# *Intermittency Studies in DIII-D*

*Presented by J. Boedo*

*For*

*D. Rudakov, R. Moyer, S. Krasheninnikov, G. McKee, D. Whyte, S. Allen, D. Colchin, T. Evans, A. Leonard, A. Mahdavi, G. Porter, P. Stangeby, J. Watkins, X. Xu and the DIII-D Team.*

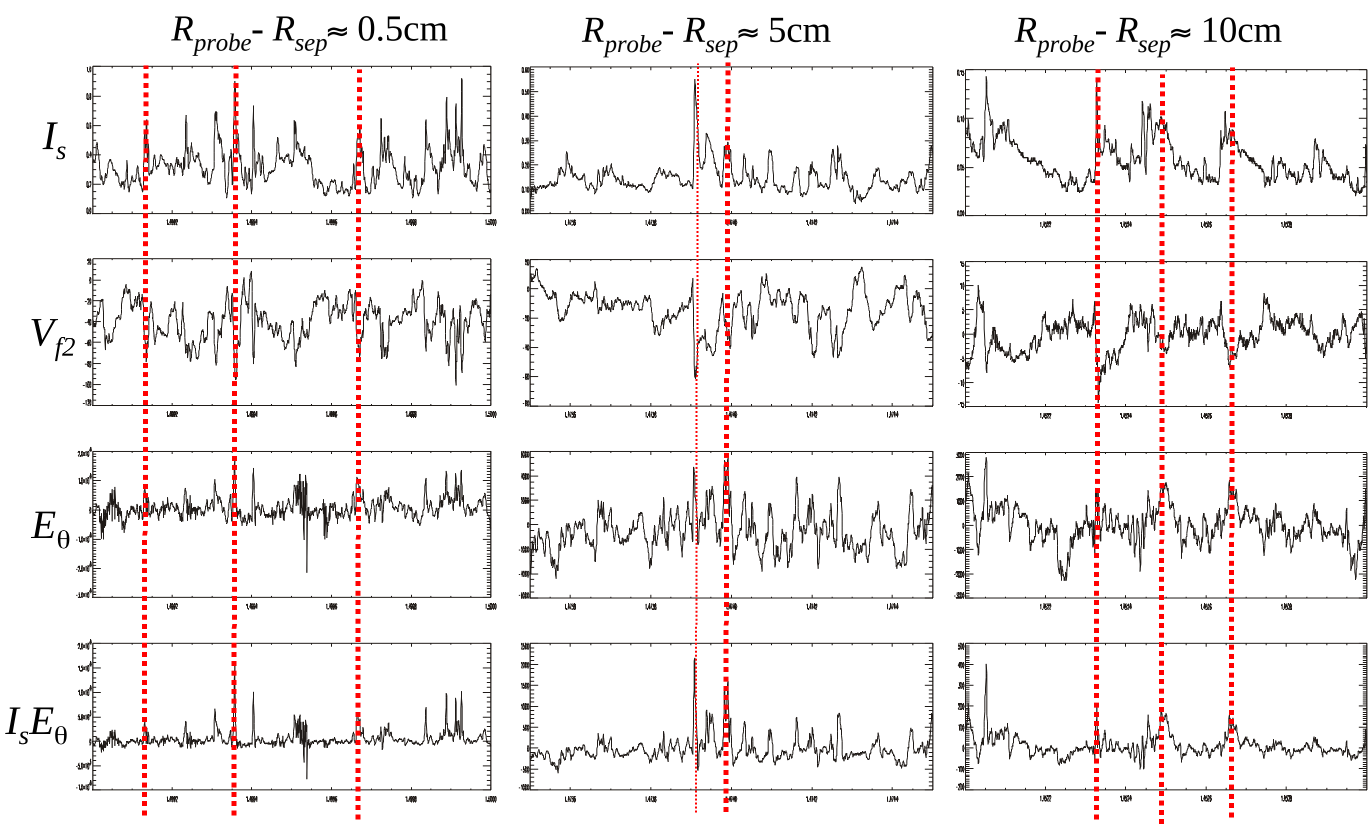
# Motivation

*•Recent results from ALCATOR C-MOD [La Bombard, APS2000] have indicated that strong recycling occurs at the main chamber wall.*
*•DIII-D research [D. Whyte] has determined that the walls are a large source of carbon.*

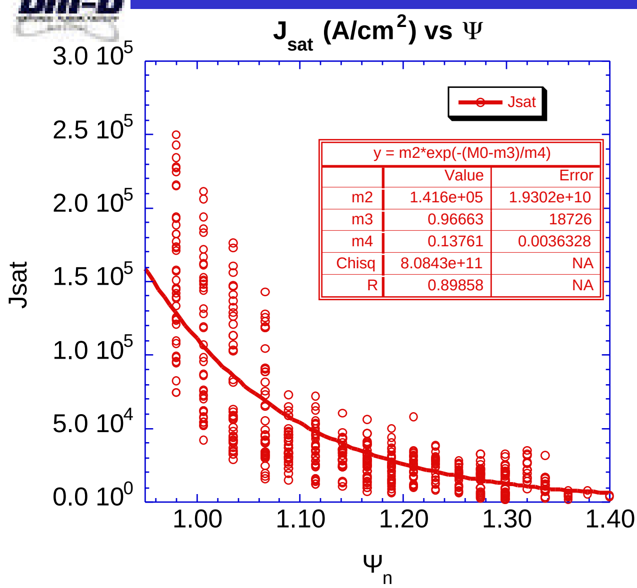
*•What is then the mechanism that brings plasma to the walls?*

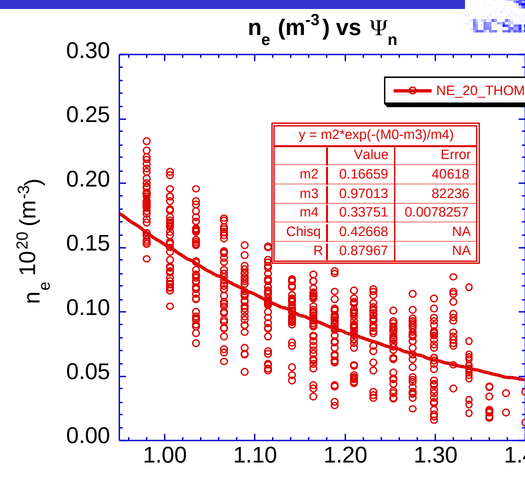
*•Previous results in DIII-D [Moyer, 96] indicated that transport in the far SOL was stronger than thought.*
*•Profiles in the far SOL of various tokamaks [Boedo 98, Heller 99]feature flat profiles in the far SOL => diffusion?*
*•Intermittency has been identified as a significant source of transport in various devices*
 - *•Tokamaks: Heller 99 (CASTOR), others*
 - *•Linear: Nielsen 96, Lehmer 96, Antar 2001*

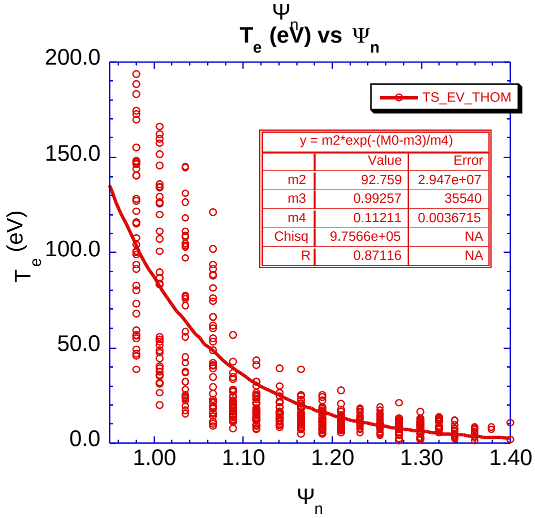
# Intermittency in DIII-D Apparent in Short Time Scale (1ms)



