VDE Modeling with M3D-C1

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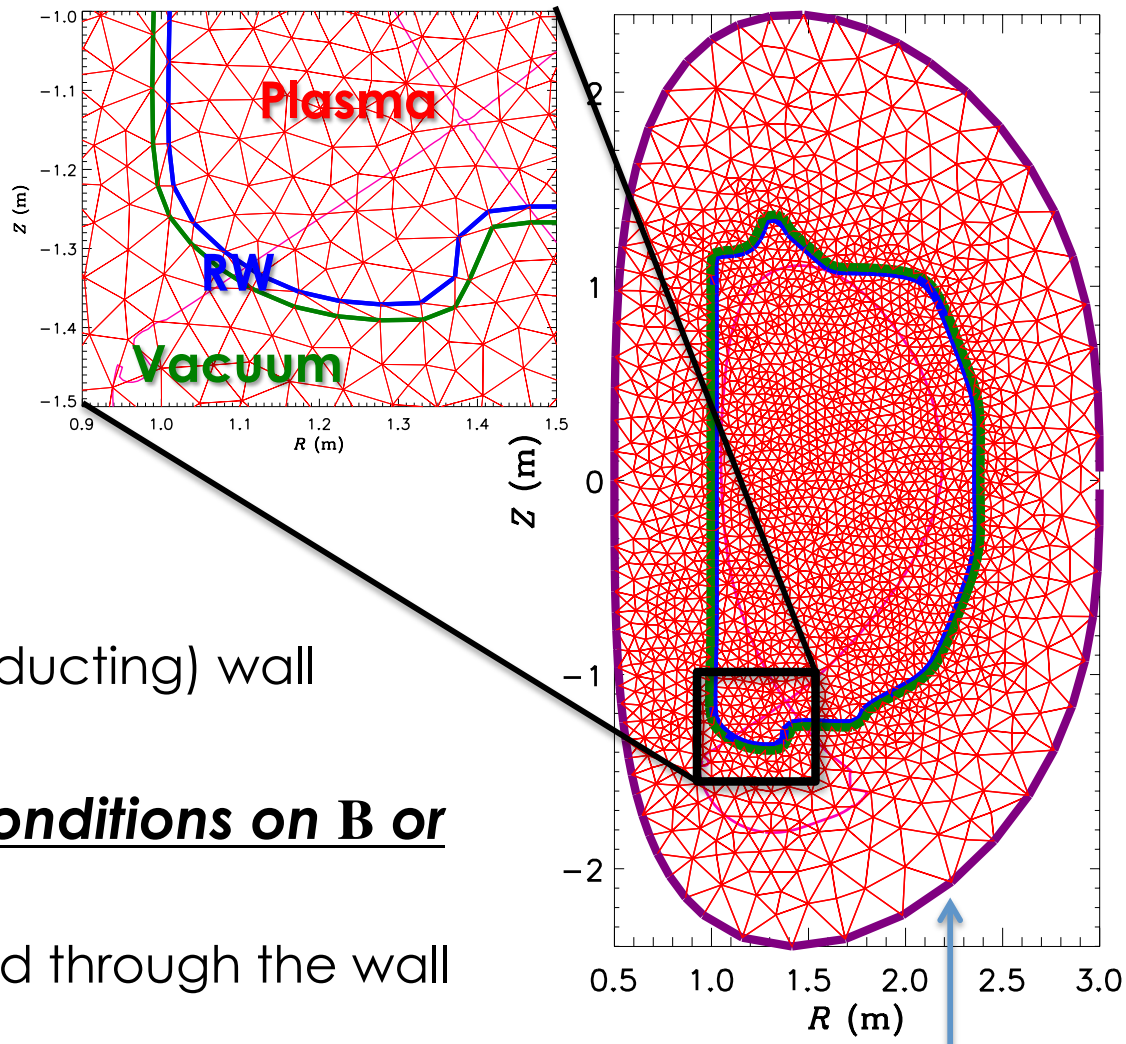
New Resistive Wall Capability In M3D-C1 Includes Wall And Vacuum Regions In Simulation Domain

- **3 regions inside domain:**
  - Vacuum ($\mathbf{J} = 0$)
  - RW ($\mathbf{E} = \eta_W \mathbf{J}$)
  - Plasma (Extended MHD)



- **Boundary conditions:**
  - $\mathbf{v}$, p, n set at inner wall
  - $\mathbf{B}$ set at outer (superconducting) wall

