Comparison of ELM Control Using One versus Two Rows of RMP Coils in DIII-D

M.E. Fenstermacher (LLNL)

T.E. Evans, T.H. Osborne, M.J. Schaffer, J.S. deGrassie, P. Gohil, R.J. Groebner, A.W. Leonard, R.A. Moyer, P.B. Snyder

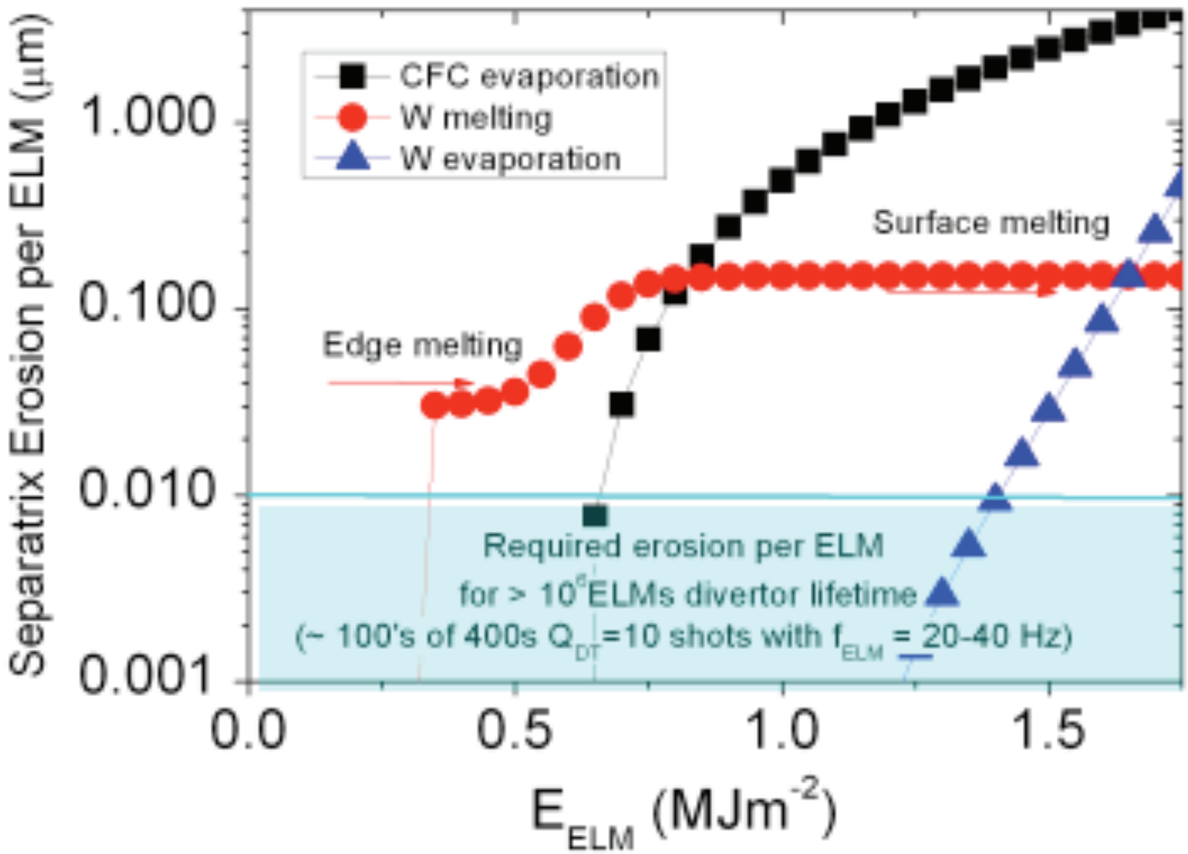
Presented at the
50th APS Annual Meeting of
the Division of Plasma Physics
Dallas, Texas

