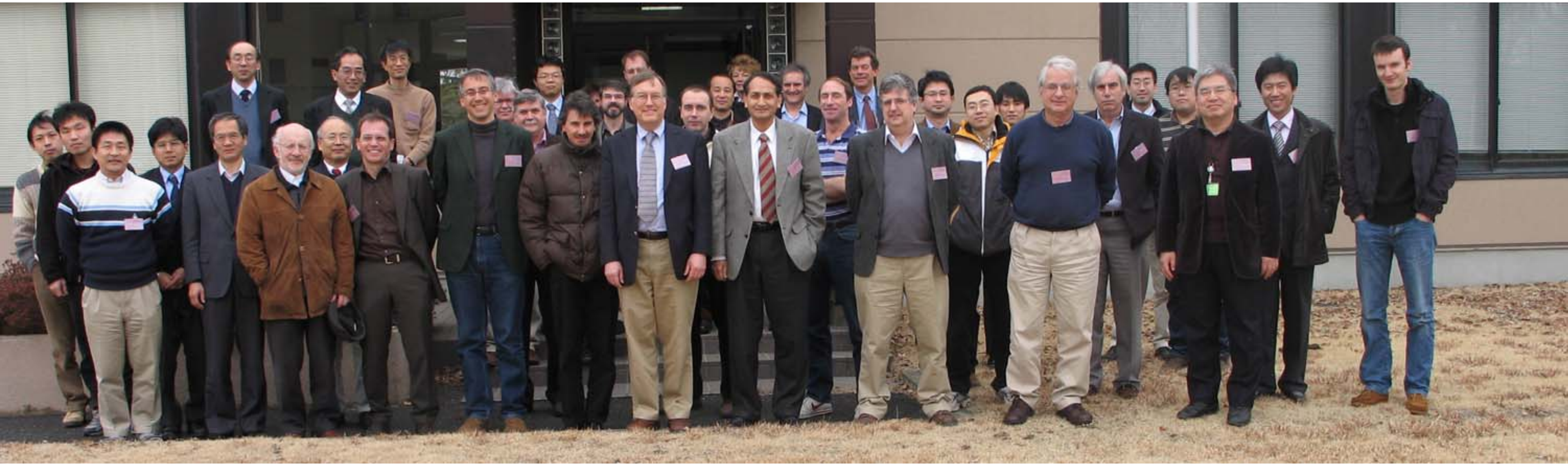
Summary of Joint Meetings of IEA Large Tokamak Workshop, US-Japan MHD Workshop and ITPA MHD Topical Group Meeting

JAERI Naka site

February 25-29, 2008



Theory and Computation Highlights

For CEMM Meeting 3/30/2008

S.C. Jardin (PPPL)

Topics

You can find all the presentations at
http://www-jt60.naka.jaea.go.jp/itpa-08-naka

- Downloads are password protected. Send me an email if you want a copy of a particular presentation.

Topics: RWM
- Gunter – 3D effects
- Liu – 3D and Kinetic effects in RWM
- Tokuda – Extension of Marg2D to RWM

ELM
- Nardon – Magnetic modeling of ELM mitigation
- Menard -- RMP effects for ITER
- Becoulet – Plasma Response on RMPs

High Energy Particles

Sawtooth
- Jardin – proposed benchmark

Disruption and Vertical Stability
- Sugihara – ITER disruption studies

NTM
- Konovalov – latest developments in NTM theory

RWM

3D effects on Resistive Wall Modes for ITER and ASDEX Upgrade **S. Günter et al**

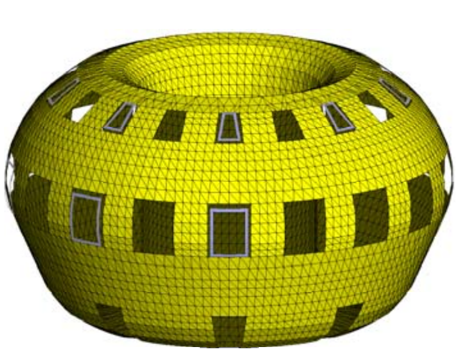
Coupled 3D (MHD) codes:

