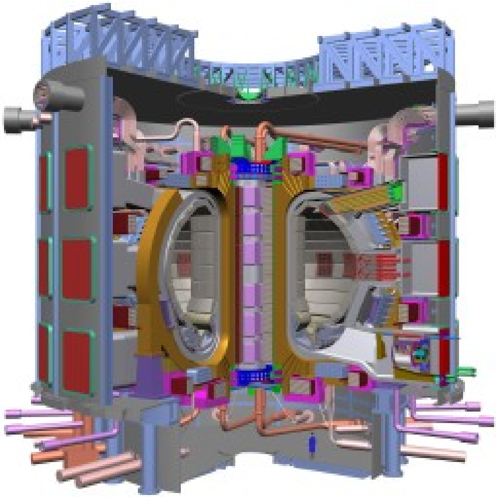
# ITER High Priority Research and possible JET collaboration

## RWM Physics

J. Menard, for MHD-SFG



25 August 2005
PPPL

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PRINCETON PLASMA
PHYSICS LABORATORY

# Outline

- RWM feedback benchmarking/modeling

- ELM-RWM interaction

- RWM critical rotation vs. $q_{min}$ in AT
  - Analysis results from DIII-D
  - Proposal to compare $\Omega_{crit}$ vs. $q_{min}$ on JET

# ITER RWM benchmarking VALEN modeling results

## 6th ITPA MHD topical group meeting

Tarragona, Spain 4 July 2005

Presented by J. Bialek

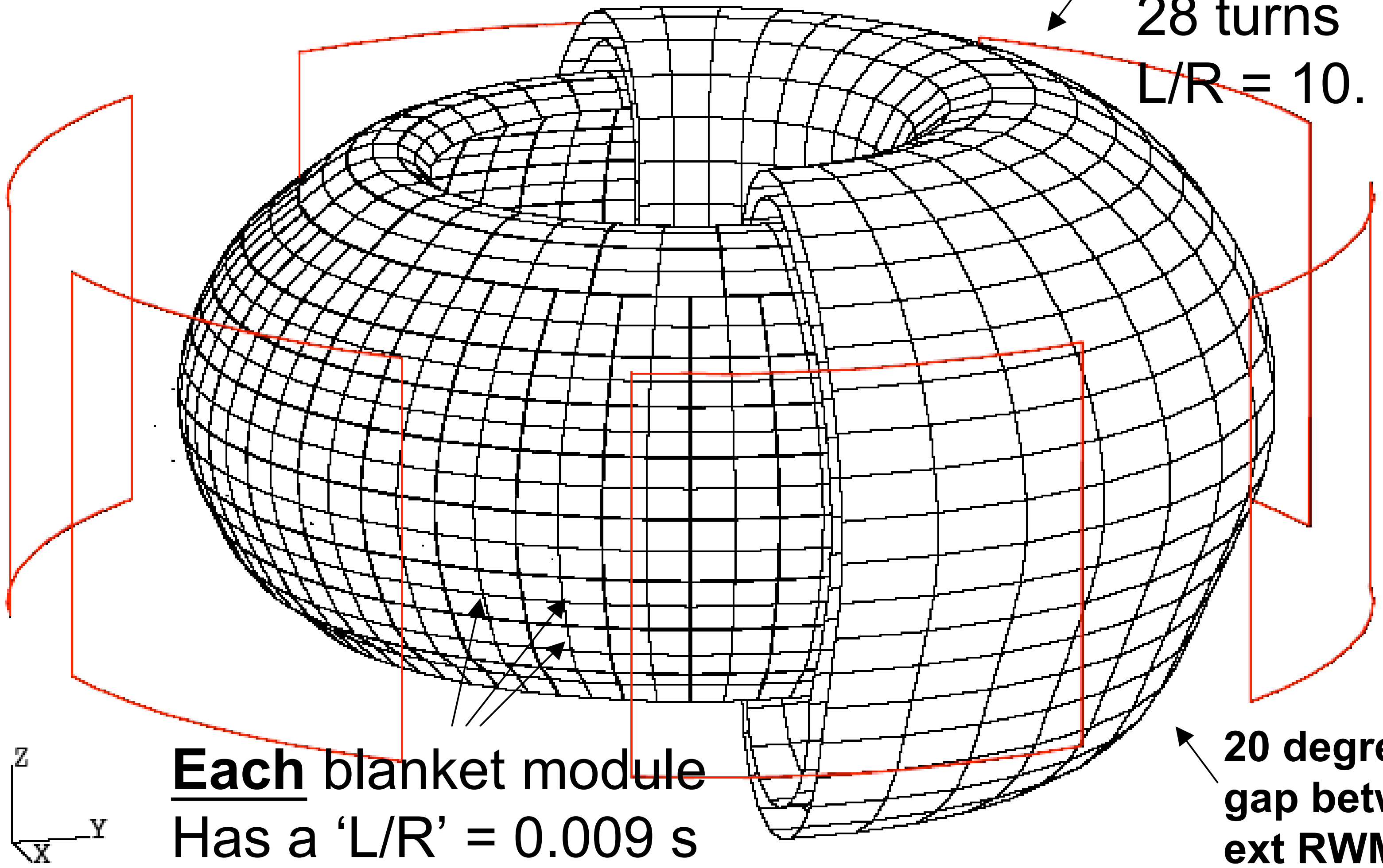
Columbia University

# ITER baseline external RWM coils shown

Cut away view of axisymmetric vacuum vessel

VALEN blanket modules visible without VV

External RWM coils cover only 2/3 of perimeter



Coil pairs have
28 turns
L/R = 10. s !

