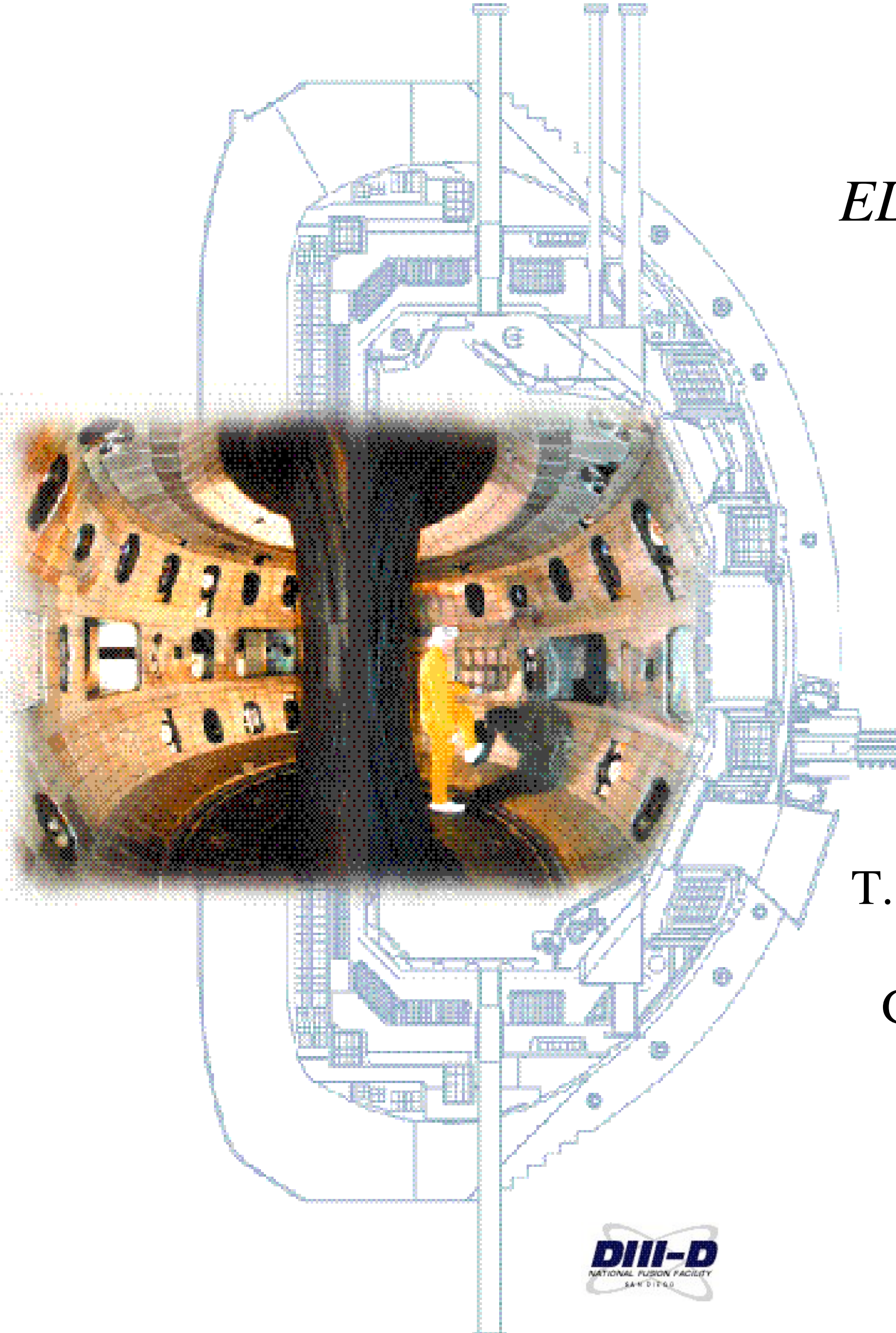
UC San Diego

# *ELM Dynamics in the SOL of DIII-D*




J. Boedo
For the DIII-D Team

Contributions from:

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R. Colchin
T. Evans, P. Snyder, K. Burrell, R. Groebner,
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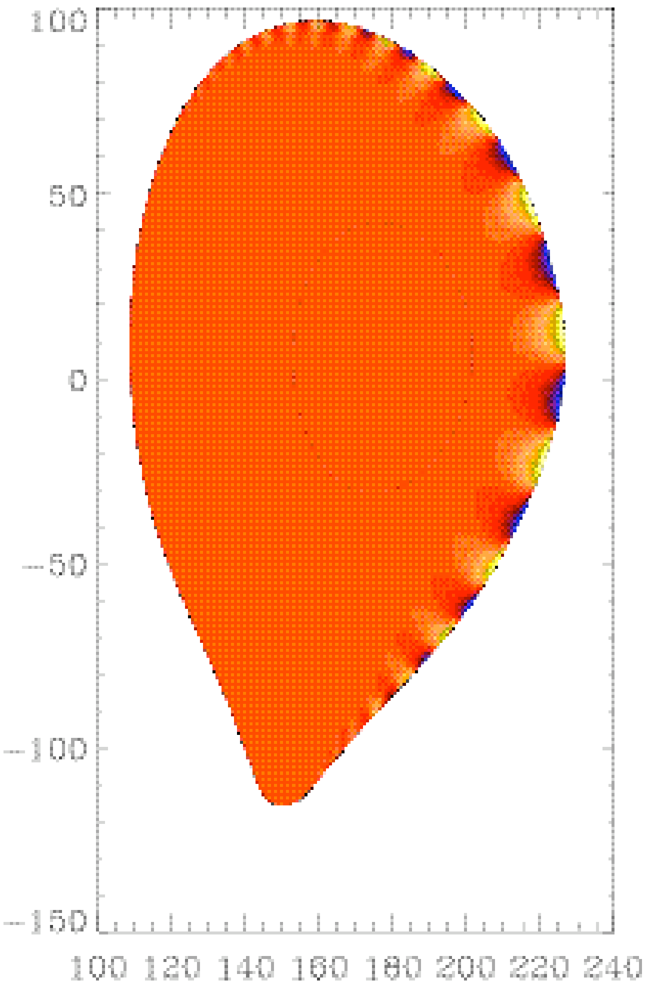
G. Porter, M. Fenstermacher, M. Groth, S.
Allen, N. Wolf
J. Watkins
H. Takahashi and L. Zeng

# *Numerical Calculations Predict ELMs have large m,n and Ballooning/Peeling Character*




Calculations address only linear phase

Non-linear phase under study (Xu, Snyder P2-156

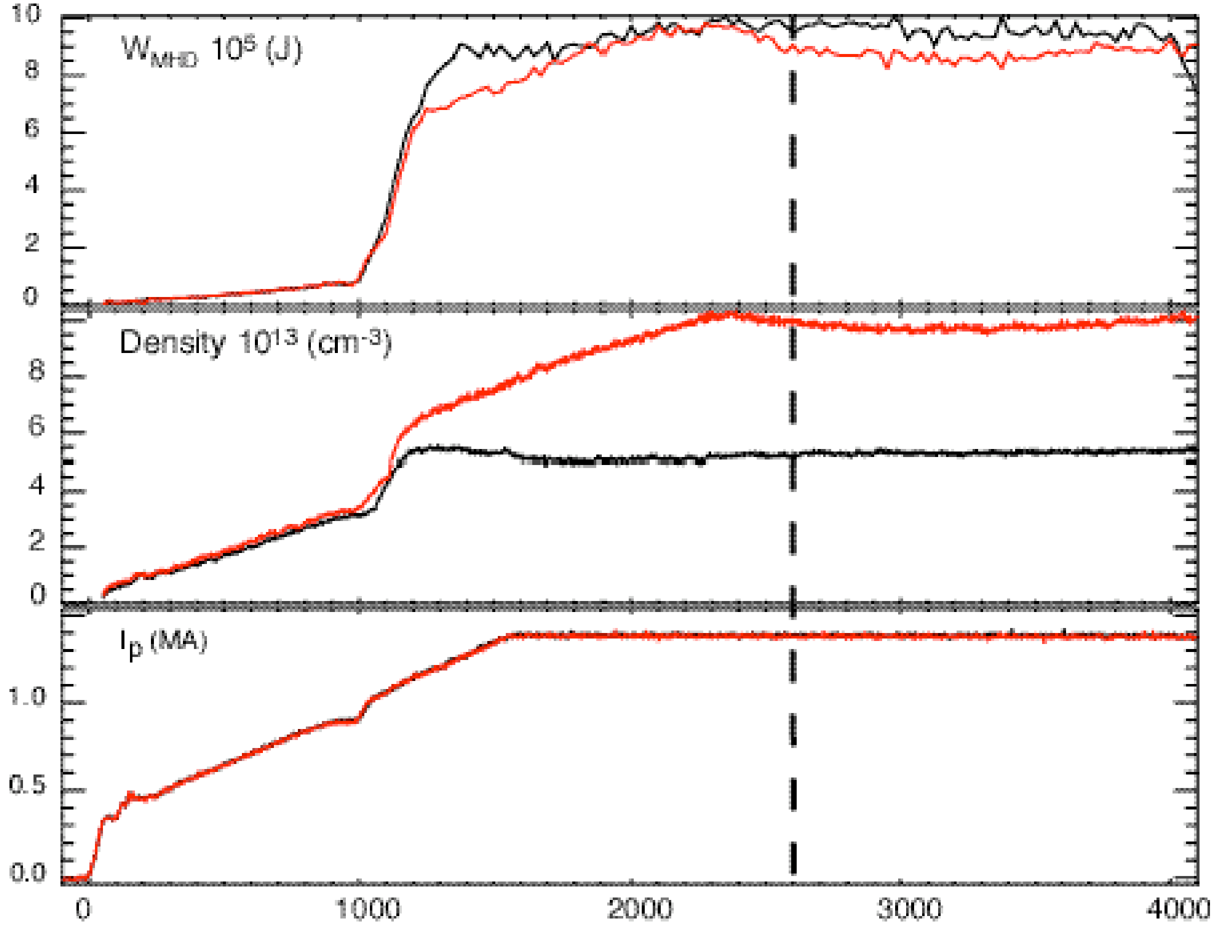
Need to test predictions and provide data to advance theory.

***P. Snyder GA***

## *Open Issues*

- •Non-linear phase characteristics
- •ELM dynamics at the LCFS and SOL
- •Composition (T and n in ELM plasma)
- •Particle and Heat fluxes to wall
- •Size
- •Motion characteristics
- •Microscopic scaling with discharge parameters

# *Density varied from n/ng~0.4 to 0.8*



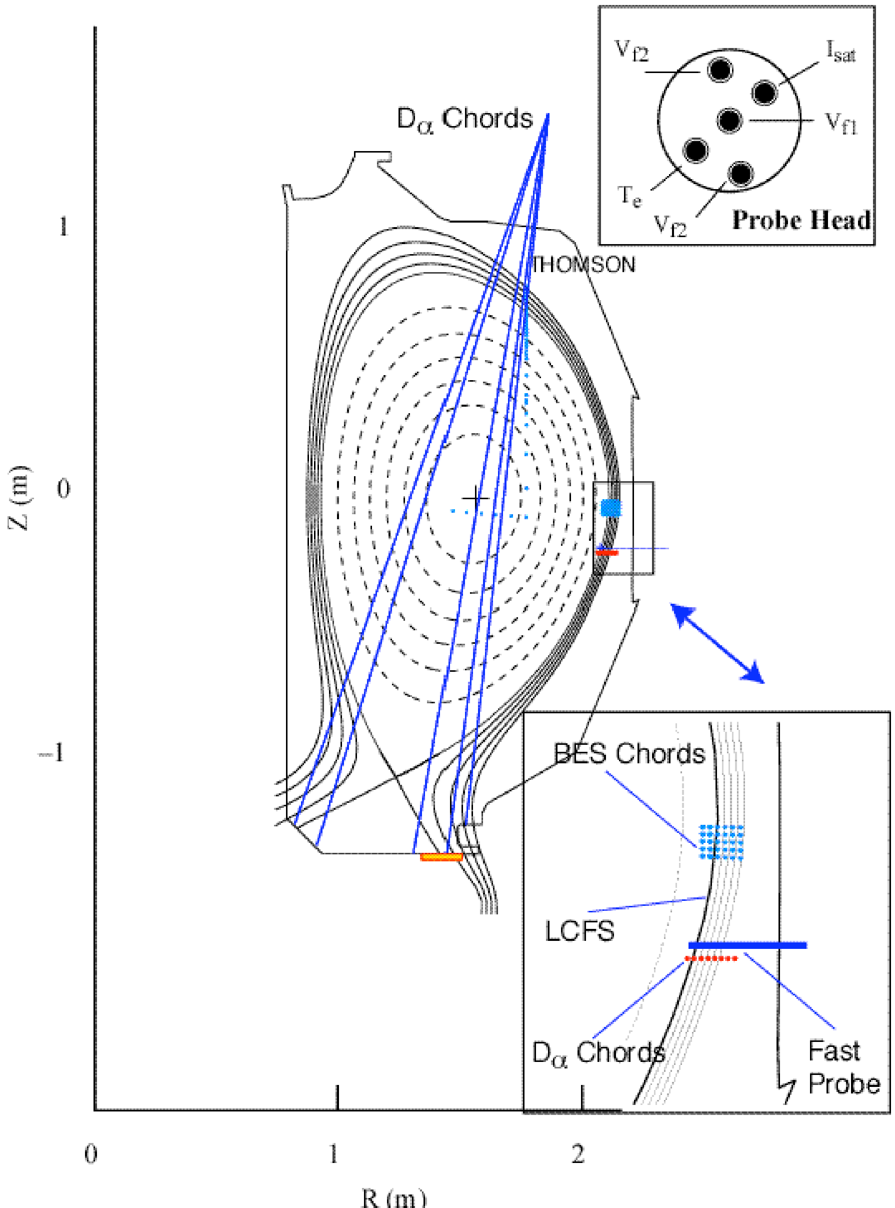

Type I ELMs

LSN

Density scan

Power scan

# *Diagnostics Utilized*




Fast diagnostics are needed

Probes
CER
Floor Photodiodes
BES
Radial diode array
Tile array
Radiometer array
etc

