Summary of ITPA Topical Group on MHD Stability

Padova, Italy

Oct 4-7, 2011

US Participants:

Theory

S. Jardin
F. Waelbroeck
J. Harris(R)
V. Izzo

Experiment

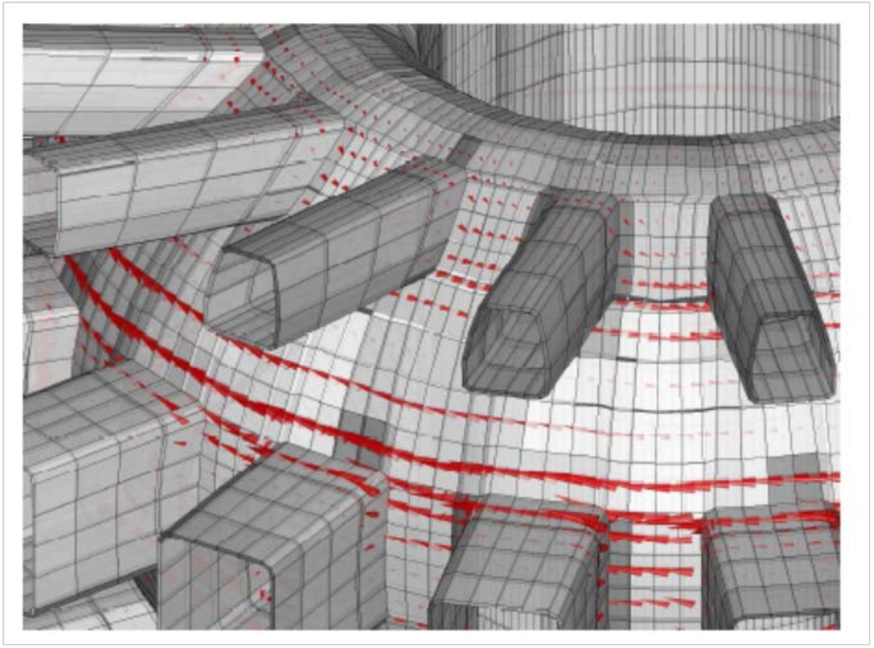
E. Strait
R. Granetz
S. Sabbagh
M. Okabayashi
J. K. Park
R. LaHaye
N. Eidietis (R)
J. Wesley (R)
D. Humphreys (R)
R. Buttery
A. K. Sen

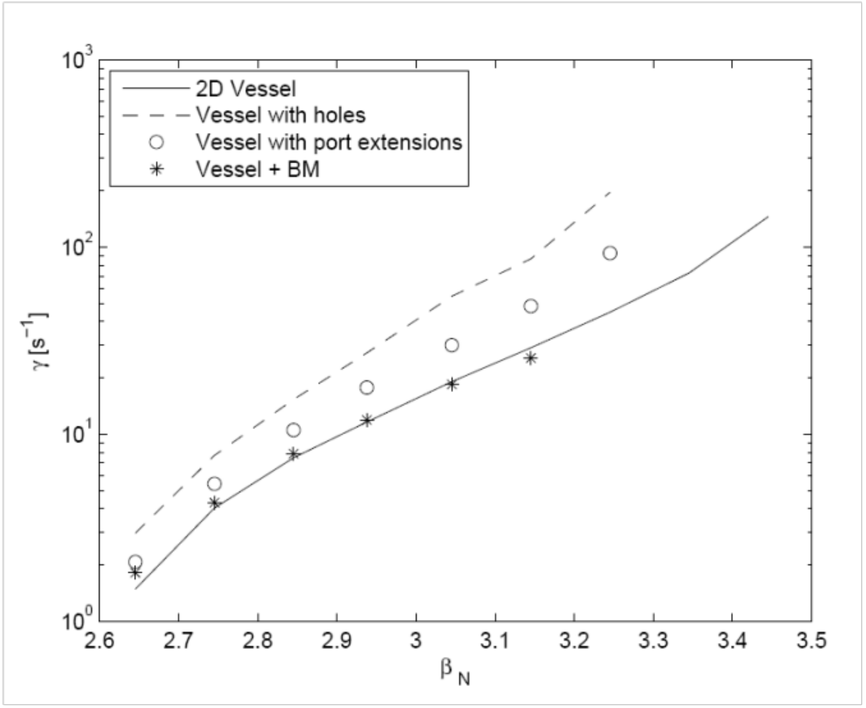
TOPICS

- 3D Physics
- Error Fields
- Resistive Wall Mode Stability and Control
- Disruption Modelling and Experiments
- Disruption Avoidance and Control
- Disruption Mitigation
- Axisymmetric Control

3D Physics: 3D electromagnetic analysis of RWMs (Villone)