**Each** blanket module
Has a ‘L/R’ = 0.009 s

**20 degree**
**gap between**
**ext RWM coils**

# VALEN RWM dispersion relation
# For ITER benchmark model with fast L/R<1 μs
# [approximates current control]

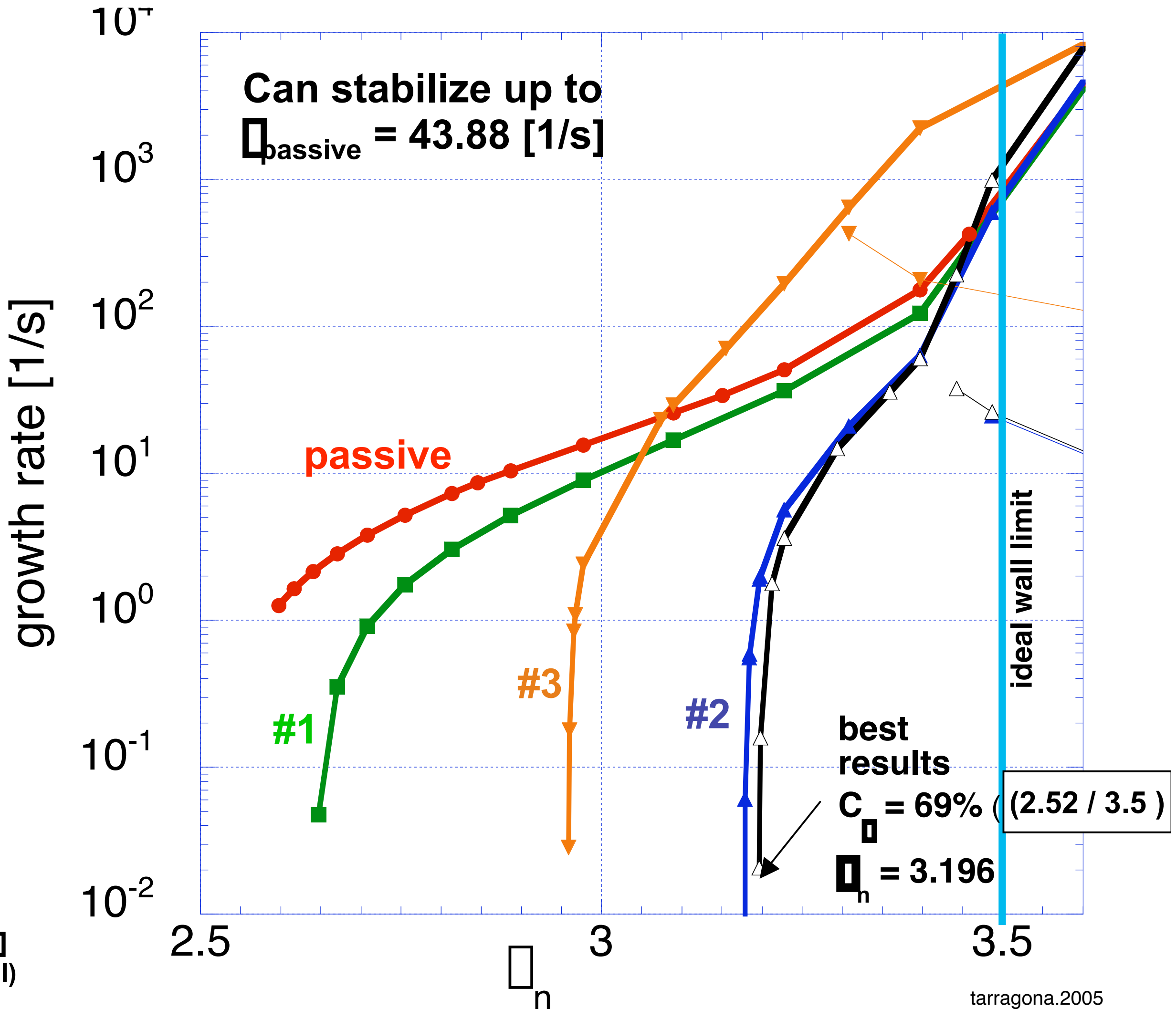
**#1 $G_p=10^{12}$[v/w] (real)**
**@ 1 gauss**
**$I_{cc}$=0.518 KA**

