Latest Results on Resonant Magnetic Perturbation Induced ELM Suppression on DIII-D

by
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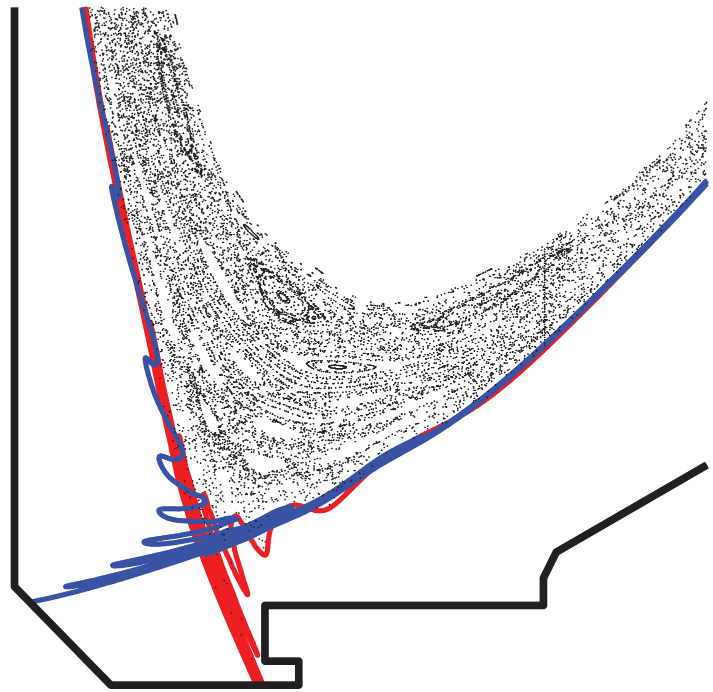
For the DIII-D ELM Control Task Force



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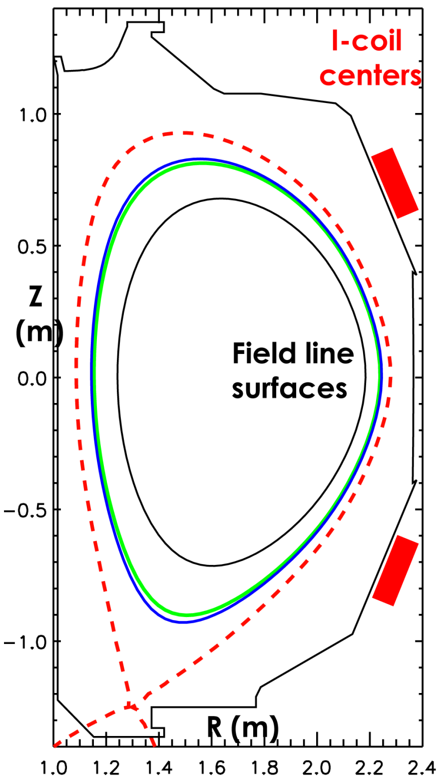
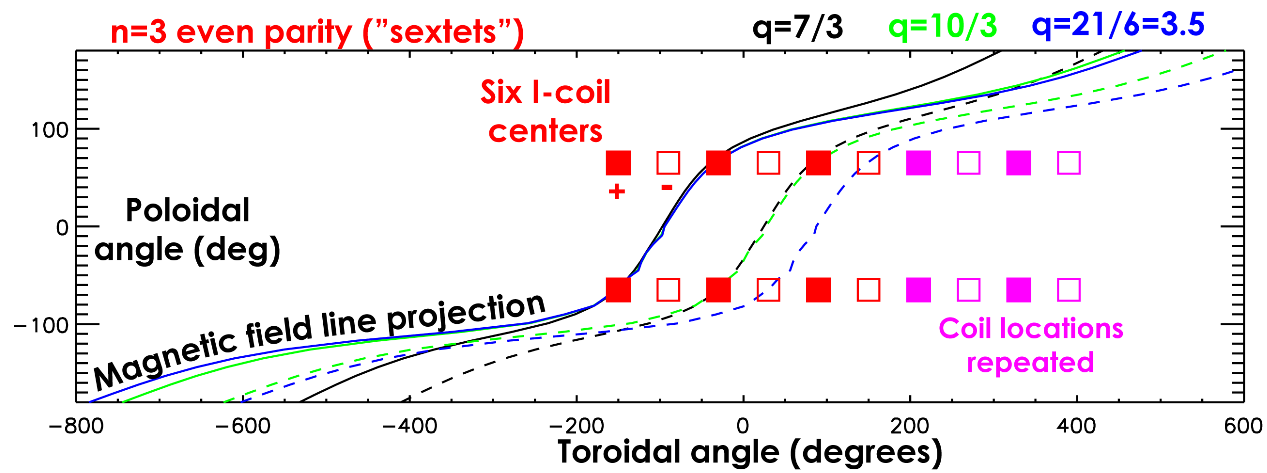
PPPL PRINCETON PLASMA PHYSICS LABORATORY

Resonant field Components Generate by Upper and Lower I-coils Leads to ELM Suppression in DIII-D

I-oils generate radial magnetic fields in plasma



Field alignment correlated with ELM suppression on DIII-D (resonance)