MARS code has been coupled to a full 3D model of the ITER vacuum vessel

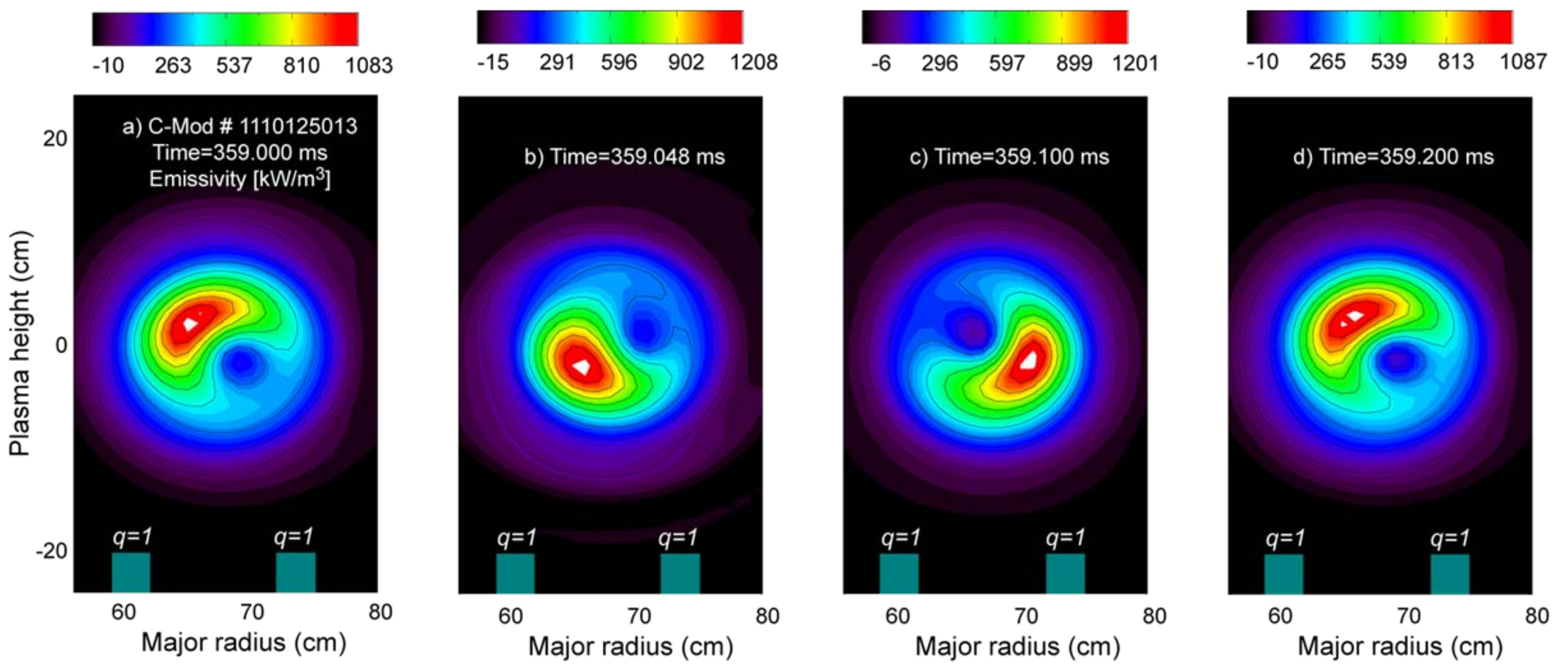




- CarMA code combines EM structures code with MARS linear plasma code
- Being used to compute RWM, n=0 mode, active control, etc.
- Relatively small effects over 2D structure model so far.
- Can we couple NIMROD M3D-C^1 to 3D structure model?

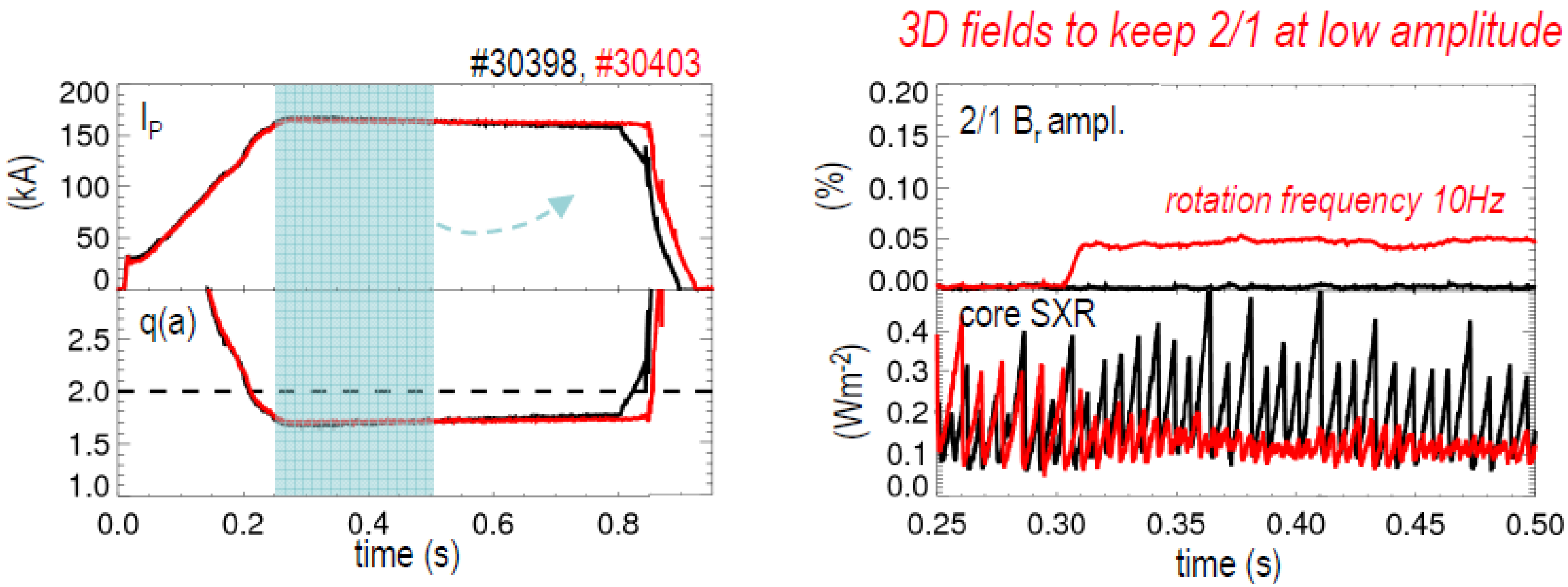
3D Physics: Formation and stability of m=1 impurity-induced snakes in Alcator C-Mod