**#2 $G_p=10^{13}$(complex c. pairs)**
**@ 1 gauss**
**$I_{cc}$ = 5.18 KA**

**#3 $G_p=10^{14}$(complex c pairs)**
**@ 1 gauss**
**$I_{cc}$ = 51.8 KA**

**Best results use**
**$G_p/G_d=10^3$**

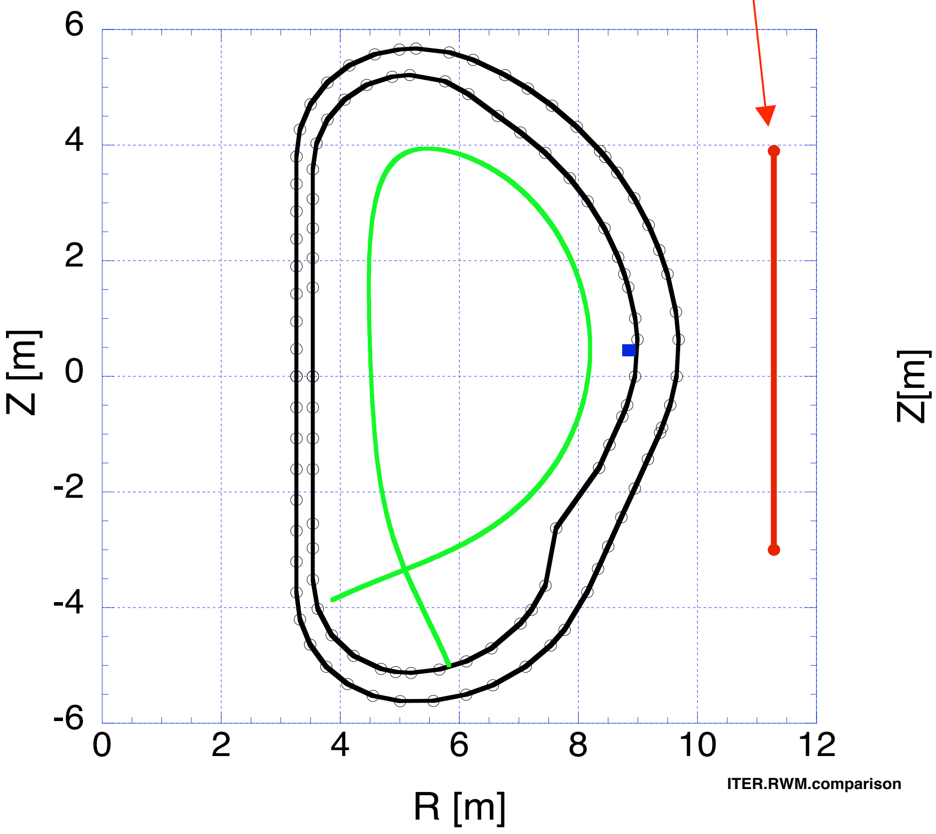
**( L/R = 16.8 μH/19.29 μΩ = 0.87 μs for each coil)**



tarragona.2005

# Benchmarking model

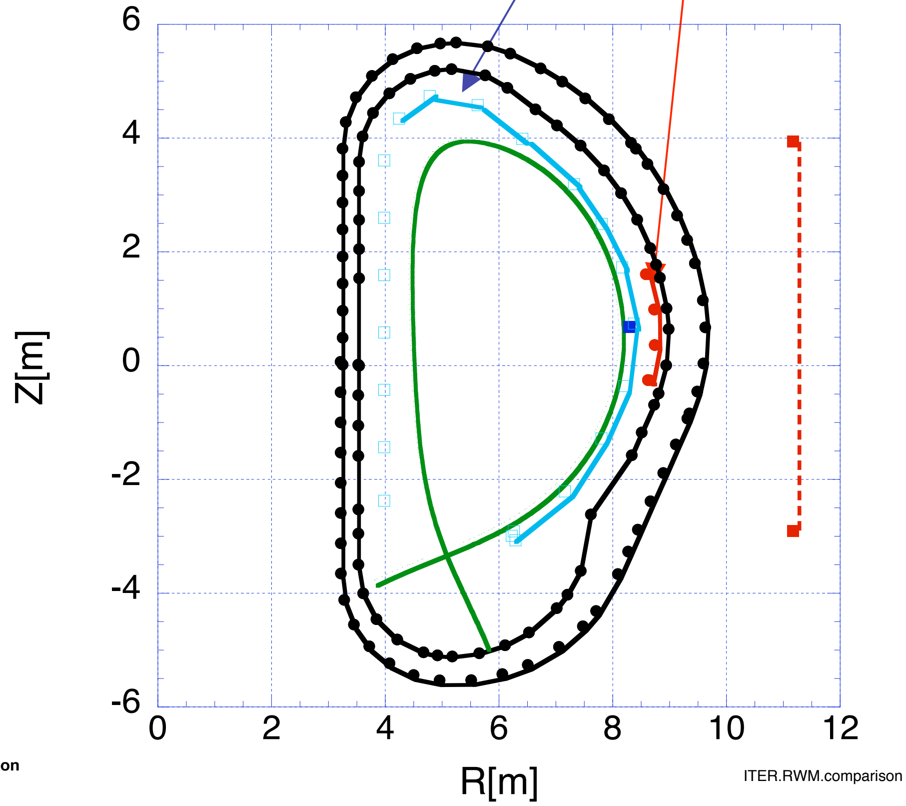
**continuous** external RWM coil
axisymmetric VV
**no** blanket modules



**ITER RWM benchmarking**
**plasma, walls, control coils,**
**& Bp sensor**

# Extended ITER model

**discrete** interior RWM coils
penetrations in VV
segmented blanket modules



**extended ITER RWM analysis**
**plasma, walls, control coils,**
**blanket modules, & Bp sensors**

# Performance with 6 external coils with 10 s time constants Same $G_p$ & $G_d$, add blanket modules to model ( no ports)

