NSTX

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Electron gyro-scale fluctuations in NSTX plasmas

David Smith, PPPL

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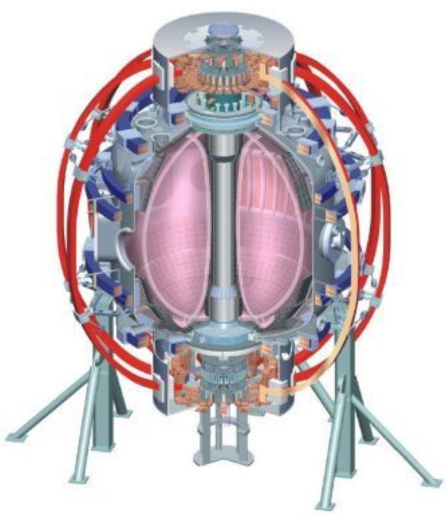

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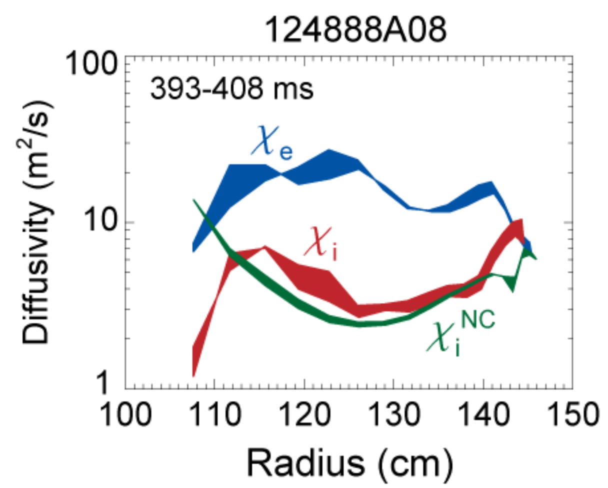
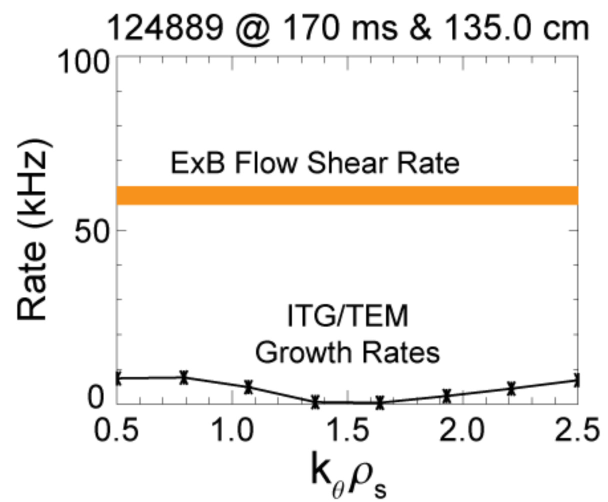
NSTX is well-suited to investigate the connection between ETG turbulence and electron thermal transport

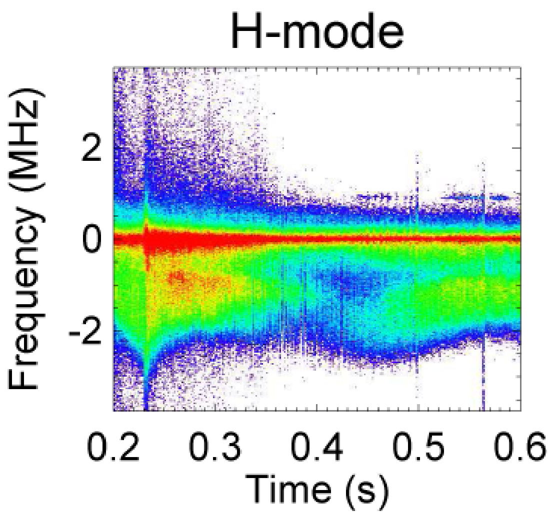
- Electron thermal transport → anomalous in all confinement regimes in all machines
- Electron temperature gradient (ETG) turbulence
  - NL GK simulations predict experimentally-relevant electron thermal transport for $\hat{s} > 0.4$ (Nevins et al, PoP 2006)
  - Electron gyro-scale fluctuations → $k_\perp \rho_e \lesssim 1$
- Turbulence & transport in NSTX
  - Large E×B flow shear with NBI → inferred ITG/TEM suppression → ion thermal transport is near neoclassical in H-mode (Kaye et al, NF, 2007 & PRL, 2007)
  - Electron thermal transport remains anomalous → what is the mechanism?
  - ETG can be linearly unstable with growth rates exceeding E×B flow shear rates

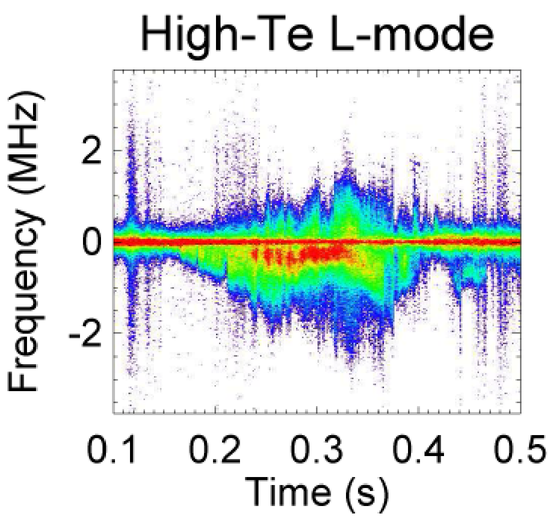




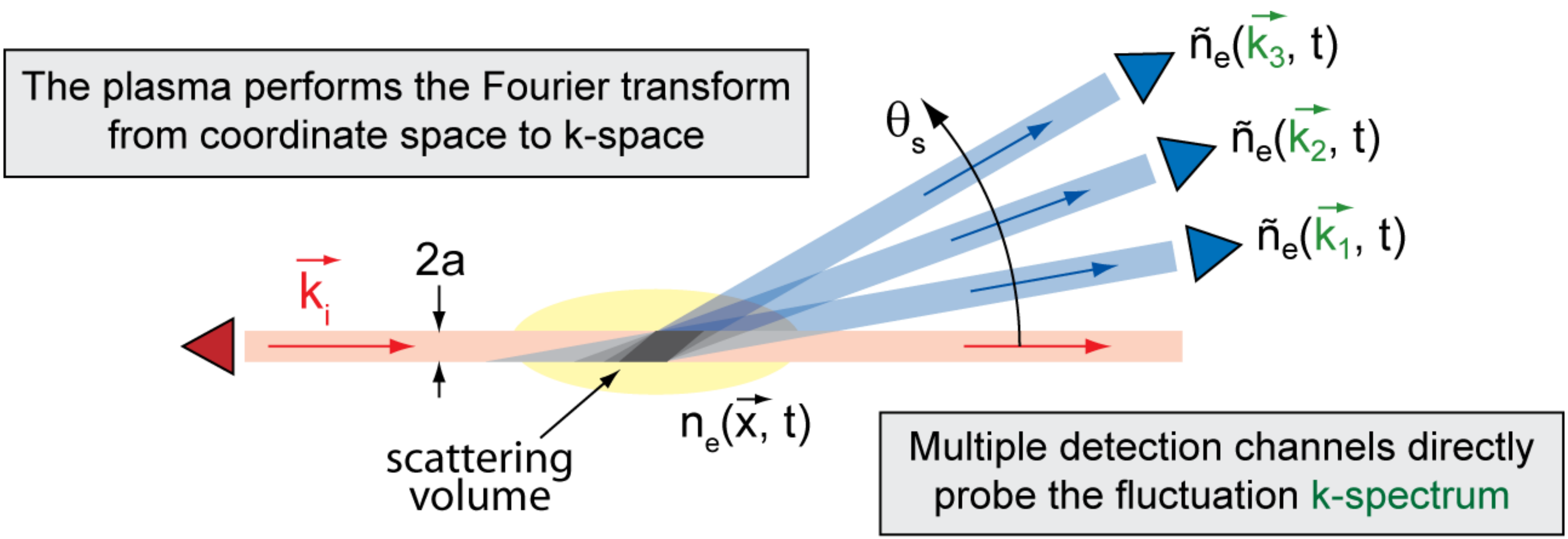
Electron gyro-scale fluctuations in NSTX plasmas

