Fluid Modelling of the Far-SOL Region (Status and preliminary results)

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Project Plan and Status

- Goal: To **extend fluid modelling up to the physical outer wall** (interesting for, e.g., ICRH)

  ⬇

  Couple ASPOEL code (development @ PoliTo based on Control Volume/Finite Elements) for far-SOL, with B2, for near-SOL

- Test case here: ASDEX Upgrade
  – Take inner boundary conditions from a B2 well converged case (frozen, i.e. not yet self-consistent)
  – First simulation is running but not completed ➔ Preliminary results to be presented

ASPOEL Model

Simplified two-fluid model (under development)

$$\frac{\partial n}{\partial t} + \nabla \cdot \left(n\overline{V} \right) = S_n$$

$$n_e = n_i = n$$

$$\frac{\partial \Gamma_{//,i}}{\partial t} + \overline{e}_{//} \cdot \left[\nabla \cdot \left(\overline{\overline{V_i \Gamma_i}} + p_i \hat{I} + \hat{\Pi}_i \right) \right] = S_{\Gamma_{//}}$$

$$n_i V_{r,i} = -D_r \nabla_r n_i$$

$$\frac{\partial}{\partial t}\left(\frac{3}{2} n_e T_e \right) + \nabla \cdot \left(\frac{5}{2} n_e T_e \overline{V}_e + \overline{q}_e \right) = -Q_{ei} + S_{E_e}$$

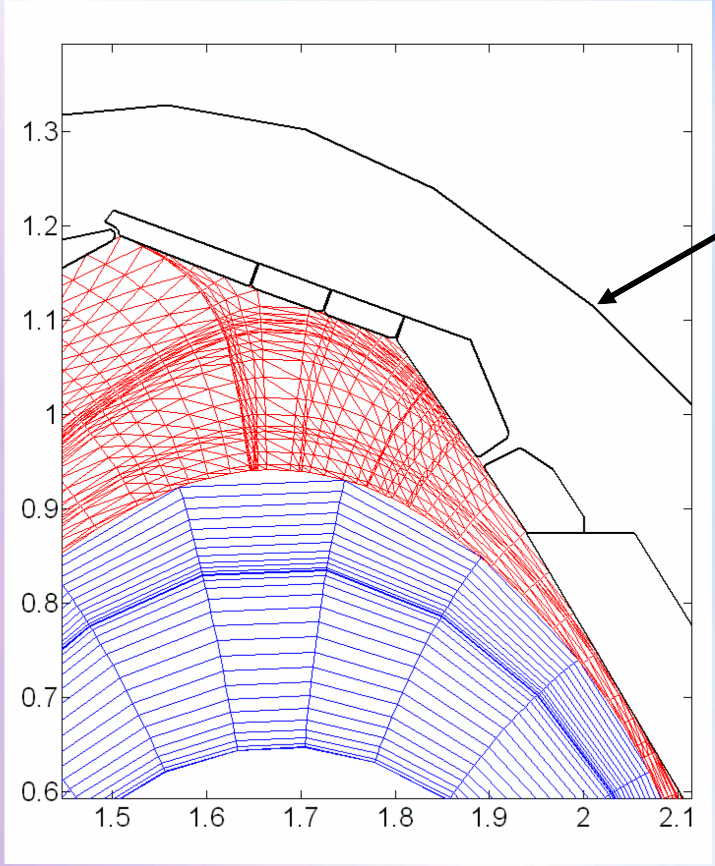
$$\frac{\partial}{\partial t}\left(\frac{3}{2} n_i T_i \right) + \nabla \cdot \left(\frac{5}{2} n_i T_i \overline{V}_i + \overline{q}_i \right) = Q_{ei} + S_{E_i}$$

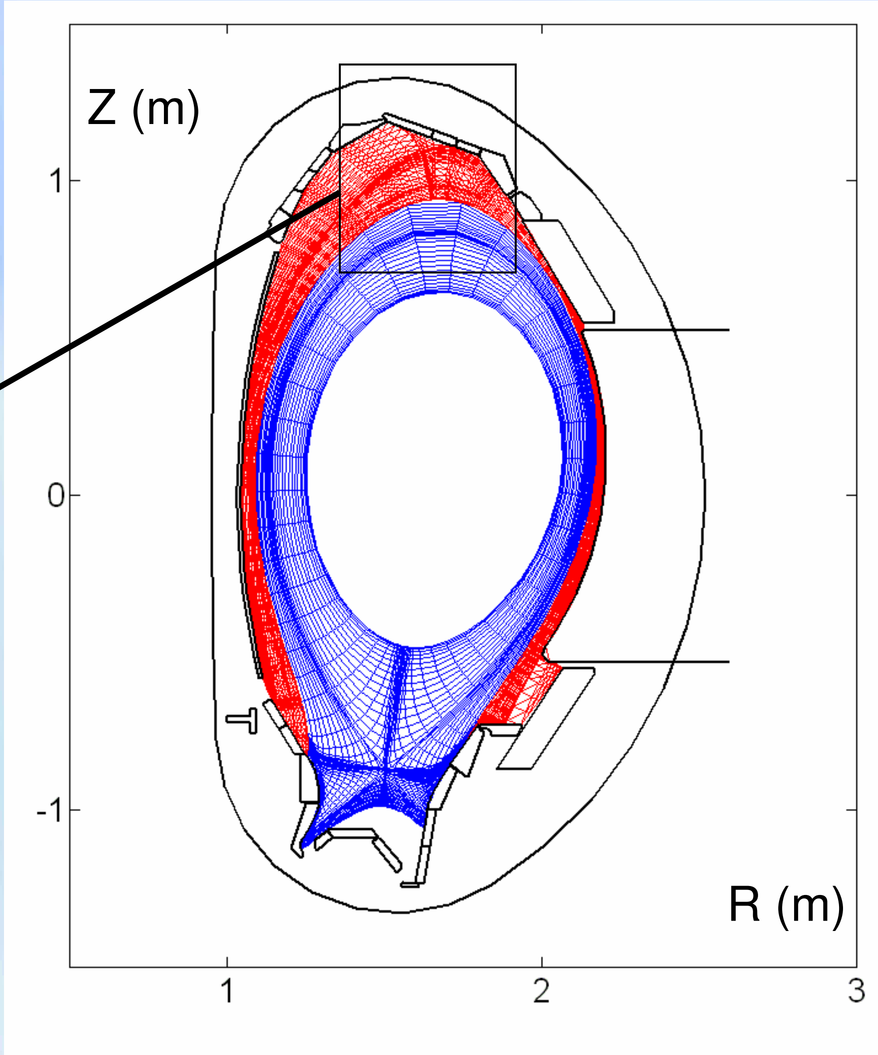
$$\overline{V}_e = \overline{V}_i$$

B2-ASPOEL Meshes

AUG shot # 18737 @ t = 4.7s

(selected by EFDA / ITER)