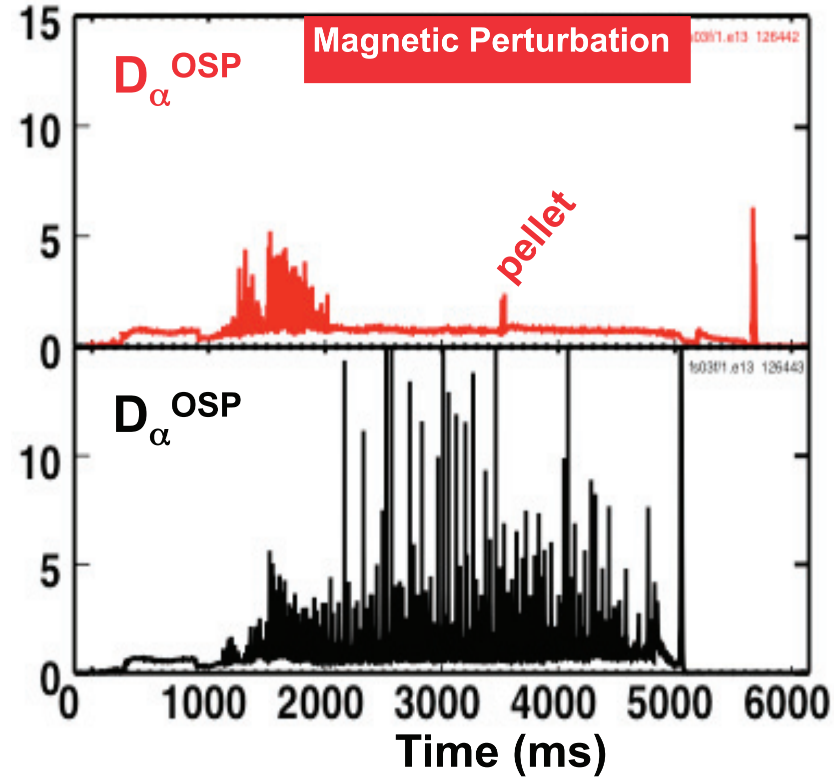
November 17–21, 2008

DIII-D
NATIONAL FUSION FACILITY
SAN DIEGO

Controlling ELMs is a critical issue for ITER Due to Divertor Erosion

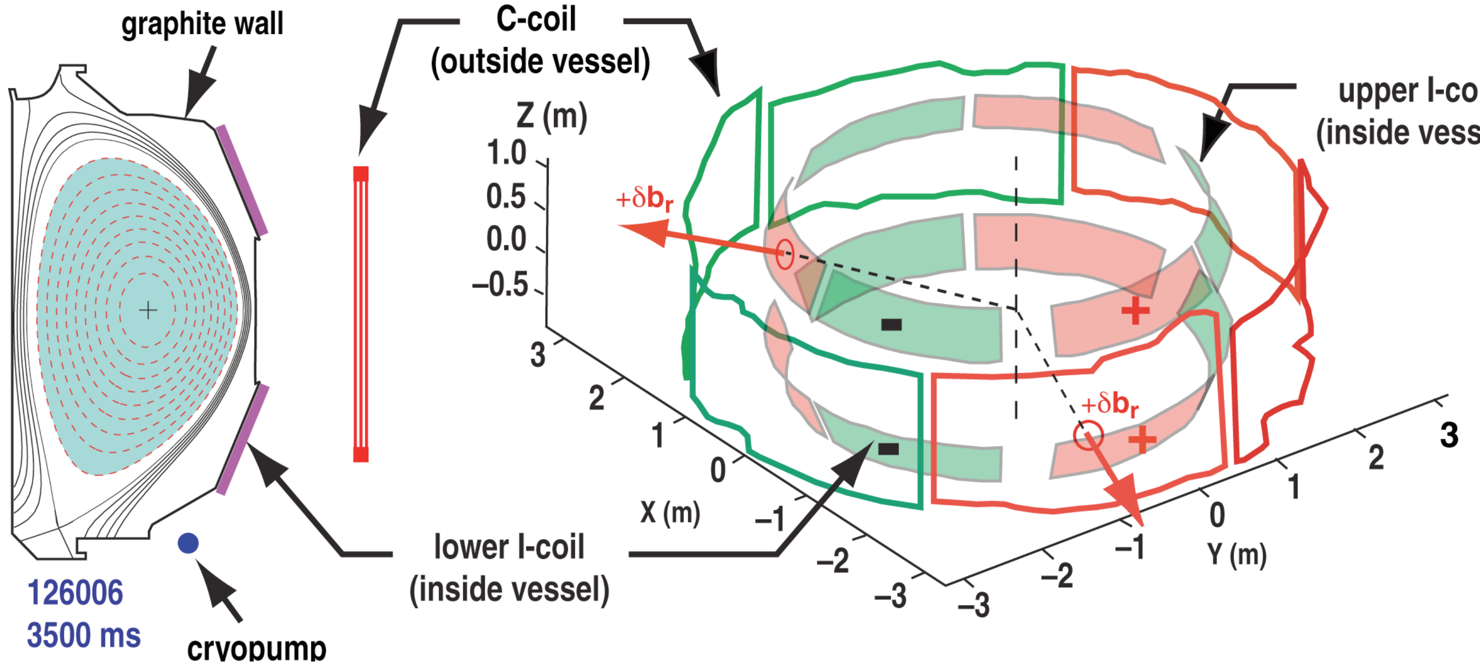
Loarte, PEP ITPA, San Diego, May 2008

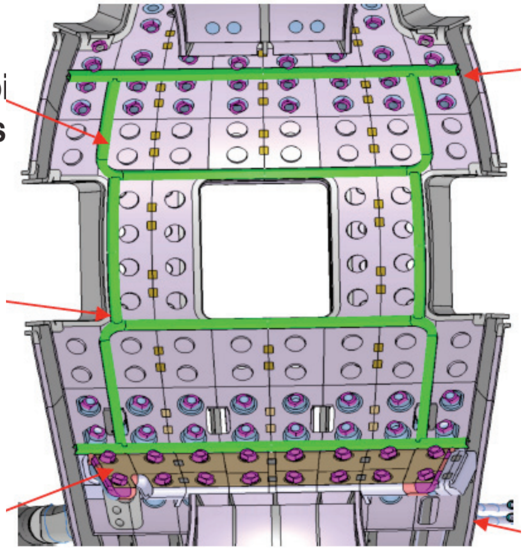




- **Type-I ELMs in ITER > 0.5 MJ/m² could potentially limit the divertor and first wall lifetime**
  - Requires 20x reduction in ELM size with minimum pedestal degradation

ELM Suppression Achieved With Two Rows of Off-Midplane I-Coils and With a Single I-coil Row at Higher Coil Current

