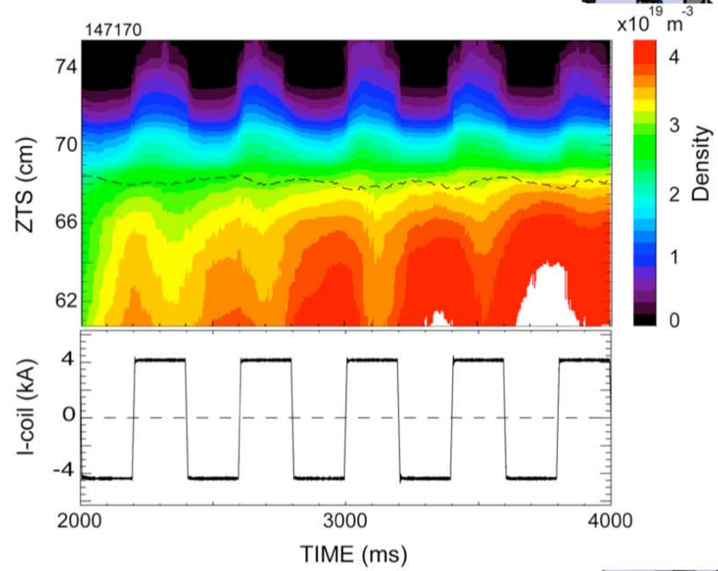
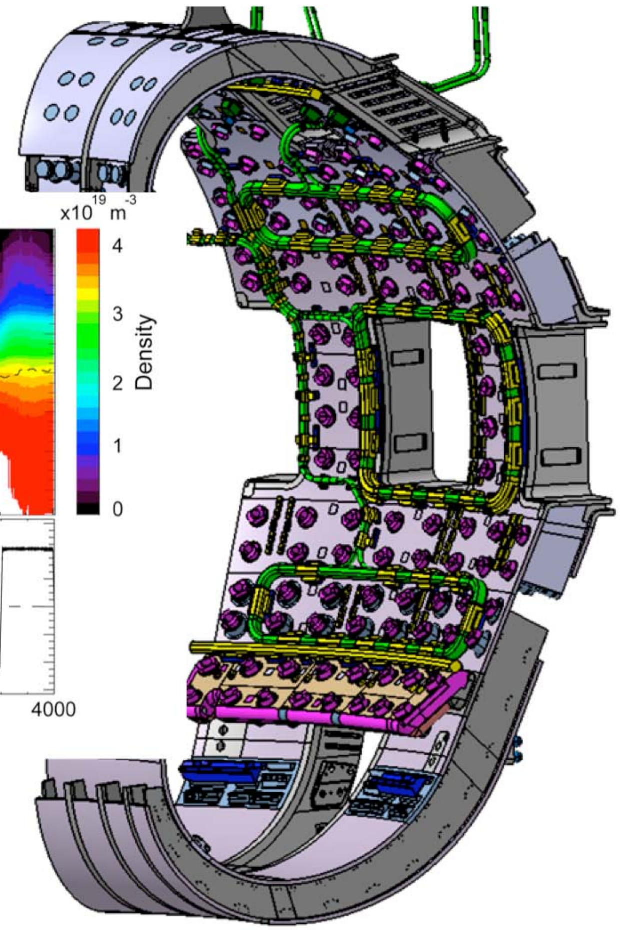
Plasma Response and Transport Effects During RMP Experiments in DIII-D

by
M.R. Wade for the DIII-D
ELM Control Task Force





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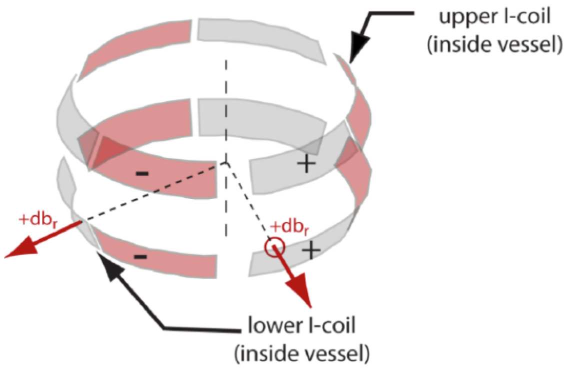
Significant Progress Made in Extending RMP ELM Suppression Operating Window and Physics Understanding

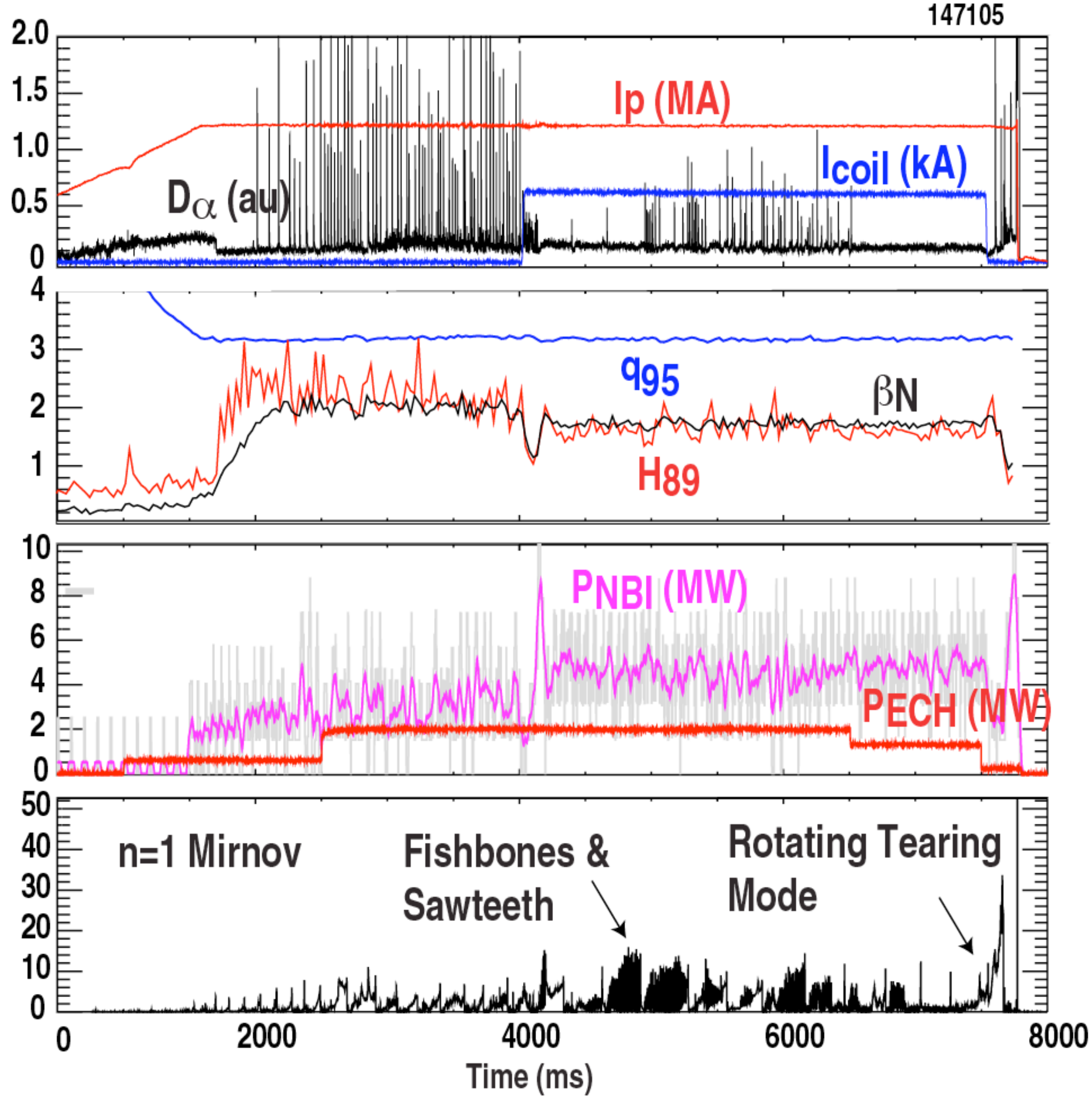
- **RMP ELM suppression extended to**
  - Single-row n=3 ELM Suppression to $q_{95} = 3.15$
  - → ***Demonstrated ELM Suppression in ITER Baseline Scenario***
  - n=2 ELM suppression
  - Near double null
  - Lower applied NBI torque

