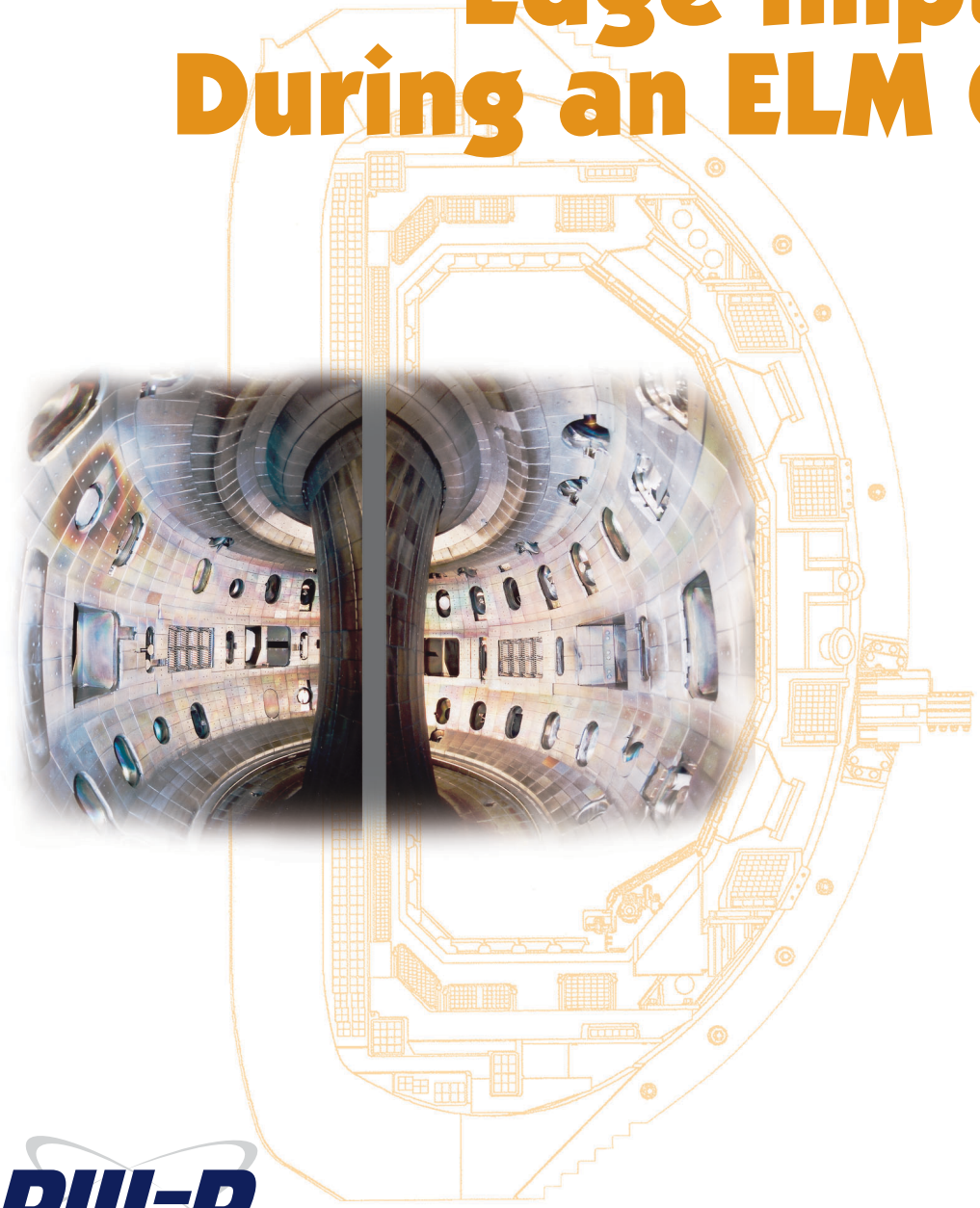
Edge Impurity Dynamics During an ELM Cycle in DIII–D



by

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in collaboration with

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T.H. Osborne,[2] P.B. Snyder,[2]
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46th Annual Meeting of
Division of Plasma Physics
Savannah, Georgia

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MOTIVATION

- The characterization of Type I ELMs has been an active area of research for the past 30 years as we seek to capture the beneficial aspects of ELMs (particle control) while mitigating their unfavorable effects (transient heat loads and erosion)

- Yet, while progress has been made, several issues with regard to the ELM cycle remain unresolved:

Snyder talk, Wed. PM

— What is trigger mechanism for the ELM?
  - ★ Studies suggests that ELMs are triggered by ideal, moderate toroidal mode number instabilities (known as a peeling-ballooning mode)

— What causes the particle and energy loss?
  - ★ While peeling-ballooning theory can qualitatively reproduce some aspects of the measured losses, some other transport mechanism appears to be necessary to explain overall effect

— How do transport properties change during the inter-ELM period?
  - ★ While it is known that improved edge confinement in H-mode is correlated with an increase ExB shear, the effect of E_r on transport during the ELM cycle is unknown

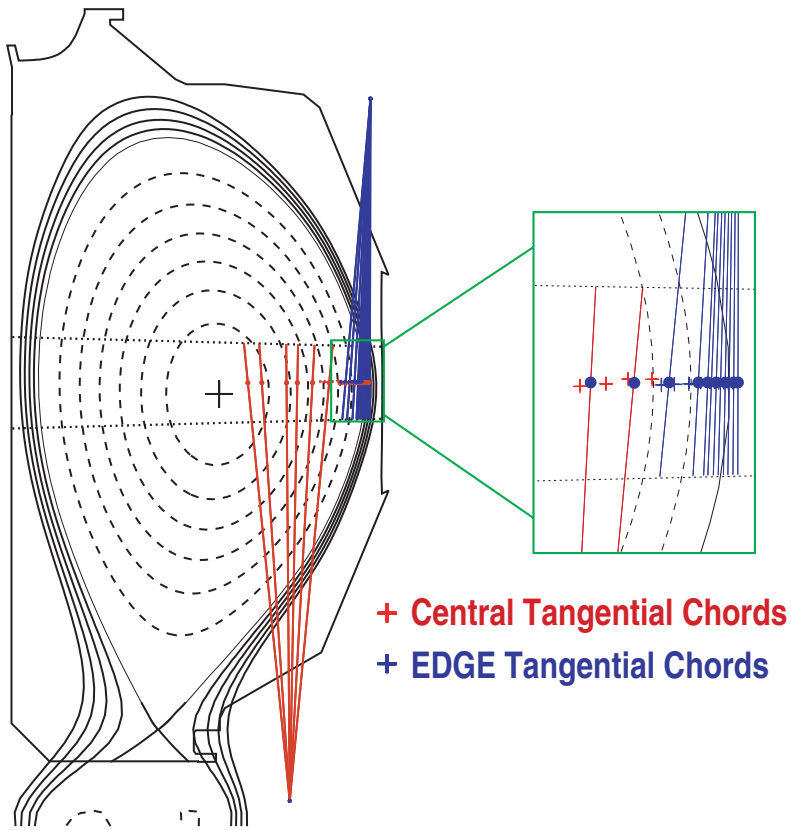
SUMMARY OF RESULTS

- Using temporally and spatially resolved measurements of the C^{+6} CER emission in the edge of an ELMing H–mode, the following observations have been made:
  - Each ELM causes a rapid (< 300 μs), localized (< 4 cm on the outboard midplane) expulsion of impurity density, energy, and momentum
  - All species respond to the ELM in a similar manner over a wide range of edge conditions
  - Density perturbation and convective energy loss is invariant over a wide range in edge collisionality
  - Initial response to the ELM suggests a convective expulsion of plasma
  - E_r well near the separatrix disappears at the ELM, but redevelops very quickly
- Analysis indicates that the initial response to the ELM is rapid convective energy loss, followed by an increase in edge thermal transport associated with the change in E_r at the ELM event

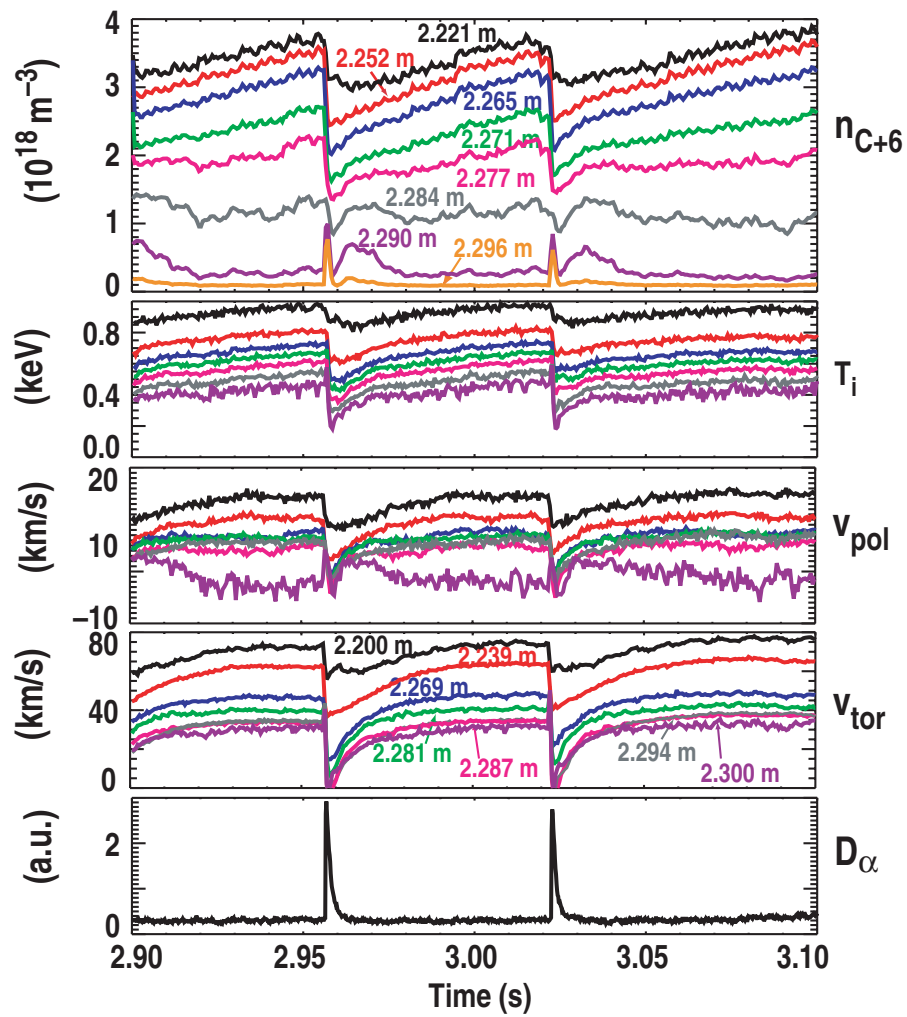
HIGH TIME RESOLUTION CER MEASUREMENT ALLOWS DETAILED STUDY OF THE IMPURITY DYNAMICS DURING THE ELM CYCLE

CER Spatial Resolution

- 3 mm for density, temperature
- 6 mm for toroidal and poloidal rotation



- Time resolution: $\geq 274\ \mu s$



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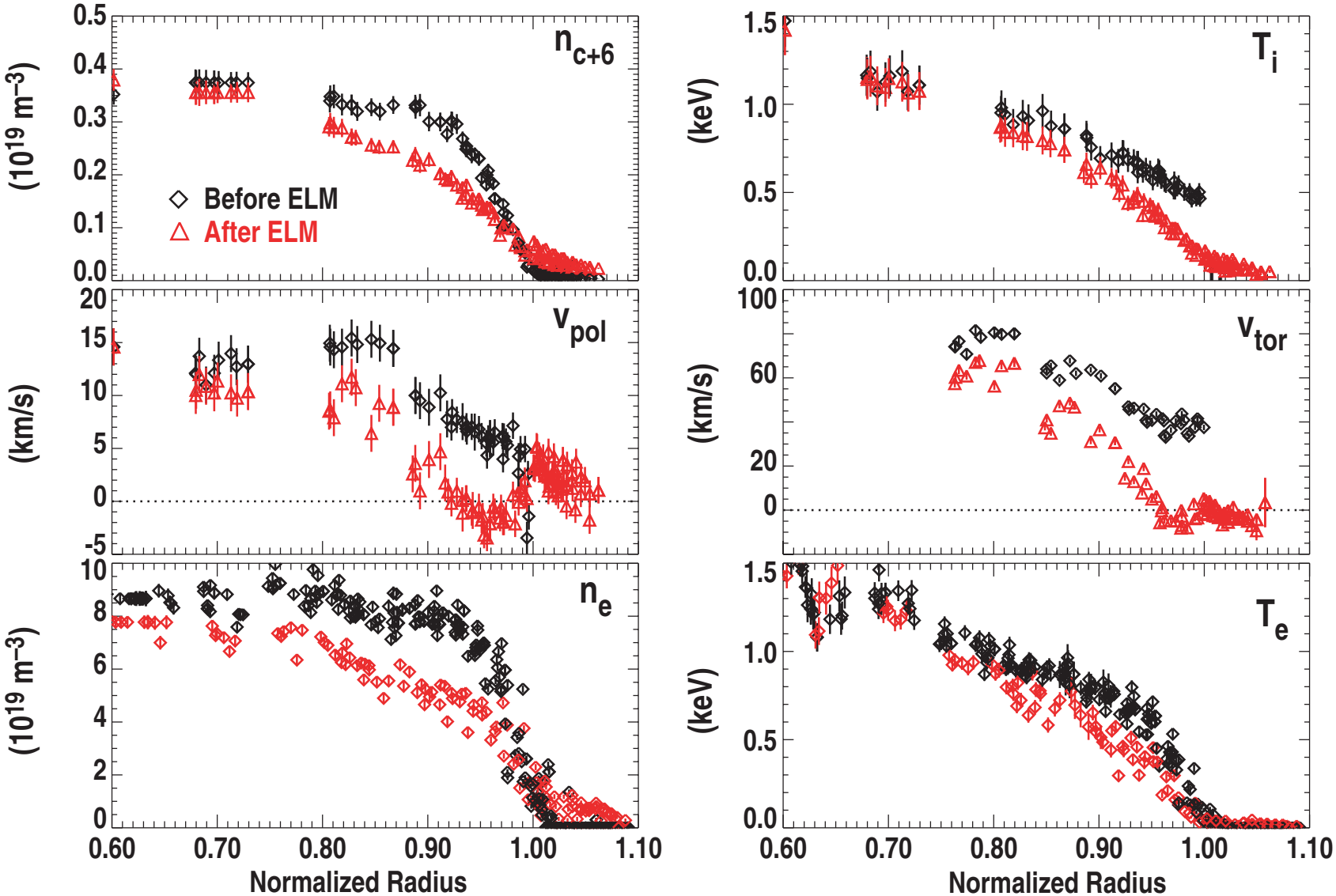
SIGNIFICANT AMOUNT OF IMPURITY DENSITY, ENERGY, AND MOMENTUM IS EXPELLED BY EACH ELM