# Thomson scattering $I_s$ Shows similar behavior



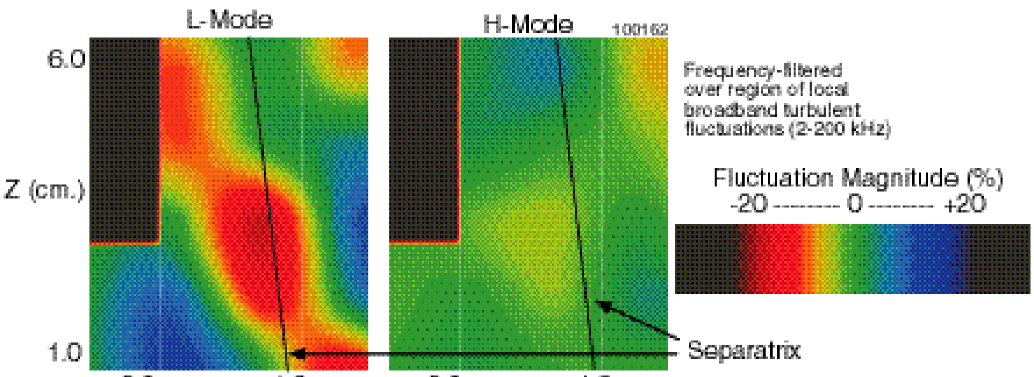



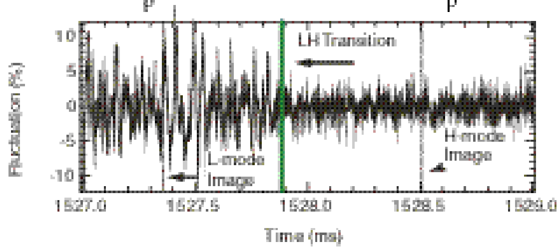

Relative Flcutuation level increases with radius

# Do Intermittent Structures Originate at the LCFS?

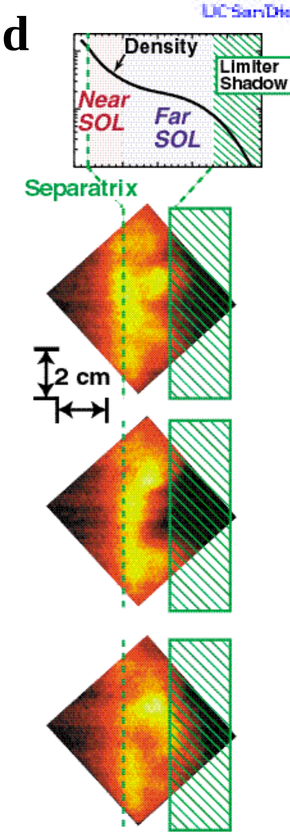
**C-Mod**

**DIII-D**



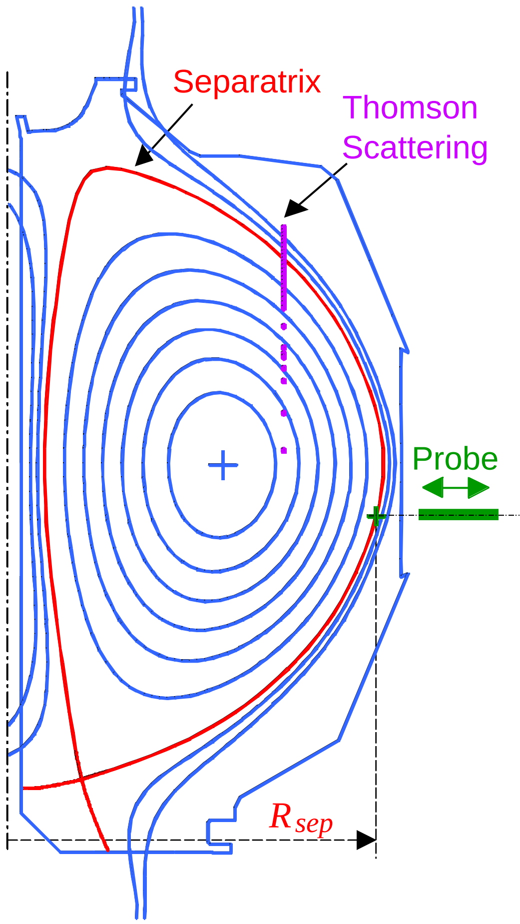



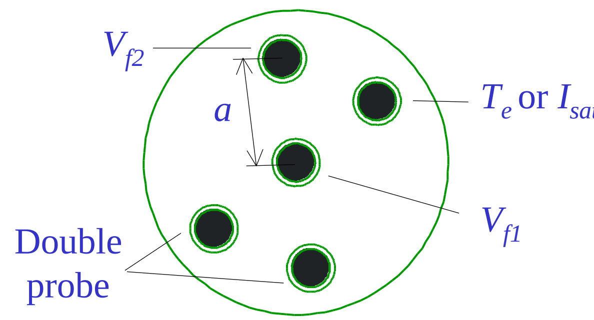

- Large, transient, coherent structures observed
- Dramatic suppression at LH Transition




Are they reduced/eliminated during H-mode?

# Experimental Arrangement on DIII-D




Probe head layout

Poloidal electric field is estimated as:

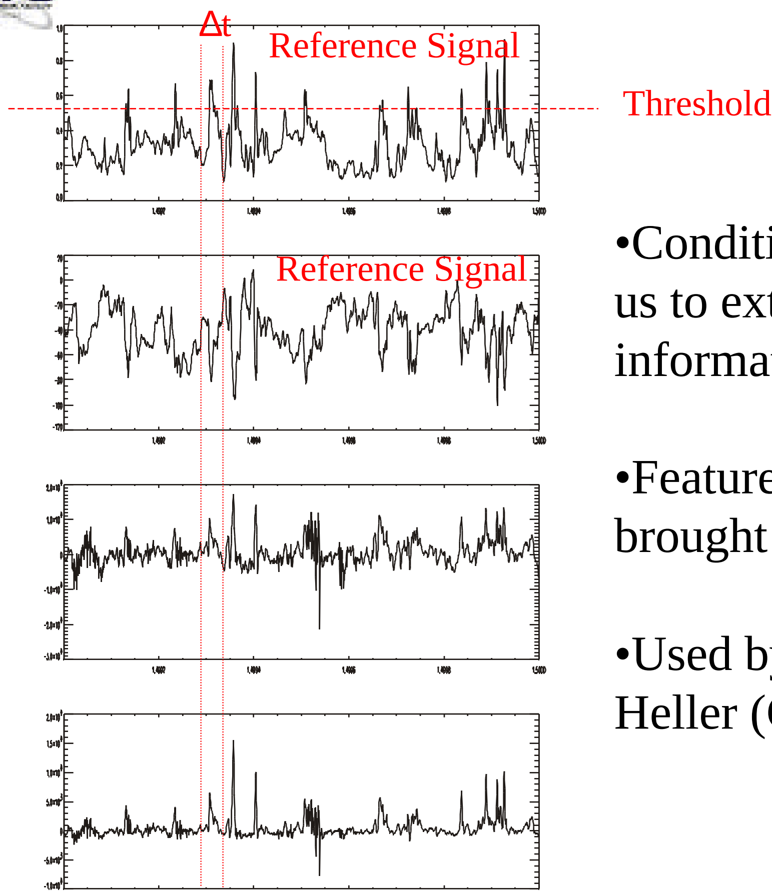
$$E_\theta \approx (V_{f2} - V_{f1})\,/a$$

The total in-and-out (plunge) time is about 0.2 s

The total plunge length is about 15 cm

$R_{sep}$ is the major radius of the separatrix (calculated by EFIT) at the probe location

# One Tool: Conditional Averaging

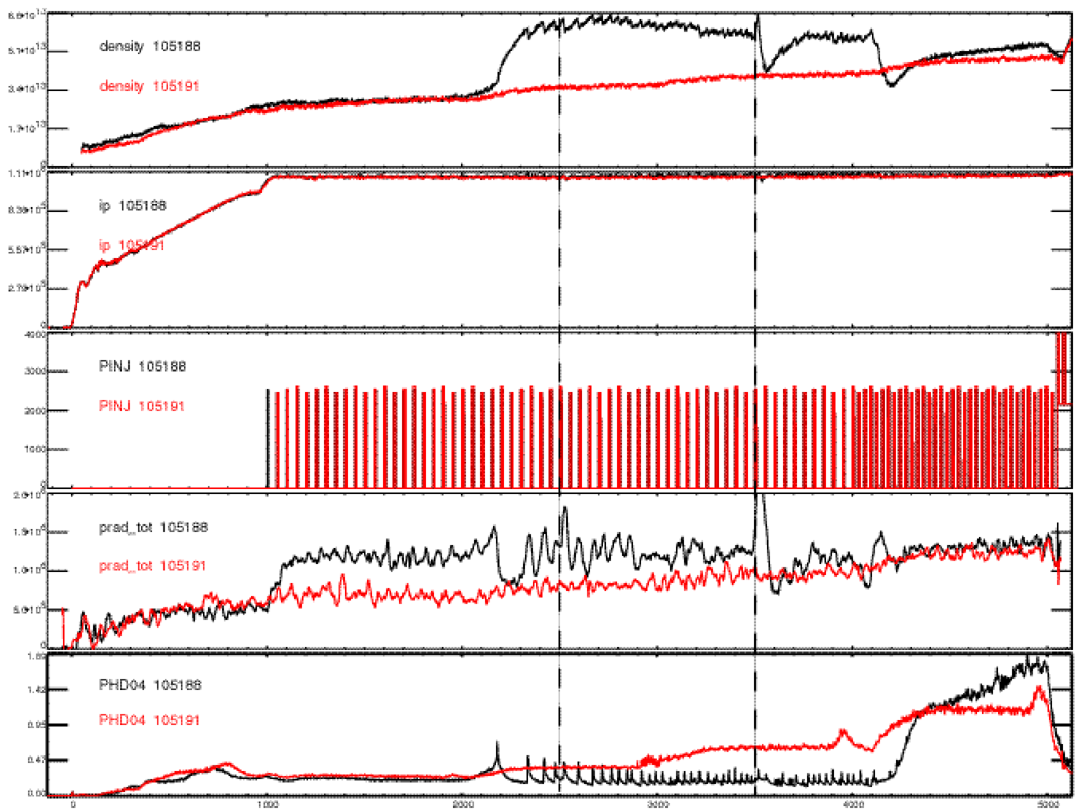



•Conditional averaging tools allow us to extract pulsed or intermittent information from a signal

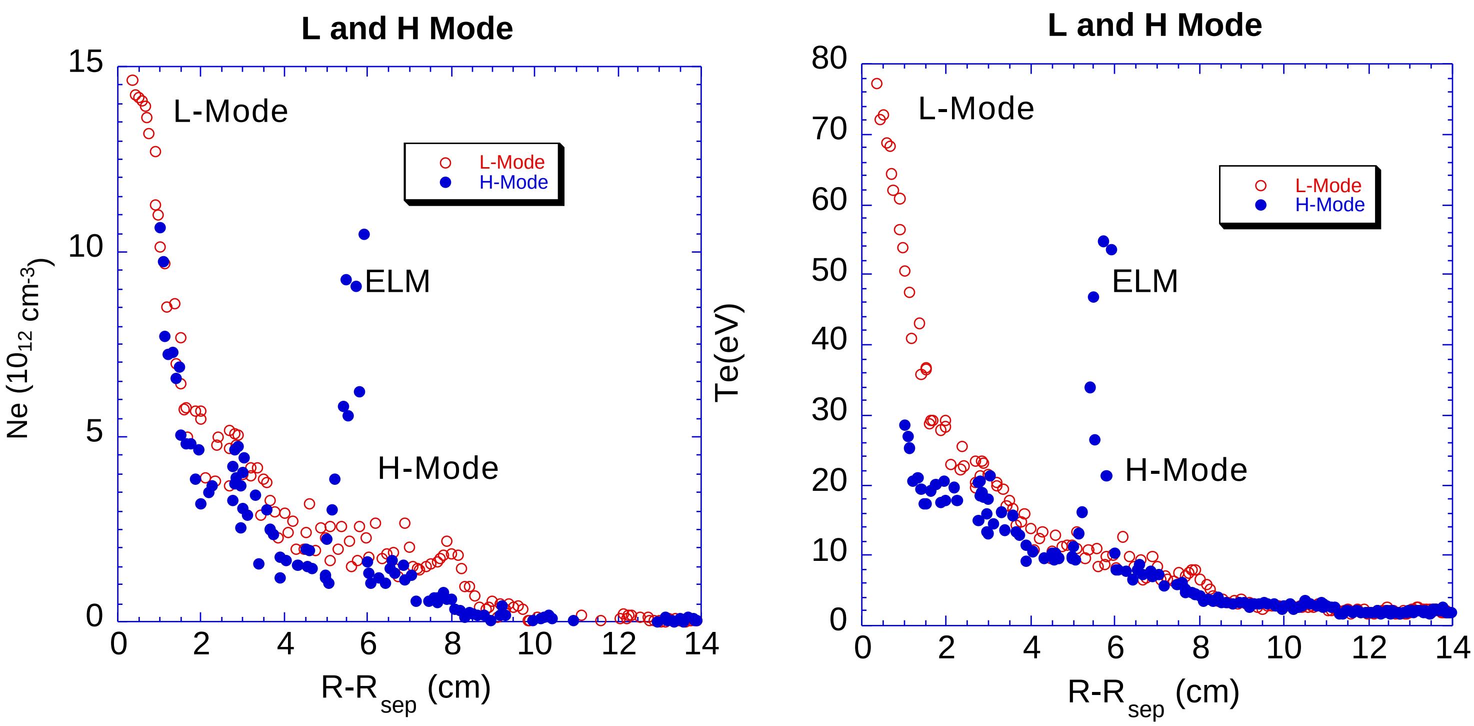
•Features that are correlated can be brought out