VMEC - equilibrium code

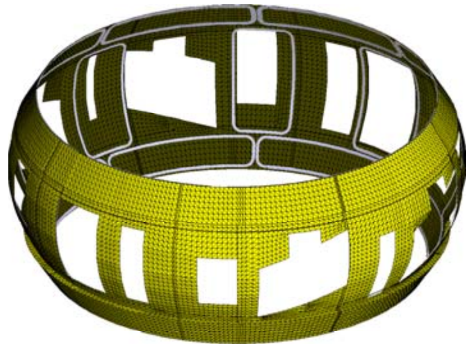
CAS3D - 3d ideal stability

STARWALL -3d, res. wall

OPTIM- feedback

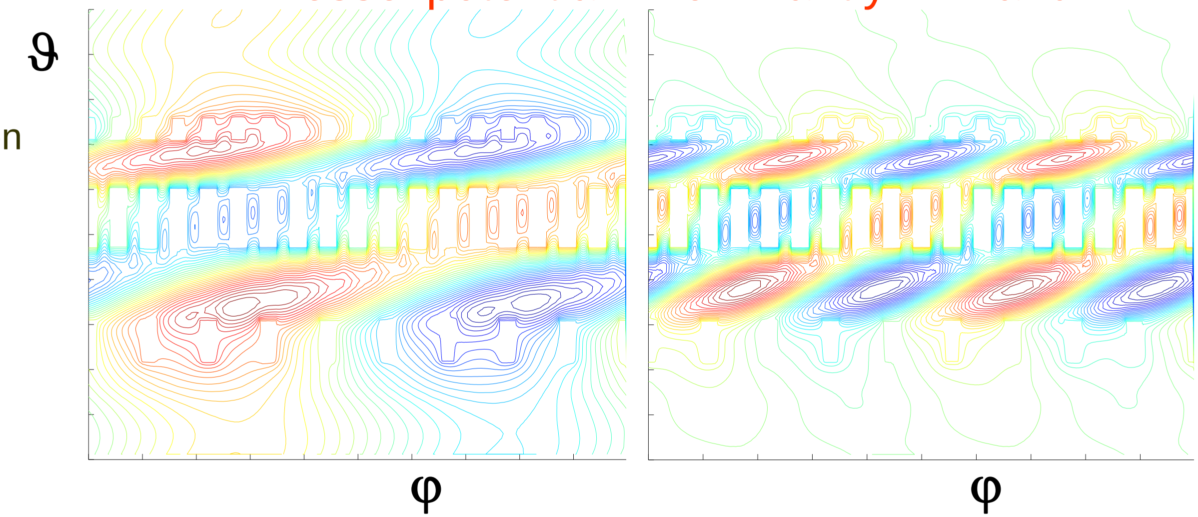


ITER

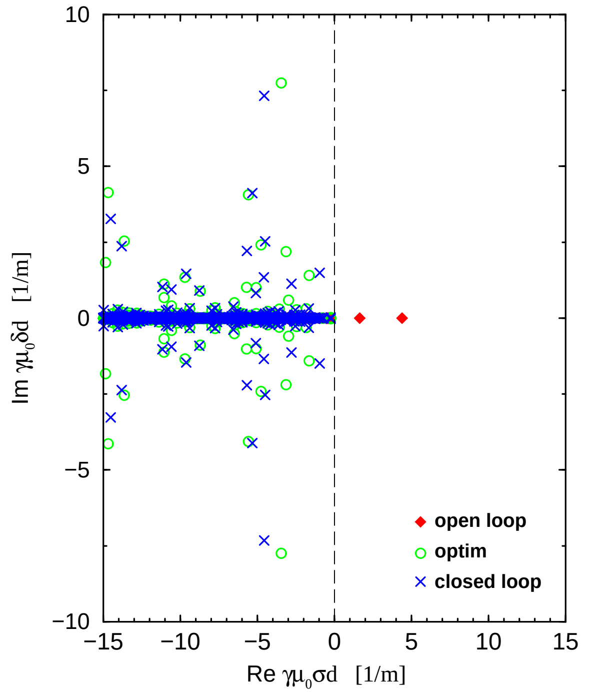


ASDEX Upgrade

ITER vessel potential : Dominantly n=1 and n=2



Fully self-consistent linear eigenfunction



- ITER 3D wall causes different n modes to couple
- simultaneous feedback stabilization of n=1 and n=2
- Much higher β values could be achieved for broader pressure profiles (lower l_i)

