Resistive Wall Simulations with JOREK

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Resistive Wall simulations with JOREK

- Why?

- How do we couple?

- What is possible already?

- How to include Halo currents?

- What needs to be done technically?

Why?

➢ Time varying magnetic fields induce **eddy currents** in conducting structures

➢ Important if distance between resonant surface and wall is significantly smaller than the poloidal wave length

➢ This is often the case (however, sometimes an ideal wall is sufficient)

JOREK-STARWALL allows to study:

- ***Plasma-wall interaction via eddy currents***
- ***Instabilities without conducting walls***

Why?

During disruptions/VDEs, currents can flow from the plasma into the walls: *Halo currents*

- ➢ Mostly poloidal if axi-symmetric

- ➢ Asymmetries observed, especially n=1

- ➢ Large asymmetric forces

- ➢ Rotating (resonances!)

- ➢ Important constraints for disruption mitigation

Halo current

Plasma

Halo region

Conducting vessel
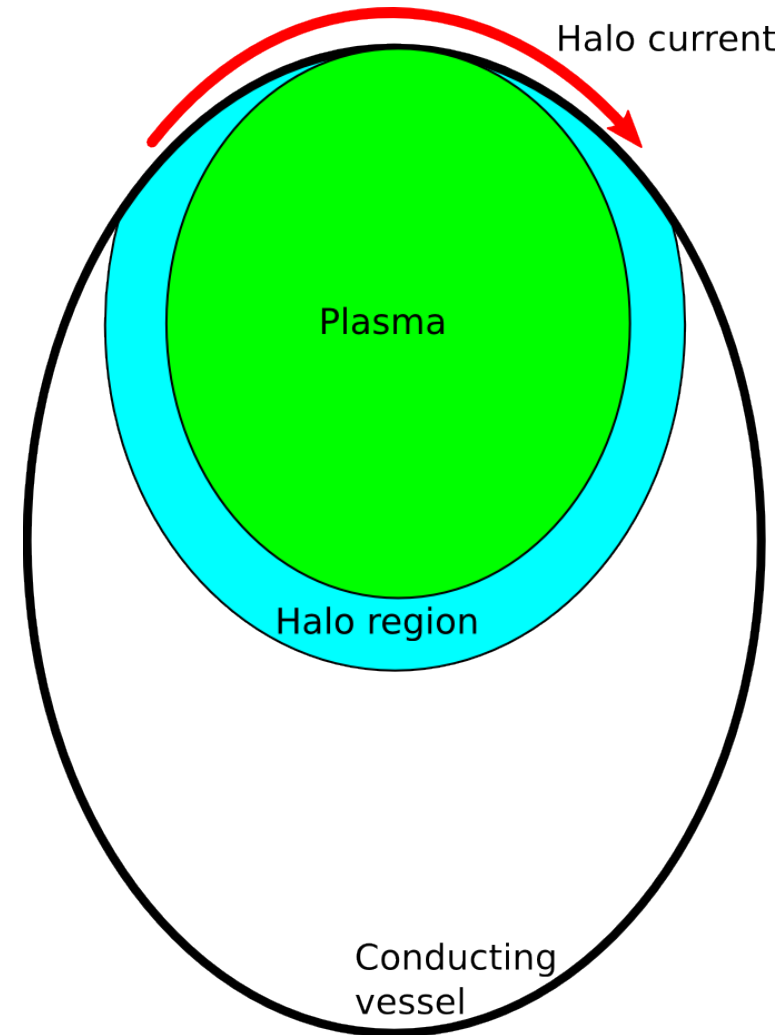
How do we couple?

STARWALL:
- Thin wall approximation, triangles, divergence-free surface currents
- 3D wall with holes
- Greens functions

[P. Merkel, M. Sempf, 21st IAEA FEC (Chengdu, China) TH/P3-8 (2006)]
[P. Merkel, E. Strumberger, to be submitted]

JOREK:
- "Response matrices" calculated by STARWALL (unit perturbations):

$$B_{tan} = \sum_i b_i \left(\sum_j M_{ij} \Psi_j + \sum_k N_{ik} Y_k \right)$$

$$\dot{Y}_k = -\frac{\eta}{d} P_{kk} Y_k - \sum_j Q_{kj} \dot{\Psi}_j$$

- Boundary integral in current definition equation from partial integration: B_{tan} plugged in (natural boundary condition)

[M. Hoelzl, P. Merkel, G.Huijsmans et al., JPCS 401, 012010 (2012)]

What is possible already?

