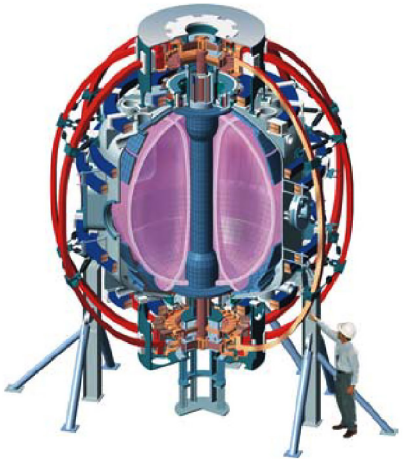
Supported by



XP-439: Investigation of Core Long WavelengthTurbulence

S. Kubota
Institute of Plasma and Fusion Research, UCLA

NSTX Results Review
September 20 – 21, 2004
PPPL

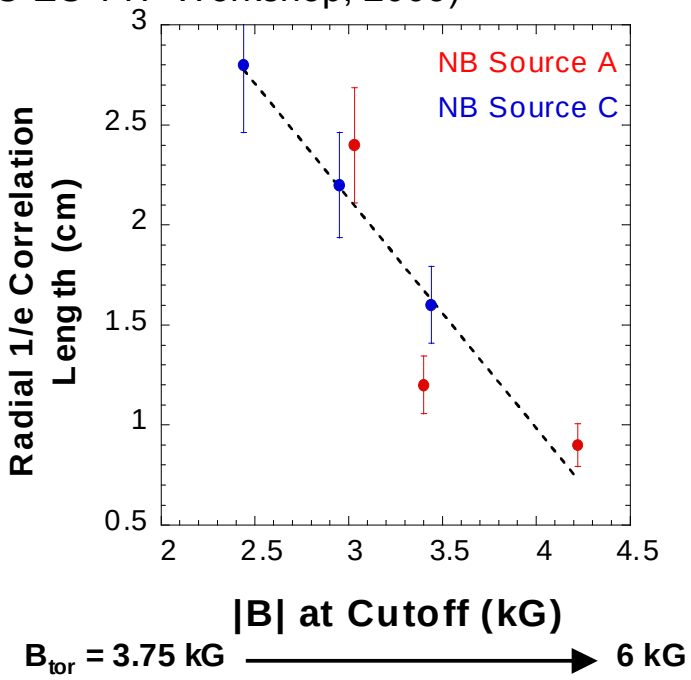
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
NYU
ORNL
PPPL
PSI
SNL
UC Davis
UC Irvine
UCLA
UCSD
U Maryland
U New Mexico
U Rochester
U Washington
U Wisconsin
Culham Sci Ctr
Hiroshima U
HIST
Kyushu Tokai U
Niigata U
Tsukuba U
U Tokyo
JAERI
Ioffe Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
U Quebec

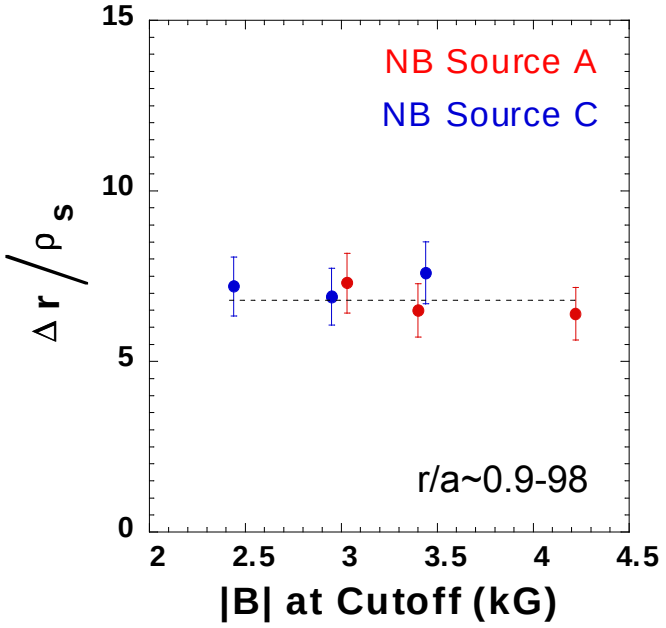
Motivation and Goals

- Motivation
  - Gyrokinetic linear stability analyses suggest the growth rates of instabilities can be small. These depend on aspect ratio, β gradient, T_e/T_i ratio, magnetic shear, etc., and location in the plasma.
  - Detailed comparison of code and experimental data necessary to elucidate turbulence driven transport.
  - First quantitative measurements of long-wavelength (ITG, TEM - $k_\theta \rho_s \leq 1$) core turbulence in ST.
- Goals
  - Characterization and correlation with confinement properties, using the correlation reflectometer and homodyne quadrature reflectometer for measurements of turbulence radial correlation lengths, fluctuation levels and spectra.
  - Detailed comparison of these quantities with those predicted by GYRO (D.R. Mikkelsen, et al.). These comparisions require detailed profile information as well as interfacing with 2D reflectometer code simulation (G. Kramer, et al.).