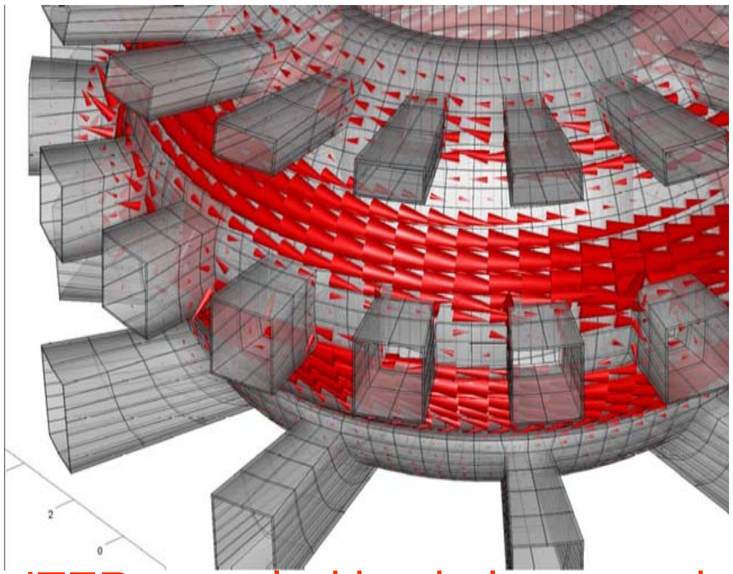
RWM

CarMa RWM Control Calculations: Y Liu

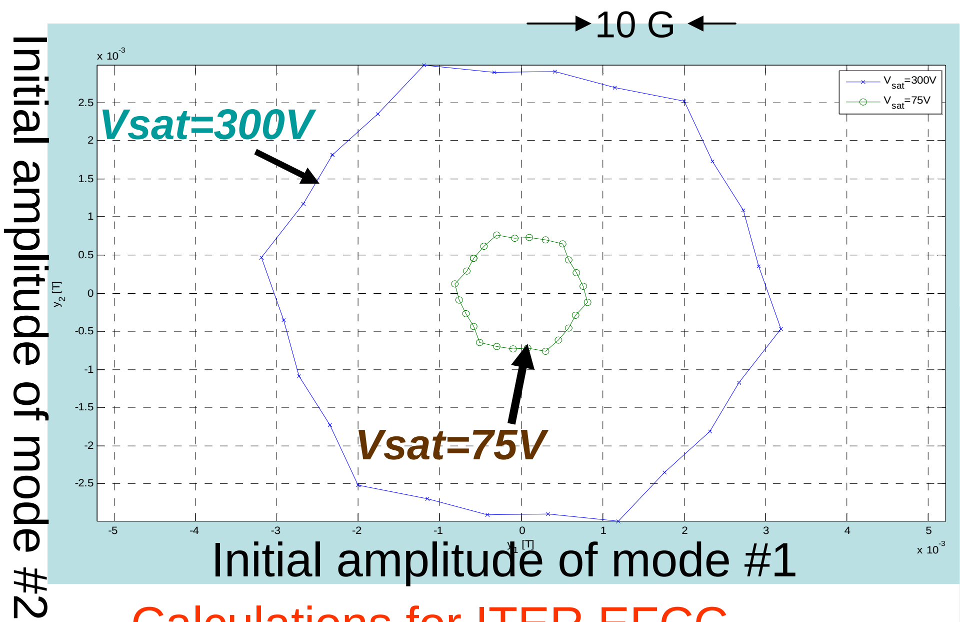
Codes are coupled (poloidal & toroidal) using equivalent surface current response:

MARS-F: stability code

CARIDDI - 3d restive wall code



- **3D holes roughly double growth rates**
- **Tubular extensions reduce growth rates to a level similar to 2D complete walls**



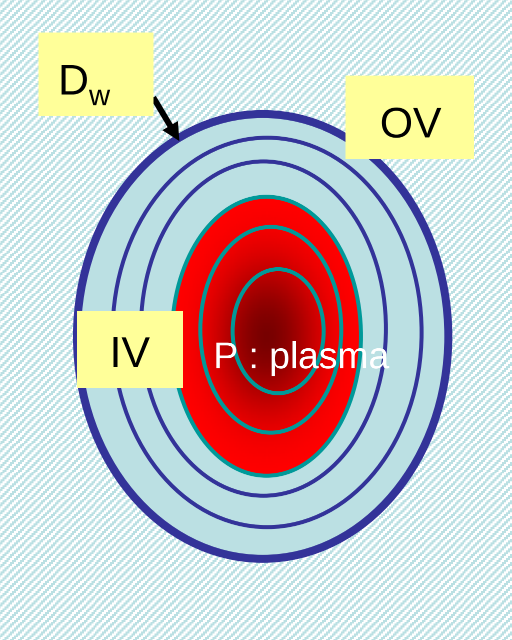
Calculations for ITER EFCC

RWM Modelling with the Inclusion of Self Consistent Kinetic Terms:

- Self Consistent eigenfunc. (non perturbative)
- Kinetic effects due to
  - bounce resonance
  - precession drift resonance
  - transit and trapped
  - bulk electrons and ions
- Results:
  - Eigenfunction structure modified by RW and further by drift kinetic resonances
  - while perturbative approach does predict full stabilization of RWM in ITER and D-III, non-perturbative approach finds much less stabilization

RWM

Extension of MARG to RWM: S. Tokuda



Extension of the Ideal MHD Variational Principle

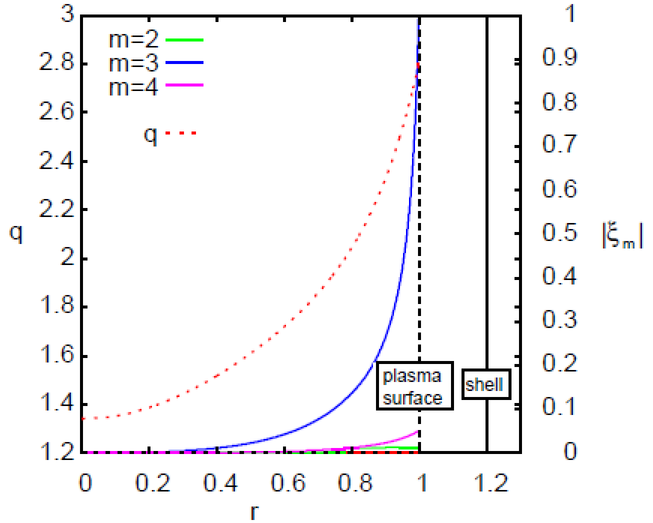
Key Assumption : Plasma inertia is neglected