Need more toroidally-spread fast diagnostics

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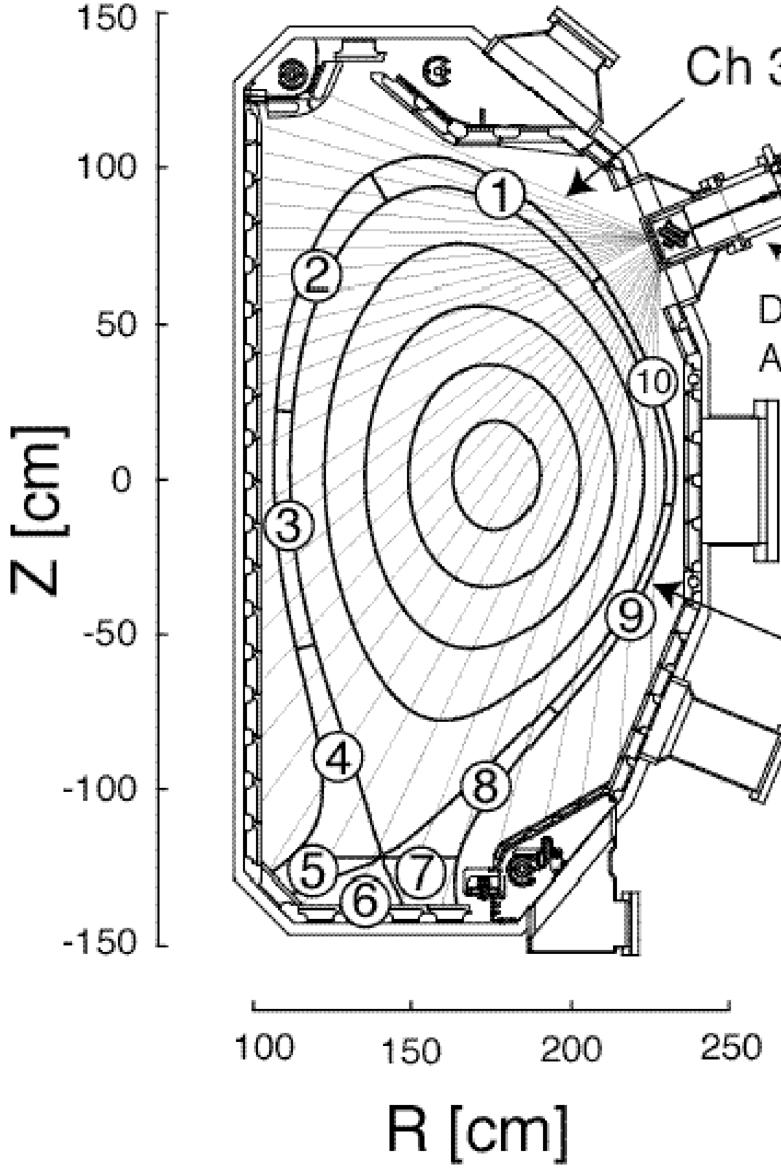
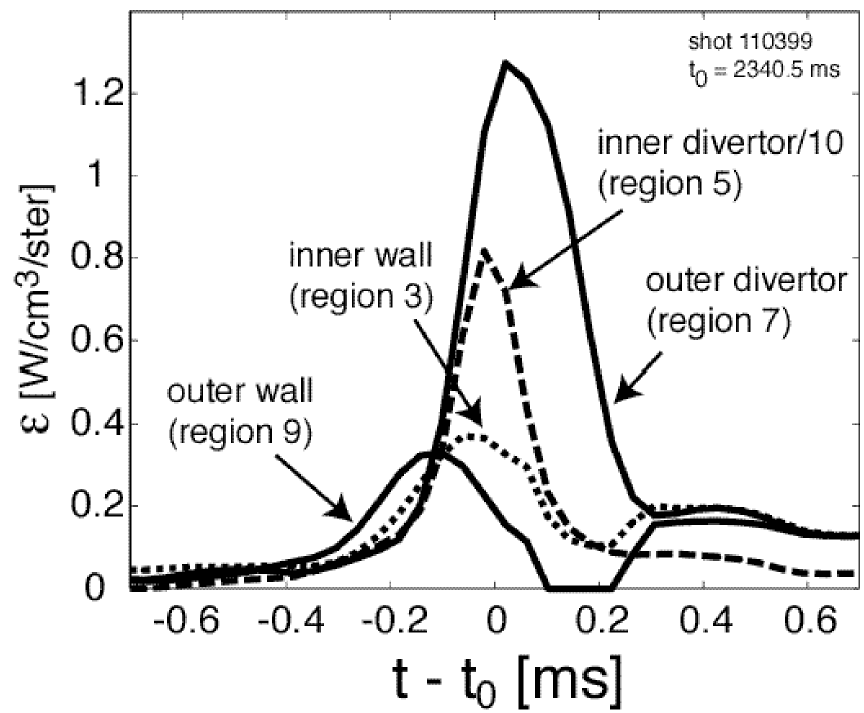



Signal rises first at the outer wall

Then inner wall

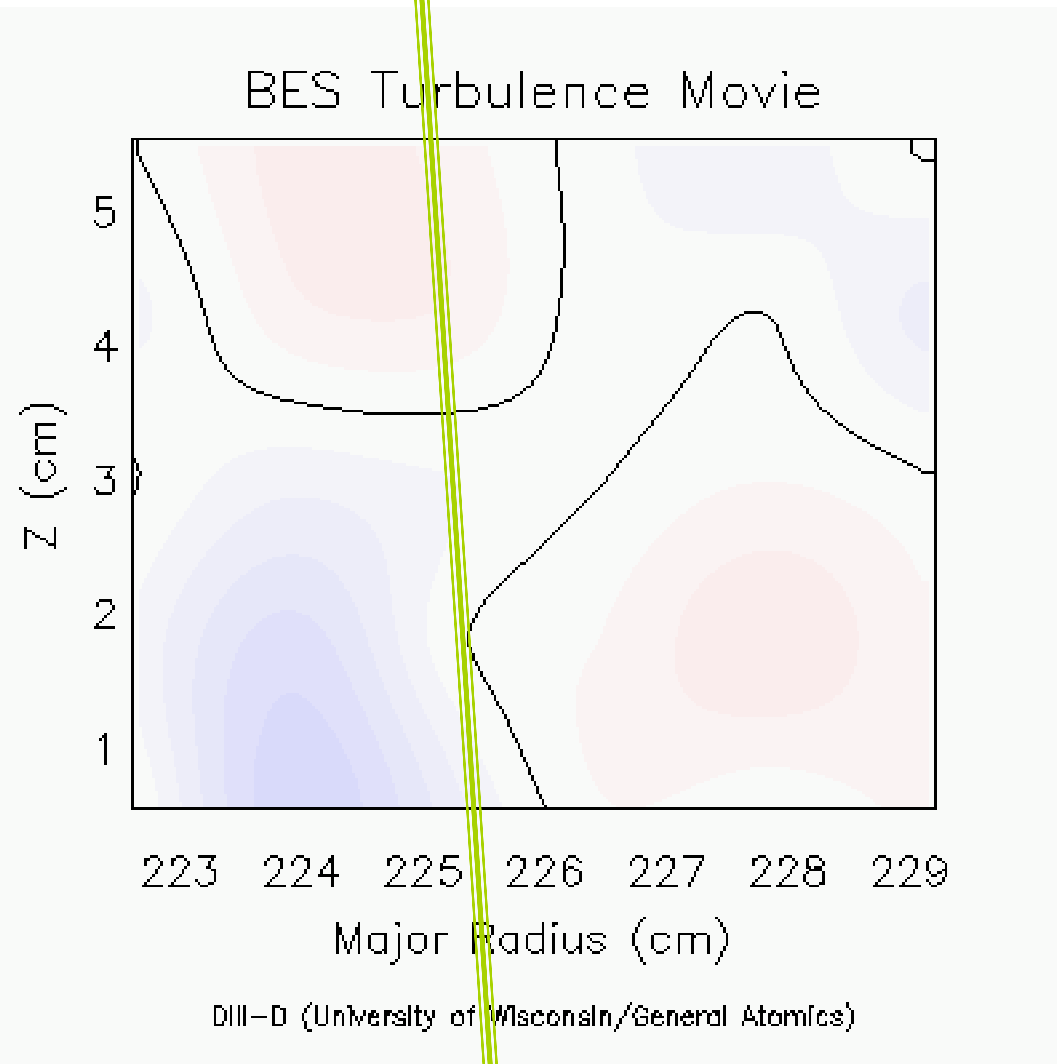
Later at the divertor






E. Hollmann, D. Gray, UCSD

# ELMs Feature Complex Structure an Dynamics




Holes and Peaks

Ejecta

Multiple Events

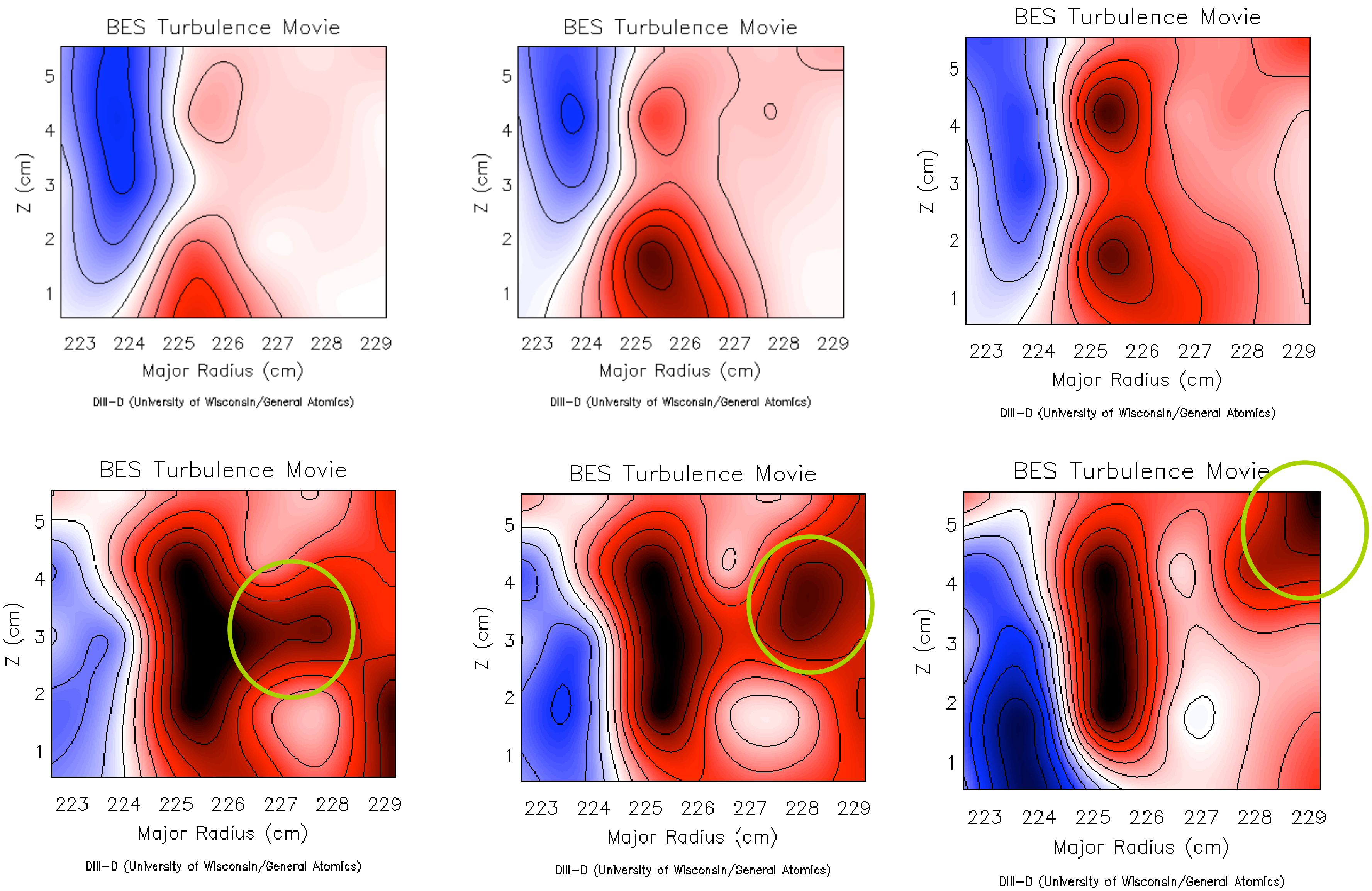
Poloidally localized

Radial size ~ 2 cm (for these shots)

Profile dips inside (mixing?)

