TWO REPORTS ON ITER CONTROL COILS

ELM Control Coils for ITER

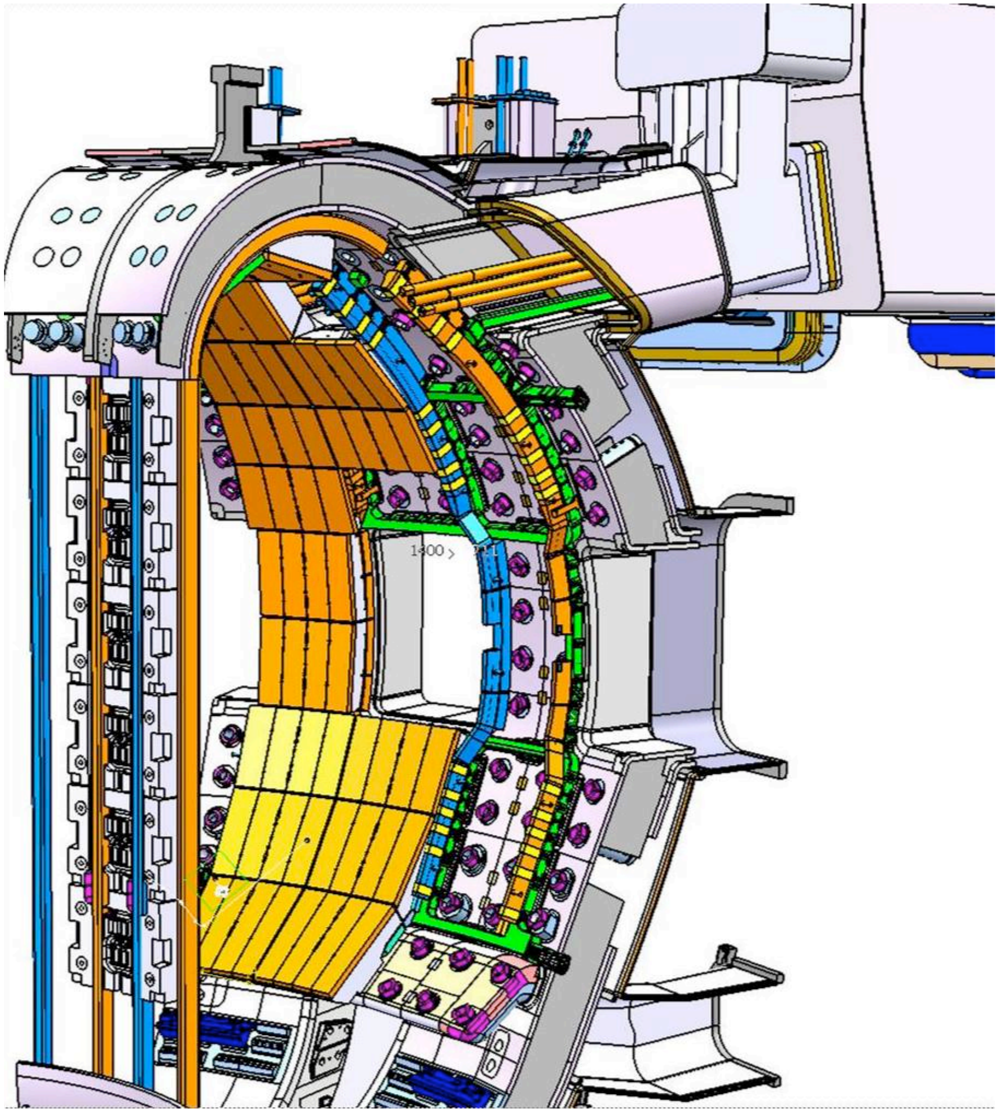
M.J. Schaffer[1] et al.

[1]General Atomics

ITER Vertical Stability Guidance from Multi-Machine Experiments

D.A. Humphreys[1] et al.

[1]General Atomics



US–Japan Workshop on
MHD Control, Magnetic Islands and Rotation
University of Texas, Austin, TX, USA
23-25 November, 2008

ELM Control Coils for ITER

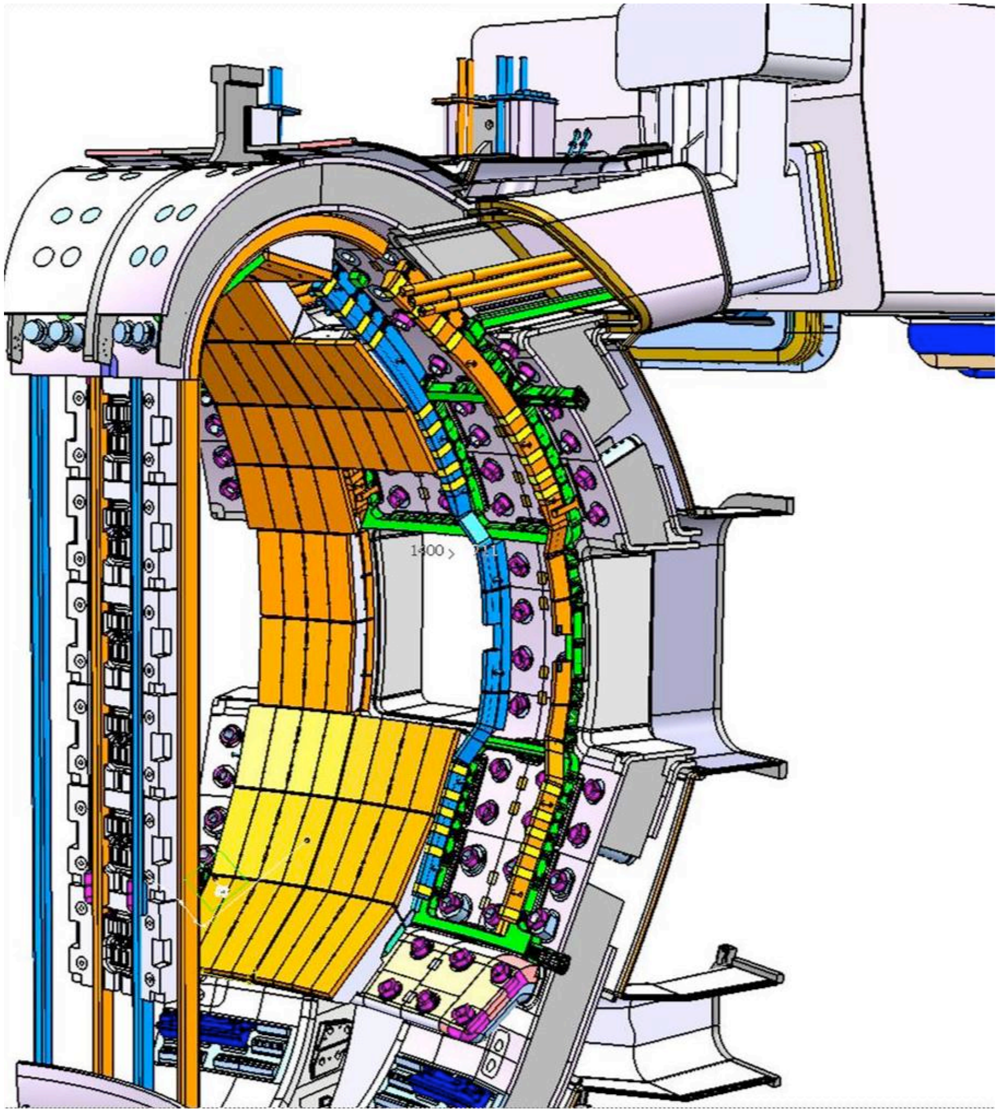
by

M.J. Schaffer[1]

with

T.E. Evans,[1] R.J. Hawryluk,[2]
M. Becoulet,[3] A.J. Cole,[4]
M.E. Fenstermacher,[5] A.M. Garofalo,[1]
V. Izzo,[6] J.E. Menard,[2] R.A. Moyer,[6]
E Nardon,[7] T.H. Osborne,[1] J-K Park,[2]
H. Reimerdes,[8] S.A. Sabbagh,[8]
P.B. Snyder,[1] M.P. Aldan[9]

[1]General Atomics
[2]PPPL
[3]Assoc. Euratom-CEA
[4]Univ. Wisconsin, Madison
[5]LLNL
[6]UC San Diego
[7]Euratom/UKAEA Fusion Assoc., Culham Sci. Centre
[8]Columbia Univ.
[9]UC Berkeley



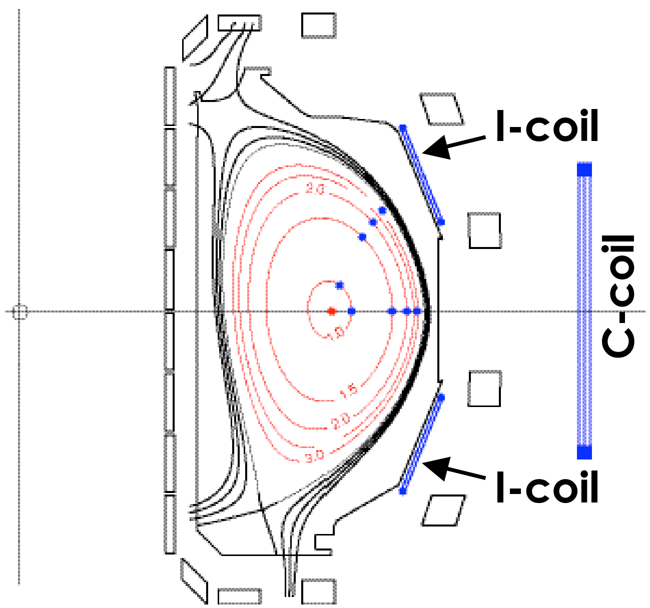
US–Japan Workshop on
MHD Control, Magnetic Islands and Rotation
University of Texas, Austin, TX, USA
23-25 November, 2008

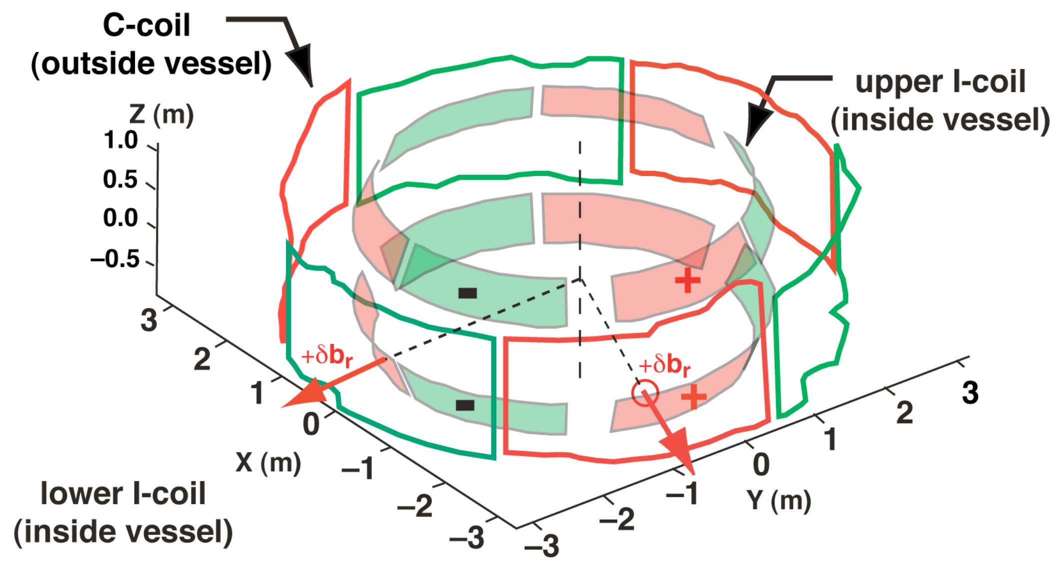
Type I ELMs are Not Tolerable in ITER. Control them by Resonant Magnetic Perturbations

- ITER Type I ELM pulses will melt W and vaporize C divertor surfaces.
  - Need ~20-fold reduction of worst case ELM pulse energy
- DIII–D experiments show that small Resonant Magnetic Perturbations (RMPs) of $\delta B_{res}/B_{T0}$ = ~5 $\times 10^{-4}$ at plasma edge can suppress ELMs with little confinement loss[1]
  - RMPs reduce edge ∇p and $J_{||}$ to below ELM threshold[2]
  - JET[3] and NSTX[4] RMPs modified ELMs, but still far from ITER goal
  - RMP-induced transport is mostly particle convection, not thermal conduction; not yet understood; no predictive theory
- ITER design had no place for RMP coils
  - Difficult decision with major cost, schedule consequences
  - Scale-up from experiments had many unanswered physics questions
- ITER stimulated intensive experimental and theoretical work

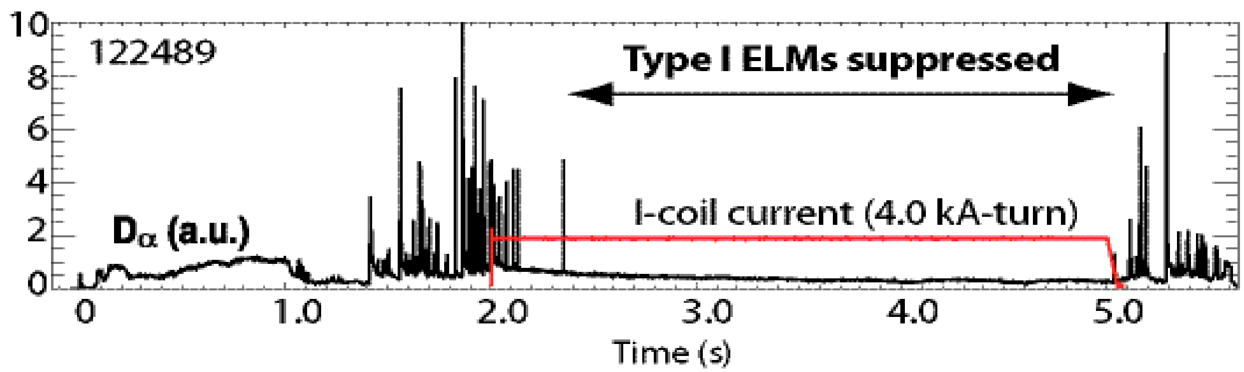
[1]Evans et al, PRL **92** (2004) 235003; Evans et al, NF **48** (2008) 024002; Evans, JP6.00070
[2]Snyder, NF **47** (2007) 961 [3]Liang, PRL **98** (2007) 265004 [4]Hawryluk, GO3.00001