$$\delta W = \delta W_P + \delta W_{IV} + \delta W_{OV} + D_W$$

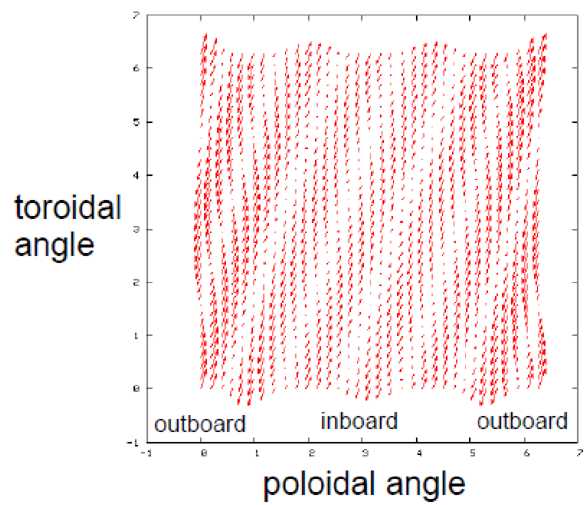
Eigenvalue Problem for RWMs

$$\begin{pmatrix} A & T^{pw} \\ T^{wp} & C \end{pmatrix} \begin{pmatrix} \mathbf{x} \\ \mathbf{a} \end{pmatrix} = \gamma \begin{pmatrix} 0 & 0 \\ 0 & D_W \end{pmatrix} \begin{pmatrix} \mathbf{x} \\ \mathbf{a} \end{pmatrix}$$

x : radial displacement on the plasma surface
a: normal component of the magnetic filed on the shell



Eigenfunction in plasma region

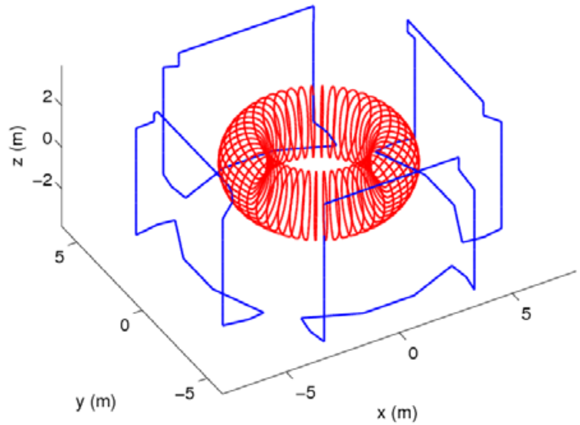


Eddy current pattern in shell

New Extensions underway

- adding inertia as matching conditions at rational surfaces
- next goal is to include rotation by Frieman-Rotenberg equation around rational surfaces.

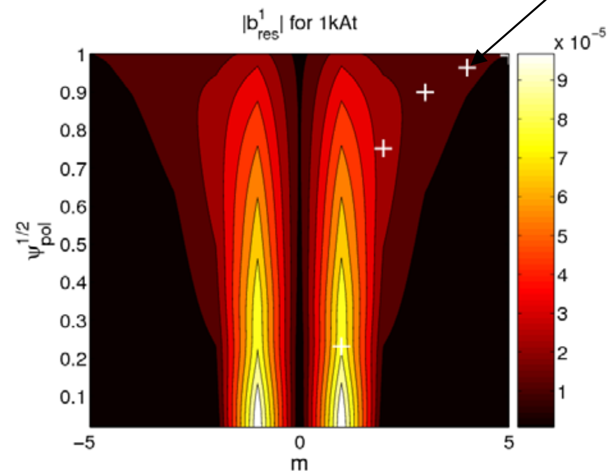
Magnetic Modeling of ELM Mitigation: Nardon



