DEPENDENCE OF TURBULENCE AND TRANSPORT ON THE TOROIDAL MACH NUMBER

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SAN DIEGO, CALIFORNIA
APRIL 18, 2007

THE UNIVERSITY of WISCONSIN MADISON

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

OVERVIEW AND MOTIVATION

- **Examine the dependence of turbulence and transport on toroidal rotation *and* rotational shear by varying torodial Mach Number while maintaining other dimensionless parameters nearly constant:**

$$\mathbf{M = v_{TOR}/(c_s)\ (0.2 < M < 0.45)}$$

  - L-mode and H-mode plasmas examined

- **Obtained comprehensive fluctuation data set:**
  - 2D turbulence measurements obtained over radial profile ($0.4 < r/a < 1.0$)
  - BES measured $\tilde{n}/n$, v_θ, $L_{c,r}$, $L_{c,\theta}$, τ_c (focus of this discussion)
  - FIR, Doppler Refl., PCI, Langmuir probes, high-k backscattering
  - L-mode and H-mode (focus here is L-mode)

- **Provide turbulence & transport data set for comparison with 3D simulations**
  - Contribute to V&V process, discussed this morning
  - C. Holland poster, this meeting

- **Preview:**
  - Not a large variation in turbulence parameters in L-mode
  - Subtle effects in correlation properties

