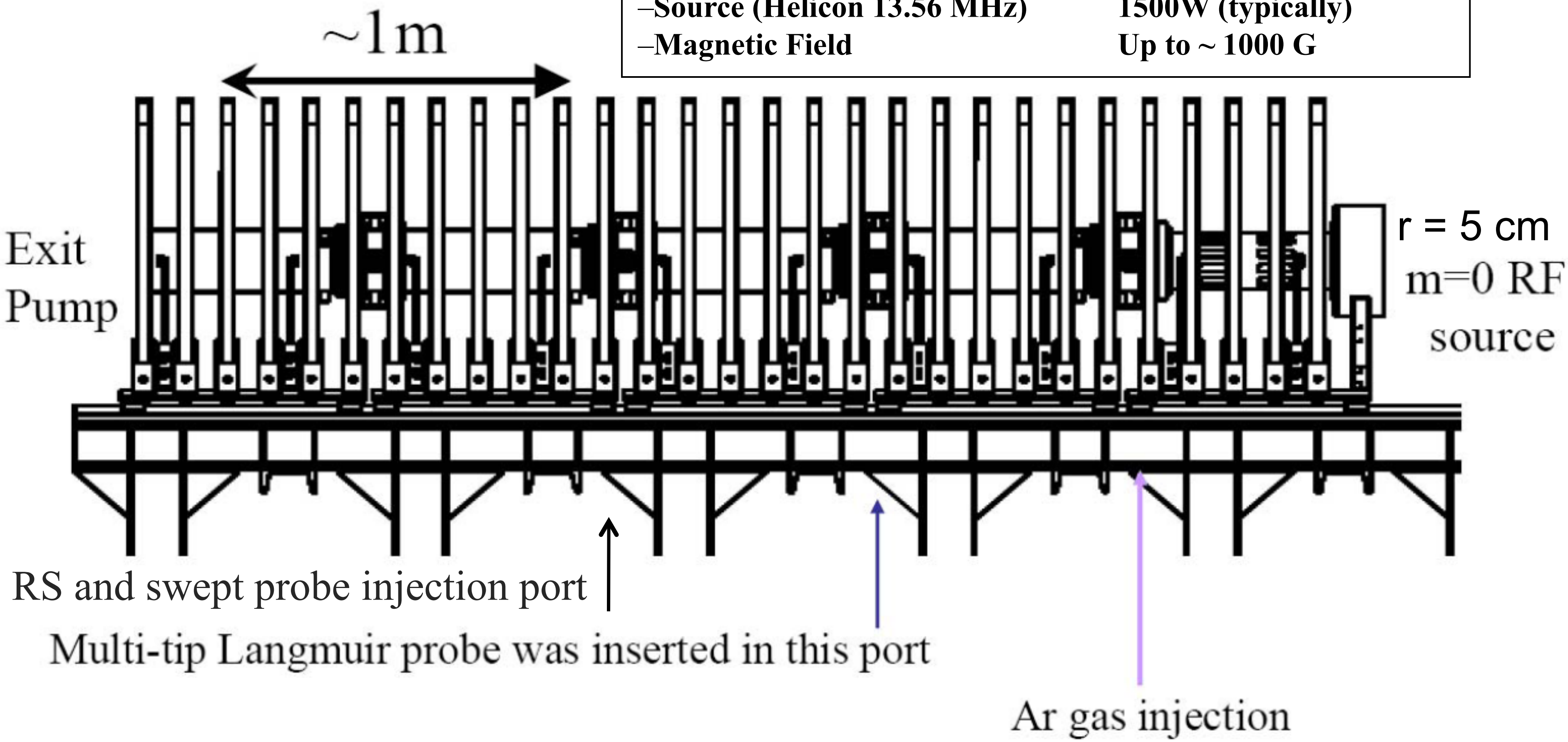
The loss can be prevented if insulated end plates are used. For identical source parameters:

$$(J_{\perp})_{IBC} > (J_{\perp})_{CBC}$$

* J. R. Myra *et.al.*, Phys. Plasmas, 15, 032304 (2008)

Controlled **S**hear **D**e-correlation **E**xperiment

CSDX parameter	Typical value
Gas pressure	0.5 - few mTorr
T_e	~ 3 eV
T_i	~ 0.7 eV
n_e	1-10 x 10^{12} cm^{-3}
Source (Helicon 13.56 MHz)	1500W (typically)
Magnetic Field	Up to ~ 1000 G



Experiment: Insulating BC (IBC)