Previous Measurements and New Hardware

(M. Gilmore, US-EU TTF Workshop, 2003)

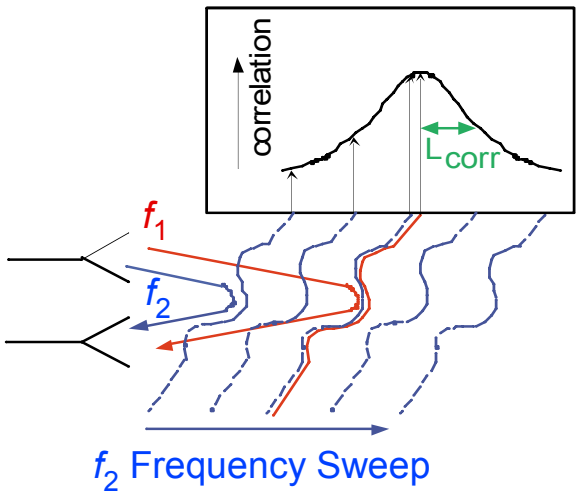




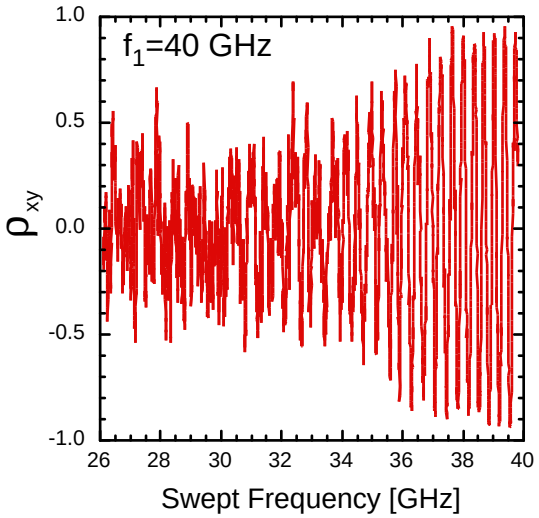
- New system uses a higher frequency band (26-40 GHz, n_{cr}~0.85-2.0x10^{13} cm^{-3}) for access to higher densities and has better time resolution (15 ms).
  - Measurements down to ρ~0.3 have been achieved.
- Additional homodyne quadrature reflectometers at (30, 42 and 49 GHz) available for measurements of $\Delta\phi$ (fluctuation level and spectrum).
- Above systems have fast data acquisition (8 MSa/s) for observing wide range of fluctuation phenomena from slow MHD (~kHz) to CAEs (~1-2 MHz).

Turbulence Radial Correlation Lengths via Reflectometry

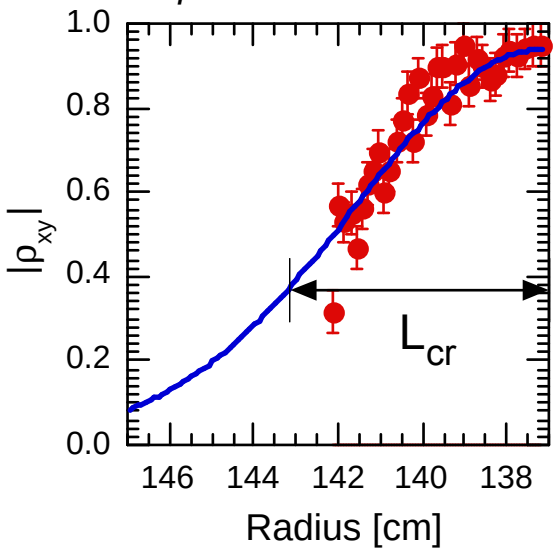
Principle of Radial Correlation Length Measurements



