High Temperature Superconducting Coating for the Beam Screen of the Future Circular Collider

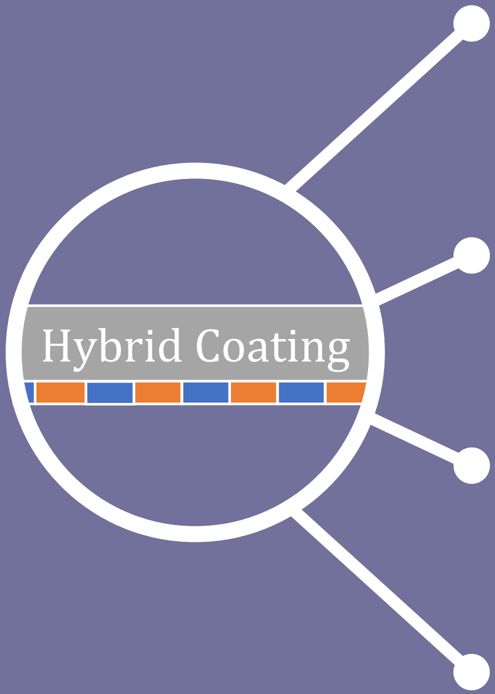
G. T. Telles[1], L. Benedetti[1], S. Calatroni[2], X. Granados[1], T. Puig[1], J. Gutierrez[1]

[1] *Institut de Ciència de Materials de Barcelona (ICMAB - CSIC), Spain*
[2] *Conseil Européen pour la Recherche Nucléaire (CERN), Switzerland*

ICMAB INSTITUT DE CIÈNCIA DE MATERIALS DE BARCELONA · EXCELENCIA SEVERO OCHOA · CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS · CERN · FUTURE CIRCULAR COLLIDER

