Investigation of long-wavelength turbulence in the core of NSTX plasmas

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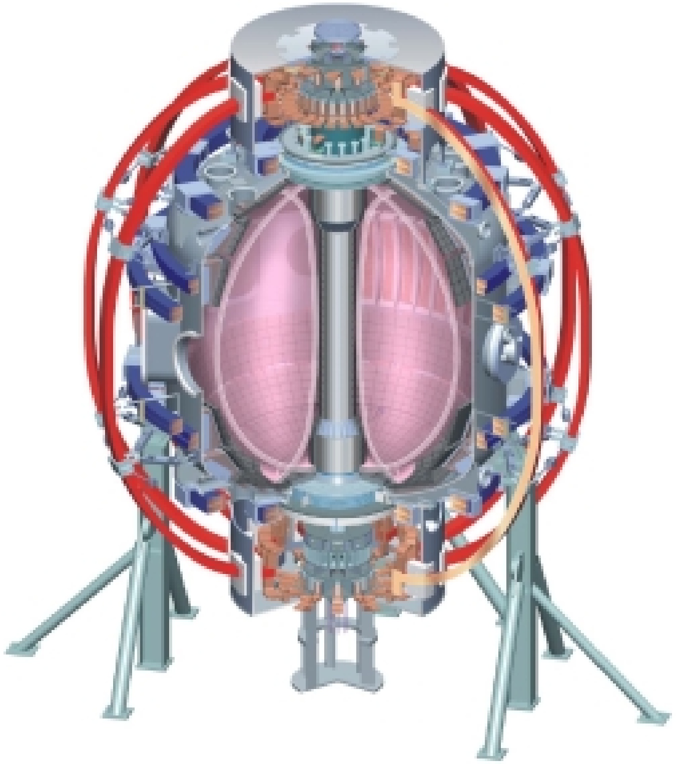


NSTX PAC 16 Presentation: 9/10/04

Goals of research

Primary Goal

- **For the first time, start quantitative characterization of long wavelength turbulence in the core of an ST plasma. L-mode plasma utilized.**

Secondary, longer term goals

- Compare experimental turbulence data with linear growth rate calculations and estimations of ExB shear flow rates.
    - should be quite different in the core of Ohmic, RF and NBI heated plasmas
- Make a direct comparison of measured turbulent correlation lengths with those predicted using non-linear, gyrokinetic calculations.
    - requires detailed profiles of electron temperature, ion temperature, density, magnetic shear, Zeff, etc. (as does above)
    - analysis using the **GYRO** code : **This work is underway – Dave Mikkelsen, Candy, Waltz et al.**
    - Also integrate data into 2-D reflectometry simulation code (Nazikian, Kramer et al)

Long-wavelength turbulence in NSTX

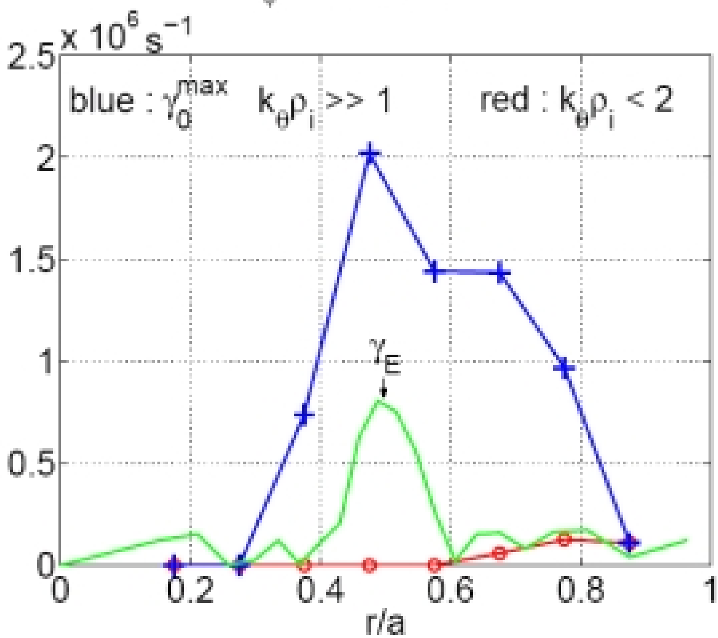
Large ExB flows expected in NBI plasmas

ITG generally predicted to be stable in core.

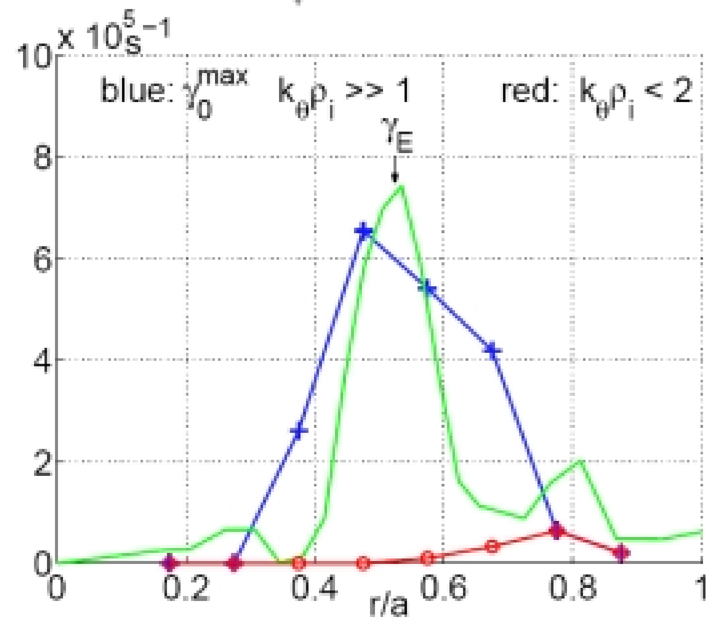
Linear stability calculations using **measured profiles**

Bourdelle et al TTF 2001

#104001, 0.28 s
NBI 1.5 MW, $\beta_T \sim 9\,\%$
$B_{T0} = 0.4$ T
$n_{e0} = 4.2\ 10^{19}\ m^{-3}$
$V_\varphi^{max} = 200$ km/s



#104370, 0.2 s
NBI 4MW, $\beta_T \sim 21\,\%$
$B_{T0} = 0.3$ T
$n_{e0} = 2.6\ 10^{19}\ m^{-3}$
$V_\varphi^{max} = 150$ km/s



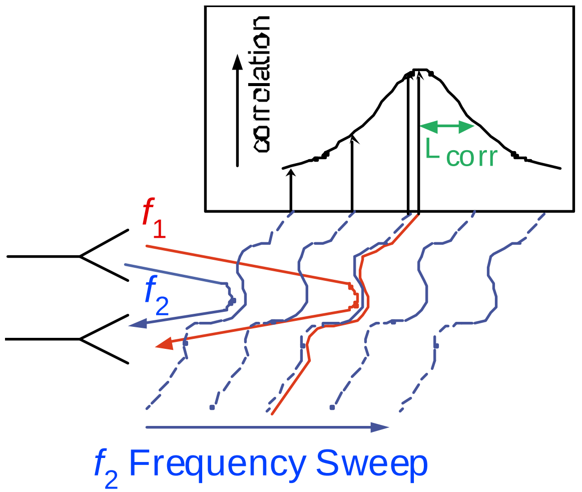
ITG appears stable inside r/a ~ 0.6 – flat ion temperature profile?