RMP ELM Suppression in DIII-D: Hardware and Typical Result



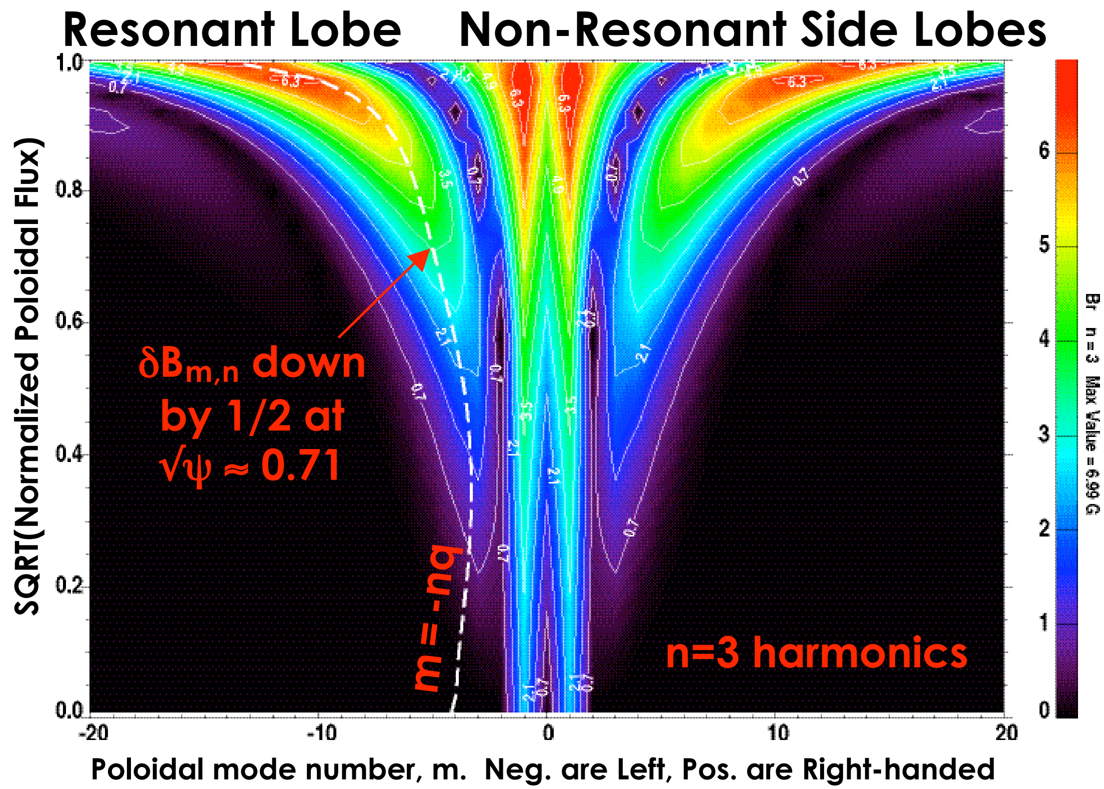


n=3 I-coil and C-coil configuration
(with even parity I-coil)

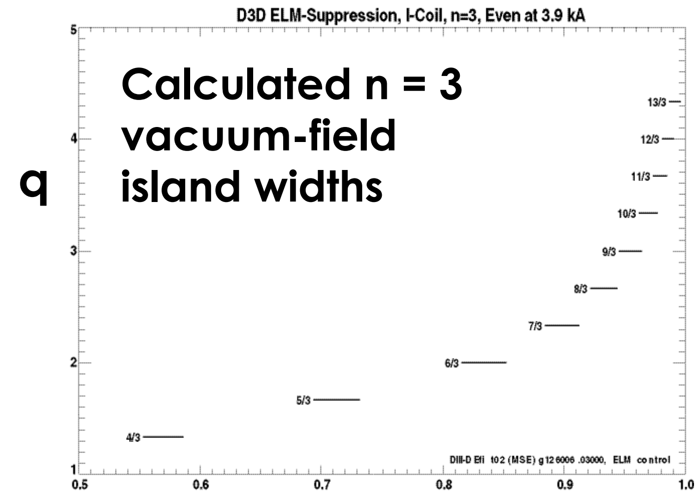


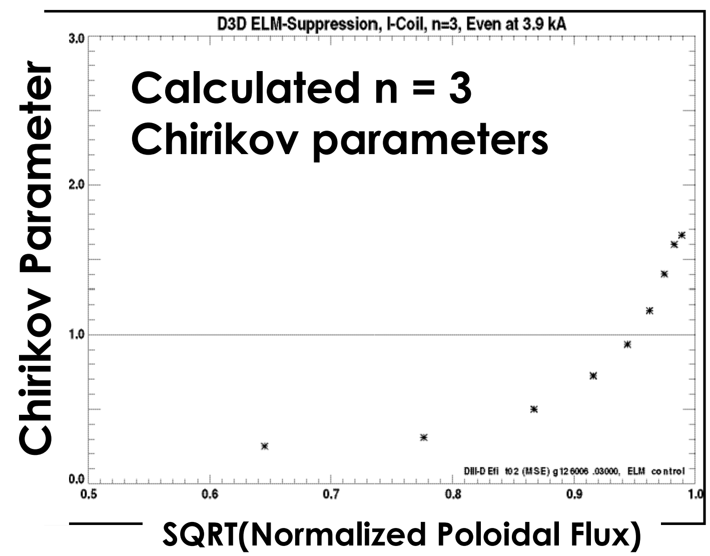
DIII-D
NATIONAL FUSION FACILITY

RMP ELM Suppression in DIII-D:
Vacuum-Field Magnetic Spectrum, Island Overlap



Helical harmonics ~ exp i(nϕ – mθ*)





Experimentally:

Sufficient Resonant δB_{res} → ELM suppression

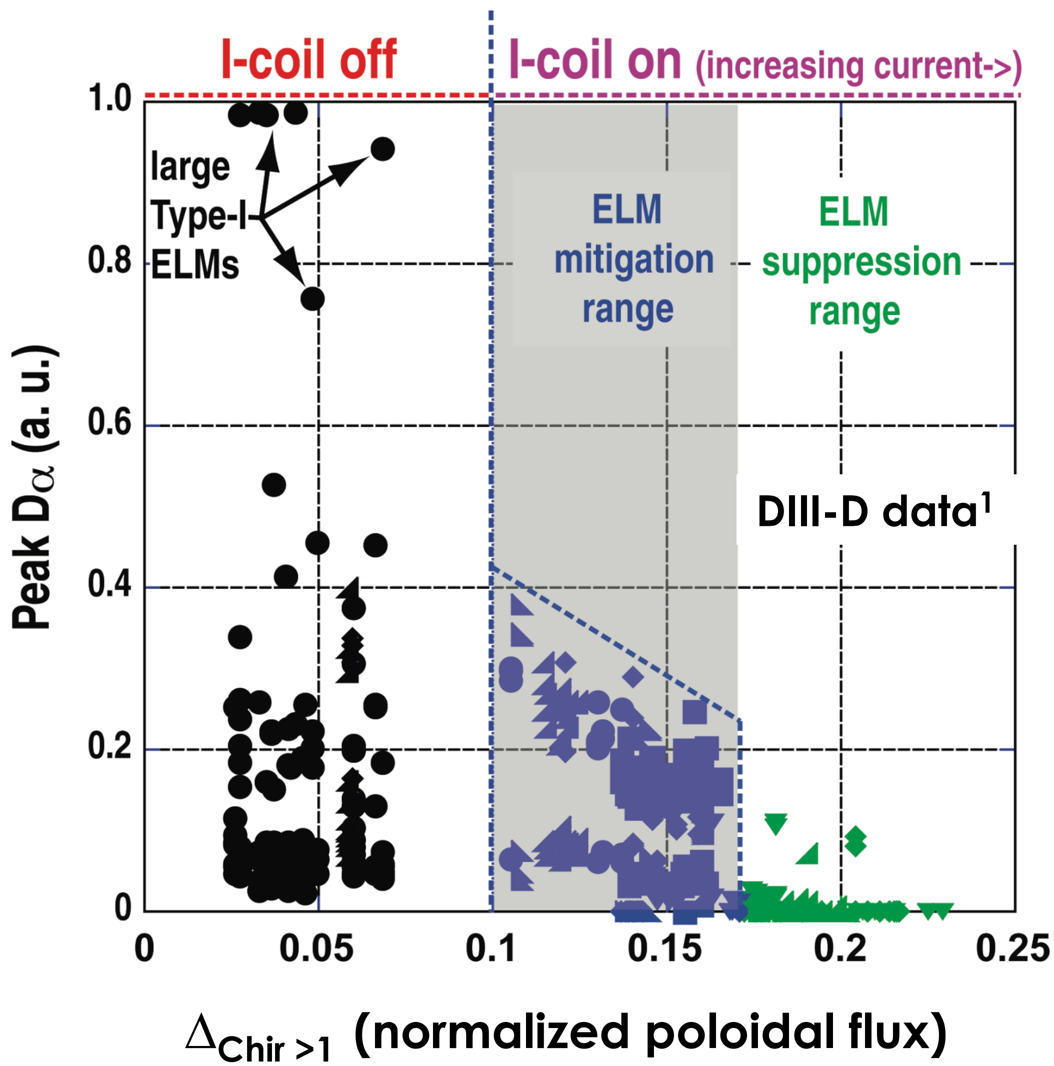
Excessive Non-Resonant δB_{nonres} → locked mode

RMP REQUIREMENTS FOR ITER

General RMP ELM-Suppression Requirements for ITER

- MUST BE RELIABLE
  - Rapid divertor erosion if ELM control fails
- Must work for <u>all</u> ITER H-mode plasmas
  - ELMs suppressed at $q_{95} \approx 7$, n=3, odd-parity lobe of I-coil in DIII–D
    and also at $q_{95} \approx 3.6$, n=3, even-parity lobe of I-coil
  - ∴ Can vary RMP coil current distributions to “tune” spectrum to q in ITER
- Must work for ITER aspect ratio and shape
  - Works for ITER-similar shape (and other shapes) in DIII–D
- Must work at ITER’s low pedestal collisionalities, $\nu^* \sim 0.1$
  - Worst-case, largest ELM pulses occur at low ν^*
  - RMP technique works in DIII–D at $\nu^* \sim 0.1$
  - ELM responses to RMP are different at $\nu^* \sim 0.1$ and ~1 in DIII–D
- Recommend flexible RMP system for unforeseen circumstances

Correlation of ELM Size with "Island Overlap" Layer Width Guided Scaling from DIII–D to ITER



- $\Delta_{Chir>1}$ ≡ width of edge layer where Chirikov island overlap parameter (calculated from vacuum δB_{res}) exceeds 1 [1]
- ELM suppression onset with sufficiently wide $\Delta_{Chir>1}$
- This is NOT the complete physics!
  - Other factors also enter
    - Plasma response, e.g., screening, amplification
- Used $\Delta_{Chir>1}$ = 0.15 (plus safety factor) for ITER "ELM coils" designs from late 2007 onward

DIII-D NATIONAL FUSION FACILITY

[1] Fenstermacher, PoP **47** (2008) 056122

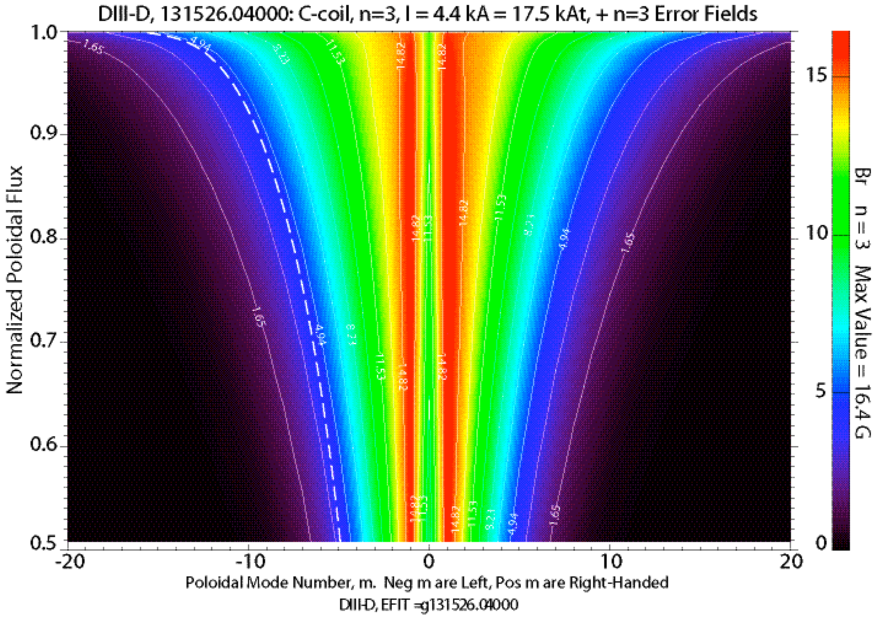
RMP ELM Mitigation vs Locked Modes

- Chirikov parameter (mitigation) ~ $(\delta B_{res})^{1/2}$
  but magnetic braking (locking) ~ $(\delta B)^2$ eventually dominates
- Islands far apart at low q and low n ⇒ need larger δB_{res} ⇒ locking
- Experimentally:
  - n=1 RMPs reduce ELMs, but lock before reaching ITER goal
    In DIII–D (I- and/or C-coils), JET[1], NSTX[2] ⇒ n=1 not good enough
  - n=2 RMPs reduce ELMs but lock before reaching ITER goal in JET[1], brief suppression in 1 shot in DIII–D ⇒ n=2 seems unreliable
  - n=3 RMPs:
    - ELMs suppressed in DIII–D by "short-z" I-coils (2 rows or 1 row)[3]
    - Not suppressed so far using "tall" coils (NSTX[2], DIII–D C-coil[3])
      - "Tall" coils make much more low-m δB_{nonres} than δB_{res}
- So far, n=3 success coincides with having sufficient resonant δB_{res} and not having excessive $\delta B_{nonres} >> \delta B_{res}$
- For ITER, recommend n ≥ 3 and limiting δB_{nonres}