Dimensionless Parameters Well-Matched for Mach Number Scan

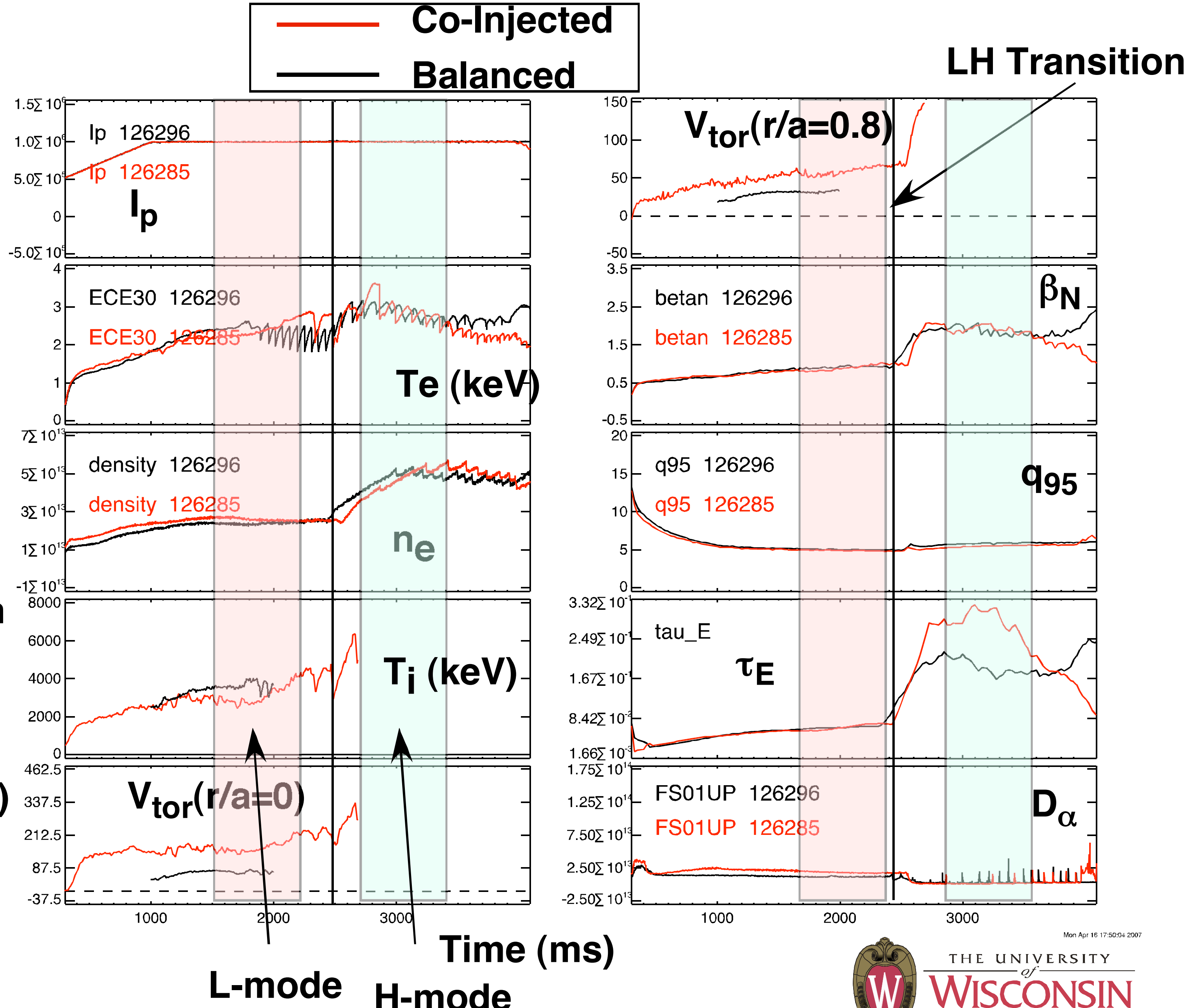
I_p = 1.0 MA

B_T = 2.0 T

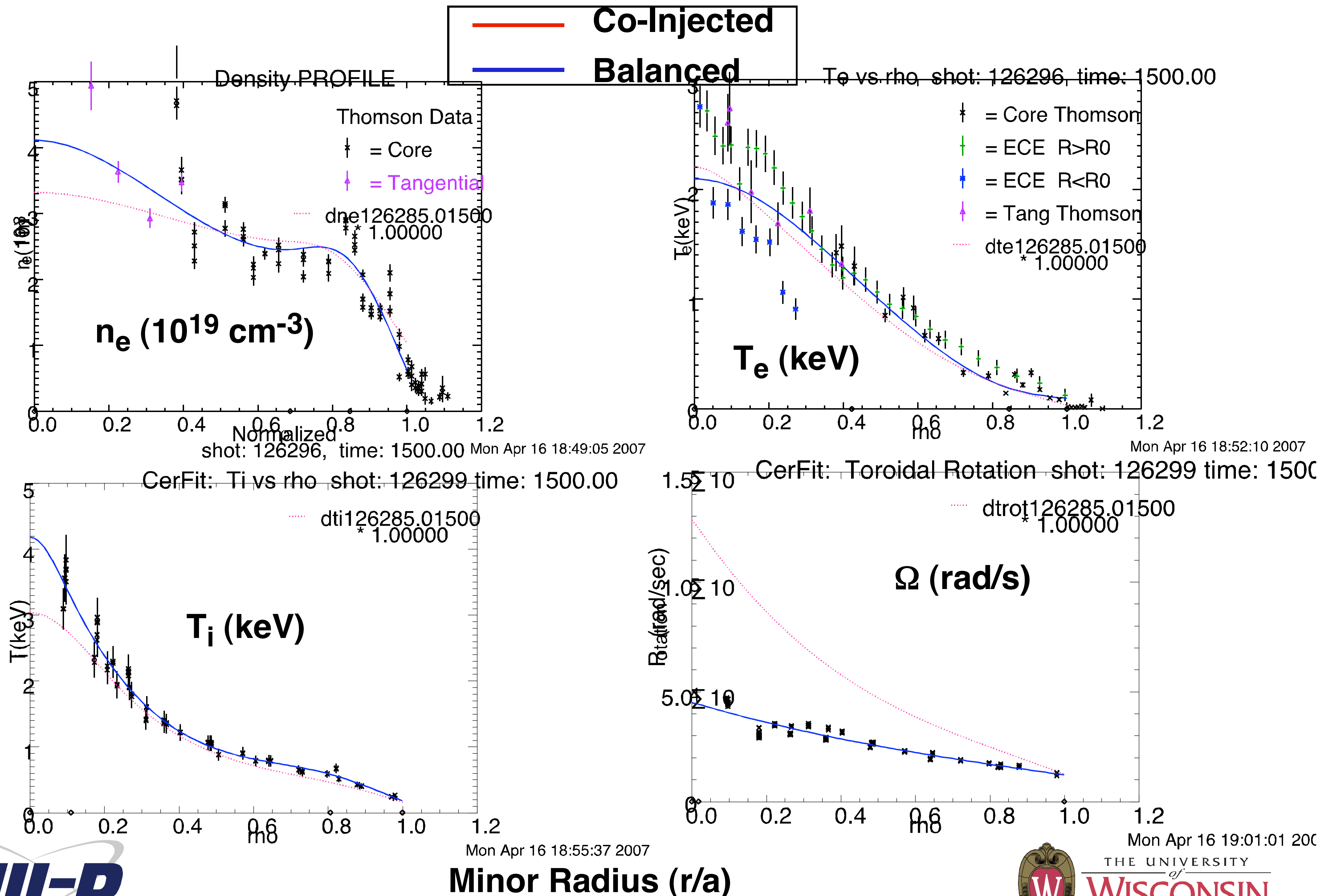
L-mode: 1.5-2.5 s

H-mode: 2.7-4.0 s

- Significant complications with LH transitions at low power (see talk by Schlossberg (McKee) tomorrow)



Profiles Reasonably Well-Matched for Mach Number Scan



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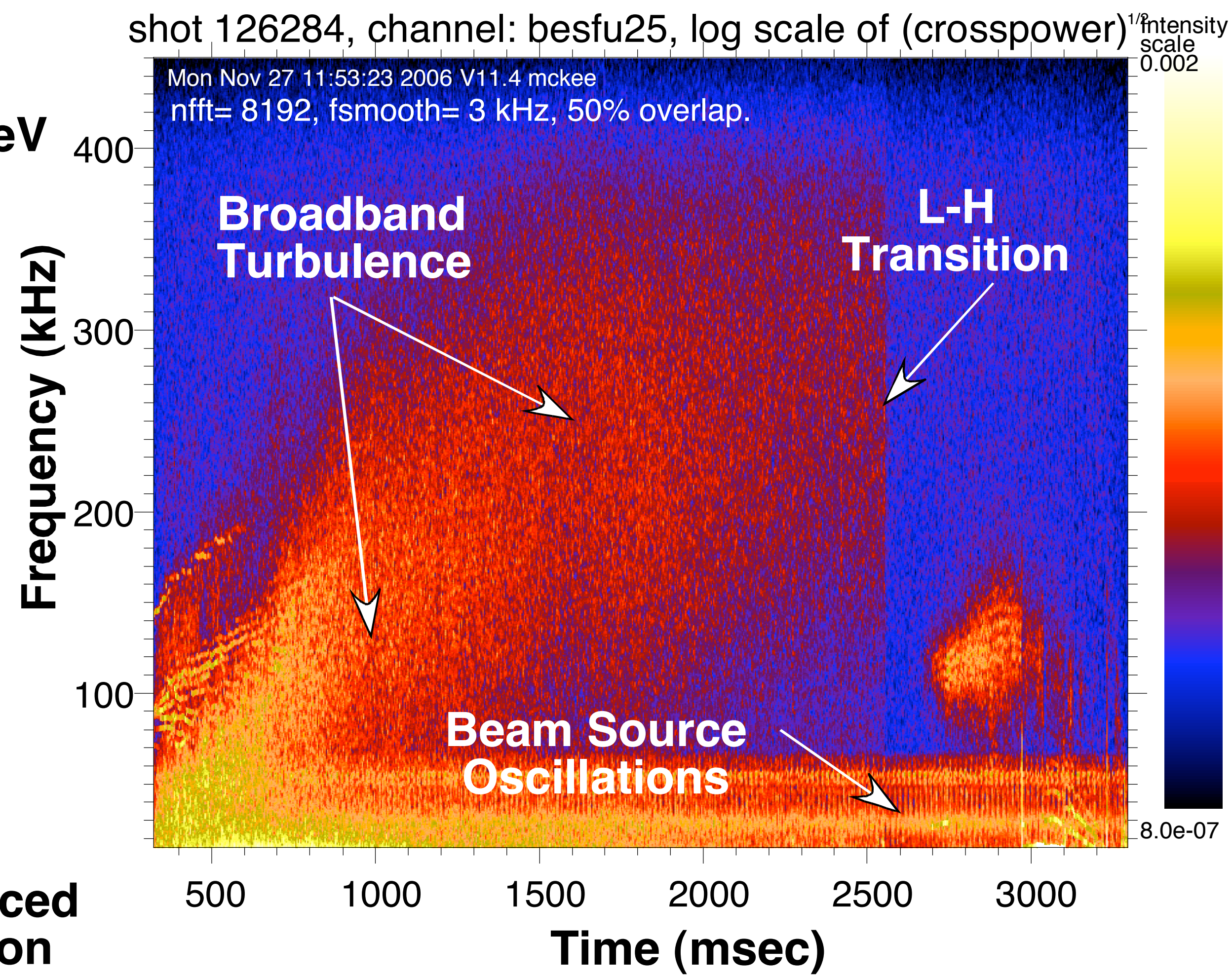
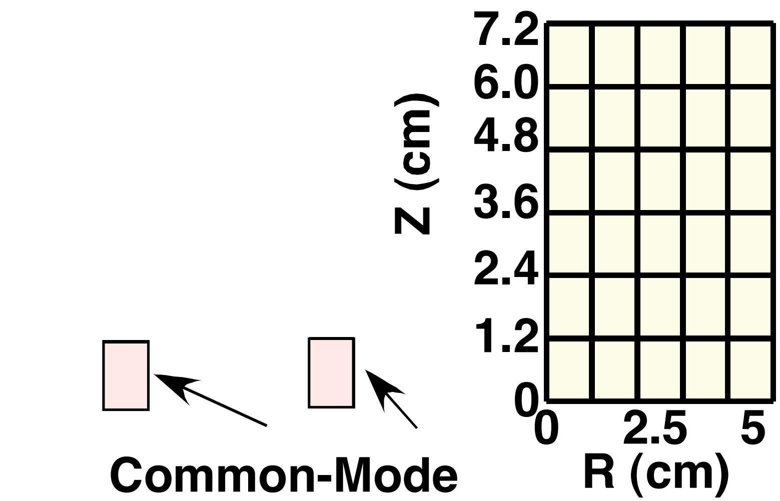
Fluctuation Spectrum Evolves Dynamically Throughout Discharge

- Measurements obtained in L-mode Discharges:
  I_p=1 MA, B_T = -2.0 T
  P_{inj} = 5 MW,
  $n_{e,o}=3\times10^{19}\ m^{-3}$, Te,o=2.2 keV
  $T_{i,o}$=2.7 keV
- Beam source oscillations arise from current or voltage noise in neutral beam source, small amplitude:
  $\tilde{n}_{BEAM}/n < 1\%$
- Common-mode rejection procedures can isolate and subtract
- Fluctuations markedly reduced in core region at LH transition