- **Resistive wall modes** – Benchmark in simplified geometry and initial cases for ITER-like plasma
[R. McAdams, Ph.D. thesis, University of York (2014)]
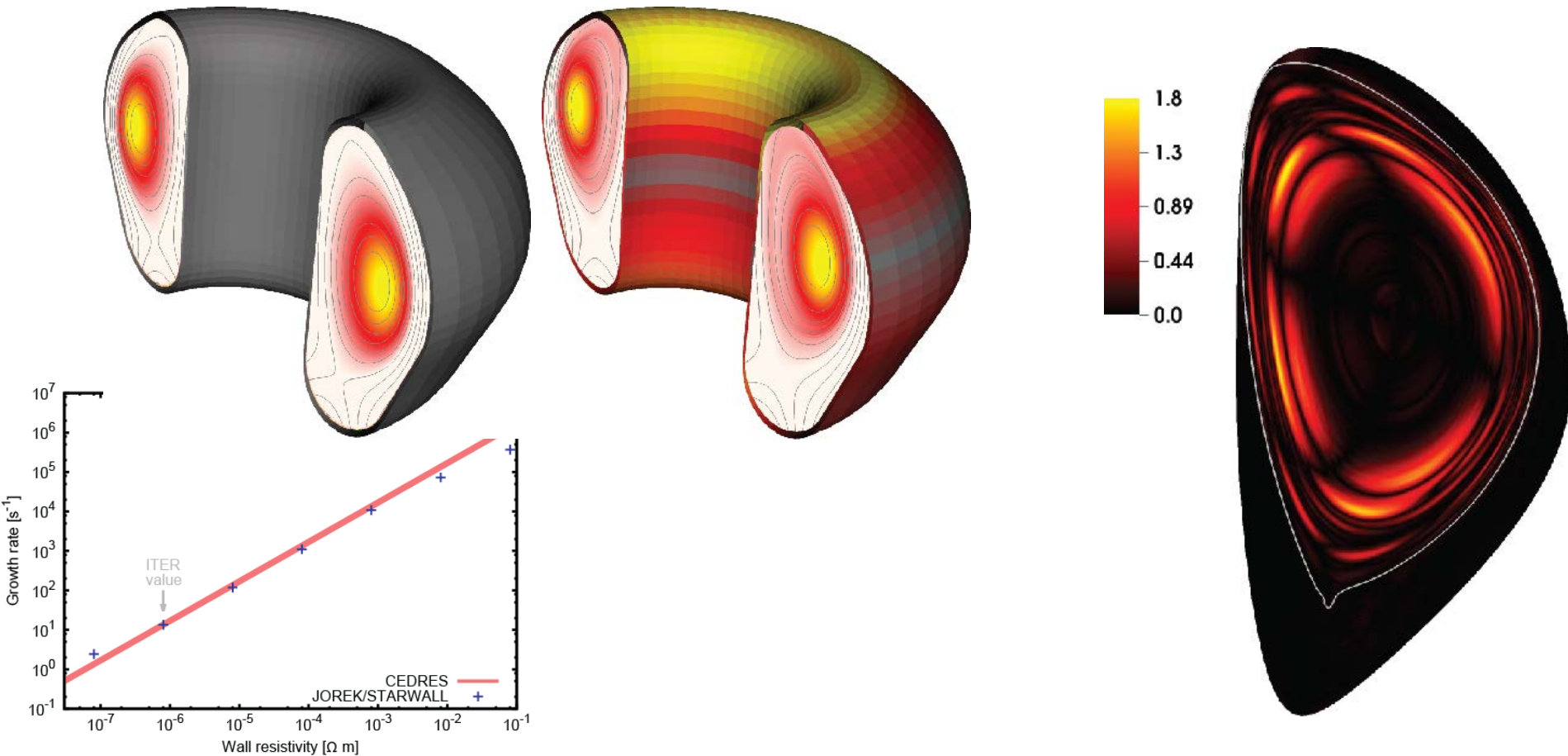