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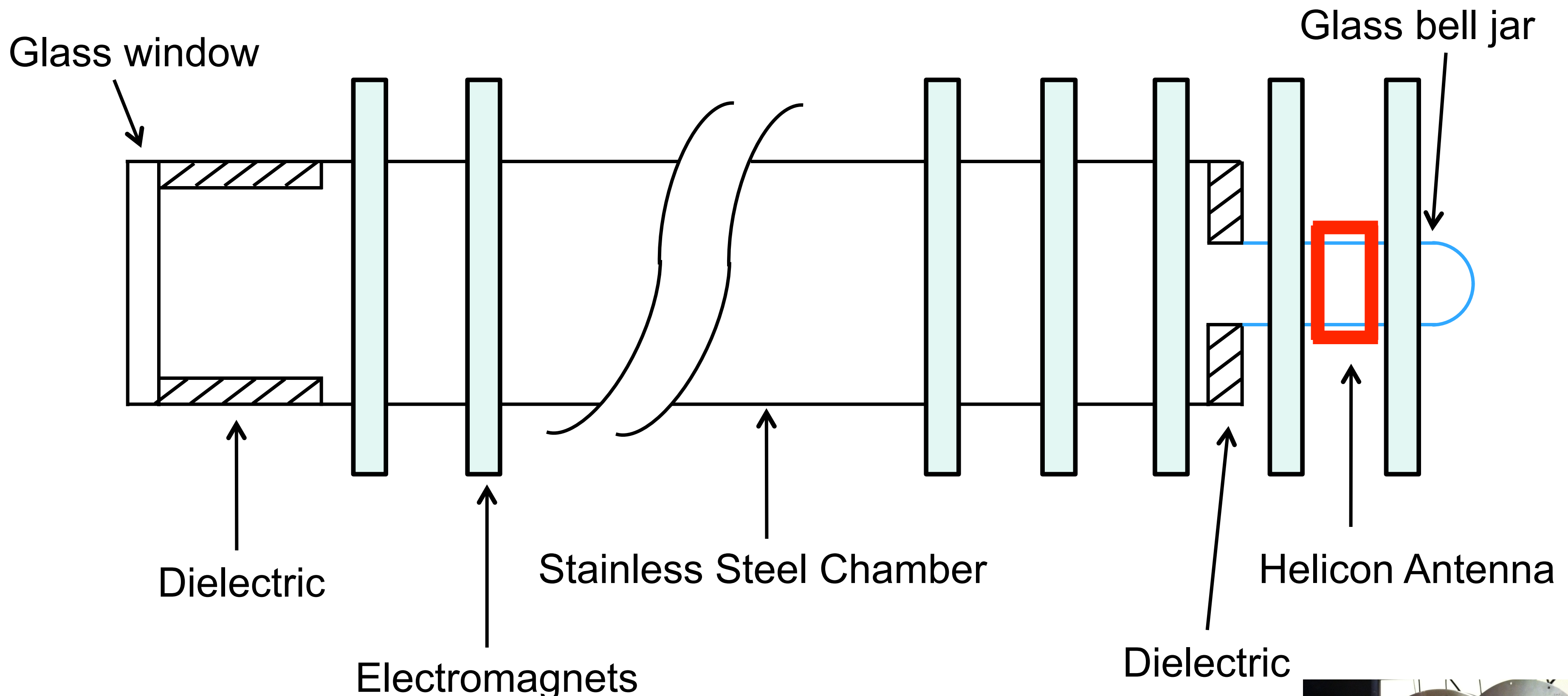
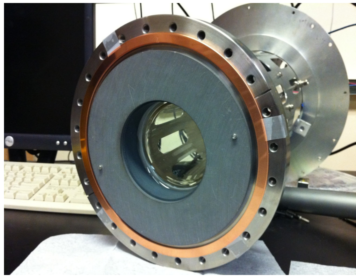
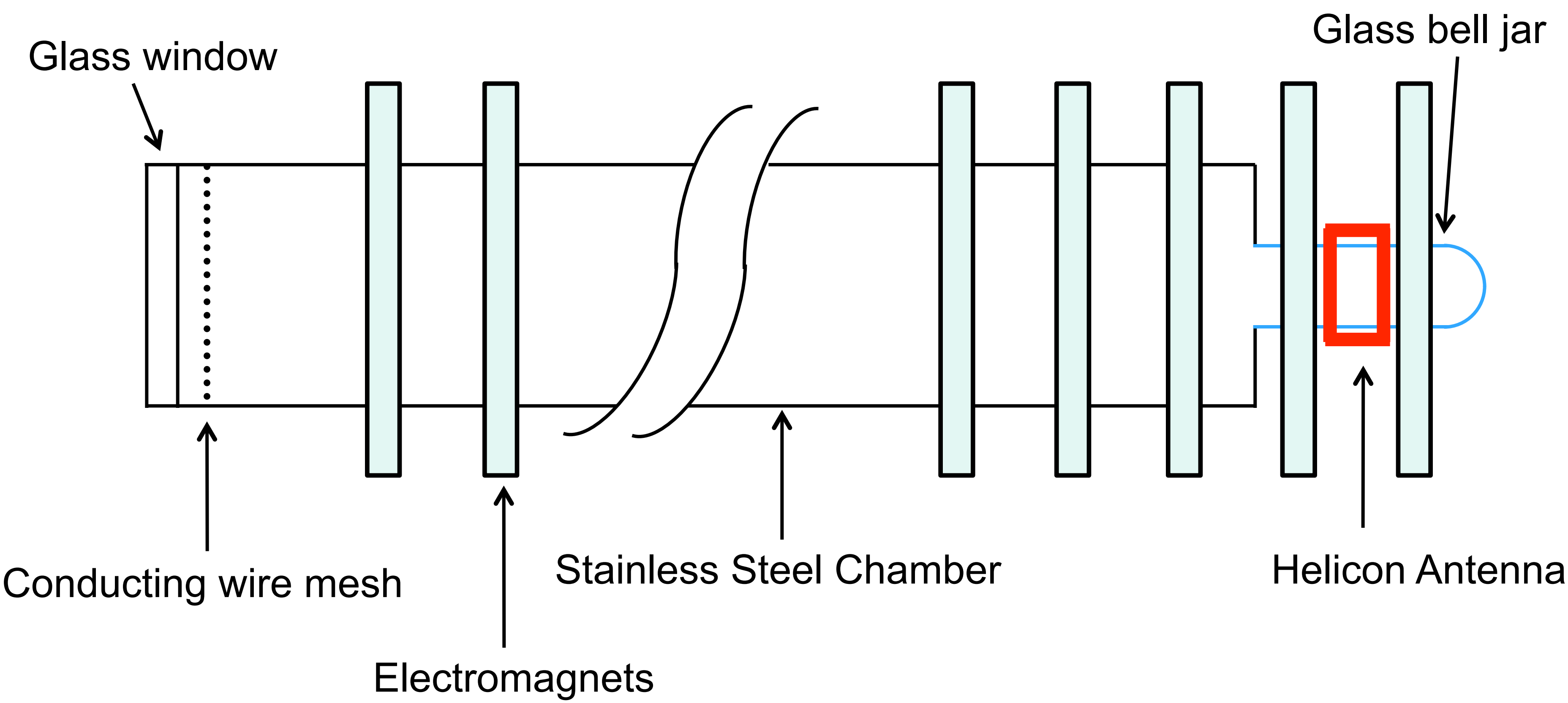




– **Ends insulated** to prevent the plasma from hitting the chamber walls

Experiment: Conducting BC (CBC)