June 13th, 2024, 11:20 (Session 3)
Parkhotel Bad Zurzach, Switzerland

Outline



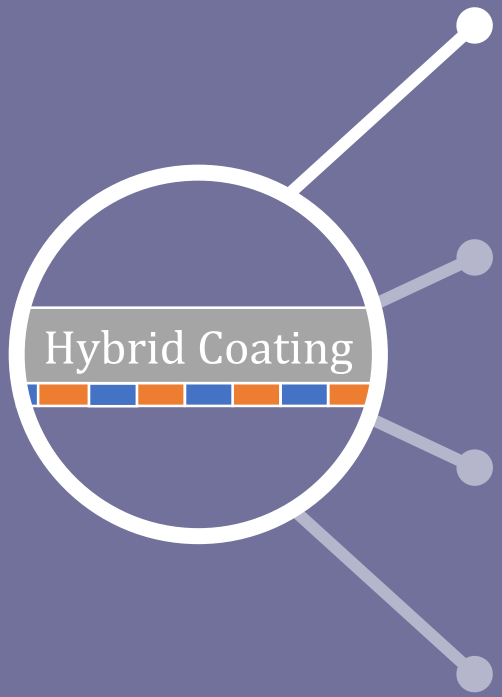
Introduction

Thermomechanical simulations during regular operation of the FCC

Thermomechanical simulations in the event of a dipole magnet quench

Conclusions

Outline

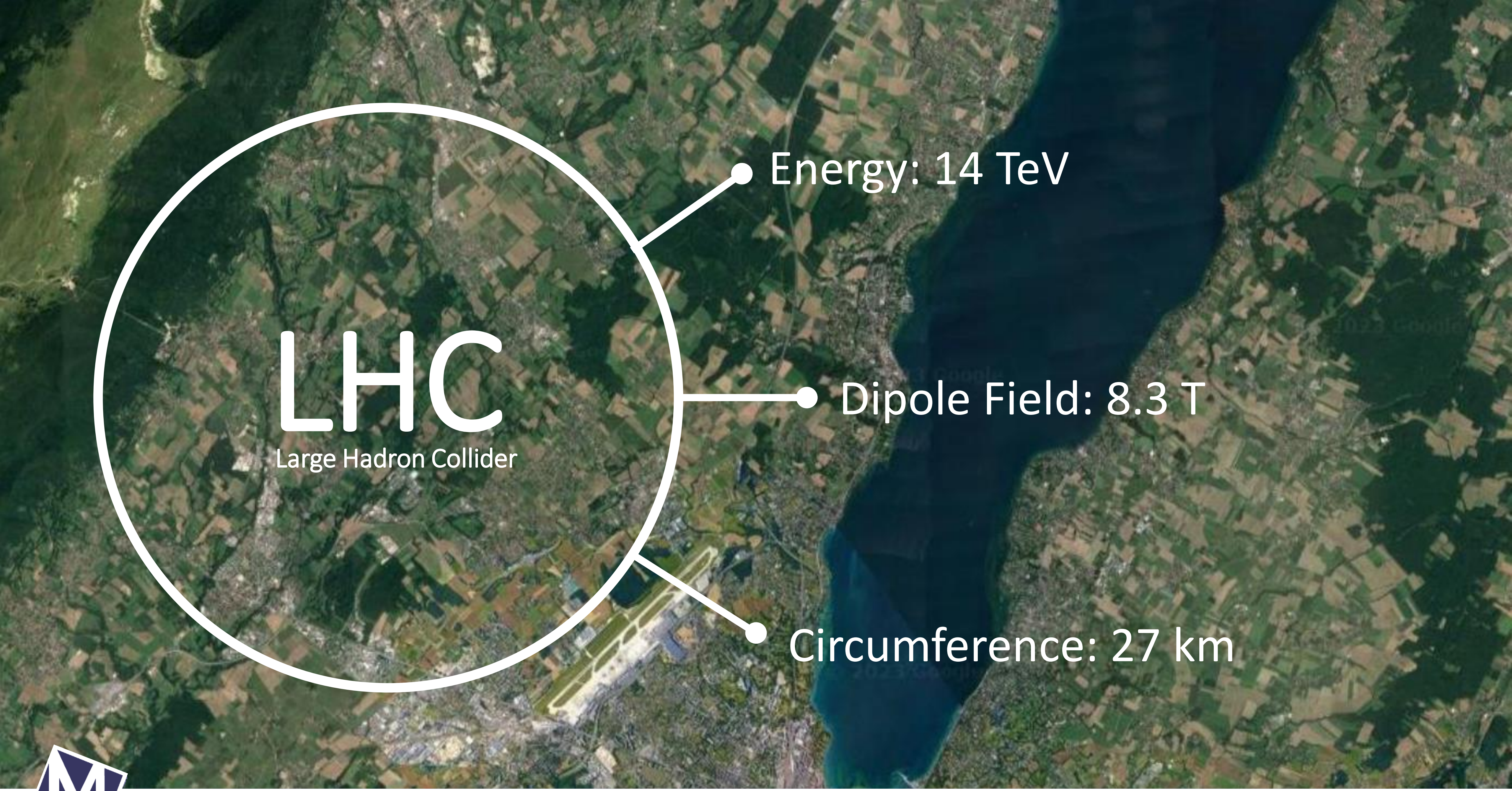


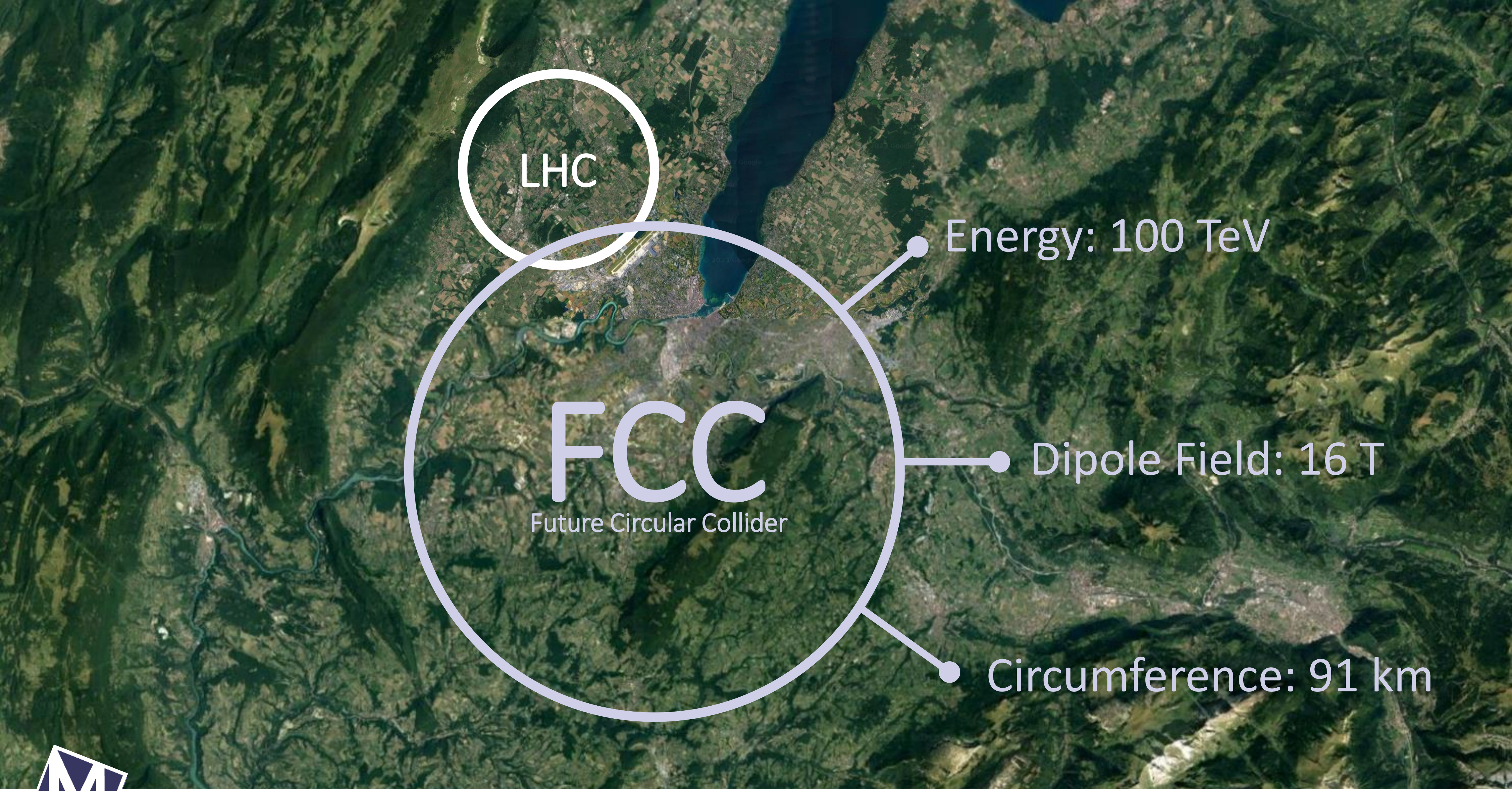
Introduction

Thermomechanical simulations during regular operation of the FCC

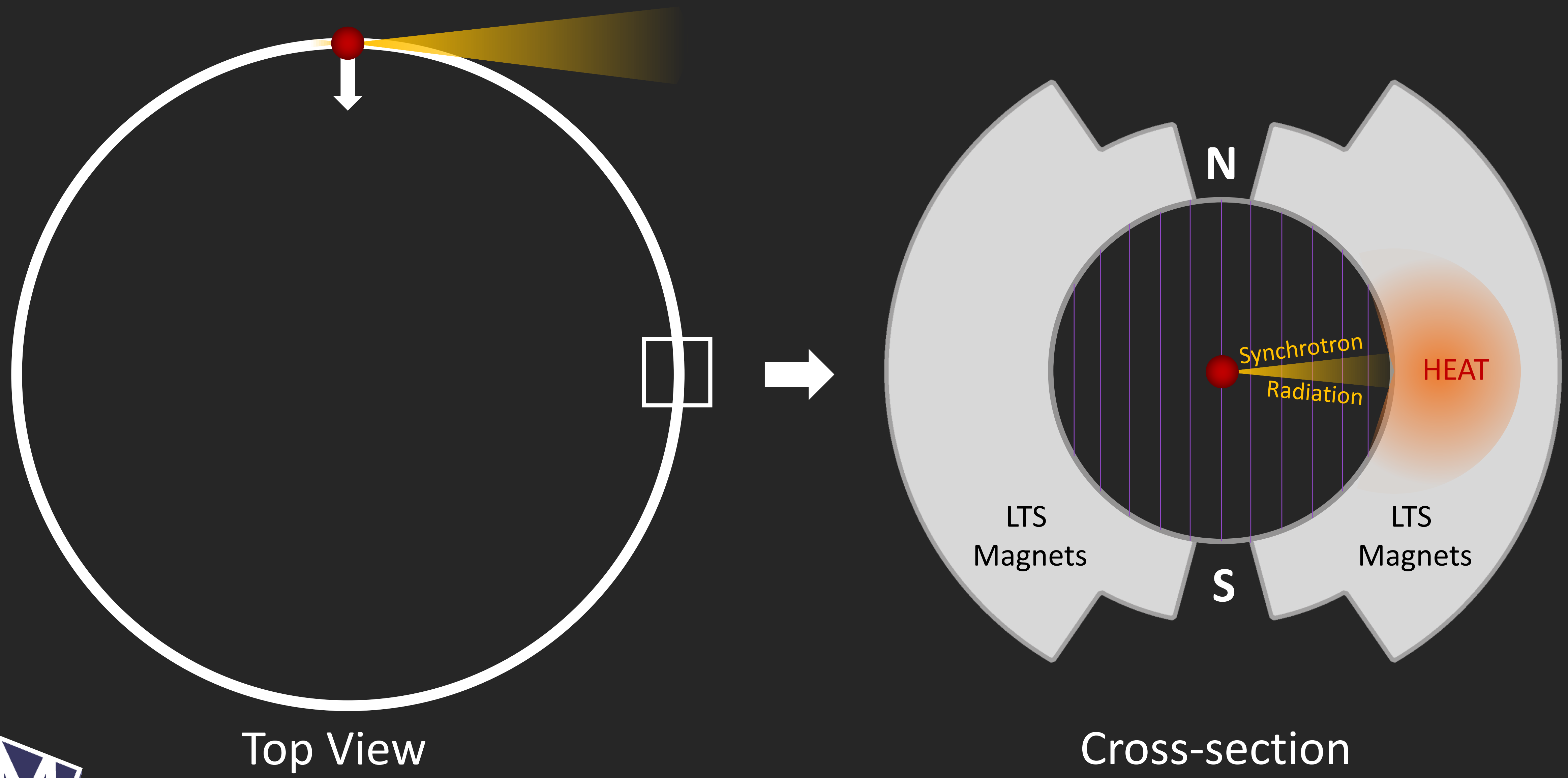
Thermomechanical simulations in the event of a dipole magnet quench

Conclusions


LHC
Large Hadron Collider
Energy: 14 TeV
Dipole Field: 8.3 T
Circumference: 27 km

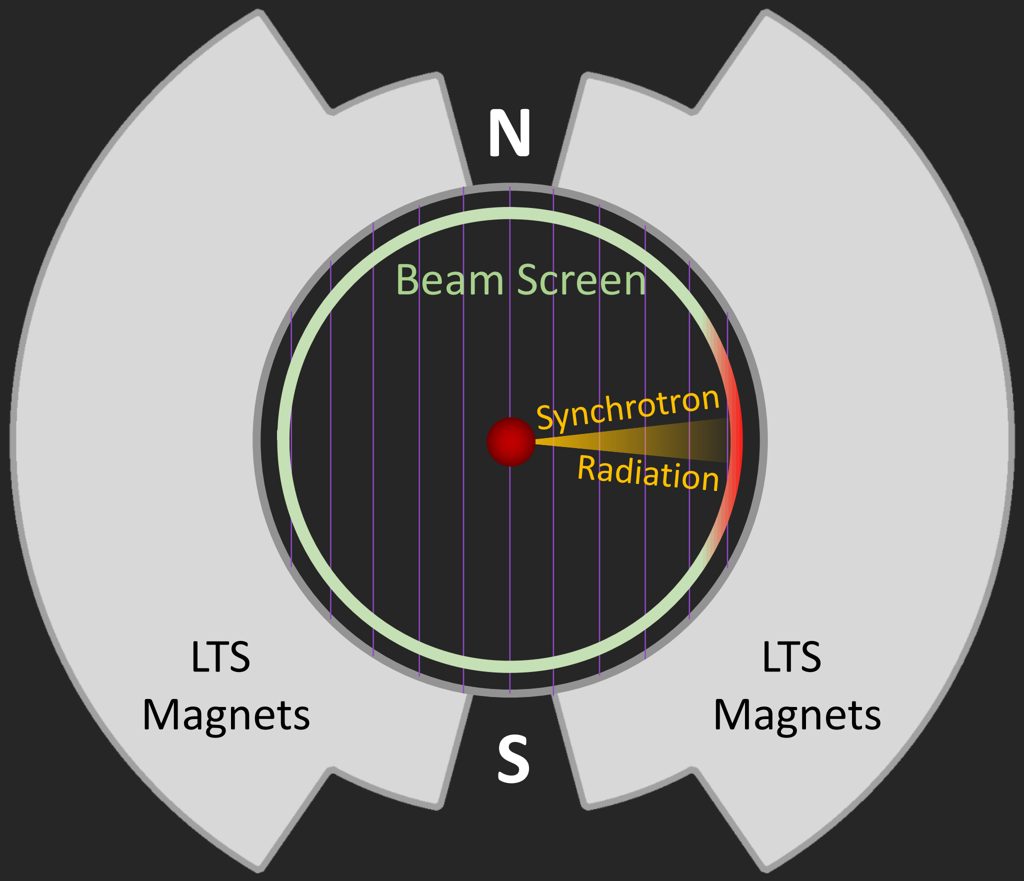

LHC
FCC
Future Circular Collider
Energy: 100 TeV
Dipole Field: 16 T
Circumference: 91 km