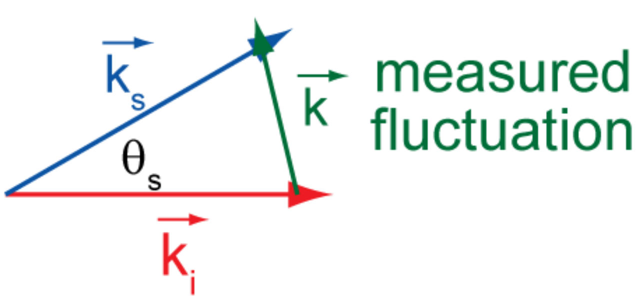
- The NSTX collective scattering system
- Electron gyro-scale fluctuation measurements and analysis
  - ETG linear critical gradient
    - High-Te L-mode w/ RF heating
    - Core measurements in H-mode w/ NBI heating
  - ETG linear growth rate and E×B flow shear rate
    - Mid-radius measurements in H-mode w/ NBI heating
  - Fluctuation amplitude dependence on B_T
  - Fluctuation k-spectra and comparison with GTS simulation
- Summary





Collective scattering encodes the fluctuation k-spectrum into the angular distribution of scattered light





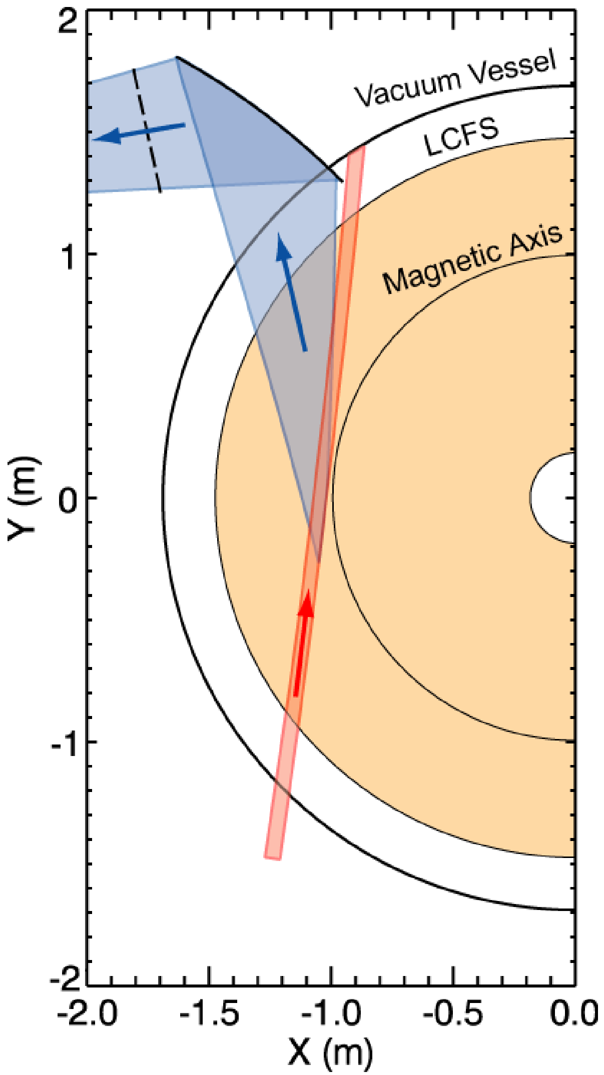
k-matching: $\vec{k}_s = \vec{k}_i + \vec{k}$

Bragg condition: $k = 2k_i \sin(\theta_s/2)$

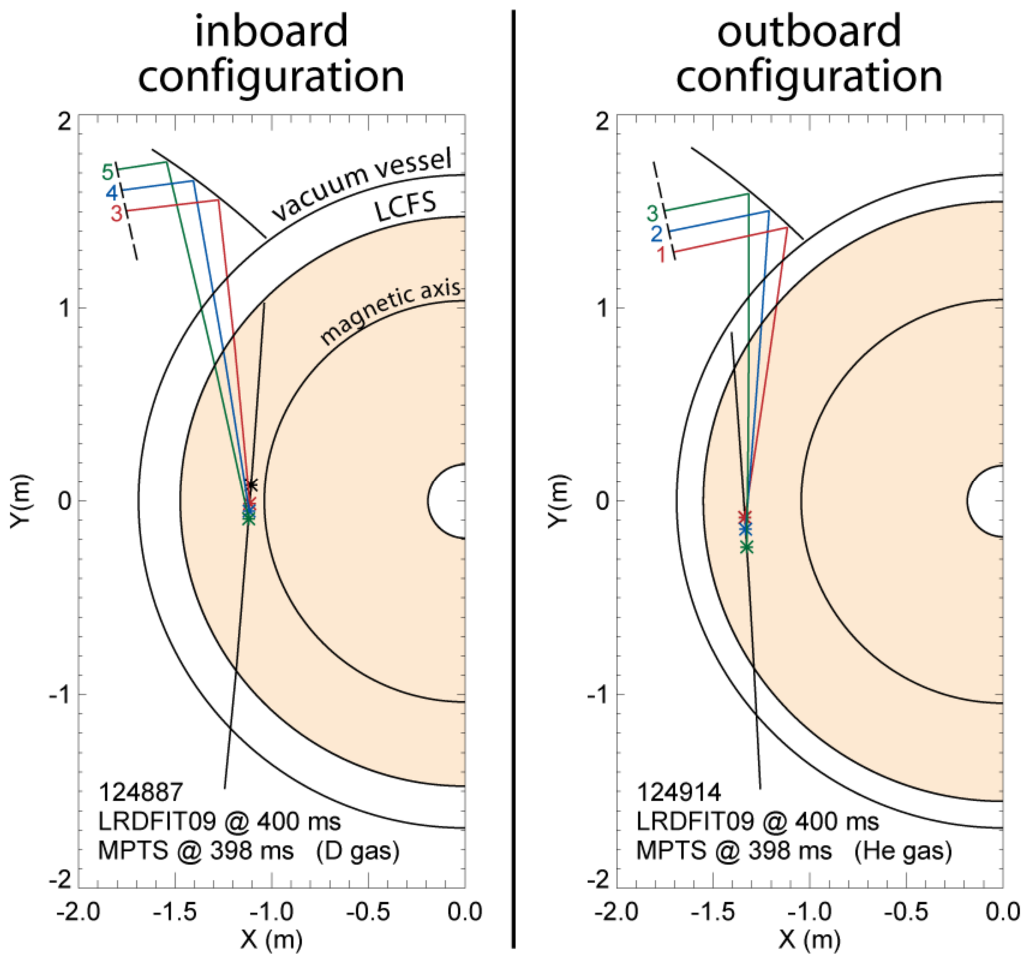
k-space resolution: $\Delta k = 2/a$

The NSTX collective scattering system measures fluctuations up to $k_\perp \rho_e \approx 0.6$

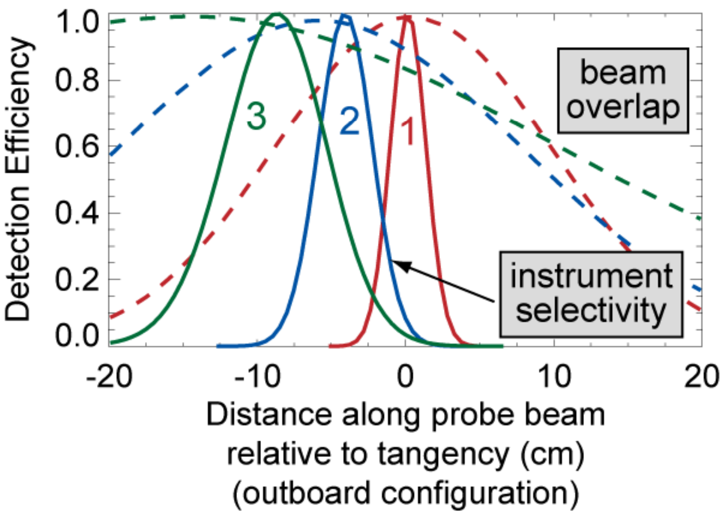
- 280 GHz collective scattering system
- Five detection channels
  - $k_\perp$ spectrum for up to five discrete $k_\perp$
    - $k_\perp \rho_e \lesssim 0.6$ and $k_\perp \lesssim 20\ cm^{-1}$
  - ω spectrum from time-domain sampling
    - 7.5 MS/s → $f \leq 3.25$ MHz
  - Heterodyne detection
- Tangential scattering
  - Beams nearly on equatorial midplane
    - Sensitive to radial fluctuations
  - Toroidal curvature enhances spatial localization along probe beam, $\Delta L \sim 10$ cm
  - Radial localization, $\Delta R \sim \pm 2.5$ cm
- Steerable optics
  - Scattering volume can be positioned throughout the outer half-plasma



Steerable optics enable good radial coverage; toroidal curvature enhances spatial localization