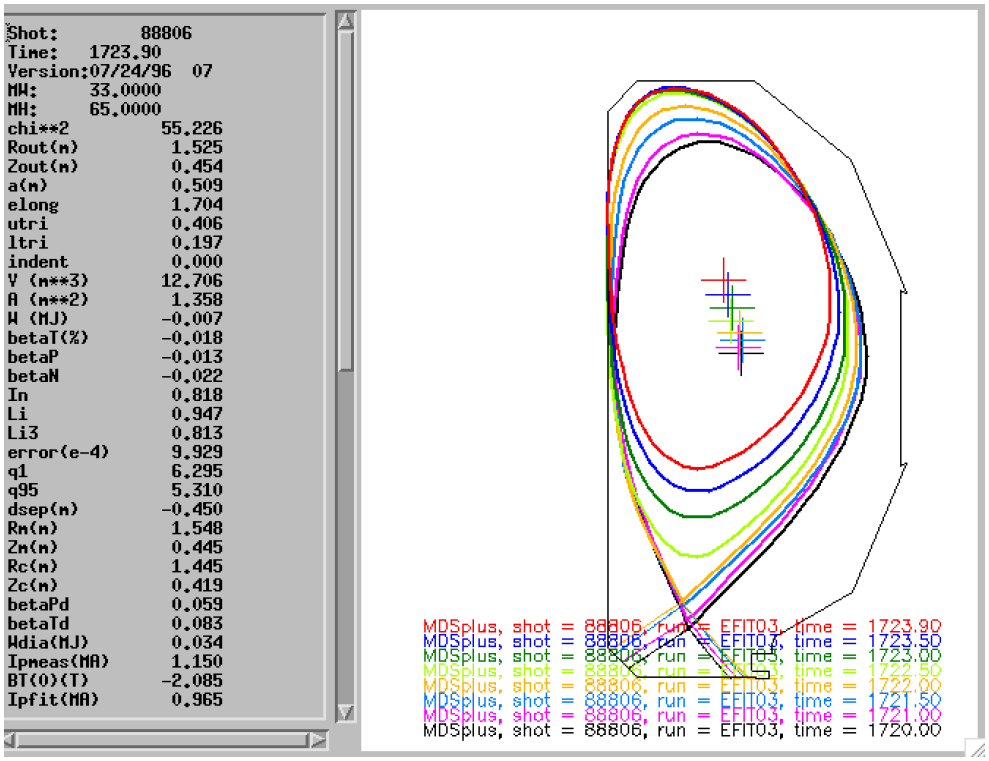
- ***<u>There are no boundary conditions on B or J at the resistive wall</u>***
  - Current can flow into and through the wall

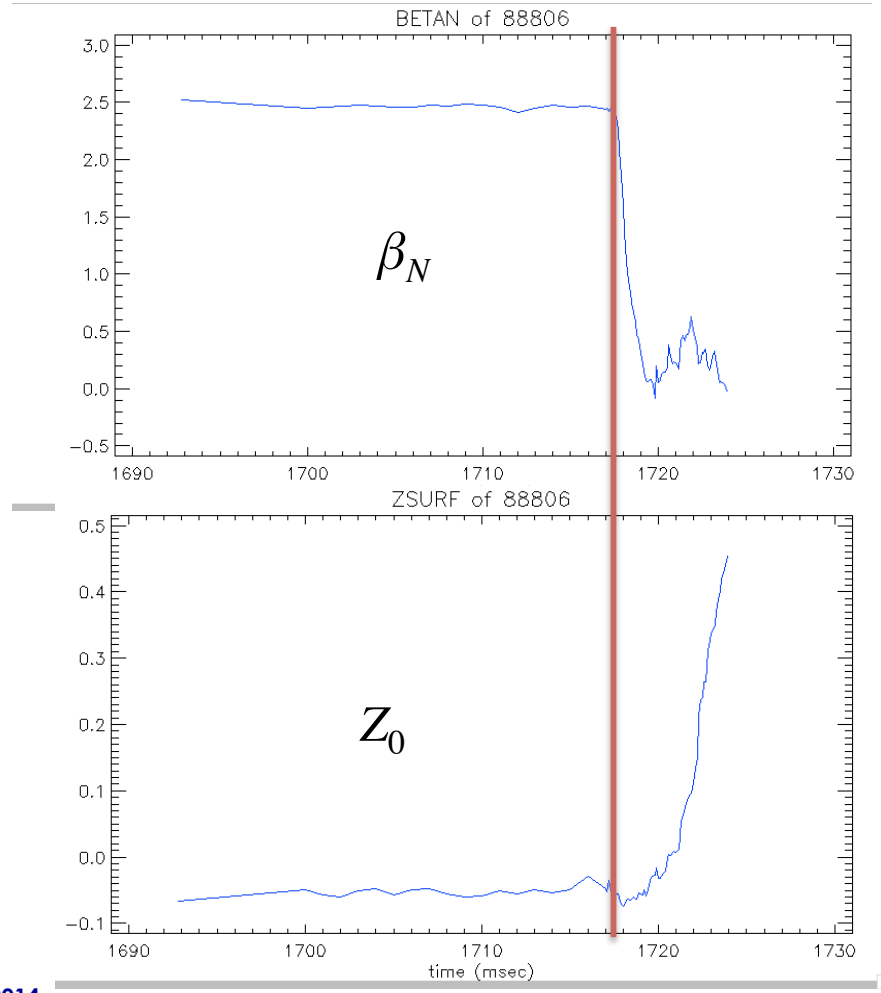
$$\mathbf{B} = \mathbf{B}_{plasma}(t) + \mathbf{B}_{coils}$$

$$\mathbf{J}_{coils} = 0$$

Nonlinear Calculation Recovers $n = 0$ Instability In DIII-D VDE Discharge

- **DIII-D discharge 088806 disrupted due to "killer pellet"**
  - Vertical stability was lost shortly after thermal quench
  - VDE timescale ~3 ms





