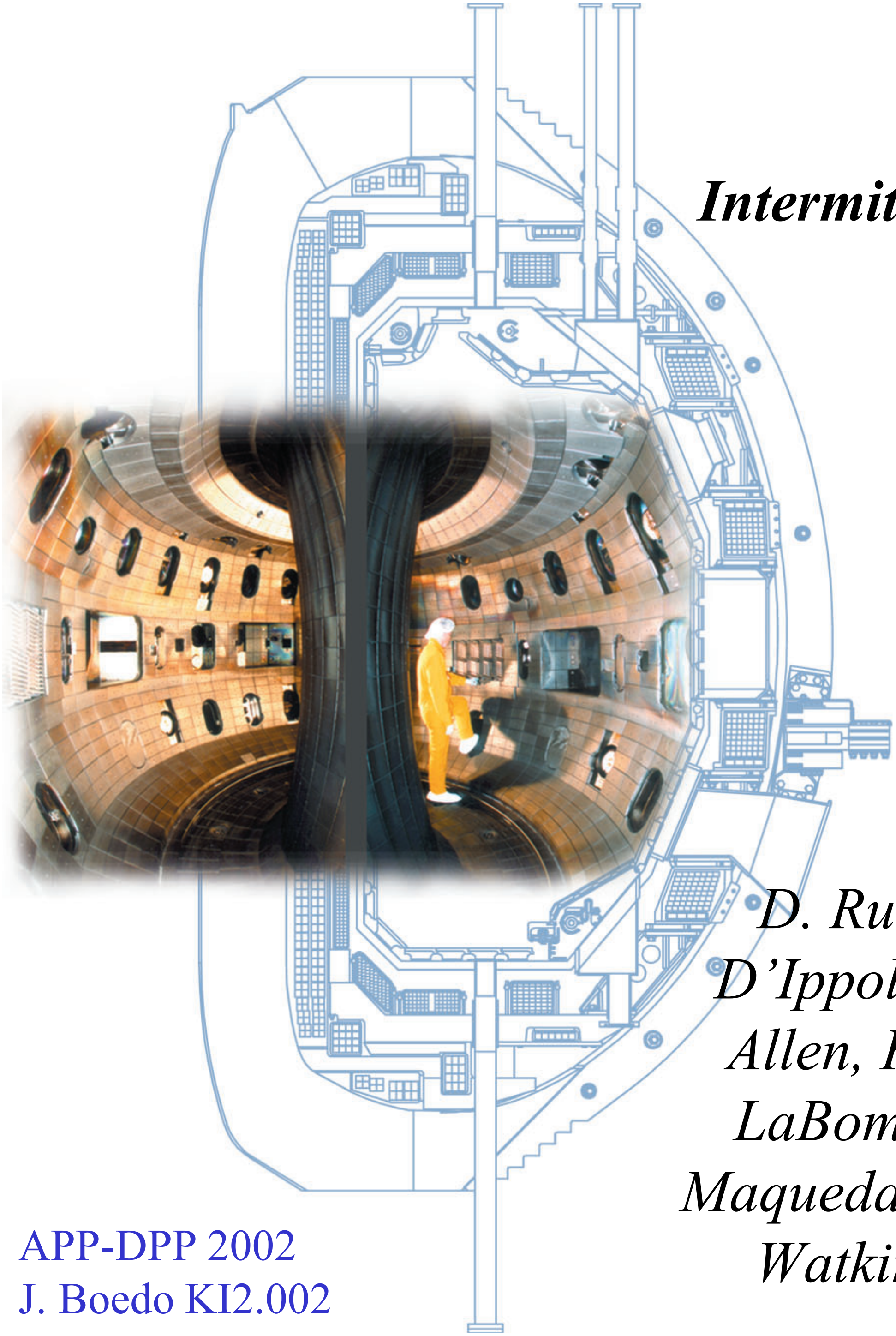


Intermittency and Transport in the DIII-D Boundary

J. Boedo
For the DIII-D Team

Contributions by

D. Rudakov, G. McKee, R. Colchin, D. D'Ippolito, W. Nevins, R. Moyer, X. Xu, S. Allen, P. Ghendrih, S. Krashenninikio, B. LaBombard, A. Leonard, A. Mahdavi, R. Maqueda, G. Porter, J. Terry, M. Schaffer, J. Watkins, P. West, D. Whyte, S. Zweben

APP-DPP 2002
J. Boedo KI2.002

Outline

- Motivation
- Diagnostics/Discharge Conditions
- Cross-field Transport
- Intermittency and Characteristics in DIII-D
- Conditional Averaging Tools
- L-H mode comparison
- Statistics at the LCFS
- L-mode Density Scan
- Theoretical Understanding

Motivation

- Results from ALCATOR C-MOD and recently from DIII-D have indicated that strong recycling occurs at the main chamber wall.

  Umanski 1998 and 1999, LaBombard 2000 and 2001, Terry et al 2001and 2002.
  See J. Terry KI2.001

- The walls are a large source of carbon in various devices.

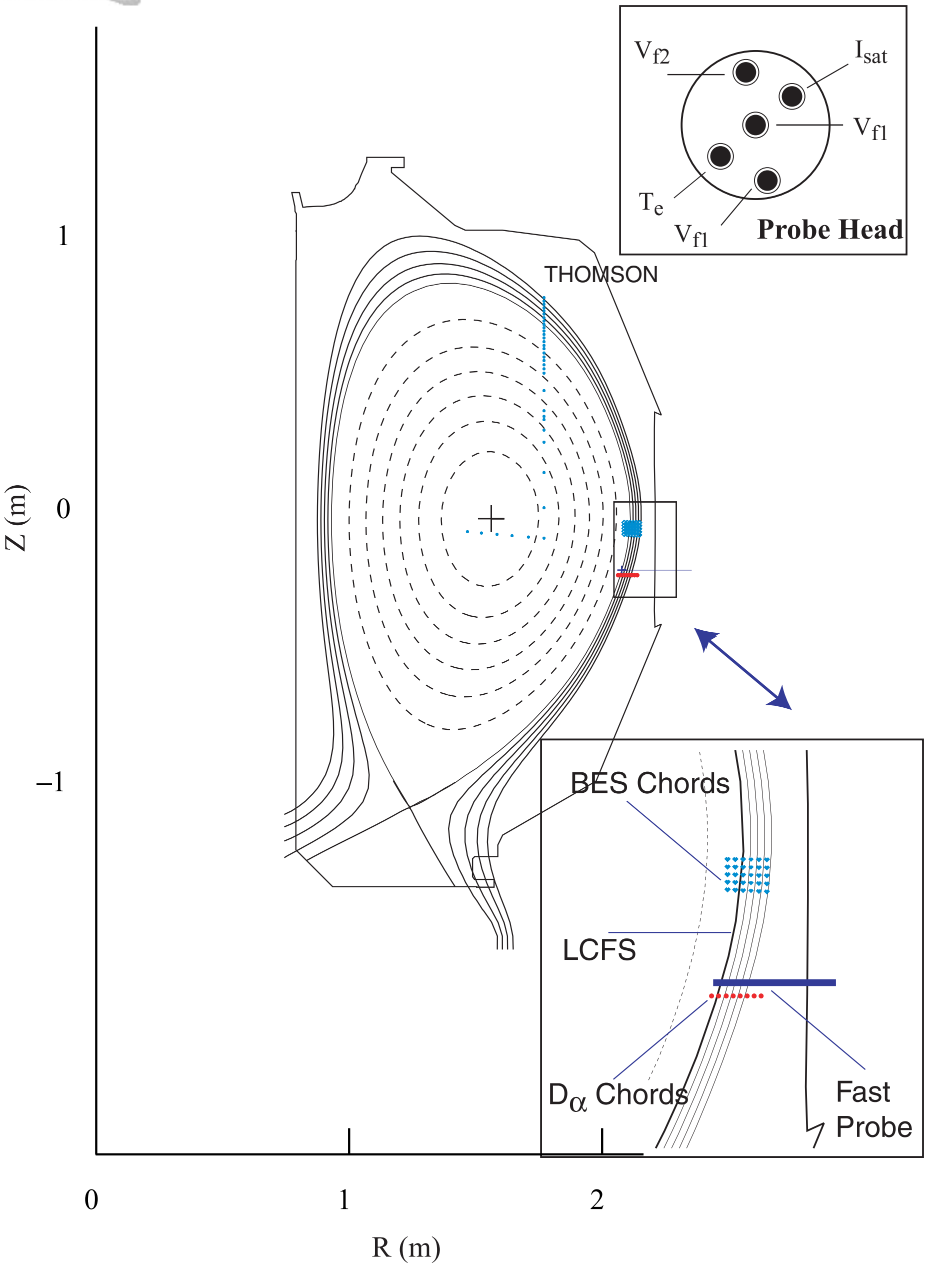
- What is then the mechanism that brings plasma to the walls?

- Previous results in DIII-D and other devices have indicated that:

  - Transport in the far SOL is stronger than thought. Moyer et al J. Nucl. Mater. 1997, Boedo, et al. 1999, 2000, Umanski 1998 and 1999, LaBombard 2000 and 2001, Terry 2001, 2002
  - Profiles in the far SOL are flat => role of diffusion? Watkins et al J. Nucl. Mater. 1992, Boedo et al RSI 1998, LaBombard 2000
  - Intermittency has been identified as a significant source of transport. Carreras et al Nielsen et al., Heller et al. Boedo et al. PoP 2001, LaBombard 2000

- Intermittency (i.e. fast, intermittent events larger than the rms level) will be characterized in detail in this presentation and connected to transport.

Fast Diagnostics Used

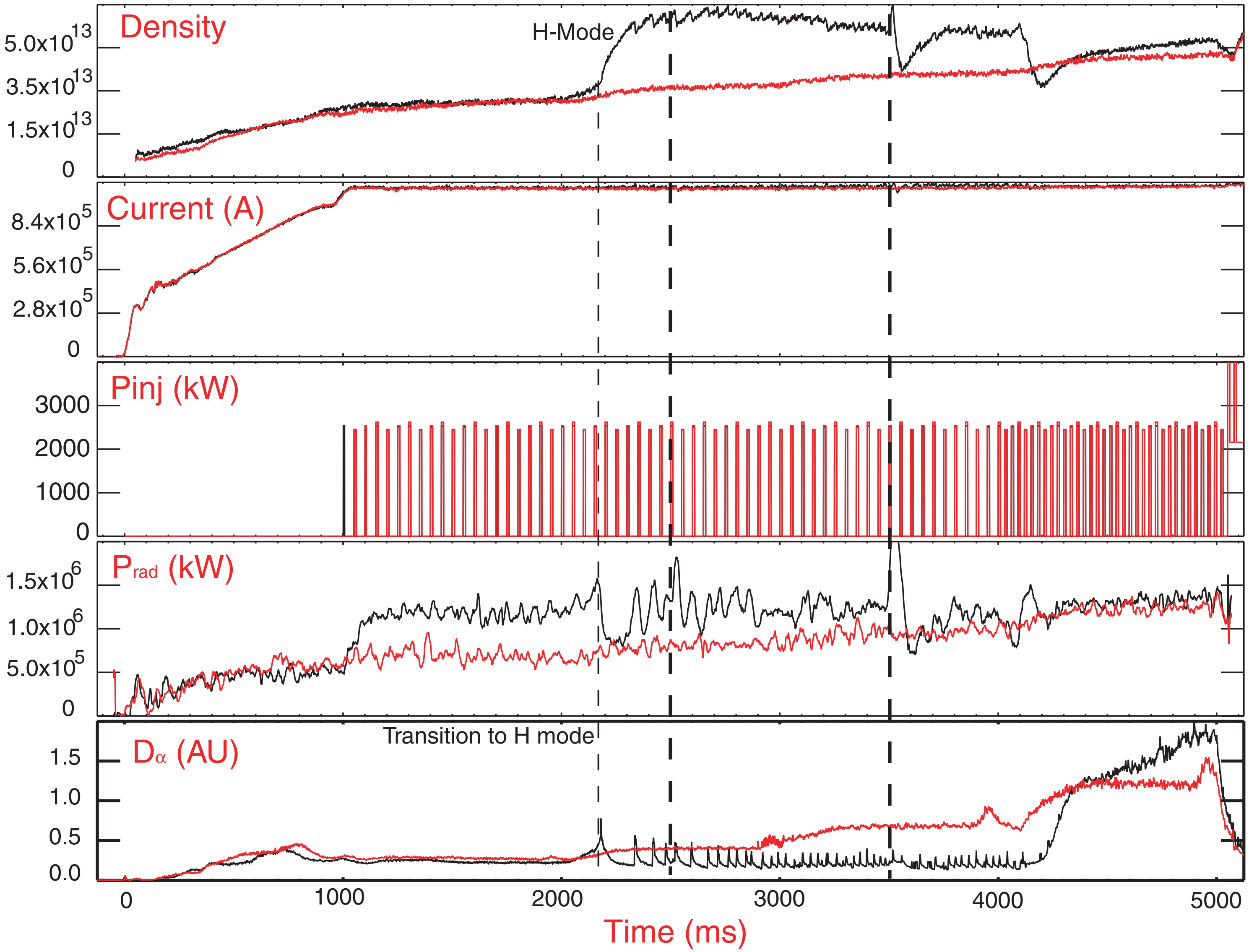


- Scanning probes
  - In and out in 200 ms
  - Total plunge is 15 cm
  - Produce I_{sat}, n_e, T_e, V_f, E_θ, V_{pl}, Γ_r, E_r
  - 1 MHz time resolution
  - ~1.5 mm spatial resolution

- Beam Emission Spectroscopy
  - 1 Mhz time resolution
  - 5x6 cm area coverage
  - 1 cm x 1cm spatial resolution