$$\eta_{jorek,wall}=10^{-5}$$
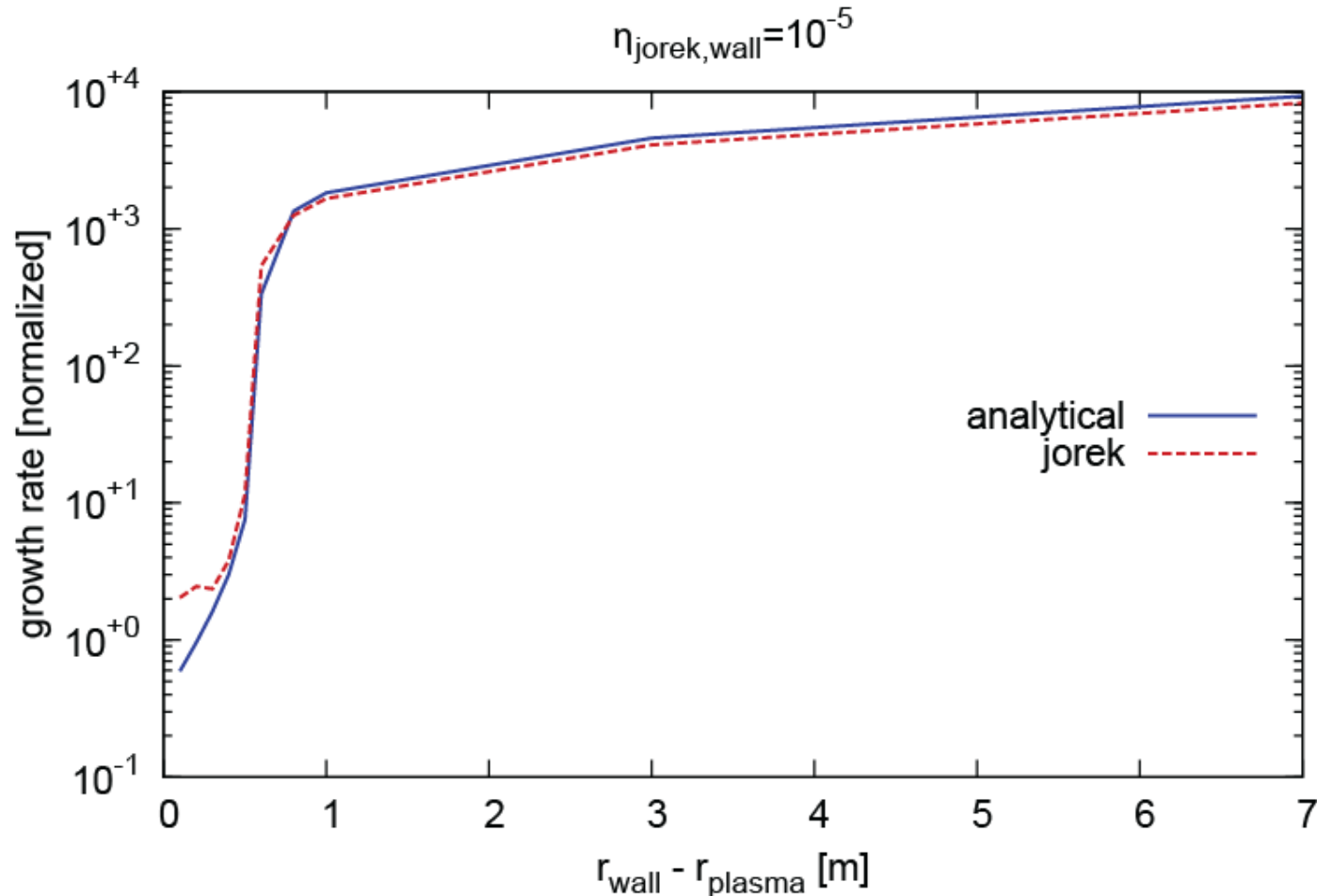
What is possible already?