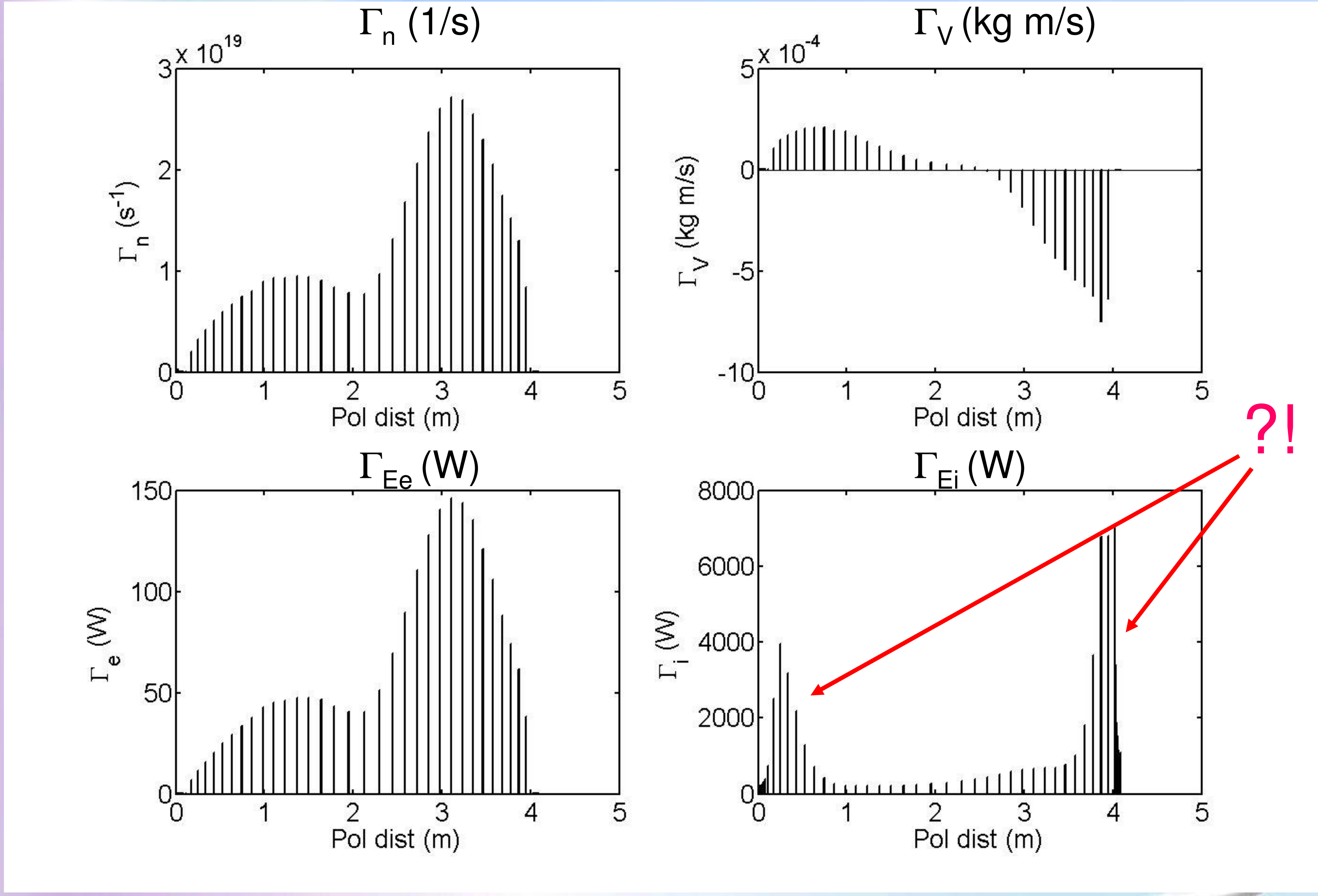




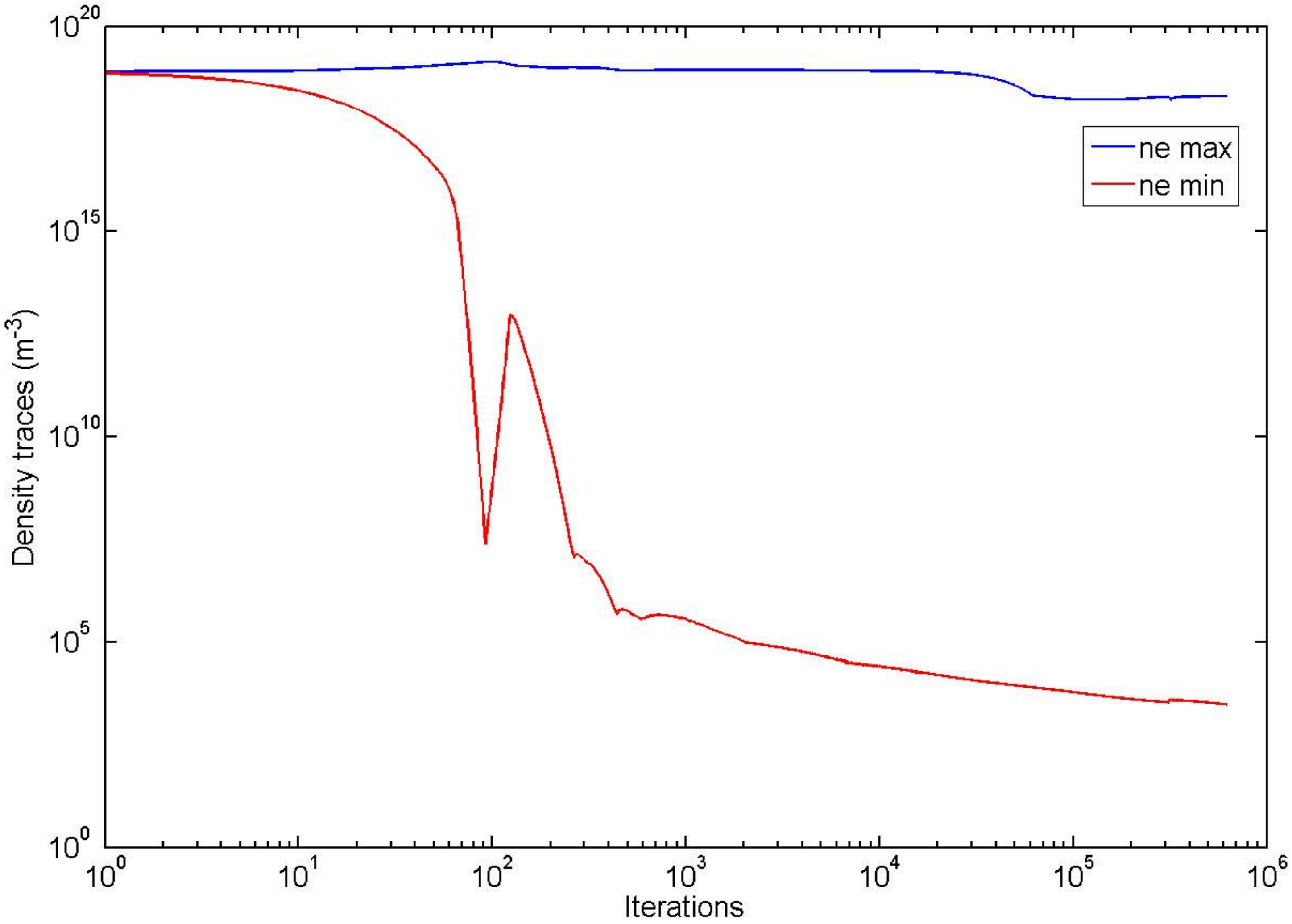
B2 mesh: 3724 cells

ASPOEL mesh: 6026 elements

Input Fluxes from B2

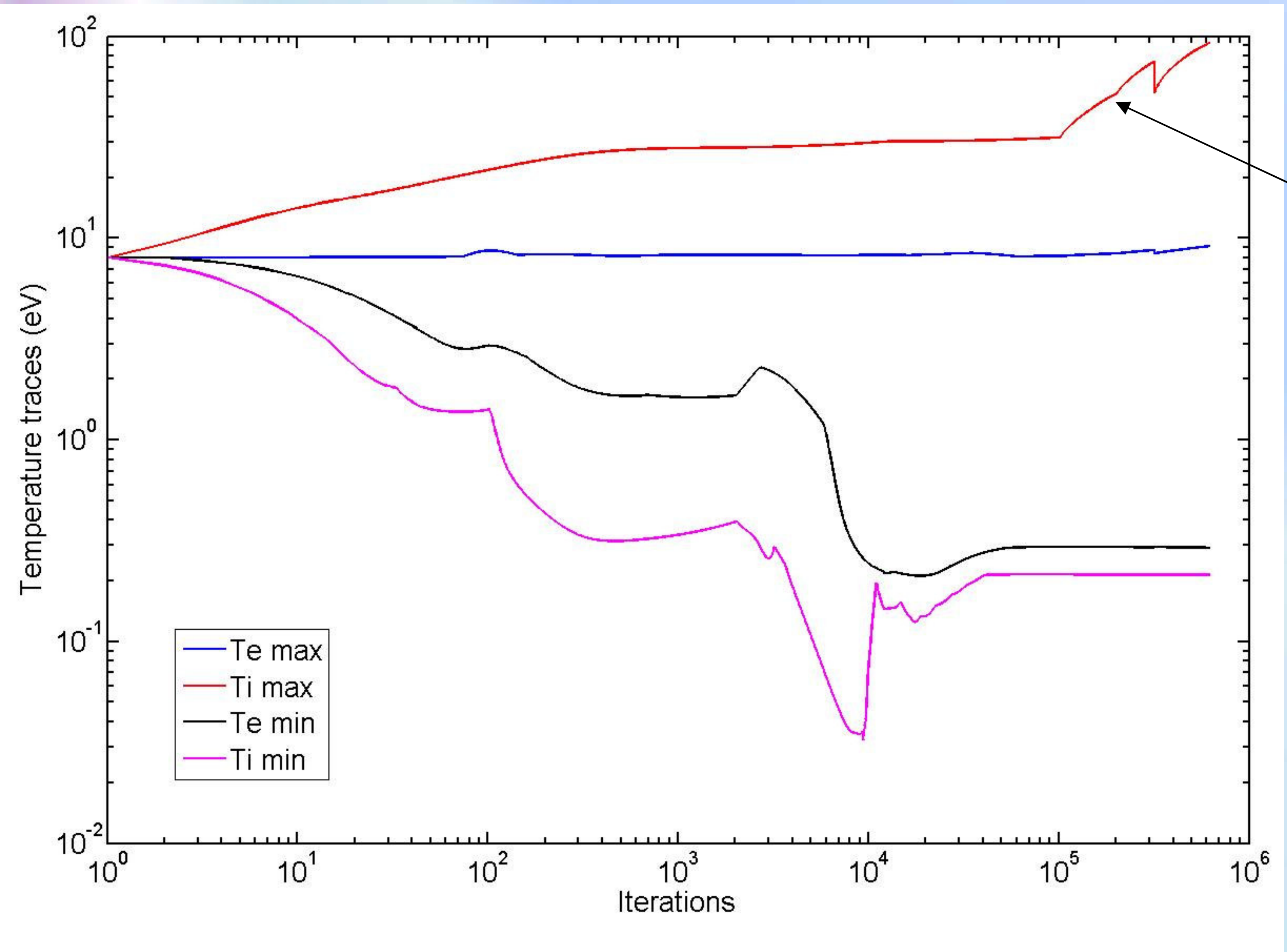


Density min/max evolution



Tend to stabilize for sufficiently many iterations