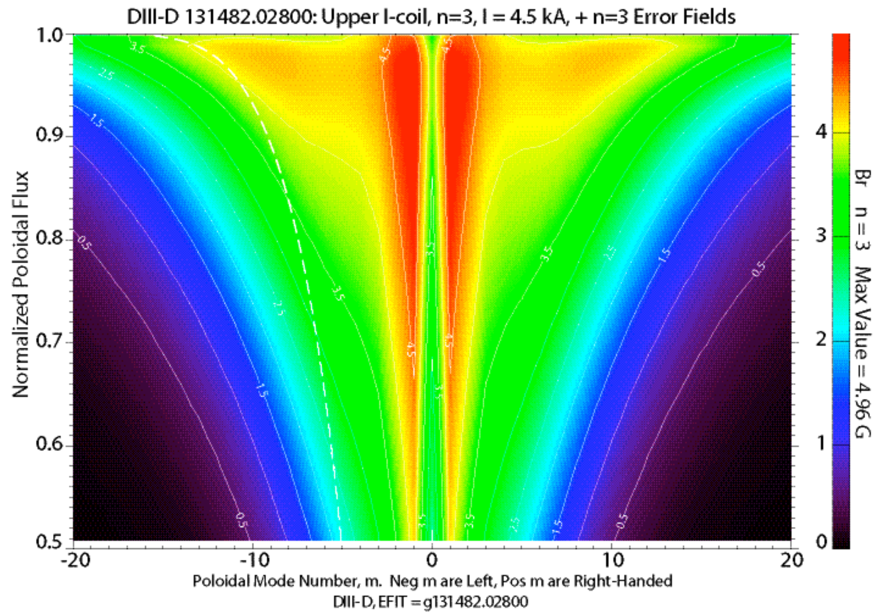
[1] Liang, PRL **98** (2007) 265004 [2] Hawryluk, GO3.00001 [3] Fenstermacher, GO3.00002

“Tall” C-coil Makes Much Larger Non-Resonant Components than 1-Row of “Short-Z” I-coil

C-coil, n=3 Harmonics



Single-Row of I-coil, n=3 Harmonics



- C-coil is tall and outside TF coil
- Vertically broad field at plasma
- Not much poloidal harmonic at resonant m’s
- Large, low-m, non-resonant δB

- I-coils are on vacuum vessel wall, close to plasma, poloidally short
- Spectrum extends with little decay to resonant m’s
- Non-resonant δB not much larger than resonant δB

ELM CONTROL COILS FOR ITER

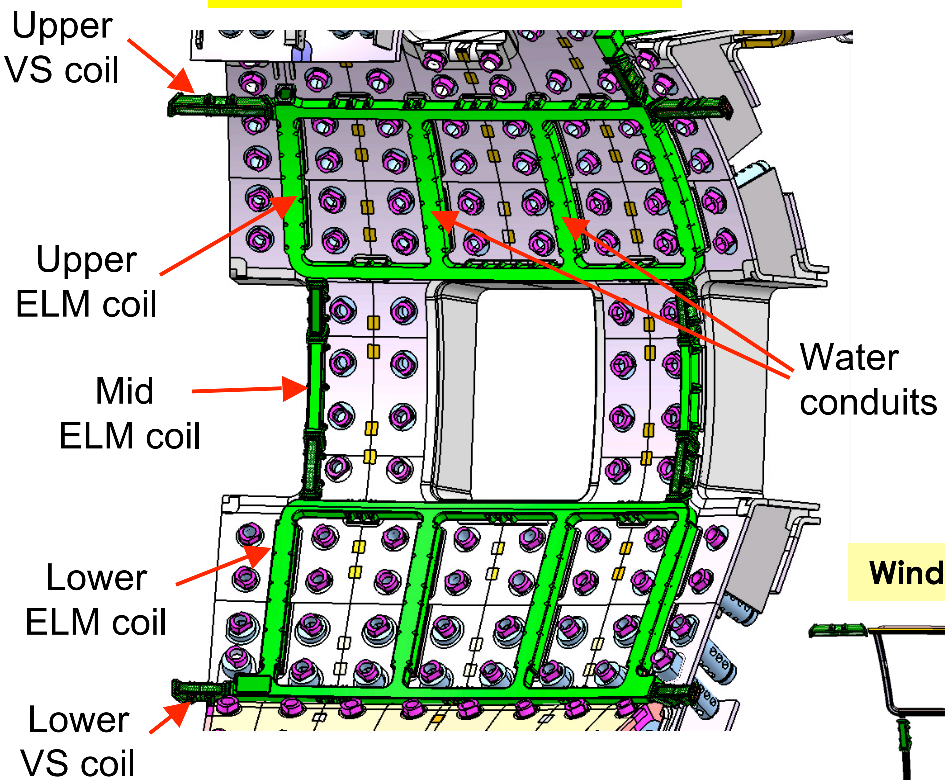
ITER ELM-Control Coil Concepts were Studied[1,2]

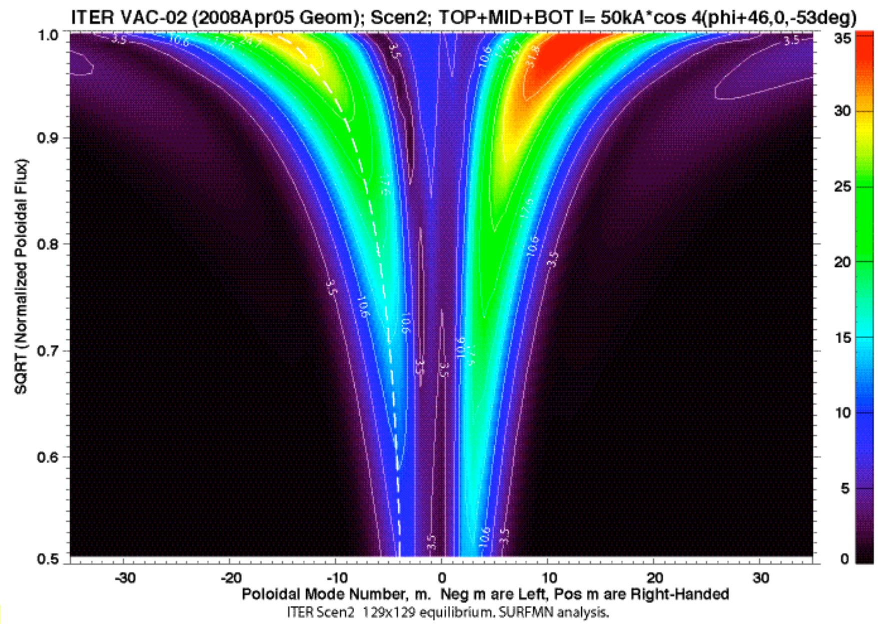
- Coils outside of vacuum vessel make δB that vary too slowly poloidally[1,2]
  - Too little high-m vs. low-m harmonic amplitudes $\Rightarrow$ too much δB_{nonres}
- A systematic study of multi-row coil arrays at "Blanket-Vessel Interface" (BVI, on ITER vacuum vessel plasma-facing wall) showed:[2]
  - n=3 and n=4 best satisfy known physics requirements
  - ITER has 18 TF coils, vacuum vessel is fabricated in 9 sections
  - N=9 coils/toroidal row give almost as much magnetic spectrum control as N=18 coils/row
- Recommended 4-rows x 9-coils on BVI to ITER Design Review (2007 Sept)
  - Rejected for complexity, cost, large schedule slip
- Presented 3-rows x 9-coils on BVI to ITER STAC-3 meeting (2008 Apr)
  - ELM coils will share same space with new Vertical Stability (VS) coils
  - STAC-4 (2008 May) recommended: Pursue RMP + VS design "VAC02", change vessel to accommodate, make installation decision later

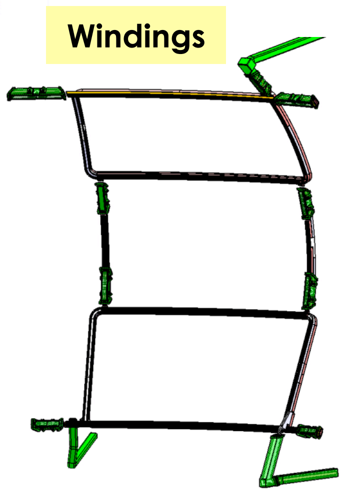
[1] Becoulet, NF **48** (2008) 024003 [2] Schaffer, NF **48** (2008) 024004

ITER "VAC02" Combines 3-row ELM Coil Array with 2 Vertical Stabilization (VS) B_{pol} Coils

40° Sector Outboard







ELM and VS coils share same vacuum "jacket" and support structure

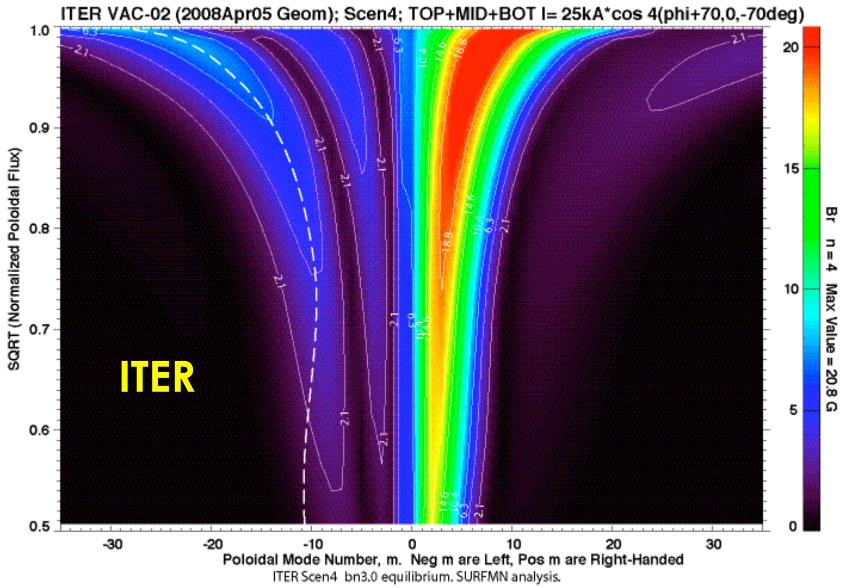
Magnetic spectrum for ITER low-q, Q=10, inductive H-mode (scenario 2)

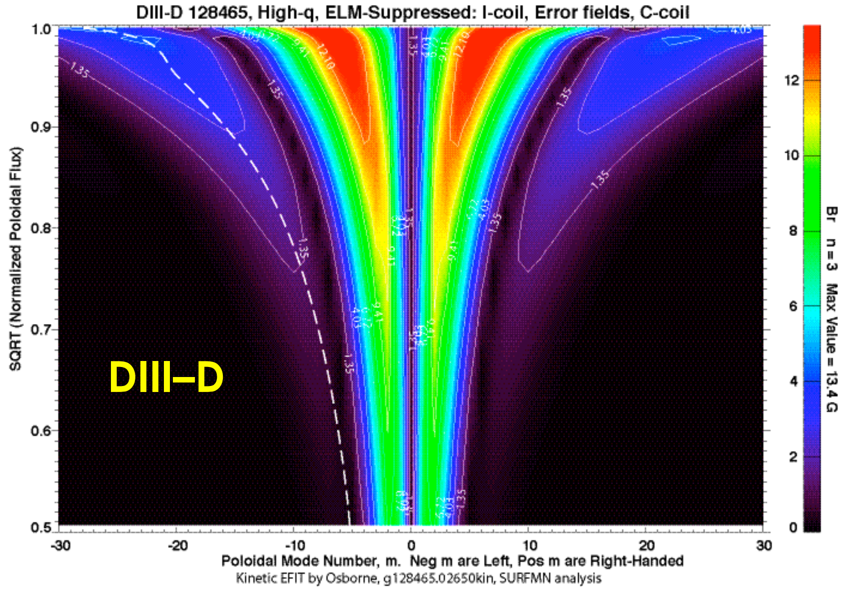
- **Less calculated non-resonant braking than DIII–D I-coil[1]**

Coil graphics courtesy of ITER Organization

[1] J-K Park, 22nd IAEA 2008, EX/5-3Rb; this meeting, GI1.00005

For high q, ITER coils make more δB_{nonres} than δB_{res}, but are comparable with DIII-D high-q suppression





- ITER high-q, advanced non-inductive (scenario 4) has ~3 times more n=4 δB_{nonres} than δB_{res}
  - VAC02 coils are “too tall”; set by ports, blanket modules
- Less $\delta B_{nonres}/\delta B_{res}$ with n=3
- Less n=4 coil current than at low-q