- D_α array
  - 8 chords
  - 1cm spatial resolution
  - 0.1 MHz time resolution

L and H Mode Discharges are Compared

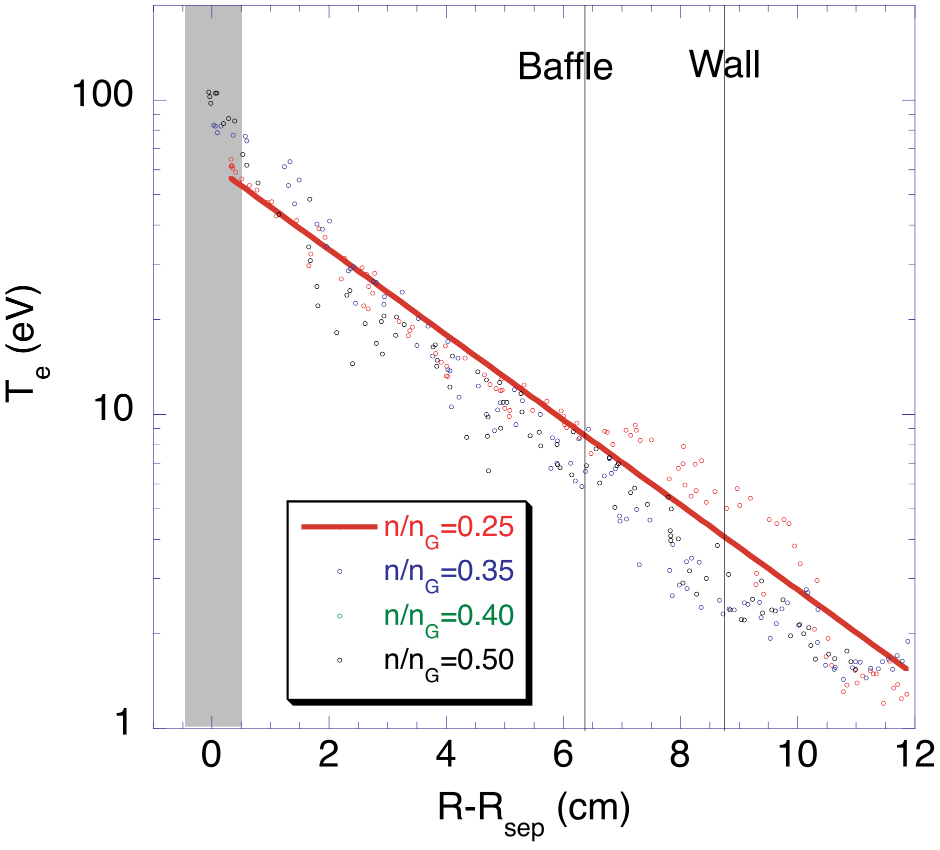


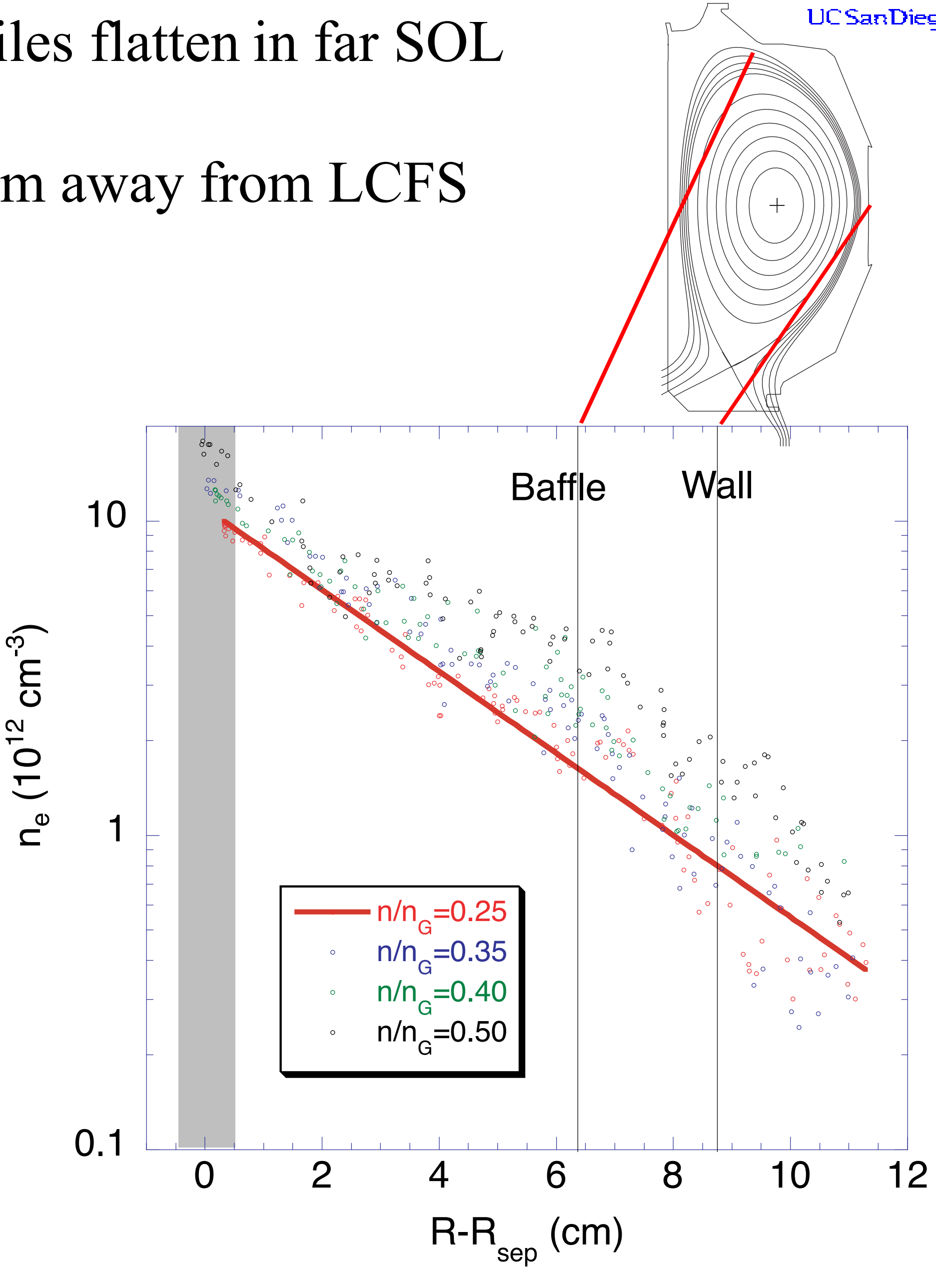
Density is stepped to search for density dependence as suggested by Alcator data

These are NOT high performance H-modes which would have lower SOL transport

Cross-field plasma transport in DIII-D is large to wall

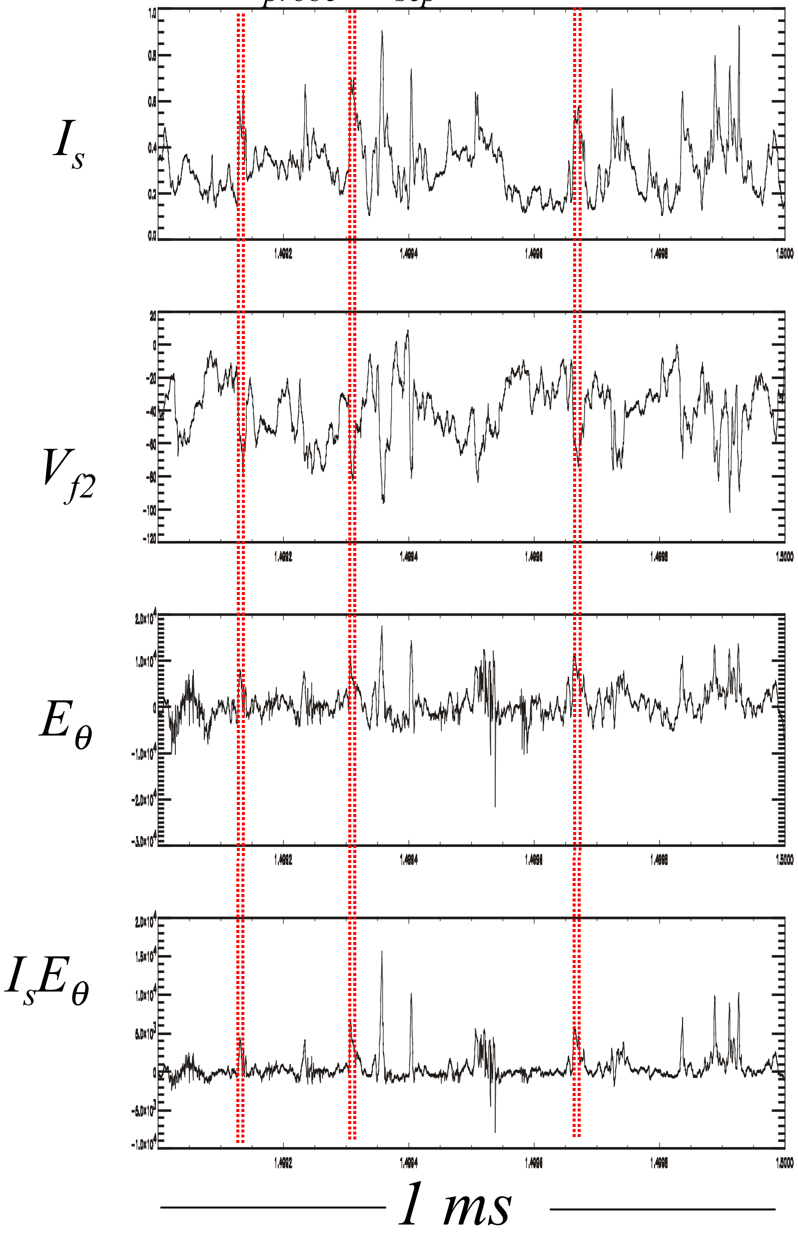
- Density and temperature profiles flatten in far SOL
- Plasma reaches the walls 12 cm away from LCFS





Convective Intermittency is Enhanced Transport Candidate

$R_{probe} - R_{sep} \approx 0.5\text{cm}$

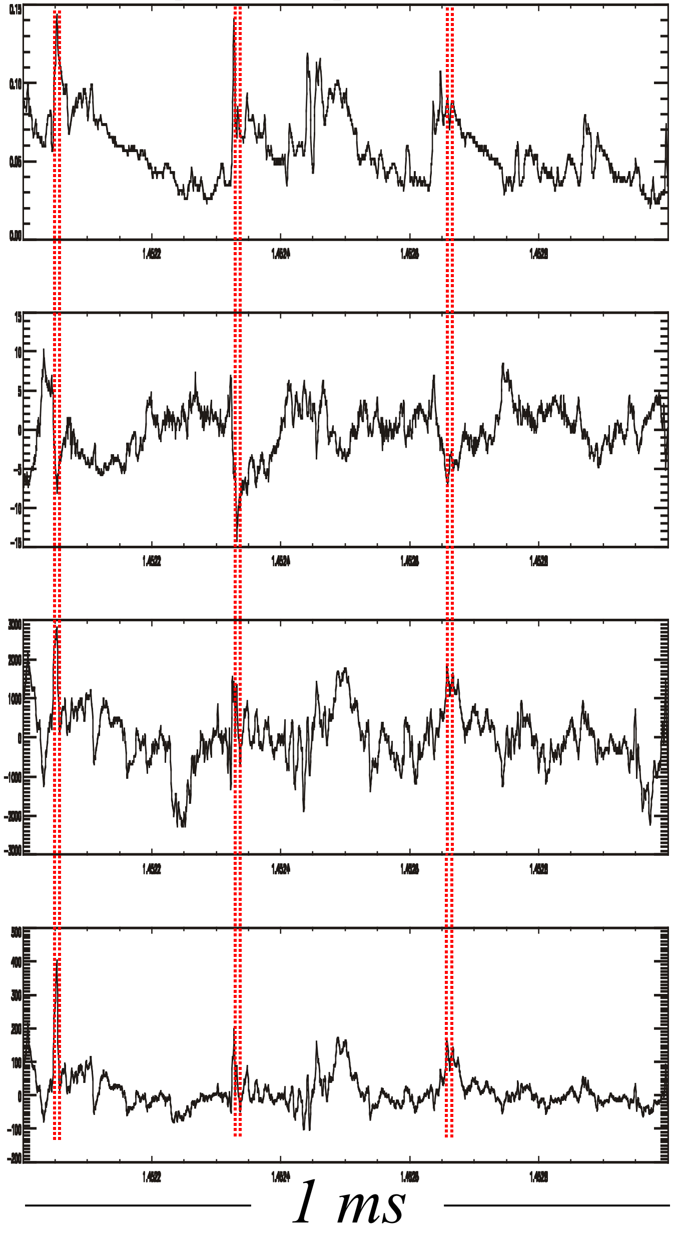


Intermittency Apparent in Short Time Scale (1ms)