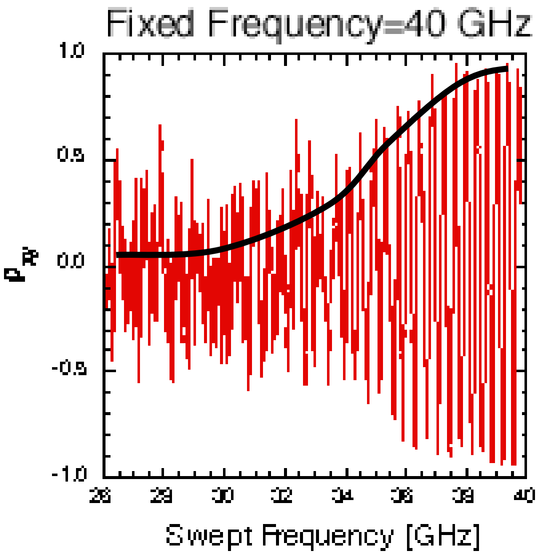
ExB shear also stabilizing in this core region

Theoretical/gyrokinetic calculations sensitive to details

- **Calculations of linear growth rates of instabilities in NSTX depend sensitively on a wide range of parameters**
  - aspect ratio, beta, gradient in beta, electron to ion temperature ratio, magnetic shear, etc.
  - sensitive to exactly WHERE you look in the plasma
- **It is clear that each case has to be analyzed individually**
  - Codes need detailed profile data for a wide range of parameters
  - Profile measurement accuracy an issue: need to select control knobs for maximum effect
- **Turbulence <u>measurements</u> in the <u>core</u> of NSTX plasmas very important**
- **Unique configuration should help unravel physics of anomalous transport in fusion plasmas**
- **Current work represents first quantitative turbulence study in the core of ST's.**
- Previous data obtained on larger aspect ratio, higher field tokamaks (DIII-D, JT-60, etc)

Turbulence Correlation Lengths via Reflectometry





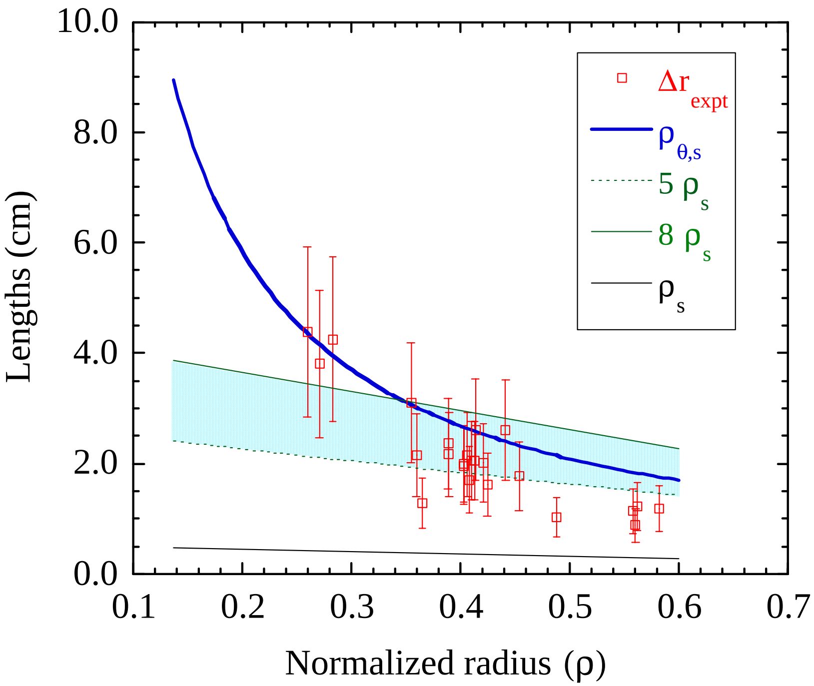
- Fixed frequency f_1 and swept frequency f_2 with identical launch and receive paths reflect from different cutoff layers in the plasma
  - Correlation coefficient of homodyne signals is modulated by the swept DC phase of f_2.

- Envelope of correlation coefficient function is mapped from frequency to radial position using density profiles from Thomson scattering

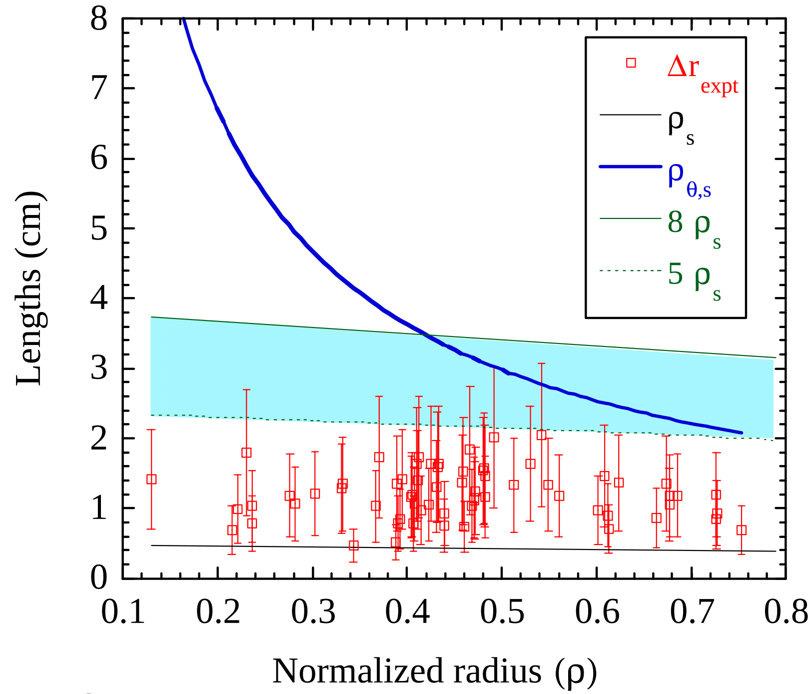
- Correlation length Lcr is defined here as the e-folding distance of the correlation coefficient function

Correlation Length Measurements in DIII-D

L-mode plasmas



QDB plasmas



Terry Rhodes, UCLA

Correlation length varied from ~5 to 10ρ_s in L –mode plasmas.

Similar results in Ohmic plasmas

Correlation length is much smaller in the core of QDB discharges. Correlation length reduces to ~ 2 to 4 ρ_s

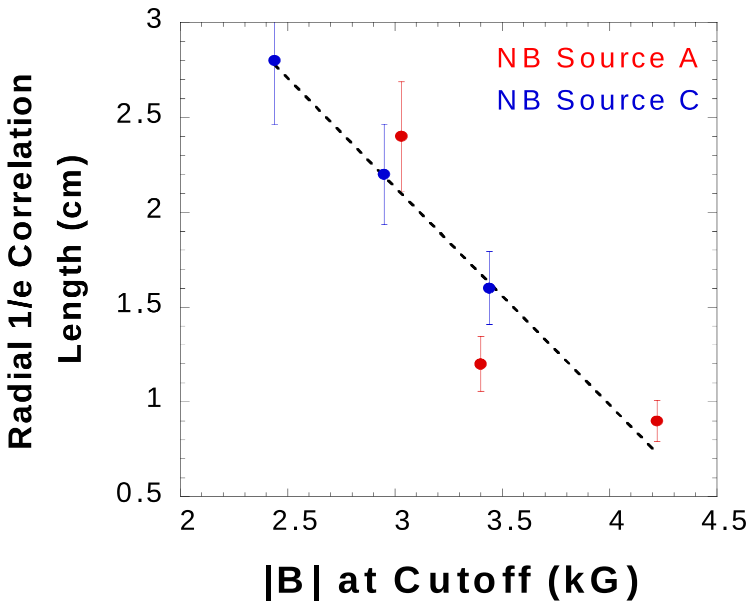
Previous correlation length measurements in NSTX