Correlation Coefficient Function vs Swept Frequency



Correlation Coefficient Function Envelope vs Radius

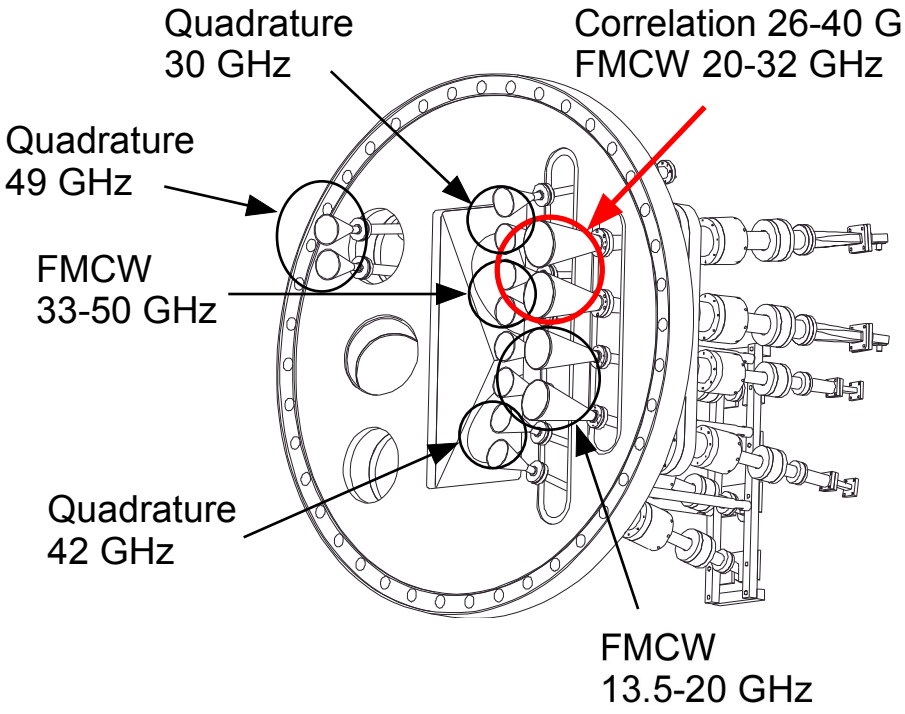


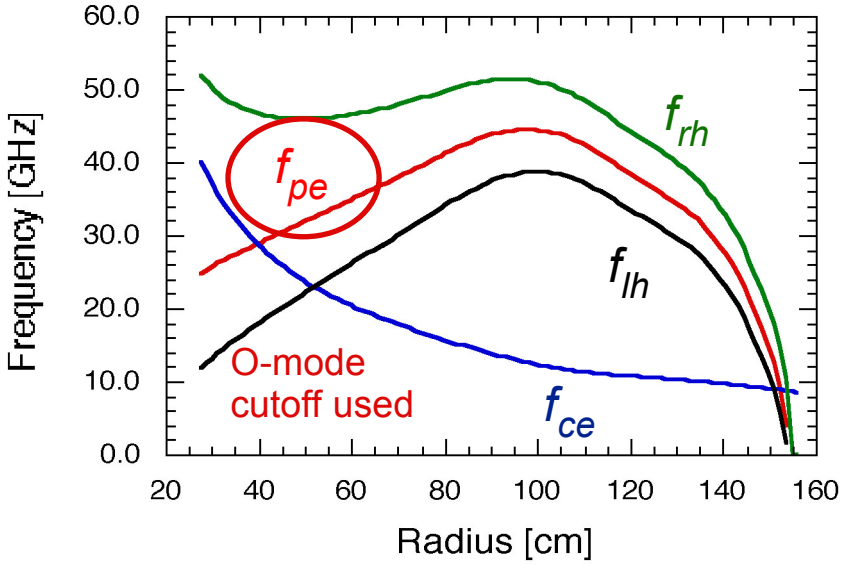
- Fixed frequency f_1 and swept frequency f_2 with identical launch and receive horns reflect from different cutoff layers in the plasma.
- Correlation coefficient function of homodyne signals *x* and *y* is modulated by the swept DC phase of f_2.

$$\rho_{xy} = \frac{\langle (x - \langle x \rangle)(y - \langle y \rangle) \rangle}{\sqrt{\langle (x - \langle x \rangle)^2 \rangle} \sqrt{\langle (y - \langle y \rangle)^2 \rangle}}$$

- Envelope of correlation coefficient function mapped from from frequency to radial position using density profiles from Thomson scattering.
- Correlation length L_{cr} is defined here as the *e*-folding distance of the correlation coefficient function envelope.

Reflectometer Diagnostics on NSTX





Device Parameters for These Experiments:

R_0	= 100 cm
a	= 55 cm
I_p	= 0.58-85 MA
B_T	= 0.32-0.44 T
κ	= 1.9
δ	= 0.45

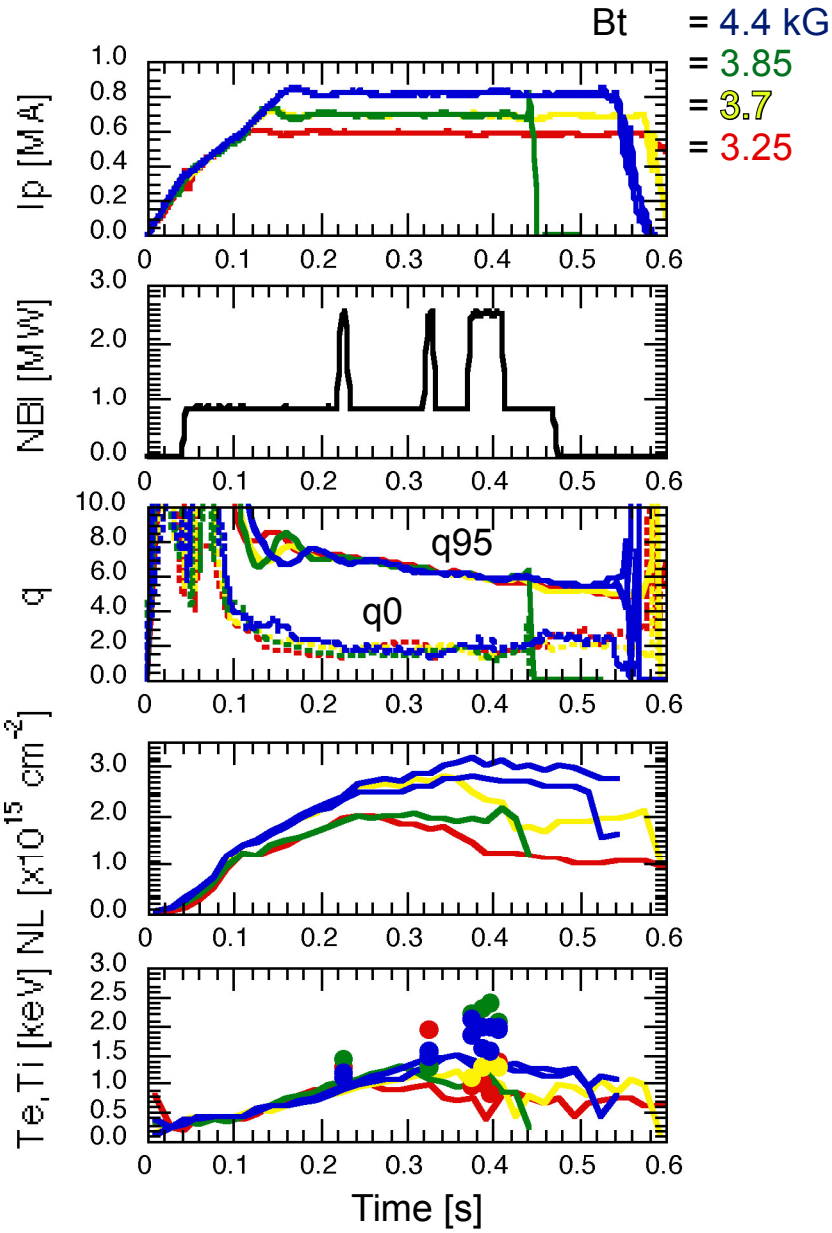
Array of reflectometer horns aligned perpendicular to magnetic flux surface at edge.

