Turbulent radial correlation lengths in the DIII-D tokamak

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Turbulent Radial Correlation Lengths in the DIII-D Tokamak[1] T.L. RHODES, J.-N. LEBOEUF, E.J. DOYLE, C.L. RETTIG, University of California, Los Angeles, R. SYDORA, University of Alberta, R.A. MOYER, University of California, San Diego, K.H. BURRELL, D.M. THOMAS, General Atomics — Measurements of radial correlation length Δr of density fluctuations have been made on the DIII–D tokamak in Ohmic and L–mode discharges. These measurements span the radii $\rho \approx 0.5$-1.0 and are found to scale approximately as $\rho_{\theta,s}$ or $8 \times \rho_s$. Here $\rho_{\theta,s}$ is the ion Larmor radius calculated using the local T_e and B_θ while ρ_s is the same except calculated using the total magnetic field, B_{tot}. Currently, these scalings are not distinguishable over the radii involved due to uncertainties. The measured values of Δr are similar to what is expected from drift wave like fluctuations, including ion temperature gradient driven turbulence. The data were obtained primarily from a heterodyne reflectometer system, however, data from other diagnostics are also presented. Comparison to analytical and numerical models will be made. Such comparisons can be important as they serve to benchmark theory and codes as well as to help identify the type(s) of turbulence involved.

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☐ Prefer Oral Session
☒ Prefer Poster Session

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Special instructions: DIII-D Poster Session 1, immediately following RA Moyer

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Abstract

Measurements of the radial correlation length Δr of density fluctuations have been made on the DIII-D tokamak in ohmic and L-mode discharges. These measurements span the radial region $\rho \sim 1$ to $\rho \sim .5$ and are found to scale approximately as $\rho_{\theta,s}$ or 5-8 ρ_s. Here $\rho_{\theta,s}$ is the ion Larmor radius calculated using the local electron temperature and the poloidal magnetic field while rs is the same except calculated using the total magnetic field. Currently, the two scalings ($\rho_{\theta,s}$ or 5-8 ρ_s) are not distinguishable over the radii involved due to their error bars. The measured values of Δr are similar to what is expected from drift wave like fluctuations, including ion temperature gradient driven turbulence. The data were obtained primarily from a heterodyne reflectometer system, however, data from a lithium beam probe and Langmuir probes will also be presented. Comparison to analytical and numerical models is underway and the results will be reported. Such comparisons can be important as they serve to benchmark theory and codes as well as to help identify the type(s) of turbulence involved.

Points in Presentation

I. Experimental correlation lengths consistent with several analytical expressions: both slab and neo-classical ion temperature gradient driven modes as well as electron drift waves.

II. Experimental correlation lengths have magnitude and radial dependence similar to 5-8xρ_s or $\rho_{\theta,s}$.

III. Comparisons with numerical codes underway, find consistency found between gyro-kinetic code and experimental correlation lengths.

Motivation

- From W.M. Tang, "Microinstability theory in tokamaks", Nuclear Fusion 18 page 1089 (1978).
- "Small scale disturbances can be a serious obstacle to efficient confinement because they give rise to anomalous transport levels well above those associated with classical Coulomb scattering.
- Hence it is important to:
  - Determine relevant stability criteria for normal tokamak operation.
  - Investigate possible configurations and conditions which could inhibit the onset of the instabilities.
  - Obtain estimates of particle and thermal transport if such modes cannot be avoided."

Indentification

Control

Prediction

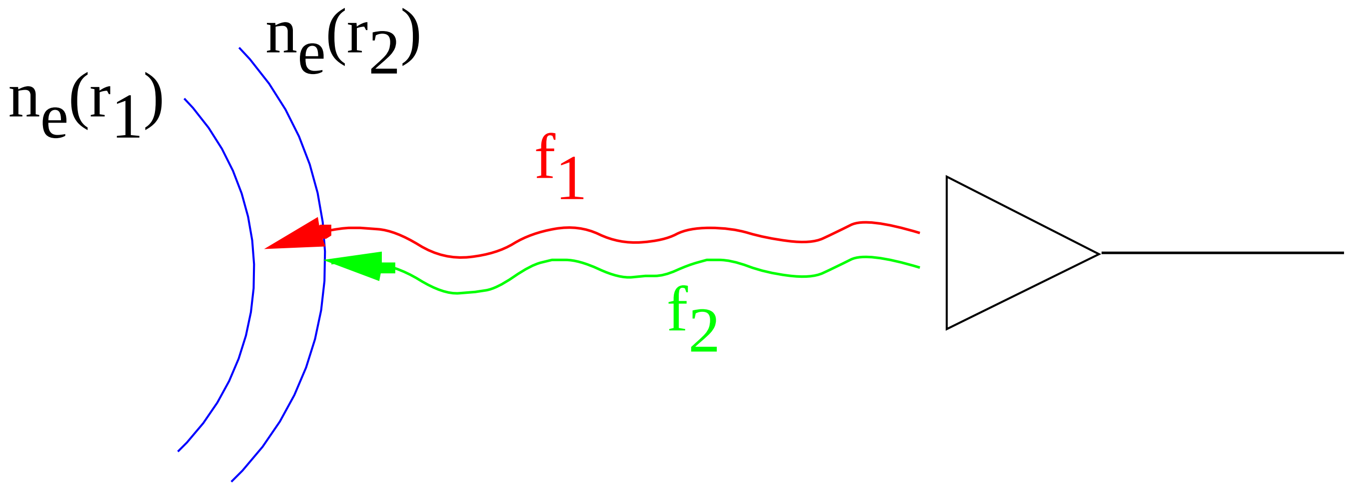
Motivation

- In this study the question of identification of the instability is addressed by comparing experimental measurements to analytical predictions of radial correlation lengths.

- These measurements are also compared to numerical calculations.

- In this way both identification and prediction are addressed since the predictive capability of any theory or simulation depends upon how close it comes to describing the particular system.

Correlation reflectometry



- **Launch two different frequencies** f_1, f_2 into plasma.
- Microwaves reflect from different locations.
- Reflectometer responds to fluctuations at different radial positions.
- Correlate resulting two signals:
  - $S_1 = A_1 \cos(\Phi_1(t))$
  - $S_2 = A_2 \cos (\Phi_2(t))$

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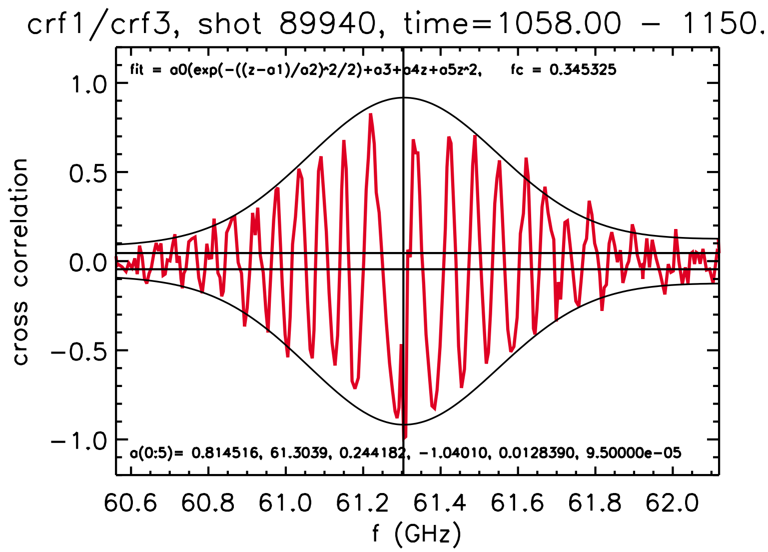
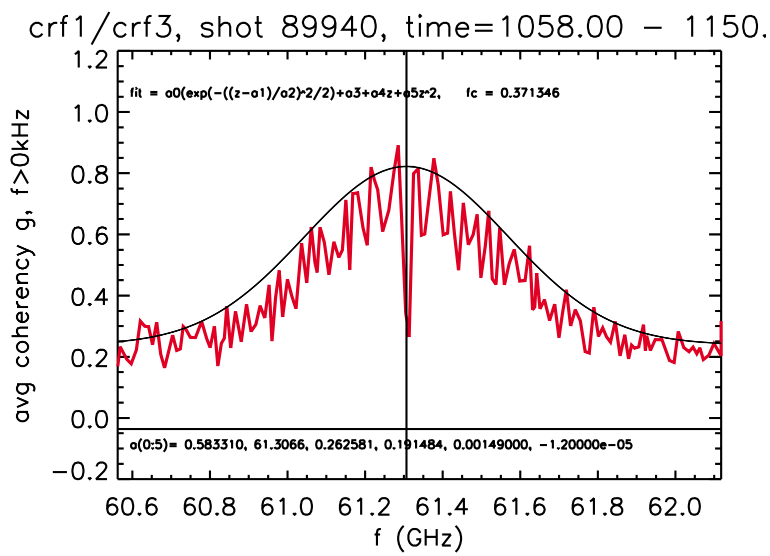
Correlation reflectometry





- Launch two different frequencies f_1, f_2 into plasma.
- **Sweep one frequency relative to another.**
- Correlate resulting two signals:
  - $S_1 = A_1 \cos(\Phi_1(t))$
  - $S_2 = A_2 \cos(\Phi_2(t))$

