Nonlinear Resistive Wall Simulations

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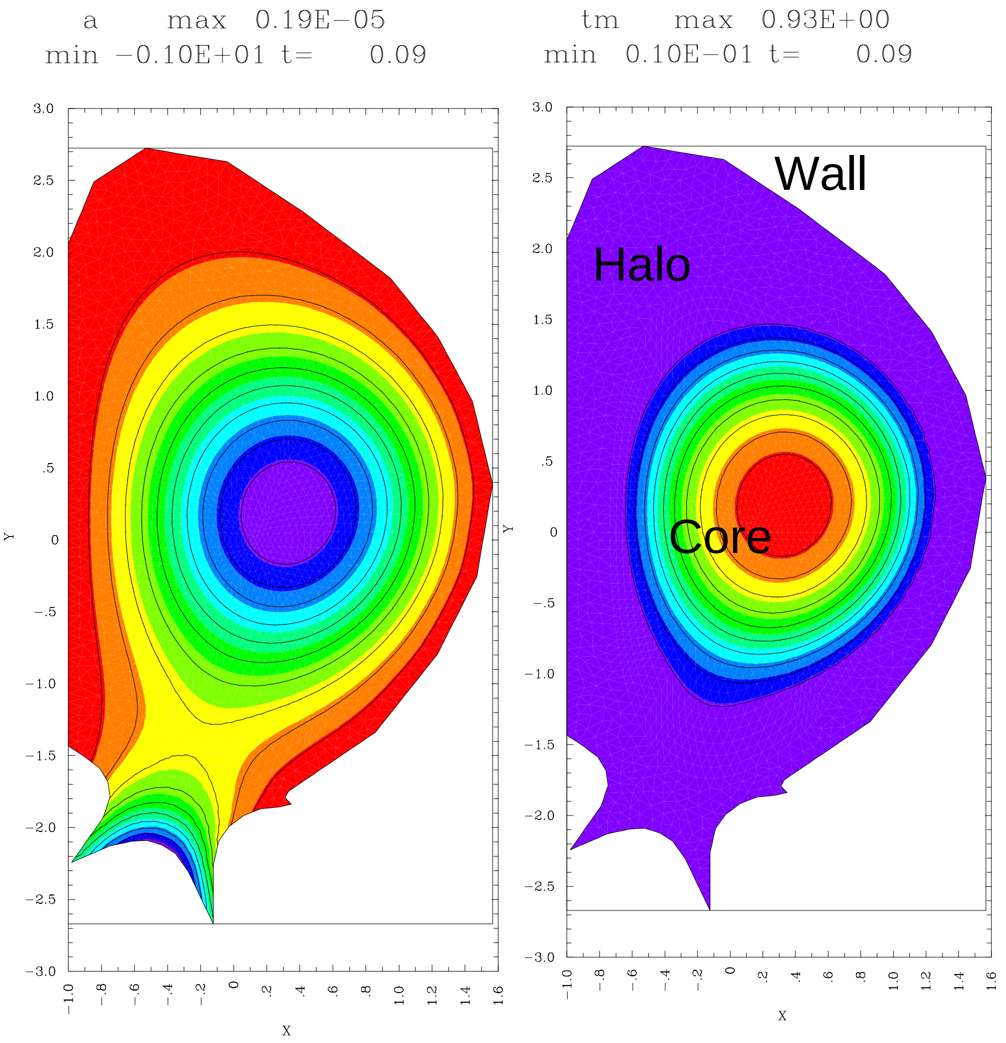
Resistive wall effects

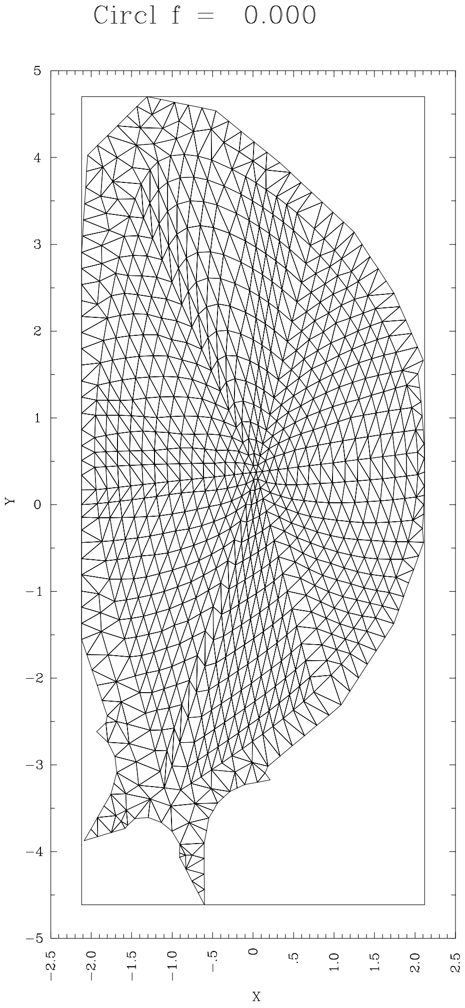
- **For several applications, plasma is modeled as core, halo, resistive wall**
- **Applications include**
  - **Vertical displacement events (VDE)**
  - **Halo currents in 3D disruptions**
    - **VDE is faster during disruption**
    - **Toroidally asymmetric stresses on wall**
  - **Resistive wall modes**
    - **Disruptions and halo current**
    - **NSTX comparison with MARS**
    - **Destabilization by magnetic error fields**

3 plasma regions

- Core – hot
- Halo – cold
- Wall – intermediate
  - Separatrix can isolate core from halo
  - Thermal conduction keeps halo at wall temperature



M3D Mesh Generation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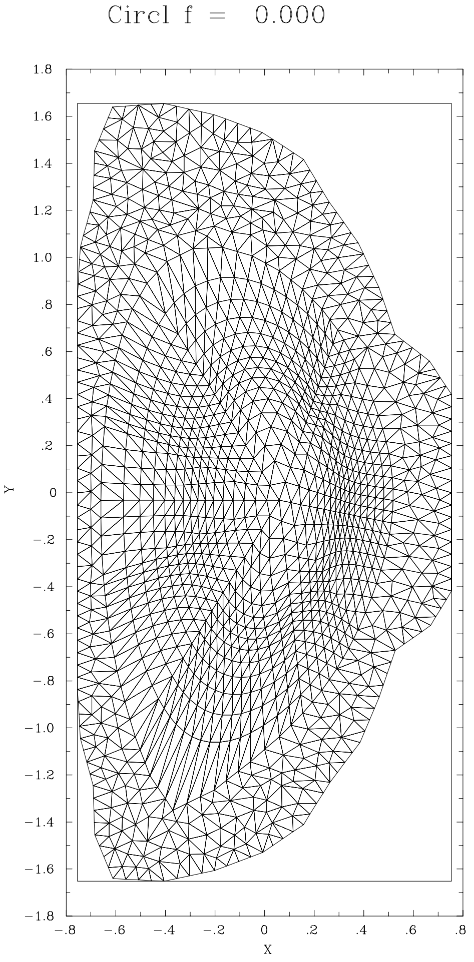
Mesh generated from EQDSK data (ITER and NSTX examples, low resolution)

Closed flux surfaces: flux aligned
M3d triangular mesh generator
Outside separatrix: Triangle code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Resistive wall: Vacuum field

Continuity condition from plasma to vacuum across thin resistive wall, where n is the normal to the wall

$$B^p \cdot n = B^v \cdot n$$

GRIN solves vacuum field with Green's functions, returns tangential vacuum field components. These are used to advance the magnetic field in the plasma.