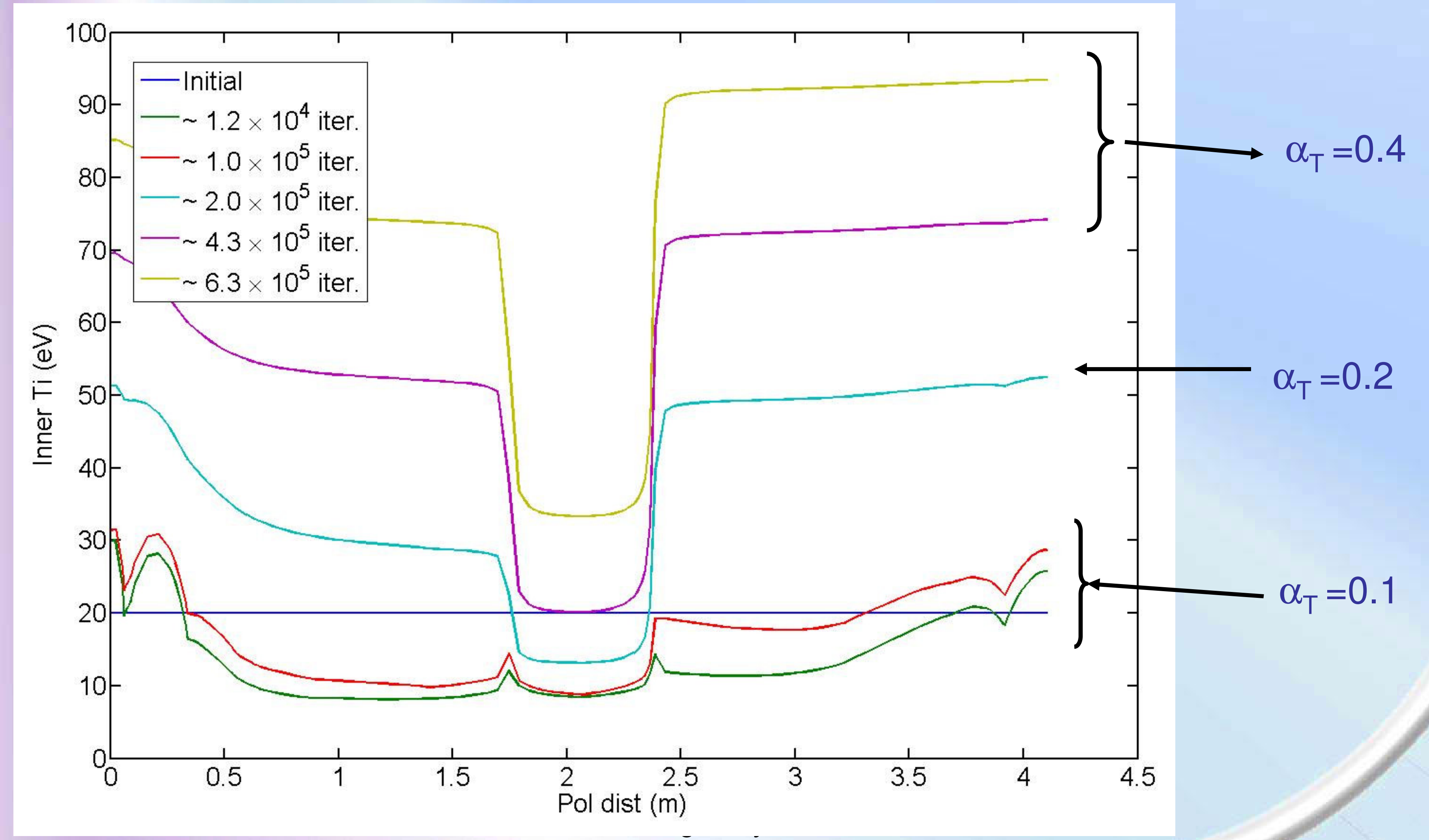
Ti min/max evolution



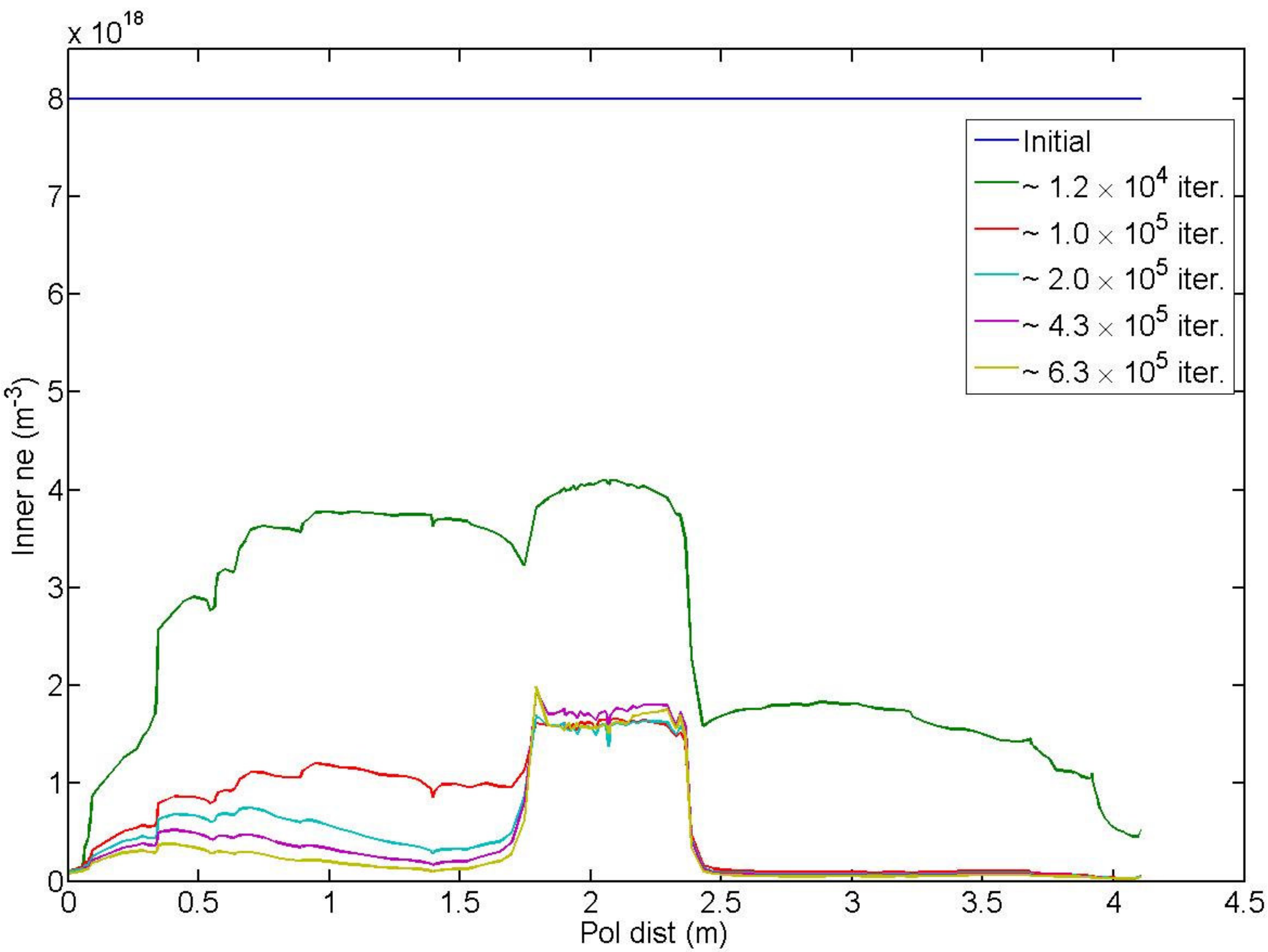
$T_i$max still increasing! 🡐

Maybe a problem from severe boundary condition at B2 interface + effect of relaxation parameter alphaT