(Granetz, Delgado-Aparicio, Sugiyama)



- Stationary m=1 structure in x-ray emission caused by high-Z injection
- Snake structure rotates with plasma
- Snake structure survives many sawtooth crashes !
- Sugiyama to model?

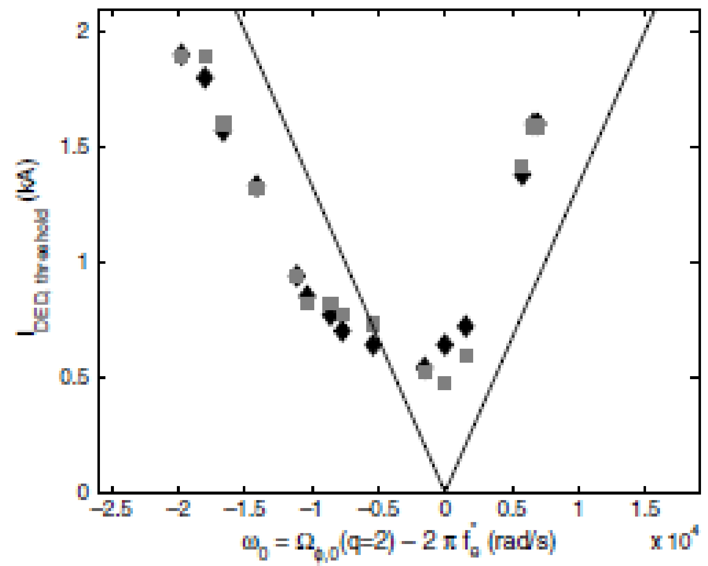
3D Physics: Sawtooth tailoring by the application of external 3D magnetic fields in RFX-mod Ohmic tokamak plasmas (Piovesan)



- The RFP "RFX" can run as a Ohmically heated tokamak
- The magnetic feedback system can stabilize the 2/1 mode and allow q(a) < 2 operation
- If the feedback system allows a 2/1 mode at low amplitude, sawtooth is suppressed
- Instead of sawtooth, obtain a stationary m=1 kink deformation of the core.
- Can we model this?

3D Physics: Plasma Response to Resonant Magnetic Perturbations—Waelbroeck, et al.

- Misc. topics on RMPs involving 11 authors
- Theory says there should be no error-field threshold if the electron rotation frequency is zero. Experimentally, there is a non-zero error-field threshold. Koslowski NF **46** (2006), DeBock NF 48 (2008)
- Can we resolve this by modeling?



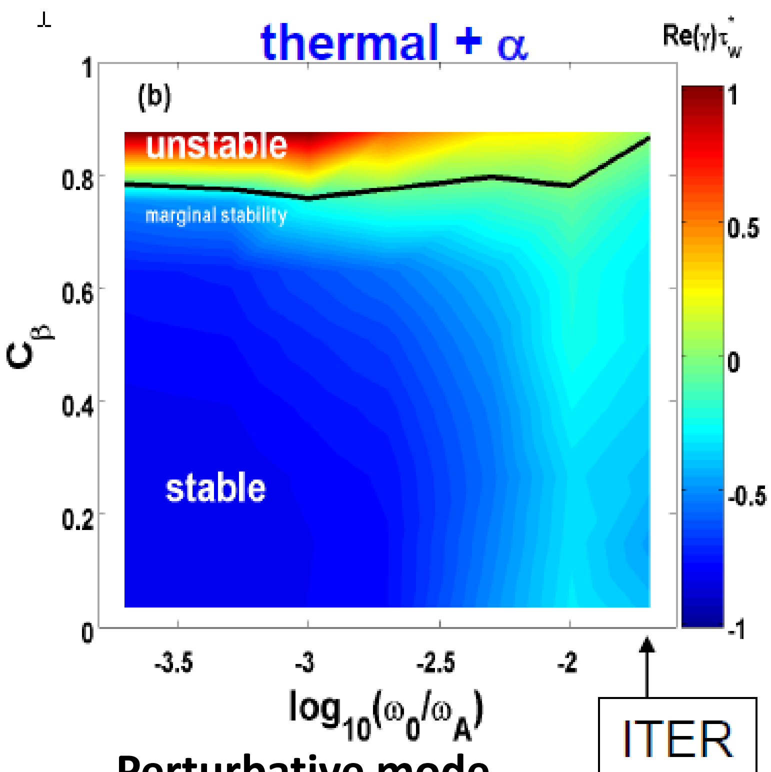
- Suppressed RMPs give rise to particle transport: The same currents that produce the breaking force also transport particles.