**Gain settings:**

**$G_p = 10^9$ [v/w]**

**$G_d = 10^9$ [v/v]**

**Best $\beta_n$ = 3.177**

**( with all blanket modules)**

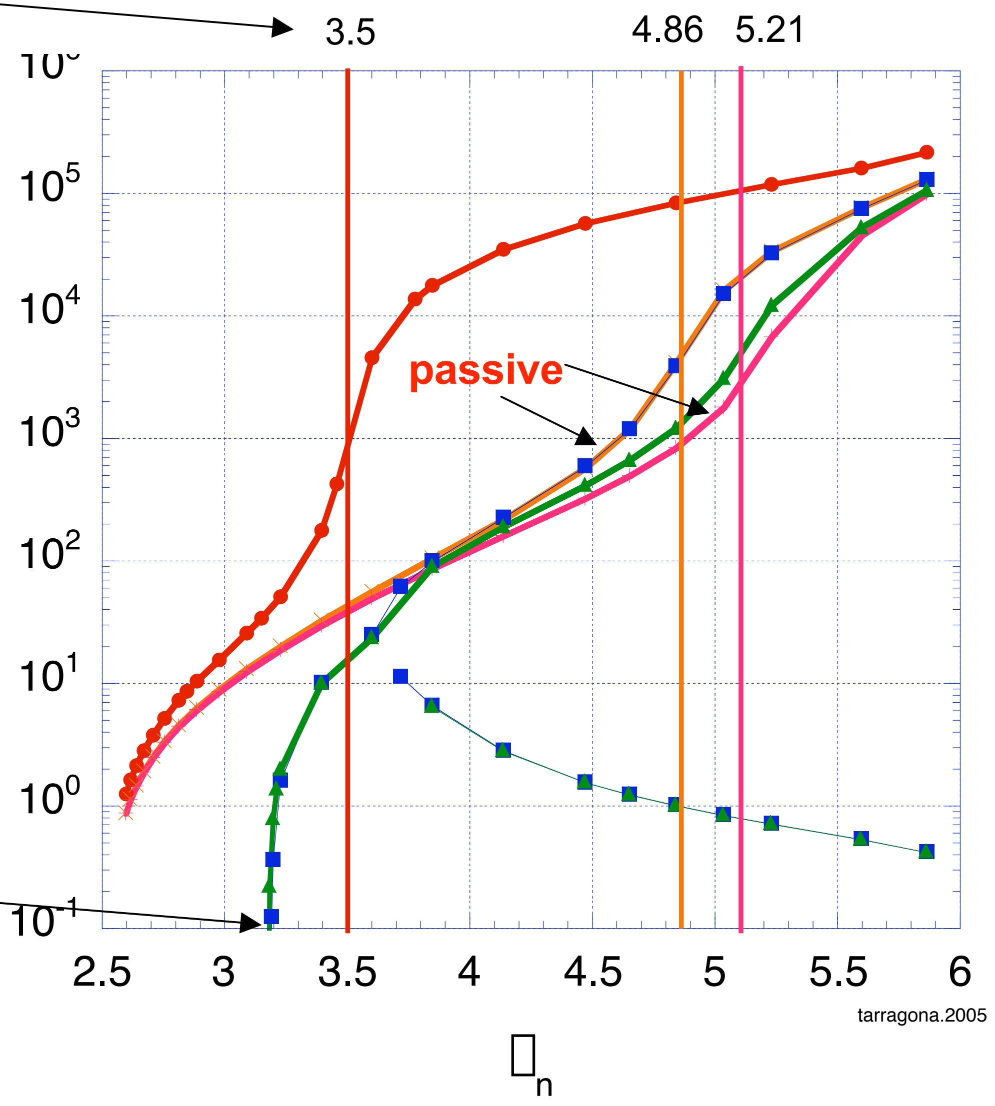
**Best $\beta_n$ = 3.189**

**( with blanket modules removed from mid plane ports)**

**Best**

**Results**

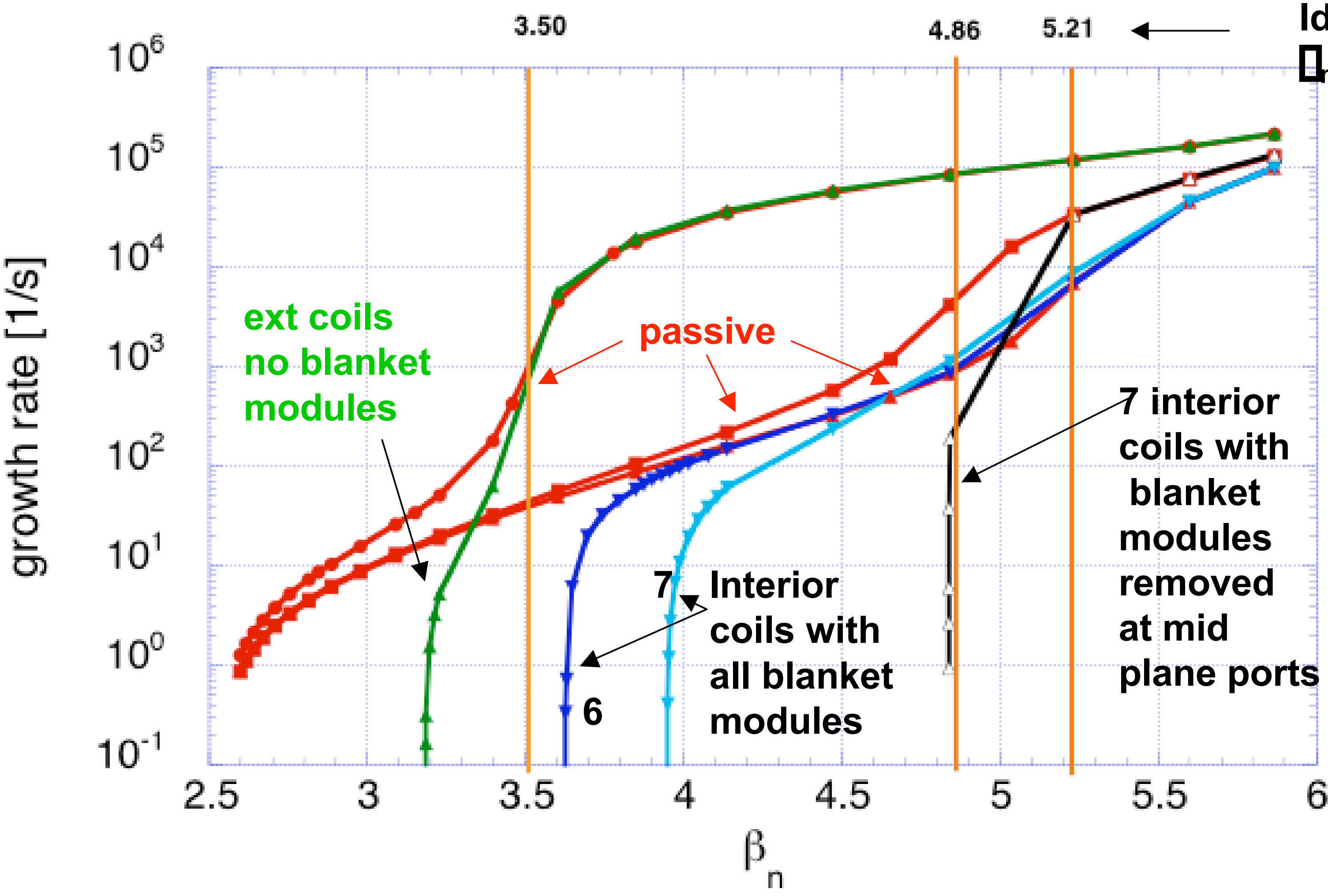
**About same as benchmark !**



Recall ideal wall $\beta_n$ limits

