Simulation of Halo Currents in ITER with M3D

H. R. Strauss
New York University
strauss@cims.nyu.edu

I. Resistive Boundary Conditions using GRIN
II. Inner "vacuum" region
III. Halo Current, Toroidal Peaking Factor
IV. 2D VDE simulation
V. 3D Disruption

I. Resistive Boundary Conditions using GRIN (A. Pletzer)

- plasma surrounded by a toroidally symmetric resistive wall
- vacuum beyond resistive wall
- $\mathbf{B}_n$ continuous (thin wall approximation)
- GRIN computes $\mathcal{Z}$, where $\mathbf{B}_t^{out} = \mathcal{Z}\mathbf{B}_n^{out} = \mathcal{Z}\mathbf{B}_n^{in}$
- M3D provides $\mathbf{B}_n^{in}$ and $\mathbf{B}_t^{in}$
- $\mathbf{E} = (\eta_w/\delta)\mathbf{n}\times(\mathbf{B}^{out} - \mathbf{B}^{in})$

The $\mathcal{Z}$ matrix depends on the shell geometry only. It is computed before launching a nonlinear M3D calculation.

$\mathbf{B}^{out}$ vacuum field

- $\nabla \cdot \mathbf{B} = 0 = \nabla \times \mathbf{B} \Rightarrow \mathbf{B} = \nabla \psi^{out} \times \nabla \phi + \nabla \lambda + I_0 \nabla \phi$
- $\Delta^* \psi^{out} = \nabla^2 \lambda = 0$
- $\psi^{out}(R, Z), \lambda = \Sigma_{n=1}^{N} \lambda_n \exp in\phi$

Green's functions

GRIN calculates 'impedance' $\mathcal{Z}$ matrix elements from Green's identity

$$\oint d\ell R \left\{ G_n \frac{\partial \lambda}{\partial n} - \frac{\partial G_n}{\partial n} \lambda \right\} = 0.$$

where $G_n(R, Z; R'Z')$ is Green's function for the Laplace equation, for $n > 0$. Similarly for $n = 0$. using Green's function for the Grad Shafranov equation.

$\mathbf{n = 0}$ External Current Source Model

Given a set of boundary points, R_i, Z_i, and $\psi_i^{out} = \psi^{in}$ on the boundary, $n = 0$ part of the solution is

$$(\frac{\partial \psi^{out}}{\partial n})_i = \sum_j \mathcal{Z}_{ij}^0 \psi_{vj} + S_i.$$

$$E_\phi = \frac{\eta_w}{\delta}(\frac{\partial \psi^{out}}{\partial n} - \frac{\partial \psi^{in}}{\partial n})$$

S accounts for external currents that ensure that ψ is initially constant on the boundary. $\partial \psi^{in}/\partial n$ found from an ideal equilibrium calculation, with $\psi^{in} = 0$ on the boundary. From $E_\phi = 0$,

$$S = \frac{\partial \psi^{in}}{\partial n}$$

II. Inner "vacuum" region

- "vacuum" – high resistivity η
- $\eta \sim T^{-3/2}$
- η has 3D spatial variation
- T evolution
  - advection, compression
  - large parallel thermal conductivity, using "artificial sound" method
  - small cross field thermal conductivity

III. Halo Current, Toroidal Peaking Factor

- 2 D Magnetic Field,

$$\mathbf{B} = \boldsymbol{\nabla}\psi \times \boldsymbol{\nabla}\phi + I\boldsymbol{\nabla}\phi$$

- 2 D poloidal current,

$$\mathbf{J}_p = \boldsymbol{\nabla} I \times \boldsymbol{\nabla}\phi$$

.