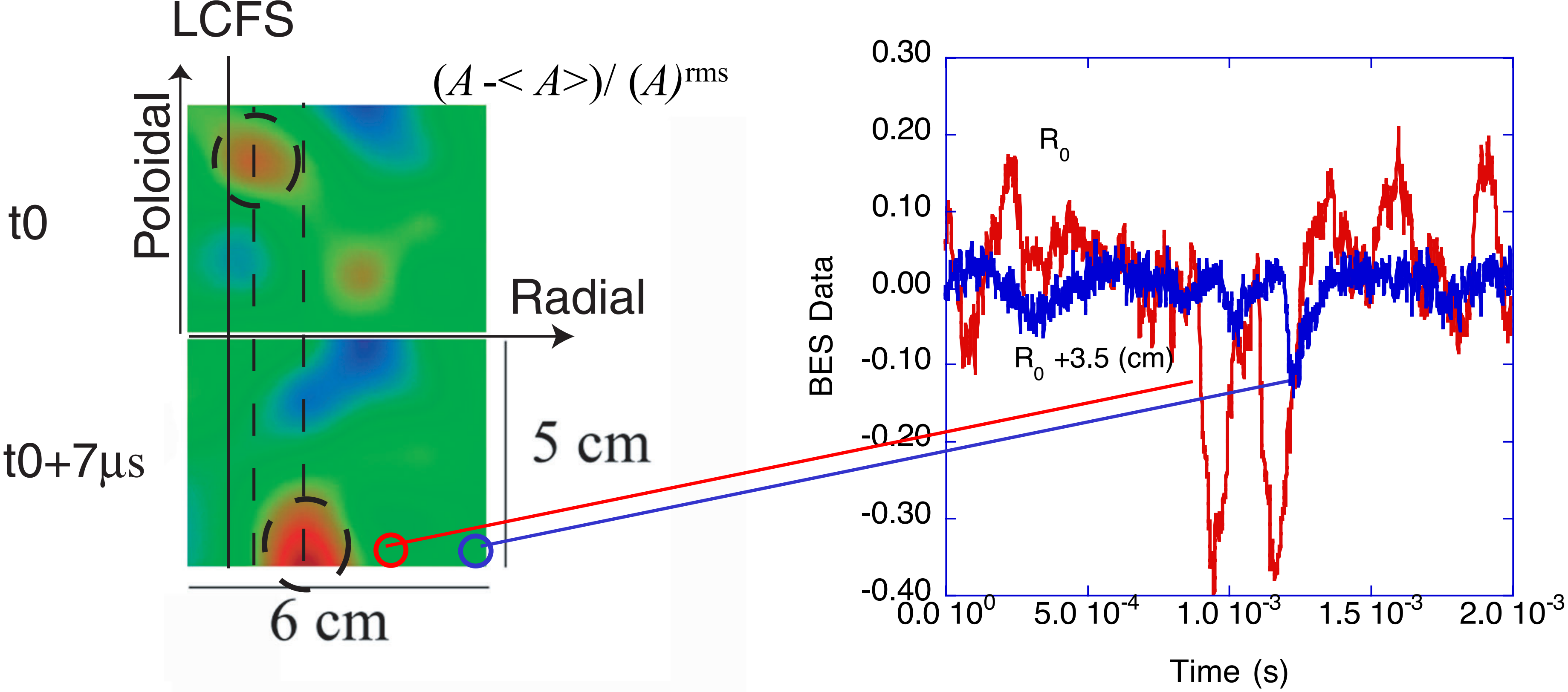
Plasma objects with higher n and T than the background are present

Intermittent plasma objects IPOs

$R_{probe} - R_{sep} \approx 10\text{cm}$



Intermittent Objects Imaged by BES

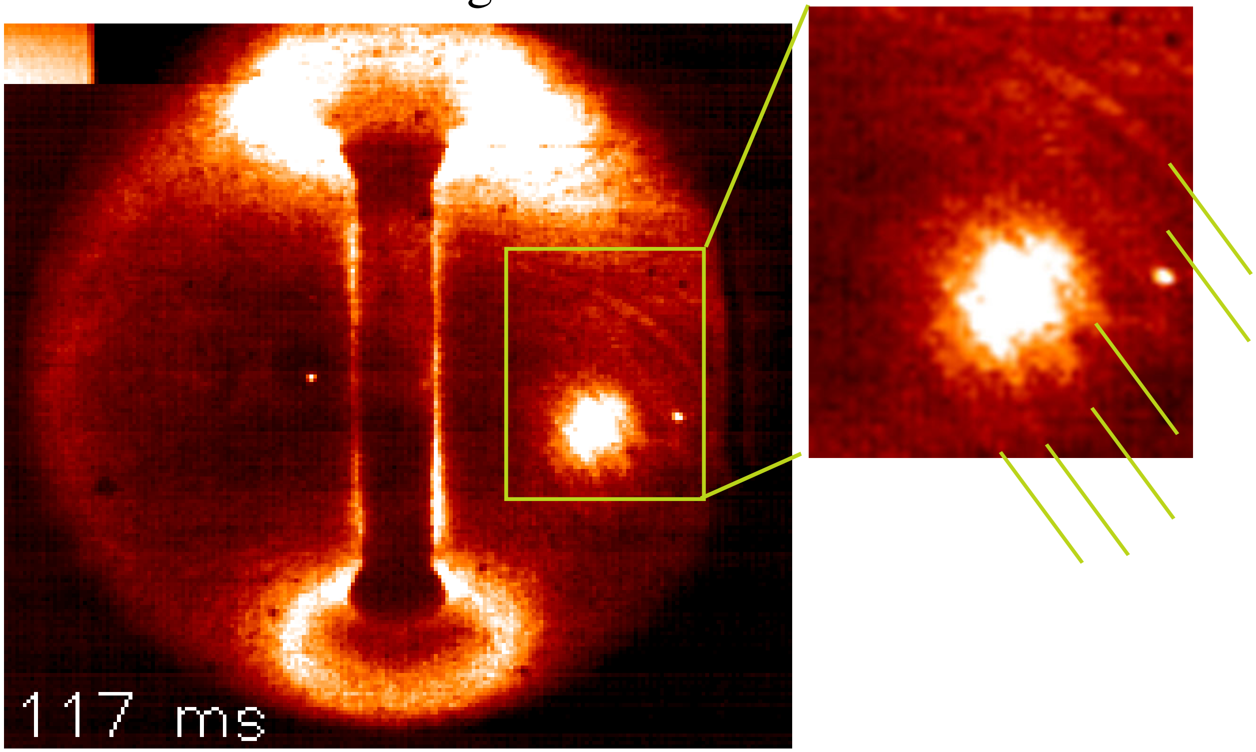


- BES shows complex dynamics of the intermittent density objects
- Objects move poloidally at ~5000 m/s at the LCFS, slow down in SOL
- Objects move radially at ~1200 m/s at the LCFS
- Objects are 2X2 cm in size poloidally
- Are IPOs elongated along B?

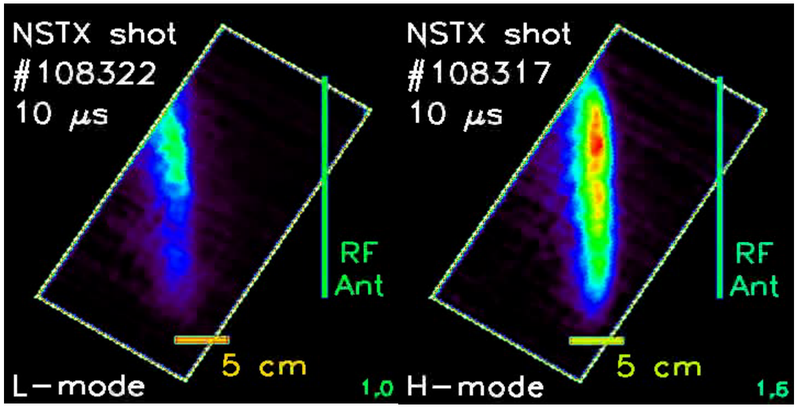
G. McKee, U Wisconsin (2001)

Structures are Elongated along B

- Imaging from various machines (NSTX, ALCATOR-C MOD, etc) show striations along B

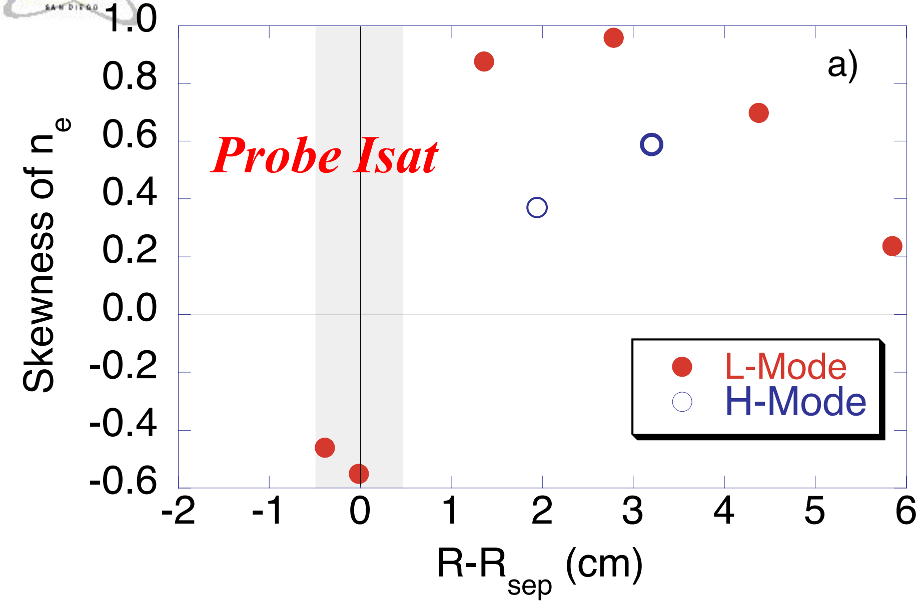


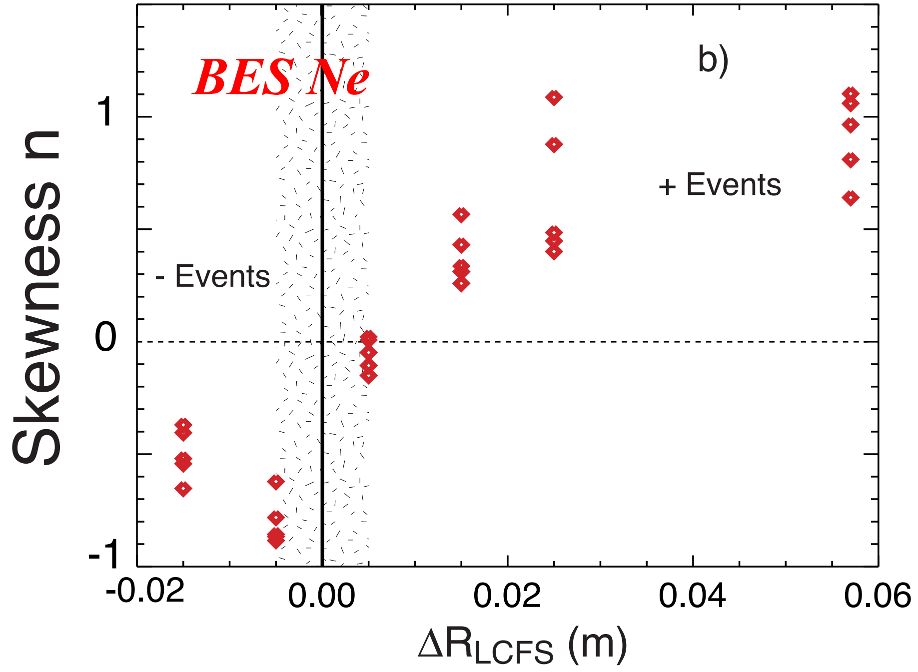
Objects elongate and lose particles at the ends, concept used to study the IPO dynamics



See
GP1.115 R. Maqueda, ANL (2002)
C01.008 S. Zweben, PPPL (2002)

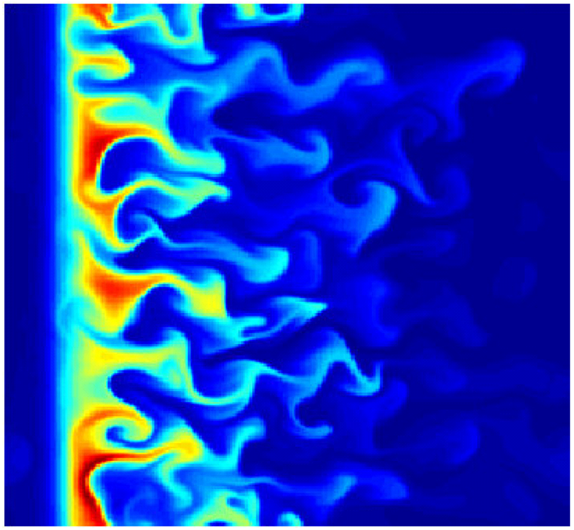
Creation at LCFS Suggested by Skewness





$$Skew = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{x_j - \bar{x}}{\sigma}\right]^3$$