- **Vertical displacement events** (without Halo currents) – Benchmark with CEDRES++ in ITER-like geometry
[M. Hoelzl, G.T.A. Huijsmans, P. Merkel, C. Atanasiu, E. Nardon, K. Aleynikova, F. Liu et al., JPCS 561, 012011 (2014)]
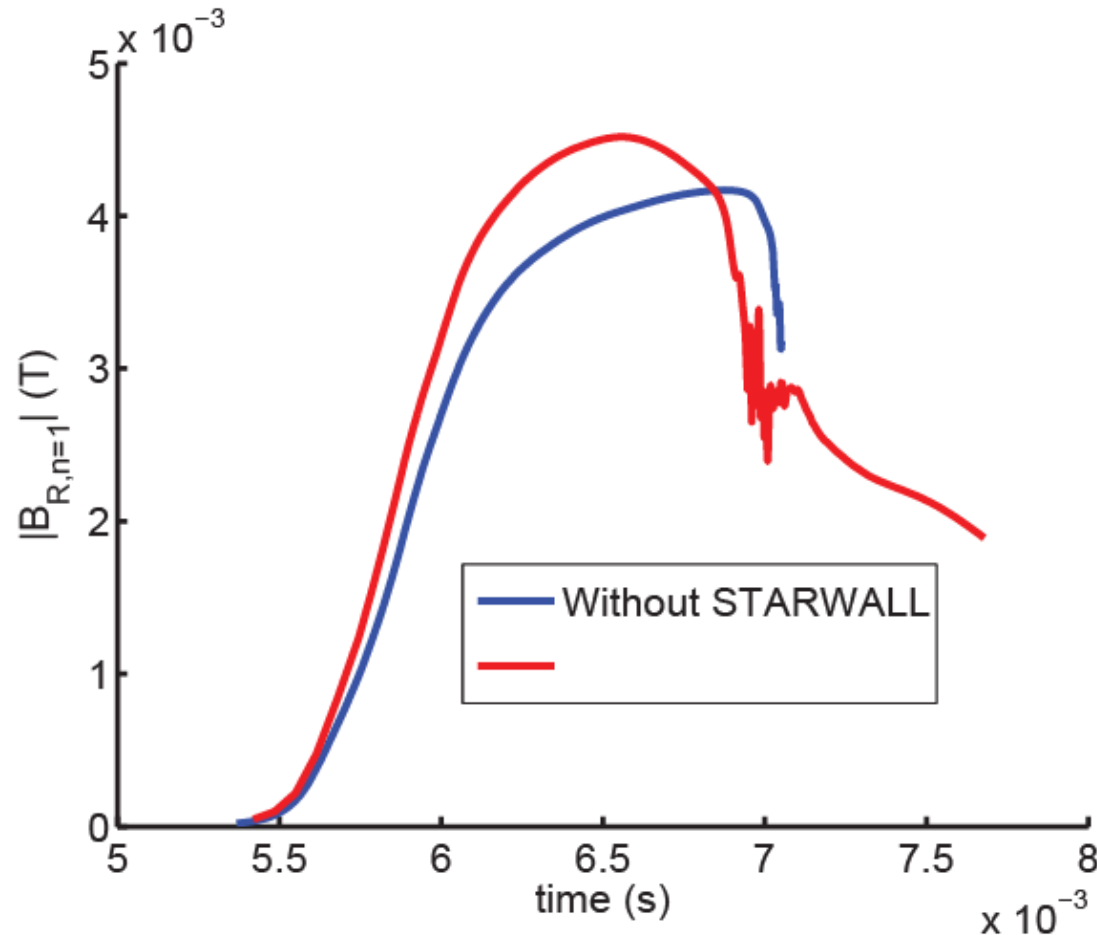
What is possible already?