Vacuum calculations show large island overlap with ELM suppression

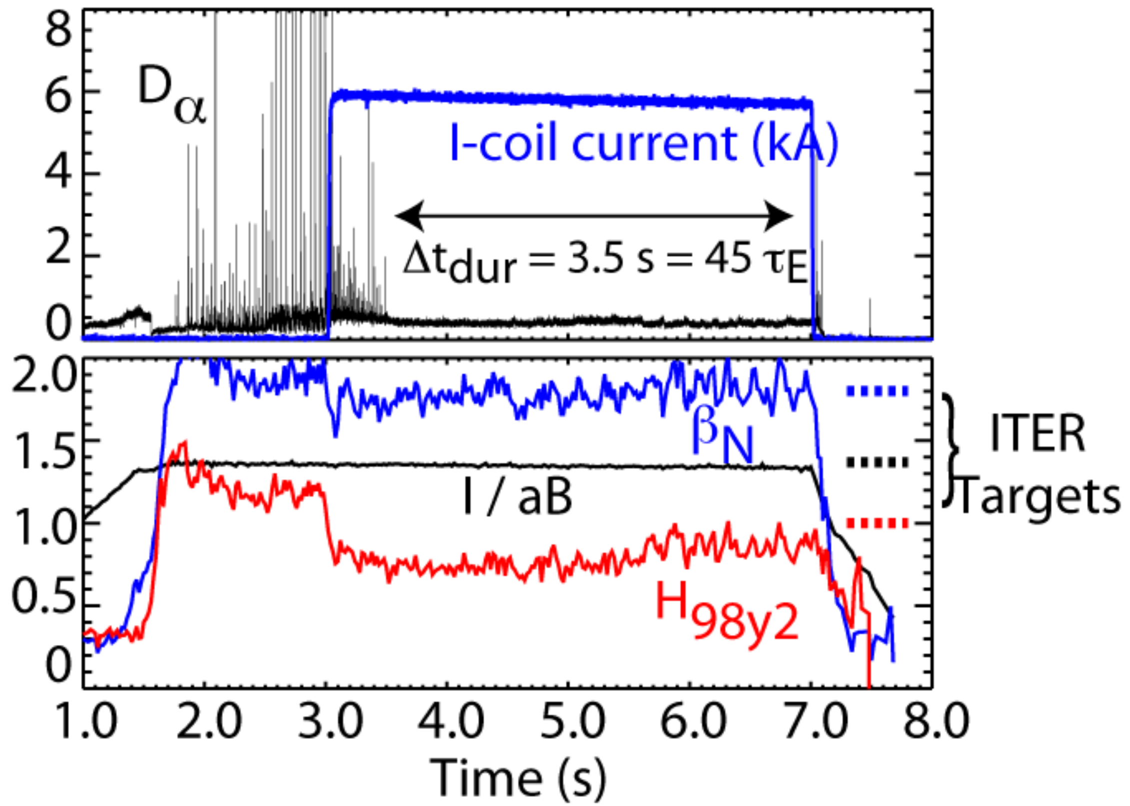
Challenge is to expand operating space and extrapolate to ITER

Extension to ITER: Robust ELM Suppression Sustained for Long Duration in ITER Baseline Scenario

- **Sustained for 45 τ_E**
- **Achieved with n=3 RMP from single row of I-coils**
- **Close match to ITER specs.**

	I/aB	β_N	H_{98}	$\nu_{*,ped}$
DIII-D	1.40	1.8	0.9	0.12
ITER	1.41	1.8	1.0	0.10

- **Confinement degradation observed early, improves later**
- **Next: extend to low rotation, optimize confinement**



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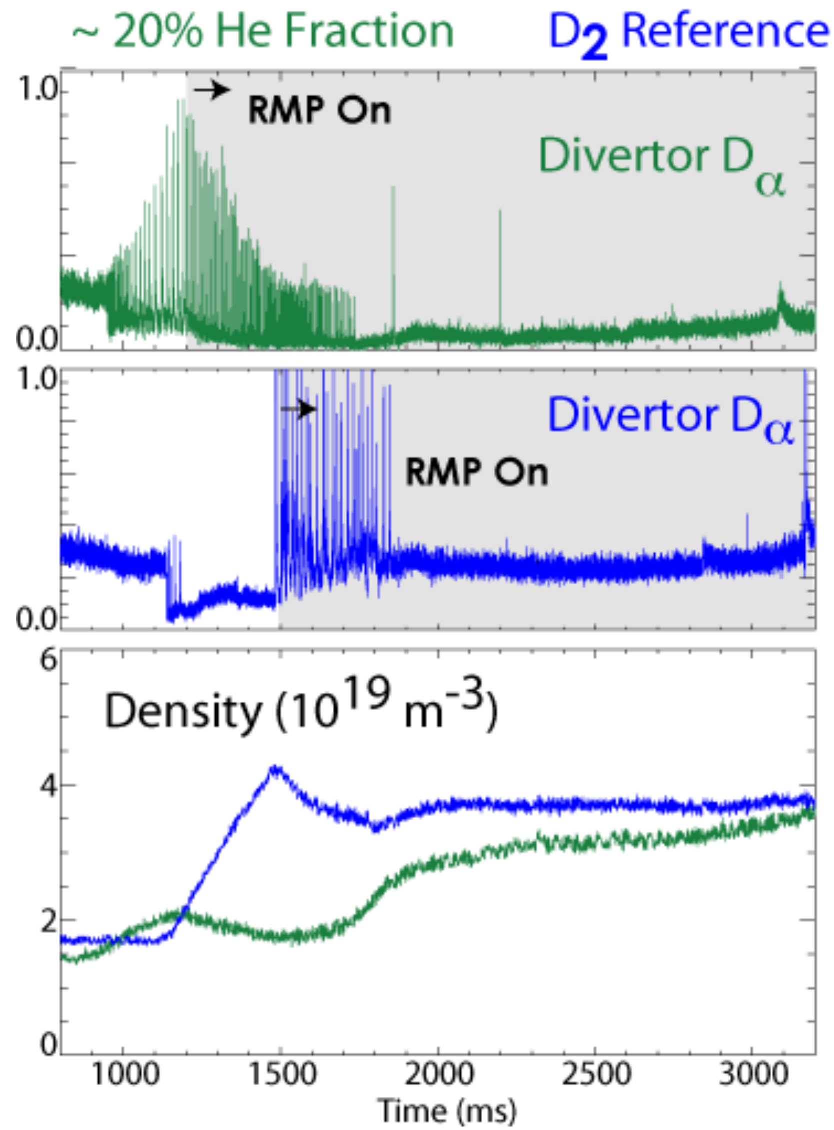
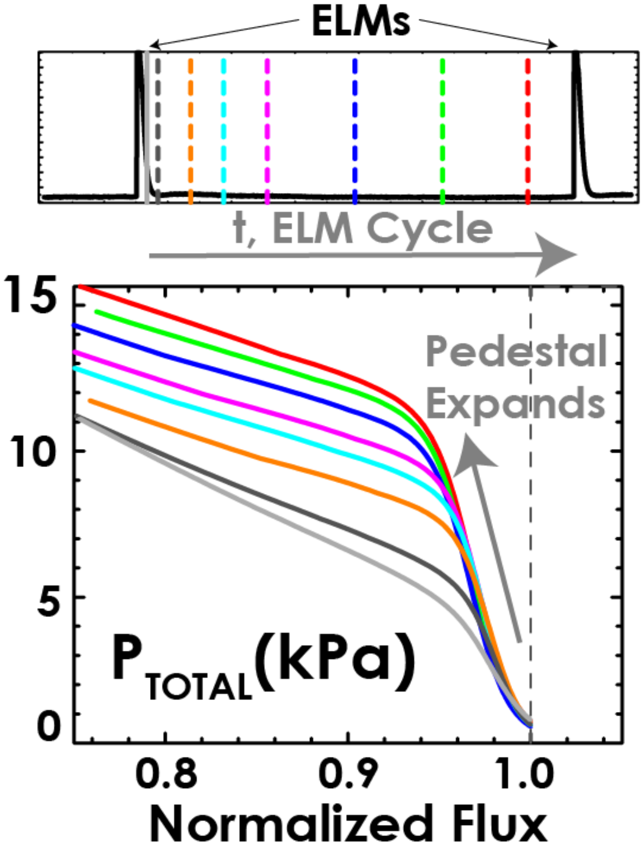
Extension to ITER: ELM Suppression Demonstrated in ITER Baseline with Helium