•Used by Fillipas (TEXT), Nielsen, Heller (CASTOR)

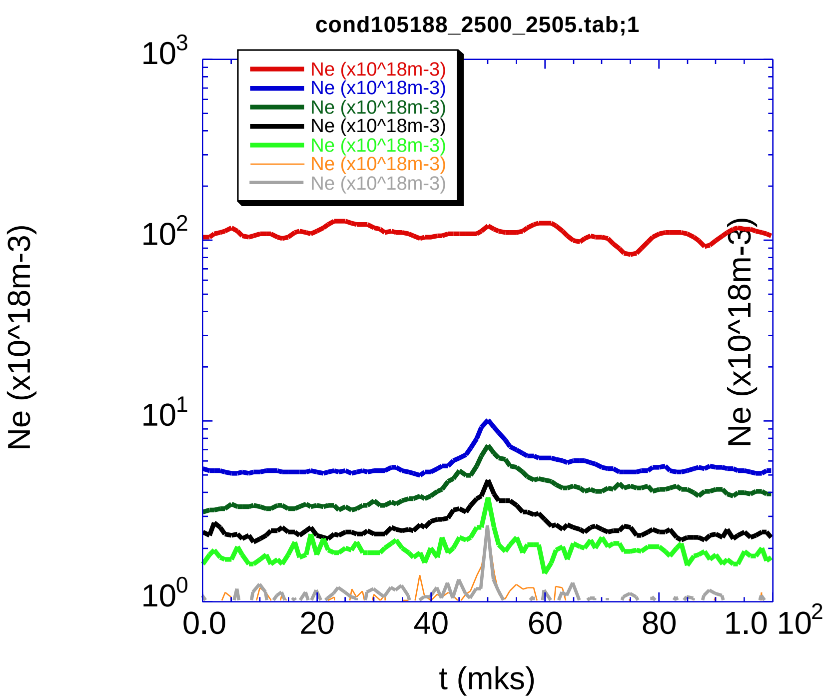
# Search in L and H Mode Discharges

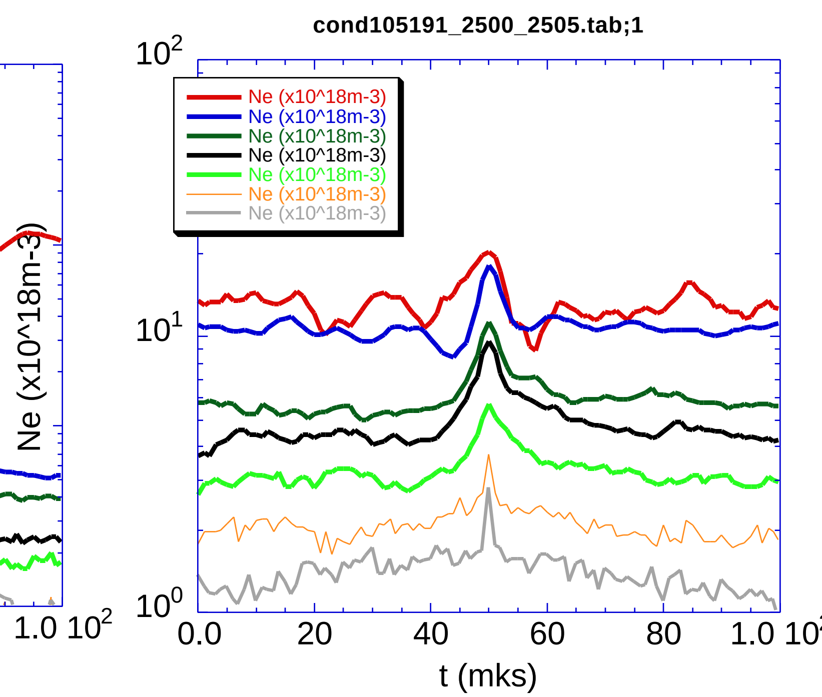


# Edge/SOL Profiles L-H Comparison

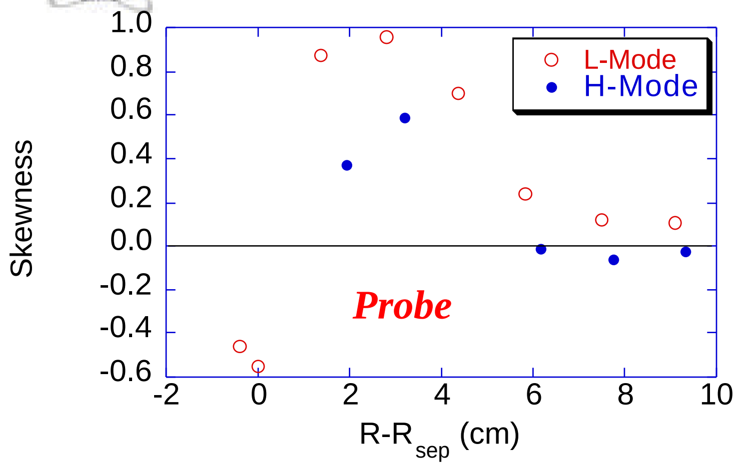


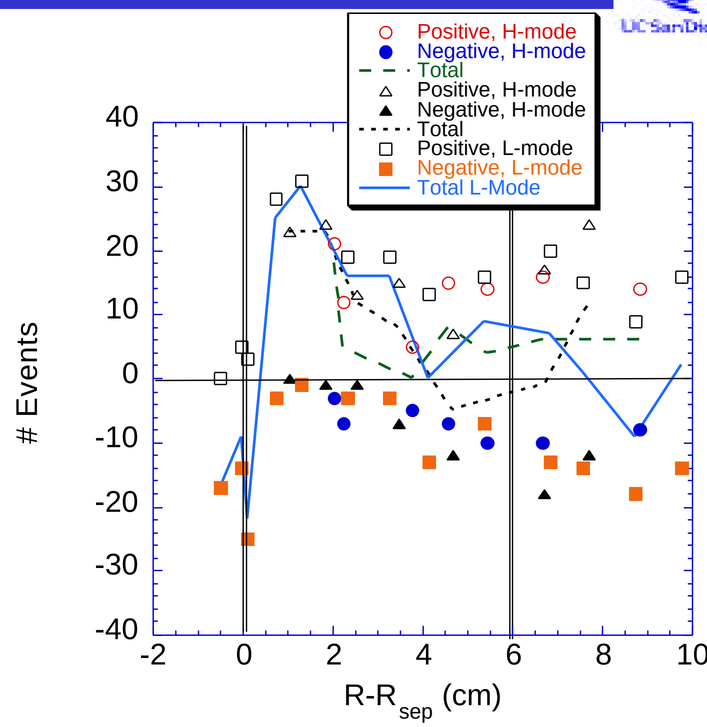
# Ne Bursts vs R in L and H-mode

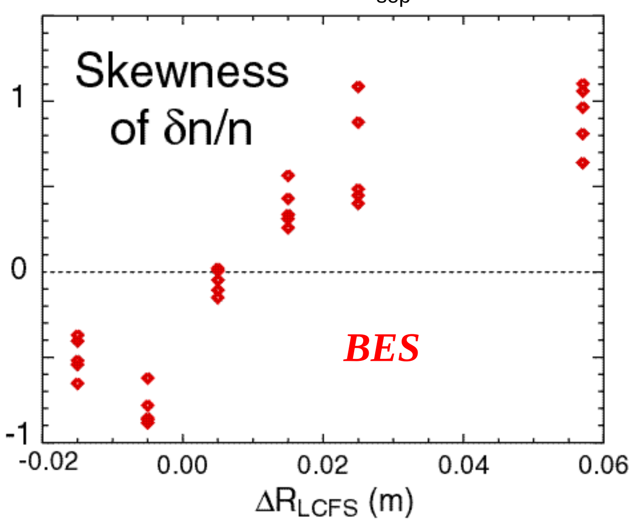


# Skewness and Event Count Suggests Creation at LCFS



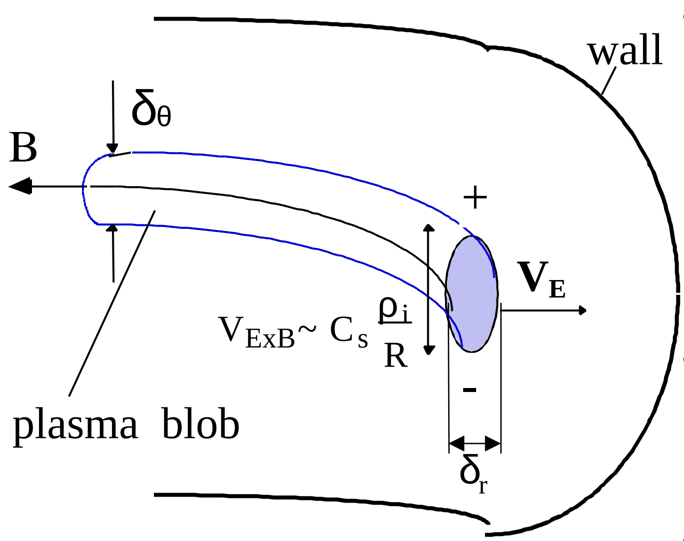




*Negative events dominate inside LCFS and positive events from LCFS to the wall*

*Difference between L and H mode!!!*

# A Simple Interpretative Model: Sergei Krasheninnikov's



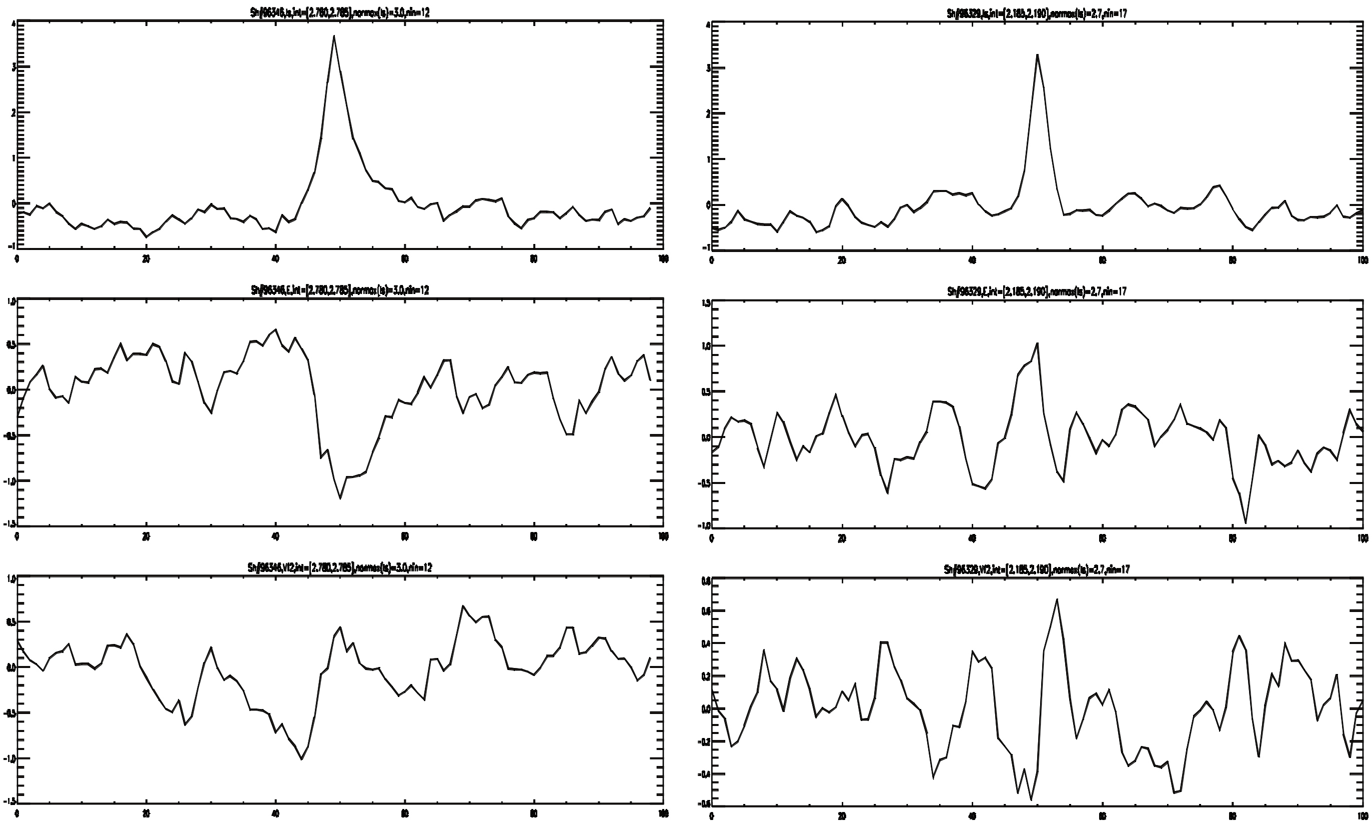

- High density plasma structures detach from the bulk plasma due to turbulence effects resulting in plasma stratification in the region around separatrix.
- These structures extended along the magnetic field lines.
- Propagate to the outer wall due to plasma $\vec{B} \times \nabla B$ polarization and associated $\vec{E} \times \vec{B}$ drift.

**From Sergei's APS'00 poster and 2001 PRA**

# Reversal of Bt results in reversed object polarization

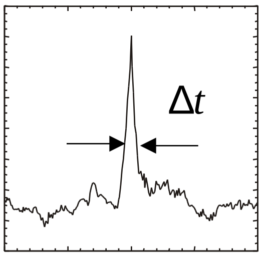
Shot#96346  reversed Bt

Shot#96329  normal Bt



*The GradB drift polarization mechanism is supported!!*

