Progress of Sawtooth Studies with M3D

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CEMM Meeting

Rochester, NY

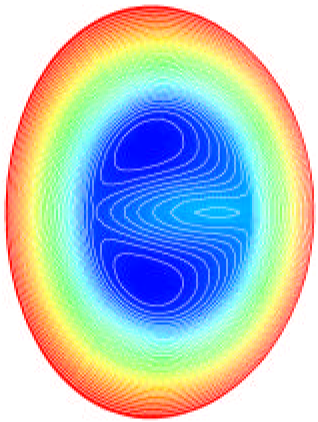
April 21, 2002

Outline

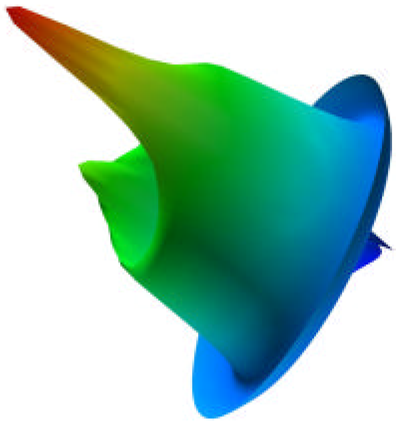
- Axisymmetric sawtooth scaling study
  - Extension of previous work on current holes
  - MHD reconnection confirmed
- Internal m=1, n=1 mode in FIRE
  - Used JSOLVER, PEST to map stability boundaries for ideal (1,1) modes
  - M3D shows growth rates, stochasticity

Review of Previous Current Hole Work

- 2D study based on FIRE-like equilibrium
- Off-axis current drive applied
- Central current density was clamped by axisymmetric sawteeth



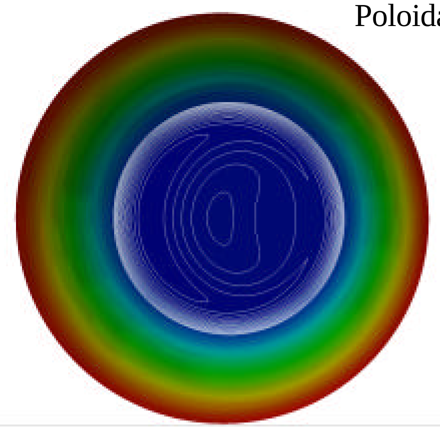
Poloidal flux, $t = 22.5\,t_A$



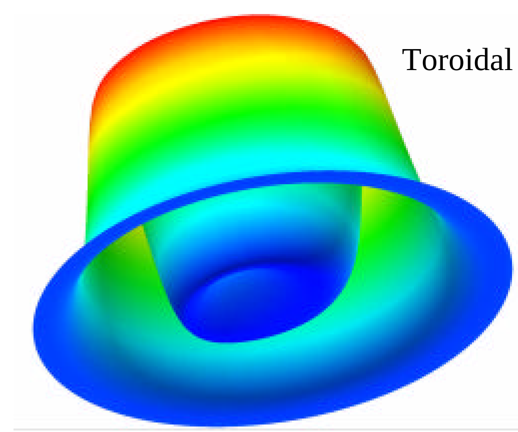
Toroidal current density, $t = 22.5\,t_A$

Follow-up Work

- Circular cross-section gives simpler behavior
- Lower *h*, ν with high-resolution mesh
- Reconnection followed for several periods to get scaling



