Part II. Perfect conducting first wall

Recently. Boozer has claimed (with a simple model) that, **even in a perfect conducting ITER first wall limit**:

- a cold VDE could occur (no active controls will be effective in this situation) and
- q(a) could drop down to ~2 even when the plasma current is still large ($I = \sim 0.75\ I_0$ -- 11.25 MA for ITER --), therefore allowing halo currents to emerge.

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Halo currents and vertical displacements after ITER disruptions

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Two features of the walls[6] surrounding the ITER plasma make vertical displacement events different from those in any existing tokamak with a divertor. (1) The first wall, the closest structure to the ITER plasma, has what are called "fingers" to quickly transfer currents—induced or halo—to the blanket modules. This reduces the forces on the first wall but makes the effective conducting wall the blanket modules, which are further from the plasma. If a vertical displacement event pushed plasma into the spaces between the fingers and allowed currents to flow between them, large and potentially unacceptable forces could be exerted on the first wall. (2) The electrical conductivity of the blanket modules is sufficiently great to

Boozer's models

Circular cross-section large aspect-ratio approximation:

$$q = \frac{2\pi B_t a^2}{\mu_0 R I} \rightarrow \left(1 - \frac{|\delta|}{b}\right)^2 \frac{q_0 I_0}{I} \qquad \delta = Z_{mag}(t) - Z_{mag}(0)$$

Boozer's perfect-conductor-limit model:

Boozer uses this expression in a simplified VDE problem and gets:

$$\frac{q}{q_*} = \left(1 - \frac{|\delta|}{b}\right)^2 \frac{I_*}{I}$$

$I_* q_* = I_0 q_0$ leads to the previous result. But, from the force balance, he gets

$$\frac{I_*}{I} = 1 + 0.8225 \frac{\delta^2}{b^2}$$

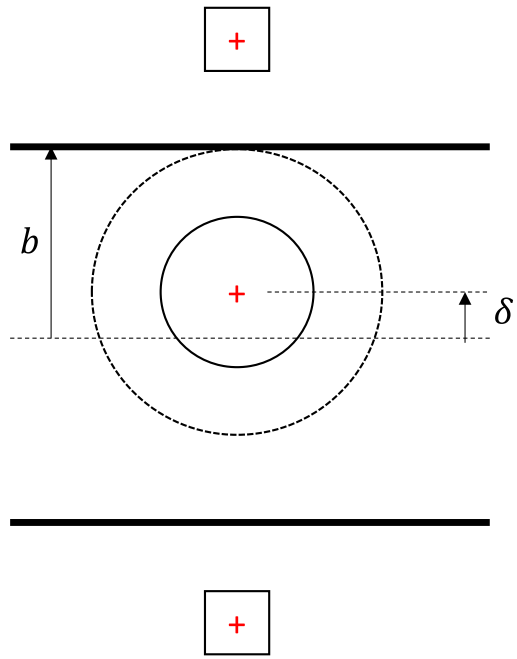
And I_* can be expressed as (bx is the x-point position)