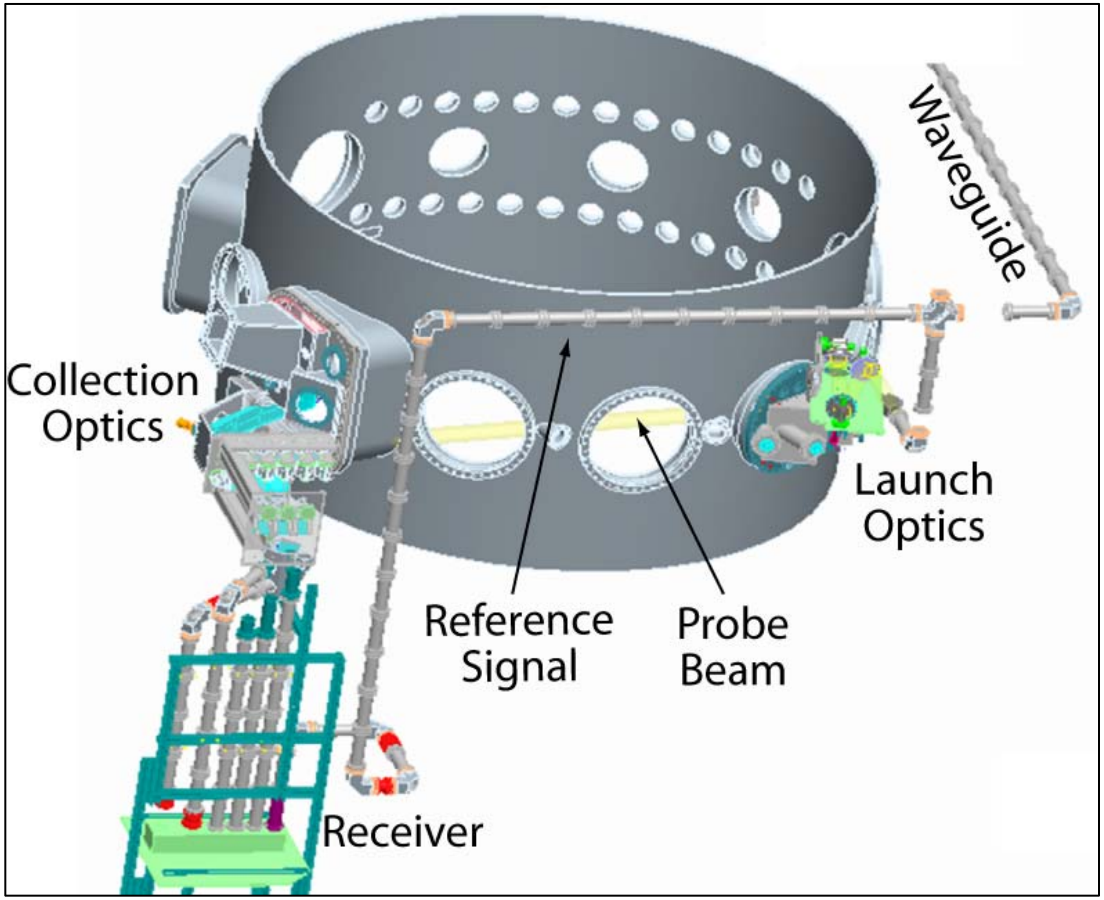
Large toroidal curvature imposes an instrument selectivity function that constricts the scattering volume within the overlap volume along the probe beam.



Mazzucato, PoP, 2003

Mazzucato, PPCF, 2006

Scattering system hardware

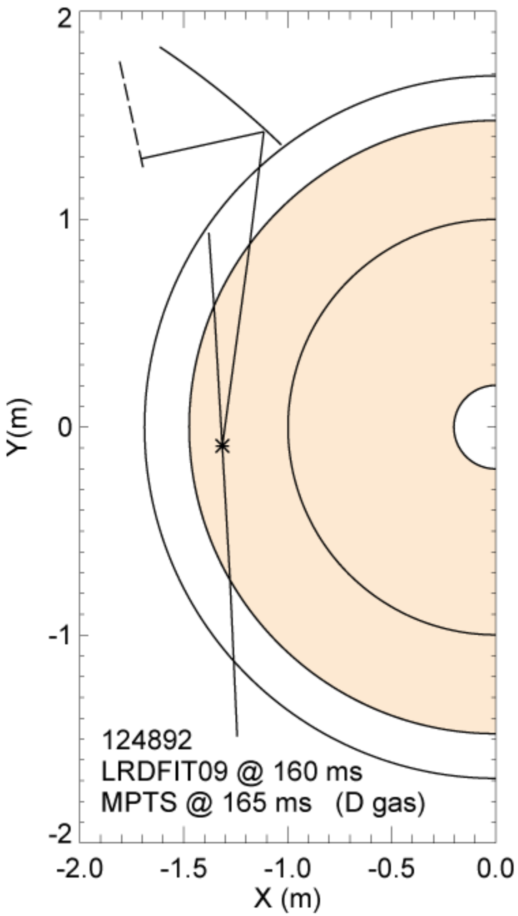


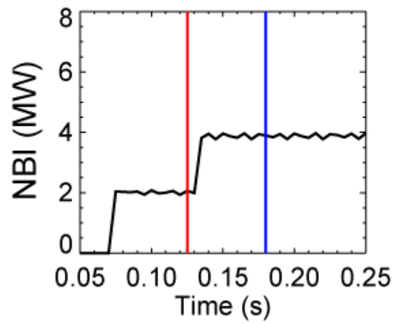
- BWO source
  - ~100 mW at 280 GHz
- Overmoded, corrugated waveguide
  - low-loss transmission
- Probe & receiving beams
  - quasi-optically coupled with 5 cm dia. waist
- Heterodyne receiver
  - five channels
  - two mixing stages
  - quadrature detection with 7.5 MHz bandwidth
  - reference signal from BWO

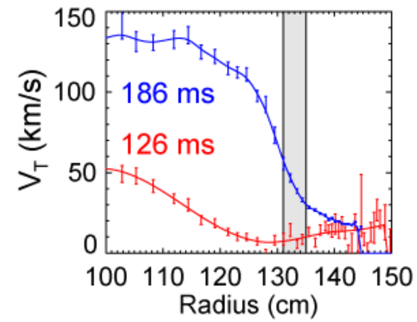
D. R. Smith et al, in press, RSI

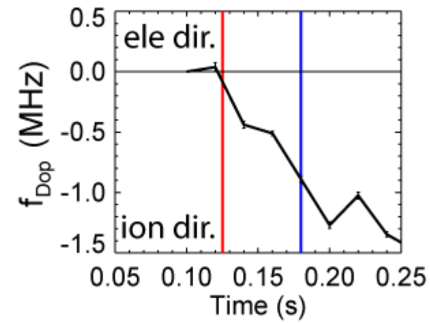
Toroidal rotation from NBI produces a Doppler shift in fluctuation spectra toward the ion drift direction

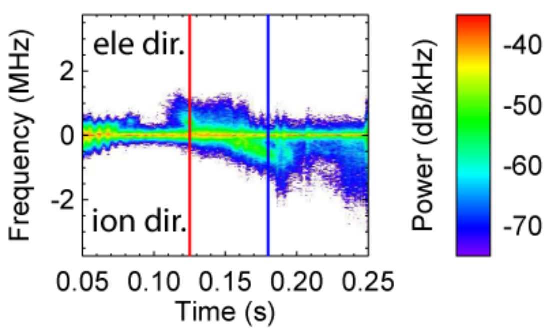
3.5 kG, 700 kA, 4 MW NBI, R=133 cm, r/a≈0.55