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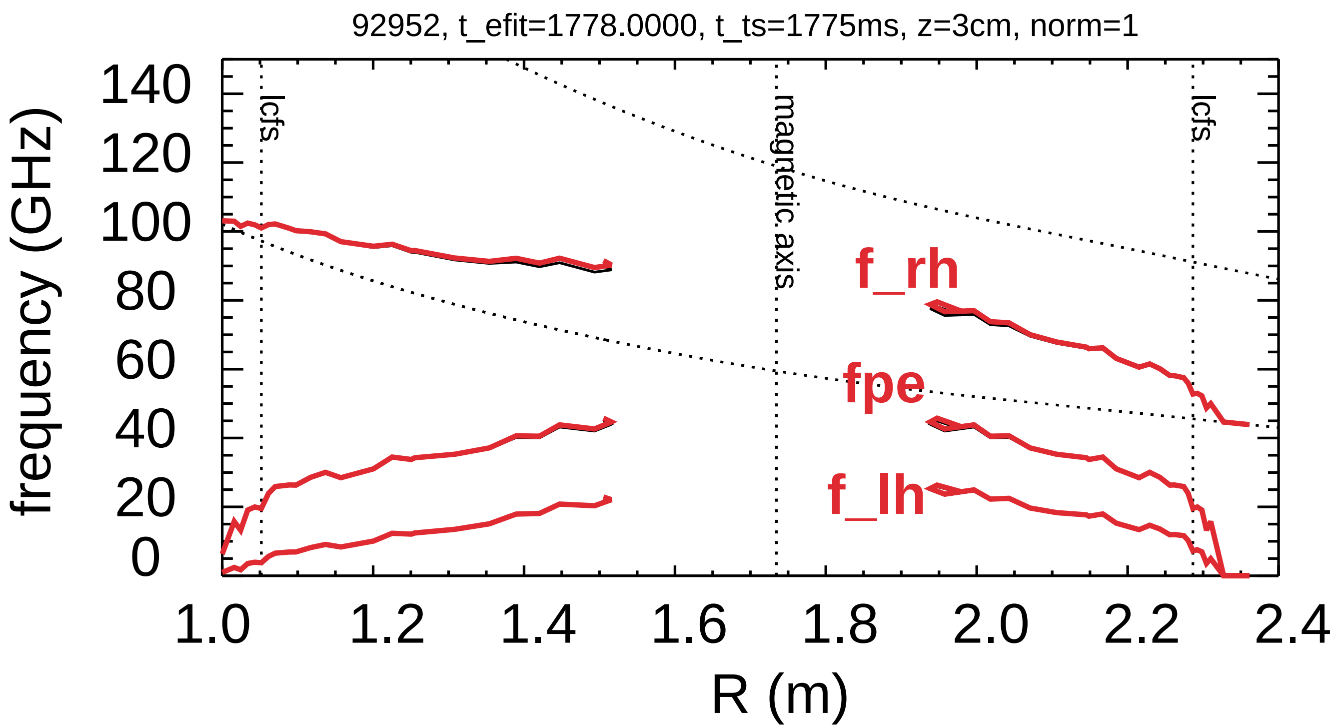
Cutoffs used for correlation reflectometry



- Launch two different frequencies f_1, f_2 into plasma.
- Sweep one frequency relative to another.
- **Able to use either f_{RH} or f_{pe} cutoffs.**

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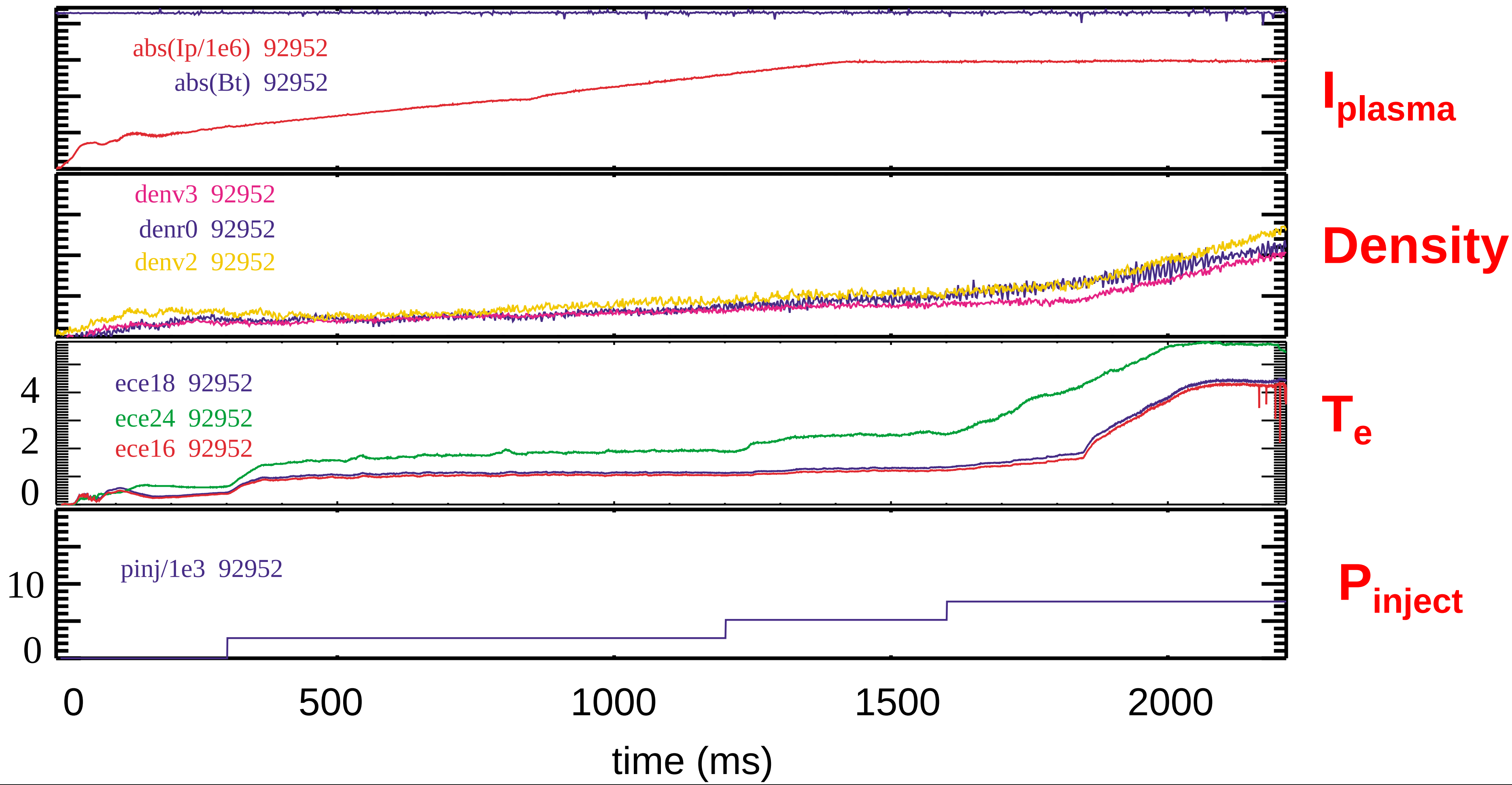
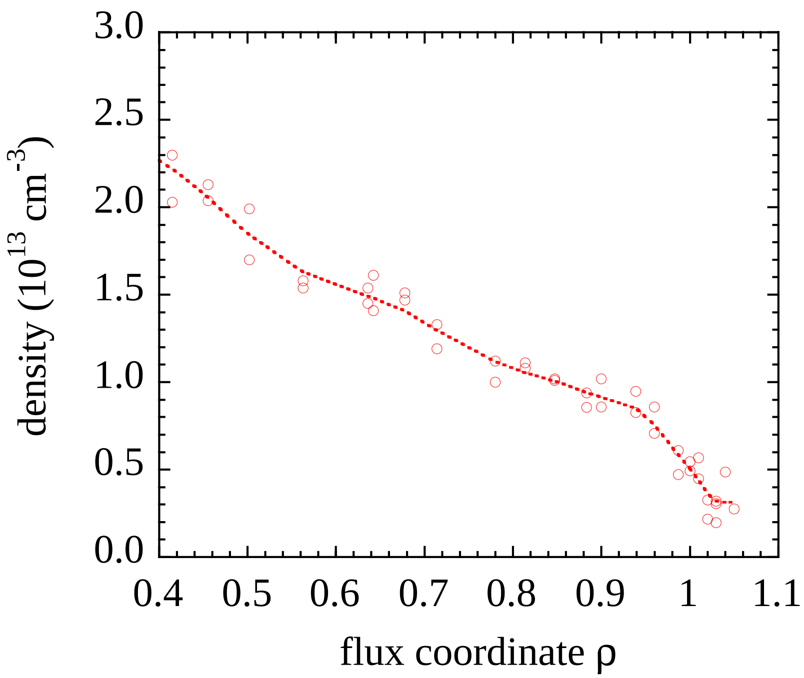
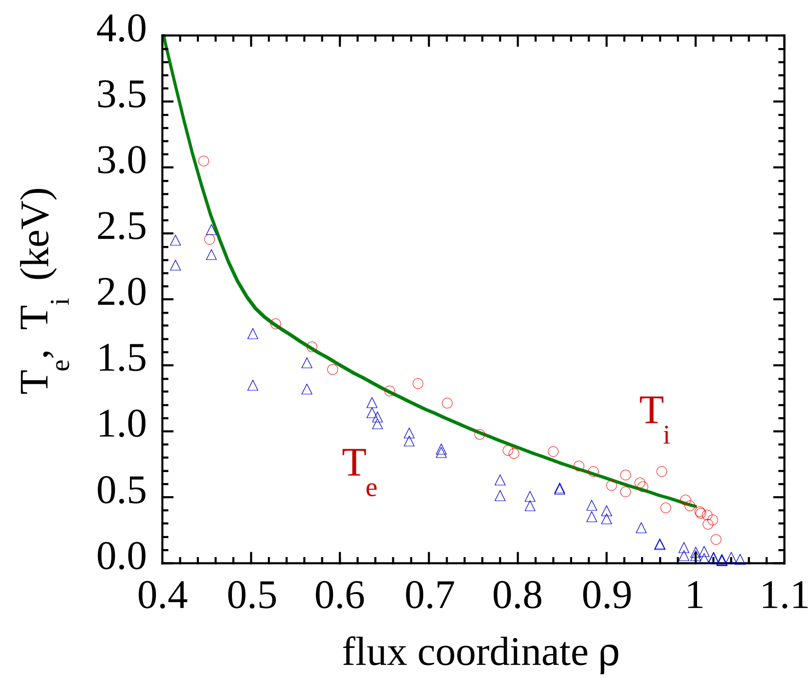
Plasma conditions for this study: L-mode