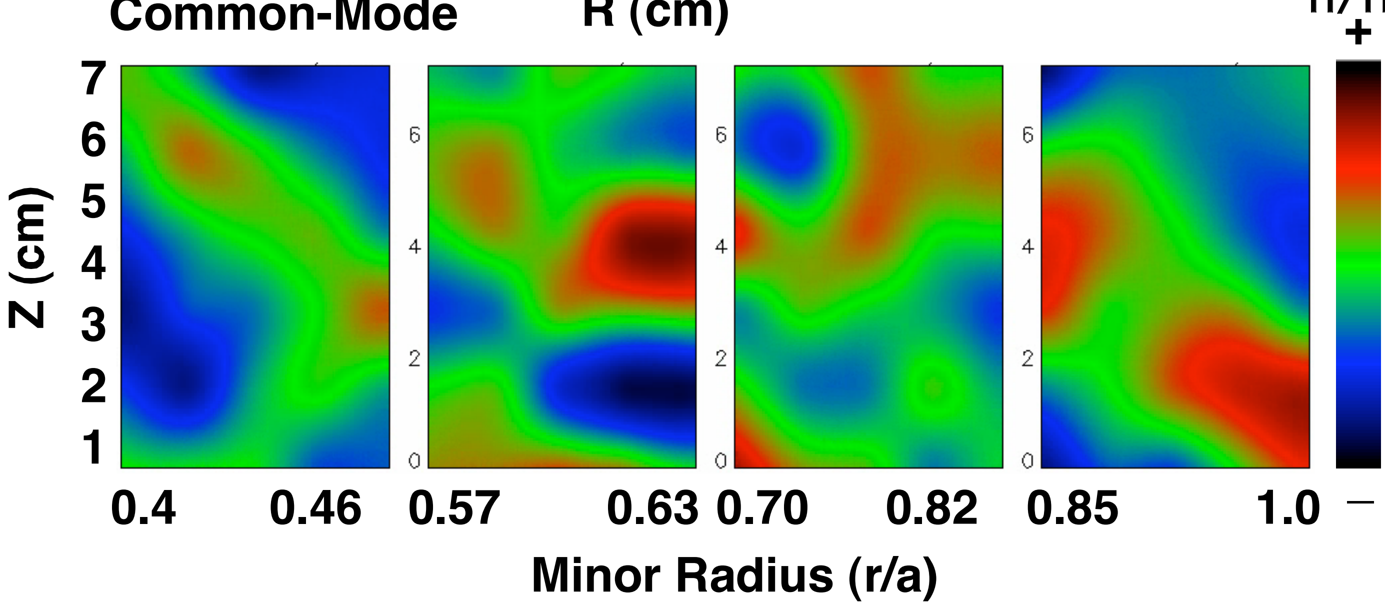
Cross-Power Spectrum at r/a=0.64 (ΔZ=1.2 cm)

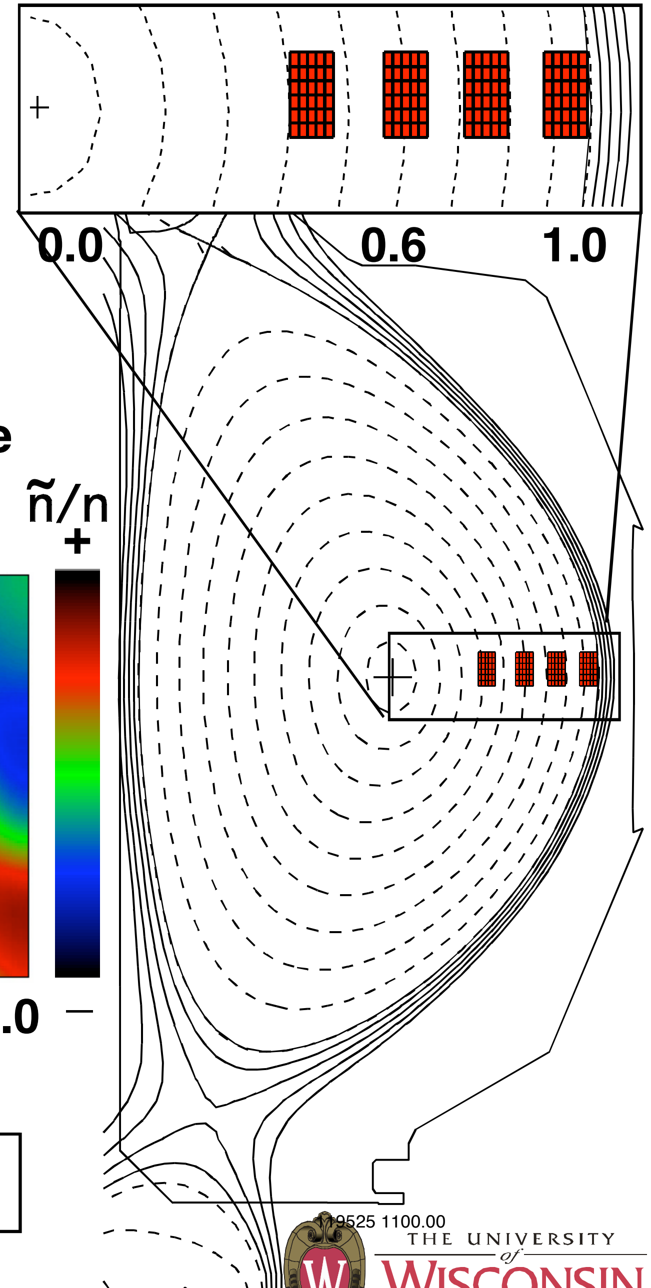


2D Measurements of Core Plasma Turbulence Obtained with High-Sensitivity BES System Across Minor Radius