- **ITER will first operate in a non-nuclear Helium phase**
- **On DIII-D ELM suppression with 20% helium fraction (n_{He}/n_e)**
  - Same for D plasmas with similar density
- **ELMs return at higher He fraction (same for D)**
  - TBD: role of density vs He fraction



No RMP: H-mode Pedestal Evolution Consistent with Peeling-Ballooning Stability Limit

- **Height and width of pedestal expands between ELMs**



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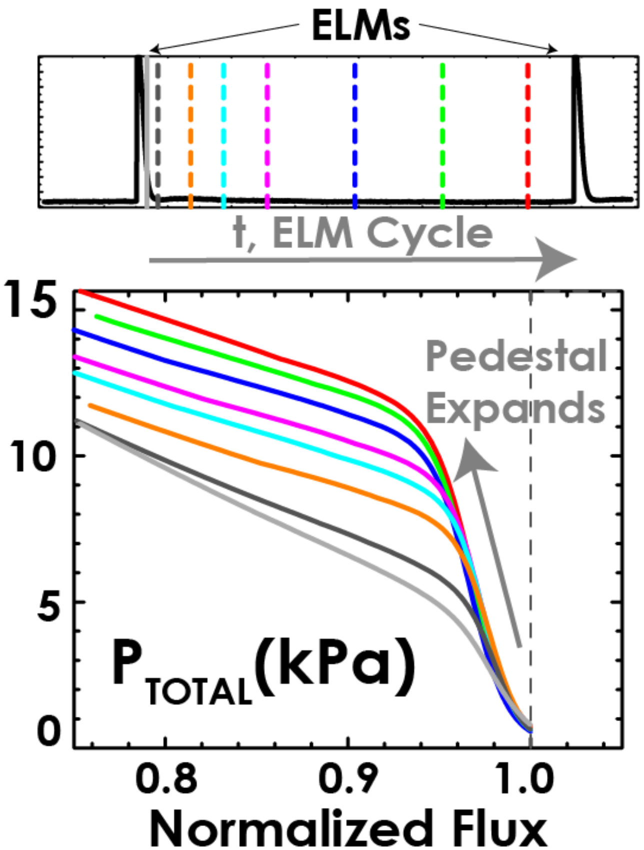
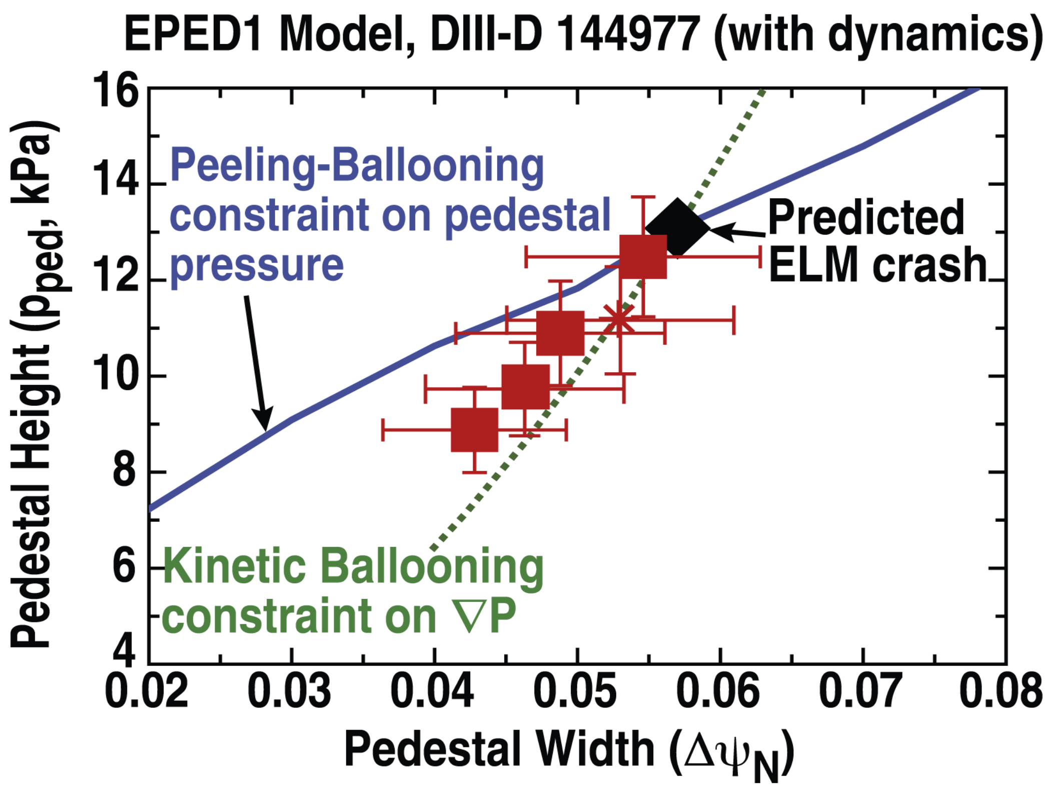
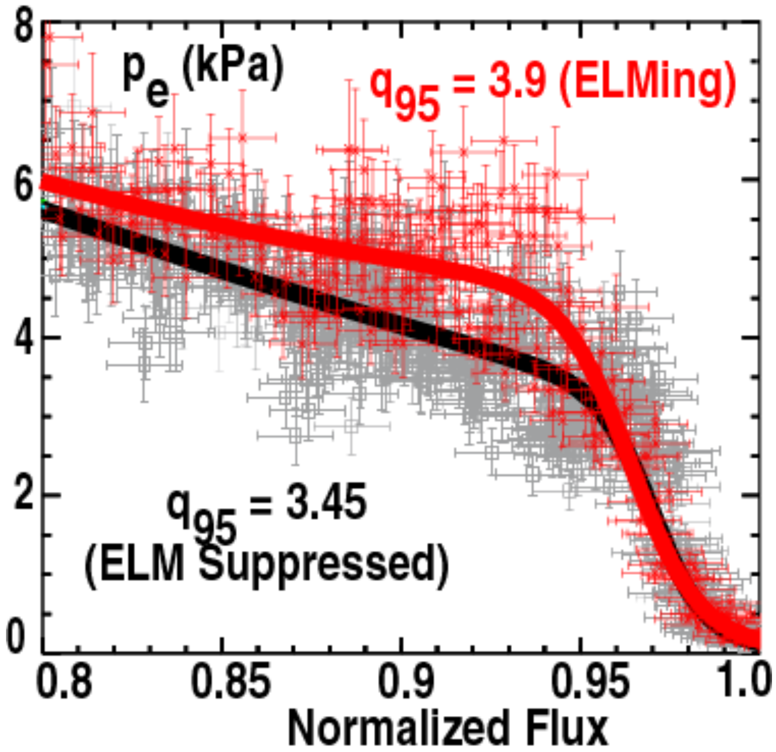