- Profile constructed from data taken across a set of reproducible ELMs during an outer gap sweep

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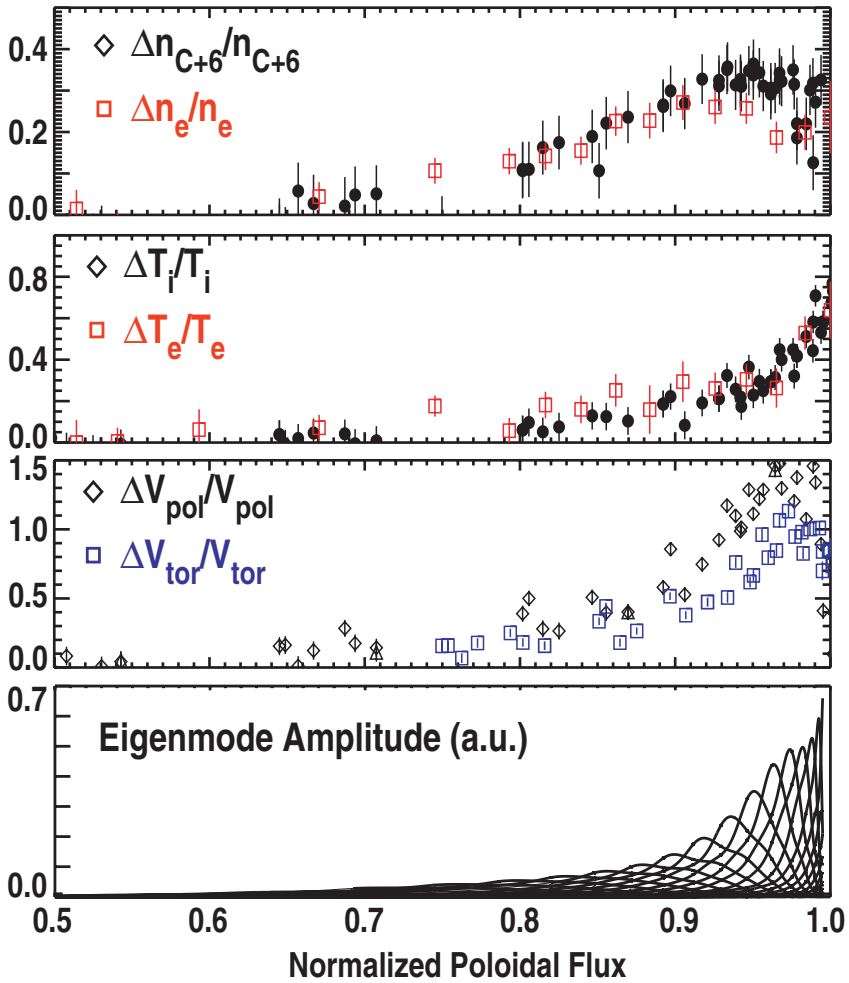
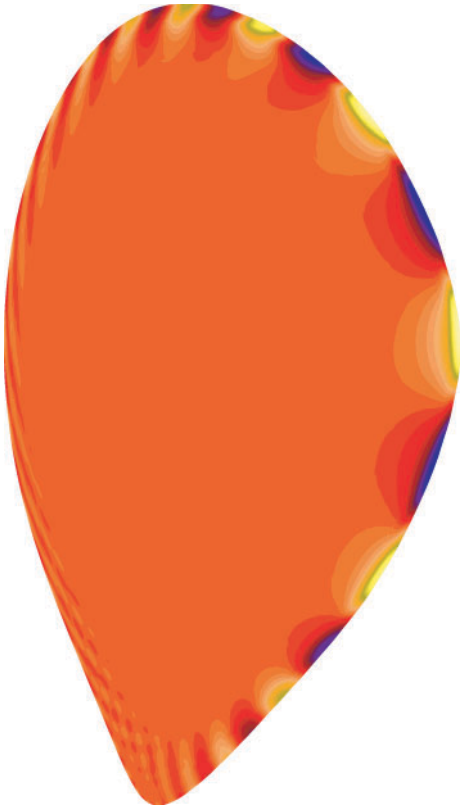
n_{C+6} and n_e PERTURBATION NEARLY IDENTICAL; T_i and T_e PERTURBATION ARE SIMILAR AND CONSISTENT WITH PEELING BALLOONING EIGENMODE



Eigenmode structure calculated by ELITE (n = 6)



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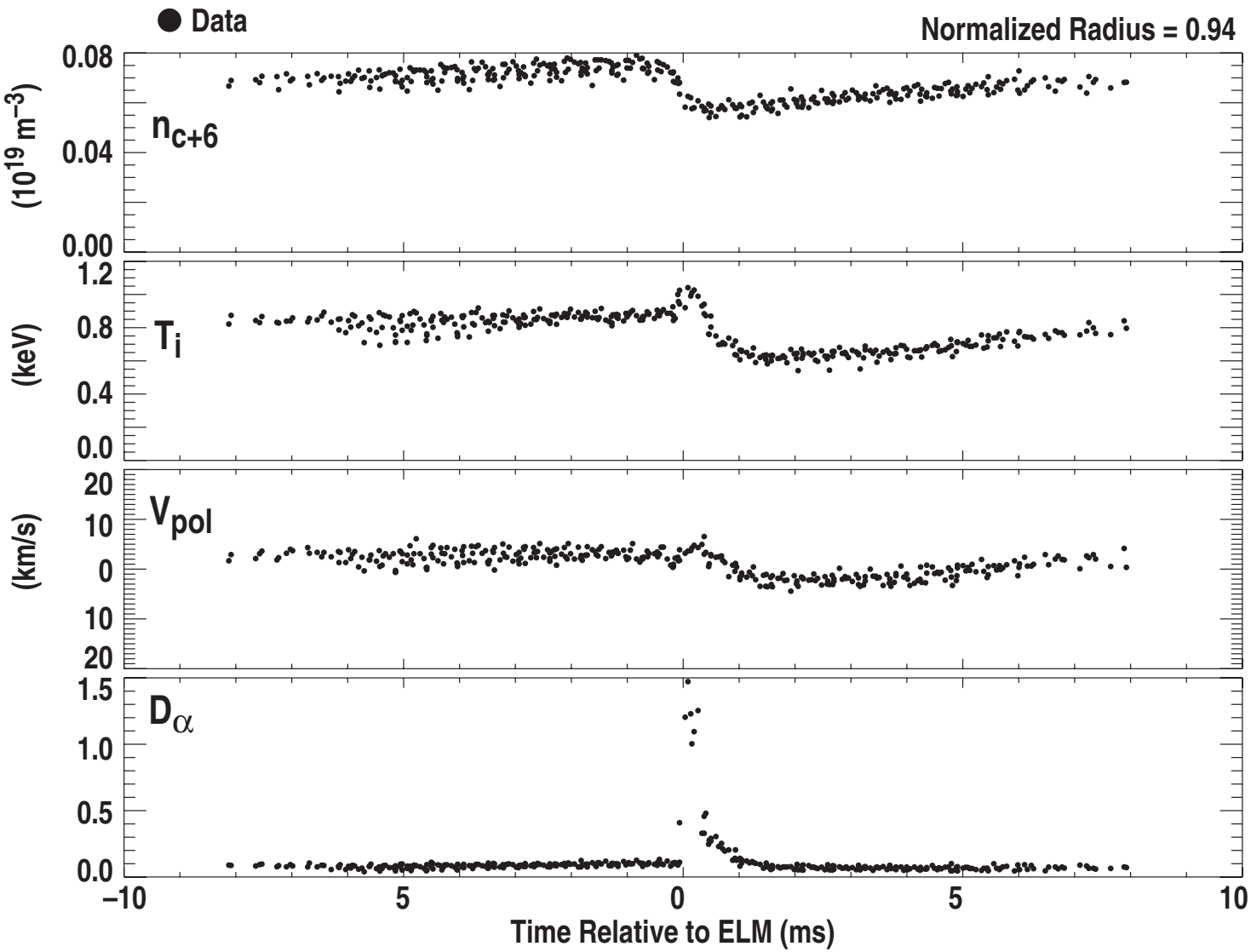
ORGANIZING TEMPORAL DATA WITH RESPECT TO ELM CYCLE IMPROVES TIME RESOLUTION AND PERTURBATION ANALYSIS



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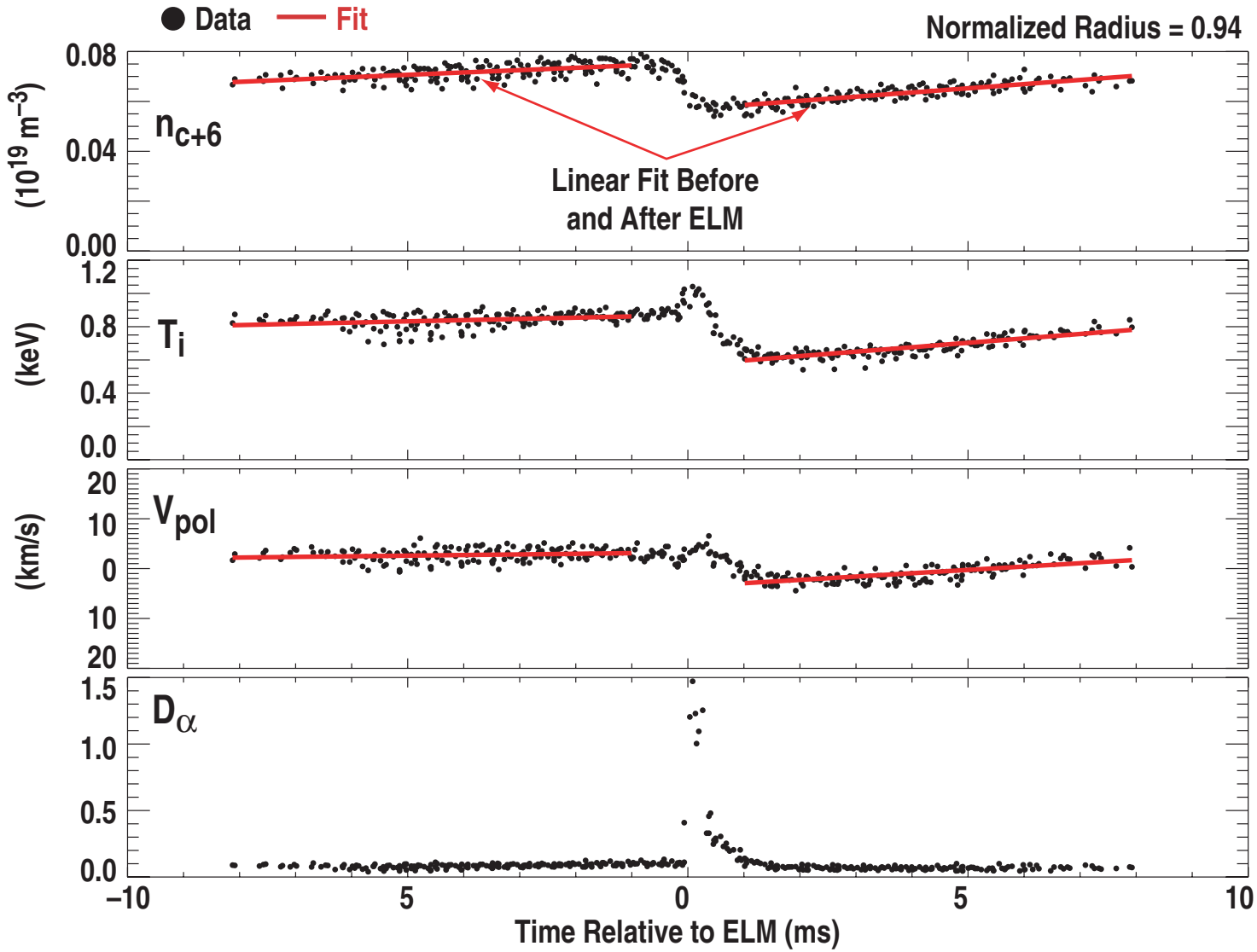