- DIII–D vacuum n=3 RMP from ELM suppression at q_{95} = 7.2 had ~3 times more δB_{nonres} than δB_{res}
  - It also used comparable resonant n=1
  - Did not lock
- Apparently satisfactory

PLASMA RESPONSE EFFECTS

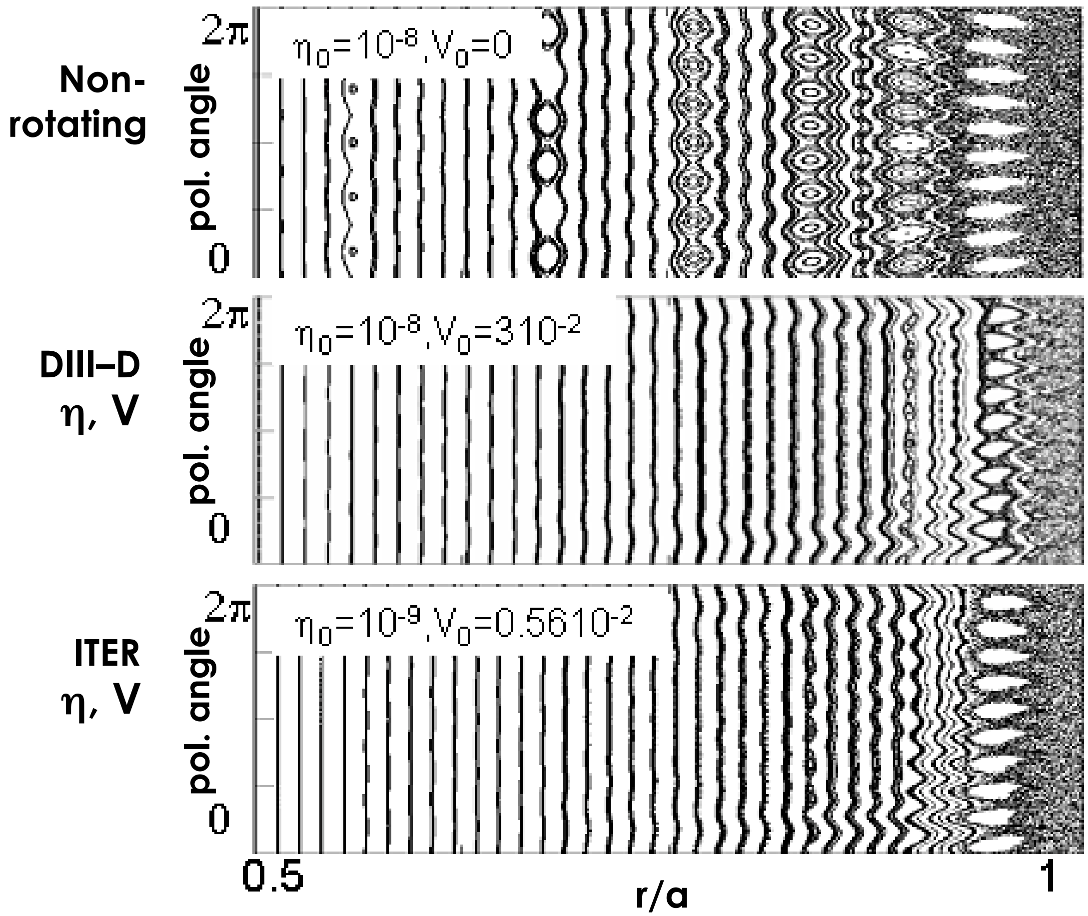
Tokamak Plasma Response to External δB is Large; Important to Include It in RMP Theory

- **Amplification and Shielding (Screening) modify δB_{vacuum}**
- **Amplification is mainly due to the least stable MHD mode[1,2]**
  - **Large in tokamaks,[1,2,3] $|\delta B| >> |\delta B_{vacuum}|$ inside much of plasma**
- **<u>Resistive MHD</u> dominates in slowly rotating plasmas**
  - **Driven tearing mode $\Rightarrow$ large islands $\Rightarrow$ strong braking $\Rightarrow$ locked[4]**
  - **"BAD SHOTS", useless for fusion**
- **<u>Ideal MHD</u> dominates for sufficient rotation**
  - **Absence of large islands**
  - **$\delta B_r \times v_o$ drives $\delta J_{||}$ on rational surfaces, reducing locally resonant components of δB_r, their associated islands $\Rightarrow$ Resonant braking[4]**
    - **"Shielding" or "screening" is absence of "island opening"**
  - **"GOOD SHOTS", required for fusion**
  - **Substantial magnetic surface deformation, internal δB**
    - **$\Rightarrow$ Non-Resonant braking**
- **Experiments see amplification as increased δB_{vac} outside of plasma**

[1] J-K Park, PRL **99** (2007) 195003
[2] J-K Park, GI1.00005
[3] J-K Park, NF **48** (2008) 045006
[4] Fitzpatrick, NF **33** (1993) 1049

Plasma Shielding Modeled at Realistic Resistivities in Simplified Geometry

Computed at realistic resistivity η with reduced MHD and circular cylinder[1]

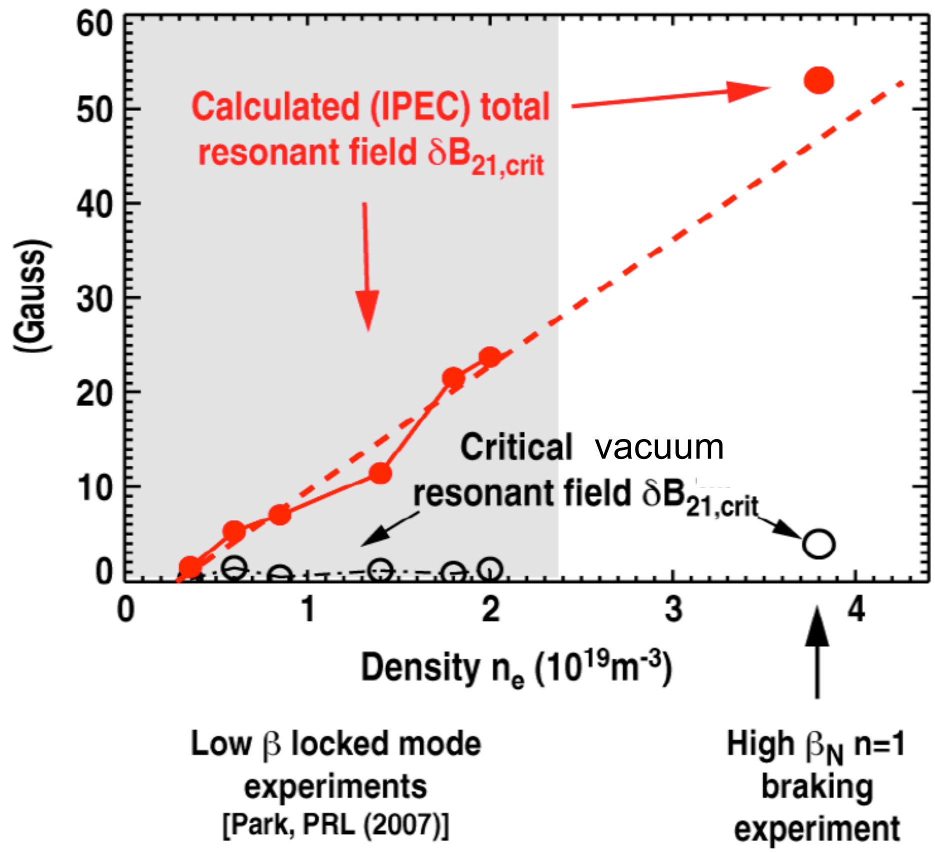


- δB is amplified at zero velocity
  - Penetrates resonant surface in a resistive time
  - Opens saturated islands
- Realistic rotation screens hot core but not edge layer
  - Core surfaces deformed, but closed
    - Amplified δB
  - Stochastic edge
- Favorable edge RMP with good core
- Calculations with ITER geometry but $\eta_0 \sim 10^{-6}$ are qualitatively similar

[1] M. Becoulet, EPS 2008; IAEA 2008

Plasma Response with Realistic Tokamak Equilibria Show Large Amplifications

Computed Total and Vacuum Resonant δB at q=2



DIII–D data:
Constant torque ≈ zero.
Varied error geometry and β.

- IPEC[1,2] (Ideal Perturbed Equilibrium Code) computes ideal plasma response to non-axisymmetric external perturbations, with real geometries and equilibria
  - Ideal MHD models screened plasmas
- Total δB_{res} in plasma greatly exceeds vacuum δB_{res} [2]
- Locking (or critical) vacuum δB_{res} is linear with n_e only when β, error geometry, torque are kept constant[3,4]
- Critical total δB_{res} is linear with n_e even when geometry and β were varied here
- ∴ Total δB_{res} is the true cause of resonant magnetic braking

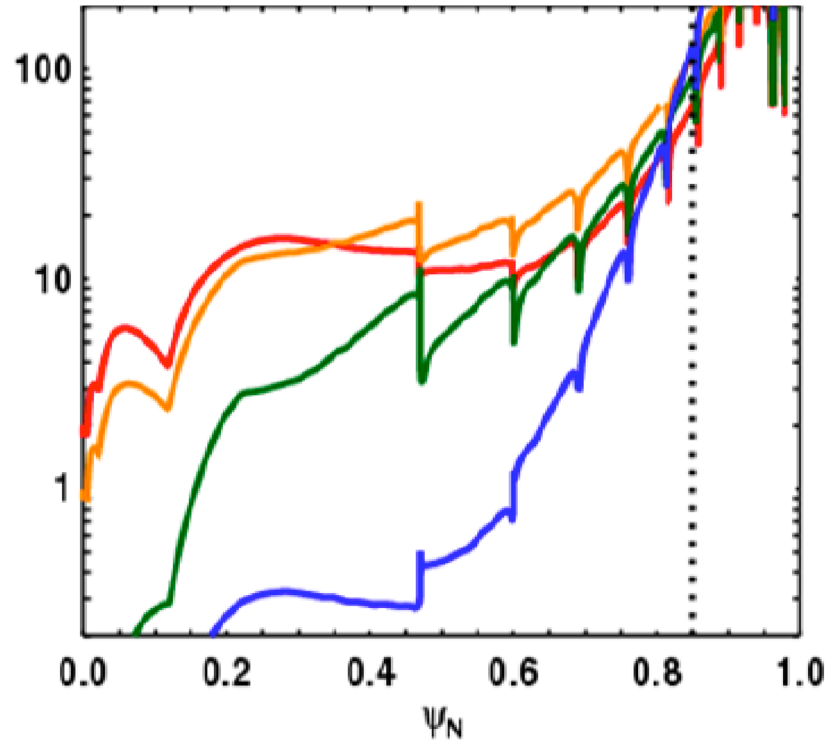
[1] J-K Park, PoP **14** (2007) 052110
[2] J-K Park, GI1.00005
[3] Buttery, NF **39** (1999) 1827
[4] S. Wolfe, PoP **12** (2005) 056110

NON-RESONANT BRAKING

Will Neoclassical Toroidal Viscosity (NTV) Slow ITER Plasma Rotation Excessively?

- Large NTV braking ~ 1/ν predicted for ITER in low-ν collisionality regime
- K. Shaing's NTV theory[1], being applied by Cole, Becoulet, J-K Park
  - Two low-collisionality regimes relevant to ITER: 1/ν and ν_ν$^{1/2}$
- ITER 3-row ELM coils meet Chirikov condition with less NTV rotation damping if ratio between midplane row and off-midplane row currents is optimized[2]

A Predicted Rotation Damping Rate [/s]



Legend:
One row of the midplane coils
Two rows of the off-midplane coils
Three rows of the coils
With many, many more coils

[1] K.C. Shaing, PoP **10** (2003) 1443; PoP **15** (2008) 082505 & 082506

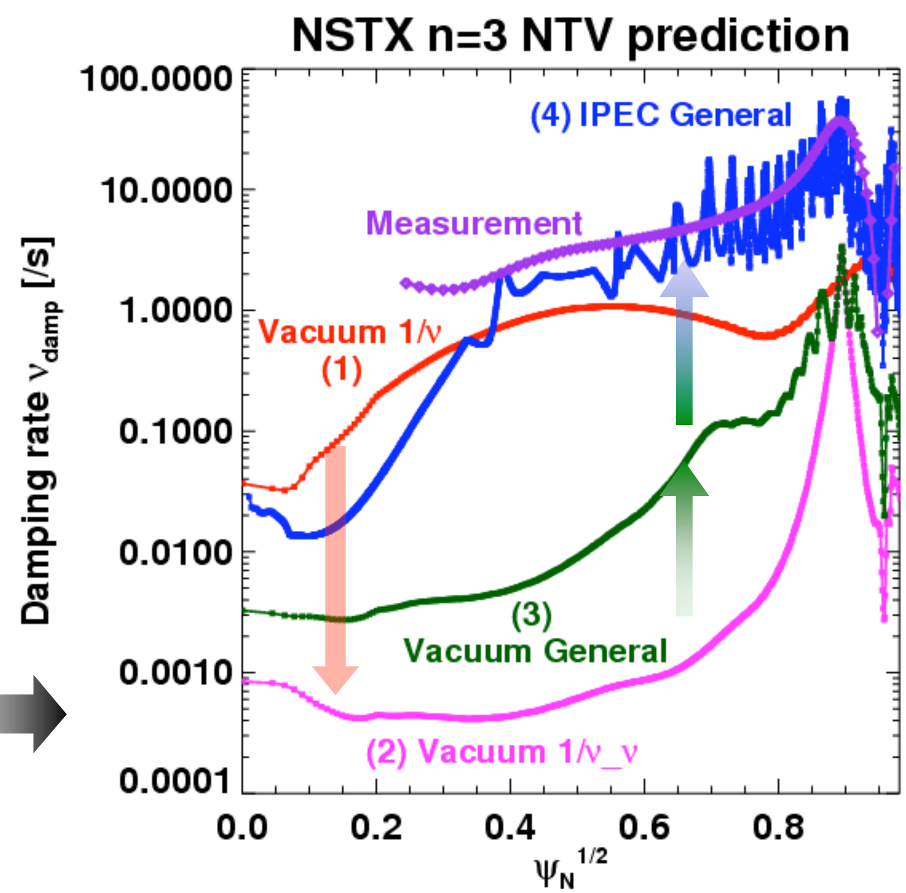
[2] J-K Park, 22nd IAEA 2008, EX/5-3Rb; this meeting, GI1.00005