***G. McKee, Univ. Wisconsin***

# *ELM detail over a total of ~20 μs from BES frames*

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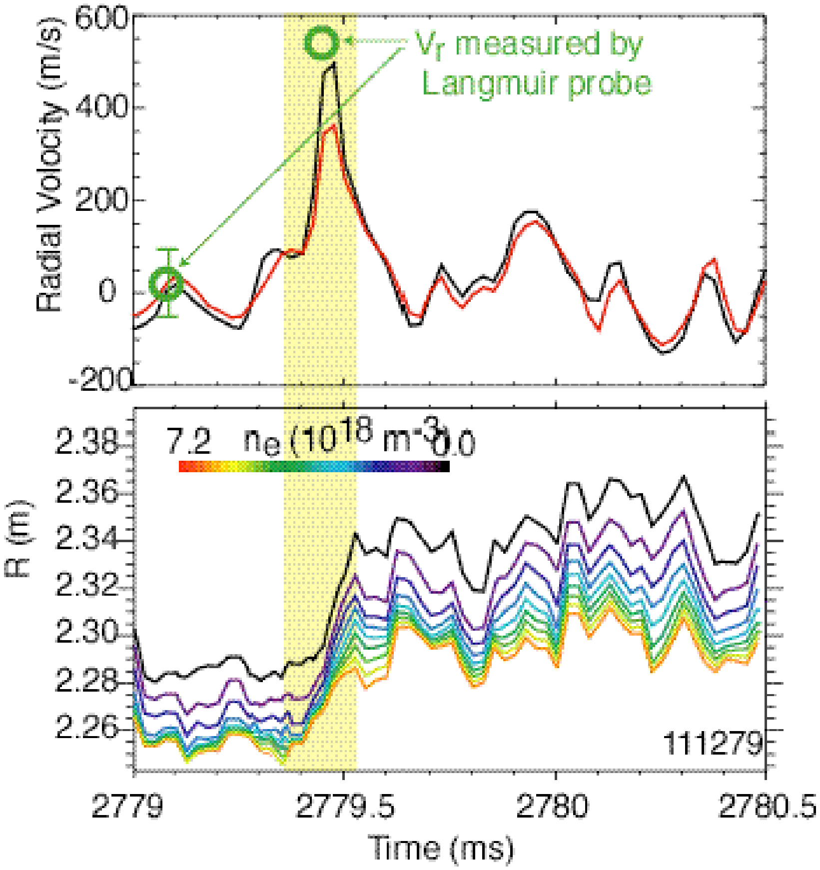
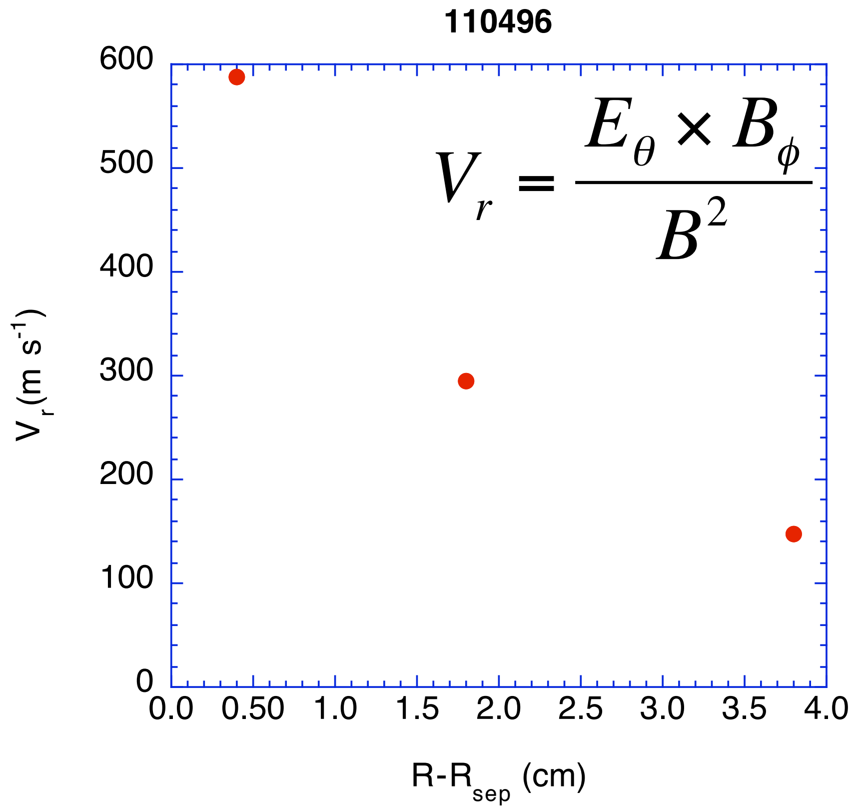
***G. McKee, Univ. Wisconsin***