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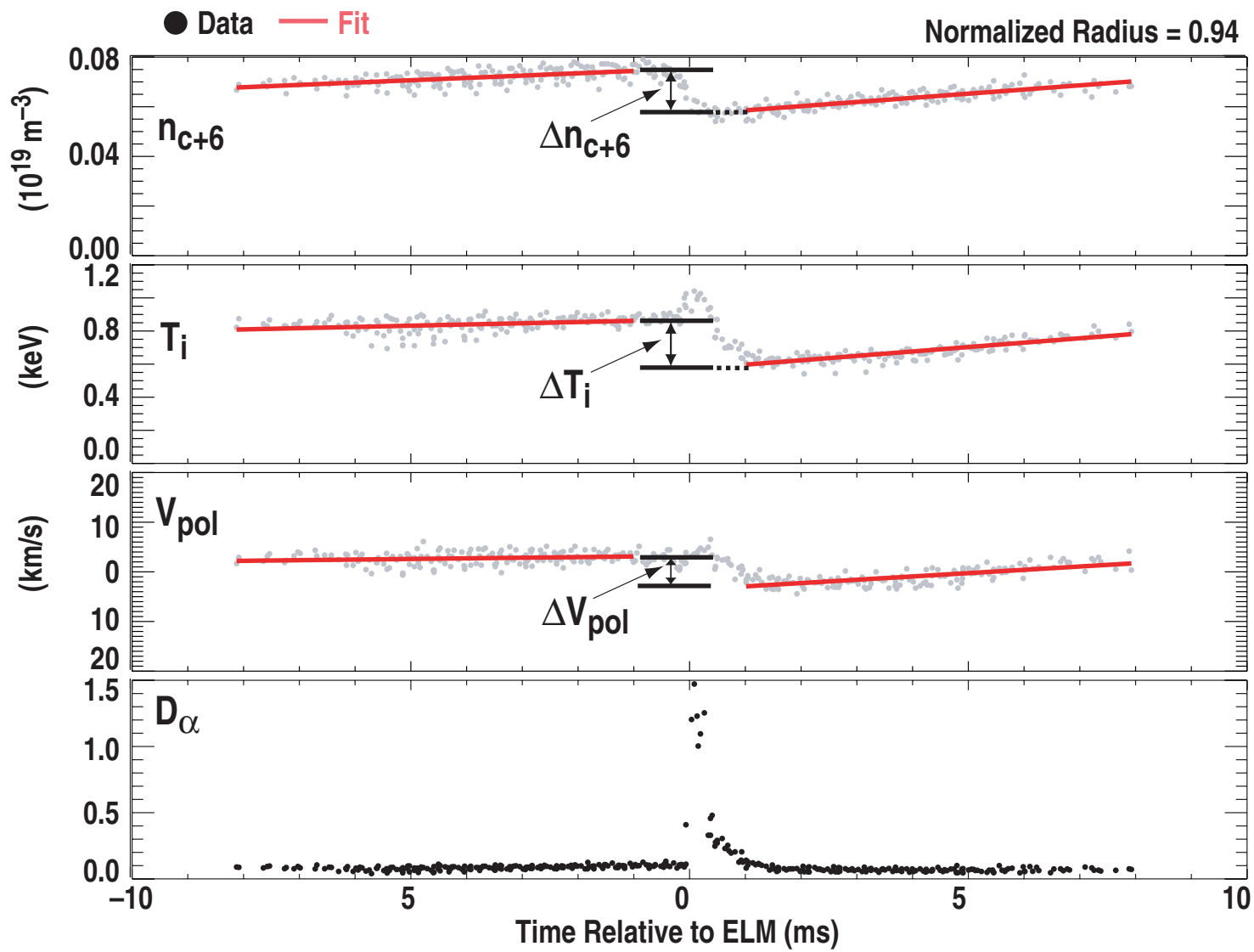

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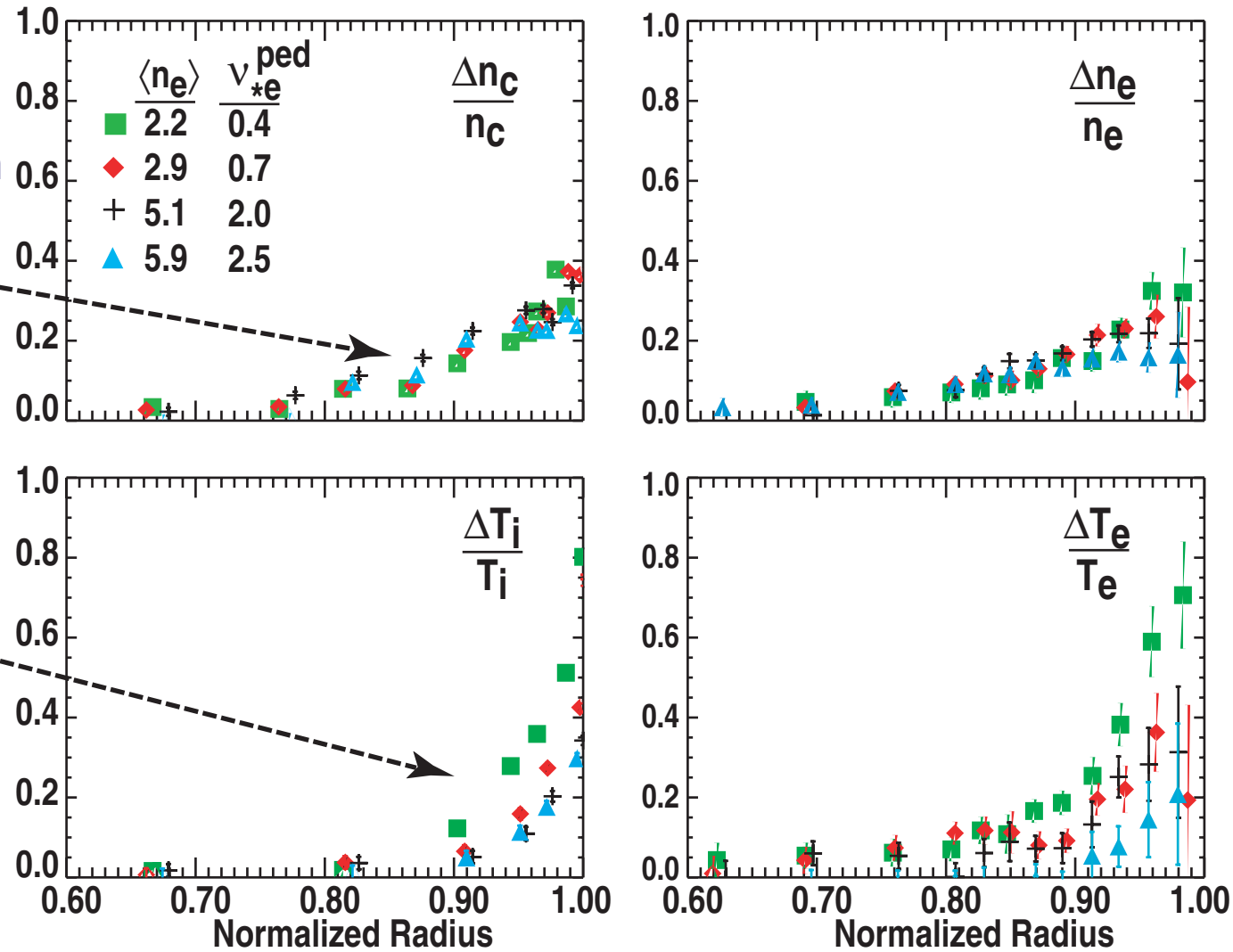
OVER A WIDE RANGE IN DENSITY, ELECTRON AND IMPURITY RESPONSE ARE NEARLY IDENTICAL

- Density perturbation constant as $\langle n_e \rangle$ increases
- Temperature perturbation decreases as $\langle ne \rangle$ increases



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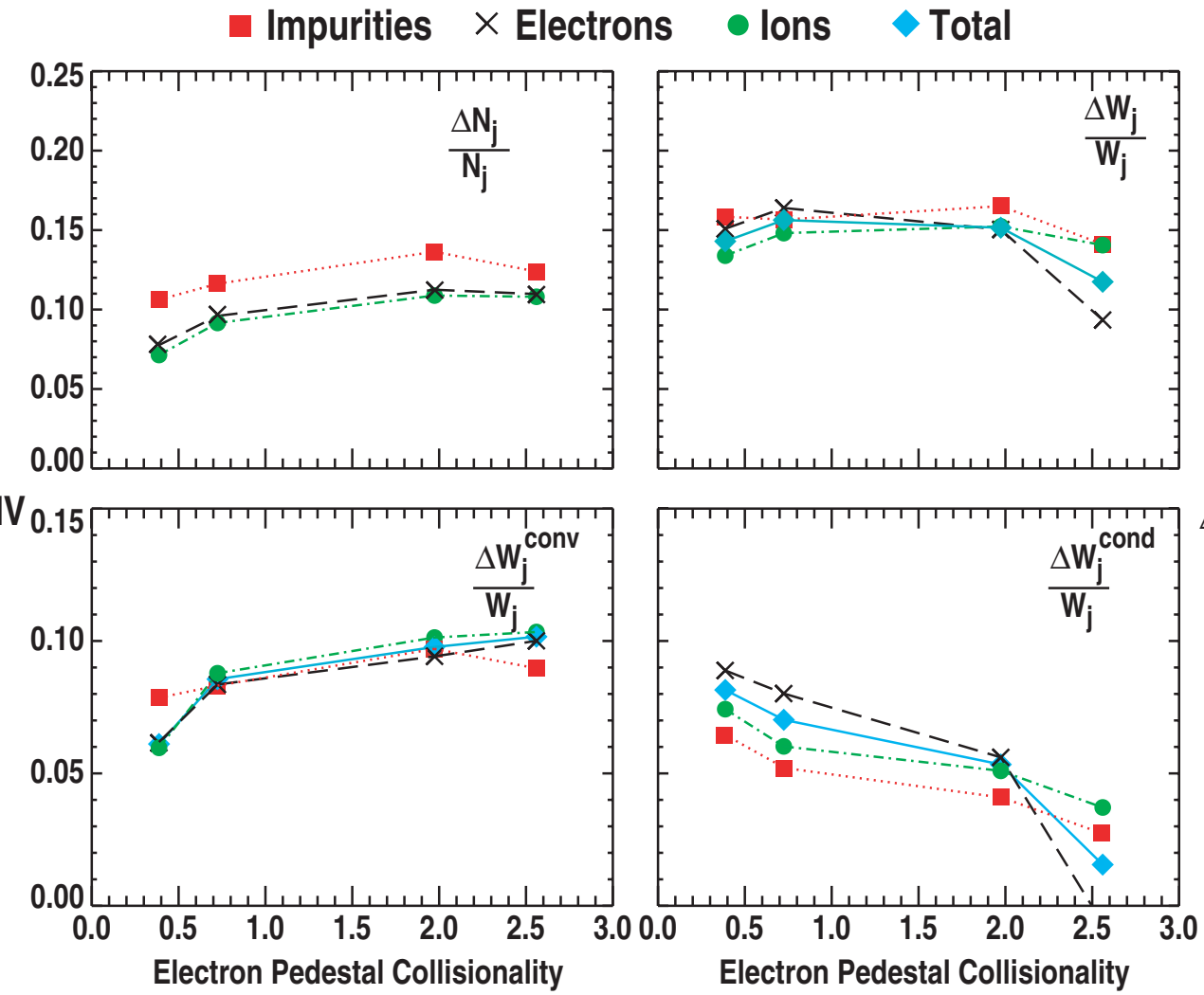
PARTICLE LOSS AND CONVECTIVE ENERGY LOSS INSENSITIVE TO COLLISIONALITY WITH IONS AND ELECTRONS SHARING EQUALLY

$\frac{\Delta N}{N} \approx 10\%$

$\frac{\Delta W}{W} \approx 15\%$

$\Delta W^{conv} = \frac{3}{2} \int \Delta n_j T_j \, dV$

$\Delta W^{cond} = \frac{3}{2} \int \Delta T_i \bar{n} \, dV$



- Convective loss insensitive to ν_{*e}^{ped}
- Conductive loss decreases with to ν_{*e}^{ped}

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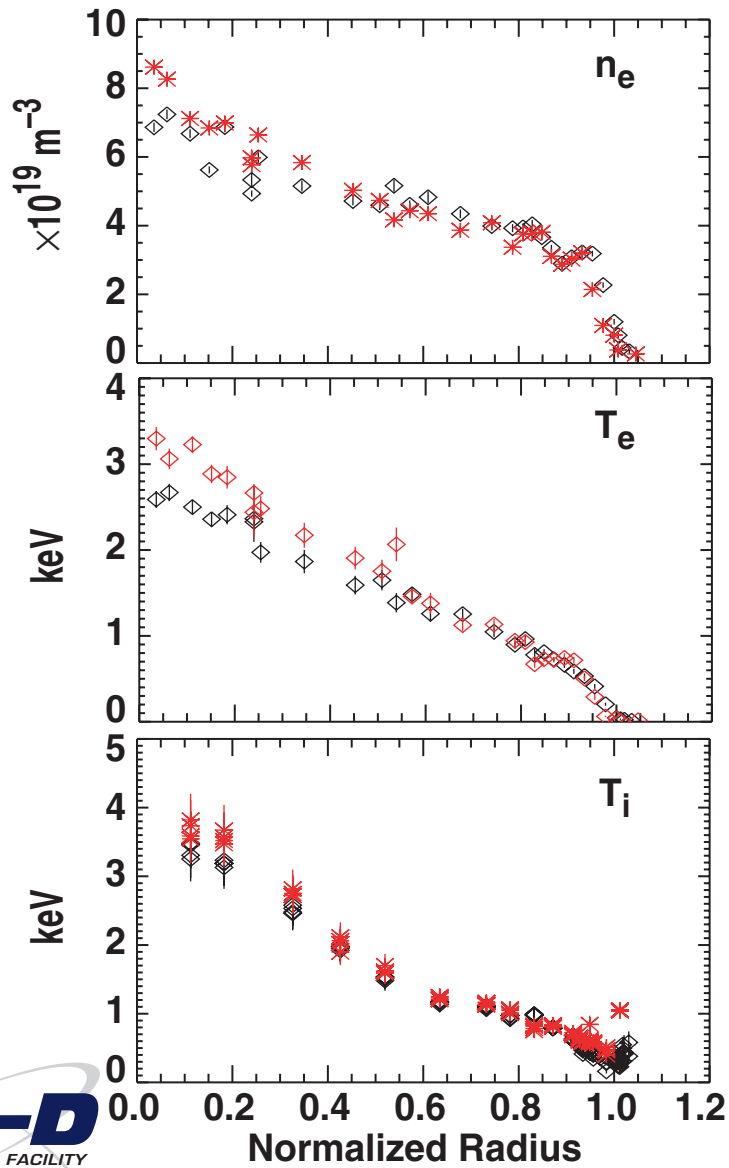
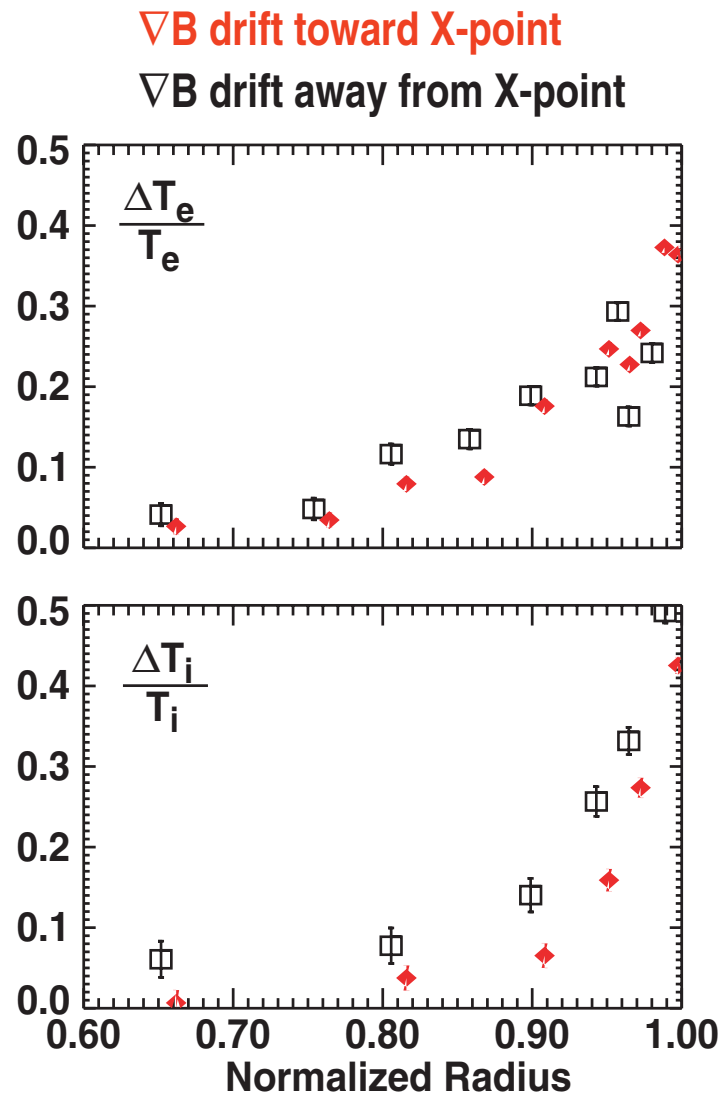
ALTHOUGH PROFILES ARE NEARLY IDENTICAL, PERTURBATION CHANGES AS TOROIDAL FIELD DIRECTION IS CHANGED