$$\frac{I_0}{I_*} = 1.2337 \frac{{b_{x0}}^2}{b^2}$$

Example (ITER): if $\frac{b_{x0}}{b} = 1 \rightarrow I_* = 0.81 I_0 = 12.2$ MA

We need to define bx/b

Combining all this we can get
$q = q(|\delta(t)|/b)$

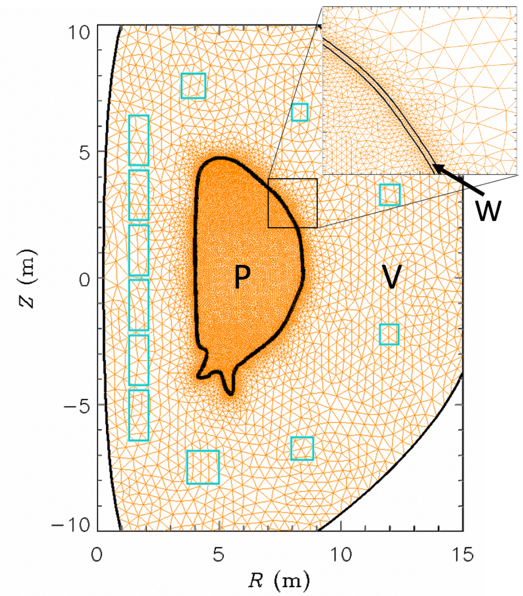


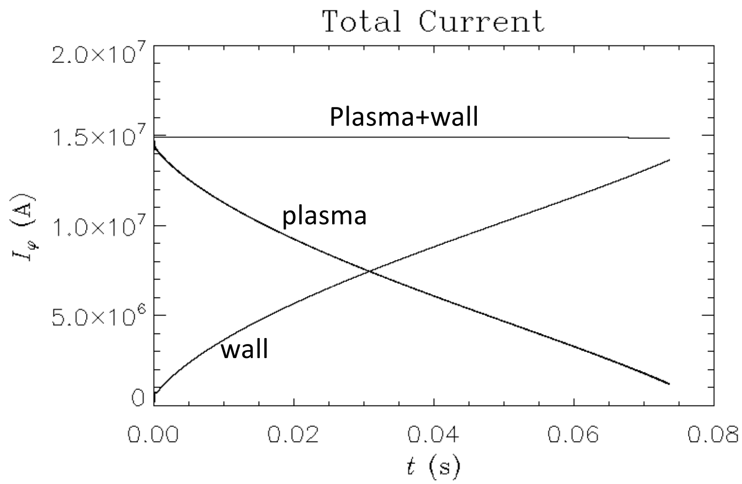
Wall current is calculated with the image method.
DOES NOT consider CQ induction!

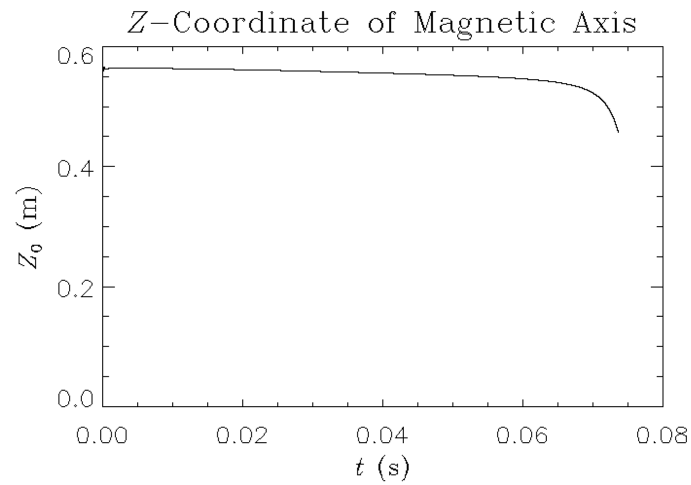
ITER – thin wall – ideal wall limit– Cold VDE

We explore a case in which the first wall acts as an ideal conductor

TQ was initiated at the beginning → Te falls from 25 keV down to 30 eV (this triggers the Current quench)

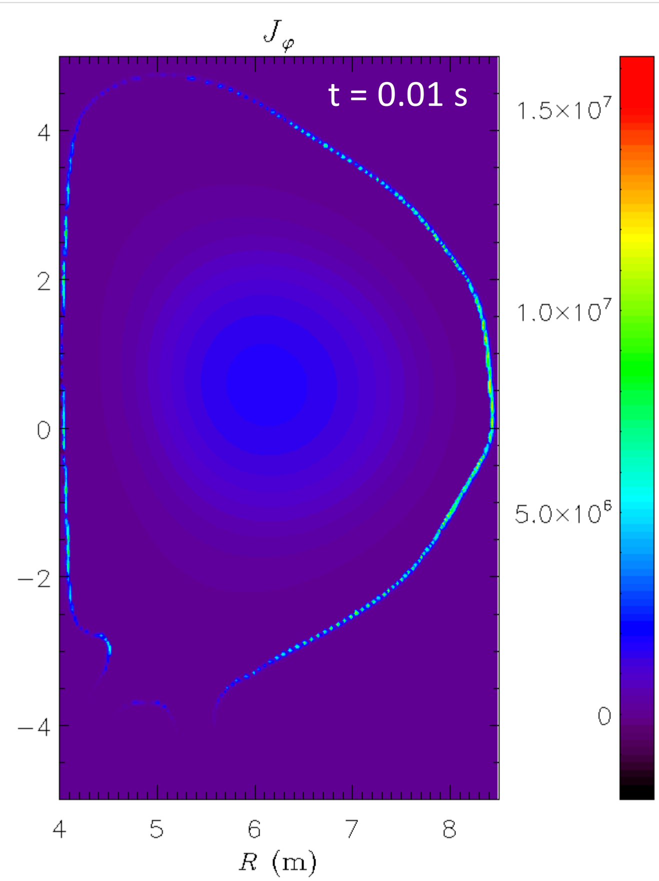






We found that this case is very stable!