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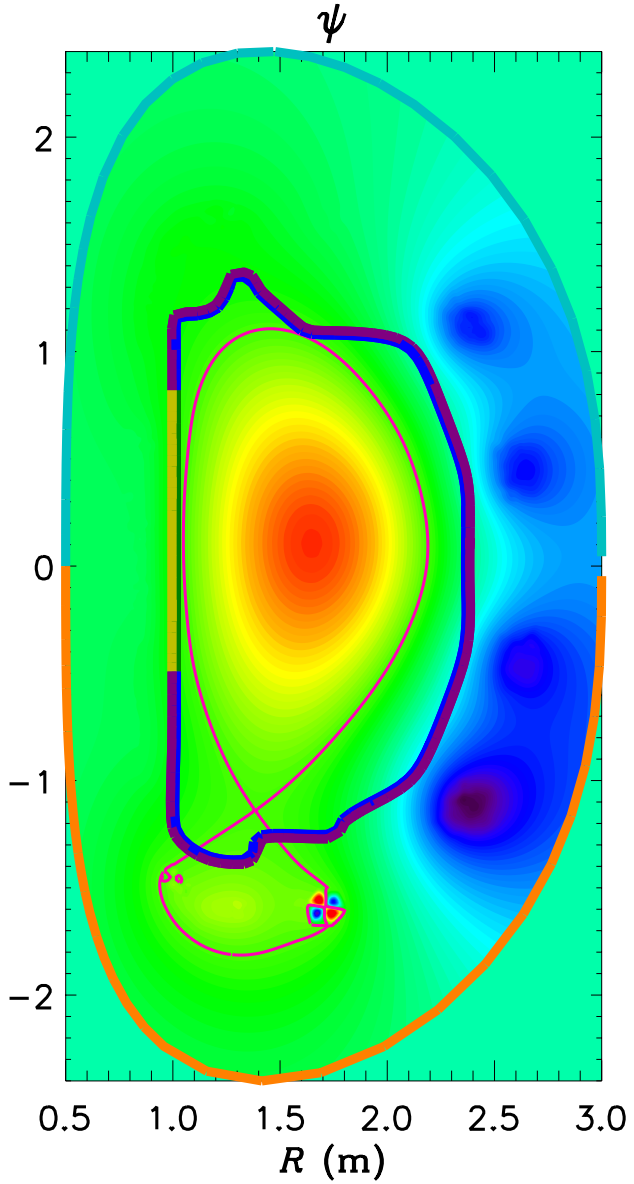
Nonlinear Calculation Initialized From EFIT Reconstruction

- **M3D-C1 is initialized using the reconstructed equilibrium just before TQ ($t = 1720$ ms)**
  - Equilibrium is re-solved on M3D-C1 grid
- **Nonlinear $n = 0$ calculation uses fairly realistic plasma parameters**
  - Spitzer resistivity: $S_0 \approx 6.8\times10^7$
  - Anisotropic thermal conductivity: $\chi_{\parallel}/\chi_{\perp} = 10^6$
  - Anomalous perp. transport: $100 < \chi_{\perp} < 800\ \mathrm{m}^2/\mathrm{s}$
- **RW approximates first wall, not vacuum vessel here; using "modern" first wall, different from old experiment**



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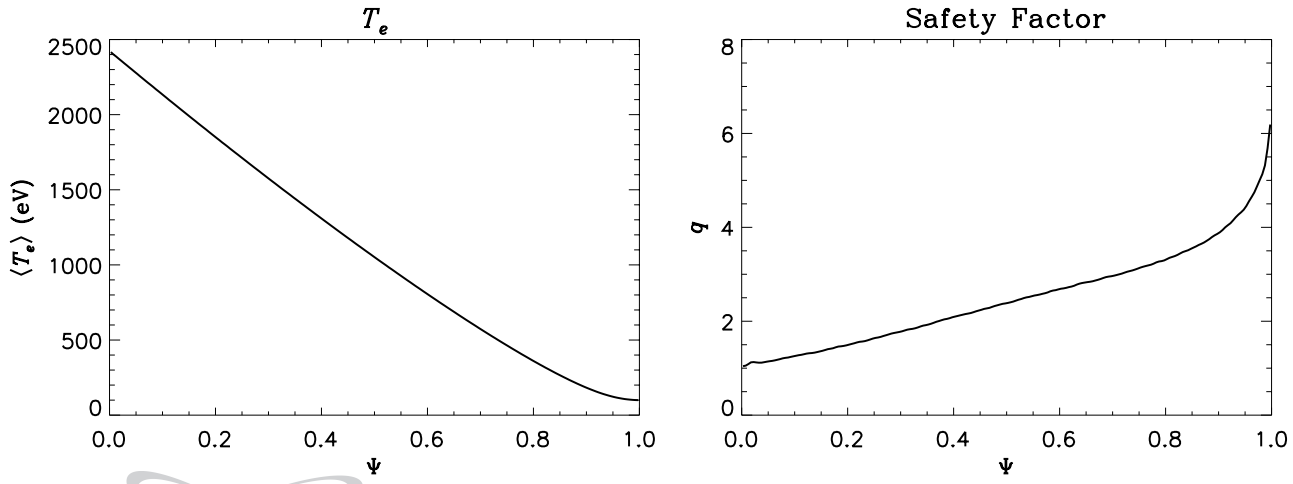
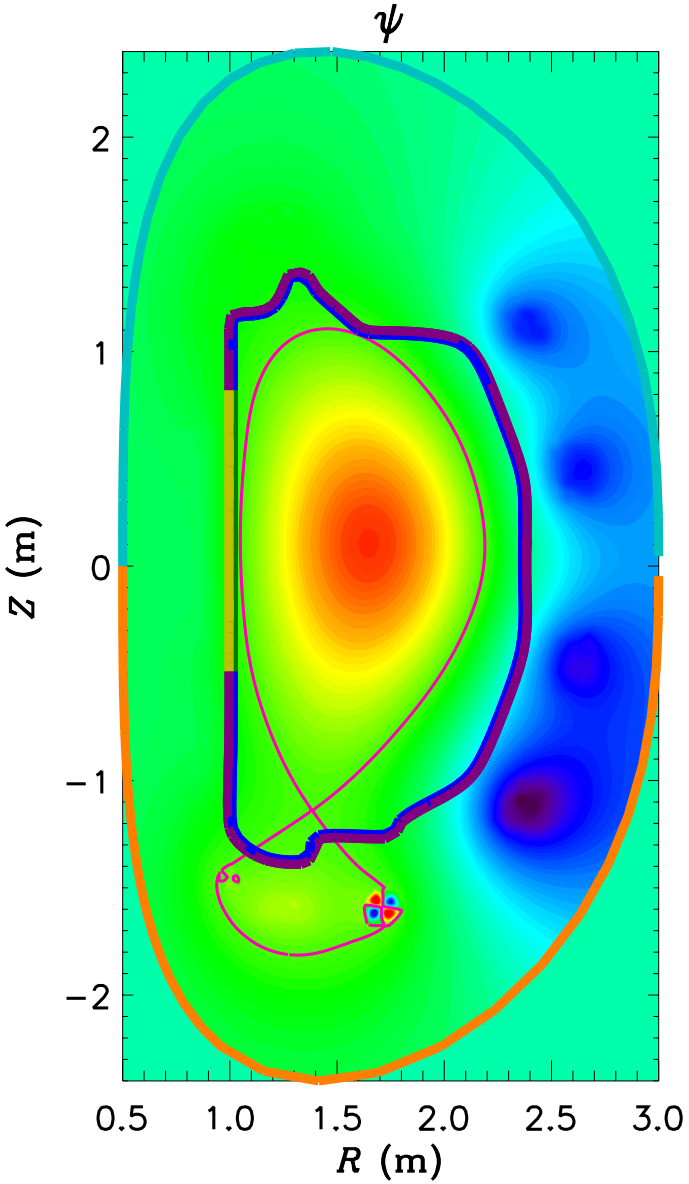
These Calculations Are A "First Try"; Not Suitable For Quantitative Validation