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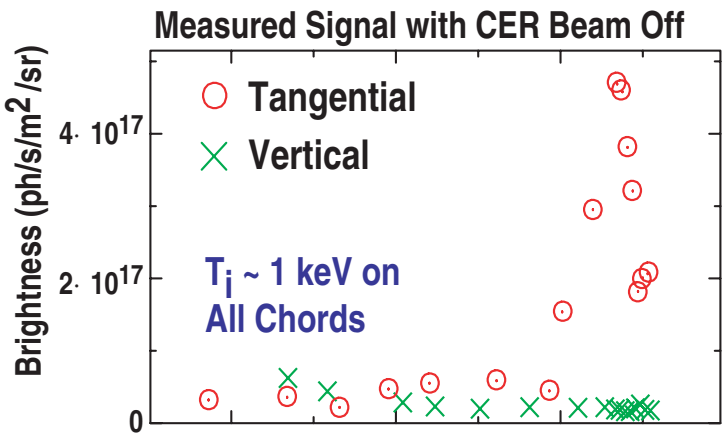
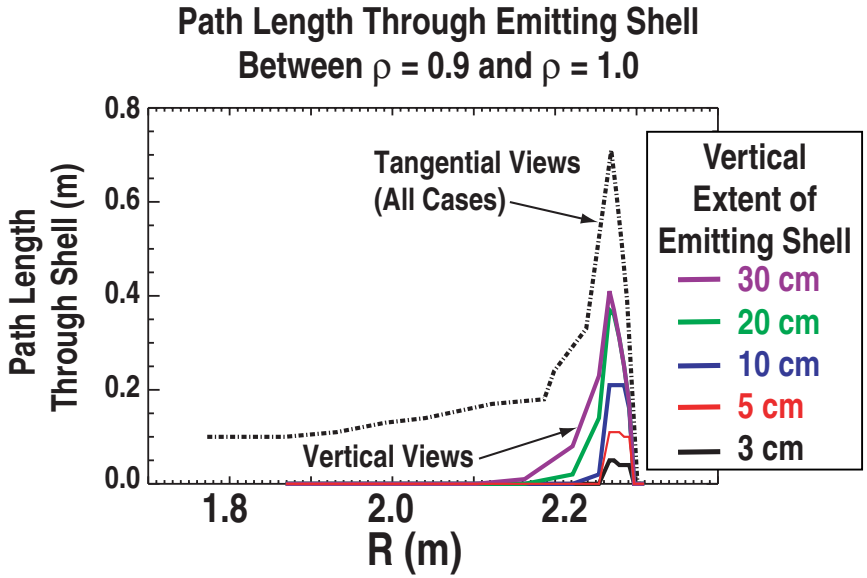
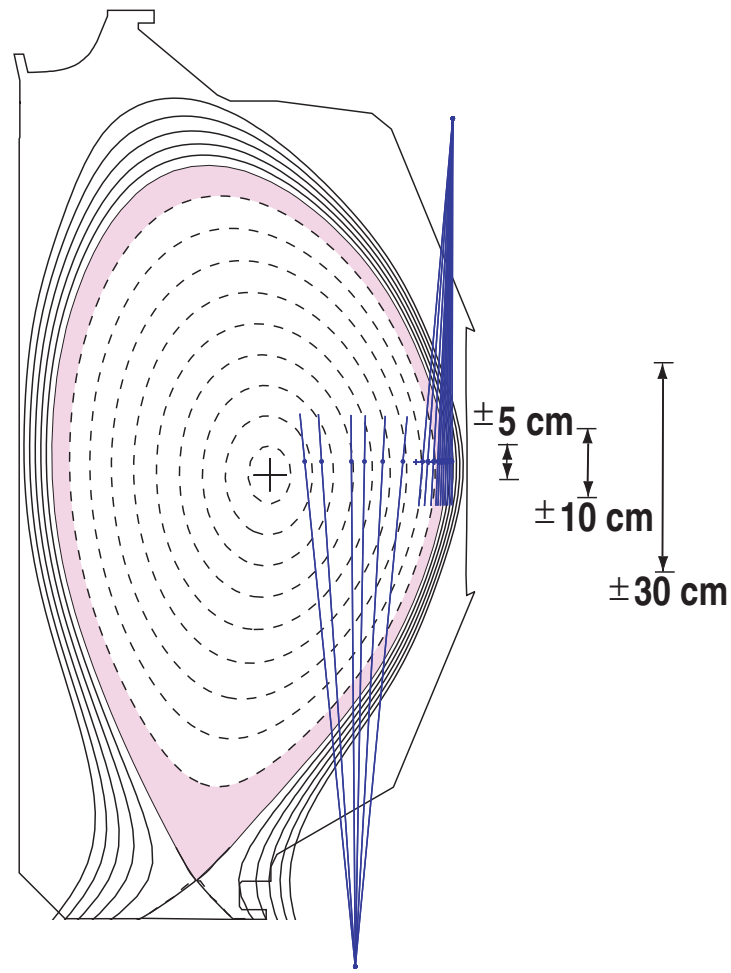
COMPARISON OF TANGENTIAL AND VERTICAL VIEWS SUGGESTS POLOIDALLY LOCALIZED PASSIVE EMISSION DURING ELM







- Measured data requires emission shell to have limited vertical extent (<5 cm)
  Interaction with outer wall not ruled out but deemed unlikely source

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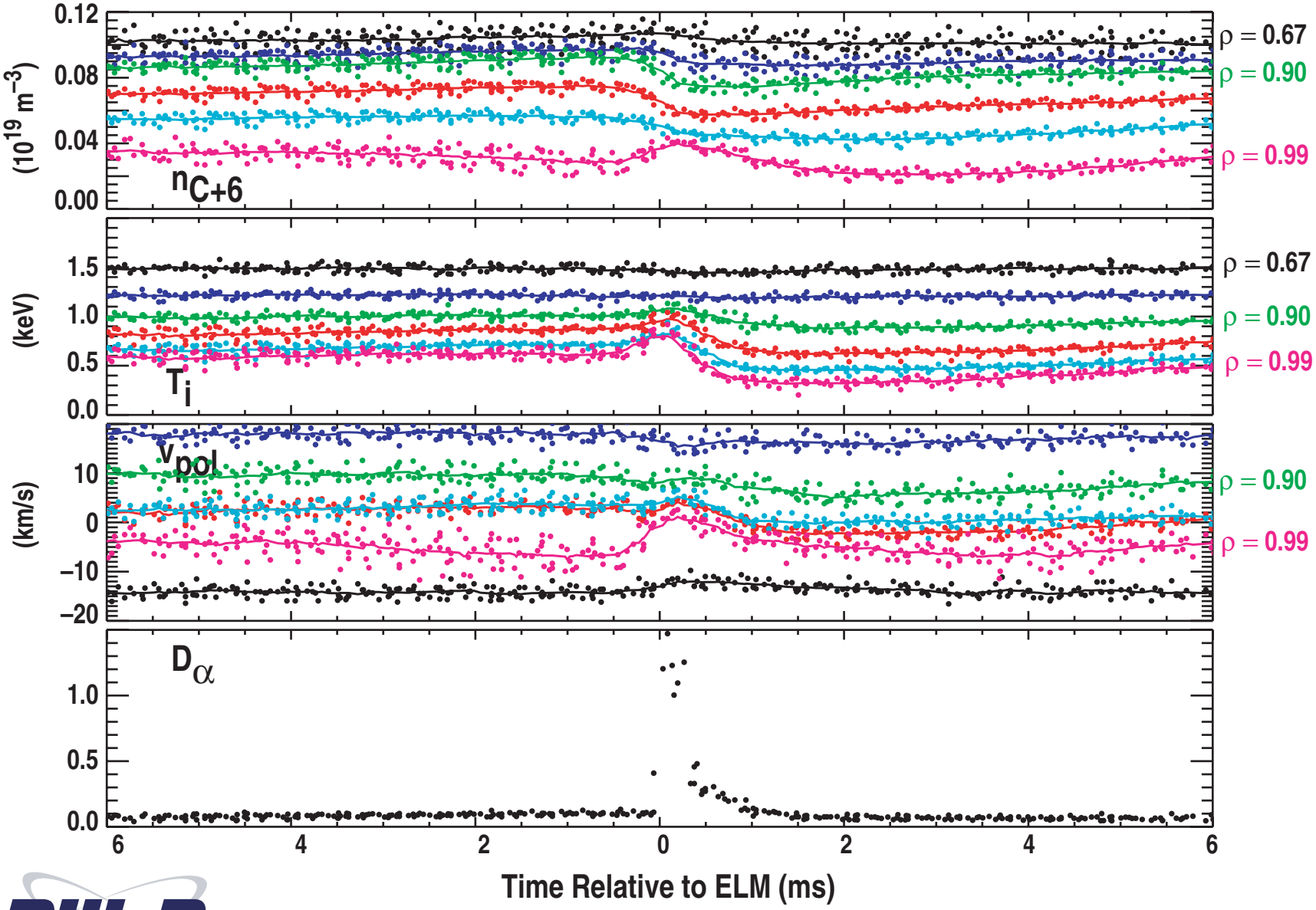
INITIAL RESPONSE TO ELM IS A RAPID DECREASE IN DENSITY AND SLIGHT INCREASES IN TEMPERATURE AND ROTATION VELOCITY



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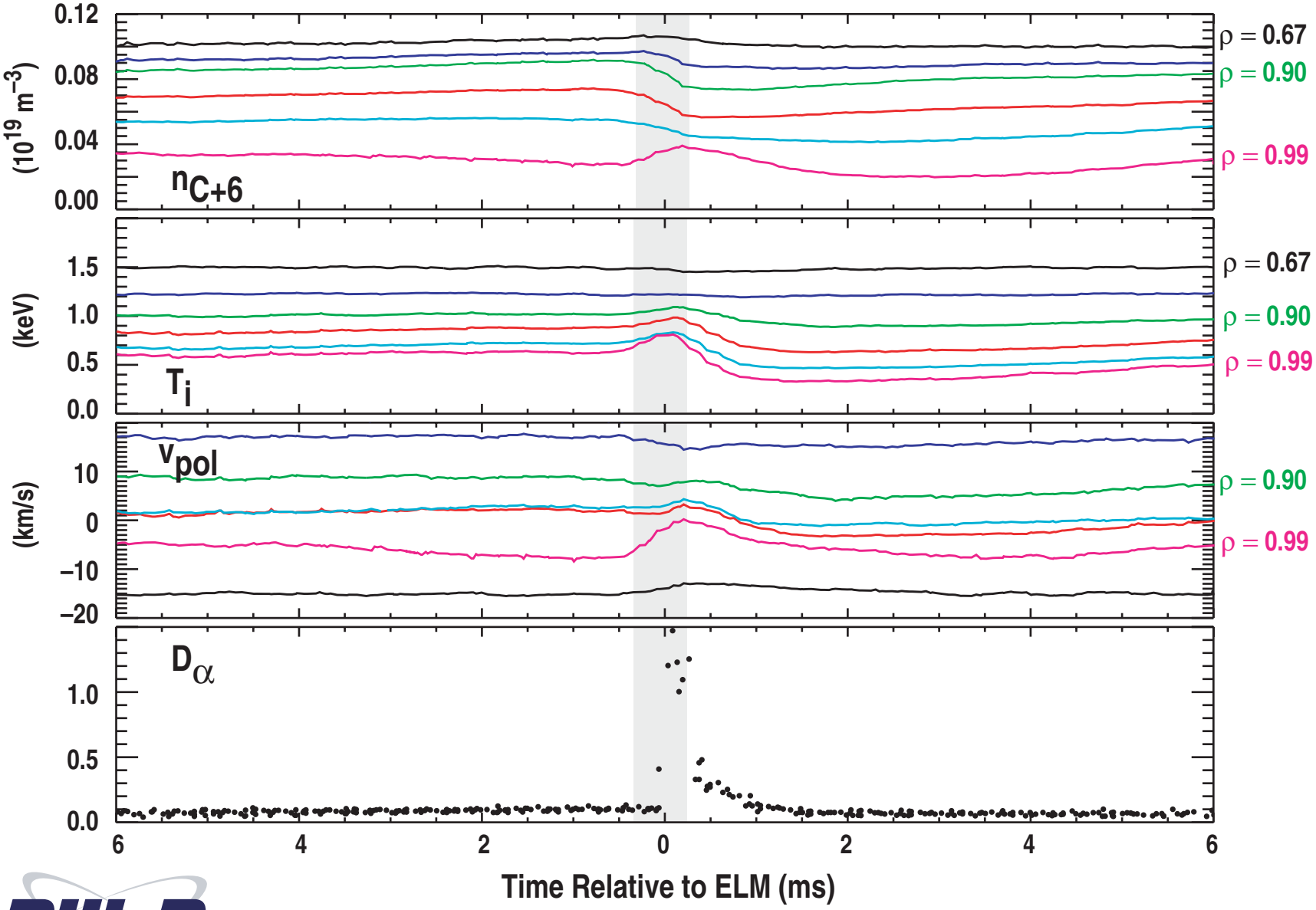