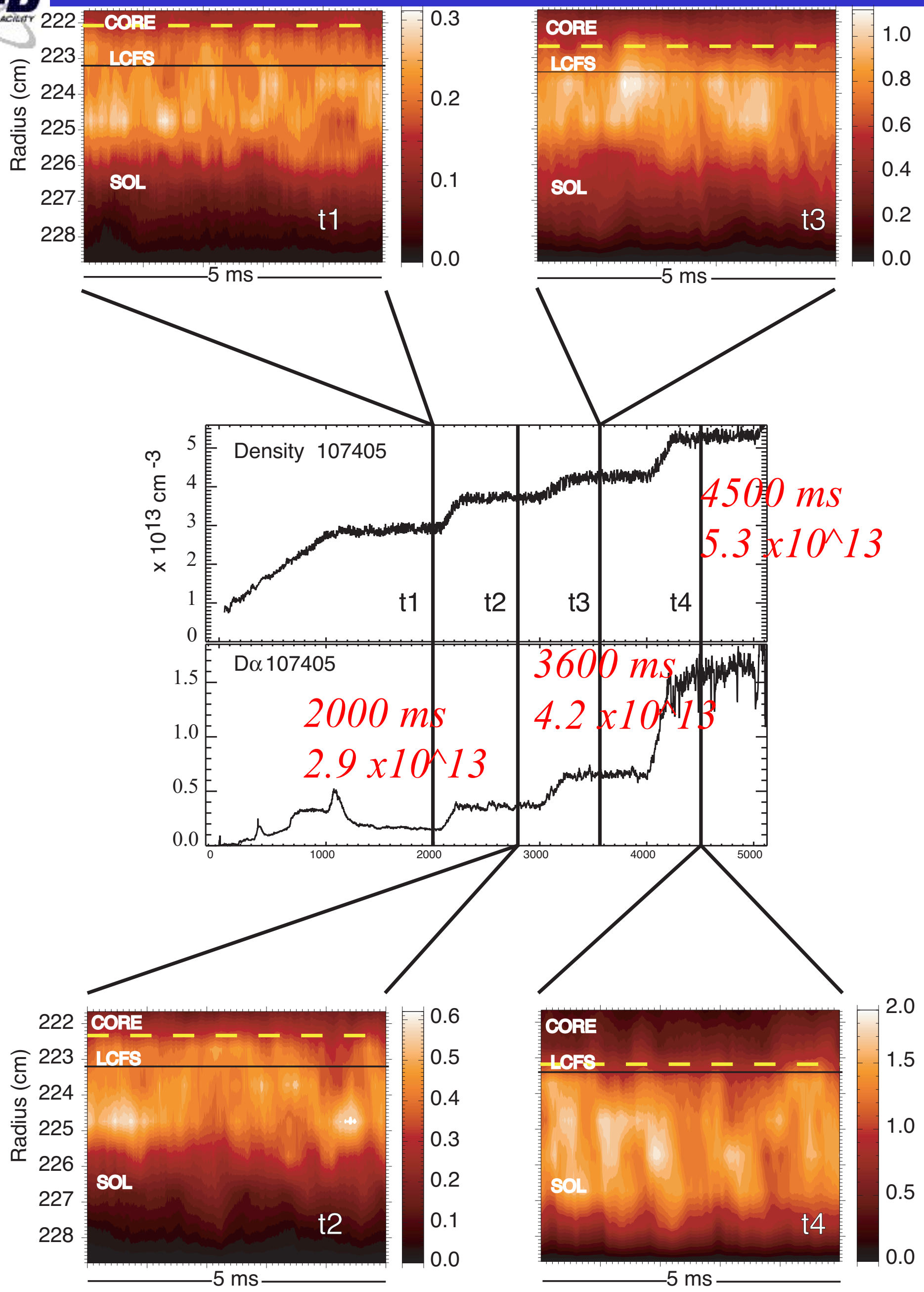
- Skewness (measures asymmetry) is negative inside or at LCFS
- Skewness is positive in the SOL
- Profiles at the LCFS “peel off” into the SOL. Fingering occurs



P. Ghendrih, 2002

Bora, 92, Turney, Moyer *et al* APS’99, Carreras 99, 2000

Intermittency Characteristics Change with Density



4500 ms
5.3 x10^13

3600 ms
4.2 x10^13

2000 ms
2.9 x10^13

Intermittent events observed from the LCFS to the SOL

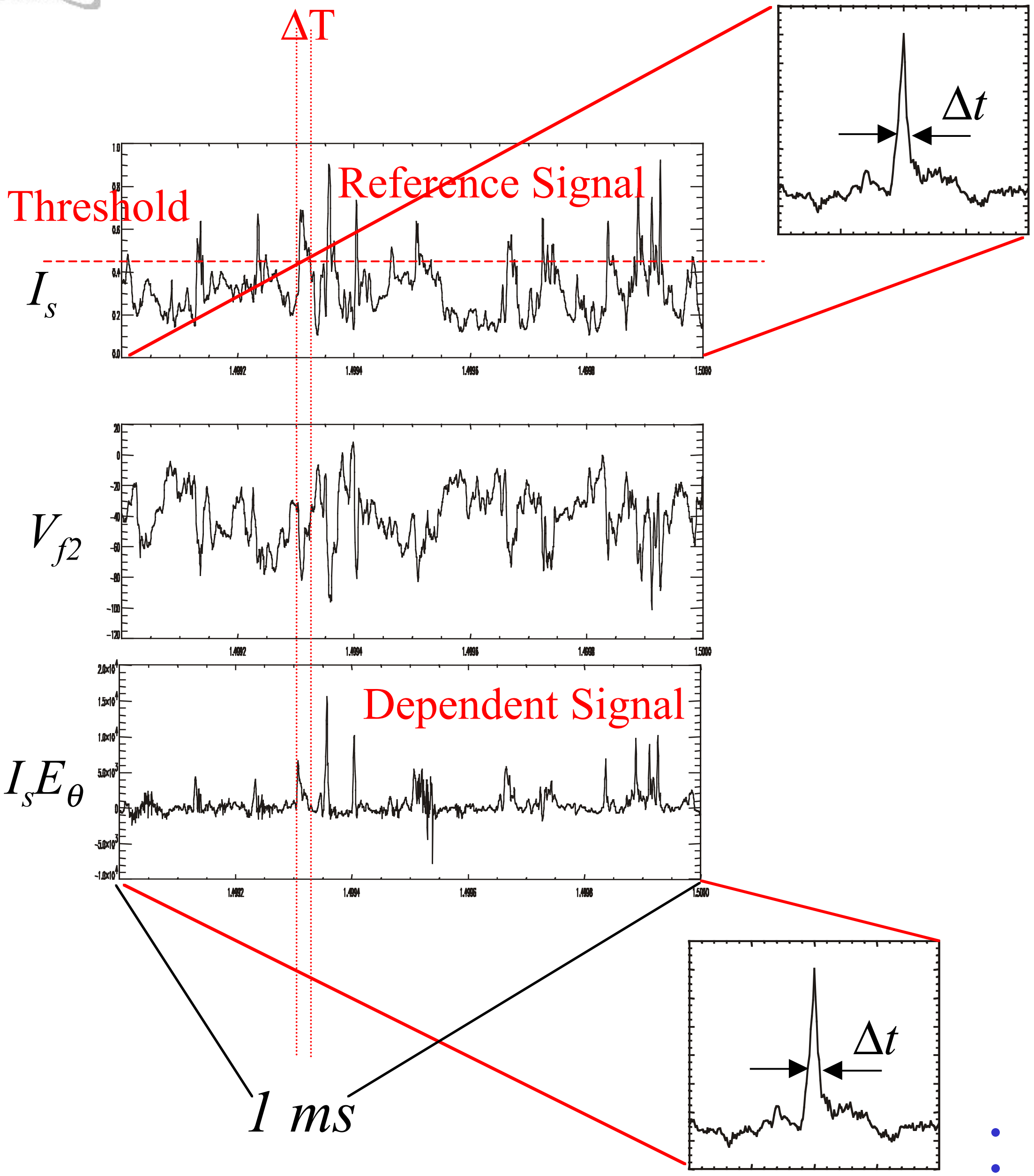
Intensity increases with averaged core density

Creation at the LCFS

Outward displacement outward from LCFS observed at highest density

See Greenwald G01.001
R. Colchin, ORNL (2002)

Conditional Averaging used to Separate Coherent Structures



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

- One signal is the reference.

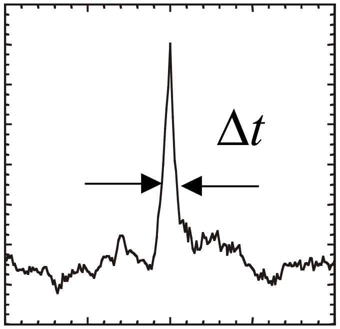
- The rest of the signals are sampled as per the reference one.

- Correlated features are brought out

- Data processed in 5 ms slices, threshold of 2.5 rms

- V. Filippas, et al (TEXT 95), A. H. Nielsen et al (96),
- Heller (CASTOR 99)

Object Size and Velocity Can Be Calculated from Probe Data



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

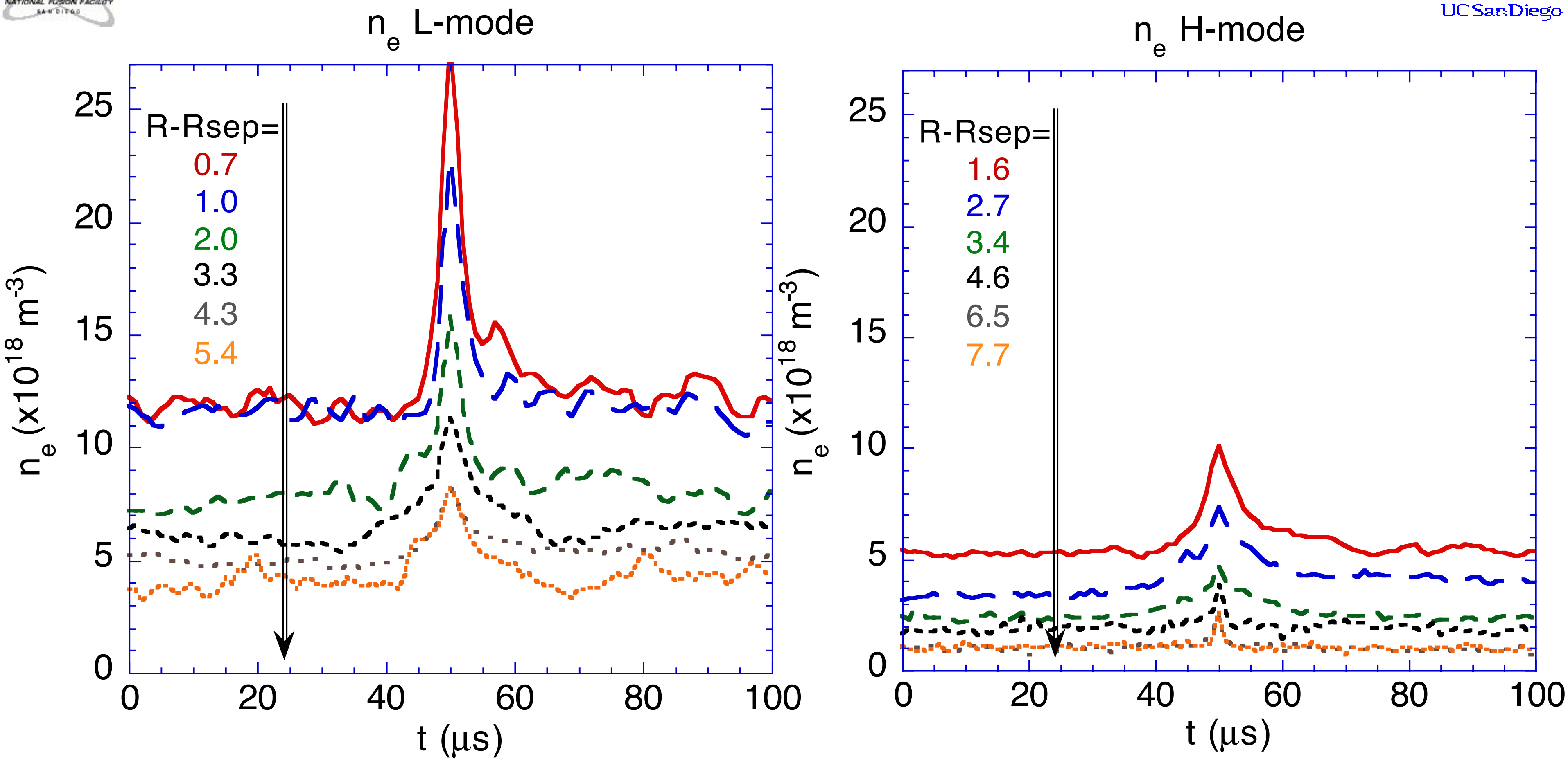
V_r can be calculated as E_θ / B_φ

	R_{probe}- R_{sep} (cm)	Δt (s)	E_θ (V/m)	V_r(m/s)	δ_r(cm)
LCFS	0.5	1.5×10^{-5}	4000	2000	3
	5	2×10^{-5}	1500	750	1.5
Wall	10	1.5×10^{-5}	500	250	0.37

- The radial size of the objects can be calculated at ~2 cm at LCFS
  - Agreement with BES
- The bursts are slowing down, decaying and thinning poloidally as they move out (stretching along B_T)
- Rate is about 10^3-10^4 per s

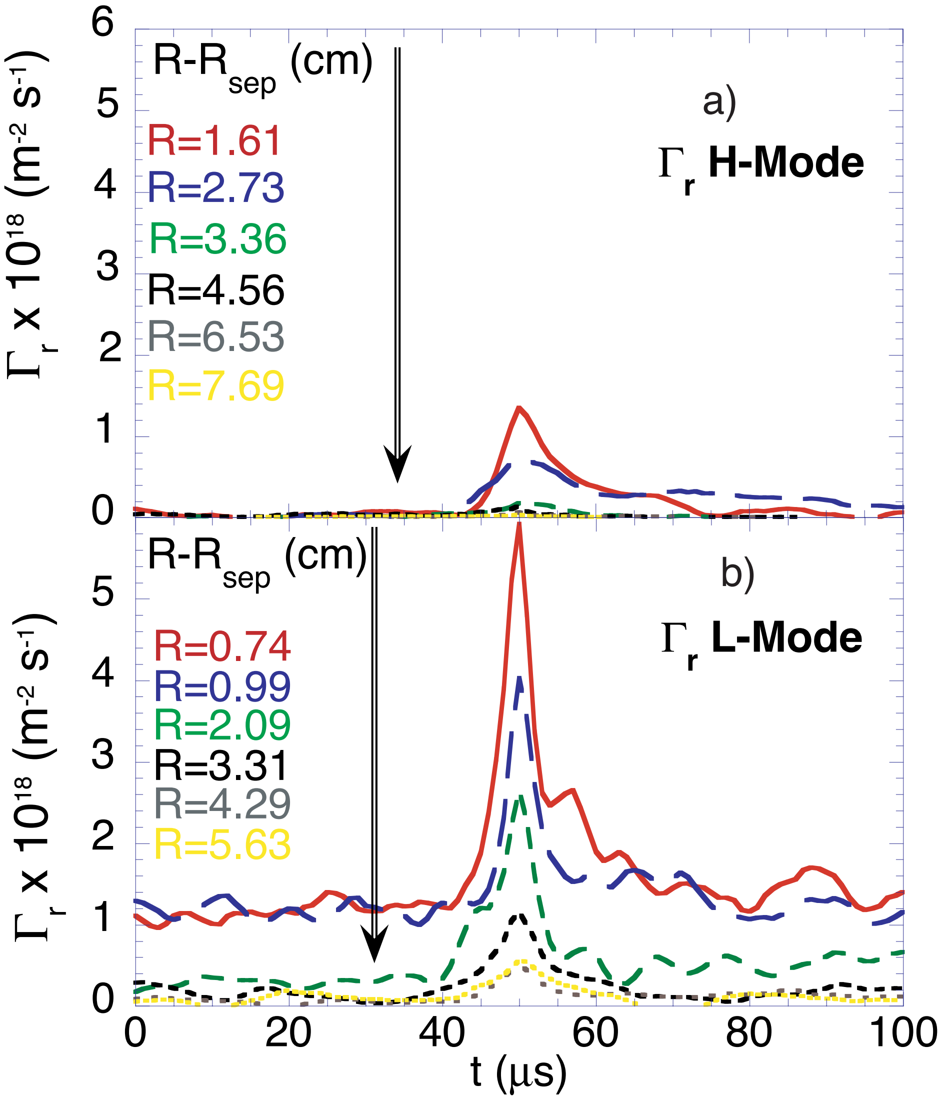
- **Boedo, et al POP 2001, Krashenninikov PLA 2001,**
- **D'Ippolito, PoP 2002**

