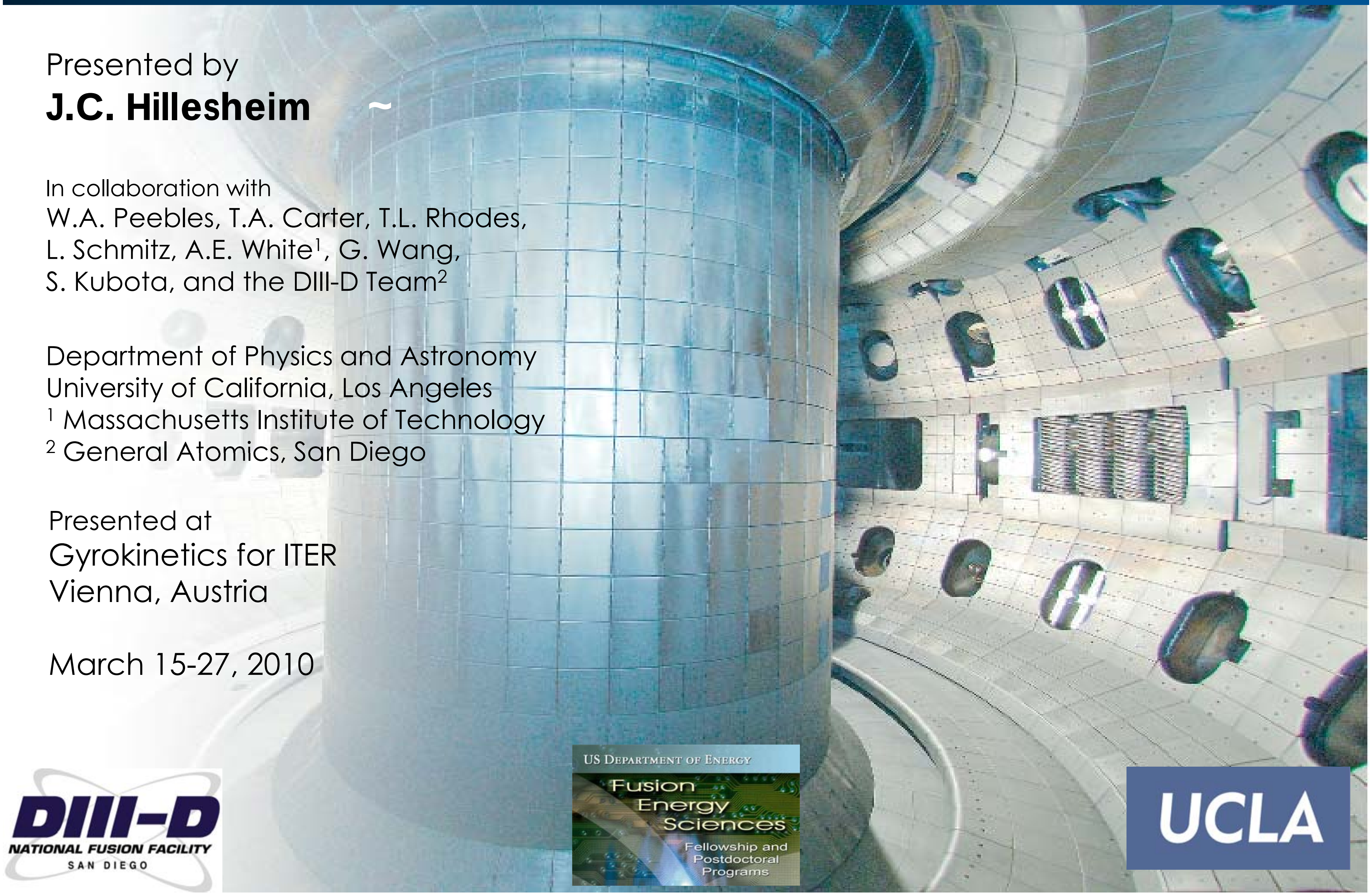
Developments in Millimeter-wave Tokamak Turbulence Measurements



Presented by

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In collaboration with

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US DEPARTMENT OF ENERGY Fusion Energy Sciences Fellowship and Postdoctoral Programs