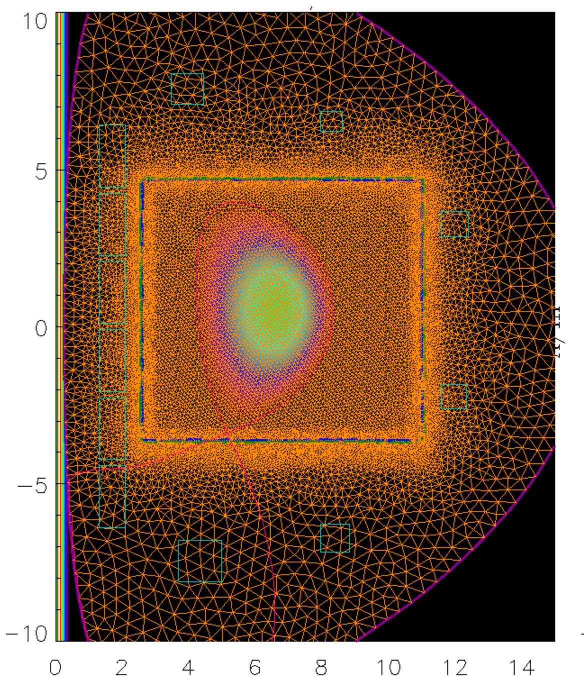
ITER – thin wall – ideal wall limit– Cold VDE



Current quench induction is very important in the side walls

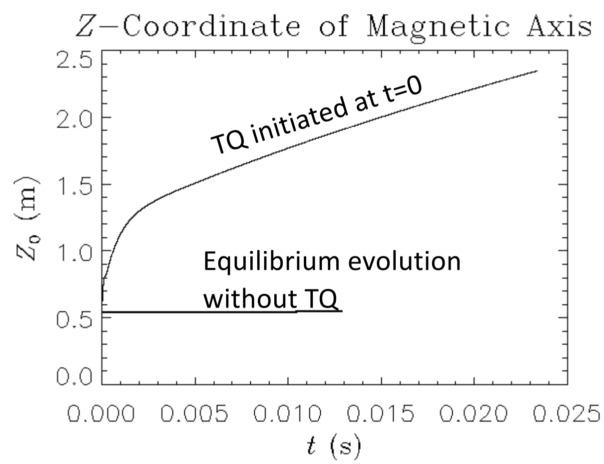
Approaching to Boozer's model: Rectangular wall

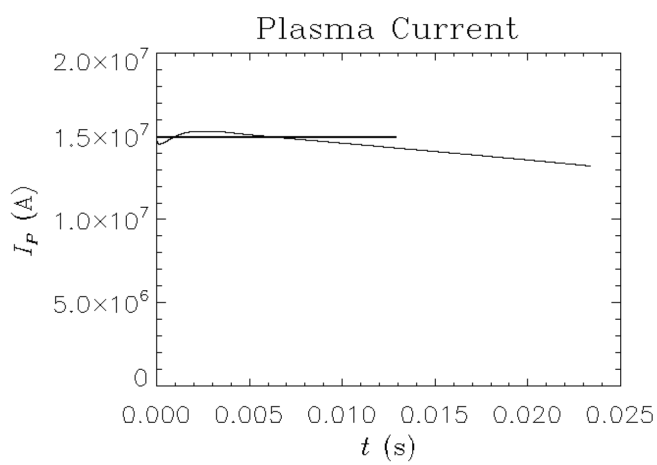
To approach the Boozer's model, we simulate a VDE with a very conductive rectangular wall. Side walls are placed as far as possible



- Top/bottom walls are equidistant to the magnetic axis
- Separatrix (bx/b) is ~ 1
  - With this assumption, I_* ~ 0.81 I_0 = 12.1 MA

We initiated a TQ at t=0 in order to produce a CQ.