Generalized NTV + IPEC B-field Improve Consistency between Theory and Experiment

- Important new physics in NTV theory :
  - a) Toroidal precession rates (ω_E), which are often faster than the collisional rates (ν)
  - b) Trapped particle bounce rates (ω_b), which can resonate with the precession (ω_E, ω_B)
  - c) Variation of field strength along the perturbed magnetic field lines, which includes plasma response

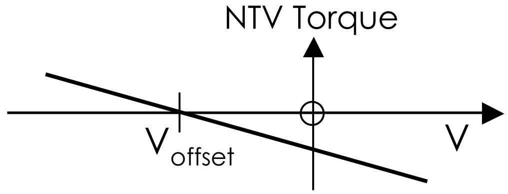
(1) (a), (b) and (c) are all ignored
[*Zhu et al, Phys. Rev. Lett. (2006)*]
(2) (a) is included
(3) (a) and (b) are included
(4) (a), (b) and (c) are all included

NSTX
n=3 rotation braking experiment



Predicted NTV "Offset" Torque[1] Observed in DIII–D[2]

- **Predicted from Shaing theory by Cole[1]**

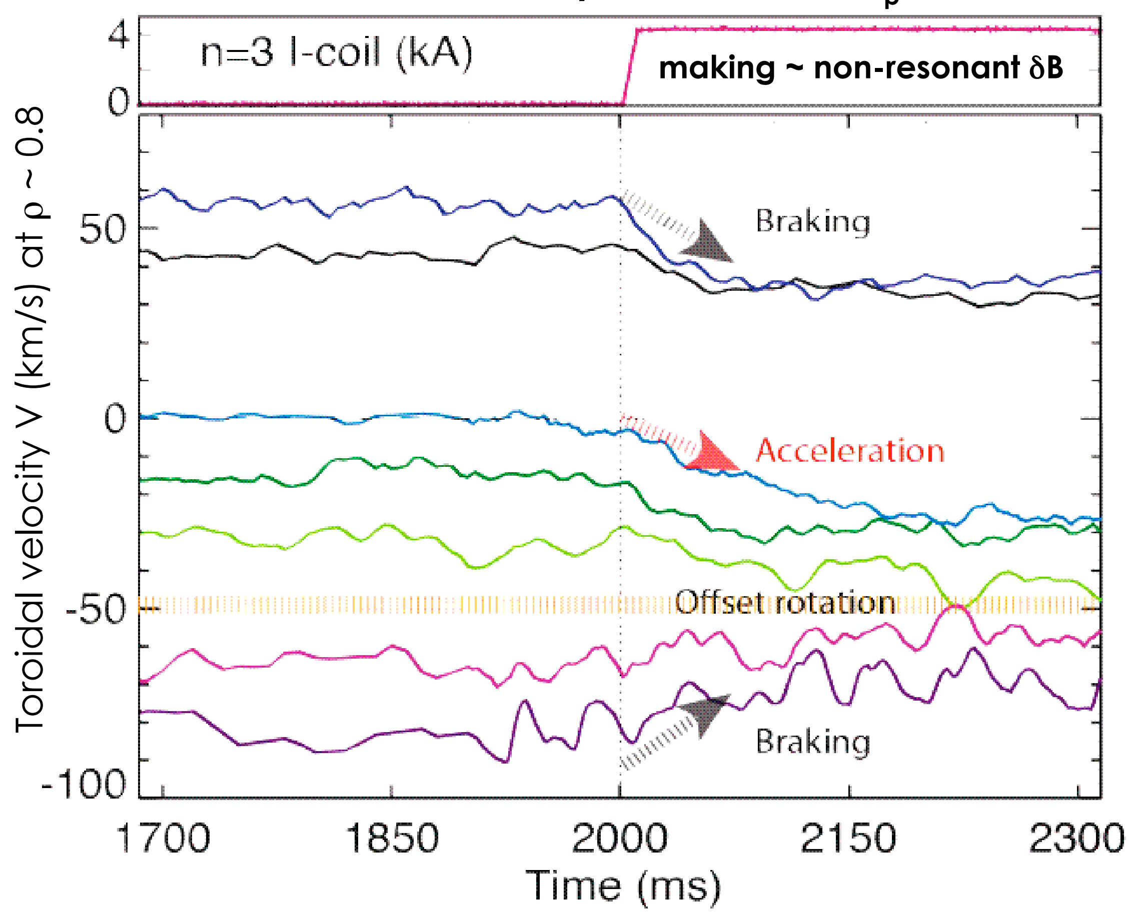


$$T_{\mathrm{NTV}} \sim -(\delta B)^2 (V_{\mathrm{tor}} - V_{\mathrm{offset}})$$

V_{offset} in ion diamagnetic ($-I_p$) direction

- **NTV V_{offset} by TF coil ripple may explain counter-I_p velocities in JET edge[3]**
- **RMP ELM control δB might actually supply the dominant torque to rotate ITER plasmas[2]**
  - **An advantage!**

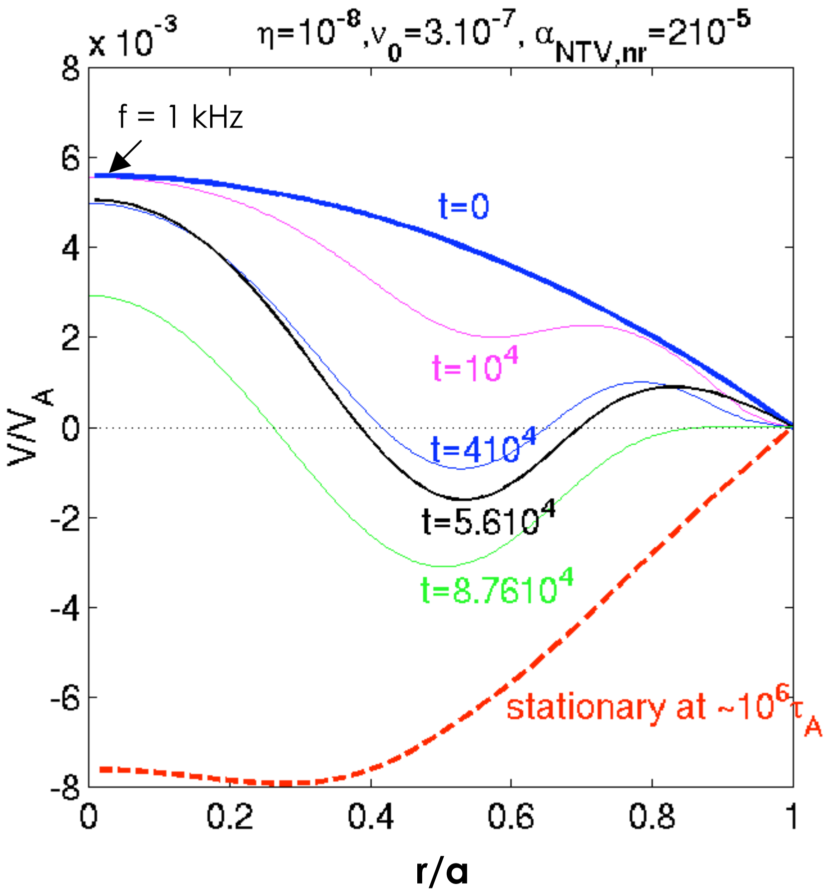
Plasmas driven with different beam torques are braked or accelerated by non-resonant δB toward an offset velocity in the counter-I_p direction[2]



[1] Cole, PRL **99** (2007) 065001; PoP **15** (2008) 056102
[2] Garofalo, PRL **101** (2008) 195005; This meeting BI2.00002
[3] de Vries NF **48** (2008) 035007

Time-Dependent Simulation: Spinning ITER Plasma Forced to NTV Offset by ELM-control RMP

Computed with reduced dissipative MHD and circular cylinder plasma[1]; RMP applied at t=0



- Used 1/ν NTV model and vacuum δB
  - Approximation (1) in J.-K. Park's page
- Though driven by steady ITER beam source, the NTV torque dominates in ITER
- Final state rotates about as fast as initial beam-driven plasma
- The model does not address stability as rotation passes through zero
- RMP ELM control might rotate ITER

[1] M Becoulet 22nd IAEA 2008, TH/2-1Ra

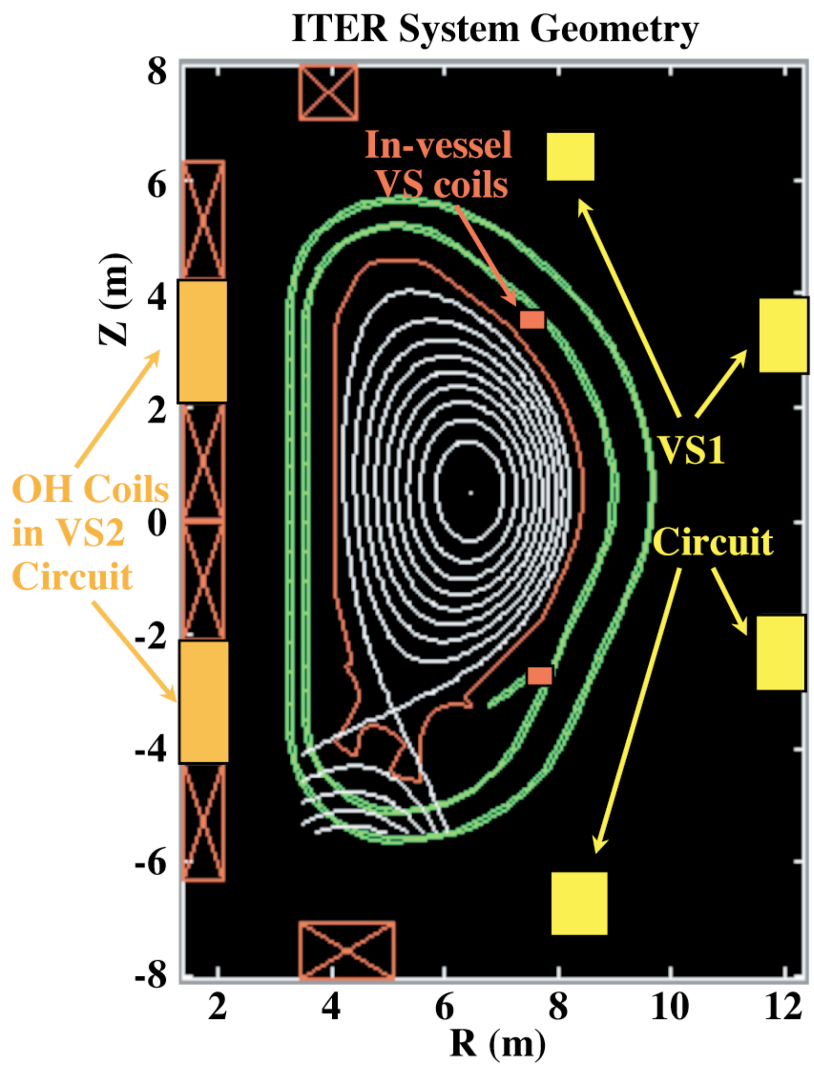
SUMMARY

- Experimental success so far coincides with having sufficient δB_{res} and not having excessive $\delta B_{nonres} >> \delta B_{res}$
- Experimental evidence supports ELM suppression over operational q range
- Tokamak response to external δB is large
  - Resonant braking data fit by calculated total in-plasma δB_{res}
  - Neoclassical Toroidal Viscosity braking and acceleration (torque offset) observed in experiments and are being computed with increasing sophistication
  - Should include plasma amplification and shielding in RMP theory
- NTV by RMP in ITER might sustain plasma rotation
  - ITER ELM coils can adjust to vary the NTV somewhat
- ITER stimulated intensive experimental and theoretical work

ITER Vertical Stability Guidance from Multi-Machine Experiments

D.A. Humphreys, T.A. Casper,*
N. Eidietis, M. Ferrara,† D. Gates,‡
B. Hudson, I. Hutchinson,† G.L. Jackson,
E. Kolemen,‡ J.A. Leuer, J. Lister,§
L.L. LoDestro,* T.C. Luce, W.H. Meyer,*
L.D. Pearlstein,* F. Sartori,£ A. Portone,#
M.L. Walker, A.S. Welander, S.M. Wolfe†

*Lawrence Livermore National Laboratory
†Massachusetts Institute of Technology
‡Princeton Plasma Physics Laboratory
§EPFL-CRPP, Lausanne
£EFDA-JET, Culham
#Fusion for Energy, Barcelona