T_i Inner Boundary Evolution



Density Inner Boundary Evolution

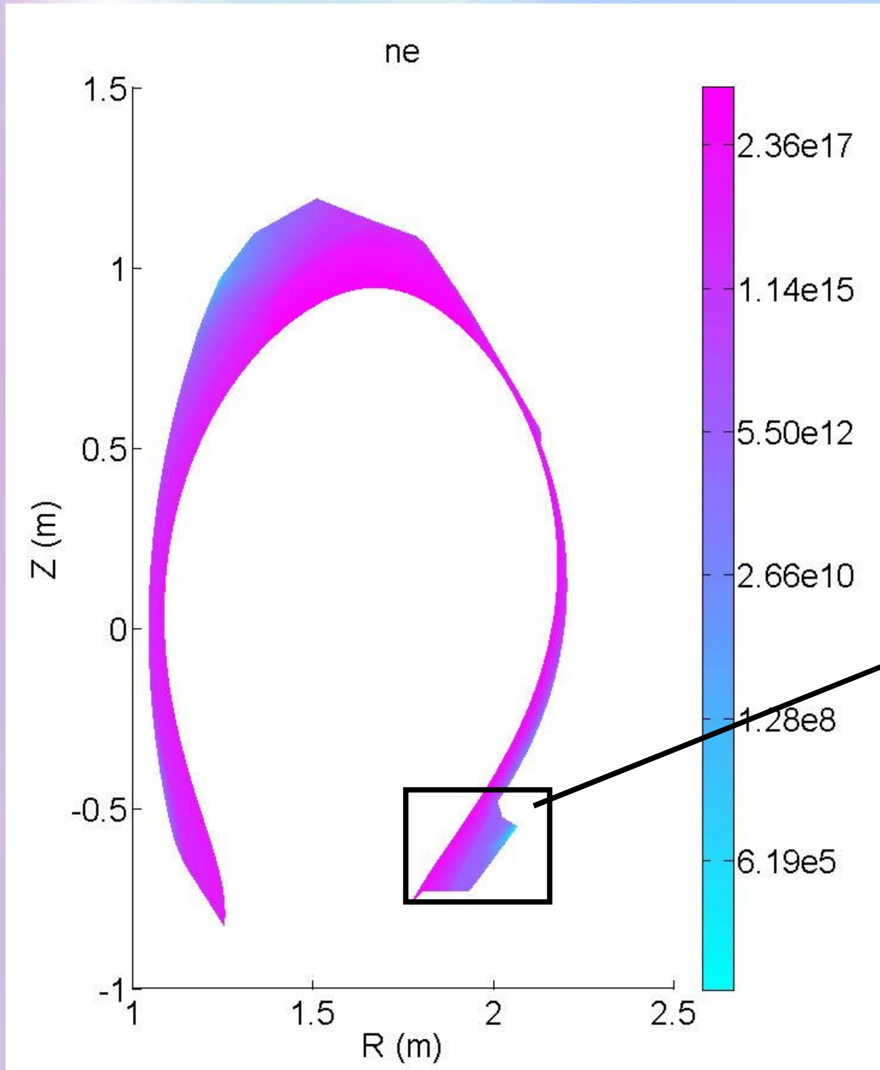


Slowly stabilizing

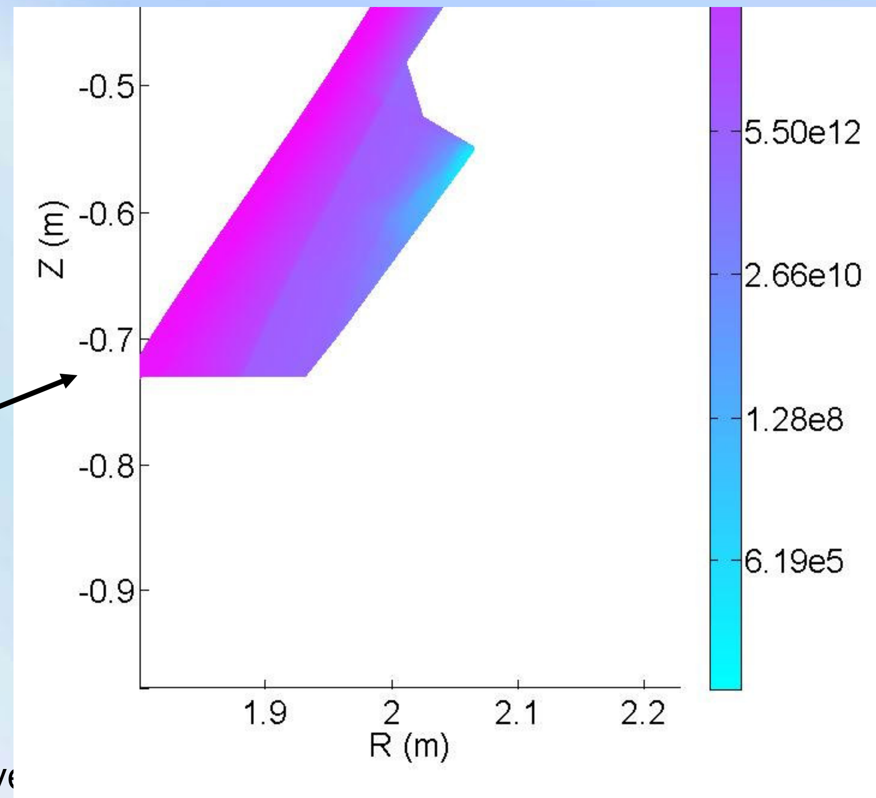
Global Conservation Check

- Particles:
  - Input/Output ~ 0.998 → OK
- Energy (ions + electrons, because of equipartition)
  - Input/Output ~ 6.38
    - Still far from convergence

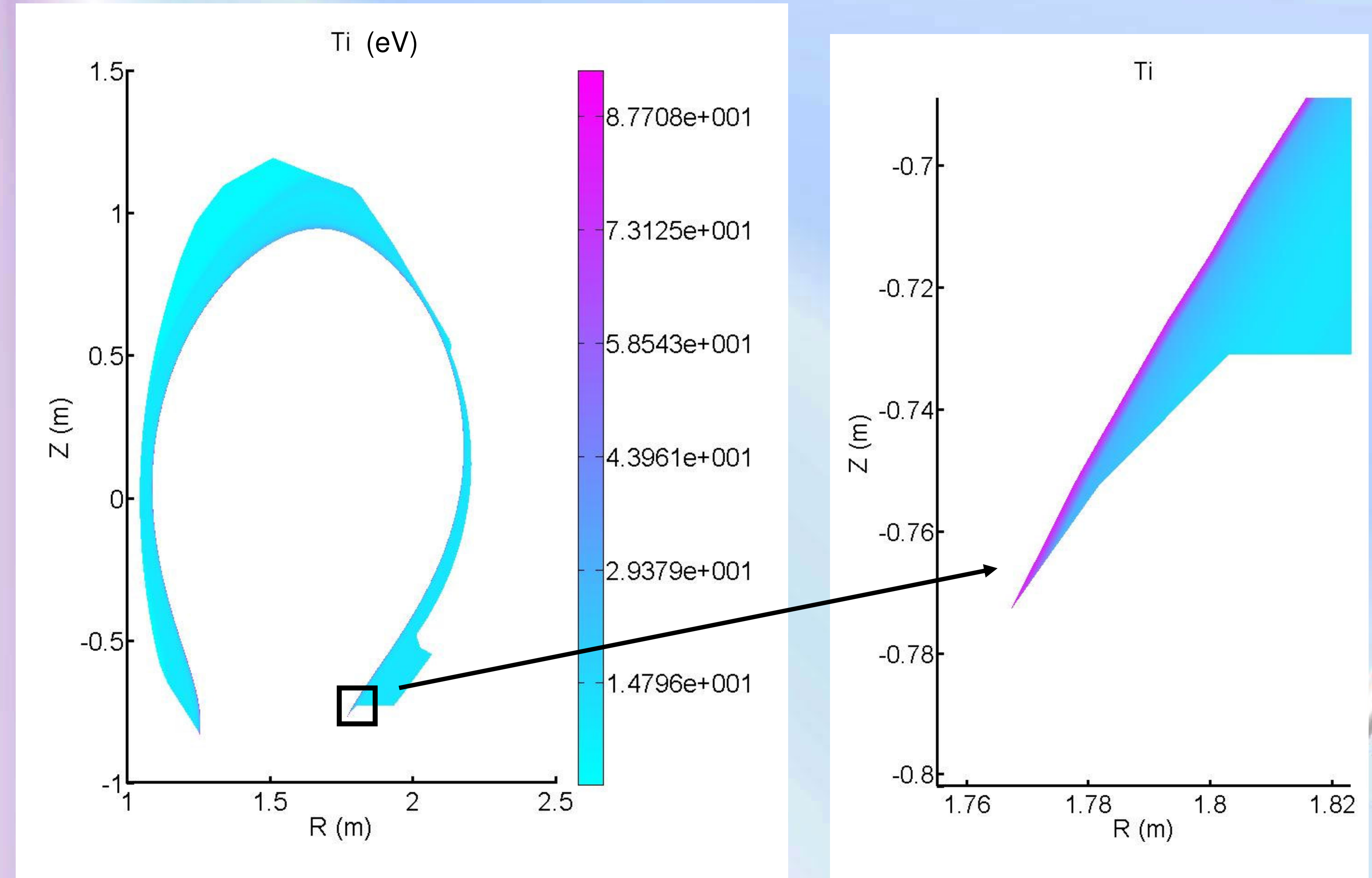
Ne View Log-scale



A minimum density develops in the most isolated domain region



Ti map



Ti (eV)
1.5
1
0.5
0
-0.5
-1
Z (m)
1
1.5
2
2.5
R (m)
8.7708e+001
7.3125e+001
5.8543e+001
4.3961e+001
2.9379e+001
1.4796e+001
Ti
-0.7
-0.72
-0.74
-0.76
-0.78
-0.8
Z (m)
1.76
1.78
1.8
1.82
R (m)

B2 Ion Heat Flux (I)

- B2 radial heat flux does not fit into the form

$$\frac{\Gamma_{E,i}}{S} = \frac{5}{2}\Gamma_n T_i - n\chi_{i,r}\frac{\partial T_i}{\partial r}$$

For example:

$\Gamma_n = nV_r \approx 4.3\times 10^{17}$ (1/m²/s) $\lambda_{T_i,r} = T_i/(\partial T_i/\partial r) = 0.5$ (m)

$T_i \approx 3.2$ (eV) $n \approx 6.4\times 10^{16}$ (m⁻³) $\chi \approx 0.5$ (m²/s)

$$\frac{\Gamma^i_{E,r}}{S} \approx 0.58 \quad \text{(W/m}^2\text{)}$$

B2 corresponding value: 26 (kW/m²) !!!