Measurements in very edge plasma, rho ~.95, ρ* scan

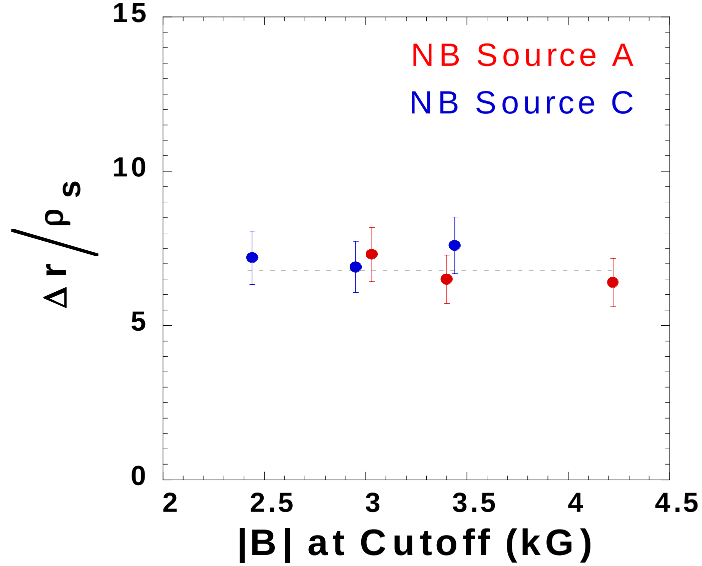
- Mark Gilmore (now at UNM) performed correlation length measurements of long wavelength modes in NSTX – but only in edge plasma at rho ~0.95

I_p/B_T ~ held constant edge q_{cyl}

Δr vs. |B| at cutoff



Δr normalized to ρ_s vs. |**B**|



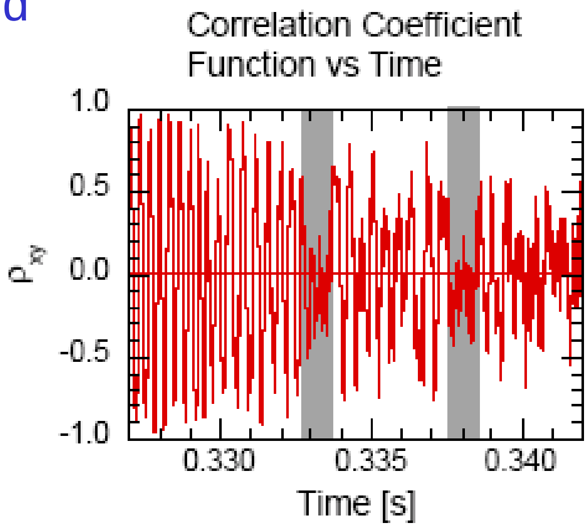
Long wavelength turbulent modes clearly exist in the edge plasma of NSTX - reflectometry, probes, GPI

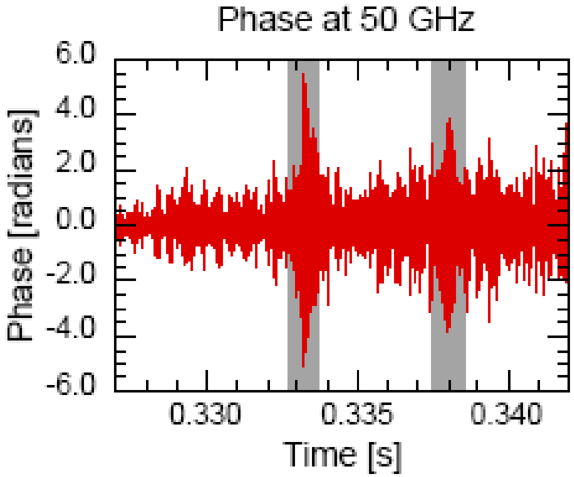
Comparison with gyrokinetic codes in edge region very difficult

Further motivates core measurement.

Challenges for core reflectometer measurements in NSTX

- In the core plasma, density profiles tend to continually evolve
  - Previous data taken in edge : density gradient constant for extended period
  - In the core, gradients are evolving – cutoff layer a moving target
- Need to identify interesting plasmas, where profile shape allows access to core via reflectometry
  - Precludes very high power NBI and H-mode discharges – accessibility at low field
- MHD & fast particle driven modes make correlation analysis somewhat more complicated

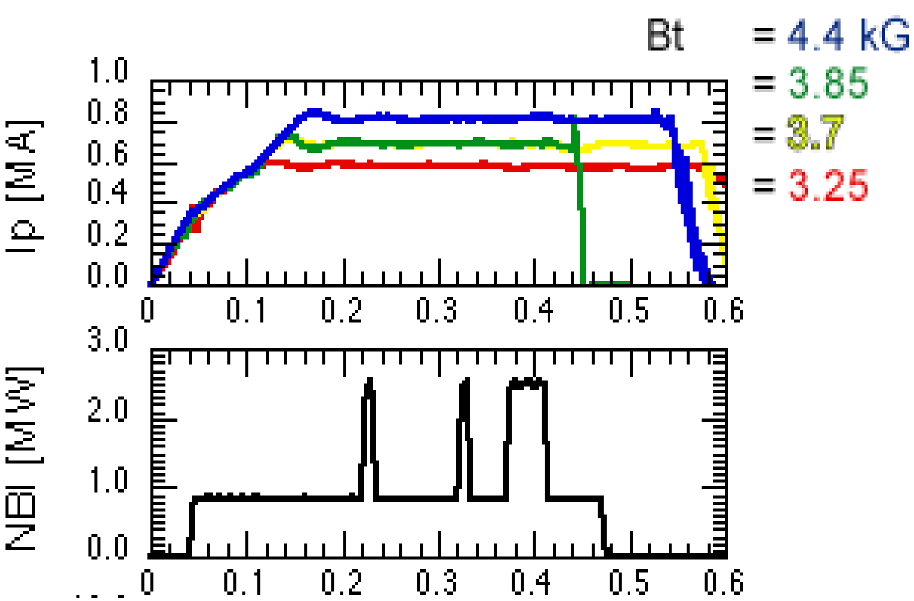


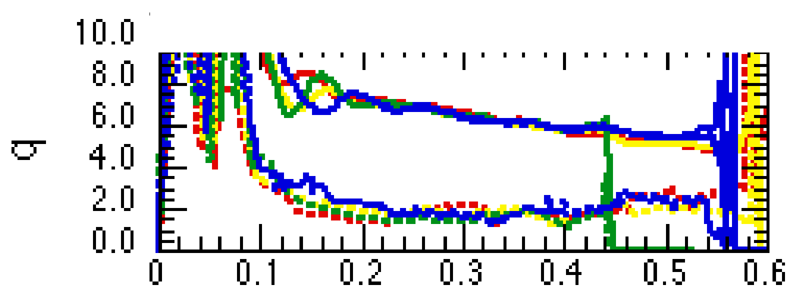


- Correlation drops out when large amplitude modes appear.