- Influence of wall onto MHD modes during **disruption**
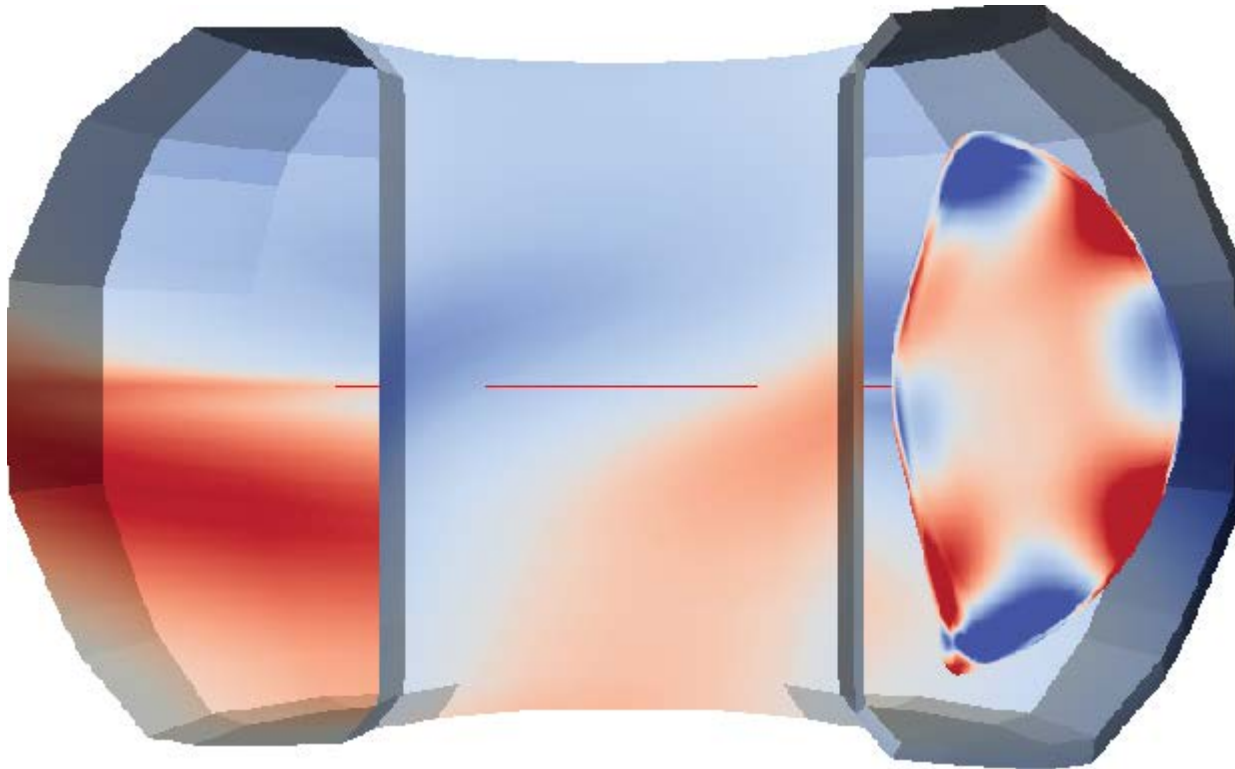 [A. Fil, E. Nardon, M. Hoelzl, et al., unpublished]

- Influence of wall onto **quiescent H-Mode**
  [F. Liu, G.T.A. Huijsmans, et al., EPS (2014)]

How to include Halo currents?

A) Directly in JOREK (for first tests and as a benchmark)

- Full MHD model
- Add a grid region for the wall and solve there:

$$\frac{\partial \boldsymbol{A}}{\partial t} = -\eta \nabla \times \nabla \times \boldsymbol{A}$$

- Set $\delta\rho = \delta T = \delta\boldsymbol{u} = 0$ at the boundary
- Add vacuum region (directly or via response matrices):

$$\nabla \times \nabla \times \delta\boldsymbol{A} = 0$$

- Apply to 2D and 3D VDE ITER cases
- Hopefully finished this summer

[M. Hoelzl, K. Lackner, G. Huijsmans]
[ITER project on Halo currents]

How to include Halo currents?