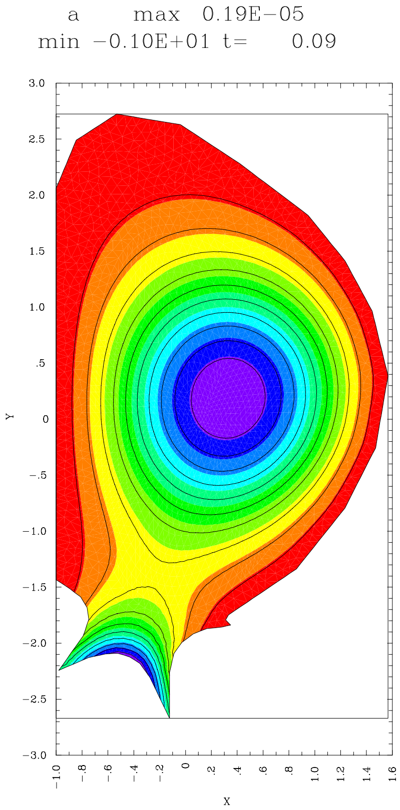
$$B = \nabla \times A$$

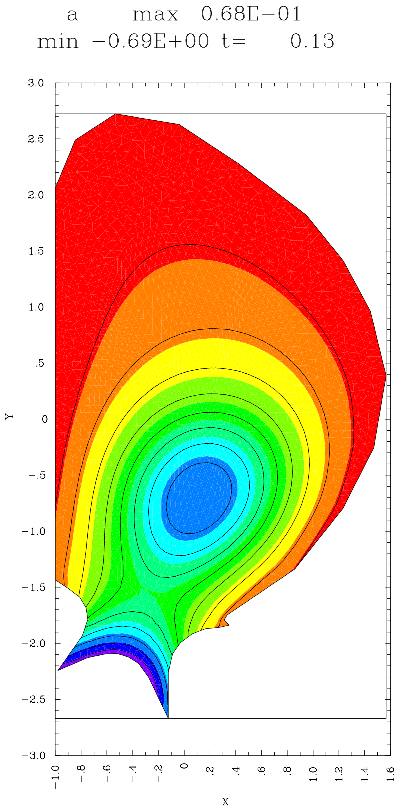
$$\frac{\partial A}{\partial t} = \frac{\eta_w}{\delta} n \times (B^v - B^p)$$

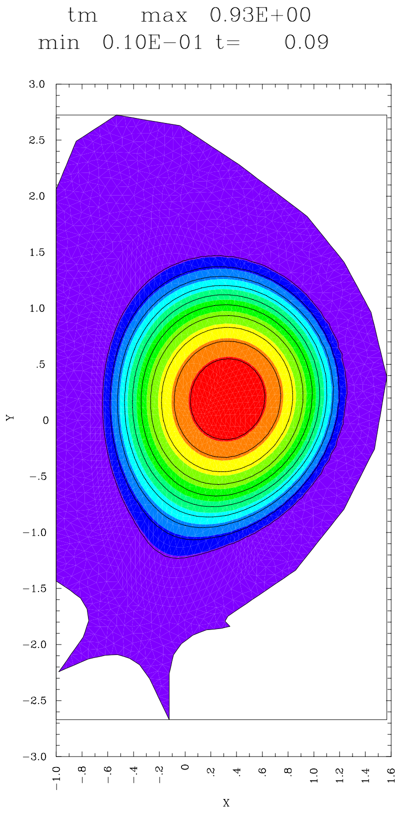
Where η_w, δ are the wall resistivity and thickness

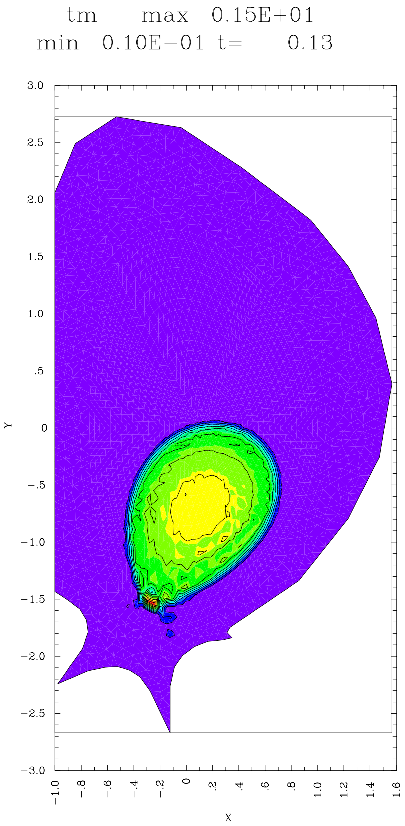
VDE Instability

- 2D, occurs in elongated configurations
- Plots of poloidal flux and temperature
- A 2D resistive wall mode