- 1 MHz sampling
- $k_{\perp}\rho_{I} < 2.5\ cm^{-1}$
- 2 common-mode channels

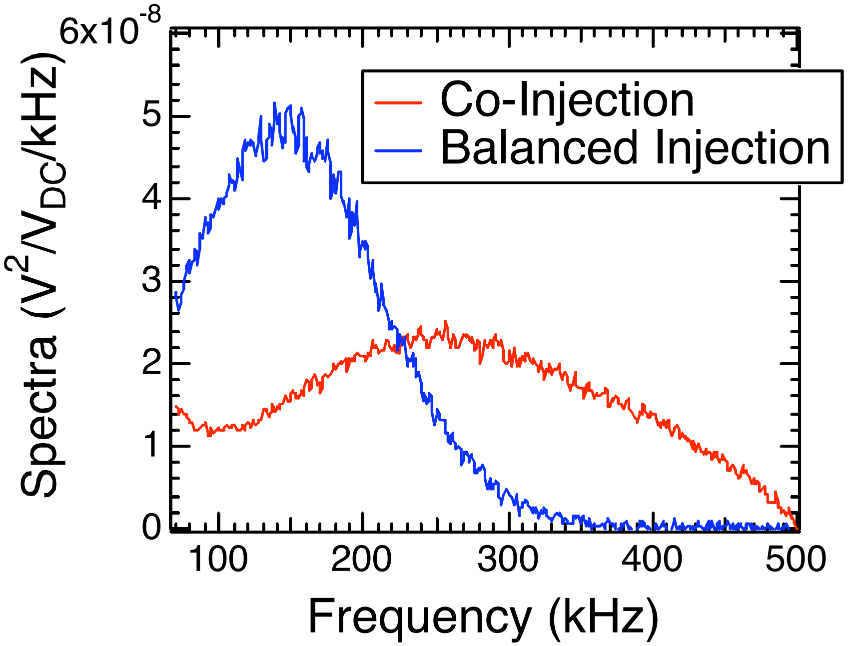




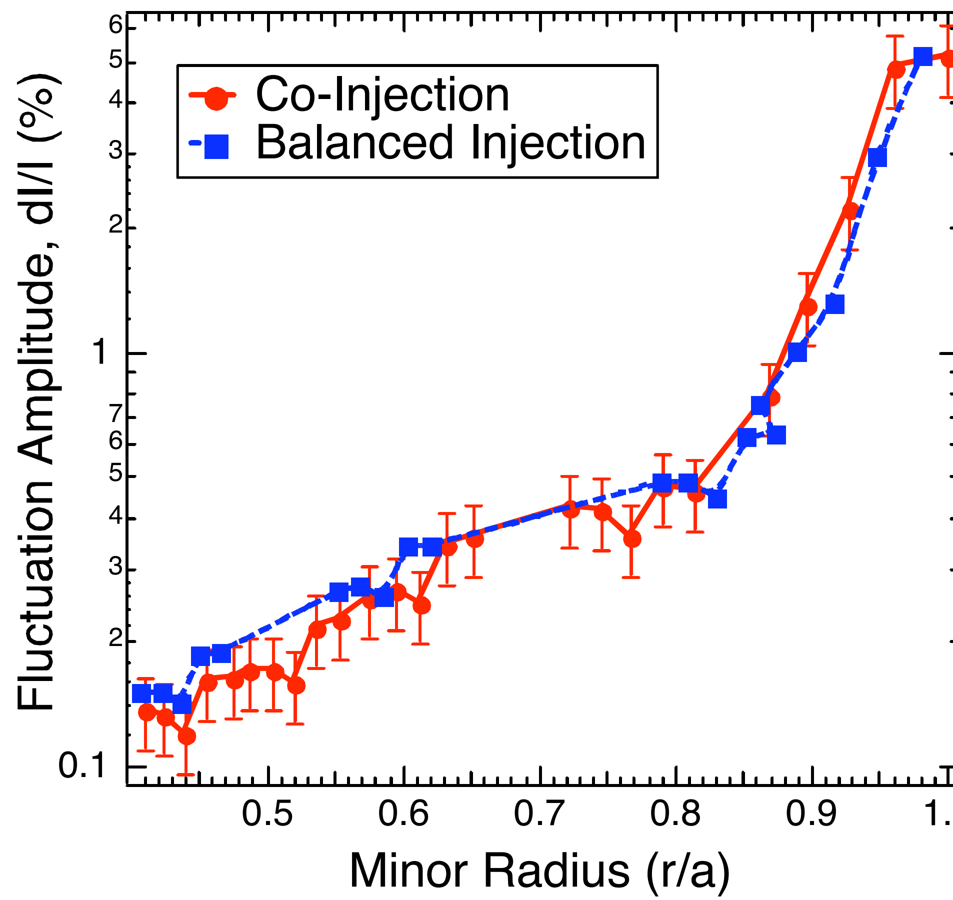
ñ/n	0.4%	0.7%	0.9%	2-10%

Rotation Affects Frequency Spectra, but has Little or No Effect on Fluctuation Amplitude

Comparison of Density Fluctuation Spectra



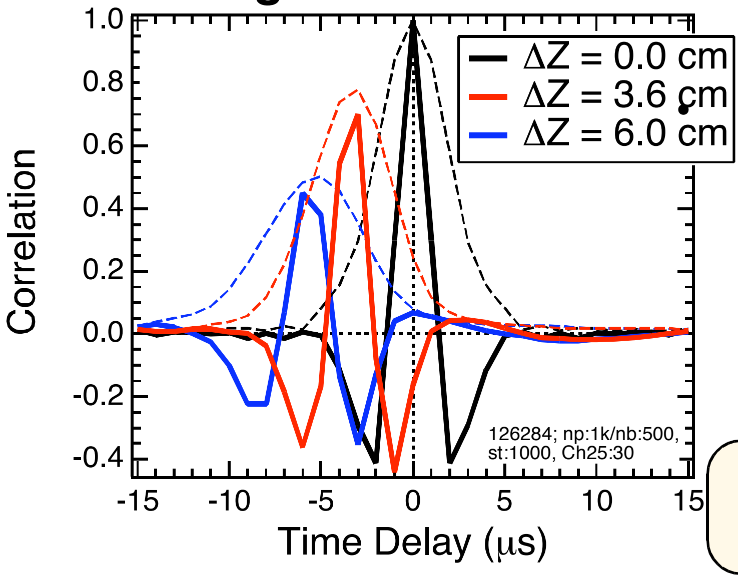
Integrated Fluctuation level (70 < f < 400 kHz) virtually unchanged with *M*



- **Nearly identical amplitudes, but edge characteristics differ**

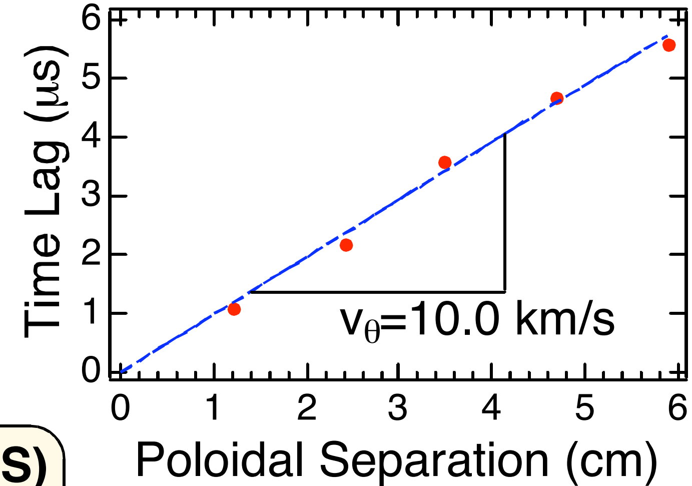
Turbulence Advects Poloidally at the Local ExB Velocity

Time-Lag Cross Correlation

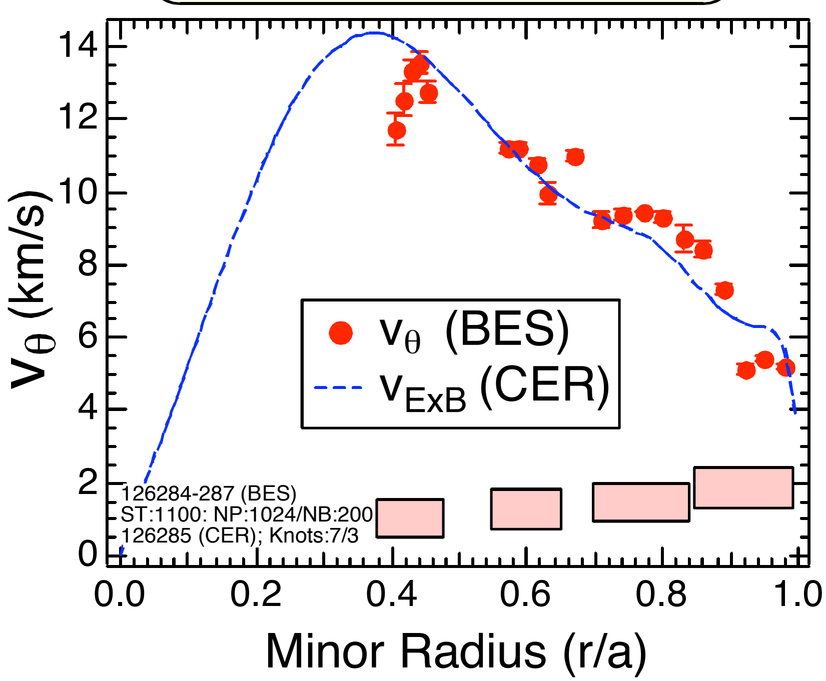


Turbulence Velocity determined from poloidal cross-correlation time-lag analysis from BES

Poloidal Velocity Measurement



Comparison of v_θ (BES) and ExB (from CER)



No indication of dominant flow direction relative to ExB (e.g., ion vs. electron diamagnetic)