Scale (cm)

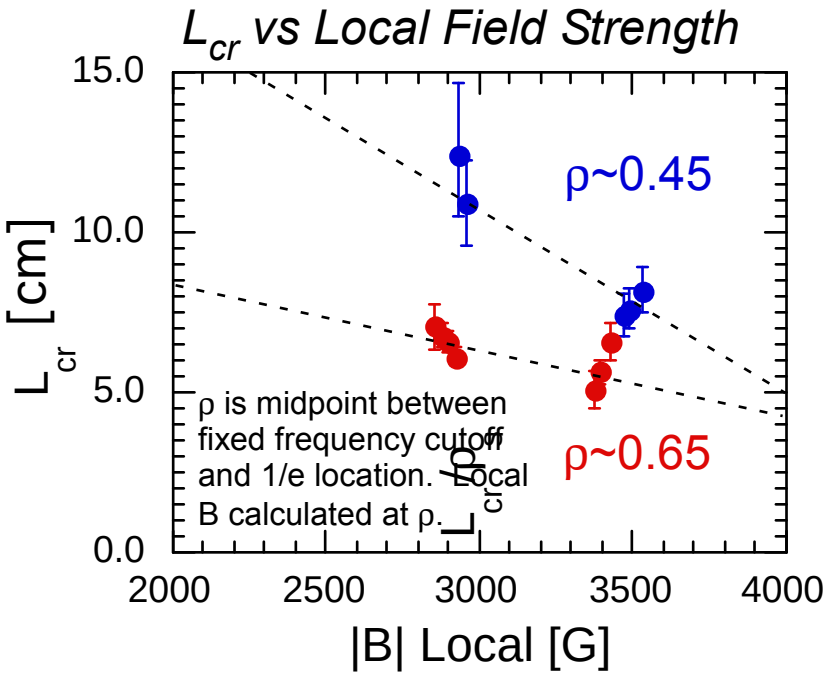
NSTX Vacuum Vessel

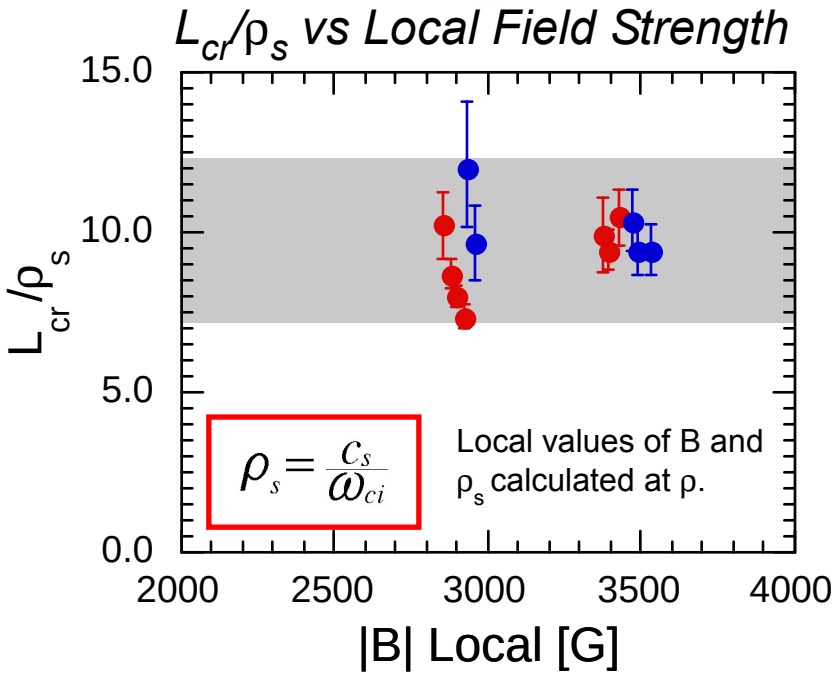
Experimental Conditions Investigated

- Various scans were performed:
  - ρ* scan at constant q.
  - I_p Scan at fixed B_t.
  - B_t Scan at fixed I_p.
- Radial scan by changing fixed-frequency of correlation reflectometer: 30, 35, and 40 GHz (n_{cr}=1.1, 1.5 and 2.0x10^{13} cm^{-3}).
- Conditions were difficult:
  - MHD and beam-driven instabilities (fishbones, TAEs, CAEs) were a problem.
  - Collapse of T_e and n_e due to pressure peaking during middle of discharge.
  - Will need to revisit under better conditions.
- Preliminary estimates of L_{cr}, $\Delta n_e/n_e$.
- Three comparisons presented here:
  - ρ* scan: B_t=3.7 and 4.4 kG, ρ~0.45 and 0.65.
  - ρ* scan: B_t=3.25, 3.85 and 4.4 kG, ρ~0.7.
  - Radial scan for B_t=4.4 kG, I_p=850 kA.