B2 Ion Heat Flux (II)

- Where does this difference come from?
  - The heat ion heat flux terms from ASPOEL and B2 might in principle be different

$$q_{iy} = \frac{3}{2} n T_i \frac{B_z}{B^2} \frac{1}{h_x} \frac{\partial \phi}{\partial x} + \frac{5}{2} n T_i \left(-\frac{D}{T_e + T_i} \frac{1}{h_y} \left(\frac{\partial p}{n \partial y} - \frac{3}{2} \frac{\partial T_e}{\partial y} \right) - D_{AN}^{n} \frac{1}{h_y n} \frac{\partial n}{\partial y} - D_{AN}^{p} \frac{1}{h_y n} \frac{\partial p_i}{\partial y} \right)$$

$$- n \chi_{iy} \frac{1}{h_y} \frac{\partial T_i}{\partial y} + \frac{5}{2} n T_i \tilde{V}_y^{(dia)}$$

Not strictly equal to

$$\frac{5}{2} \Gamma_n T_i - n \chi_{i,r} \frac{\partial T_i}{\partial r}$$

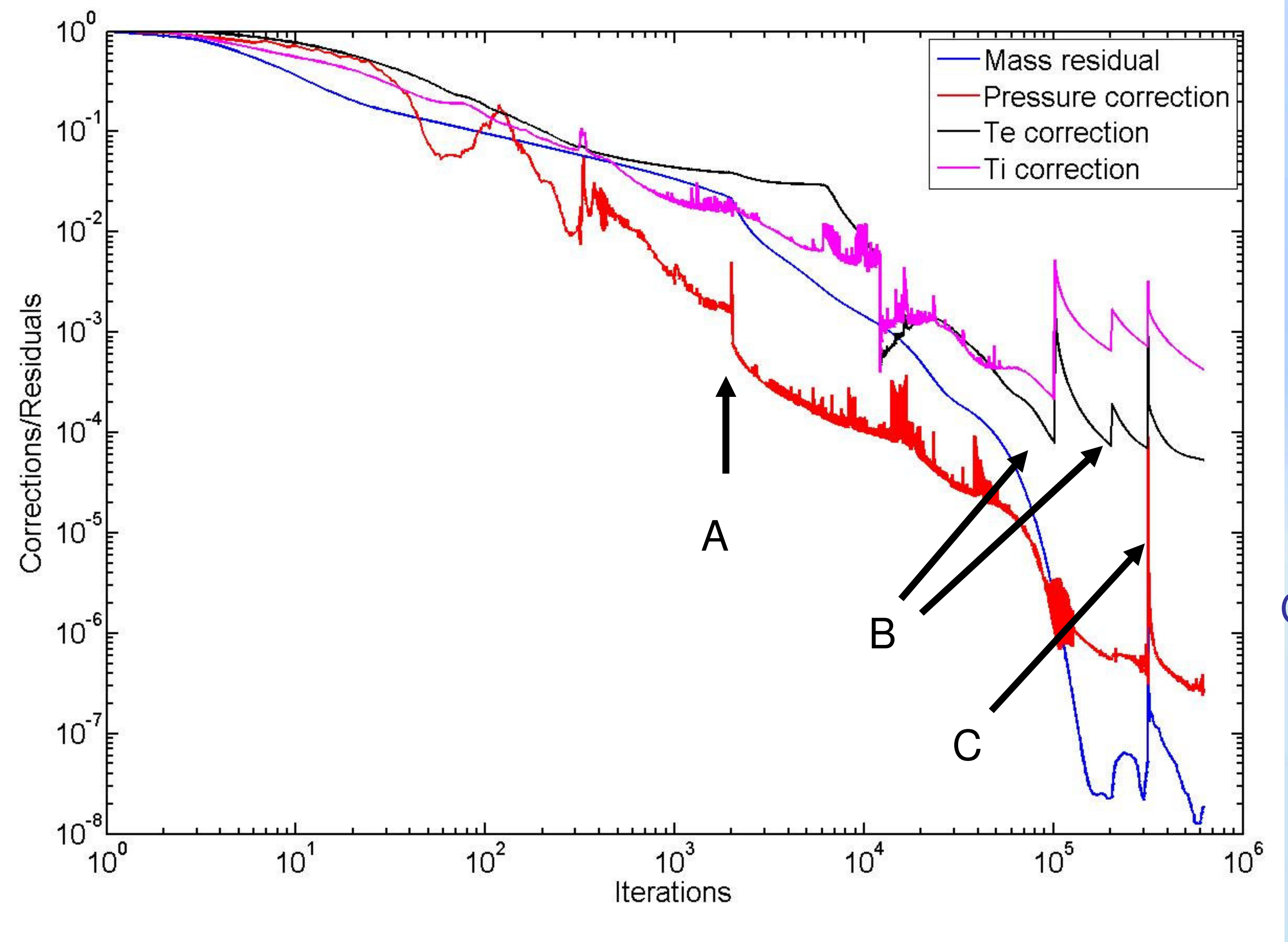
May the difference be so large? To be investigated

Conclusions

- An ASDEX Upgrade case is being investigated. Preliminary results of not yet fully converged run were shown
- Run is very slow, possibly influenced by large number of nodes in far SOL region, not optimized relaxation parameters, …
- Continuity, parallel momentum results show some reasonable features
- Ion/electrons show the most critical behaviour. Open issues:
  - Effect of very strong ion energy input fluxes from B2
  - Strong influence of relaxation parameter

Additional Slides

Residuals and Corrections



A:

α_p 0.1 -> 0.8,
α_v 0.3 -> 0.1

B:

α_T 0.1-> … -> 0.4

C:

Change radial visc.

Definitions

$\overline{R}_M^0$ Mass residual ➔ $R_M^k = \left\|\overline{R}_M^k\right\|_2 / \left\|\overline{R}_M^0\right\|_2$

$\delta\overline{p}^k = \overline{p}' - \overline{p}^{k-1}$

$\overline{p}^k = \overline{p}^{k-1} + \alpha_p\left(\delta\overline{p}^k\right)$

P correction ➔ $\delta p^k = \left\|\delta\overline{p}^k\right\|_2 / \left\|\delta\overline{p}^0\right\|_2$

$\delta\overline{V}^k = \overline{V}^k - \overline{V}^{k-1}$ V correction ➔ $\delta V^k = \left\|\delta\overline{V}^k\right\|_2 / \left\|\delta\overline{V}^0\right\|_2$