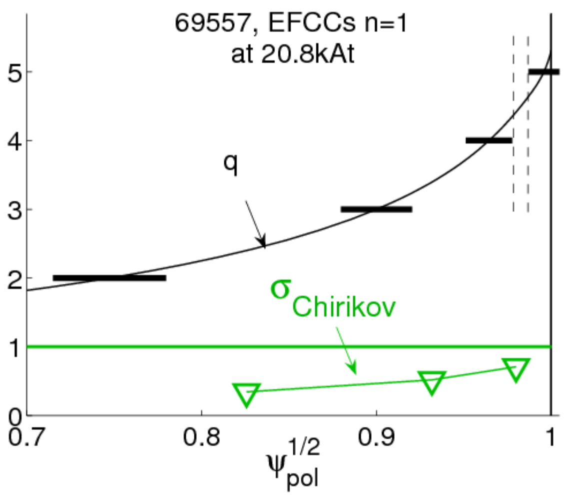
Vacuum Modeling

Fourier spectrum

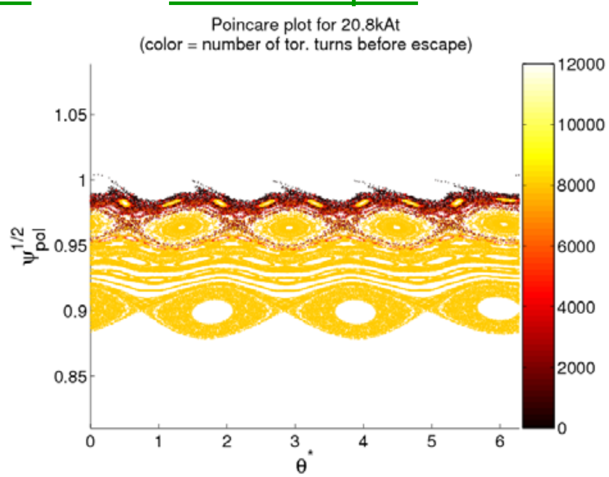
Resonant surfaces (q = m/1)



Analytical estimation of islands width



Poincare plot



$$\sigma_{Chirikov} \propto \left[B^{r}_{res} q q' \right]^{1/2} \geq \frac{2}{3}$$

Good rule for ergodization and ELM mitigation

Good Agreement between Chirikov Criteria and Poincare plot

ELM

RMP effects for ITER: J. Menard

IPEC uses Ideal MHD code to calculate singular currents at rational surfaces using a singular perturbation theory

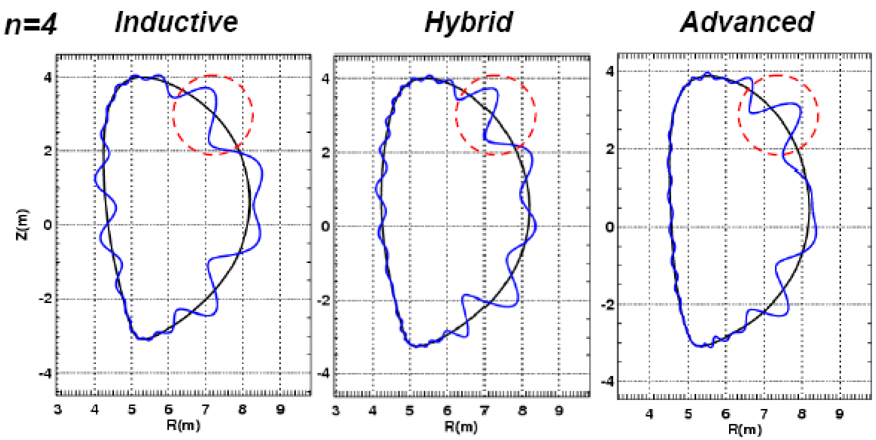
→ These currents then used to evaluate Chirikov parameter AND to evaluate K.C. Shaing's formula for Neoclassical Toroidal Viscosity

→ Optimization algorithm generates edge perturbation with $\sigma_{Chirikov}$ sufficient for island overlap, and to minimize NTV torque

→ Result of optimization is desired external vacuum field pattern

Plotted is poloidal distribution of $\delta \mathbf{B}_{ext} \bullet \hat{n}$ →

Optimal RMP external field for ITER



ELM

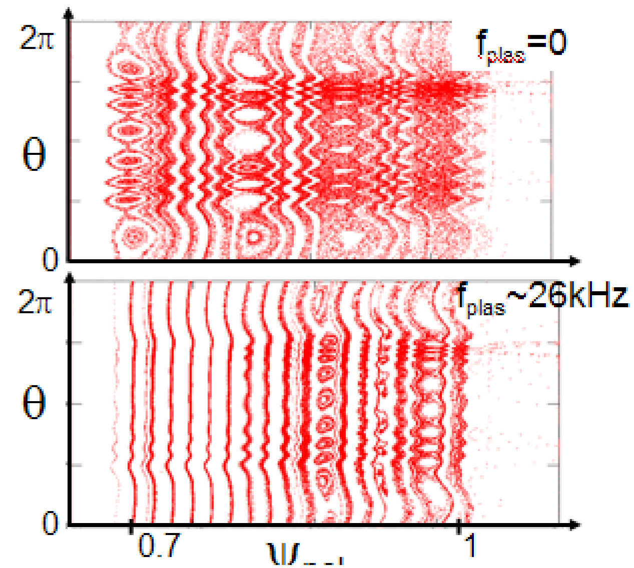
Plasma Response to RMPs: **Becoulet**

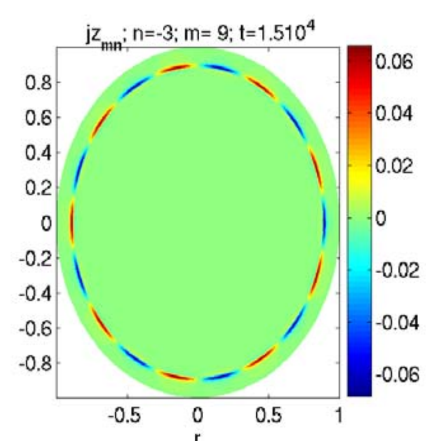
Cylindrical non-linear reduced MHD code (RMHD) with toroidal rotation and braking due to RMPs.