- Kinetic (gyro) electrostatic simulations show turbulent breaking from islands

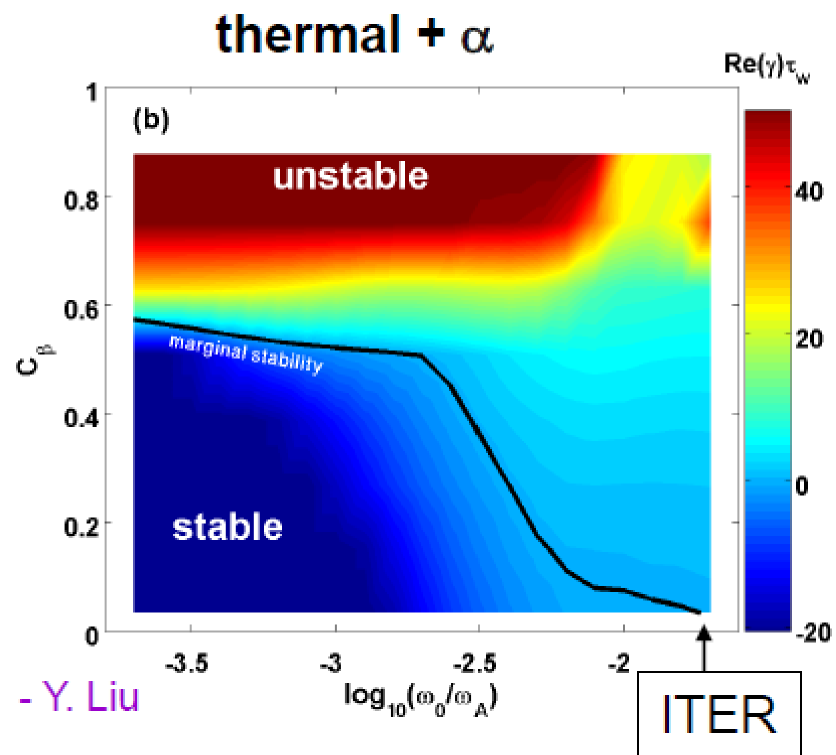
- Electromagnetic GYRO simulations show unlocking and screening of islands in broad agreement with fluid predictions except for the turbulent breaking

Error Fields and RWM Control: Benchmarking RWM stability physics between codes and experiments….S. Sabbagh

- Benchmark kinetic codes: HAGIS, MARS-K, MISK in non-perturbative mode
- Predictions for ITER from MARS-K: Perturbative and non-perturbative predictions very different for low rotation. When run in self-consistent approach, shows RWM stability only at the no-wall beta limit (C_β = 0) without active feedback.
- ➔ non-perturbative modeling seems to be only relevant approach!



Perturbative mode



Non-Perturbative mode

Error Fields and RWM Control: Error field threshold study in NSTX high-β plasmas – J.K. Park

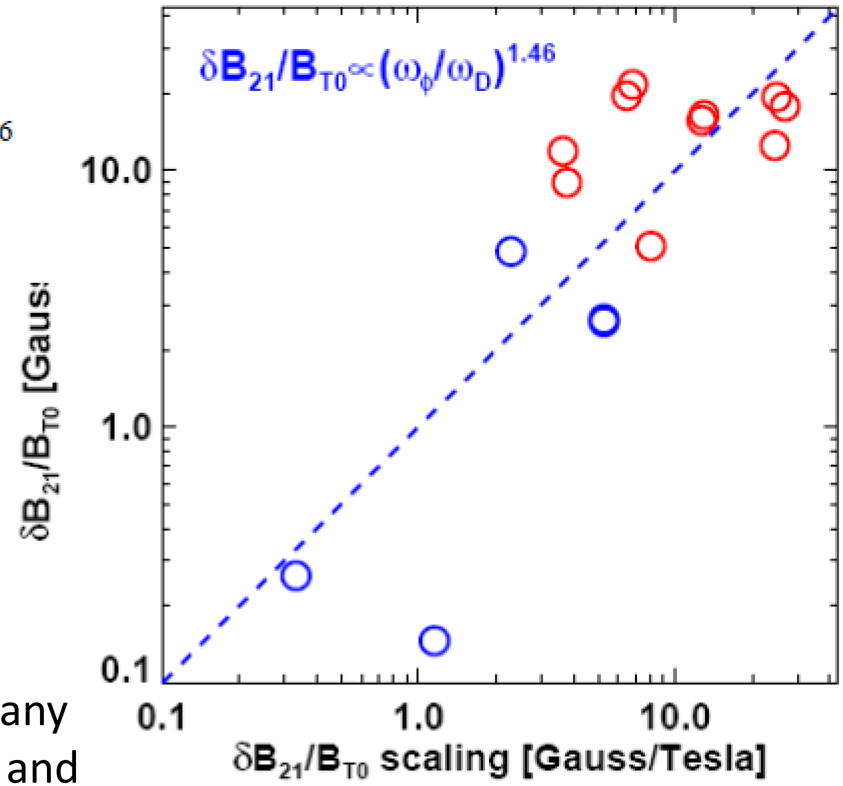
A (2,1) locked mode will appear when:

$$\frac{\delta B_{21}}{B_{T0}} \cong 2.2\times10^{-4}\, n_e^{0.60} B_{T0}^{0.45} s^{0.76} R_0^{1.74} \left(0.22\frac{\omega}{\omega_D}\right)^{1.46}$$

Total (2,1) field (including 3D perturbed currents in plasma)

Experimentally inferred from many NSTX experiments, both Ohmic and NB heated, some with n=3 breaking to reduce rotation.