- **Physics understanding of processes leading to ELM suppression is emerging**
  - Edge plasma response consistent with RMP-induced island near pedestal top impeding further widening of pedestal such that peeling-ballooning instability not encountered

ELM Suppression Demonstrated in ITER Baseline Scenario (q_{95} = 3.15)

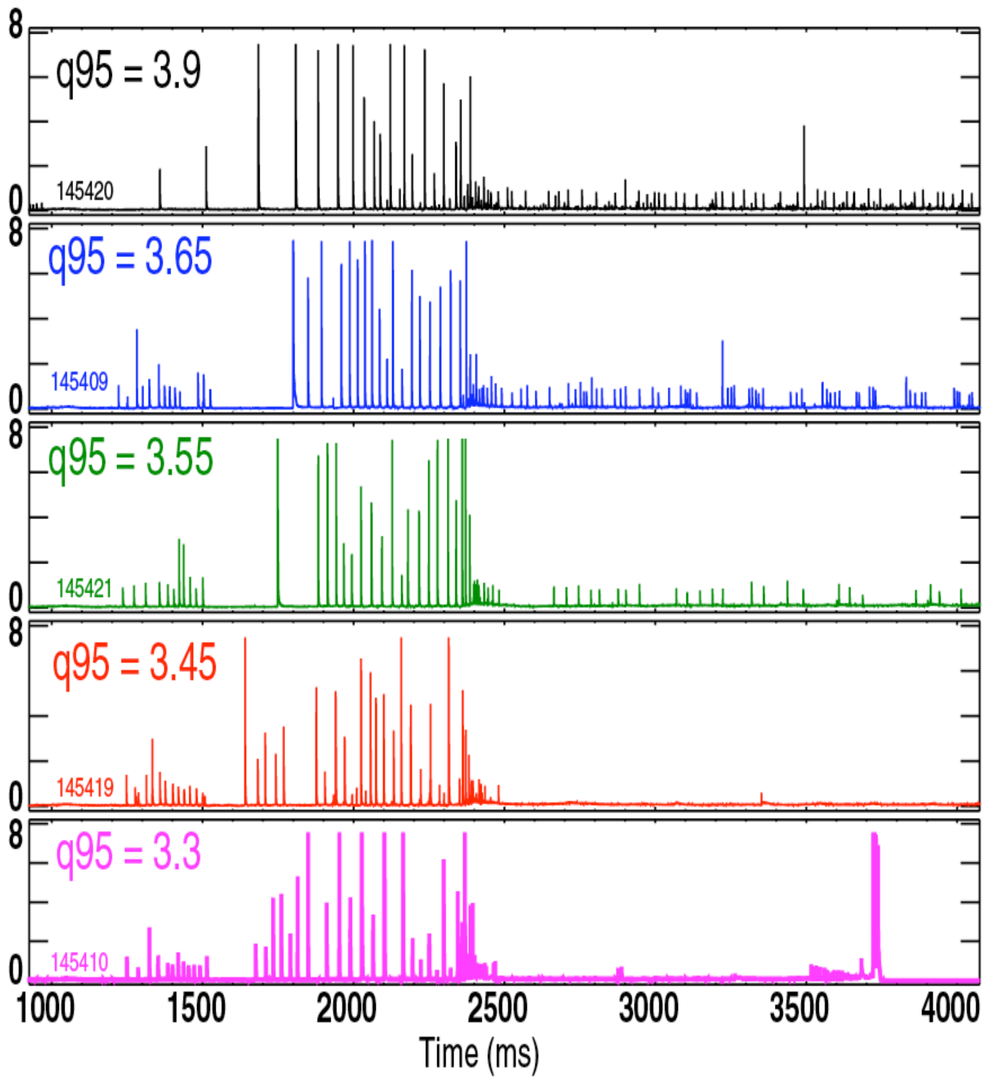
- **ITER Shape, β_N = 1.8, H_{89} = 1.8**
- **Sustained for >1 s limited by**
  - Transients due to internal m=1/n=1MHD
  - Duration of ECCD for tearing mode control
- **Achieved with single row n=3 I-coil RMP (upper row only)**