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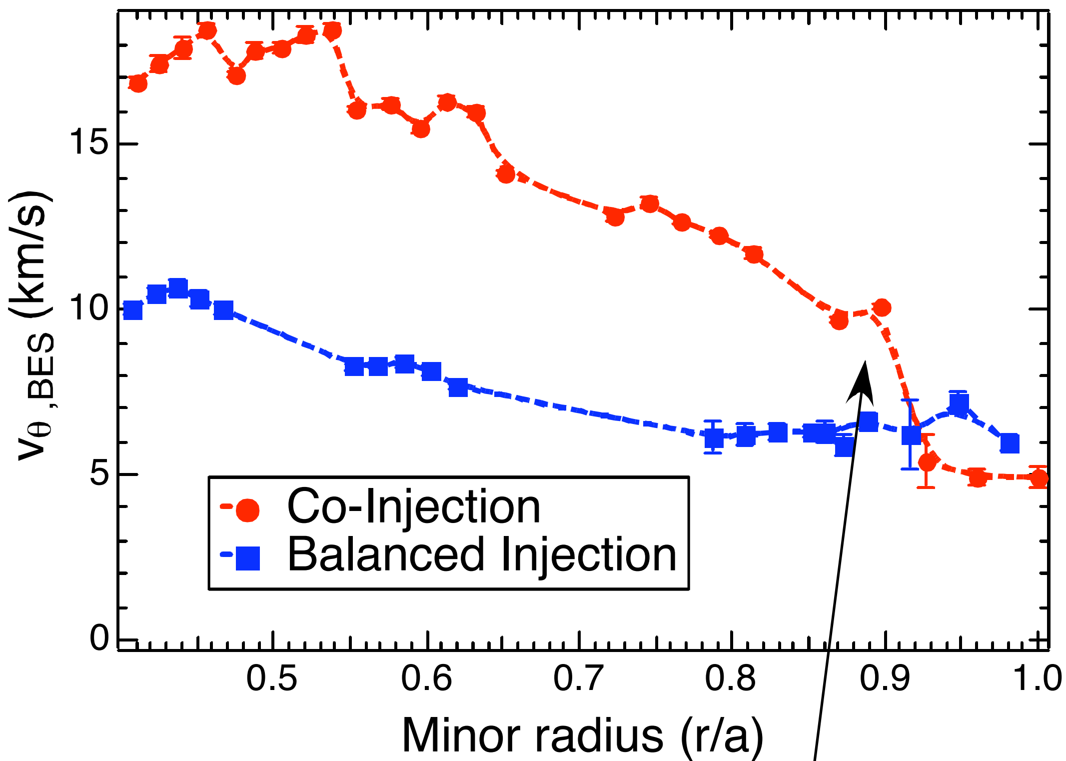
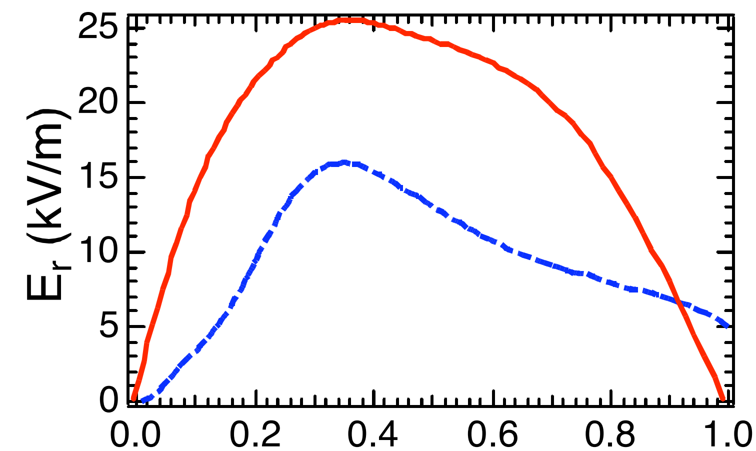
Radial Electric Field, Shearing Rate and Turbulence Velocity Vary Significantly with Toroidal Mach Number

Comparison of Turbulence Advection Velocity Profile (from BES)

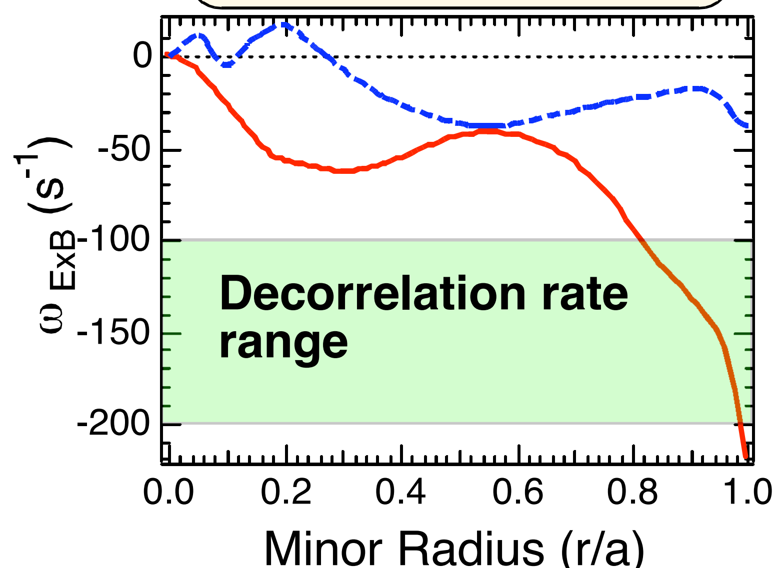


Large local shear in v_θ profile
$(d(v_\theta)/dr \sim 5\times10^5\ s^{-1})$

Radial Electric Field



ExB Shearing Rate



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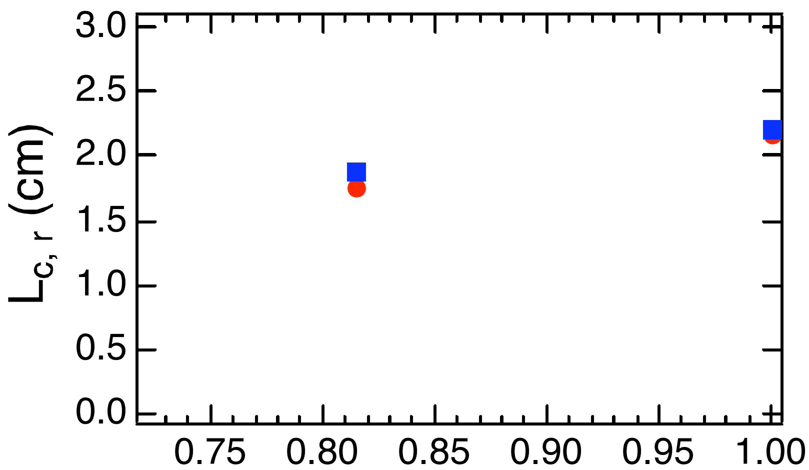
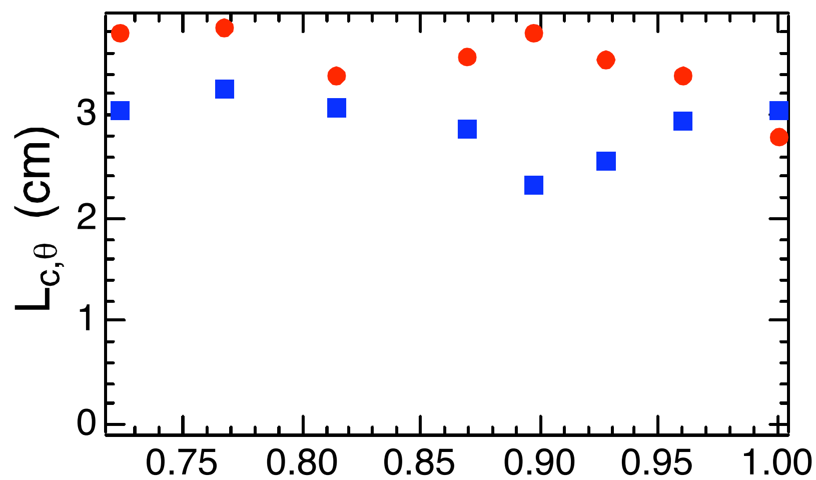
CORRELATION PARAMETERS SHOW MODEST DEPENDENCE ON ROTATION/ROTATIONAL SHEAR

