Effect of B-field Dependent Particle Drifts on ELM Behavior in the DIII-D Boundary Plasma,*

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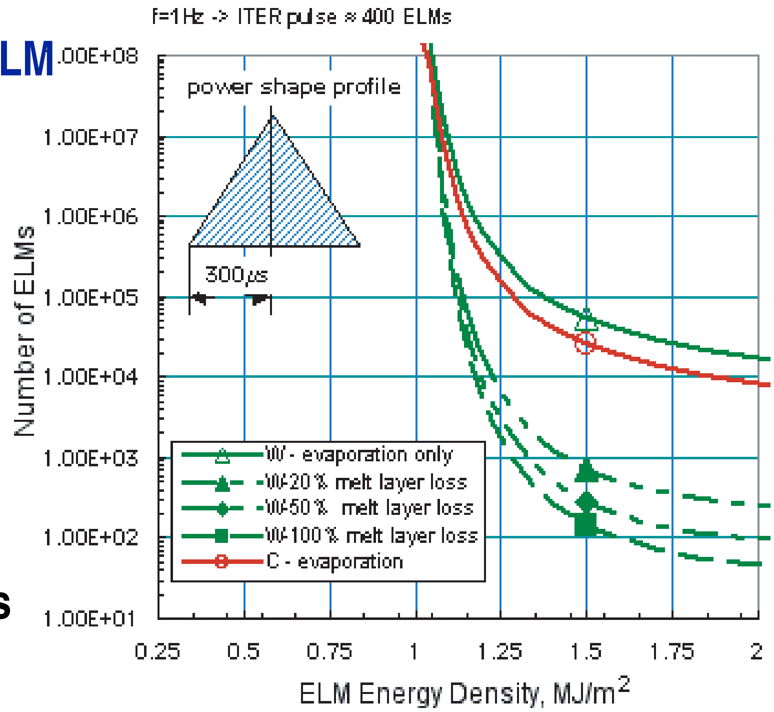
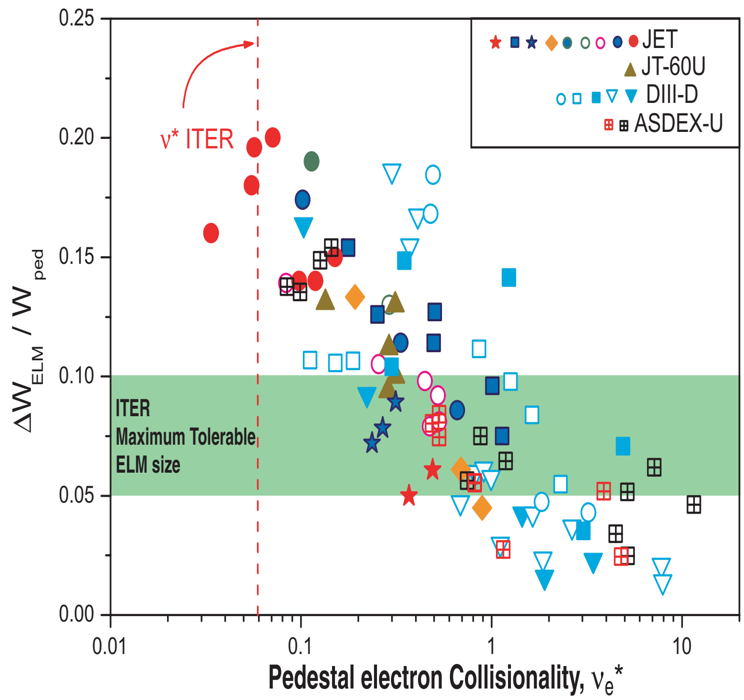
Motivation - Type I ELMs could limit PFC life-time in burning plasma tokamaks - “Minimum Energy” ELMs at high n_e might be tolerable

- To design future PFCs requires knowledge of ELM energy, spatial profile on surfaces and deposition time.
  - Pedestal stability-key to reducing ELM sources
  - SOL and divertor effects-key to reducing ELM fluxes on PFCs



- ELMs behavior in the boundary very different at low and high n_e
  - Midplane pedestal perturbation different
  - Difference in divertor plasma response complex because pre-ELM divertor conditions strong function of density



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Summary I: SOL / divertor response to ELMs is a strong function of n_e for LSN $\nabla B \downarrow$

- ELM expelled pedestal particles appear far out (~ 4 cm) in SOL; T_e^{SOL} not perturbed even with ΔT_e^{ped} at low n_e.
- Pedestal refueled by multi-step charge exchange neutrals; fast response consistent with local neutral source during ELM (main chamber surfaces)
- At low n_e: inner leg burns-through during ELM; large heat flux observed
- At high n_e: outer leg during ELM:
  - Carbon radiation burns-through to near target
  - Large particle flux increase
  - Target electron density and D_α drop
  - No heat flux observed
- Rapid rise in midplane and divertor D_α, and target j_{sat} at thermal energy loss
- SOL parallel pulse propagation times consistent with ion sound speeds at moderate - high density
  - Inner D_α delayed ~ 250 μsec after outer D_α
  - Midplane to divertor radiation pulse propagation times ~ 100 μsec

Summary II: SOL / divertor response to ELMs is a strong function of B_T direction

- D_α and P_{rad} Timing during ELMs:
  - LSN ∇B ↓ :
    - Low n_e: Delay of inner vs. outer divertor D_α reduced below ion convection times in SOL, P_{rad} delay negative (inner occurs before outer)
    - High n_e: Delays consistent with ion convection timescale
  - LSN ∇B ↑ :
    - High and low n_e: Delay below ion convection timescale
- Heat Flux during ELMs:
  - LSN ∇B ↓ High δ : Peak inner / outer heat flux asymmetry $\leq$ 2x at low n_e, even larger at high n_e
    - Outer ELM peak heat flux reduced with n_e
  - LSN ∇B ↓ Low δ : Peak inner / outer heat flux asymmetry ~2x at low n_e, drops to ~1.5 at high n_e
  - LSN ∇B ↑ Low δ : Peak inner / outer ratio ~ 2 independent of density
  - Surface layer effects may play a role in measurement

Summary III: Initial UEDGE ELM modeling with drifts shows features of B_T dependence

- Model assumptions guided by measurements
  - Midplane instability and particle loss appear for 200-500 μsec before pedestal thermal energy loss

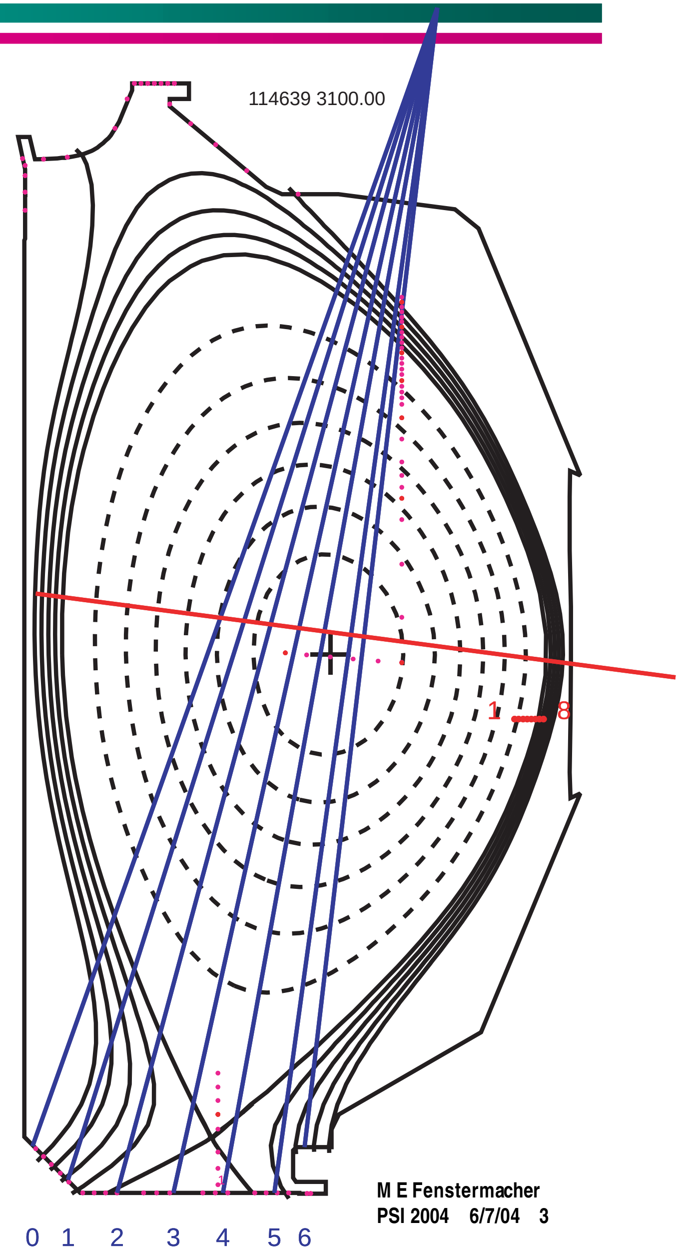
- Model Verification and Fluid Simulations
  - ELM energy transport by parallel ion convection at ion sound speeds verified by measurements
  - Initial UEDGE simulations show characteristics of ELM propagation at ion sound speed
    - Delays of inner D_α from outer D_α timing
    - Slower D_α rise time in inner vs outer divertor

- Some of B_T dependence consistent with each of two models:
  - Changing ExB produces vastly different pre-ELM divertor conditions ==> ELM response is different even though ExB and other particle drifts not playing a role during ELM event
  - ExB particle drift play a strong role during ELM due to large Te gradients (E-field) created by ELM purturbation

Configuration and Diagnostics

DIII-D fast diagnostics used in this poster cover both the outer midplane and lower divertor

Parameter	Fast Diagnostic	Rate / Integration time
SOL ne, Te profiles	Reciprocating probe	≤ 1000 kHz
Pedestal ne, Te	Thomson scattering	1 ns @ 6 ms
Midplane D_α	Filterscopes array	≤ 100 kHz
Midplane inner SOL line radiation	Gated, intensified camera	20 us @ 17 ms
n_e^{ped} gradient	Reflectometry	≤ 10 kHz
Total radiated power	Bolometer array	≤ 500 kHz
Divertor line radiation	Gated, intensified camera	20 us @ 17 ms
Target heat flux	IRTV line scan	≤ 9 kHz
Target ion flux	Target probes	≤ 100 kHz
Toroidal target current	Tile current array	≤ 200 kHz
Calibrated divertor line radiation	Filterscopes array	≤ 100 kHz
Divertor line density	Interferometer	≤ 50 kHz
Edge ion temperature	CER	≤ 2 kHz



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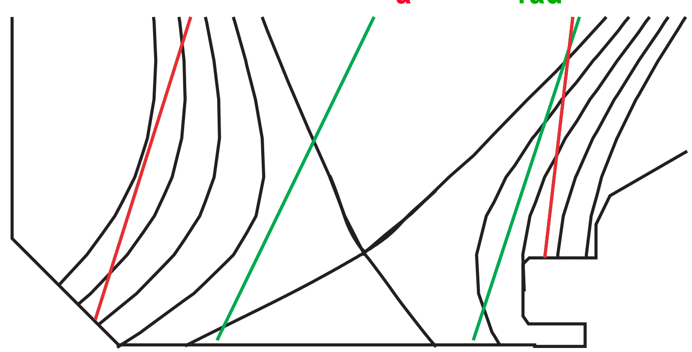
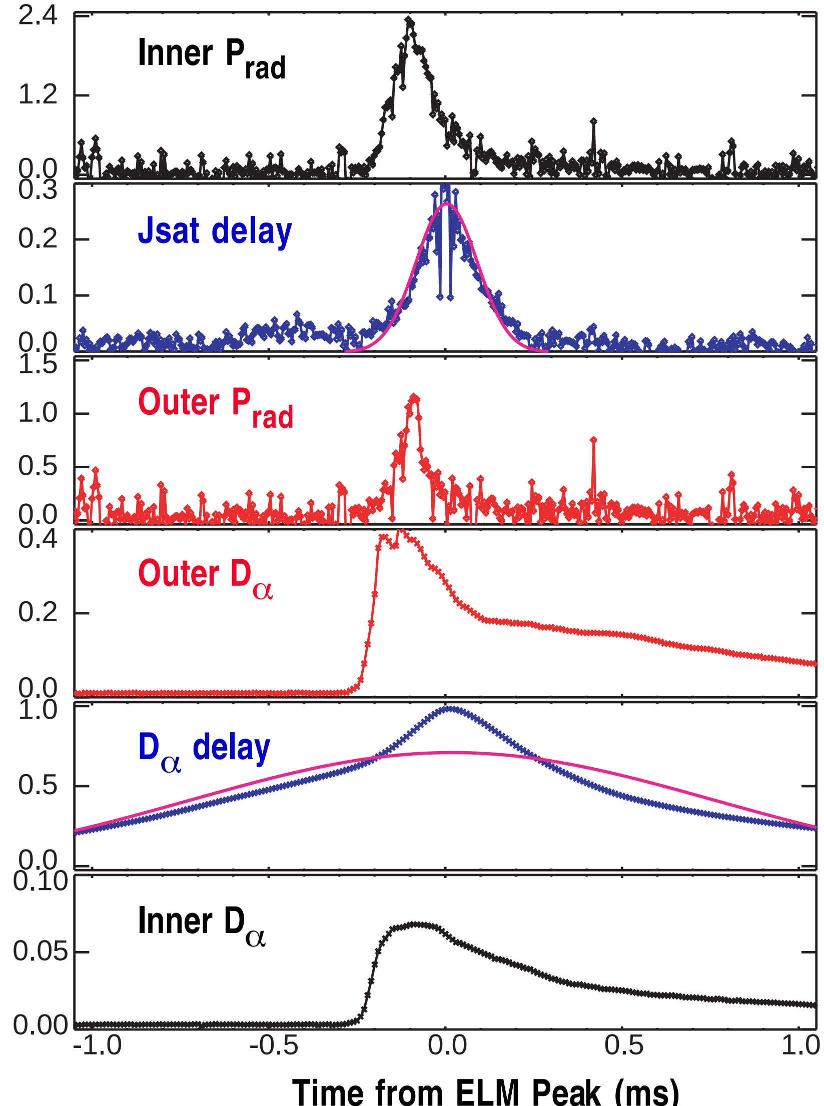
Cross correlation analysis finds delay of ELM response in one signal compared with another.

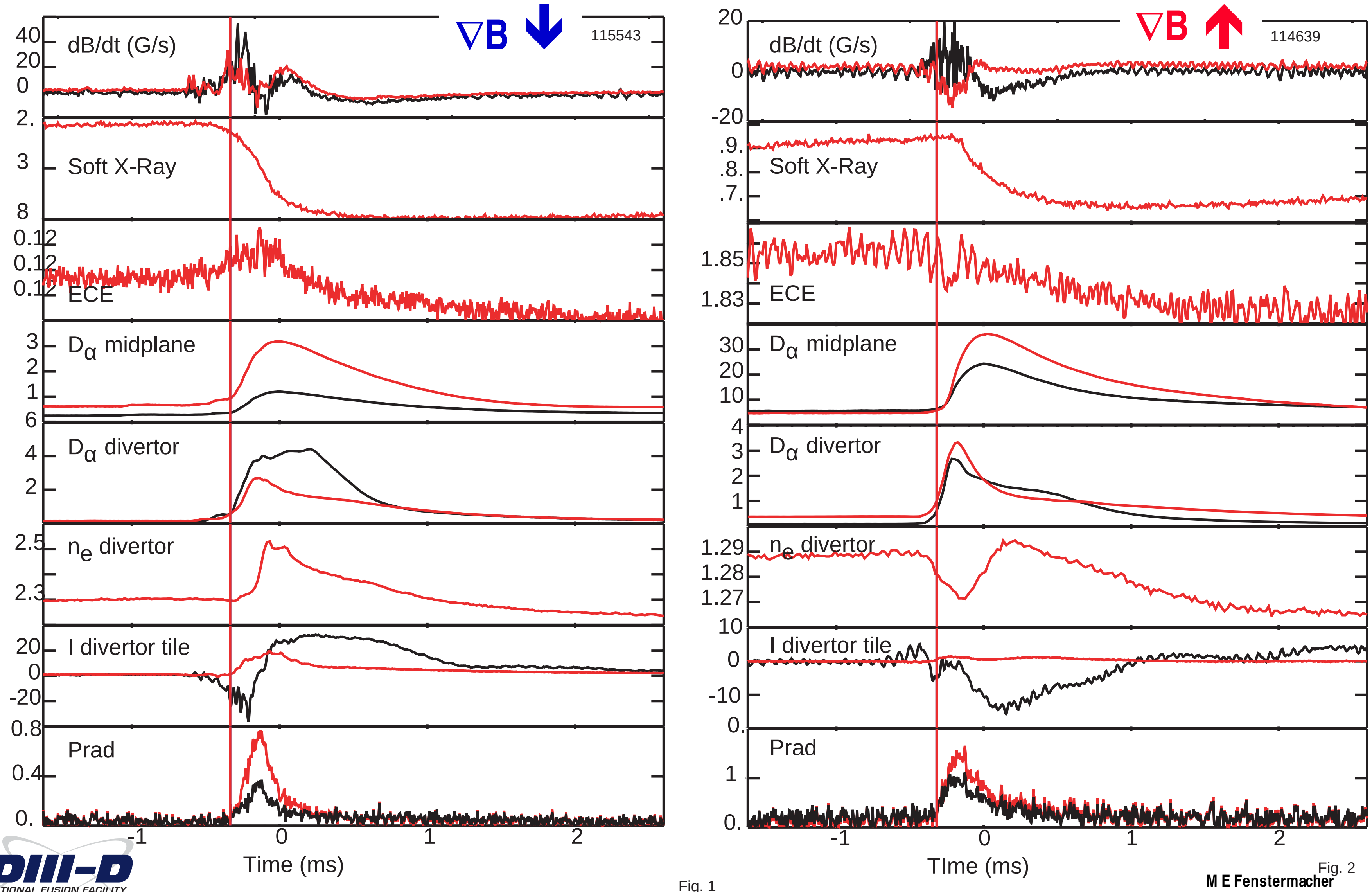
- Cross correlation of signals applied in ~ 8 ms window centered on the ELM event at midplane
- Delays of peak response dominates over delay of initial response.

Geometry of divertor D_a and P_{rad} Chords





Average ELM behavior in ∇B ↓ vs ∇B ↑ shows changes in inner vs outer asymmetry but similar timing



Background: LSN $\nabla B \downarrow$ from 2002

Conclusions: Model of SOL ELM propagation by ion convection supported by some, but not all, of the ELM data

- **Model says:**
  - Deposition profile should be set by perpendicular vs. parallel transport in SOL
  - Deposition time set by $L_{||} / C_s$ for ELM expelled ions
  - ELM energy may be limited if ELM duration < ion transit time to targets
- **Model supported by data:**
  - Density dependence of inner vs. outer target delays
  - ΔT_e^{ped} delay until $\Delta t_{ELM} \sim L_{||} / C_s$
  - Divertor density rise higher than n_e^{ped} due to release of trapped neutrals
- **Model not supported by data:**
  - Some inner vs. outer SOL delays backwards (eg. P_{rad}, J_{sat})
  - Outer target heat flux width not wide enough to be consistent with observed midplane density perturbation in the far SOL, even narrower on the inside
  - Fast T_e^{ped} drop in low density case - more like reconnection
- **Comparison of ELM propagation with ion Bx∇B drift into vs. out of divertor should increase understanding of ELM propagation physics.**

Backup Slides

DIII-D fast diagnostics used in this poster cover both the outer midplane and lower divertor

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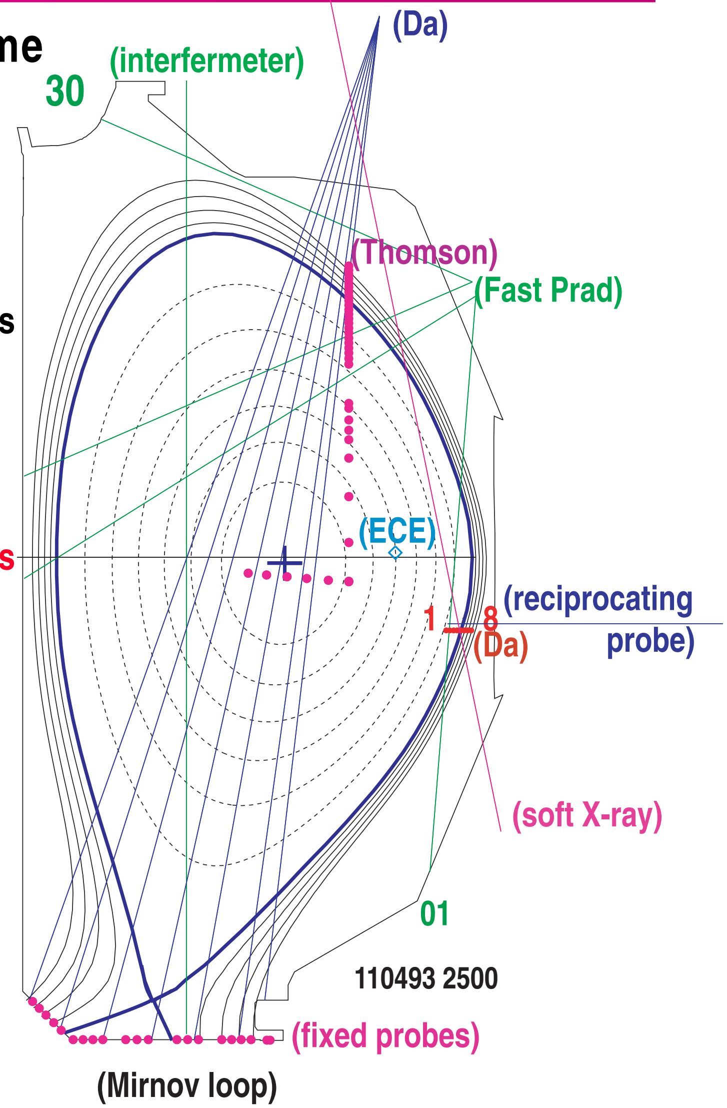

Simple model of ELM particle and energy transport in the SOL and divertor supported by calculation results*

- Instability flattens density and temperature profiles (electrons and ions) at the outer midplane separatrix
- Fast electrons on field lines connected to targets go to targets in electron transit time (~ several μsec)
  - Sheath potential raised and electron conduction gets cut-off
  - T_e in SOL equilibrated somewhat
- Local ions in sheath strike target at high energy - take out some fraction of ELM electron energy (~ 10 μsec)
- ELM expelled ions transit to elevated sheath at ion sound speed (T_i^{ped}) ~ several 100 μsec
  - ELM ions falling through sheath remove ELM electron and ion energy
- Neutrals from increased recycling of ELM ions dissipate in recycling time scale (~ several ms).