# Graphical summary VALEN RWM best results

## Internal RWM coils perform significantly better than external RWM coils



Ideal wall $\beta_n$ limits

ext coils
no blanket
modules

passive

7 Interior
coils with
all blanket
modules

6

7 interior
coils with
blanket
modules
removed
at mid
plane ports

# Feedback Stabilization of Resistive Wall Modes in DIII–D

by
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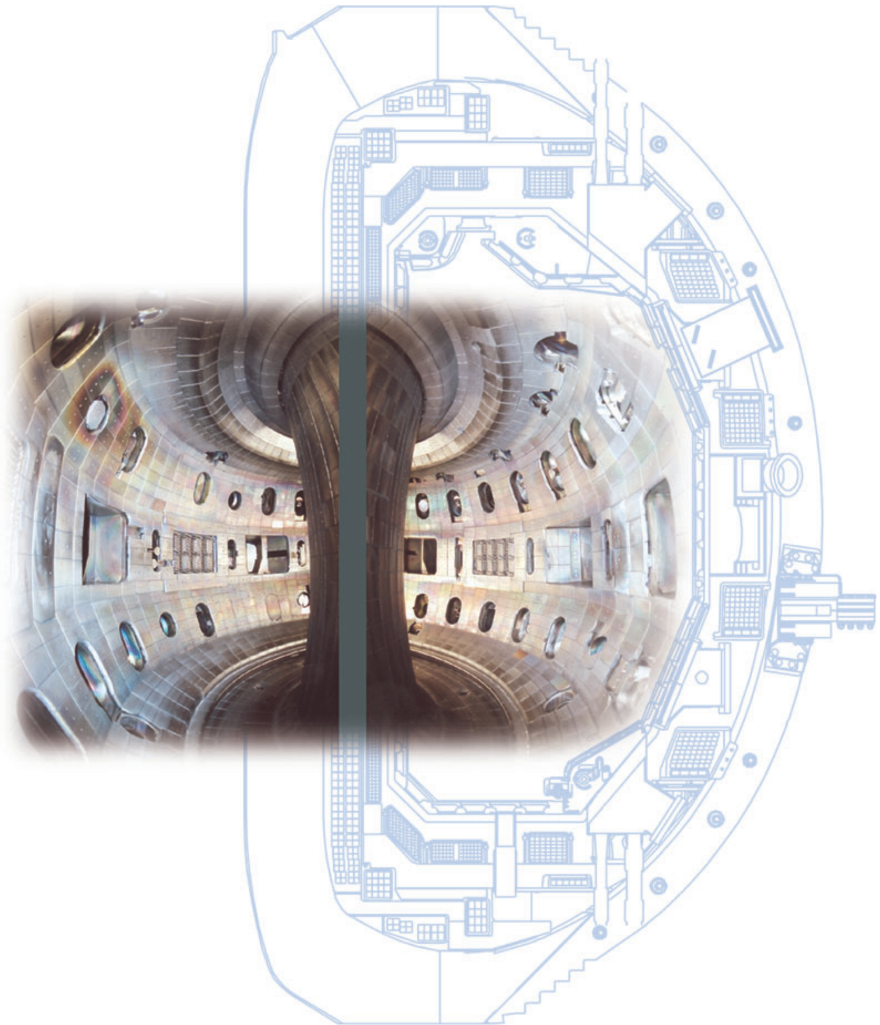