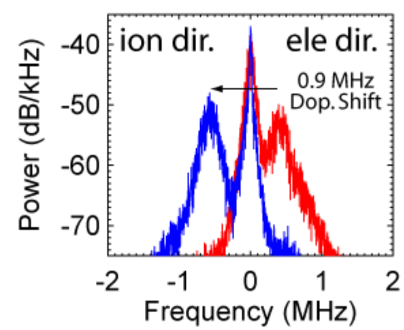








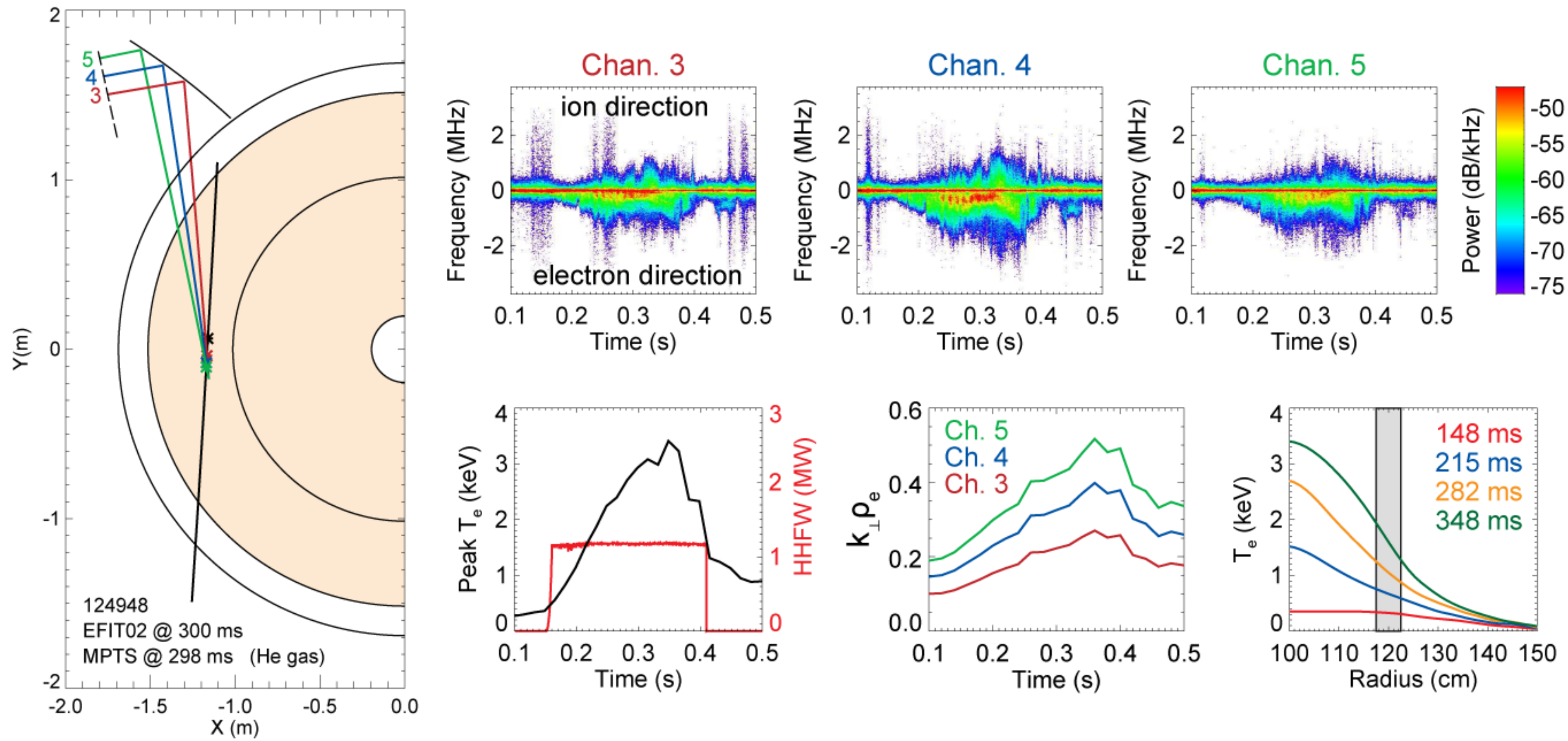




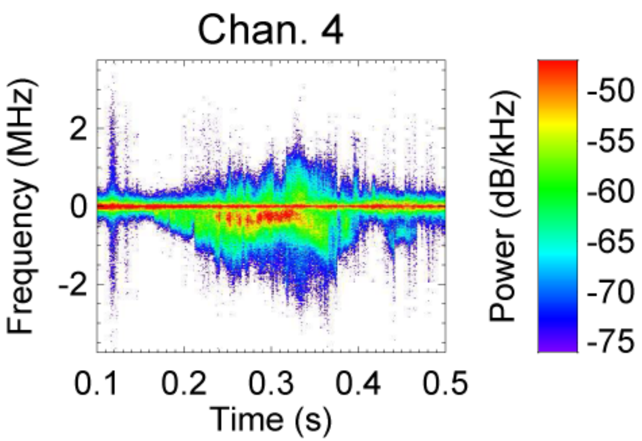
Spurious reflections of the probe beam produce the ubiquitous interferometric signal at 0 Hz.

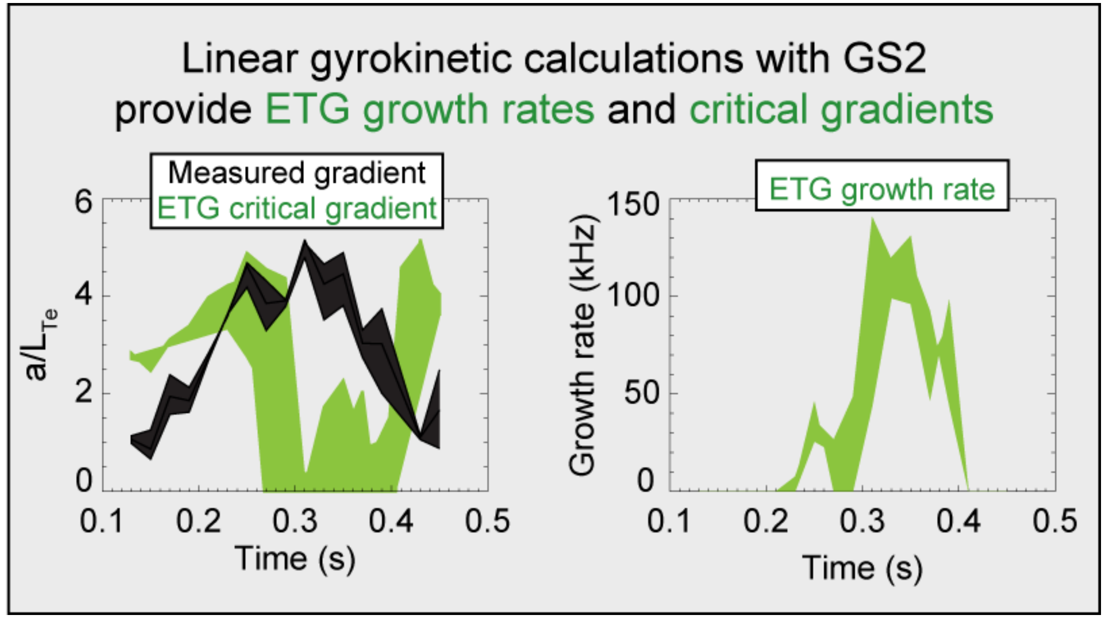
Enhanced fluctuations observed in core region of high-Te L-mode plasma