* A. Bergmann 2002 submitted to NF
D. Tskhakaya PSI02 submitted to JNM
T. Rognlien PSI02 submitted to JNM

Complicating effects may be important in SOL / divertor ELM transport

- More ELM electron energy may get to targets on short time scale if:
  - Secondary electron emission at targets reduces sheath build-up
  - High energy ions striking targets liberate trapped neutrals increasing local ion source
- Perpendicular transport in upper SOL may reduce ions available to carry ELM energy to targets
- Impurity release by fast ion physical sputtering on targets produces radiation
- Loss of pedestal thermal energy (ΔT_e^{ped}) may require instability duration > ion transit time to targets
  - ΔT_e^{ped} may not occur until instability has been growing for an ion transit time
  - If ion transit time is long, ΔT_e^{ped} may not occur at all

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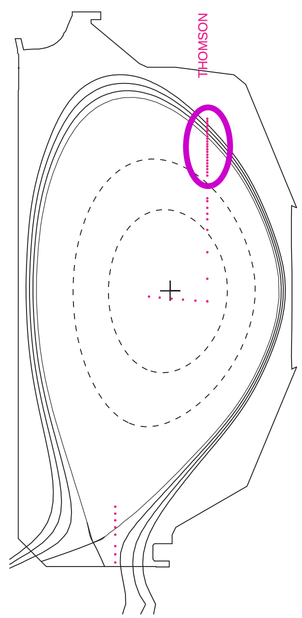
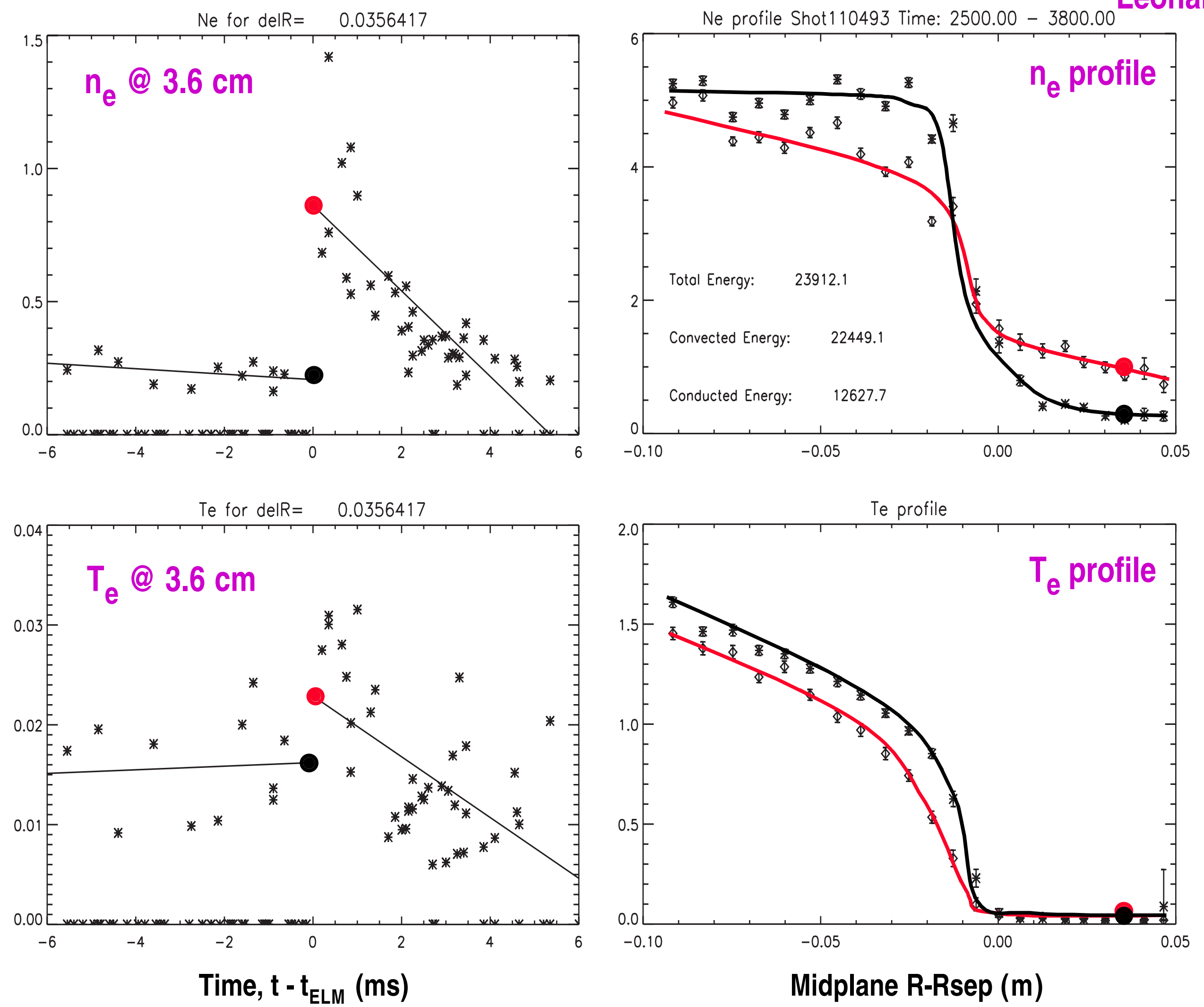
Low n_e ELMs: Thomson profiles show particles lost from pedestal appear in the far SOL; pedestal ΔT_e not seen in SOL

Leonard

- Linear extrapolation to ELM time may underestimate perturbation in the SOL





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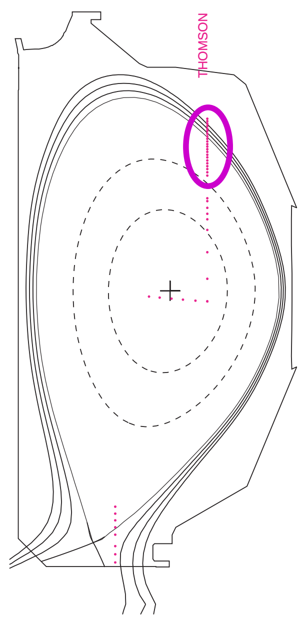
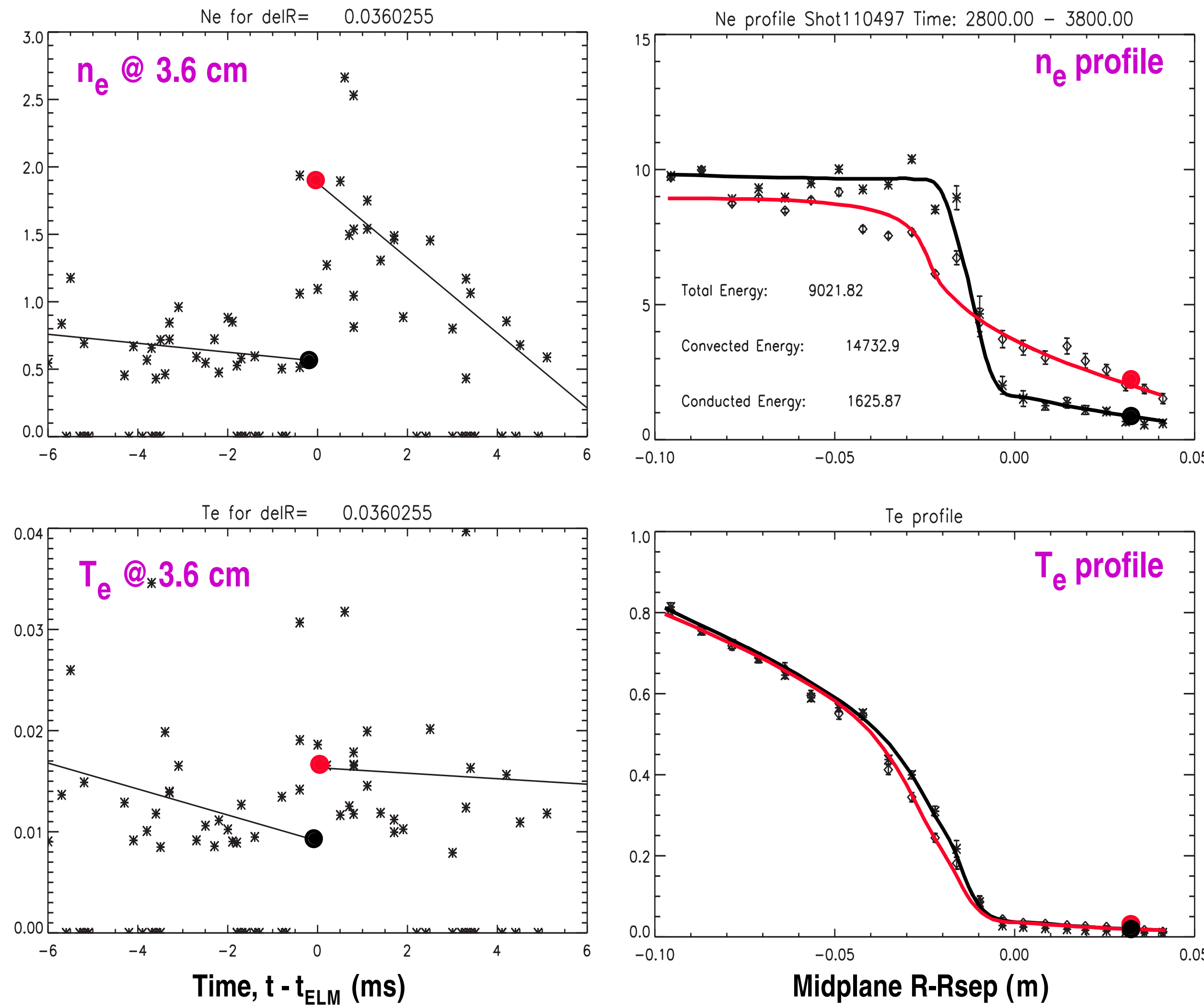
High n_e ELMs: Particles seen far out in SOL at midplane; pedestal ΔT_e very small

Leonard

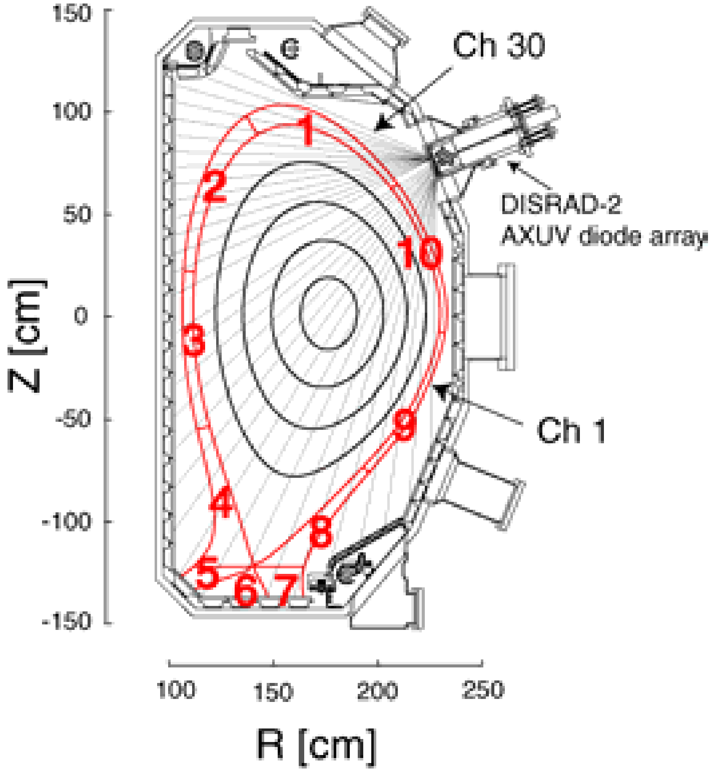
- Greater scatter in high ne data - higher SOL turbulence levels

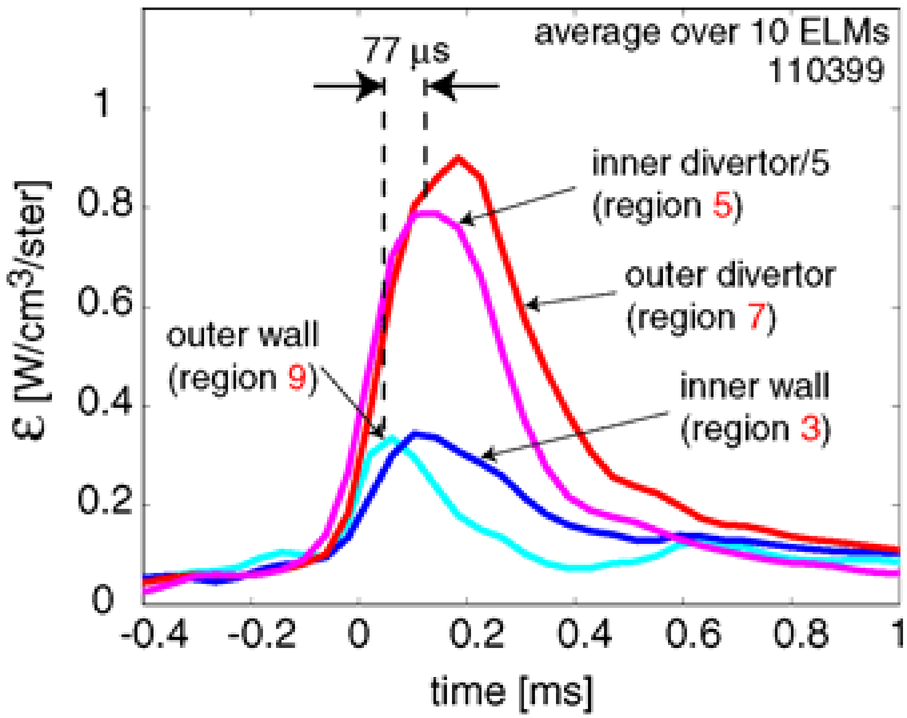




Low n_e ELMs: fast bolometer chords show propagation of pulse around SOL to divertors

E. Hollmann

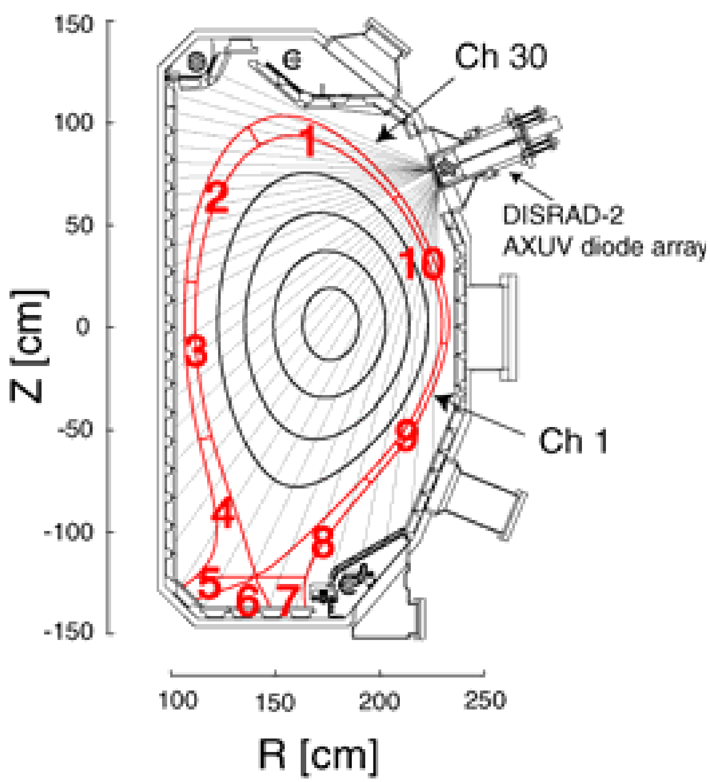


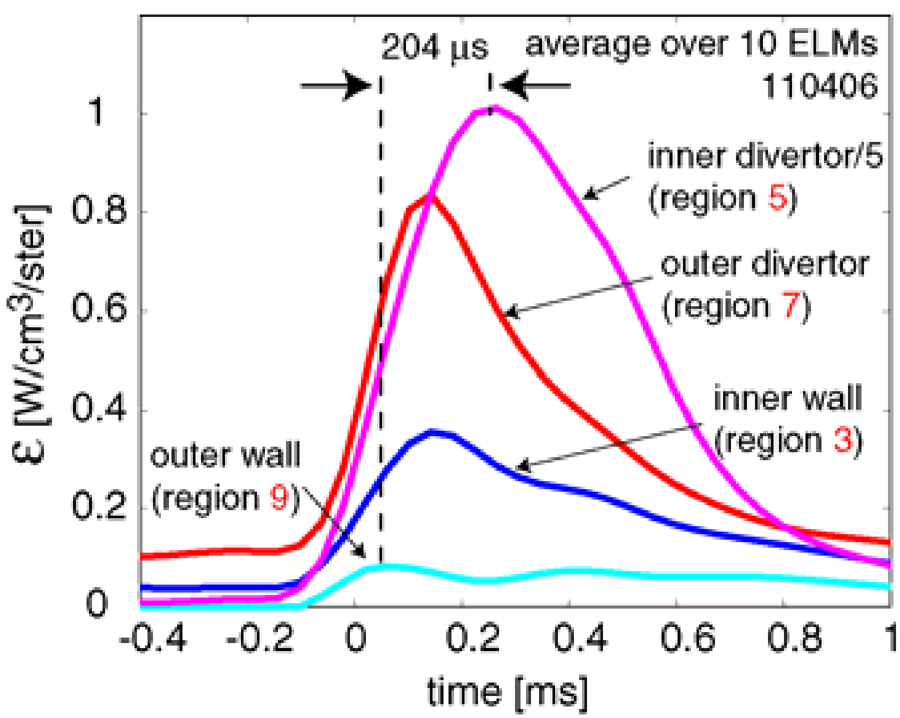


- **Delays are consistent with ion transit time (outer midplane to inner strike point ~ 100 µs) not electron conduction time.**

High n_e ELMs: Fast bolometer chords show propagation of pulse around SOL to divertors

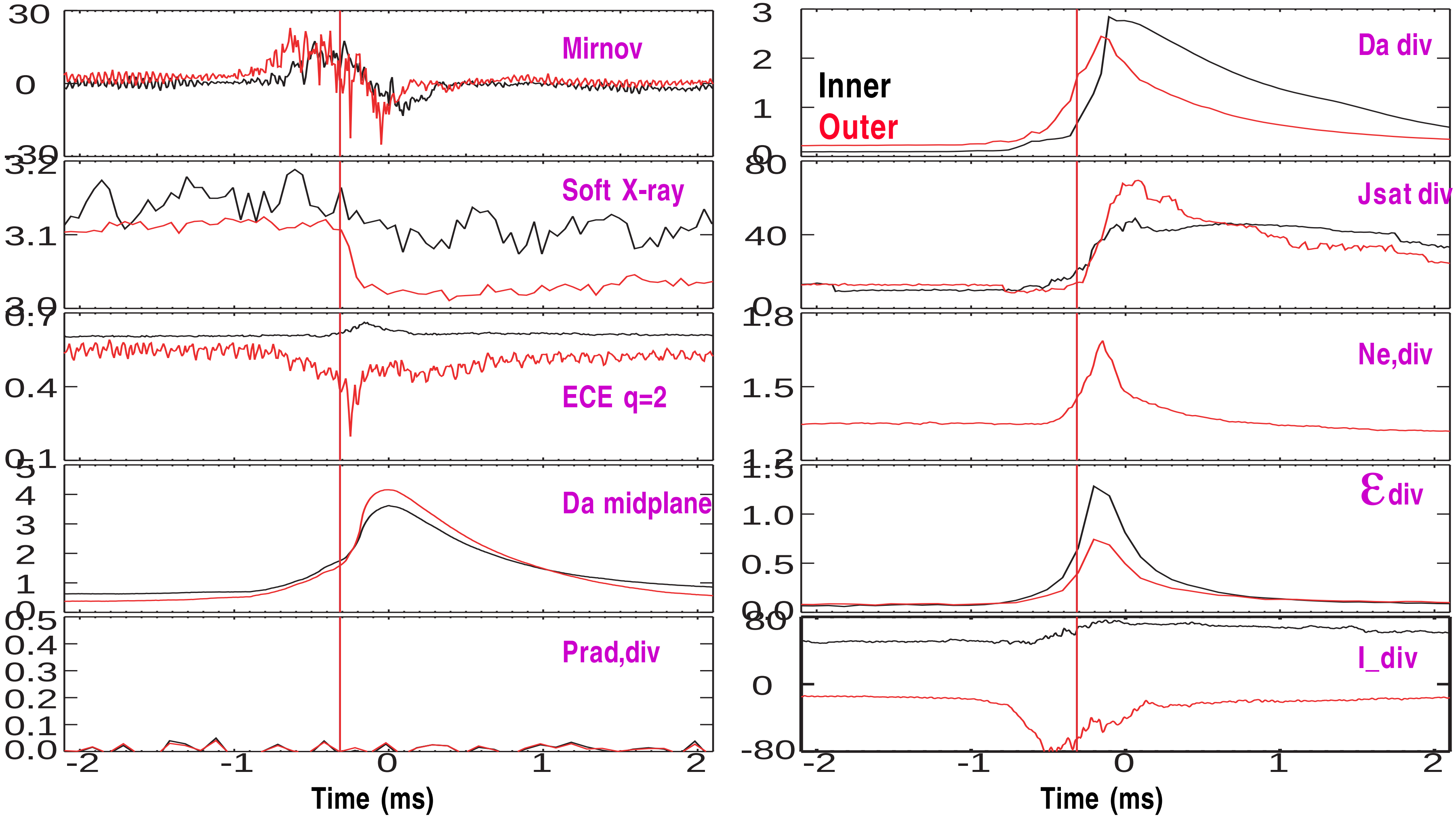
E. Hollmann





- Delays are consistent with ion transit time (outer midplane to inner strike point ~ 100 µs) not electron conduction time.