The Beam Screen



The Beam Screen

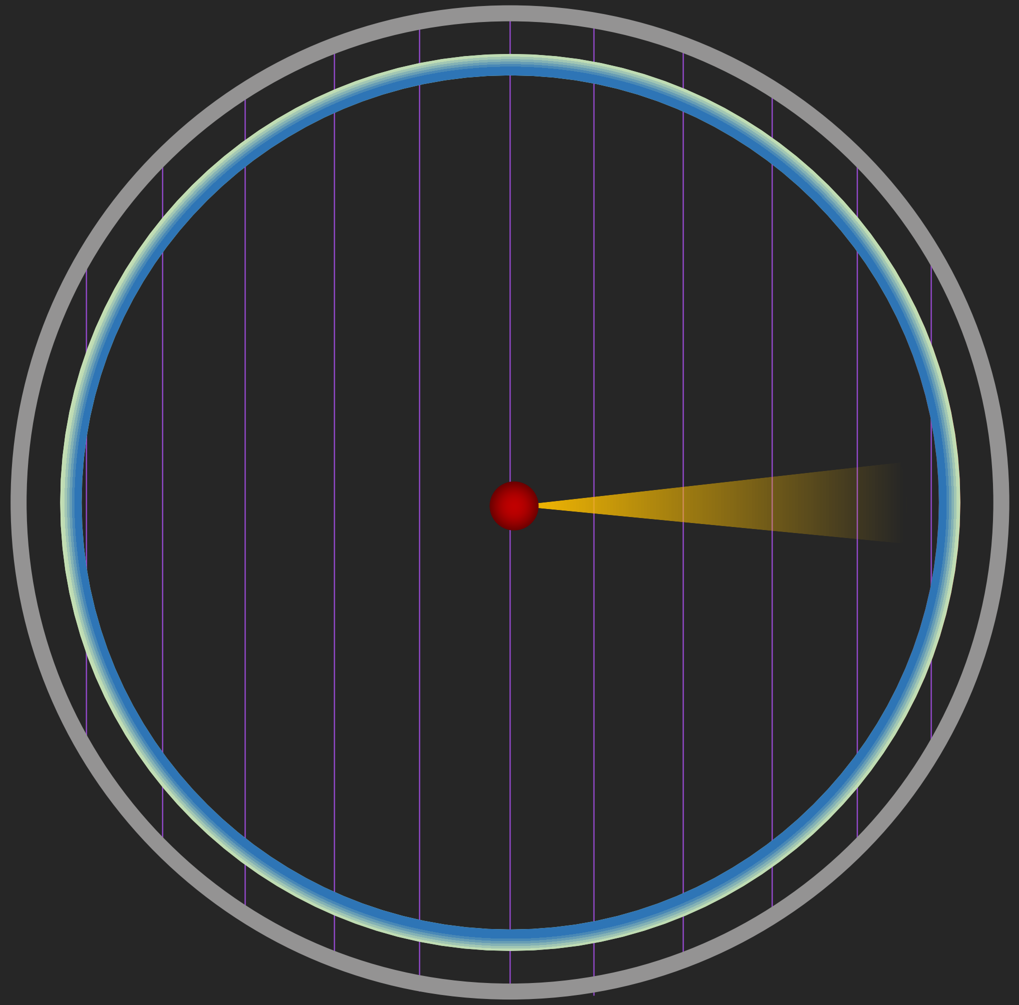
- Syncrhtron Radiation heats LTS magnets. To avoid this, the **beam screen (BS)**, a stainless steel pipe surrounding the beam orbit, intercepts and absorbs it, redirecting the heat.



The Beam Screen

- Shields Magnets from SR

- The beam induces image currents in the beam screen. To prevent these currents from disturbing the beam orbit, the BS must be covered with a low impedance coating.