Ne Bursts Larger in L-mode



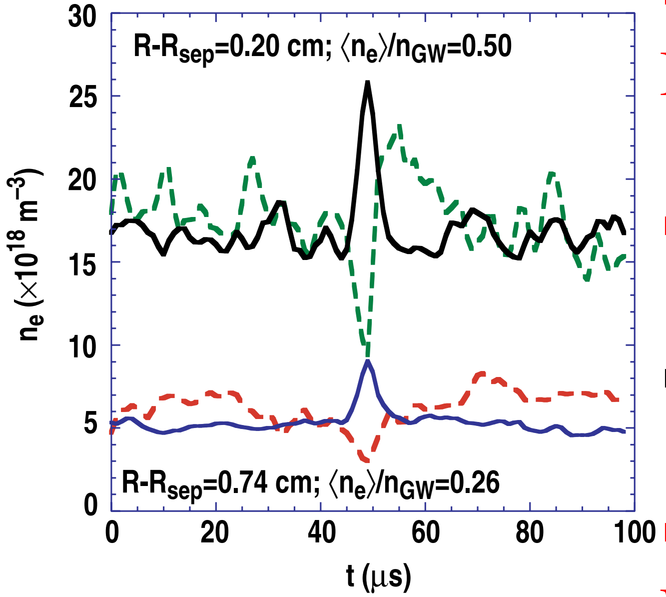
- Density events are large (~2 x background)
- Events are larger in L-mode

Particle Flux larger in H-mode

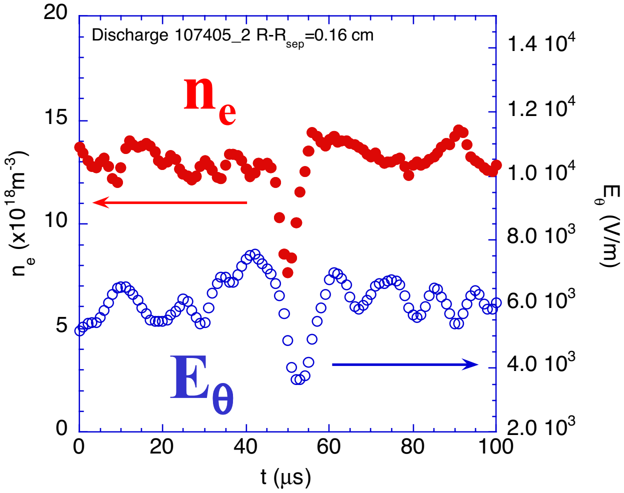


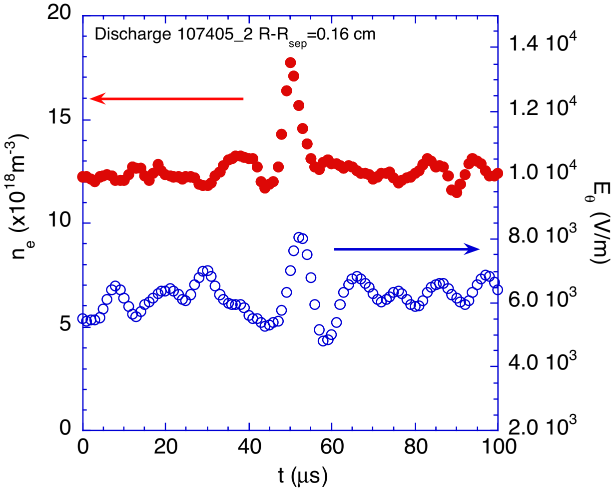
- H-mode ExB Flux is lower
- L-mode flux is much higher in the SOL
- H-mode flux decays faster

Positive and Negative IPOs Exist at LCFS



- Near the LCFS there positive and negative IPOs of similar size
- 5 ms event count similar in L and H mode
- Positive events dominate in SOL
- Negative events can dominate at or inside LCFS





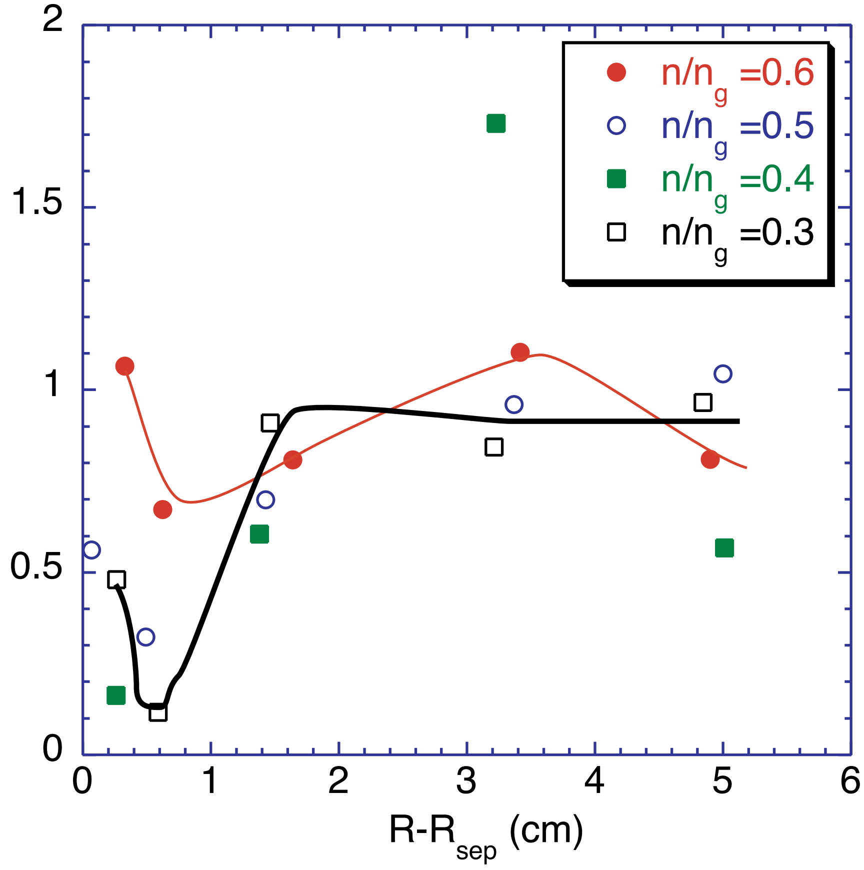
$$V_r = \frac{E_\theta \times B_t}{B_t^2}$$

Negative IPOs move inward, positive ones move outward

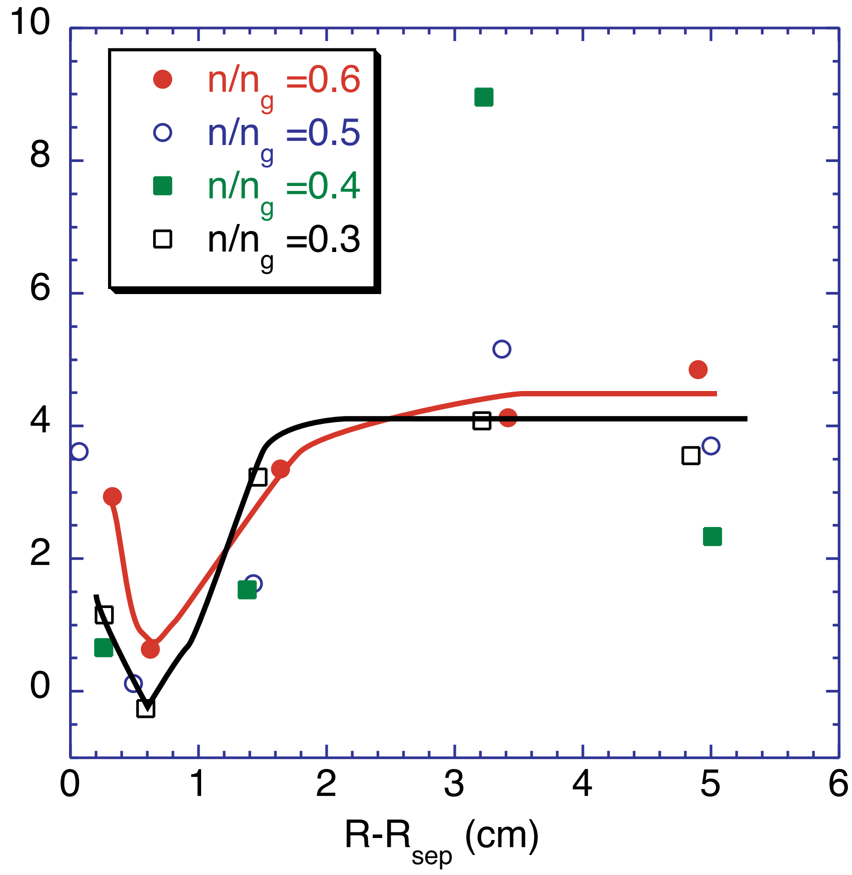
Statistics Show Dependence on Density

- As L-mode density increases, skewness increases near LCFS
- Both Skewness and Kurtosis exhibit features near LCFS

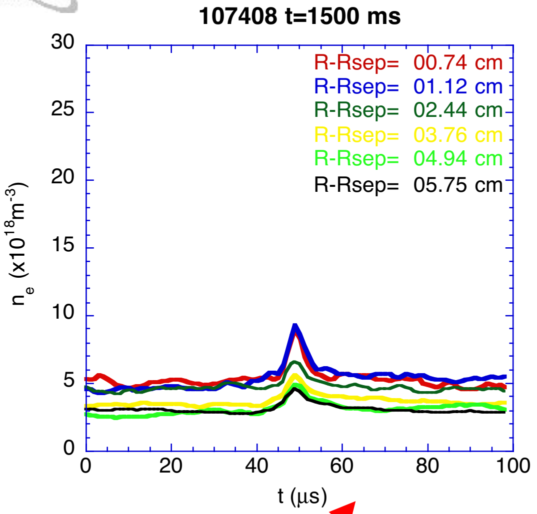
Skewness

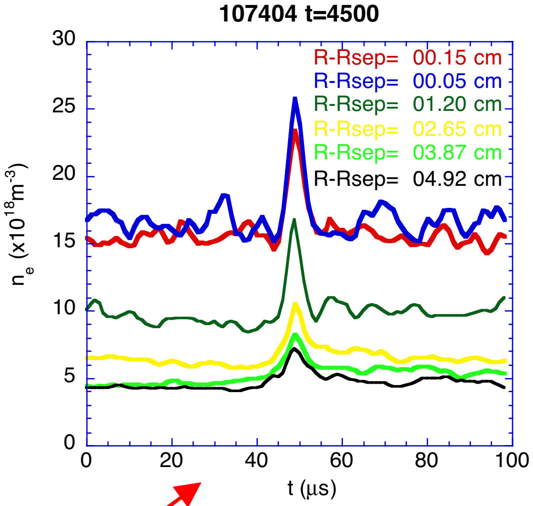


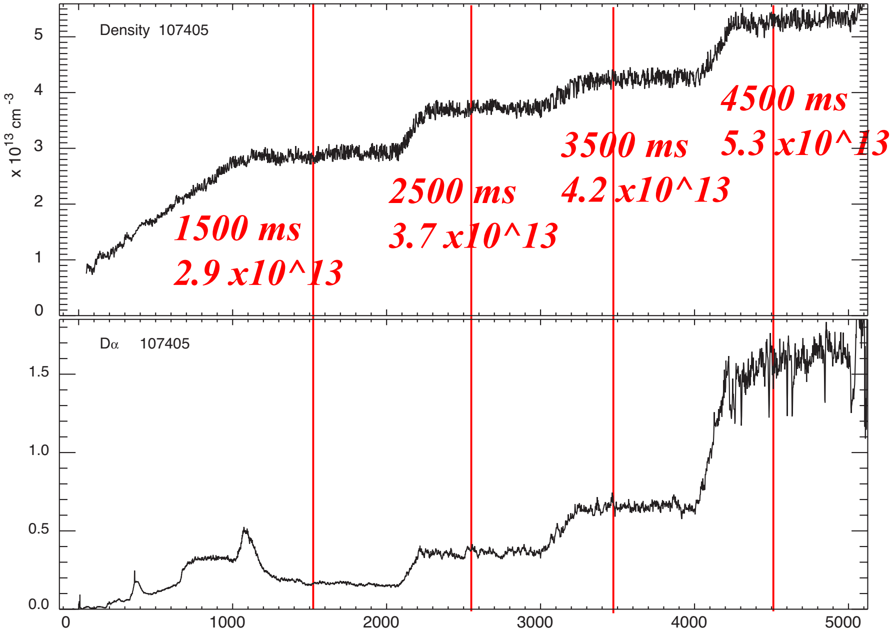
Kurtosis



IPO Density Increases with Ne in L-Mode







IPO rate increases with density:

2×10^3 low Ne

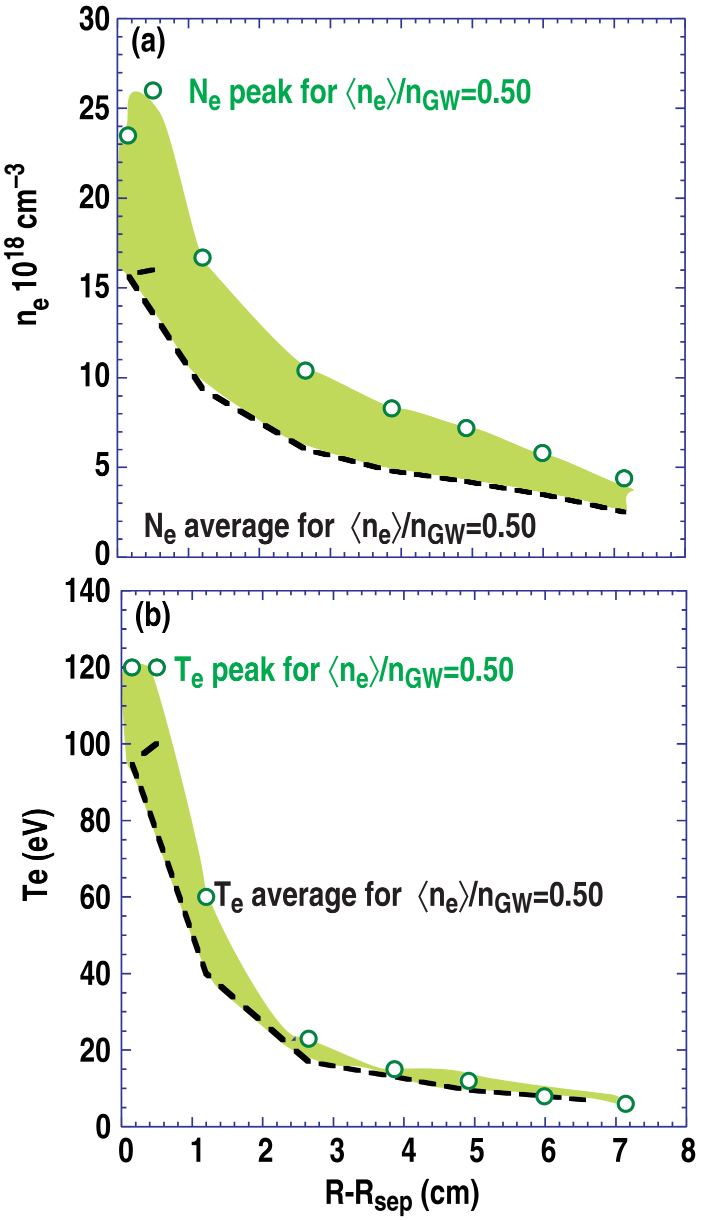
5×10^3 high Ne

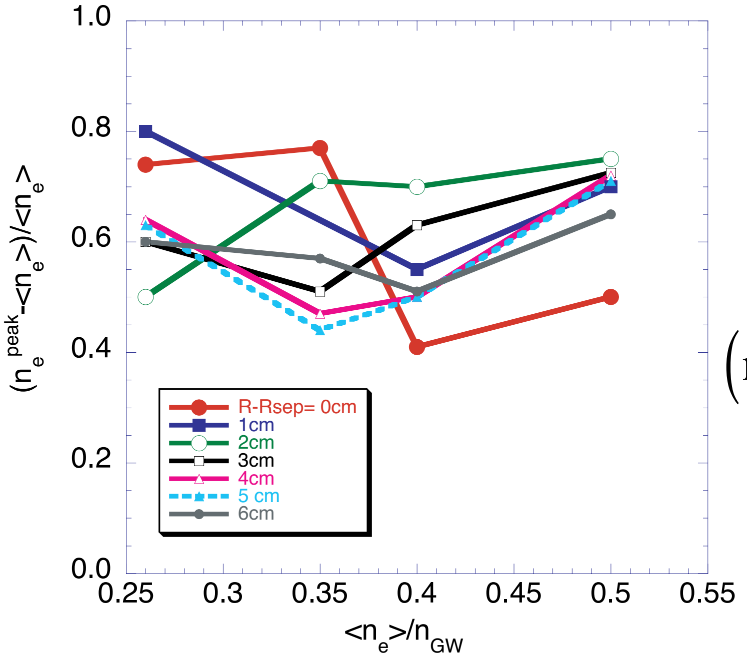
IPO Density Decays Slower than Temperature

- IPO peak density decays within ~2.5 cm
- Same as averaged density
- IPO peak temperature decays within mm
- Much faster than the background Te decay length!
- As predicted (D. D'Ippolito, S.Krasheninnikov)

$$n(r,t) = n(r)\Big/\left(1+t/\tau_T\right)^{2\alpha/\alpha_T} \quad \alpha_T = \alpha S_E;\ \tau_T = 2\Big/\left(\alpha_T T_0^{1/2}\right)$$

$$T(t) = T_0\Big/\left(1+t/\tau_T\right)^2$$

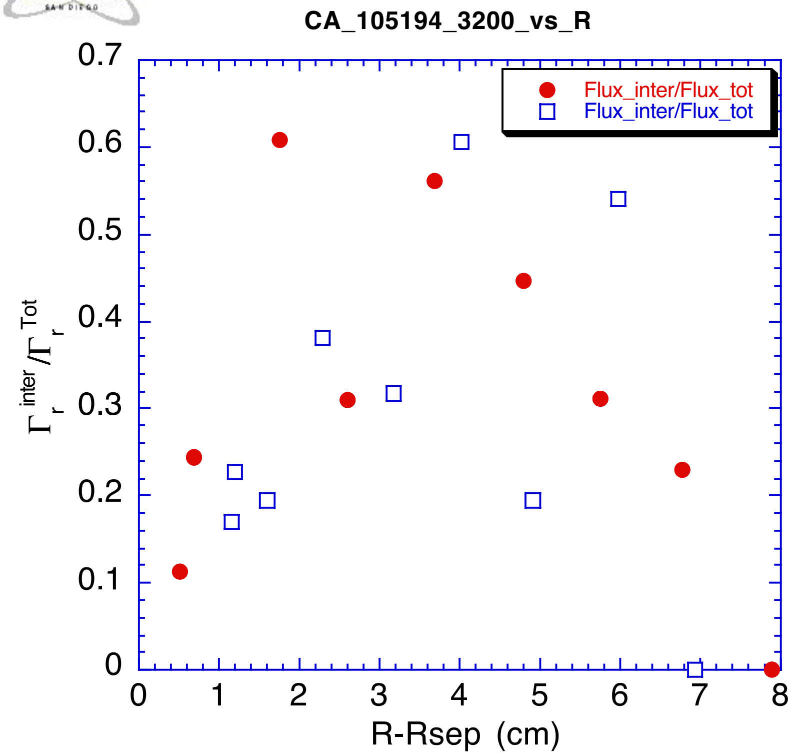


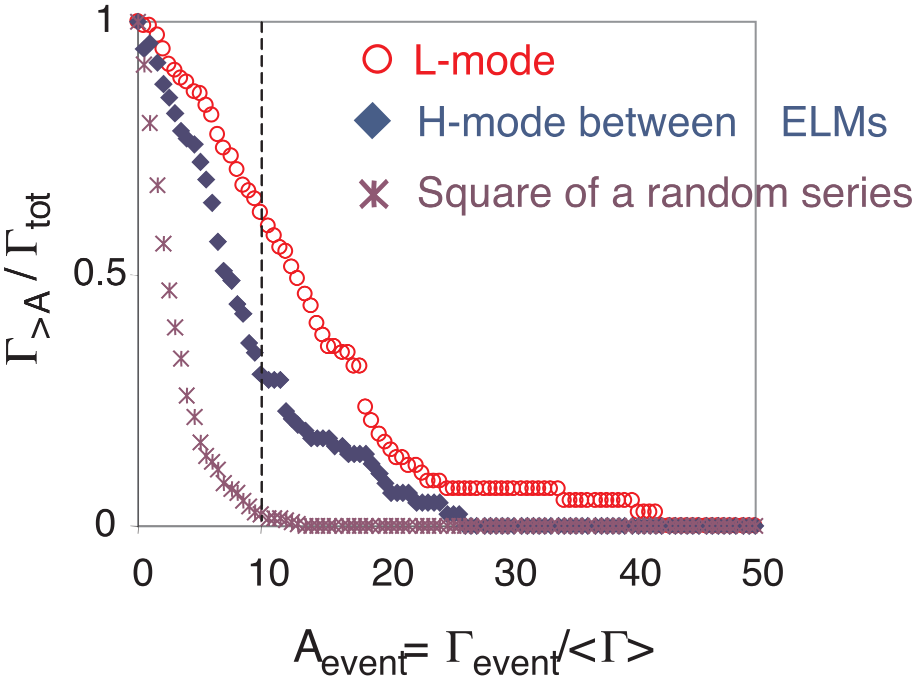


Relative importance is density independent!

$$\left(n_e^{peak} - \left\langle n_e^{aver}\right\rangle\right)\Big/\left\langle n_e^{aver}\right\rangle$$

IPOs >2.5 rms carry ~50% of total ExB transport



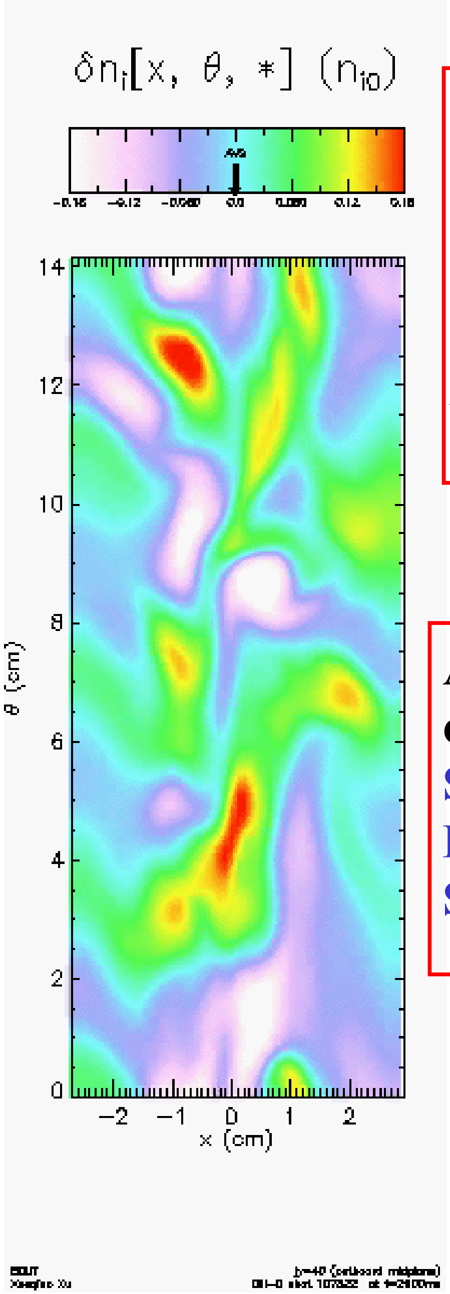


Fraction of transport due to IPOs: $(\Gamma_{rI})/(\Gamma_{rT})$

Varies from 02 to 0.6 of total ExB Flux.

Not much fractional difference between H and L modes although H-mode net flux is much lower!