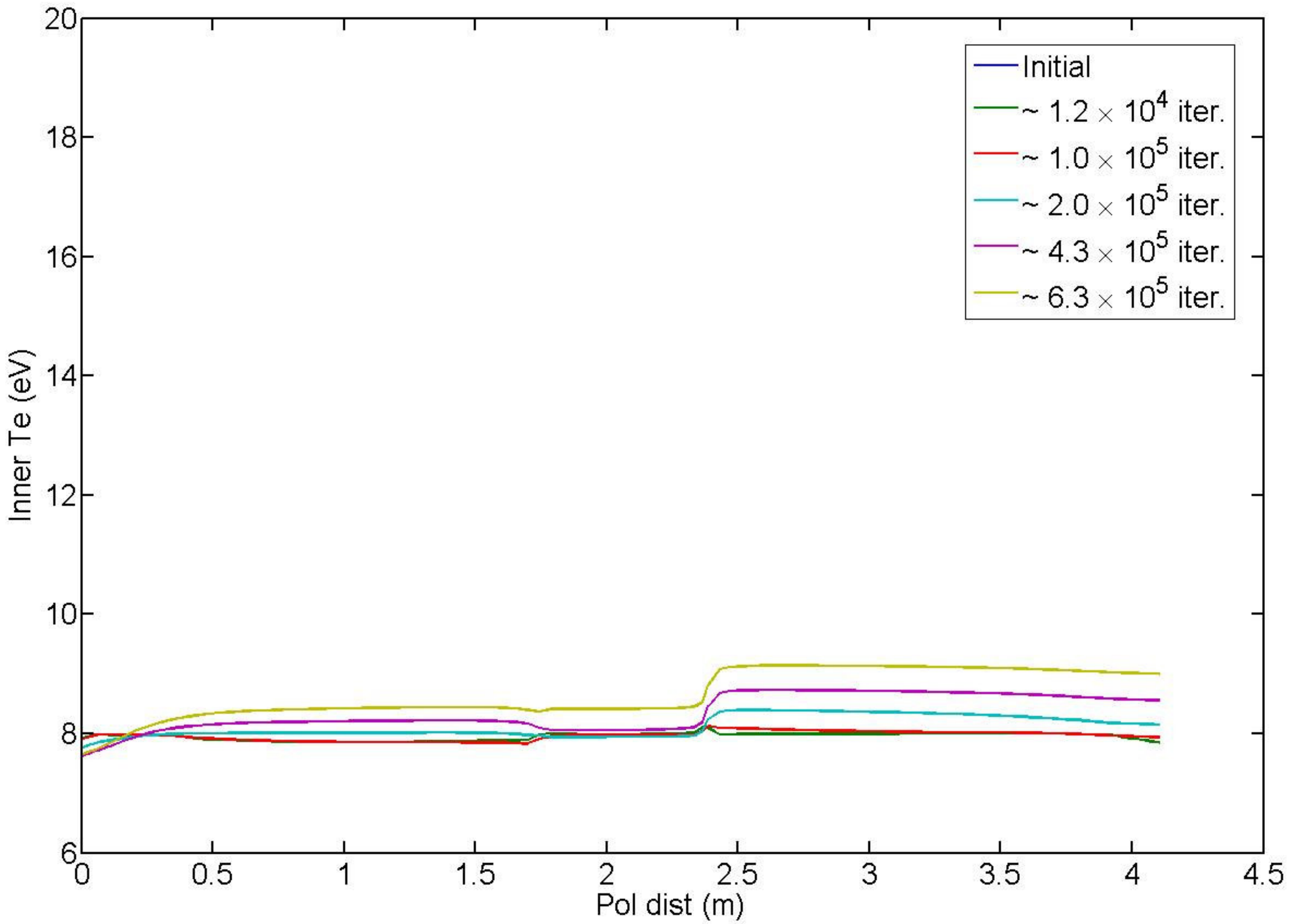
$\delta\overline{T}^k = \overline{T}^k - \overline{T}^{k-1}$ T correction ➔ $\delta T^k = \left\|\delta\overline{T}^k\right\|_2 / \left\|\delta\overline{T}^0\right\|_2$

Generic relaxation:

$$A\overline{\phi}^k = \overline{Q} \quad \longrightarrow \quad \left[\frac{D_A}{\alpha} + \left(A - D_A\right)\right]\overline{\phi}^k = \overline{Q} + \frac{1-\alpha}{\alpha} D_A \overline{\phi}^{k-1}; \quad D_A = diag\left(A\right)$$