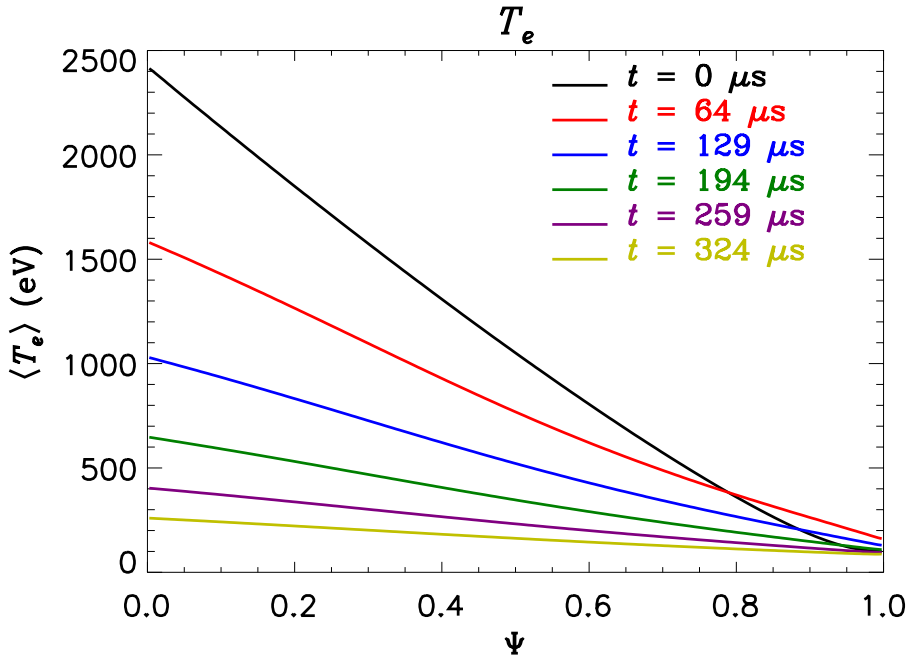
- **Simulations done at low resolution**
  - 5059 elements, ~320k DOFs
- $T_{SOL} \approx 100$ eV → $\eta_{SOL} \approx 1.6\times10^{-6}\ \Omega\,\mathrm{m}$
- **Single-Fluid, no sources**
- **Wall is uniform thickness (2 cm), resistivity**





Simulations Include Thermal Quench Stage

- **A thermal collapse happens on ~$100\ \mu s$ timescale, due to large perpendicular thermal conductivity**
  - Not caused by any MHD activity or convective transport