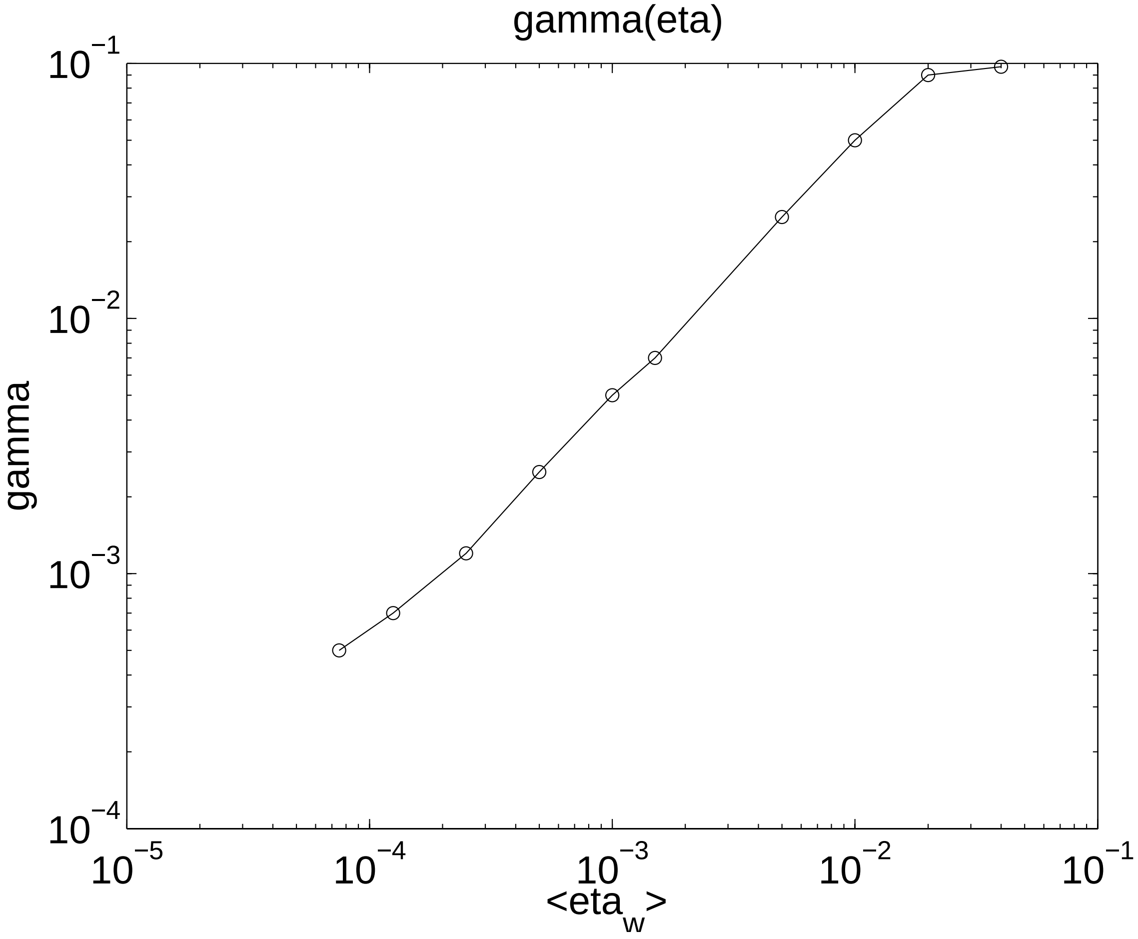


need resistivity contrast to get linear scaling of growth rate with wall resistivity

- halo resistivity
  has to be larger than wall resistivity, which must be larger than core
- limiting case: ideal core,
  vacuum halo

$$\gamma = 4\frac{\eta_w}{\delta a}$$

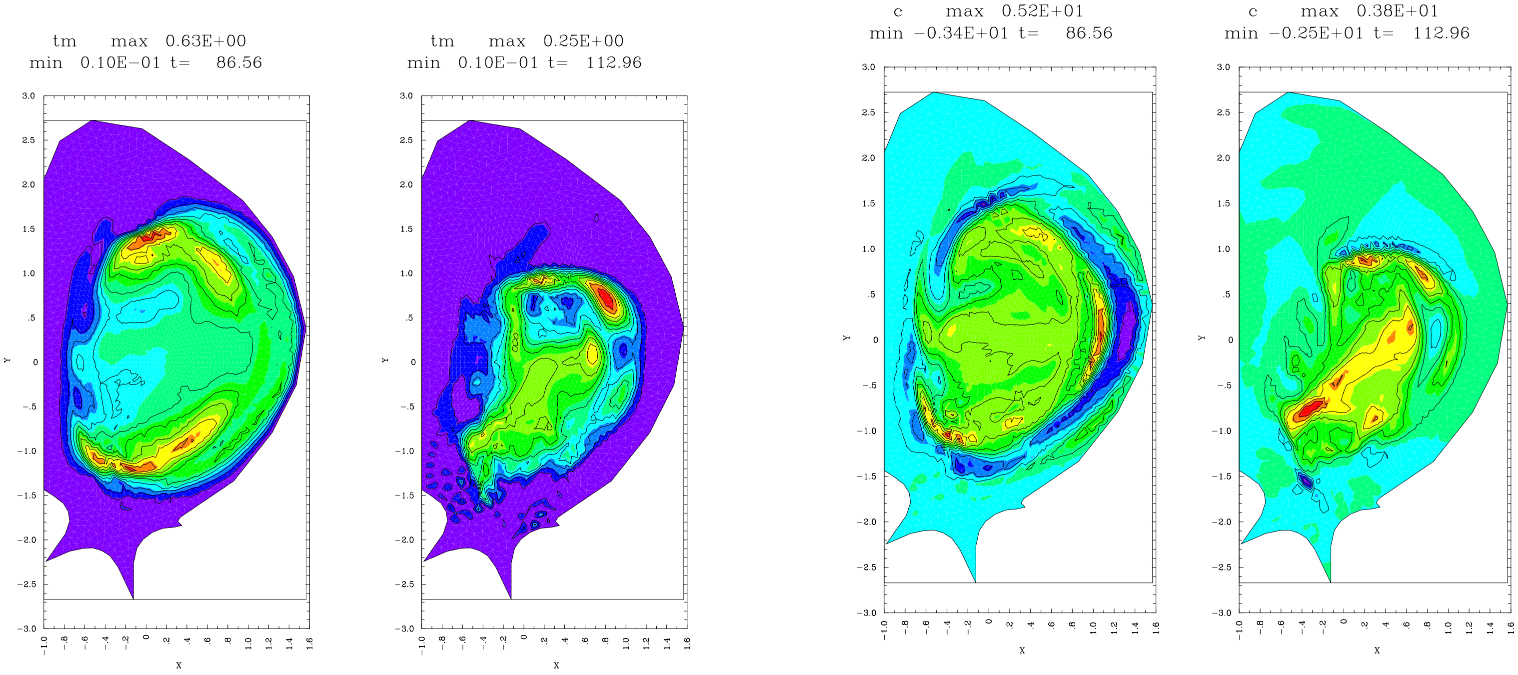
$$\eta_h > \eta_w > \eta_c$$



3D disruptions, halo current and VDEs

- Examples-
  - Nonlinear internal kink with large inversion radius
    - Magnetic field becomes stochastic
    - Causes thermal transport and quench
    - In turn causes current quench
    - Large toroidally asymmetric halo currents
    - Causes VDE growth rate enhancement
  - Resistive wall mode
    - Small toroidal asymmetry of halo current