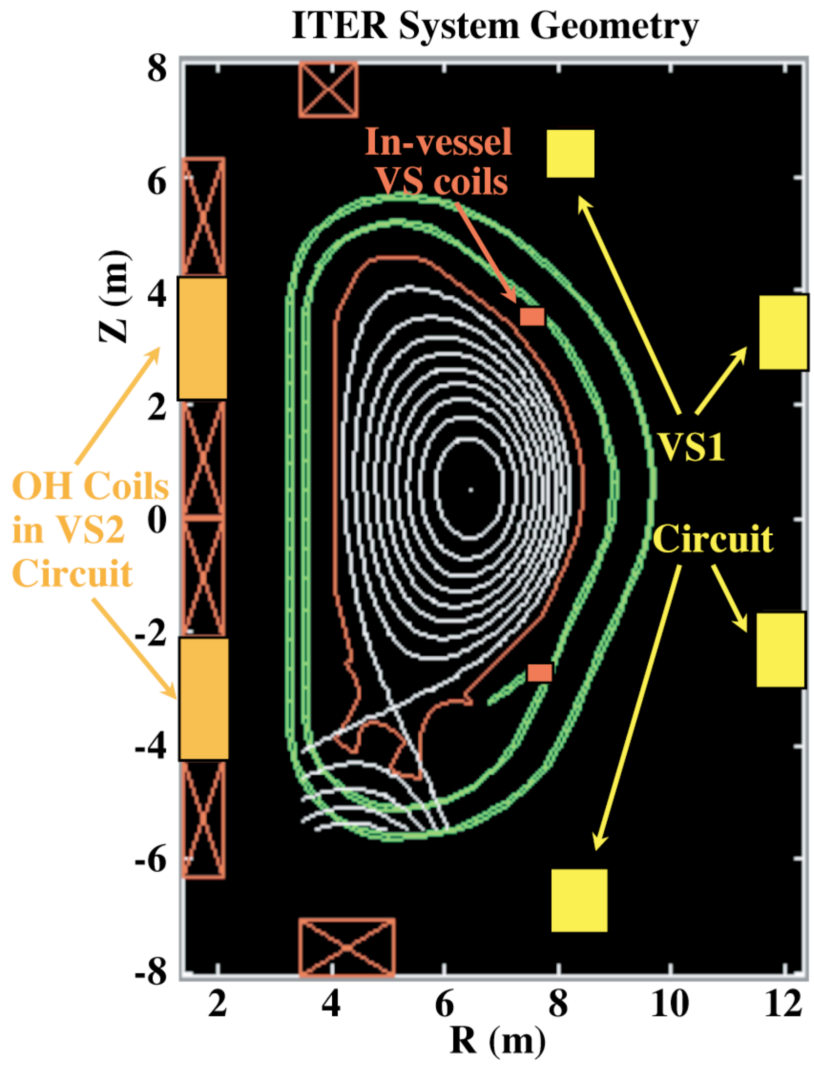


US–Japan Workshop on
MHD Control, Magnetic Islands and Rotation
University of Texas, Austin, TX, USA
23-25 November, 2008

ITER Baseline System Uses Four Outboard Coils for Vertical Stability (VS) Control

- Baseline system:
  - "VS1" circuit of
    4 outboard coils (PF2-5)
    6 kV operating voltage

- Proposals to enhance VS system include (from 2007-08 Design Review and STAC studies):
  - Add "VS2" circuit of
    2 central solenoid coils
    6 kV operating voltage
  - Add in-vessel VS coils mounted on vessel wall behind blanket modules

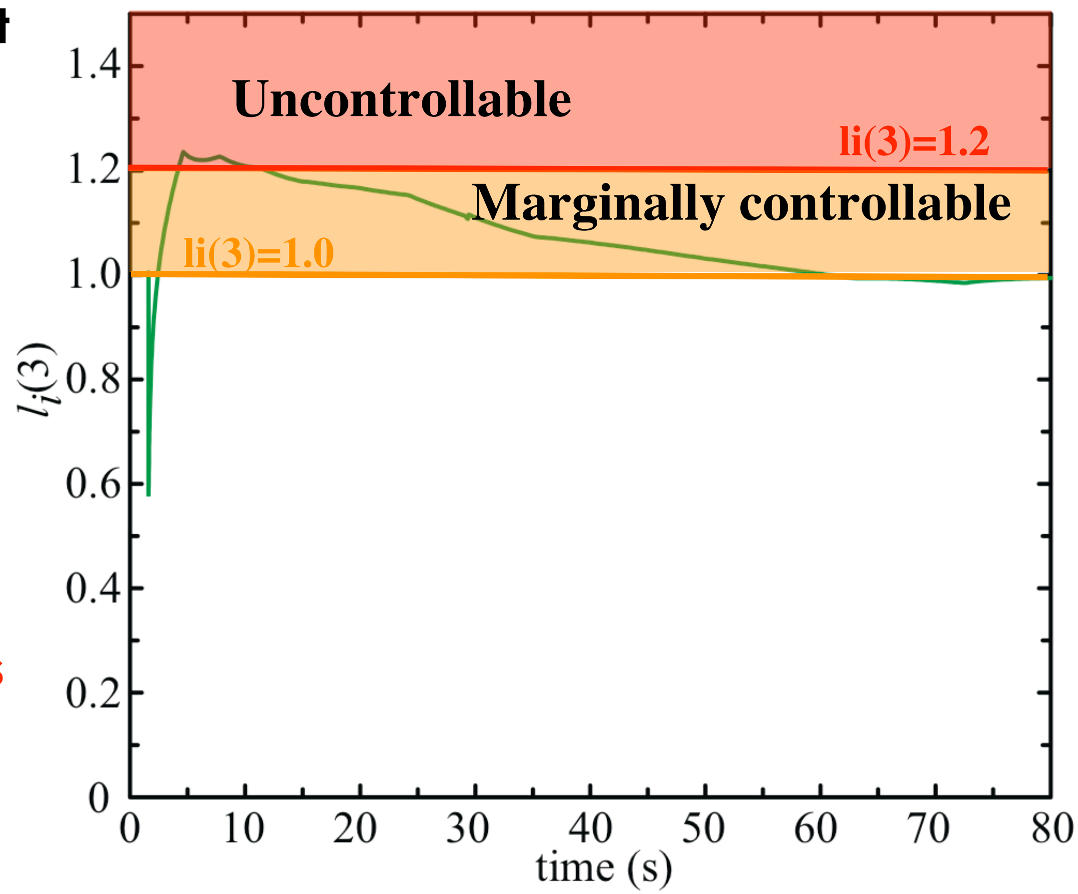


Baseline Scenarios Challenge Vertical Control Capability of Baseline Control System

- 1.0 < $\ell_i(3)$ < 1.2 during rampup at full elongation is marginally controllable by baseline VS1 system
- Uncontrollable ($\ell_i(3)$ > 1.2) conditions can occur, e.g.,
  - in baseline startup scenario
  - at high q_{95}
  - in rampdown
- **What level of performance does ITER require?**
  - **Need a metric…**

Casper, PO3.14
Jackson, JP6.82

Corsica ITER Rampup Simulation

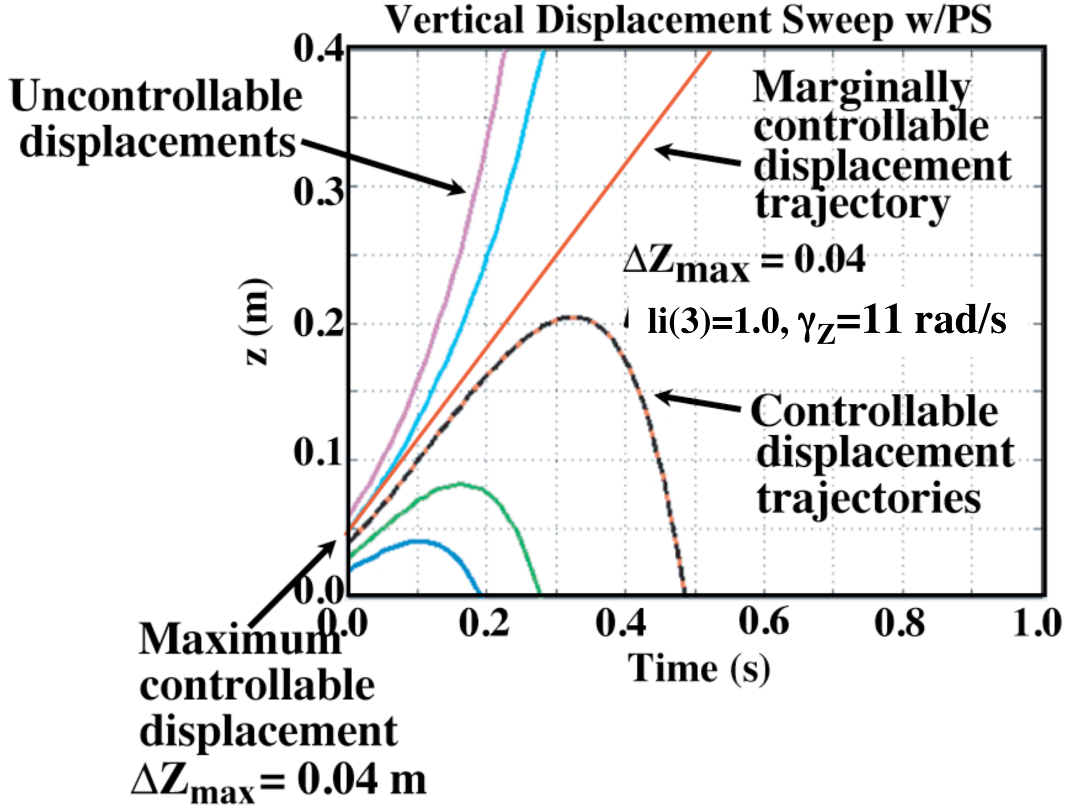


Maximum Controllable Displacement Metric Addresses Consequences of Different Voltage & Current Limits

Defining $\Delta Z_{MAX}/a$ Metric

- Let plasma drift a distance ΔZ
- Apply fully saturated step voltage commands to power supplies:
  - Maximum and fastest possible radial B to oppose vertical motion
- ΔZ_{MAX} = maximum value of ΔZ beyond which vertical motion cannot be reversed
  - A measure of "best possible"
  - NOT a true control demonstration
- $\Delta Z_{MAX}/a$ is machine-independent metric for guidance in ITER design

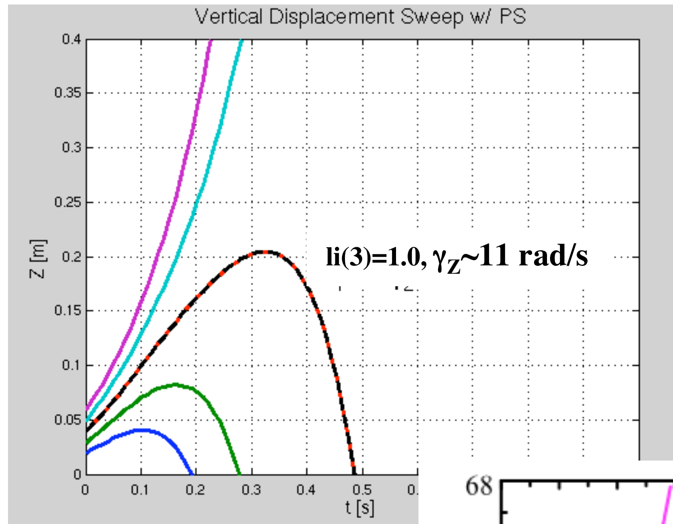
Example of Analysis and Gedanken Experiment to Calculate ΔZ_{max}



$$\Delta Z_{\max} = \frac{\partial z}{\partial I_V}\frac{M_{*VC}}{L_{*V}}\frac{V_{sat}}{L_C}\frac{1}{\gamma_z}\left(1 - e^{-\frac{\Delta I_{\max} L_C \gamma_z}{V_{sat}}}\right)e^{-\gamma_z T_{PS}}$$

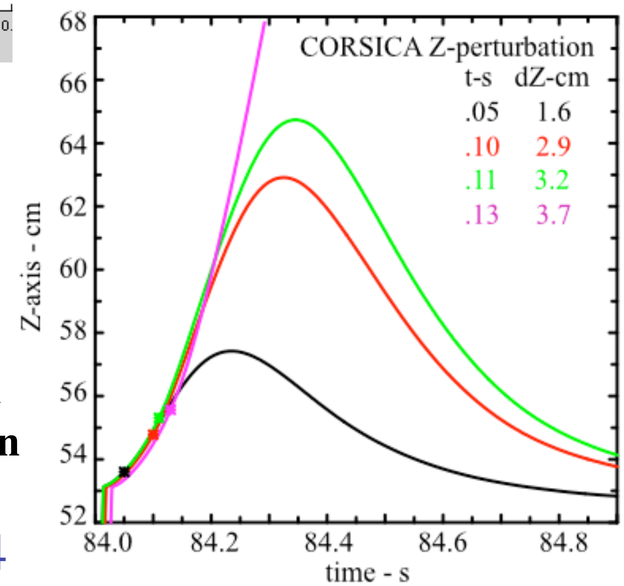
ITER Analyses Find $\Delta Z_{max}/a$ ~ 2% for Baseline VS1 System at End of Rampup Equilibrium

- **Linear rigid TokSys model:**
  $\Delta Z_{max}/a \approx 2.1\%$



Rigid TokSys plasma model

- **Nonlinear nonrigid Corsica simulation:**
  $\Delta Z_{max}/a \approx 1.8\%$



Nonrigid Corsica plasma simulation

Casper, PO3.14

- **Is $\Delta Z_{max}/a$ ~ 2% sufficient? Need experimental guidance…**

Data: $\Delta Z_{max}/a$ ~ 2% Guarantees Control Loss
$\Delta Z_{max}/a$ ~ 4% Marginal in DIII-D and C-Mod