5.5 kG, 600 kA, 1.2 MW HHFW, R=120 cm, r/a≈0.28



Enhanced fluctuations occur when ∇Te exceeds the ETG critical gradient

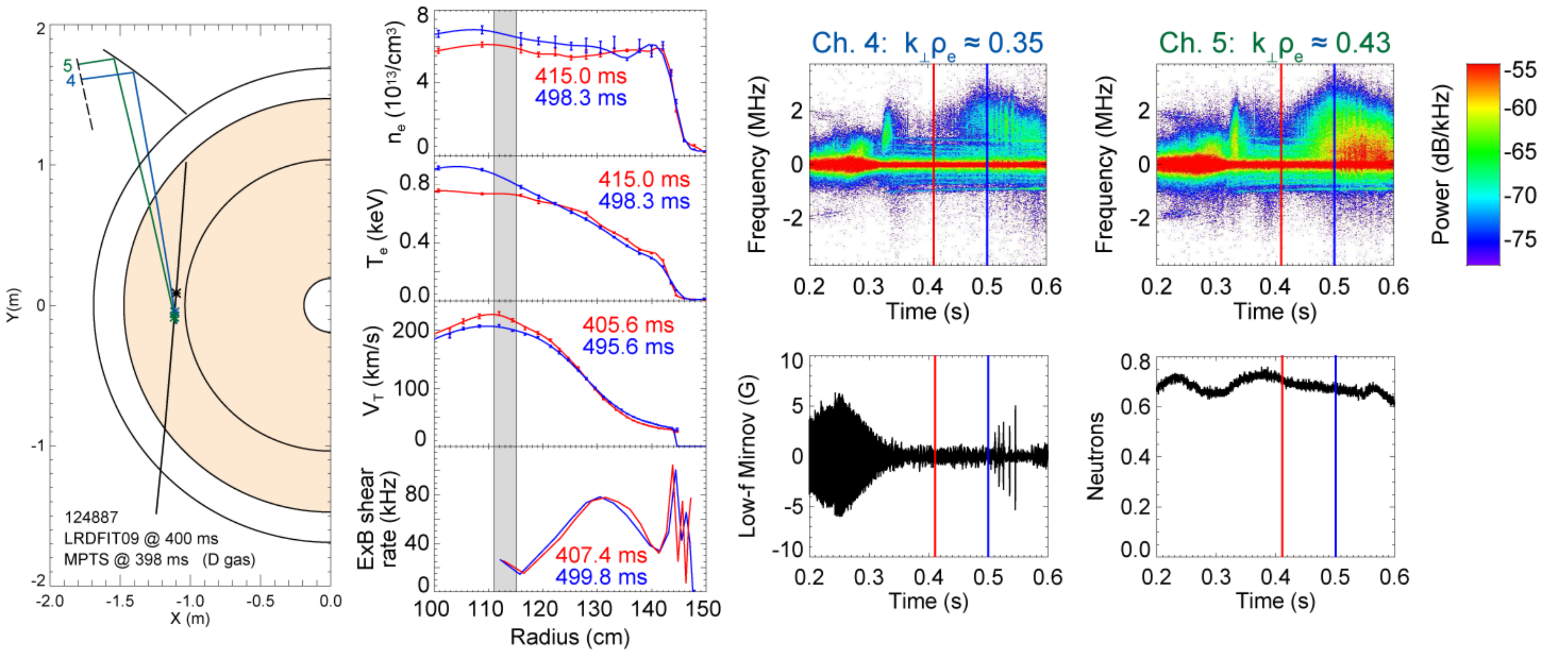




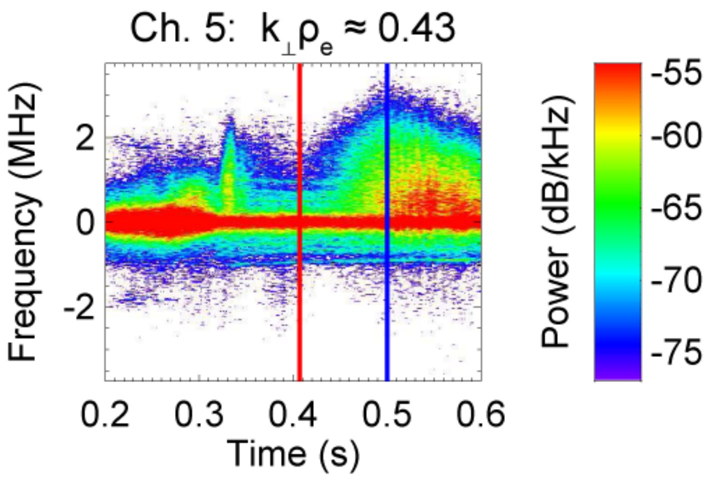
Mazzucato et al, PRL, 2008

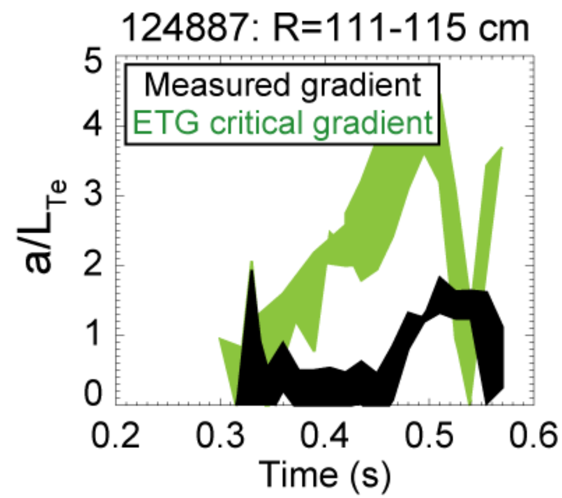
Enhanced fluctuations observed in core region of NBI-heated H-mode plasma

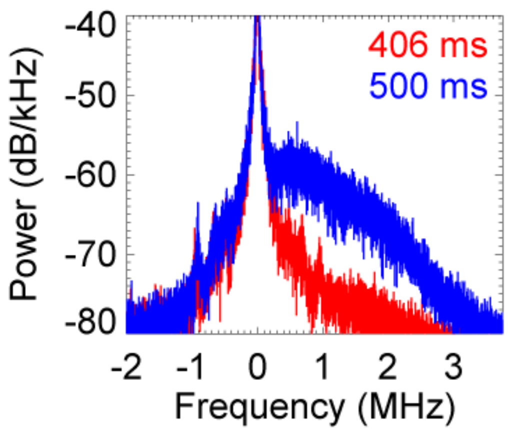
4.5 kG, 700 kA, 4 MW NBI, R=113 cm, r/a≈0.15