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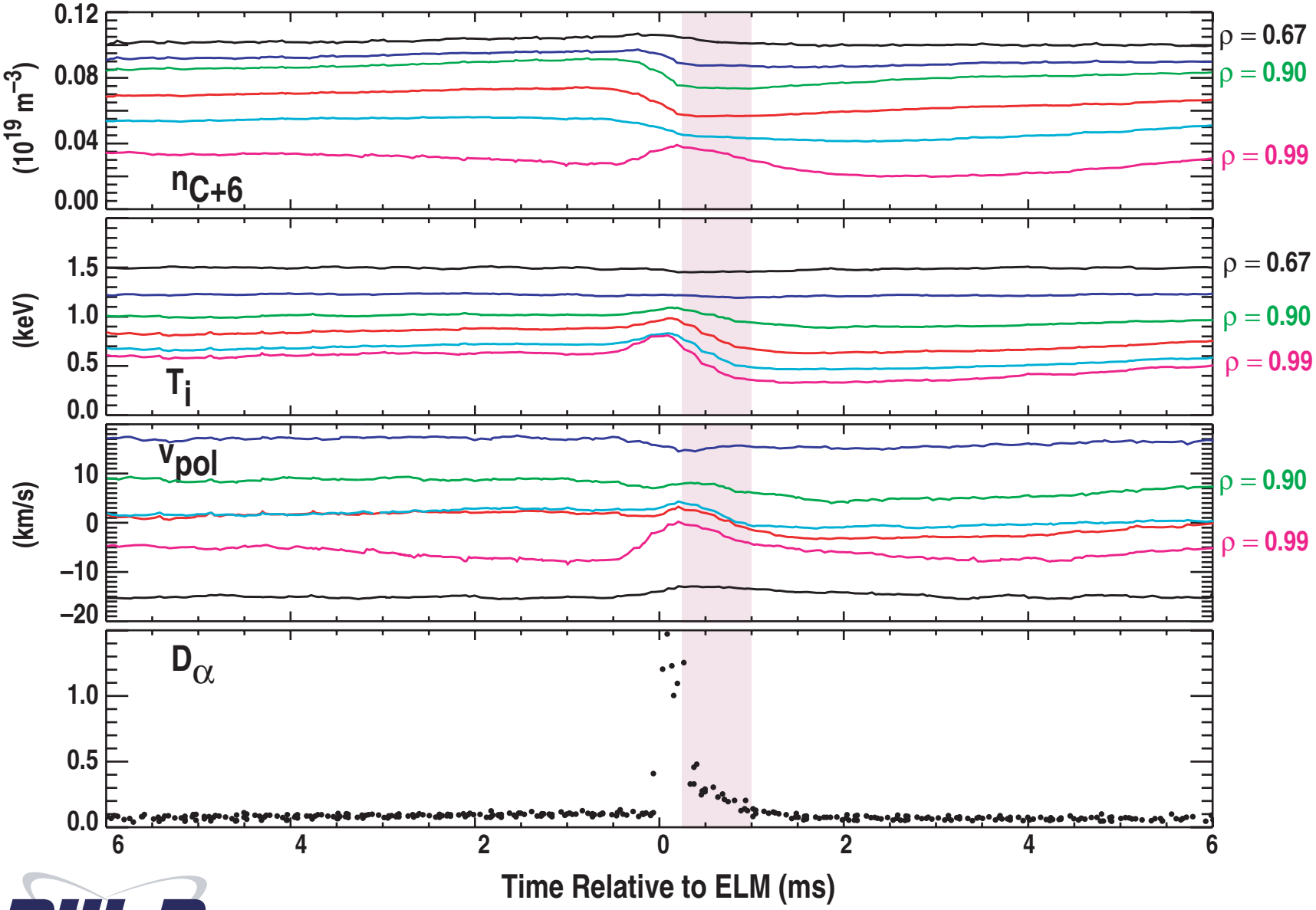
FOLLOWING INITIAL RESPONSE, TEMPERATURE AND ROTATION VELCOITY DECREASE OVER A 1 MS TIME SCALE



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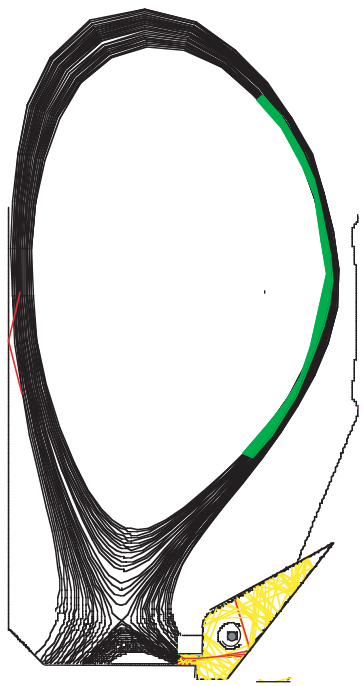
PRELIMINARY MODELING USING THE SOLPS (B2-EIRENE) SCRAPE-OFF LAYER TRANSPORT CODE REPRODUCES SOME QUALITATIVE FEATURES

- Solps* edge transport code follows time-dependent evolution of edge plasma including impurities and neutrals

*Schneider et al., Contrib. Plasma Phys 40 328 (2000).
Reiter, J. Nucl. Mater. 196-198, 80 (1992)

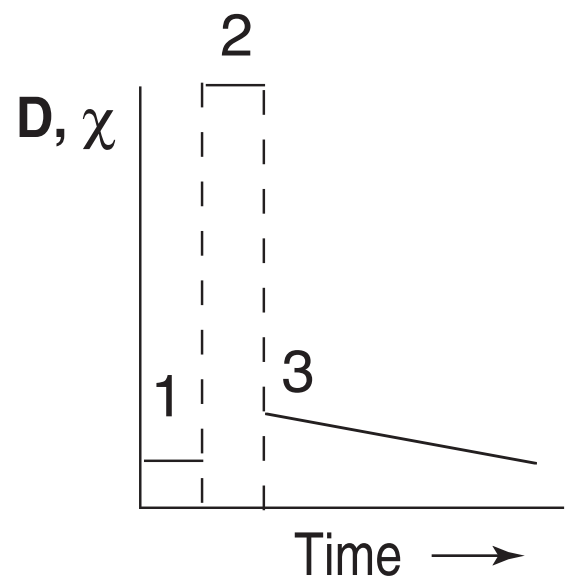
- Transport model for ELMs:

  Assume ELM only affects transport on outboard midplane (green area)



Transport time dependence (schematic):

1. Pre- ELM
2. Strong Enhancement (100 ms) at ELM
3. Loss of barrier, 2 x pre-ELM value
4. slow improvement to pre-ELM value



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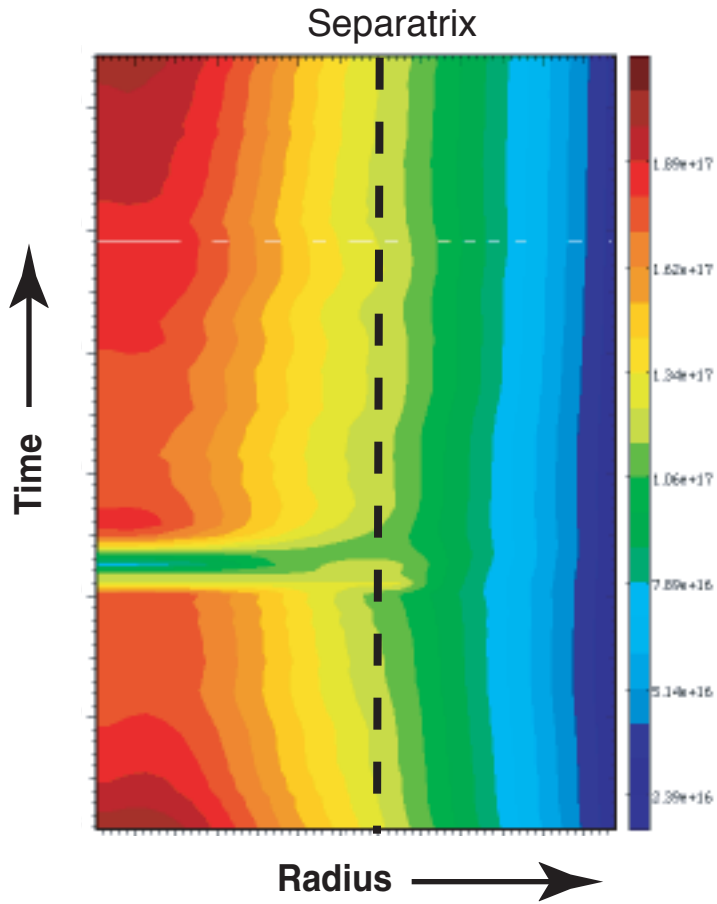
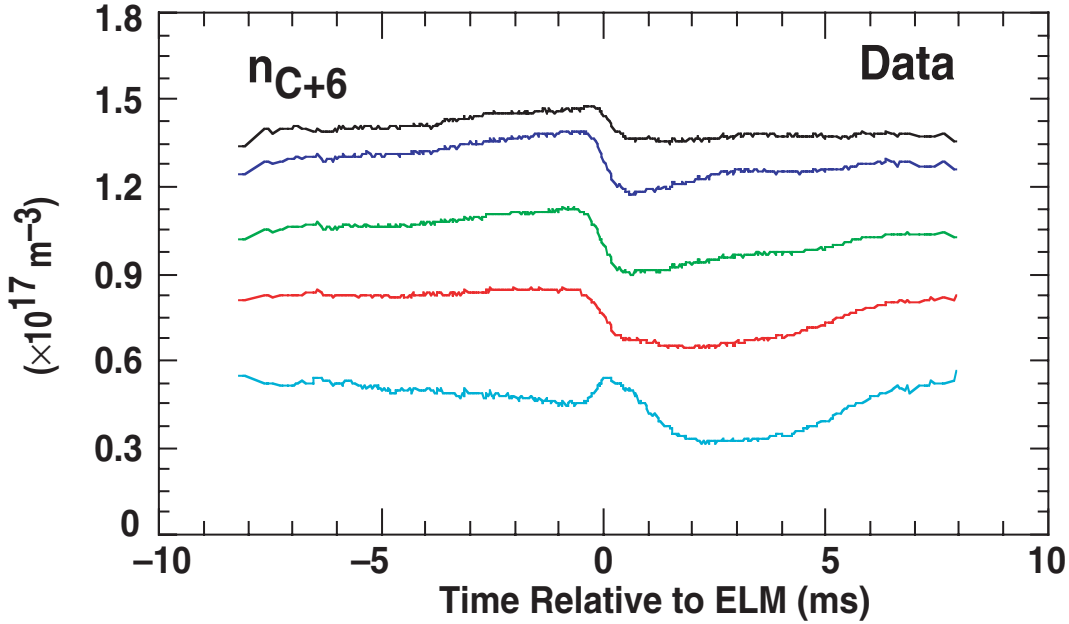
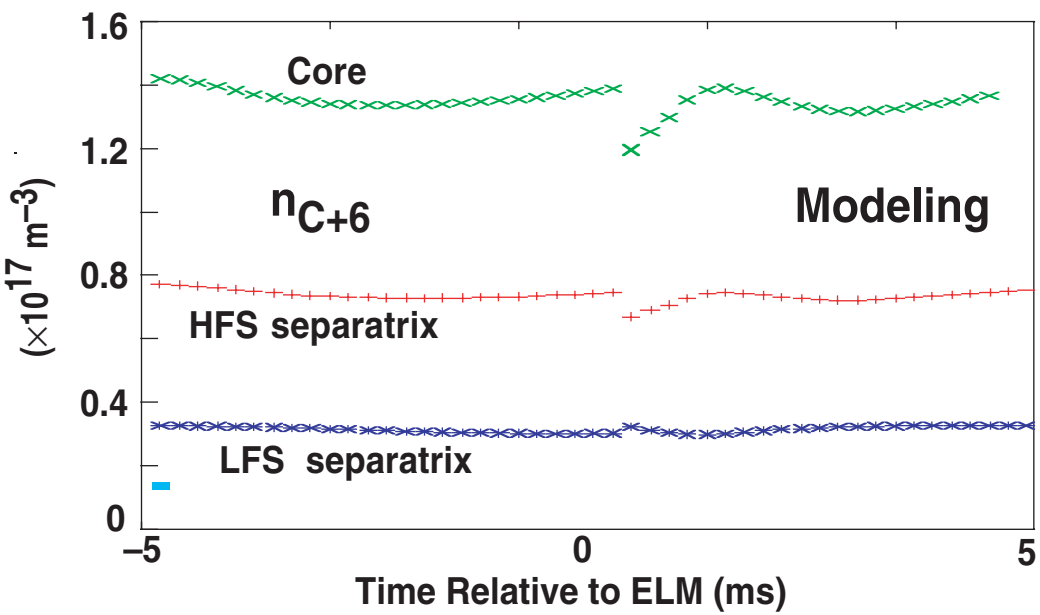
PRELIMINARY MODELING USING THE SOLPS (B2-EIRENE) SCRAPE-OFF LAYER TRANSPORT CODE REPRODUCES SOME QUALITATIVE FEATURES

n_{C+6} Evolution from solps (B2-EIRENE)