- Experimental data obtained in 7.5 MW beam heated L-mode plasma

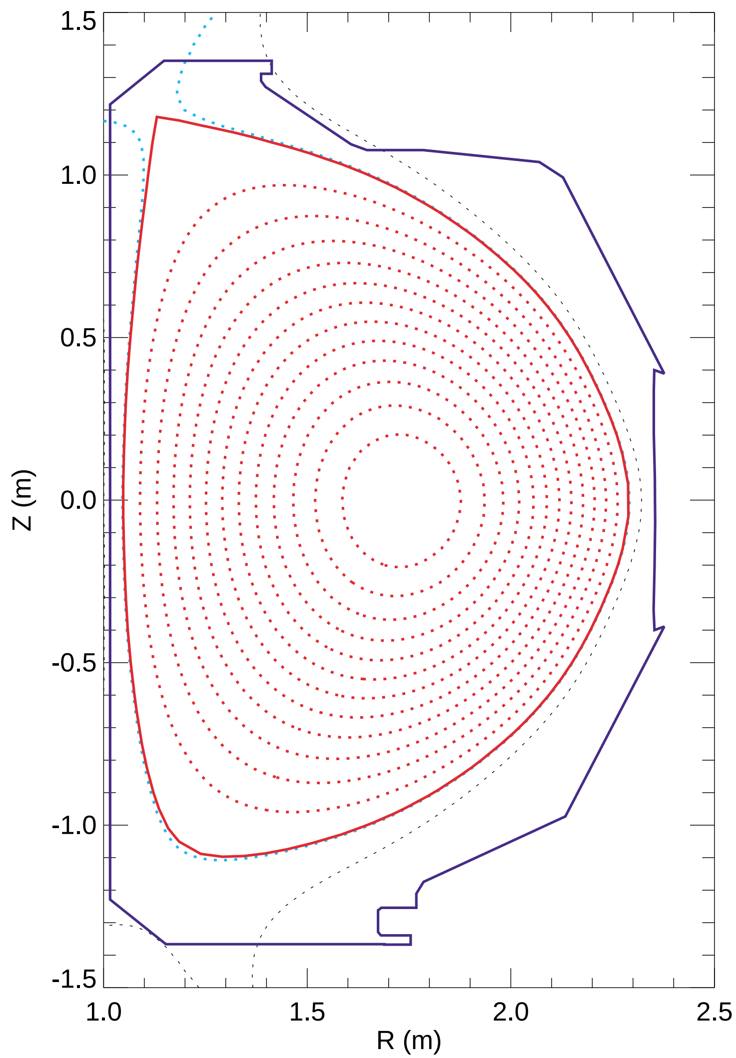


L-mode discharge parameters: $n_e(\rho)$ and $T_{e,i}(\rho)$





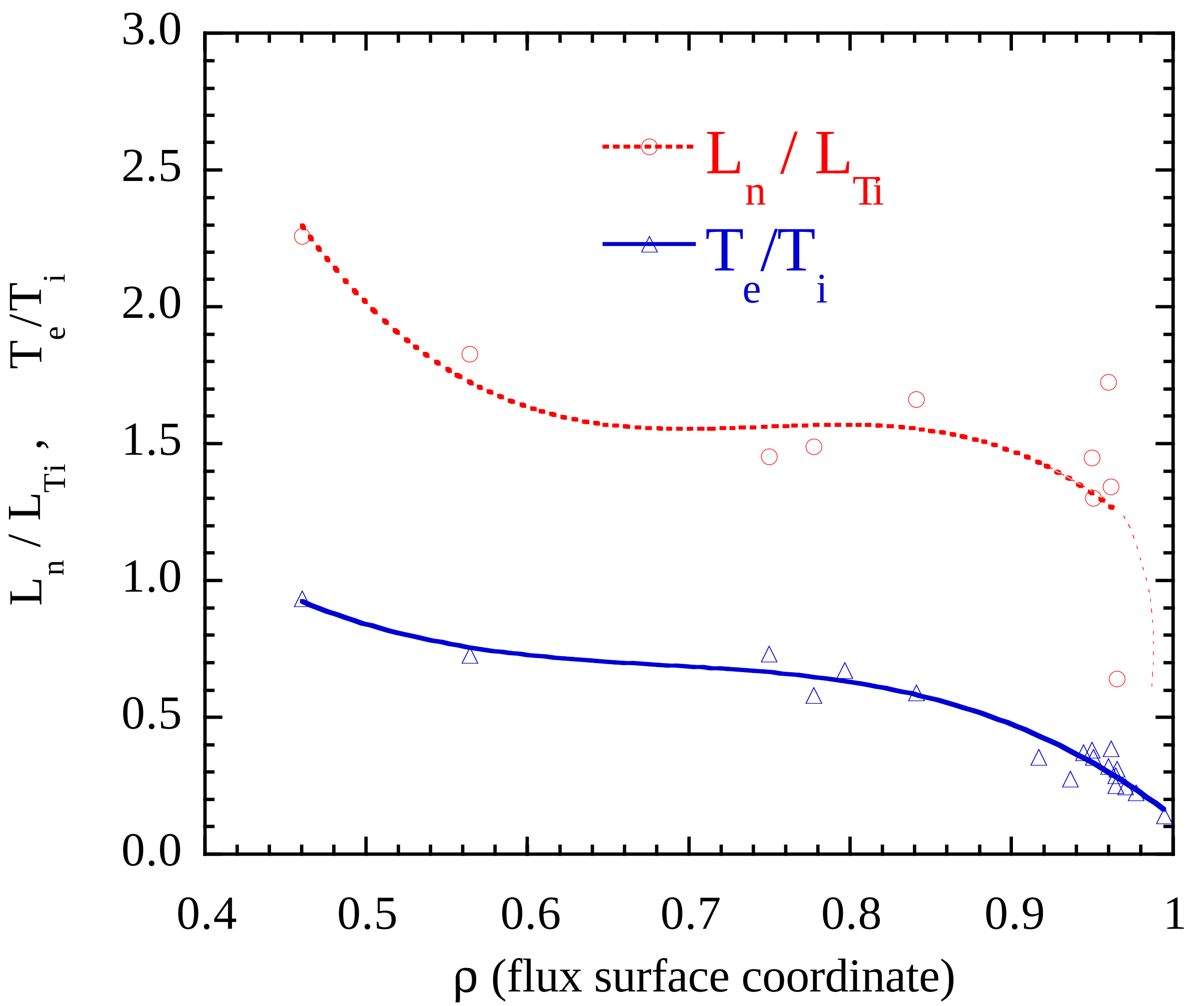
L-mode discharge parameters: plasma shape