– **Ends are conducting** so currents can flow through them

IBC and CBC have similar radial profiles for plasma density, electron and ion temperatures

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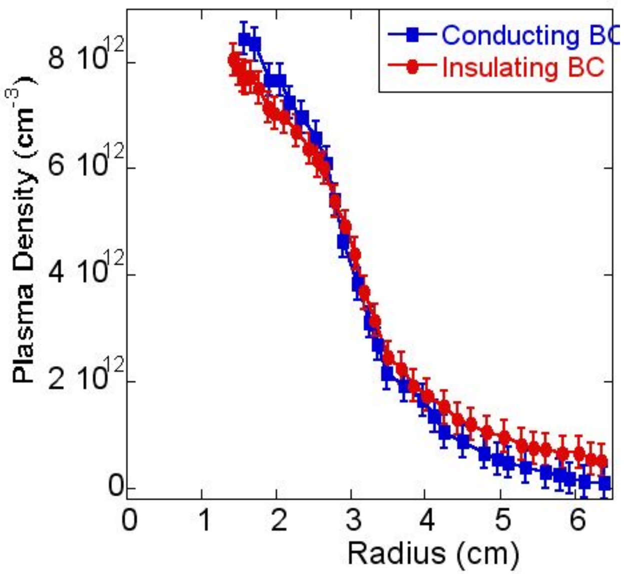
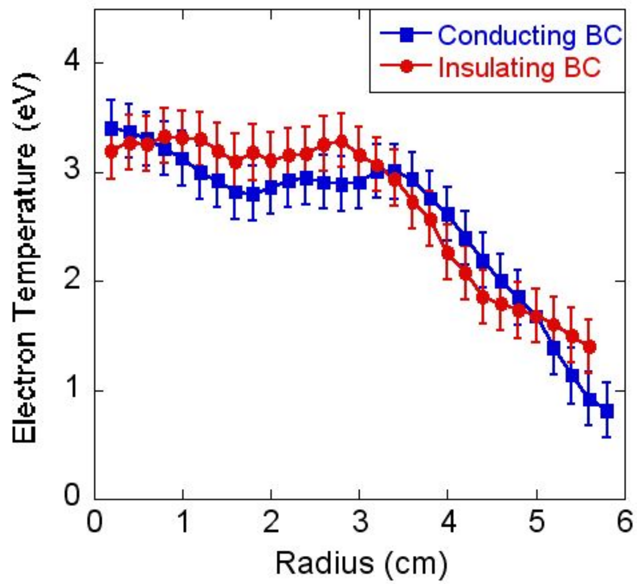
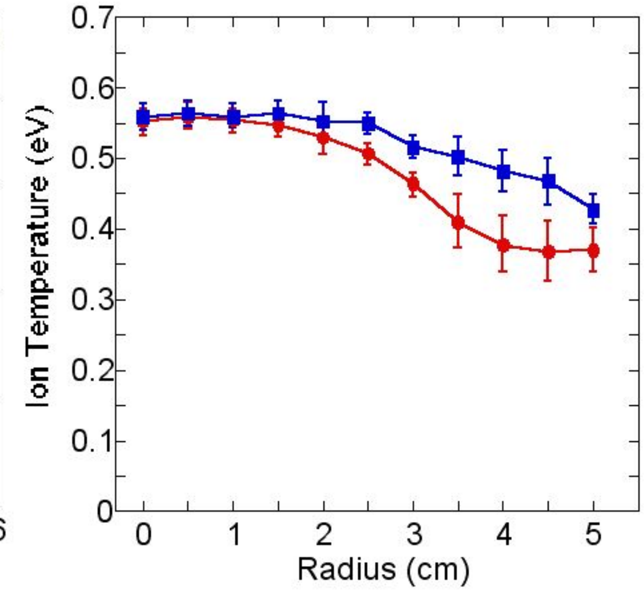
Plasma density