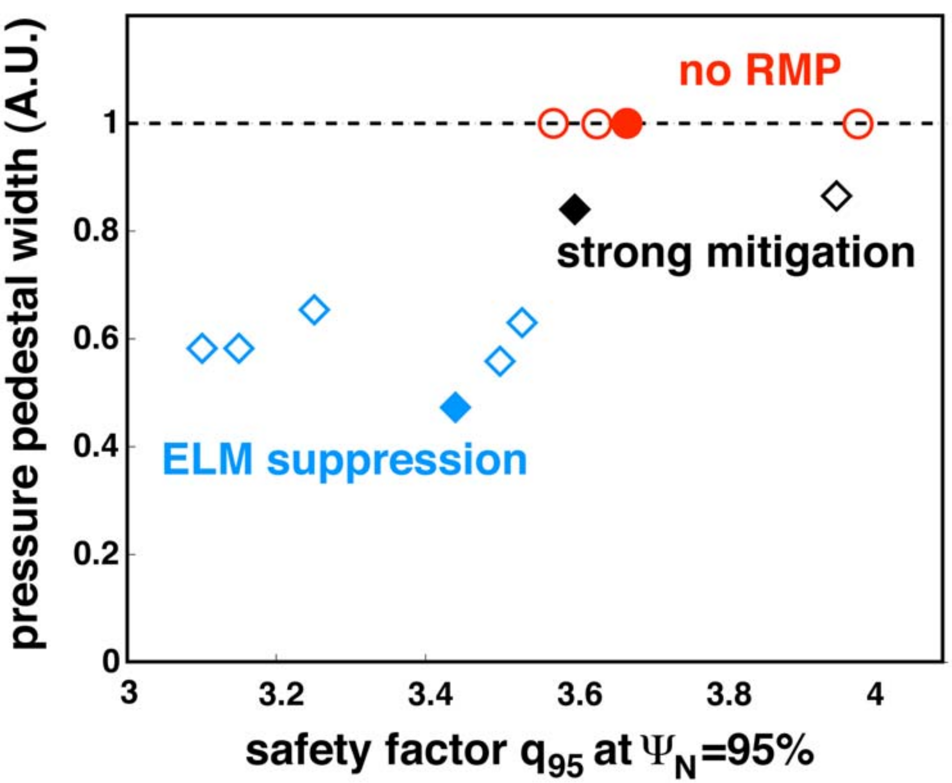


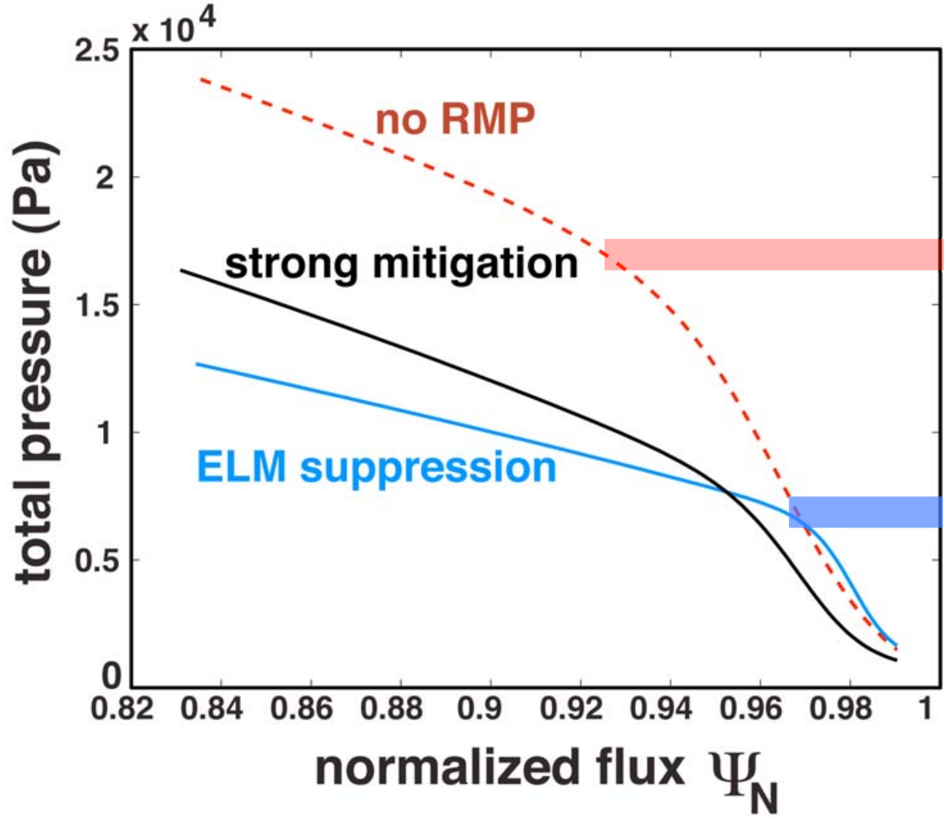
Recent Research Focused on Determining Physics Responsible for q_{95} Sensitivity

- **Previous work showed narrow ELM Suppression window near q_{95} = 3.5**
  - Confirmed in fine-scale q_{95} shot-to-shot scan
- **Systematic reduction in ELM frequency as ELM Suppression window approached**
- **Also provided excellent documentation opportunity**
  - High resolution edge data
  - Turbulence response



High Resolution Edge Measurements Reveal Strong Reduction in Pedestal *Width* in ELM Suppressed Cases



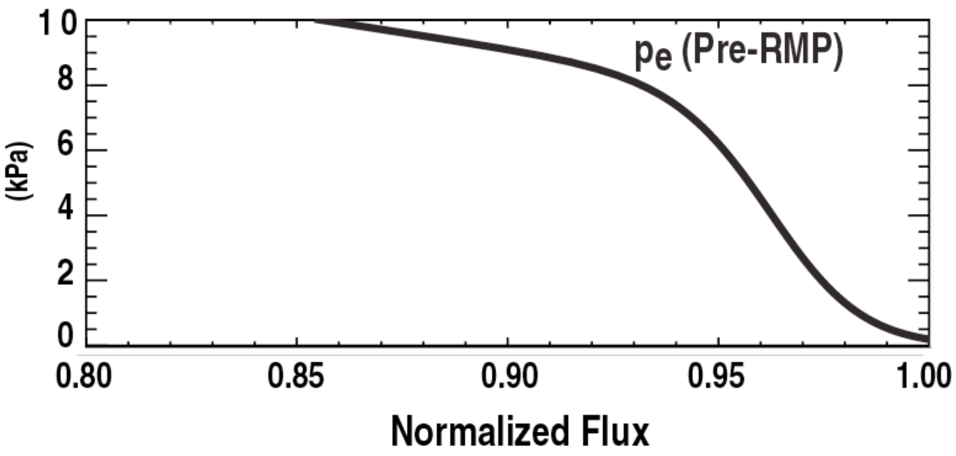


- **Observed pedestal width consistent with EPED based model of ELM suppression**
  - Critical width for suppression is <~3%, in agreement with EPED
- **What is constraining pedestal width in ELM-suppressed cases?**

Emerging Physics Picture: Island Formation Limits Further Expansion of Pedestal Width

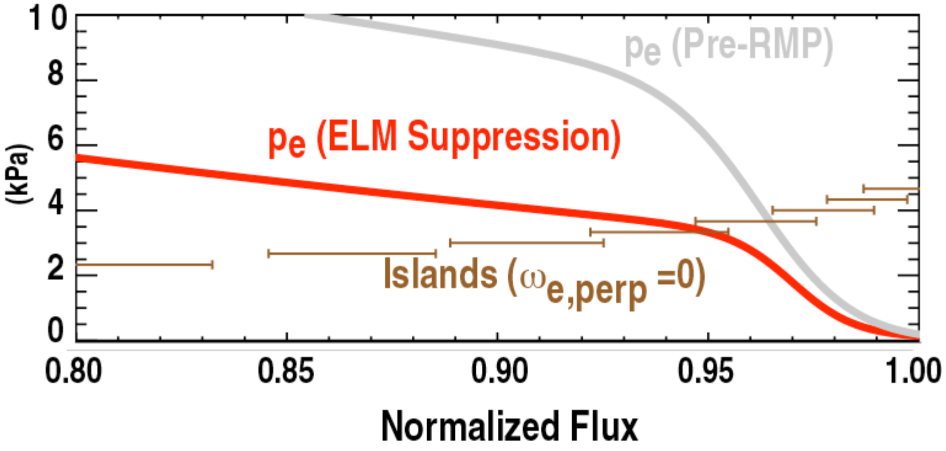
- **Without RMP, pedestal width continues to expand until peeling-ballooning stability limit encountered**

Snyder CI2.00005



Emerging Physics Picture: Island Formation Limits Further Expansion of Pedestal Width

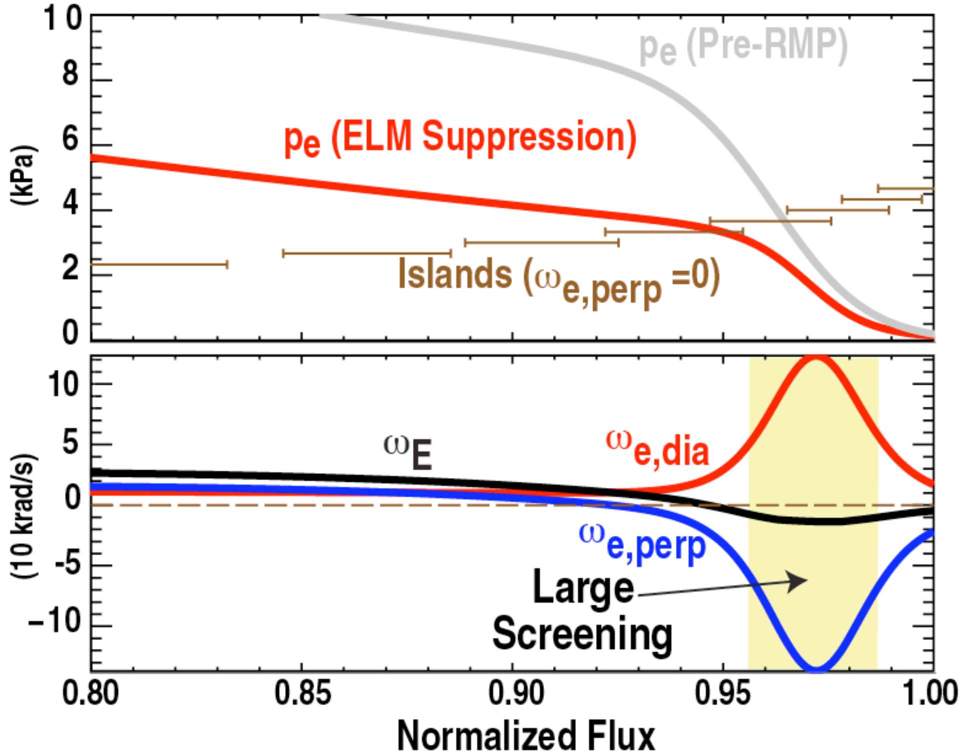
- **In vacuum picture, RMP creates island chain over entire edge region**
  - But, how does one reconcile sustainment of large gradient in pedestal region?