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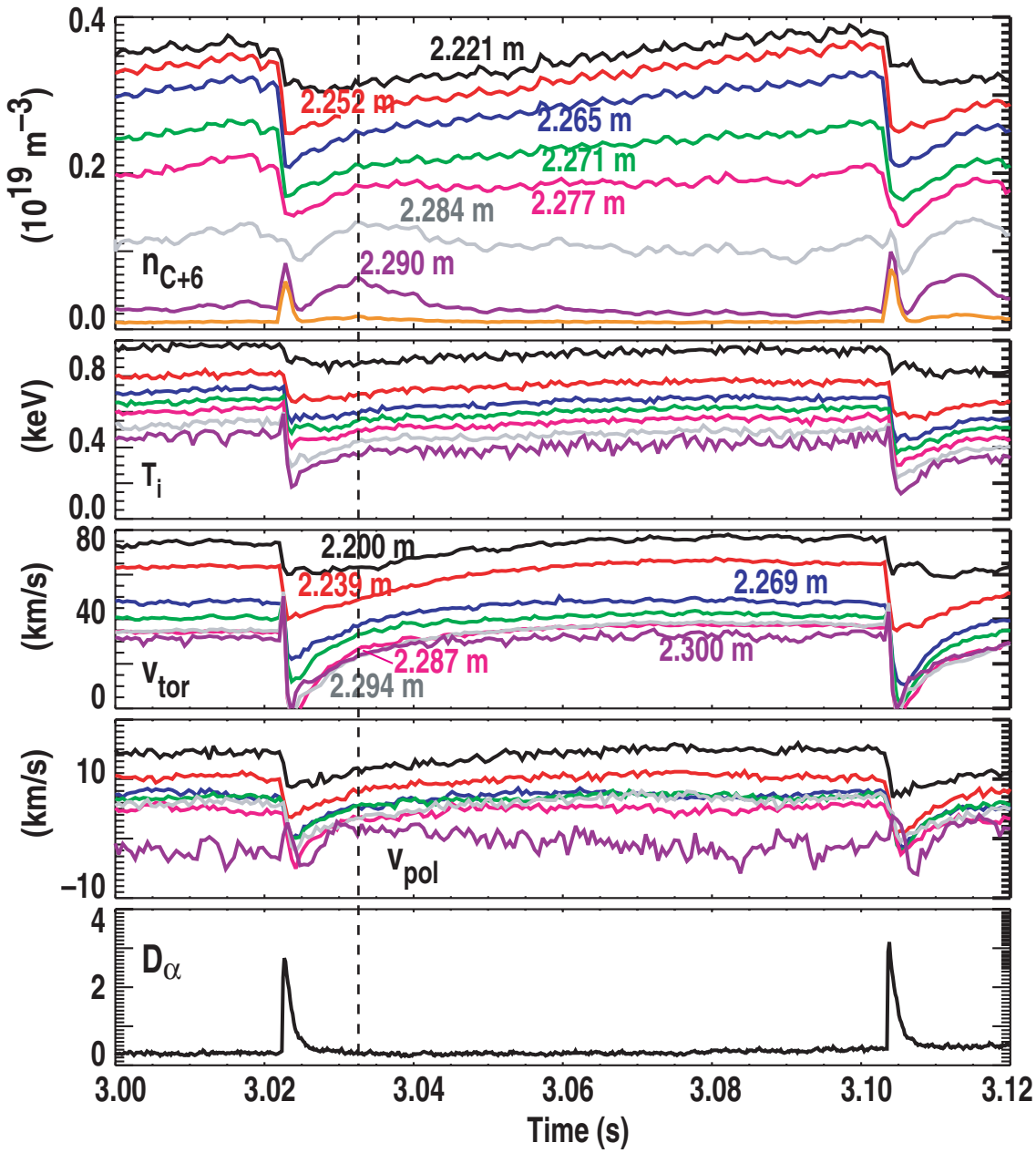
INTER-ELM PHASE CONSISTS OF TWO DISTINCT PHASES

Recovery Phase

- $t\text{-}t_{ELM}$ <10 ms
- Density increases in SOL and near separatrix



Improved Transport Phase

- $t\text{-}t_{ELM}$ >10 ms
- Gradients continue to increase throughout phase

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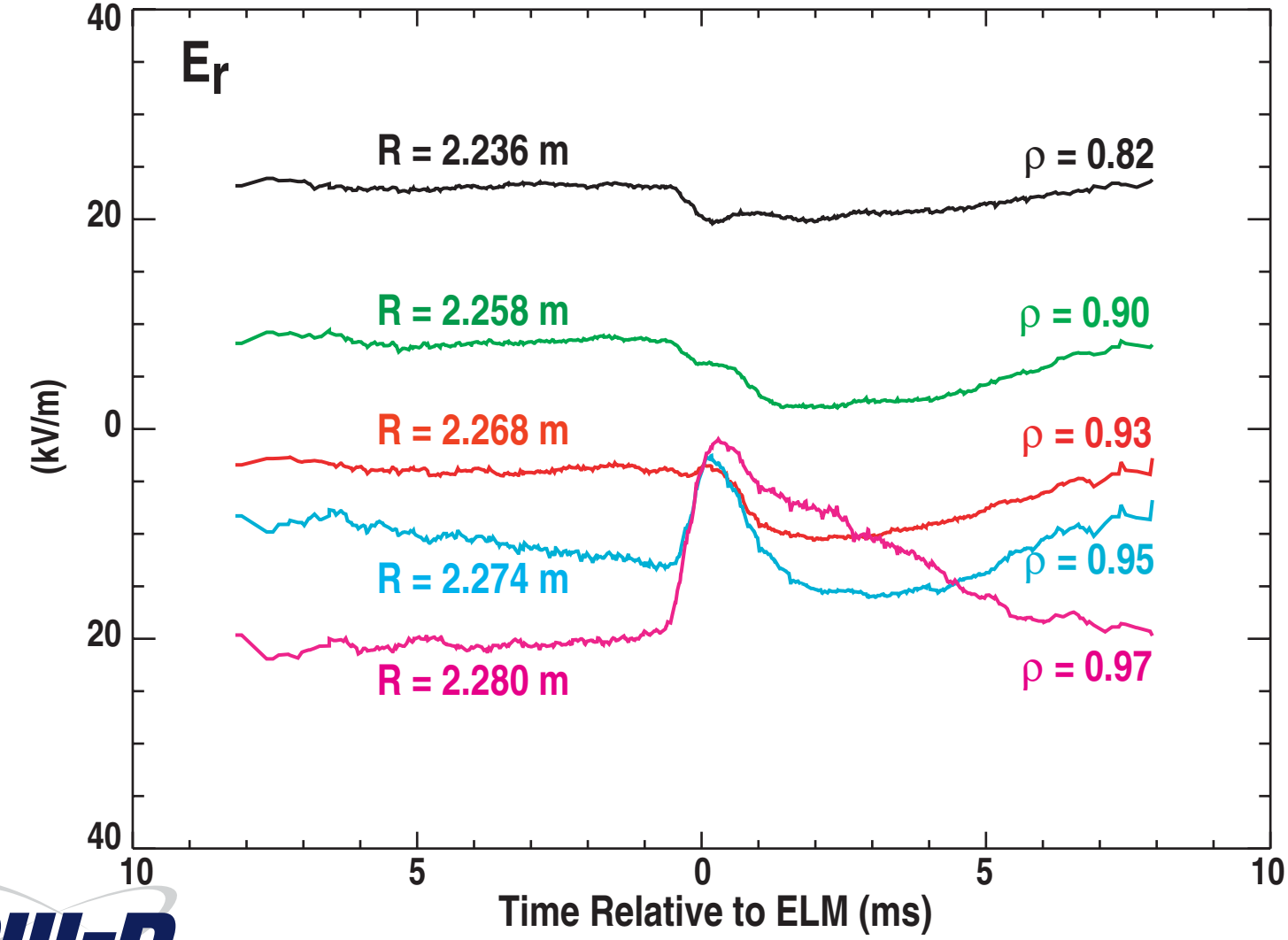
E_r SHEAR REDUCED SIGNIFICANTLY BY ELM EVENT

$$E_r = \frac{1}{Zen_z} \nabla p_z - V_\theta B_\phi + V_\phi B_\theta$$



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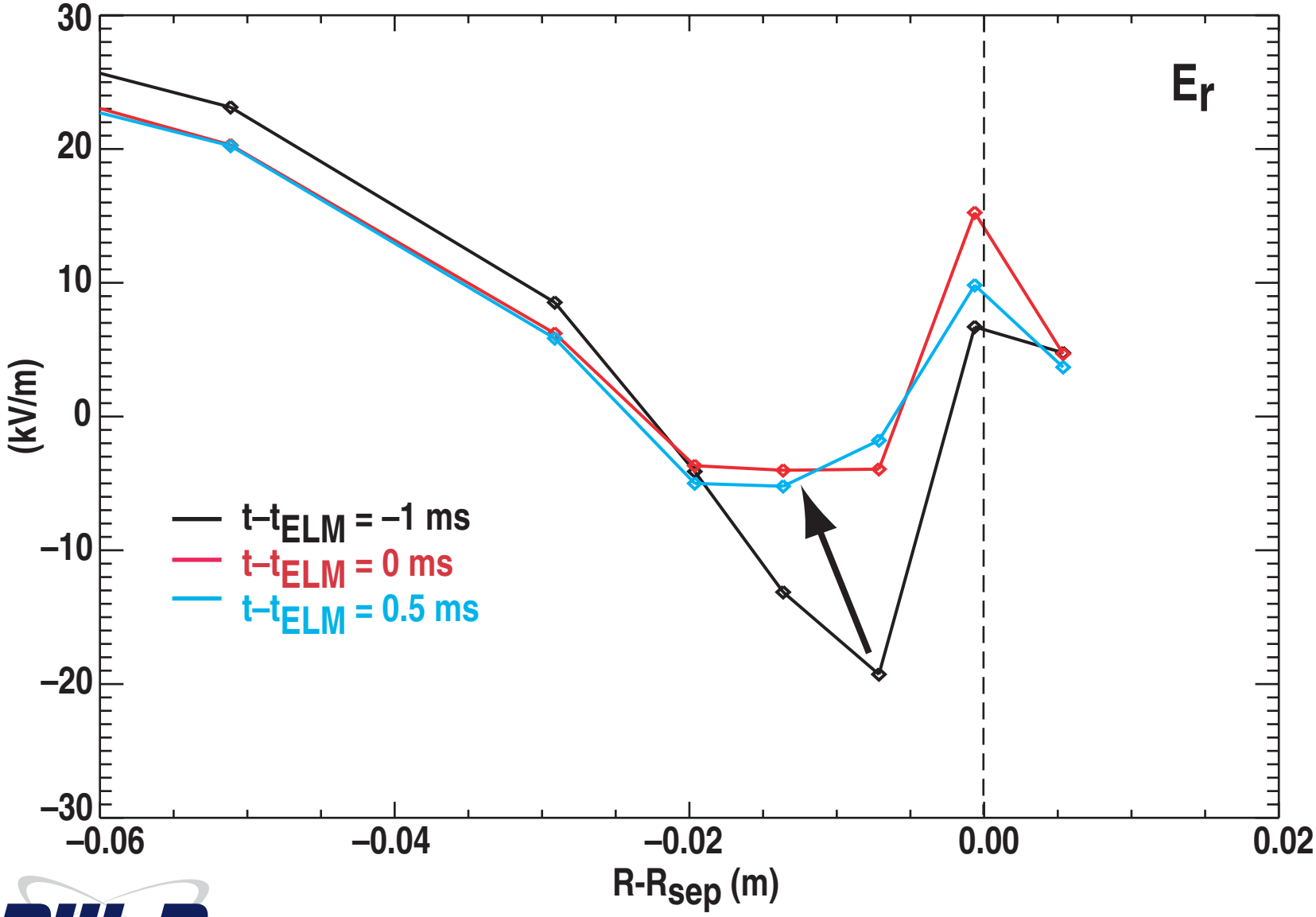
E_r WELL NEAR SEPARATRIX OBITERATED BY ELM



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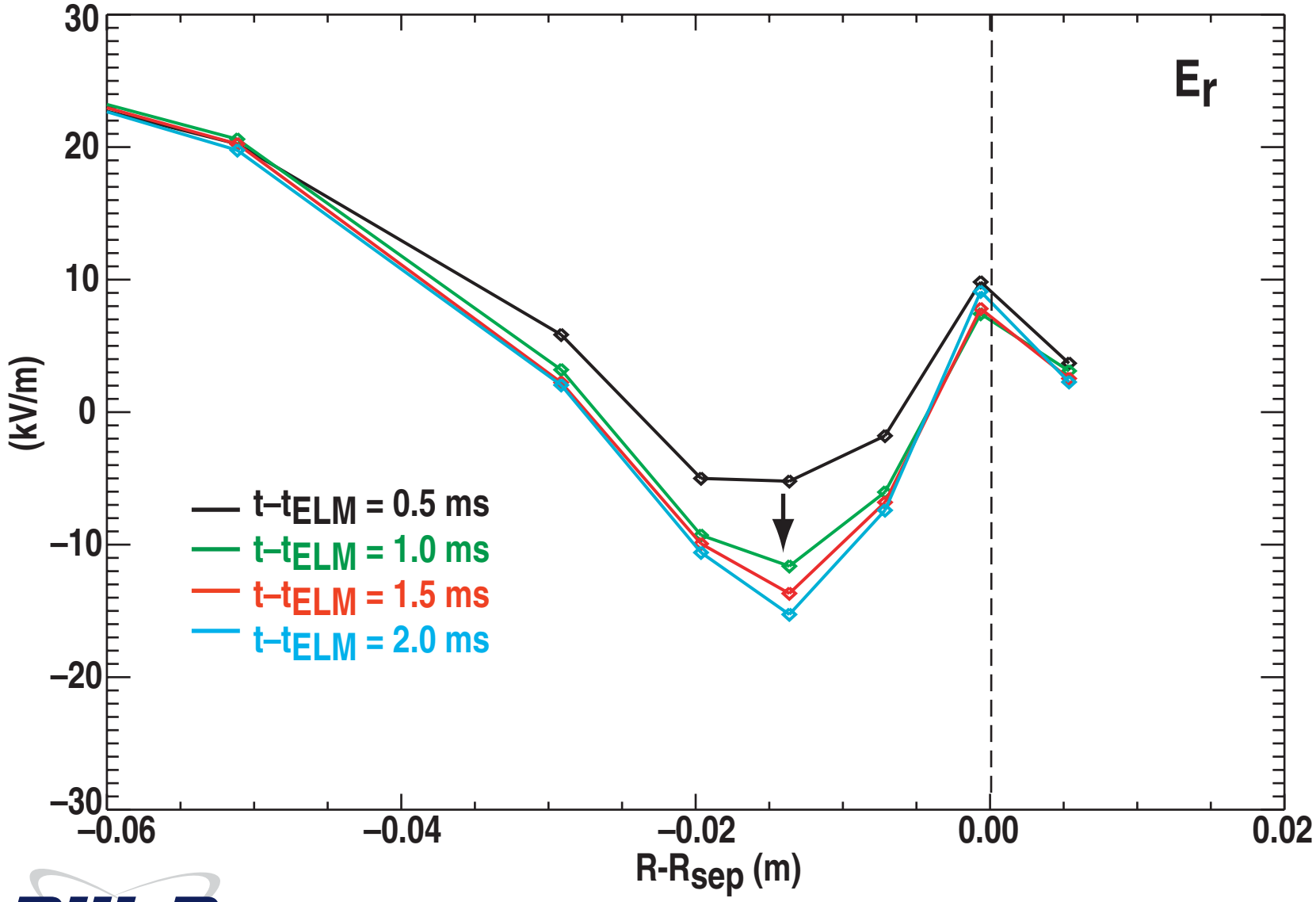
"SECONDARY" E_r WELL FORMS VERY QUICKLY AFTER ELM