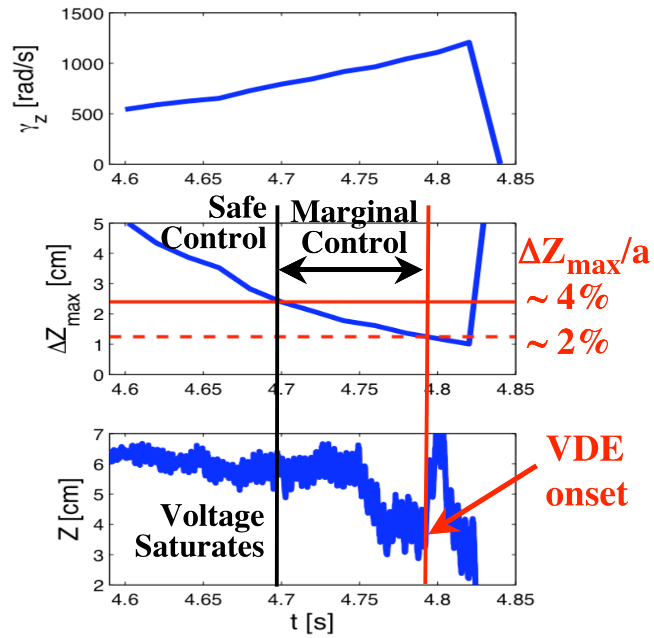
- **Experiments performed in DIII-D and C-Mod changed elongation (growth rate) to find limit to vertical control**
- **Guaranteed loss of vertical control when $\Delta Z_{max}/a$ ~ 2%**
- **Marginal ΔZ_{max} in both machines corresponds to $\Delta Z_{max}/a$ ~ 4%**
- **"Safe" operation in both machines corresponds to $\Delta Z_{max}/a$ > 5%**
- **Typical robust operation corresponds to $\Delta Z_{max}/a$ > 10%**

γ [rad/s]

DIII-D

ΔZ_{max} [cm]

Z [cm]



C-Mod

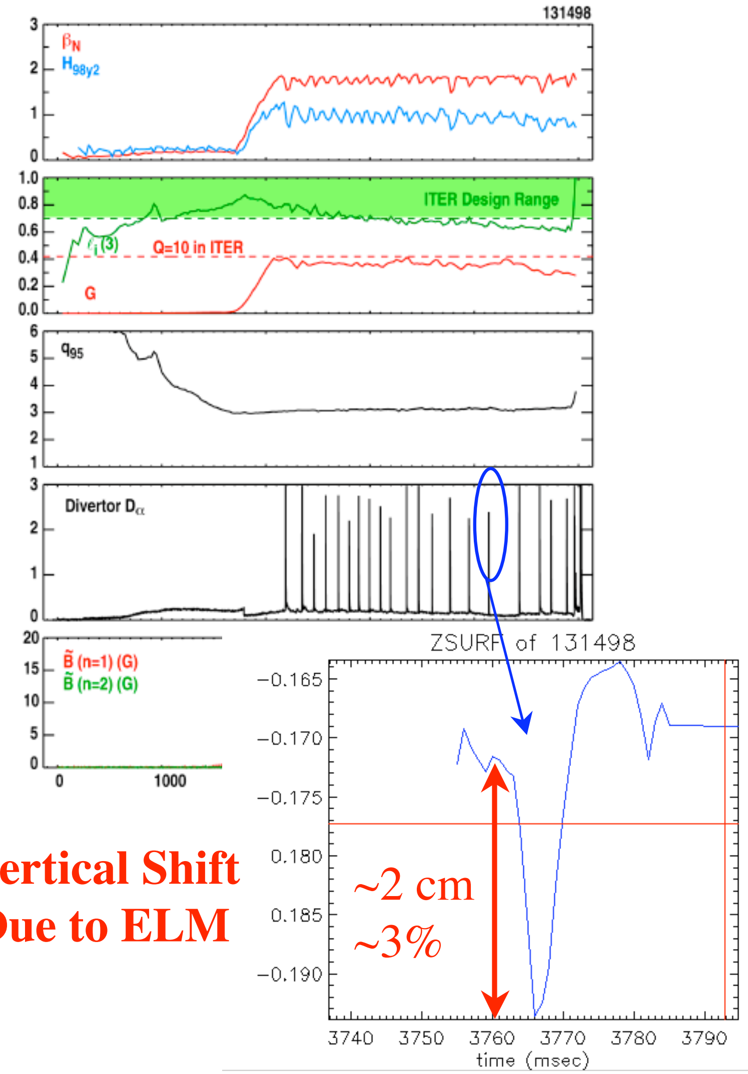
Case	γ_z (rad/s)	m_s ~τ_z/τ_{wall}	ΔZ_{max} (cm)	$\Delta Z_{max}/a$ (%)	ΔZ_{max}/ <ΔZ_{noise}>
1	210	0.41	2.8	13%	28
2	260	0.37	2.1	9.7%	21
3	310	0.33	1.5	6.9%	15
4	410	0.28	0.8	3.7%	8

Unsafe C-Mod Operating Point

Disturbances Also Will Require ITER to Have Sufficient $\Delta Z_{max}/a$ Capability

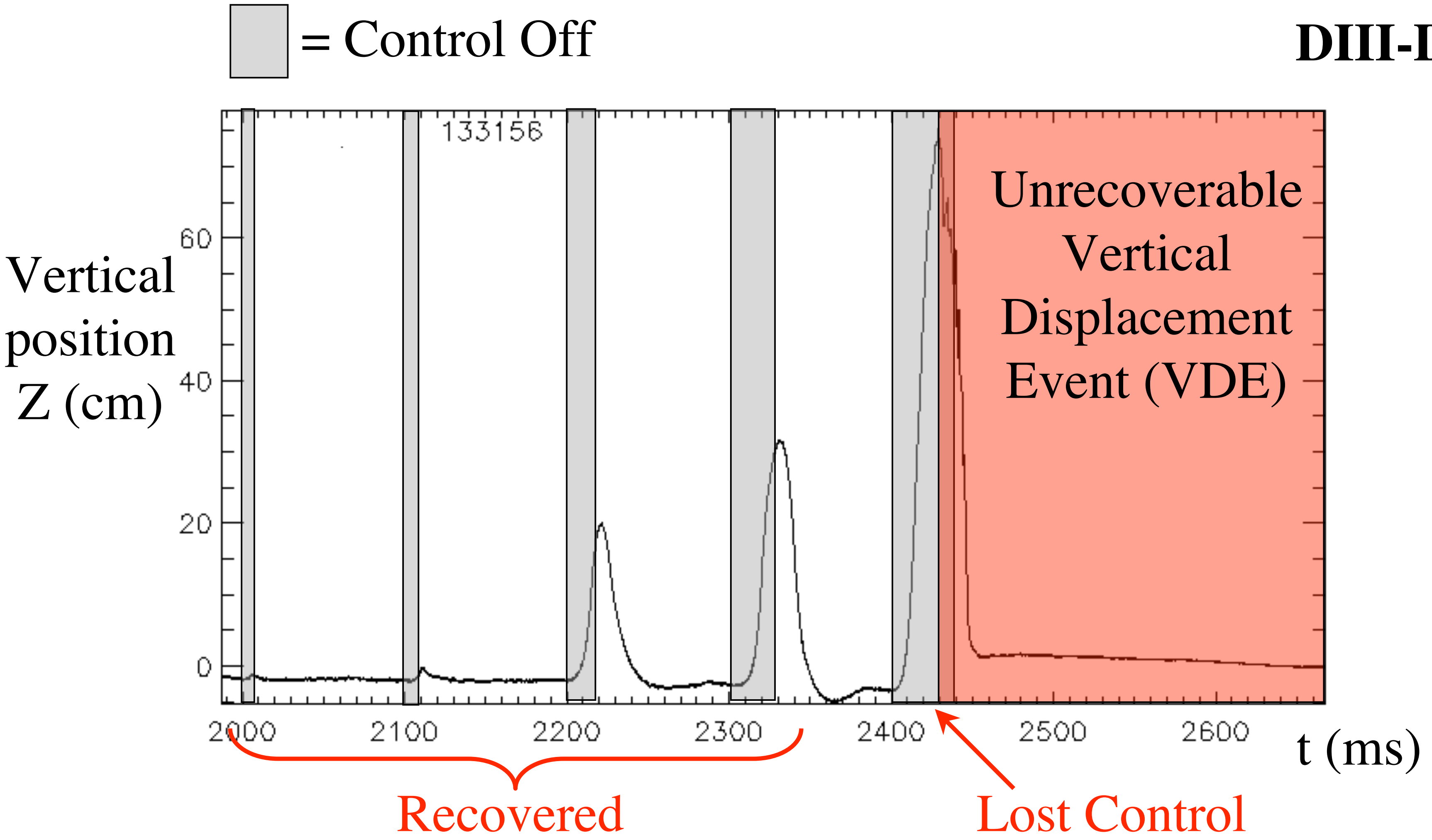
- **Noise imposes typical control limits in DIII-D, Alcator C-Mod, JET, NSTX**
  - **Noise-driven $\langle Z \rangle_{RMS}/a \sim 0.5\text{-}1\%$ in these**
- **It is possible that ITER will have lower noise**
  - **CRPP-Lausanne working on magnetic diagnostics/noise reduction**
  - **Noise reduction demonstrated in TCV $\langle Z \rangle_{RMS}/a < 0.2\%$**
- **But large plasma disturbances may set the practical noise limit for control**
  - **DIII-D ITER demonstration discharges produce ELM-driven plasma perturbation $\Delta Z_{ELM}/a \sim 3\%$**

DIII-D ITER Demonstration Plasma



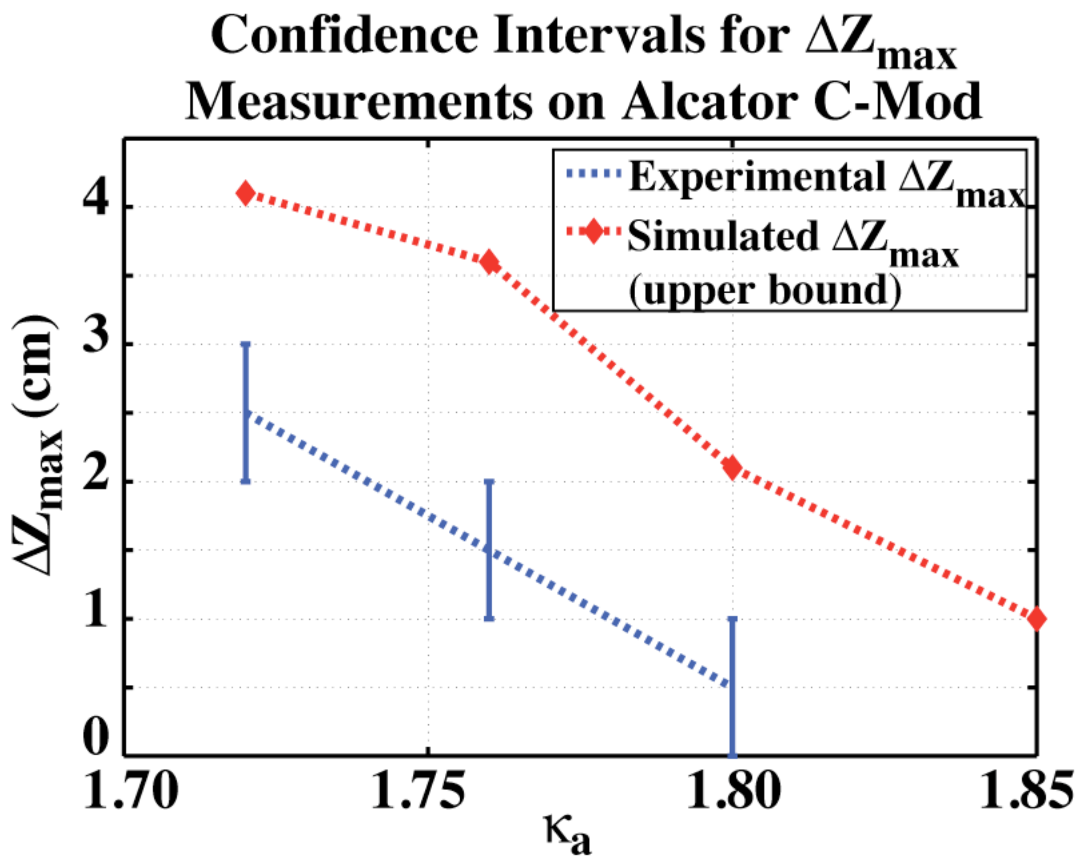
Vertical Shift Due to ELM

Experiments Varying the Control-Off Time and Vertical Displacement Search a Large ΔZ Space in One Shot



Alcator C-Mod ΔZ_{max} Experiment Shows Predicted Values Are 30–100% Above Experimental Values