# What can we learn quantitatively from these measurements?




$$\Delta t \approx \delta_r / V_r$$

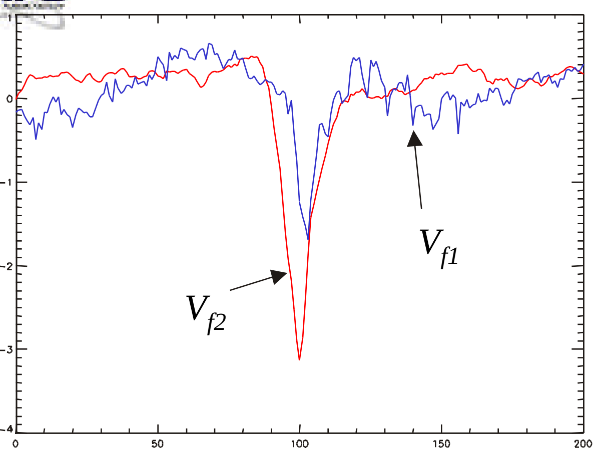
$V_r$ can be calculated as $E_\theta / B_\varphi$ ***as per Sergei's model and simple ExB force***

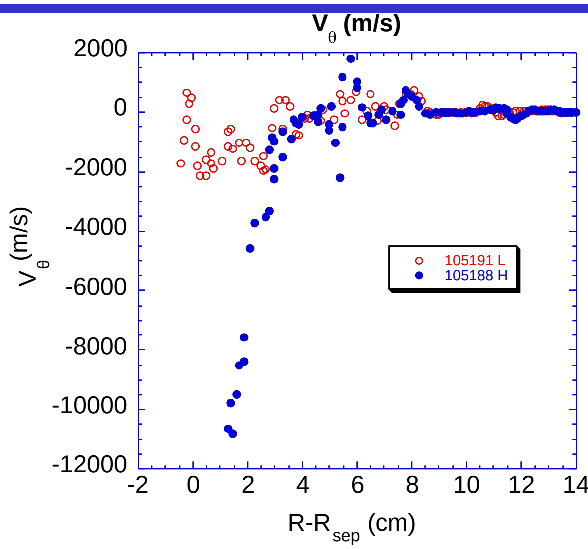
| | $R_{probe}$ - $R_{sep}$ (cm) | $\Delta t$ (s) | $E_\theta$ (V/m) | $V_r$(m/s) | $\delta_r$(cm) |
|---|---|---|---|---|---|
| LCFS | 0.5 | $1.5\times10^{-5}$ | 4000 | 2000 | 3 |
| | 5 | $2\times10^{-5}$ | 1500 | 750 | 1.5 |
| Wall | 10 | $1.5\times10^{-5}$ | 500 | 250 | 0.37 |

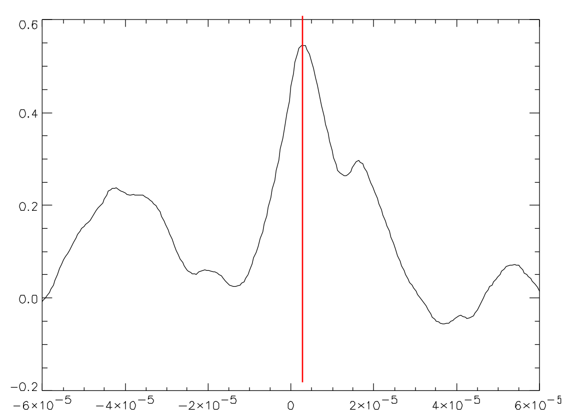
*The radial size of the objects can be calculated at ~2 cm at LCFS!*
*The bursts are slowing down, decaying and thinning as they move out*
*There about $10^4$ of these per s!*

Probes are essential instruments for these studies due to their dense datasets and high bandwidth

# Poloidal Velocity is significant in L and H Mode

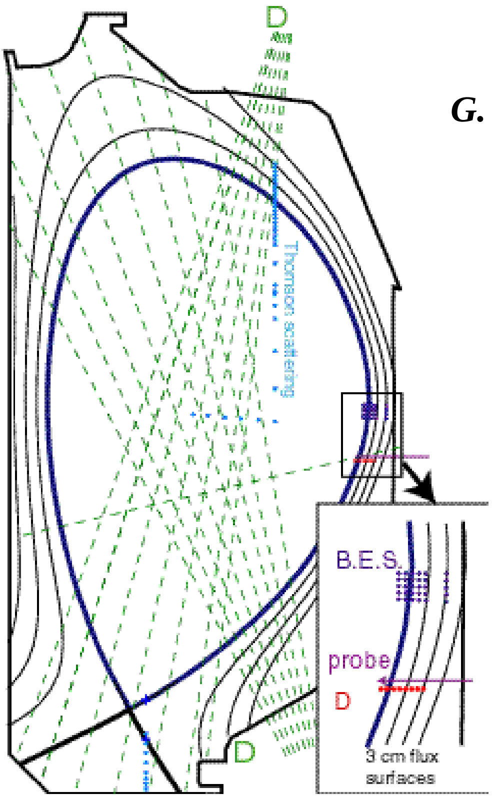


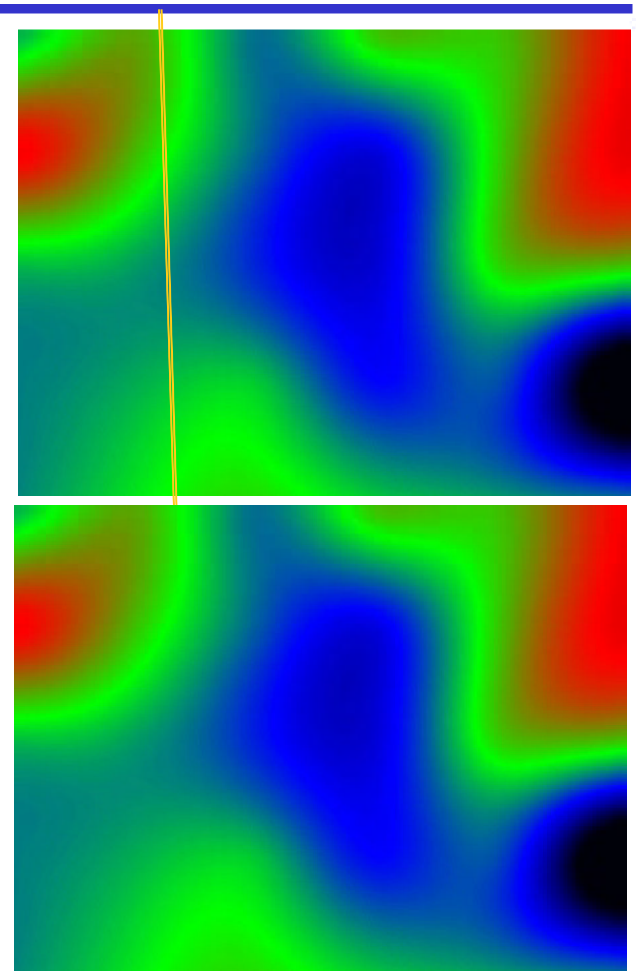

- **$V_{f1}$ is lagging behind $V_{f2}$ by 1-1.5μs**
- **For the tip separation of 5.2mm: $V_\theta$ = 5.2e-3/1.2e-6 ≈ 4300 m/s**
- **Cross-Correlation measurements yield $V_\theta$ = 5.2e-3/3.0e-6 ≈ 1733 m/s**
- **This velocity is directed down, towards X-point, same direction as $V_r \times B$**
- ***Poloidal size at LCFS is ~ 2cm!!***