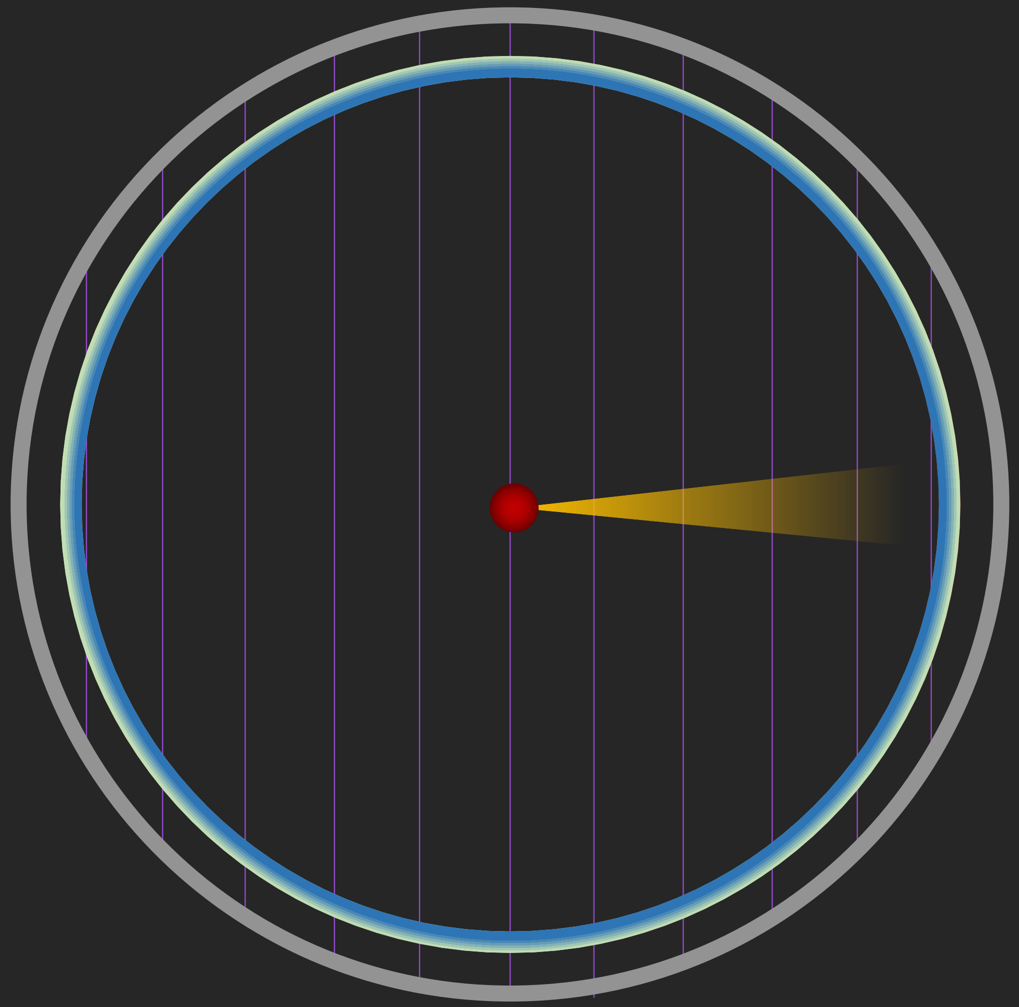


The Beam Screen

- Shields Magnets from SR

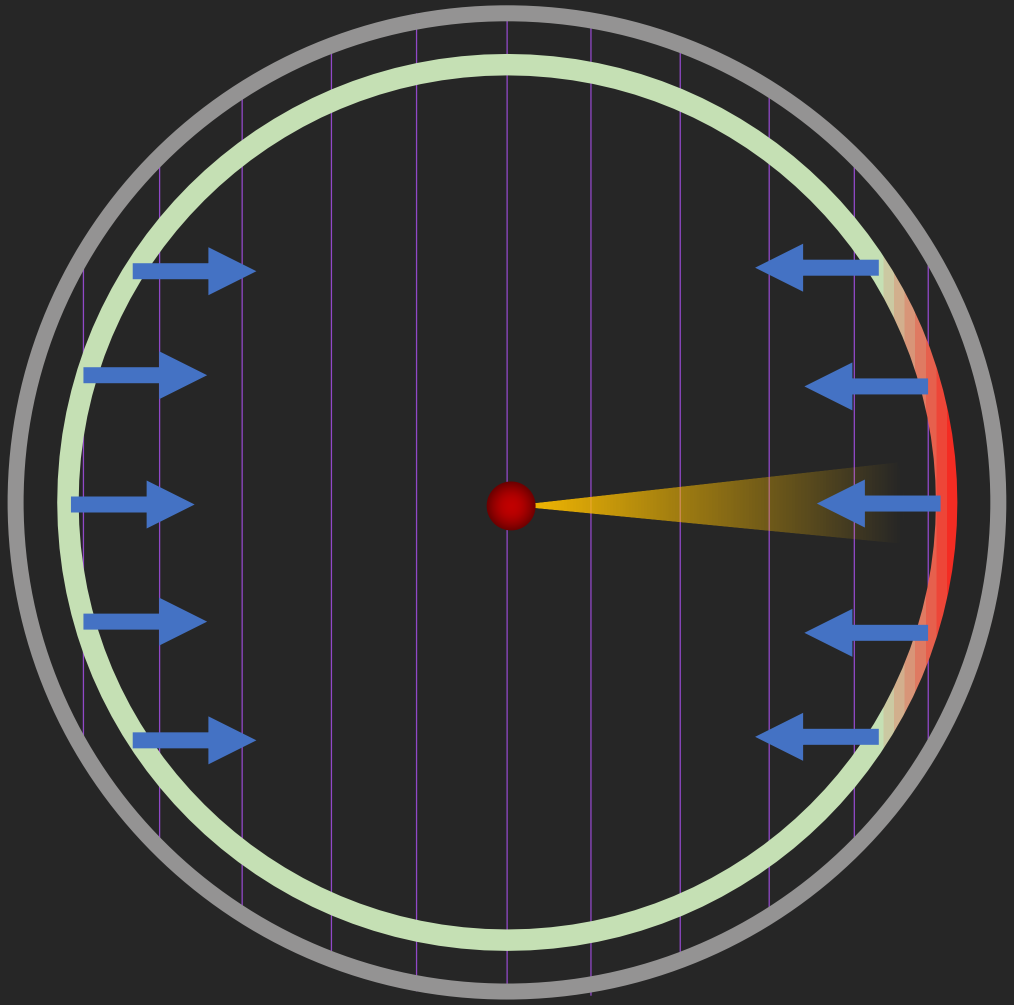
- Has low surface resistance

- This coating must also not disturb the magnetic field around it, which would otherwise disrupt the beam orbit as well.



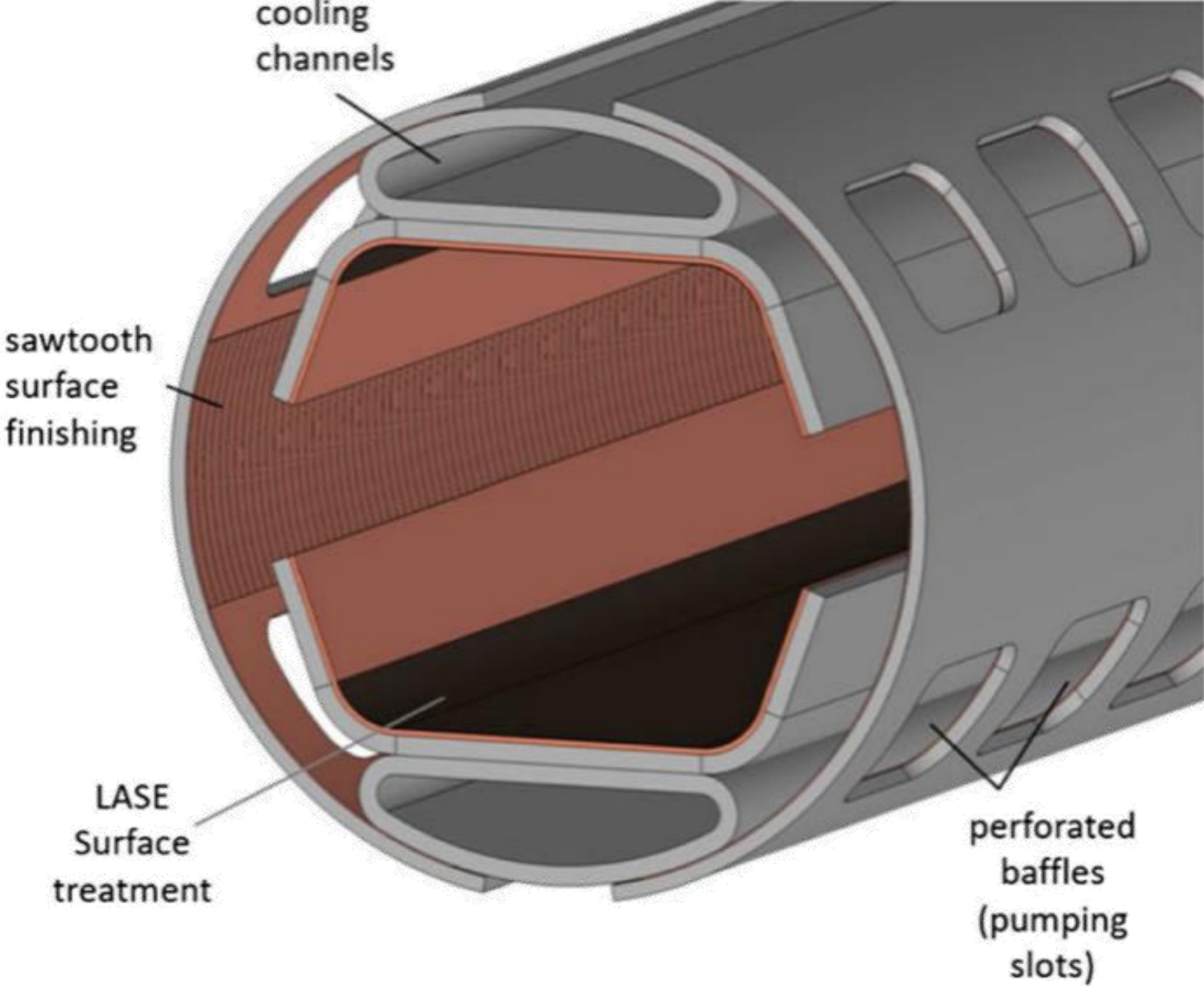
The Beam Screen

- Shields Magnets from SR
- Has low surface resistance
- Allows high field quality
- Finally, it must withstand the thermomechanical loads during regular operation and in a magnet quench.



The Beam Screen

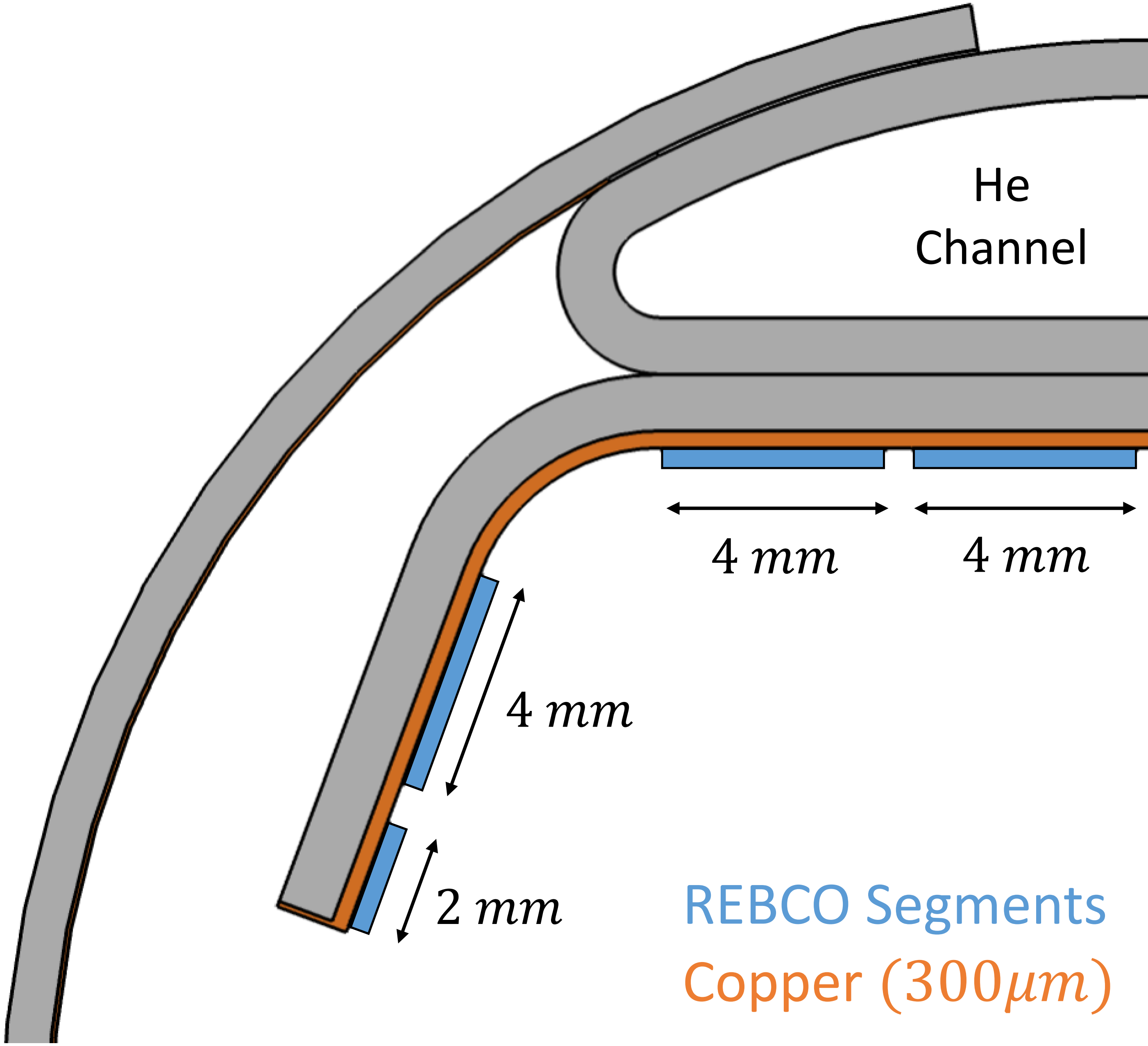
- Shields Magnets from SR
- Has low surface resistance
- Allows high field quality
- Is thermomechanically robust