Emerging Physics Picture: Island Formation Limits Further Expansion of Pedestal Width

- **Large pressure gradient region in edge also has large electron fluid rotation**
  - $|\omega_{e,perp}| >> 0$

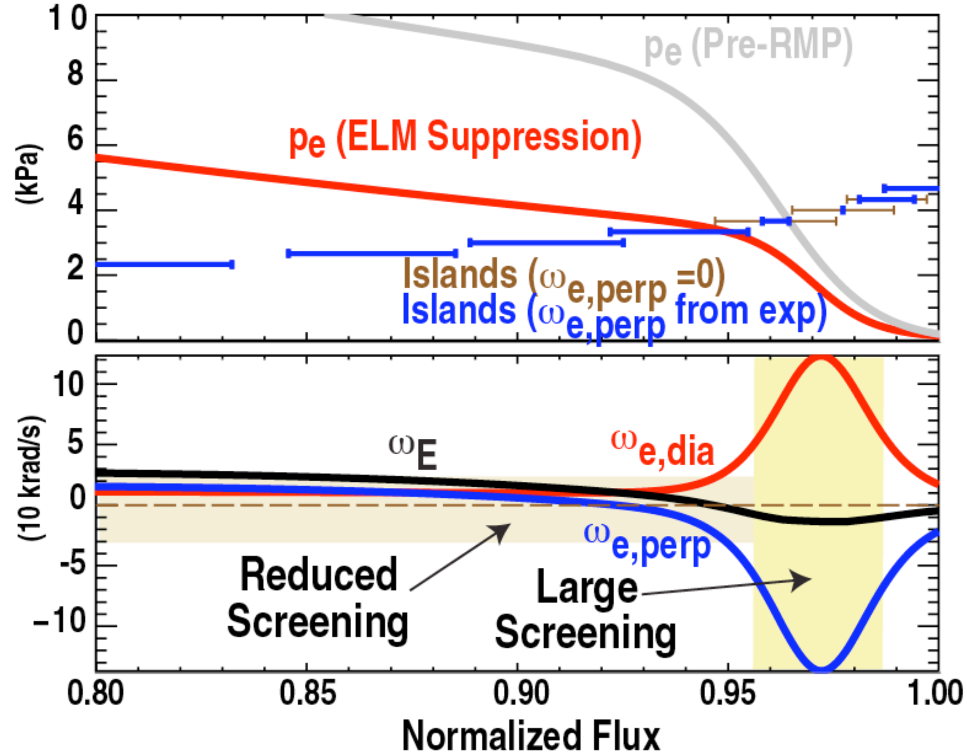
- **Theory predicts significant field screening in this region**



Ferraro JI2.00002

Emerging Physics Picture: Island Formation Limits Further Expansion of Pedestal Width

- **Large pressure gradient region in edge also has large electron fluid rotation**
  - $|\omega_{e,perp}| >> 0$
- **Theory predicts significant field screening in this region**
  - **Small (non-existent?) islands**
- **Conversely, $|\omega_{e,perp}| \sim 0$ just inside pedestal region**
  - **Island formation possible**



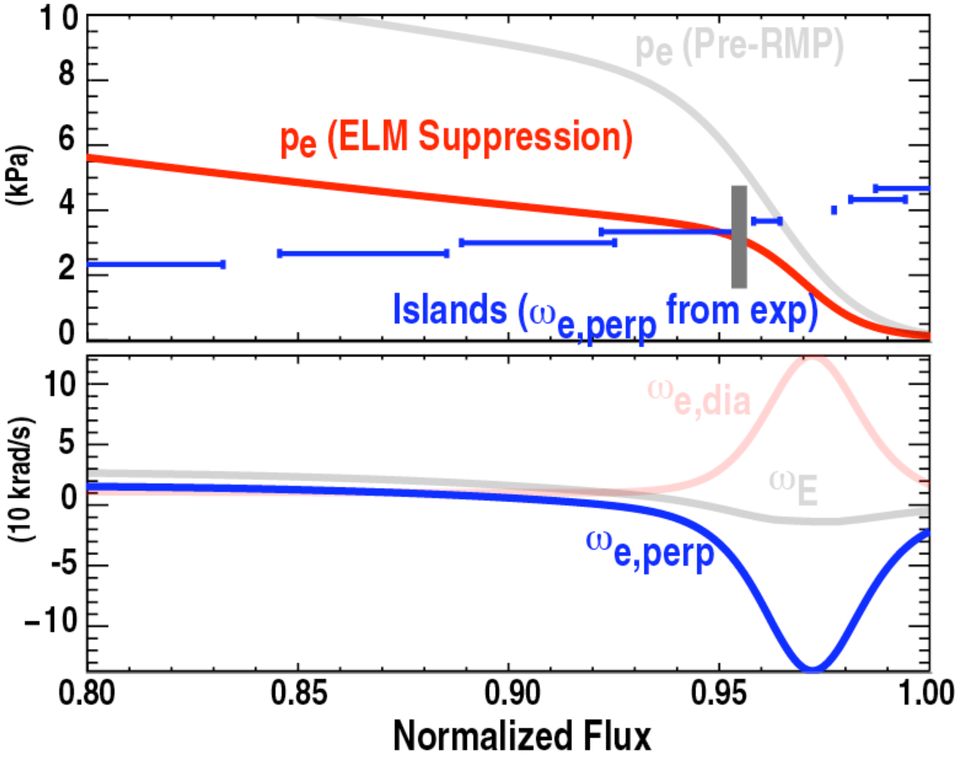
Ferraro JI2.00002

Emerging Physics Picture: Island Formation Limits Further Expansion of Pedestal Width

Working Hypothesis:

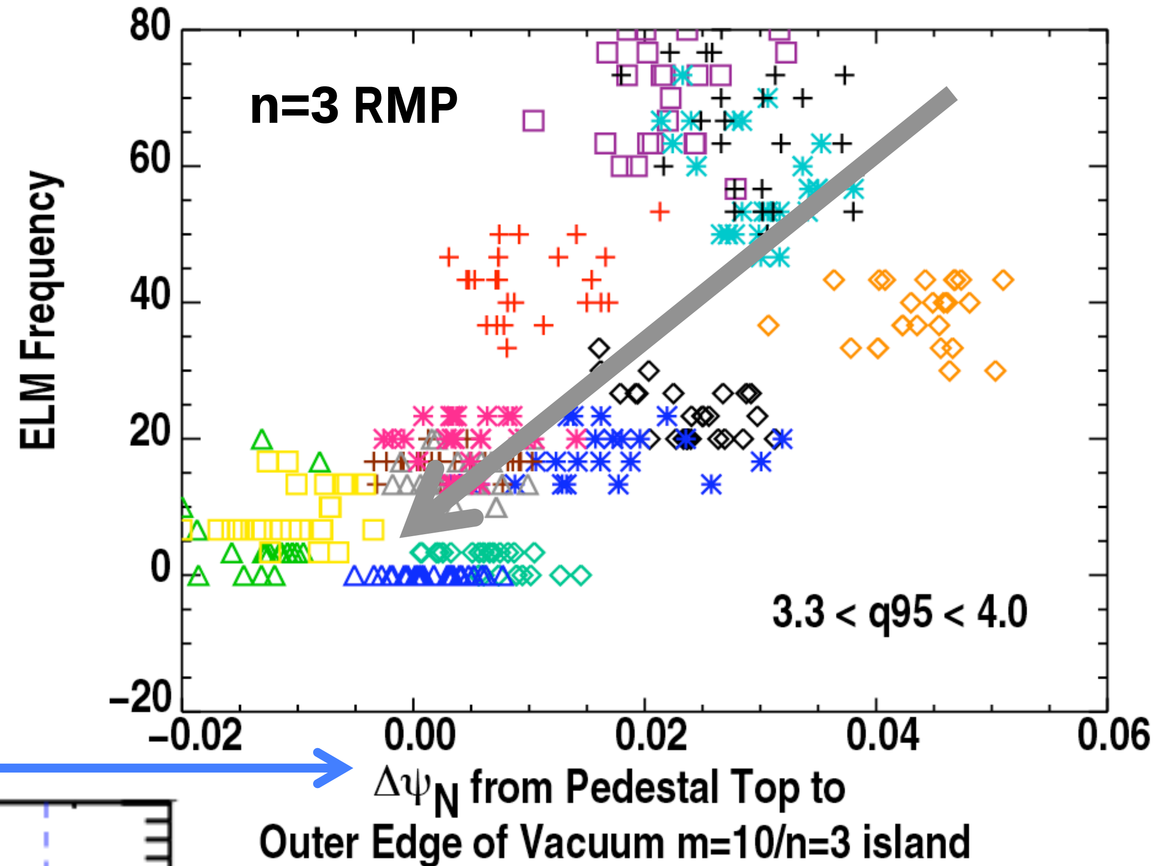
1) **RMP induces island just inside top of pedestal**