# Various Diagnostics Indicate Structures Exist

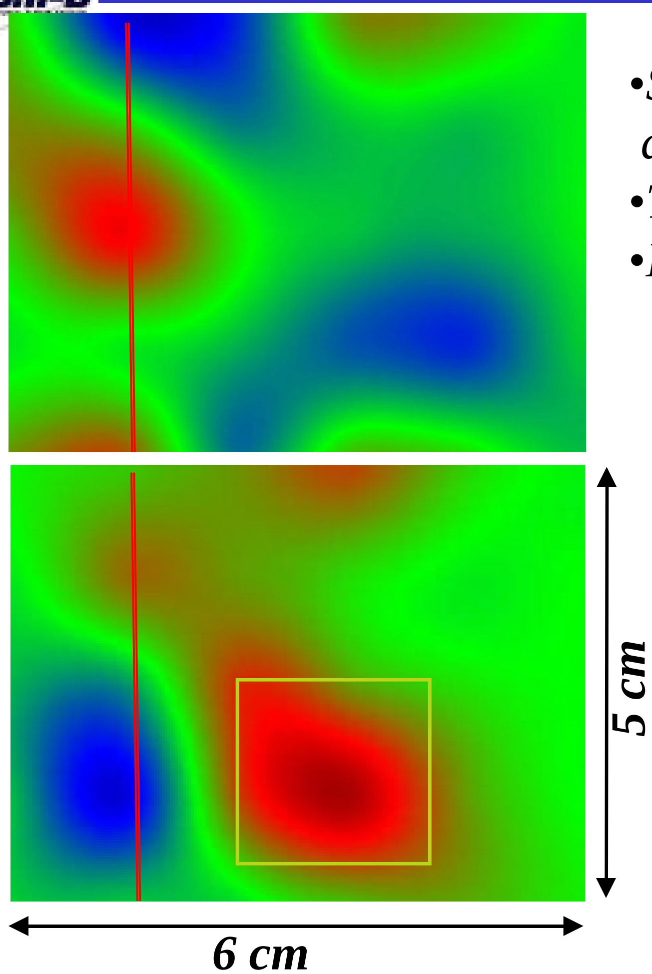



***G. McKee, UW***

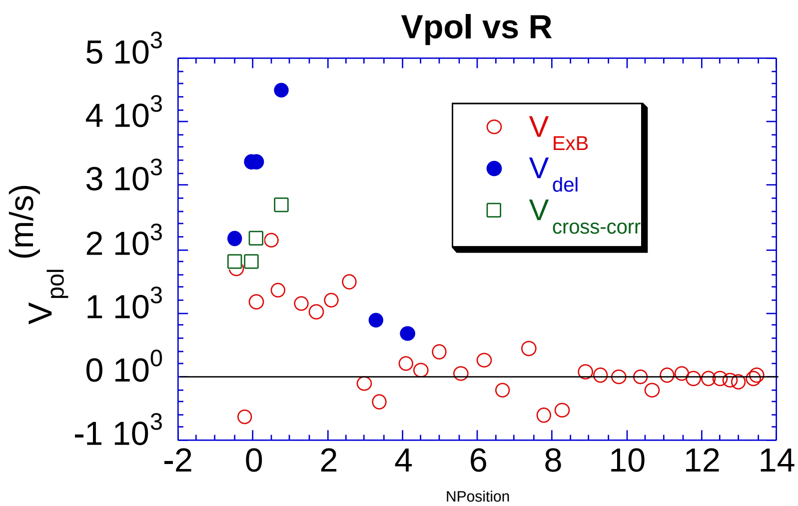
***D, Colchin ORNL,***
***D. Whyte UCSD***



# BES Data Confirms Presence of Structures and Size



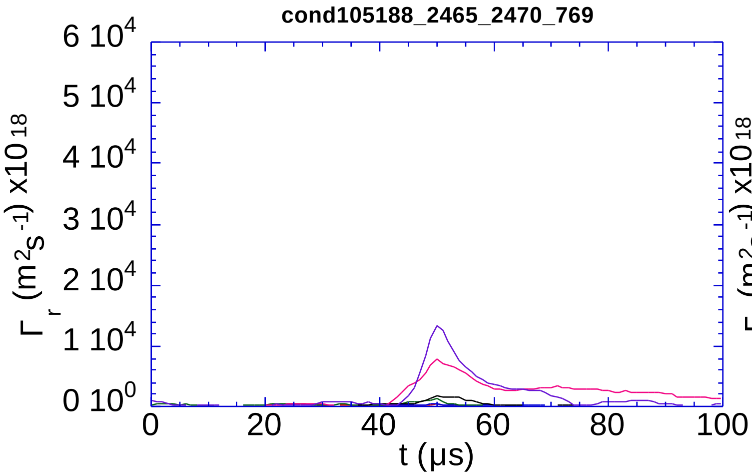

- *Structures move poloidally at ~5km/s at the LCFS*
- *The size near the LCFS is 2x2 cm*
- *In agreement with probes!!*



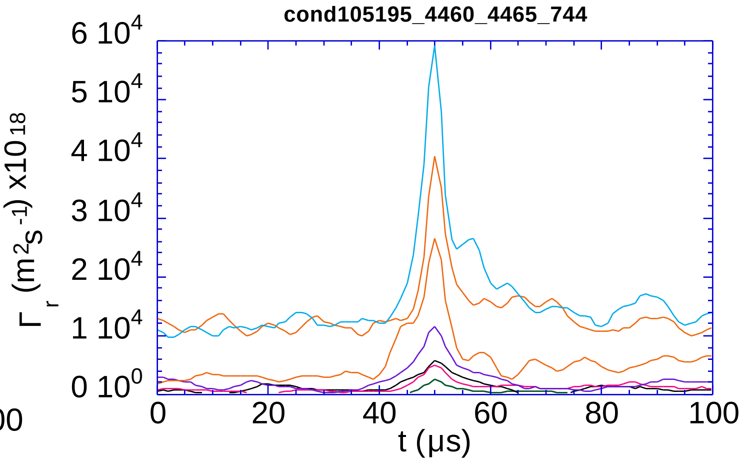

***G. McKee, UW (2001)***

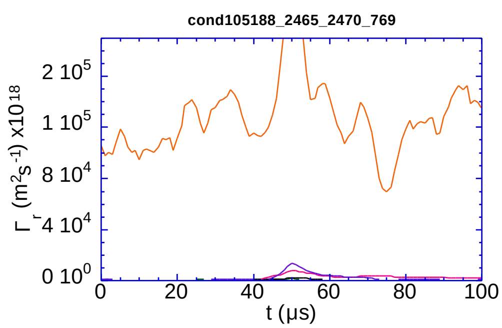
# Flux vs R, L and H-mode

*H-Mode*




*L-Mode*

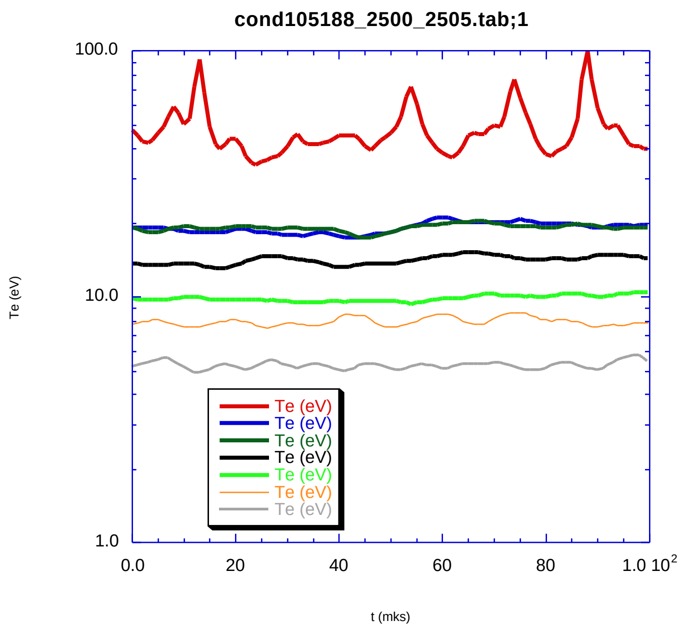


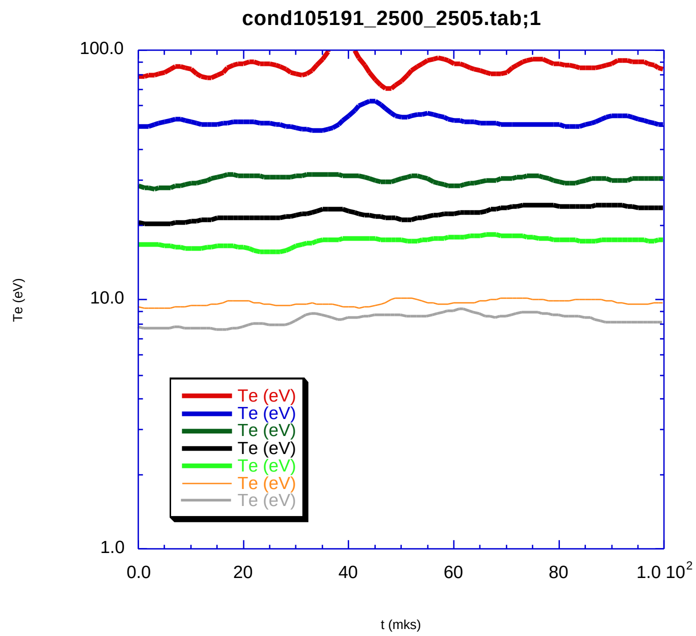




*ExB Flux is much higher at LCFS and falls rapidly with R (within 0.5 cm)*

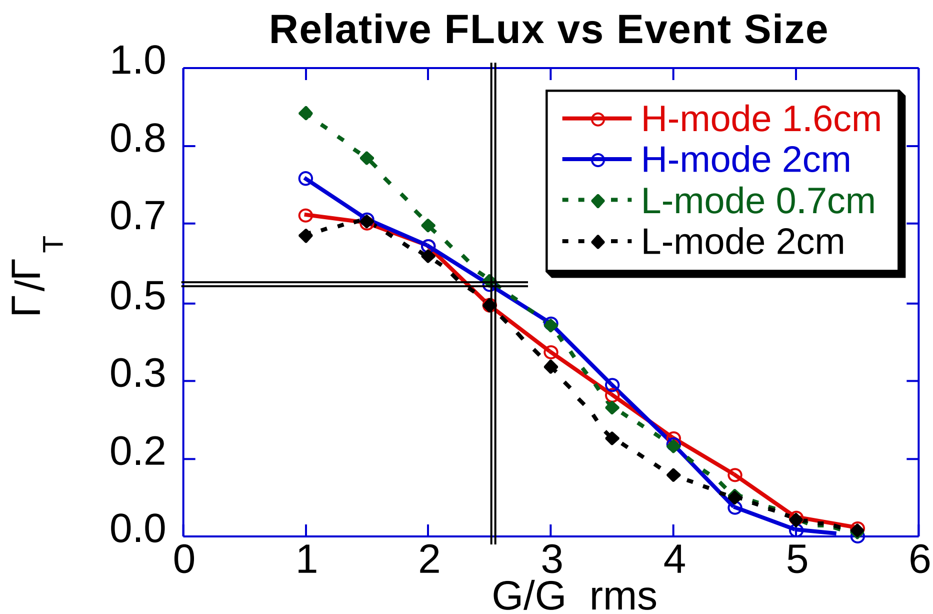
*Flux is much higher in L-mode in the SOL*