UCLA

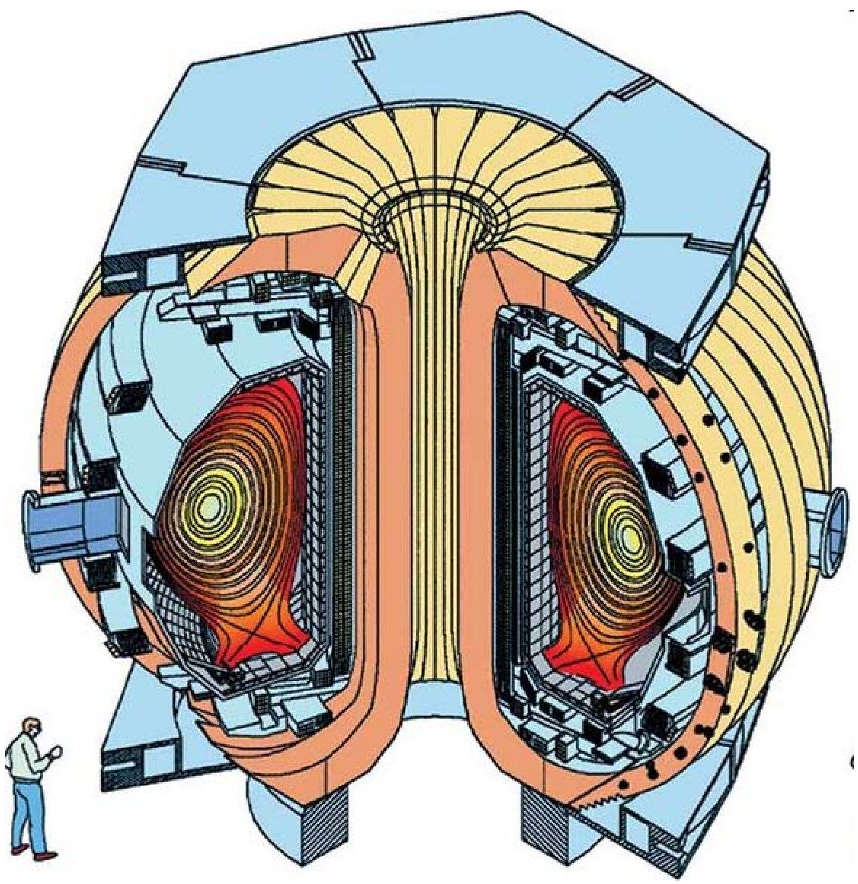
Summary

- **Multichannel Doppler backscattering diagnostics**
  - Fast time resolution, high spatial resolution measurements of intermediate-k density fluctuations and ExB flows

- **Coupled reflectometry-electron cyclotron emission diagnostic**
  - Measurements of the phase angle between low-k electron density and electron temperature fluctuations

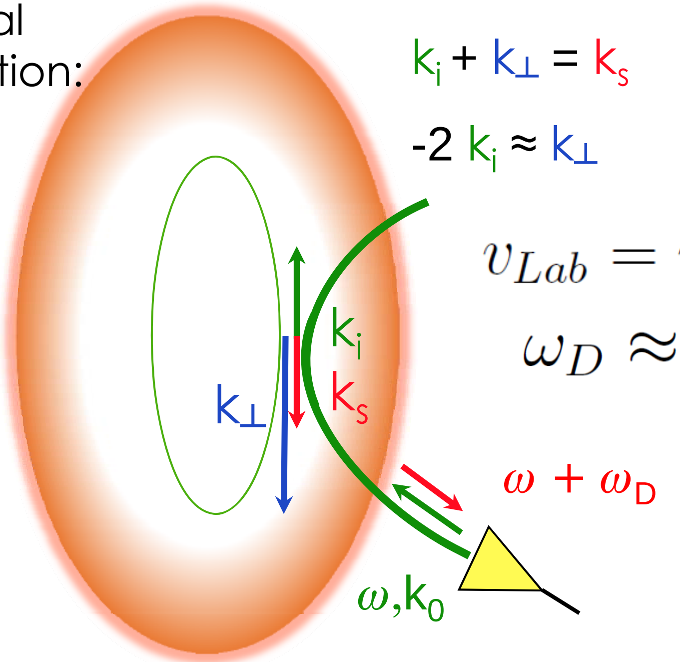
DIII-D Parameters

- **Typical DIII-D L-mode Parameters**
  - R~1.67 m
  - a~0.67 m
  - $B_T(0)$~2 T
  - Ip~1-2 MA
  - $T_e(0)$~2-3 keV
  - $n_e(0)$~5x10^{13} cm^{-3}



Principles of Doppler Backscattering

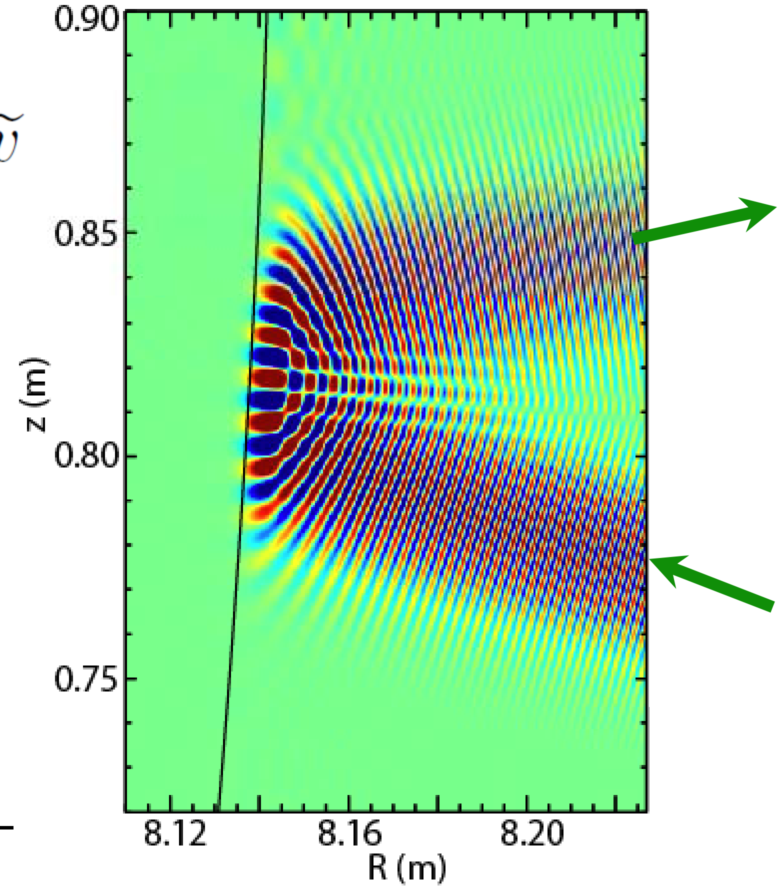
Poloidal Cross-section:



$$v_{Lab} = v_{E\times B} + \widetilde{v}$$

$$\omega_D \approx k_\perp v_{Lab}$$

Fullwave calculation focusing on scattering region:



- **DBS measures the *radially localized* propagation velocity and fluctuation level of intermediate-k turbulent structures**
  - Wavenumber range: $k_\perp \rho_i$ ~ 1-4, $k_\perp$ ~ 2-15 cm^{-1}
  - Radial spatial resolution: Δr < 1 cm
  - Wavenumber resolution: $\Delta k_\perp / k_\perp \leq 0.4$