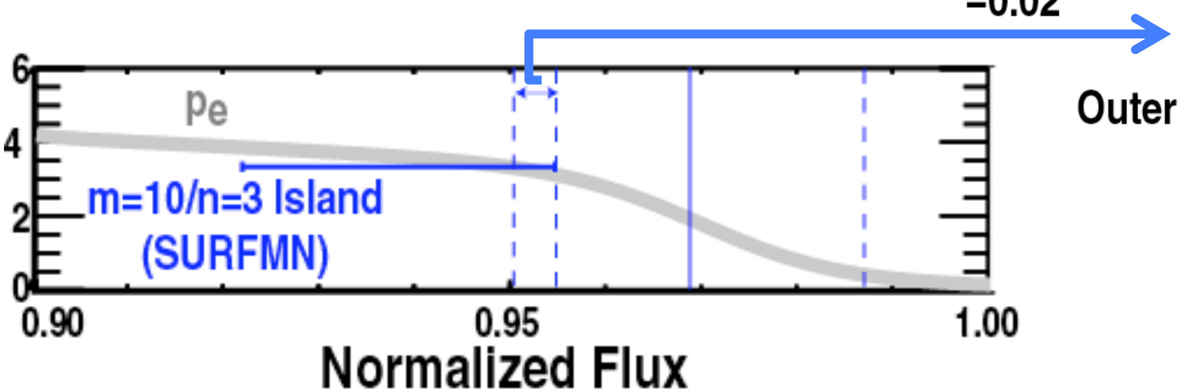
2) **Island provides sufficient transport to prevent further expansion of pedestal width**
→ Peeling-ballooning stability limit not encountered



Degree of ELM Mitigation Correlated with Alignment of Pedestal Top and Outer Extent of m=10/n=3 Island

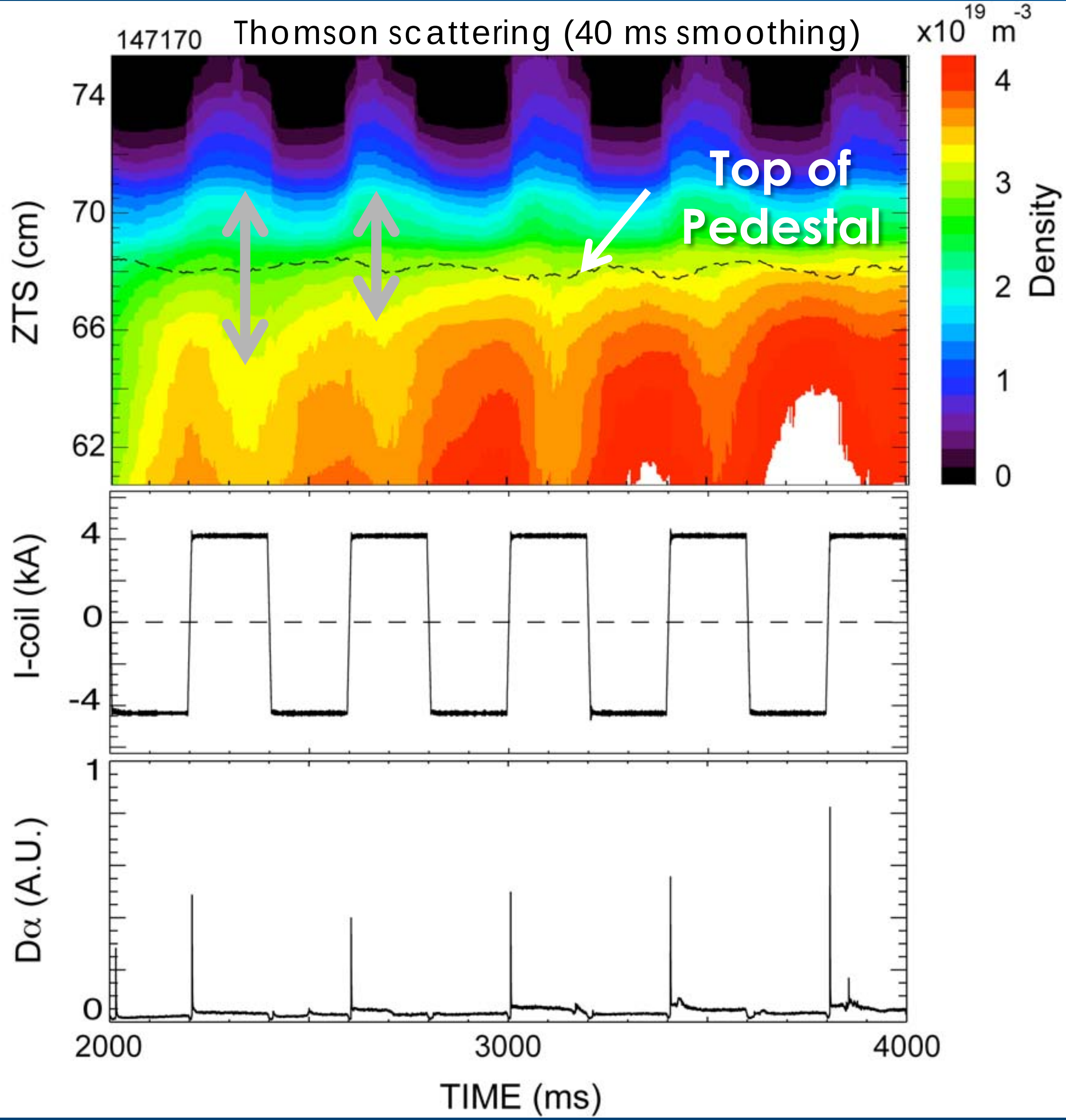
- **Island location and widths based on SURFMN vacuum field analysis**