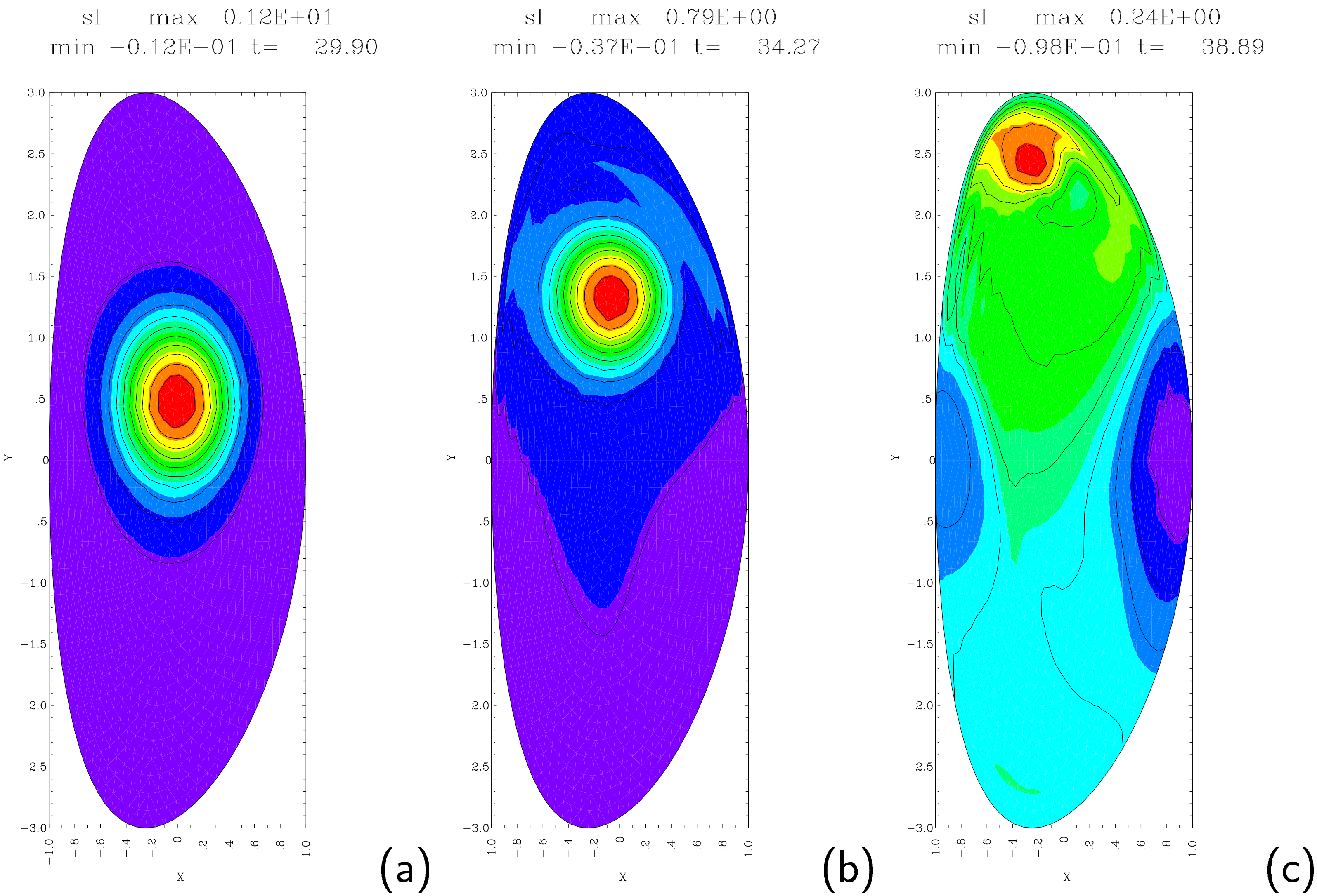
- Halo current flows along I. Contours of I intersecting the resistive shell are halo currents. $J_{halo} = J_p$ in halo region.

$$J_{halo} = \int d\ell |J_n| (R/R_0) = \int d\ell |\frac{\partial I}{\partial \ell}| / R_0$$