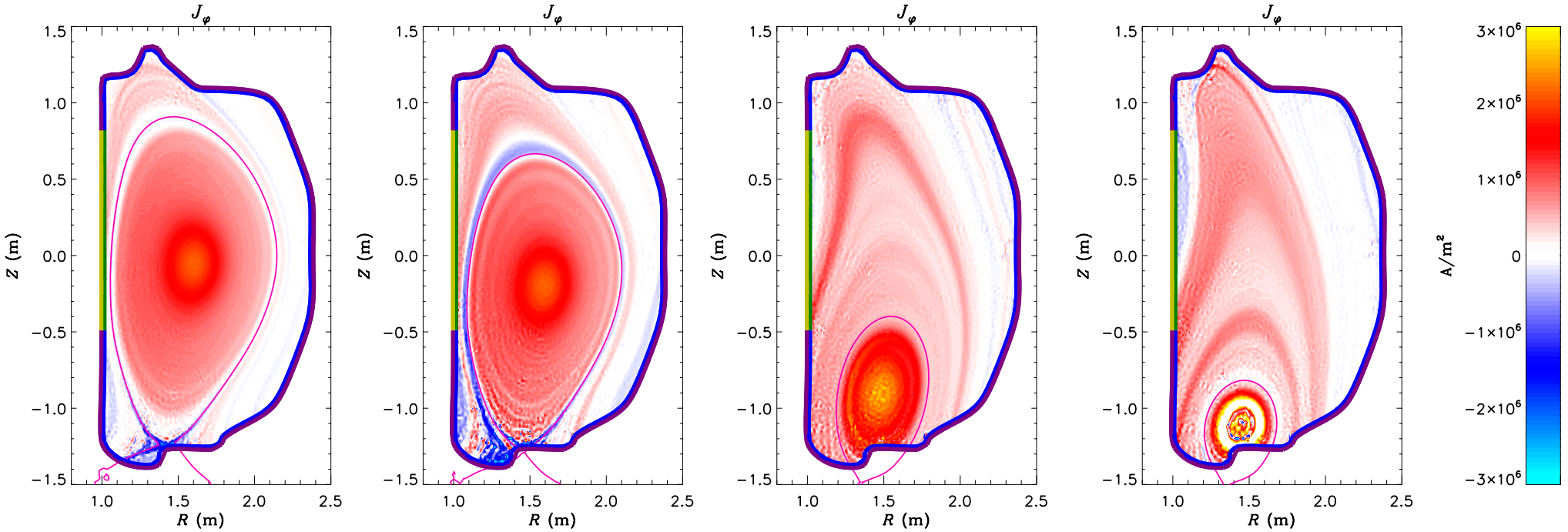


- **At some point during the TQ, the plasma becomes vertically unstable**

Calculation Shows Vertical Displacement Into Lower Divertor

- **Both co-I_P and counter-I_P currents are seen in the open field-line region**

- **Plasma always moves to lower divertor, unlike in experiment**
  - Maybe due to different wall configuration?



$t = 2.27$ ms $t = 2.59$ ms $t = 2.92$ ms $t = 3.24$ ms

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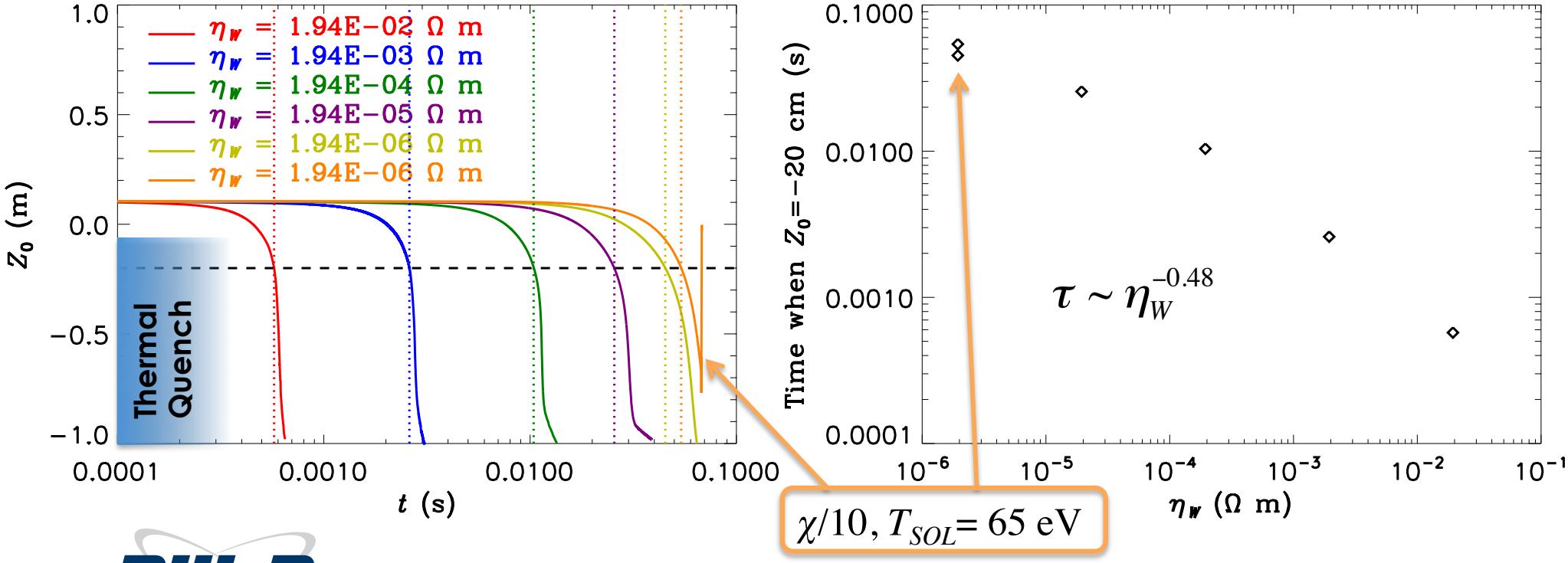
Timescale of VDE Scales Inversely with $(\eta_W)^{1/2}$

- **Given wall thickness** $\delta = 2$ cm **and a poloidal scale length** $d =$ 50 cm, **resistive wall diffusion times range from** ~6.5 ms **to** ~0.65 μs