Wed Nov 10 09:55:00 1999

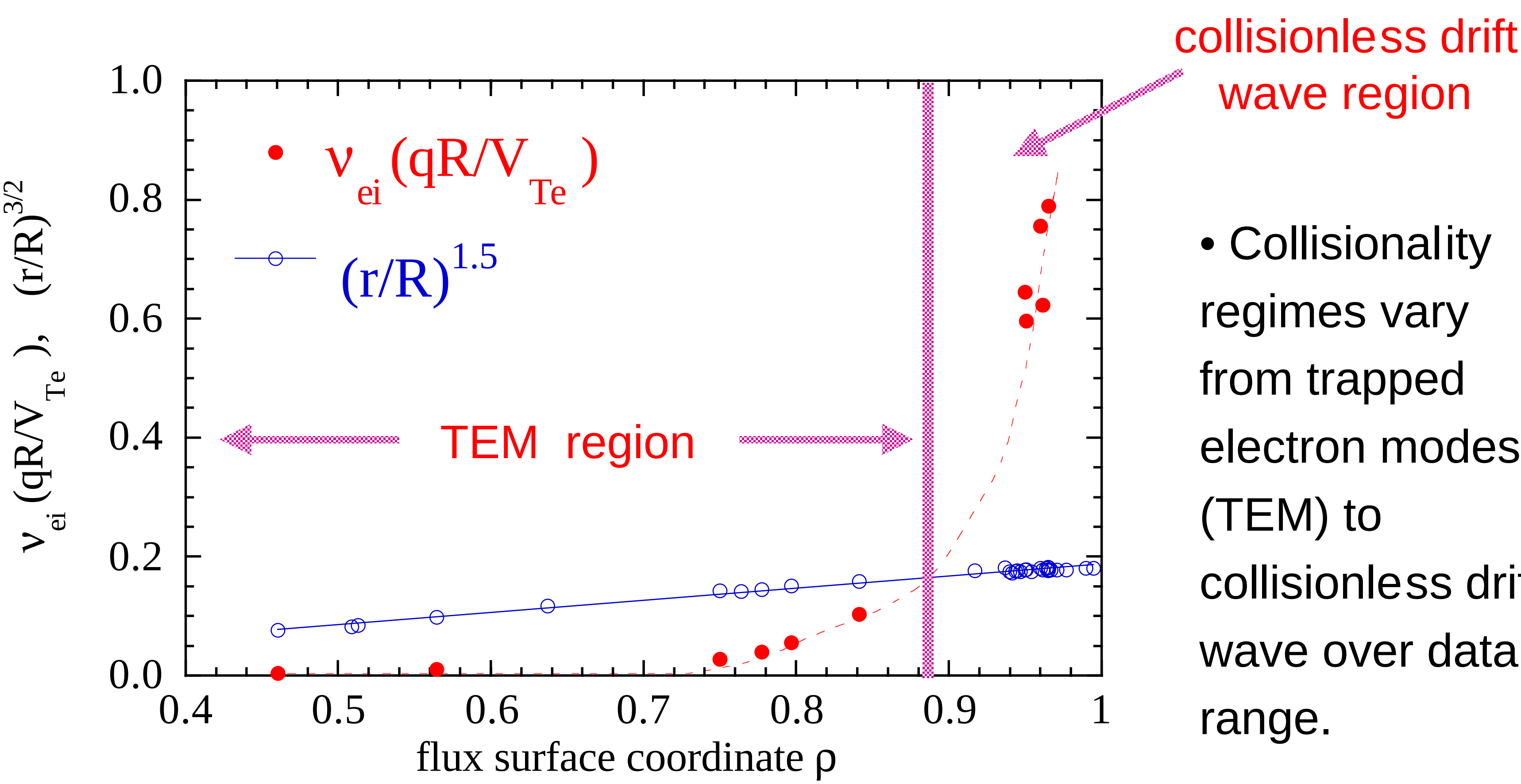
shot number =	92952	
efit time =	1778.0000	
configuration = SNT		
mw, mh =	65	65
Ip [A]=	1.47056e+06	
r(z)out [cm]=	166.908	4.08328
ssep [cm]=	0.510698	
bcentr =	-2.12281	
betapd =	0.718757	
betat, betap =	1.33527	0.606963
Vol, Area =	21.2327	2.12832
NB power inj. [W]=	0.00000	
qmerci =	1.07556	
q1,q95 =	14.6999	4.98326
qqmagx =	1.12707	
r(z)magx [cm]=	173.540	-0.236279
r(z)seps1 [cm]=	113.812	-118.919
r(z)seps2 [cm]=	113.081	117.880
taudia(mhd) =	1997.01	1686.40
terror =	0	
chisq =	17.7646	
wplasm =	786846.	
wplasmd =	931772.	
utri, ltri =	0.866554	0.607761
r(z)vsout [cm]=	118.857	135.150
r(z)vsin [cm]=	101.600	119.186
zuperts [cm]=	78.1256	
ssibry(mag) =	0.0194948	-0.336168
in(out)er gap =	3.19179	6.37550
up(low)er gap =	10.8787	24.2740
a, li =	62.1164	1.14936
vloop =	0.317283	
elongm =	1.39132	
kappa =	1.83470	

Stability parameters indicate linear ion temperature gradient (ITG) instability



- L_n/L_{Ti} > ~2/3 sufficient for linear ITG instability.
- Ratio T_e/T_i also enters into linear ITG stability calculations.

Collisionality regime: collisionless electron drift wave in edge and trapped electron mode deeper into core



- Collisionality regimes vary from trapped electron modes (TEM) to collisionless drift wave over data range.

Collisionality consistent with dissipative or collisionless TEM?

Definitions of various parameters

- Δr = experimentally measured turbulent radial correlation length.
- ρ_s **=** Larmor radius using electron temperature and ion mass.
- ρ_i **=** Larmor radius using ion temperature and mass.
- $\rho_{\theta,s}$ **=** Larmor radius using electron temperature and ion mass and poloidal magnetic field
- $\rho_{\theta,\, i}$ **=** Larmor radius using ion temperature and mass and poloidal magnetic field

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Analytic correlation lengths

Electron drift wave, slab (EDW)

$$\frac{L_s}{L_n}\left(\frac{T_e}{T_i}\right)^{1/2}\rho_s$$

F.Y. Gang, et al. *Phys. Fluids* B **3**, 68 (1991)

Slab ITG

$$\rho_s\left[\frac{1+\eta_i}{\tau}\right]^{1/2}$$

G.S. Lee and P. Diamond, Phys. Fluids 29 3291 (1986)

$$\rho_s\left[\frac{qR}{\hat{s}L_n}\frac{1+\eta_i}{\tau}\right]^{1/2}$$

H. Biglari, et al., Phys. Fluids B 1, 109 (1988)

Toroidal ITG

$$\rho_s\left[\left(\frac{q}{\hat{s}}\right)^2\frac{R}{2L_n}\frac{1+\eta_i}{\tau}\right]^{1/4}$$

H. Biglari, et al., Phys. Fluids B 1, 109 (1988)

neo-classical ITG

$$\rho_{s,\theta}\left[1+\eta_i\right]^{1/2}$$

Y.B. Kim, et al. Phys. Fluids B 3, 384 (1991)

Mesoscale structures

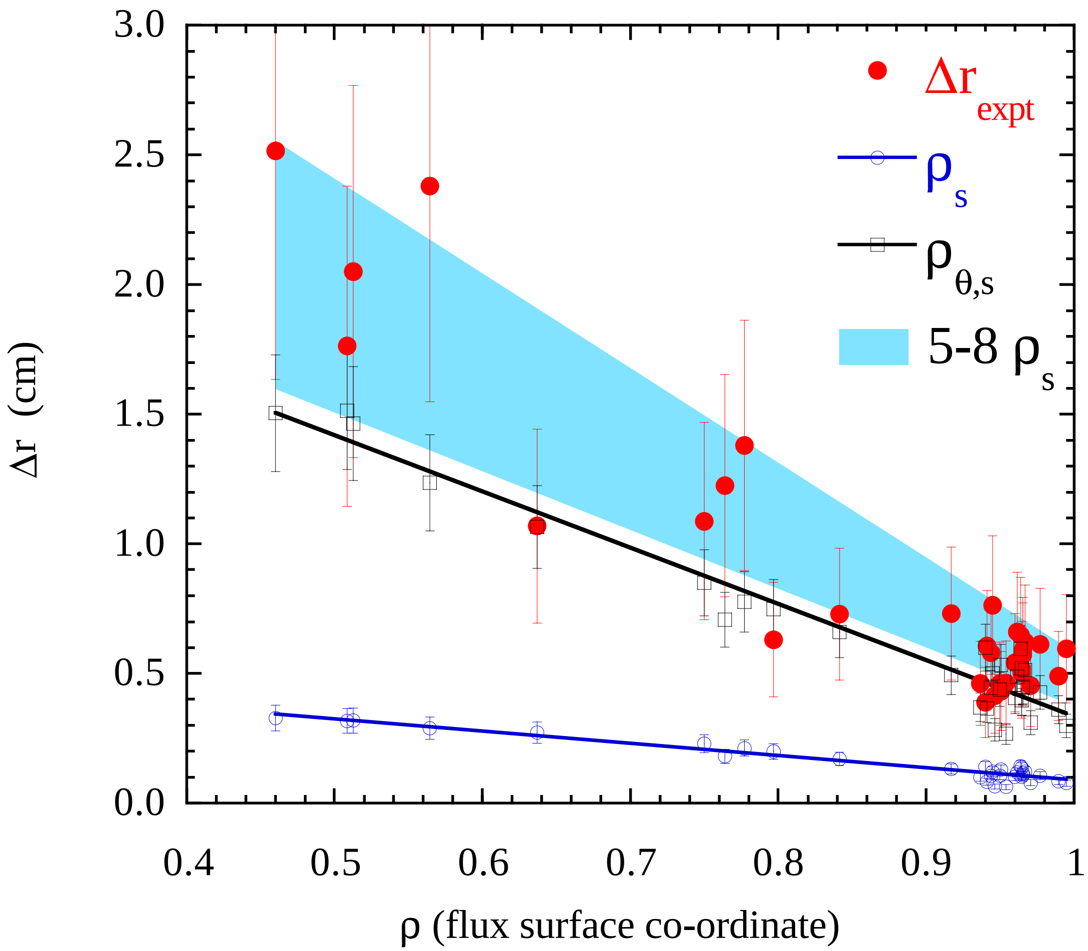
$$\left(\rho_i L_{Ti}\right)^{1/2}$$

Romanelli and Zonca, Fluids B 5, 4081 (1993)