Thermal and current quench during disruption

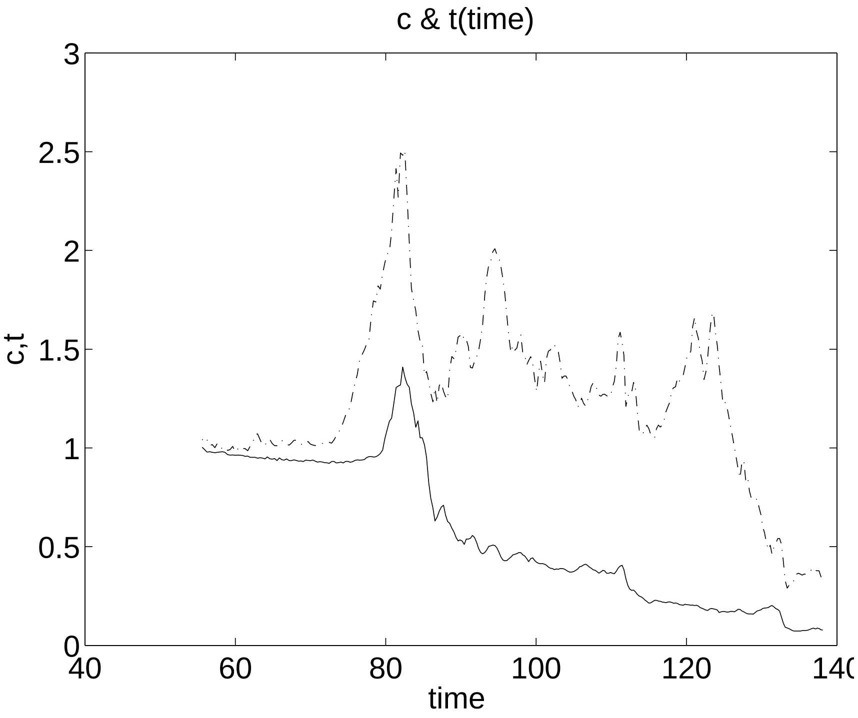


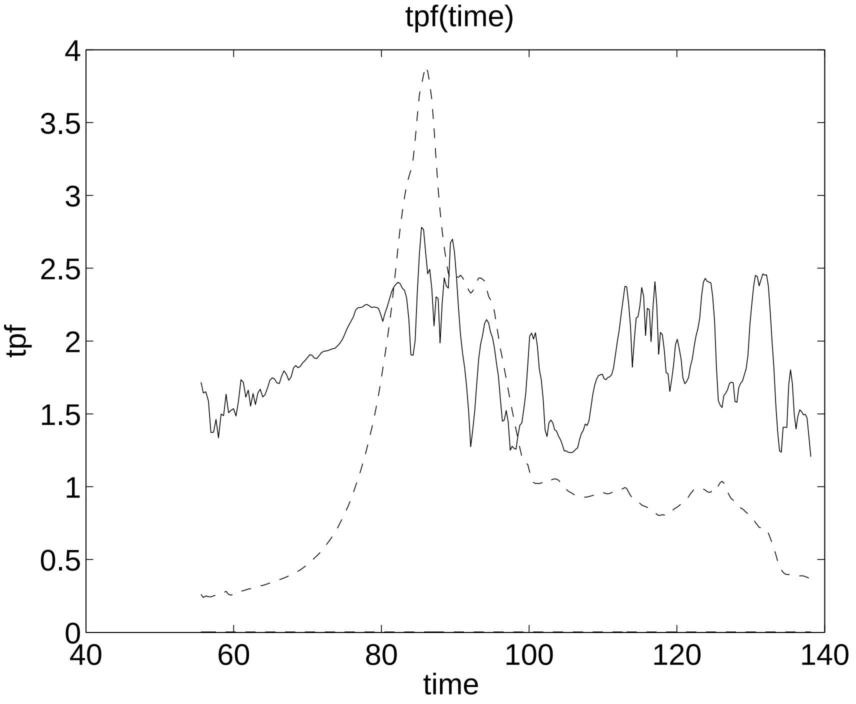
Thermal conduction along stochastic magnetic field cools plasma
High resistivity quenches current