Low n_e ELMs: Multi-diag. timing shows evidence of ELM particle transport from pedestal before thermal energy loss



- Two phases to ELM build-up: particle loss followed by rapid thermal energy loss

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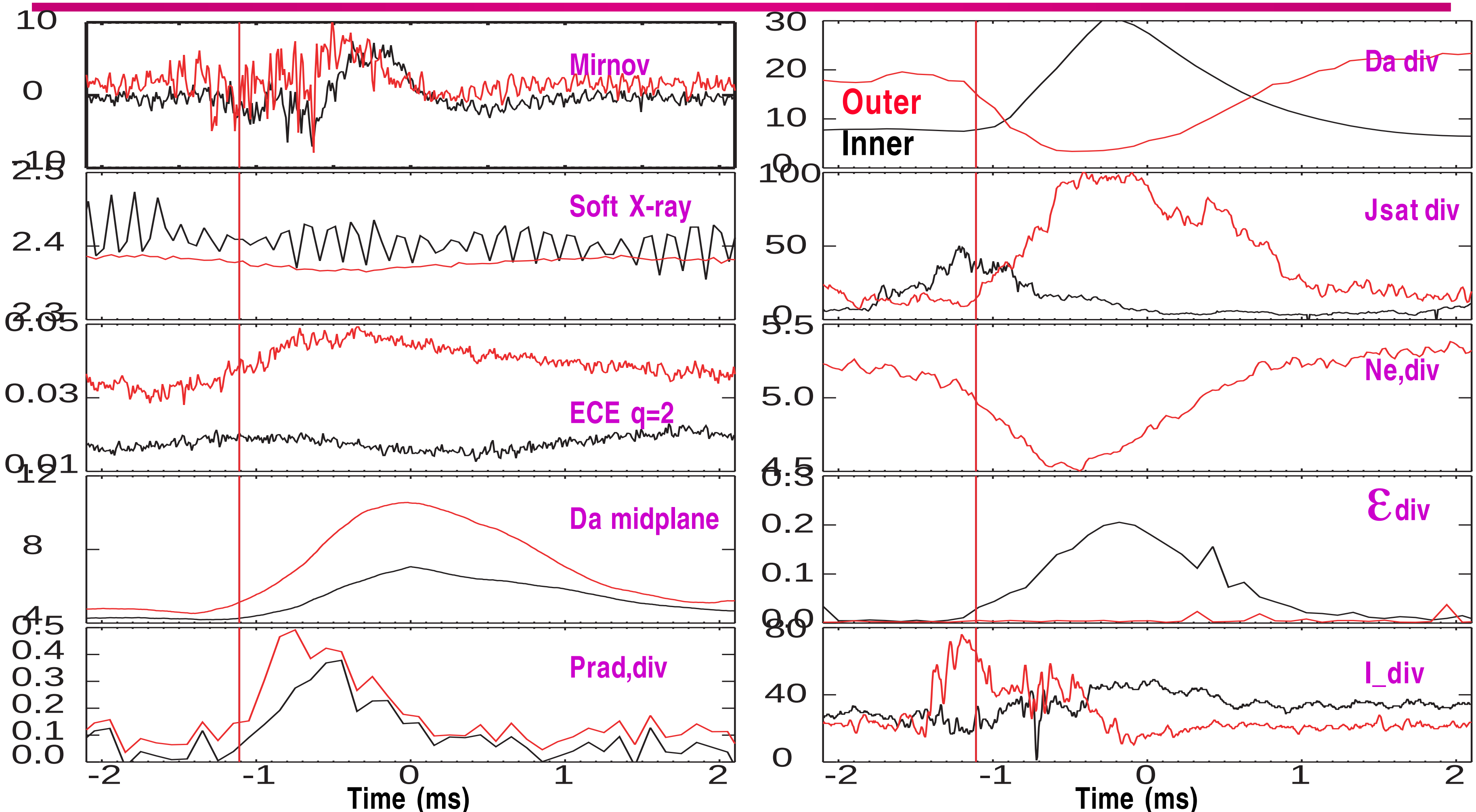
High n_e ELMs: Multi-diag. timing shows completely different behavior of outer divertor n_e and heat flux vs. low n_e ELMs



- No rapid rising phase observed consistent with lack of thermal energy loss
- No measurable outer target heat flux - still unexplained

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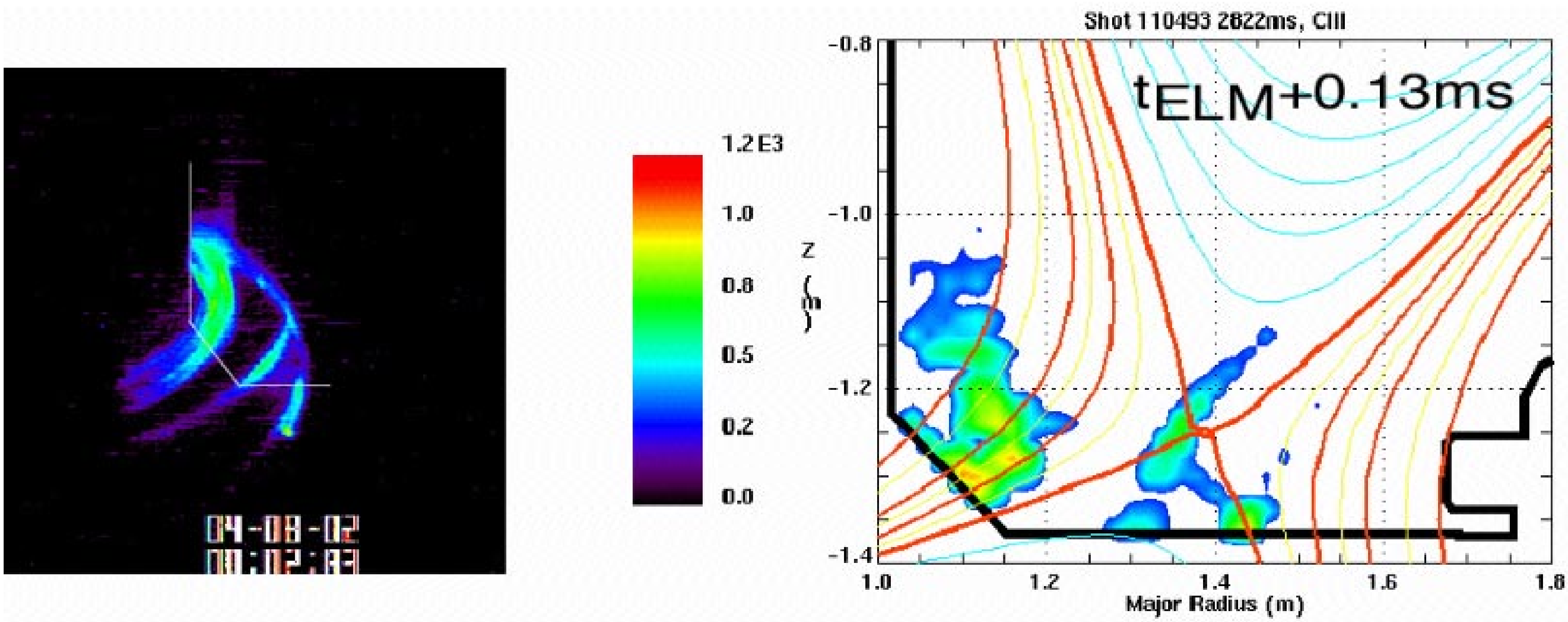
Low n_e ELMs: Gated divertor TV shows burn-through of inner divertor leg: CIII moves from X-point to inner strikepoint

Groth PSI02



- Burn-through occurs between 10 and 130 μsec after the ELM start

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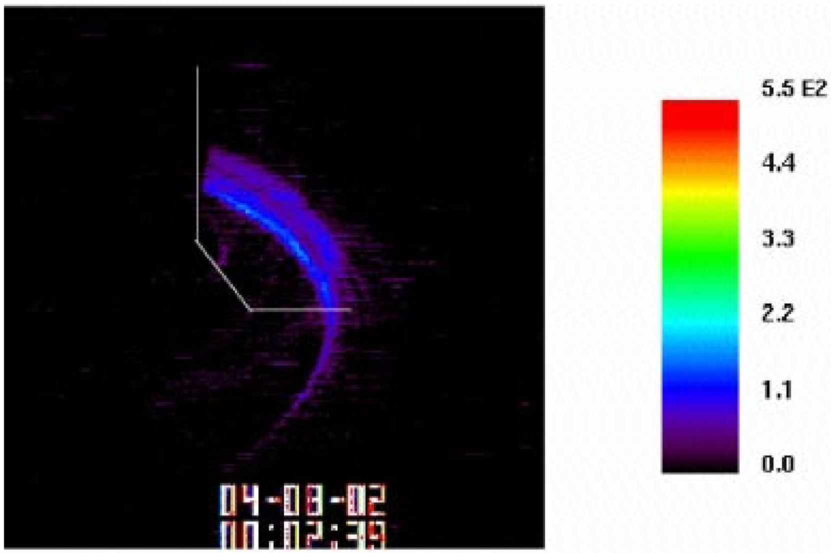
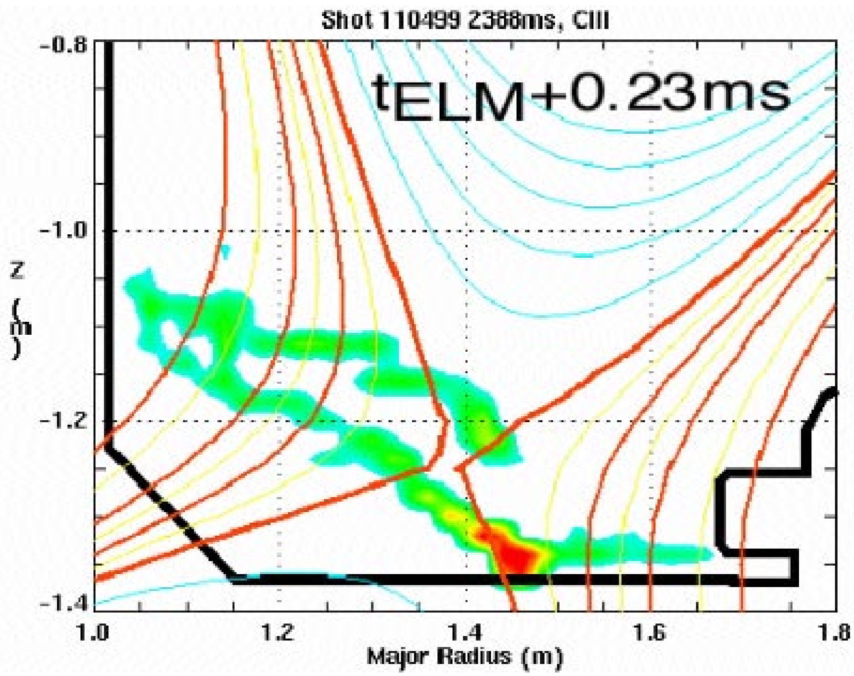
High n_e ELMs: Gated divertor TV shows burn-through of outer divertor leg: CIII moves from X-point to outer strikepoint

Groth PSI02





- Radiation increase near X-point occurs between 80 and 110 μsec after ELM start
- Burn-through occurs between 110 and 230 μsec after the ELM start

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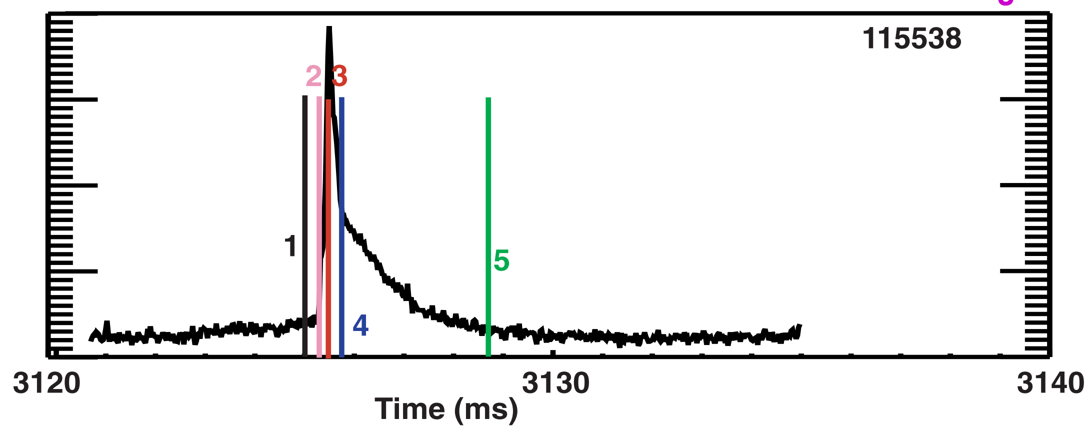
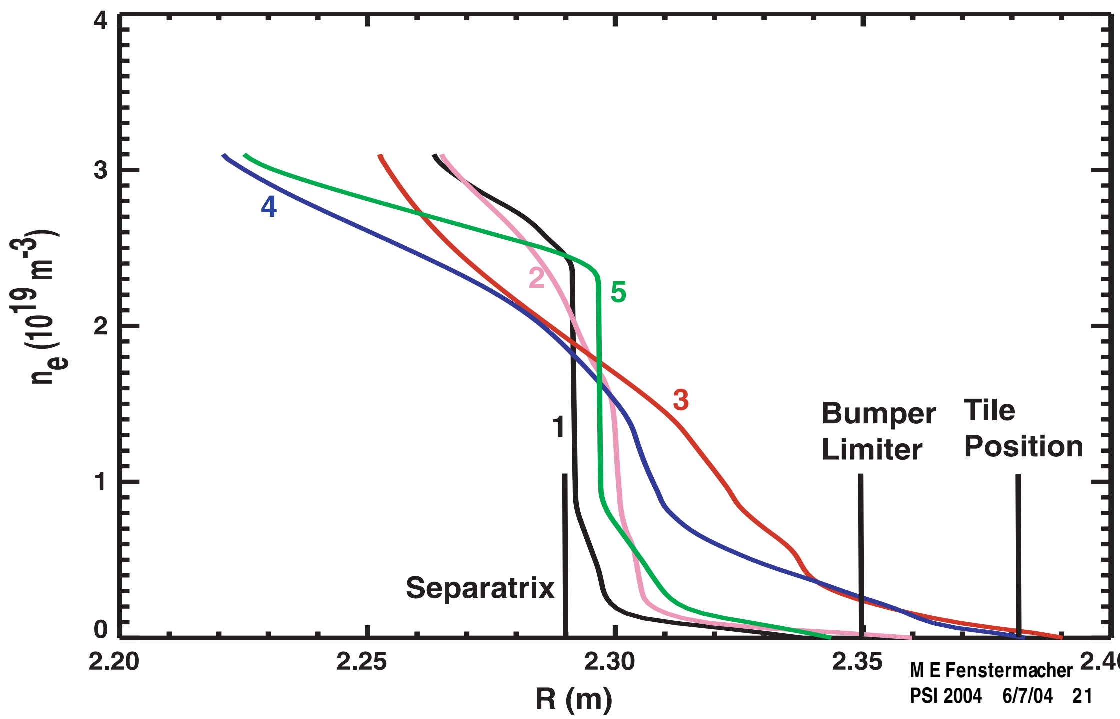
Comparison of $\nabla B \downarrow$ vs. $\nabla B \uparrow$ Effects

LSN ∇B ↓ Low δ ELMs: Particle perturbation seen much farther out in midplane SOL than ΔT_e, especially at low ne

Zeng

- Reflectometer shows reduction of pedestal density [curves 1,2,3,4]
- Density lost from pedestal appears in SOL at limiters [curves 3,4]
- Recovery of pre-ELM density profile takes ~ 3 ms [curves 4 , 5]
- During ELM $n_e \sim 10^{19} m^{-3}$ at 3.5 cm ($3\ \lambda_{ne}^{\text{pre-ELM}}$) from pre-ELM separatrix [curve 3]





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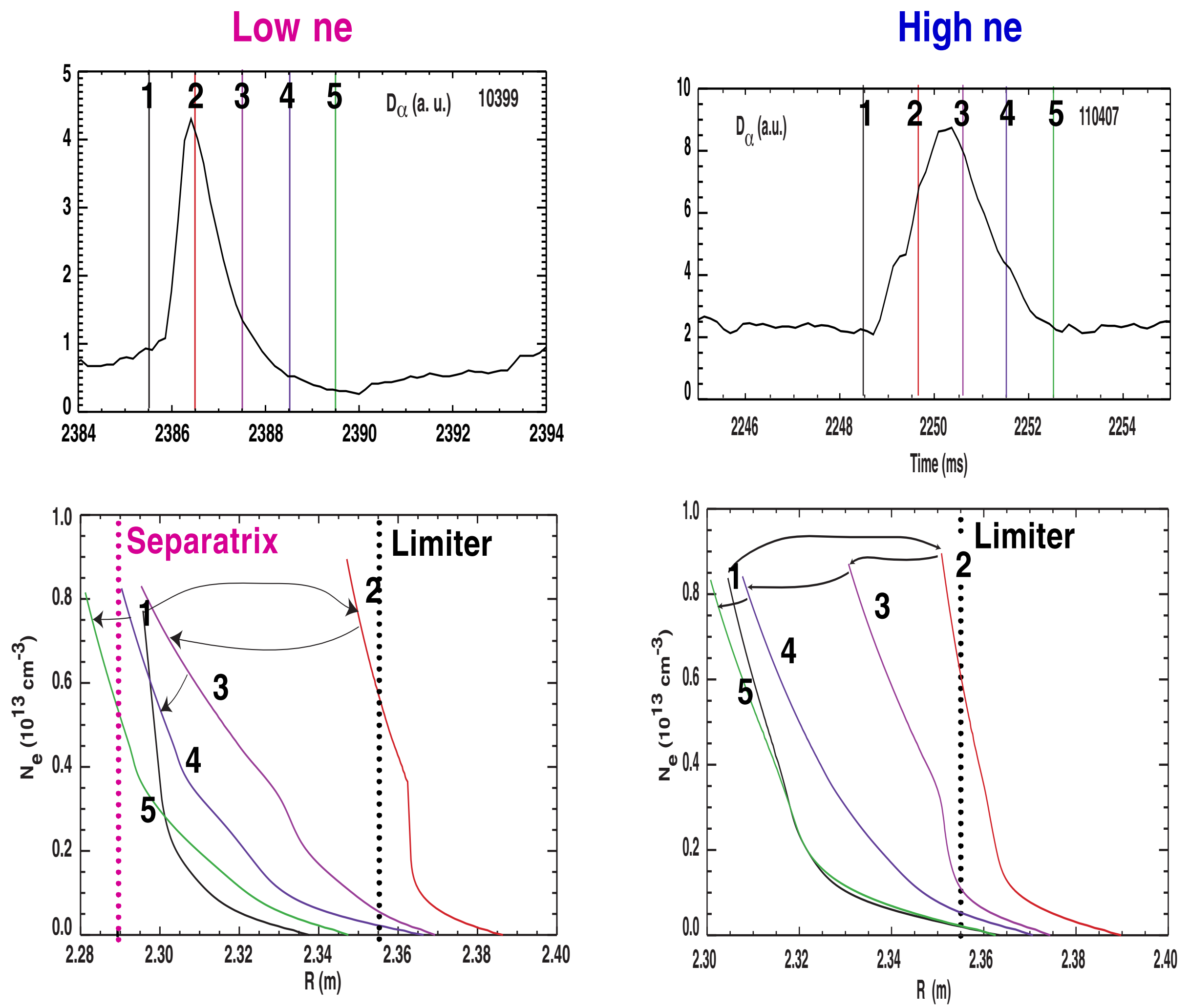
LSN ∇B ↓ High δ ELMs: Particle perturbation seen much farther out in midplane SOL than ΔTe for both low and High n_e

Zeng, Leonard

- Reflectometer shows motion of density out to the limiter region (5cm from separatrix) in ~500 μsec [curves 1 -->2]
- Recovery of pre-ELM density profile takes ~ 1.5 ms [curves 2 --> 5]



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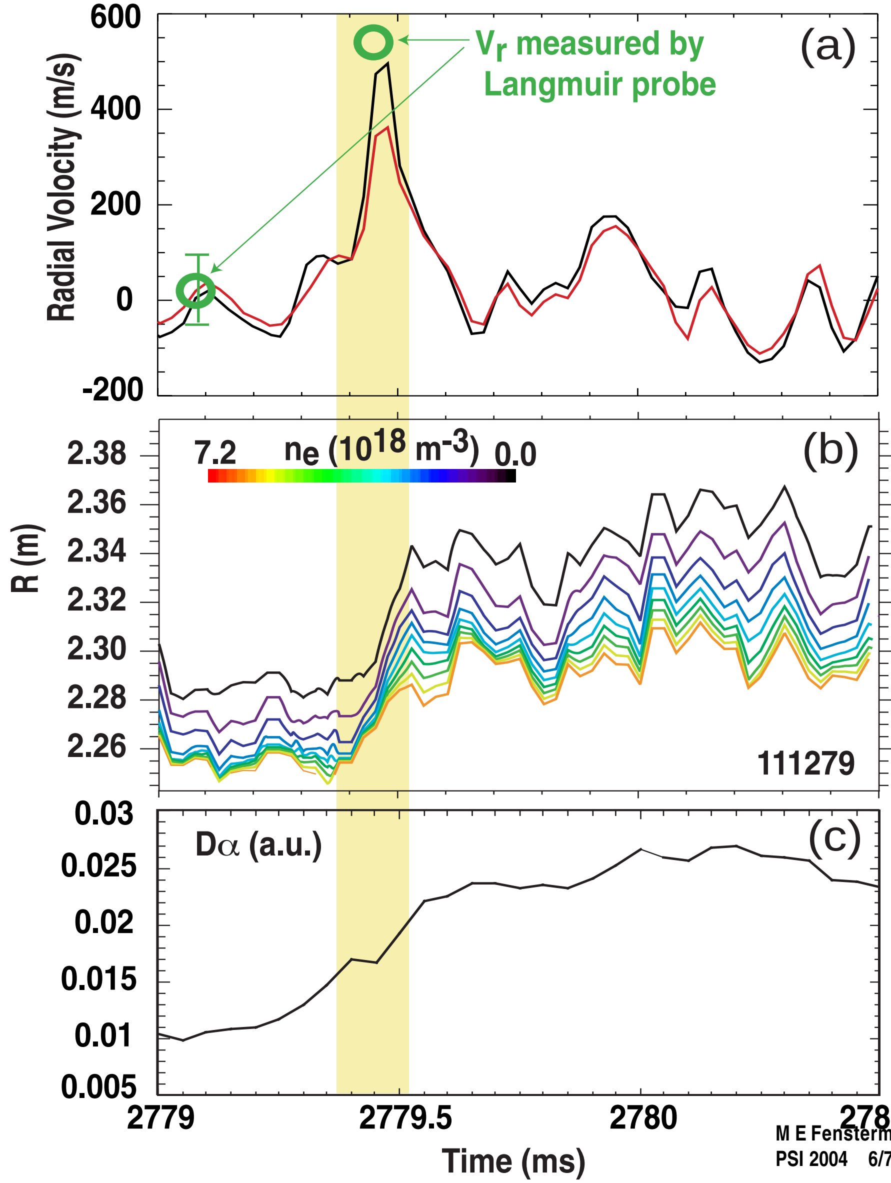
Low n_e High δ ELMs: Radial velocity ~ 600 m/s from reflectometer agrees with ExB velocity from probes

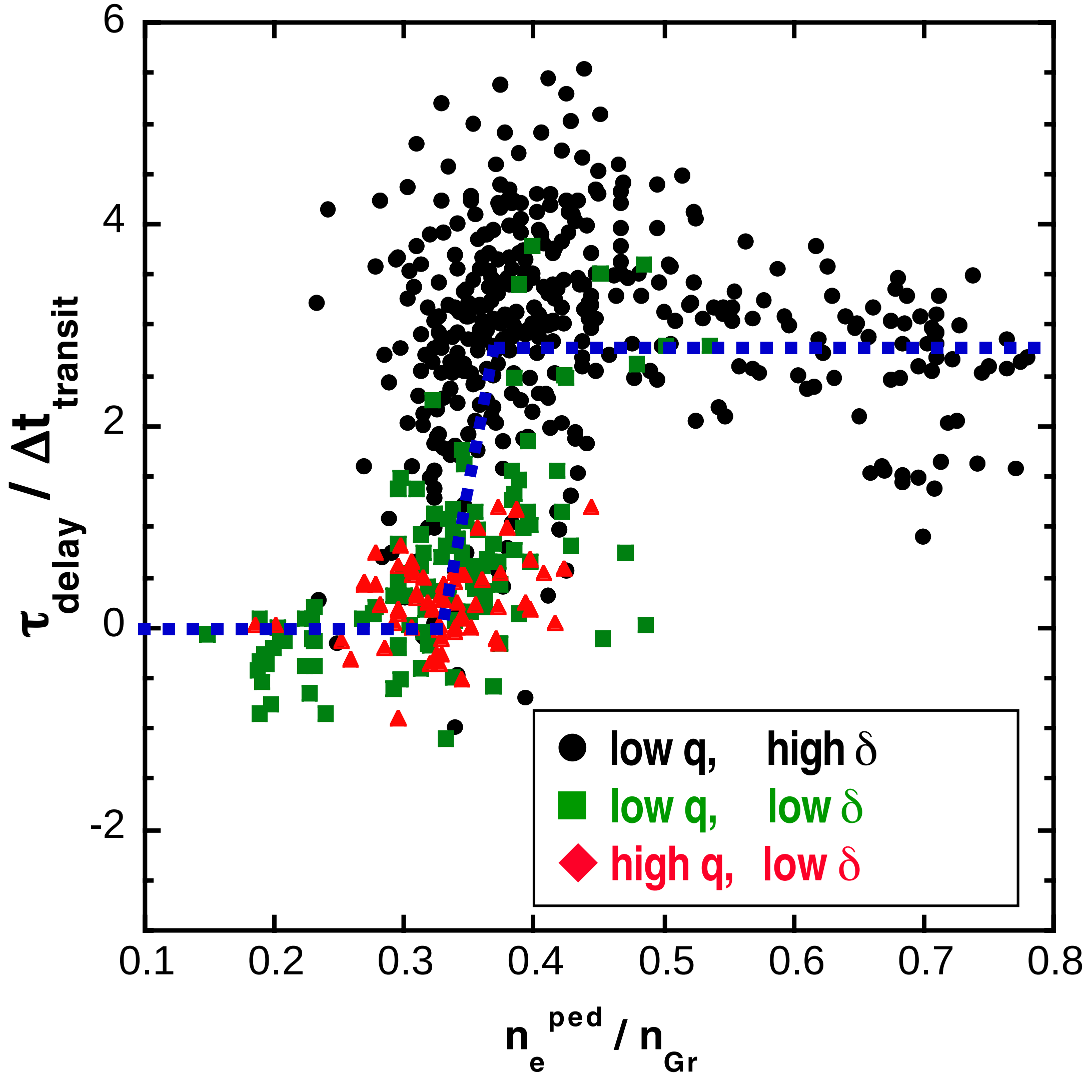
Zeng, Boedo

- Reflectometer data to 40 kHz shows radial velocity of 500 m/s for 5e19 m-3 surface at midplane
- Probe measurement of “density blobs” shows ExB radial velocity of 550 m/s



LSN ∇B ↓ ELMs: Delay of inner vs outer D_α about 3x the difference in ion transit times from midplane to targets.