# Te Bursts vs R, L and H-Mode



# Spikes >2.5 rms are ~ 50% of total ExB transport




Relative spike amplitude: $(I_s E_\theta - \langle I_s E_\theta \rangle) / (I_s E_\theta)^{rms}$

Not much difference between H and L modes

# Intermittent ExB transport already accounted for

$$\Gamma^{tot} = \left| D \quad n \right|_{NEOCLASSICAL} + \frac{1}{B_{\varphi}} \left\langle \tilde{n} \tilde{E}_{\theta} \right\rangle$$

$$\left| \frac{1}{B_{\varphi}} \left\langle \tilde{n} \tilde{E}_{\theta} \right\rangle \right|_{BROADBAND} + \left| \frac{1}{B_{\varphi}} \left\langle \tilde{n} \tilde{E}_{\theta} \right\rangle \right|_{INTERMITTENT}$$

"Diffusive"
classical and
neoclassical
losses

"Turbulent"
driven by wide-band
elecrostatic
turbulence

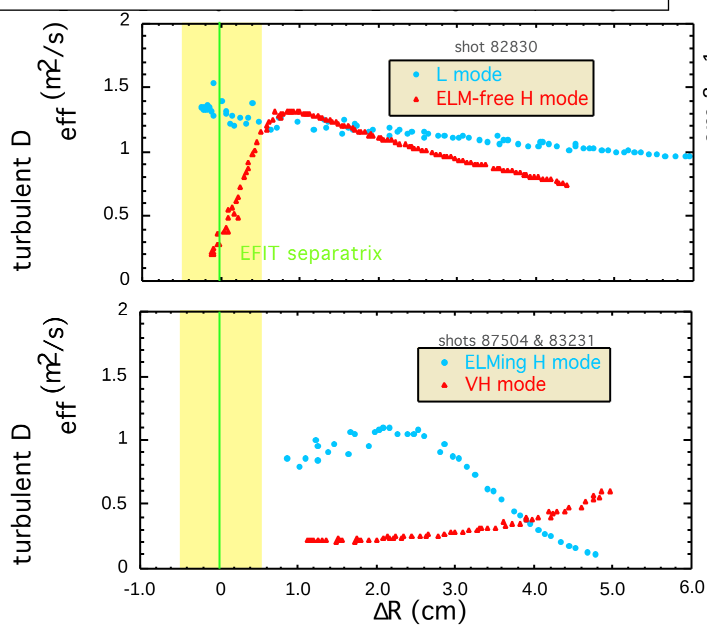
"Convective"
Blobs
SCALE?

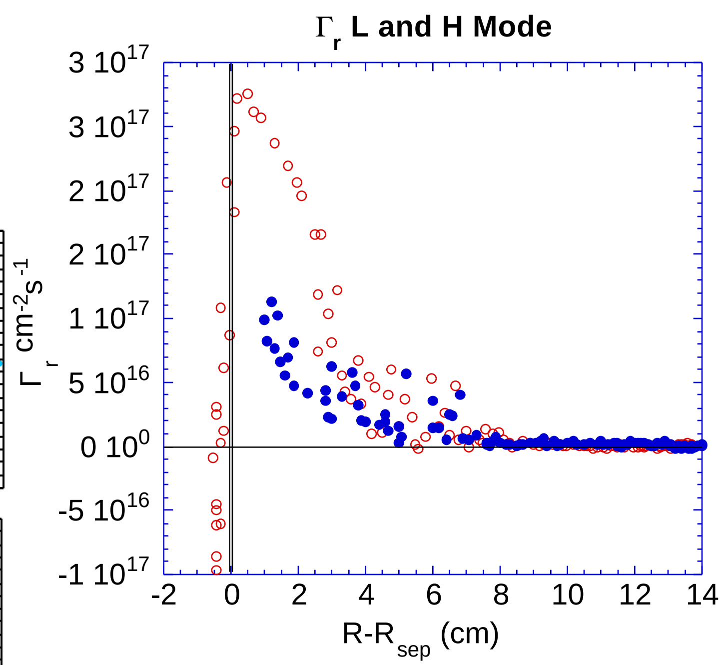
- However, the dynamics of these blobs is quite different
- Instead of diffusing, they convect.