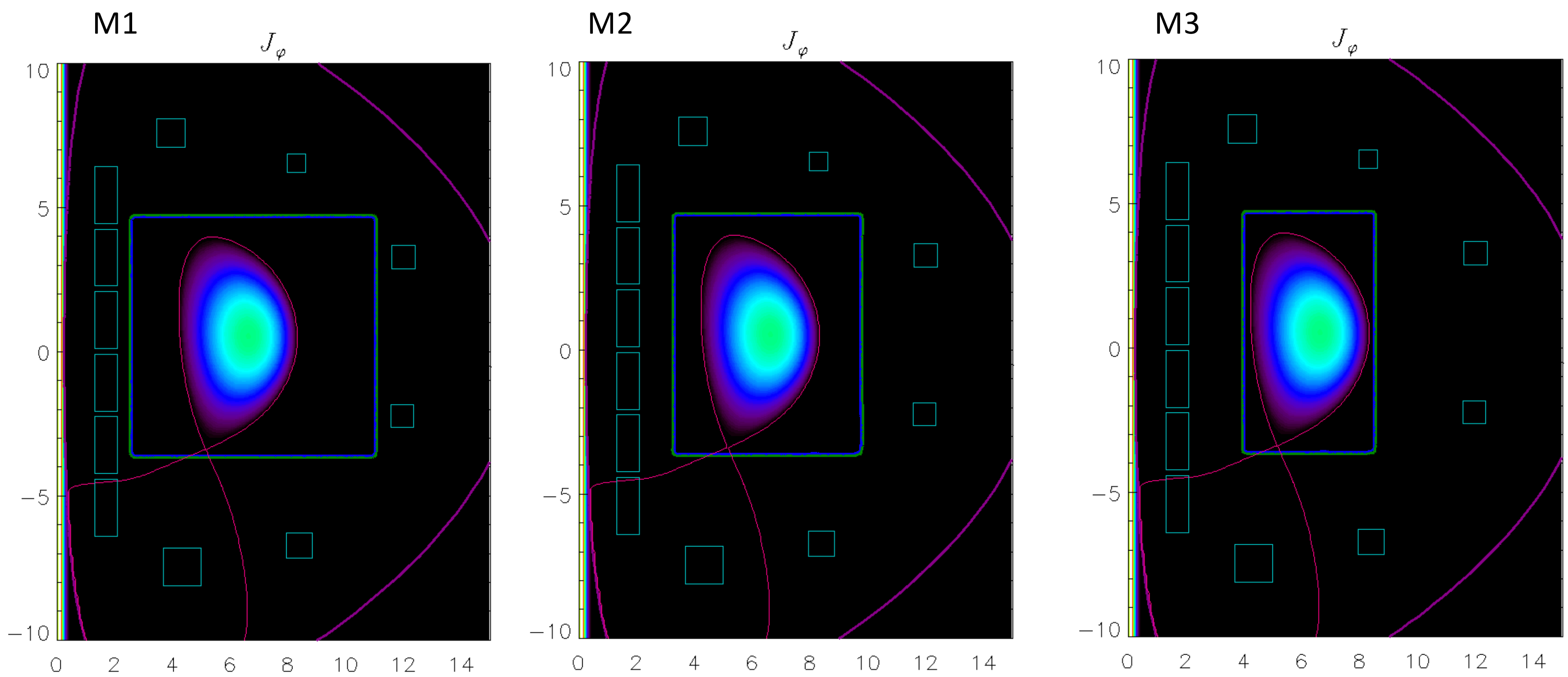


With a TQ, the result is unstable even when 'Ip' > I_*

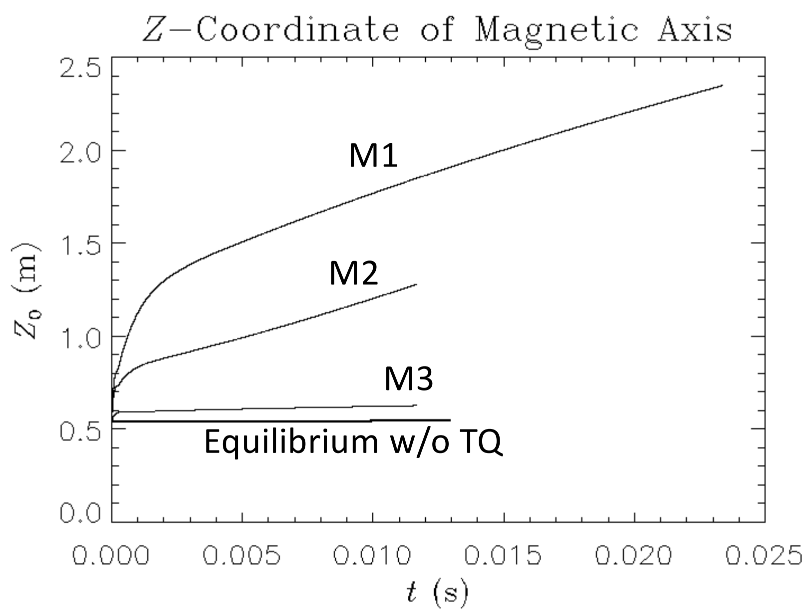
Elongation seems to play a role even in the ideal conducting wall limit (?)

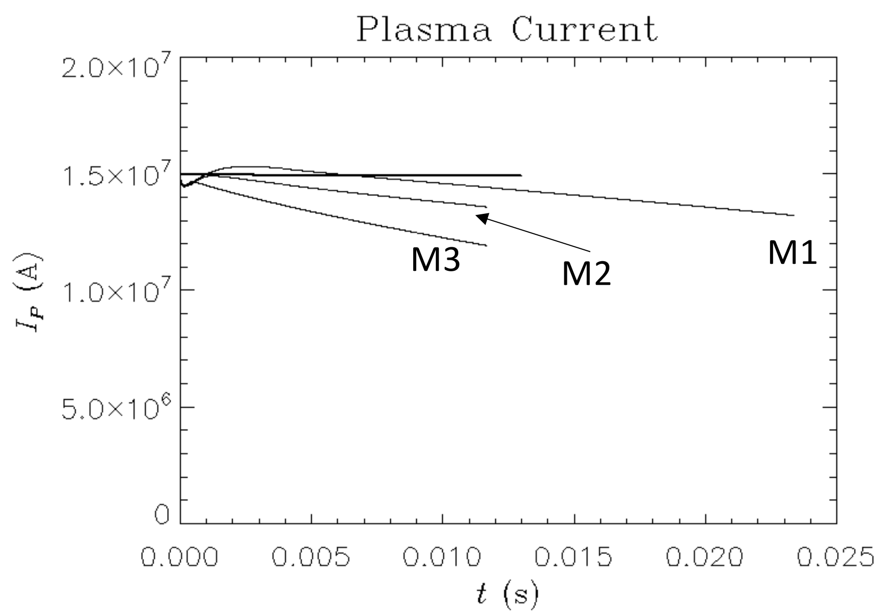
Approaching to Boozer's model: Rectangular wall