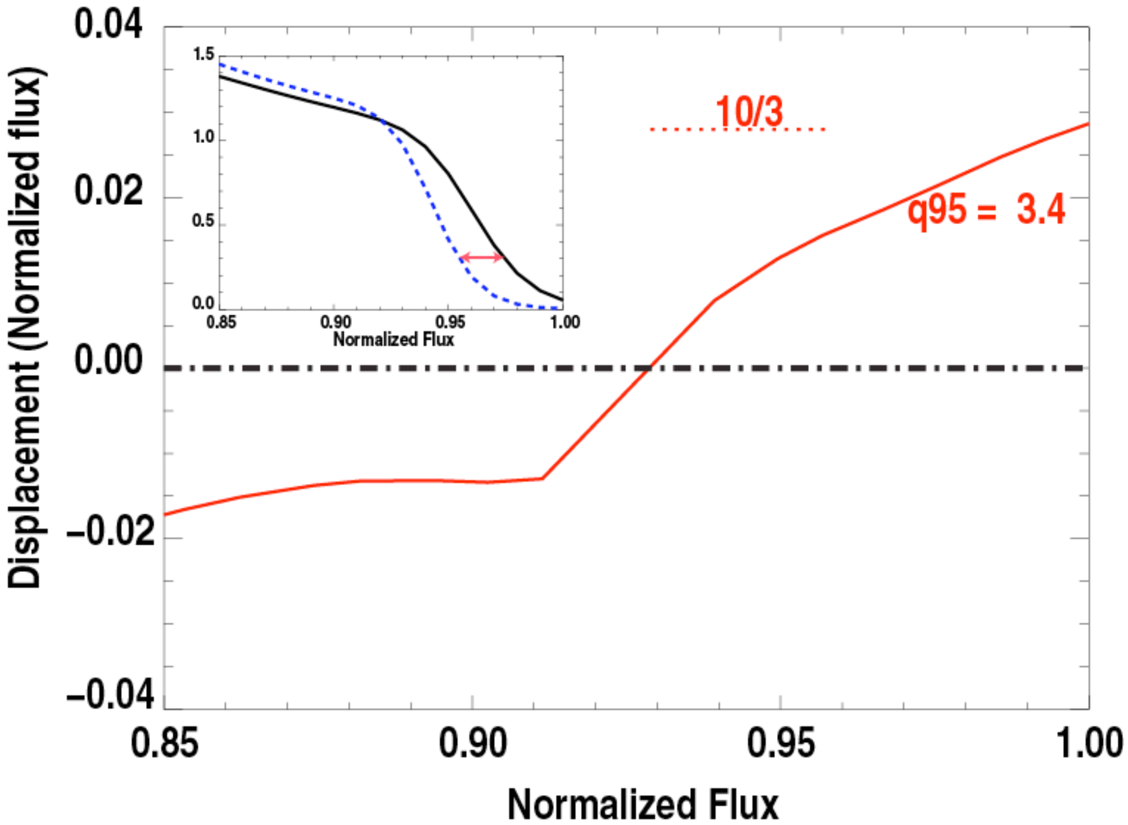
Island-Like Displacements Observed During n=3 RMP Toroidal Phase Shifts

- **Toroidal phase of n=3 RMP switched by 60º every 200 ms**
- **Thomson scattering density contours separate only in 0º phase**
  - Evidence for island formation??
- **ELM suppression sustained except during RMP phase shift**



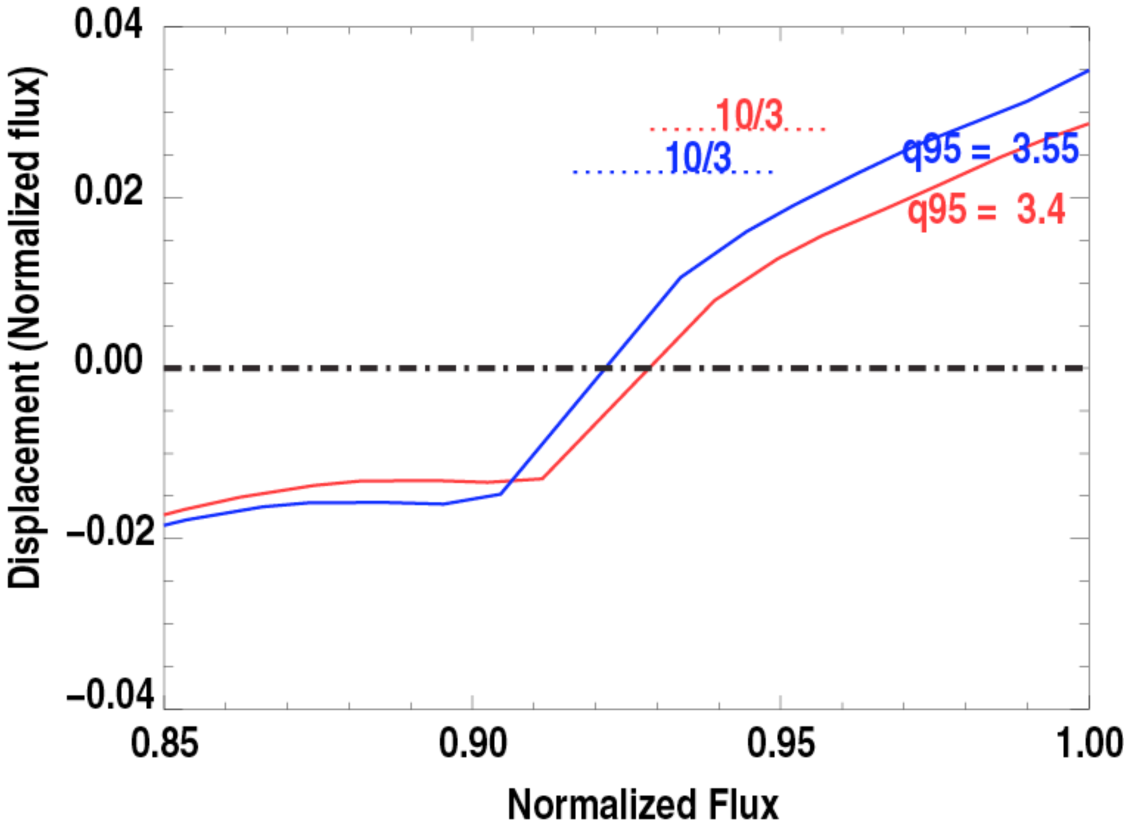
Edge Temperature Phase Inversion Layer Correlated with Computed m=10/n=3 Island Location

- **Displacement between 0º and 60º phasing of n=3 RMP**
- **Phase inversion occurs near calculated location of m=10/n=3 island**
- **Size of displacement is comparable to computed island size ($\Delta\psi_N \sim 0.02$)**



Edge Temperature Phase Inversion Layer Correlated with Computed m=10/n=3 Island Location

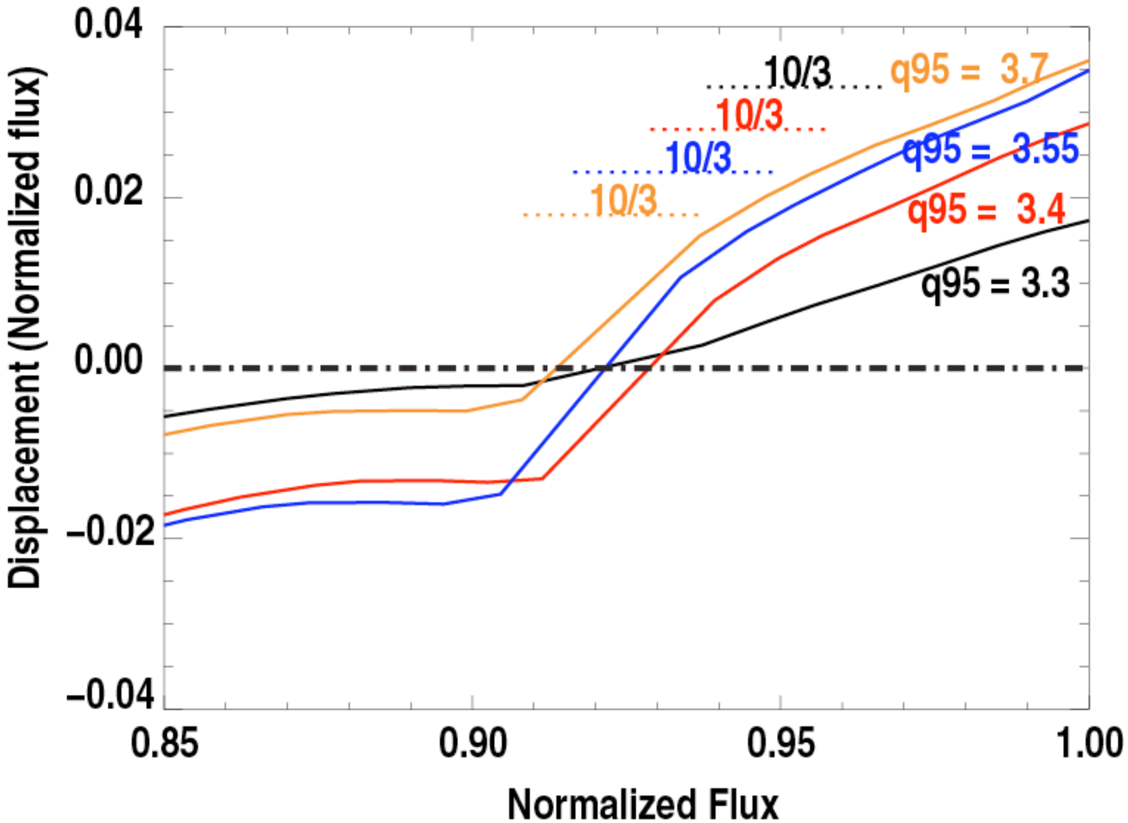
- **Inversion layer moves progressively inward as q_{95} increases**
  - Consistent with movement of m=10/n=3 island location