Presented at the
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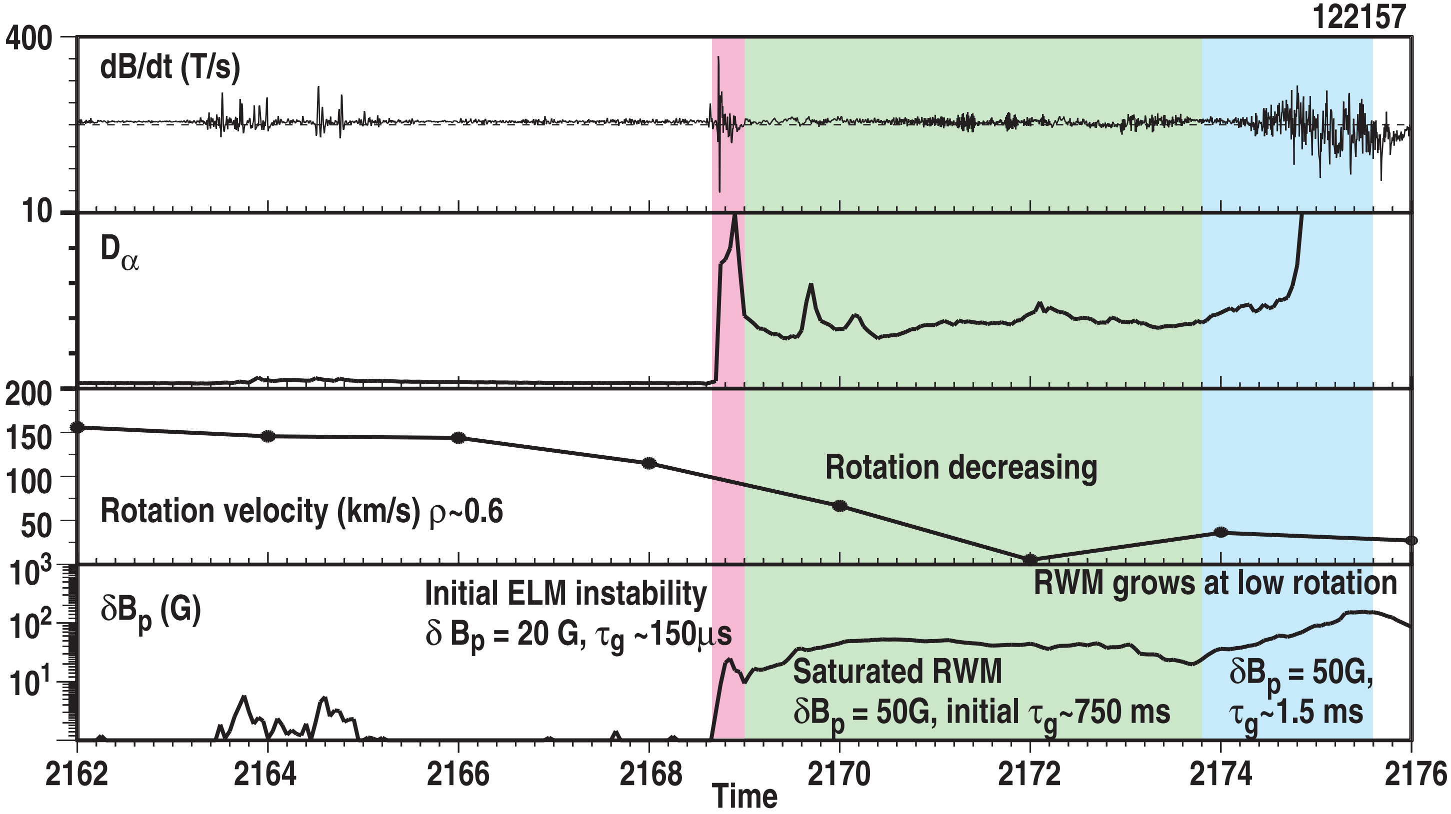
MHD, Disruptions, and Control
Tarragona, Spain

July 4–July 6, 2005

# ELMs Can Trigger Growth of An Unstable RWM

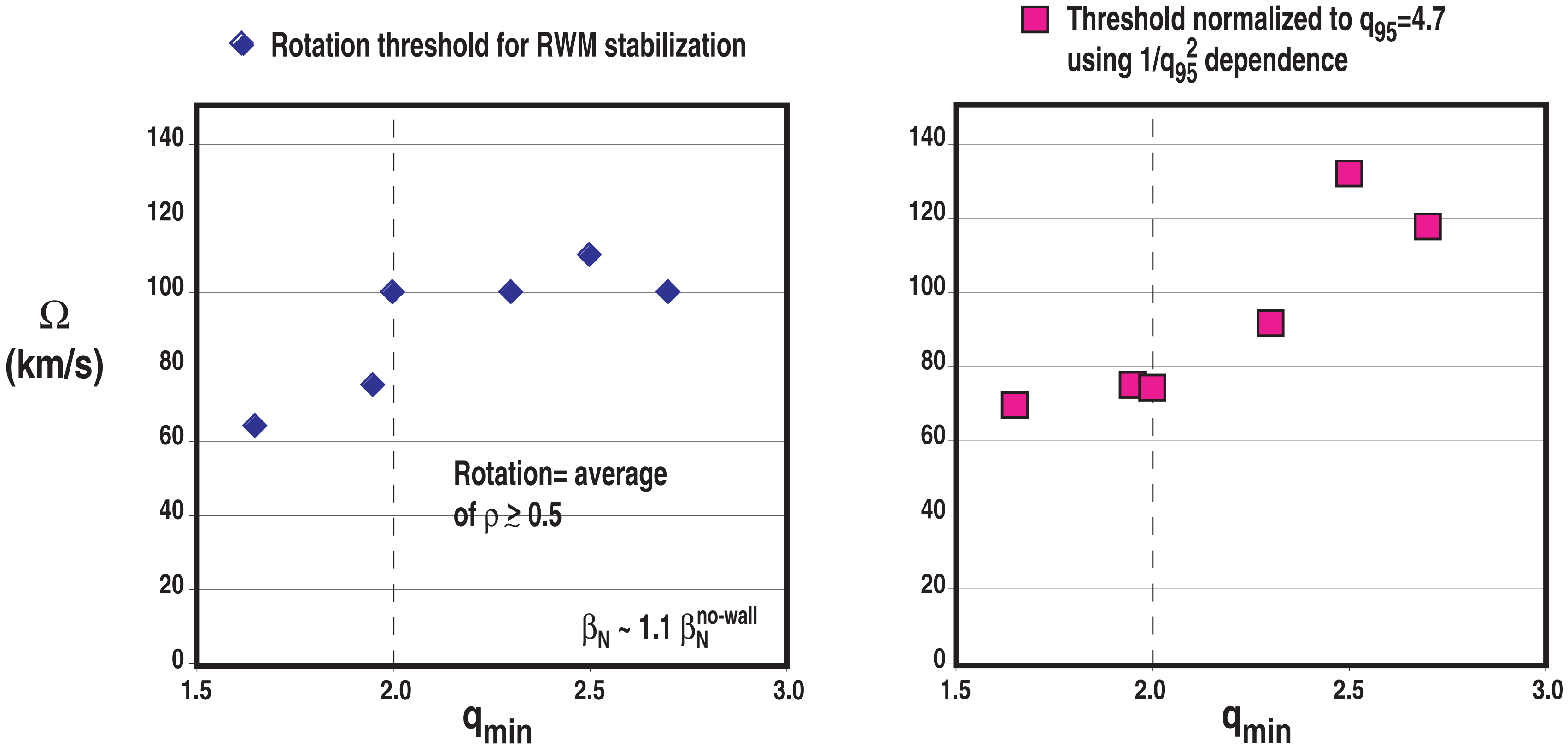
- **Hypothesis: Near marginal stability for the RWM . . .**
  - ELM excites a weakly damped RWM at finite amplitude
  - Magnetic braking by the RWM causes plasma rotation to decrease
  - If sufficient braking occurs during the damping time, the RWM becomes unstable