Bringing the side walls closer improves the stability



Approaching to Boozer's model: Rectangular wall





Bringing the side wall closer improves the stability (as already shown with ITER first wall model)

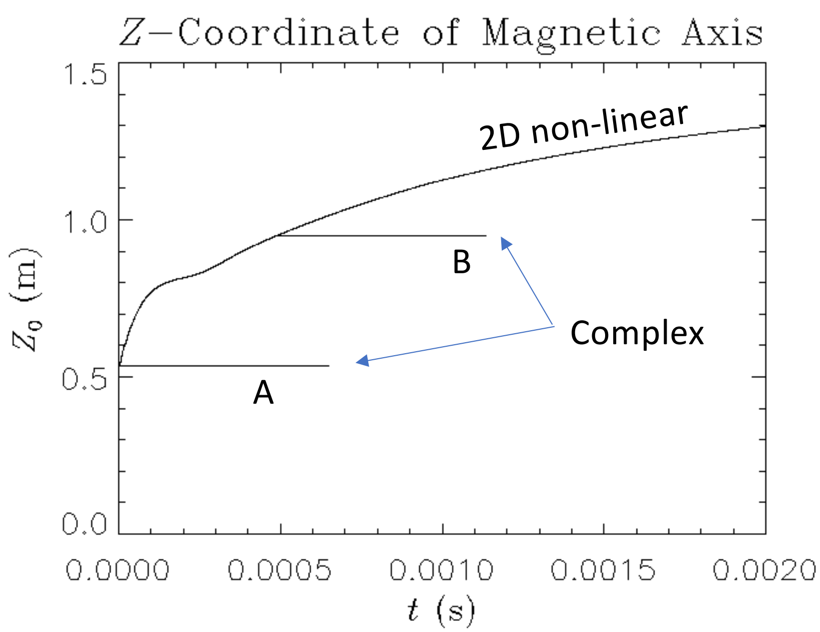
BUT… ALL OF THEM STILL SEEM TO BE UNSTABLE (EVEN M3)

So… Are the initial configurations ideally unstable?