- All ITER coil designs investigated produce “DIII-D like” edge ergodization
  - $\sigma_{Chirikov} > 1$ for $\psi^{1/2} > 0.9$
- RMP penetration time ~ $1/\eta$
  - DIII-D: 0.15s (top of pedestal)
  - ITER 1.5s
- Edge islands are less screened by rotation. Central islands are more screened
- Non-resonant harmonics are not screened by rotation, and contribute to NTV

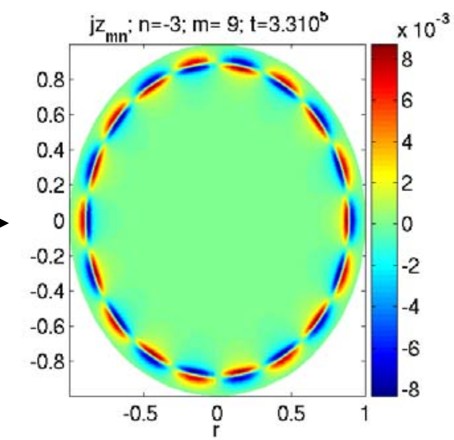
“Screening” of RMPs by plasma rotation
(was modelled by rotating boundary)

$$\delta\psi = \psi_{n=3}\sin(n(\varphi + 2\pi f_{plas}\cdot t))$$





Without rotation, sheet currents develop at rational surfaces



These currents dissipate after resistive time.

SAWTOOTH

Proposed Intl. Benchmark
S. Jardin

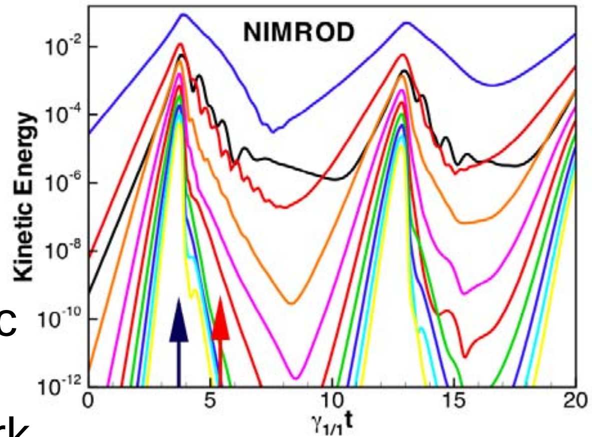
- Breslau (M3D) and Sovinec (NIMROD) have performed detailed nonlinear benchmark using full 3D MHD equations
- Initial equilibrium specified analytically
- Invite international partners to participate in benchmark

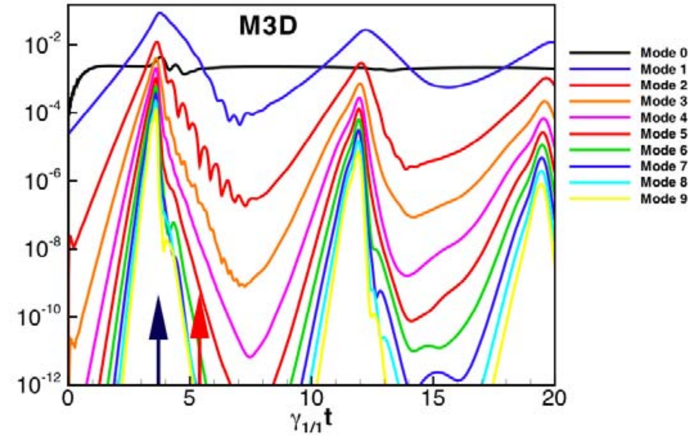
$$p(\psi) = p_0\left[\alpha\tilde{\psi} + (1-\alpha)\tilde{\psi}^2\right], \quad T(\psi) = T_0\tilde{\psi}$$

$$\frac{V_L}{2\pi\eta(T)} = \frac{\langle \mathbf{J}\bullet\mathbf{B}\rangle}{\langle \mathbf{B}\bullet\nabla\varphi\rangle}$$