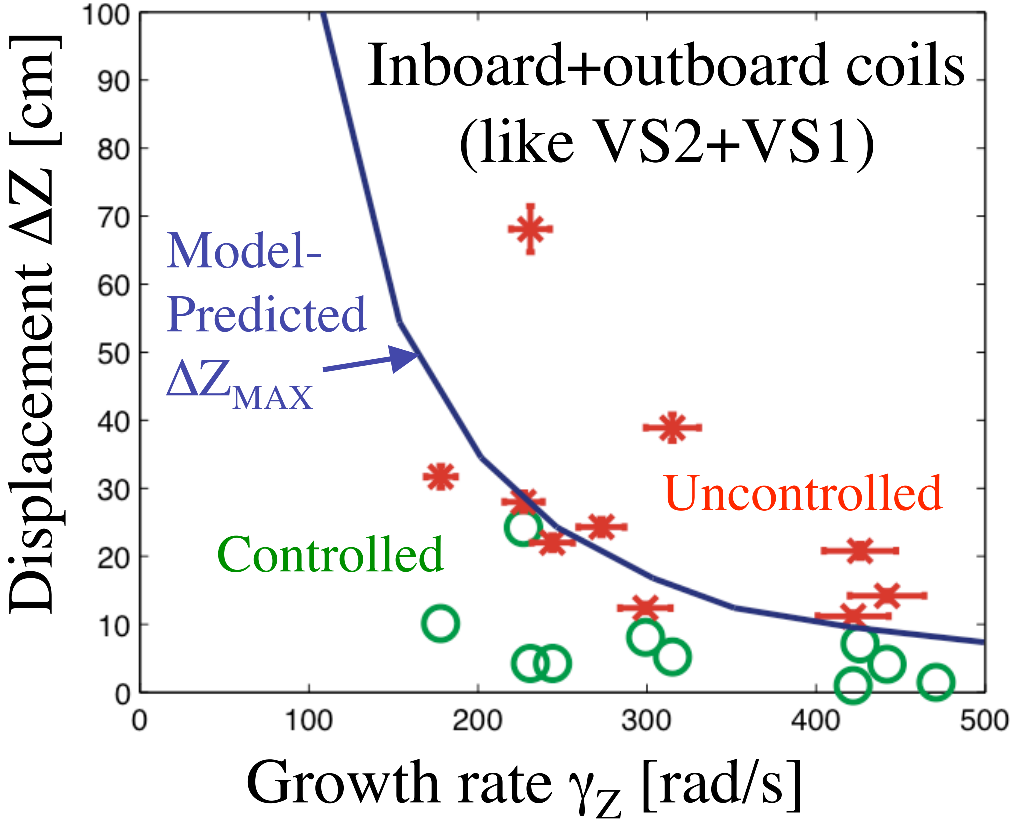
- Elongation κ_a varied, vertical control disabled for varying periods
- Calculated ΔZ_{MAX} ~ 30–100% above best experimental values for each κ_a
- Alcator C-Mod ΔZ_{max} are set by coil current limit, not by voltage limit
  - Similar to proposed ITER in-vessel coils



DIII–D ΔZ_{max} Experiment Shows Predicted Values Are 20-30% Above Experimental Values

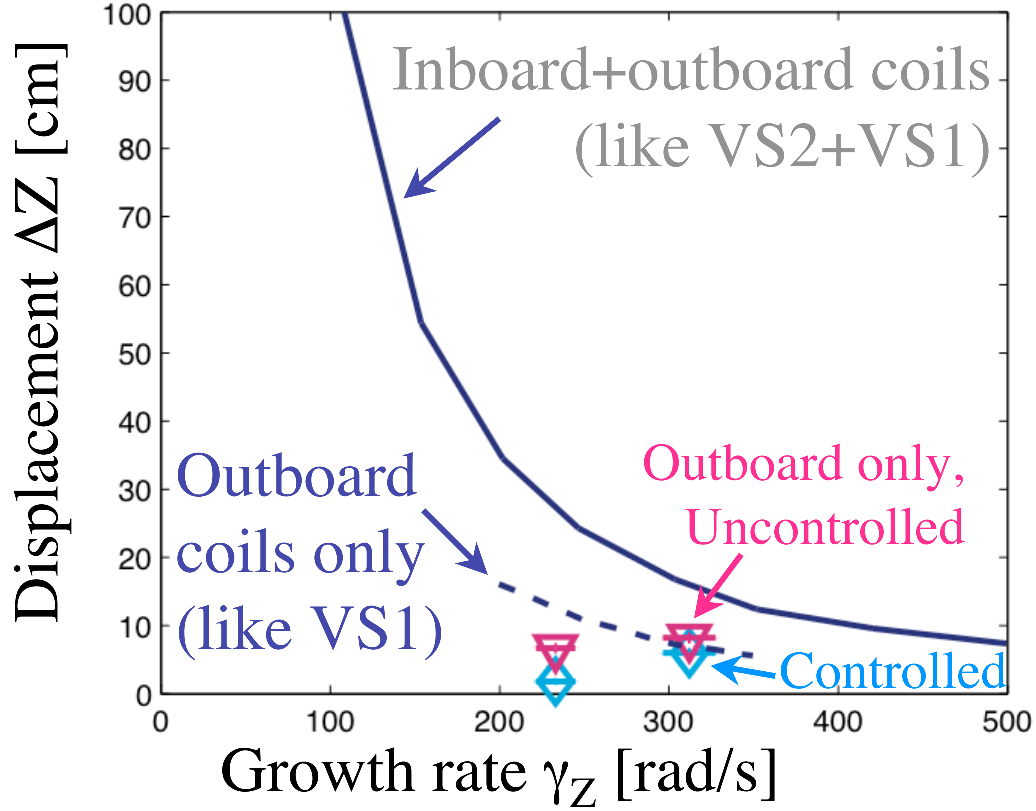
- **Elongation varied to vary growth rate in different discharges**

- **Calculated ΔZ_{max} ~ 20 – 30% above experimental limit**



DIII-D ΔZ_{max} Experiment Shows Use of Inboard Coils Approximately Doubles Performance

- **Use of inboard+outboard coils in DIII–D roughly doubles ΔZ_{max} from outboard-only**

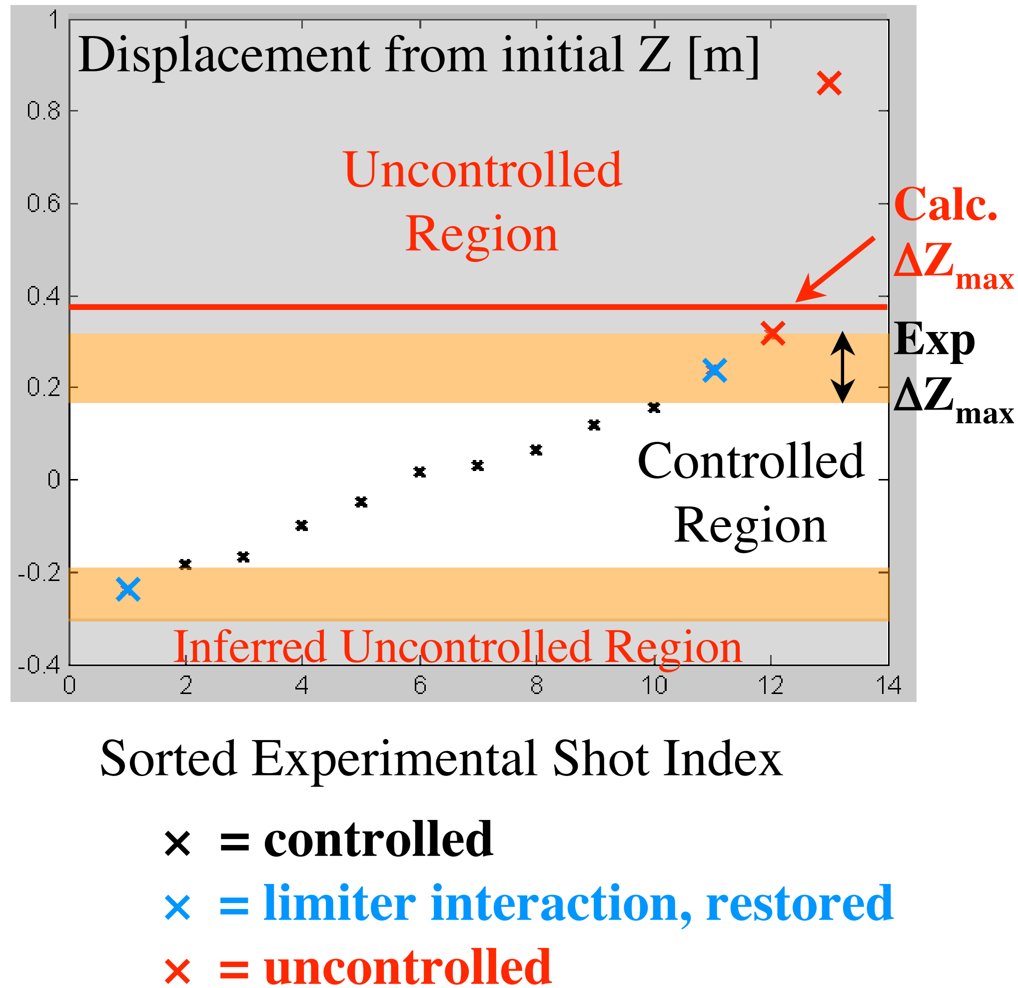


NSTX ΔZ_{max} Experiment Also Shows Predicted Value Is ~30% Greater Than Experimental Values

- **Single equilibrium target was studied shot-by-shot**
  - **Varied initial vertical drift**
  - **Single growth rate and ΔZ_{MAX} value**
  - **Finely resolved range of ΔZ cases**

- **Calculated value of ΔZ_{MAX} ~ 30% above experimental best**

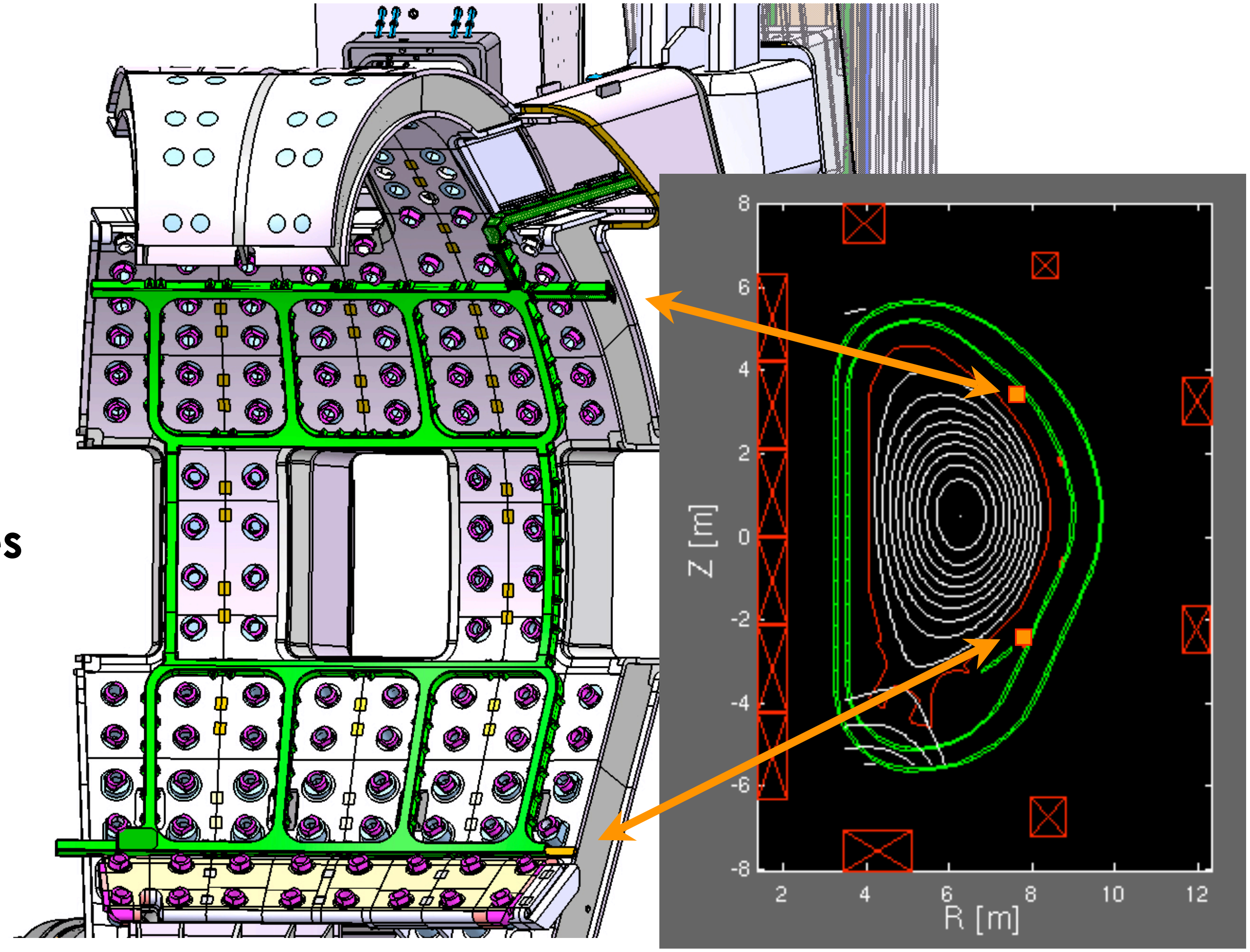
- **Potential roles of nonaxisymmetric conductors, nonlinear interaction with limiter**
  - **Suggests need to model 3D effects of ITER conductors**



Kolemen, NP6.117

ITER Design Now Incorporates In-Vessel Coils for Increased Vertical Control Capability

- In-vessel coils alone provide $\Delta Z_{max}/a \sim 5\%$ capability
- Share space, jacket, and most design features with ELM control coils
- Pose significant engineering design, fabrication, and maintenance challenges



Summary and Conclusions

- **Multi-machine experiments for vertical control performance have:**
  - Quantified performance in present devices
  - Partially validated theoretical performance scalings
  - Translated performance data into metric specifications

- **Experiments/analysis have provided key motivation for improving ITER vertical control capability:**
  - $\Delta Z_{max}/a > 5\%$ required for robust control at edge of ITER operating space
  - $\Delta Z_{max}/a \sim 2\%$ is capability of ITER baseline system
  - ITER in-vessel coils being designed to provide $\Delta Z_{max}/a > 5\%$
  - Discrepancies between calculation and experiment emphasize need for margin in design

- **Work remains to carefully analyze physics of control limits:**
  - Details of noise-determined control limits
  - Types, magnitudes, detailed histories of disturbances to expect in ITER