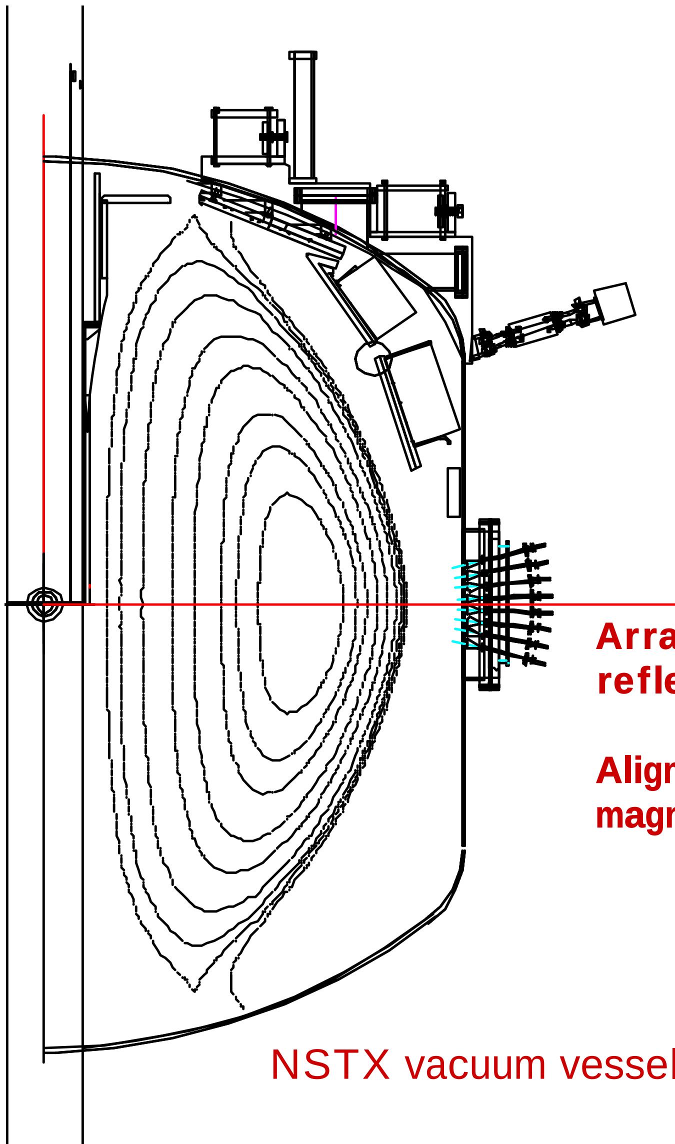
L-mode plasmas investigated

- **Initial data from single beam, NBI discharges.**
  - **Performed magnetic field/ρ* scans in L mode plasma: XP 439**
  - Plan comparison with predictions from **GYRO**
  - Future plans also include study of rf only and Ohmic plasmas,where role of ExB flow should be significantly less
  - **Also data from XP 411:** Investigation of improved electron confinement in low density/shear reversal L-mode discharges





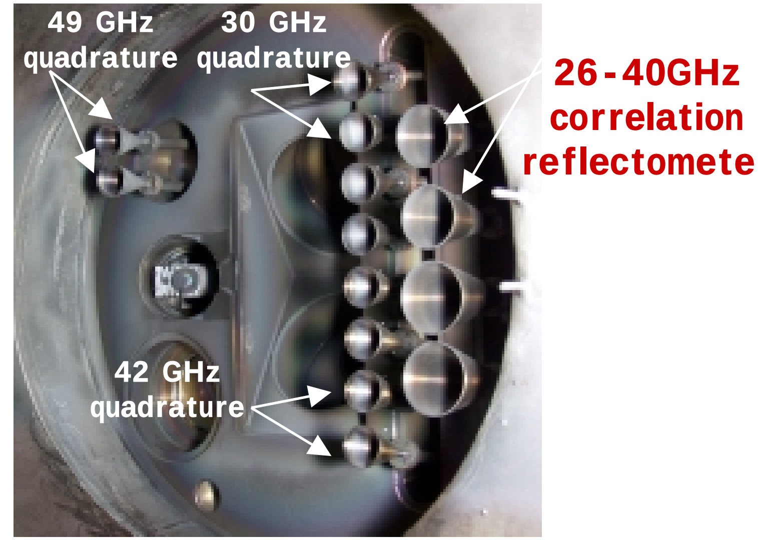
Reflectometry turbulence measurements on NSTX



Array of microwave reflectometer horns.

Aligned perpendicular to magnetic flux surfaces.

NSTX vacuum vessel

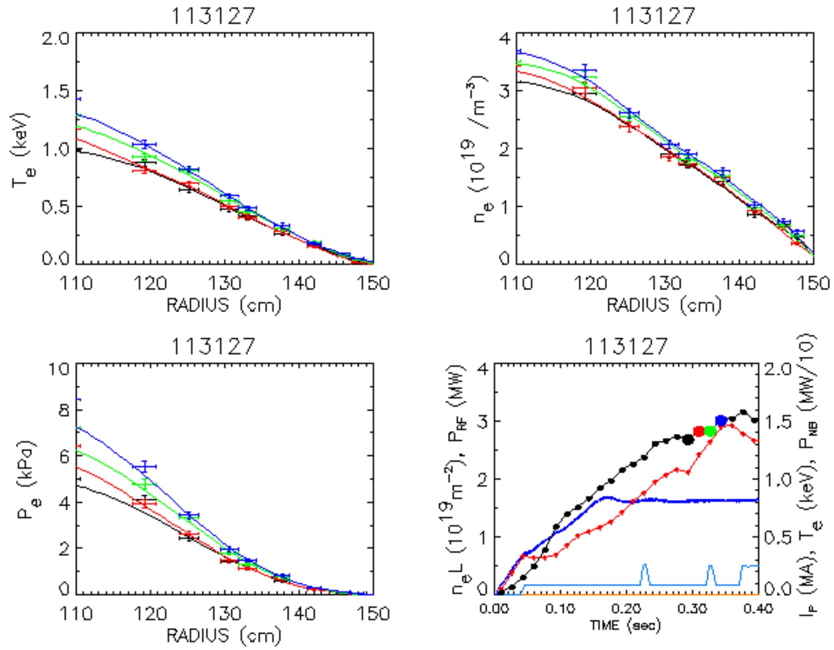


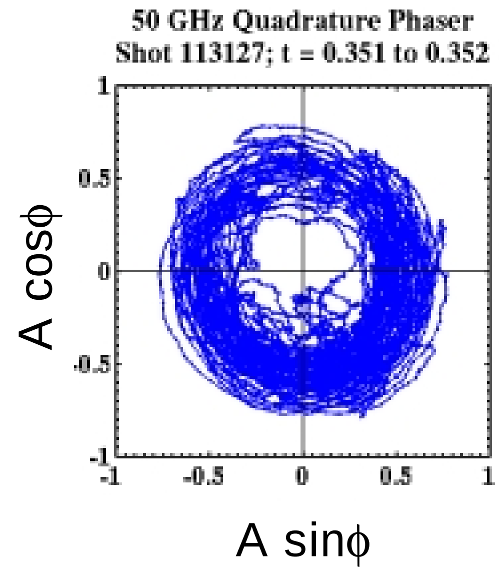
Device Parameters for These Experiments:

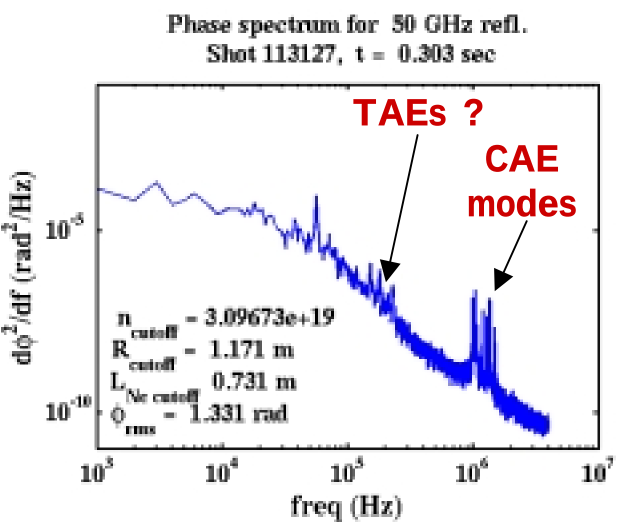
R_0	= 95 cm
a	= 62 cm
I_p	= 0.58-85 MA
B_T	= 0.32-0.44 T
κ	= 1.9
δ	= 0.45