# *ELMs Move Radially at ~ 500 m/s at the LCFS*



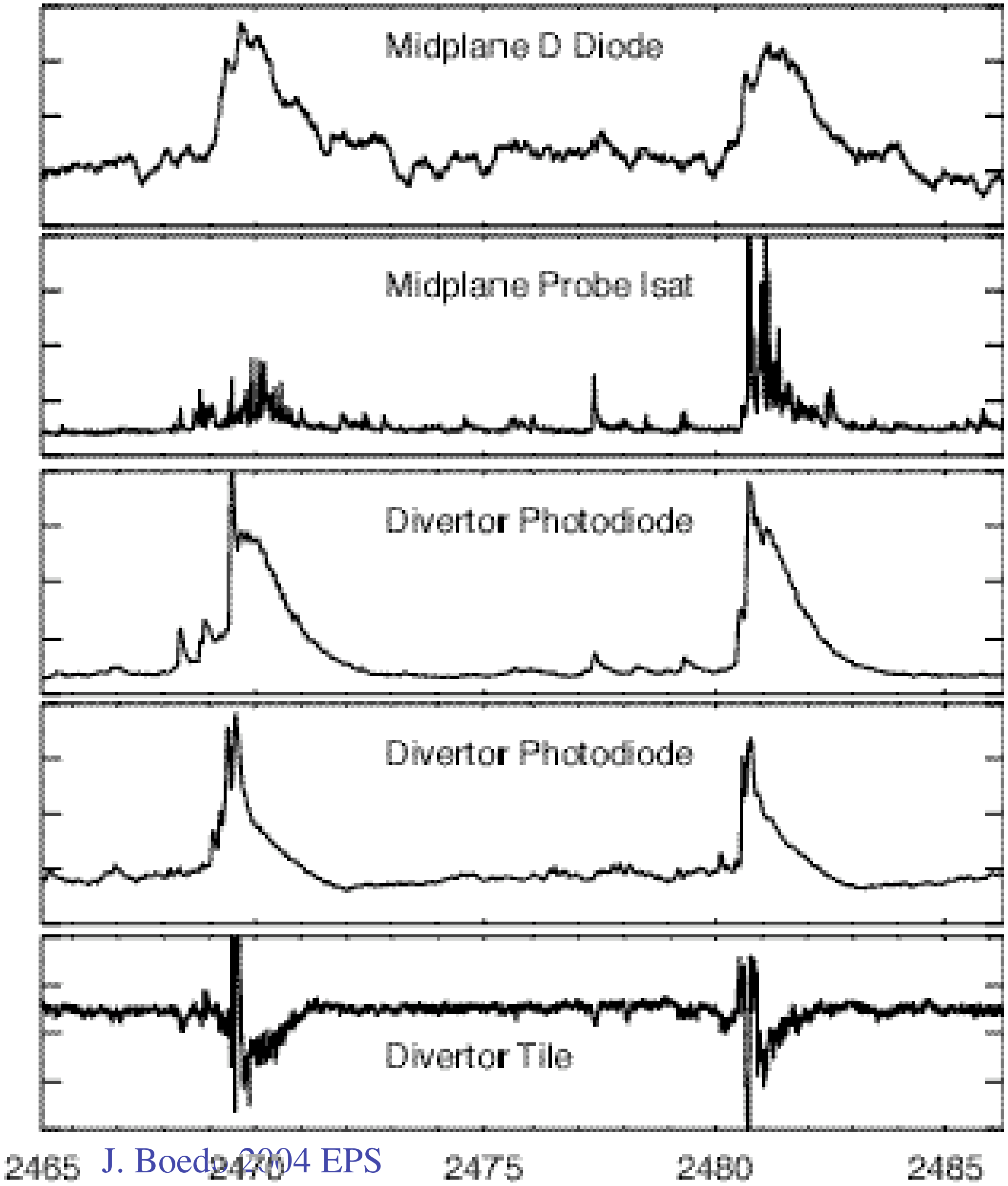

*L. Zeng, G. Wang, UCLA*




Reflectometry and Probes agree

Velocity reduces with R to ~120 m/s

# *When Observed in Detail ELMs Reveal Structure*

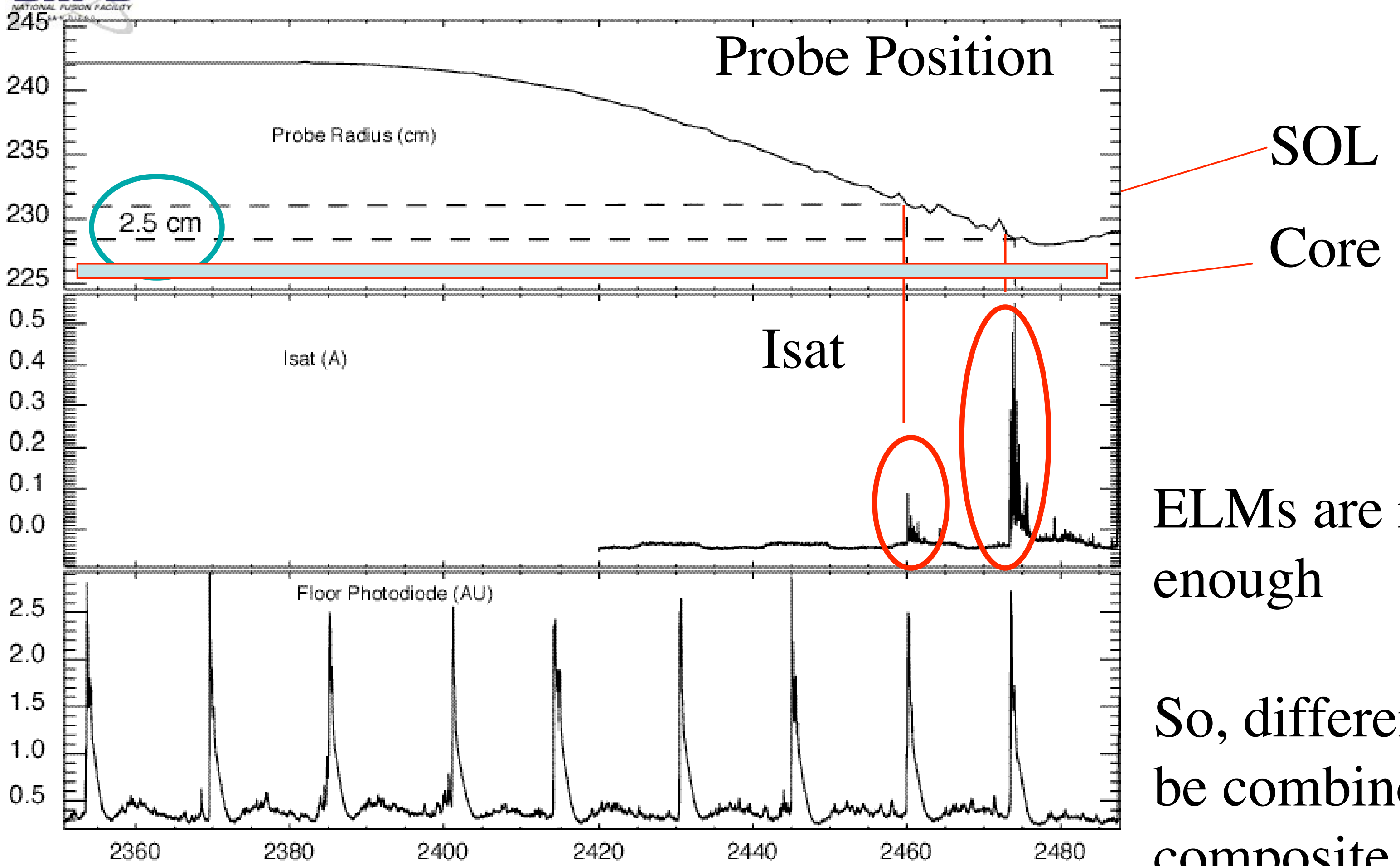



Fast Diagnostics show more and more features

Probe is ~1 MS/s
Diodes 100 KS/s
Tile array 1 MS/s
CER 500 KS/s

Seen in JET, MAST

# *Probe Samples ELMs at Various Radii*

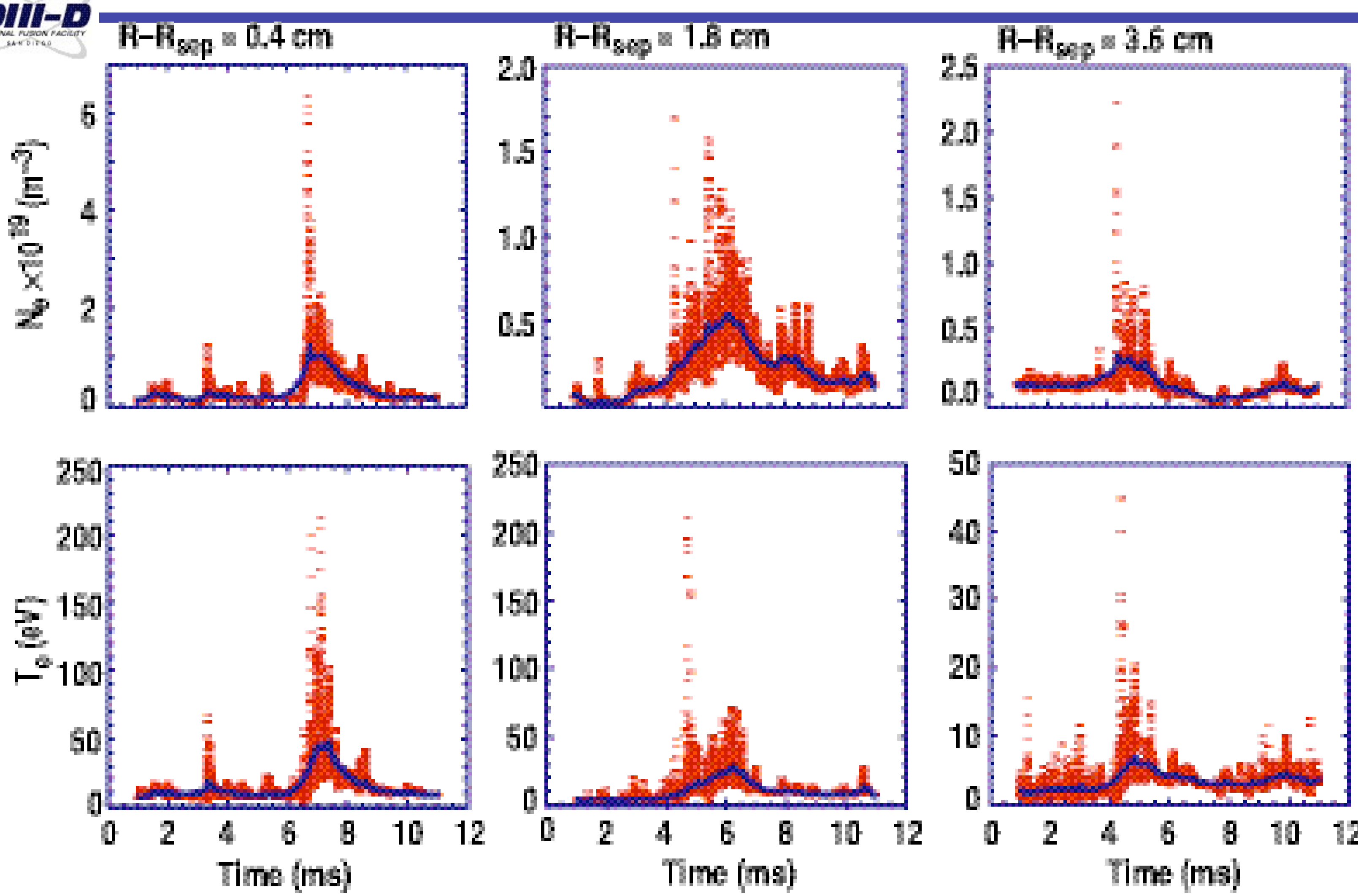



ELMs are reproducible enough

So, different ELMs can be combined into a composite

Radial variations can be inferred

# *Probe Data: Some Initial Details*

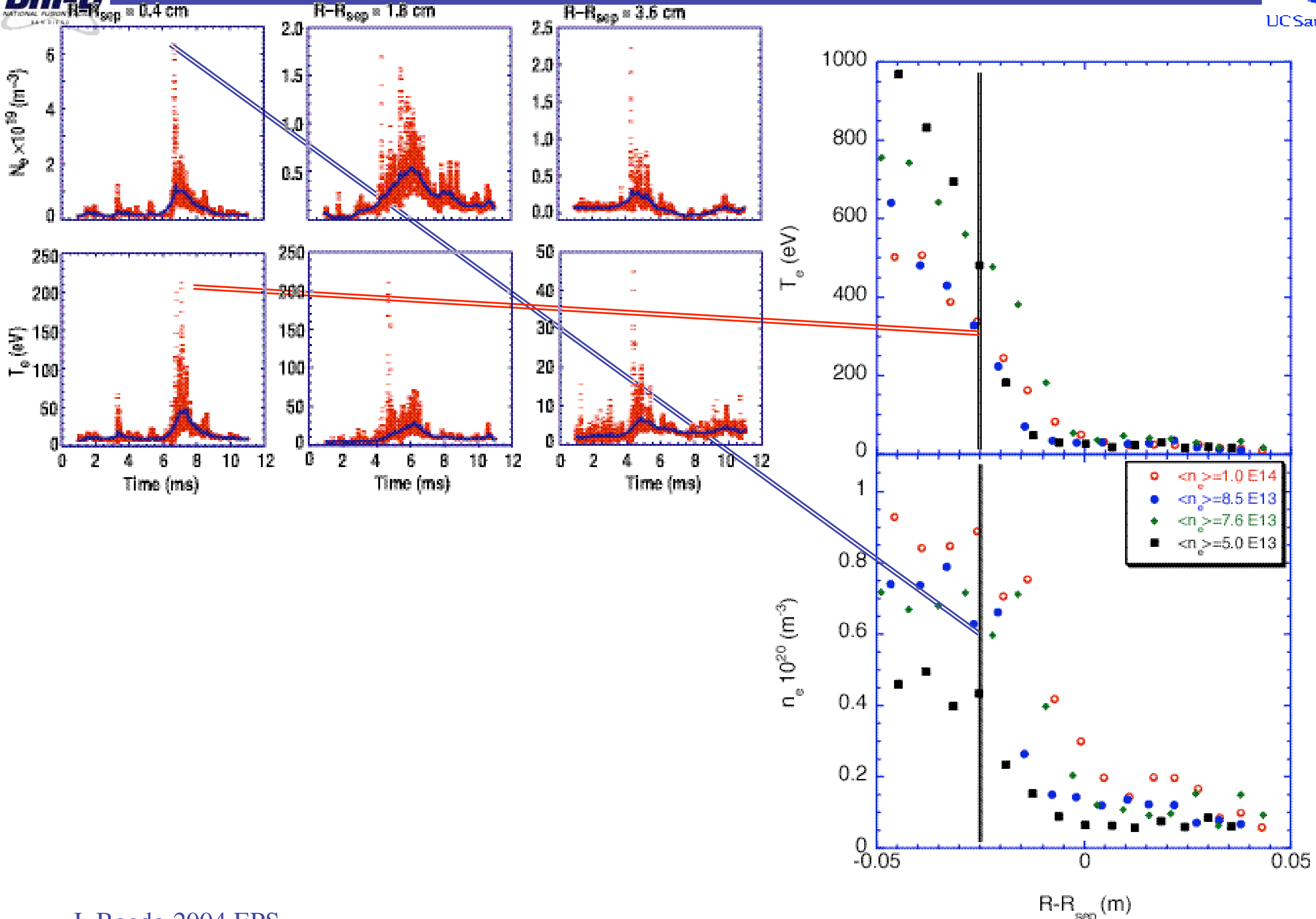



ELM is comprised of multiple events

Initial fast rise, decaying amplitude events

Large burst density ~1-6 E13 m-3. Background (~2-10 E 18 m-3)

# *ELM Carries Plasma From Pedestal*

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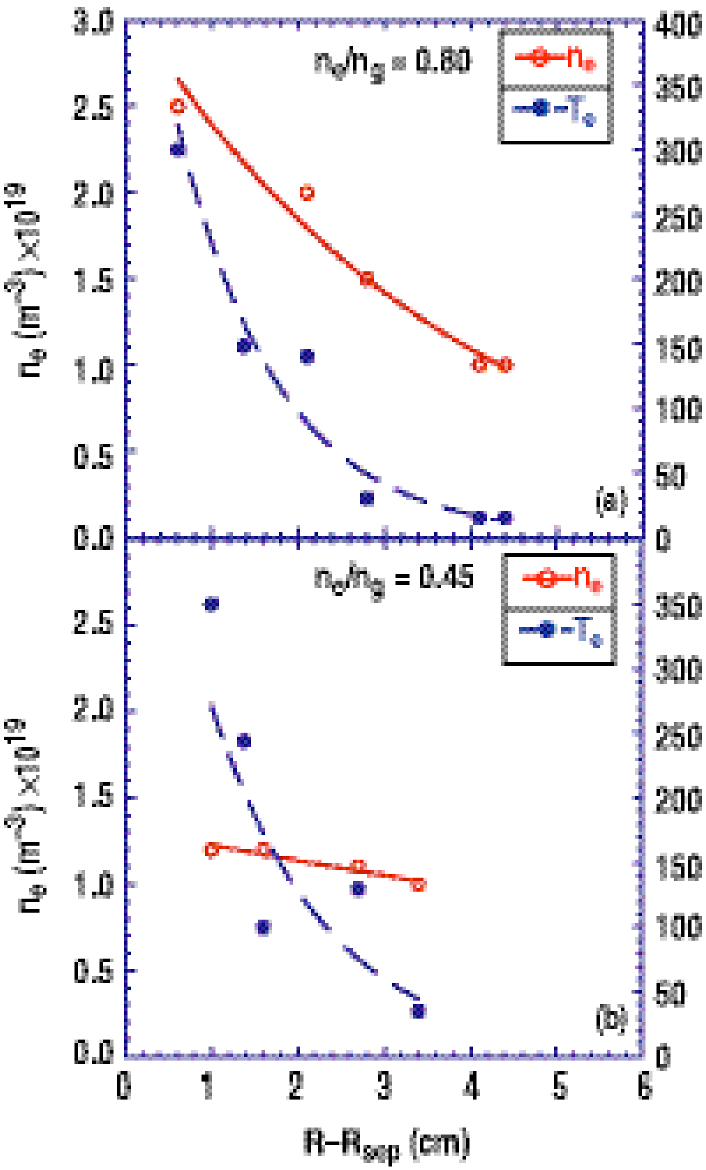
# *Probe: Energy Content Decays Faster than Particle Content*




Density Dependence of decay length

High Ne: Ln=3.8 cm
Lt= 1.2 cm
Low Ne: Ln=13 cm
Lt=1.3 cm

Particles strike wall unhindered at low Ne!

| $\langle n_e \rangle / n_{GW}$= 0.8 | $\Gamma_r^{ELM}$ ($m^{-2}$ $s^{-1}$) | $Q_r^{ELM}$ (J $m^{-2}$ $s^{-1}$) |
|---|---|---|
| LCFS | 1.0 $10^{22}$ | 1,800,000 |
| Wall | 1.5 $10^{21}$ | 21,600 |

| $\langle n_e \rangle / n_{GW}$= 0.45 | $\Gamma_r^{ELM}$ ($m^{-2}$ $s^{-1}$) | $Q_r^{ELM}$ (J $m^{-2}$ $s^{-1}$) |
|---|---|---|
| LCFS | 5.6 $10^{21}$ | 1,323,000 |
| Wall | 1.8 $10^{21}$ | 27,000 |

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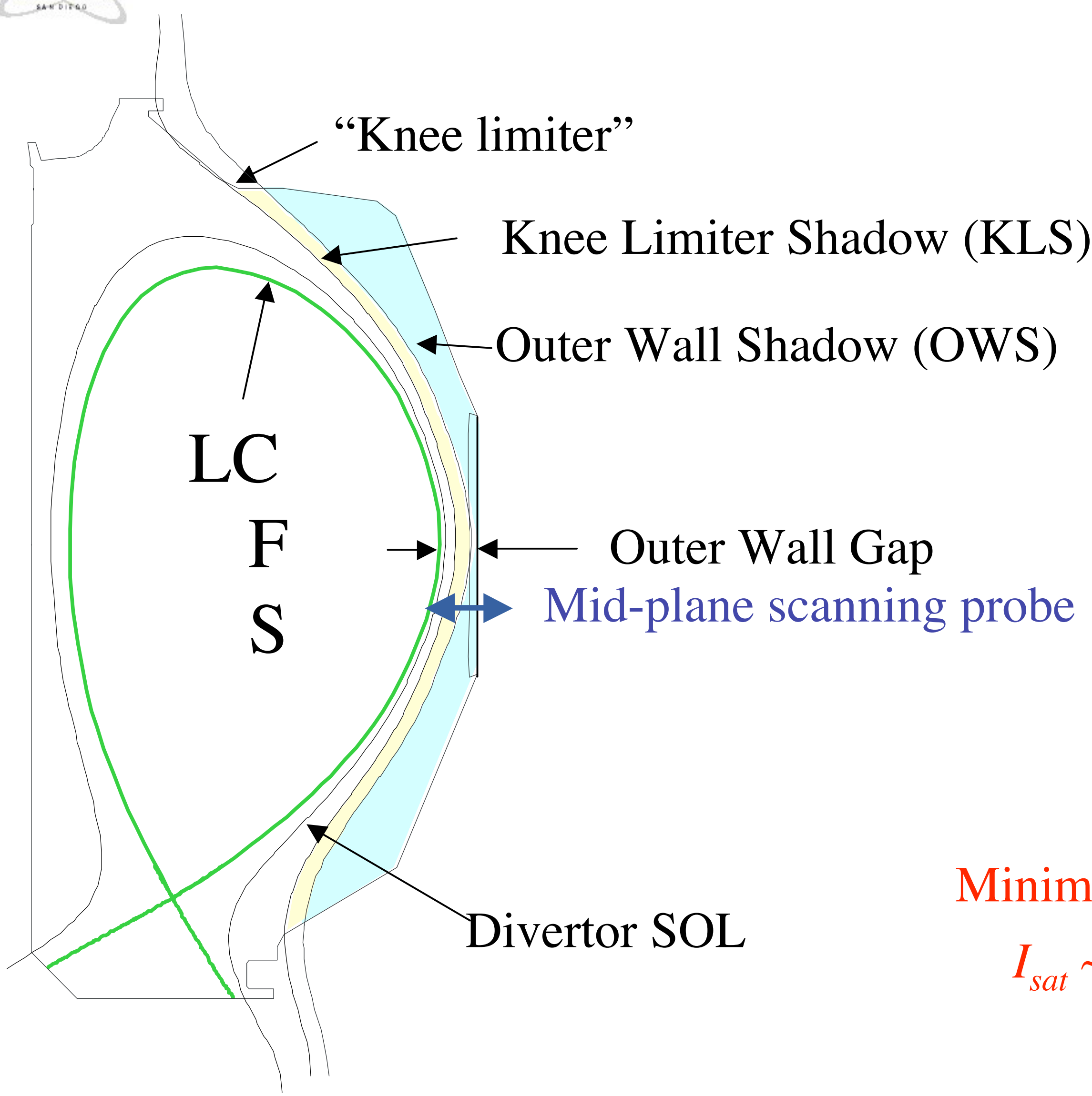
# *SOL and Diagnostic Arrangement for Wall Measurement*