- **ELMs may determine the minimum feedback current requirement**
  - Alternatively, ELM suppression may reduce the requirements for RWM feedback current

# Threshold Rotation for RWM Stabilization Increases with $q_{min}$

- **Previous experiments have suggested a dependence $\Omega_{crit} \sim 1/q_{95}^2$**



- **These experiments suggest a dependence on $q_{min}$: $\Omega_{crit} \sim q_{min}^2$**

# Ideal and Resistive Plasma Stability Modeling for DIII–D AT Scenarios

by
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DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

PPPL
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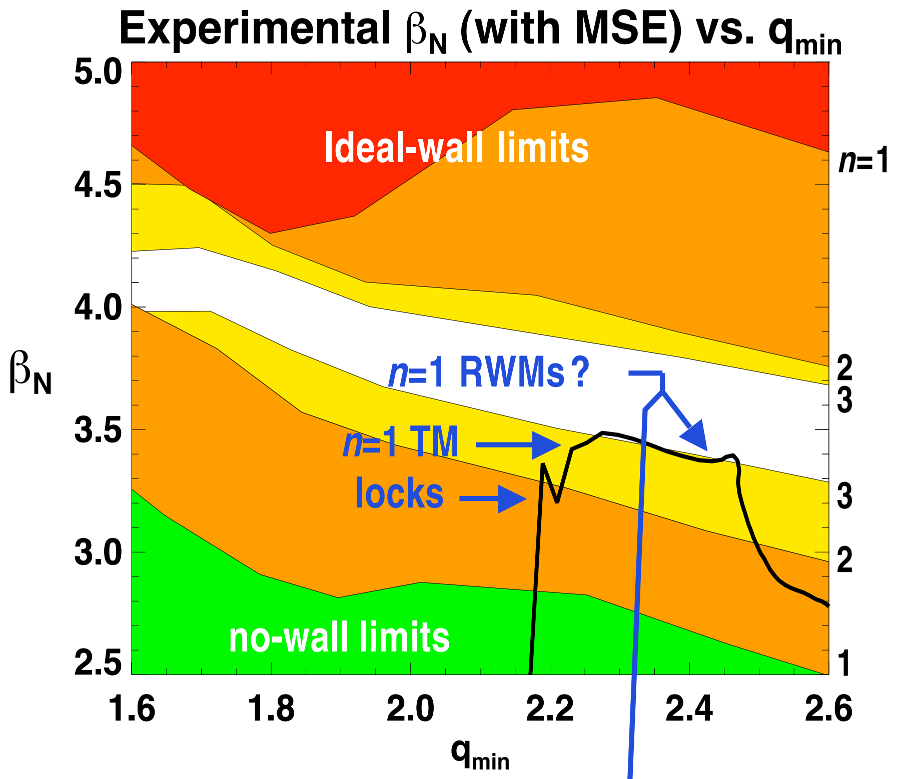
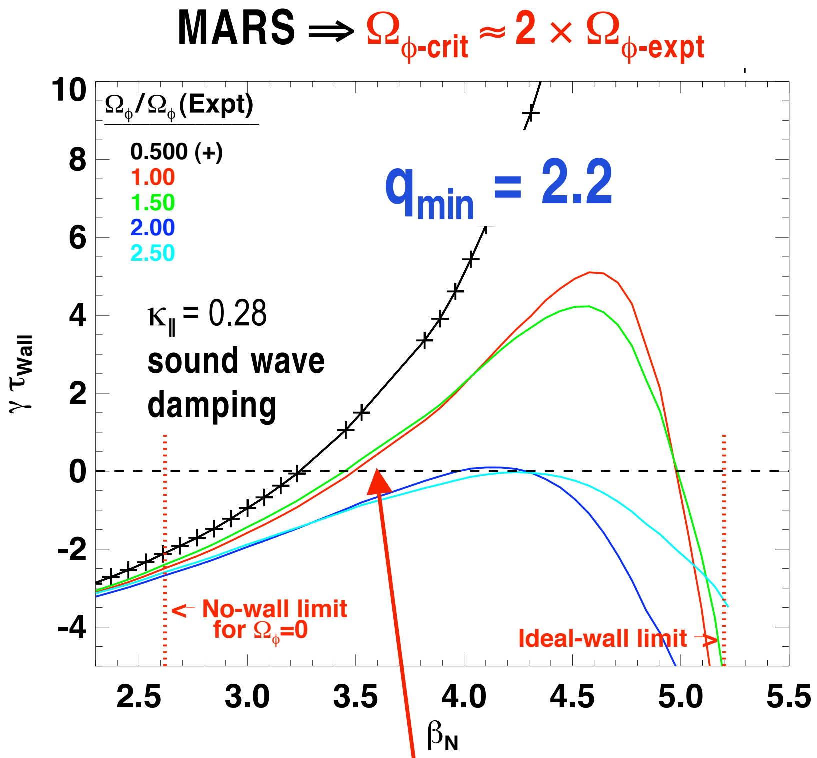
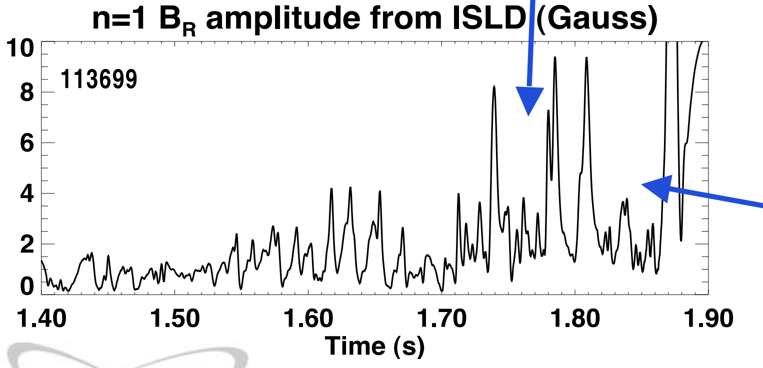
# $q_{min}$ >2 MAY BE MORE UNSTABLE TO *n*=1 RESISTIVE WALL MODES