Radial Correlation Length



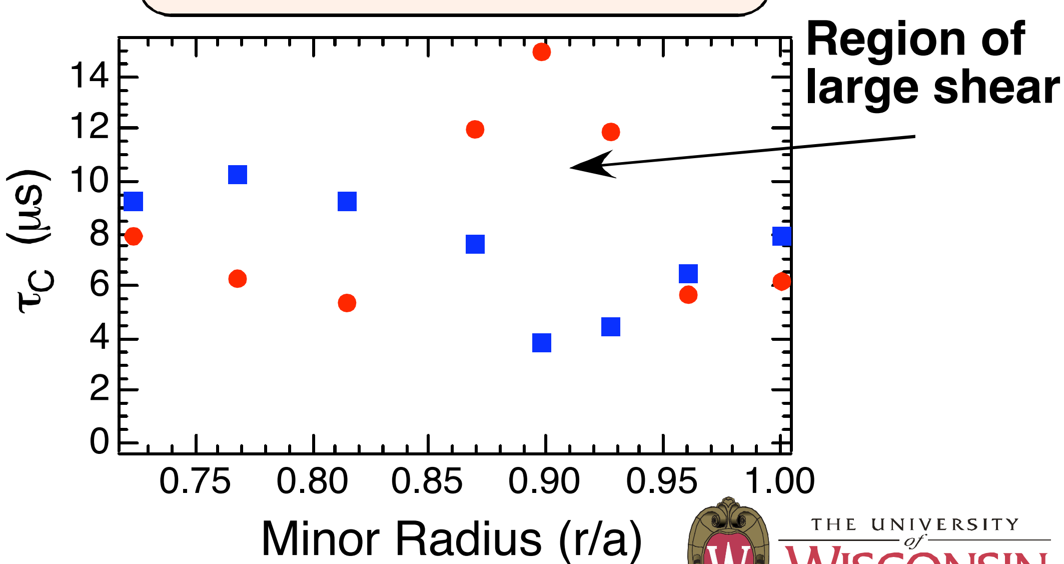
Poloidal Correlation Length



- $L_{c,\theta} > L_{c,r}$
- $L_{c,\theta}$(Co-Inj) > $L_{c,\theta}$(Balanced)
- Super-simple assessment of decorrelation rate:

  $1/\tau_c \approx \gamma \approx \gamma_{lin} - \gamma_{ExB}$

Decorrelation Time



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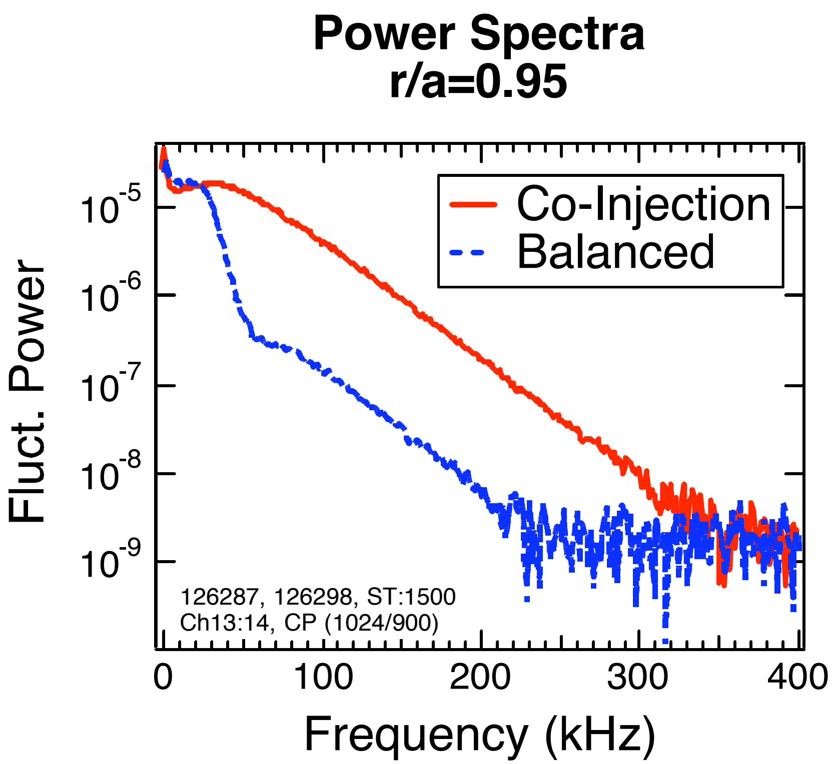
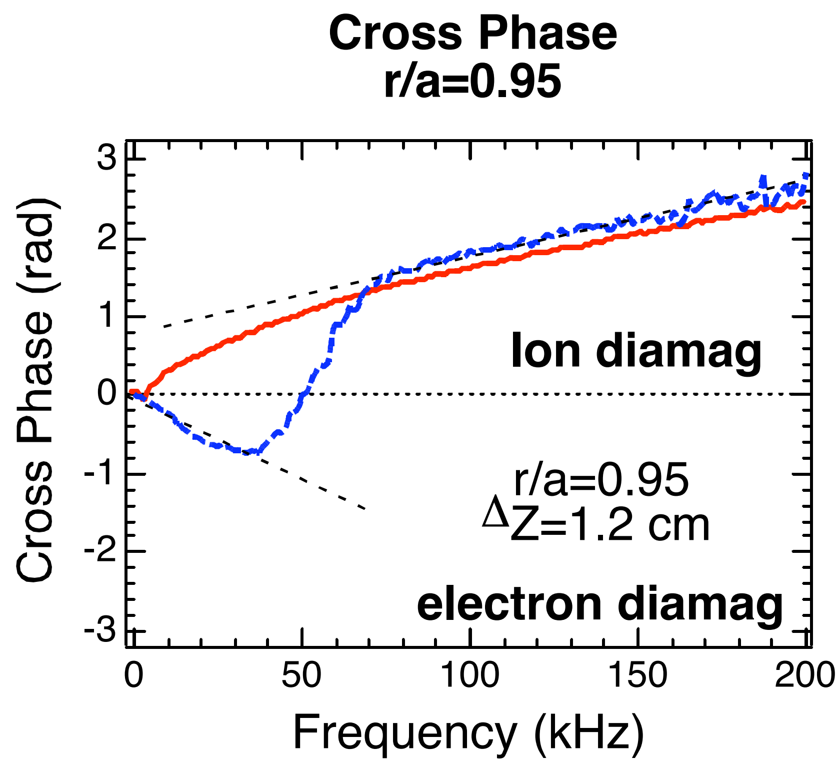
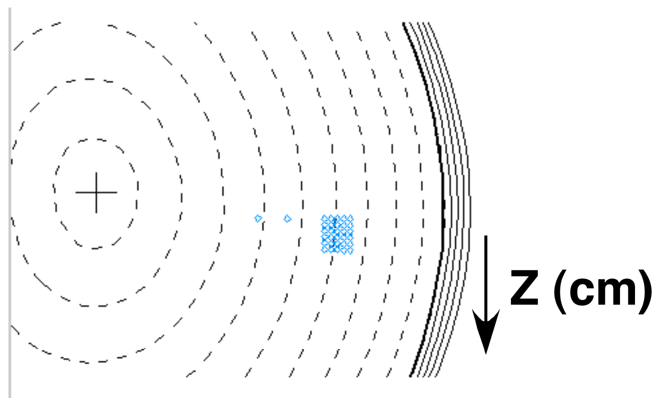
Balanced-Injection Discharges Exhibit Significant Dispersion in Edge Fluctuations: Not observed in Co-Injection