KLS + OWS = LFS wall SOL

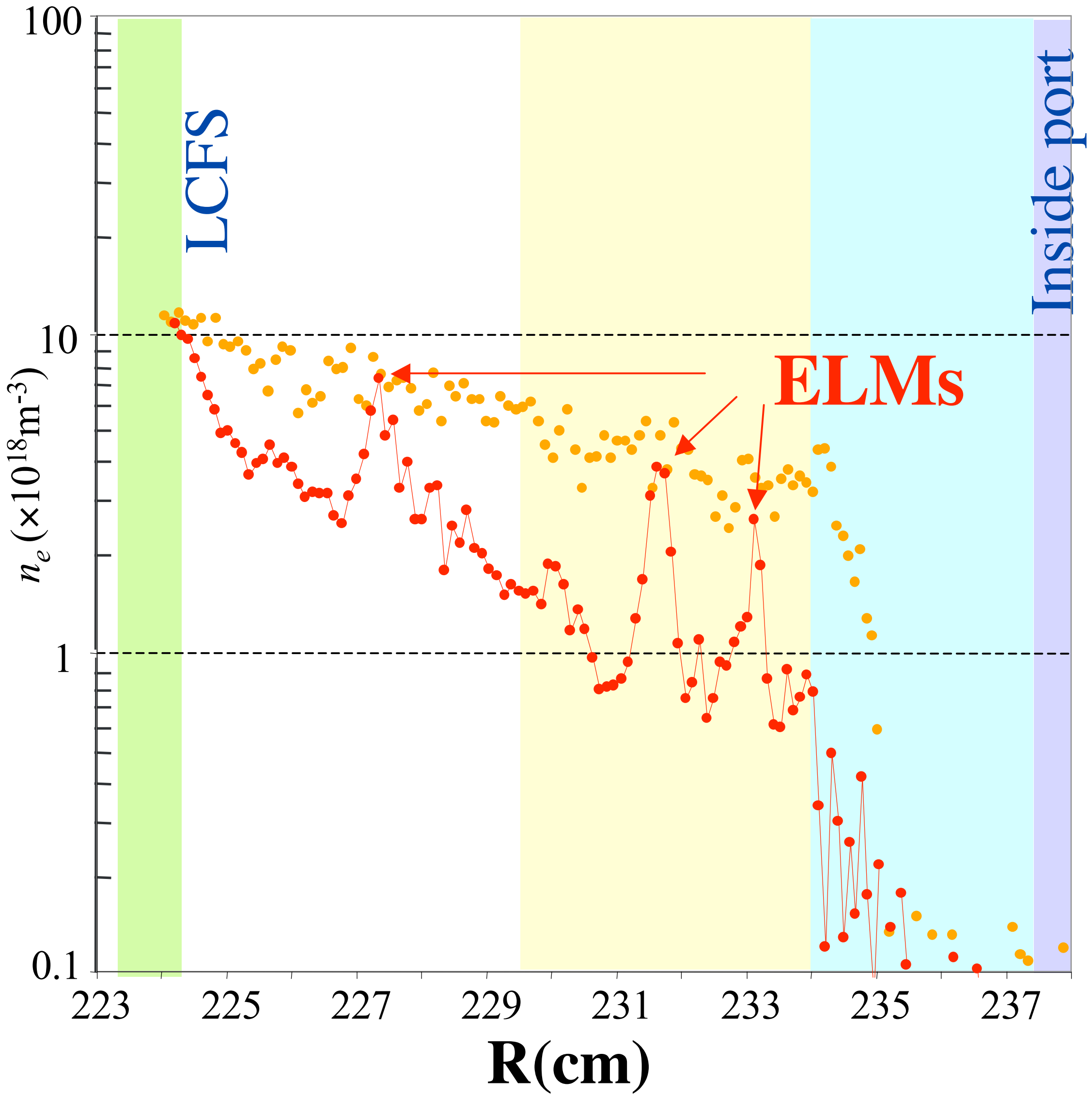
- Spatial resolution: ~ 2 mm
- Temporal resolution: 1 μs

Minimum resolved values:

$I_{sat}$ ~ 1 mA, $n_e$ ~ $10^{11}$ $cm^{-3}$, $T_e$ ~ 3 eV

***D. Rudakov, UCSD***

# *Scanning Probe: ELMs SOL density is similar to L-mode density*




Scanning Probe:
R == Time

**LSN configuration**

**L-mode**

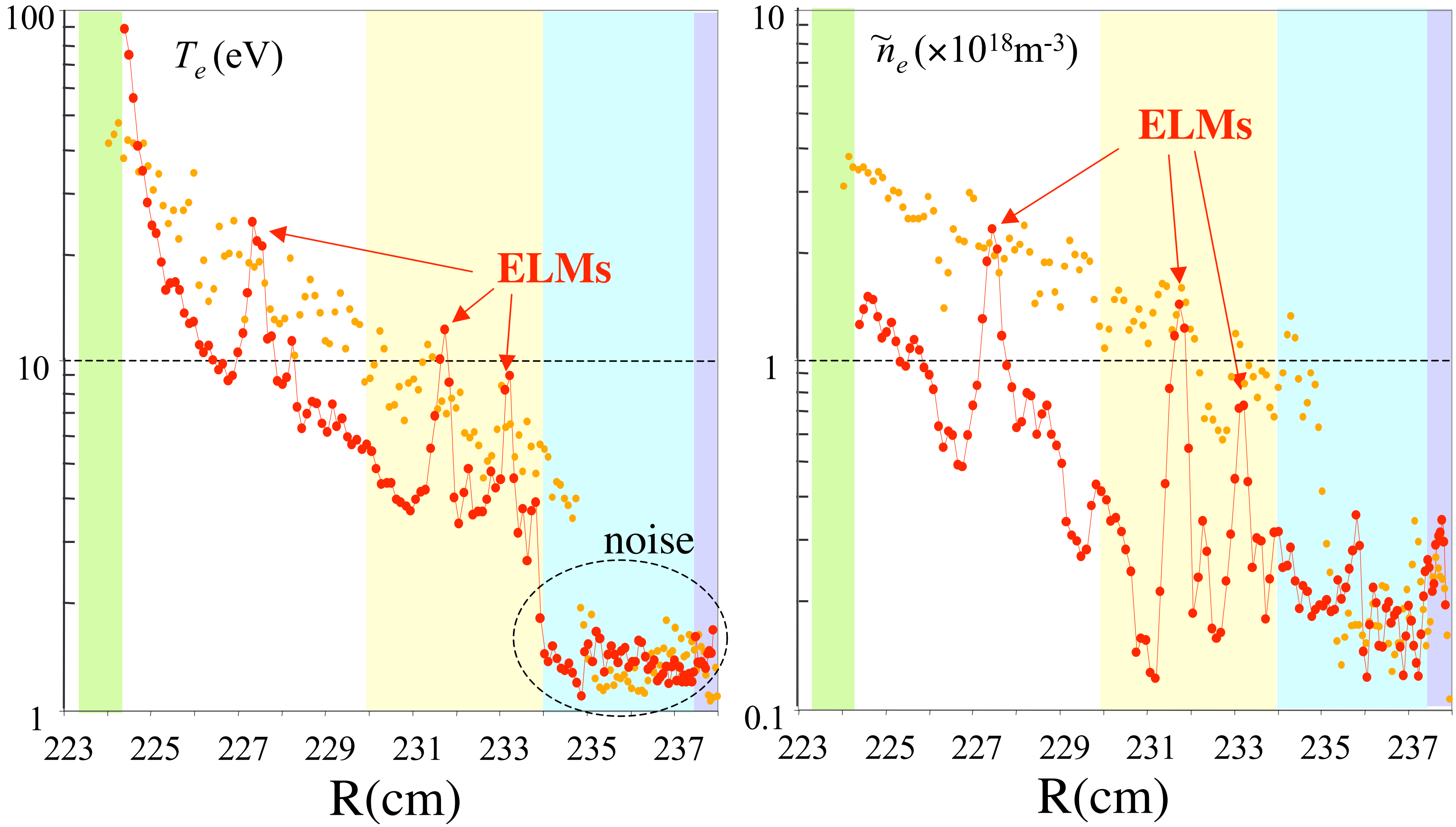
$f_{Gw}$~ 0.58

**H-mode**

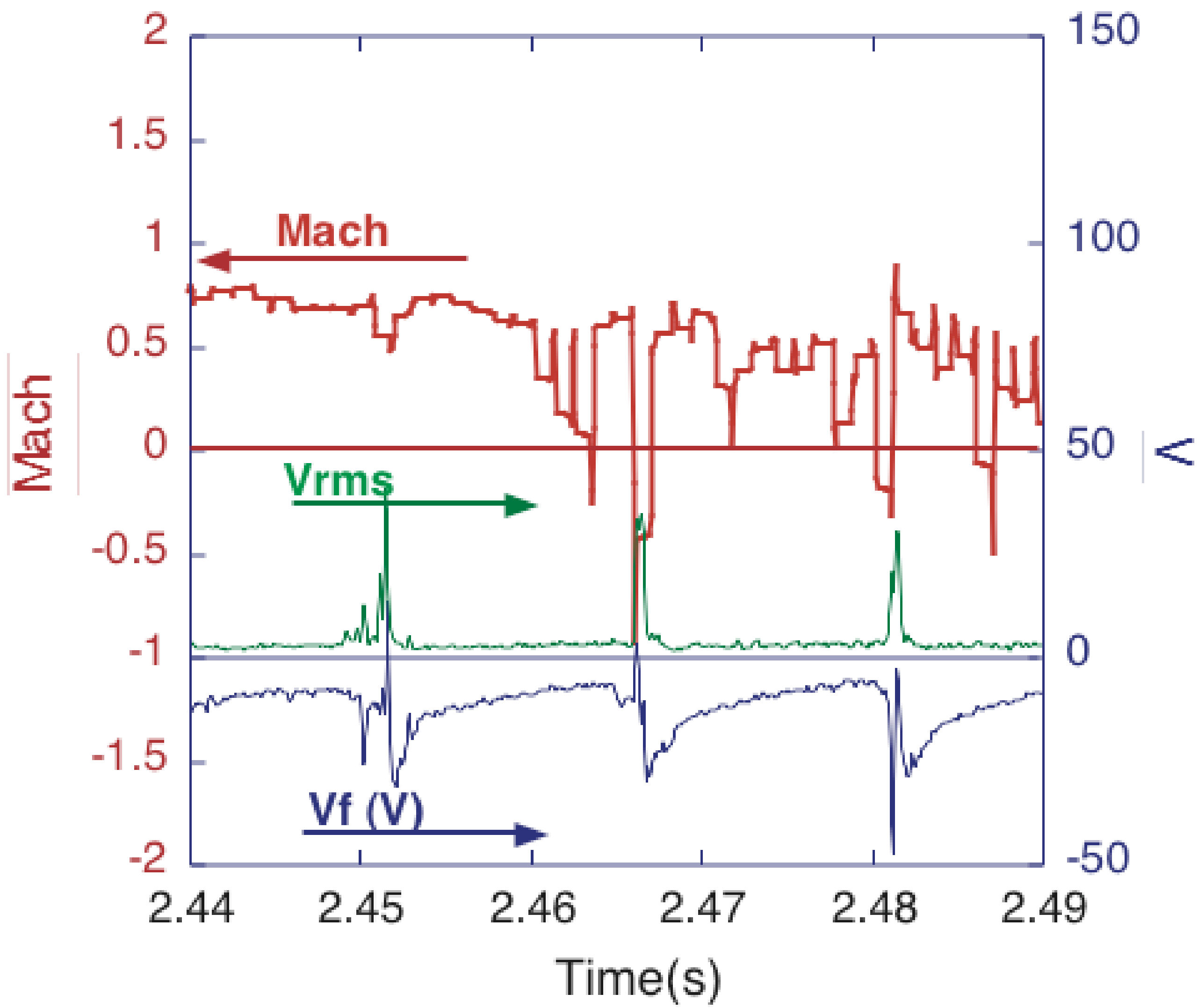
$f_{Gw}$~ 0.65

- Between ELMs SOL density is below L-mode values by a factor of 5 - 8
- During ELMs SOL density reaches L-mode levels

# *Te and ne fluctuation levels during ELMs, comparable to L-mode*



# *Probe: ELM Divertor Dynamics*



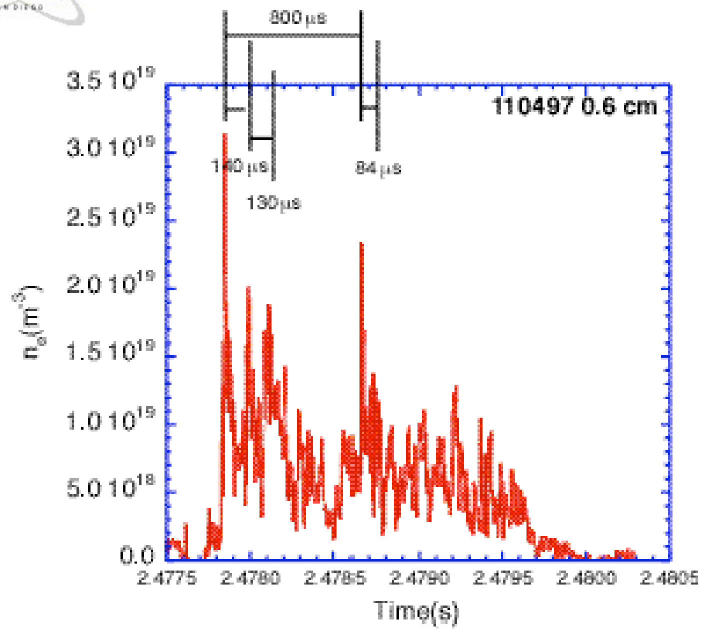

Scanning Probe:
R == Time

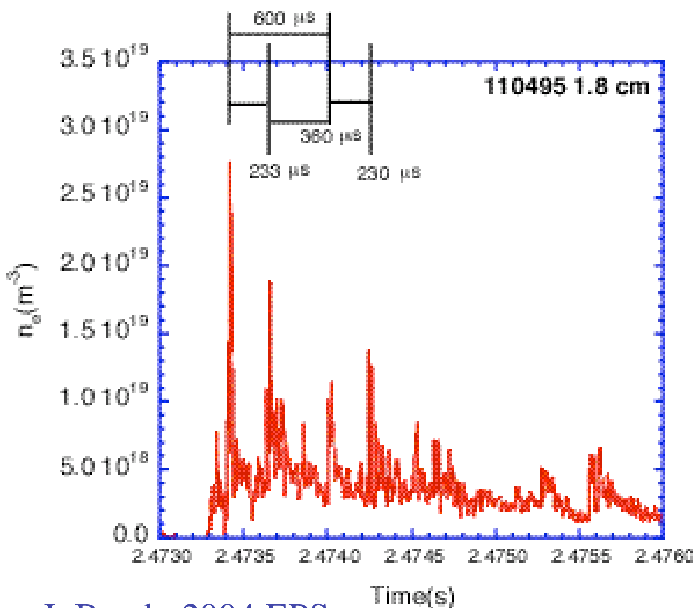
ELMs slow down divertor parallel plasma flow in SOL

Flow reversal is sometimes observed

Potential is perturbed before plasma arrives at the floor

# *ELM Motion and Radial Extent*




Pulses reach wall ~ 100-300 µs

If <u>purely radial motion</u> is assumed:

Peaks are ~ 20-40 µs long $\delta r = V_r \times \delta t$

Using measured $V_r$ then δr~3-5 cm ( see BES) per burst!