- Toroidal peaking factor -

$$tpf = 2\pi \frac{max\{J_{halo}(\phi)\}}{\int d\phi J_{halo}}$$

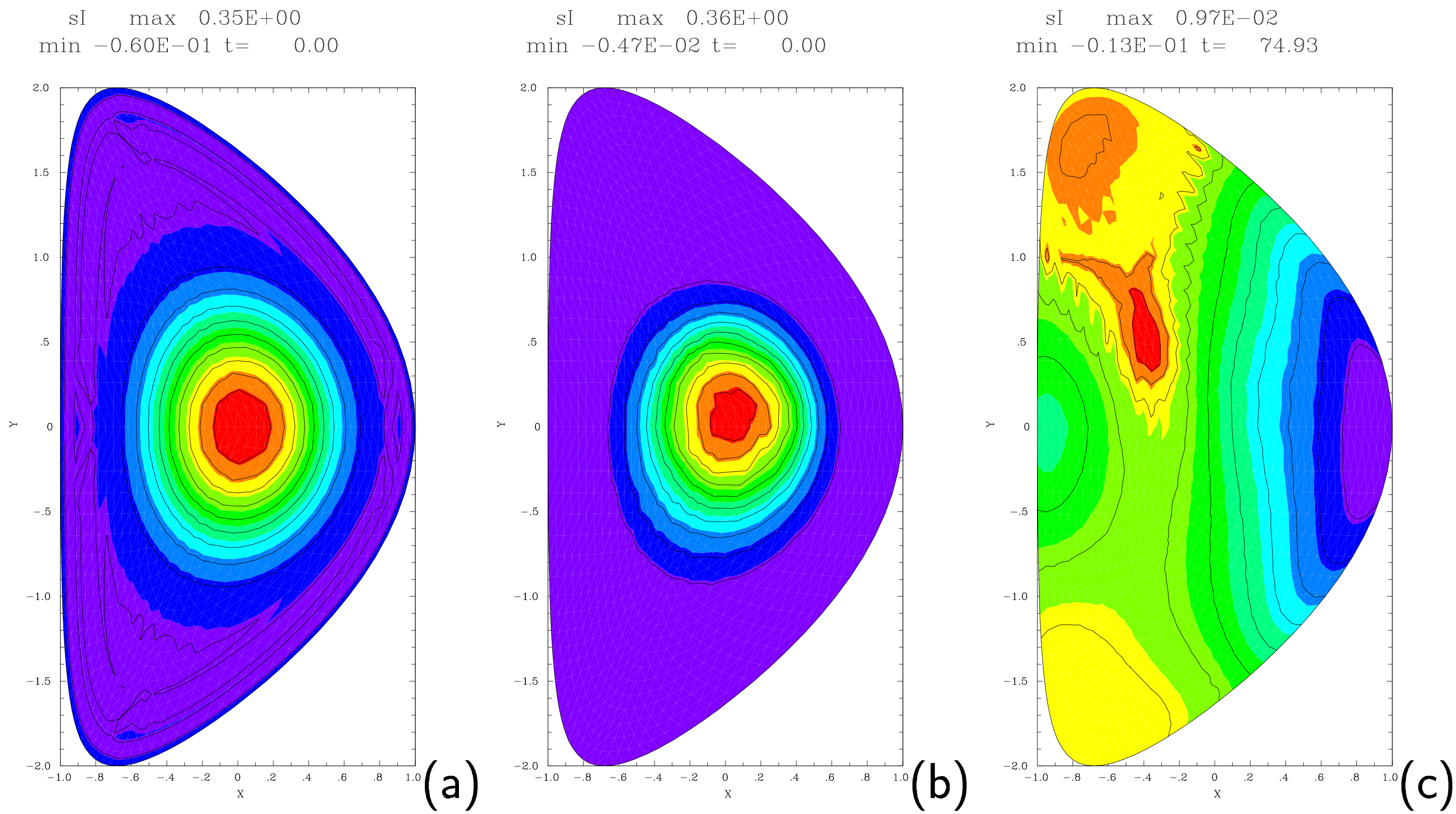
IV. 2D VDE simulation