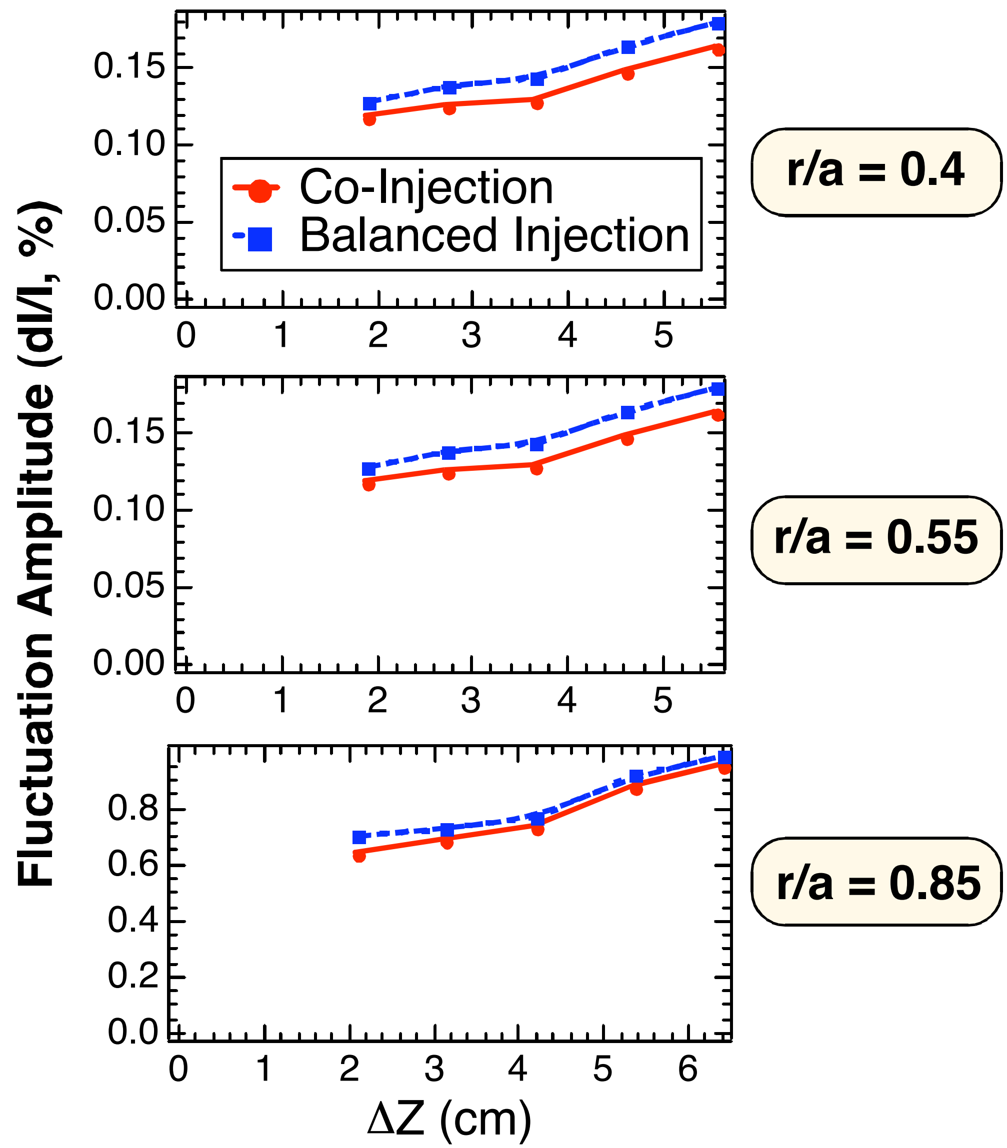




- Dual-mode behavior in Balanced-injection discharge in edge region (r/a~0.95)
- Counter-propagating low-frequency mode (electron diamagnetic direction)
- How does this affect transport?

Fluctuation Amplitude Increases with Poloidal (Z) Position



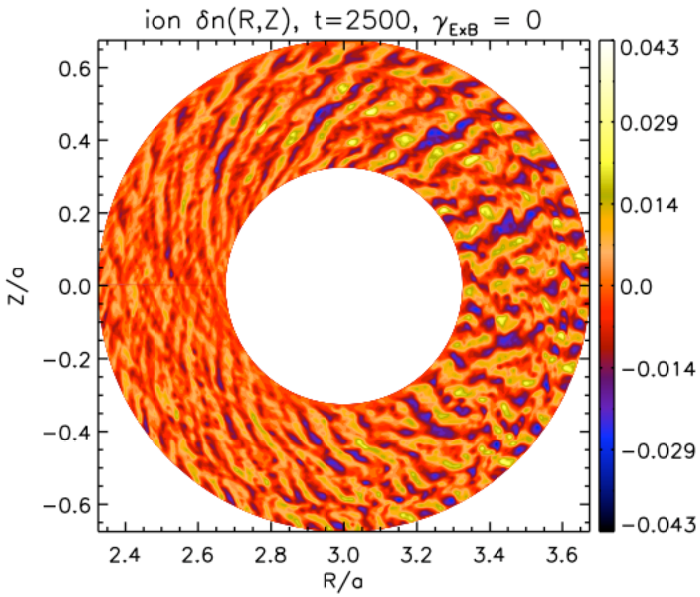


Stronger Turbulence

- $\Delta Z_{BES} << L_{Plasma}$
- **Suggests peak fluctuation amplitude is "rotated" away from outboard mid-plane**

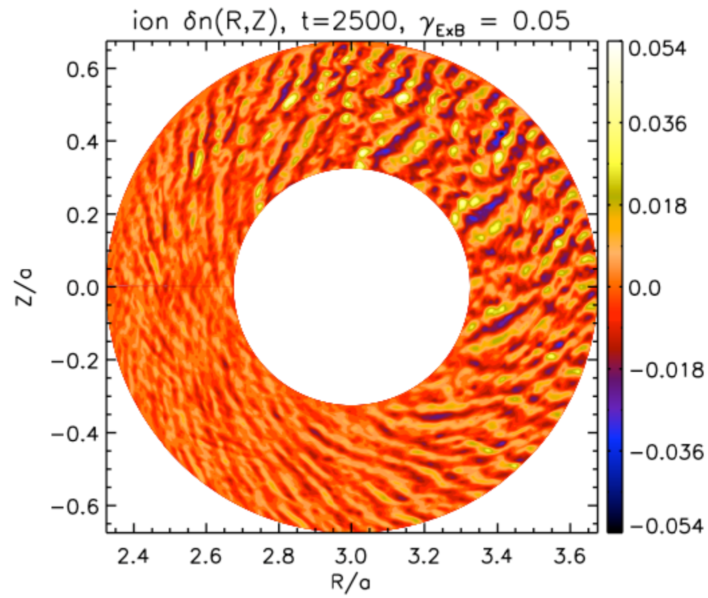
GYRO Simulations Show Effect of Rotation and Rotational Shear on Turbulence

No Shear
$\gamma_{ExB} = 0$



Fluctuation structure peaks at outboard midplane "Ballooning-like"

Shear
$\gamma_{ExB} = 0.05\ (c_s/a)$



Center of fluctuation structure peaks at finite θ

- **Measurements and simulations suggest off mid-plane peaking of density fluctuation amplitude in direction of equilibrium poloidal ExB flow**