Density matters; bigger bursts at high ne

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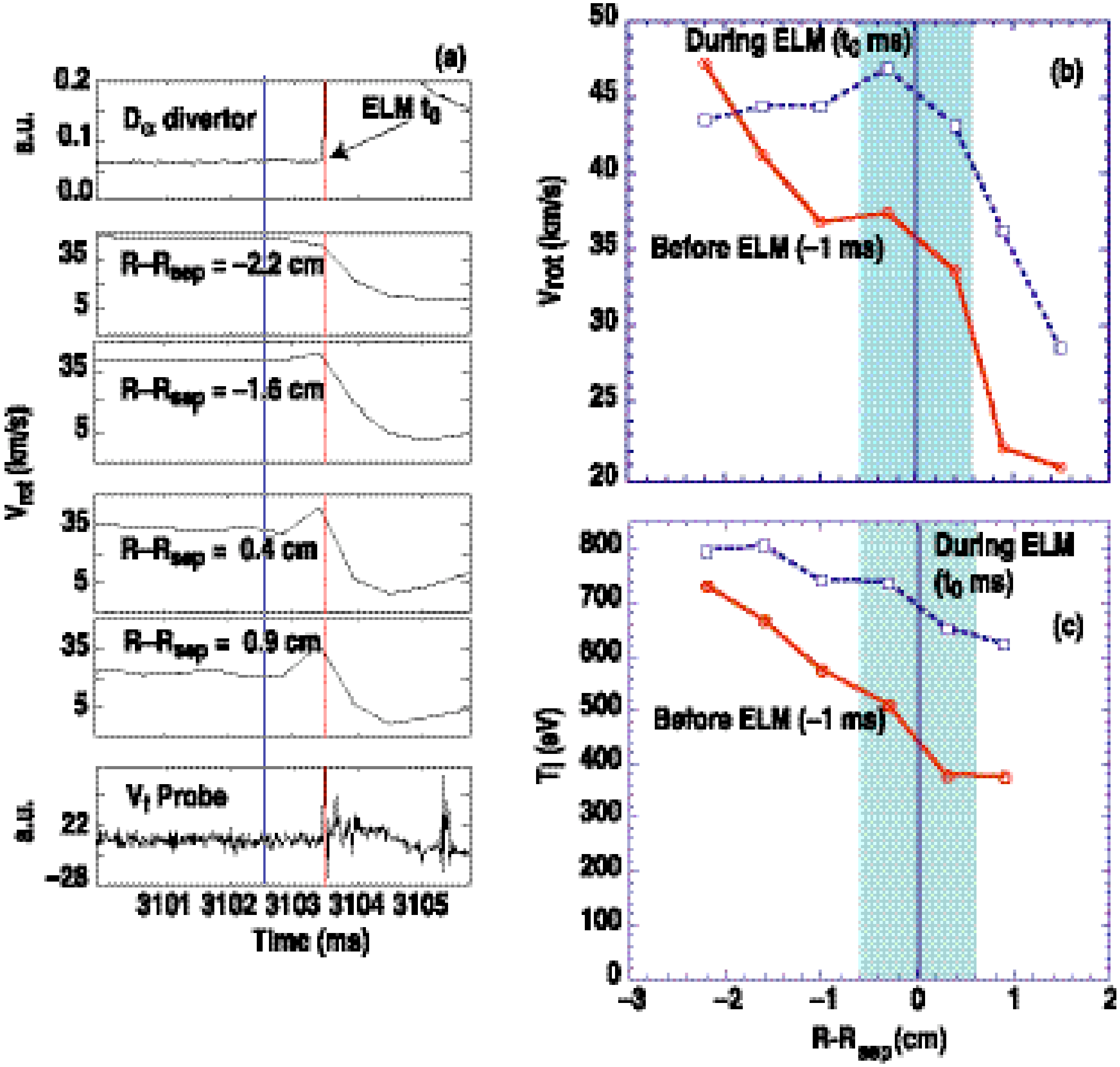
What shape/volume do ELMs really have?

Bursts should be poloidally localized (even if several tubes burst). Toroidally?

Burst should extend along field lines. We ***know*** ELMs strike the floor/walls everywhere.

Why everywhere within +- 200 μs ?? (ion transit time from midplane ~ 100-150 μs) How does ~localized plasma source extends toroidally ***and*** poloidally?

# *Fast CER Indicates ELM Plasma Rotation*




Vrot in SOL increases transiently during ELM

Rotation ~30-40 km/s, as in top of density pedestal

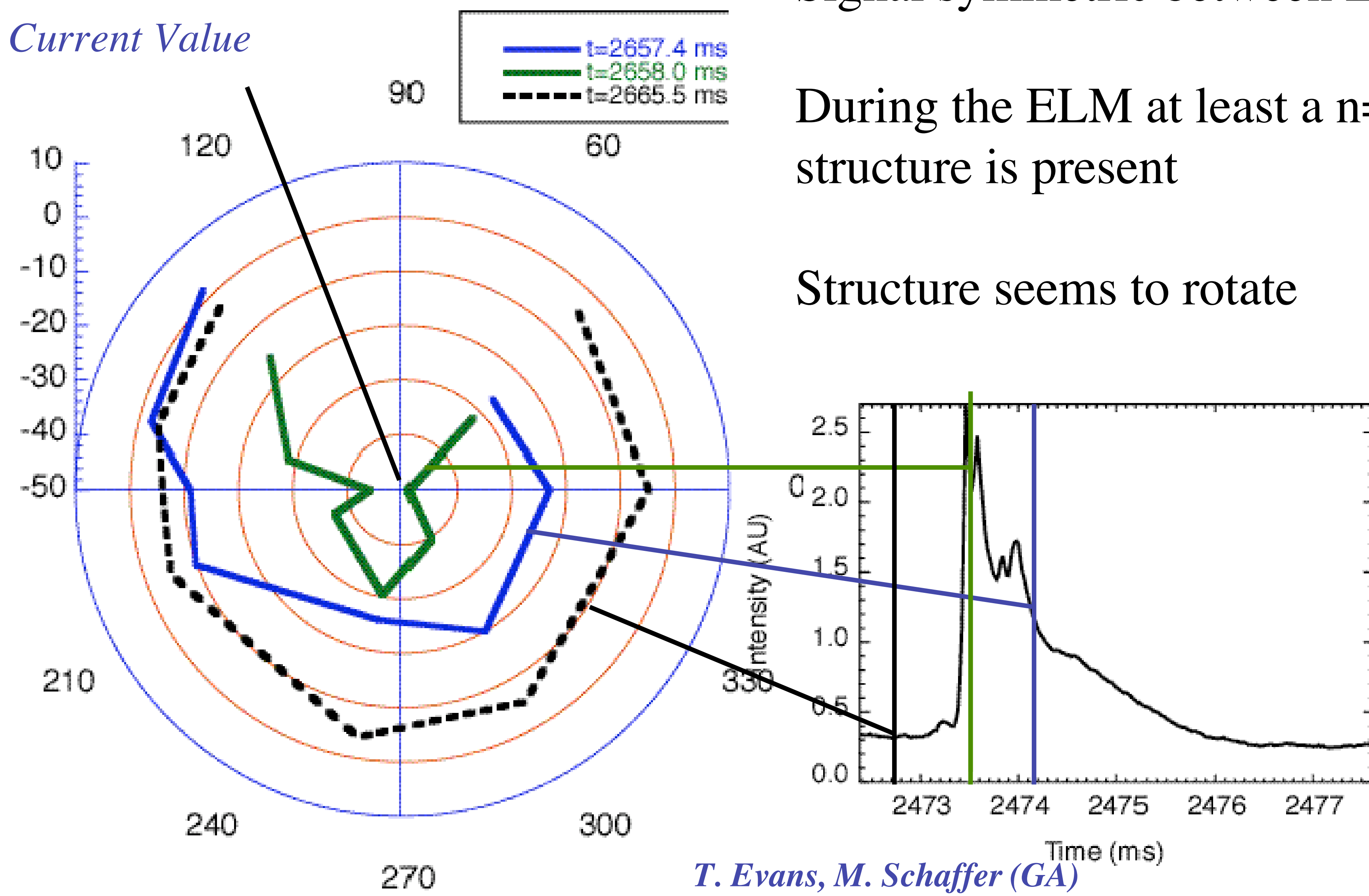
SOL Ti during ELM ~600-700 eV, as in top o density pedestal

# Tile Array Shows Asymmetry and…. Rotation?

Signal symmetric between ELMs

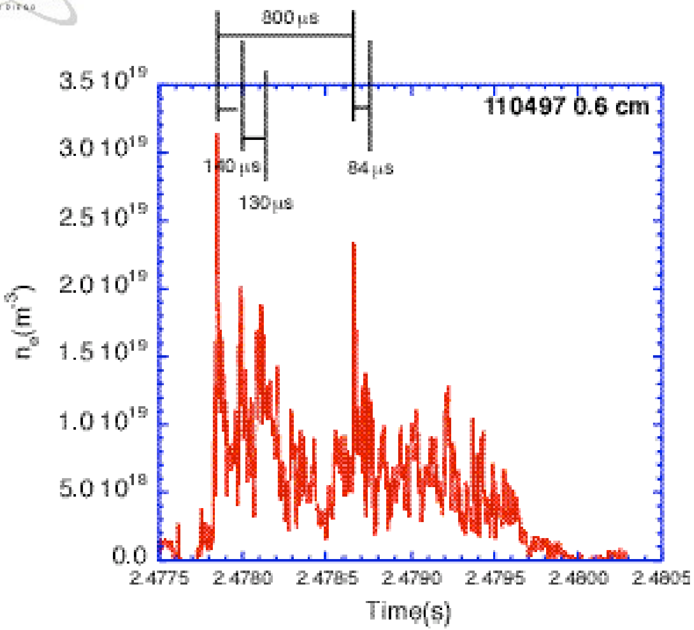
During the ELM at least a n=1 structure is present

Structure seems to rotate



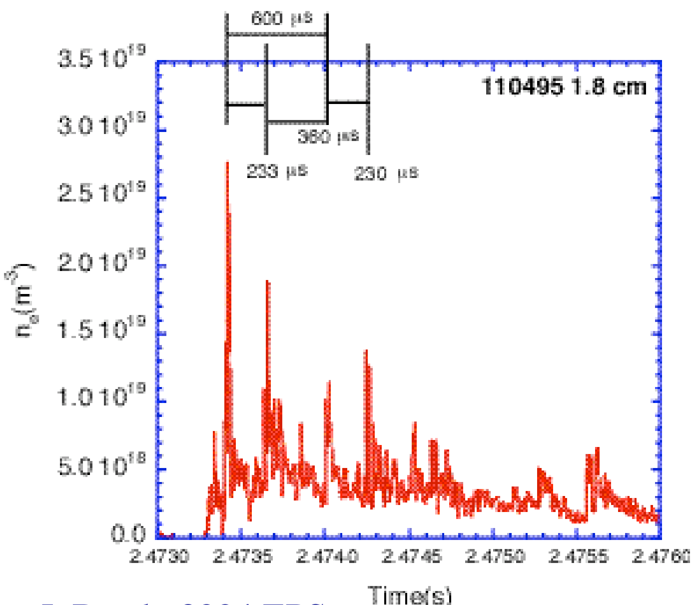

*T. Evans, M. Schaffer (GA)*
*H. Takahashi (PPPL)*

# *Bursty Character Result of Rotation? Re-Interpretation*




Perhaps an n=3 structure (or multiple filaments) rotating with T=800 μs

At R=2.30, v~18 Km/s, compared to ~25 km/s CER at LCFS




Perhaps an n=2 structure (or multiple filaments) rotating with T=600 μs

At R=2.30, v~24 Km/s, compared to ~25 km/s CER at LCFS

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## *Summary/Conclusions*

ELMs are not single events but composed of multiple bursts

The bursts exist on top of a background plasma (created by the  bursts)