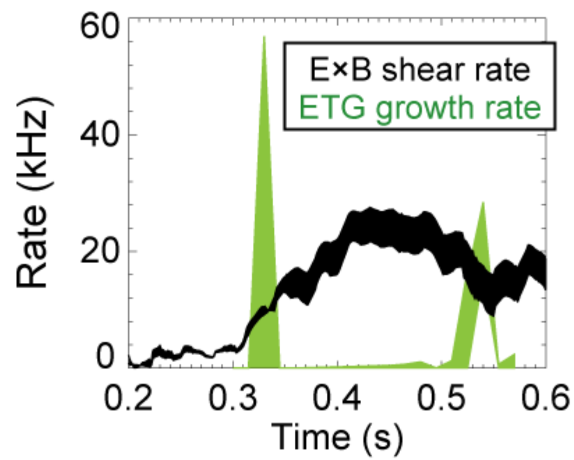


Enhanced fluctuations generally occur when ∇Te exceeds the ETG critical gradient



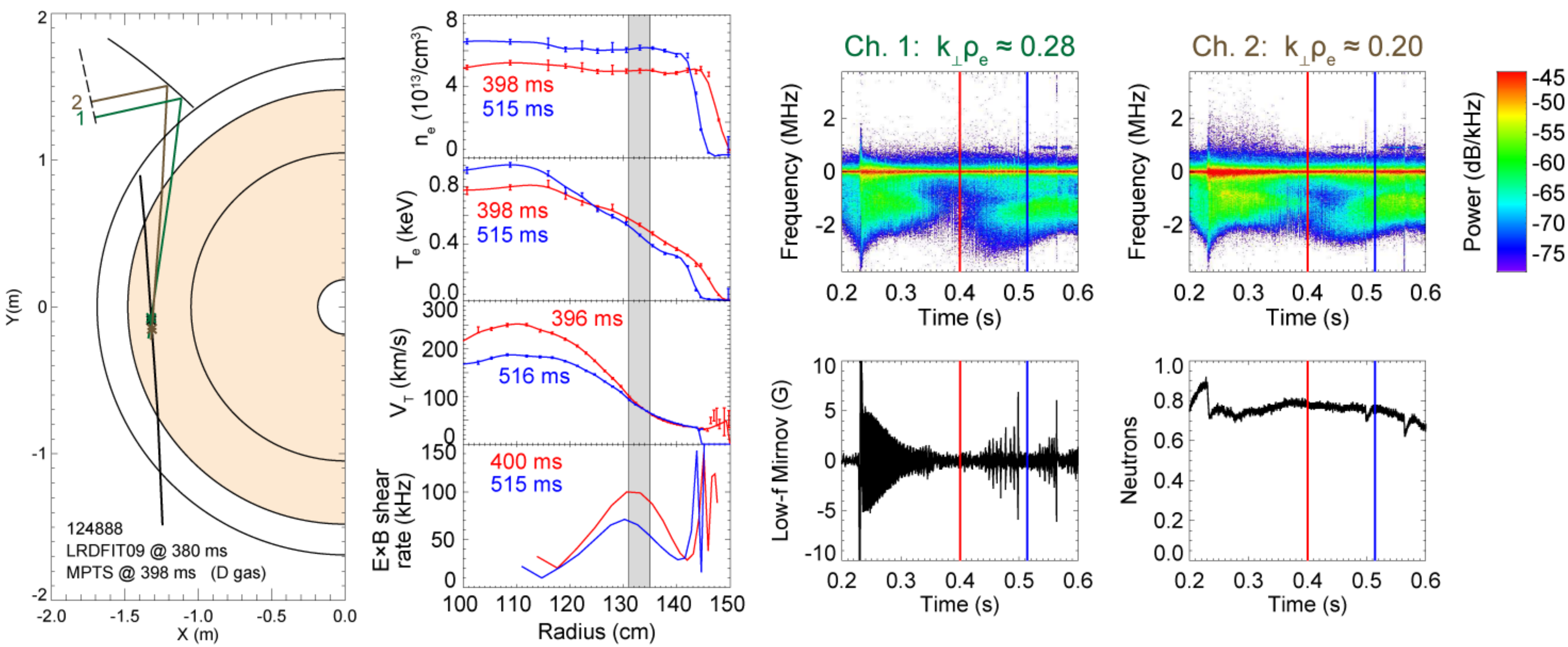




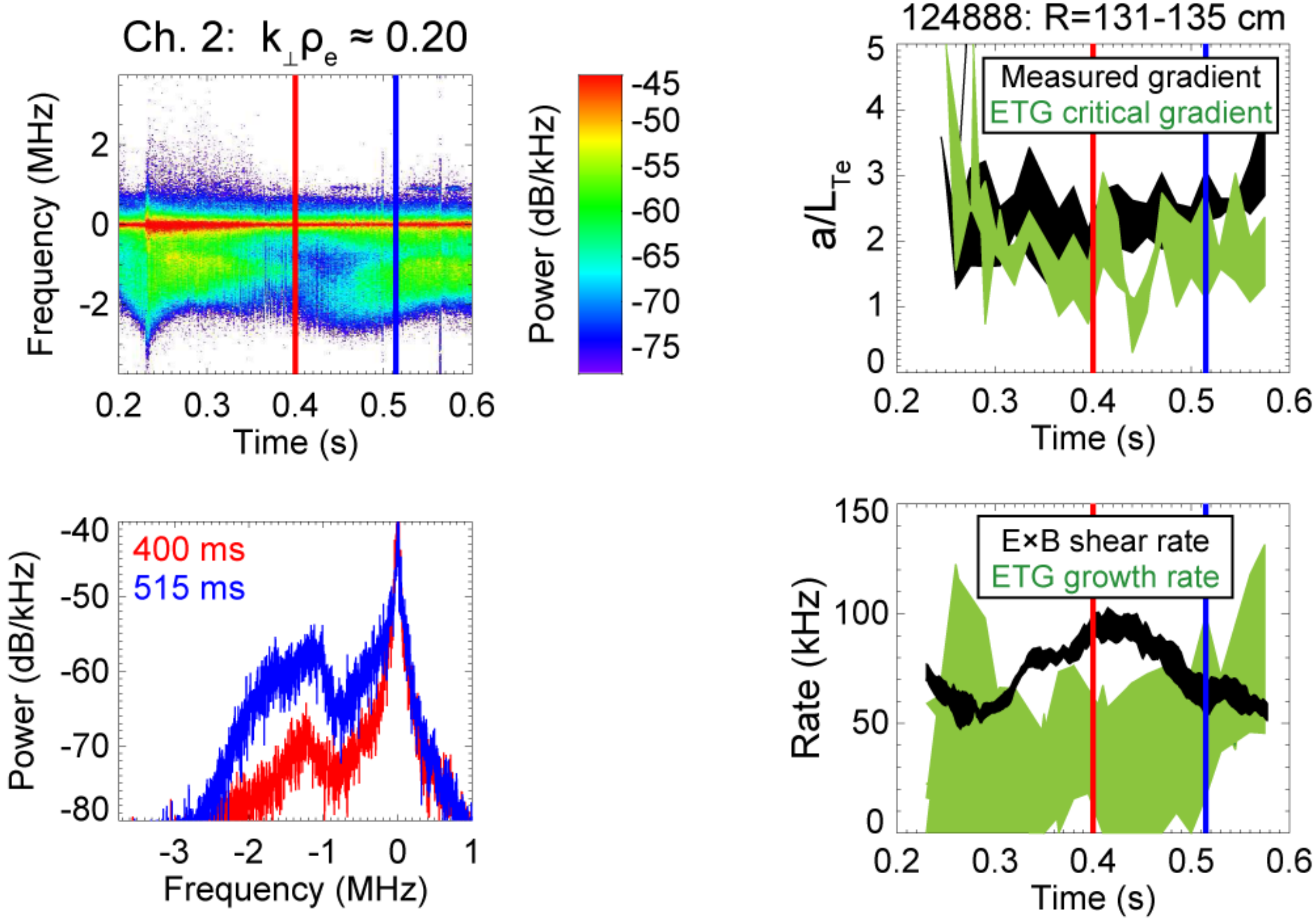


Enhanced fluctuations observed at mid-radius in NBI-heated H-mode plasma

4.5 kG, 700 kA, 4 MW NBI, R=133 cm, r/a≈0.55



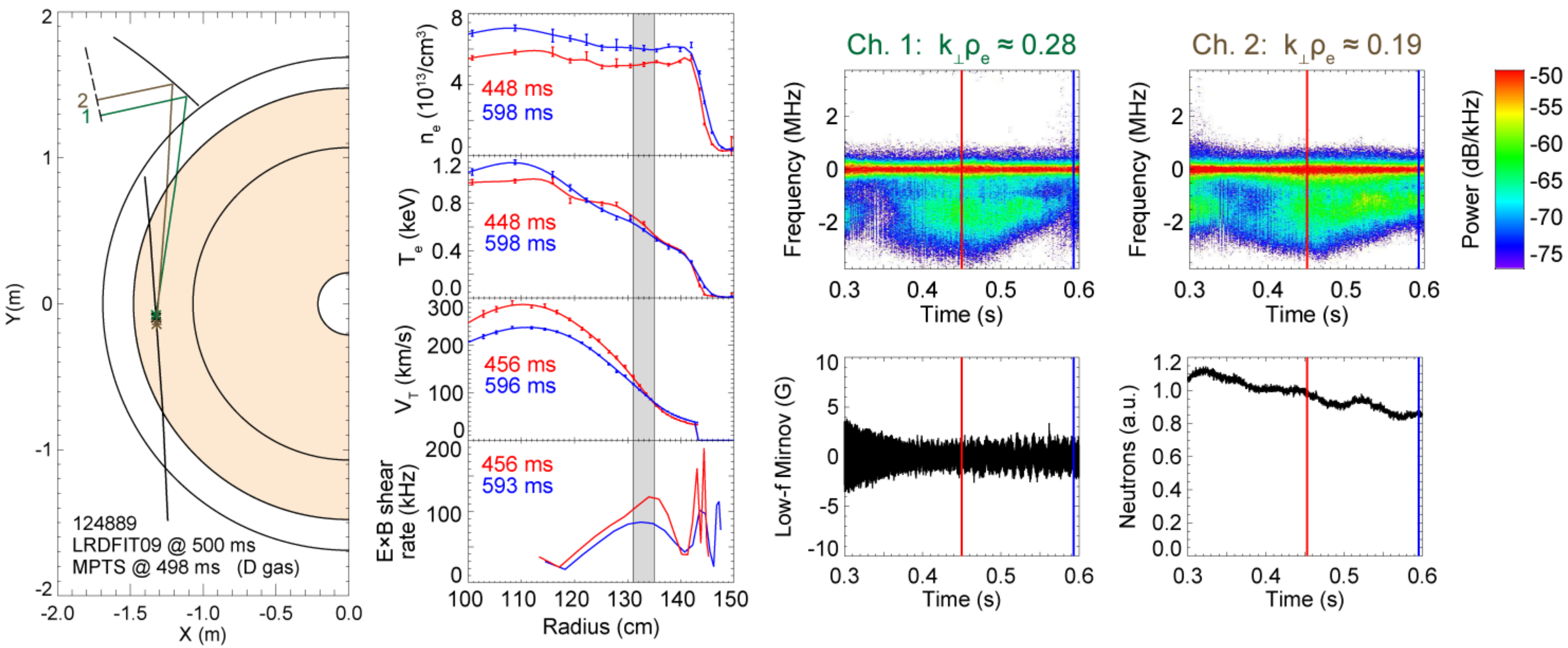
Near ETG marginal stability, fluctuation amplitudes decrease when the E×B shear rate exceeds the ETG growth rate



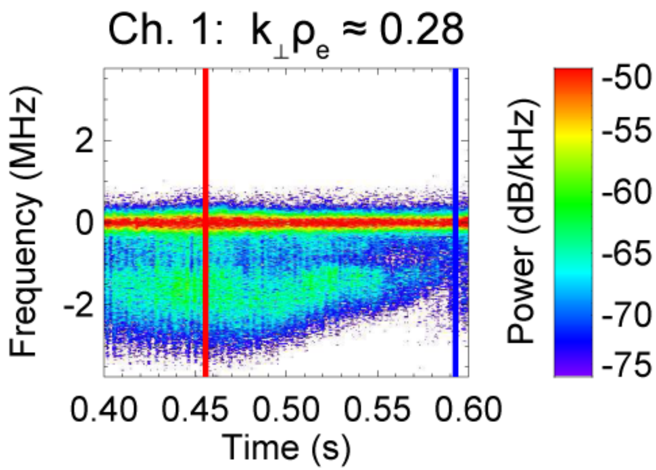
D. R. Smith et al, to be submitted to PRL