- Ion transport assumed at sound speed evaluated at pedestal Te
- Scatter increases and delay time drops to small value at very low density
  - Evidence of fast electron effects ?
  - Evidence of change in character of ELM from ballooning to peeling dominated ?



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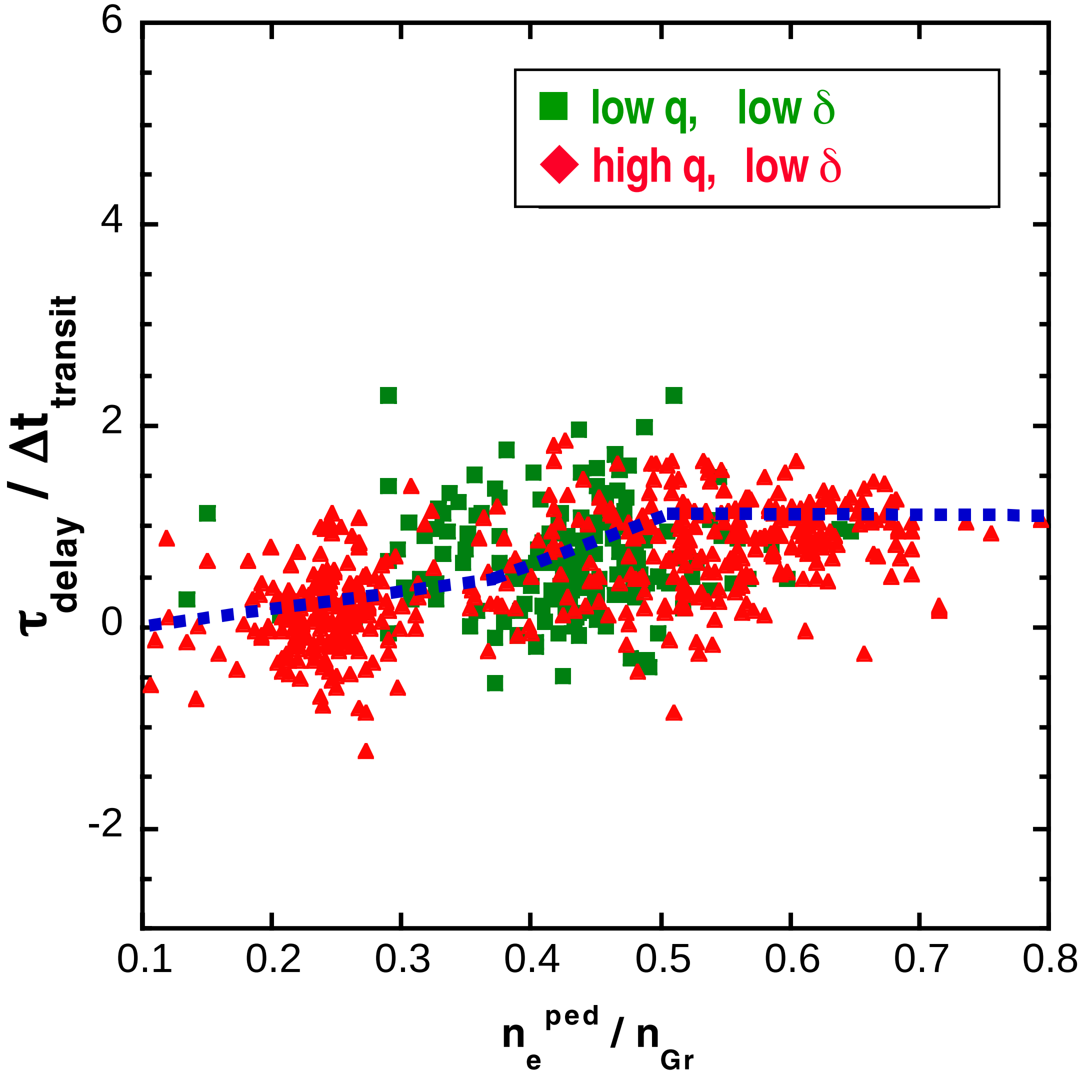
LSN ∇B ↑ ELMs: Delay of inner vs outer D_α with ∇B↑ much smaller than in ∇B↓ case.

- With ∇B out of divertor inner leg plasma conditions similar to outer leg

- Dependence of delays on ∇B direction may be due to:
  - Difference in pre-ELM divertor conditions ?
  - Role of ExB drifts during ELM event ?



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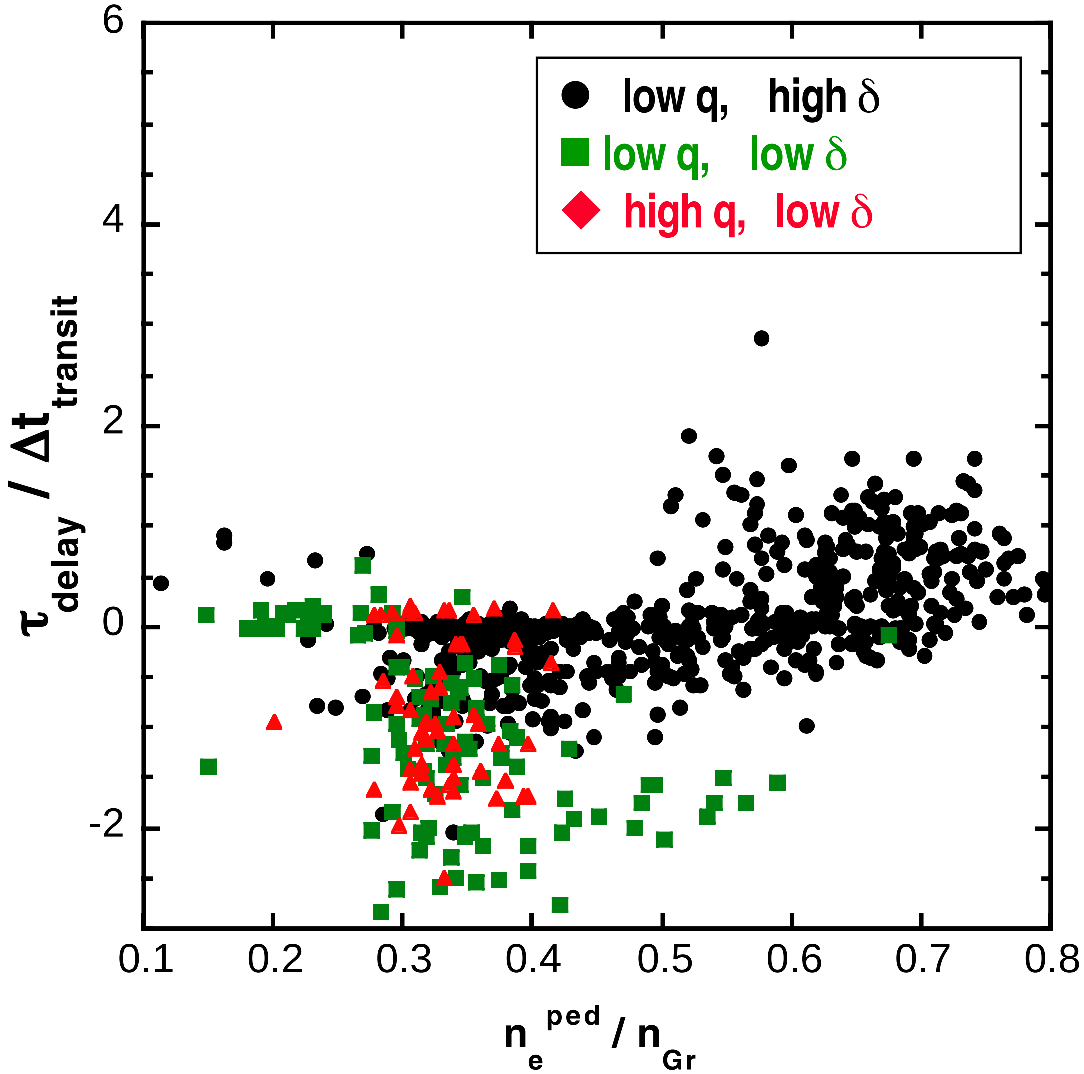
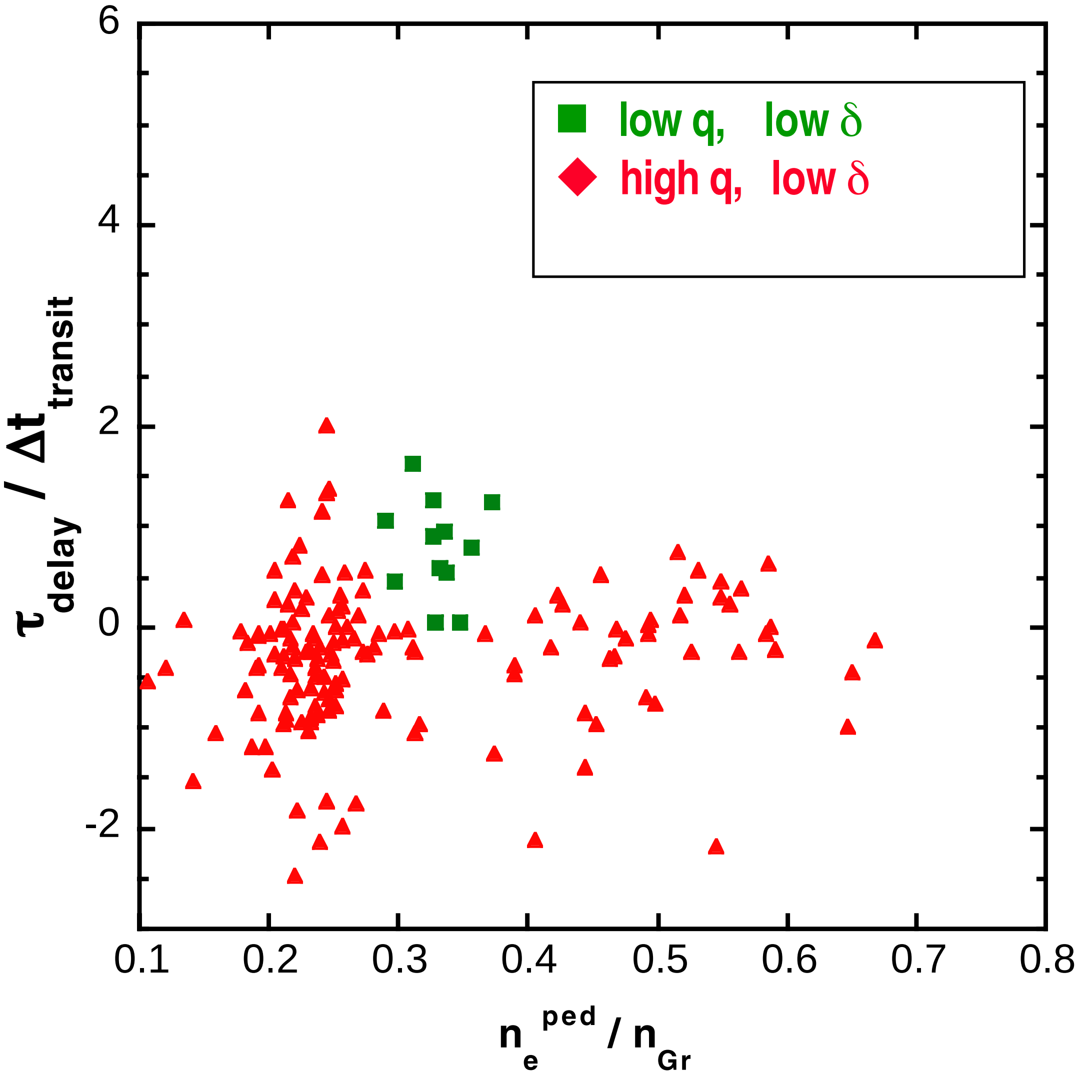
LSN $\nabla B \downarrow$ ELMs: Delay of inner vs outer P_{rad} less than D_α delay

- At high n_e the delay is 2x smaller than in D_α
- At low ne, ELM P_{rad} (inner) before ELM P_{rad} (outer)
  - This also seen in analysis of spatial zones by Hollman (2002)
  - Fast electron pulse burns through detached inner divertor ?



LSN ∇B ↑ ELMs: Delay of inner vs outer P_{rad} similar to delays of D_α

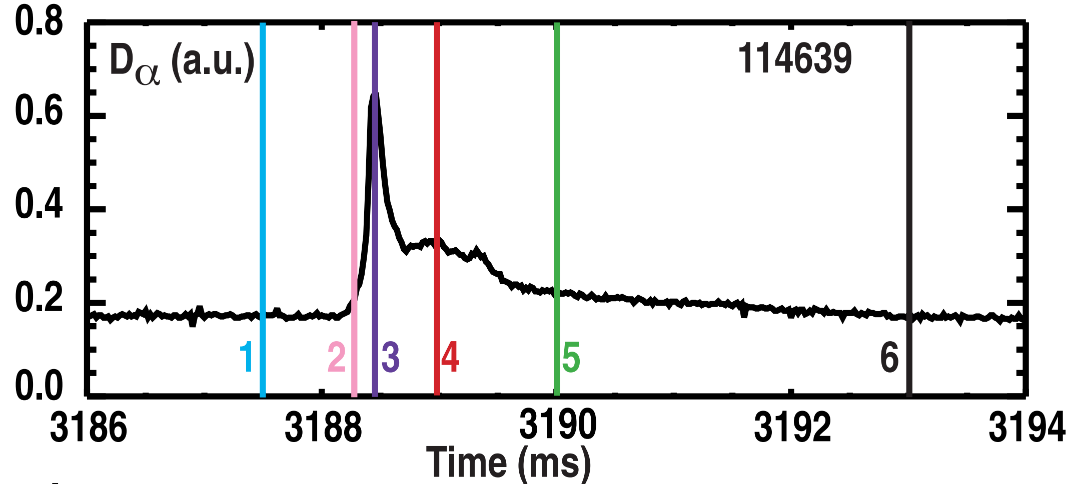
- Data set limited to high q shots because outer P_{rad} saturated at low q
- Small delay (albeit with large scatter)
  - No clear variation with density

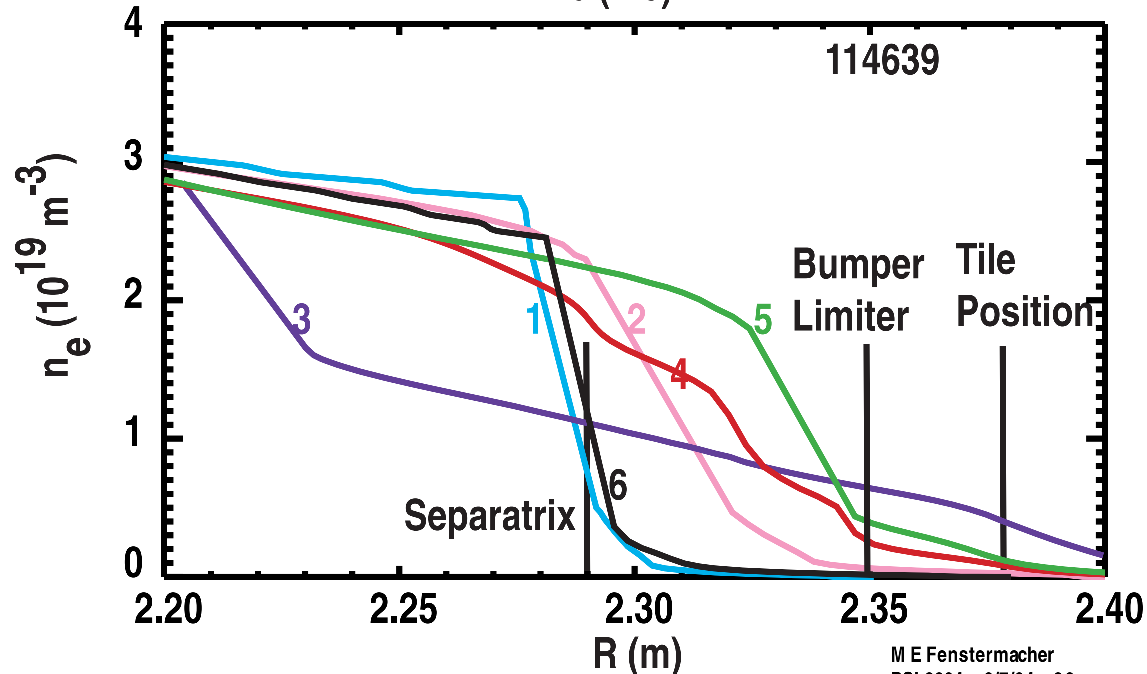


LSN $\nabla B \uparrow$ Low δ ELMs: Δn_e seen much farther out in midplane SOL than ΔT_e, especially at low n_e

Zeng

- Reflectometer shows reduction of pedestal density [curves 2 -->3]
- Density lost from pedestal appears far out in SOL; n_e~$10^{19}m^{-3}$ at 4.5 cm (4 $\lambda_{ne}^{pre\text{-}ELM}$) from pre-ELM separatrix [curve 3]
- Recovery of pre-ELM density profile takes > 1.5 ms [curves 4 , 5, 6]
  - Intermediate recovery stage with “pedestal” in the SOL (curve 5)
  - Full recovery after ~ 5 ms (curve 6)





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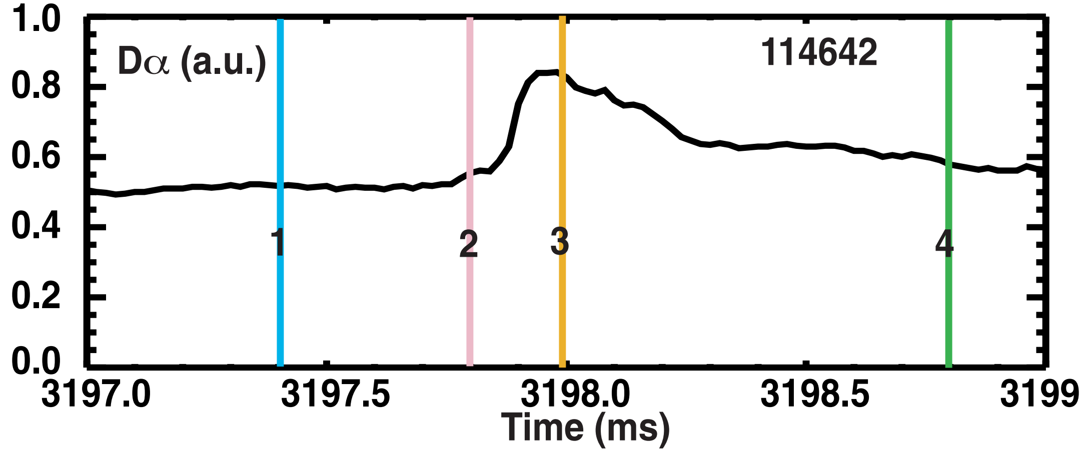
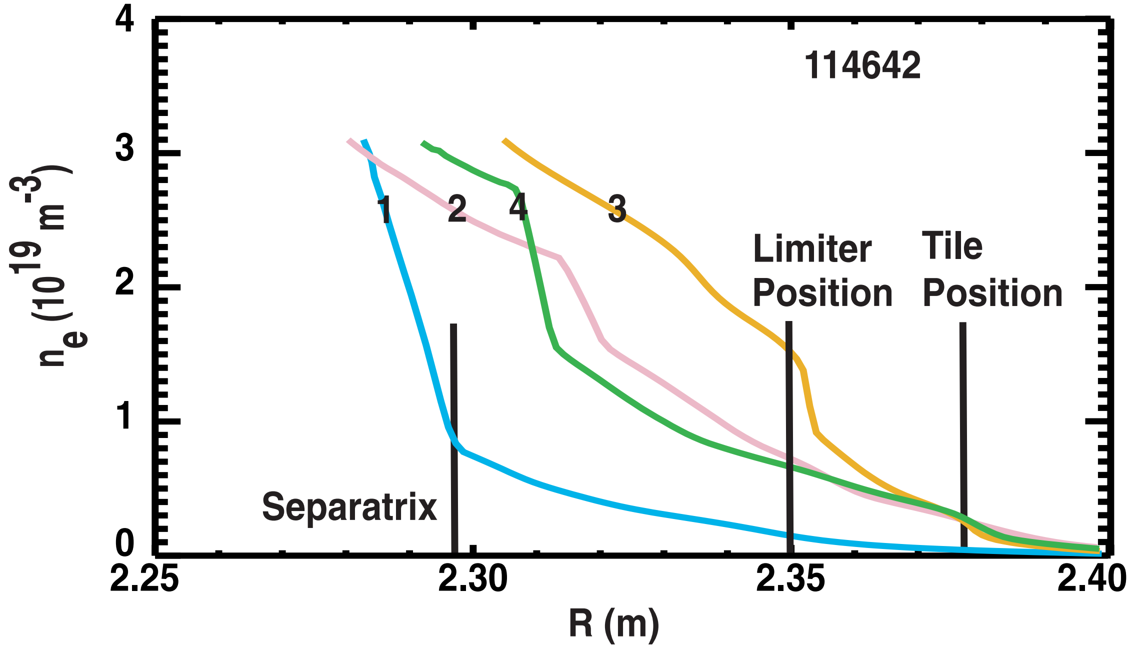
LSN ∇B ↑ Low δ ELMs: Δn_e seen much farther out in midplane SOL than ΔT_e also at high n_e