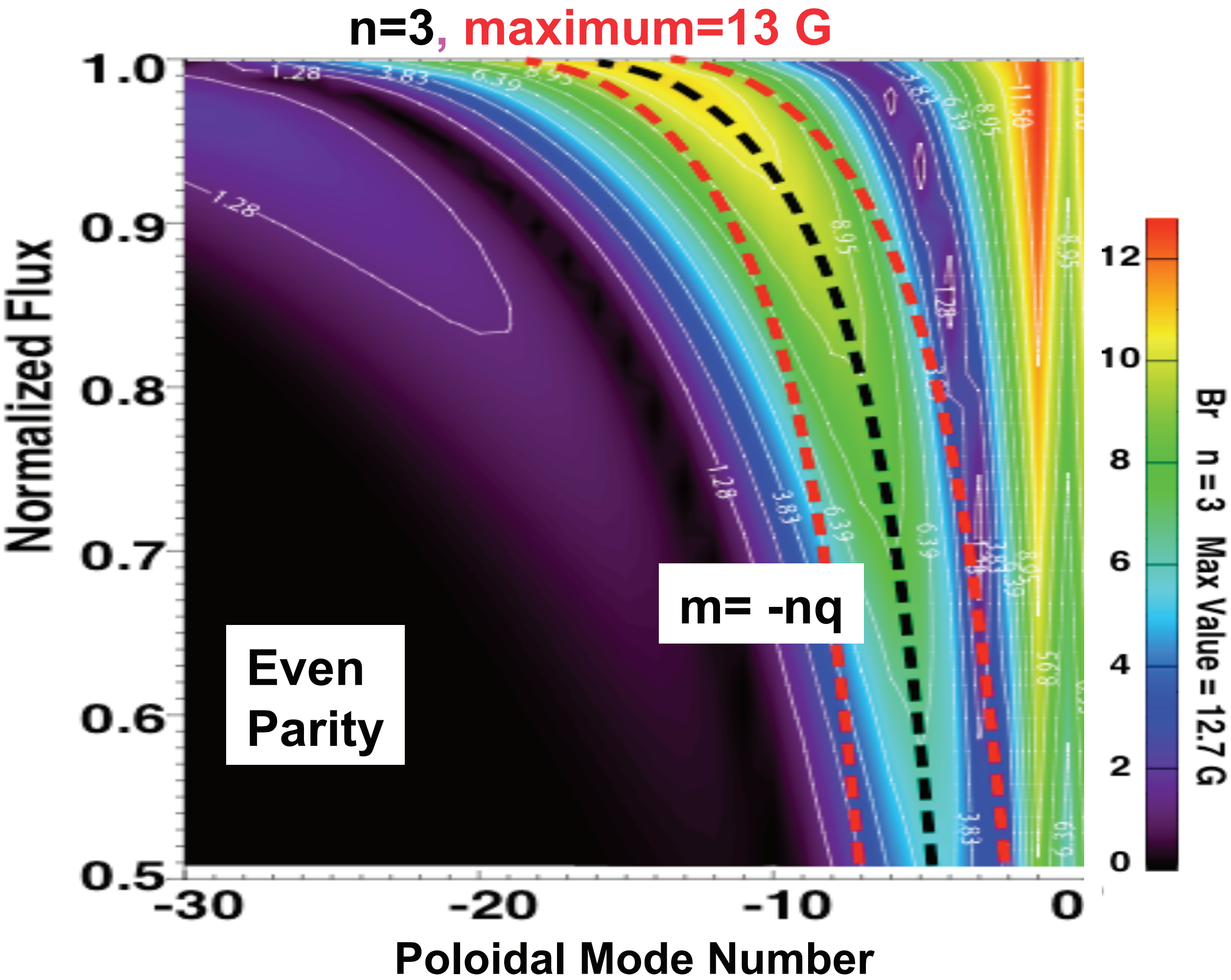




Schematic of ITER RMP coil design

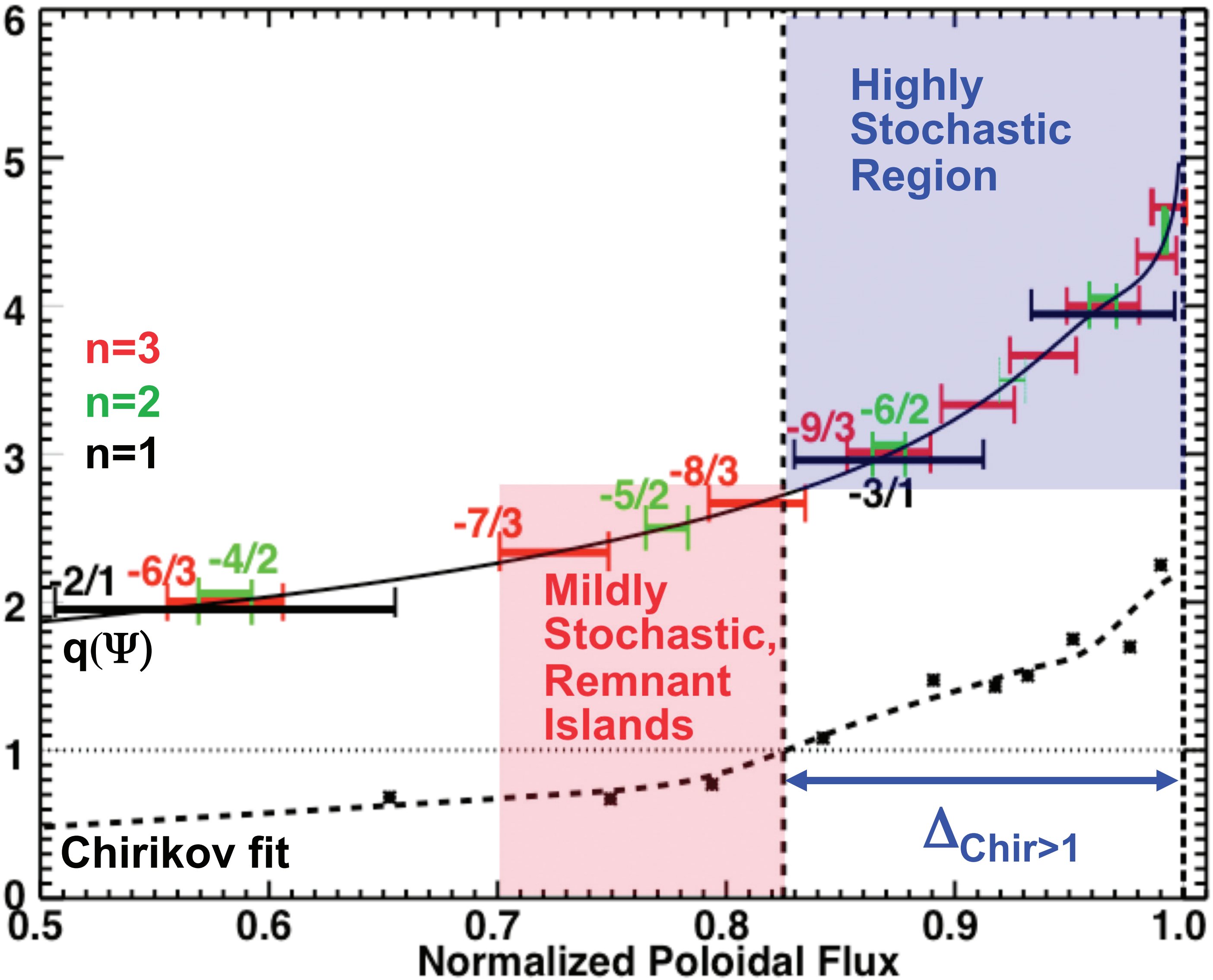
- ELM suppression achieved with similar pedestal perturbation strength using n=3 RMPs from one or two toroidal I-coil rows
  - Required coil current ~50% higher in single row case
  - Consistent with coil geometry effect on the RMP spectrum
- No suppression with n=3 C-coil at similar pedestal perturbation
- ELM suppression with DIII-D RMP coils supports ITER design