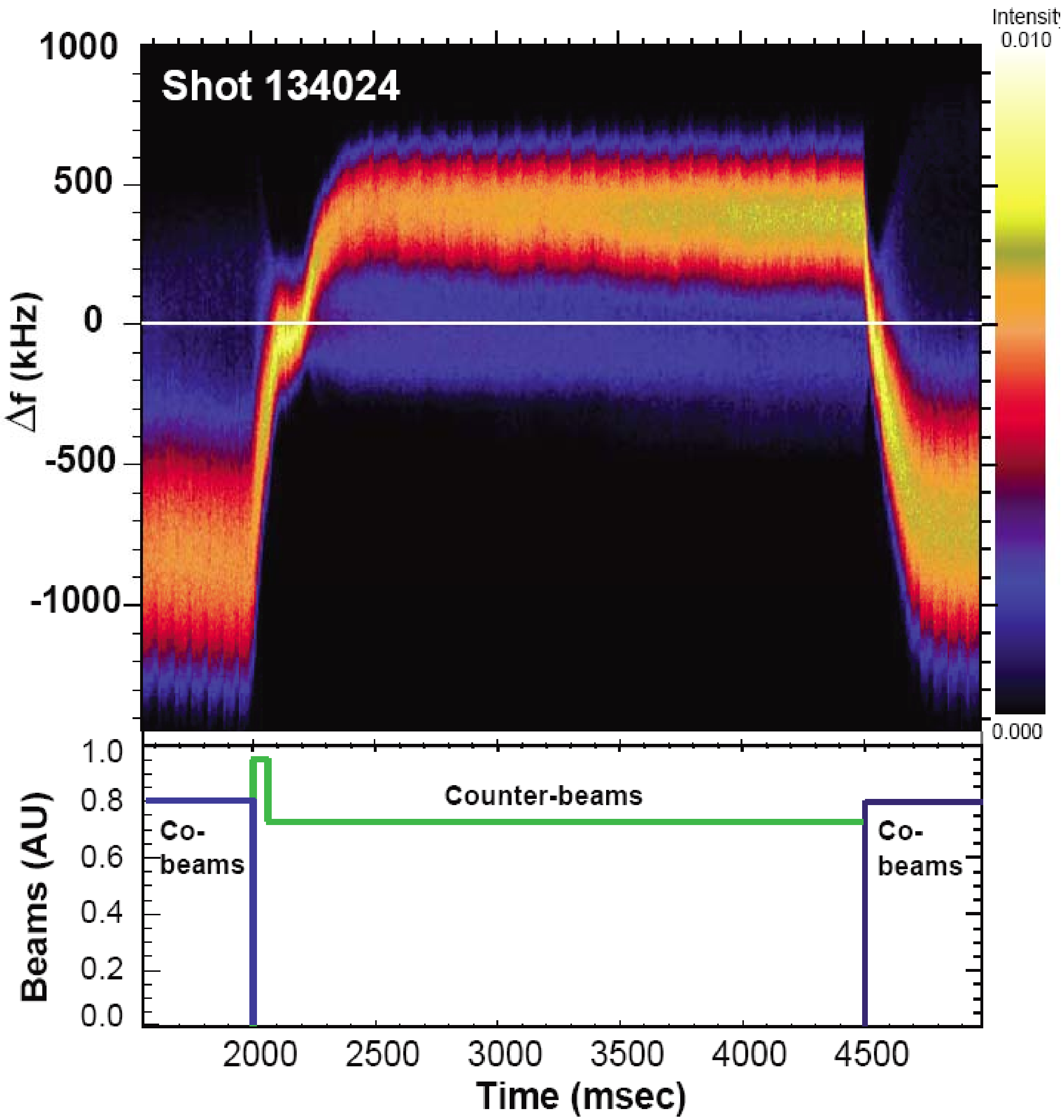
Doppler Backscattering can Measure the Propagation Velocity of Turbulence in the Laboratory Frame

- **Propagation velocity of turbulent structures results in Doppler shift in lab frame:**