Poloidal flux



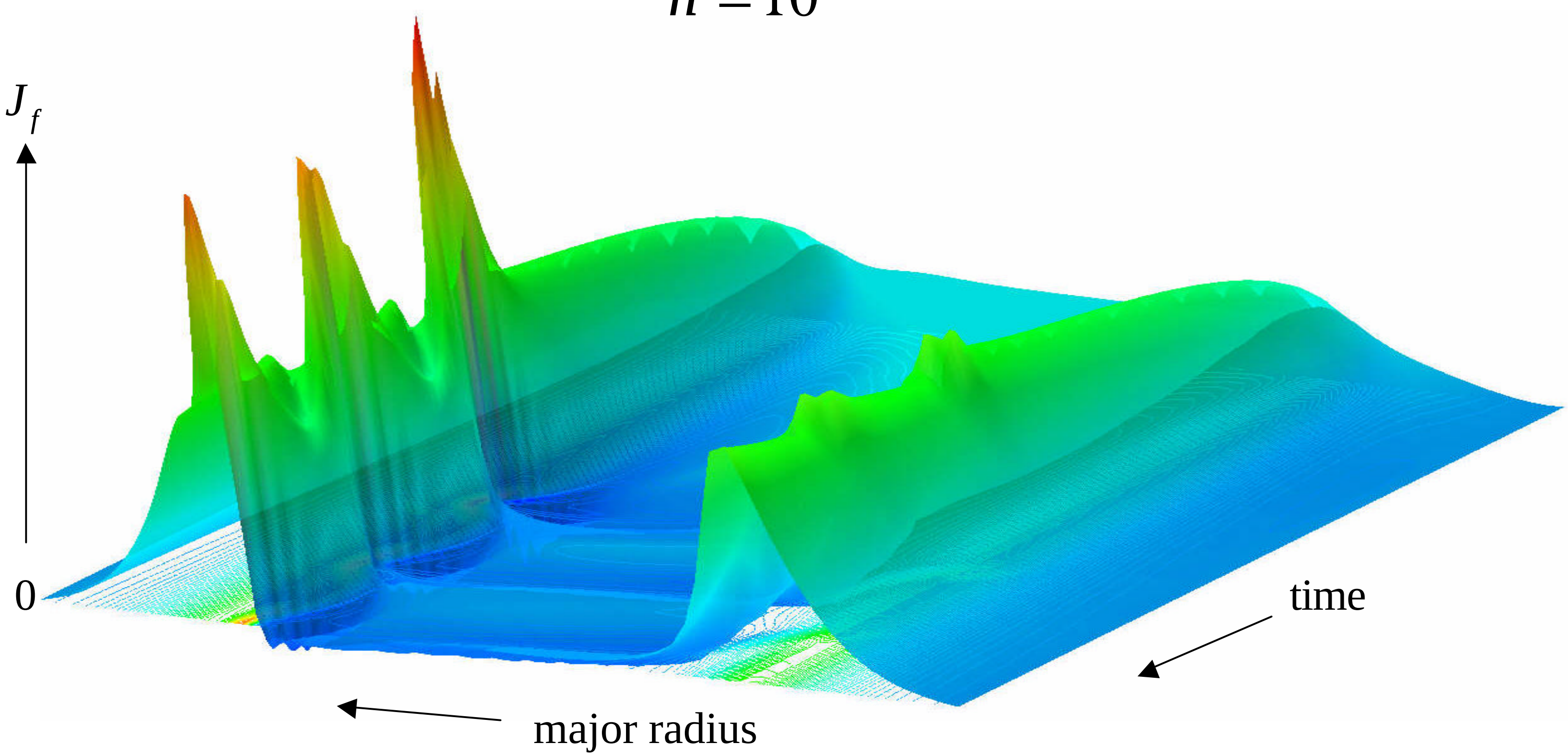
Toroidal current density

$h = n = 10^{-4}$

$t = 236.7 t_A$