Non-linear Simulations Feature Intermittency

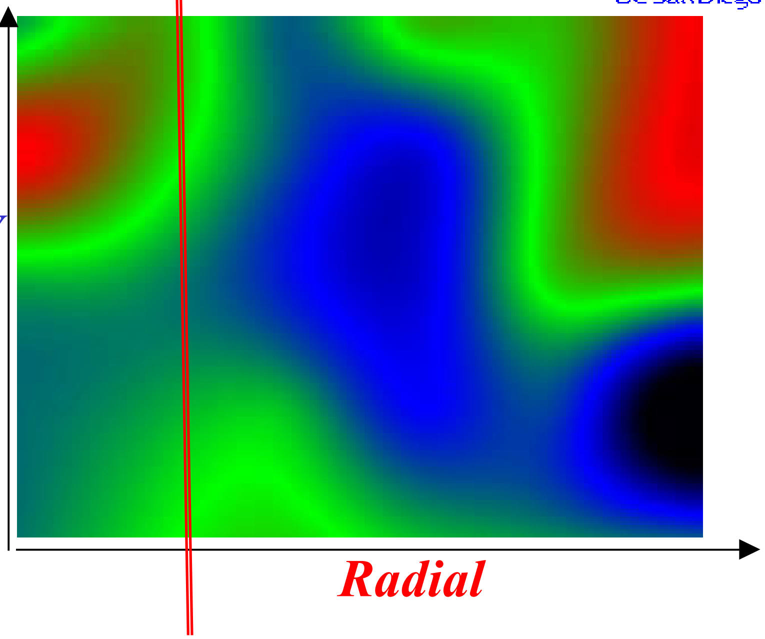


BOUT: 3D Non-linear Braginskii code for the edge. *X. Xu,W. Nevins, LLNL*

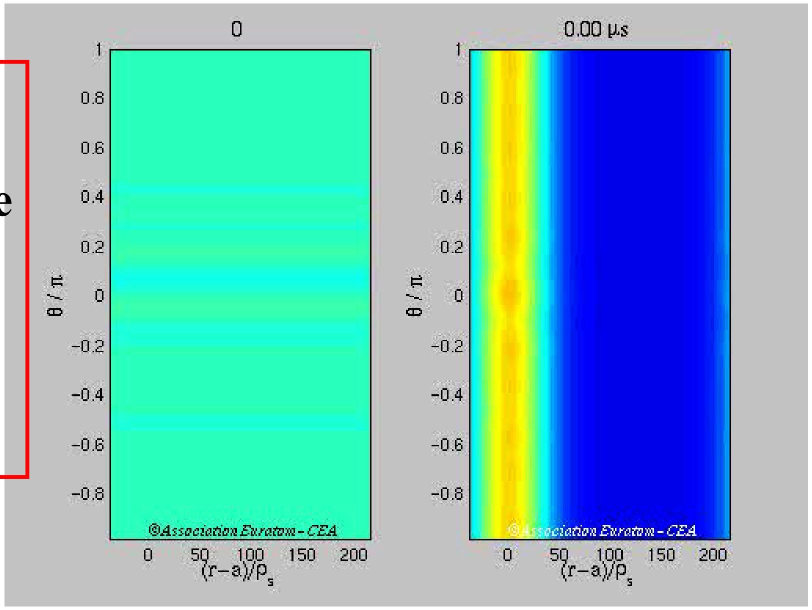
Analytical calculations. **S.Krasheninnikov, D. D'Ippolito S. Galkin(GP1.149)**

BES data
5cm x 6 cm
1μs resolution
G. McKee, UW

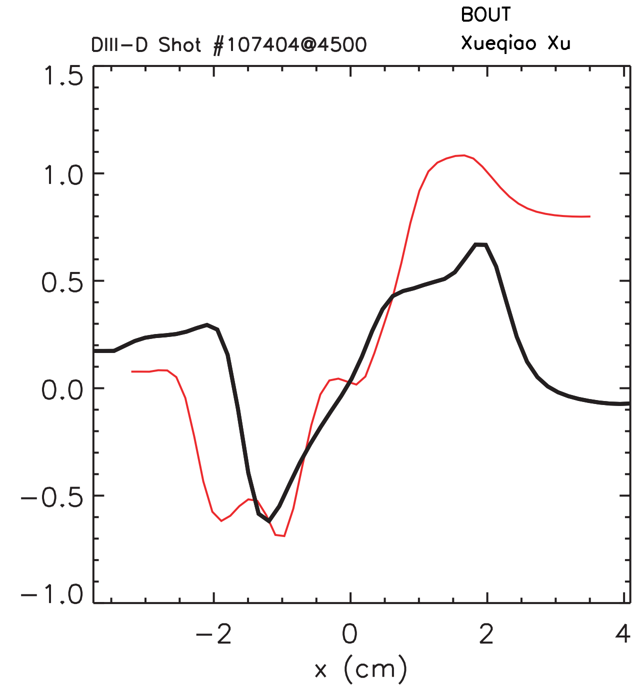
Poloidal

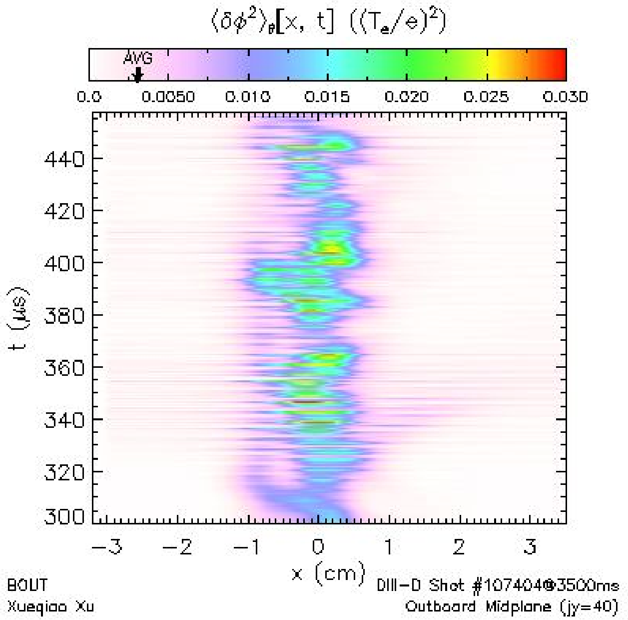


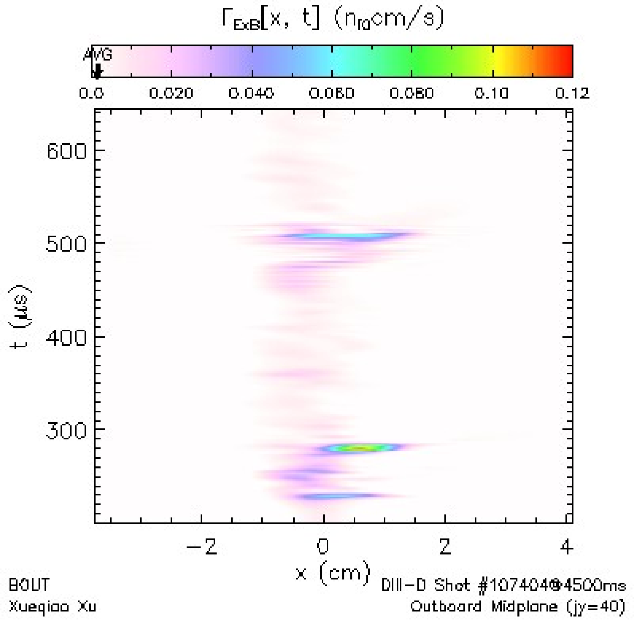
2D Non-linear fluid code for the edge ***P. Ghendrih, CEA***



Virtual Diagnostics Compare to Experimental Results







X. Xu, W. Nevins (LLNL)

- Skewness profiles from BOUT similar to experimental results
- Potential and Flux are highly intermittent

Summary and Conclusions

- Intermittency exists in DIII-D in L and H-mode
  - Amplitudes greater in L-mode

- Structures carry up to 50% of ExB transport
  - What is the nature of radial transport? Diffusion, Convection, etc.

- Edge/SOL radial transport is still poorly understood

- Structures convect heat and particles to the wall
  - Structure density and related particle flux scales with density in L-mode
  - Heat flux decays faster than particle flux

- The structures are created near the LCFS and die off in the far SOL

- Simulation codes can now produce similar structures (non-linear phenomena)

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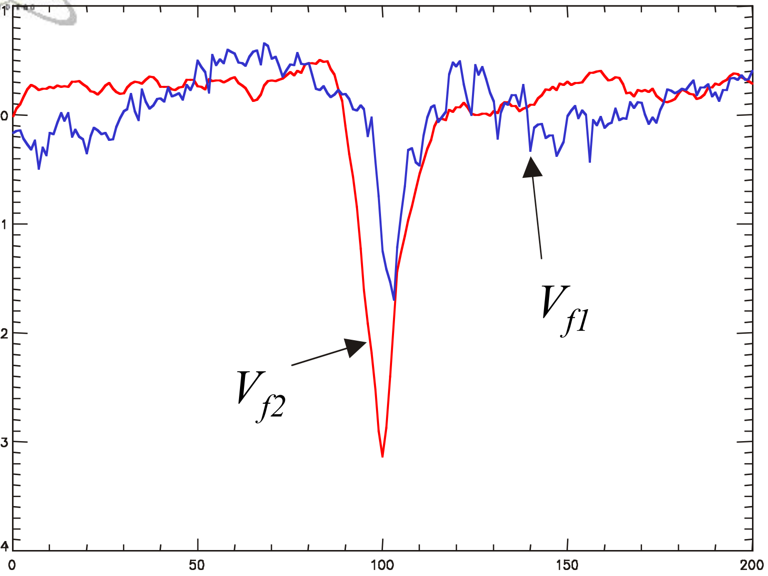
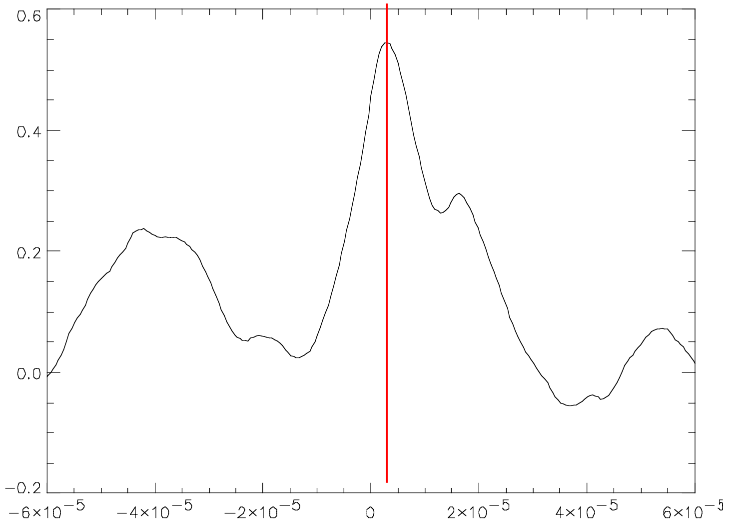
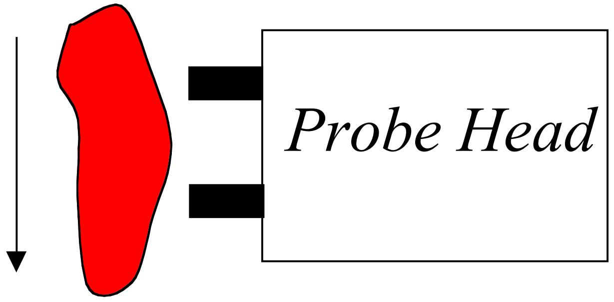
Theory
S. Krasheninnikov, Phys. Lett. A **283**, 368 (2001)
extension to include vorticity and temperature blobs, statistical averages over blob size distributions, symbiotic relation between blobs and neutral
D. A. D'Ippolito, J. R. Myra, and S. I. Krasheninnikov, Phys. Plasmas **9**, 222 (2002)
electromagnetic corrections to the blob theory and their relation to the density limit. This paper shows that a 1D blob convection model predicts in
J. R. Myra, D. A. D'Ippolito, S. I. Krasheninnikov, and S. A. Galkin, presented at the *29th EPS Conference on Plasma Physics and Controlled Fus*

Probes: Methods to Calculate Poloidal Velocity





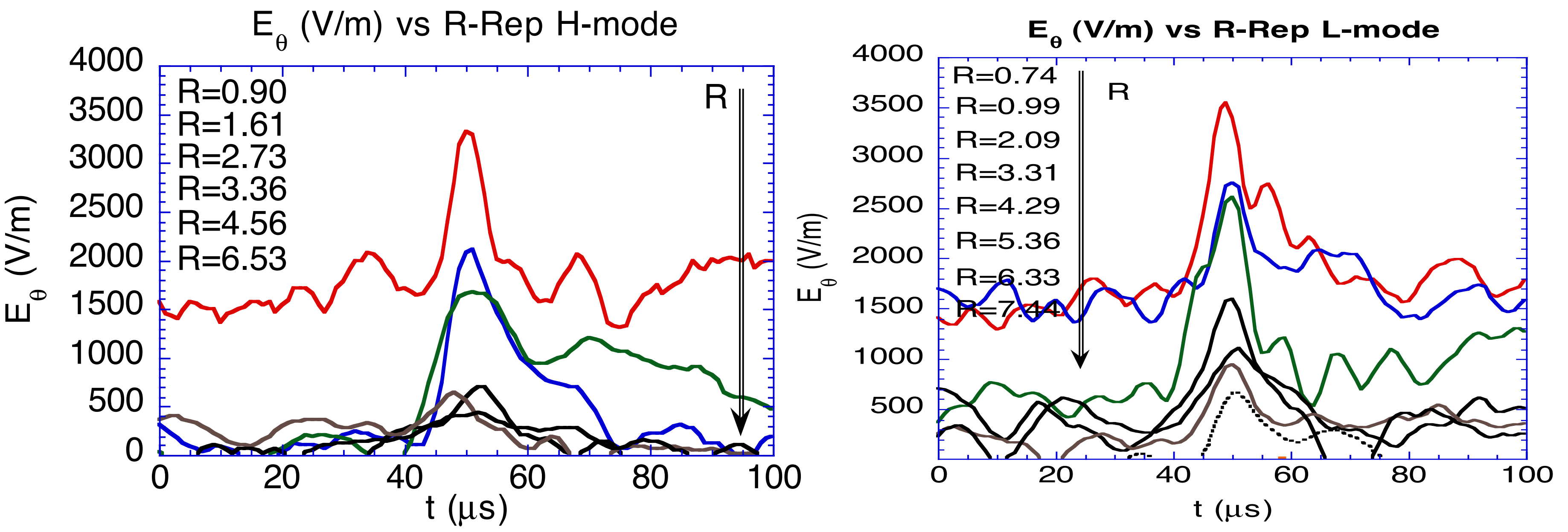


- ***Time-delay between two conditionally averaged potentials***
  - ***V_{f1} is lagging behind V_{f2} by 1-1.5μs***
  - ***For the tip separation of 5.2mm: $V_\theta = 5.2e\text{-}3/1.2e\text{-}6 \approx 4300$ m/s***

- ***Time-lag cross-correlation***
  - ***Yields $V_\theta = 5.2e\text{-}3/3.0e\text{-}6 \approx 1733$ m/s***

- ***Both techniques indicate the velocity is directed down, towards X-point, same direction as $E_r \times B$***