$$v_{Lab} = v_{E\times B} + \widetilde{v}$$

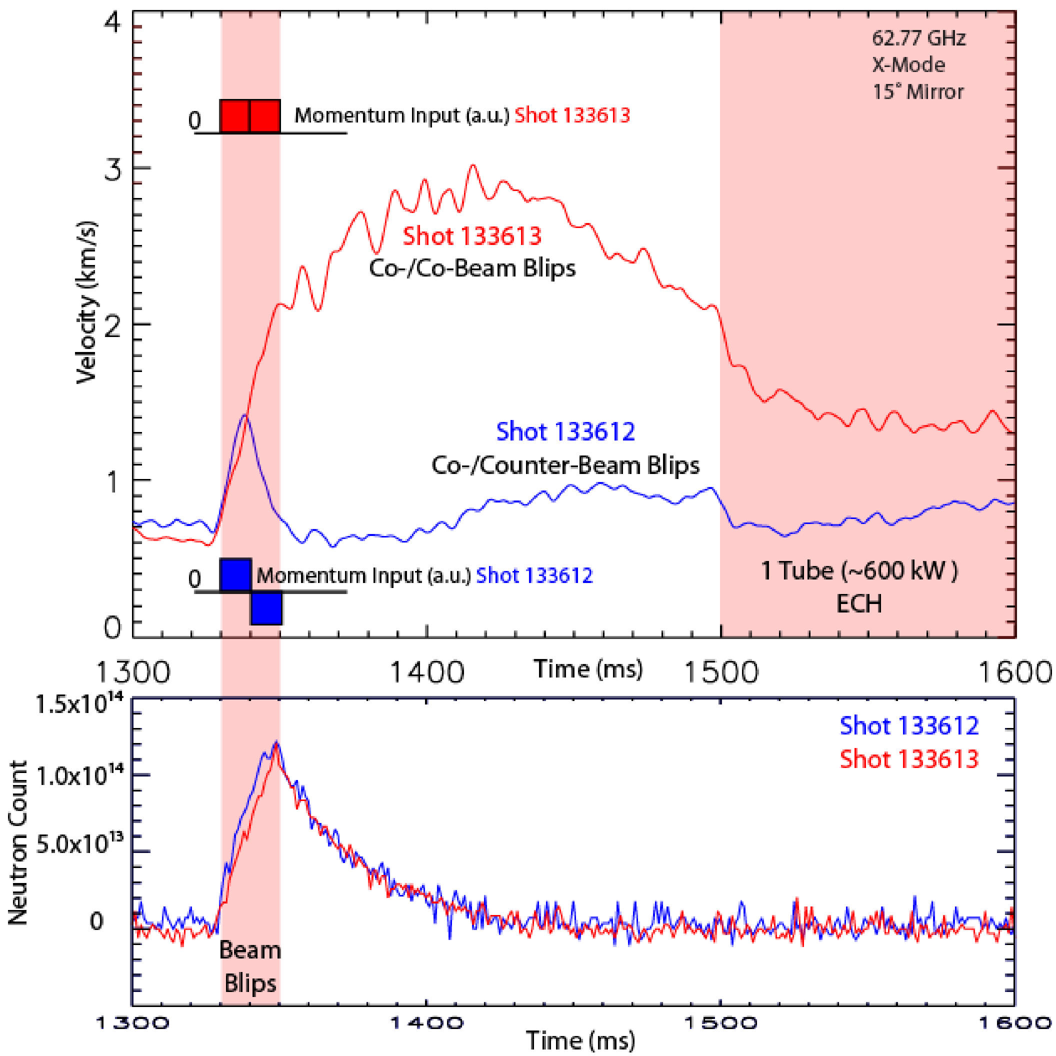
$$\omega_D \approx k_\perp v_{Lab}$$

- **Example of Doppler shift changing due to change in neutral beam injection**

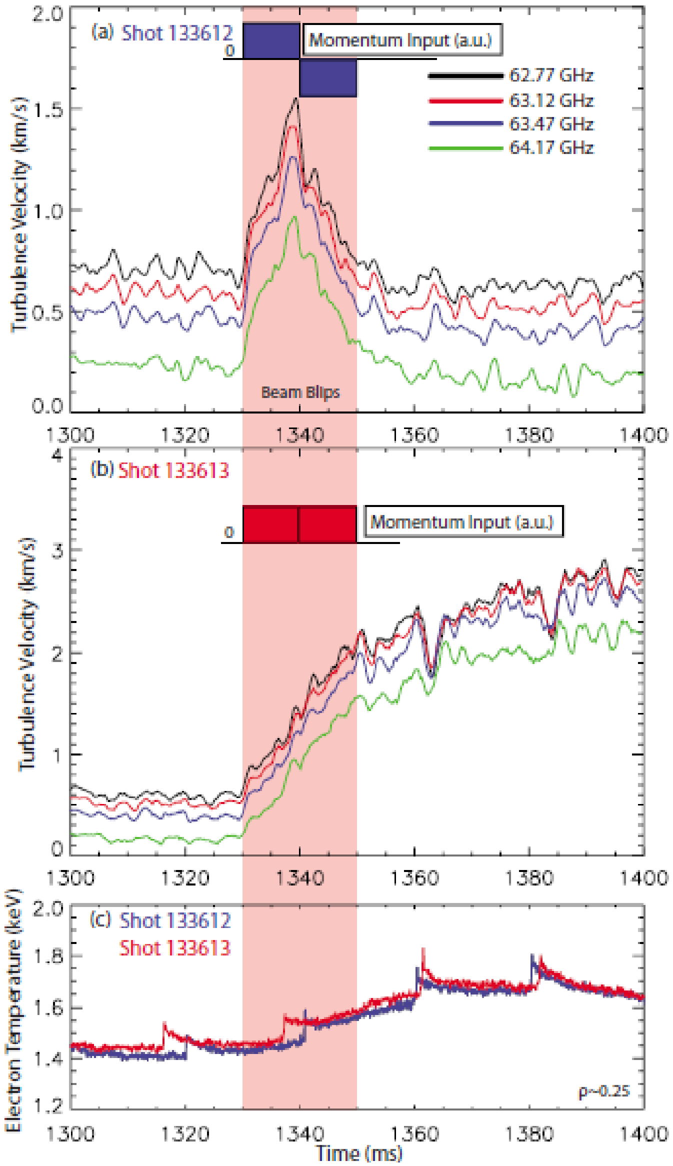


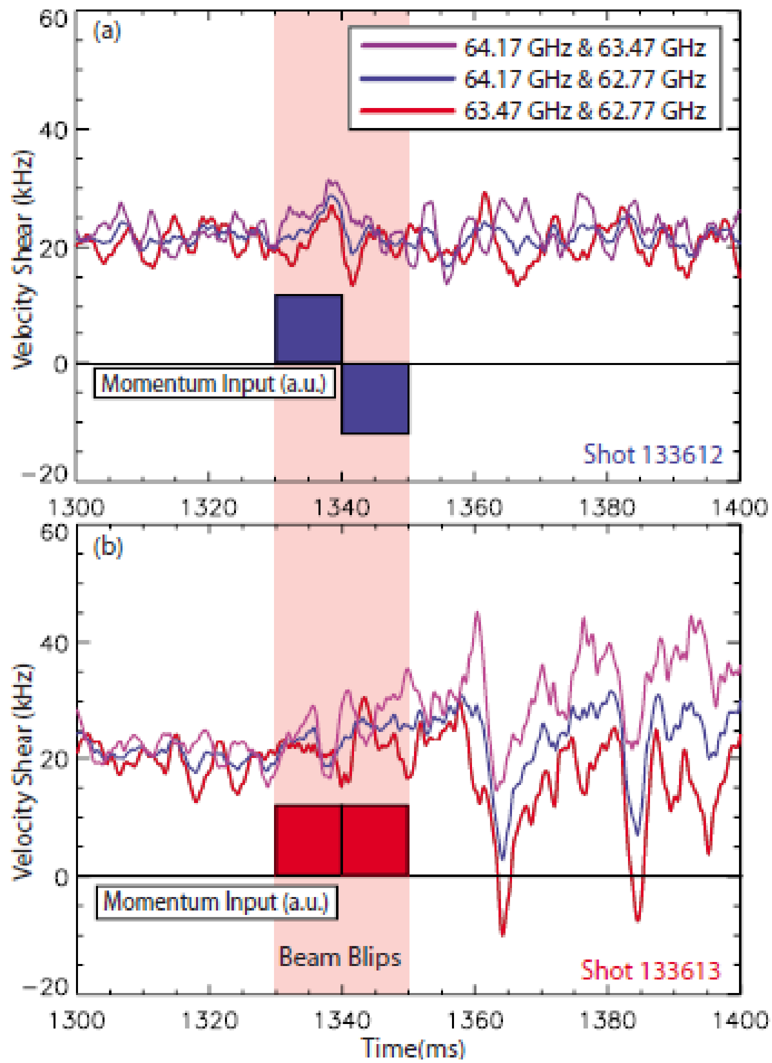
Momentum input from neutral beam blips

- **Short duration neutral beam blips used for MSE CER**
- **Nearly Identical shots except for direction of second 10 ms beam blip**