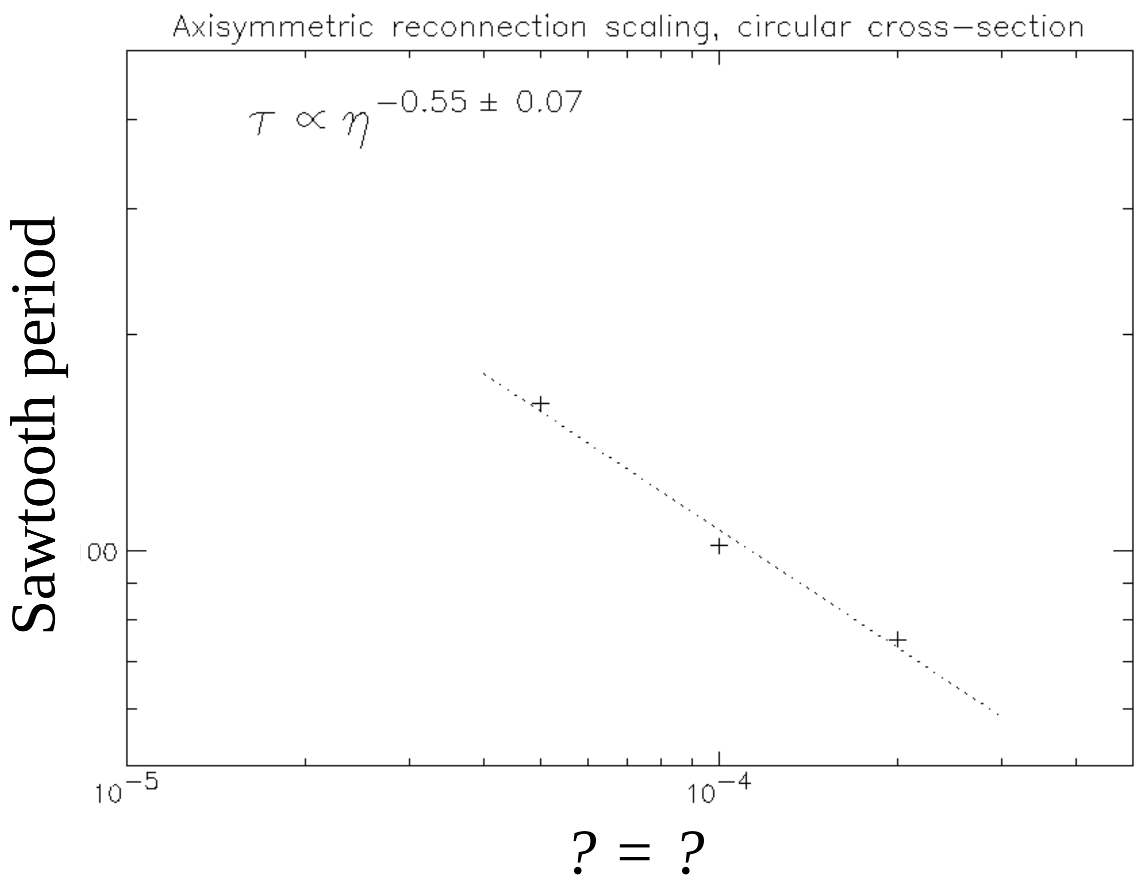
Current Density History at Midplane

$h = 10^{-4}$



- Repeated reconnection events keep current flat in center.