- **VDE timescale is longer than resistive wall time**
  - Doesn't seem strongly affected by T_{SOL}; need more cases

$$\tau_W = \frac{\mu_0 d \delta}{\eta_W}$$



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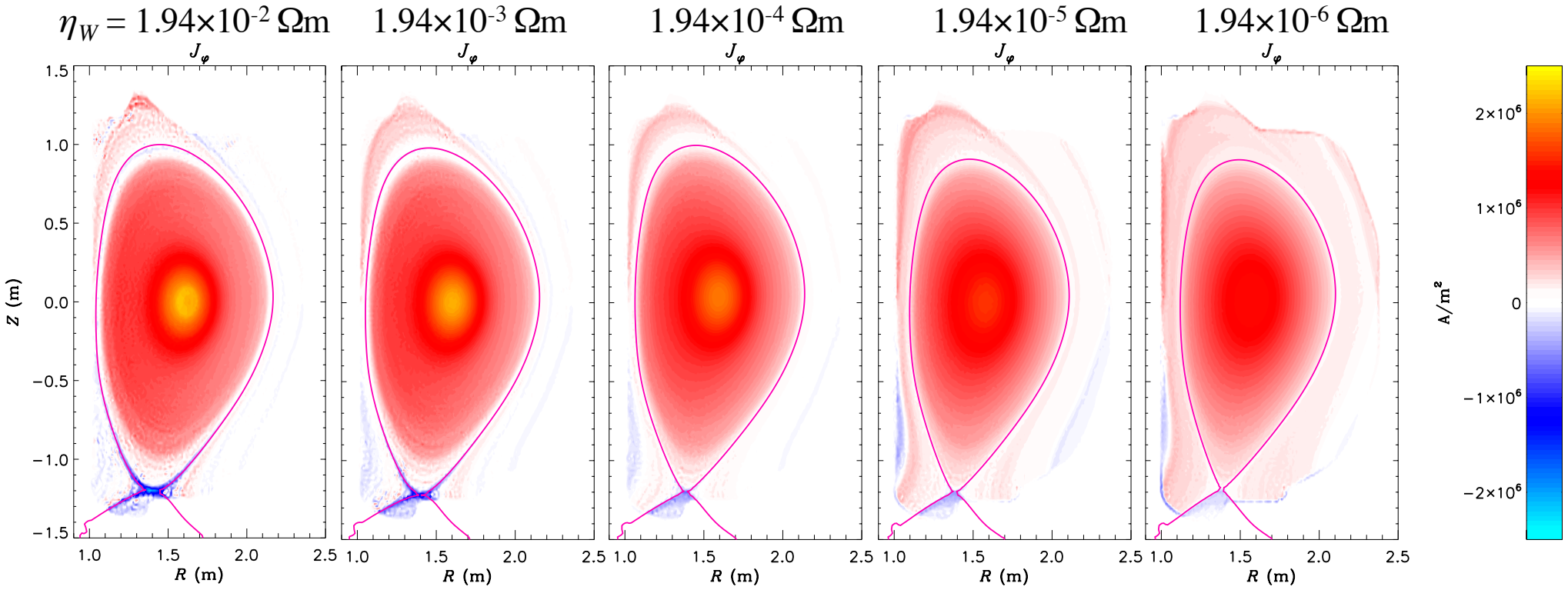
Currents in Wall and Open Field-Line Region Change with η_W

- At early stage of VDE, currents in the wall are stronger at lower η_W
- Counter-I_p currents are significantly stronger at higher η_W



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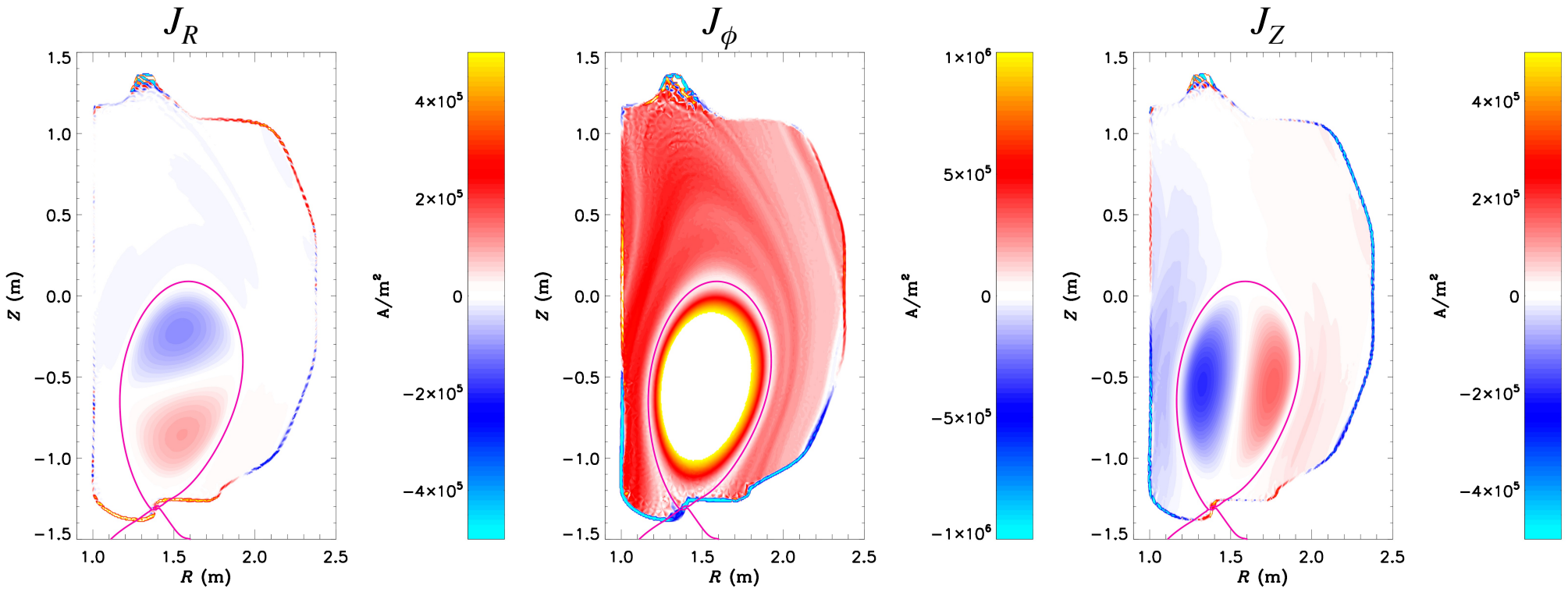
Wall Currents are Mostly Inductive