$$\left(\rho_i L_{Ti}/\hat{s}\right)^{1/2}$$

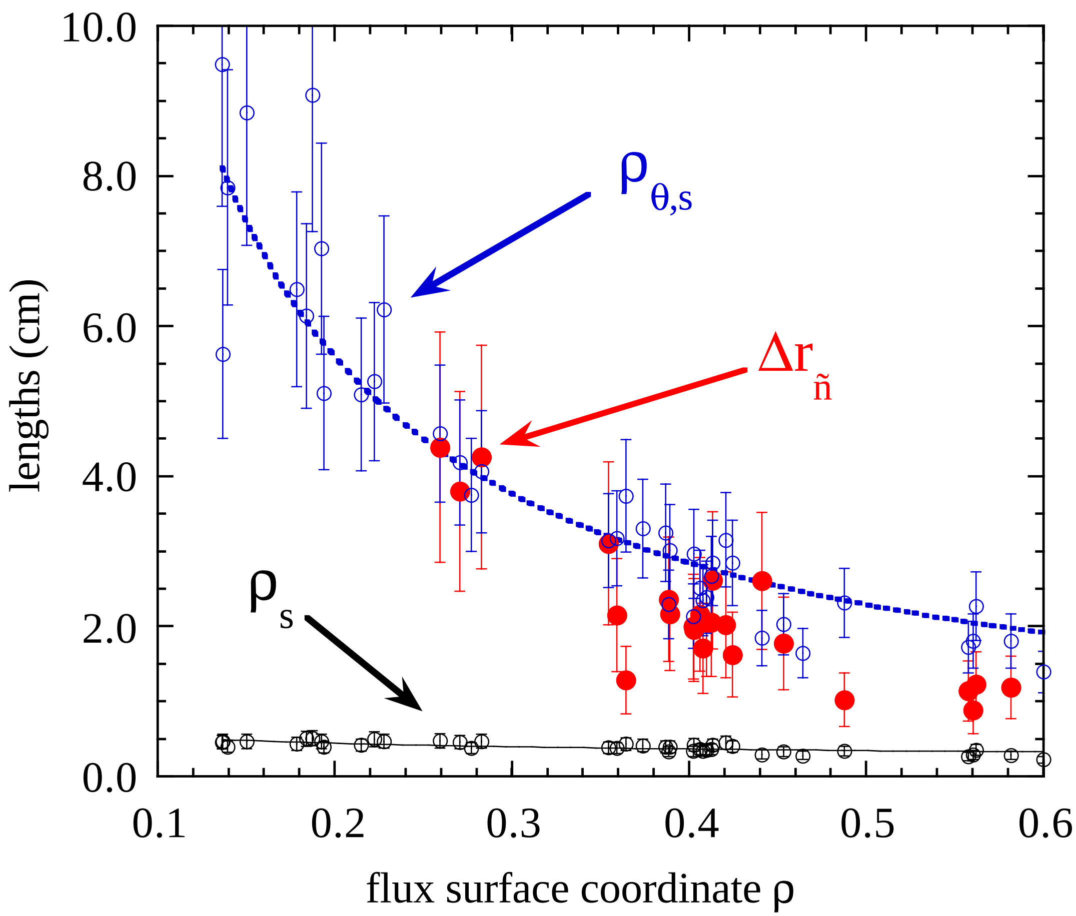
Conner, et al., PRL **70** 1803 (1993)

Radial correlation length greater than ρ_s, approximately same as either $\rho_{\theta,s}$ or 5-8 ρ_s



- Generally $\Delta r > \rho_s$
- $\Delta r \sim$ 5-8 ρ_s is general prediction of many theories.
- Δr increases towards core being
  - 0.5-1 cm at edge
  - as much as 3-4 cm in deep core ($\rho \sim 0.2$)

Similar observations for multiple plasma conditions: $\Delta r > \rho_s$, $\Delta r \approx \rho_{\theta,s}$ or 5-8 ρ_s



- Second set of data.
- B_z=1.9T, I_p=625kA
- not sawtoothing.
- reaches ρ ~.25
- similar results.

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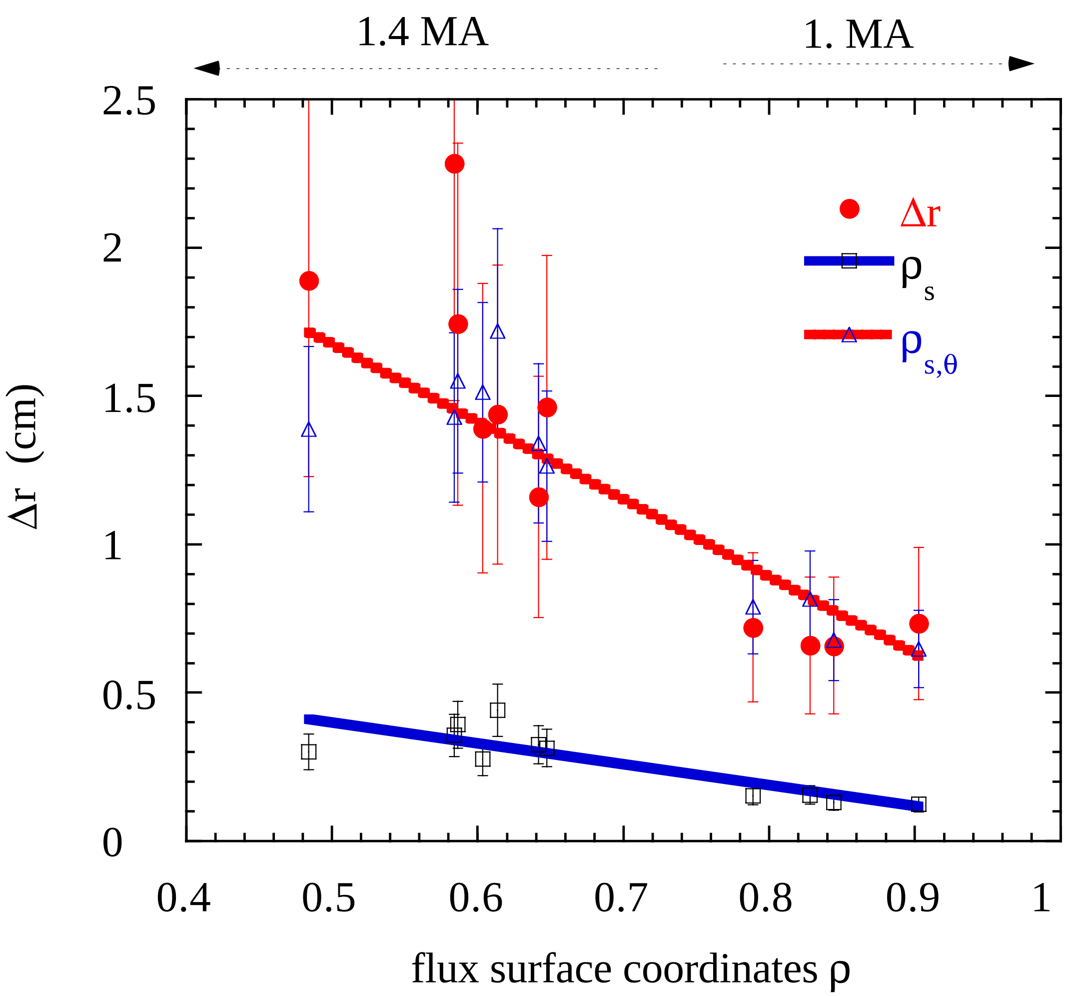
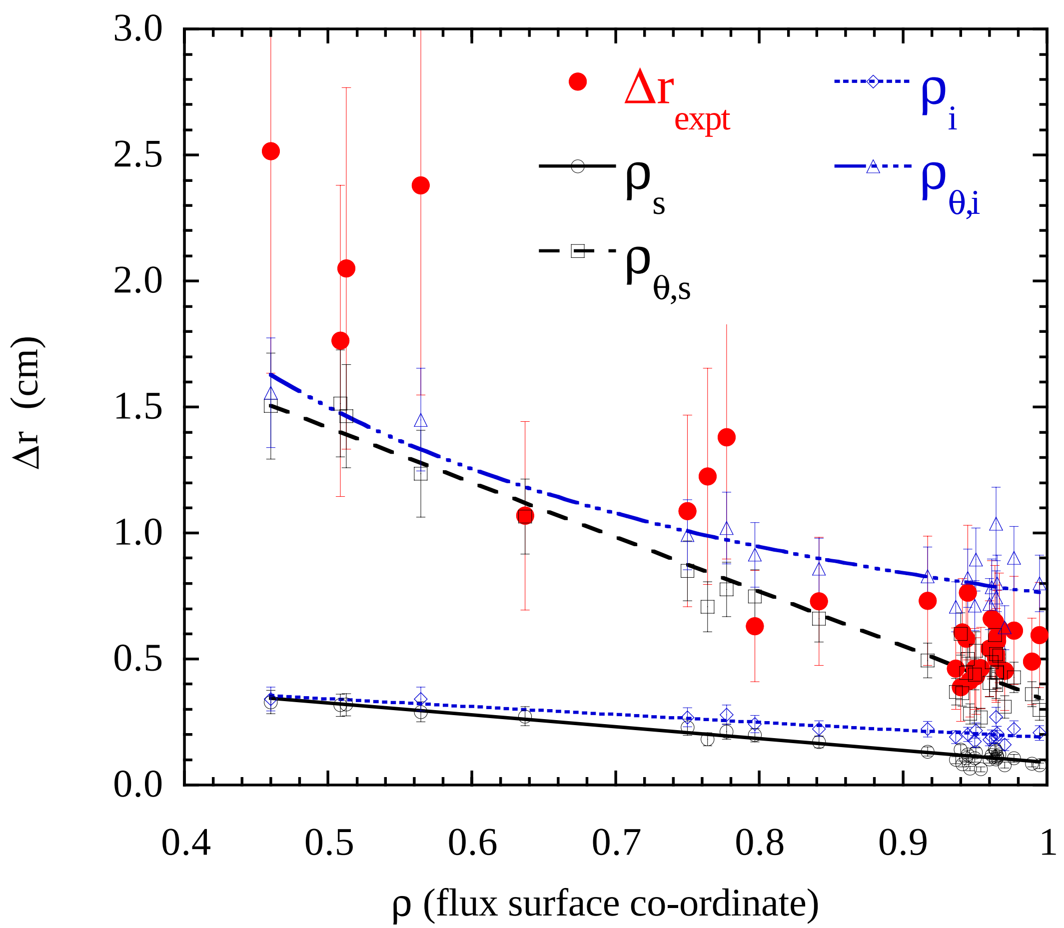
Similar observations for multiple plasma conditions: $\Delta r > \rho_s$, $\Delta r \approx \rho_{\theta,s}$ or 5-8 ρ_s



- I_p scan.
- similar results.