- Pedestal width determined by critical gradient for KBM, height determined by P-B boundary



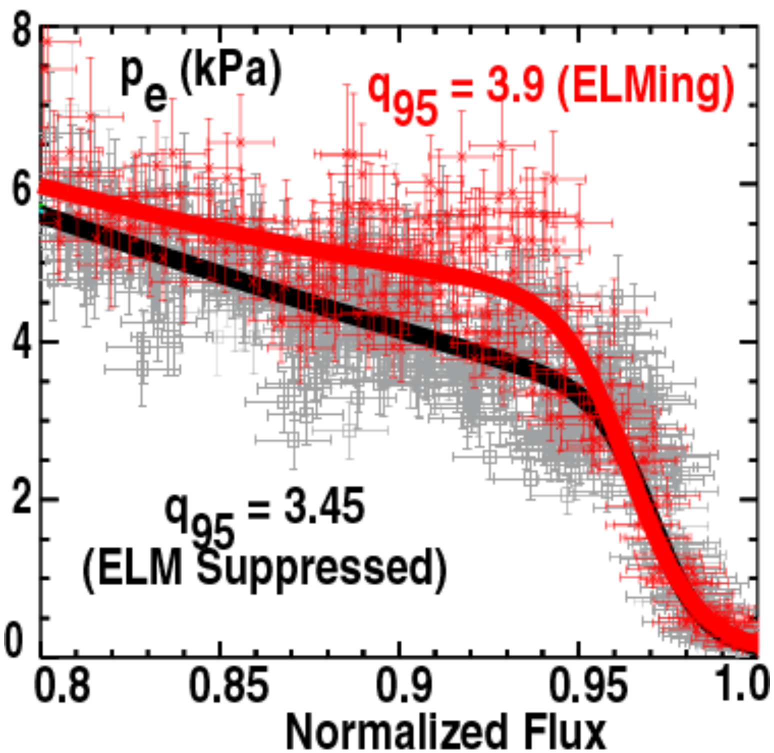
With RMP: Pedestal Expansion Terminates and ELMs are Suppressed, Consistent with Peeling-Ballooning Stability