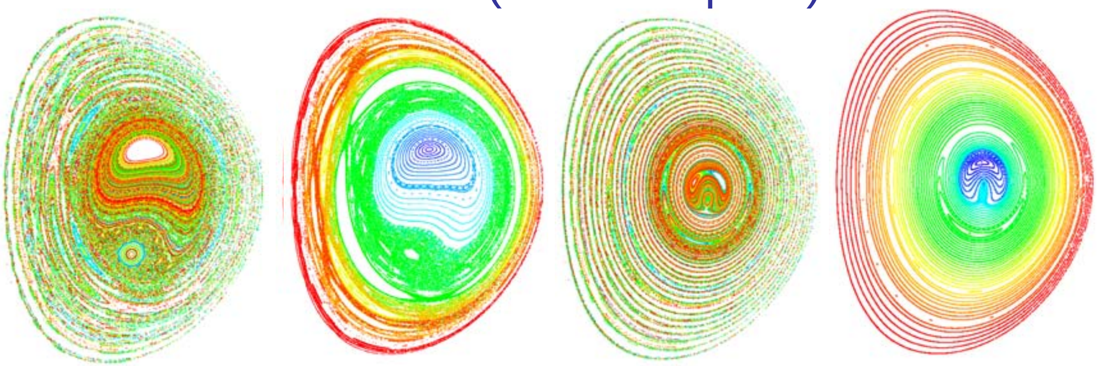
$$\kappa_\perp = \frac{1}{T'\left\langle|\nabla\psi|^2\right\rangle}\left[\frac{V_{loop}}{2\pi\mu_0}\left\langle\frac{|\nabla\psi|^2}{R^2}\right\rangle\right]$$

$$R(\theta) = R_0 + a\cos\left[\theta + \delta\sin(\theta)\right]; \quad z(\theta) = a\kappa\sin(\theta)$$



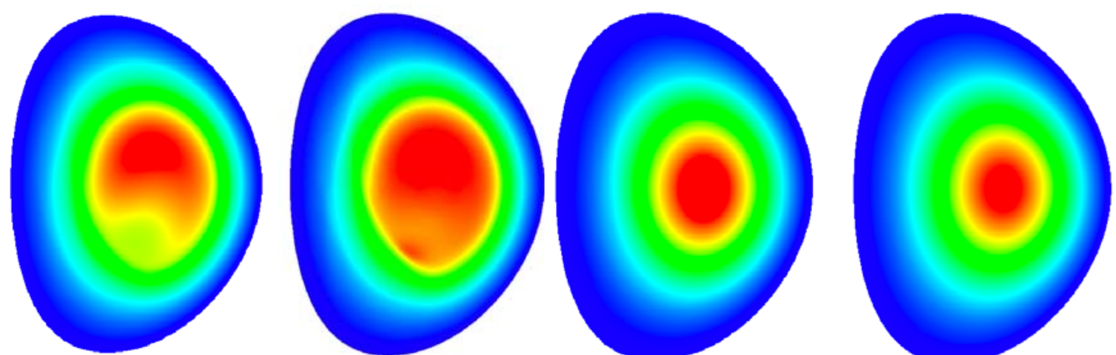


Flux surfaces (Poincaré plots)



$t=t_1$ (M3D) $t=t_1$ (NIMROD) $t=t_2$ (M3D) $t=t_2$ (NIMROD)

Temperature contours



$t=t_1$ (M3D) $t=t_1$ (NIMROD) $t=t_2$ (M3D) $t=t_2$ (NIMROD)