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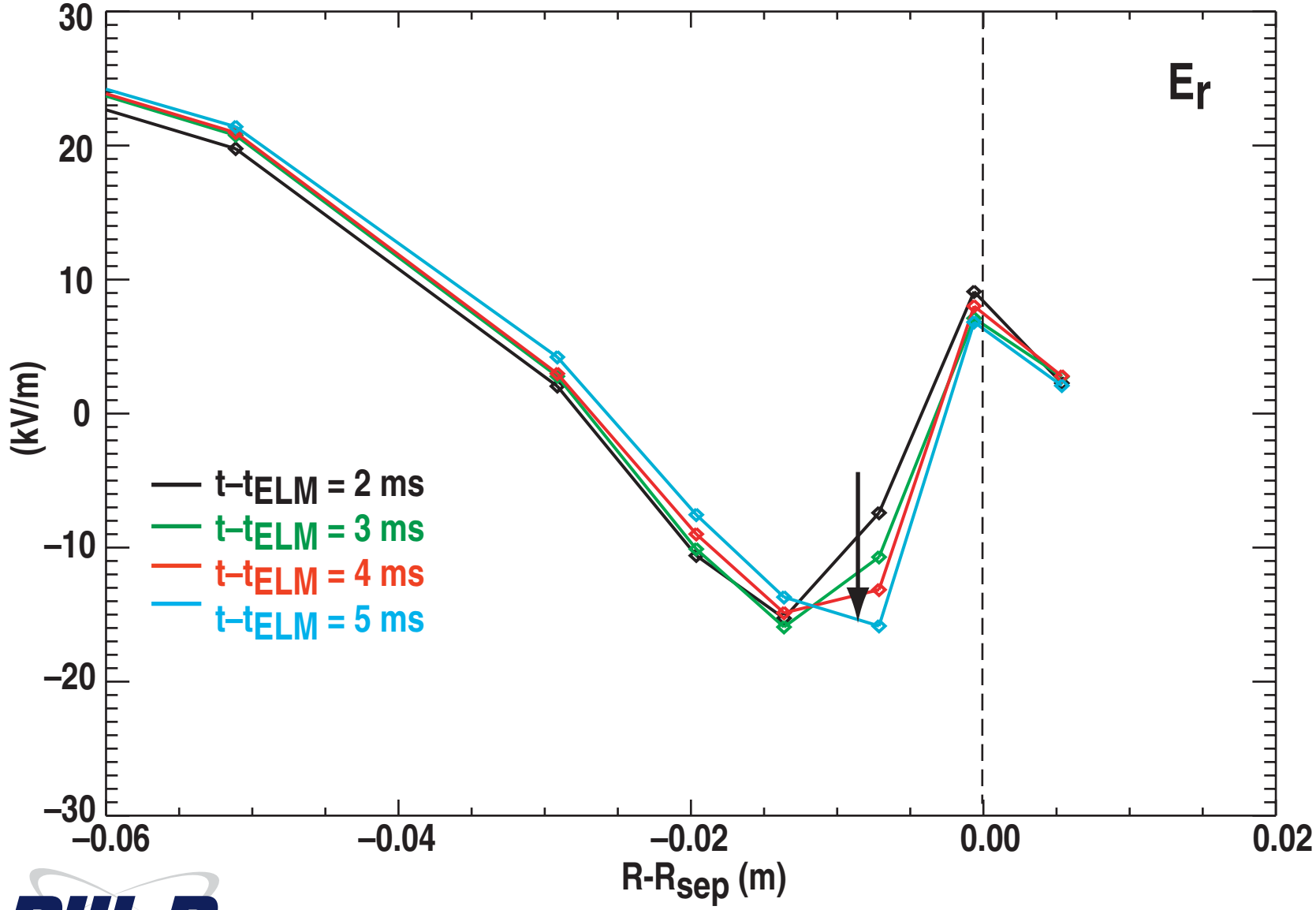
E_r AT "PRIMARY" WELL LOCATION STEADILY DECREASES AFTER ELM UNTIL WELL IS FORMED



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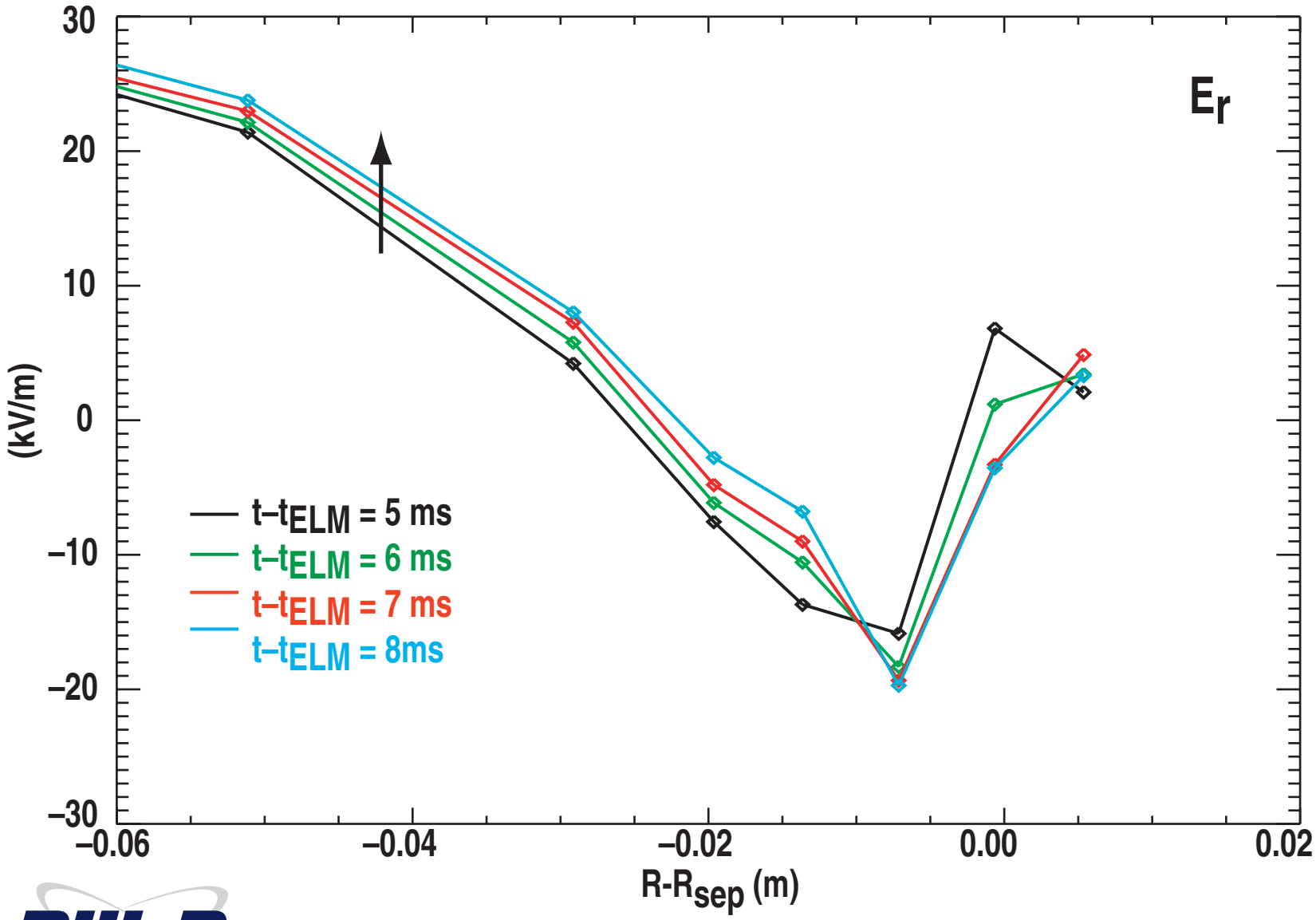
E_r SHEAR CONTINUES TO INCREASE THROUGHOUT INTER–ELM PERIOD



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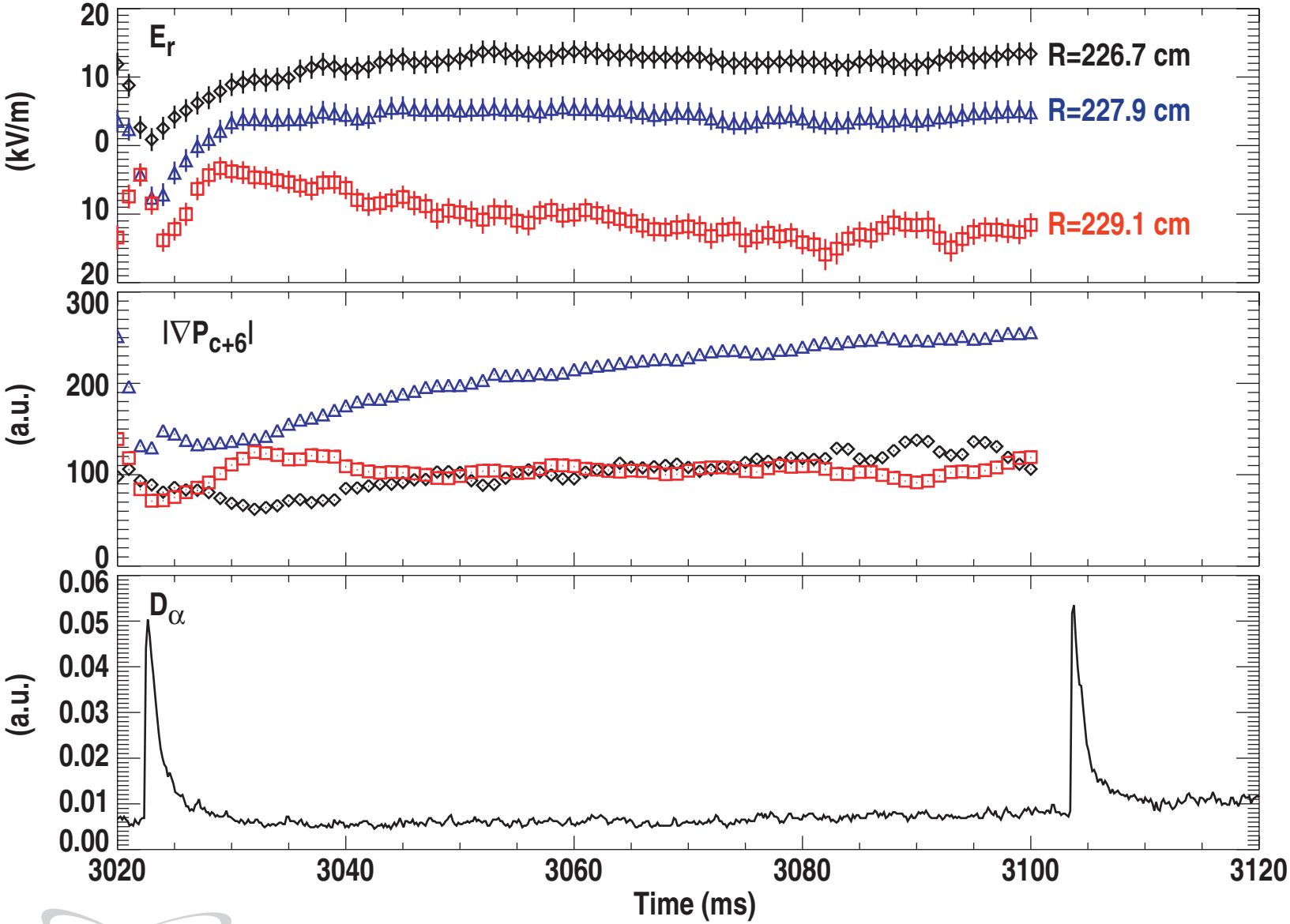
AS E_r WELL DEEPENS THROUGHOUT INTER-ELM PERIOD, TRANSPORT CONTINUES TO IMPROVE INSIDE THE WELL REGION