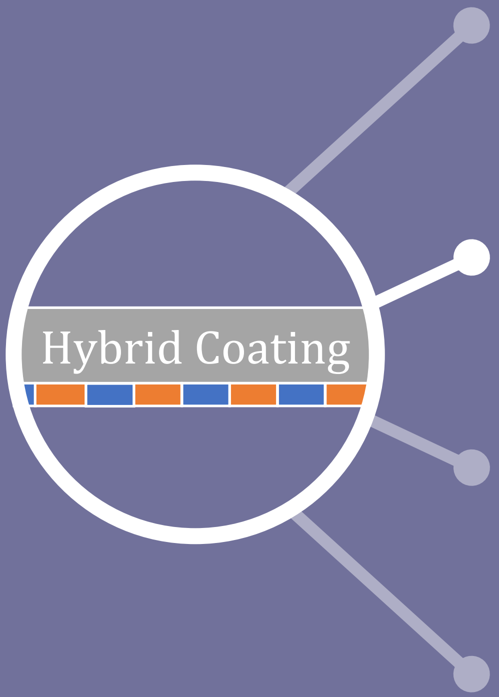
Is there a better coating than copper at 50 K?

The Hybrid Coating

- Shields Magnets from SR ✓
- Has low surface resistance ✓
- Allows high field quality ✓
- Is thermomechanically robust



Outline



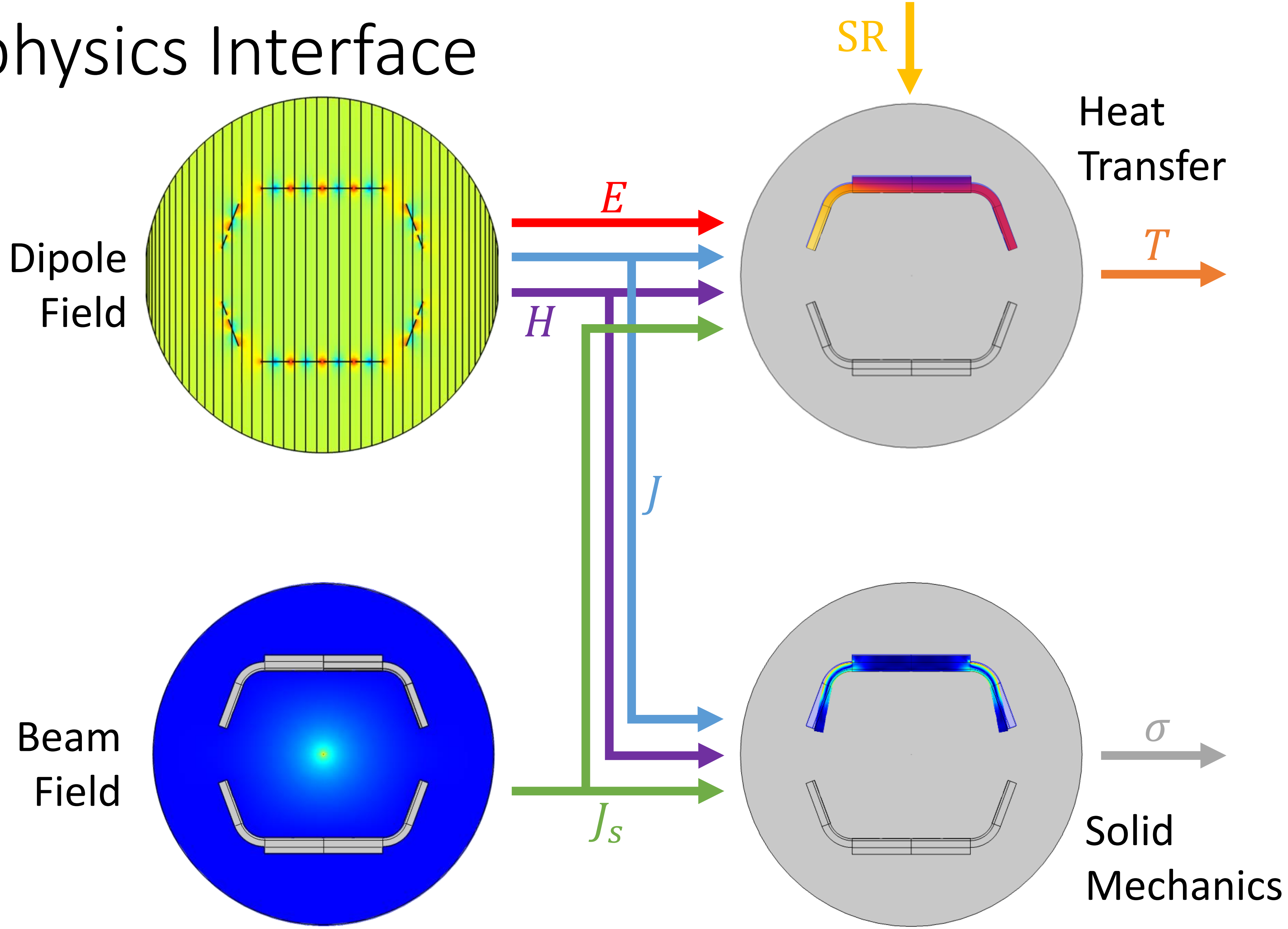
Introduction

Thermomechanical simulations during regular operation of the FCC

Thermomechanical simulations in the event of a dipole magnet quench

Conclusions

Multiphysics Interface



Simulation model: H-formulation FEM

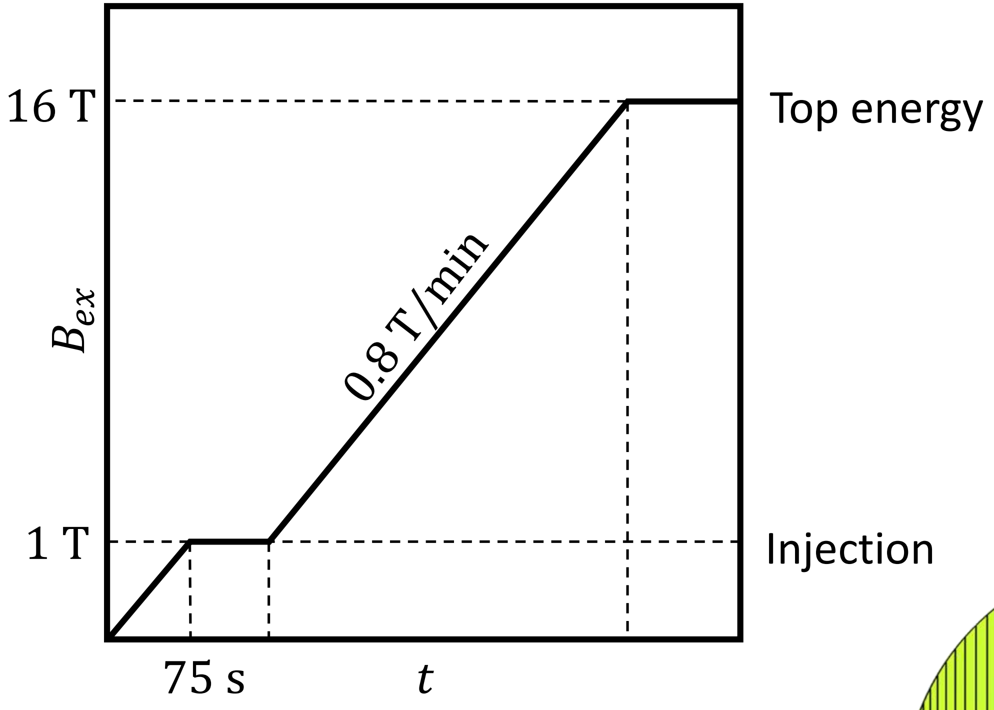
$$\nabla \times \vec{H} = \vec{J}$$

$$\nabla \times \vec{E} = -\frac{\partial B}{\partial t}$$

$$\vec{B} = \mu_0 \vec{H}$$

$$\vec{E} = \rho \vec{J}$$

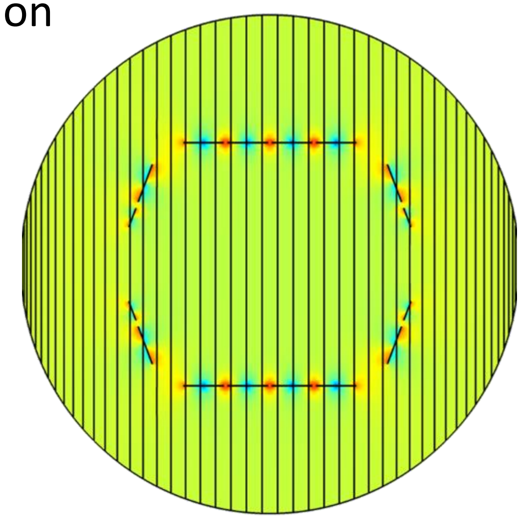
$$\rho = \frac{E_c}{J_c(\vec{H})}\left(\frac{J}{J_c(\vec{H})}\right)^{N(\vec{H})-1}$$