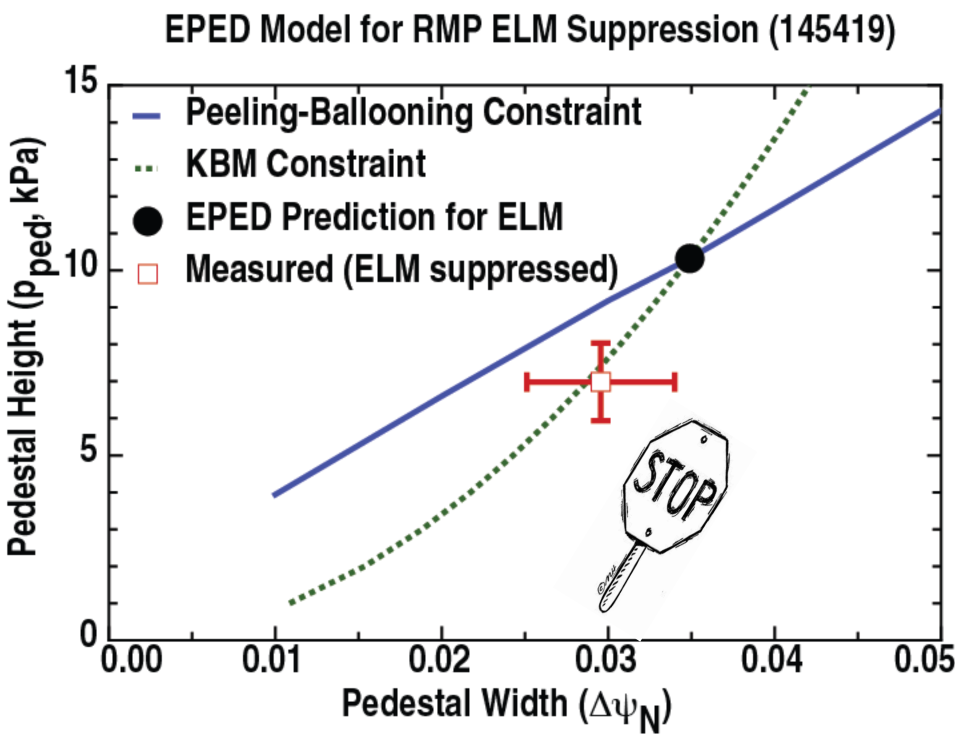
- **ELMs are suppressed in narrow windows of q-95**



With RMP: Pedestal Expansion Terminates and ELMs are Suppressed, Consistent with Peeling-Ballooning Stability

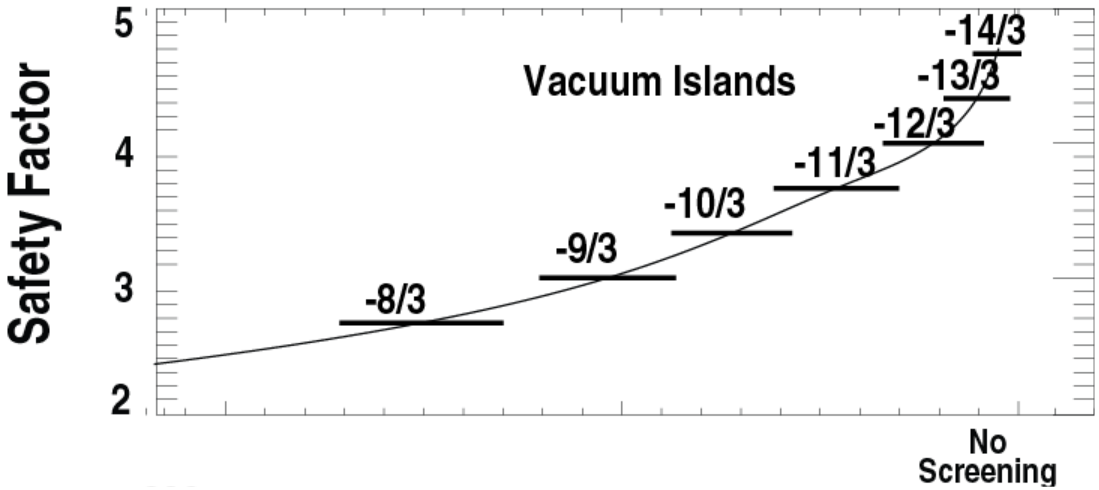
- ELMs are suppressed in narrow windows of q-95
- q-95 sensitivity suggests island alignment with top of pedestal is key





Theory Predicts Island Formation at top of Pedestal in Co-rotation Plasmas

- **Vacuum model predicts strong island overlap**
- **Weak sensitivity to q-95**
  - Counter to observation



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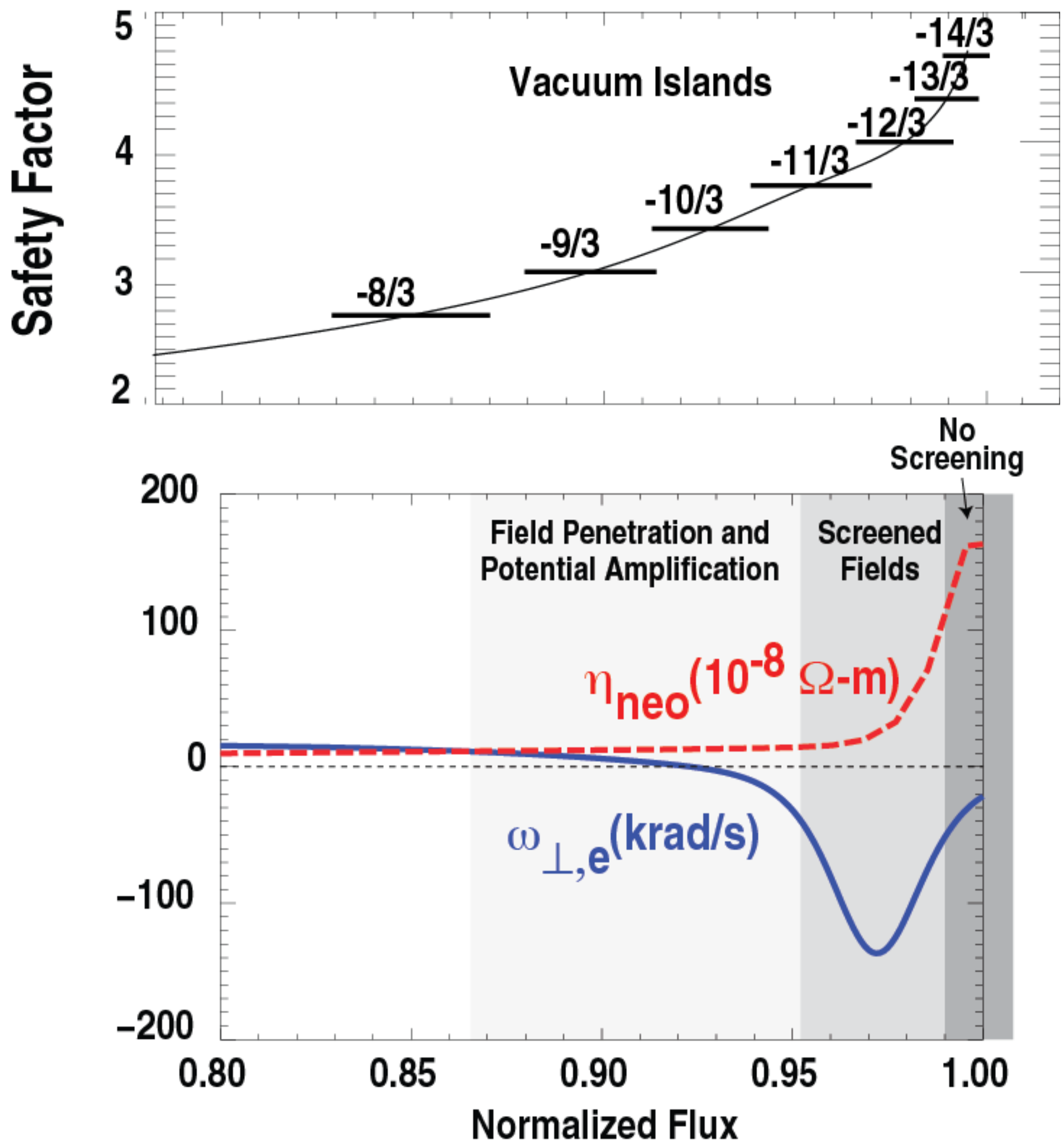
- **But theory predicts penetration at top of pedestal when $\omega_{\perp,e} = 0$**