ELM Suppression With Two Coil Rows Optimized For Pitch Resonance of RMP With Field Lines --> q_{95} Window



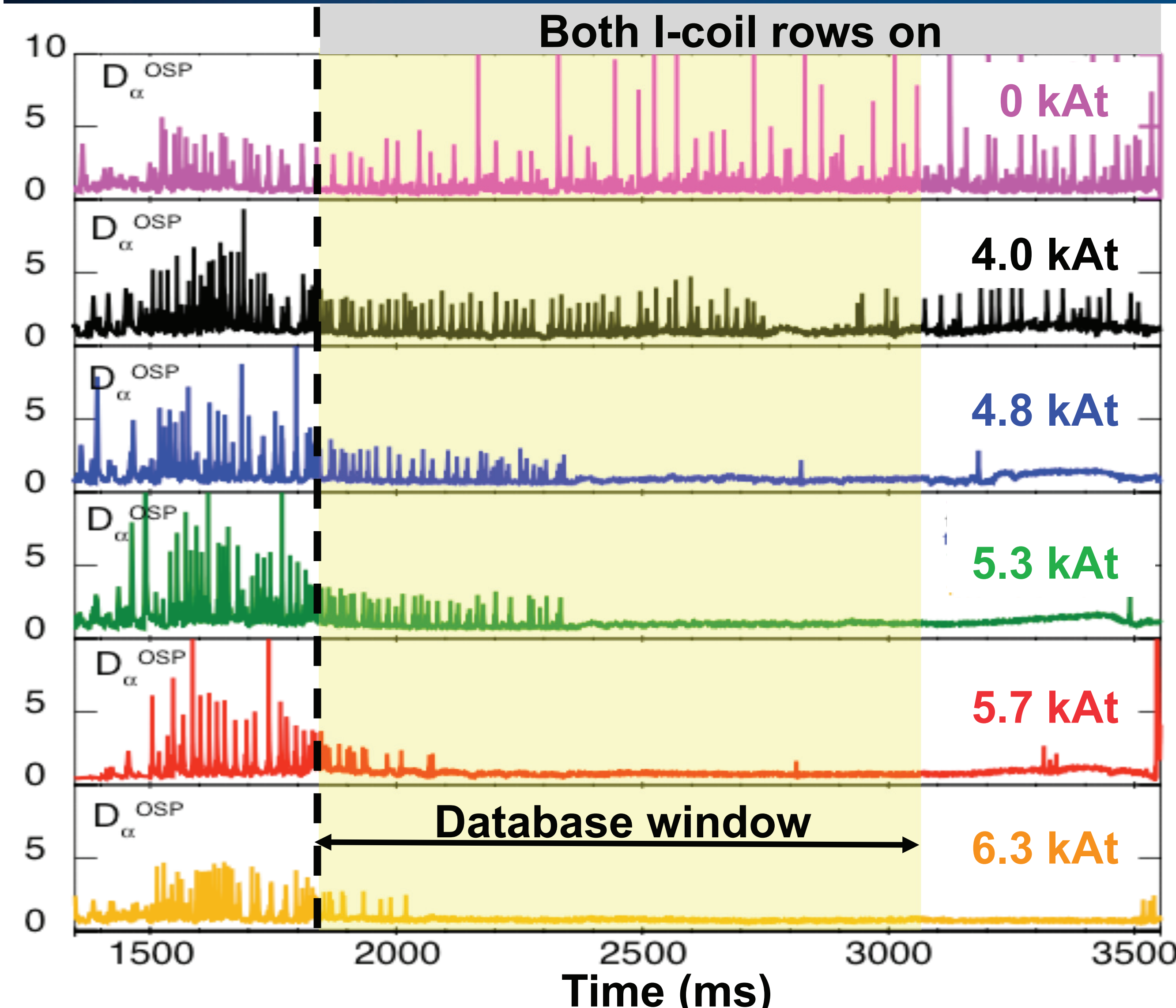
- Multiple resonance windows consistent with pitch alignment
- Suppression window increased with I-coil current
  - Suppression for Δq_{95} = 0.30 at 3 kAt
  - Suppression for Δq_{95} = 0.50 at 4 kAt
- Suppression window also increased with n=1 C-coil current plus n=3 I-coils

For Resonant q95, Vacuum Island Calculations Suggest Remnant Islands Adjacent to Stochastic Region