Zeng,

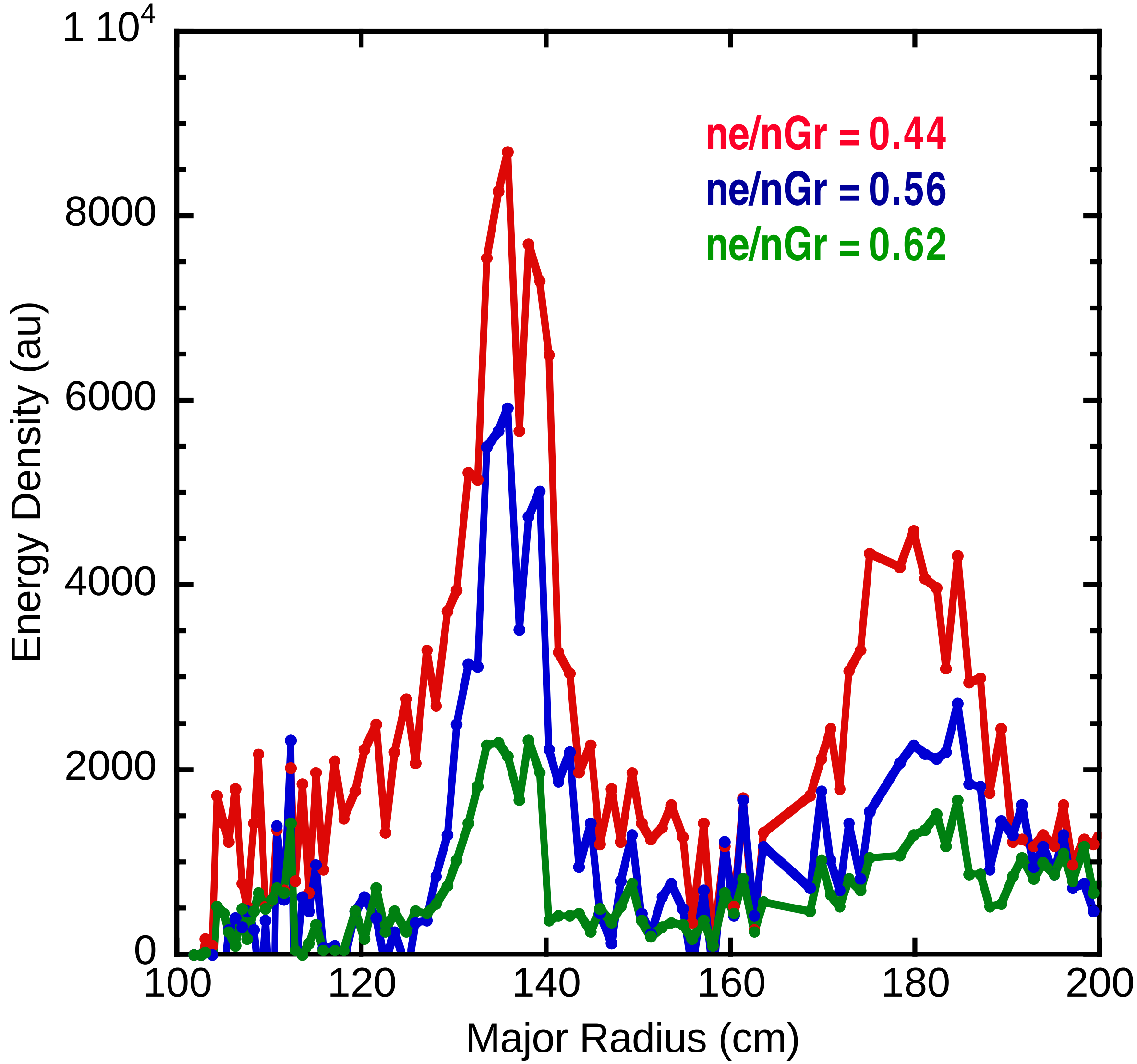
- Reflectometer shows particles ejected into SOL [curves 1, 2, 3]
- Density profile modified before large Dα rise [curve 2]
- Far SOL density rise to $n_e \sim 10^{19} m^{-3}$ at 6 cm (5 $\lambda_{ne}^{pre-ELM}$) from pre-ELM separatrix [curve 3]
- Recovery of pre-ELM density profile takes >> 1 ms [curves 3 ,4]





LSN ∇B ↓ ELMs: Inner / outer target energy density asymmetry during ELMs decreases slightly with n_e

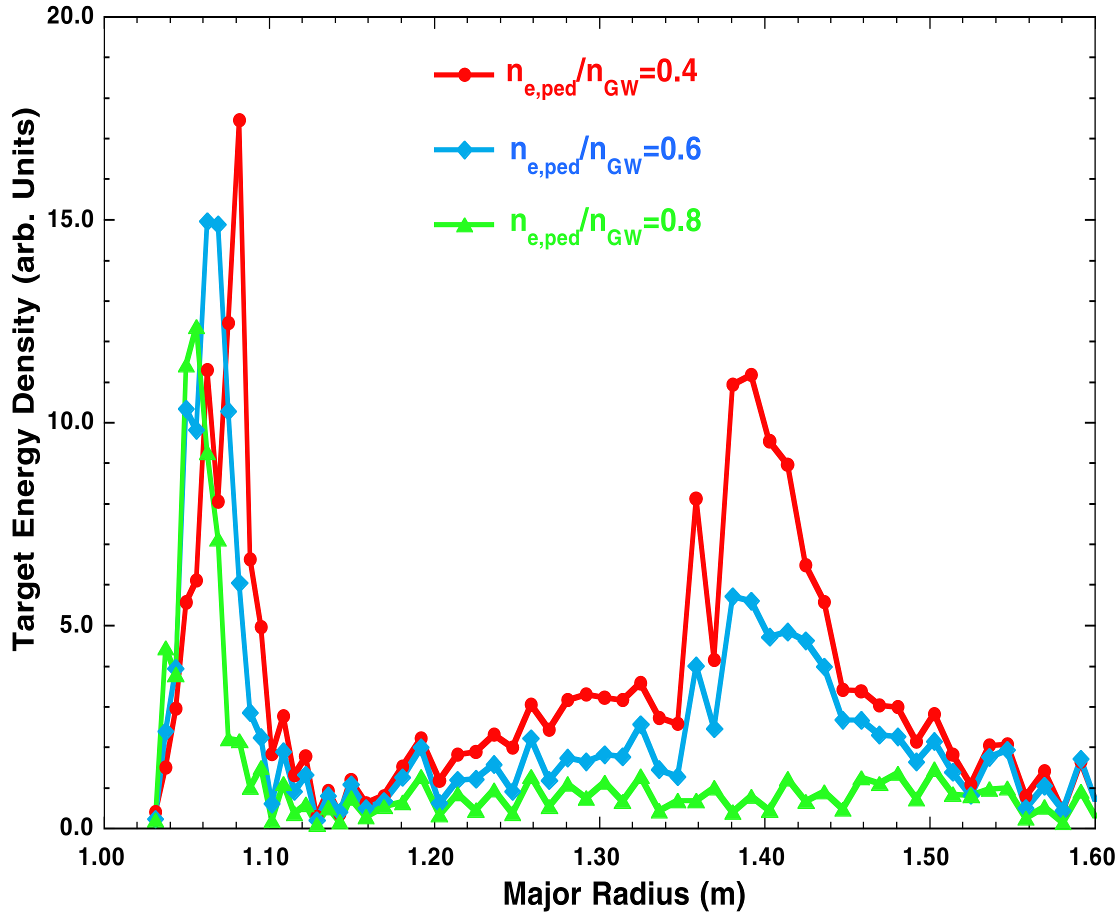
- Inner / outer peak energy density ratio ~ 2 at low n_e/n_G ~ 0.4, ratio decreases to 1.5 at higher density, n_e/n_G > 0.6
- Profiles averaged over 10 - 20 ELMs.
- Surface layer effects may be playing an important role in these results.



LSN ∇B ↓ ELMs: Inner / outer target heat flux asymmetry during ELMs increases with n_e; profile broadens ≤ factor of 2

Lasnier, Leonard PSI02 Invited

- Outer target heat flux drops to near zero at high density
- Peak of inner heat flux profile moves away from SP
- Inner / outer energy ratio ~ 2 from previous experiments - still working on present calibrations
- ELMs broader than time averaged by 2x on outer leg but narrower by up to 1.5x on inner leg.



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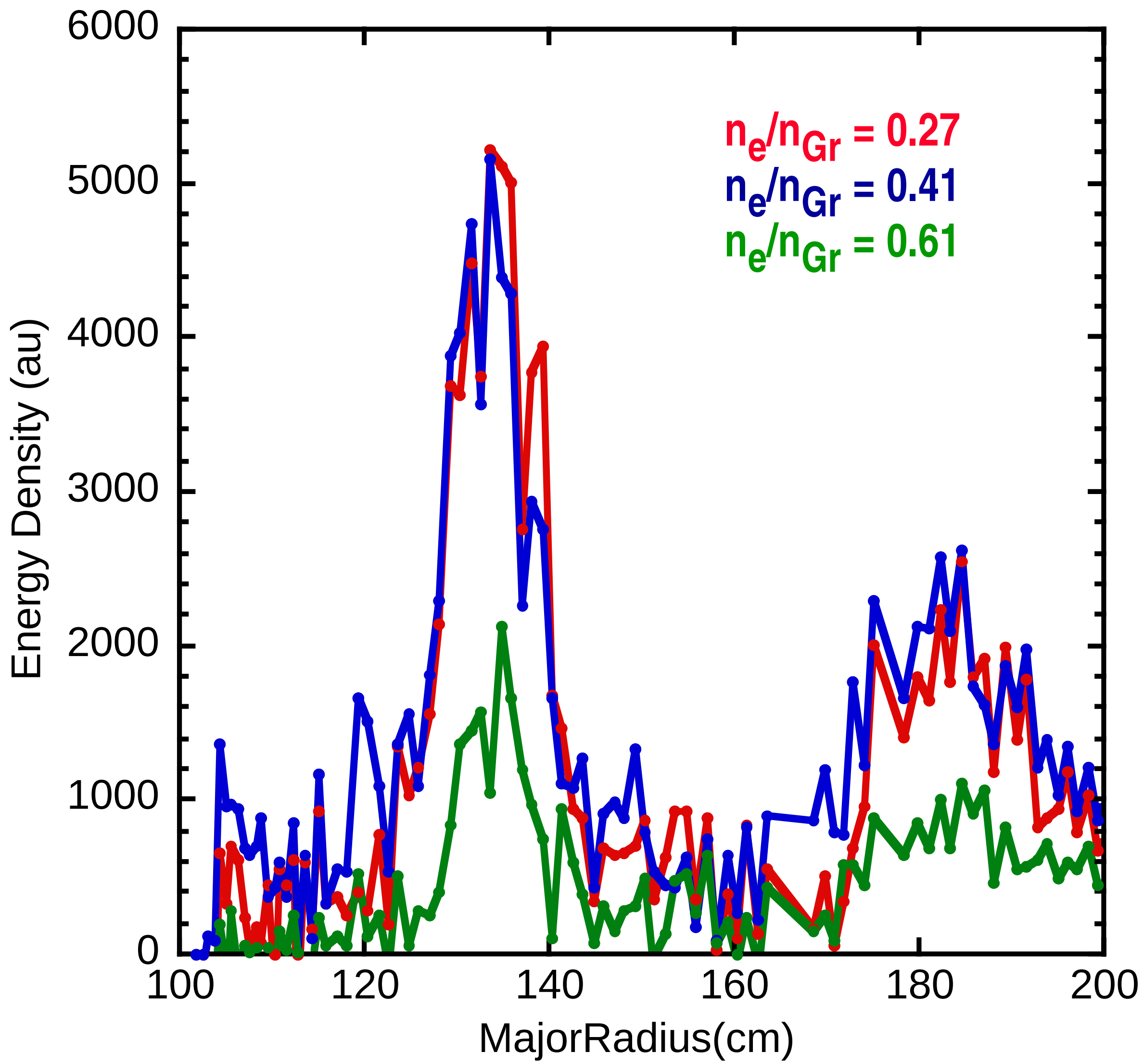
LSN ∇B ↑ ELMs: Inner / outer target energy density asymmetry during ELMs nearly constant with n_e

- Little change in profiles from low to moderate density, $0.27 < n_e/n_{Gr} < 0.4$
- In / out asymmetry ~ 2.0 independent of density
- Profiles averaged over 10 - 20 ELMs.
- Surface layer effects may be playing an important role in these results.



Comments: SOL/divertor ELM behavior depends on both n_e and B_T-dependent particle drifts

- **Delays of inner vs outer D_α and $P_{rad} = f(n_e, B_T)$**
  - ELM poloidal character may change with n_e
  - Fast electron effects may dominate at low ne; ion convection at high ne
  - Difference in pre-ELM divertor conditions with B_T may play a role

- **Pedestal particles ejected far into midplane SOL, 3 - 5 $\lambda_{ne}^{pre\text{-}ELM}$, independent of n_e, B_T**
  - Ejected T_i (and heat flux) at main chamber wall not known
  - Ejected T_e falls rapidly with radius in SOL

(see also Zeng O-29 Rudakov O-24 , Boedo P2-5)

- **Asymmetry of peak energy density weak $f(n_e, B_T)$**
  - Asymmetry decreases slightly with n_e for ∇B ↓; nearly constant for ∇B ↑
  - May be contaminated by surface layer effects

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UEDGE SS and ELM Modeling - ∇B ↓

UEDGE SS and ELM Modeling - ∇B ↑

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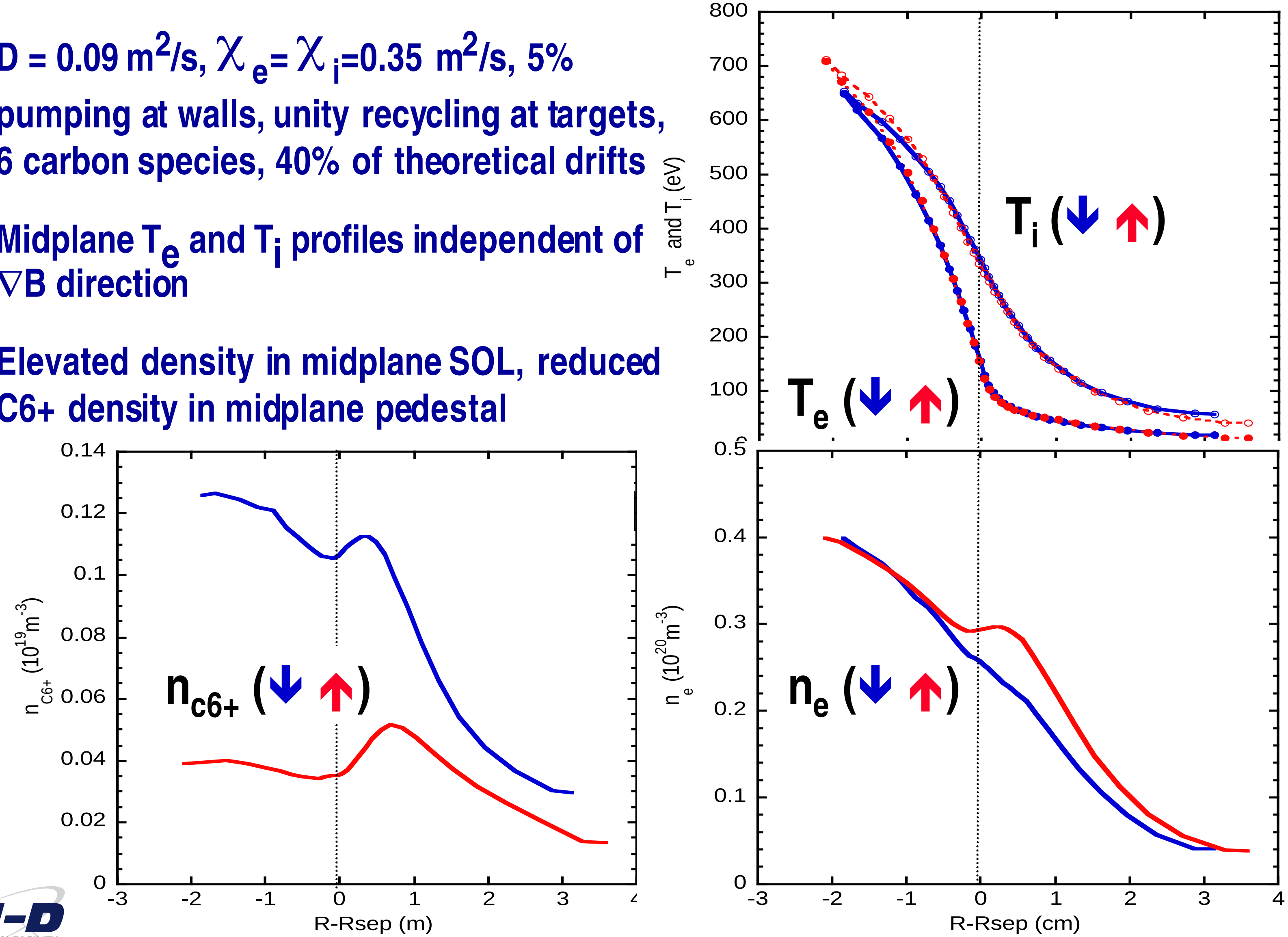
UEDGE simulations of pre-ELM ∇B ↓ vs ∇B ↑ cases show similar midplane T_e, T_i but changes in density profiles

- $D = 0.09\ m^2/s$, $\chi_e = \chi_i = 0.35\ m^2/s$, 5% pumping at walls, unity recycling at targets, 6 carbon species, 40% of theoretical drifts
- Midplane T_e and T_i profiles independent of ∇B direction
- Elevated density in midplane SOL, reduced C6+ density in midplane pedestal



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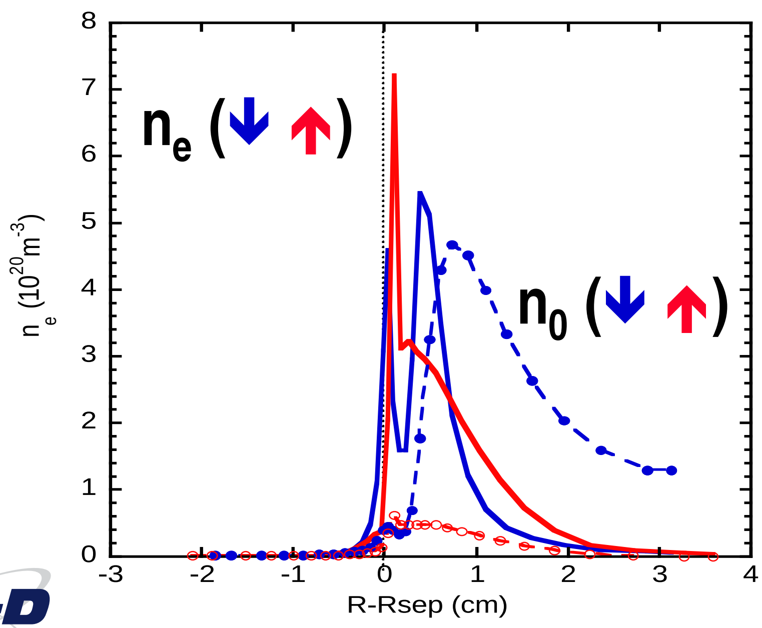
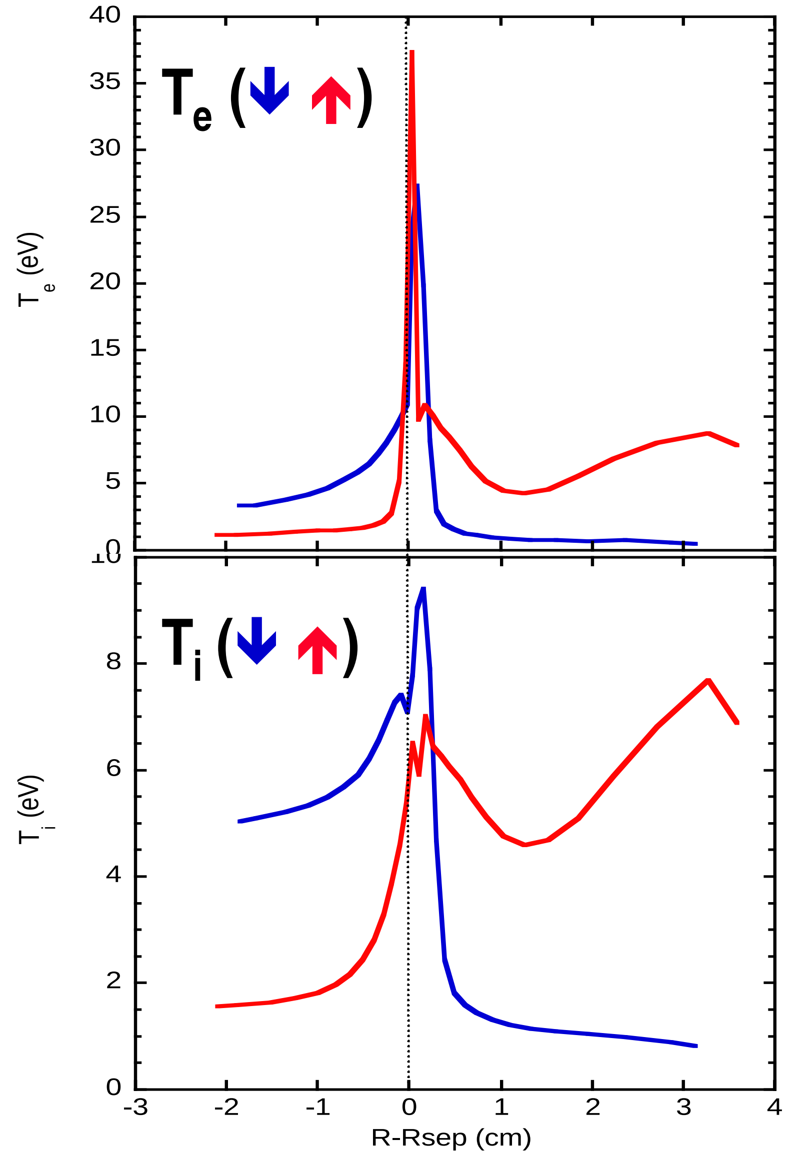
UEDGE simulations of pre-ELM ∇B ↓ vs ∇B ↑ cases show completely different inner divertor conditons.