# Broadband Turbulence Particle Flux L-H Mode

**Effective diffusion coefficient flattens or increases in the SOL**

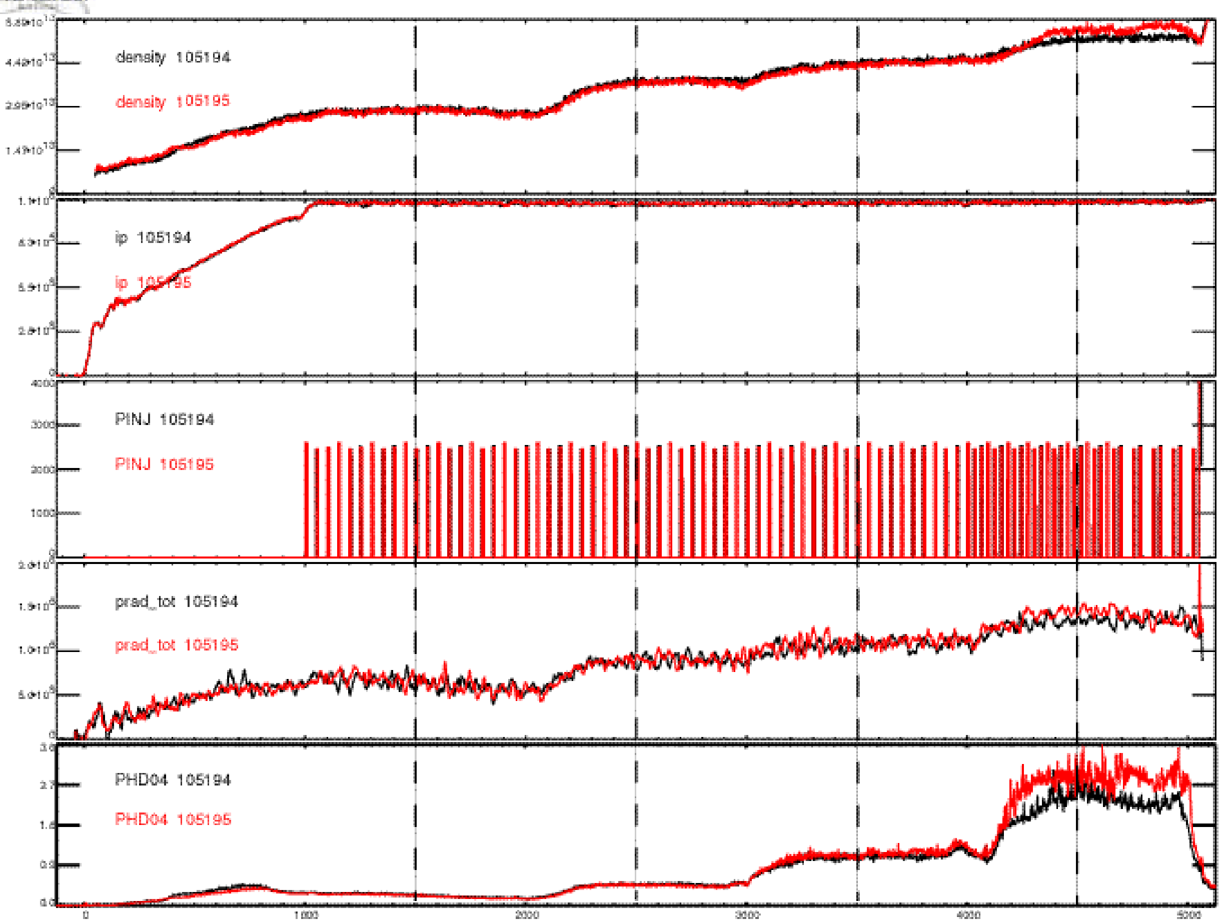
$$D_{eff} = \frac{\tilde{\Gamma}}{n}$$



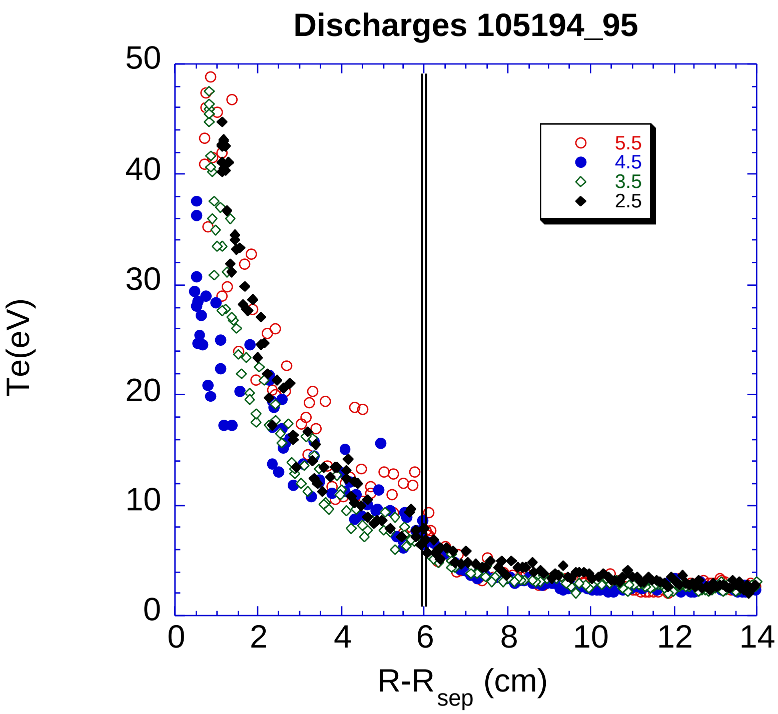

R. Moyer 92-95

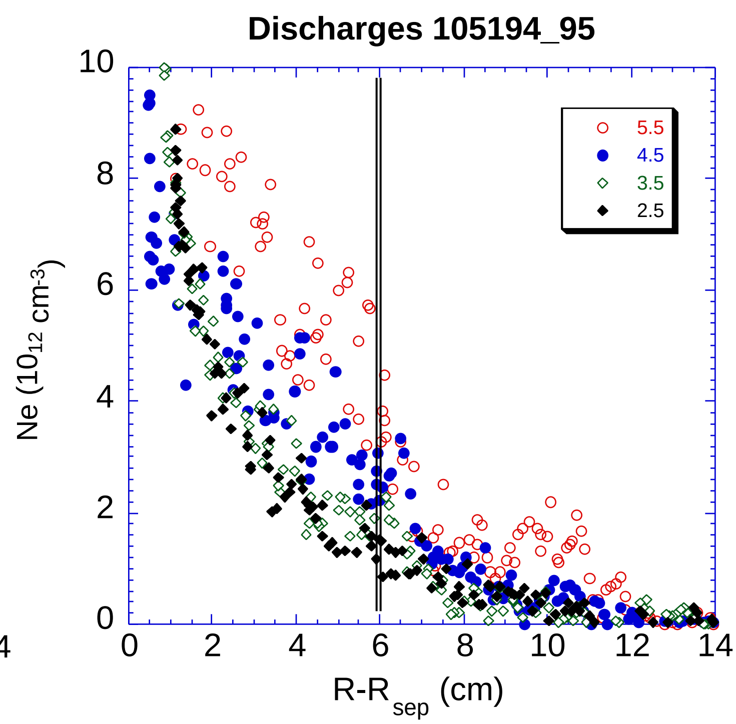
# L Mode $n_e$ scan Comparison Discharges



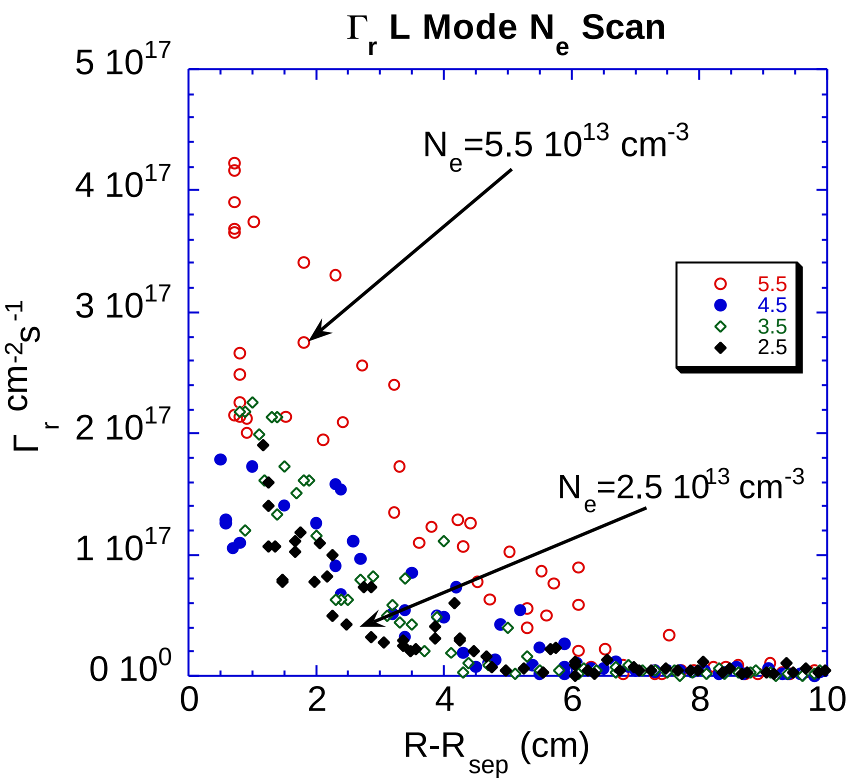

***Four Density Plateaus***

# Edge/SOL Profiles $n_e$ Scan



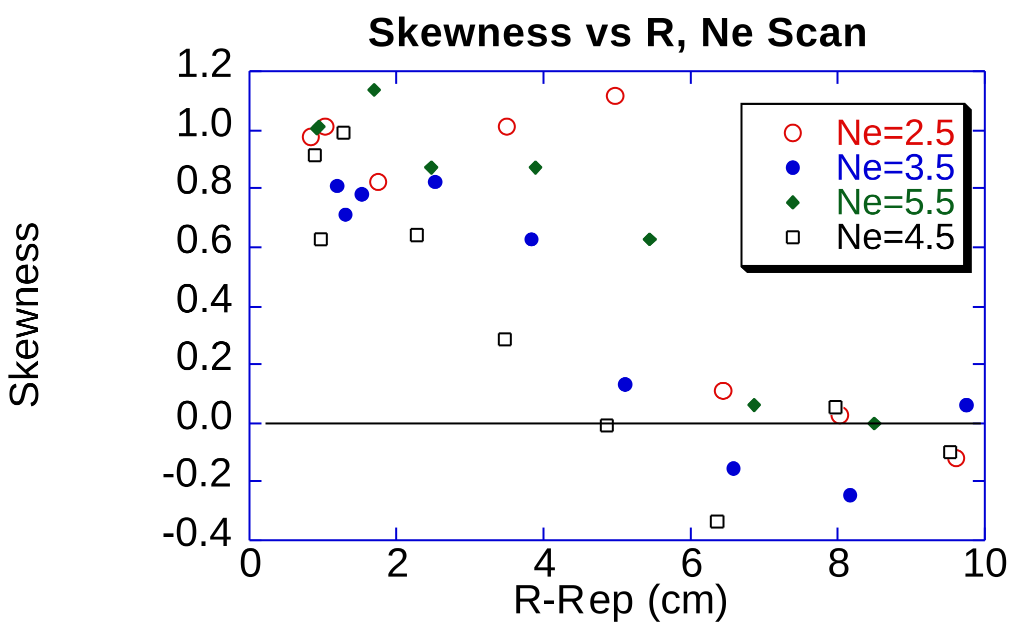



# Broadband Turbulence Particle Flux Ne Scan

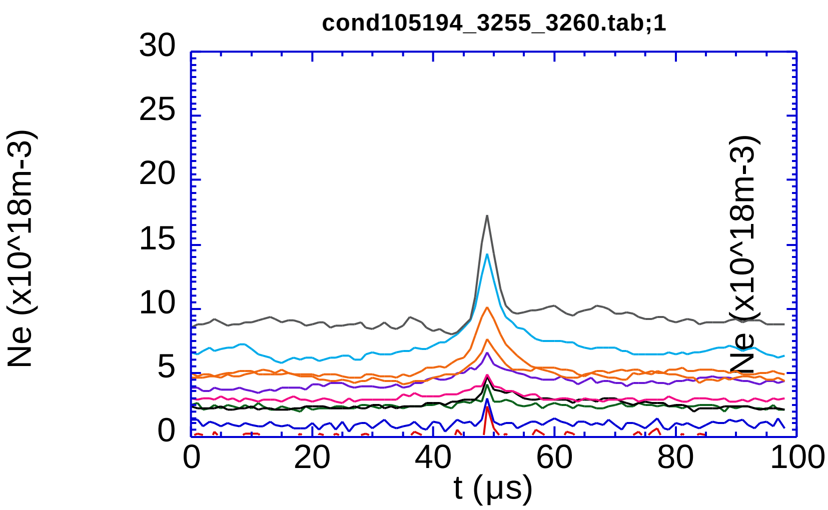


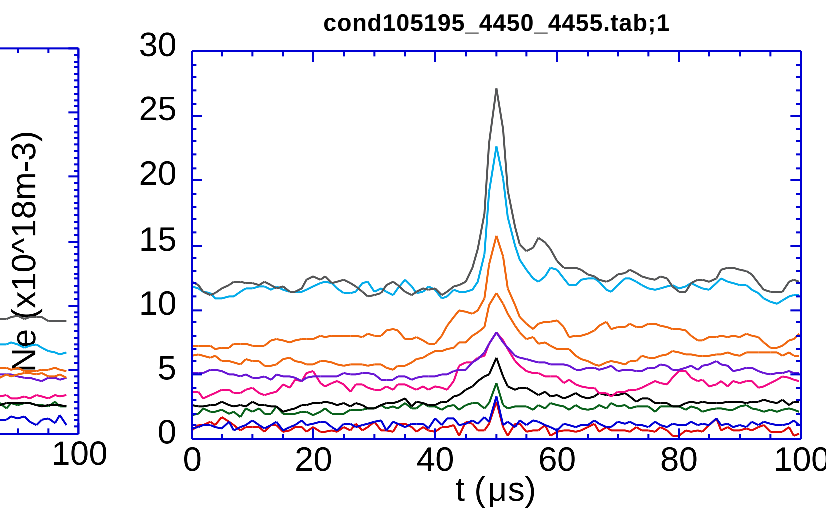

- ***Flux Increases with density***
- ***Flux roughly accounts for particle inventory***

# Skewness Shows Trend with Density

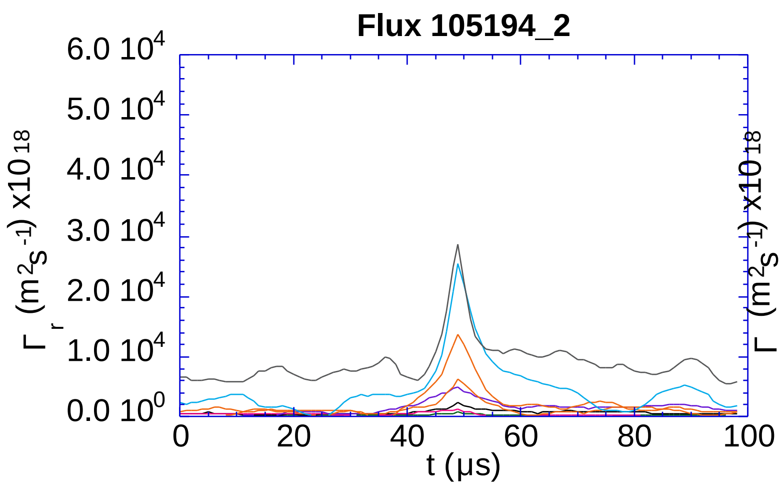


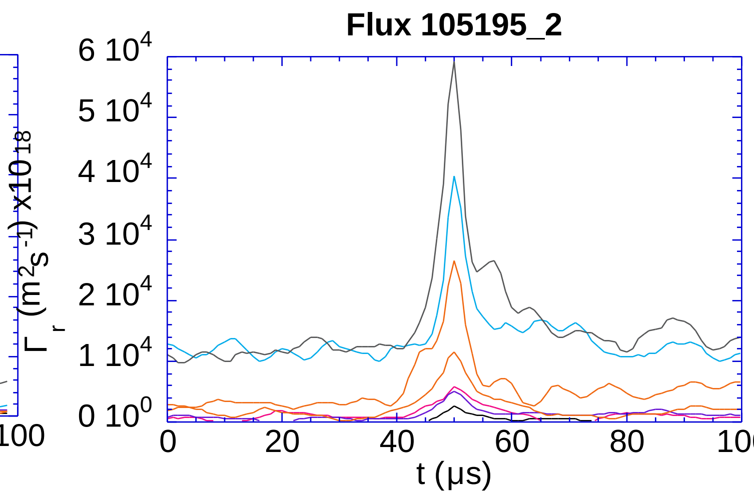
# Higher ne Pulses for higher averaged ne