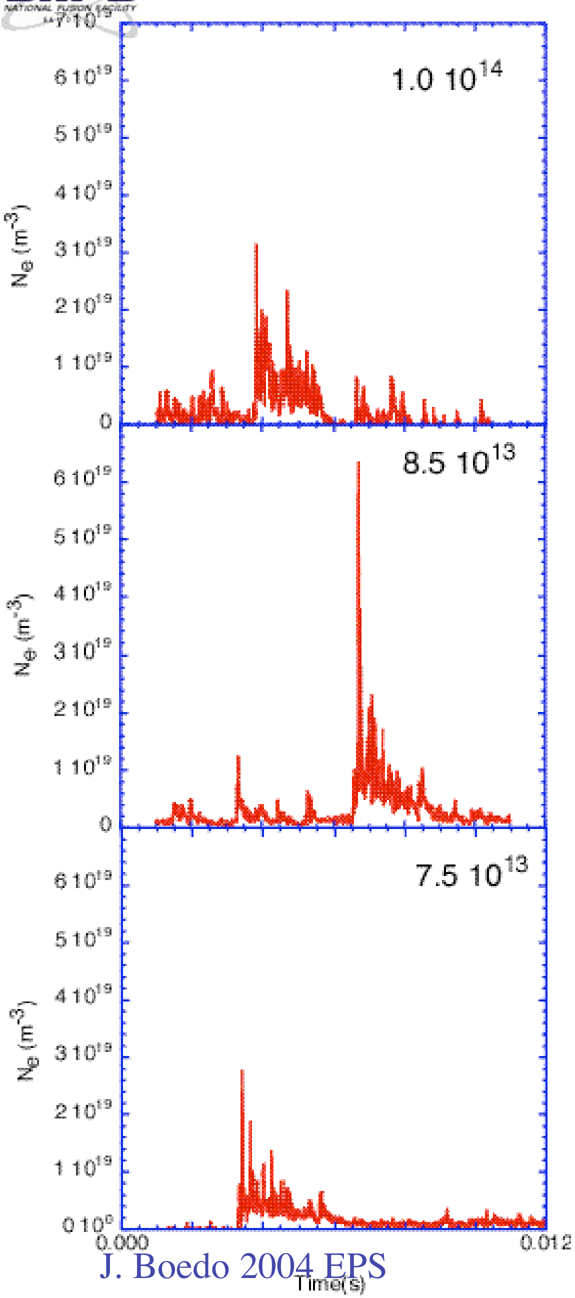
ELM plasma decays with radius. Heat flux faster than particle flux I.e. heat ends in divertor plates, particles recycle off walls

ELM particle flux at wall comparable to L-mode flux

ELMs affect (reduce in most cases) plasma flows at divertor

ELM motion may be radial+ toroidal+ poloidal

# *Density Scan: ELMs Scale with Ne Only at lower <Ne/$N_G$>*



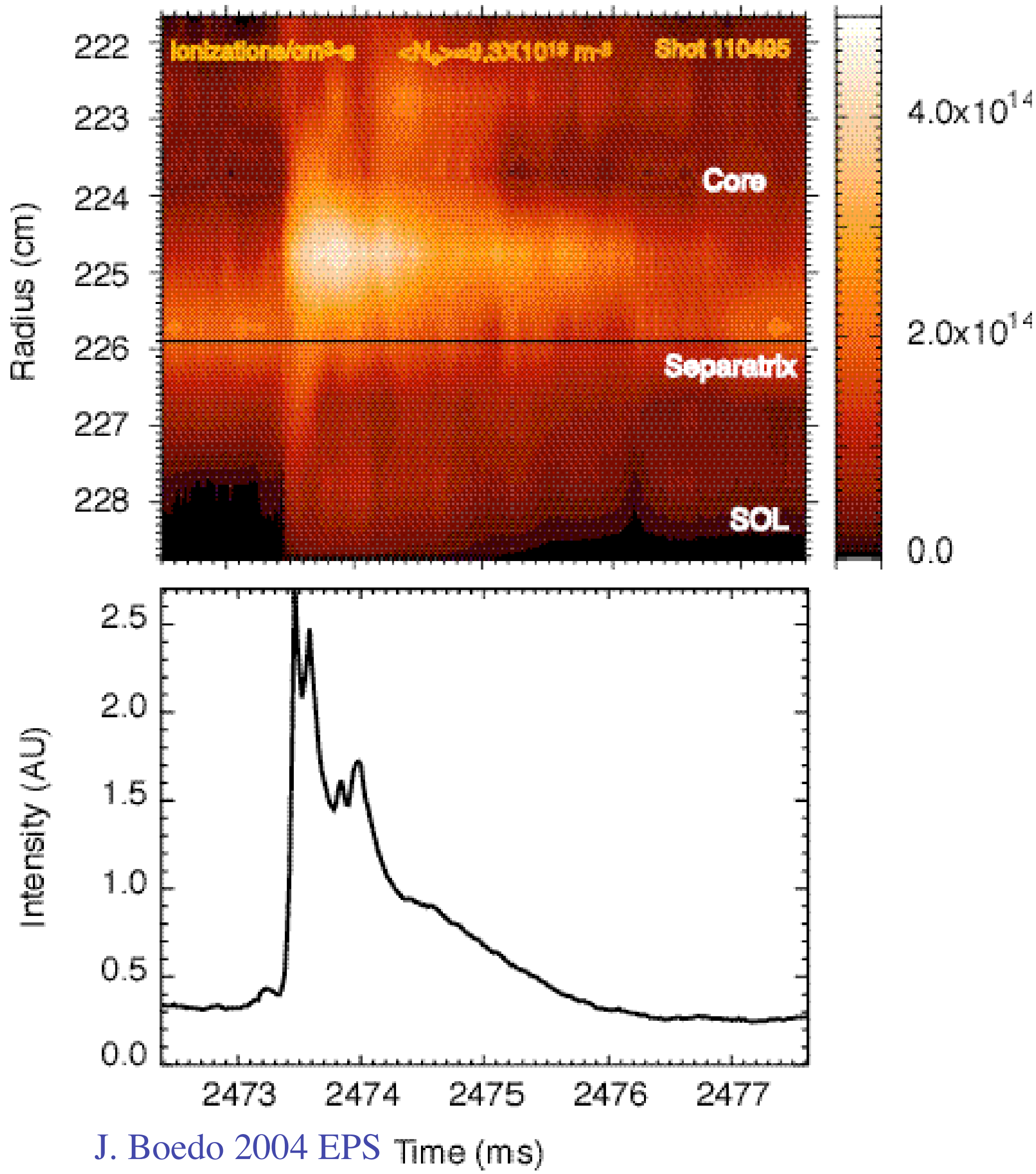

ELMs peak density increases with discharge Ne

At Ne/Ng~ 0.8 the peak density drops

ELM more grassy

Same results as produced by A. Leonard.
Searching for a benign ELM regime

## *Tangential Photodiode Array Shows Bursty Behavior*

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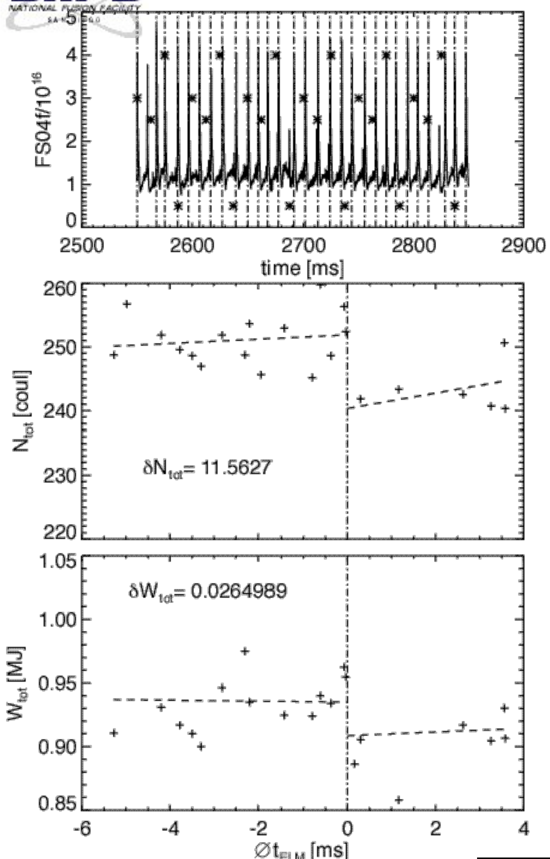
ELM occurs near the LCFS

Starts with a large burst

Multiple bursts of decaying amplitude follow

# *ELM Volume is Estimated*




Get ELM particle and energy content from TS (A. Leonard, G. Porter)

Use local n and T from probe $E_{ELM} = 2 \times \frac{3}{2} nkT \times V_{ELM}$

Divide by number of bursts (approx. 6)

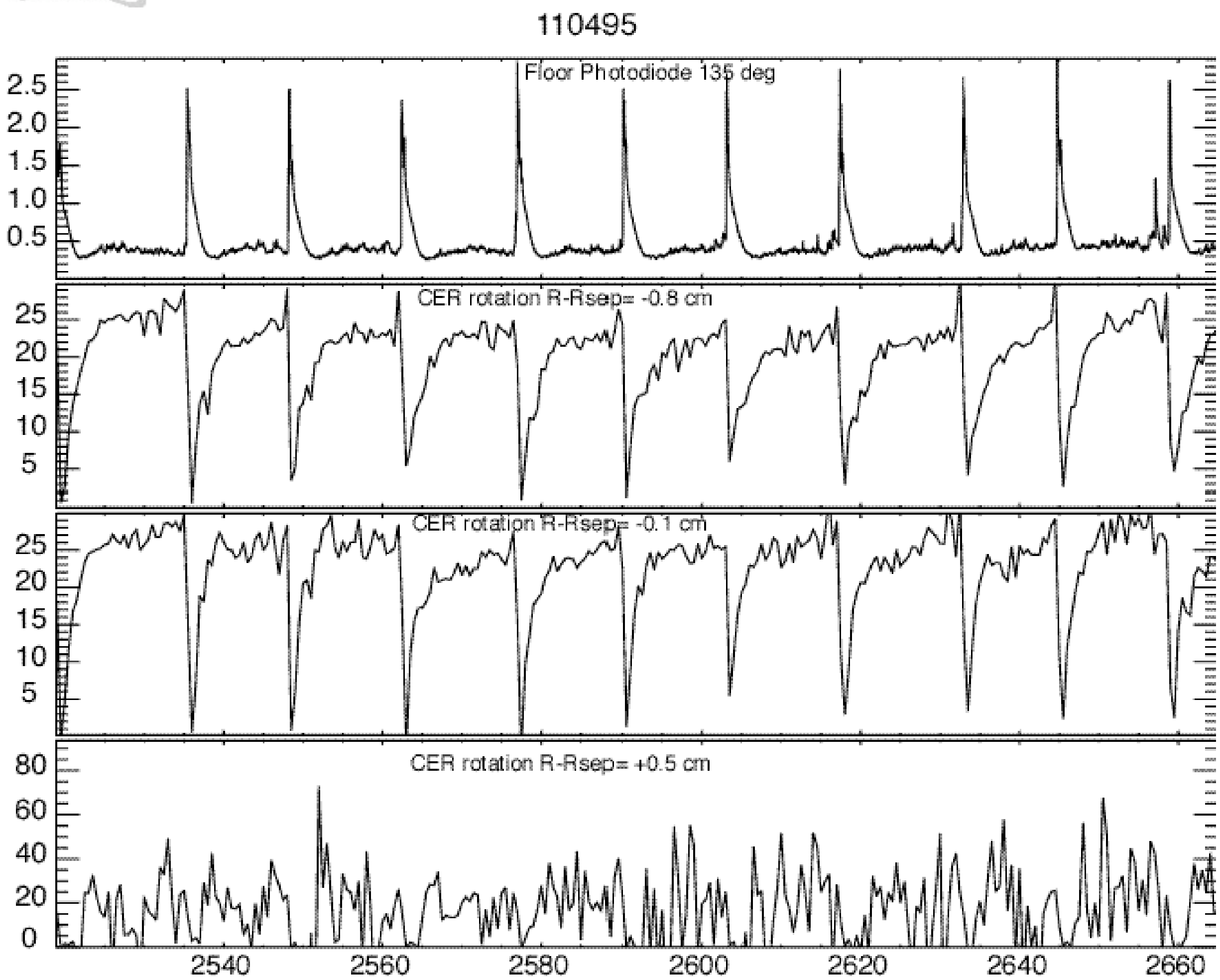
Push some more $V_{ELM} = L \times \partial r \times \partial \theta \approx \frac{2\pi R q \kappa}{2} \partial r \partial \theta$

Poloidal extent is ~1.3 - 0.4 m for m=1

| $n_e$ | $N_{tot}$ | $N_{ELM}$ | $E_{tot}$ (MJ) | $E_{ELM}$ (MJ) | $V_{ELM}$ ($m^{-3}$) | $V_{ELM}$ ($m^{-3}$) MP |
|---|---|---|---|---|---|---|
| 5.0E13 | 9.1E20 | 1.25E19 | 0.9 | 0.04 | 21 | 3.5 |
| 8.5E13 | 1.6E21 | 2.1E19 | 1.0 | 0.03 | 18 | 3.0 |
| 1.0E14 | 1.8E21 | 2.5E19 | 1.0 | 0.03 | 7.2 | 1.2 |