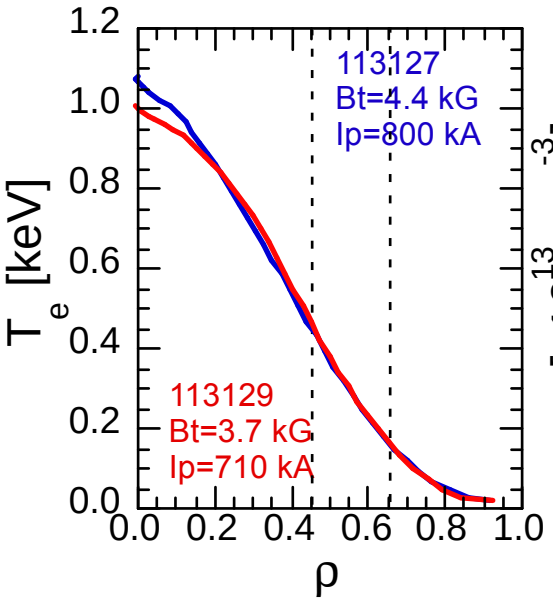


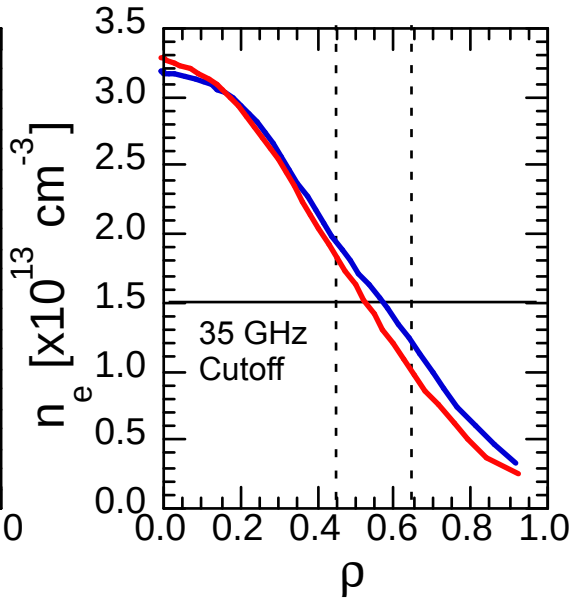
ρ* Scan: L_{cr}~5-12 cm at ρ~0.45 and 0.65



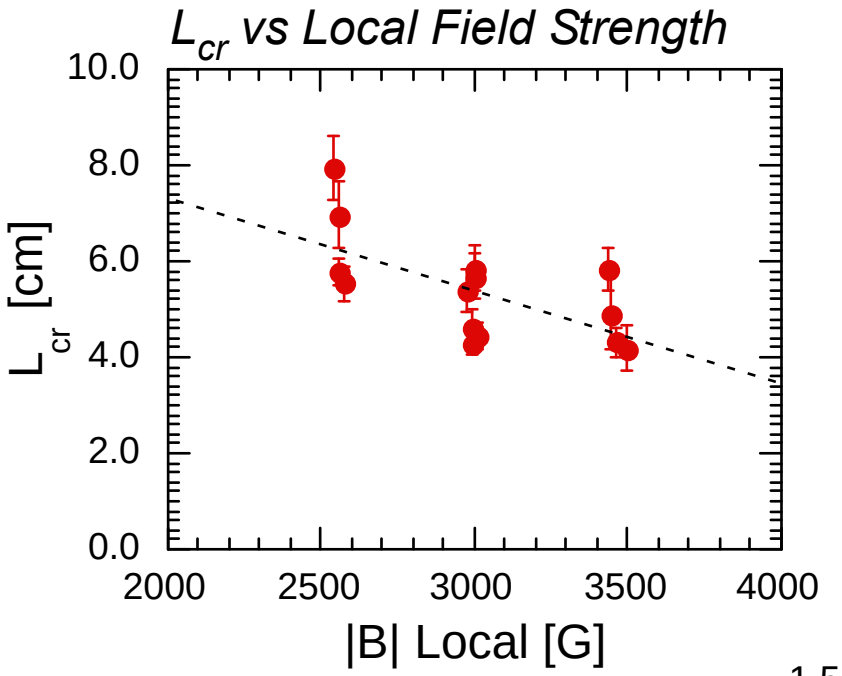


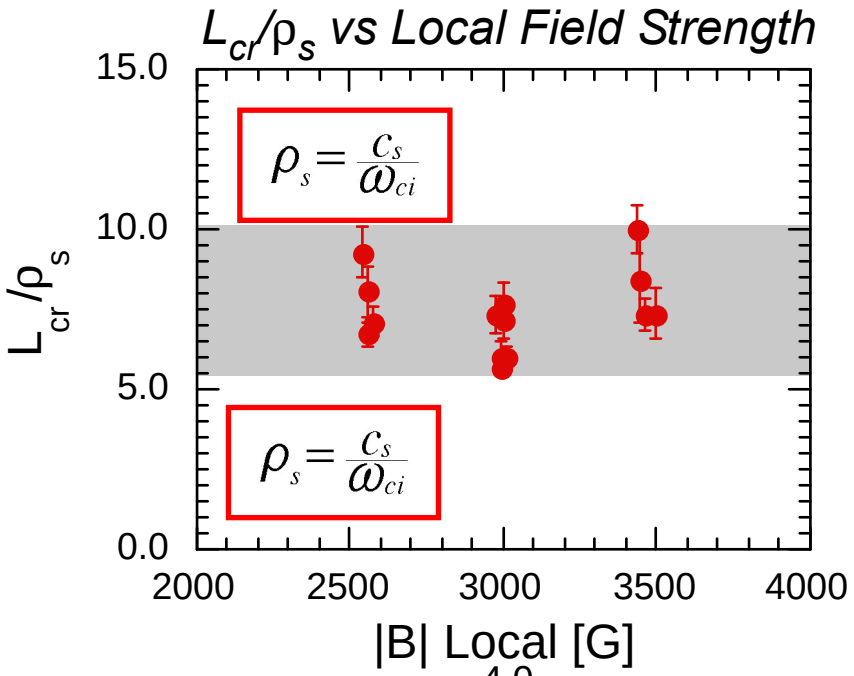
- B_t=3.7 and 4.4 kG, f_{fixed}=35 GHz.
- L_{cr} ranges from 5-12 cm at ρ~0.45 and 0.65; increases inversely with ρ and B.
- L_{cr} normalized by ρ_s is roughly constant (~7-12).
- Measurement location (ρ) is taken as midpoint between fixed frequency cutoff and 1/e location.