Radial correlation length approximately same as either $\rho_{\theta,s}$ or $\rho_{\theta,i}$



- Within error bars Δr not differentiated from $\rho_{\theta,s}$ or $\rho_{\theta,i}$

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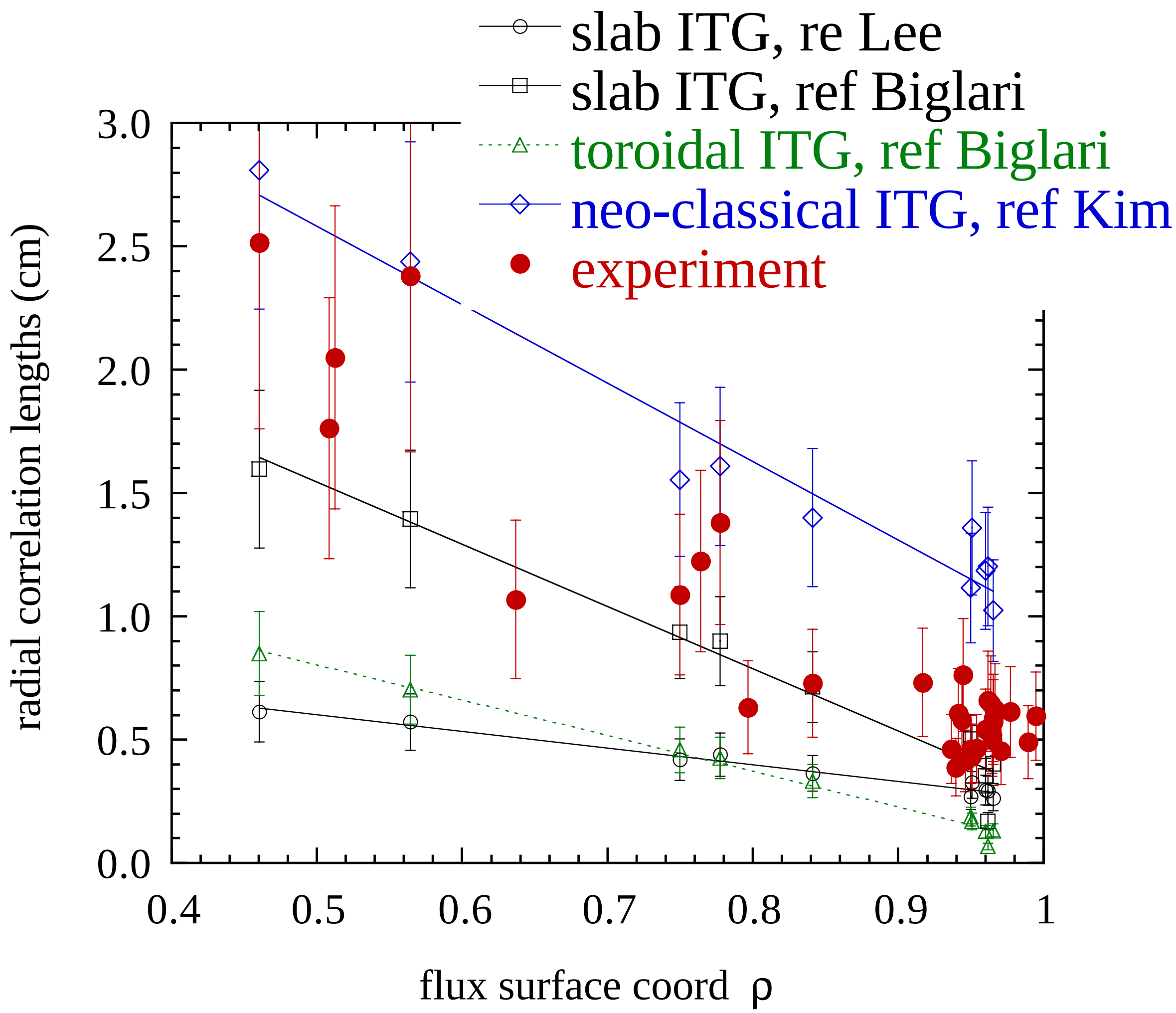
Radial correlation length consistent with slab or neo-classical ITG driven turbulence



- Experimental values larger than slab ITG model of Lee, et al. and toroidal ITG model of Biglari, et al.
- Data consistent with both slab ITG of Biglari, et al. And neo-classical ITG of Kim, et al.

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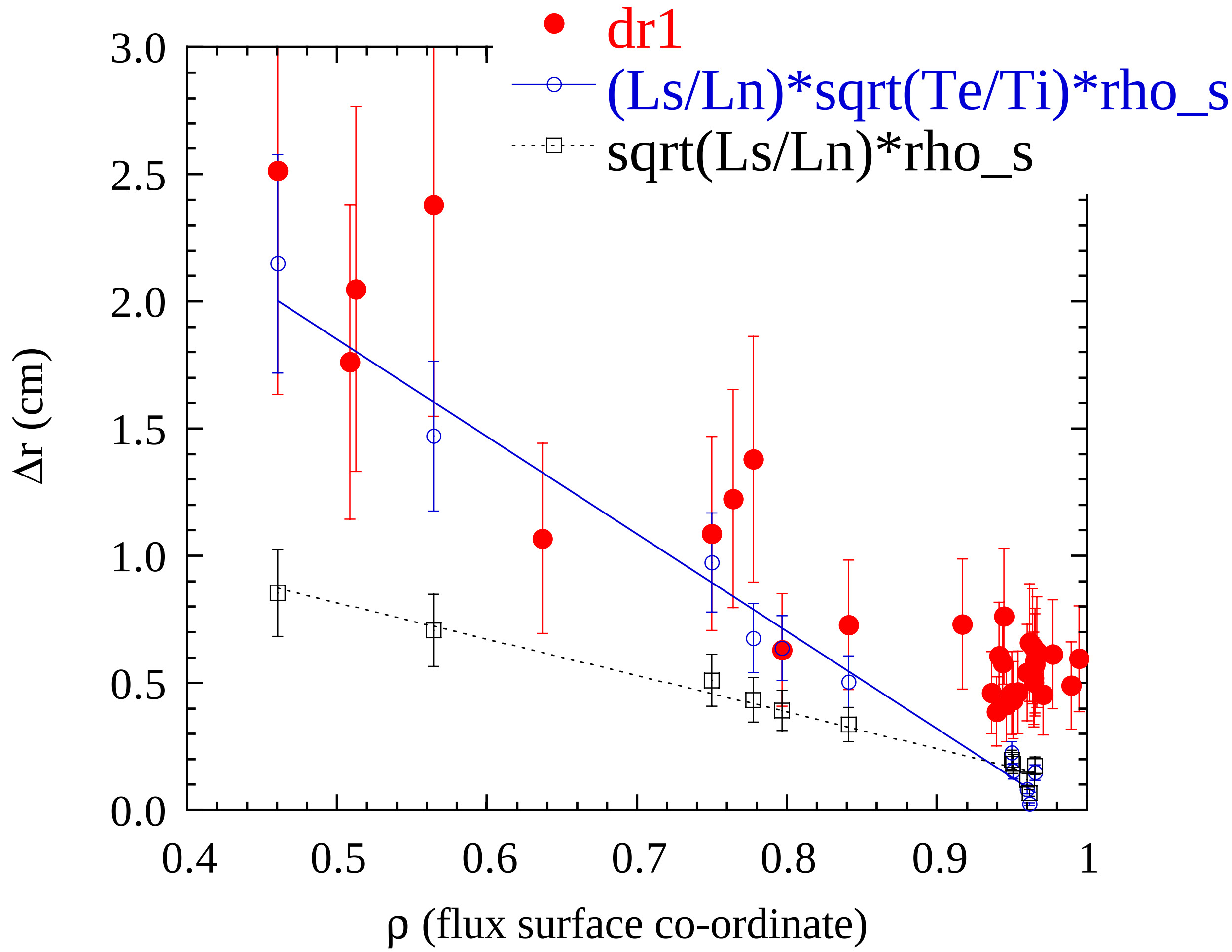
Radial correlation length consistent with electron drift wave



- Data also consistent with generic electron drift wave type correlation length $(L_s/L_n)(T_e/T_i)^{1/2}\rho_s$ for radii < 0.9