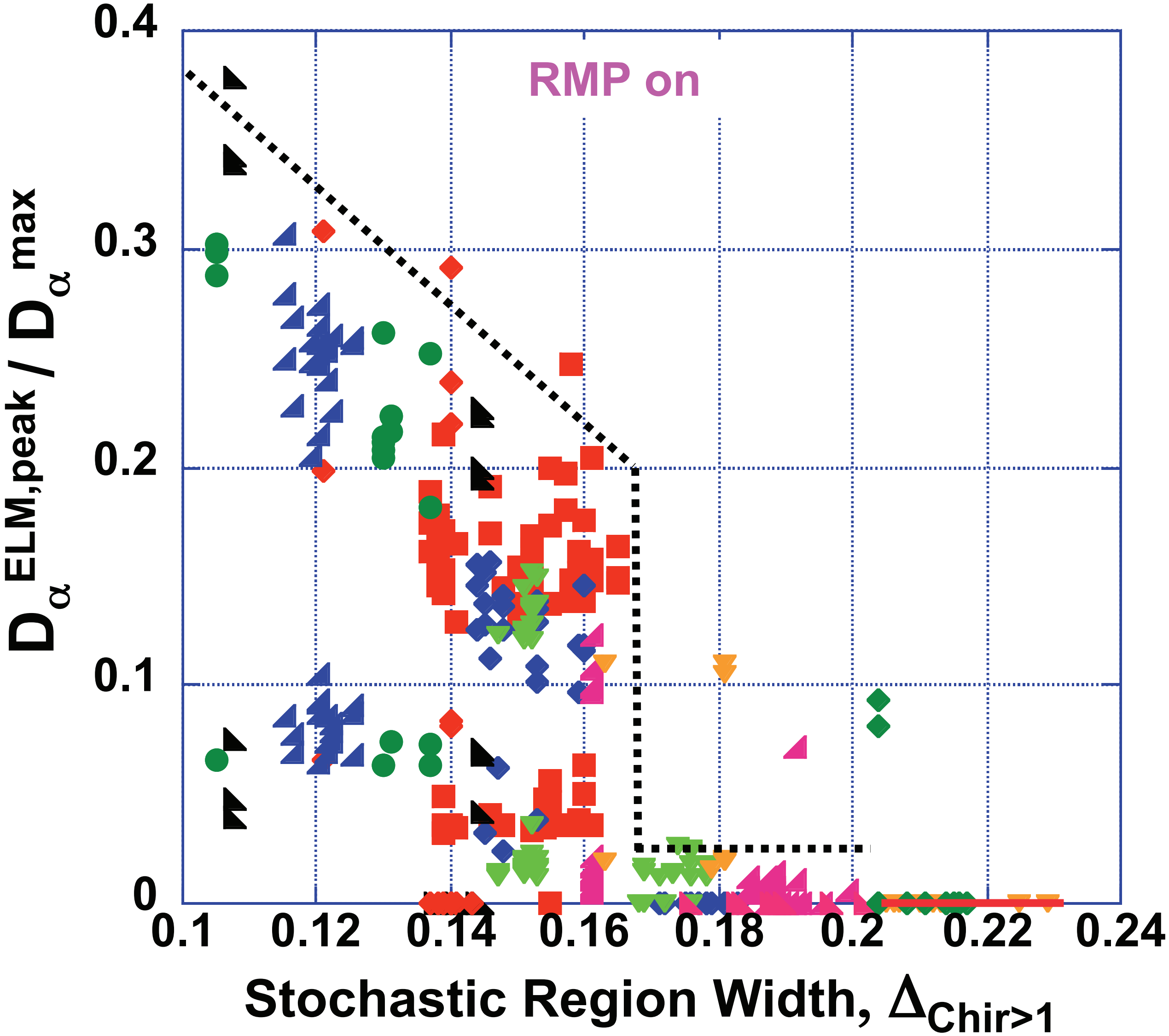
- Stochastic region from q~3 surface outward
- Remnant islands at q=8/3, 5/2, 7/3 surfaces may be weakly coupled
- Interface region $0.80 < \Psi_N < 0.85$

Current Scan With Both I-coils Provides Variation in Width Of Stochastic Region in ELMing and ELM Suppressed Periods



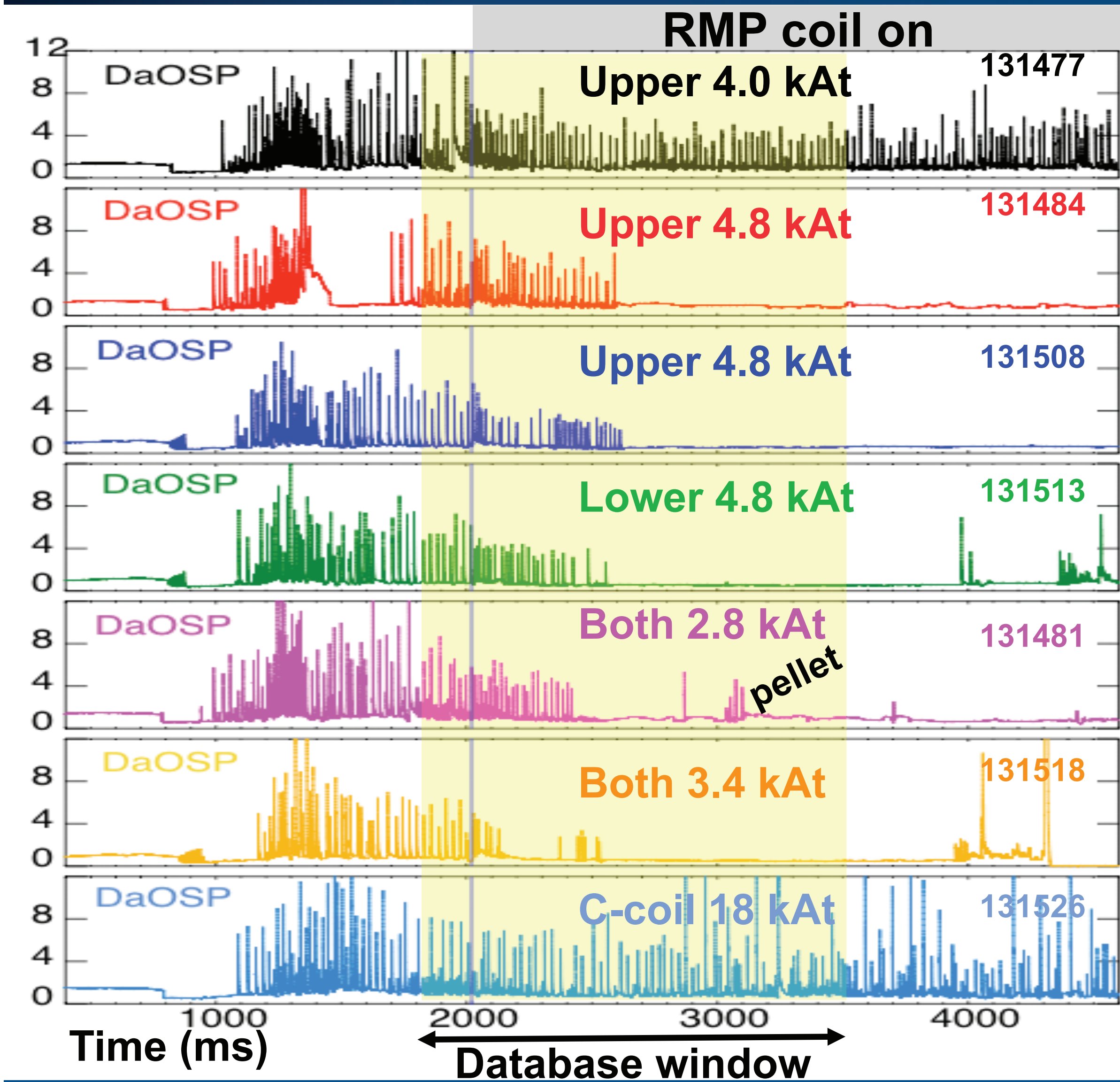
- Database of ELM size vs stochastic region width, $\Delta_{Chir>1}$
  - Vacuum $\Delta_{Chir>1}$ from kinetic EFITs
  - I-coil current scan provides $\Delta_{Chir>1}$scan
  - Multi-ELM sampling during pedestal evolution after I-coil turn-on