We ran the linear version of the code and we found that

M1 equilibrium is stable under small perturbation (Case A in figure)

Z growth rate = 0. (eps = 1.e-3)



Is the COMPLEX version set appropriately?

- Case A is the evolution of the equilibrium
- Case B is a restart from a 2D non-linear run. I was expecting here to find it unstable.

C1input changes from 2D to Complex (case B):

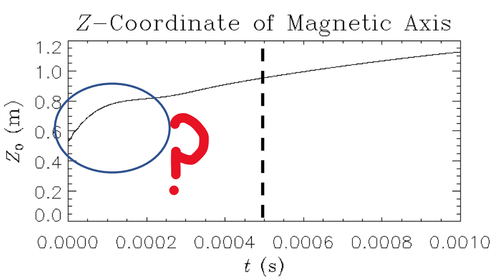
- irestart = 1 → 3
- imp_bf = 0 → 1
- linear = 0 → 1
- eps = 1.e-8 → 1.e-2
- ntor = 0

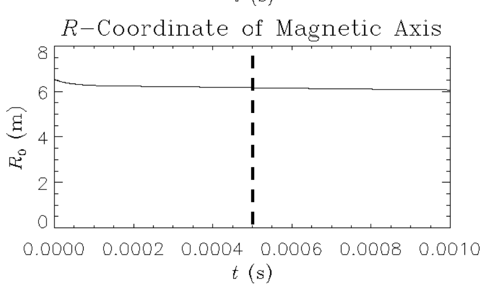
So… Are the initial configurations ideally unstable?

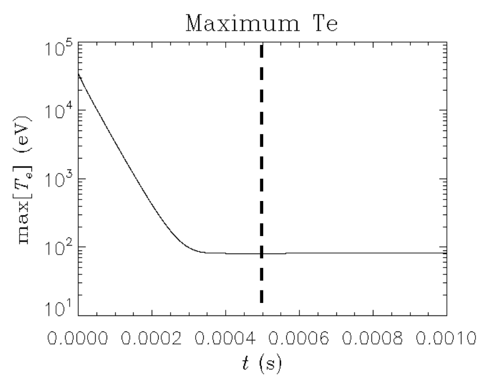
We ran the linear version of the code and we found that M1 equilibrium is stable under small perturbation

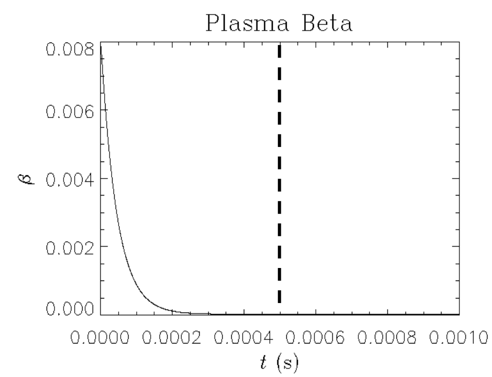
Z growth rate = 0. (eps = 1.e-3)

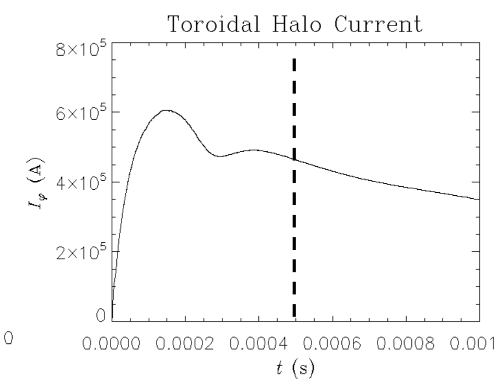
However… when setting a TQ, the plasma gets an initial displacement that might lead it to an ideally instable condition.