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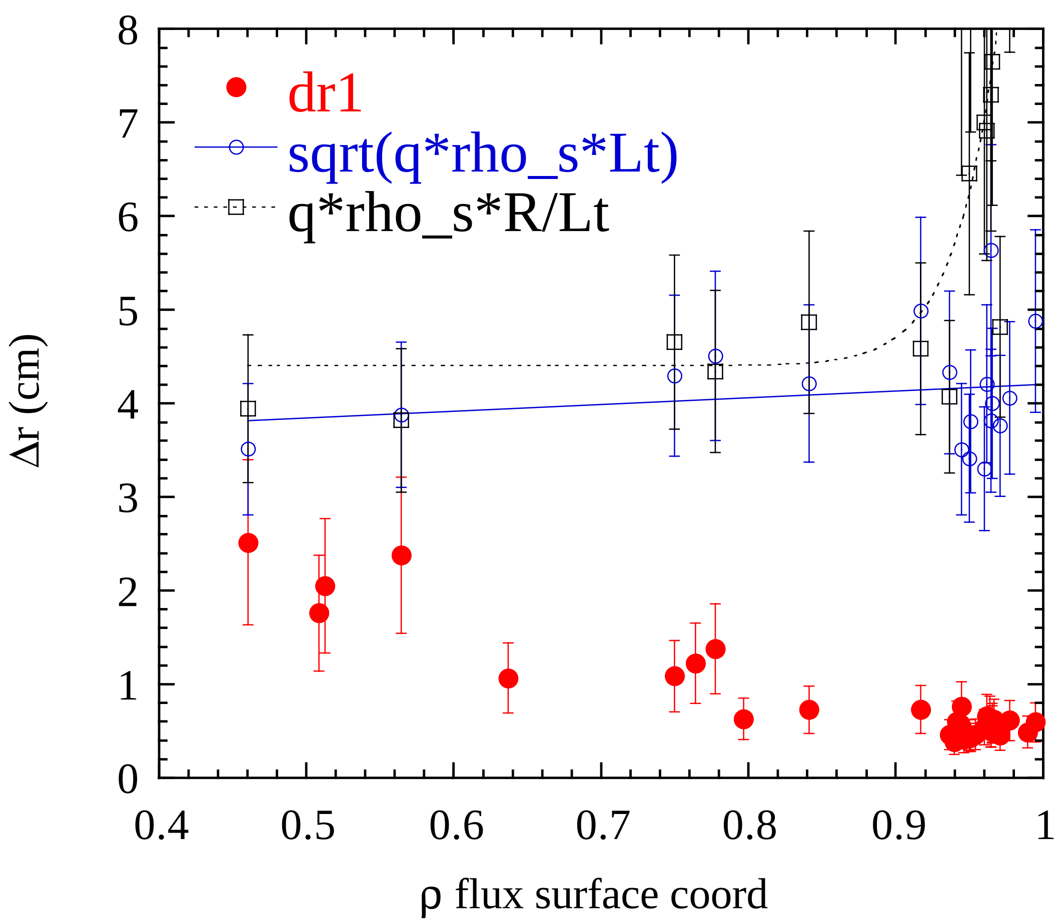
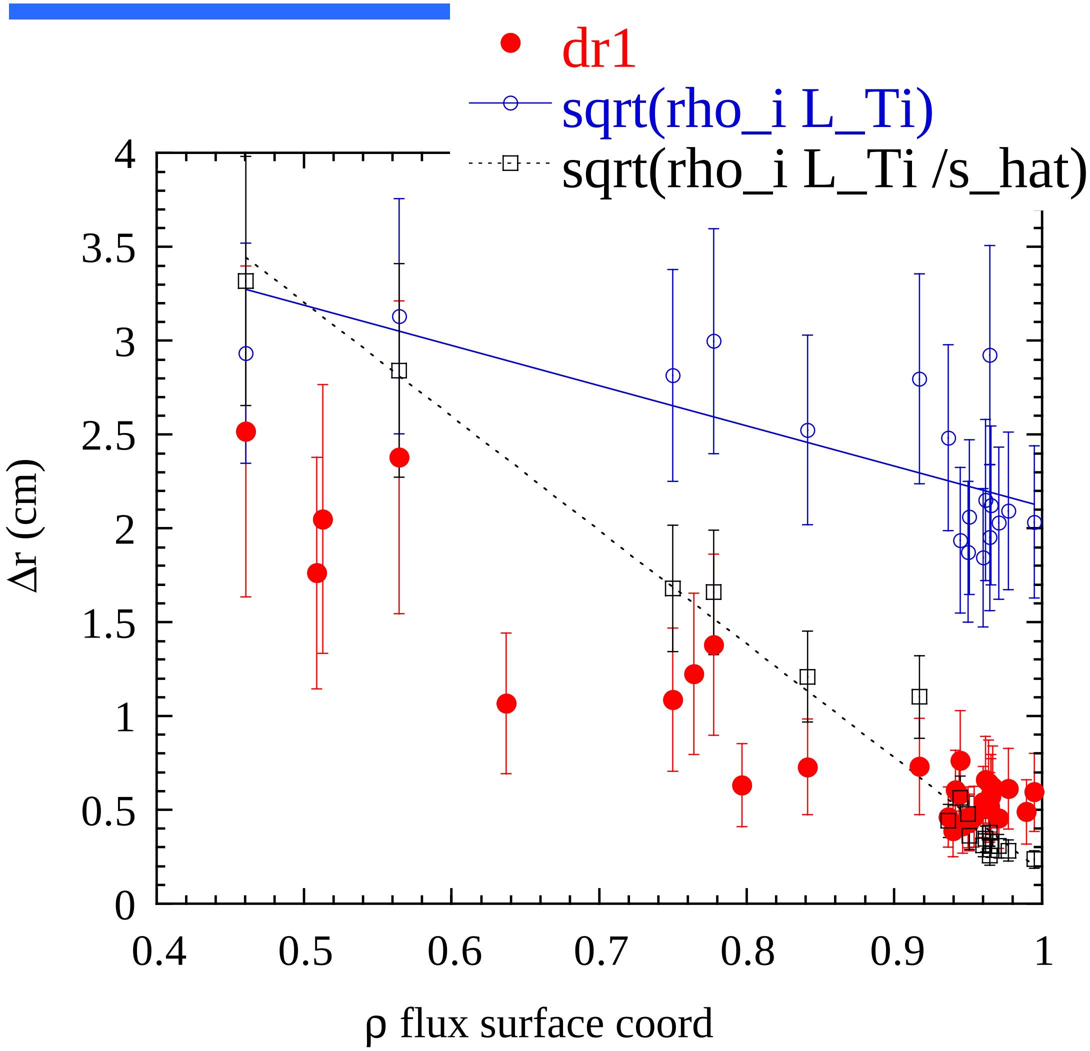
Radial correlation length **not** consistent with some mesoscale Δr



- Data doesn't agree with these mesoscale predictions in either magnitude (except possibly in core) or radial dependence
- Could be due to zonal flows suppressing longer scales?

Radial correlation length is consistent with some mesoscale Δr



- Data not consistent with $(\rho_i L_{Ti})^{1/2}$ mesocale.
- Data is consistent with Conner, et al. $(\rho_i L_{Ti}/s)^{1/2}$ mesoscale.
- However, at edge this mesoscale prediction is of order .3 cm! This is due to large shear parameter s_hat and small ρ_i.

Need dedicated experiments and closer connection to theory and simulation

- Experimental error bars preclude definitive conclusion.
- Experiments can be designed to differentiate between predictions.
- Possibility that near equality of different predictions is a real physics result - plasma supports various types of turbulence/modes simultaneously.
- Also possible to compare data to numerical modeling.
  - Able to model specific discharges and conditions.
  - Compare multiple measurements to codes.
  - A beginning of this comparison is shown next.

Compare turbulence measurements to numerical modeling: Gyro-kinetic code

• Global gyrokinetic particle code [R. D. Sydora, V. K. Decyk, and J. M. Dawson, Plasma Phys. Control. Fusion **38** (1996) A281-294]

- Whole plasma cross section
- Full radial profiles
- Toroidal geometry (Cartesian coordinates)
- Circular cross section
- Adiabatic electrons
- Massively parallel implementation using MPI and PLIB parallel particle manager developed by Viktor Decyk