$$Q = JE$$

$$\vec{F}_V = \vec{J} \times \vec{B}$$

Dipole Field

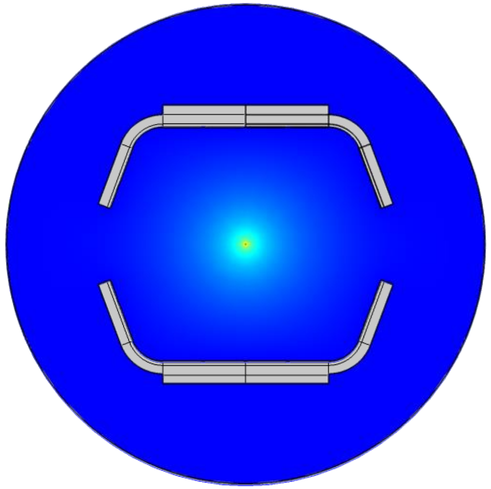


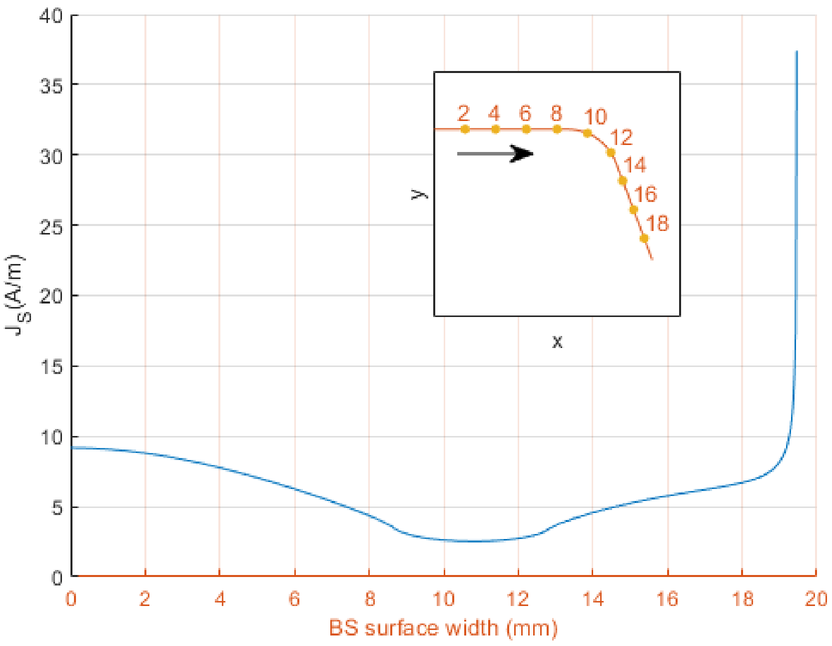
- Goal: solve Maxwell equations to obtain the average surface current J_s induced by the particle beam.

- The average beam current $J_{beam} = 0.5\ \mathrm{A}$ is imposed at the very center of the vaccum chamber.

- All materials are considered perfect conductors.

Beam Field





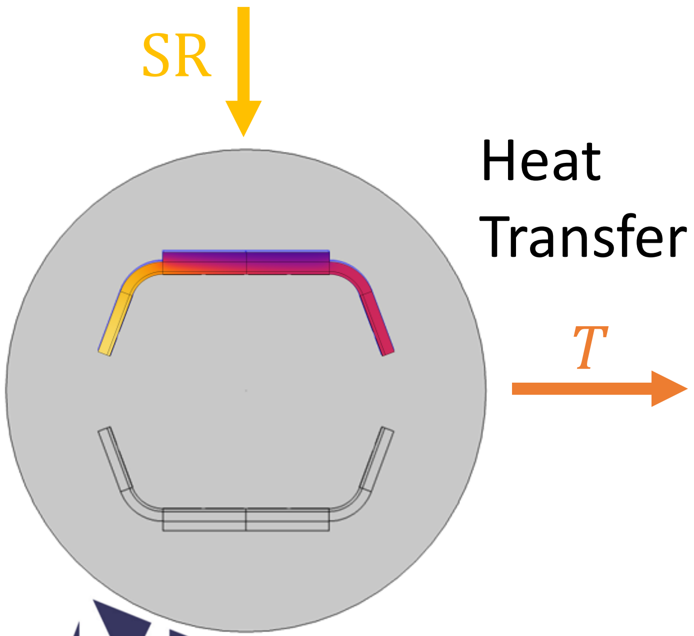
$$R_s^{cu} = k\sqrt{\omega}$$

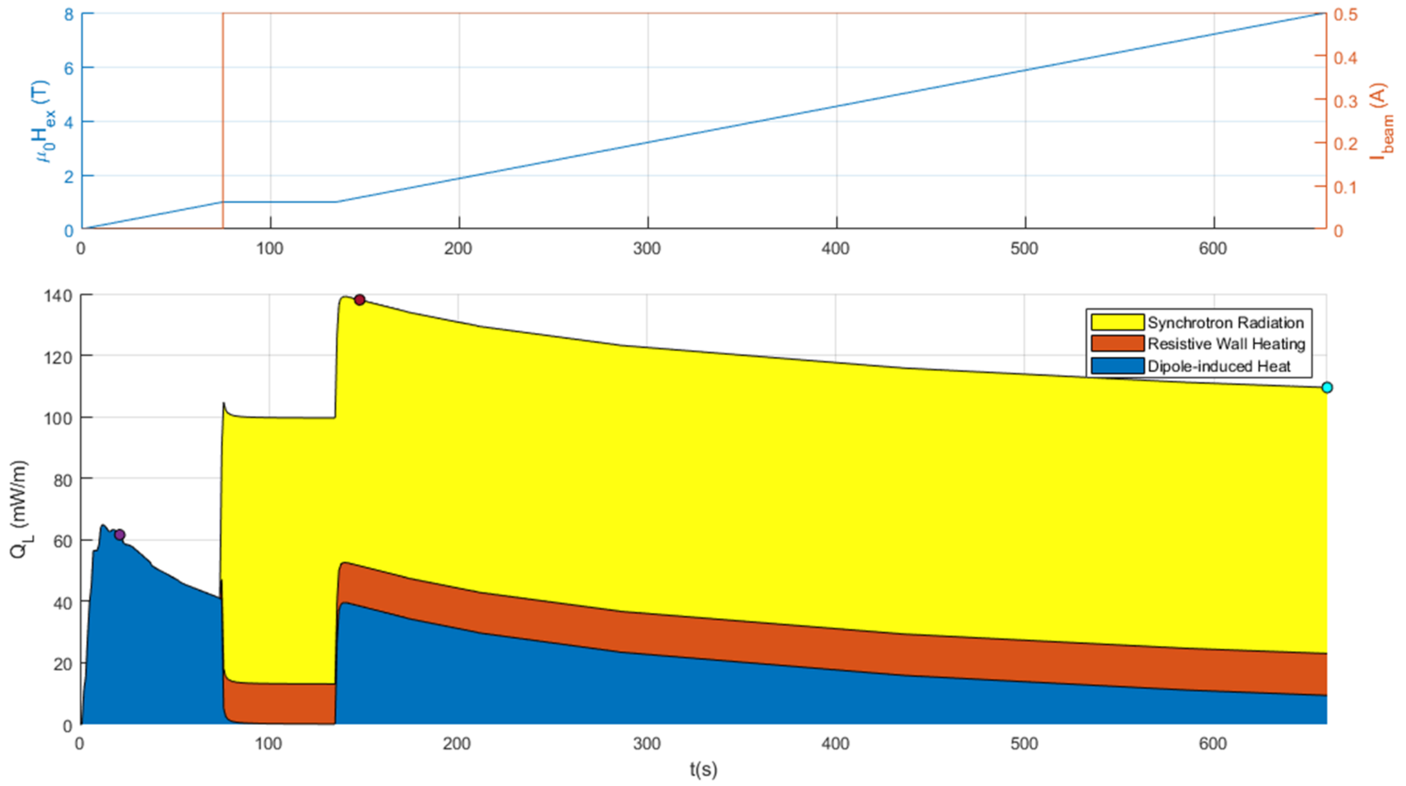
$$R_s^{sc} = (k_1\sqrt{B} + k_2)\omega^2$$