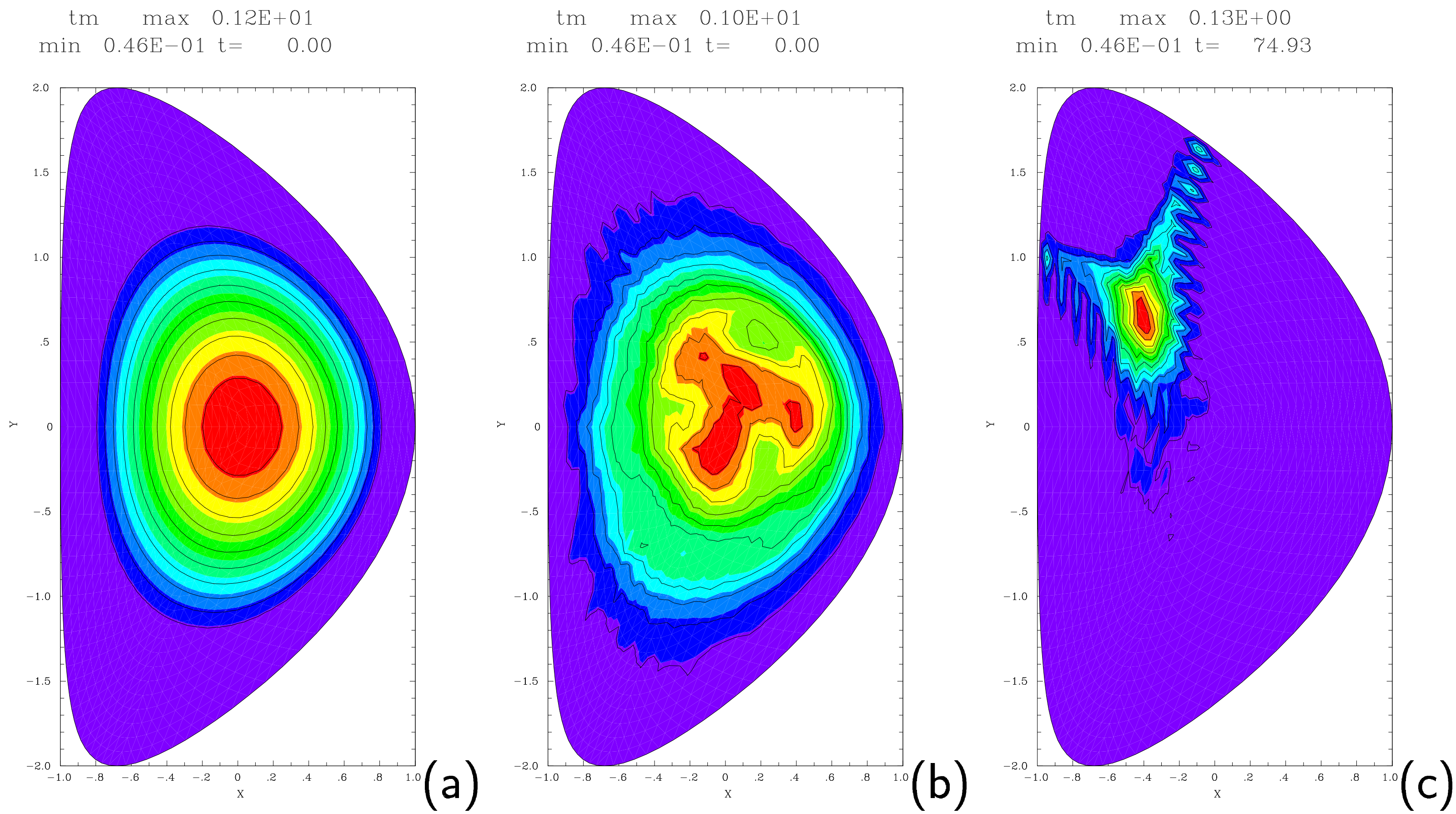
RB_ϕ evolution in a VDE

V. 3D Disruption

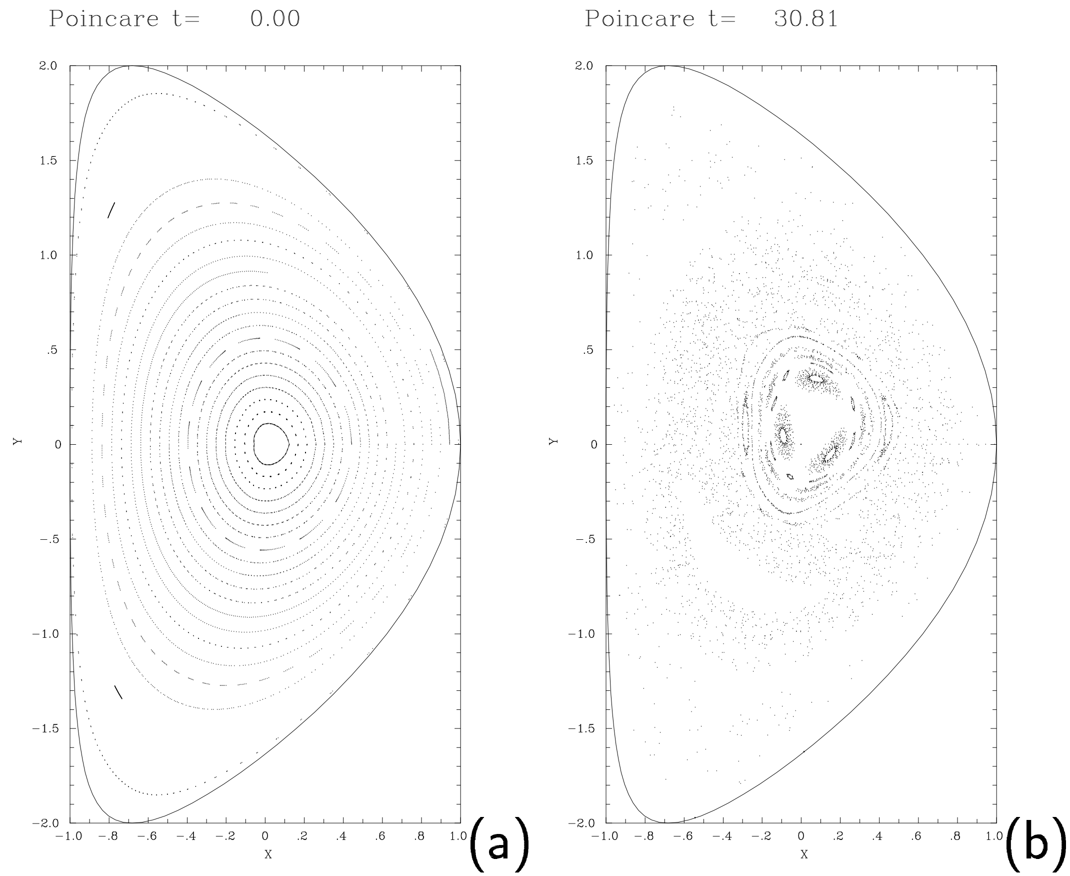
- large inversion radius $m = 1$ mode
- stochastic field & T collapse
- VDE is independent of $m = 1$ mode
- thermal quench causes current quench before VDE reaches the wall
- tpf depends on quench rate vs. VDE growth rate