Electron temperature

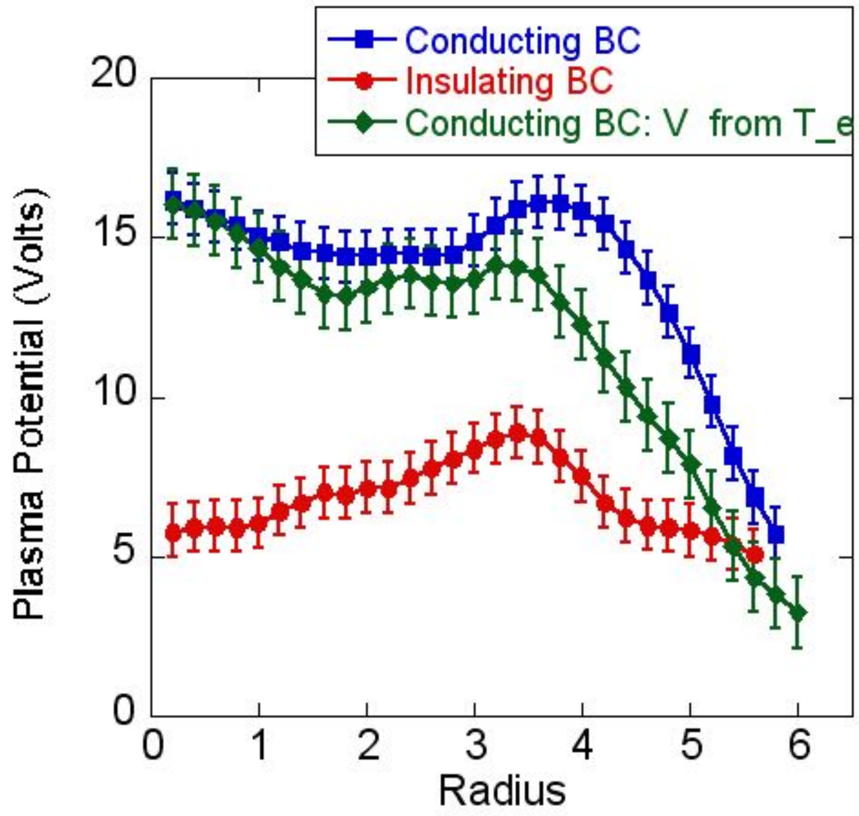


Ion temperature



B = 1000 G; Power = 1.5 KWatts; Pressure = 3.2 mTorr

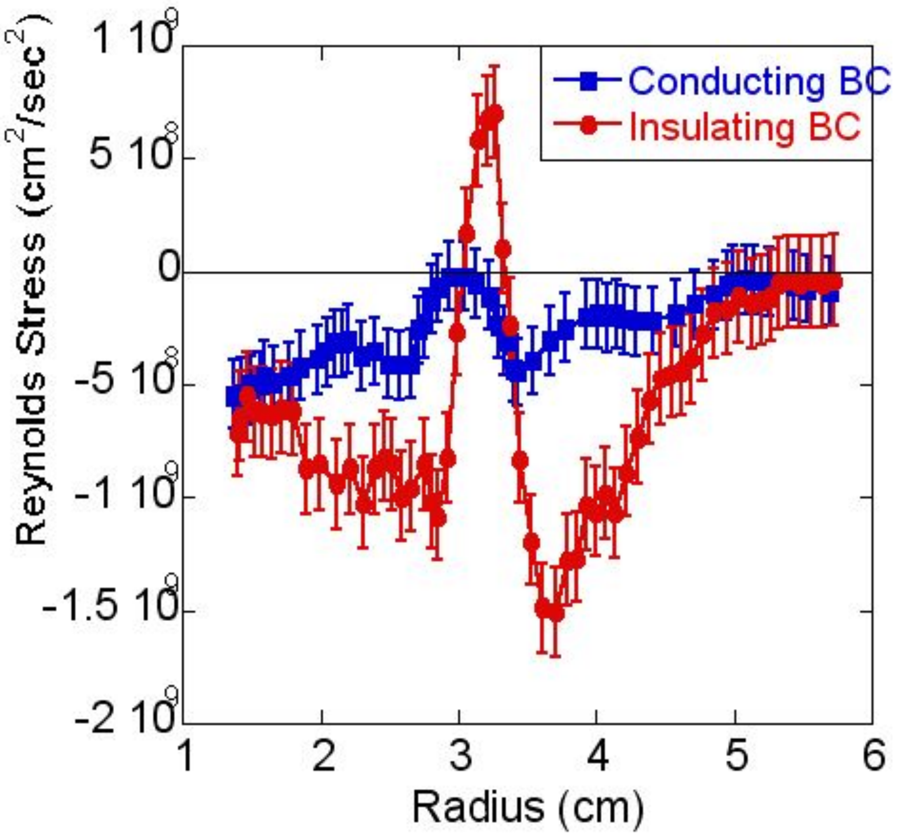
Radial profiles of plasma potential are affected by the change in the boundary