Example of fast time scale ExB flow and flow shear measurements





Direct Analysis of DBS Phase for High Time Resolution Measurements of Flow Fluctuations

- **The phase (referenced to a signal at the launch frequency) of the backscattered electric field can be analyzed directly to study coherent flow oscillations such as GAMs**
  - To see this, assume the lab frame velocity is due only to the GAM:

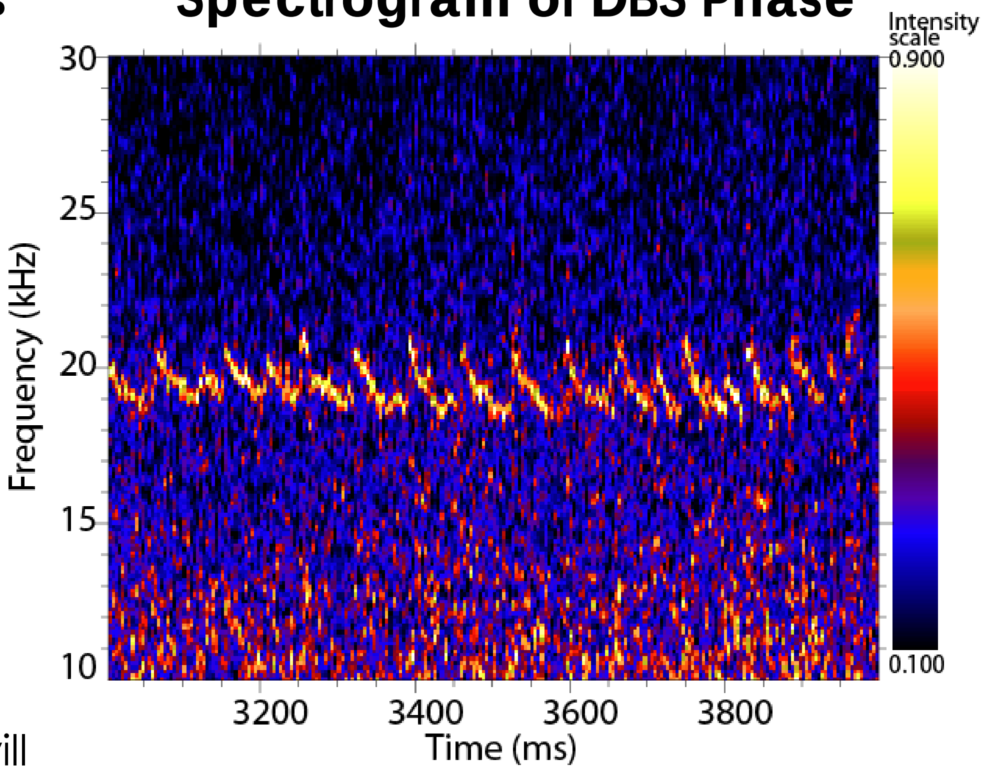
$$v_{Lab} = v_{GAM} \cos\left(\omega_{GAM} t\right)$$