Correlation of Maximum ELM Size With $D_{Chir>1}$ Provided Guidance For Scaling Up DIII-D Results to ITER Design



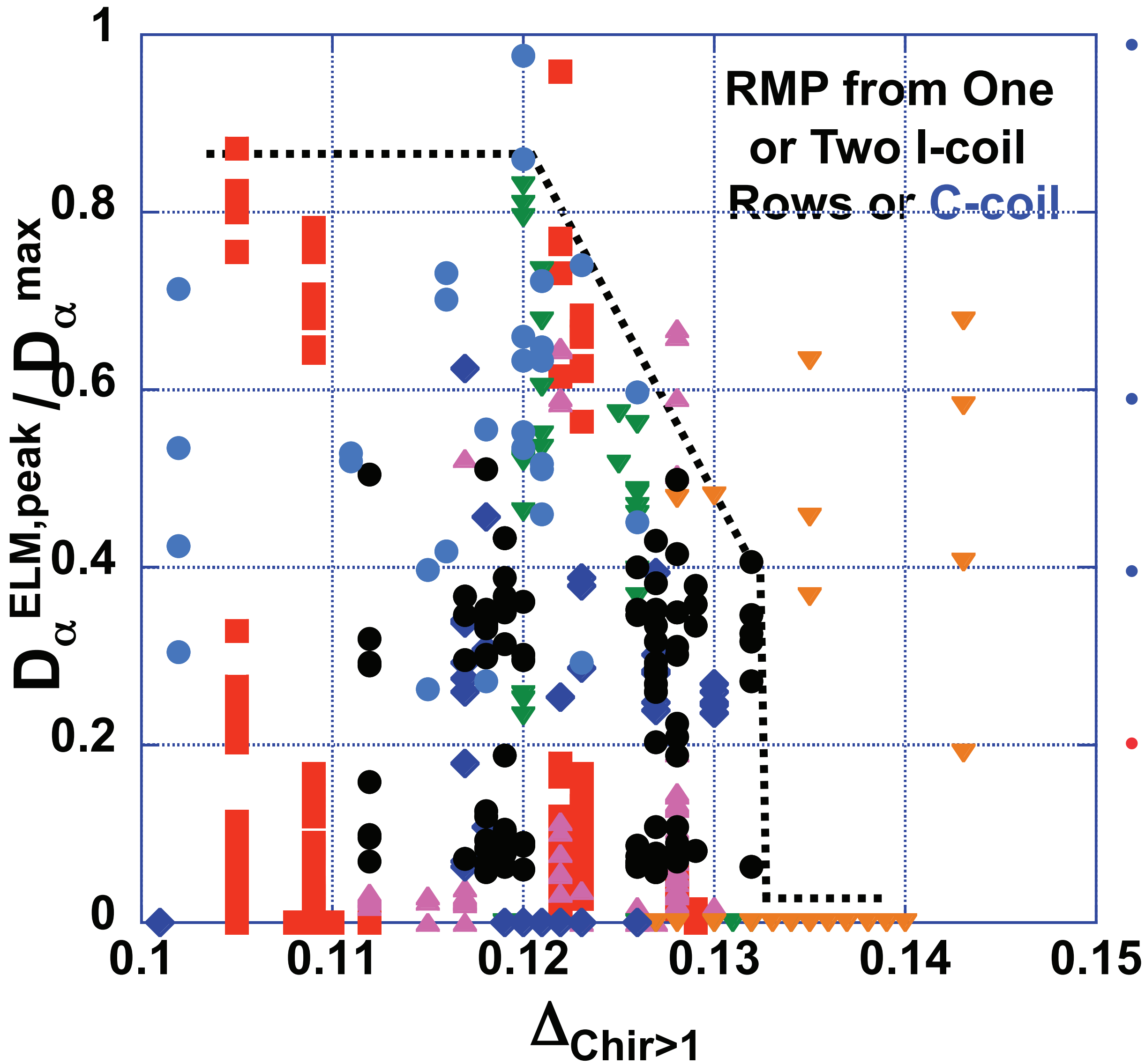
- Maximum ELM size decreases with overlap region width to $\Delta_{Chir>1}$ = 0.16
- 10x decrease in maximum ELM size at q_{95}=3.6 for $\Delta_{Chir>1}$ > 0.165
- No detectable ELMs for $\Delta_{Chir>1}$ > 0.2
- ITER coil design at 60 kAt achieves $\Delta_{Chir>1} \geq 0.165$

Set of Discharges From Comparison of One vs Two Coil Rows Provides Dataset To Test Overlap Width Guidance