Edge Temperature Phase Inversion Layer Correlated with Computed m=10/n=3 Island Location

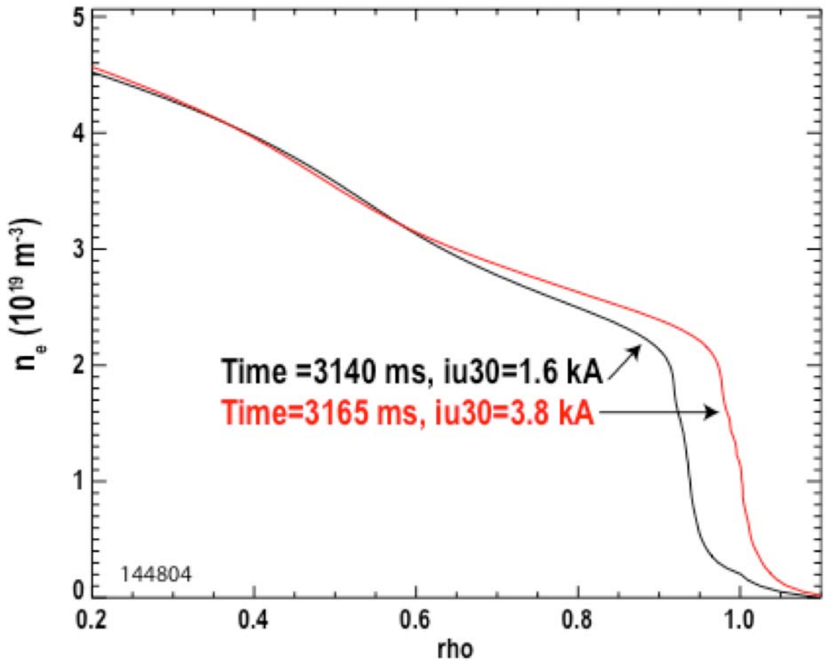
- **Location of phase change moves progressively inward as q_{95} increases**