Poloidal halo current asymmetry during disruption

Halo current $$I_{halo}(\phi) = \oint | n \cdot J | R dl$$

Toroidal peaking factor $$tpf = I_{halo}(\max) / I_{halo}(avg)$$

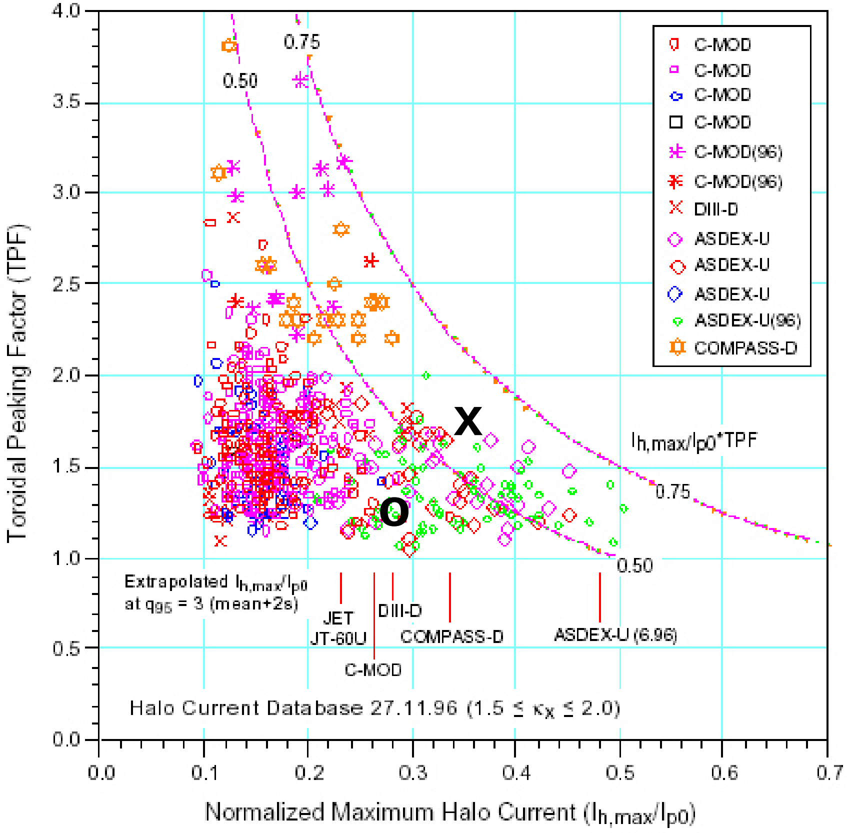




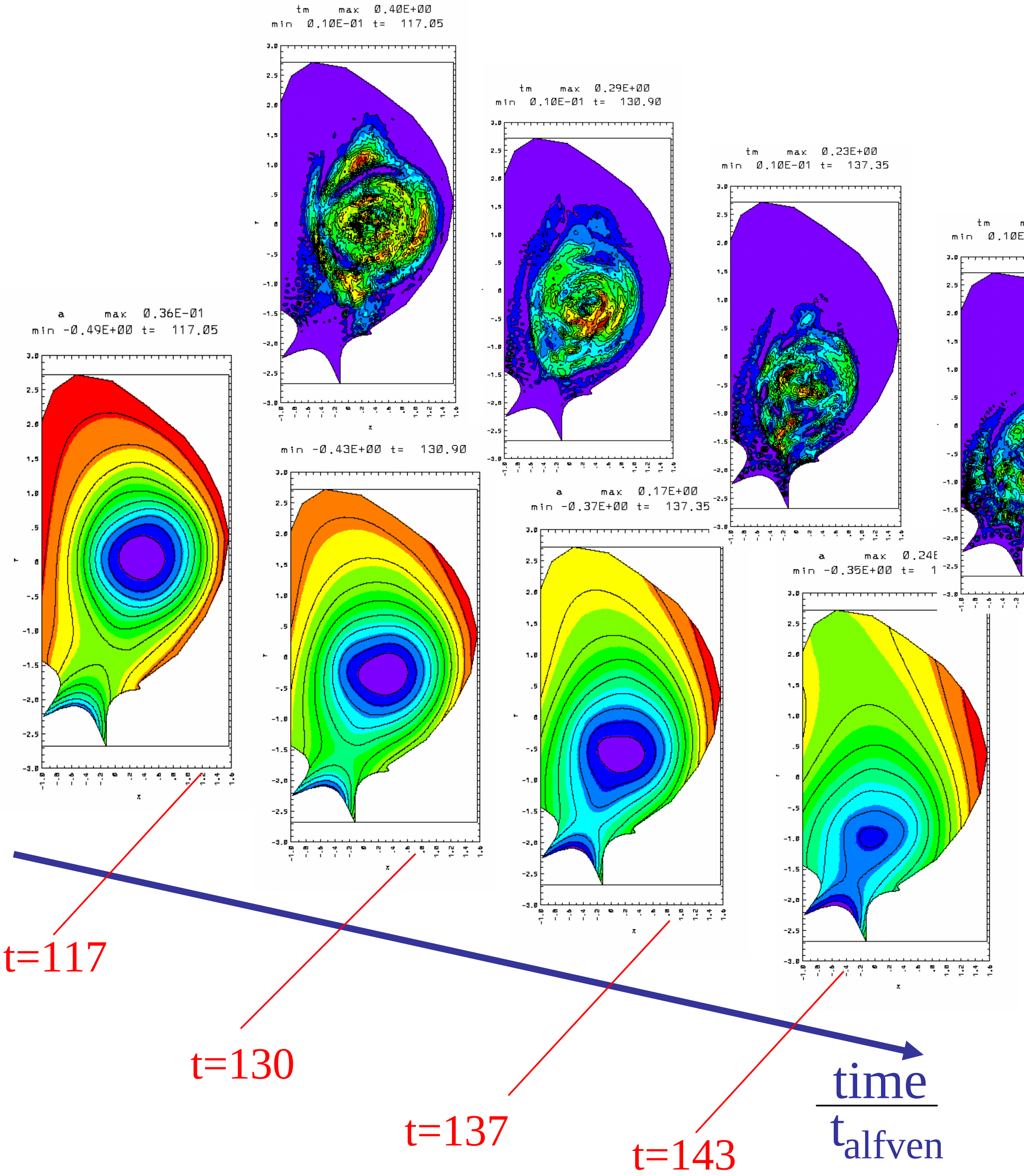
3 timescales: thermal quench, current quench, VDE

Toroidal peaking factor and halo current in simulations are consistent with ITER database

X – kink instability
O – resistive wall
mode



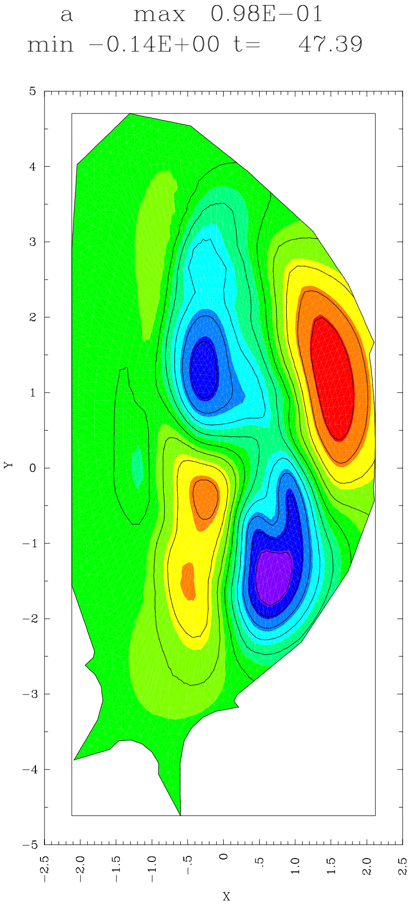
TPF x halo current / total current = peak halo current / total current < 1



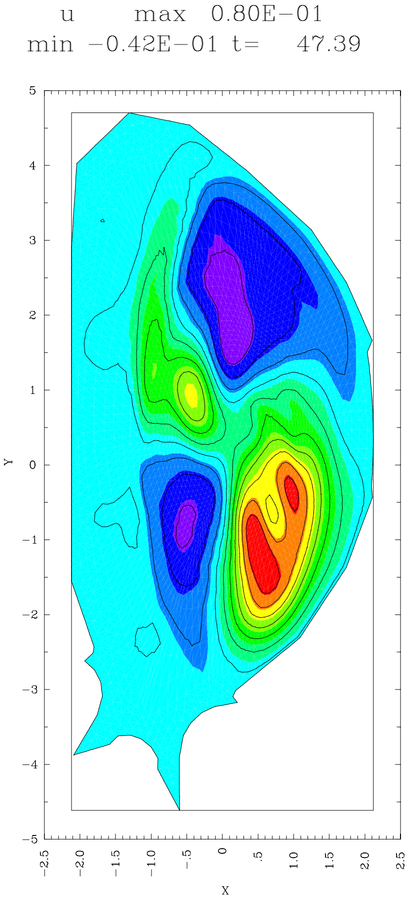
VDE is TWICE AS FAST during 3D disruption, compared to a 2D simulation.