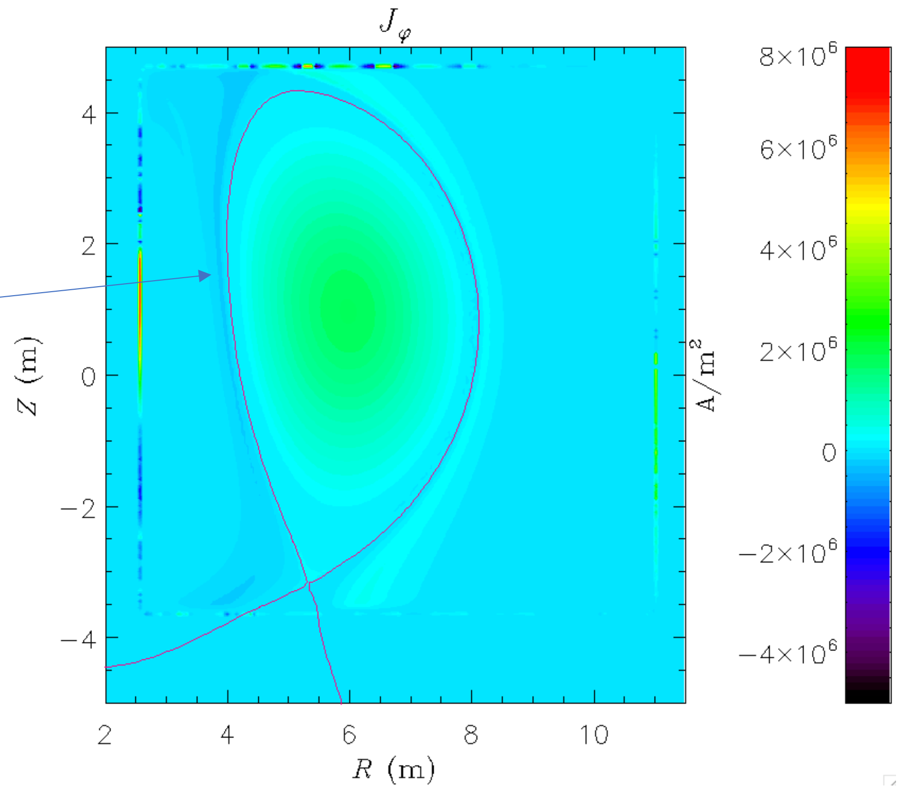
Dash line is the time for TS1 (next slide)

Halo currents seem to be significant during this phase

Current densities at TS=1 (t=0.49 ms)

Since the side walls are far away, part of the 'response' due to plasma changes is produced in the open field line region

Negative toroidal Halo currents (repelling the small inward motion?)