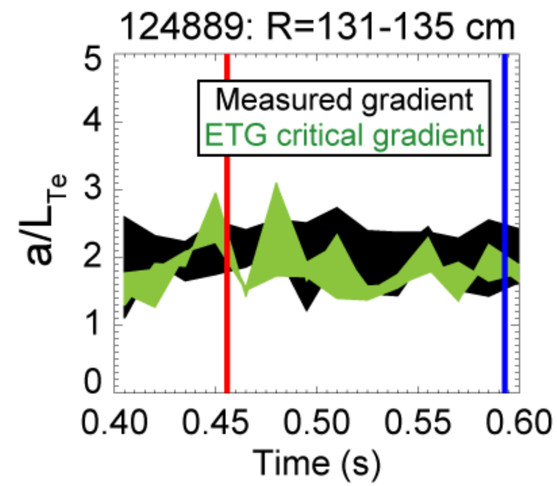
E×B shear rate is larger at higher B_T, yet enhanced fluctuations are still observed

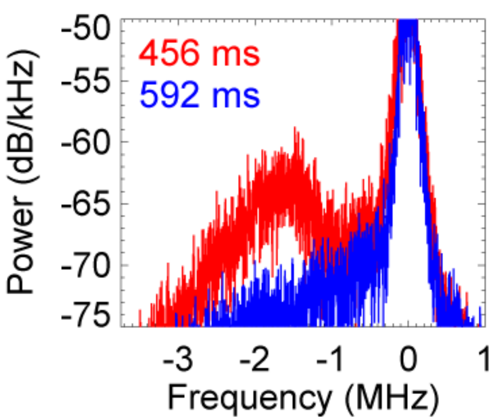
5.5 kG, 700 kA, 4 MW NBI, R=133 cm, r/a≈0.55

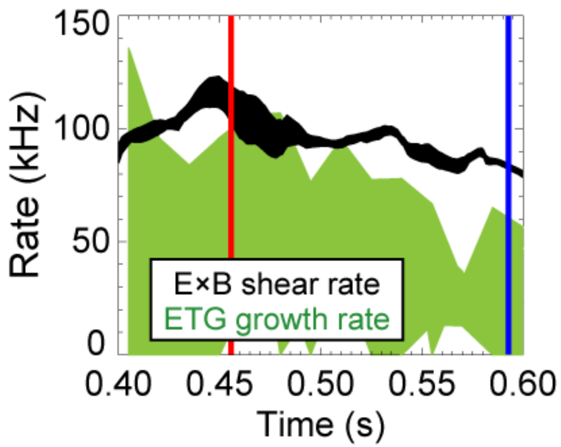


Near ETG marginal stability, fluctuation amplitudes decrease when the ETG growth rate drops below the E×B shear rate



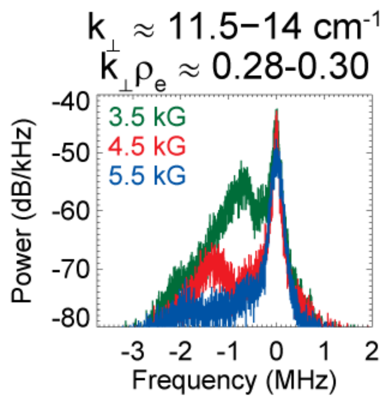


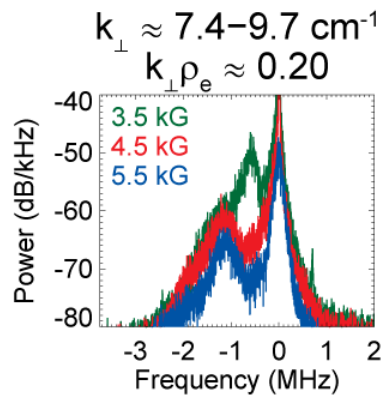


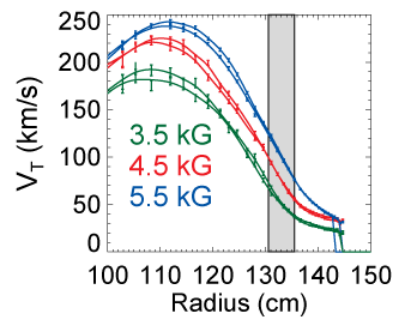


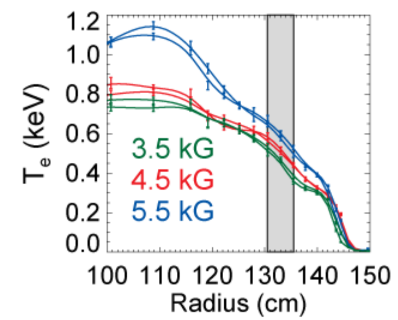
Fluctuation amplitudes decrease at higher B_T with similar E×B shear rates, ETG growth rates, and ∇Te

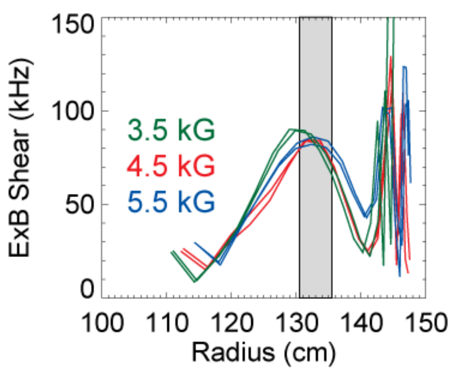
3.5 kG: 124892 @ 330-340 ms
4.5 kG: 124888 @ 340-350 ms
5.5 kG: 124889 @ 590-600 ms