- ∇B ↓ inner divertor - Detached
  - n_e and n_0 high to far SOL
  - T_e and T_i below 2 eV except very close to ISP
- ∇B ↑ inner divertor - Attached
  - n_e 2x lower and n_0 10x lower in SOL
  - T_e and T_i =4 - 8eV throughout SOL





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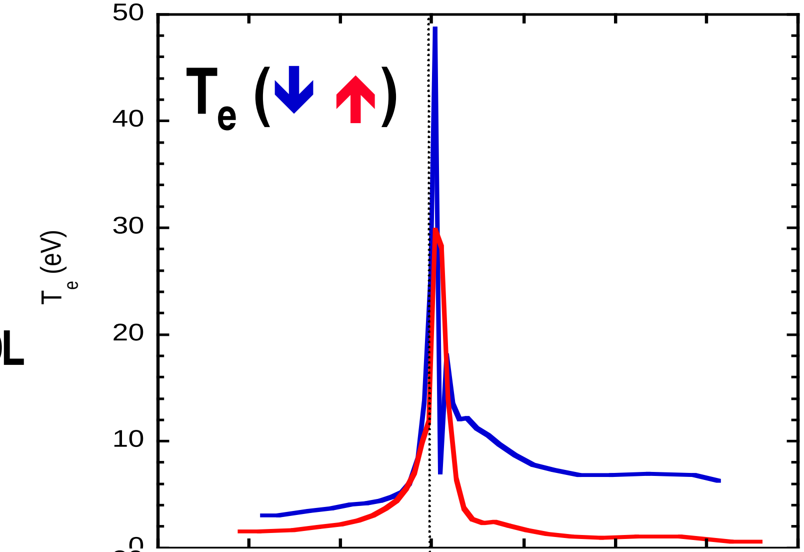
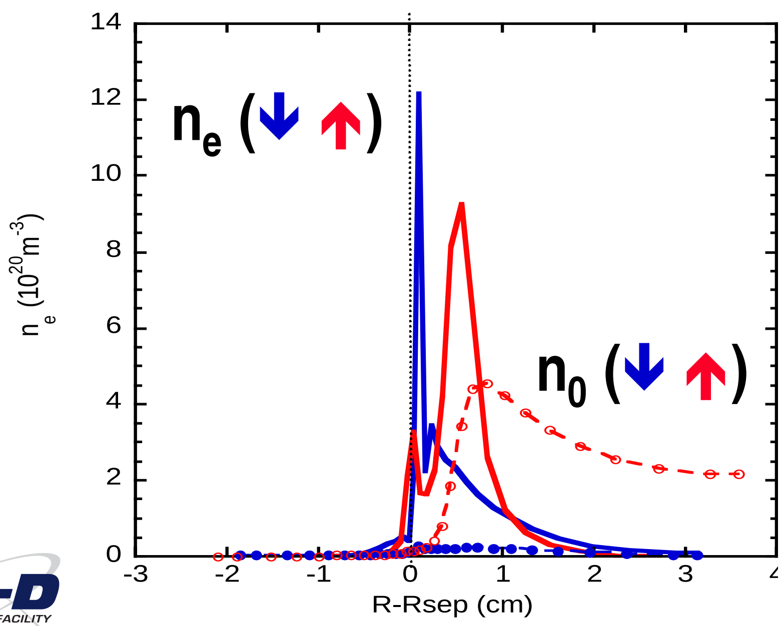
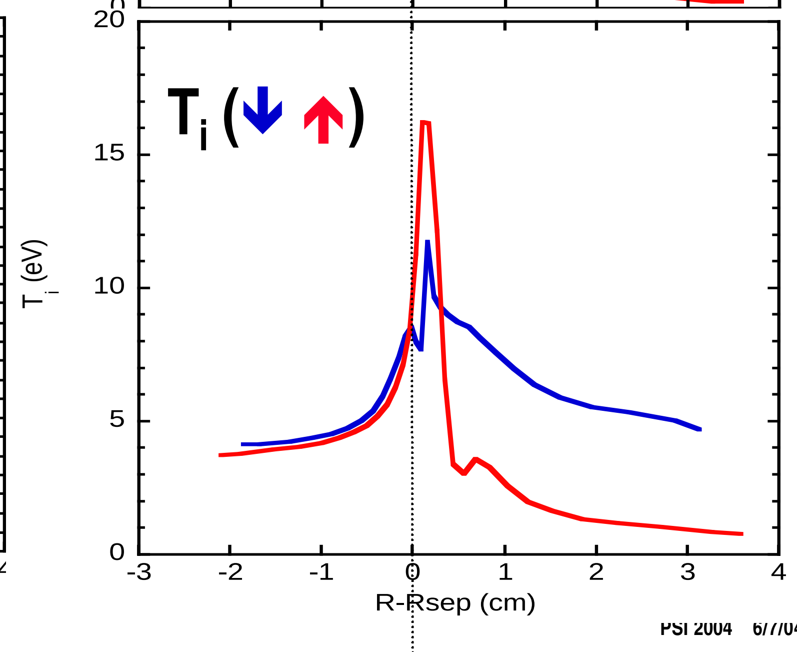
UEDGE simulations of pre-ELM ∇B ↓ vs ∇B ↑ cases show very different outer divertor SOL plasma

- ∇B ↓ outer divertor - Attached far SOL
  - n_e and n_0 low to far SOL
  - T_e and T_i = 5-8 eV into far SOL
- ∇B ↑ outer divertor - Detached far SOL
  - n_e 5x higher and n_0 10x higher in SOL
  - T_e and T_i < 2 eV throughout SOL

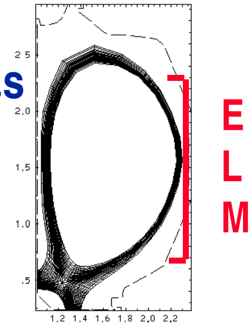


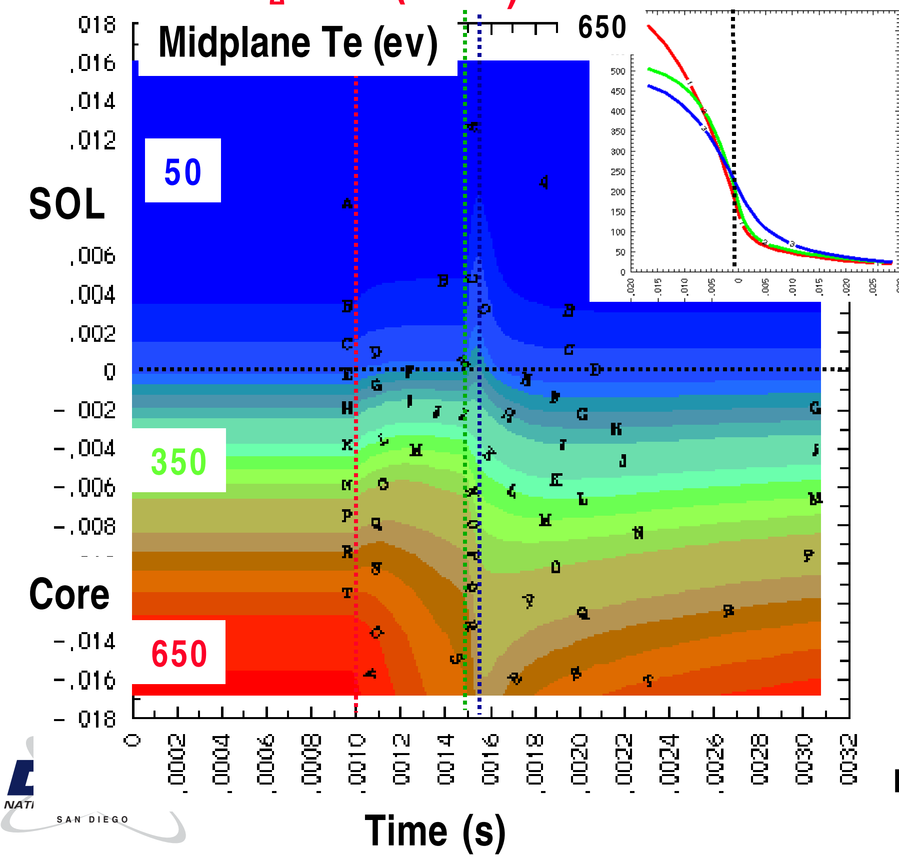




UEDGE ELM simulation shows pedestal behavior similar to low n_e case

- Exponential radial and Gaussian poloidal perturbation near midplane
- At 1.0 ms, increase $D_\perp$ by 10x for 500 μs, then add increase of χ by- 10x for 50 μs
- Relaxation phase with transport coefficients from between-ELM solution
- Pedestal T_e loss without substantial SOL increase - similar to data
- Pedestal n_e loss (small) with n_e increase into far SOL - similar to data





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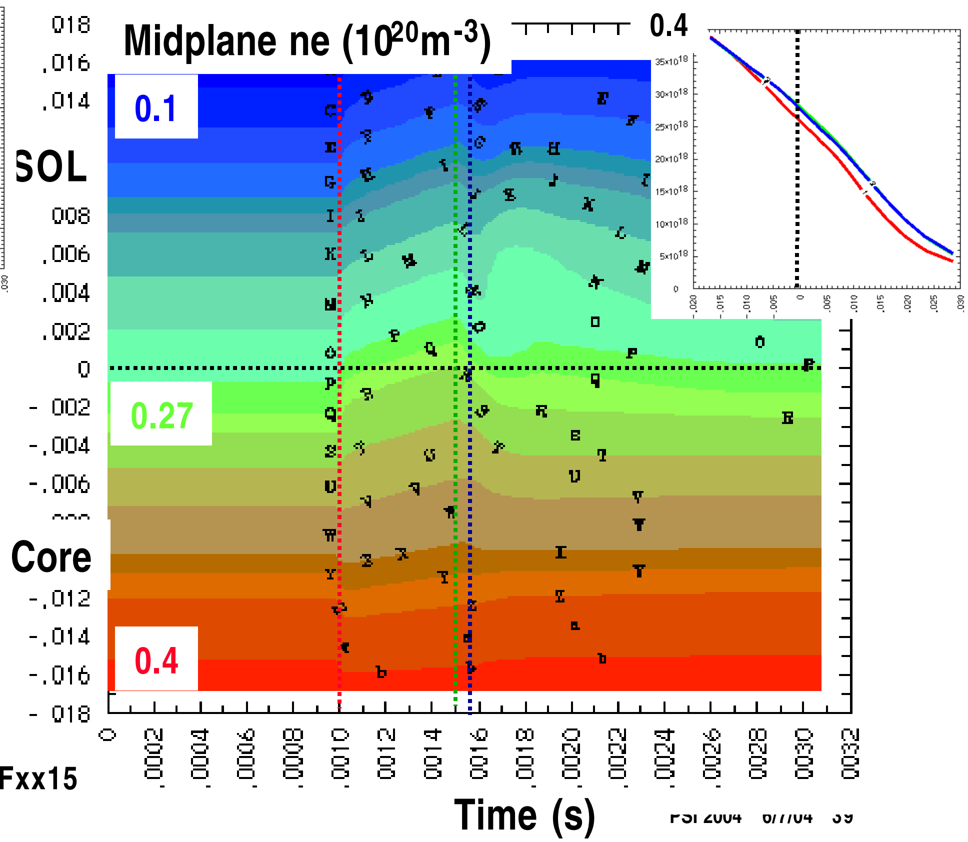
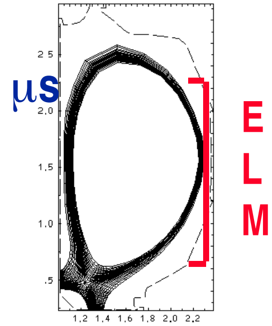
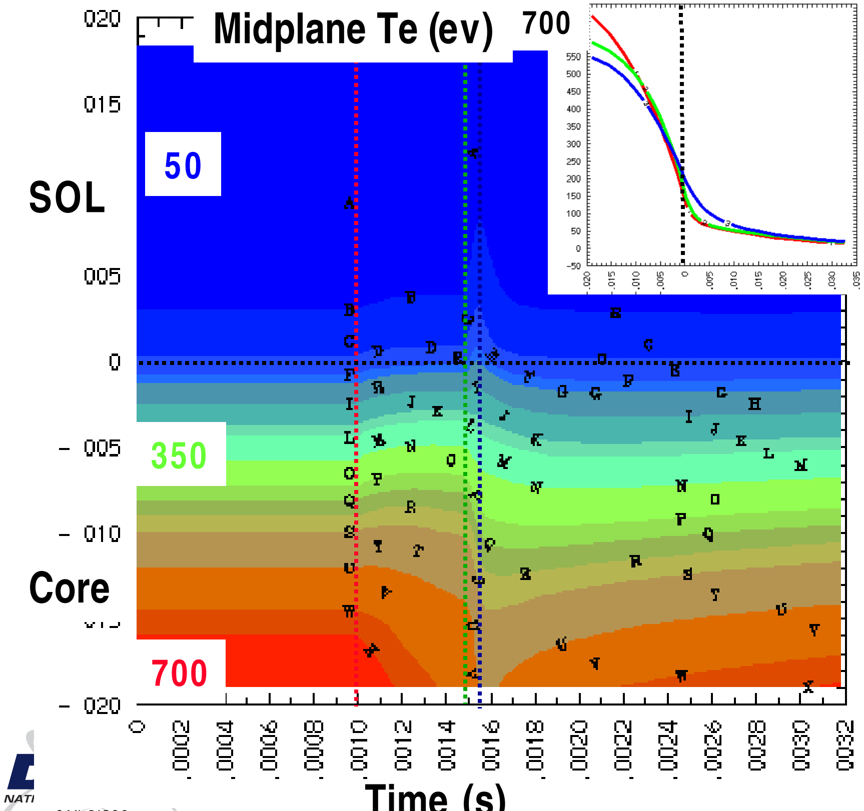
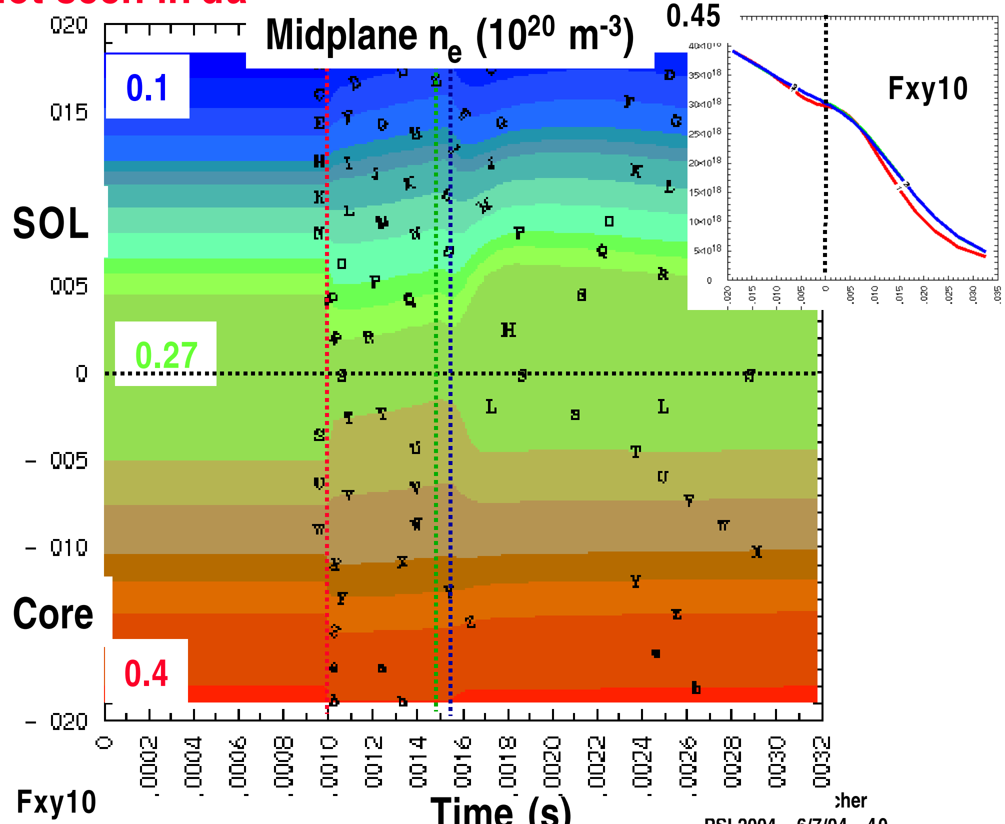


UEDGE ELM simulation with ∇B ↑ shows weak perturbation of midplane profiles

- Exponential radial and Gaussian poloidal perturbation near midplane
- At 1.0 ms, increase $D_\perp$ by 10x for 500 μs, then add increase of χ by 10x for 50 μs
- Relaxation phase with transport coefficients from between-ELM solution
- Almost no SOL T_e perturbation - similar to data
- SOL density bump flattens during ELM - not seen in data

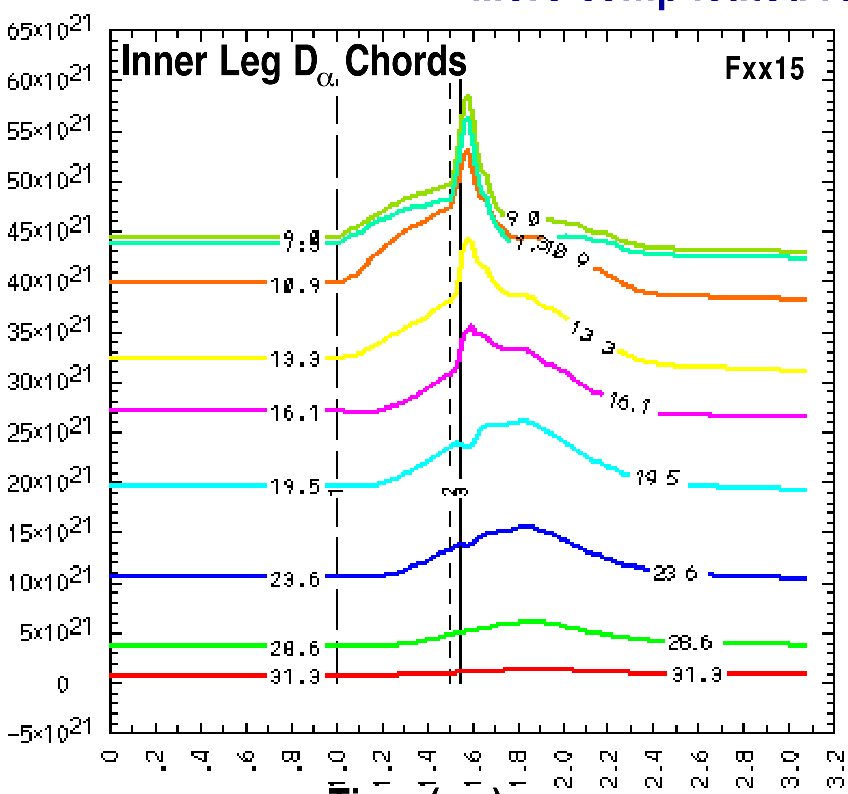


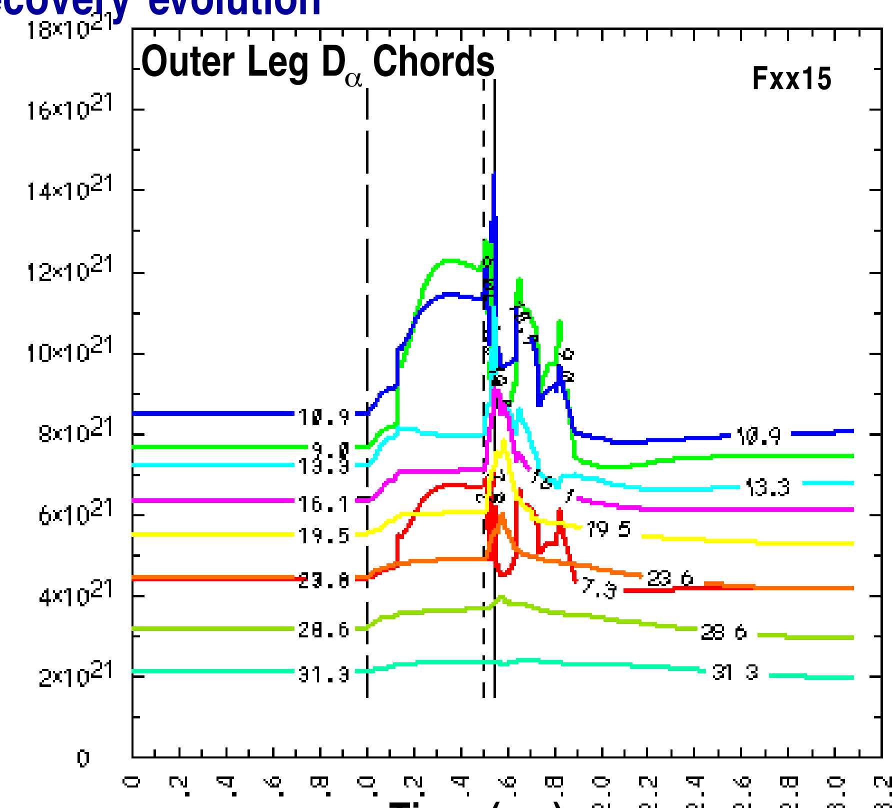




D_α chord integrals vs. time from UEDGE solution simulate filterscope signals

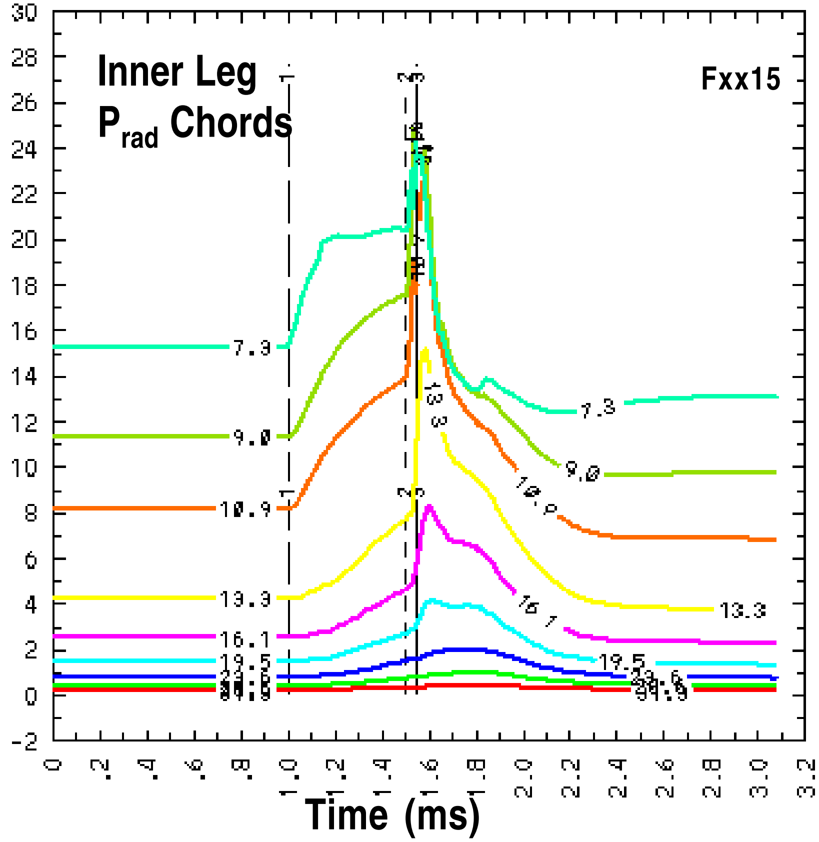
- **Inner Divertor:** - Initial slow D_α rise at $D_\perp$ increase
  - Fast D_α rise at χ increase
  - Long slow (several ms) recovery on recycling timescale
- **Outer Divertor:** - Similar response to $D_\perp$ and χ increases
  - More complicated recovery evolution