B = 1000 G; Power = 1.5 KWatts; Pressure = 3.2 mTorr

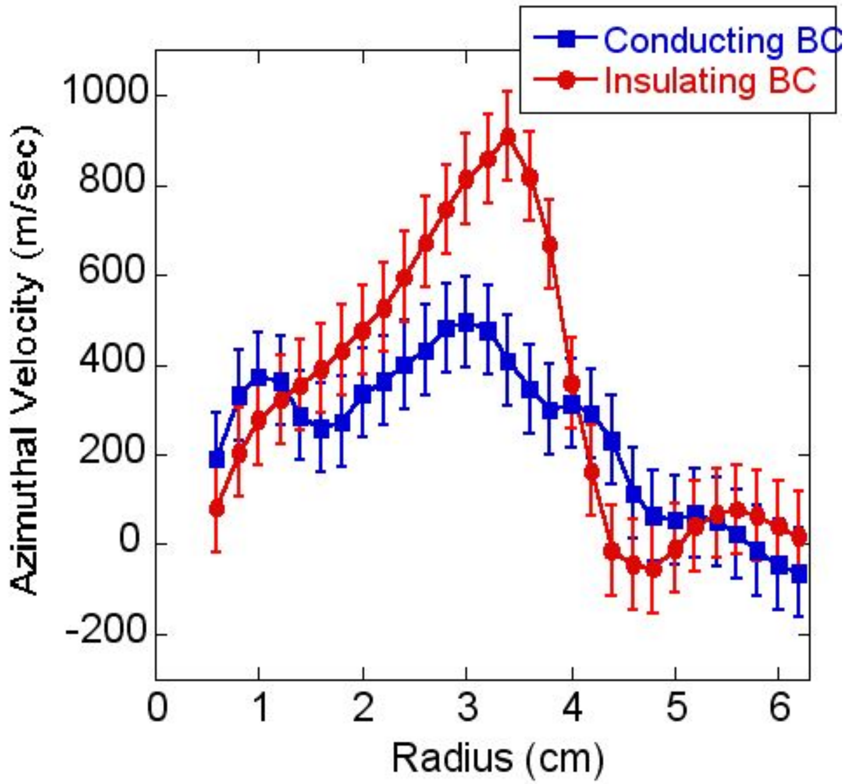
Reduced Reynolds Stress in the CBC

$$RS = \left\langle \tilde{v}_r \bullet \tilde{v}_\theta \right\rangle$$

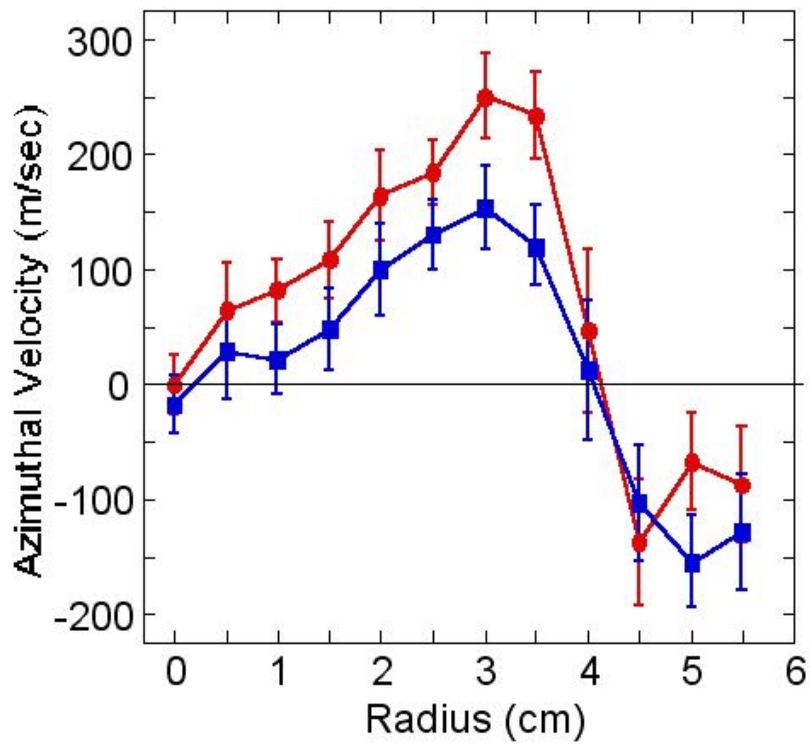


B = 1000 G; Power = 1.5 KWatts; Pressure = 3.2 mTorr

Radial profiles of azimuthal velocity by Time Delay Estimation (TDE) and Laser Induced Fluorescence (LIF) show a reduced peak flow and weaker shear in the CBC



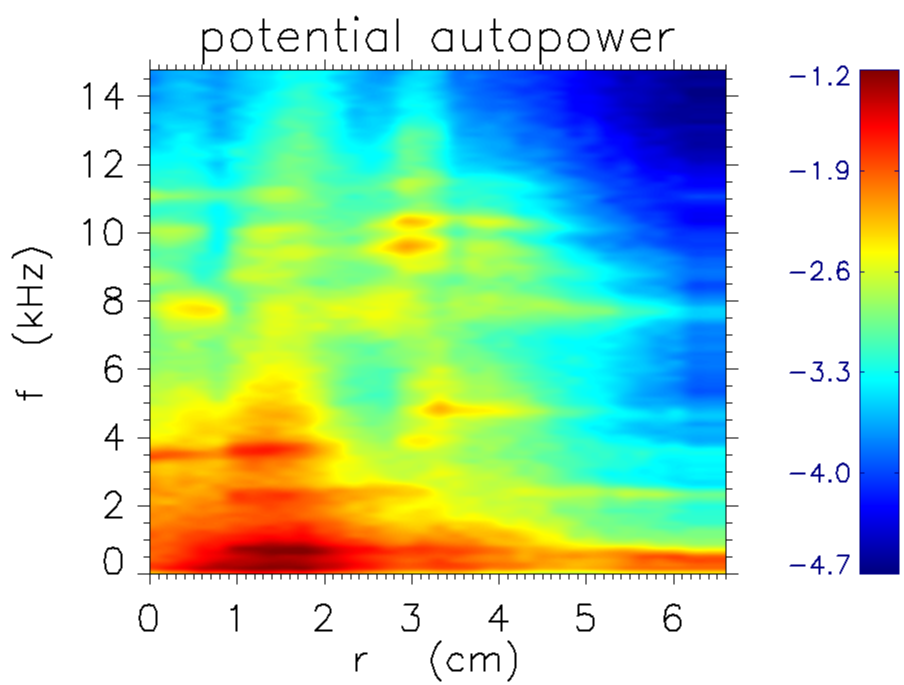
TDE



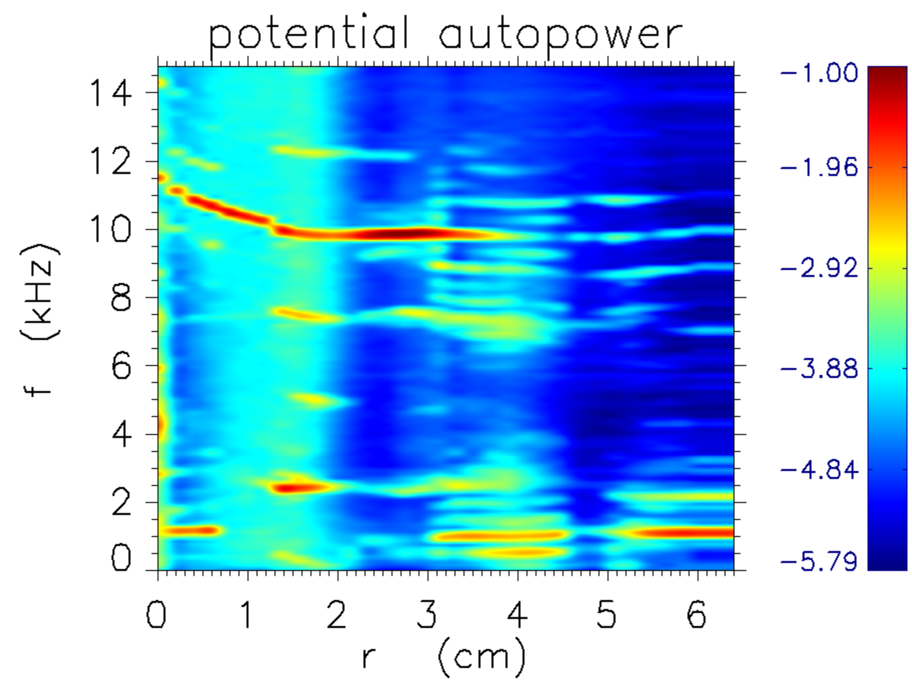
LIF

B = 1000 G; Power = 1.5 KWatts; Pressure = 3.2 mTorr

Radial profiles of potential fluctuations are also affected: No broadband turbulence or low frequency zonal flow in the CBC