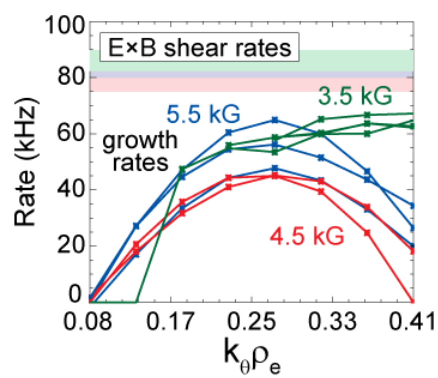


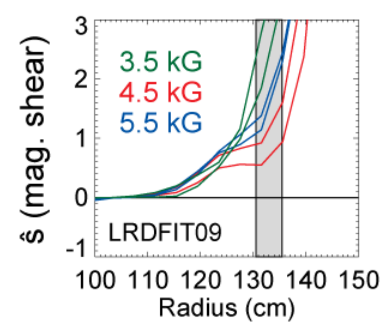


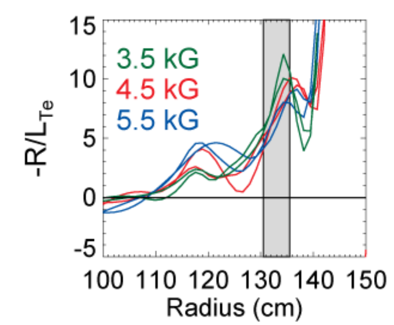








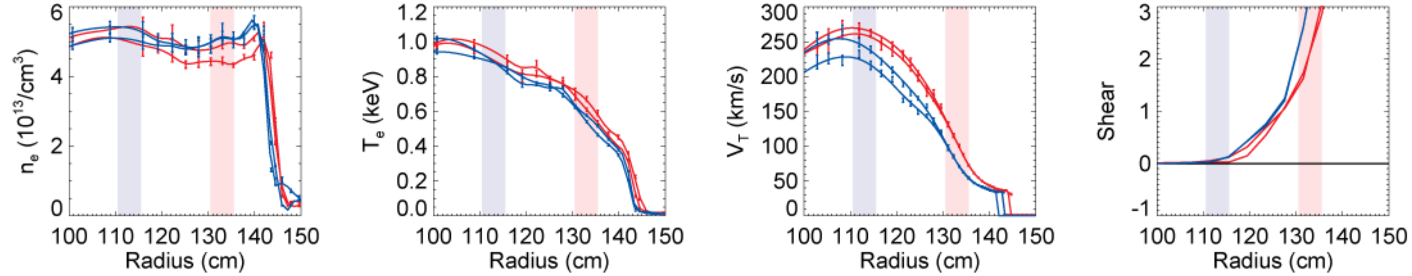


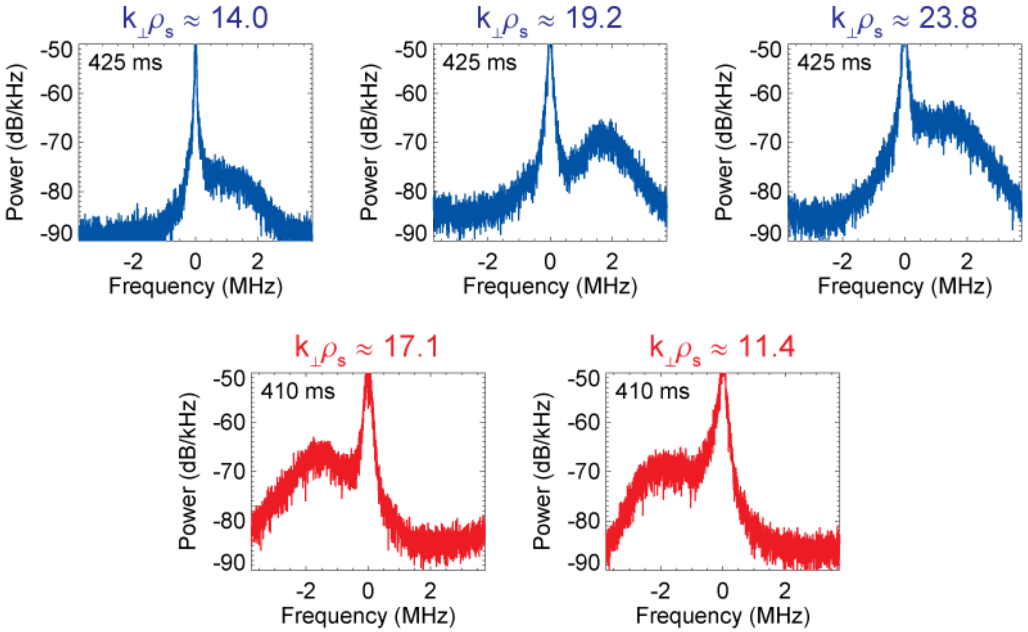


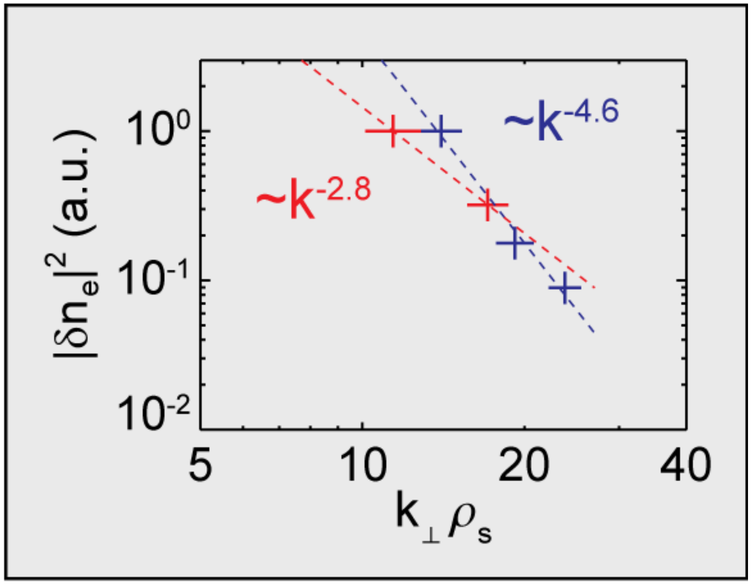
In H-mode, k_r-spectrum is steeper near core compared to mid-radius

124885 @ 415-430 ms & r/a ≈ 0.18
124889 @ 400-415 ms & r/a ≈ 0.54

5.5 kG
700 kA
4 MW NBI

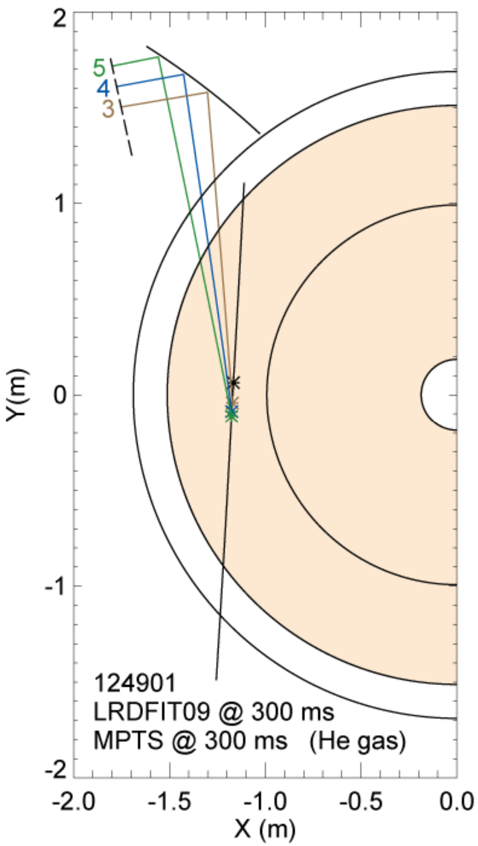


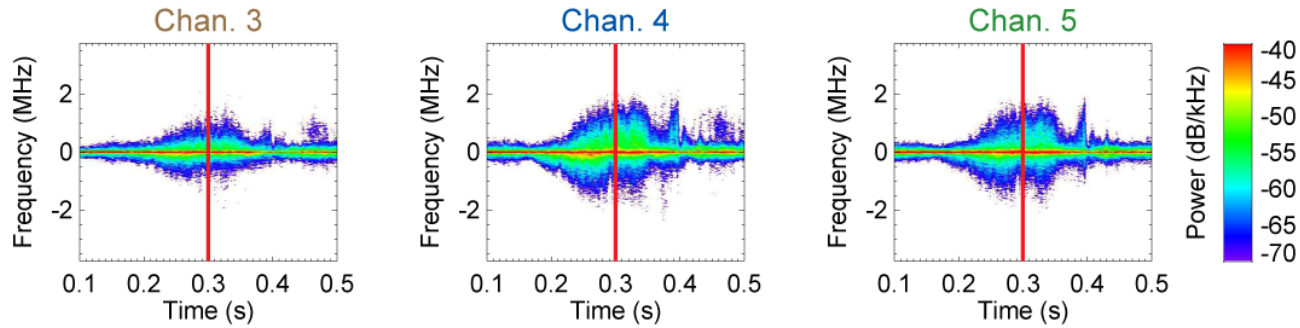


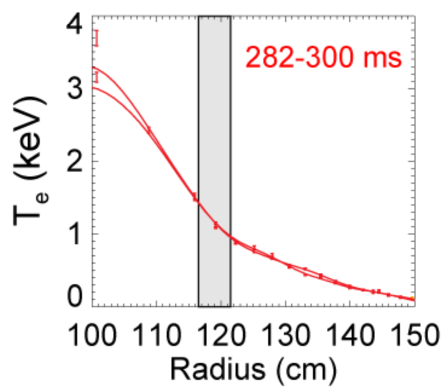


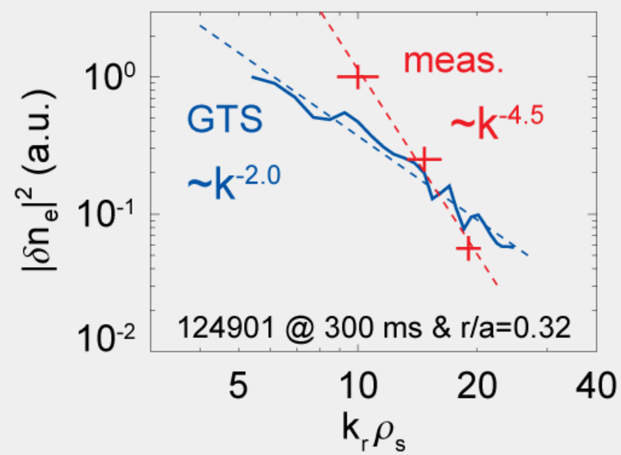
Measured k_r-spectrum in L-mode plasma is steeper than k_r-spectrum from GTS simulation

5.5 kG, 600 kA, 2 MW HHFW, R=119 cm, r/a≈0.32









GTS: S. Ethier, W. Lee, and W. Wang

"Global" NL GTS simulation is electrostatic with adiabatic ions and actual mass ratio

Summary

- The NSTX collective scattering system is a valuable tool for investigating ETG turbulence
- Enhanced fluctuations coincide with ∇Te exceeding the ETG critical gradient
- Fluctuation amplitudes decrease when the E×B shear rate exceeds the ETG growth rate
- Fluctuations amplitudes decease at higher B_T
- In H-mode, k_r-spectrum is steeper near core compared to mid-radius
- Comparisons between measured fluctuations and “global” nonlinear GTS simulations have begun