Scaling Results

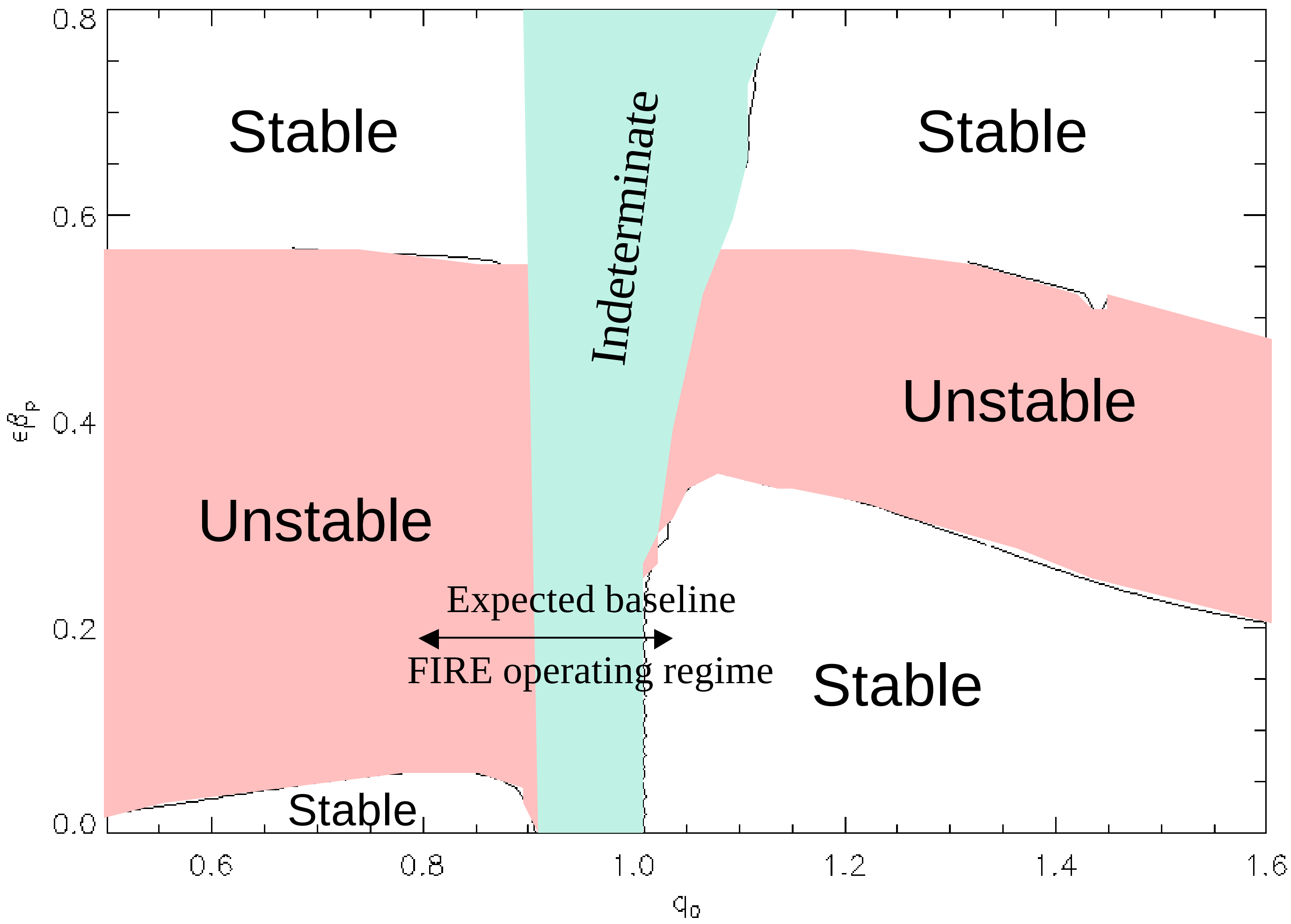


- Sawtooth repeats for at least two cycles before damping viscously.
- Sawtooth period scaling is consistent with MHD reconnection.