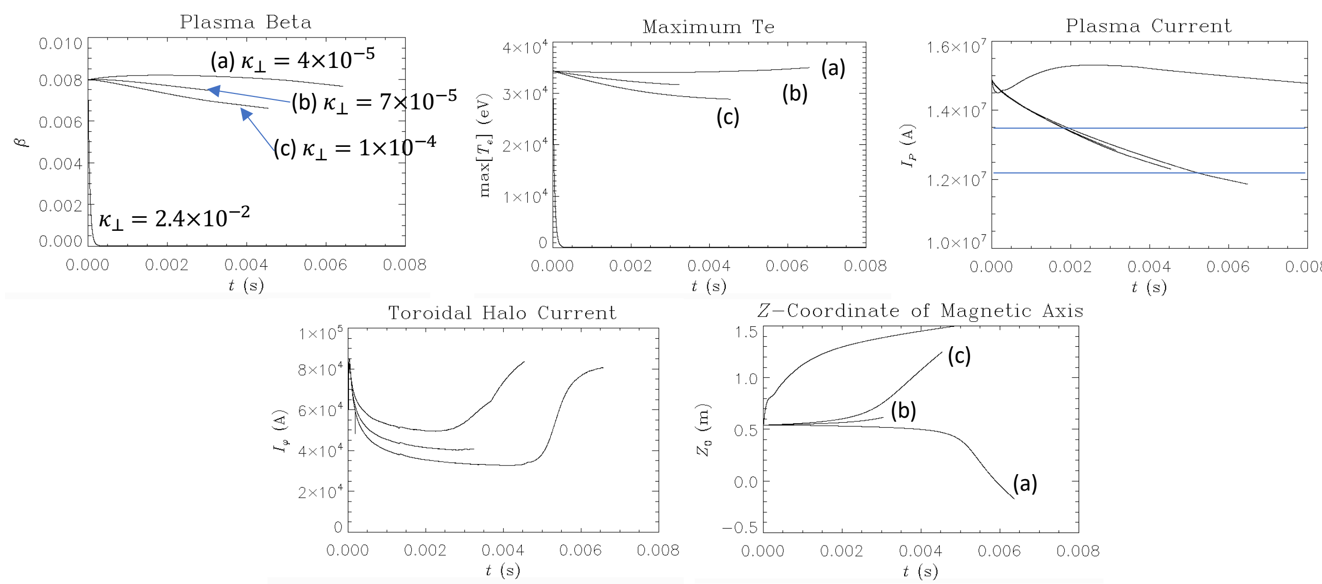


So… can we produce a CQ w/o dropping β and w/o halo currents?

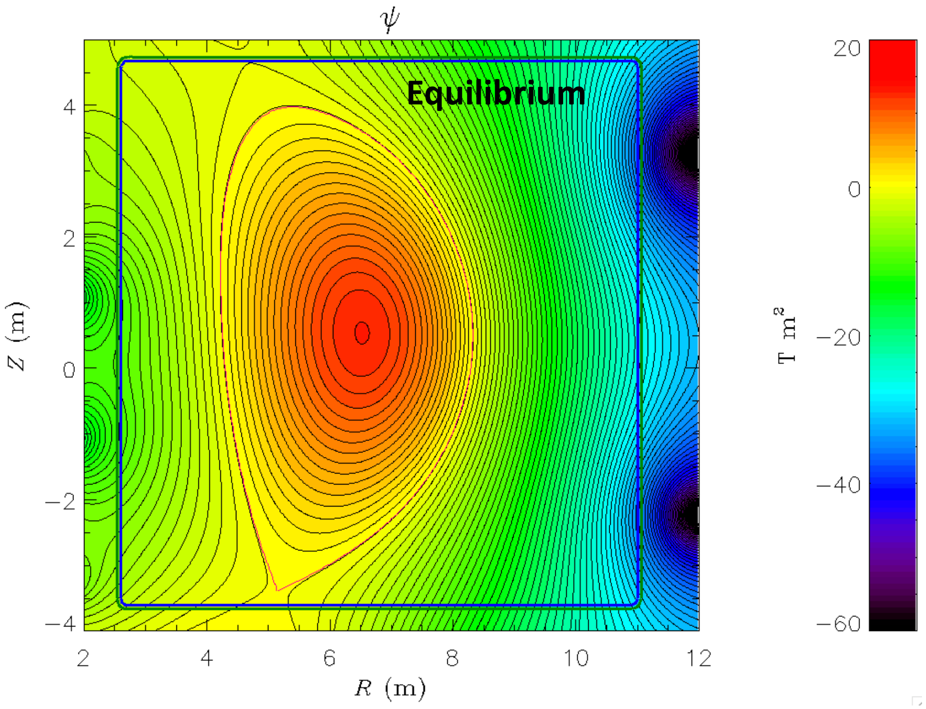
Thermal quench produces a fast drop in plasma beta. This contracts the plasma and also heats the halo region. Even with a very high kappar, some halo can emerge during the TQ.

To avoid this. We started a series of simulation:

- **No Thermal quench**
- **Increasing eta_fac = 1 → 10e5** to induce a current quench.
- **Kappa_perp is slightly adjusted** to balance ohmic heating from the CQ.



Comparing with Boozer's model



$$\frac{I_0}{I_*} = 1.2337\,\frac{{b_{x0}}^2}{b^2} \qquad z_{mag,0} = 0.54$$

lower x-point

$z_{x0} = -3.38,\ z_b = -3.6$

Therefore

$$\frac{b_{x0}}{b} = 0.95 \qquad I_* = 0.9 I_0 = 13.5 \text{ MA}$$

upper x-point

$z_x = z_b = 4.67$

Therefore

$$\frac{b_{x0}}{b} = 1.0 \qquad I_* = 0.81 I_0 = 12.2 \text{ MA}$$