$$\omega_D = k_\perp v_{GAM} \cos\left(\omega_{GAM} t\right)$$

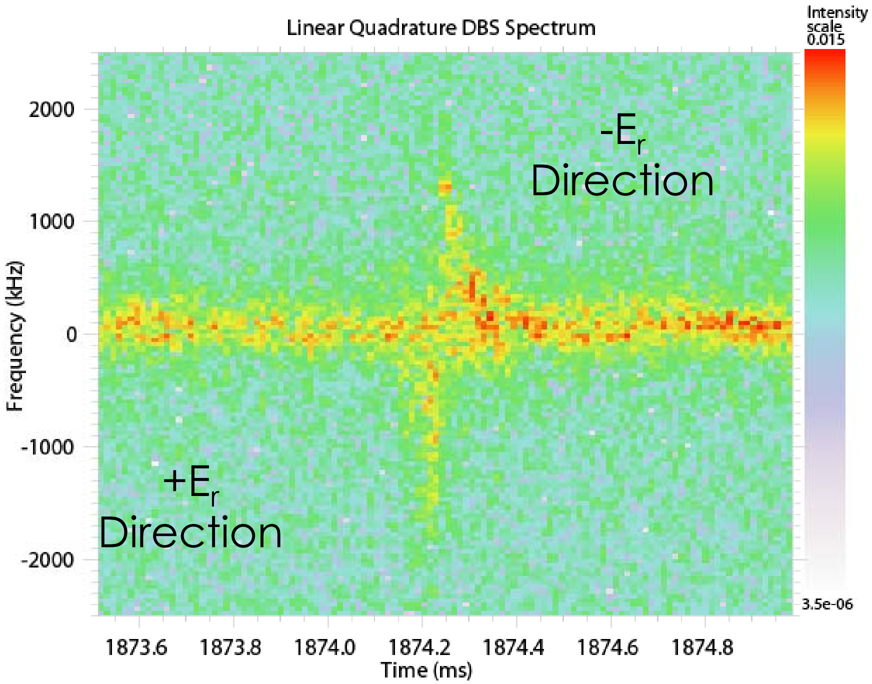
$$\varphi_{GAM}(t) = \frac{k_\perp v_{GAM}}{\omega_{GAM}} \sin\left(\omega_{GAM} t\right)$$

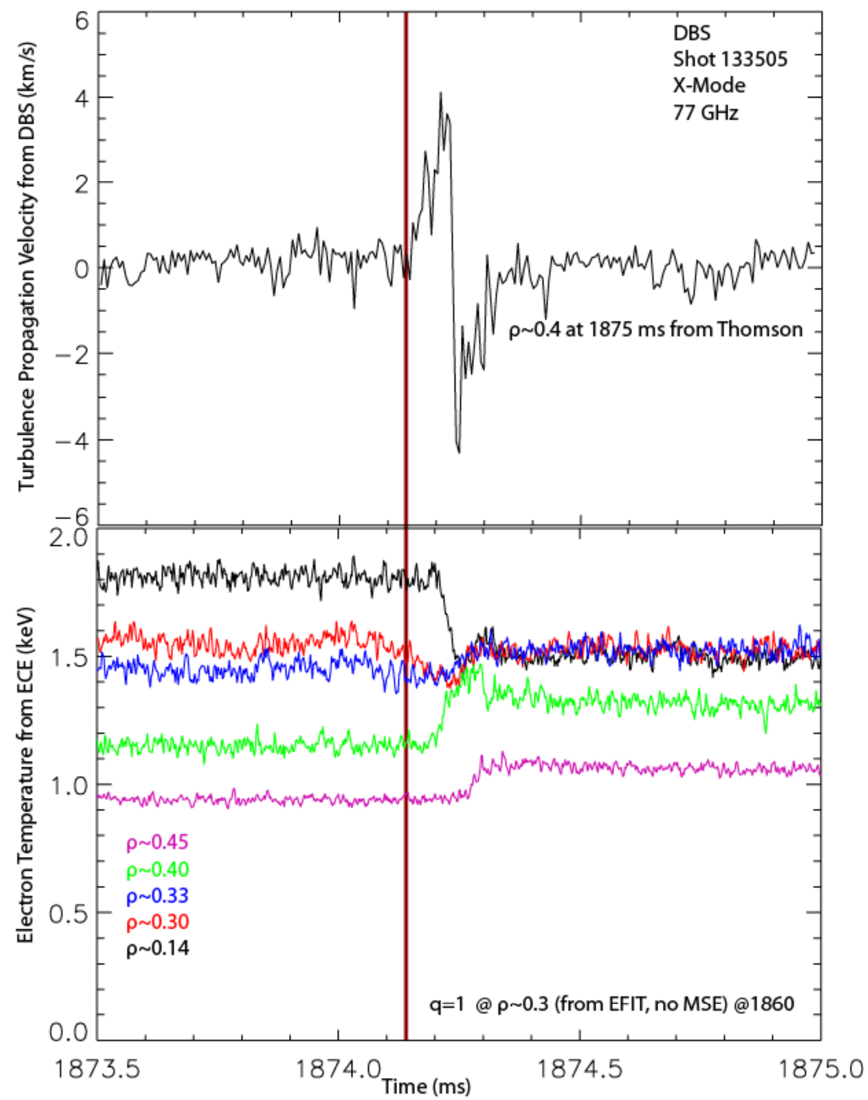
  - The Fourier transform of the phase will then be sharply peaked at the coherent mode
  - Detailed structure of coherent modes can be measured with the multichannel DBS systems at DIII-D