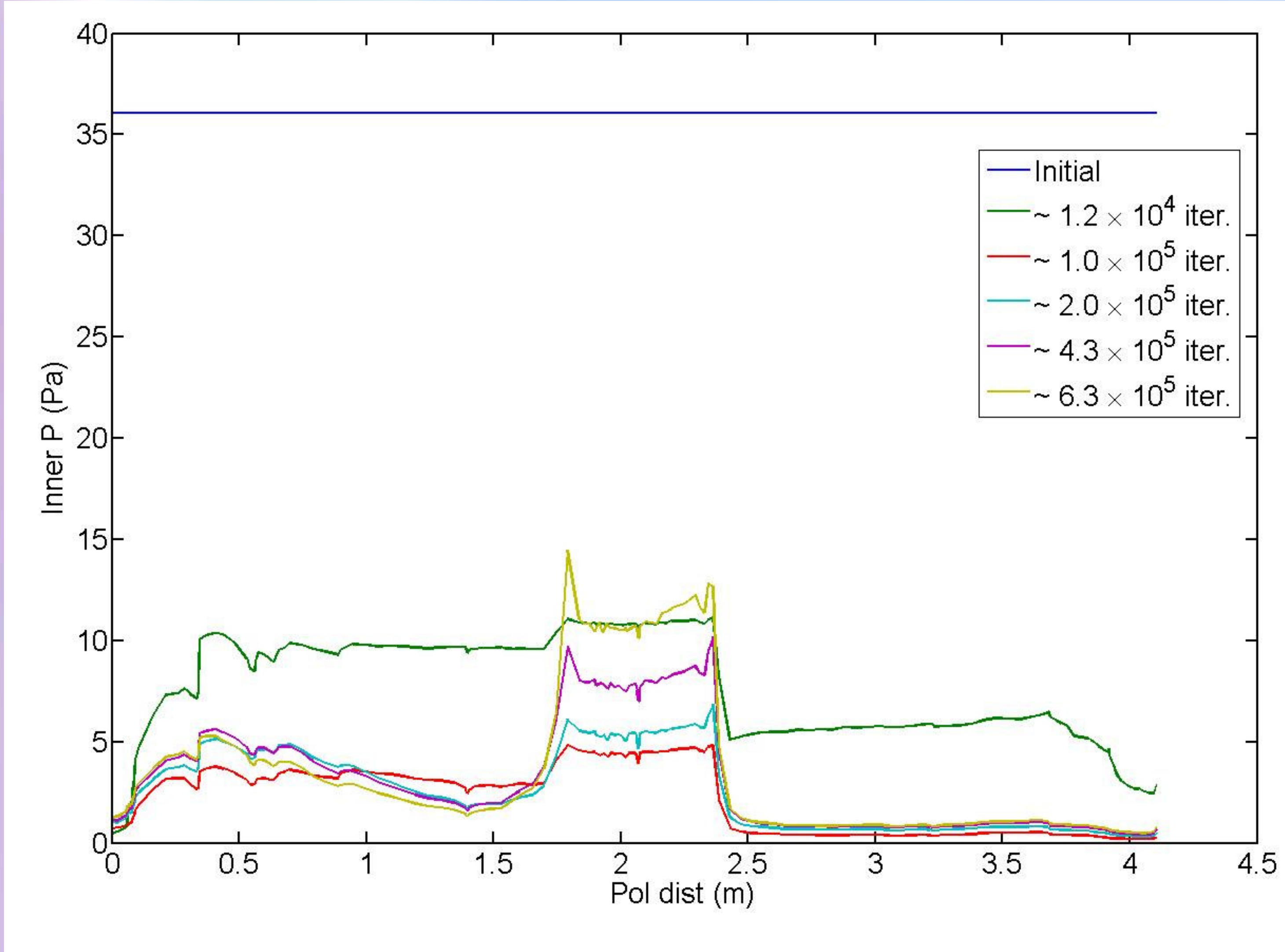
ϕ = T, V

T_e Inner Boundary Evolution



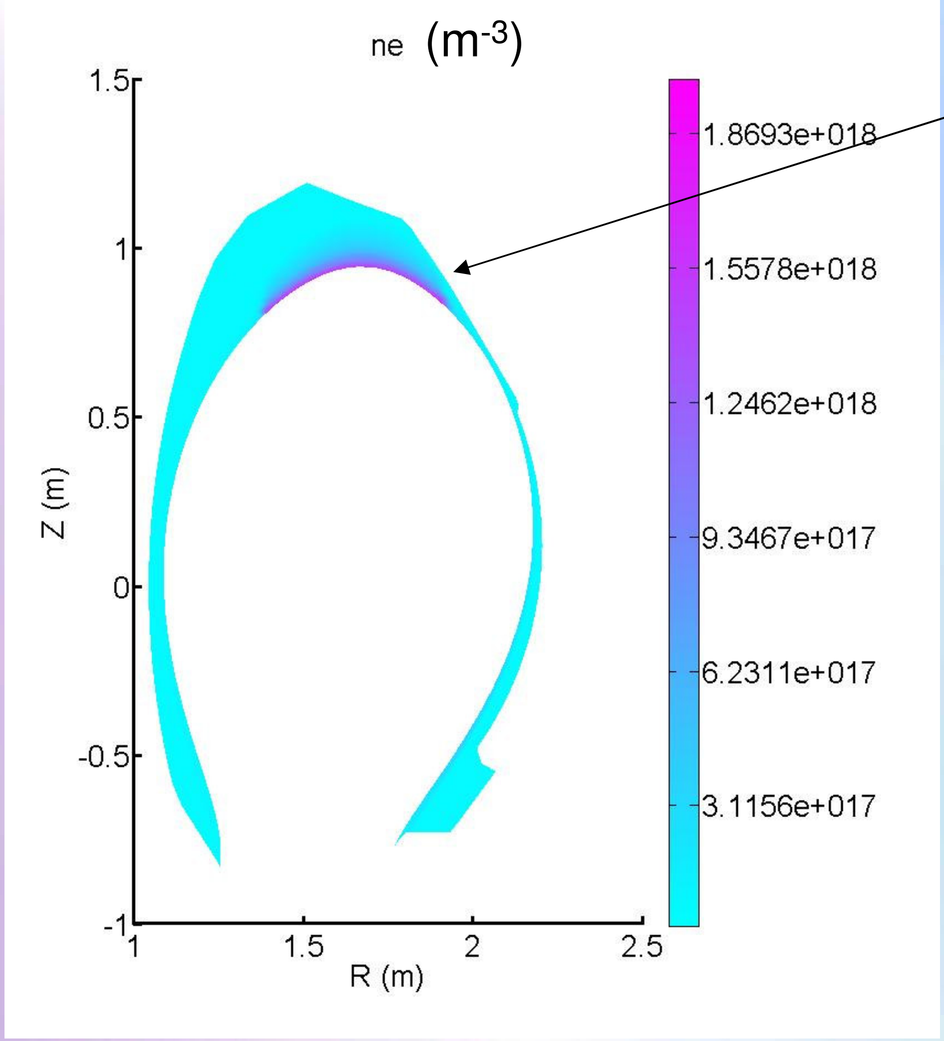
Slowly but steadily evolving

Pressure Inner Boundary Evolution



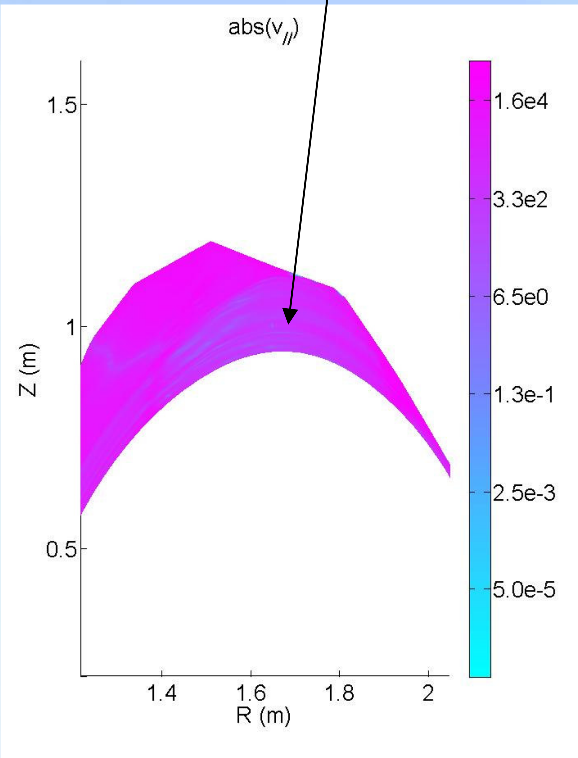