$$\omega_{\perp,e} = \omega_{ExB} + \omega_{e,dia}$$



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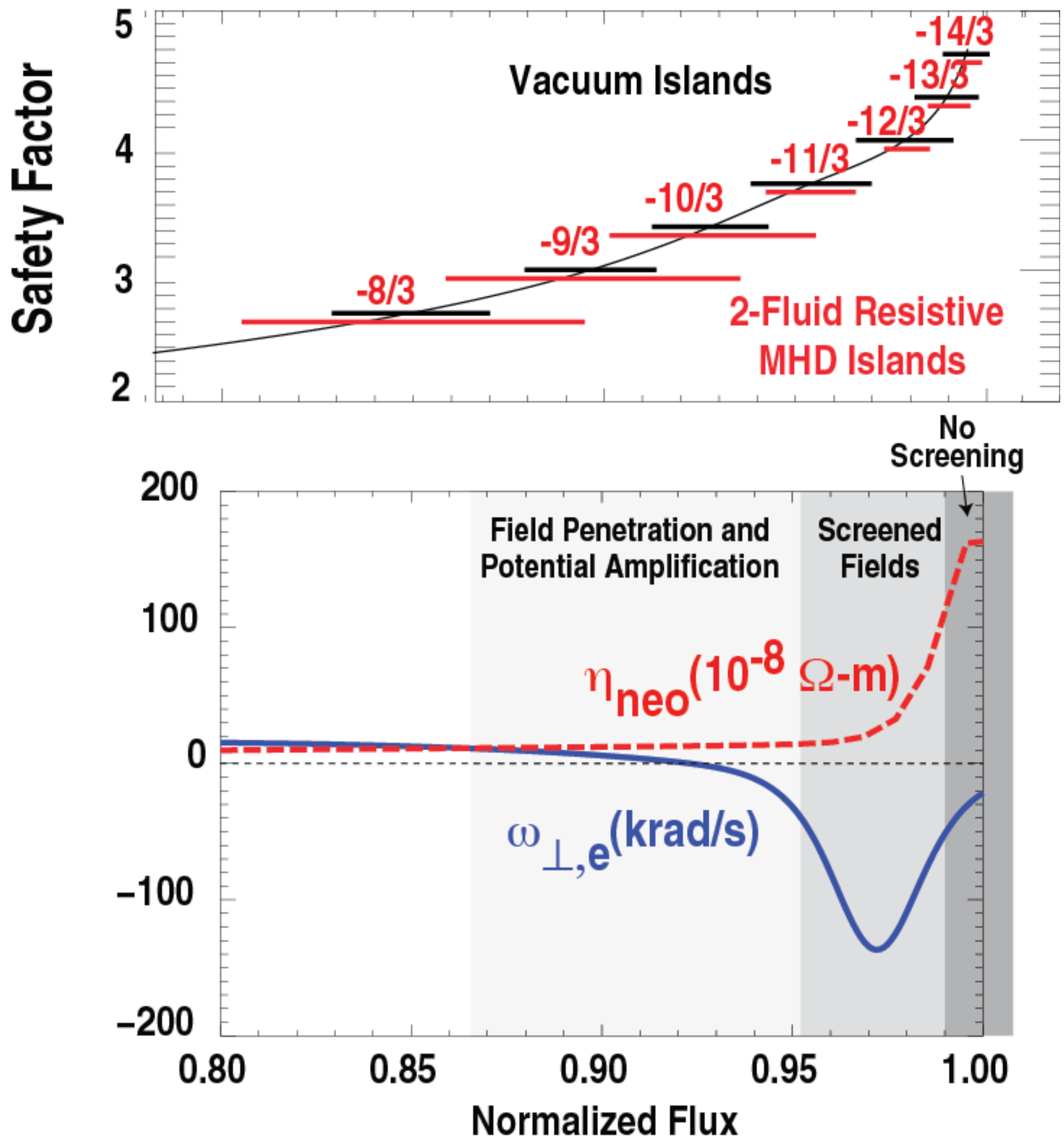
- **Restores q-95 sensitivity for ELM suppression by island formation**
  - Alignment of island to top of pedestal