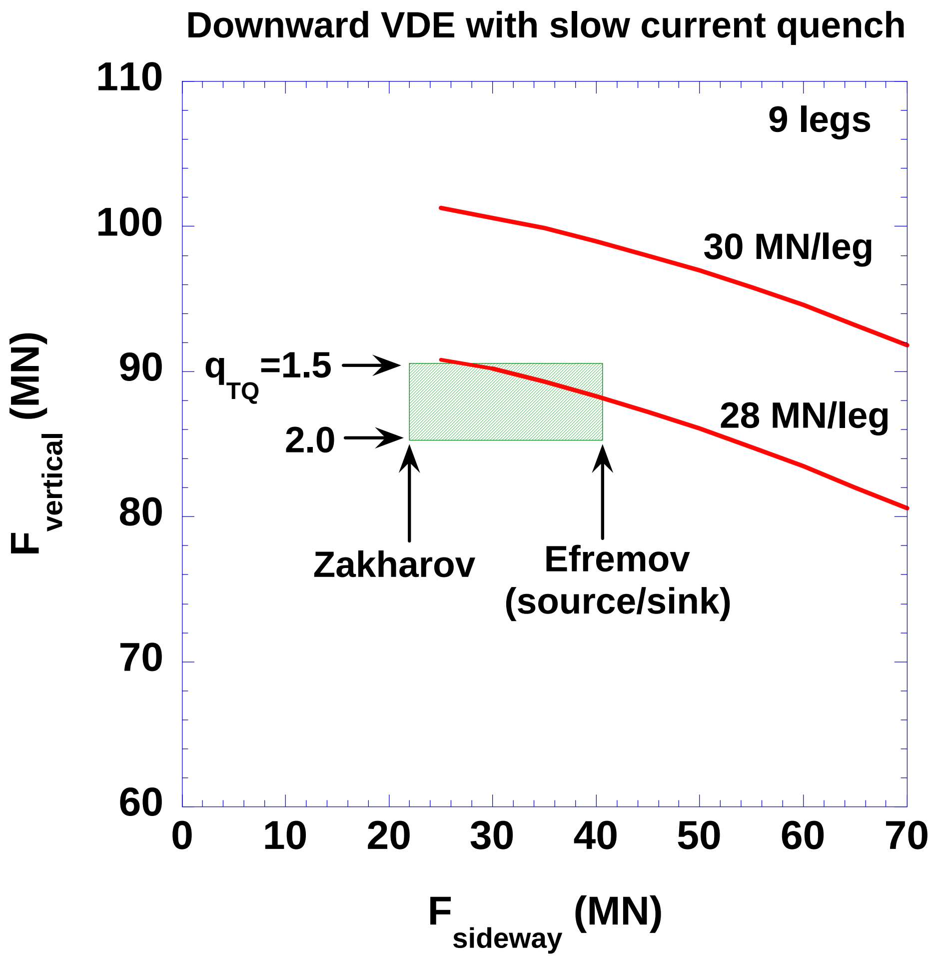
ITER Disruption Studies: Sugihara

- New JET observations of large toroidal asymmetry and large sideways force during slow current decay after upward VDE

- Depending on how this is extrapolated to ITER, could exceed present specification

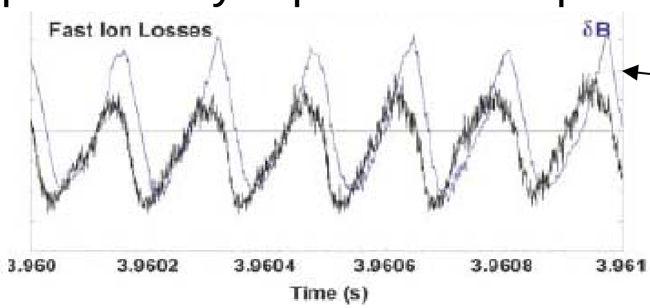
- Three models:
  - Source/Sink model (Efremov)
  - Wetted kink mode model (Zakharov)
  - Asymmetry of vertical halo current due to radial shift

- Strongly encourages 3D modeling by parties



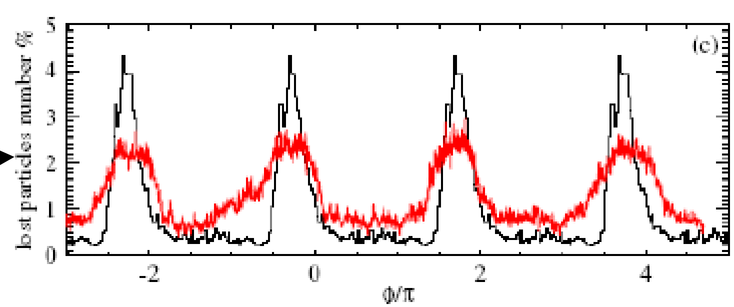
Latest Developments in NTM Theory: **Konovalov**

- New contributions to the island evolution equation were identified
  - Island Induced Bootstrap Current (K. C. Schaing 2006, 2007)
  - Geodesic Plasma Compressibility effect (Smolyakov 2007)
  - Neoclassical contributions due to variation of perturbed pressure along the island magnetic surface (Smolyakov, 2004)
  - Correction to diffusive heat transport across magnetic islands (Holzl and Gunter 2007)
- ORBIT simulations of NBI ion losses correlated with (2,1) NTM in ASDEX-U qualitatively reproduced experimental data



Exp

Theory



- Extensive numerical simulations are necessary to clarify mechanisms determining island rotation, mode coupling, polarization drift

Summary

Opportunities for CEMM in resolving ITER MHD issues

RWM
- Nonlinear RWM simulation in presence of ELMs, tearing modes, etc
- Extend to 3D vacuum vessel with ports, etc.

ELM
- Simulation of full ELM cycle (CPES)
- Simulation and understanding of different ELM types
- Nonlinear simulation of ELM mitigation by RMPs and/or pellet pacing, including rotation

Sawtooth
- Extend CDX-U simulation to ITER parameters
- Include energetic particles in self-consistent sawtooth simulation
- Nonlinear model of Sawtooth de-stabilization using ICRF (SWIM)
- Quantitative modeling of NTM seeding from sawtooth

Disruption and Vertical Stability
- Linear and nonlinear model of Zakharov halo-kink mechanism
- Nonlinear modeling of ITER safe shutdown (pellets, MGI) including runaways

NTM
- Nonlinear model of NTMs with neoclassical extended MHD
- Modeling of RF stabilization of NTMs (SWIM)