Effect of Global Flow on Fluctuations

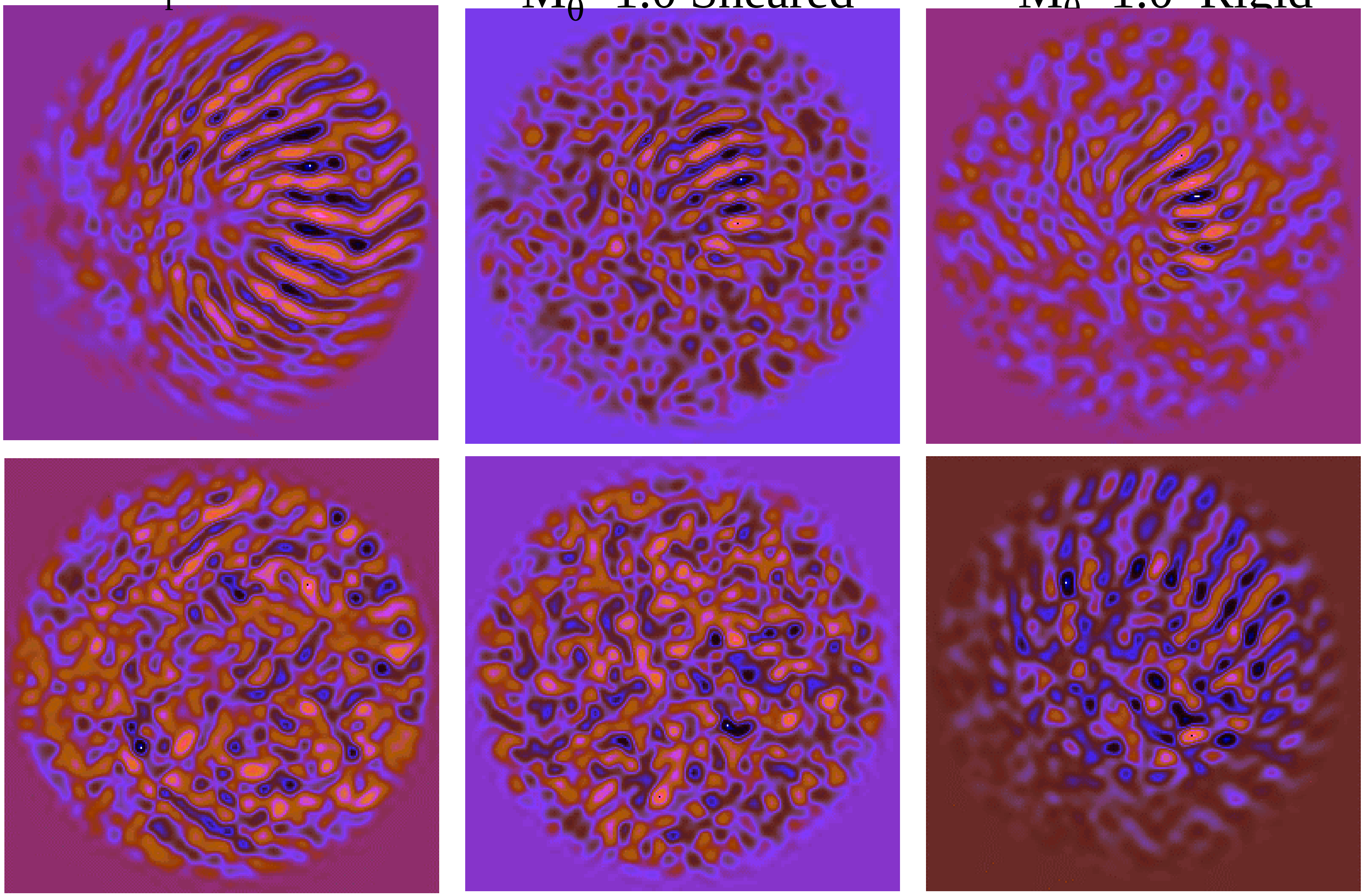
E_r=0 V/cm

E_r=28.3 V/cm
M_θ=1.0 Sheared

E_r=28.3 V/cm
M_θ=1.0 Rigid

Linear Phase

Nonlinear Steady State



From J.-N. Leboeuf, UCLA

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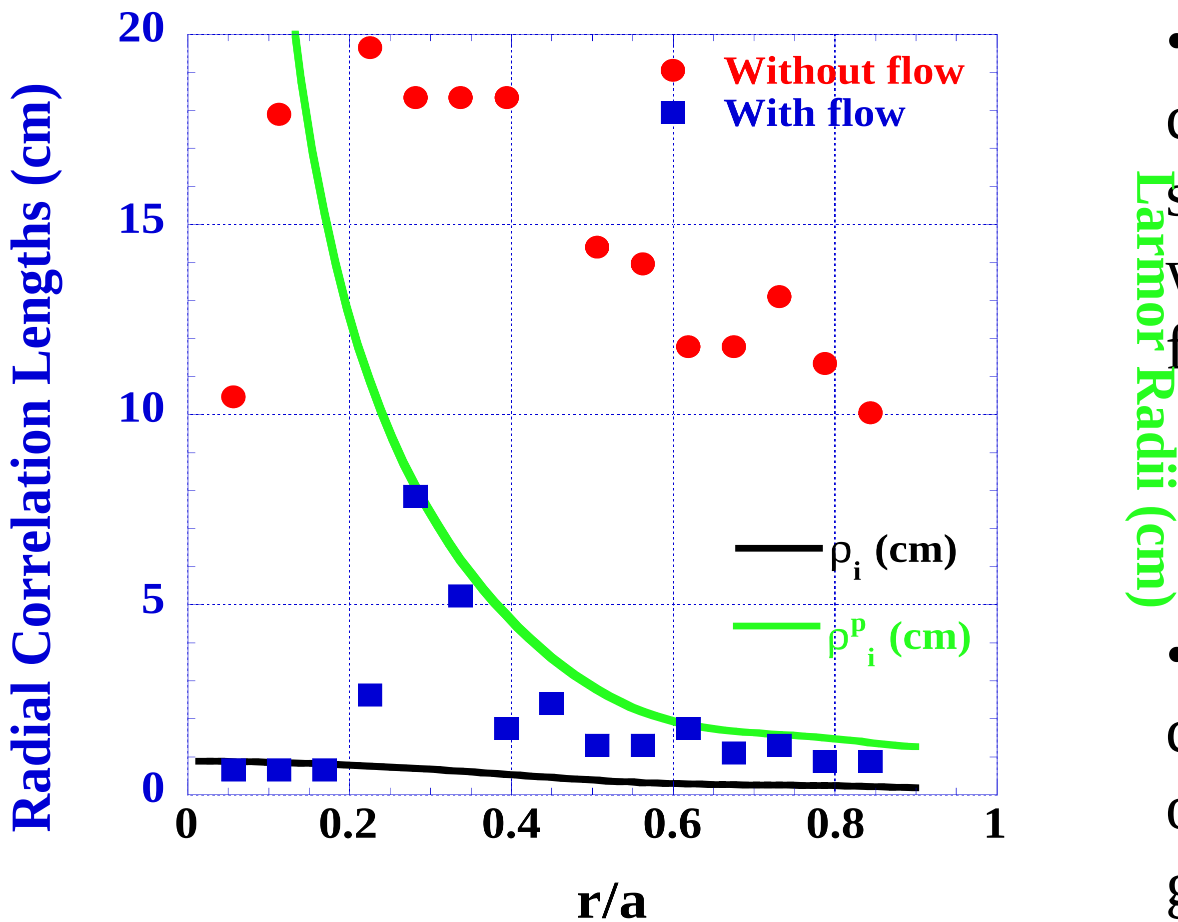
Numerical calculations: Δr without self-generated or zonal flows is very large



- Calculated radial correlation lengths significantly reduced with self-generated flow:
  - from 10-20 cm
  - to 1-8 cm.
- Calculated correlation lengths of order poloidal ion gyro-radius.

From J.-N. Leboeuf, UCLA

UCLA

See invited presentation by Jean-Noel Leboeuf

"Full Torus Gyrokinetic Calculations of Turbulence Modification by External Electric Fields in Electric Tokamak Plasmas"

Jean-Noel Leboeuf
(University of California at Los Angeles)

Session FI1 - Transport Theory.

INVITED session [FI1.04], Tuesday morning, November 16
Grand I, The Westin Seattle

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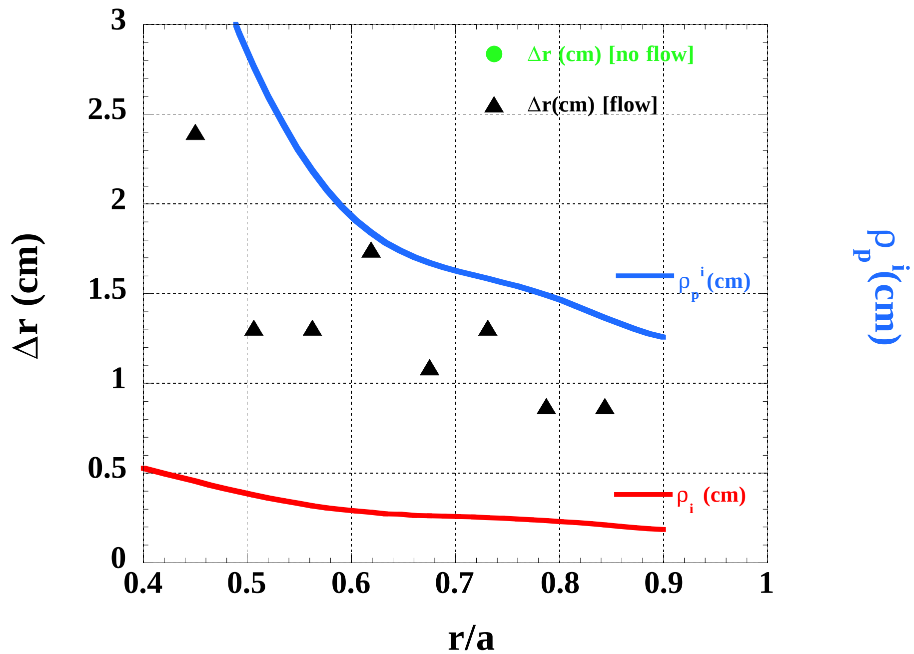
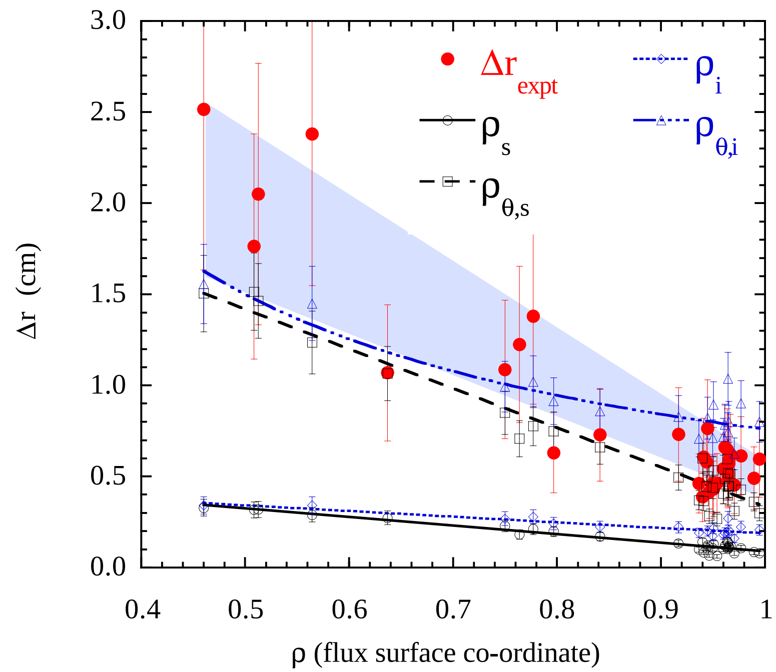
Numerical model: Δr with zonal flows consistent with experiment

Calculated



Experiment



- Calculated (Left) and experimental (Right) radial correlation lengths with self-generated flow ~ poloidal Larmor radius or 5-8 ρ_i

Future work

- Expand comparison
  - Compare other diagnostics
  - Use numerical diagnostics in code to simulate real diagnostics
    - e.g. FIR scattering looks at given range in wavenumber over a complementary volume - this can be simulated.
  - Compare frequency spectra, poloidal wavenumber, dispersion relations, fluxes, etc.
- Design specific experiments to test model predictions.

Summary

I. Experimental correlation lengths consistent with several analytical expressions: both slab and neo-classical ion temperature gradient driven modes as well as electron drift waves.

II. Experimental correlation lengths have magnitude and radial dependence similar to 5-8xρ_s or $\rho_{\theta,s}$.

III. Comparisons with numerical codes underway, find consistency found between gyro-kinetic code and experimental correlation lengths.

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