*G. Porter LLNL, A. Leonard, GA*

# *Edge CER Shows Momentum Loss During ELMs*

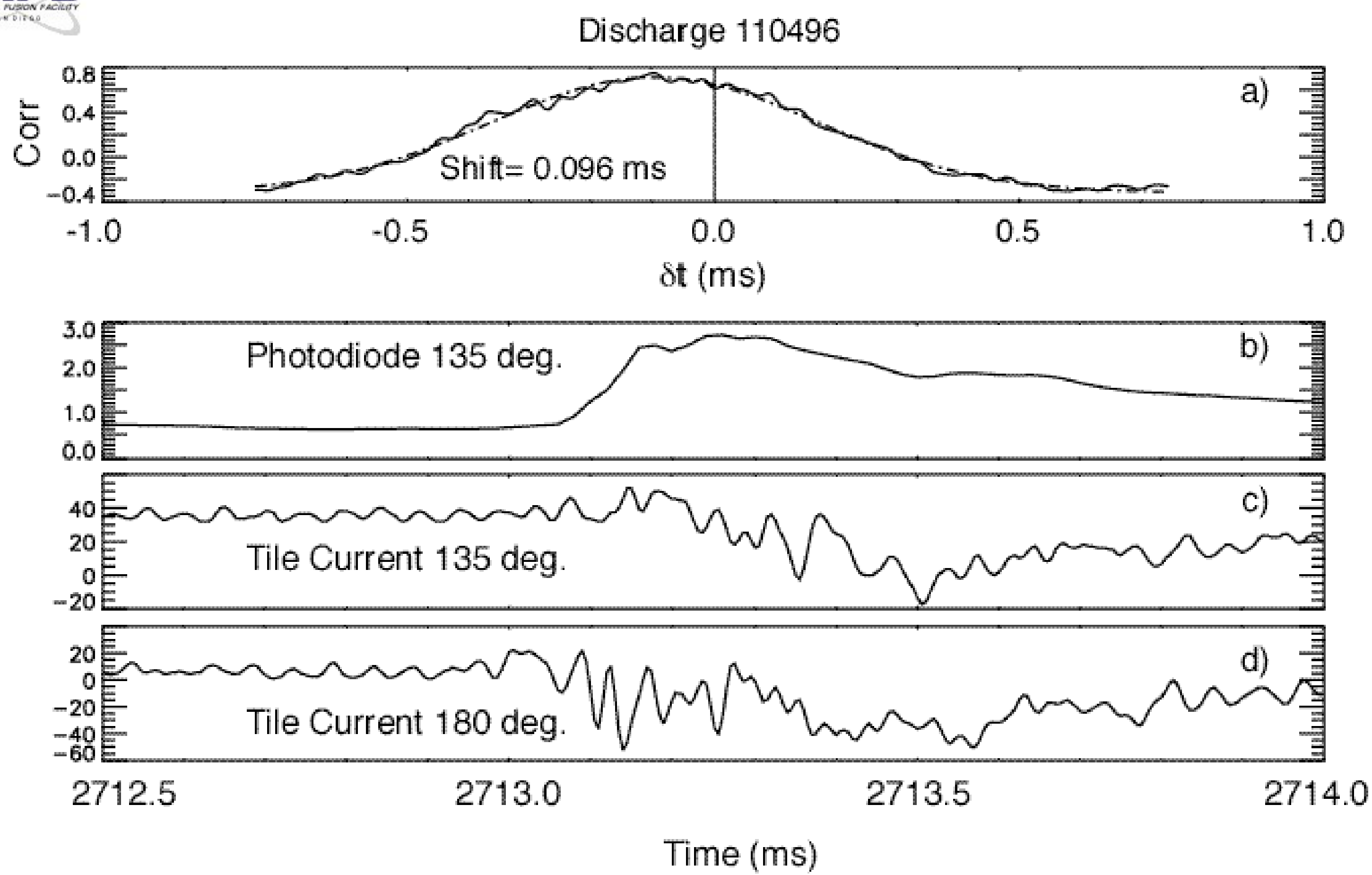



Does the ELM plasma carry that momentum into the SOL?

Edge plasma locks during ELMs

***R. Groebner, K. Burrell GA***

# *Tile Array Data Supports Rotation*



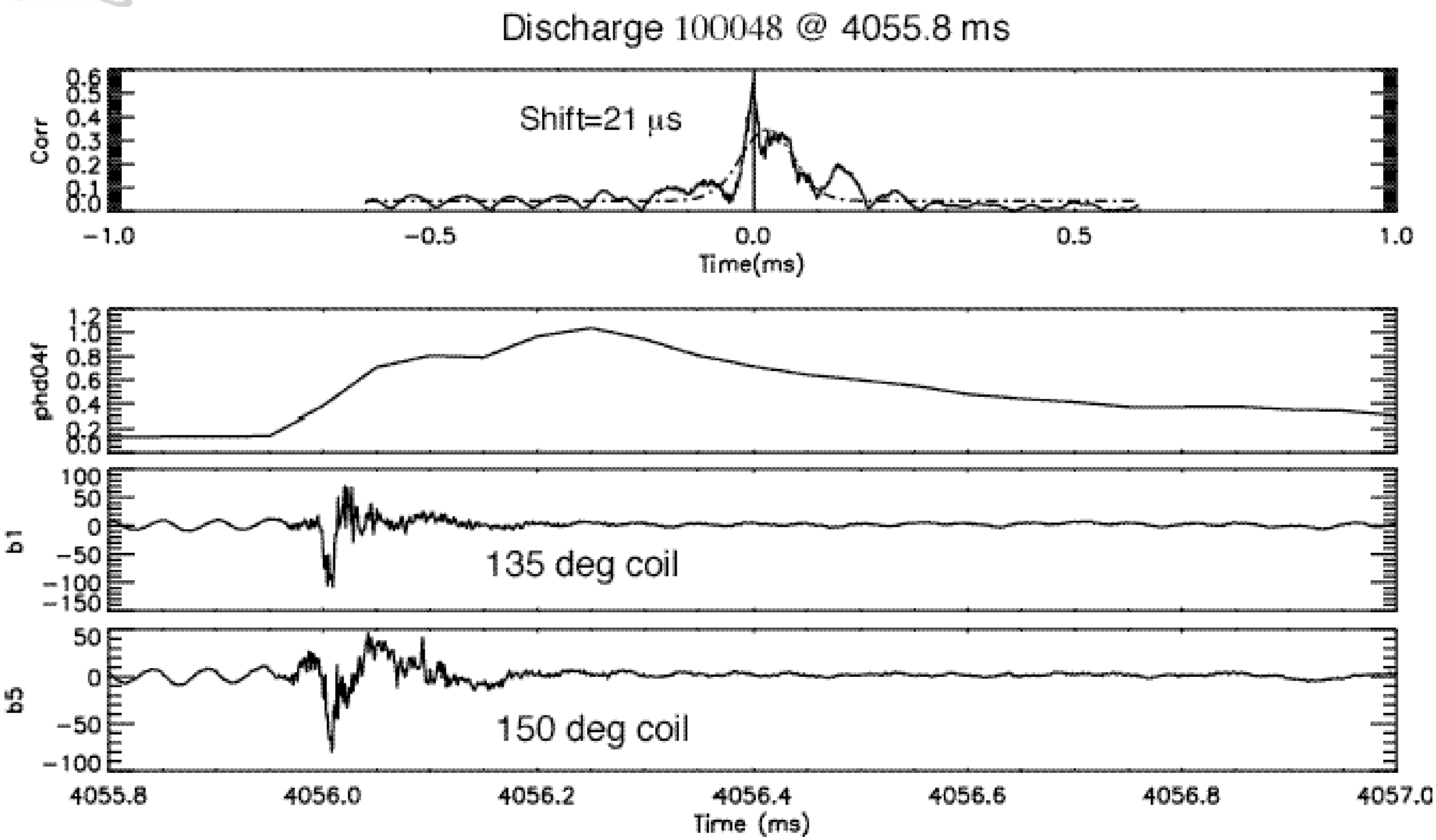

Same shot family

Tiles 45 deg apart at R=1.65 m

Inferred rotation ~ 14 km/s

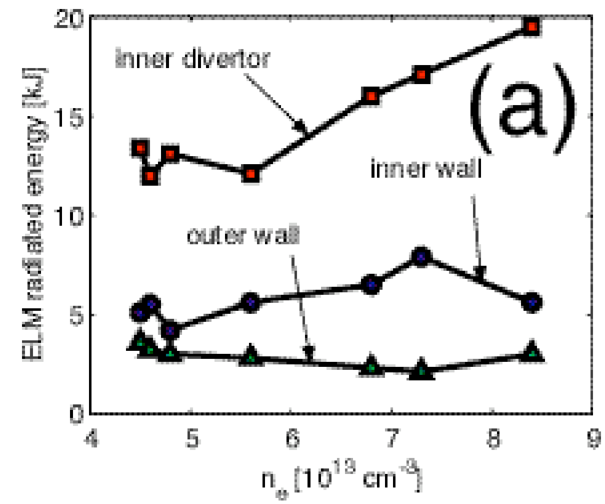
CER LCFS rotation is 22 km/s

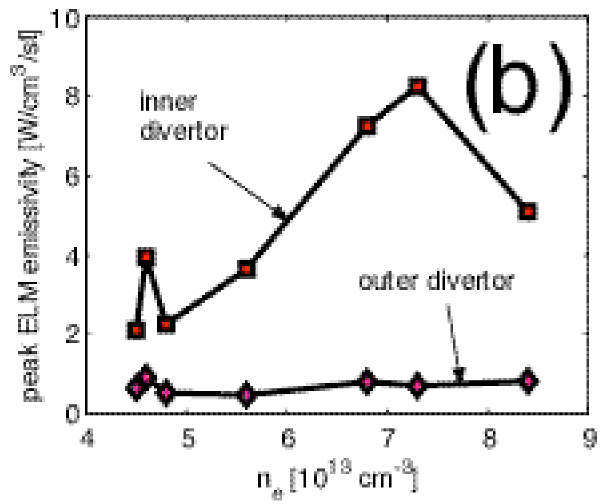
# *B-dot Coil Signals Also Delayed*

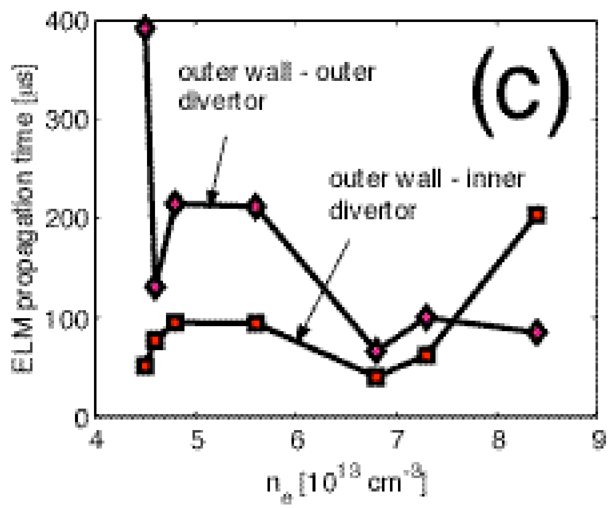



Different shot family and larger ELMs
Inferred rotation ~ 28 km/s

# *Density Scan: Inner divertor always radiates more*



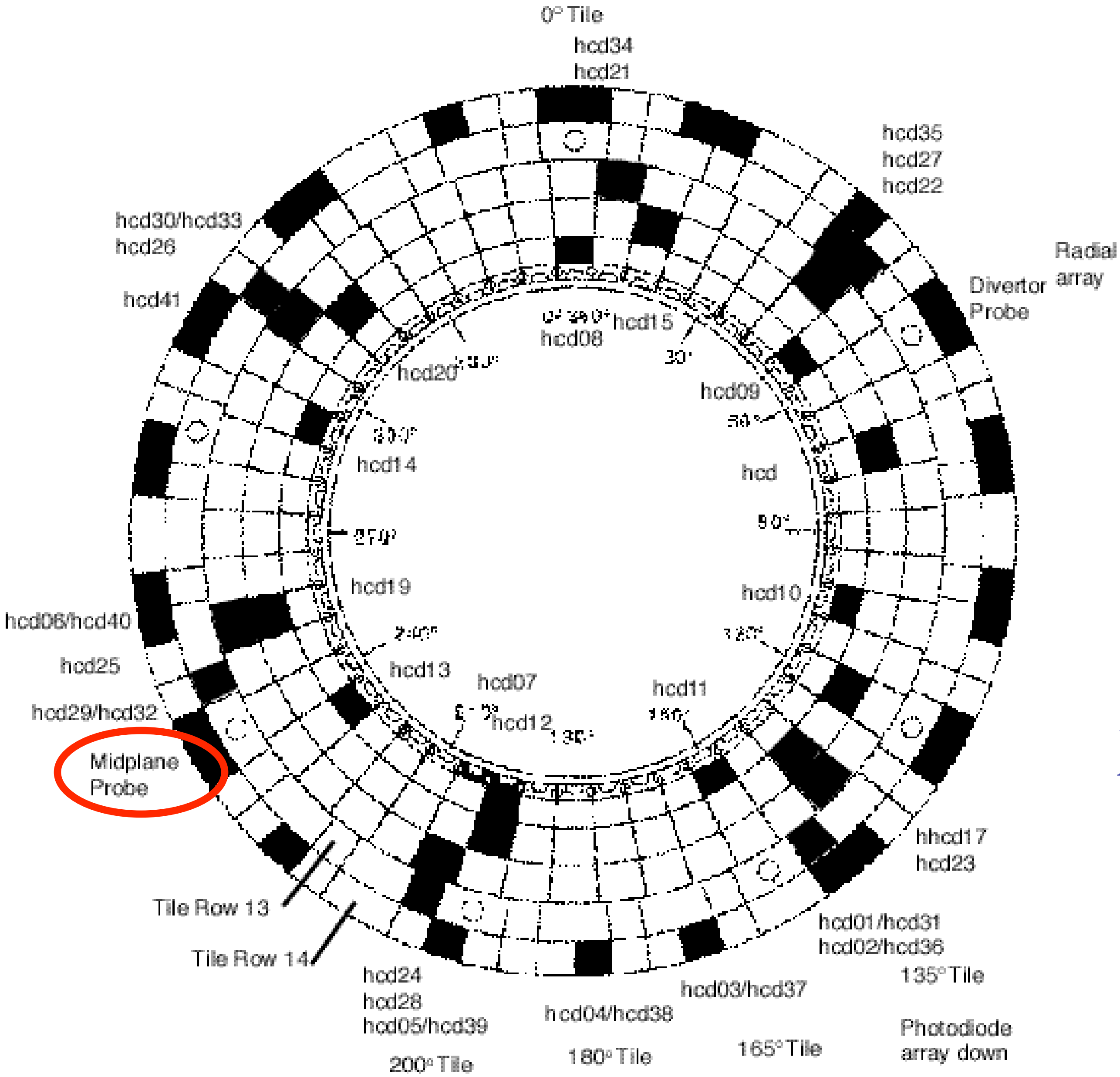

ELM radiated energy, peak emissivity and propagation time for different regions as a function of plasma density

LCFS- OD delay is larger than LCFS-ID delay ??



*E. Hollmann, D. Gray, UCSD*

# *Diagnostics Spread Toroidally and Poloidally*

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