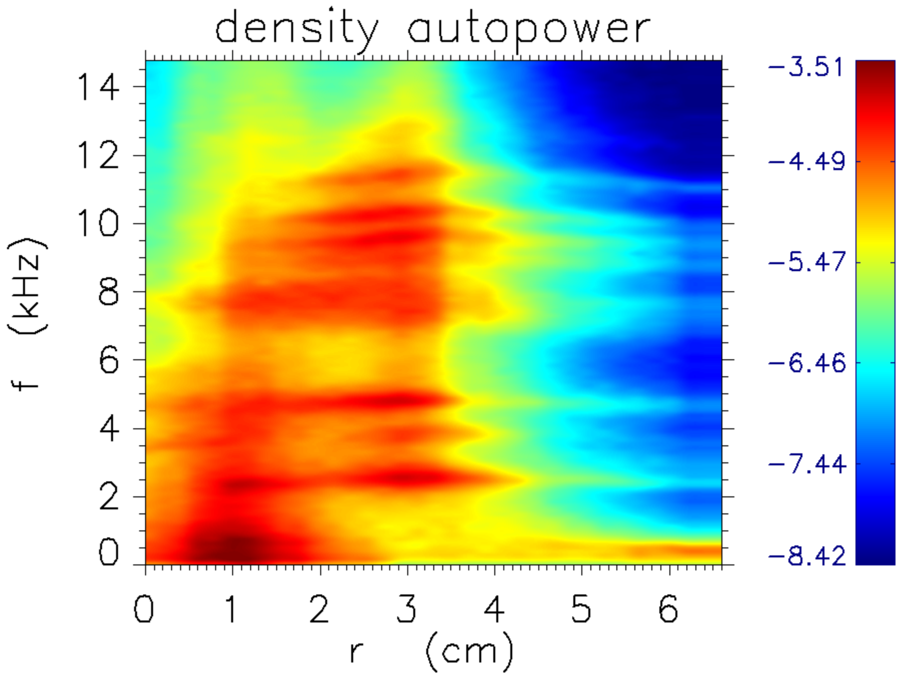
Insulating BC



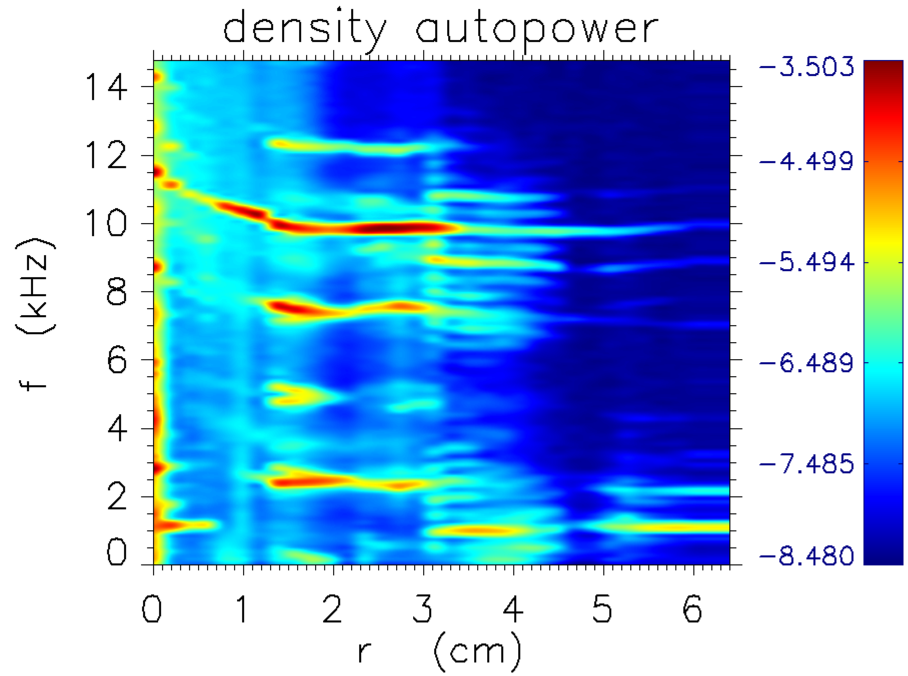
Conducting BC

B = 1000 G; Power = 1.5 KWatts; Pressure = 3.2 mTorr

Radial profiles of density fluctuations are also different: No broadband turbulence or low frequency zonal flow in the CBC