# Intermittent Flux Increases with Density



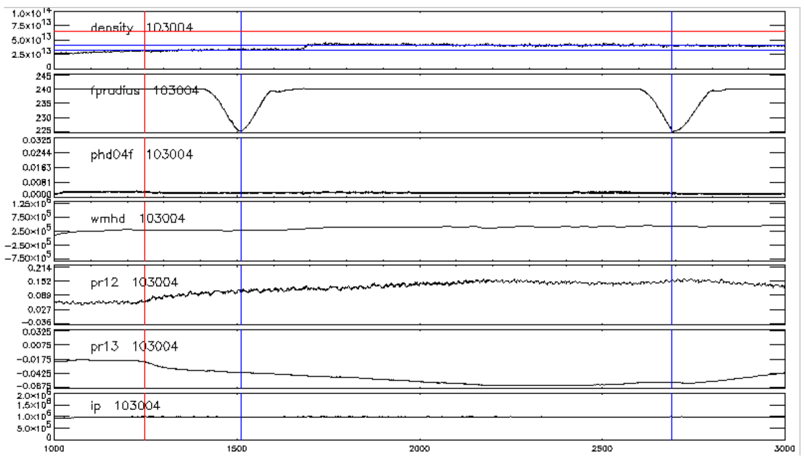
# Conclusions

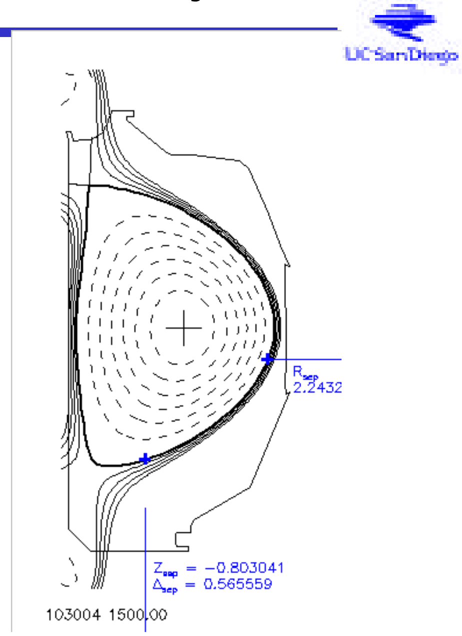
- *Intermittency exists in DIII-D in L and H-mode*
- *The structures are created near the LCFS*
- *They propagate poloidally in the ExB direction (faster than ExB?)*
- *In the framework of Krasheninnikov's model:*
  - *GradB polarization is responsible for radial motion*
  - *So far evidence supports the mechanism*
  - *Then a radial velocity can be calculated*
    - *Structures shrink from 2 cm at the LCFS to 0.5 cm at the wall*
    - *Structures slow down as they move radially*
      - *Poloidally from 5 km/s to ~0.1-0.2 km/s*
      - *Radially from 2 km/s to 0.2 km/s*
- *Other diagnostics show similar behavior (BES, D_alpha, etc)*

## This is NOT new. All the elements were available before 2000

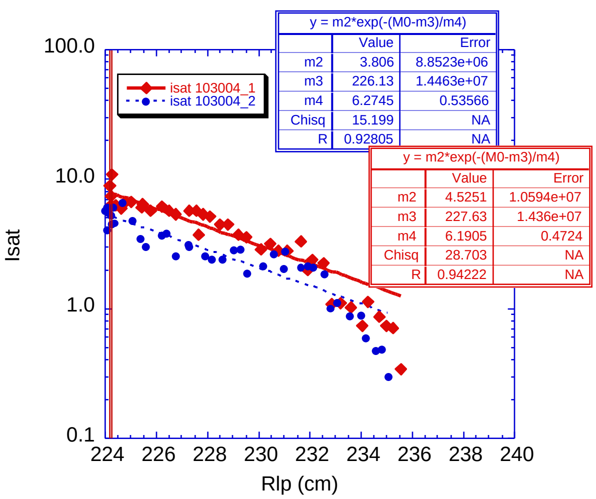
- Edge density profiles in DIII-D TEXTOR and PISCES can show different decay lengths in near and far SOL with that in far SOL often being much longer (Watkins *et al* J. Nucl. Mater. 1992, Boedo et al RSI 1998)
- Turbulent E×B transport is considerable in far SOL (Moyer *et al* J. Nucl. Mater. 1997, Boedo, et al. 1999, 2000)
- $I_{sat}$ PDFs are usually positively skewed while those of $V_f$ are negatively skewed or Gaussian (Bora, 92, Turney, Moyer *et al* APS'9, Carreras)
- While $I_{sat}$ near the separatrix has skewed PDF, PCI and BES show Gaussian PDFs for the density fluctuations (Rost *et al* APS'00)
- A. V. Filippas, et al (TEXT 95), A. H. Nielsen et al (96), Heller (CASTOR 99) etc etc.

# Intermittency-Dominated Transport is NOT Always Present




**Jsat vs R**




L-Mode

USN

High Triangularity

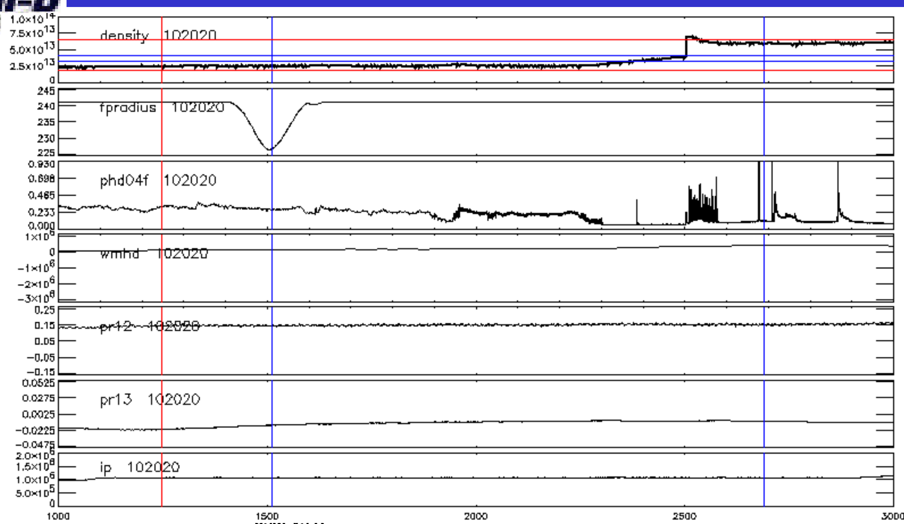
$I_p$~ 1 MA

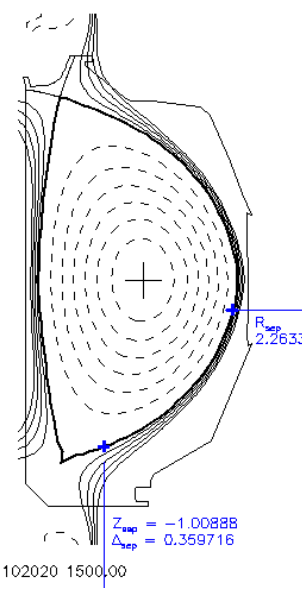
$N_e$~ 4.5 $10^{19}$

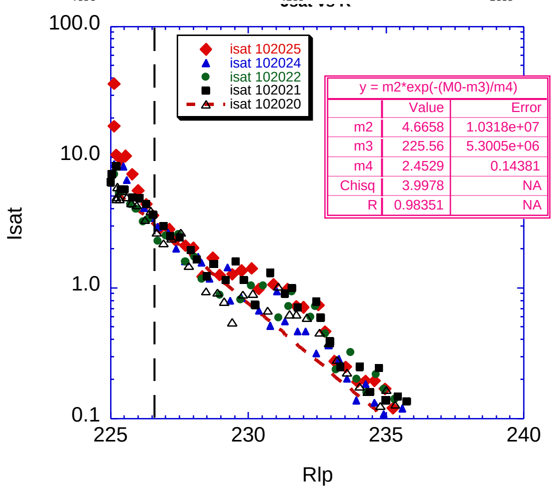
$\lambda_{Isat}$=6 cm !!!

Which explains why it has not been emphasized before!

# Significant Spikeness is NOT common in DIII-D




L-Mode

USN-DN

Medium Triangularity

$\lambda_{Isat}$= 2.5 cm !!!

# Statistical Moments Help Evaluate Intermittency

$$\text{Mean} = \bar{X} = \frac{1}{N}\sum_{j=0}^{N-1} X_{j-N/2}$$

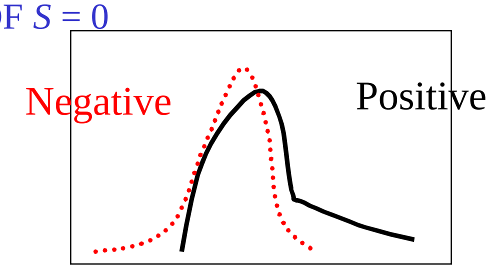
Mean value,
SMOOTH in IDL

$$\text{Variance} = \sigma^2 = \frac{1}{N}\sum_{j=0}^{N-1}\left(X_{j-N/2} - \bar{X}\right)^2$$

Square of RMS
amplitude

$$\text{Skewness} = S = \frac{1}{N}\sum_{j=0}^{N-1}\left(\frac{X_{j-N/2} - \bar{X}}{\sigma}\right)^3$$

Measure of asymmetry
of the PDF;
for Gaussian PDF $S = 0$




$$\text{Kurtosis} = K = \frac{1}{N}\sum_{j=0}^{N-1}\left(\frac{X_{j-N/2} - \bar{X}}{\sigma}\right)^4$$

Measure of flatness of
the PDF;
for Gaussian PDF $K = 3$