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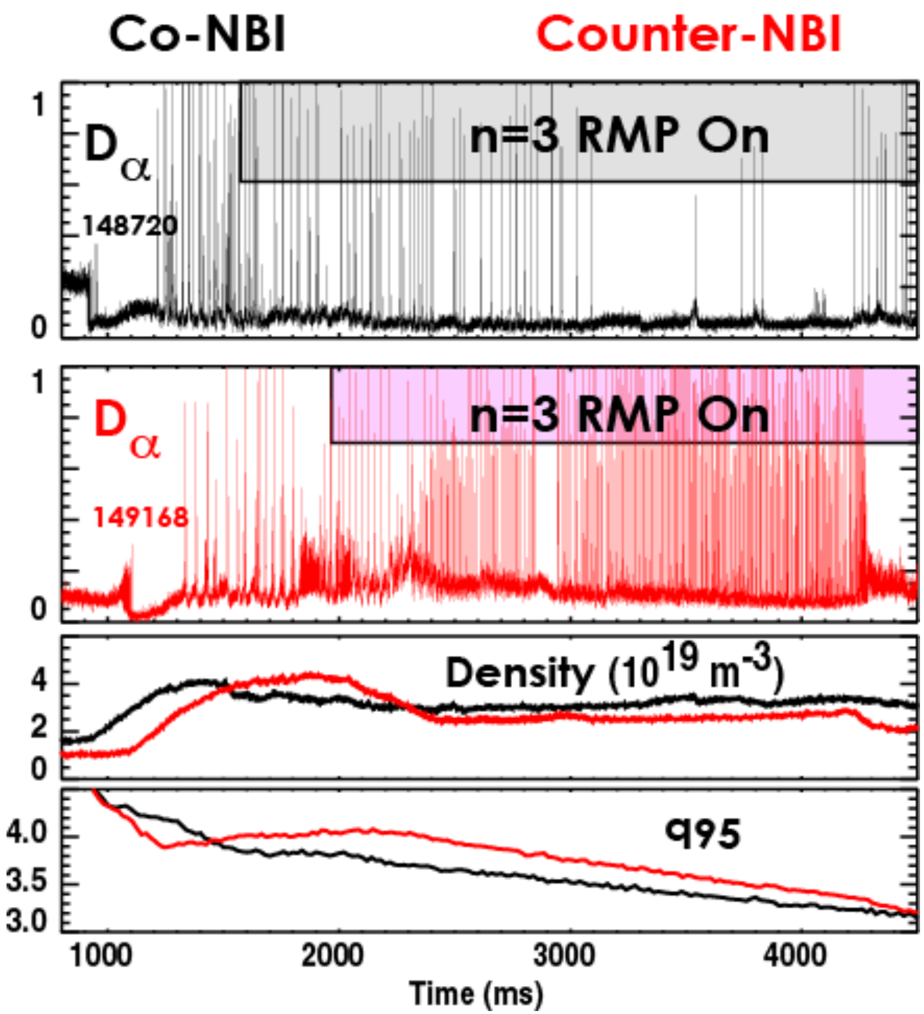
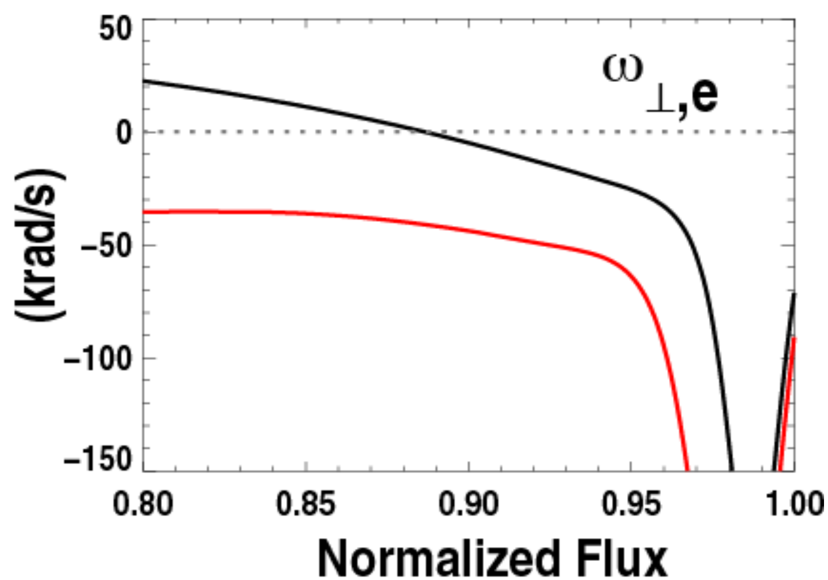
A Test of the Model: Lack of ELM Suppression with Counter-NBI Indicates Importance of $|\omega_{\perp,e}|$



- **ELMs remain in counter-NBI**
- **Suppression seen with co-NBI**
  - For comparable density
  - Implications for low rotation ITER plasmas?