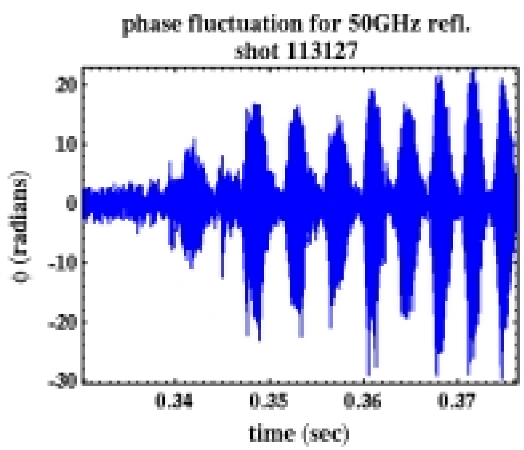
Turbulent Reflectometry Phase Spectra

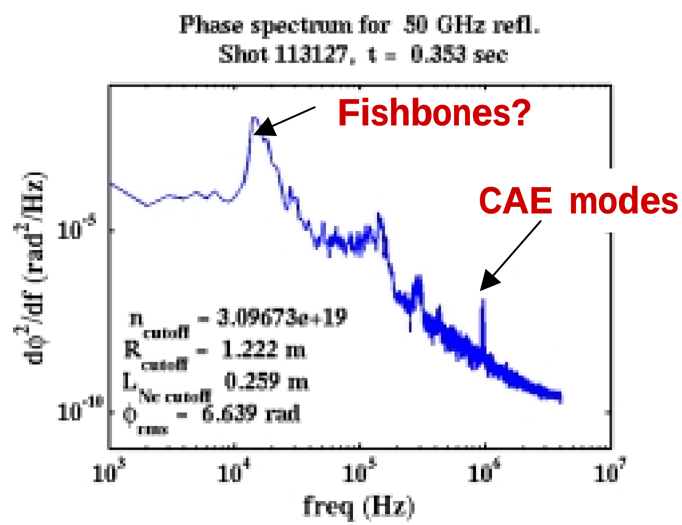
B_T = 4.4kG, Ip = 800 kA, ~1MW 60kV beam, rho ~0.25





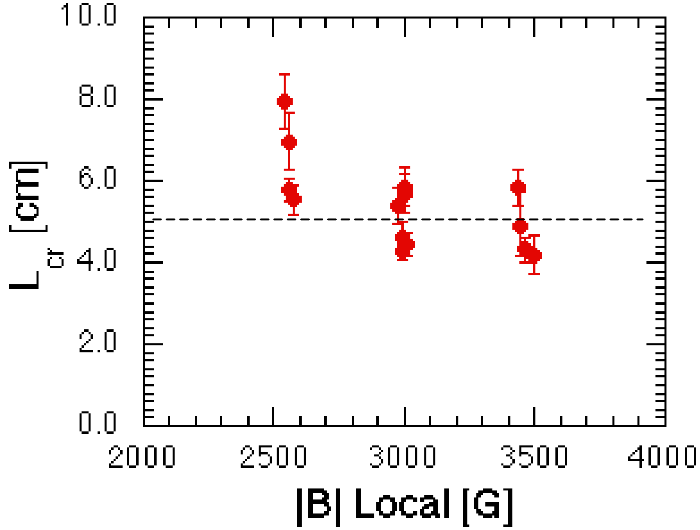


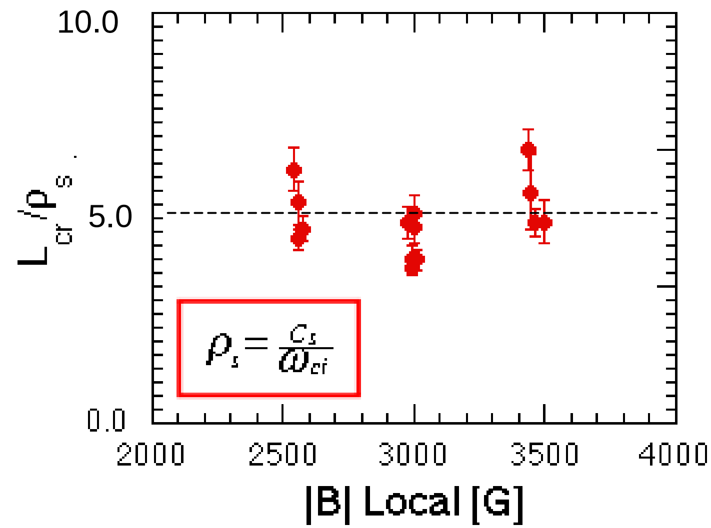




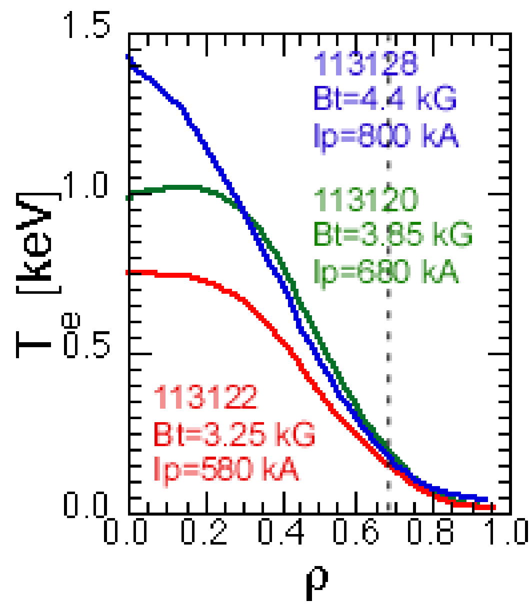
Correlation length measurements

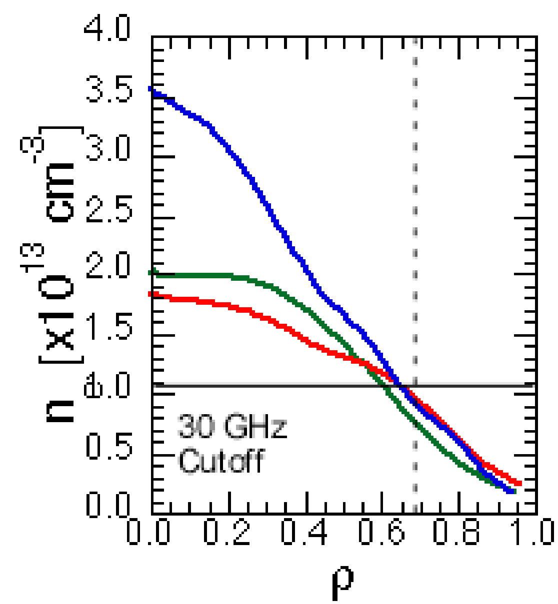
ρ* Scan: B_T=3.25, 3.85 & 4.4 kG, f_{fixed}=30 GHz, rho~.67