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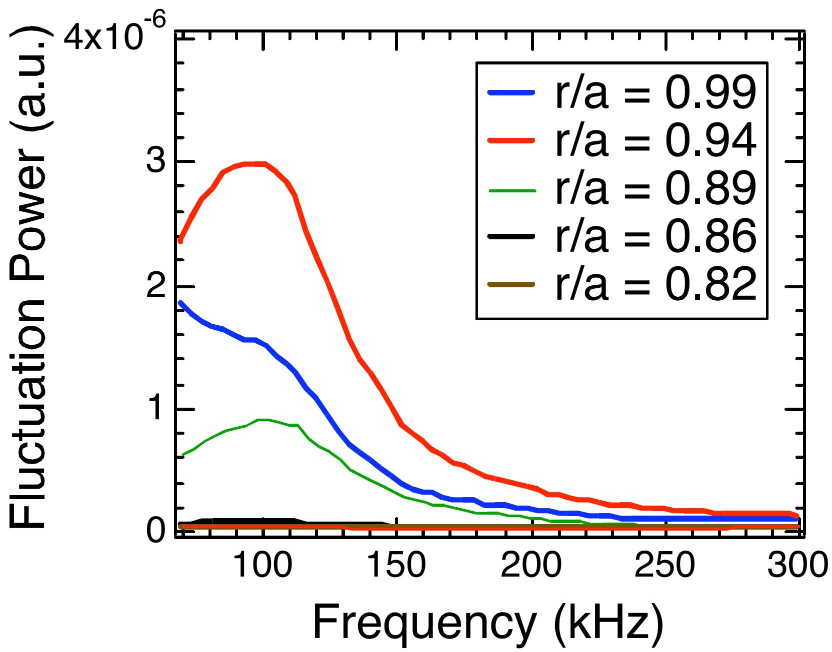
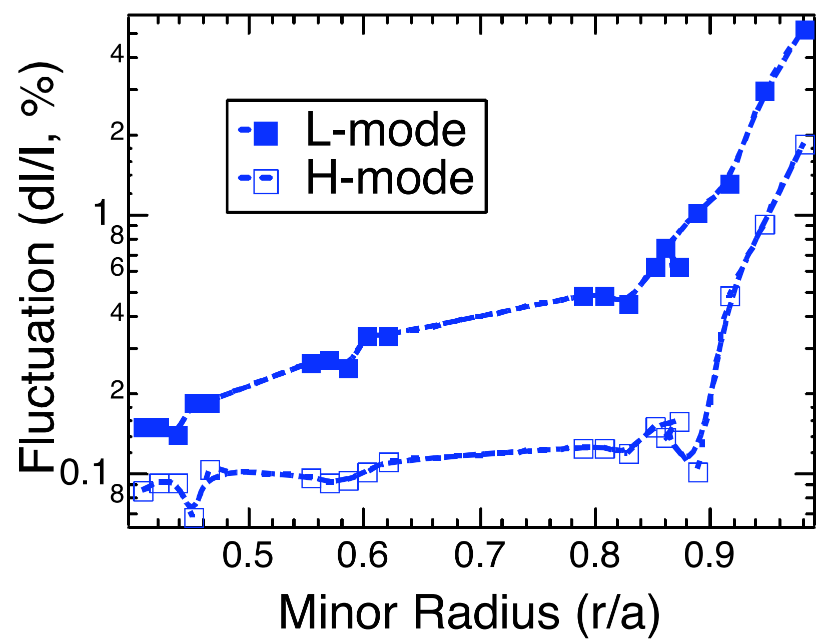
Core H-Mode Fluctuations Significantly Reduced from Those in L-Mode

Large Edge/Pedestal Fluctuations in *Co-Injection Discharges Only*



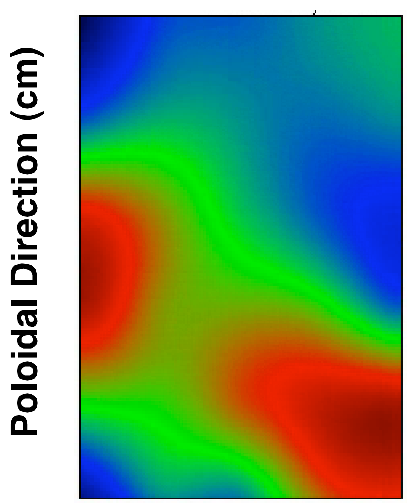
Comparison of L-mode and H-mode Fluctuation Profile Balanced Injection (70 < f < 400 kHz)



- **Large edge fluctuations imprinted on beam: can't isolate other local core fluctuations in H-mod**

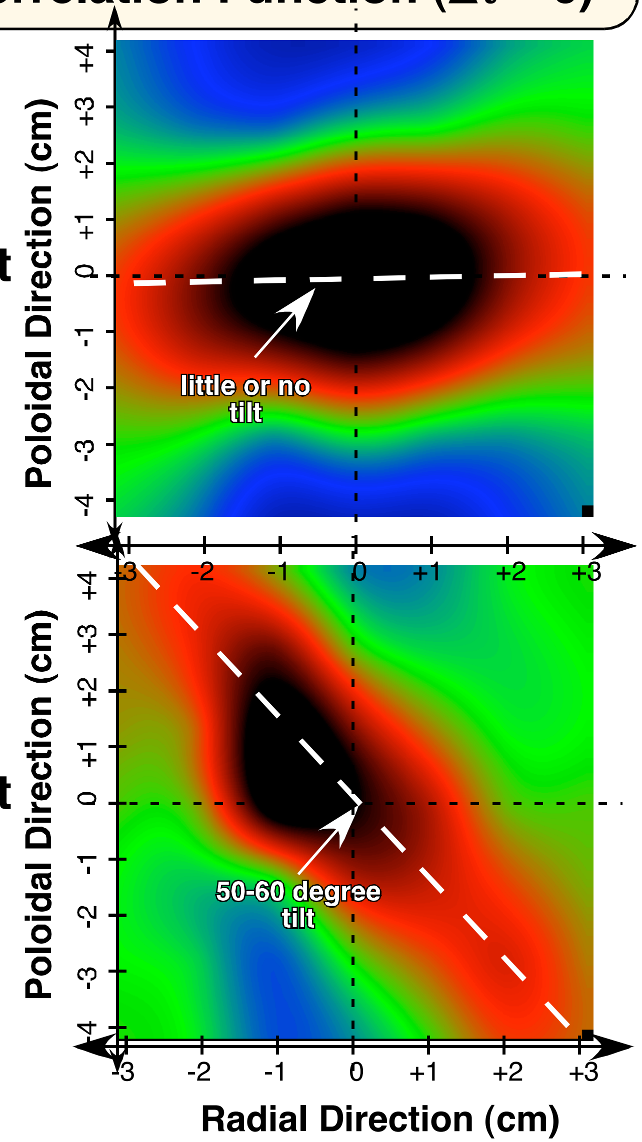
Turbulent Eddy Structures Differ in L & H-mode: Elliptical in L-mode vs. Tilted in H-mode

2D Spatial Correlation Function ($\Delta\tau = 0$)



Low-Confinement Mode

High-Confinement Mode



Eddy structures show dramatic differences between L-mode and H-mode: effects of poloidal flow shear?

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Summary & Future Directions

- **Turbulence characteristics investigated as a function of toroidal Mach #**
  - *Dimensionless scaling study*
  - *Examine effects of varying ExB shear on turbulence*
  - *L-mode and H-mode examined*
  - *Balanced injection plasmas resulted in co-rotating plasmas*
  - *Data set for V&V study*
- **Little change in τ_E with *M* in L-mode**
- **No measurable change in fluctuation amplitude profile**
  - *Poloidal (ExB) velocity varied significantly (~50%)*
  - *Increased poloidal correlation lengths at high rotation*
  - *No measurable change in radial correlation length*
  - *Reduced decorrelation rates in high shear zone (r/a~0.9)*
- **Increase in turbulence amplitude with distance from plasma midplane**
  - *qualitatively consistent with rotation of turbulence ballooning structure (GYRO)*
- **Significant increase in τ_E with *M* in H-mode (~30%)**
  - *Fluctuations amplitude several times smaller than L-mode in Balanced plasma*
  - *Co-rotating plasmas have large fluctuation structure near pedestal*
  - *Eddy structure differs in L vs. H-mode*