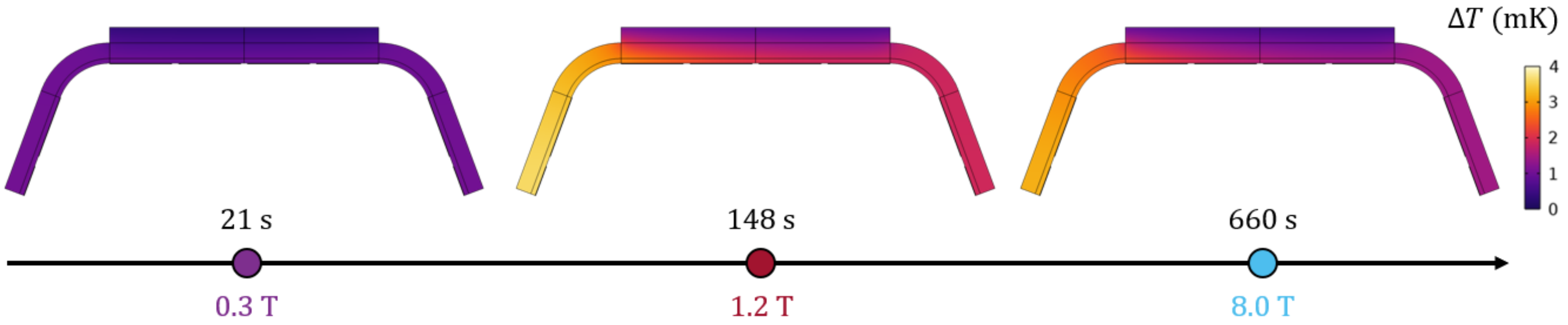
$$Q_{beam}(B,l) = \left(\frac{c^2}{\pi M f_0}\int_0^{c}\tilde{\lambda}^2(\omega)\, R_s(\omega,B,l)\, d\omega\right)\cdot J_s^2(l)$$

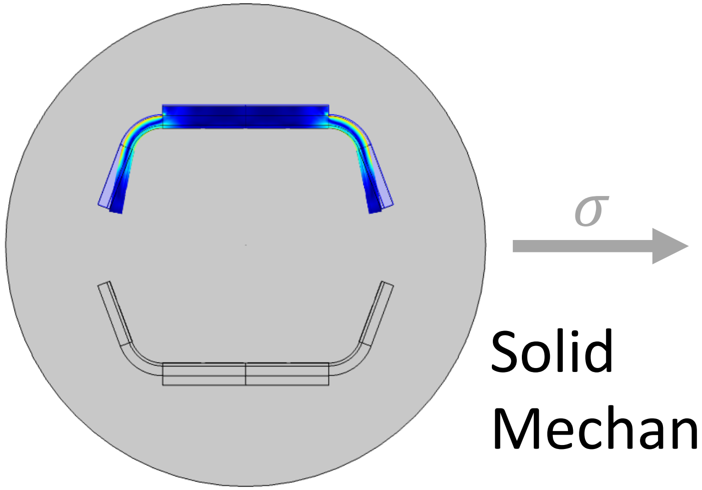
$$\vec{F}_s = \vec{J_s} \times \vec{B}$$

- Main heat contribution comes from the SR
- Only beam-induced heat during injection
- No significant shifts in temperature

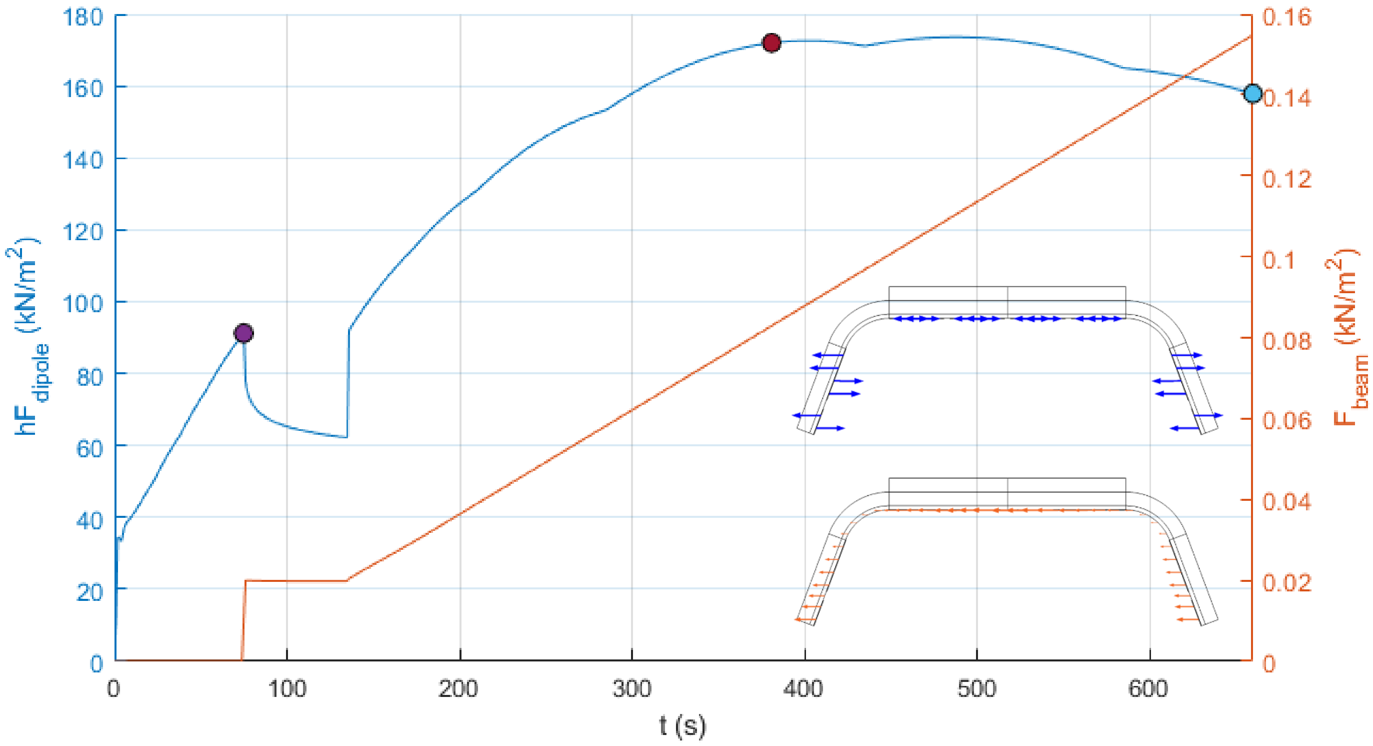




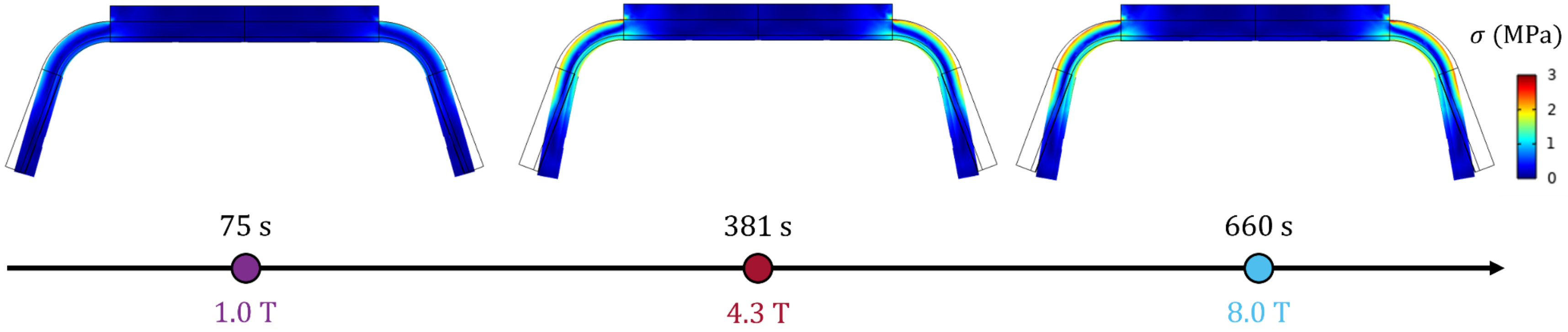




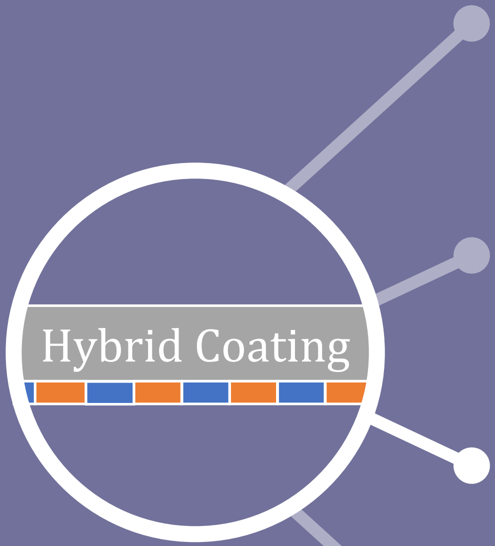
Solid Mechanics



- Main force contribution comes from the dipole field
- Symmetric dipole forces, assymmetric beam forces
- Relatively small induced stresses and deformation