- **Currents are also present in the open field-line region**
  - Magnitude may be an artifact of high T_e in the open field-line region
  - Current flows from plasma to wall to ensure $\nabla \cdot \mathbf{J} = 0$
- **Wall currents are consistent with excluding poloidal flux**



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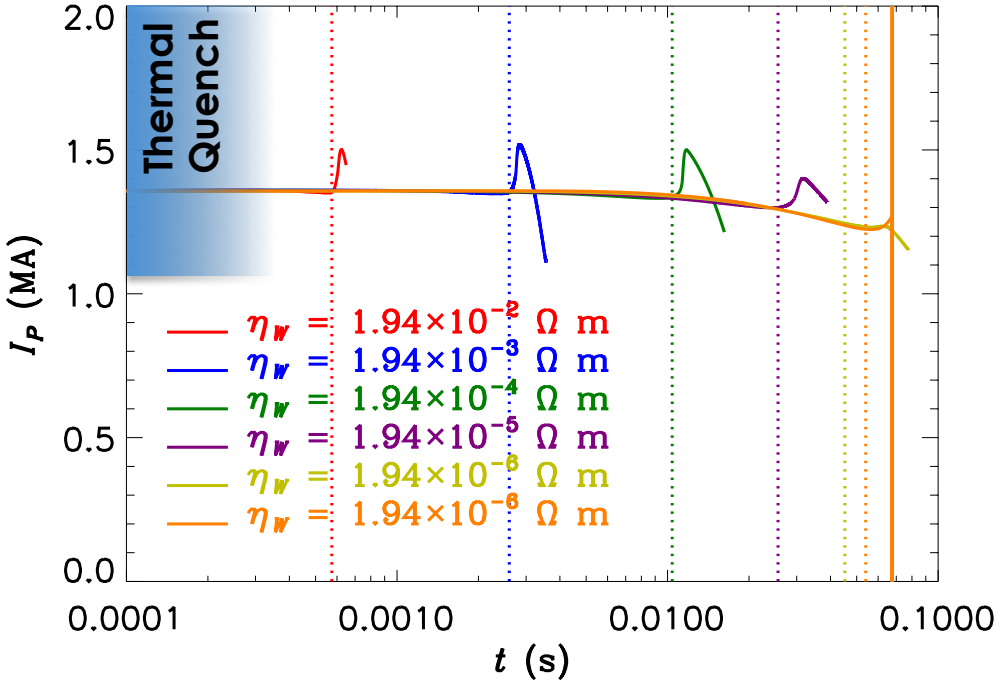
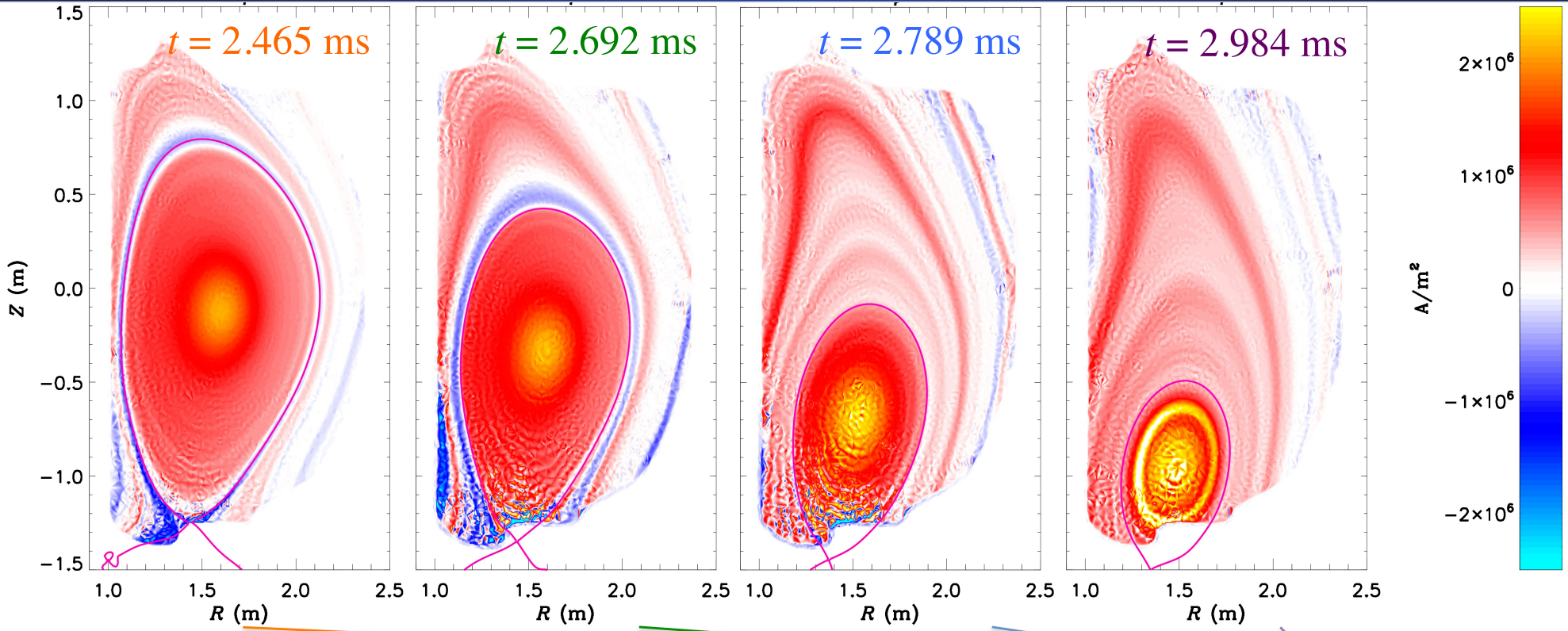
Current Spikes Observed Before Current Quench; Associated with Vertical Motion of Plasma