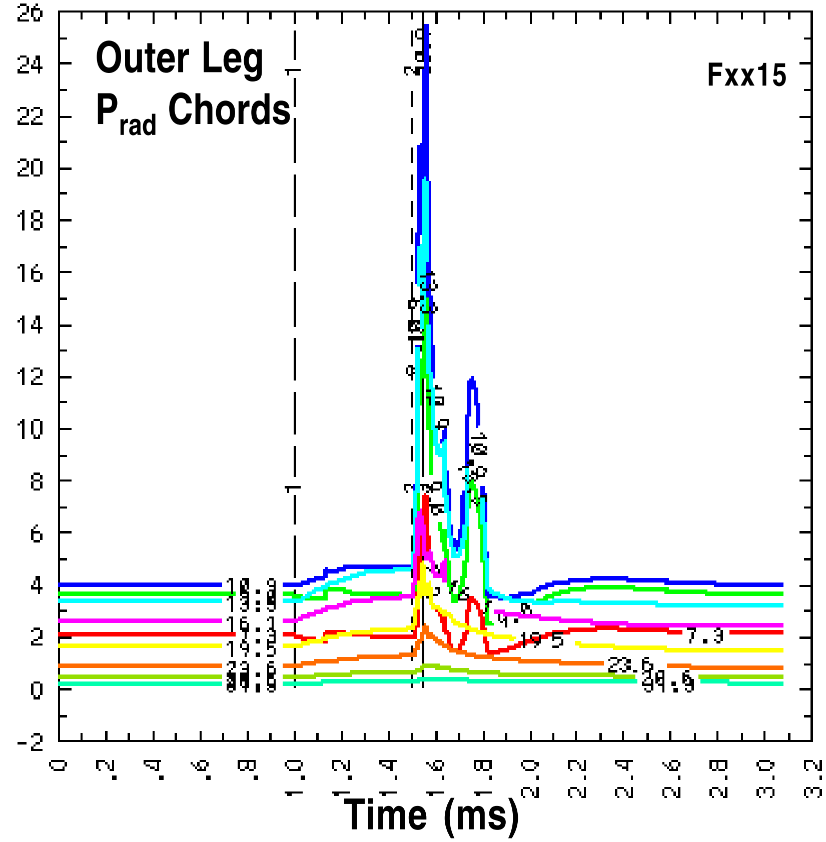




P_{rad} chord integrals vs. time from UEDGE solution simulate DISRAD-II signals

- Inner Divertor: - Sharper rise at $D_{\perp}$ change than in D_{α}
  - More rapid recovery than in D_{α}
- Outer Divertor - Relative response to χ change much larger than for D_{α}





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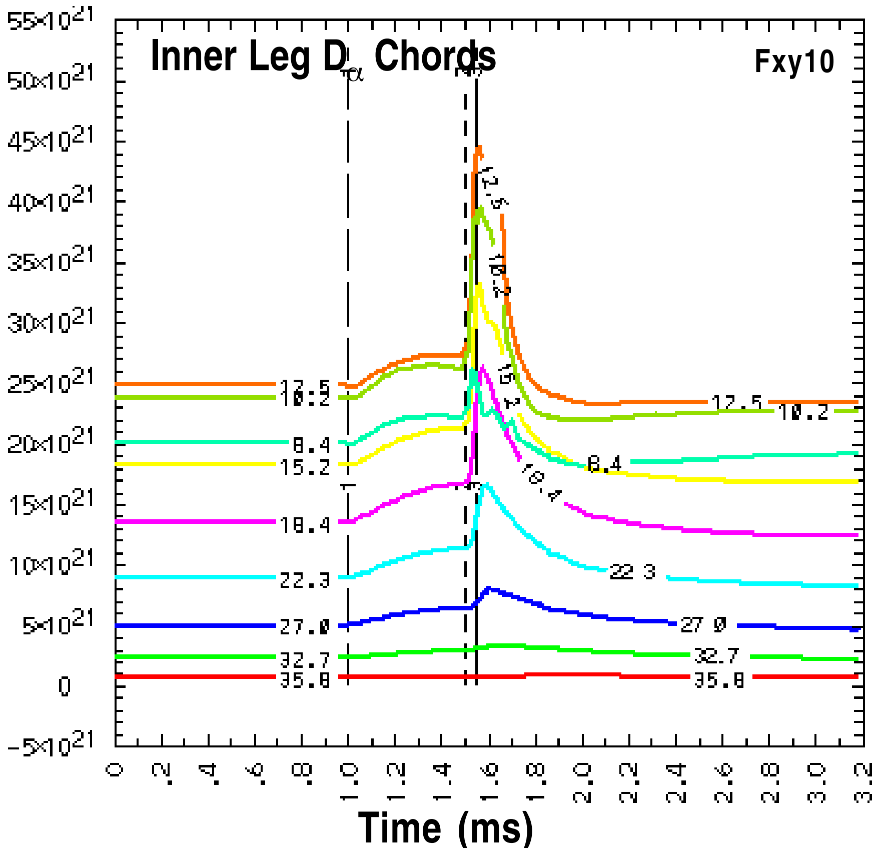
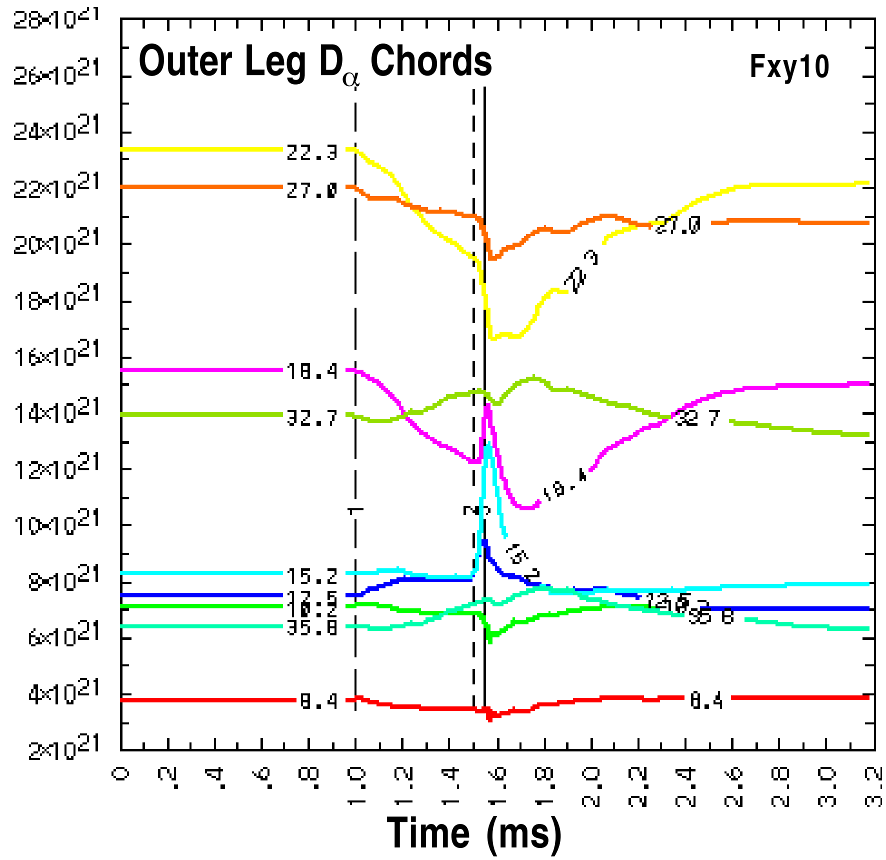
D_α chord integrals vs. time from UEDGE solution with ∇B ↑ simulate filterscope signals

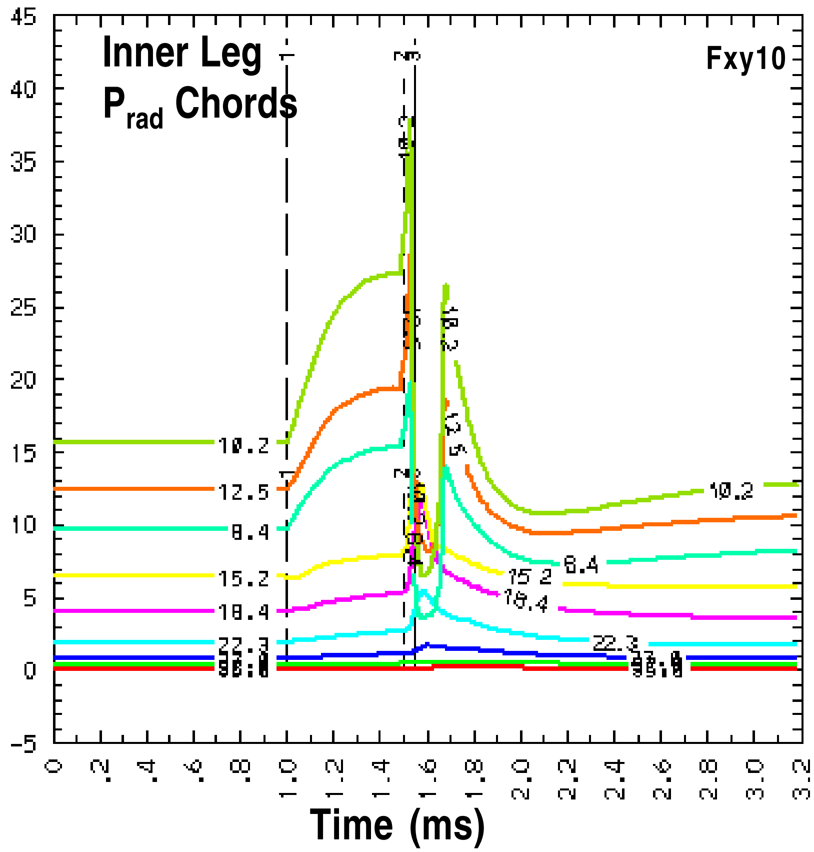
- **Inner Divertor:** - Response to $D_\perp$ change similar in ∇B ↓ and ∇B ↑
  - Response to χ change is larger in ∇B ↑ than in ∇B ↓
- **Outer Divertor** - Positive and negative response to both $D_\perp$ and χ changes - Unexplained

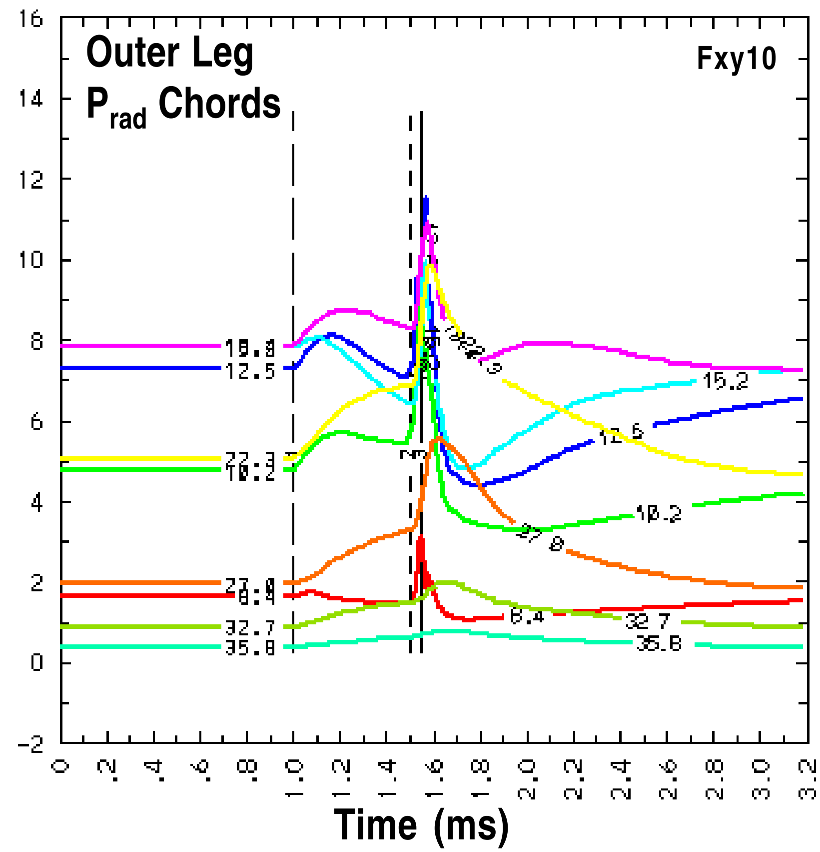




P_{rad} chord integrals vs. time from UEDGE solution with ∇B ↑ simulate DISRAD-II signals

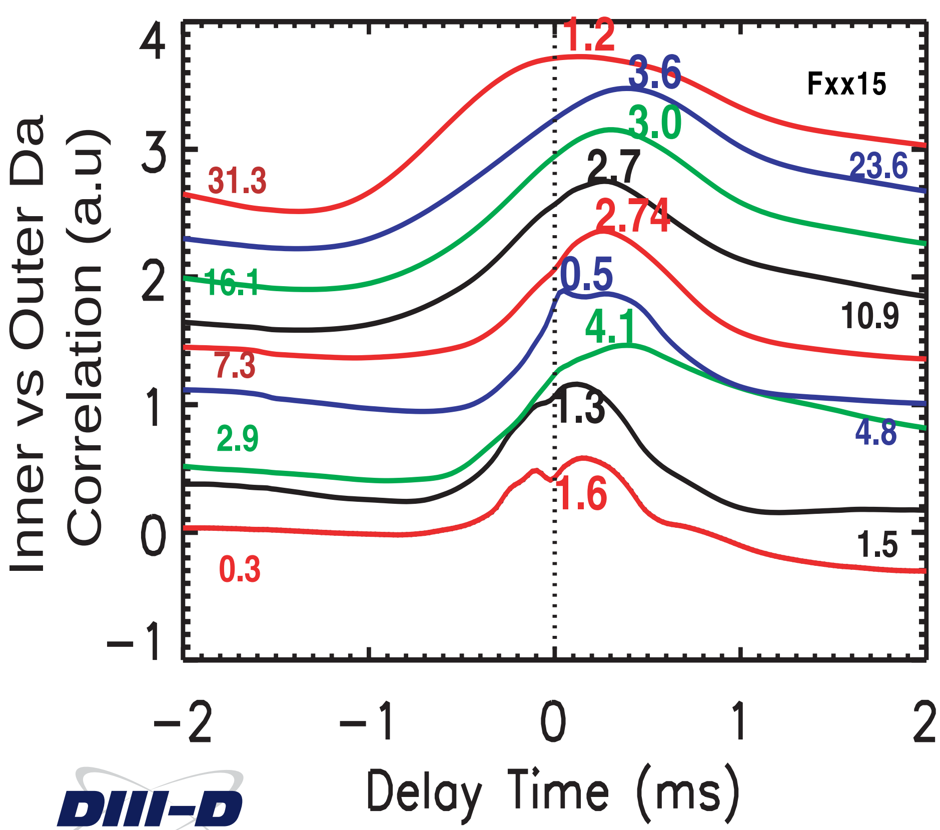
- **Inner Divertor:** - Initial response to $D_\perp$ and χ change similar in ∇B ↓ and ∇B ↑
  - Recovery phase more complicated in ∇B ↑ than in ∇B ↓
- **Outer Divertor** - Response to χ much less in ∇B ↑ than in ∇B ↓

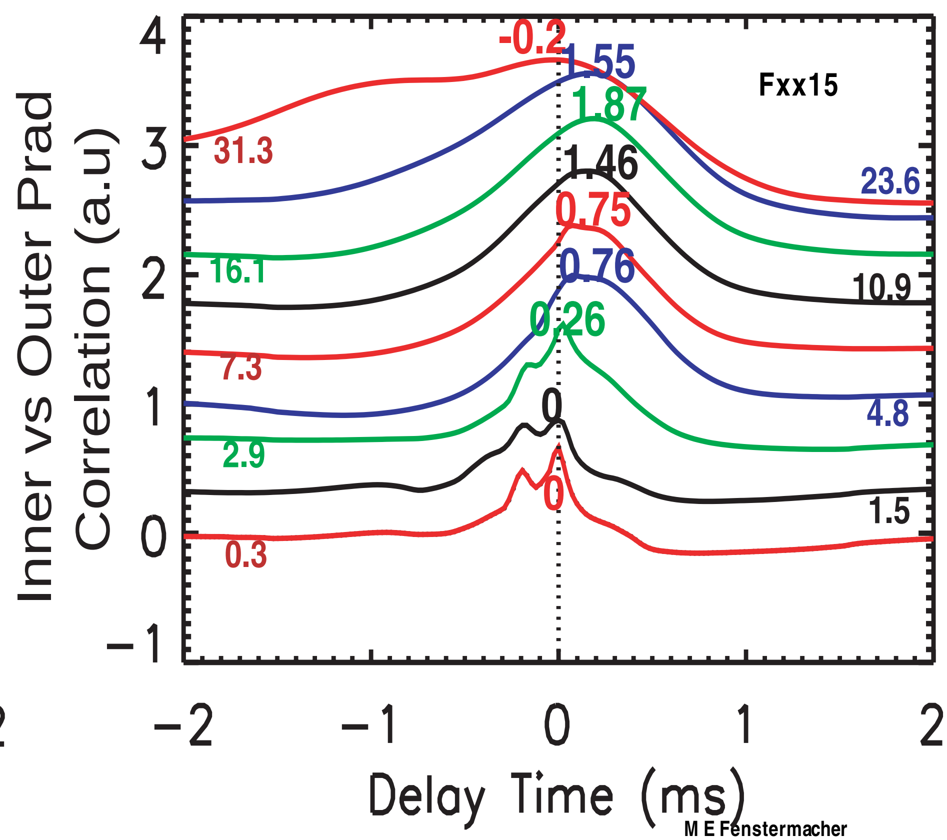




Inner vs Outer correlation of UEDGE simulated Da and Prad signals show features similar to data correlations

- **Correlation of inner vs. outer divertor synthetic DISRAD-II signals yields predictions of delays similar to observations**
  - Normalized D_α delay in the range [0.5 - 3.6] similar to data at n_e/n_{Gr} ~ 0.4
  - Normalized P_{rad} in the range [0 - 1.9] - less delay than in D_α as seen in the data





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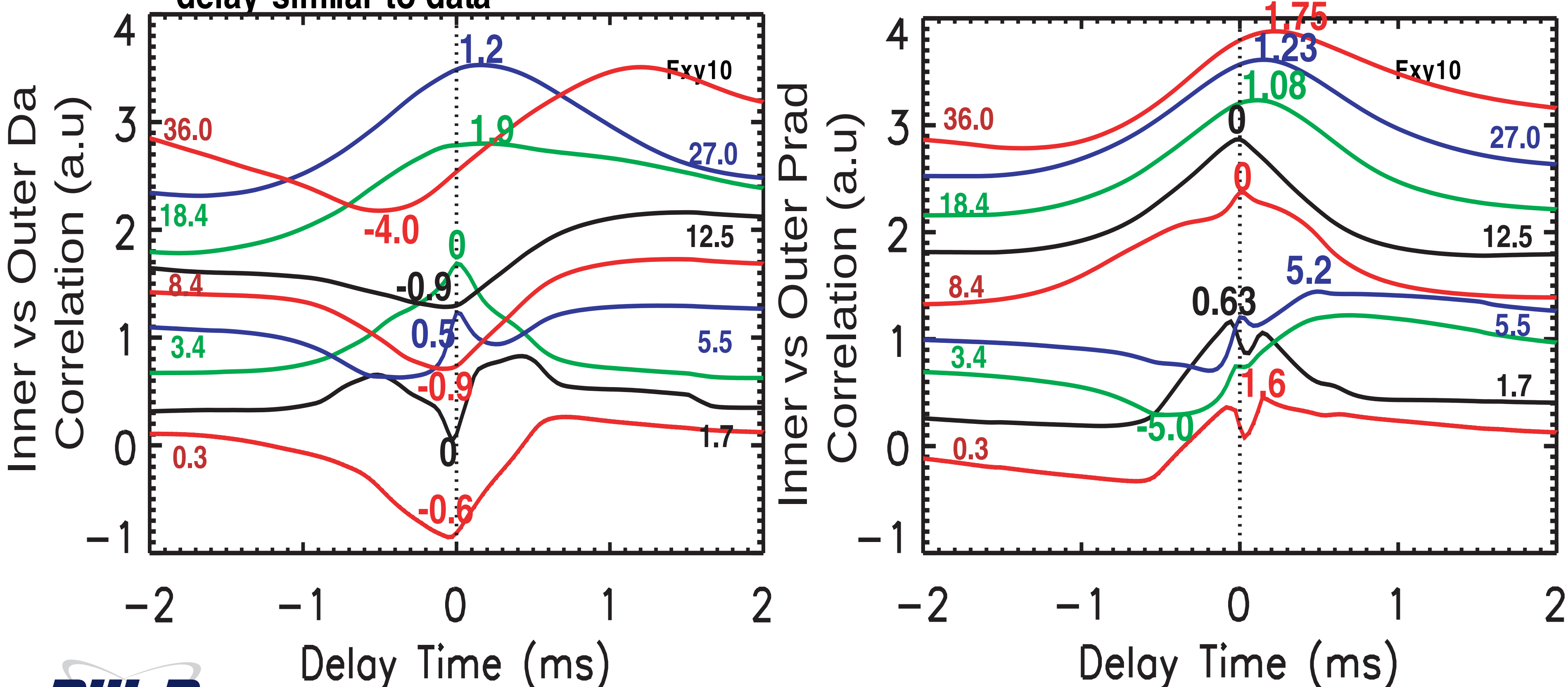
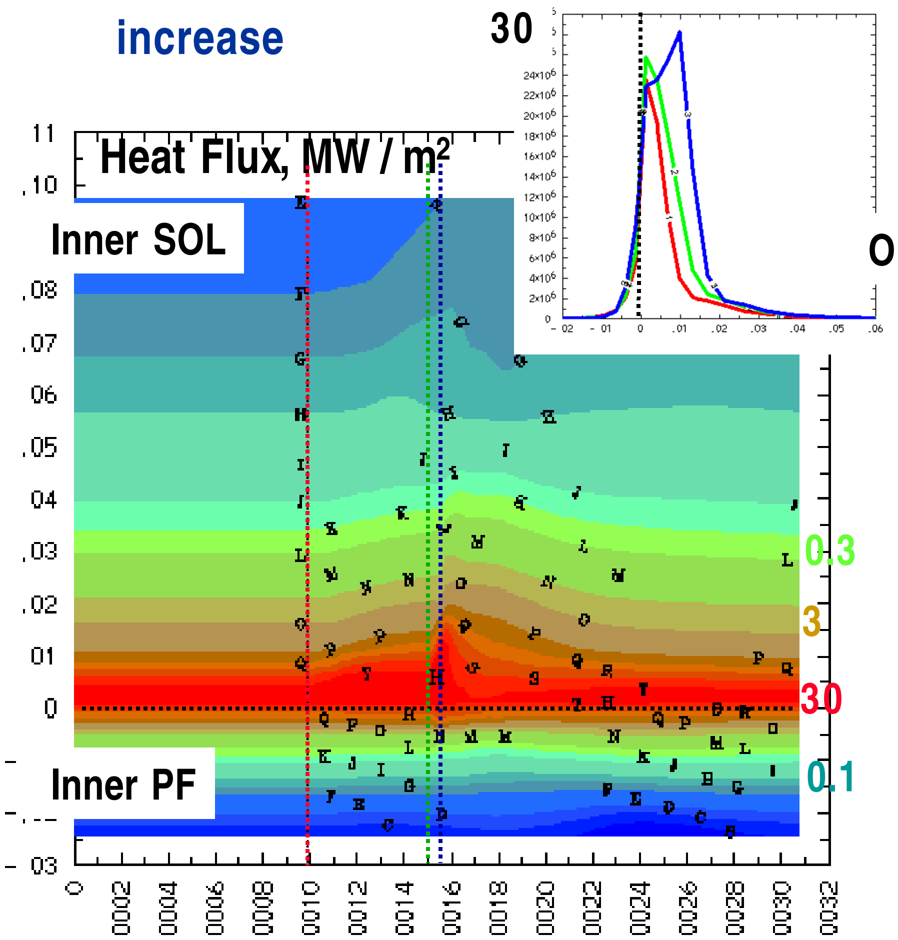
Inner vs outer correlation of Prad signals with ∇B ↑ show features similar to data correlations