Polarization is Well Defined in L and H-mode



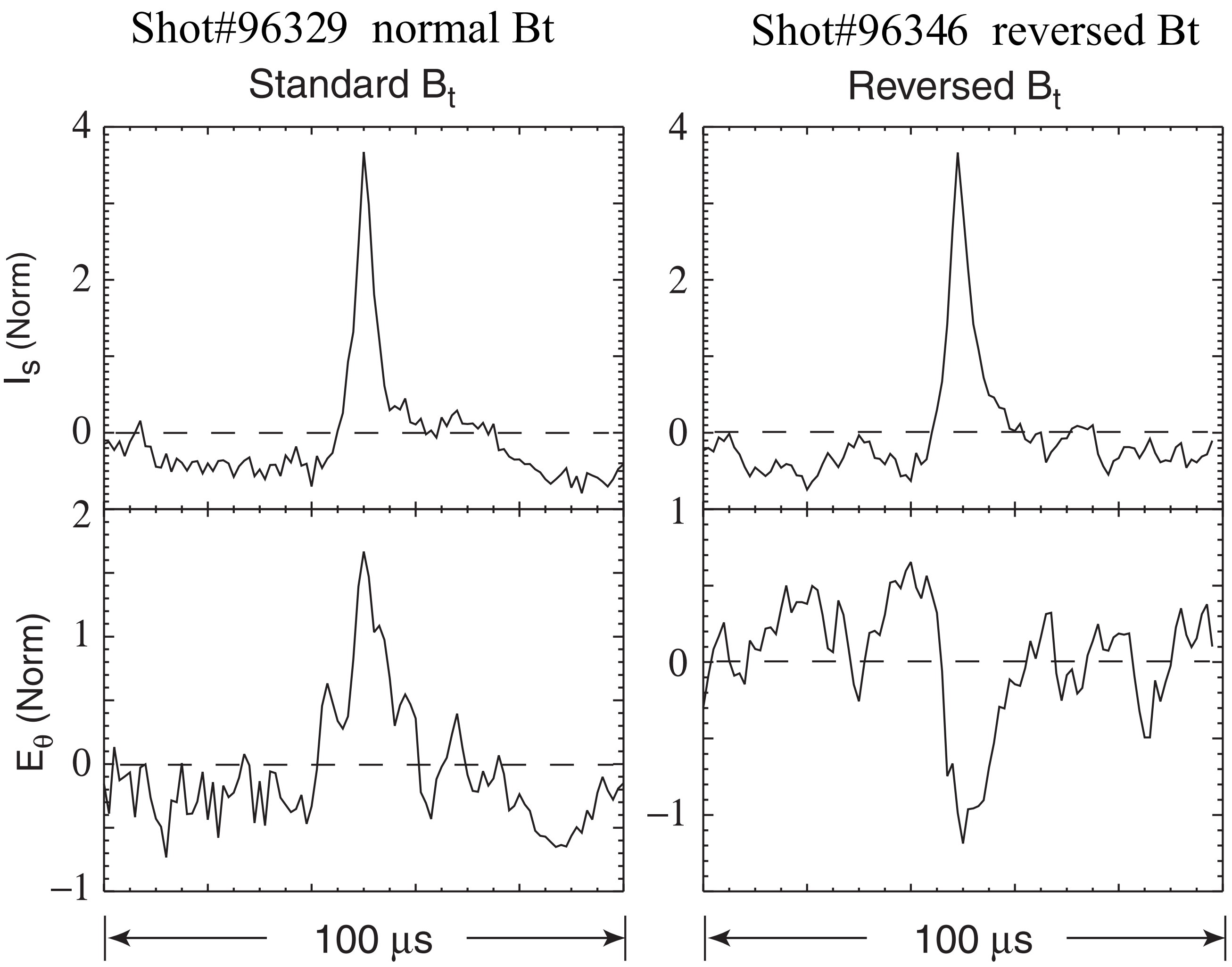
- *Objects spread with radius*
- *A "tail" is developed (shockwave-like)*
- *Well defined all the way to the wall*

BES Data Suggests Structures are quenched in H-mode

DIII-D

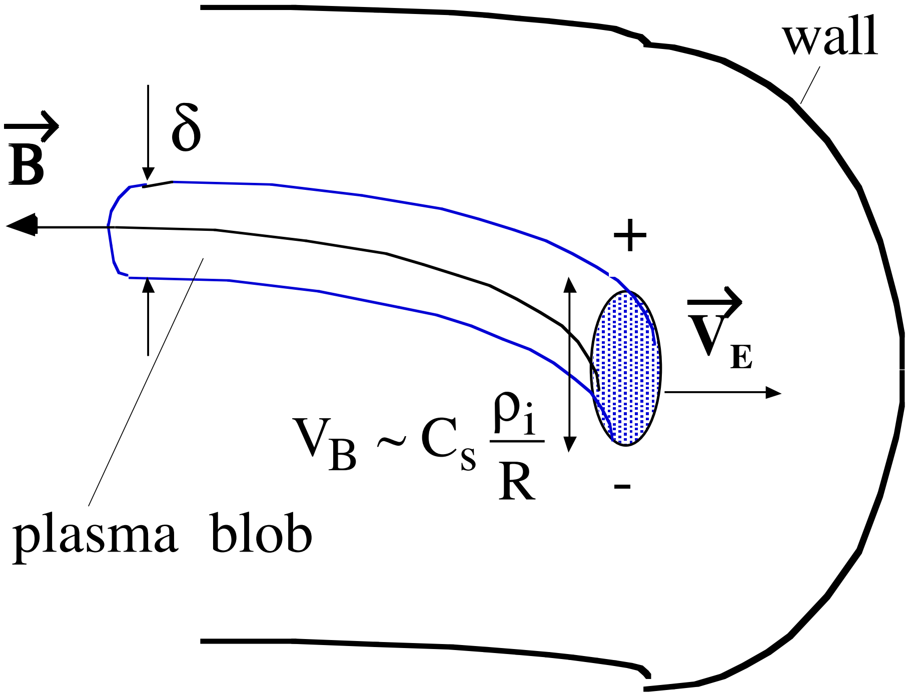
- *Will compare to probe data*

Reversal of Bt results in reversed object polarization



- *ExB flux is still outward*
- *Not in disagreement with the GradB drift polarization mechanism*

Understanding: A Simple Model: S. Krasheninnikov, D. D'Ippolitto

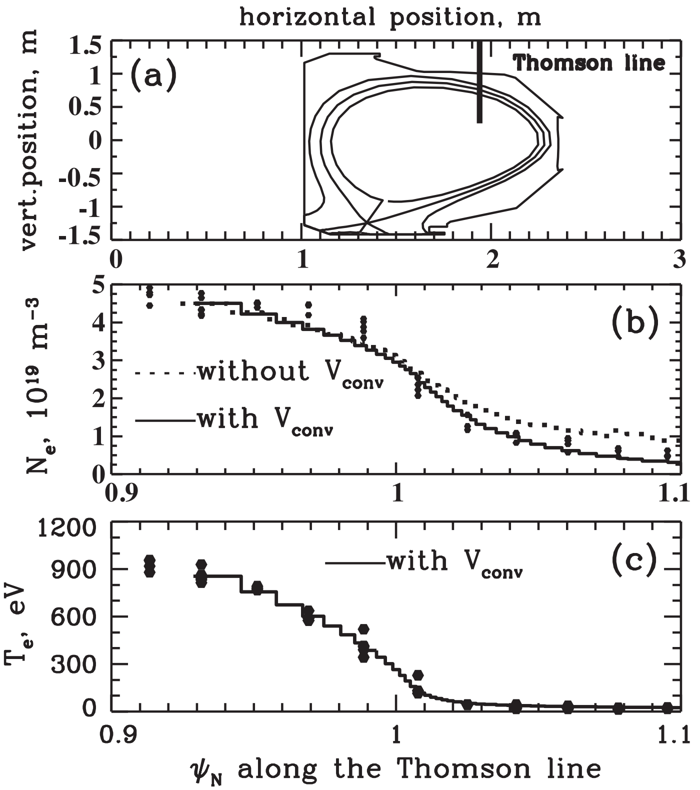


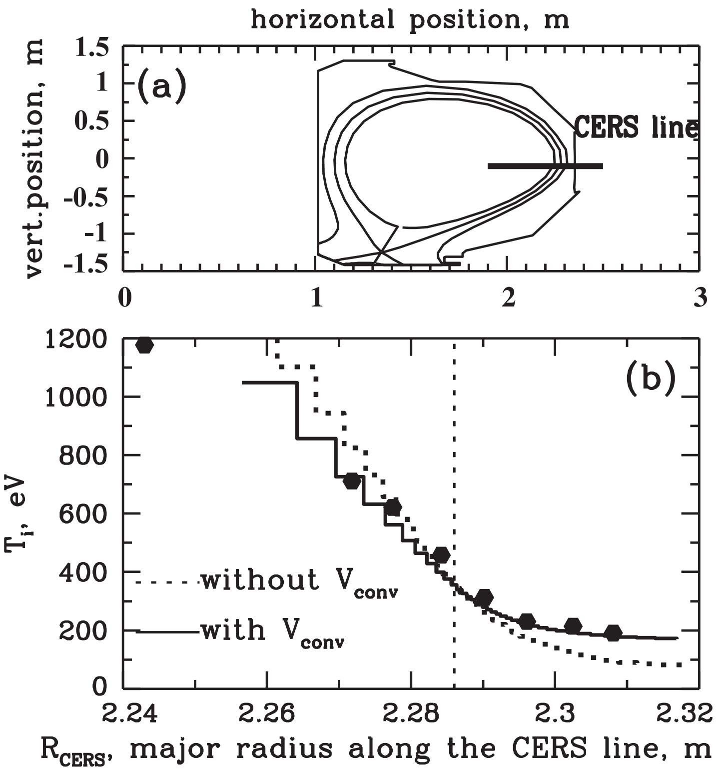
- *Plasma structures detach from the bulk plasma due to turbulence effects resulting in plasma stratification in the region around separatrix.*
- *Extructures extende along the magnetic field lines.*
- *Propagate to the outer wall due to* $\vec{B}\times\nabla B$ *plasma polarization and associated* $\vec{E}\times\vec{B}$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

Krashenninikov, APS'00 poster and 2001 PLA

Understanding: Two schools of thought in UEDGE analysis

- *Can we reproduce the edge/SOL profiles by introducing strong convection in UEDGE? (i.e. D and V, not only D)*
- *Is that approach more convincing than saturating walls, introducing drifts, augmenting recycling, reducing D?*
- *Although both approaches seem to obtain reasonable results, work is in progress to resolve this issue*





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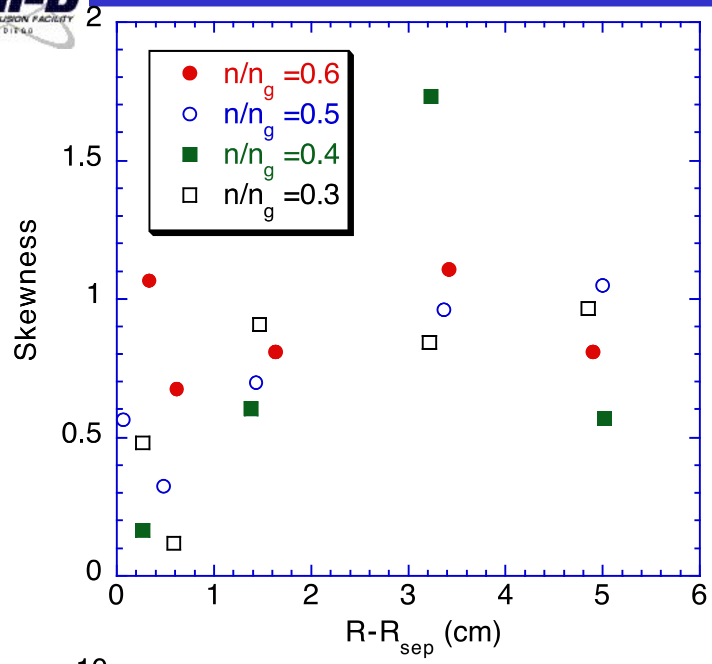
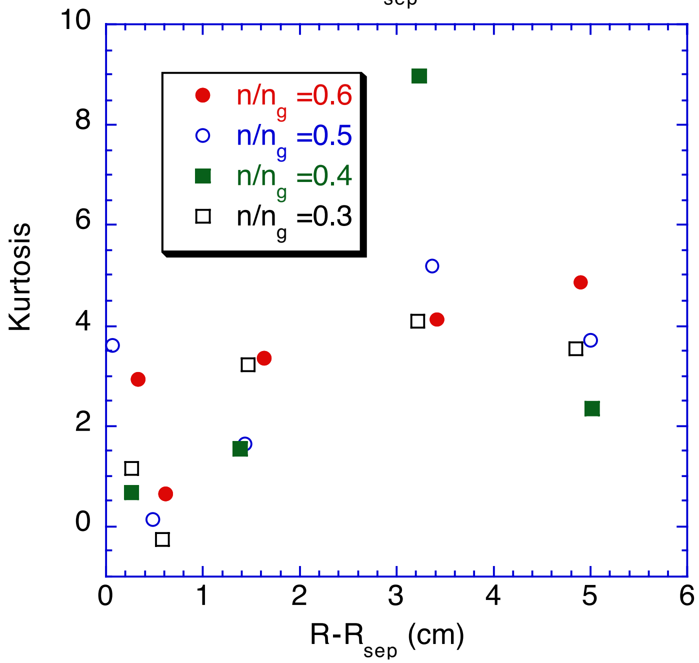


$$Skew = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{x_j - \bar{x}}{\sigma}\right]^3$$



$$Kurt = \left\{\frac{1}{N}\sum_{j=1}^{N}\left[\frac{x_j - \bar{x}}{\sigma}\right]^4\right\} - 3$$