Spectrogram of DBS Phase



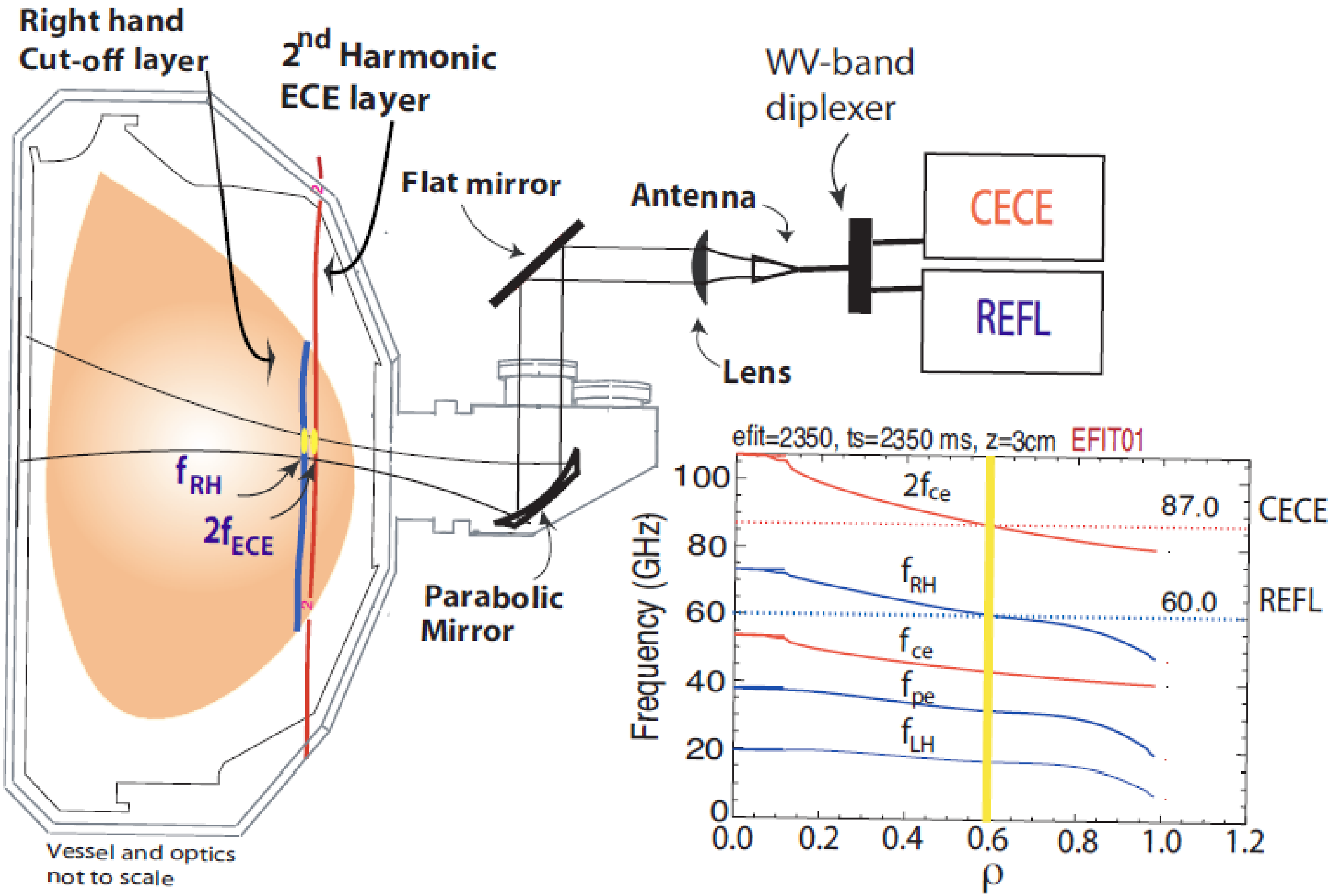
Fast time scale rotation changes observed





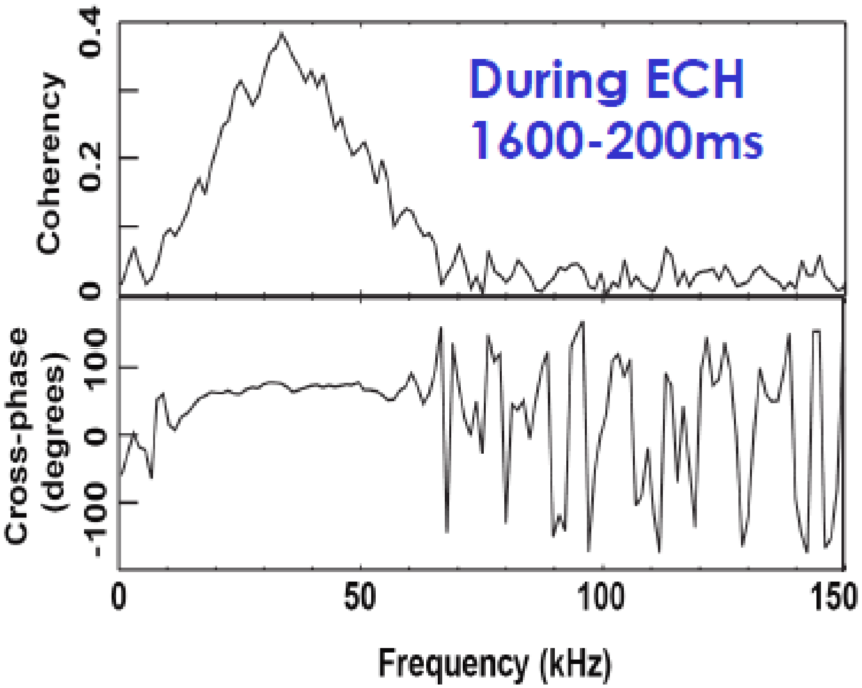
- **Much better data recently acquired**