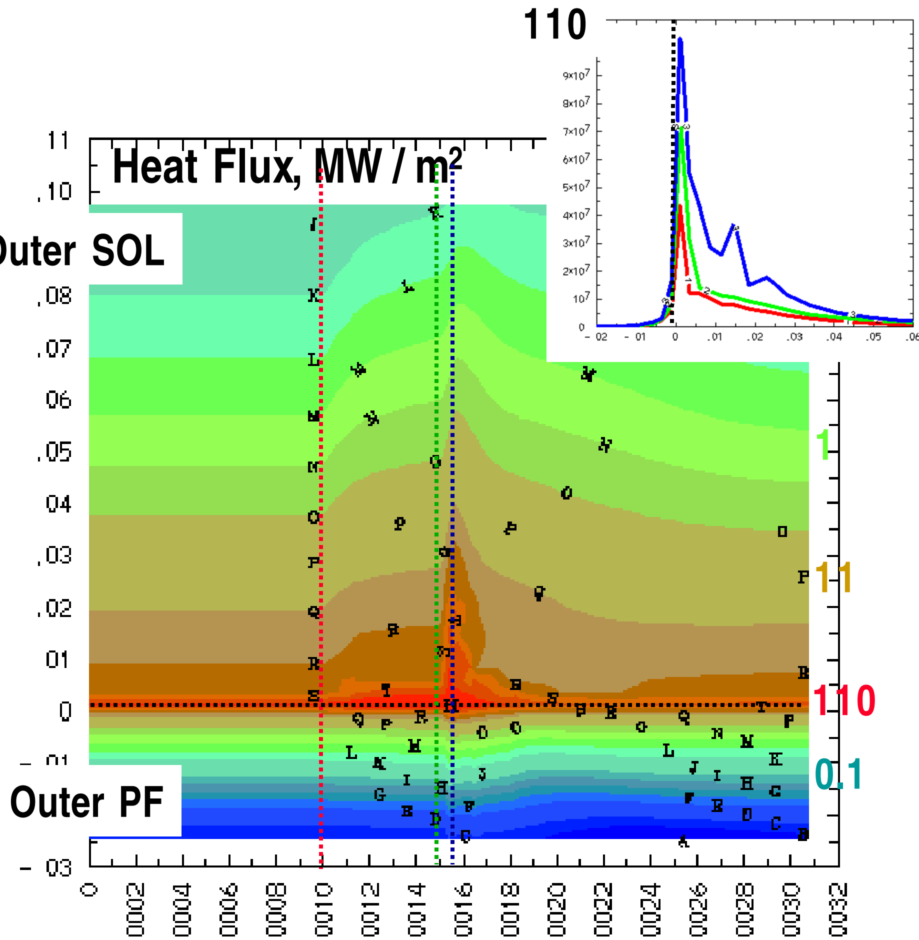
- Correlation of inner vs. outer divertor synthetic D_α and P_{rad} signals yields
  - Normalized delay of D_α in the range [-4.0 - +1.9]: similar timing inversion occurs in data at n_e/n_G ~ 0.5
  - Normalized delay in P_{rad} in the range [-5.0 - +1.8], However most radii have small delay similar to data



Simulated inner and outer target heat fluxes broaden at most by a factor of 2 during ELM

- Heat flux broadens by factors of 1.5 x (inner) and 1.2 (outer) during $D_\perp$ increase
- Heat flux profile broadening increases to 2.0x (inner) and 1.8 (outer) by end of χ increase





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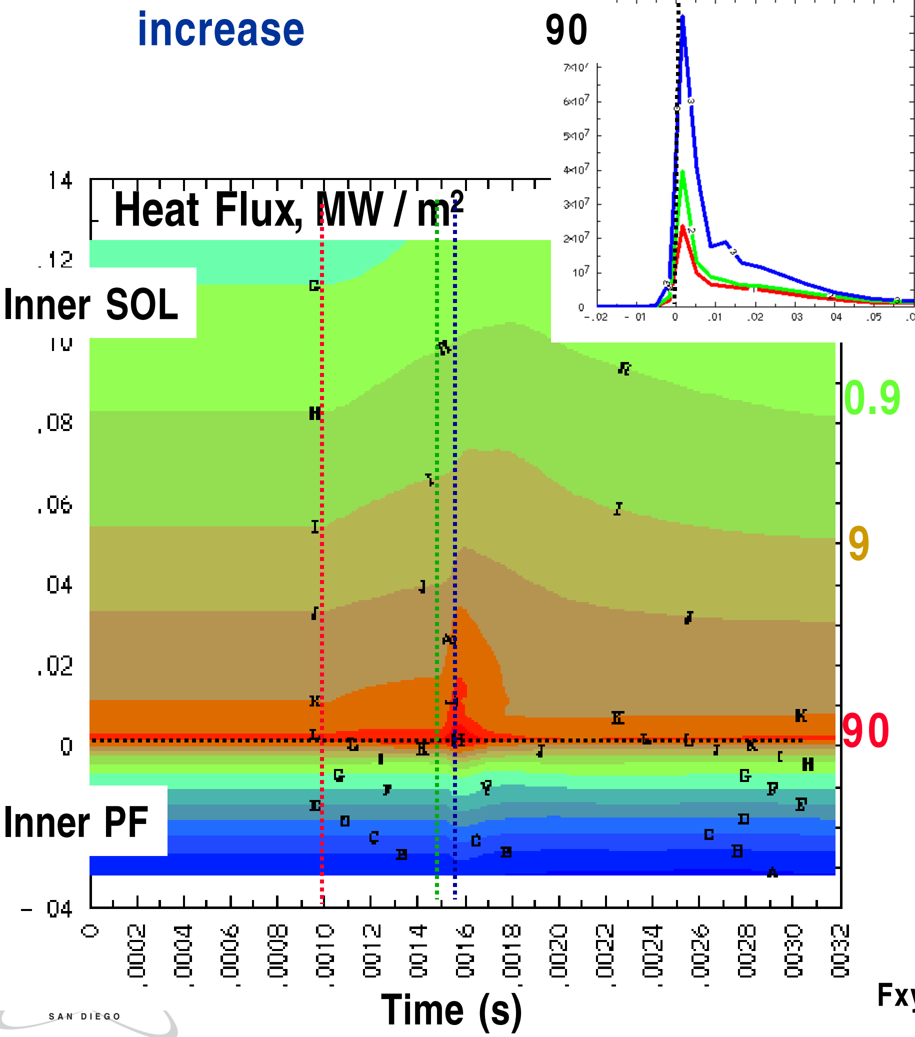
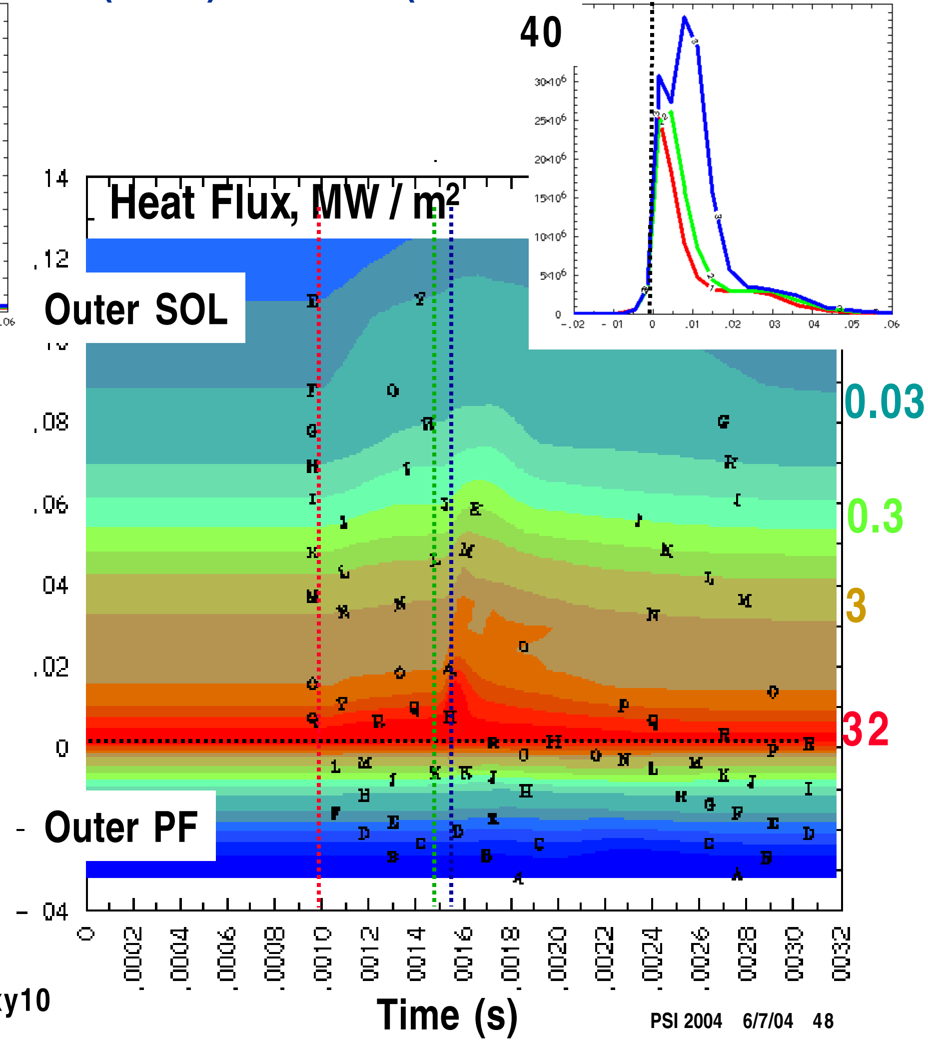
With ∇B ↑ broadening of heat flux during ELM less on inner and greater on outer target than with ∇B ↓

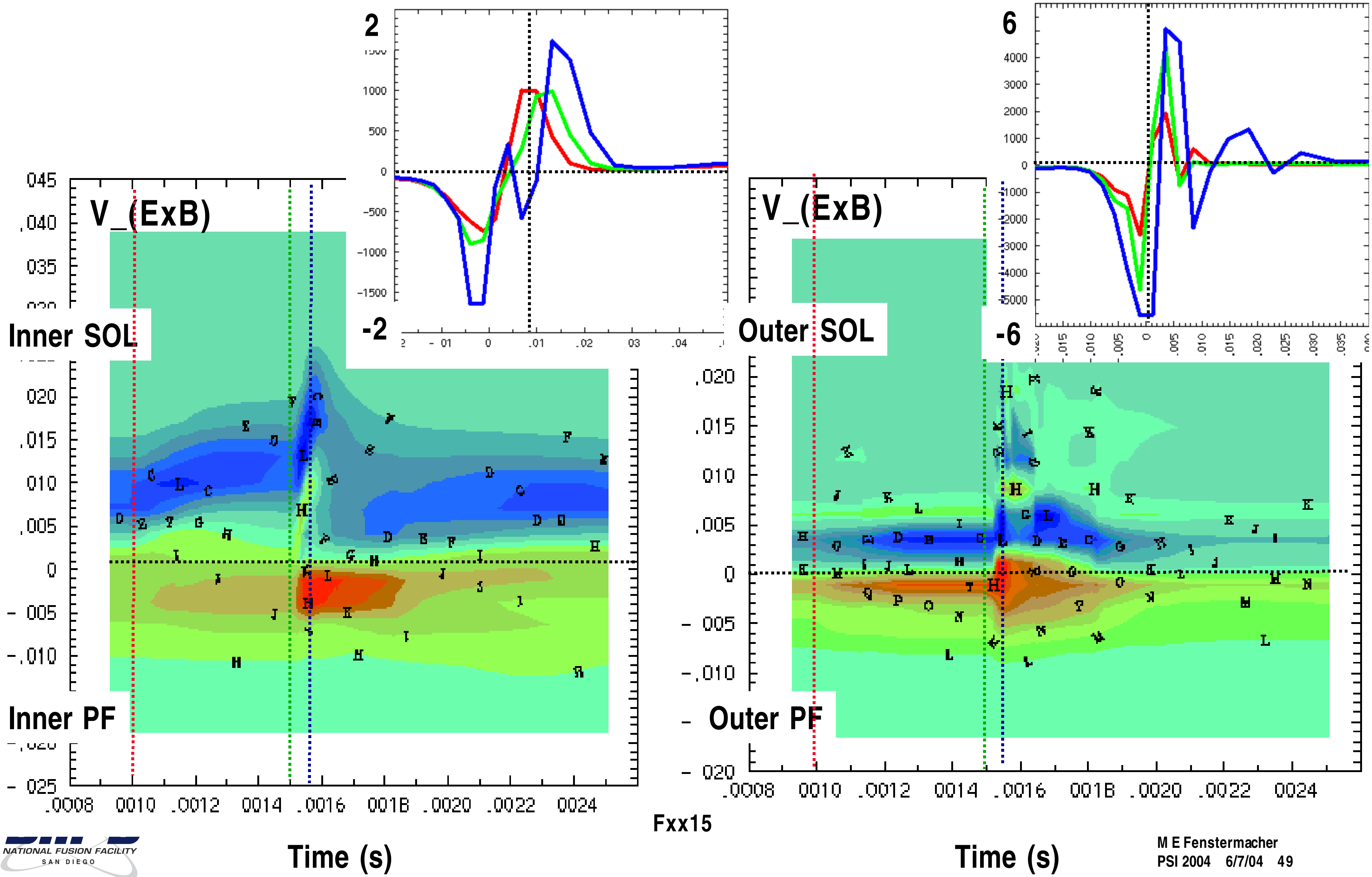
- Heat flux broadens by factors of 1.1 x (inner) and 1.5 (outer) during $D_\perp$ increase
- Heat flux profile broadening increases to 1.5x (inner) and 2.2x (outer) by end of X increase



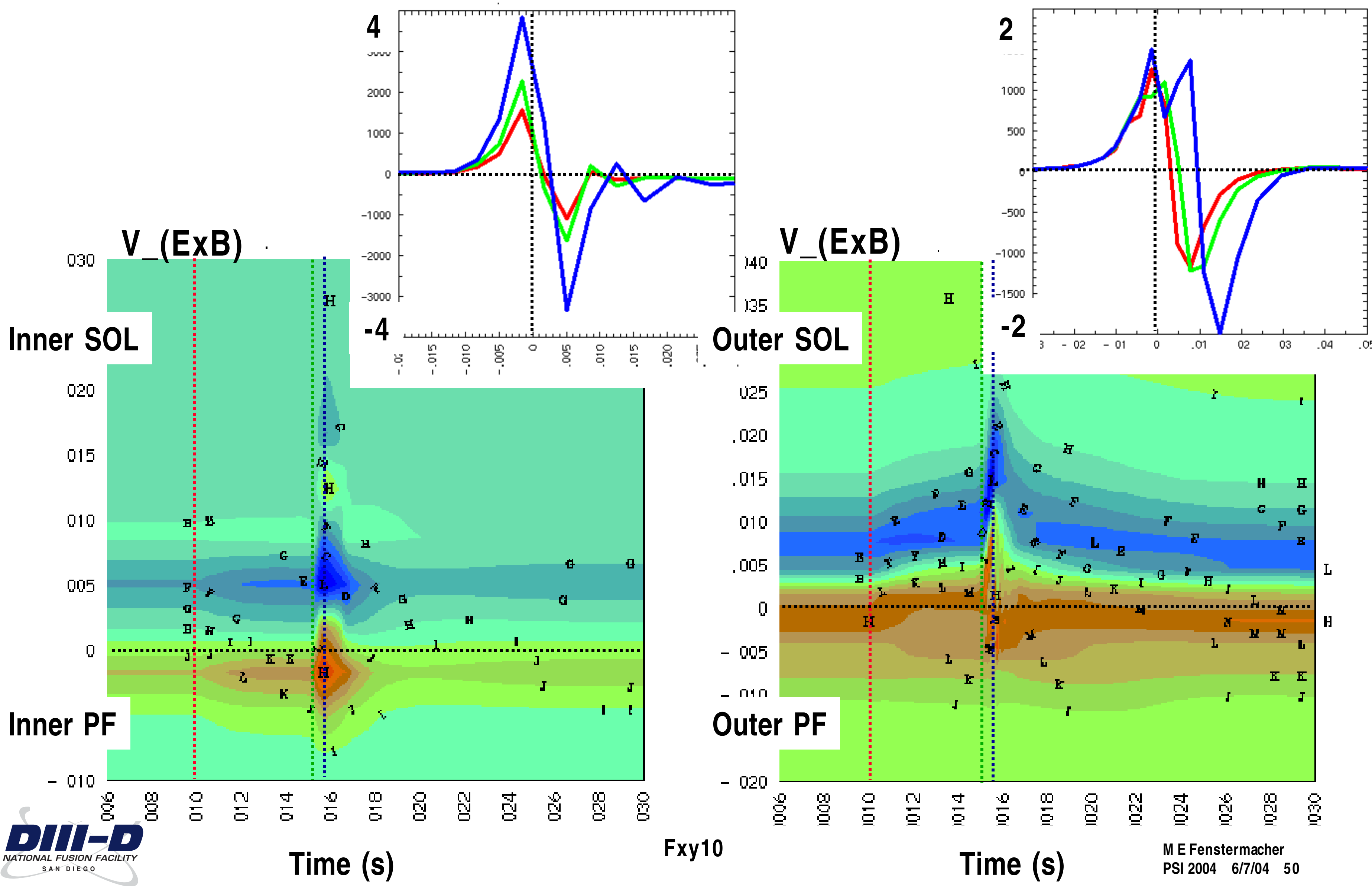
Fxy10



With ∇B ↓ private flux region poloidal ExB velocity increases 2x at ELM crash

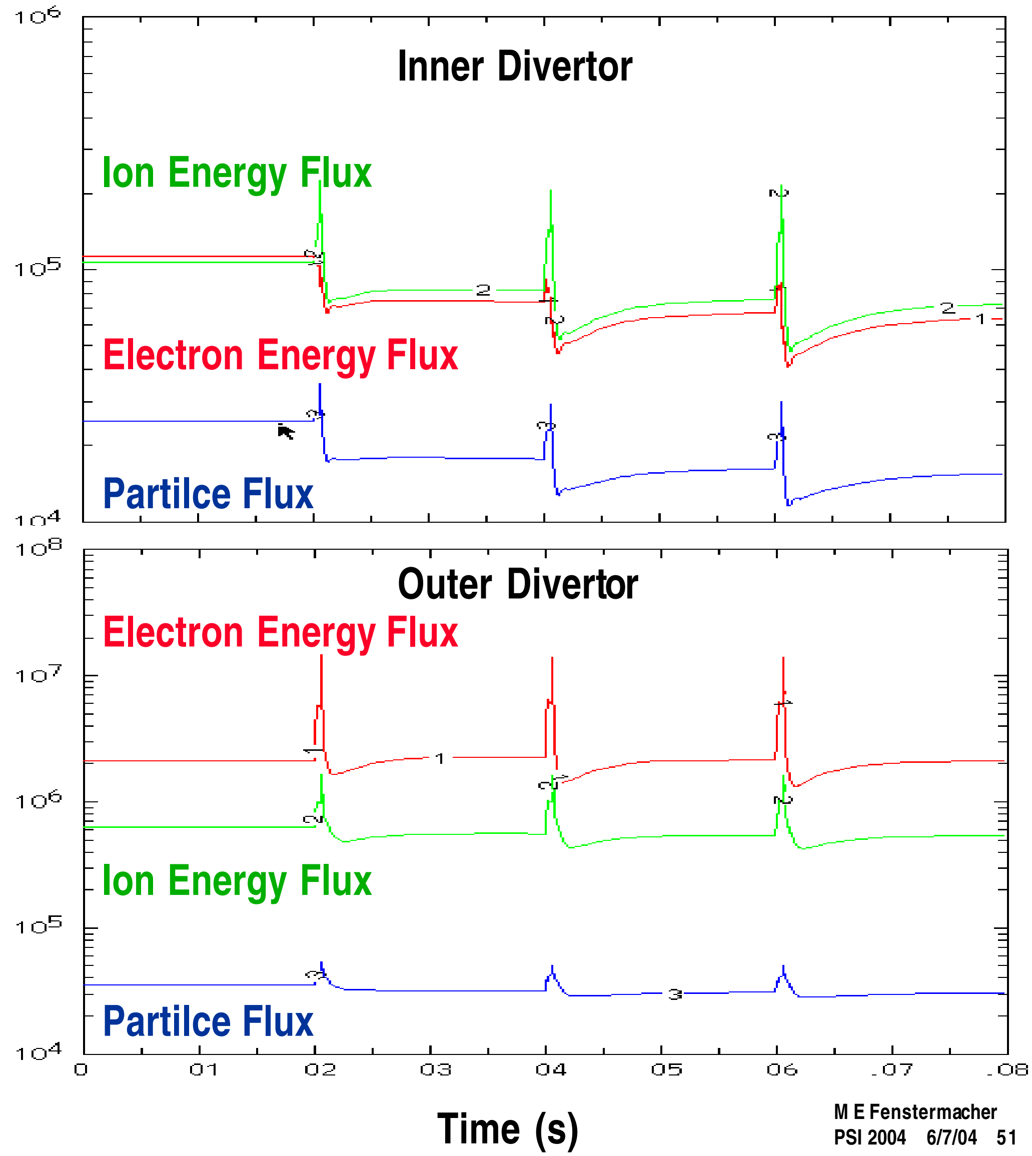


With ∇B ↑ change to PF poloidal v_{ExB} larger at inner target and smaller at outer target than with ∇B ↓



Simulation with multiple ELMs shows slow relaxation to new parameter regime between ELMs

- Divertor particle and energy fluxes between ELMs are still evolving after 3 ELMs
  - Effect stronger on inner divertor
  - Indicates long time-scale effects (carbon, neutrals) still responding to ELMs
- Future single ELM simulations should start from "ELMing equilibrium" not steady state between-ELM solution



Summary: SOL/divertor ELM behavior depends on both density and B-field dependent particle drifts

- Normalized delays of inner vs outer D_α and P_{rad} depend on n_e
  - Observations
    - Stronger n_e dependence in normal drifts direction
    - Delay greater and recovery longer for D_α than for P_{rad}
  - Possible Explanations
    - ELM poloidal character may change with n_e
    - Fast electron effects may dominate at low n_e; ion convection at high n_e

- Normalized delays of inner vs outer D_α and P_{rad} change with B-dependent drifts
  - Delays much less in reversed drifts case
  - Differences in pre-ELM divertor conditions with B_T play a role
  - Different response of E_r to ELM in normal and reversed drifts cases may affect E x B drifts during ELM evolution

- Pedestal particles ejected far into SOL independent of n_e or drifts direction

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Summary: UEDGE ELM simulations including drifts show evolution and B-field dependence similar to data

- Model of ELM as $D_\perp$ and χ increases supported by similarity of calculated and measured ELM evolution
  - Initial response of simulated D_α and P_{rad} to $D_\perp$ increase and larger response to χ increase similar to measured ELM signals
  - Pedestal density and temperature drops with SOL n_e increase and unchanged SOL T_e similar to data from low ne plasmas
  - As in the data, simulated delays larger for D_α than for P_{rad} in normal drifts case; small P_{rad} delays and positive/negative delay in D_α for reversed drifts case
  - Simulated Q_{div} broadens ~ 2x at ELM crash in normal drifts case, broadening less in reversed drifts case.
- UEDGE cases with normal and reversed drifts shows B-field dependent features seen in data
  - Delays in D_α and P_{rad} less in reversed drifts simulations consistent with measurements
  - ELM perturbation of divertor Er and poloidal particle drifts may contribute to divertor ELM response