Could explain why vertical control can be lost during disruptions

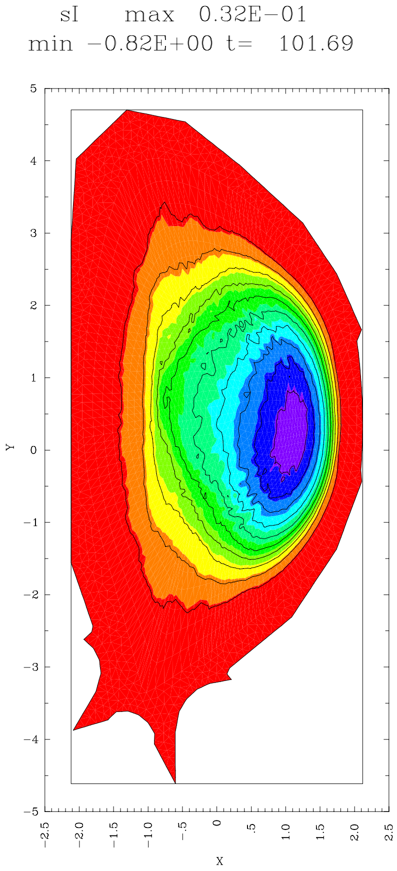
Resistive wall modes: ITER geometry



Magnetic perturbation
Nonzero on boundary

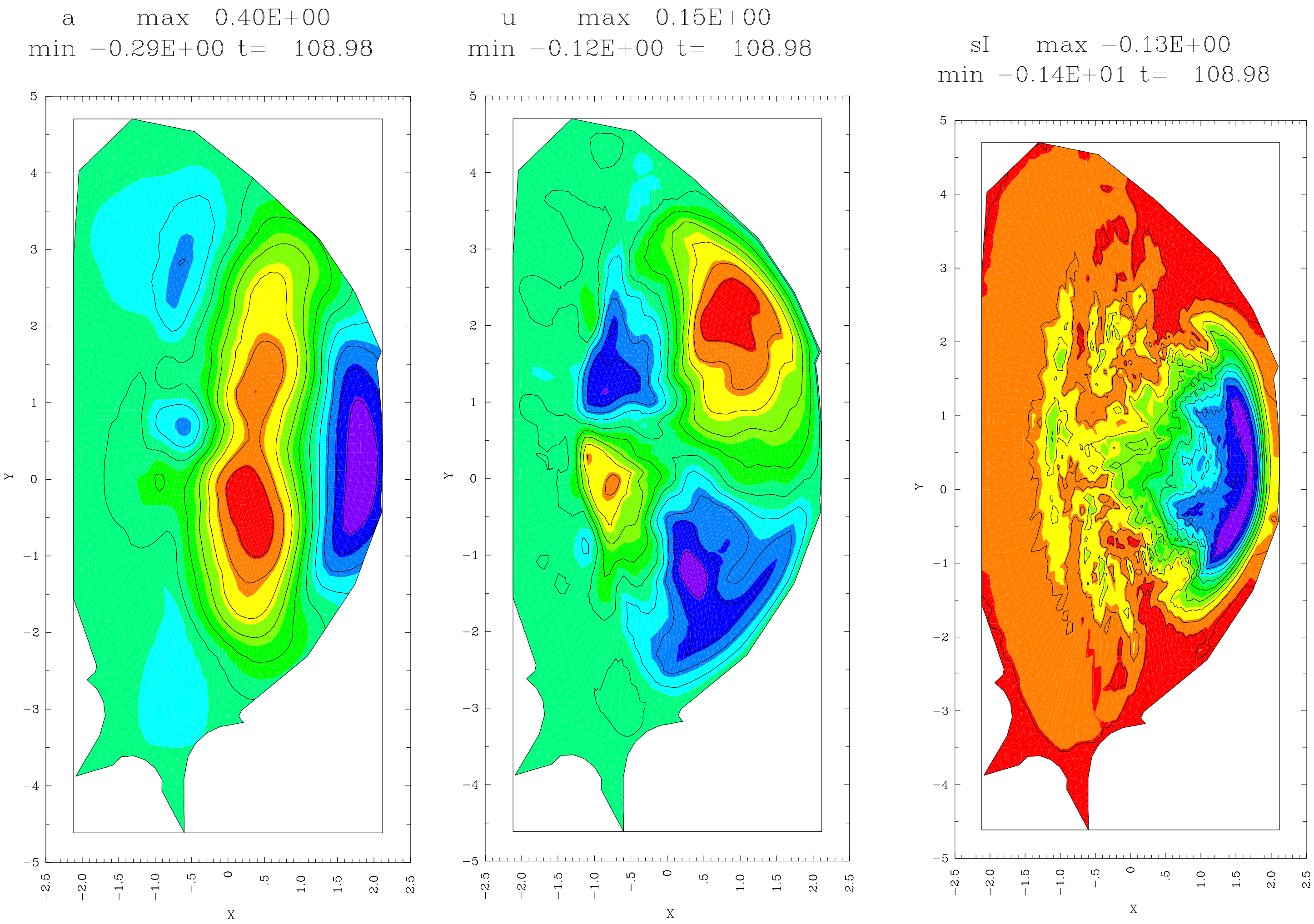


Electrostatic
potential



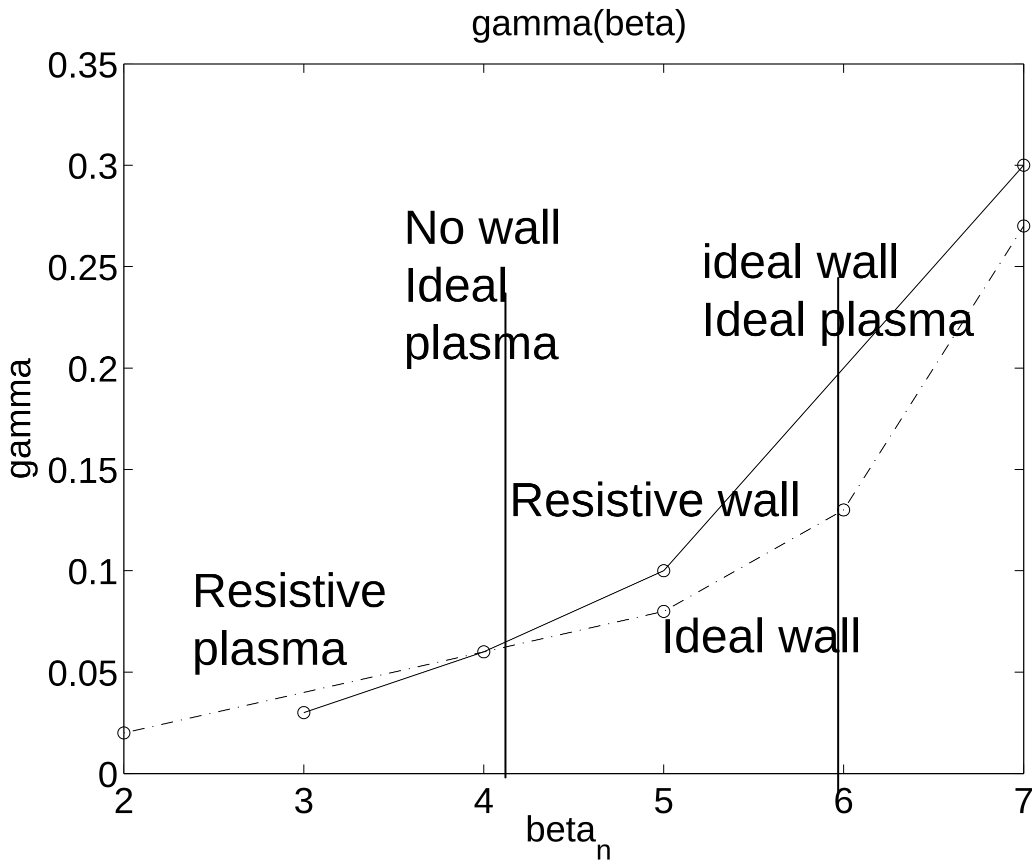
Toroidal field
Function I = RB_t

Nonlinear RWM - disruption



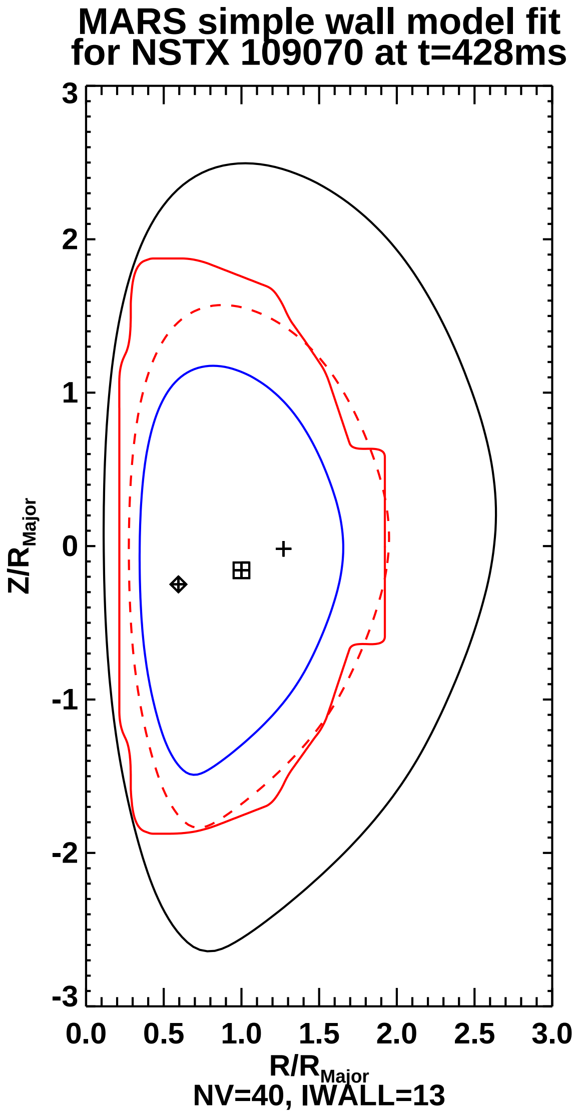
Toroidal peaking factor = 1.3

RWM resistive MHD stability in NSTX



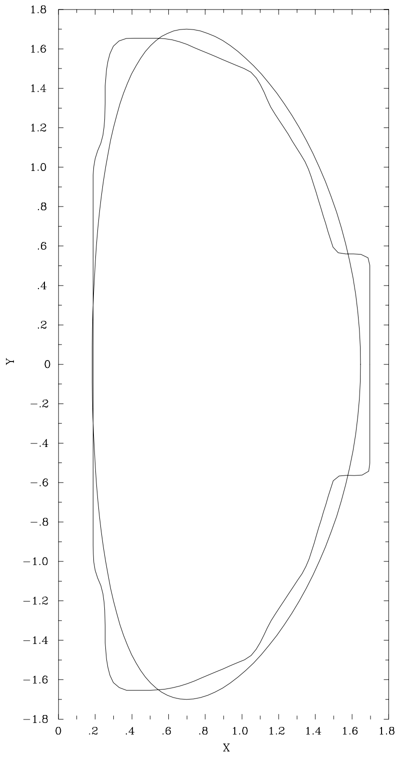