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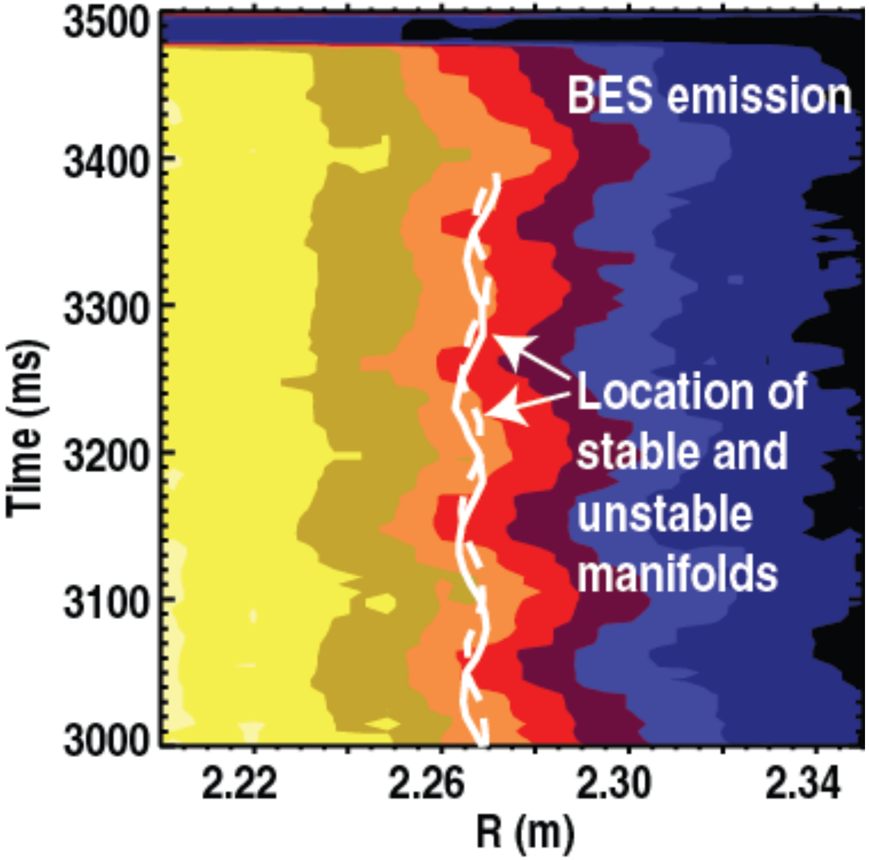
Continuous Rotation of n=2 RMP Used to Search for Islands and Plasma Kink-like Response

Top View

n = 2 B_r at midplane



- **Rotate perturbation past fixed detectors**
- **Edge displacements 4-5x larger than vacuum**
  - Consistent with plasma kink-like response
- **No island like displacements observed inside**

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Flux Surface Displacement Inferred from Temperature Profile Modification During n=3 RMP Displacement

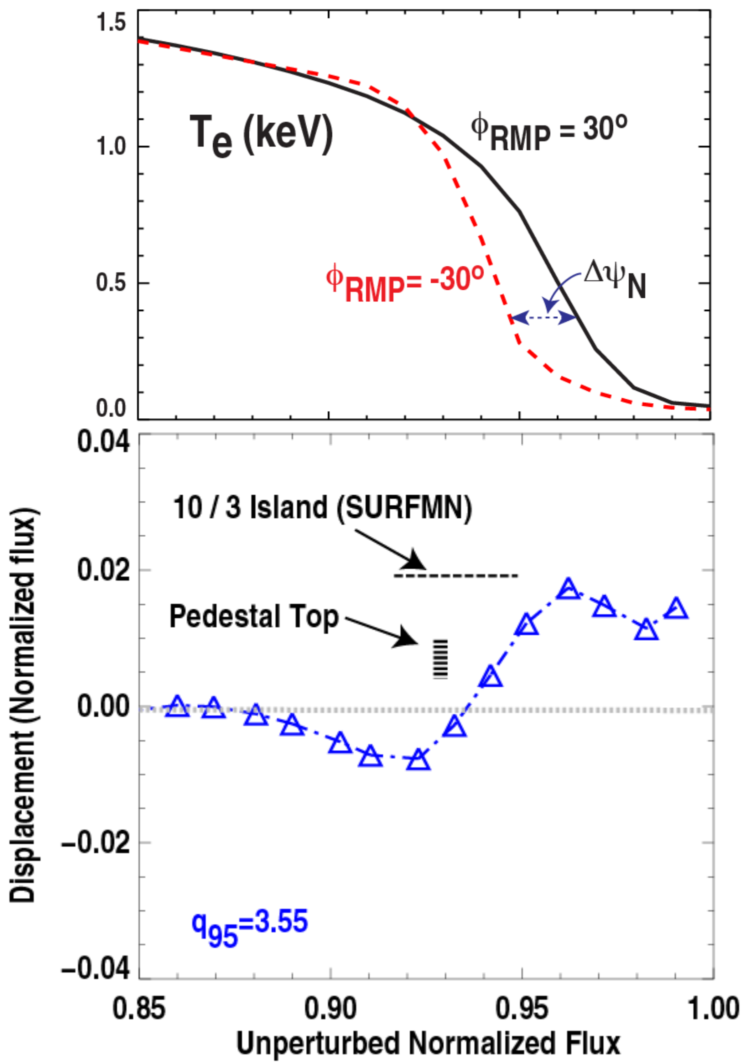
- **Six I-coils only allows a 180 deg. phase shift of n=3 RMP**
  - Toroidal rotation by 60 deg.

Top View

n = 3 B_r at midplane

Flux Surface Displacement Inferred from Temperature Profile Modification During n=3 RMP Displacement

- **Six I-coils only allows a 180 deg. phase shift of n=3 RMP**
  - Toroidal rotation by 60 deg.
- **Kink-like edge displacement of order vacuum**
  - Inferred displacement assumes Te(ψ) unchanged
- **Phase dependent flattening at the top of the pedestal**
  - Island-like
  - Ambiguity due to possible core transport modulation (Wade: IAEA)



Strong Progress made in Extension and Understanding of RMP ELM Suppression in DIII-D

- **Suppression in ITER baseline for 45 τ_E and in He**

- **Increased physics understanding:**
  - Rotation dependence of suppression
  - Measurement of plasma kink-like response (Ferraro, this session)
  - Measurement of internal displacements suggestive of islands
  - X-ray imaging of RMP near X-point (Shafer, next speaker)

- **See also R. Moyer, On the role of E_r in RMP ELM suppression**
  - Invited: Thursday Nov. 1, 12:00 noon, Ballroom BC