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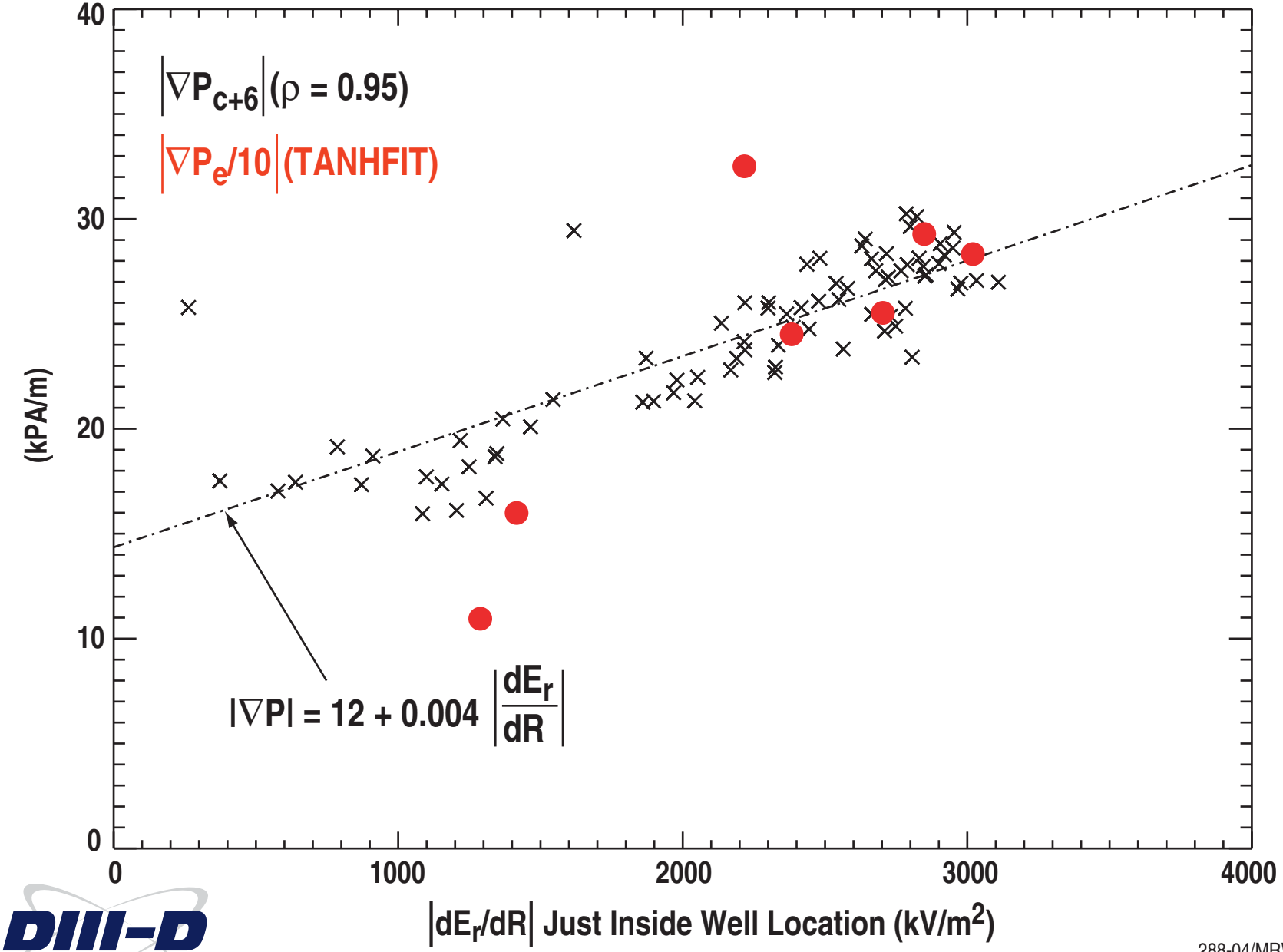
MAXIMUM PRESSURE GRADIENT IN EDGE INCREASES WITH E×B SHEAR



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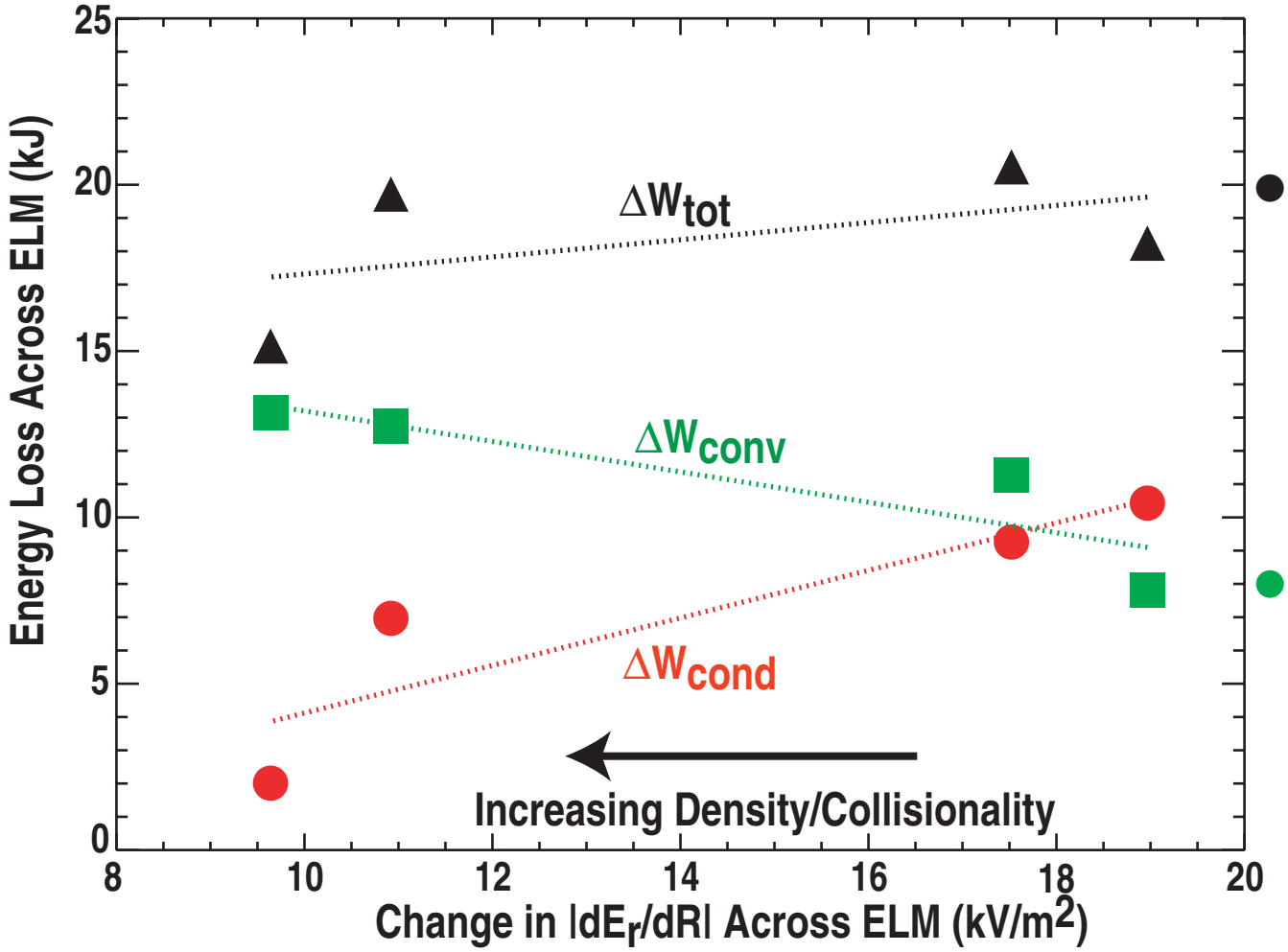
MAGNITUDE OF CONDUCTIVE ENERGY LOSS IS CORRELATED WITH E_r CHANGE CAUSED BY ELM



- ΔW_{tot} nearly constant
- ΔW_{conv} decreases slightly

- Suggest $\Delta T_{i,e}$ variation is due to transport changes associated with magnitude of E_r variation across ELM

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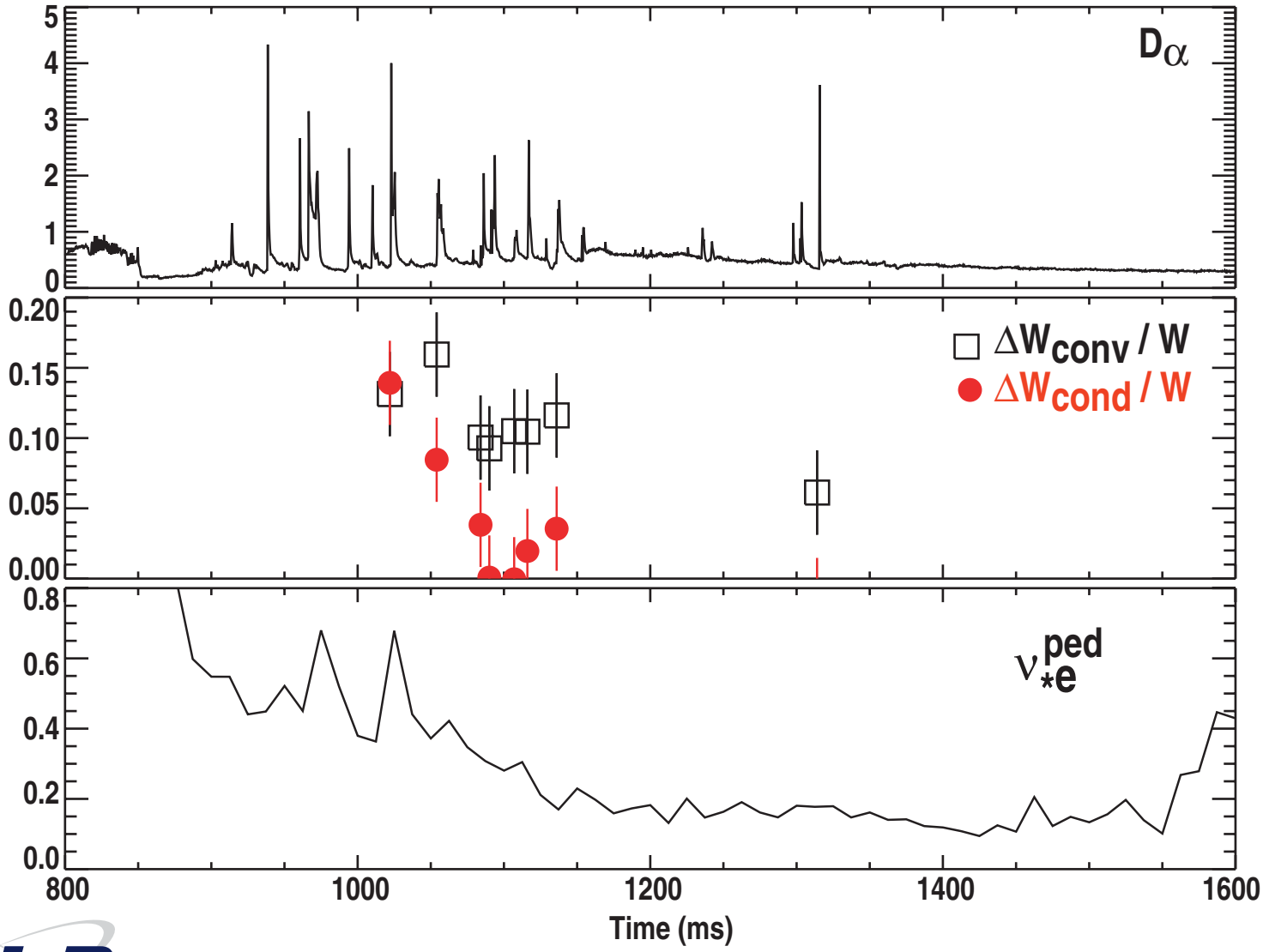
ELMING⇒QUIESCENT TRANSITION OCCURS AFTER ELMS BECOME PRIMARILY CONVECTIVE



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Burrell talk, Mon. AM

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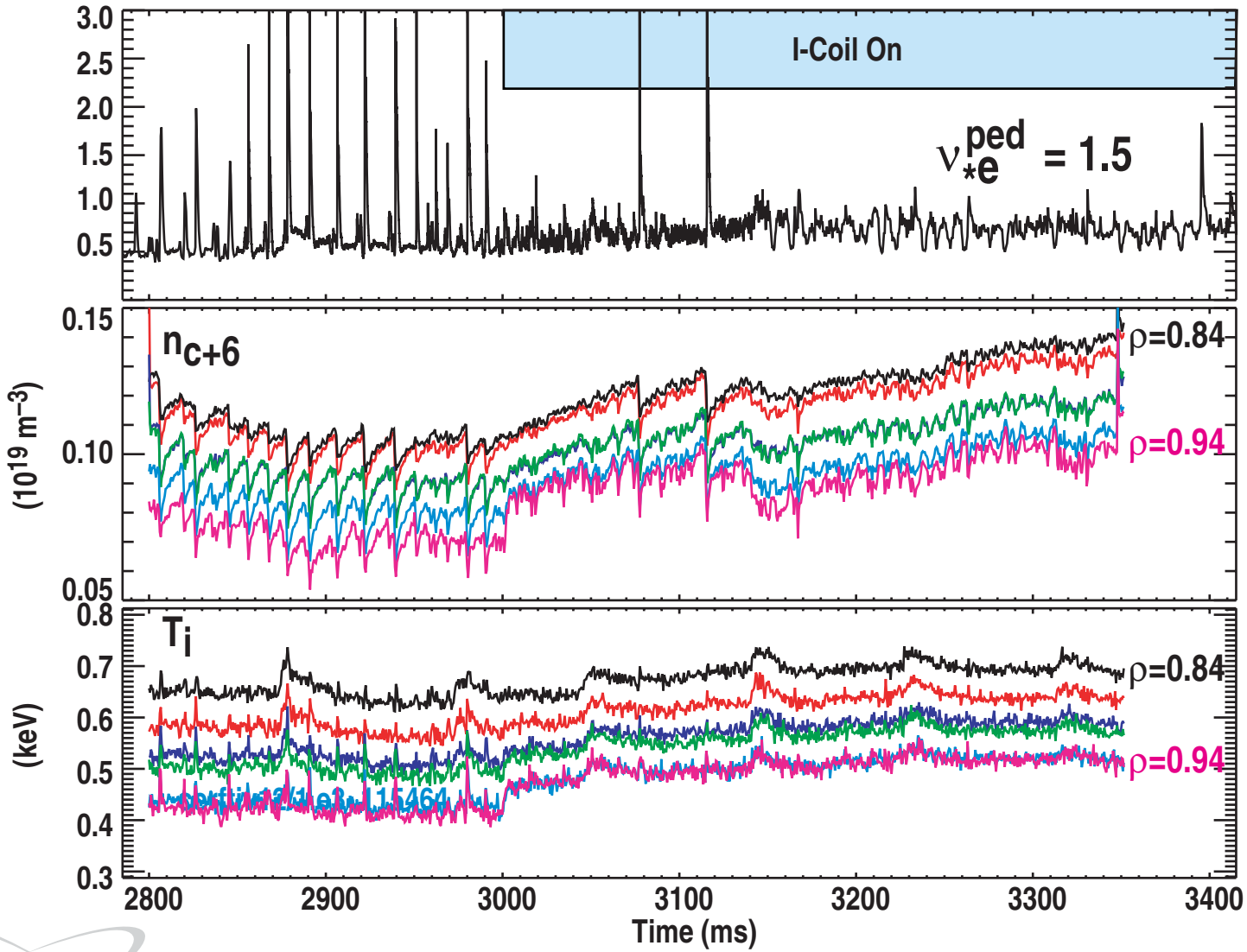
SUPPRESSION OF ELMS BY APPLICATION OF ASYMMETRIC FIELDS ONLY SEEN WHEN ELMS ARE PRIMARILY CONVECTIVE



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Moyer talk, Wed. PM

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