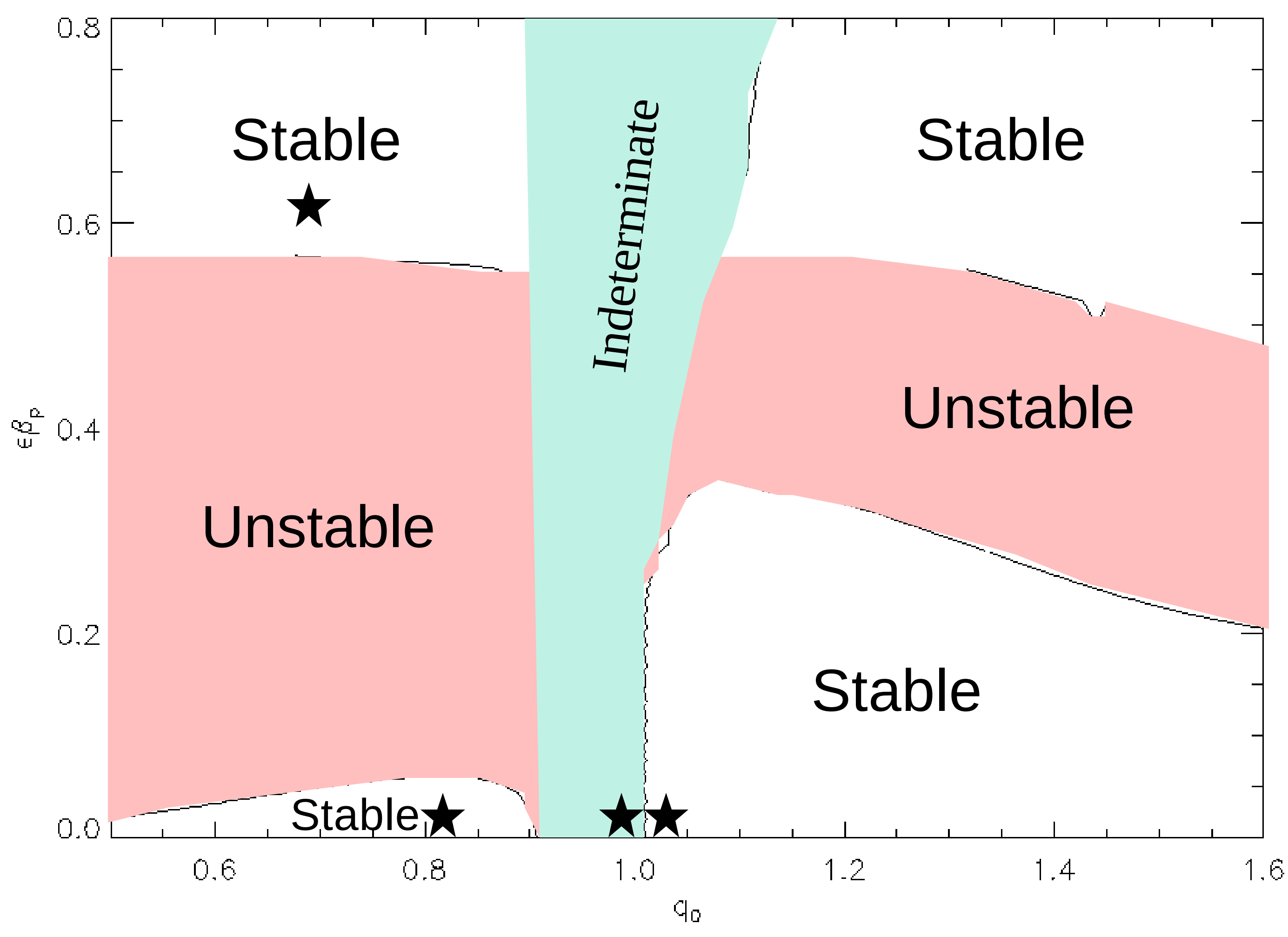
FIRE Study Procedure

- Generate a series of FIRE equilibria with JSOLVER.
- Use PEST-2 to map out regions stable/unstable to 1,1 ideal modes.
- Use M3DP to find linear growth rates, nonlinear behavior in various regions.