Threshold scaling with rotation



Modeling ?

WG-9: Criteria for Error Field Correction for ITER— R.J. Buttery, et al

- Present strategy for canceling error field in ITER is to assume dominant coupling is through least stable ideal mode … using ideal MHD code IPEC
- But, IPEC over predicts benefit of reducing q=2 resonant error field in DIII
- Need to look at origins of residual corrected error field results.
  - – Error fields brake rotation to trigger tearing

- – Total possible error: **$\delta B/B \sim 2.8 \times 10^{-4}$**
- – Cf predicted threshold **$\delta B/B \sim 1.3 \times 10^{-4}$**

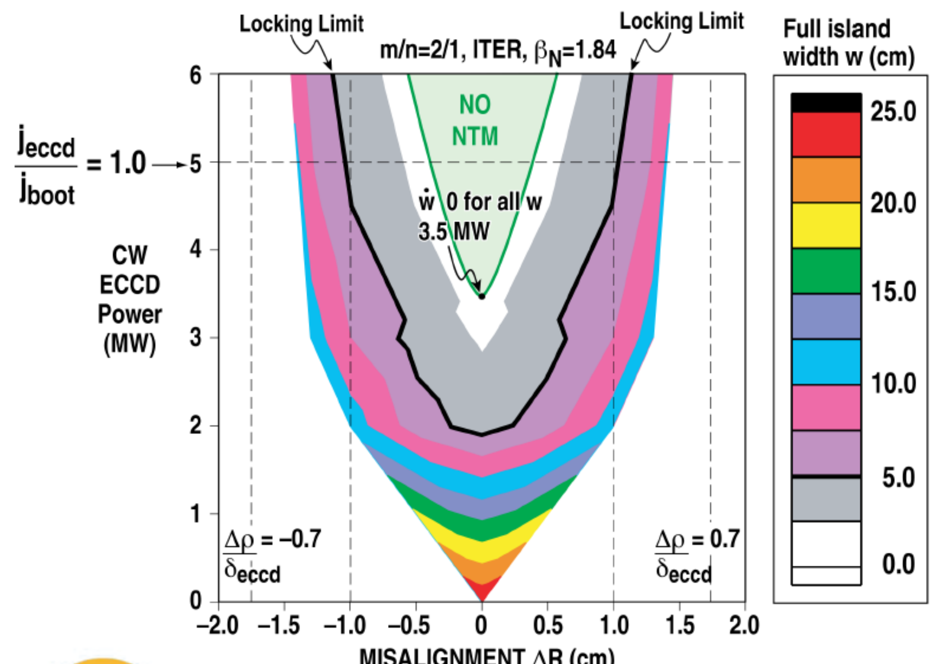
Need EF correction. However, correction benefit depends on shape of EF and coils.

- Need for further modeling interpretation to scale error field correction to ITER
  - Experiments have quantified scale of effects
  - But not which precise braking mechanisms are going on
  - Consider resistive response ? M3D-C^1 / MARS

Progress on ITER NTM Control Assessment -- R. LaHaye

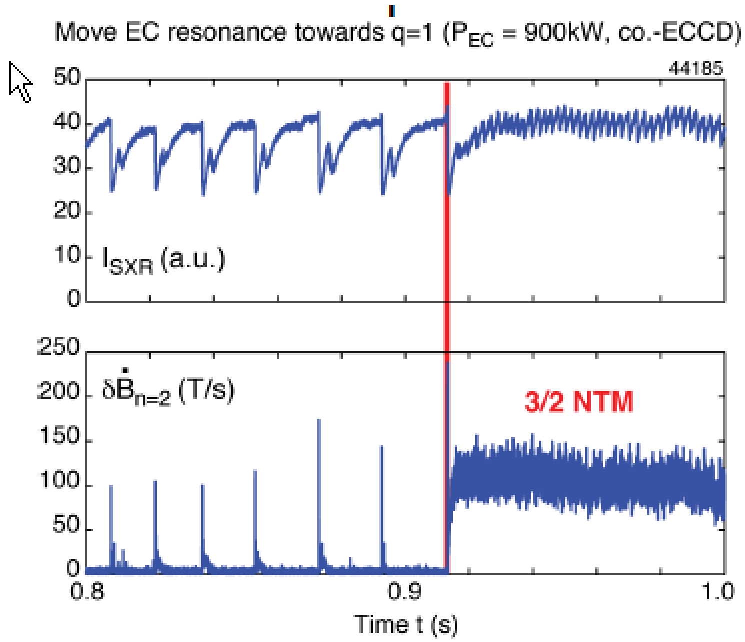
- NTMs are the principal MHD stability problem for ITER
- Uncontrolled growth is predicted to lead to confinement deterioration and possibly disruption
- Rotating island induces “eddy” currents in vacuum vessel wall
  - Exerts drag at island surface
  - Can stop plasma rotation…locks, lose H-mode, disruption
- ITER relies on successful ECCD stabilization of NTMs