Plasma resistivity makes it difficult to locate RWM stability boundary. Ideal and no wall ideal MHD stability boundaries are shown as vertical lines. Rotation is not included in the data.
2 fluid drifts and rotation stabilize resistive MHD internal modes.

M3D and MARS NSTX resistive wall


MARS simple wall model fit
for NSTX 109070 at t=428ms

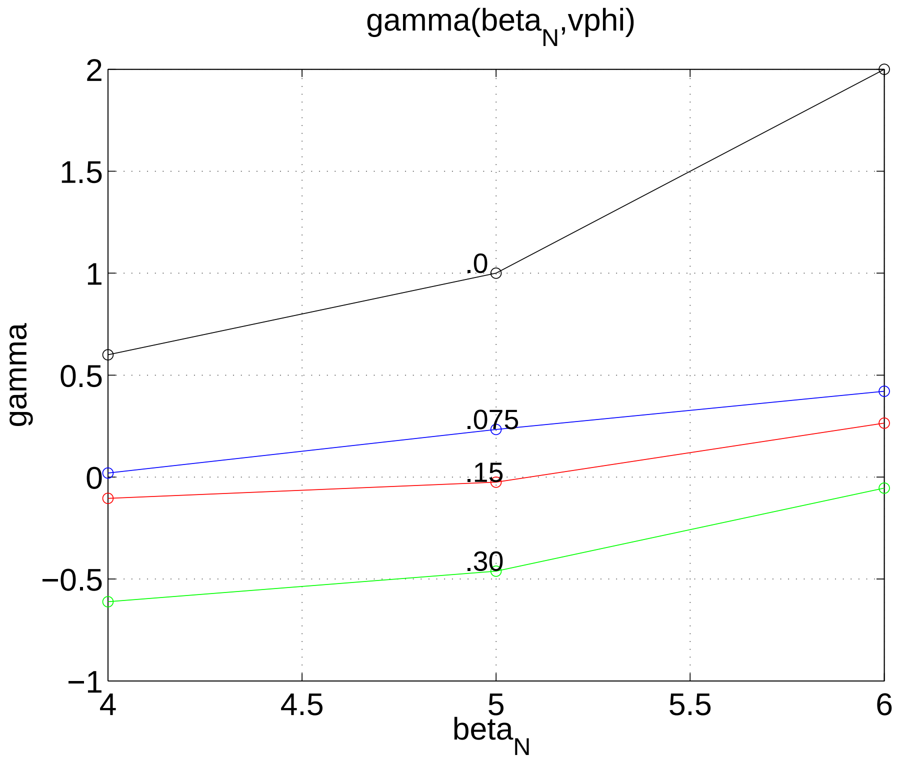
NV=40, IWALL=13

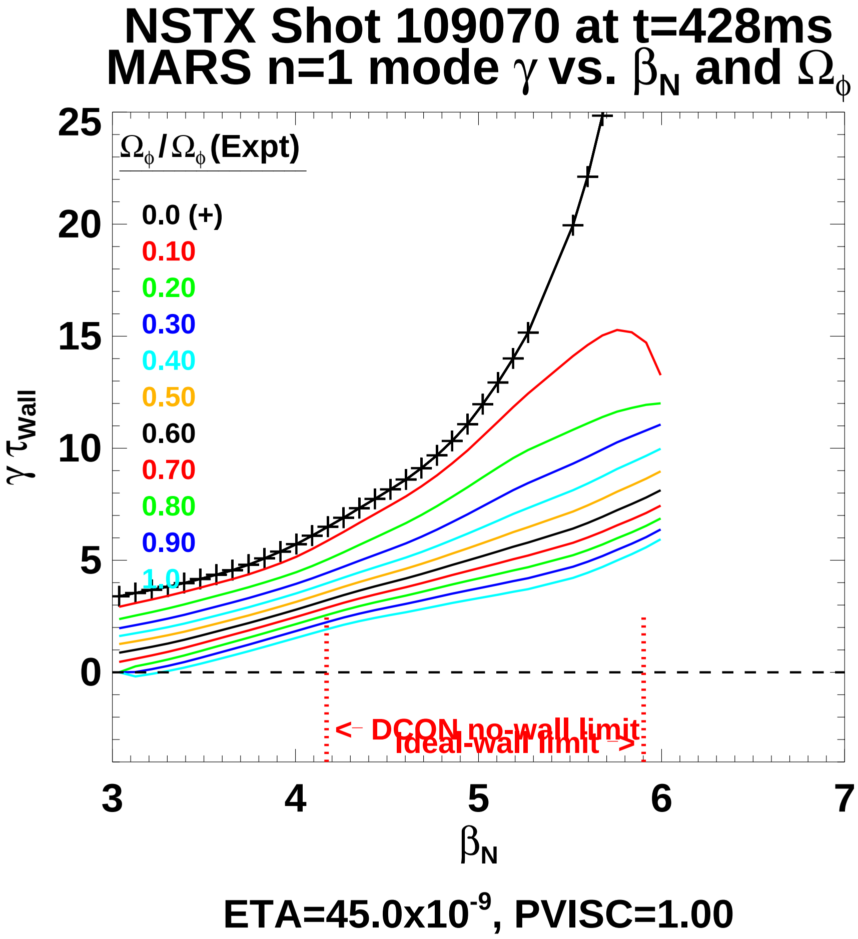
M3D resistive wall



M3D treats the region inside the resistive wall as resistive plasma. The outer vacuum boundary is at infinity.