1,1 FIRE Stability Map According to PEST



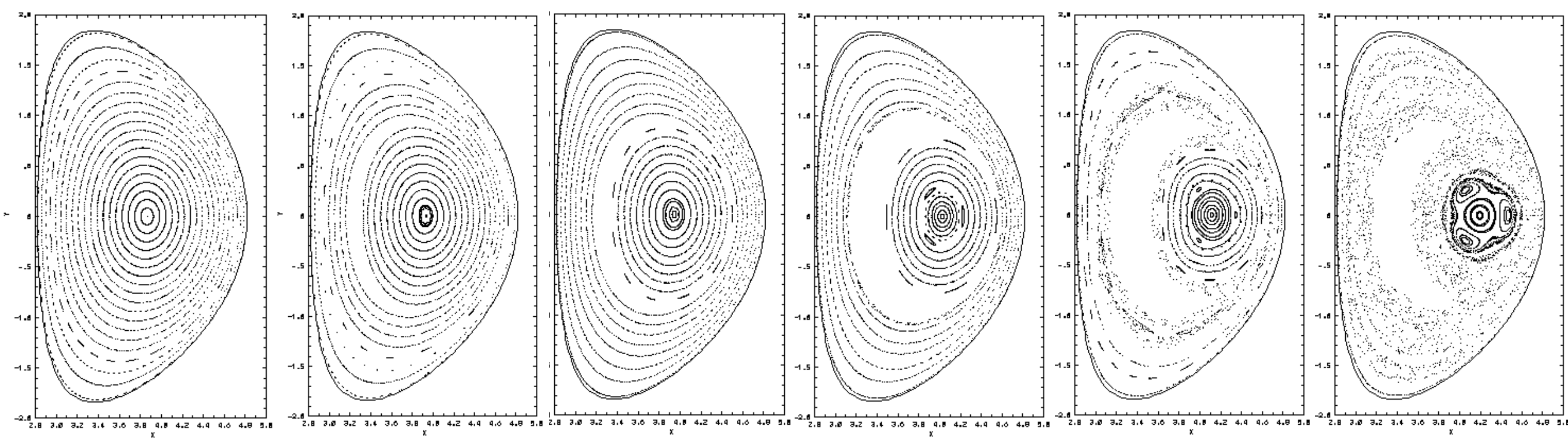
Preliminary Linear M3D Studies with S=10^4 Show Additional Unstable Regions (★)



Modes Form Large Stochastic Regions

- $q_0 \approx 0.74$; $b_p \approx 0.5 \rightarrow eb_p \approx 0.14$
- Growth rate of 1,1 mode = 0.0439

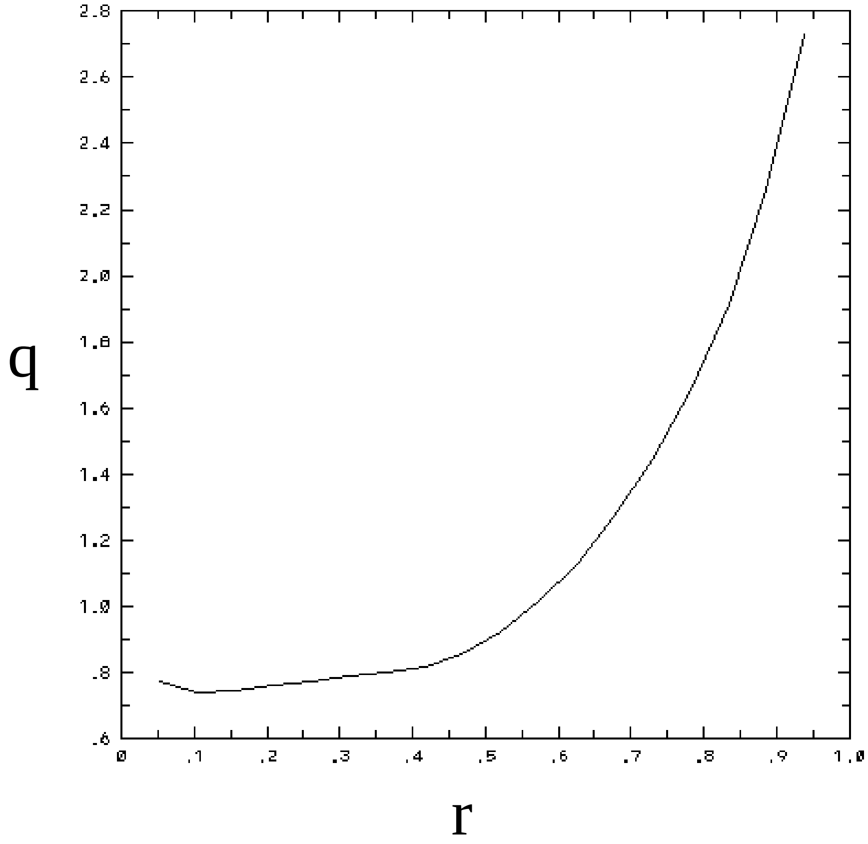
Magnetic Field Puncture Plots at Plane 0