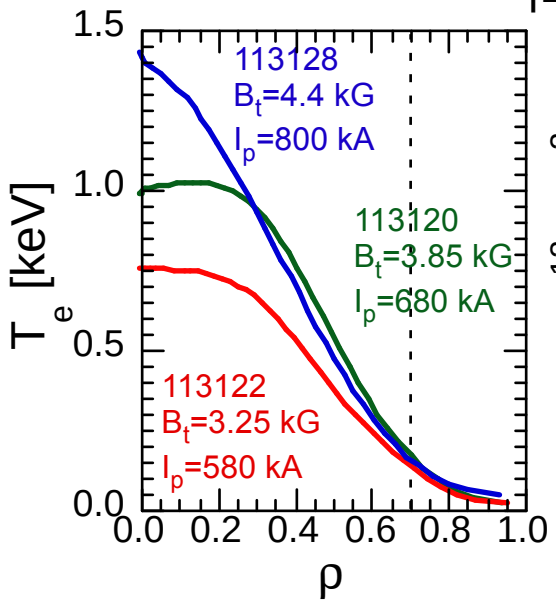


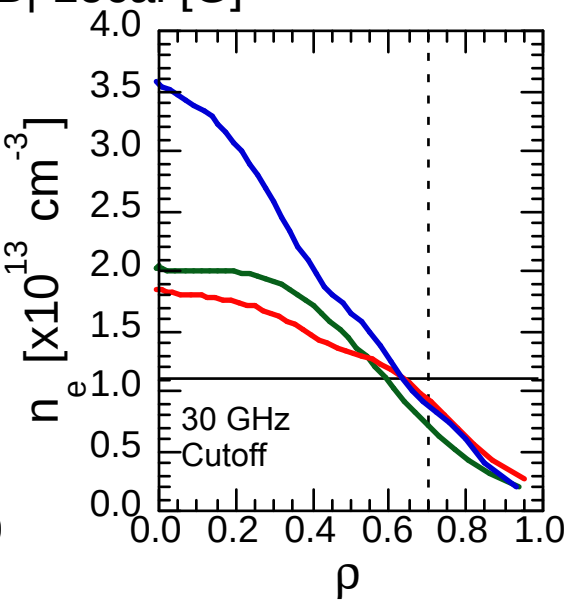
ρ* Scan: L_{cr}~4-8 cm at ρ~0.7



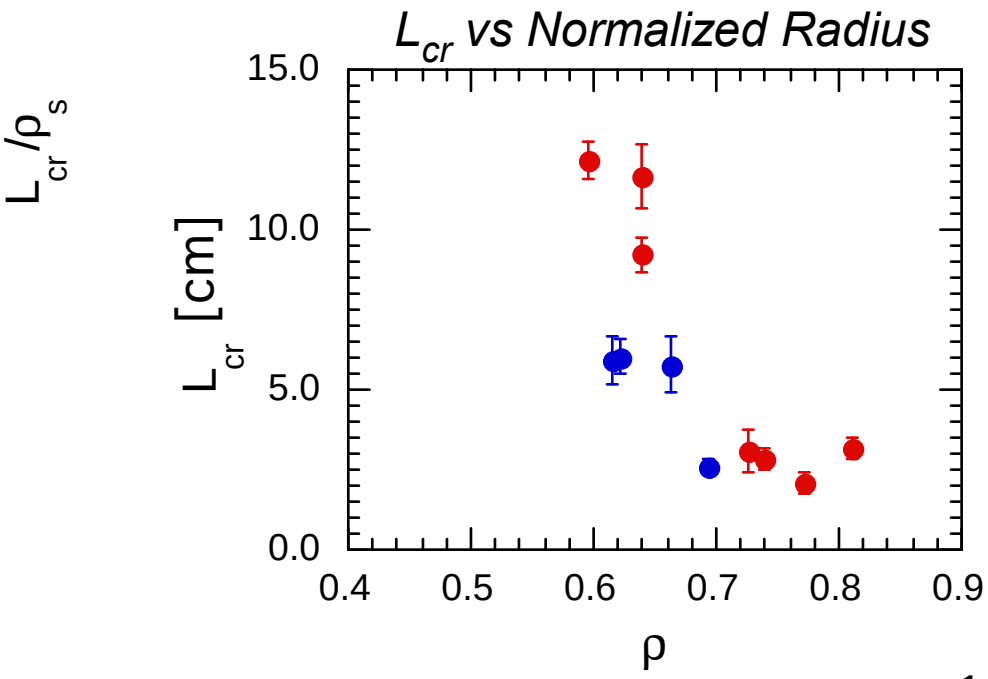


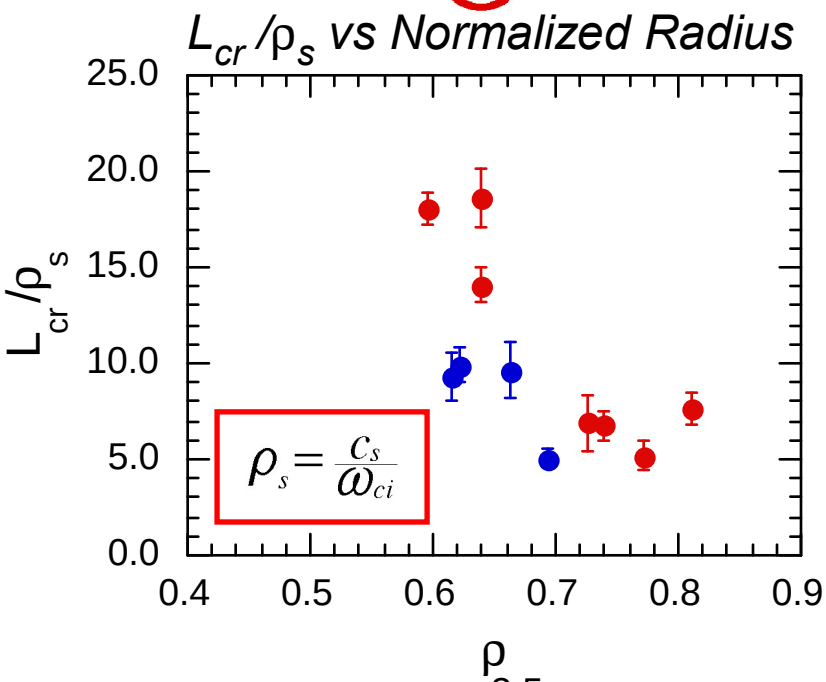
- B_t=3.25, 3.85 and 4.4 kG, f_{fixed}=30 GHz.
- L_{cr}~4-8 cm at ρ~0.7.
- L_{cr} increases inversely with B.
- L_{cr} normalized by ρ_s is roughly constant (~6-10).