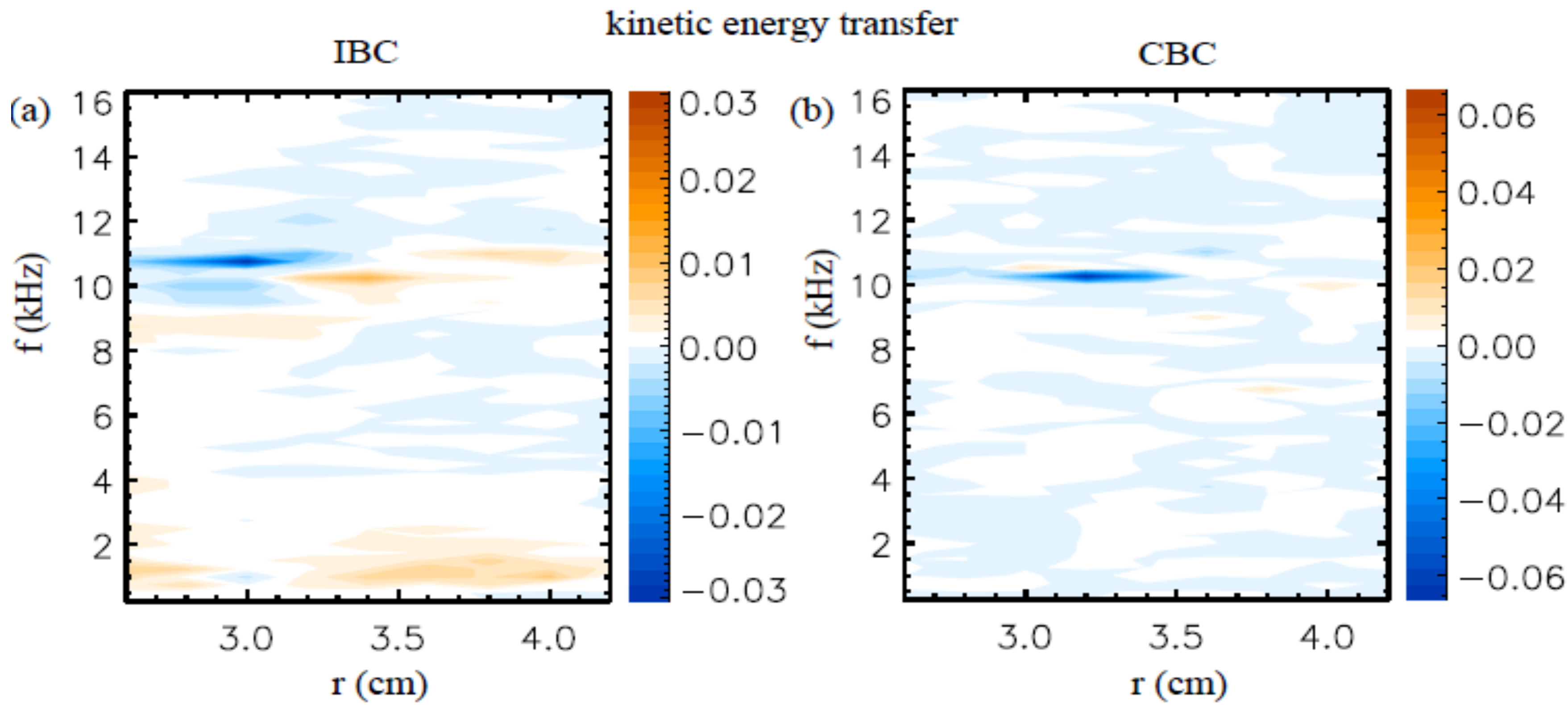
Insulating BC



Conducting BC

B = 1000 G; Power = 1.5 KWatts; Pressure = 3.2 mTorr

Kinetic energy transfer shows the inverse cascade for the IBC, but is absent for the CBC and prevents broadband turbulence



B = 1000 G; Power = 1.5 KWatts; Pressure = 3.2 mTorr

J. S. Kim *et. al.*, Phys. Plasmas 3 3998 (1996)

Results from 2-D Scrape Off Layer Turbulence (SOLT) simulations

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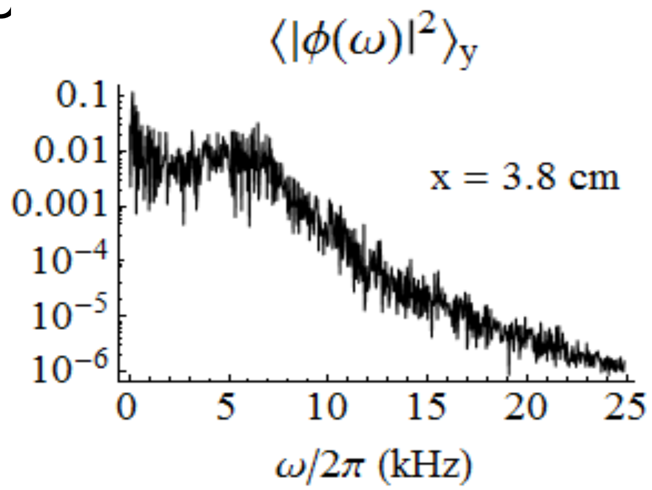
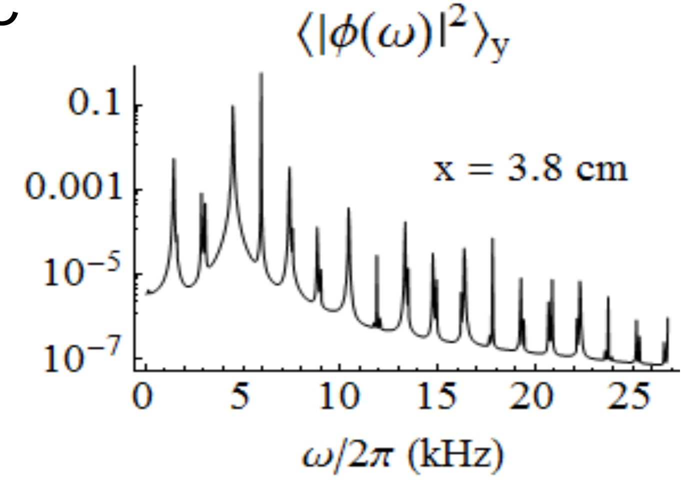
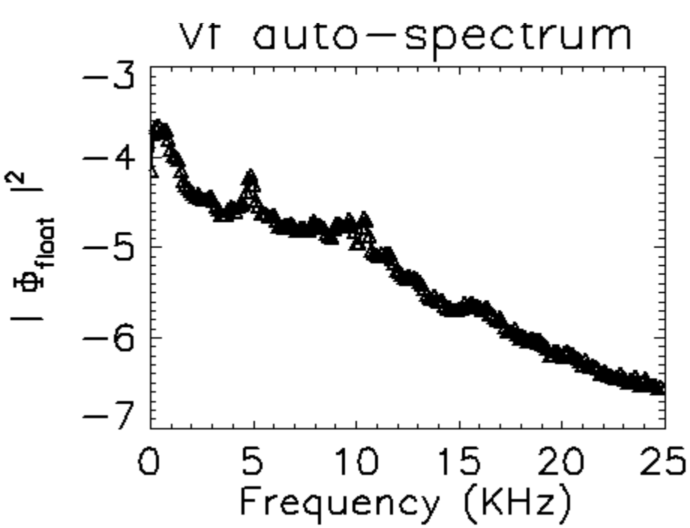
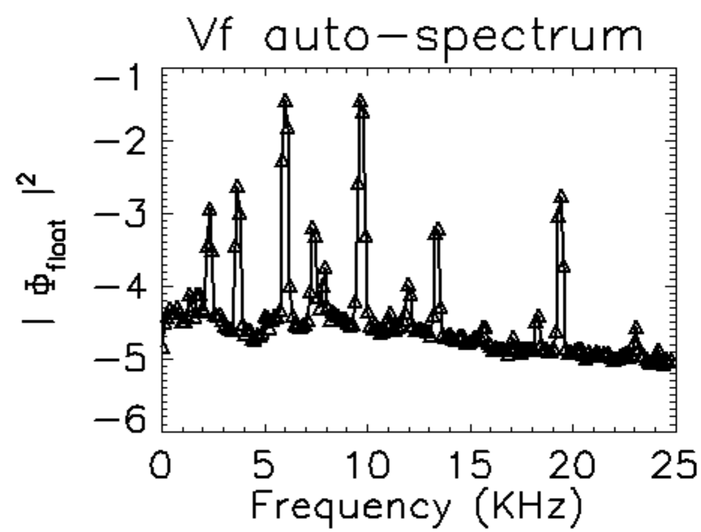
IBC