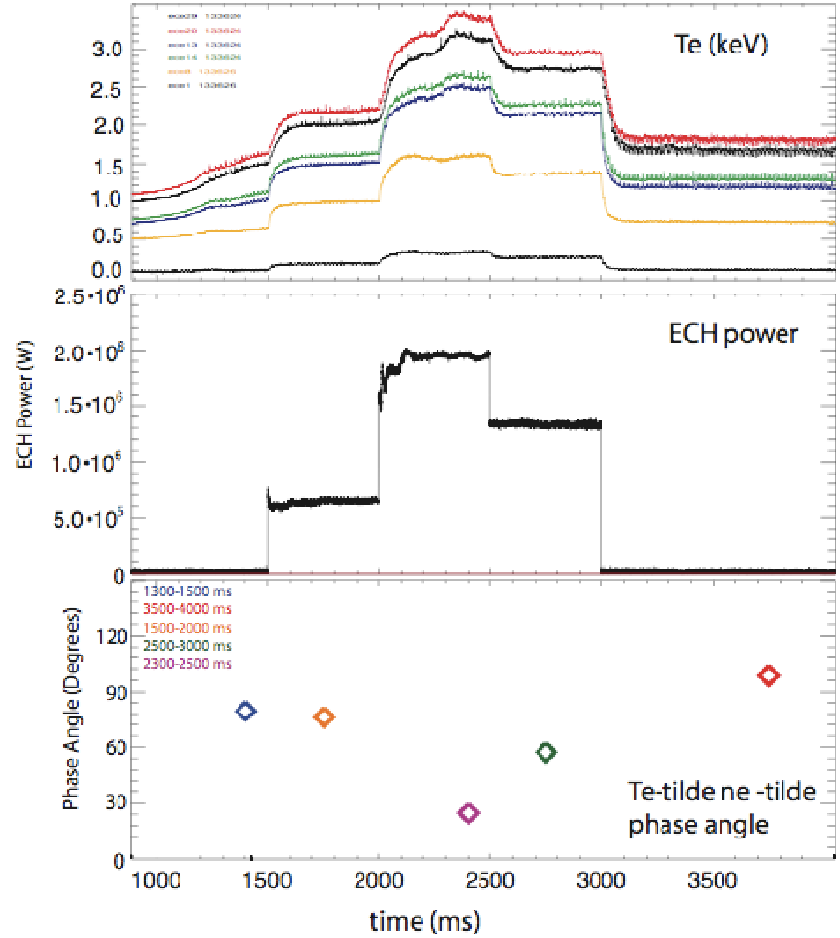
Coupled reflectometer-electron cyclotron emission diagnostic



- **Reflectometry is sensitive to low-k density fluctuations**
- **ECE is sensitive to low-k temperature fluctuations**

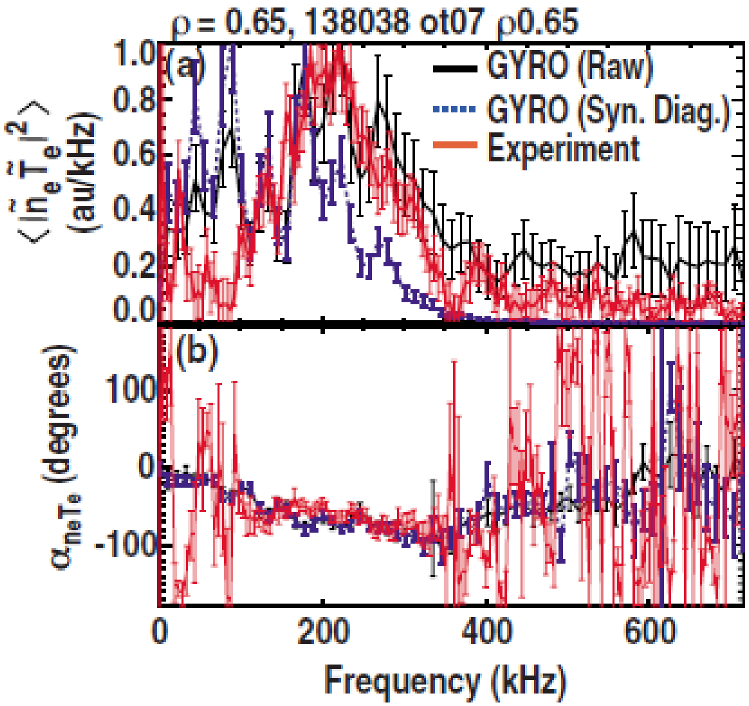
Cross phase between temperature and density fluctuations measured in an Ohmic plasma

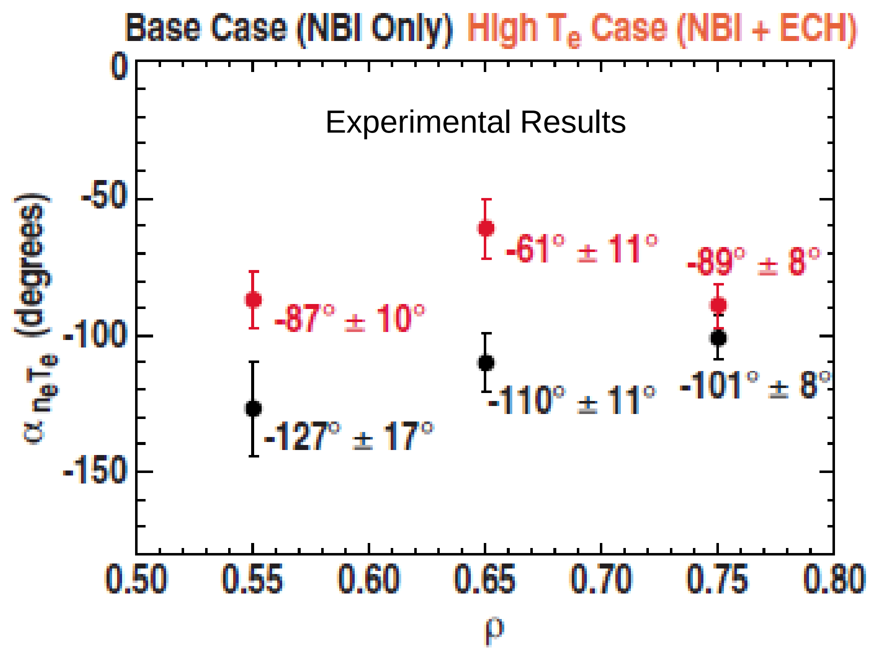




- **Subsequent experiment performed, optimized for comparison to simulation**

Phase angle measurements compared to gyrokinetic simulation from GYRO





- Figures from A. E. White et al, Phys. Plasmas 17, 056203 (2010), see paper for details of simulations and experimental conditions

- **Quantitative agreement between experiment and GYRO**
- **Compared to rho 0.55, 0.65, larger change in ExB shear at 0.75**

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