- **Outside of suppression window, displacement becomes more "kink-like"**

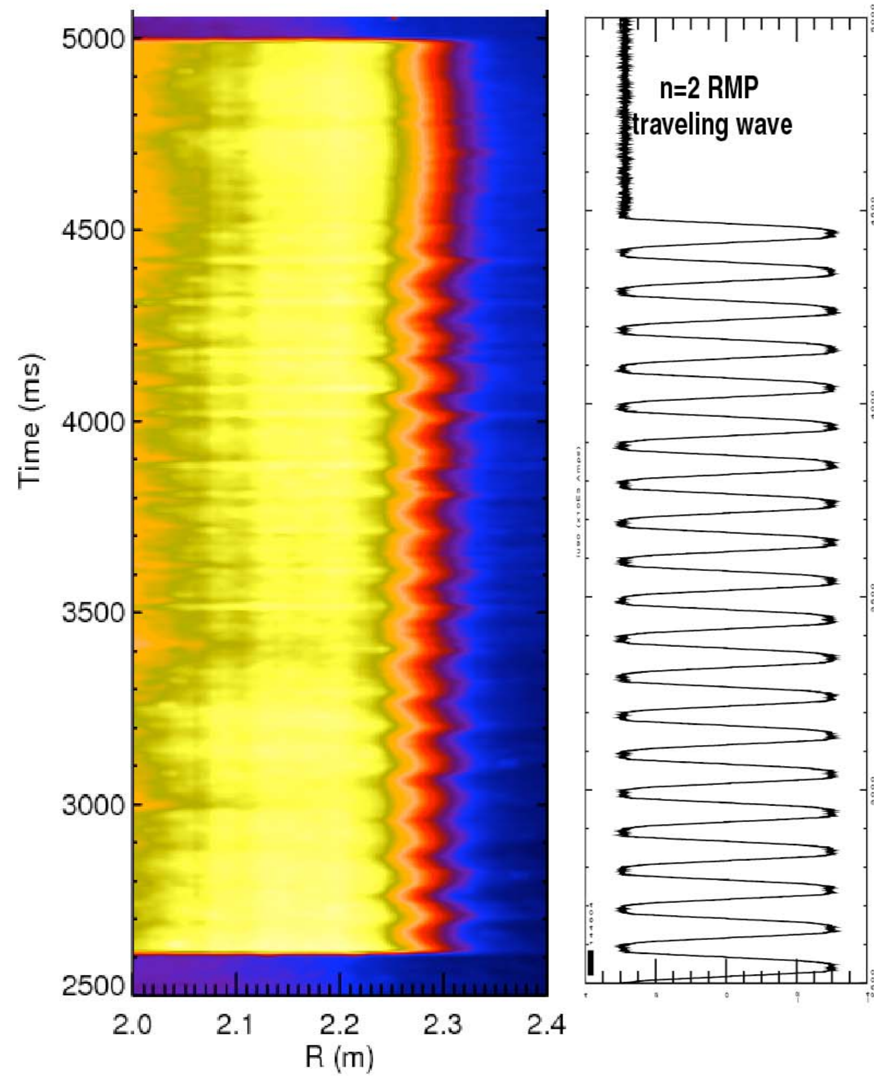


Observed Displacement Is Kink-Like When Applying n=2 Rotating RMP

Reflectometer Density Profile



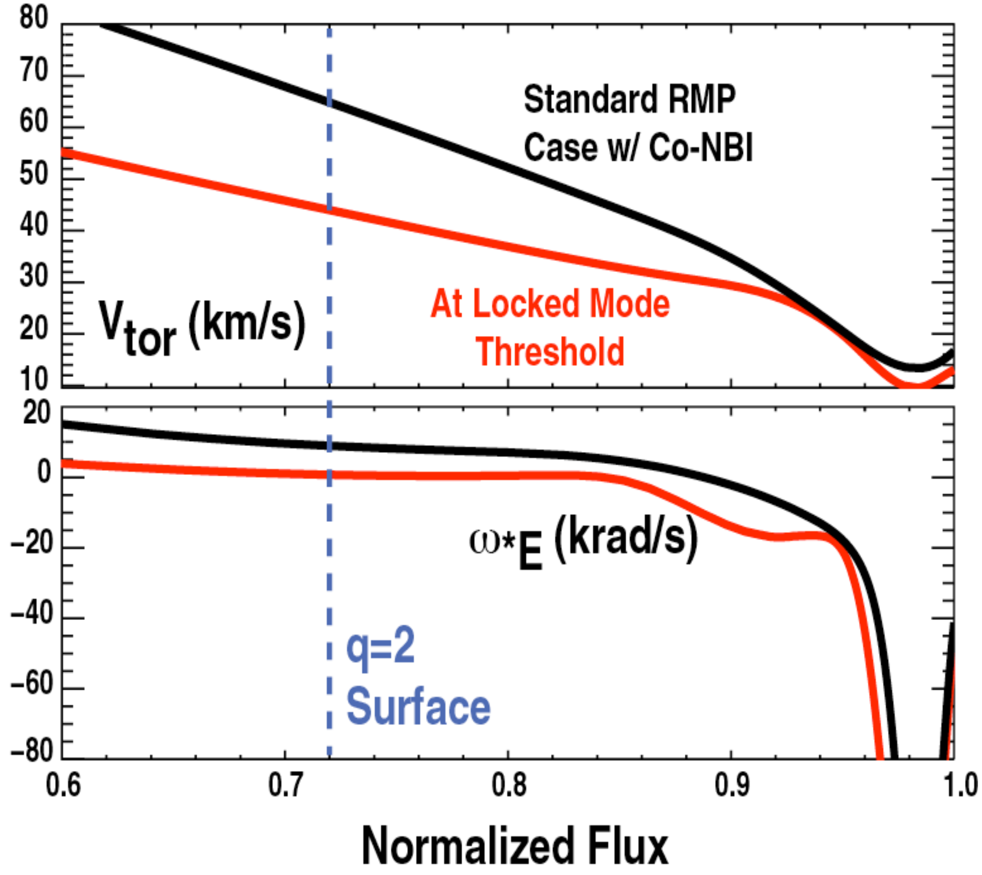
(BES using Fast Camera)



- **ELM suppression not obtained with n=2 rotating RMP**
  - Further evidence of importance of island-like displacement in n=3 cases

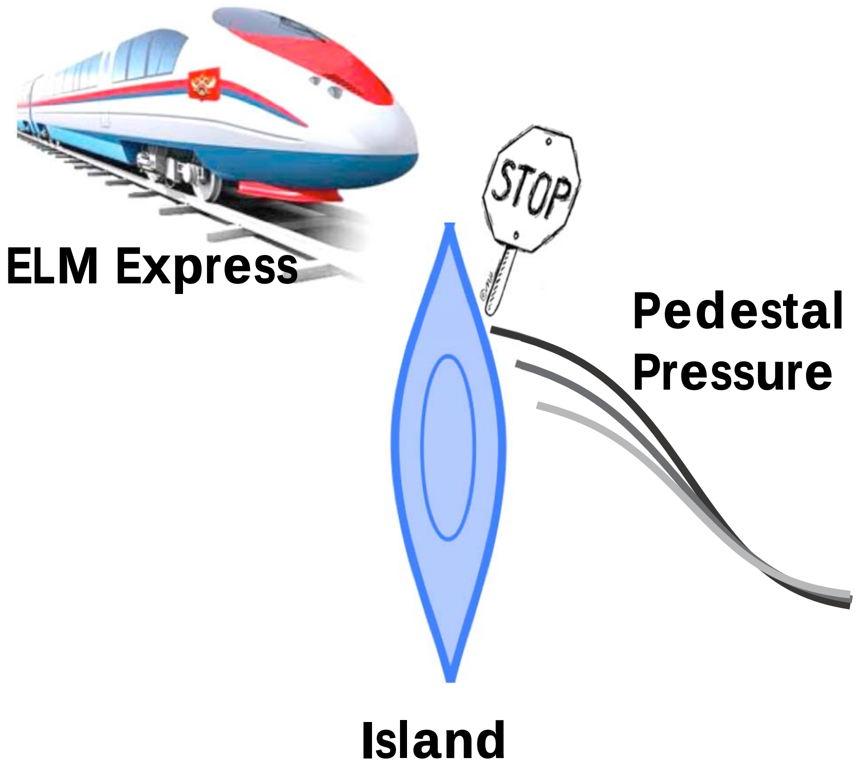
Window Between ELM Suppression and Locked Mode Onset Determined By Details of $\omega_{perp,e}$ Profile

- **While low $\omega_{perp,e}$ ~ 0 just inside pedestal is desired for ELM suppression, ...**
- **... $\omega_{perp,e}$ ~ 0 in core increases susceptibility to locked modes due to applied 3D fields**
  - May explain locked mode susceptibility in n=2 RMP cases
- **RMP localized to pedestal region is highly desired**
  - n=4 capability on ITER will reduce impact on core



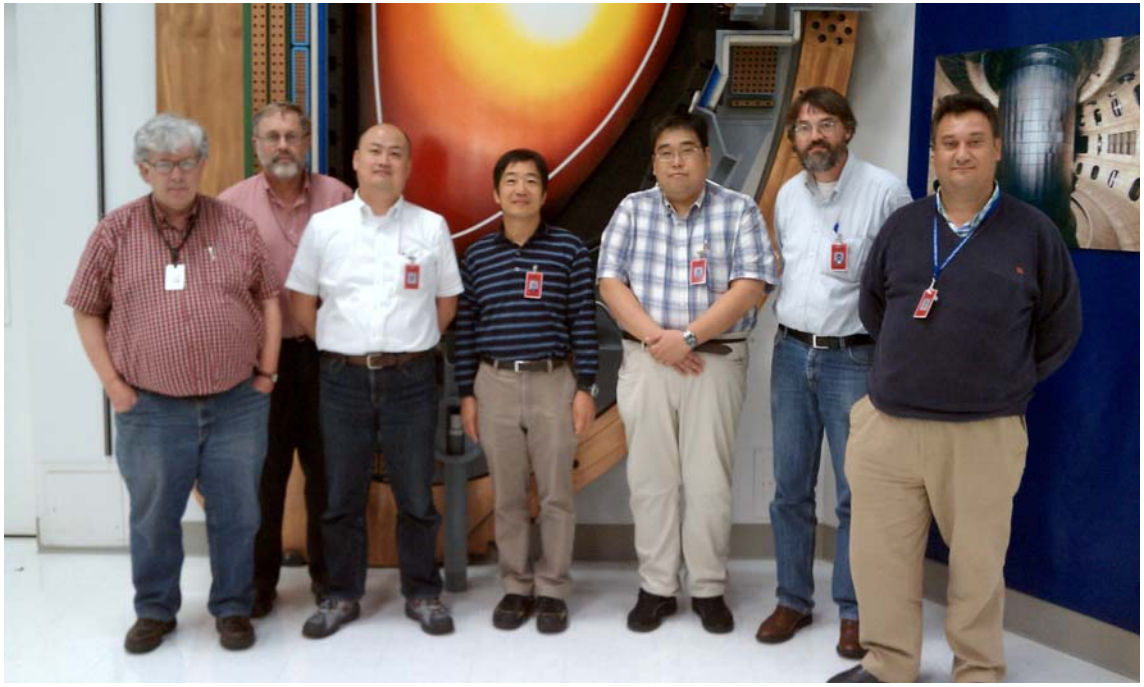
Significant Progress Has Been Made In Improving the Physics Basis for RMP ELM Suppression in ITER

- **Observations consistent with hypothesis that**
  - RMP induces island near top of pedestal
  - Transport from island impedes further widening of the pedestal
  - Peeling-ballooning stability maintained



We Appreciate the Efforts of the ITER IO and Our International Collaborators in this Research

Collaborators from ITER IO, ASDEX-Upgrade, KSTAR, and LHD



- **Also see S. Mordjick invited talk CI2.00002 and L. Zeng contributed talk GO4.00007**
- **More detail on this talk and other work can be found at the DIII-D Poster Session on Thursday afternoon**