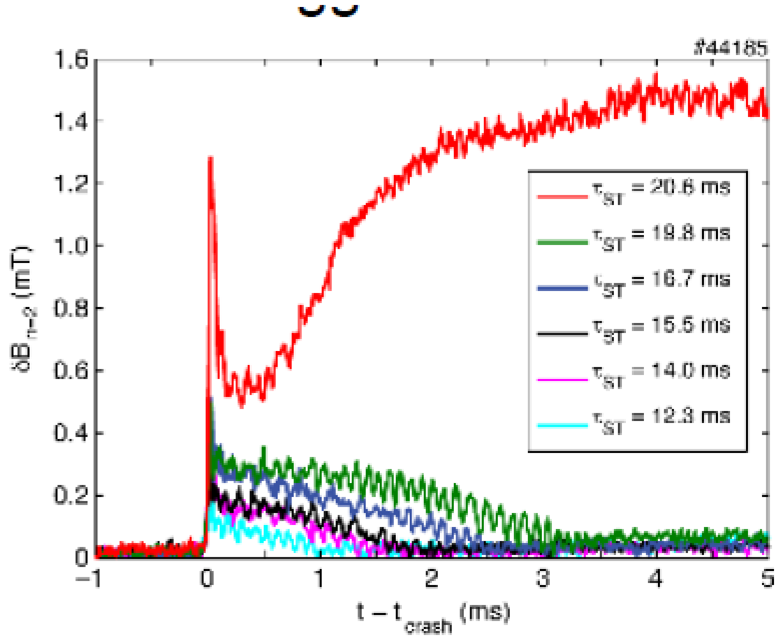
  - This graph is for un-modulated ECCD
  - Slightly less ECCD power is required for modulated power
  - To what extent can NIMROD reproduce this?