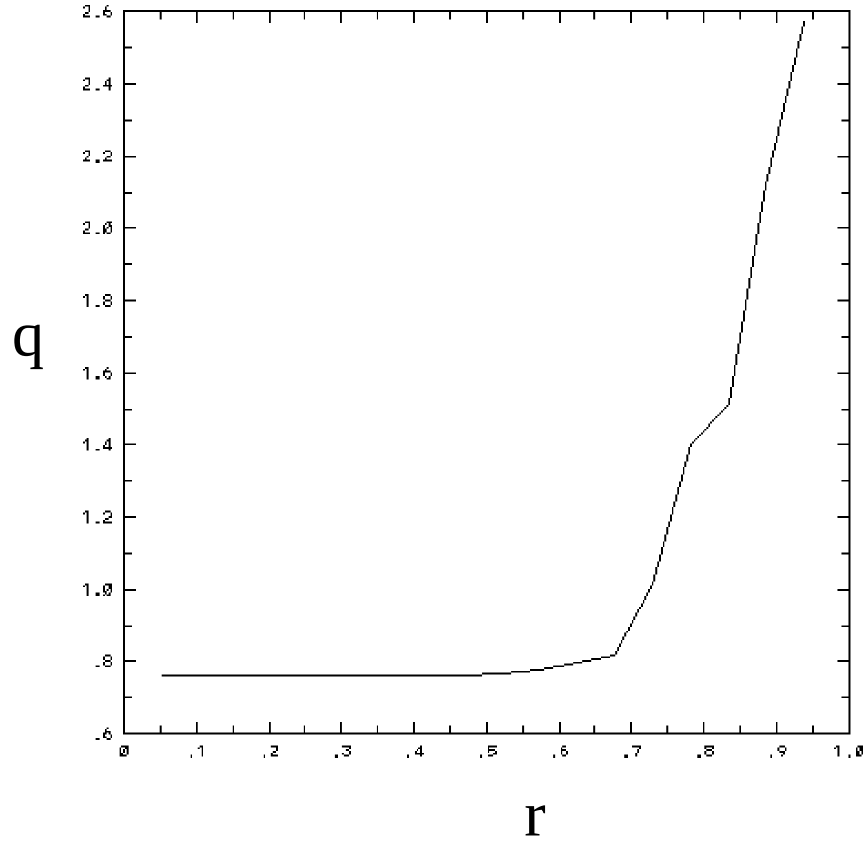
Initial state; $t = 0.0$; $t = 5.75$; $t = 32.74$; $t = 40.93$; $t = 44.76$

Mode Flattens *q* Profile

Before



After



Summary of Initial Nonlinear Study

The large stochastic regions could imply that disruptions are likely. However, more research is needed :

- Vary resolution
- Vary resistivity and viscosity
- Vary q_0, *ß*
- Vary physics model
  - Other results suggest two-fluid physics may "heal" stochastic surfaces.

Note: Stochastic annular regions for the 1,1 mode at high beta and/or noncircular cross-section were reported in Park, Monticello, *et. al.*, *Phys. Fluids B* **3**, p. 507 (1991).

Future Plans

- Resolve conflicting linear stability results
  - Compare earlier/later versions of PEST, JSOLVER
  - Improve equilibria in q_0=1 region.

- Investigate dependence of size of stochasticity region in FIRE on location in q_0, $\epsilon\beta_p$ space.