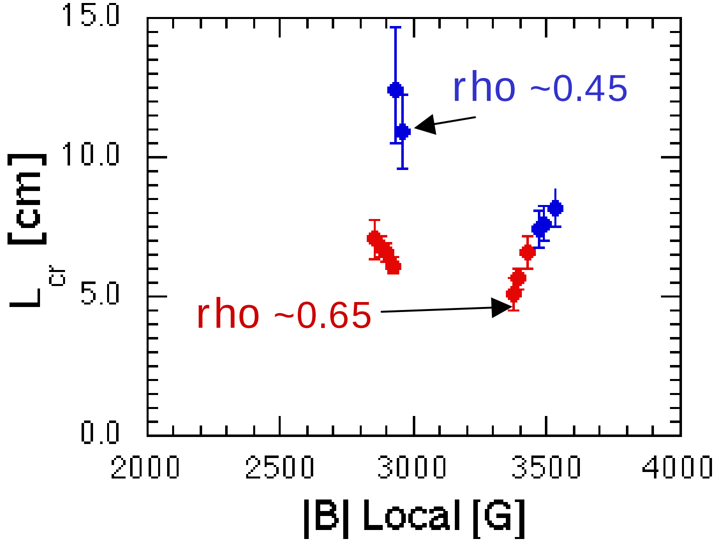


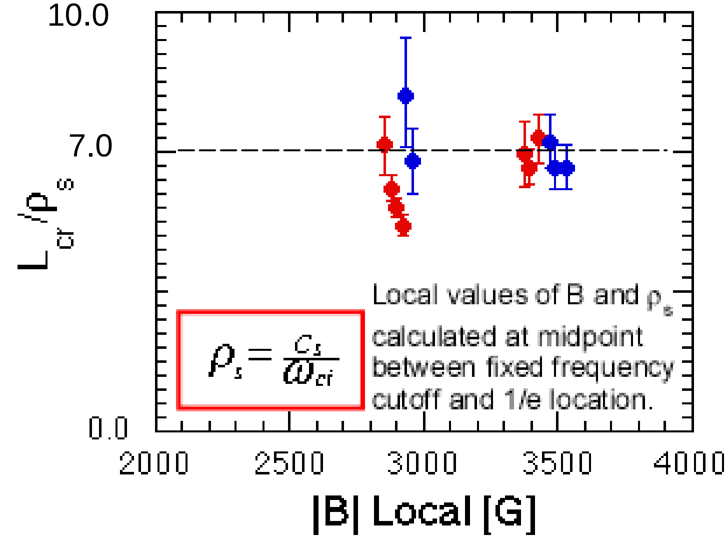
- Lcr ranges from 4-8 cm at radius of rho ~0.67.
- Lcr increases inversely with B.
- Lcr normalized by ρ_s is roughly constant (~5).
- Consistent with previous data from rho~0.95.



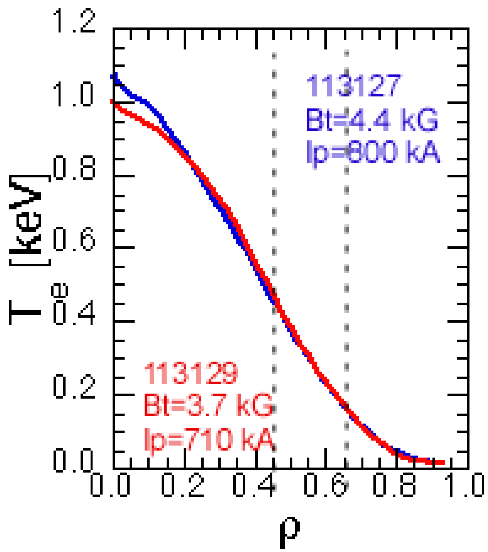


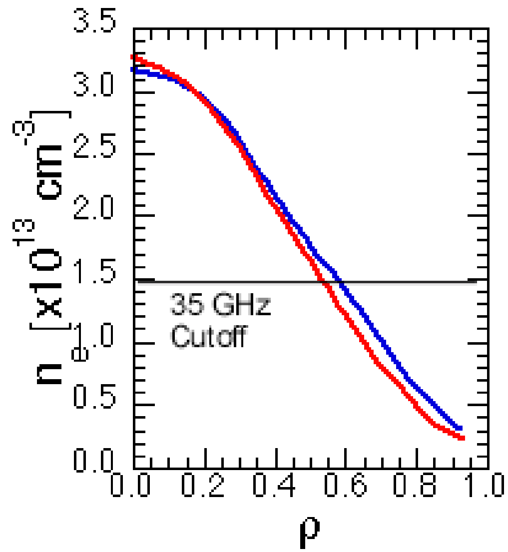
Correlation length measurements:
ρ* Scan: B_T=3.7 & 4.4 kG, f_{fixed}=35 GHz,rho ~ 0.55



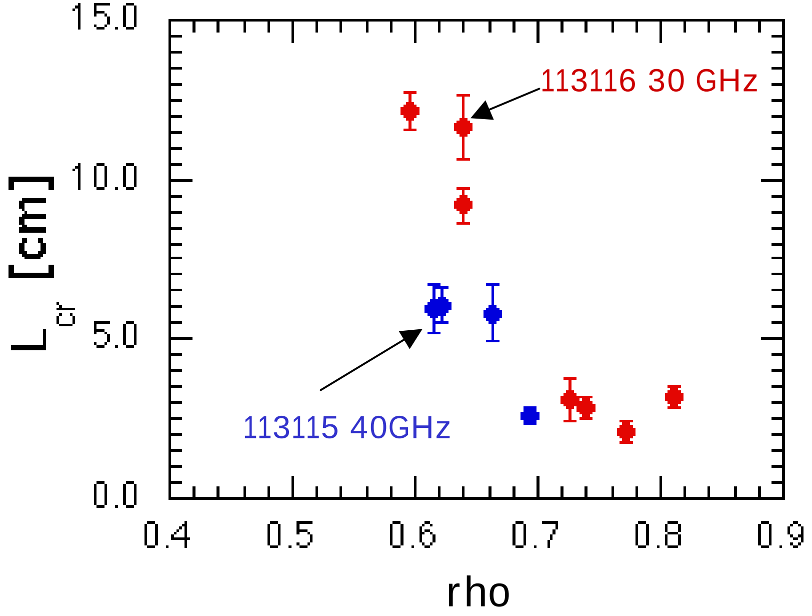


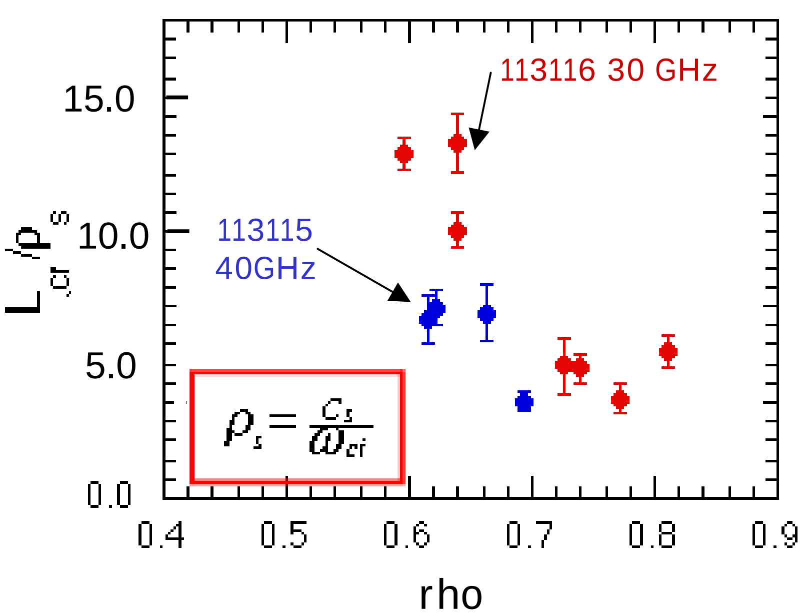
- Lcr ranges from 5-12 cm around rho ~0.45-0.65.
- Lcr tends to increase inversely with B.
- Lcr normalized by ρs is roughly constant (~7).
- Consistent with previous data but CL larger in terms of ρ_s





Radial Scan under fixed discharge conditions
: B_T=4.4 kG, Ip=850 kA, f_{fixed}=30 & 40 GHz