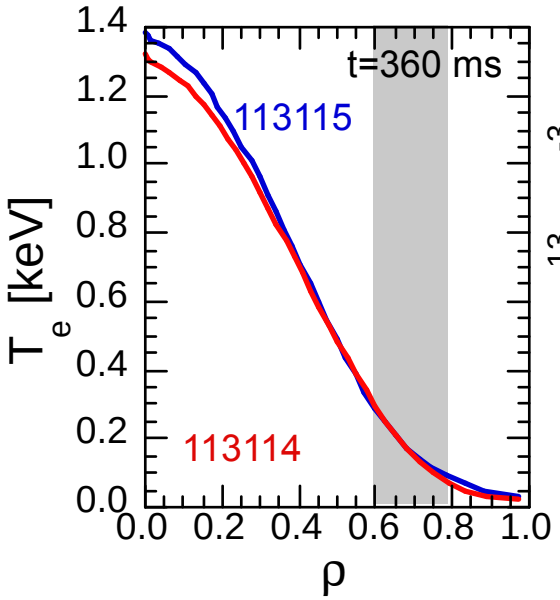


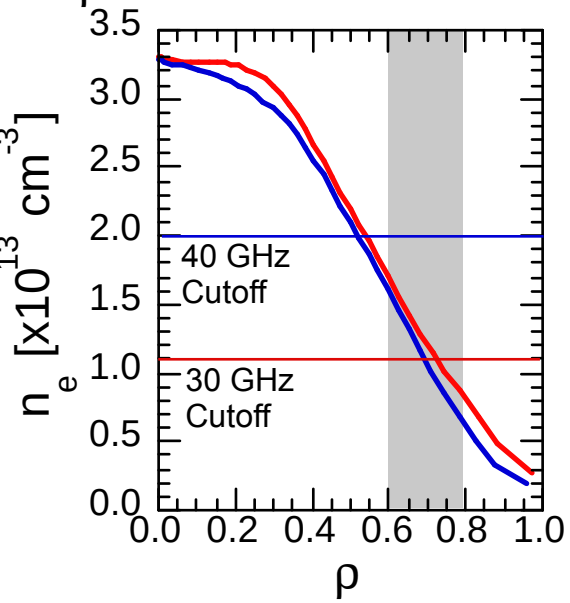
Radial Scan: L_{cr}~2-12 cm at ρ~0.6-0.8



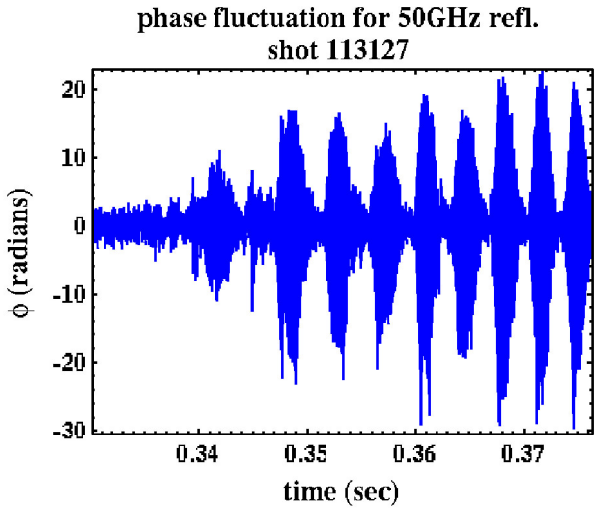


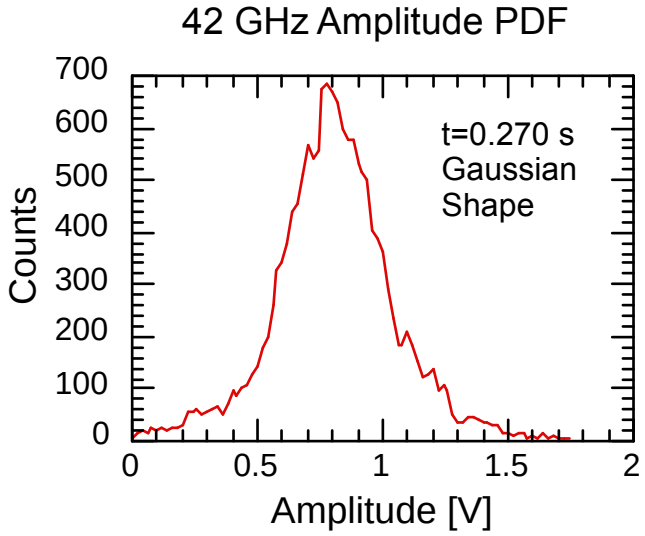
- B_t=4.4 kG, I_p=850 kA, f_{fixed} at 30 and 40 GHz.
- L_{cr} ranges from 2-12 cm over radius of ρ~0.6-0.8.
- L_{cr} increases inversely with ρ.
- L_{cr}/ρ_s varies from 5-19 over this range.