R.J. La Haye, et al., Nuclear Fusion 2008

MDC-5: Sawtooth control methods for NTM suppression-- Chapman

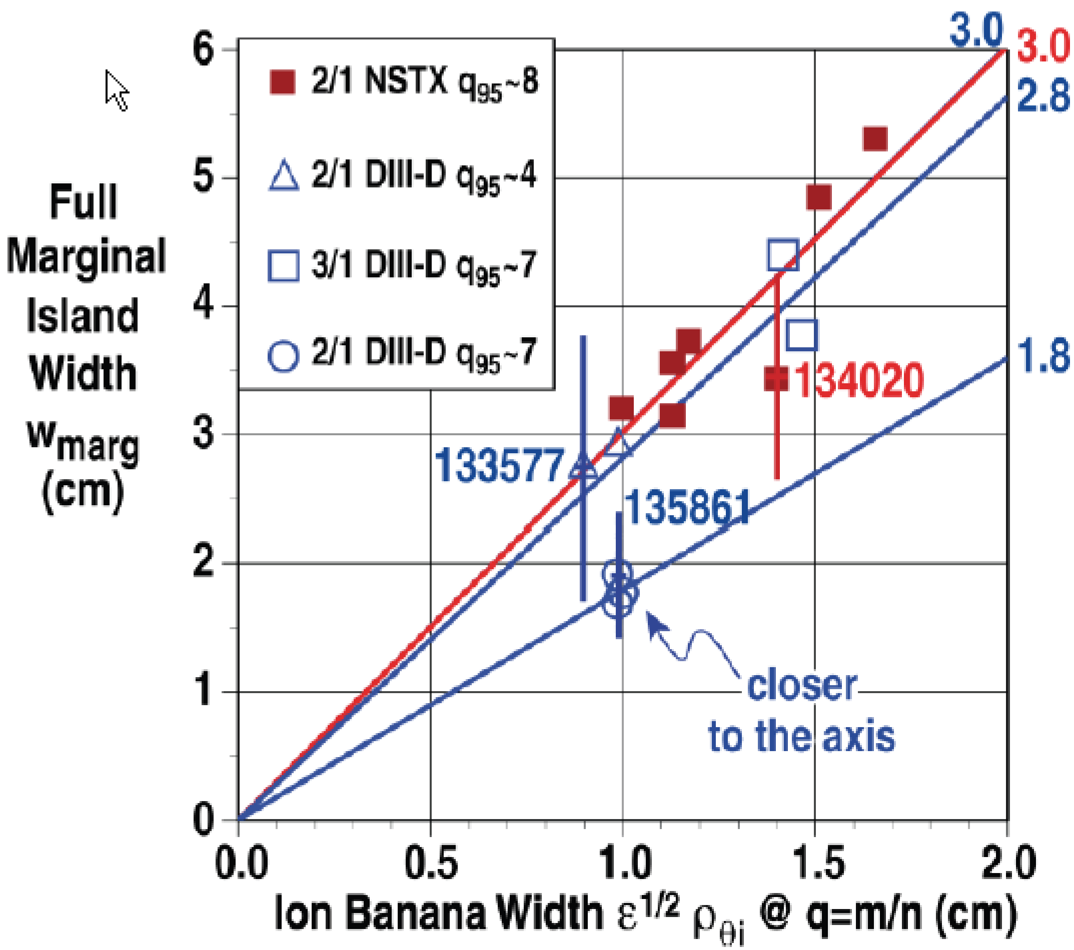




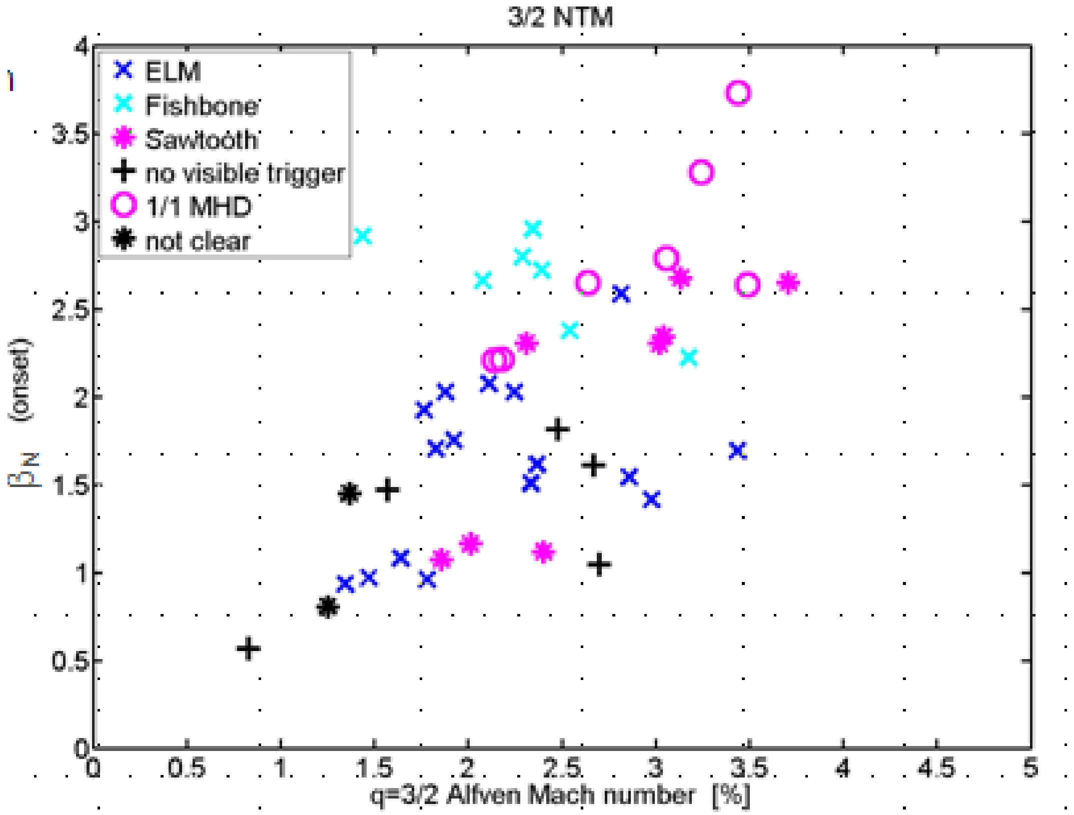
- Increase ST period by moving co-ECCD from axis towards the q=1 surface
- ST with period over 20ms generates a 3/2 NTM within 1 ms
- plasmas with larger safety factor tolerate longer sawteeth
- Experiments on TCV, DIII-D, ASDEX, JET (ICRH), FTU, Tore Supra
- This is an ideal modeling opportunity!

MDC-4: NTM aspect ratio comparison -- Maraschek

- Comparisons with MAST, AUG, DIII-D, NSTX
- Empirically, marginal island width for NTM onset (required seed island size) is 2~3 time ion banana width
- Can we reproduce this by adding neoclassical effects to NIMROD/M3D-*C*[1]?



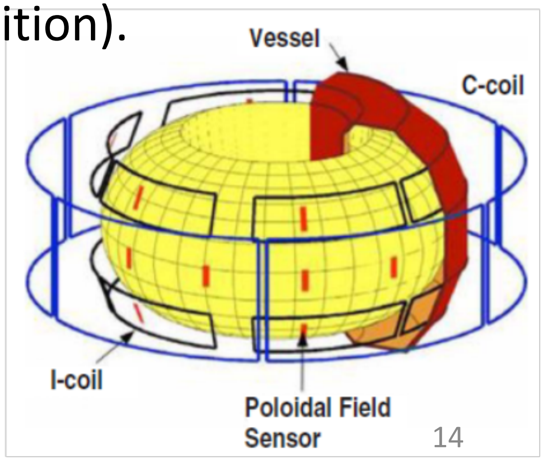
MDC-14: Rotation effects on NTMs -- Buttery



- Higher rotation velocities allow higher βN before NTM sets in.
- This data is from AUG.
- No good theory to explain β_N dependence of onset of NTM on rotation:
- seeding or underlying tearing stability?

Stabilization of disruptive locked modes by ECCD and Magnetic Perturbations -- Volpe