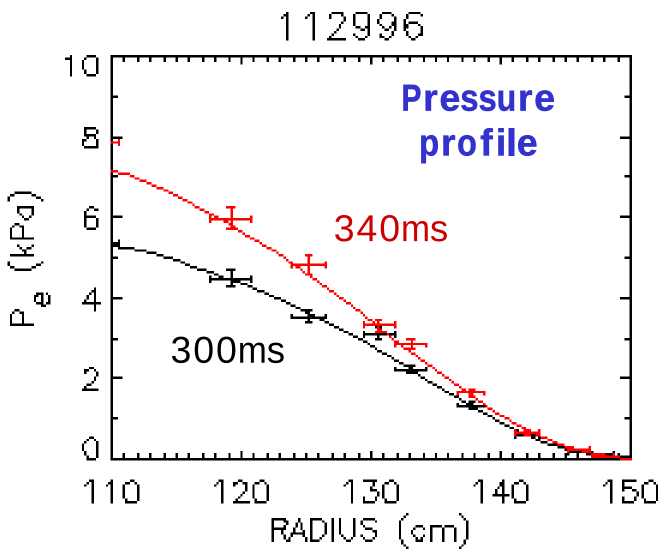
- L_{cr} ranges from 2-12 cm from rho ~ 0.6-0.8
- L_{cr} decreases significantly outward.
- L_{cr}/ρ_s decreases from 14 to 5 over this range.

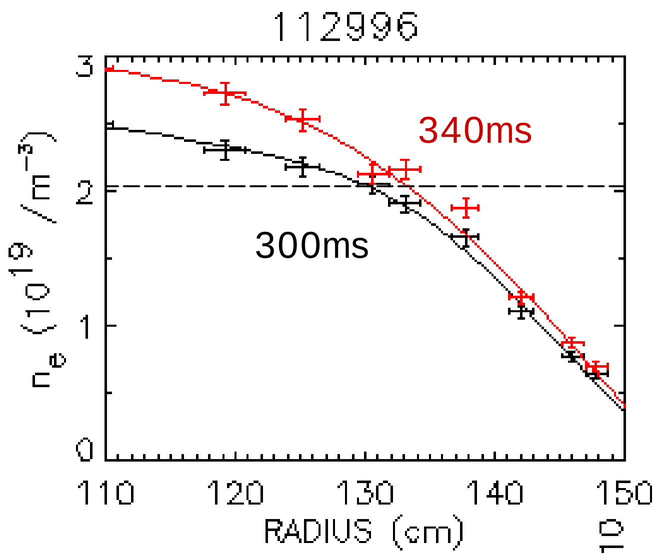
Correlation length normalized to ρ_s increases, deeper into the plasma.

Role of fast particle driven modes needs careful assessment. Note: data analysis is preliminary

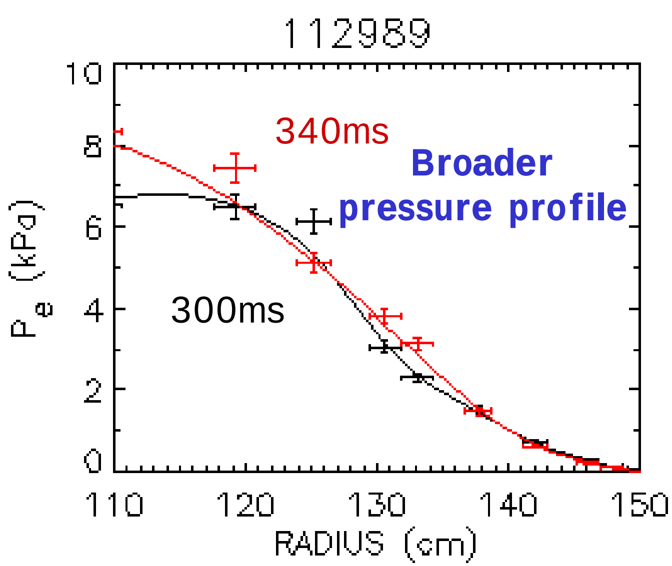
XP 411 Stutman et al:

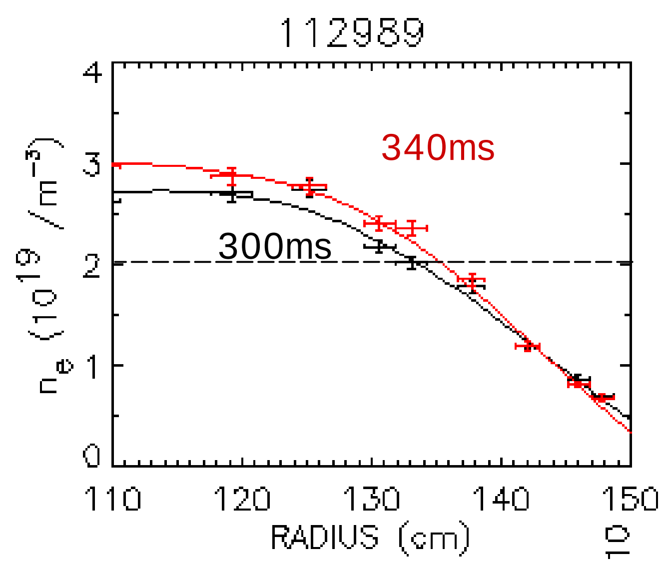
Investigation of improved electron confinement in low density/shear reversal L-mode discharges