B) In JOREK-STARWALL

Coupling condition: $\nabla \cdot \boldsymbol{J}_w = \boldsymbol{J}_{JOREK} \cdot \hat{n}_w$

But currently $\nabla \cdot \boldsymbol{J}_w = \nabla \cdot (\hat{n}_w \times \nabla \xi) = 0$ in STARWALL

We have thought of three approaches for extending JOREK-STARWALL to halo currents:

1. New current component: $\boldsymbol{J}_w = \hat{n}_w \times \nabla \xi \color{red}{+ \sigma d \nabla \Phi}$

2. "Halo current paths" between current entry points
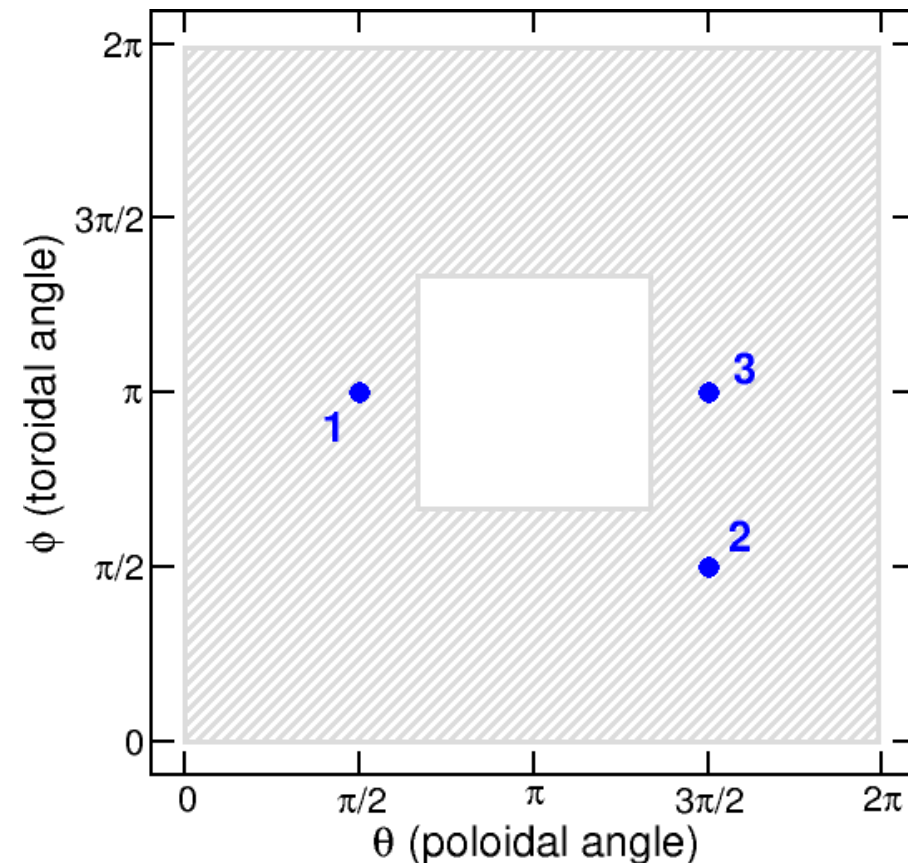
3. Independent current potentials ξ for each triangle