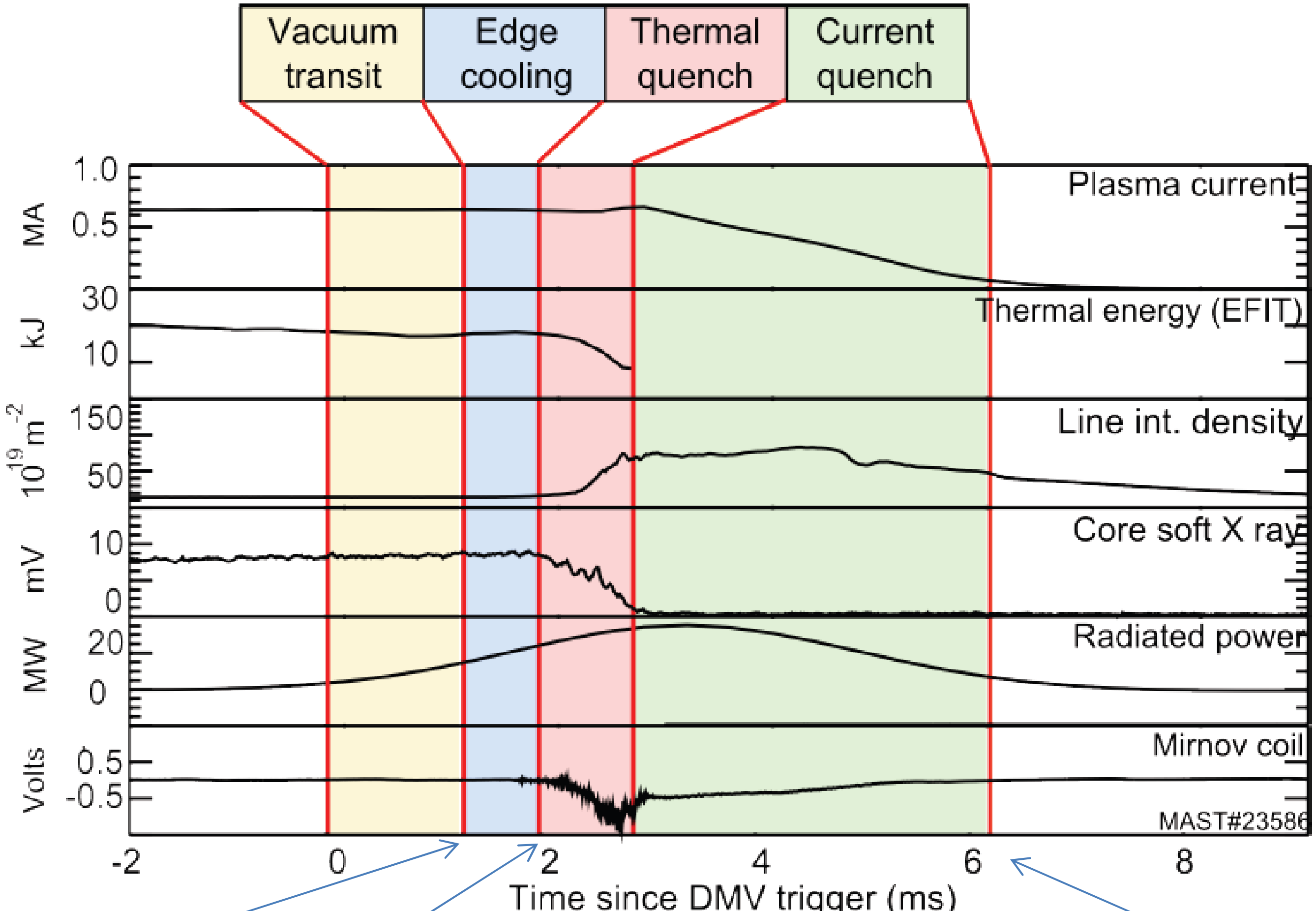
- Toroidal phase of locking was controlled by magnetic perturbations. Locked mode was rotated by RMP to a position where it could be stabilized by ECCD
- Locked Modes were completely stabilized by ECCD
- Unlocking by NBI torque was facilitated by ECCD mitigation
- Mode rotation was sustained by RMPs rotating at 20Hz, and mode stabilized by ECCD modulated at 20Hz (O-point deposition).
- Modeling?



Disruption Mitigation and RE Generation (13 talks)

- All describing experimental results except V. Izzo
- Unified picture: (Pautasso)
  - gas ionizes at plasma edge
  - only (small) fraction of impinging neutrals remains confined in plasma
  - fast diffusion along magnetic field lines slowed down by low temp.
  - slower perp. diffusion and penetration of gas from edge to q=2
  - development of large-scale MHD modes, dominated by m=2/n=1
  - magnetic field stochastization allows for fast diffusion of particles and energy respectively into and out of plasma core … thermal quench
  - subsequent current quench causes vessel forces and RE generation
- A code which models all aspects of MGI experiments and can extrapolate them to ITER does not exist
  - NIMROD (and M3D?) should be developed further for this purpose

Disruption Mitigation on MAST-Thornton, et al.



Free expansion in vacuum

Thermal quench occurs when q=2 surface is cooled

Mitigation reduces divertor energy loading to about 40% of W_{tot}

Current quench time does not change much due to MGI

MDC-17: Active Disruption Avoidance -- Maraschek

- Magnetic control of toroidal position of locked mode + ECCD in DIII-D
- Application of NBI to unlock mode by imparting torque to plasma
- Disruption avoidance (or delay) with ECRH at q=2 surface in AUG
- Avoidance of DL disruption by monitoring D_{α} in/out ratios, removal of gas puff, and adding NBI
- Modeling?

Meeting summaries are at:

https://portal.iter.org/departments/POP/ITPA/MHD

(or, contact jardin@pppl.gov …. I can send you a copy of the agenda, and I have copies of all viewgraphs)

Next meetings:

March 5-9, 2012 in Toki, Japan (in conjunction with 16th US-Japan Workshop on active MHD control.)

THEME: Effect of 3D Magnetic Fields on MHD Equilibrium and Stability: toward optimum control of toroidal plasmas. See: http://dg1.nifs.ac.jp/itpa2012

Oct 15-17, 2012 in San Diego (tentative)