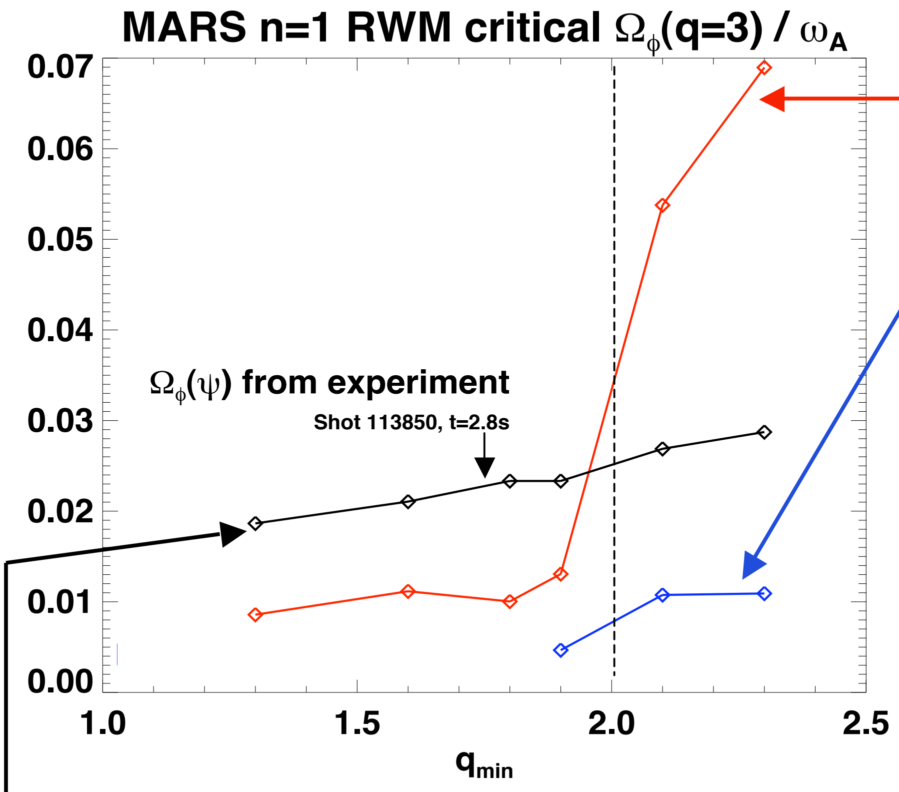
- Predict *n*=1 RWM unstable near $\beta_N$ = 3.5 for $\Omega_\phi \approx \Omega_{\phi\text{-expt}}$ for $q_{min}$ > 2
- Observe increased RWM/EF feedback activity at high $\beta_N$ (using C-coil feedback)

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

PPPL PRINCETON PLASMA PHYSICS LABORATORY

# BOTH MARS DAMPING MODELS PREDICT INCREASED $\Omega_{\phi\text{-CRIT}}$ WHEN $q_{min}$ >2

- Resonances at q=2 surface dominate collisionless damping when $q_{min} < 2$



**Sound wave (SW) damping model** predicts much larger $\Omega_{\phi\text{-crit}}$ than

**kinetic damping model** for $q_{min} > 2$

- DIII–D n=1 RWM critical-$\Omega_\phi$ studies:
  - Usually, $q_{min}$ = 1.5 – 1.8
  - $\Omega_{\phi\text{-crit}}(q=3)/\omega_A \approx 1\%$ in experiment
  - SW damping over-predicts $\Omega_{\phi\text{-crit}}$
  - Kinetic damping under-predicts

    *(La Haye, to be published in NF)*

- Actual $\Omega_{\phi\text{-crit}}$ bounded by these?

- AT shape experiment used $q_{min} < 2$
  - Experiment approached ideal-wall limits using C-coil EF correction only
  - $\Omega_{\phi\text{-expt}} > \Omega_{\phi\text{-crit}}$ from both damping models - consistent with experiment

# JET collaboration relevant to ITER:
# Stability of AT discharges on JET

- Will work through existing PPPL/DIII-D collaboration
  - T. Luce, E. Joffrin, etc.
  - Februrary/March 2006

- Task Force S2 "Test of shear optimised scenarios”

- ITPA goals:
  - Find beta limits in discharges with $1.5 < q_{min} < 2.5$ and $0 < q(0)-q_{min} < 0.5$
  - Operate above no-wall limit, **make RWMs,** compare to ITB discharges

- Contribute primarily to analysis and interpretation
  - Mode identification of beta-limiting phenomena
  - Kinetic/MSE reconstructions
    - Need to ID and create desired q-profile shape during run
  - Stability calculations – before and during experiment
  - **Are RWMs more unstable when $q_{min} > 2$?**

- PPPL contributions could/should be:
  - TRANSP analysis of discharges in support of accurate stability analysis.
  - The stability analysis itself:  DCON, MARS, PEST (Betti/Hu?), M3D…