- **Current spike onset is correlated with vertical motion of plasma, unlike TQ**

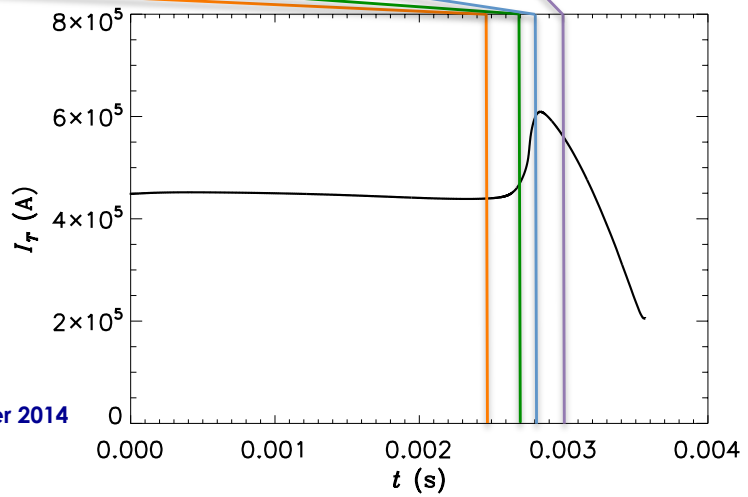


- "I_P" here only includes all toroidal current in the plasma region, but not in the resistive wall
- Spike is significantly diminished when $\eta_W < \eta_{SOL}$

Current Spike is Associated With Loss of Counter-I_P Current In Open Field-Line Region



$$\eta_W = 1.94\times10^{-3}\ \Omega\ \mathrm{m}$$



- **Plasma undergoes rapid contraction during current spike**

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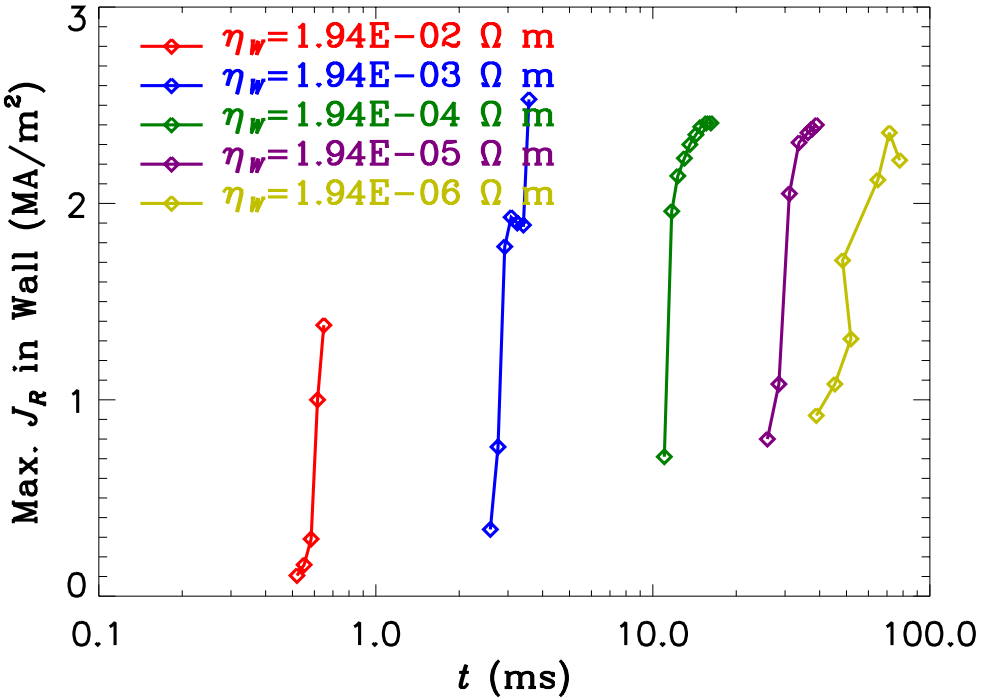
Max Poloidal Current in Wall Depends Weakly on η_W

- **Maximum J_R occurs during current quench, when plasma is limited by lower divertor**
- **Maximum J_R is roughly $2–2.5\ \mathrm{MA/m^2}$ in this case**
  - Corresponds to $F_Z \sim 500\ \mathrm{kN}$ over ~$50\ \mathrm{cm}$ of the lower divertor
- **Impulse to vessel depends on η_W because time scale changes**



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Summary

- **Resistive wall model in M3D-C1 seems to be working properly in 2D**
  - Axisymmetric nonlinear & complex linear
  - Realistic transport parameters and timescales

- **VDE calculations show how response currents flow in plasma and vessel**
  - Timescale of VDE scales roughly as $(\eta_W)^{1/2}$
  - Maximum current & force in vessel is weakly dependent on η_W → impulse decreases with η_W
  - A spike in the total current in the plasma region before the CQ is associated with the plasma contacting the wall; gets smaller when $\eta_W < \eta_{SOL}$

- **Next step: 3D**
  - Axisymmetric nonlinear, with periodic non-axisymmetric linear checks
  - Start 3D nonlinear calculation when non-axisymmetric instability found

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