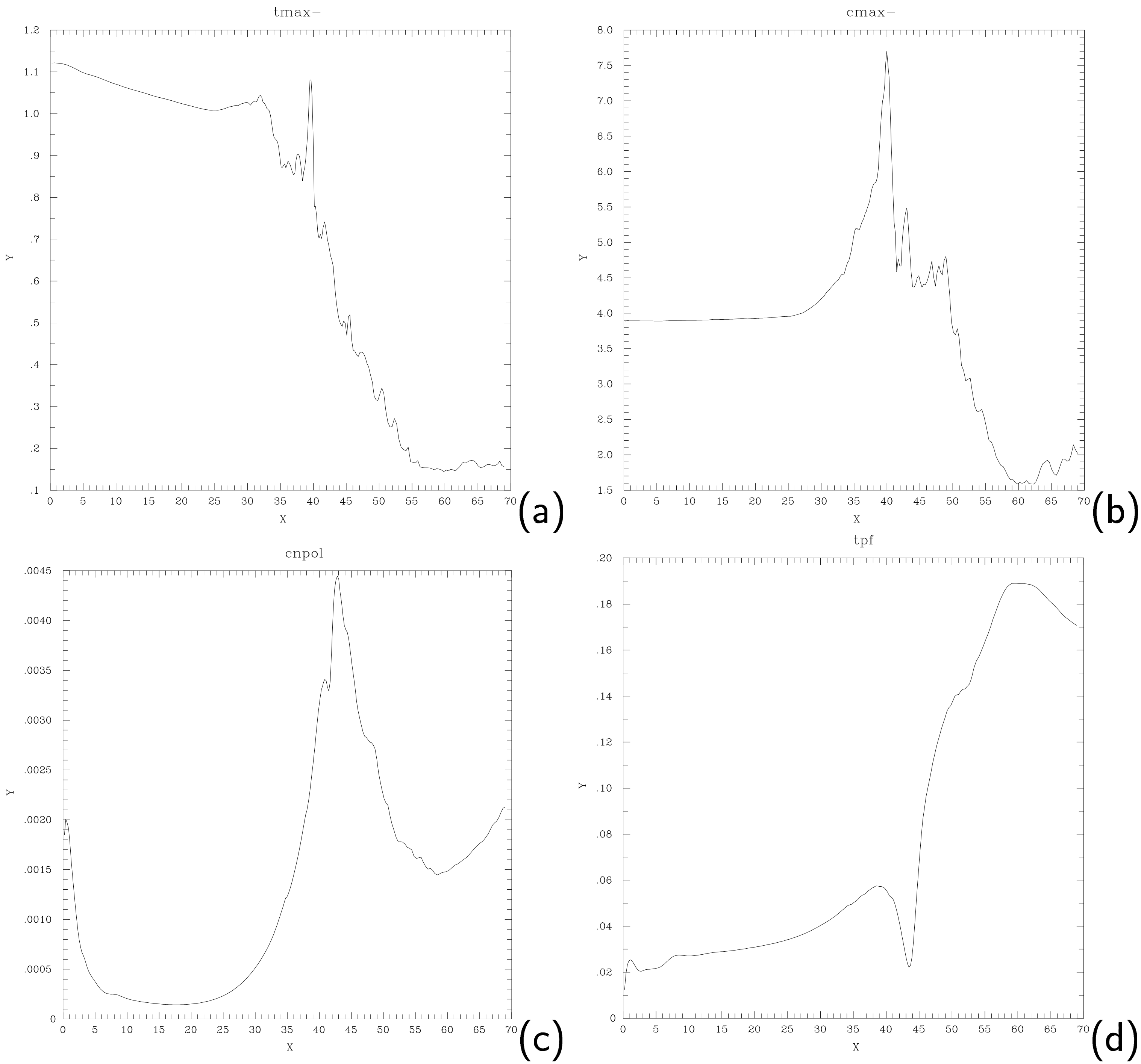
RB_ϕ evolution in a disruption



T evolution in a disruption



Poincare plots in a disruption



$(a)\ T(t)\ (b)\ RJ_{\phi}(t)\ (c)\ J_{halo}(t)\ (d)\ tpf(t)$

Conclusion

- Resistive wall boundary conditions implemented in M3D
- Vacuum fields calculated with GRIN
- Model external current sources
- inner vacuum modeled by high resistivity
- 3D resistivity $\sim T^{-3/2}$
- preliminary VDE
- 3D disruption - tpf depends on current quench vs. VDE

Further work

- ITER geometry and external currents
- worst case tpf