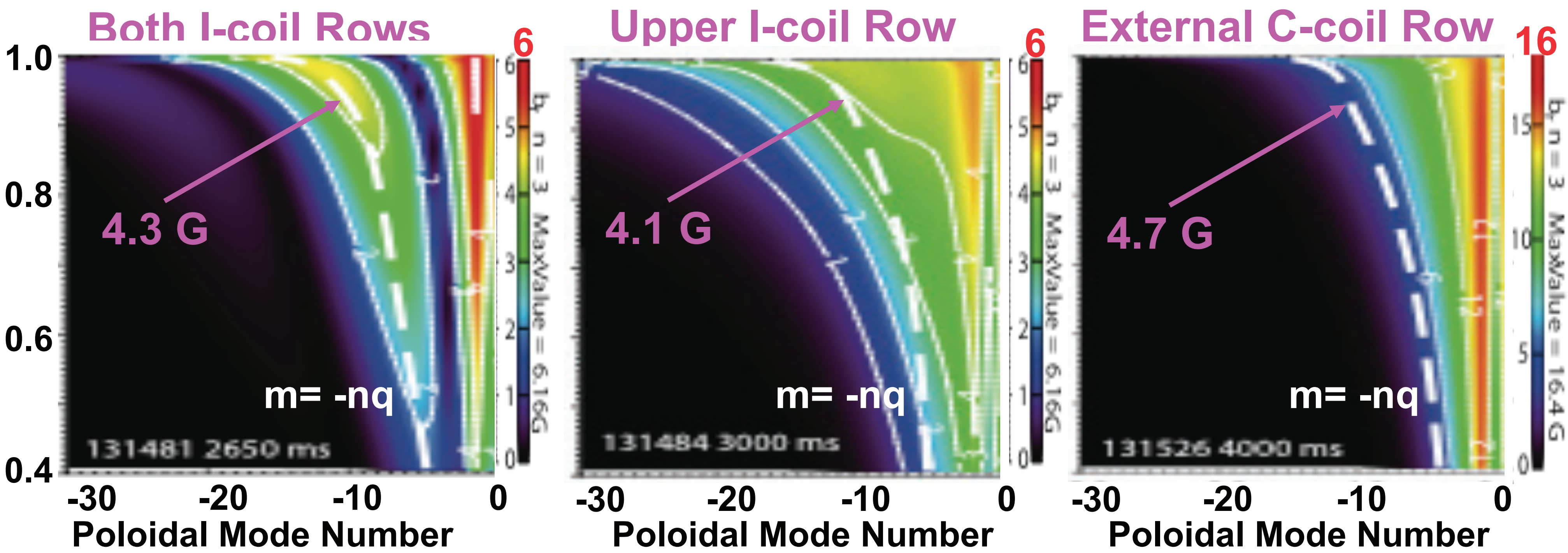
- ELM suppression with single I-coil row required ~50% more coil current
- New database of island overlap widths includes
  - Upper I-coil row alone at two coil currents
  - Lower I-coil row alone
  - Both I-coil rows at two coil currents
  - C-coil n=3 RMP
    - Not much change in ELMs

ELMs During n=3 C-coil RMP Consistent With Stochastic Region Width Ordering



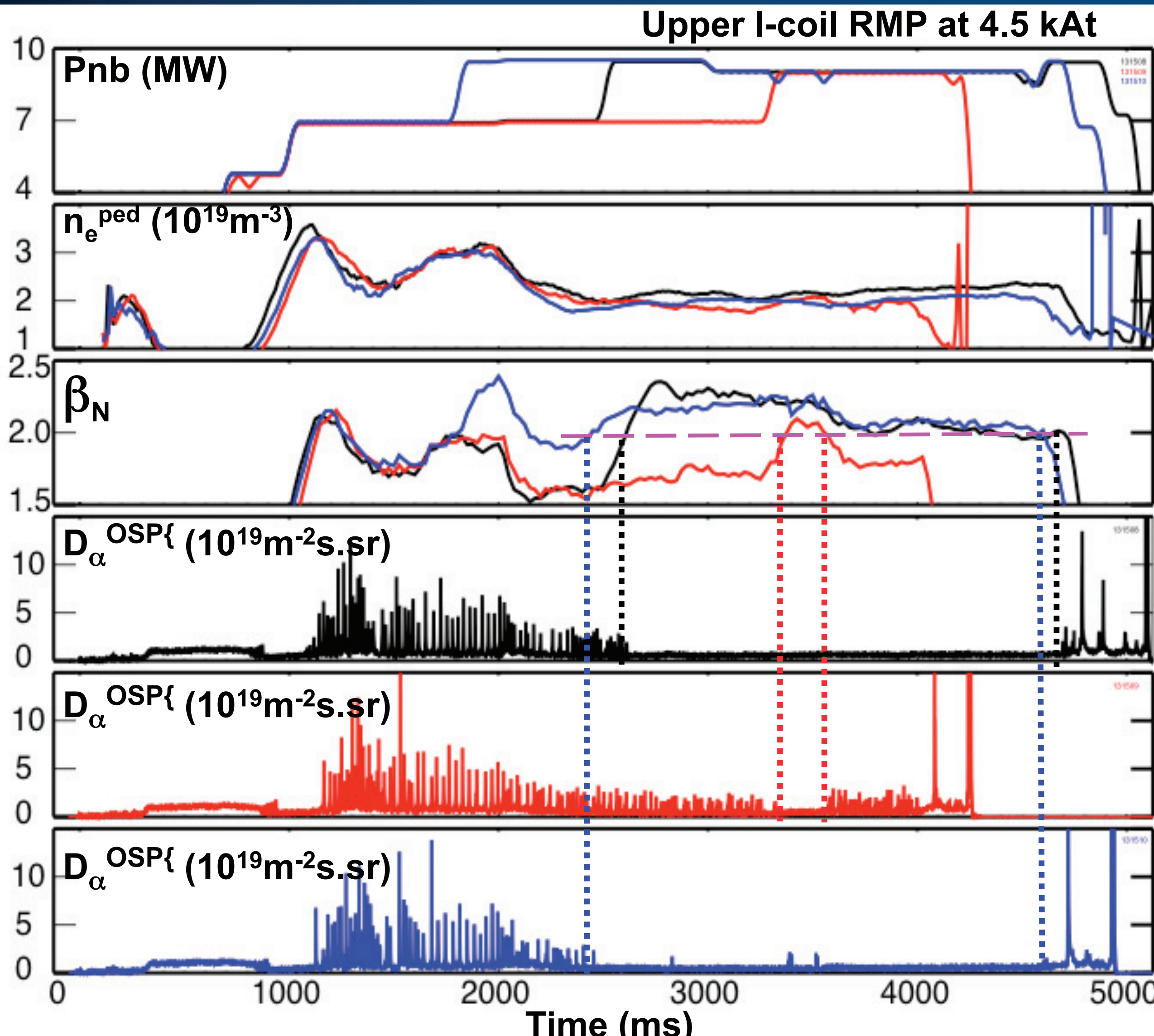
- Suppression correlated with threshold of $\Delta_{Chir>1}$ = 0.132 for this run day
  - Threshold for 2-rows run day was $\Delta_{Chir>1}$ = 0.165
- Outliers with ELMs for $\Delta_{Chir>1}$ above threshold
- Timeslices without ELMs for $\Delta_{Chir>1}$ less than threshold
- SATISFYING THRESHOLD IN $\Delta_{Chir>1}$ IS ONLY A GUIDE TO REQUIREMENTS FOR SCALING DIII-D RESULTS TO ITER COIL DESIGN