Preliminary results are consistent with MARS





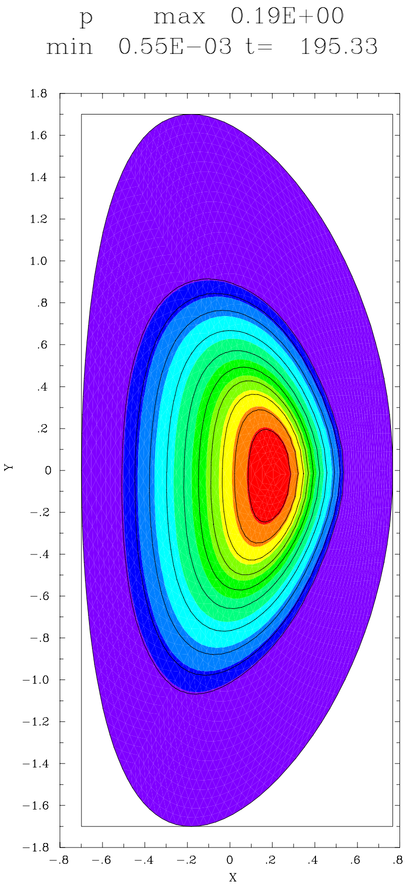
M3D shows stronger flow stabilization, because a flat rotation profile was used. MARS rotation profile was zero near the core plasma edge. M3D used cross field viscous damping, high resistivity. Benchmarking in progress.

Effect of magnetic error field

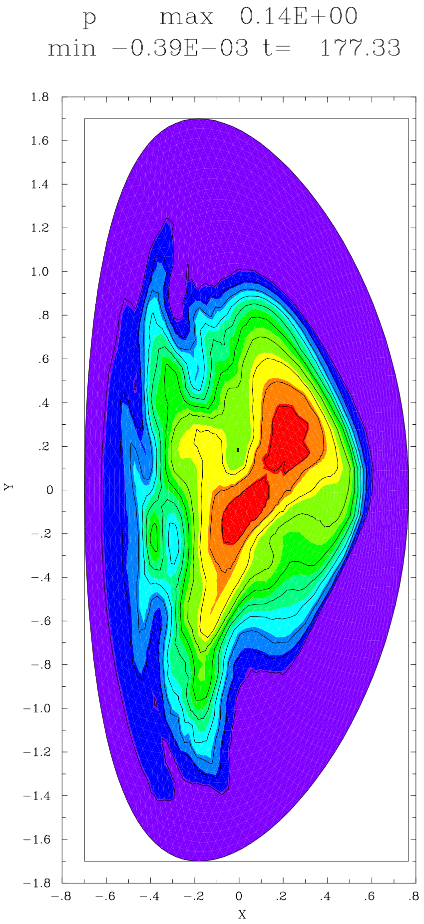
- **Nonlinear NSTX RWM stabilized by toroidal rotation, beta_N = 5, V_phi = .15 V_a**

a) No error field

b) dB/B = .001, nonlinearly disrupts.



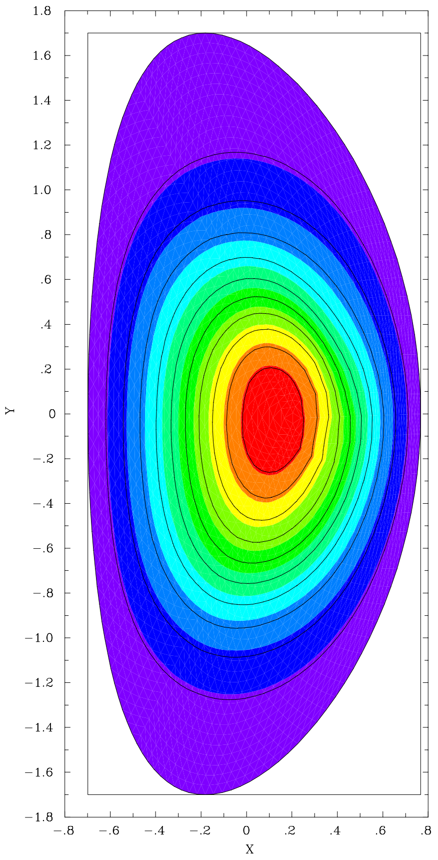
a) dB/B = 0



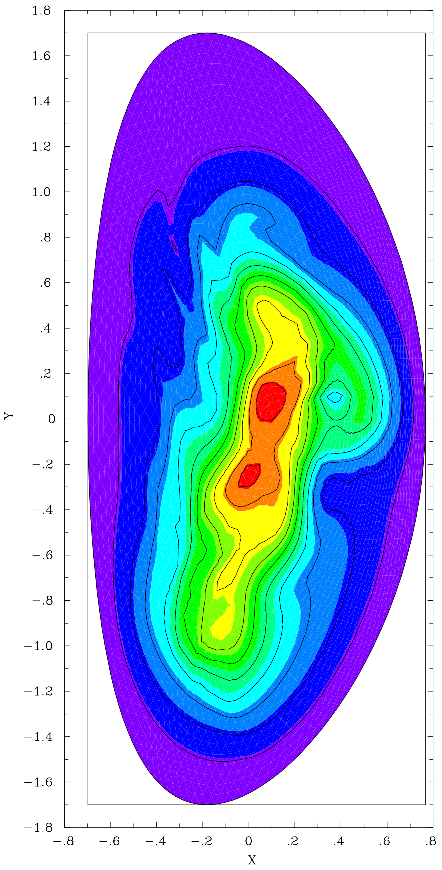
b) dB/B = .001

Error field: V_phi

Change in V_phi may destabilize RWM (viscous relaxation of V_phi in dB = 0 case is also destabilizing but slower timescale)


vphi max 0.22E−01
min 0.00E+00 t= 195.33

dB/B = 0


vphi max 0.38E−01
min 0.00E+00 t= 177.33

dB/B = .001

Future Work

- disruption simulations
  - Worst case scenario, highest halo current asymmetry
  - 3D effect on VDE
- Resistive wall modes
  - Benchmarking
  - Effect of magnetic error fields