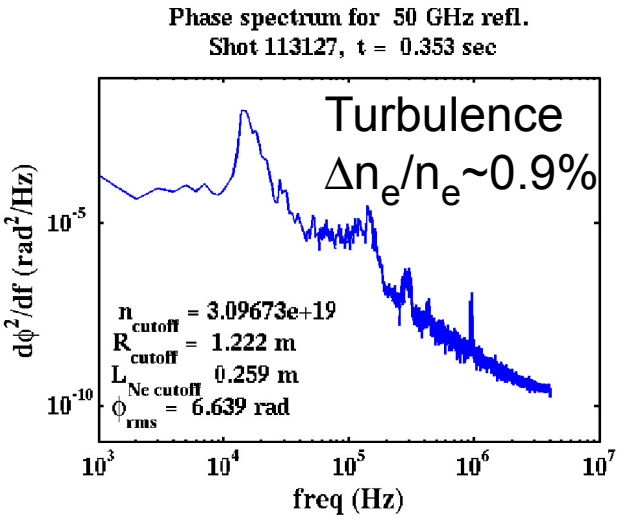


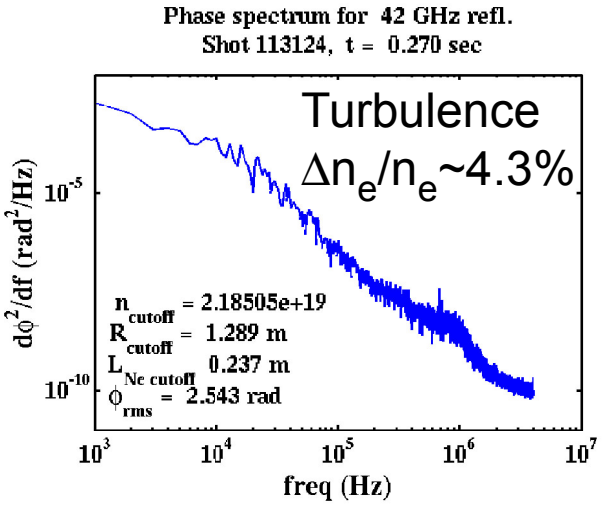


Fluctuations Observed With Reflectometers

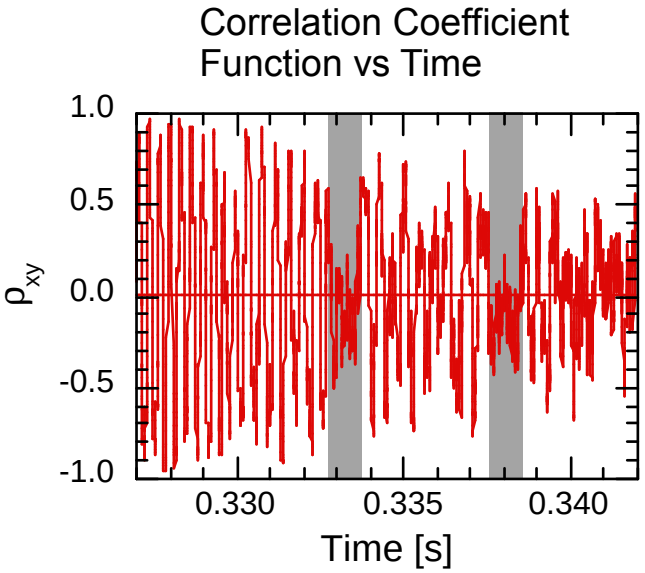


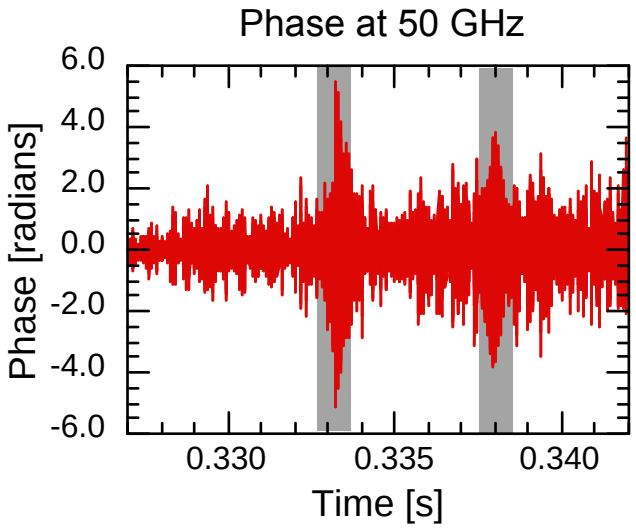






- Assumes k_r~1 cm^{-1}.





- Correlation drops out when large amplitude modes appear.

Summary for XP-439 and Future Work

- Preliminary measurements of turbulence L_{cr} and $\Delta n_e/n_e$.
  - L_{cr} ranges of 2-25 cm over ρ~0.3-0.8.
  - $\Delta n_e/n_e$ from ~0.5% in core and up to ~5% in edge.
- Complements previous edge data.
- Preliminary trends:
  - Smallest L_{cr} at the largest radius and magnetic field.
  - For matched profiles in the ρ^* scan, L_{cr}/ρ_s~6-12.
  - For radial scan, L_{cr}/ρ_s~5-19 and increases toward core.
- Tasks remaining:
  - Effects of coherent modes.
  - Comparison with rotation data, TRANSP results.
  - Comparison with results from GYRO.
  - 2D reflectometry code.
  - Similar turbulence analysis to measurements for XP-411.
- Future work:
  - Increase data set. Reproducible discharges, possibly ohmic.