Still evolving

Ne/Vpar maps

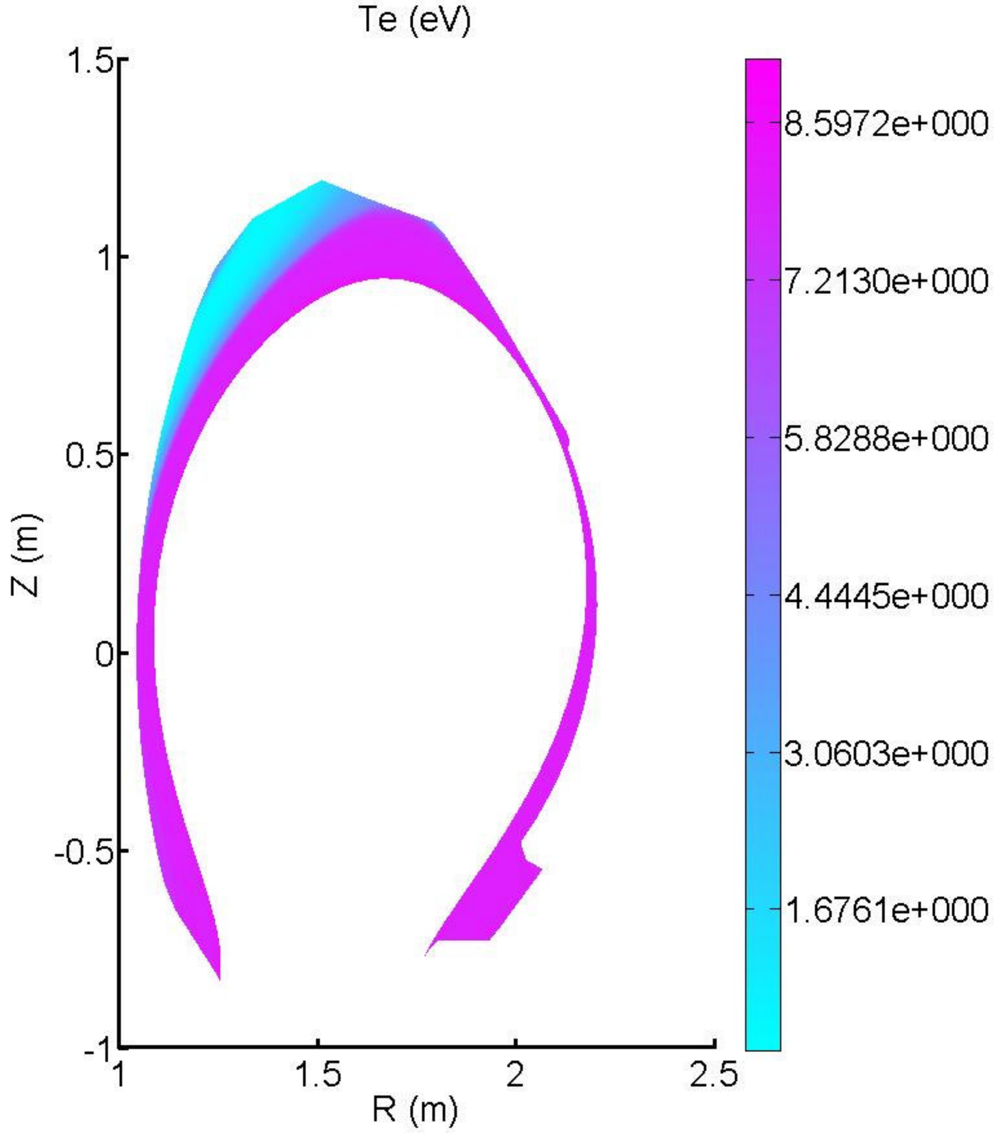


Peaking near the top

Possibly the effect of stagnation point



Te map



Te drops strongly in the upper-left corner

Possibly developing a double SOL structure