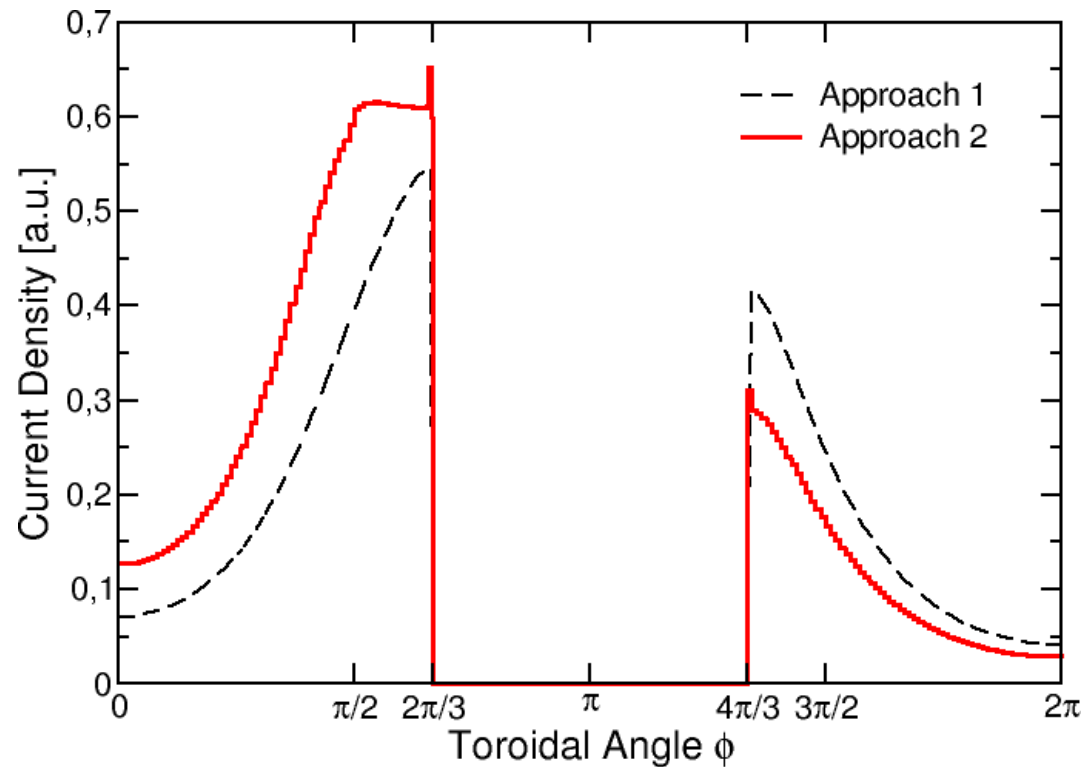# How to include Halo currents?

We decided to compare approaches 1 (new current component) and 2 (current paths) for a simple test case and decide soon afterwards which approach to implement into STARWALL.

- Torus with a single hole
- Slits at θ and $\phi = 2\pi$
- Compare current at $\theta = \pi$

How to include Halo currents?

- Qualitatively reasonable
- Test cases probably different **(very recent)**
- Analytical test case considered as well
- Next: Select an approach

[P. Merkel, C. Atanasiu, M. Hoelzl, K. Lackner]
[ITER project on Halo currents]

What needs to be done technically?

Currently: Maximum of ~100.000 wall triangles

- STARWALL on large memory node with runtime ~one week!
- In JOREK, ~half of the memory is taken by response matrices!

Aim: 500.000 wall triangles

- STARWALL run takes ~1 day and costs ~1% of JOREK run
- Response matrices in JOREK <10% of memory

STARWALL currently not parallel (a few parts OpenMP)

- Distribute matrices and use parallel libraries (ScaLAPACK etc.)

Coupling terms in JOREK not parallel (a few parts OpenMP)

- MPI-parallel calculation of boundary integral and matrix storage

[S.Mochalskyy, M.Hoelzl, R.Hatzky, HLST project]

Summary

- Why?
  - ***Plasma-wall interaction via eddy currents***
  - ***Simulations without conducting walls***
  - ***Asymmetric rotating forces caused by Halo currents***

- How do we couple?
  - ***Response matrices calculated by STARWALL (unit perturbations)***
  - ***Natural boundary condition in JOREK***

- What is possible already?
  - ***RWMs***
  - ***VDEs***
  - ***QH-Mode***
  - ***Disruptions***

- How to include Halo currents?
  - ***Axi-symmetric walls directly in JOREK***
  - ***Different approaches currently analyzed for JOREK-STARWALL***

- What needs to be done technically?
  - ***MPI parallelization of STARWALL and the coupling terms in JOREK***