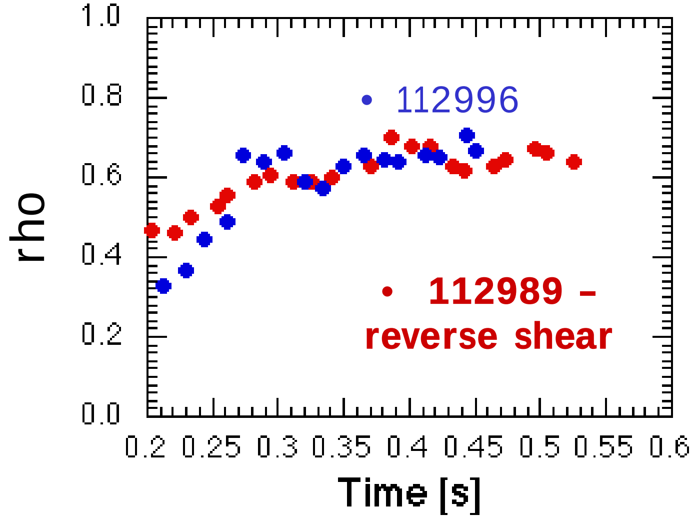
L mode plasma - beams at 125ms





Negative shear L mode plasma - early beams at 50ms

Reflectometry phase spectra

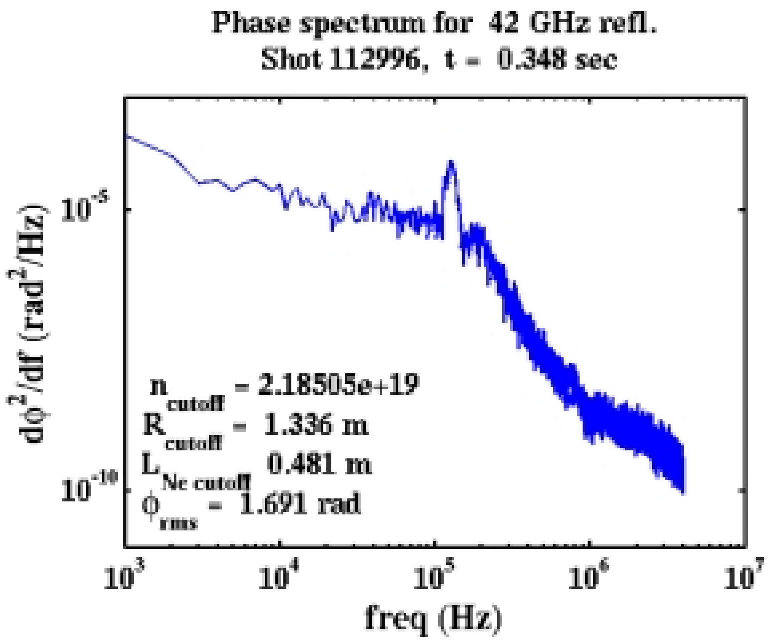


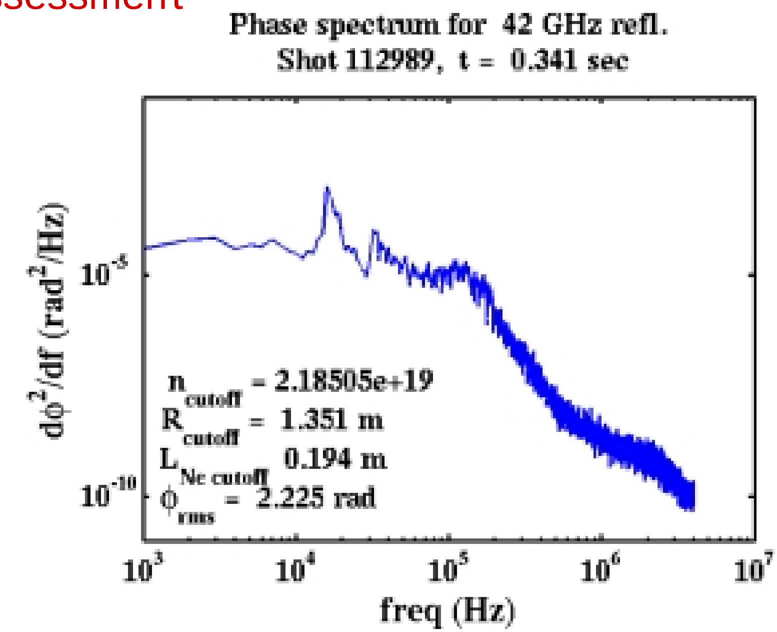
Spectra at ~345ms originate from similar radial locations: rho ~ 0.6.

As can be seen, the **local turbulent fluctuation spectra are quite similar**.

Coherent mode activity quite different and continuously evolves as a function of time.

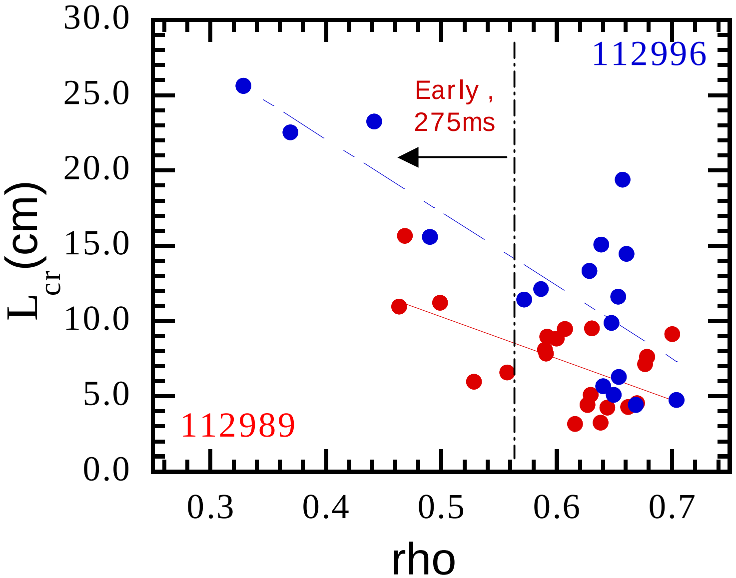
Preliminary analysis: needs careful assessment



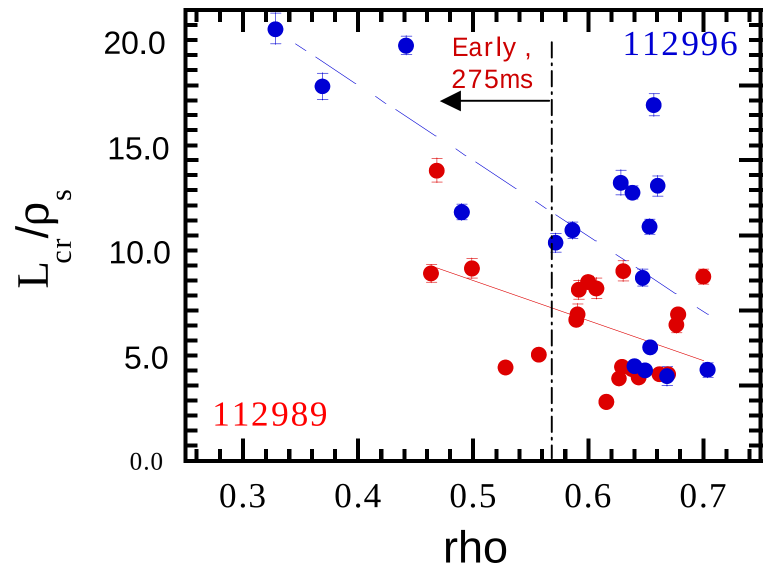


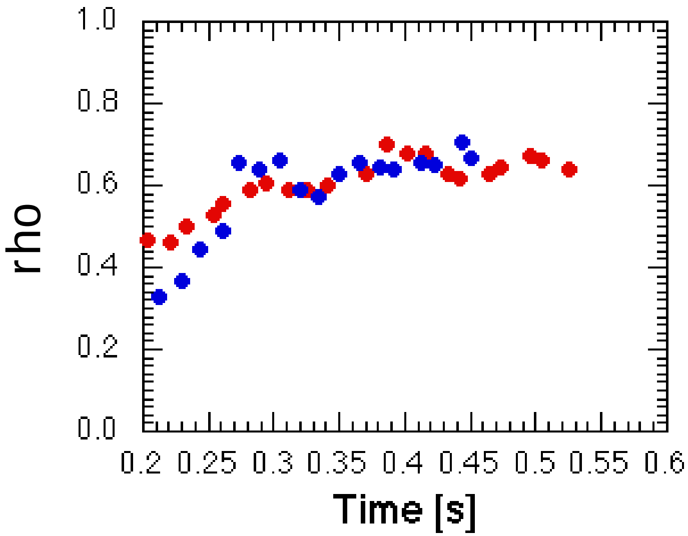
XP 411 Stutman et al: Correlation lengths vs rho

L_{cr} vs ρ



L_{cr}/ρ_s vs ρ





Correlation lengths in reversed shear discharge appear to be, on average, **shorter** than in normal L-mode. Preliminary analysis.

Note again, normalized correlation lengths increase deeper into the plasma.
Very large ratios observed deep in 112996

Summary

- For the first time, localized, quantitative turbulence data has been obtained well into the core of a spherical torus plasma. **Analysis is preliminary**.

- Turbulent correlation lengths have been measured, and spatial/ρ^* scaling studies initiated. **At a fixed location, correlation lengths normalize to a fixed multiple of ρ_s . However, this multiple increases significantly in the deep core plasma.**

- Reflectometry phase spectra have been obtained deep into the NSTX core plasma. Particle driven modes that continuously evolve are clearly evident. Careful analysis should allow determination of density fluctuation levels locally in the core.

- Comparison with gyrokinetic code (GYRO) predictions of turbulent correlation lengths is underway for the specific plasmas studied. Results by APS or sooner.

- A 2-D reflectometry simulation code (Nazikian & Kramer) will also be employed to compare with reflectometry results using GYRO output as input, etc.