Key Differences in Spectra of Resonant and Non-Resonant Components Point To Optimum For ITER



- Two internal, off-midplane, small aperture rows give localized edge resonance
- Single internal row at higher current gives resonance deeper into core
- External, large aperture row at same pedestal perturbation gives very large non-resonant components

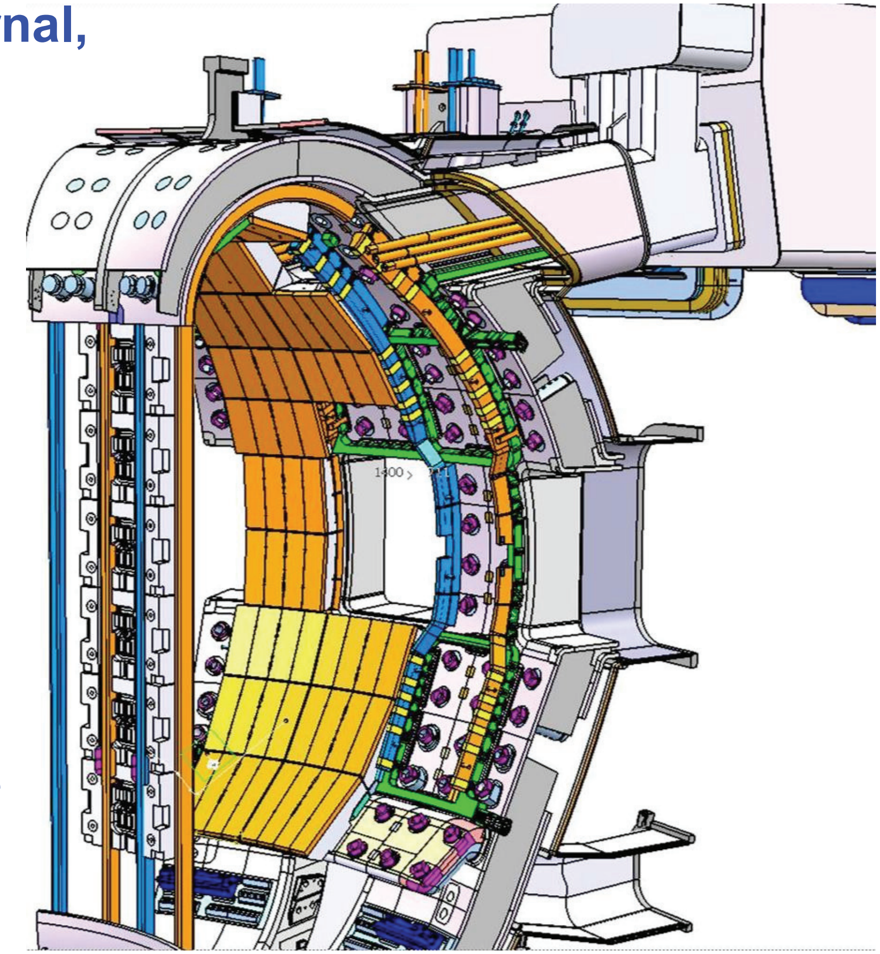
Power Step Timing Experiment Shows RMP ELM Suppression Sensitive to Beta



- Identical I-coil current
- Power step delay changes timing of ELM suppression
  - n_e^{ped} and $D_{Chir>1}$ nearly constant at ELM suppression time
- Suppression and return of ELMs correlated with beta threshold
  - P_{inj} and T_{inj} do not correlate with ELM behavior

Conclusions: DIII-D RMP ELM Suppression Results Support Multi-Row, Internal, Off-Midplane ITER Coil Design Choices

- ELM suppression using a single-row of internal, small aperture, off-midplane RMP coils
  - Correlated with stochastic region width
  - Requires ~ 50% more current per coil - consistent with coil geometry
  - Requires more NBI power and/or co-torque - beta dependence
  - Appears to be less robust to core fueling pellets and reduced input torque



- No suppression with RMP from an external, large aperture, on-midplane coil at the same pedestal perturbation strength
  - Locked modes before any ELM change

Some of the Other RMP ELM Control Presentations At This Meeting

- Weds pm Oral Contributed: Moyer PO3.00002 Particle Transport in RMP H–modes
- Tues pm Poster Session JP6: Related papers
  - Baylor JP6.00077 : ELMs Triggered From Deuterium Pellets Injected into DIII-D
  - Evans JP6.00070 : Spectral Effects on Plasma Performance in ITER Similar DIII-D RMP H-modes
  - Frerichs JP6.00073 : 3D Simulations of Edge Transport for RMP Experiments at DIII-D
  - Mordijck JP6.00074 : Comparisons of ELMing and RMP H-mode Transport Results from a 2D Fluid Code and Theoretical Models
  - Osborne JP6.00070: Edge MHD Stability of Co-injected QH-mode Discharges in DIII-D
  - Schaffer JP6.00076: ELM Control Coils for ITER
  - O. Schmitz JP6.00069 : Resonant Character of Edge Plasma Parameters in Stochastic Boundary Experiments at DIII-D and TEXTOR
  - Z. Unterberg JP6.00071 : Global Particle Balances and Wall Recycling Changes During the RMP Induced Density Pump-out in DIII-D H-mode Plasmas
  - Watkins JP6.00072 : Target Plate Particle and Power Flux During ELM Suppression Experiments on DIII-D
  - Zeng JP6.00075 : Effect of Resonant Magnetic Perturbations (RMPs) on Local Density Decay During Pellet Injection in DIII-D
- Mon am and Thurs pm Poster Session BP6 and UP6: Related papers
  - Strauss BP6.00045 : Extended MHD Effects on RMPs and ELMs
  - Kruger BP6.00043: Anisotropic Heat Transport in the Presence of Resonant Magnetic Perturbations
  - Joseph UP6.00119 : Control of edge localized modes through toroidally asymmetric scrape-off layer current perturbations
  - G. Park UP6.00133 : MHD-consistent Kinetic XGC0 study of 3D RMP effect on edge pedestal transport