CBC

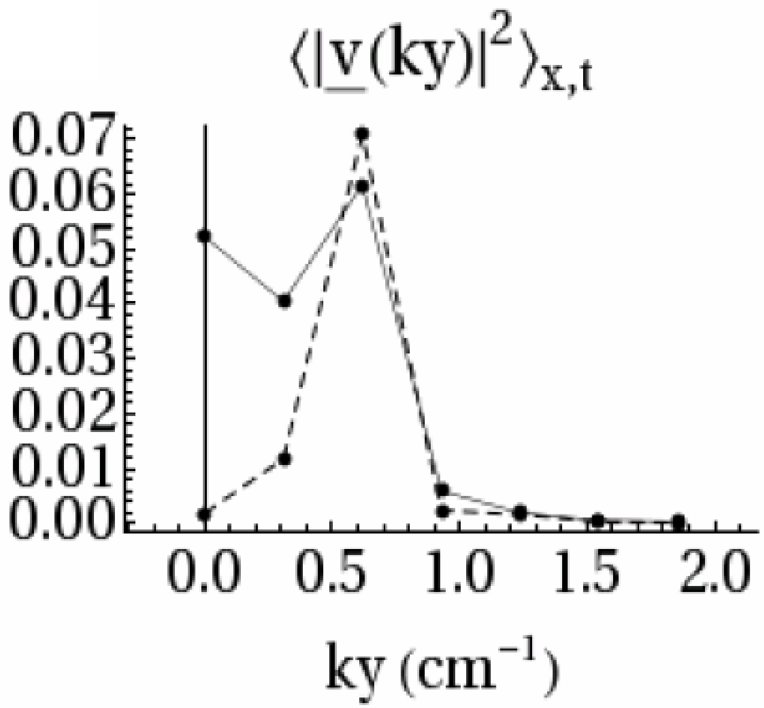




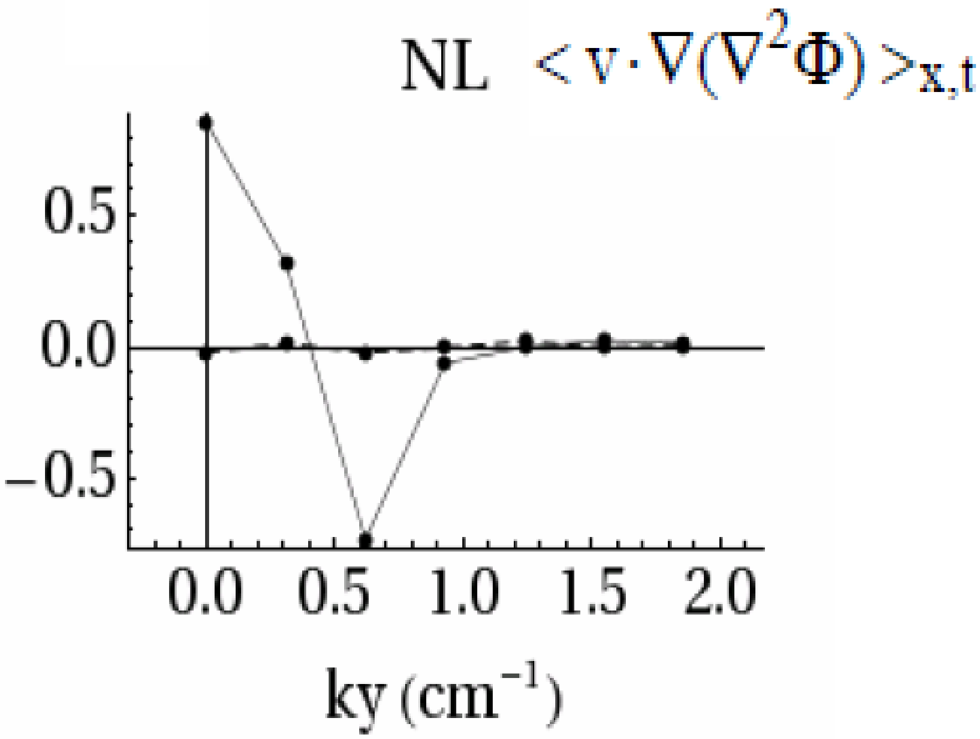


Results from 2-D SOLT simulations also show the transfer of energy to low k values in IBC, but absent in CBC

Total kinetic energy



Nonlinear term



Summary of experimental and simulation results

– IBC is characterized by broadband turbulence and inverse energy transfer to low frequency ($f = 0$) and larger spatial scales (low k), thereby driving shear flows

– CBC is dominated by coherent modes and presence of sheath dissipation diminishes inverse energy transfer

– Peak azimuthal flows are reduced and weaker shear flow (CBC)

– Reduced Reynolds Stress in the CBC

Summary: Take home points

1. The current through the sheaths can reduce the net radial polarization current (effective RS) which decreases the nonlinear coupling between modes thus hindering formation of broadband turbulence and zonal flows.

2. End boundary conditions in a linear plasma device can be a used a tool to study drift wave zonal flow interactions.

Thank You