Outline



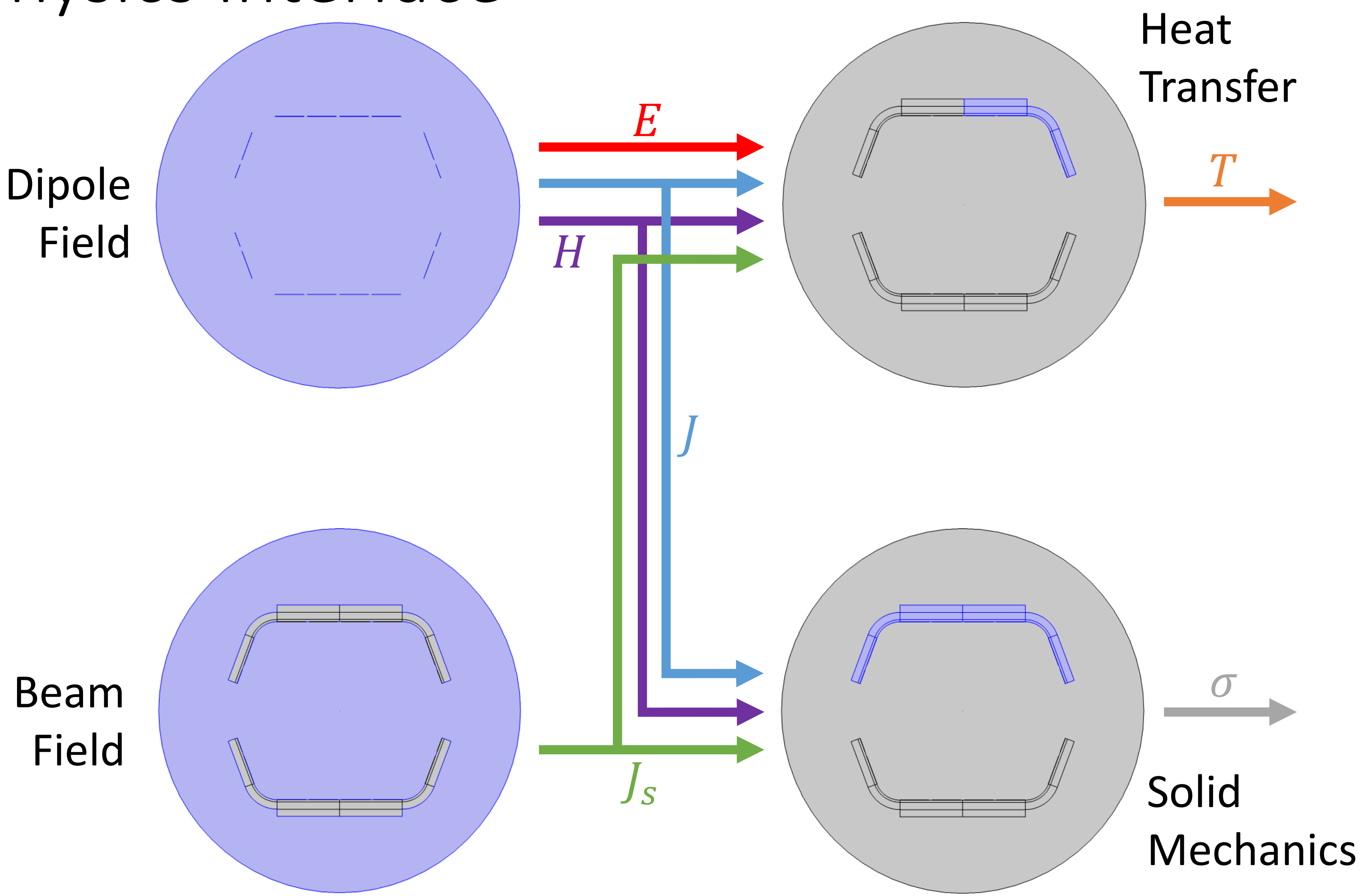
Introduction

Thermomechanical simulations during regular operation of the FCC

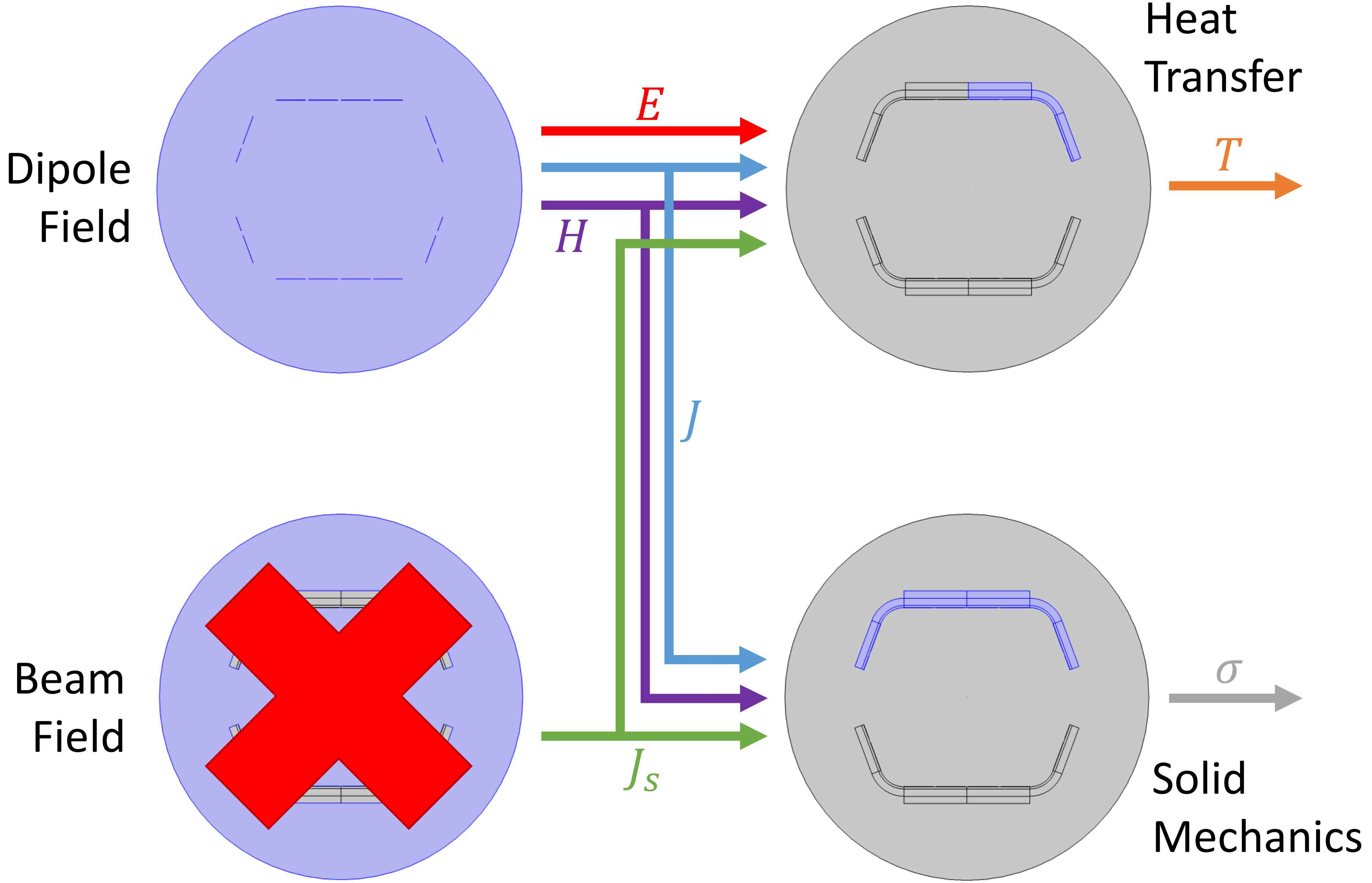
Thermomechanical simulations in the event of a dipole magnet quench

Conclusions

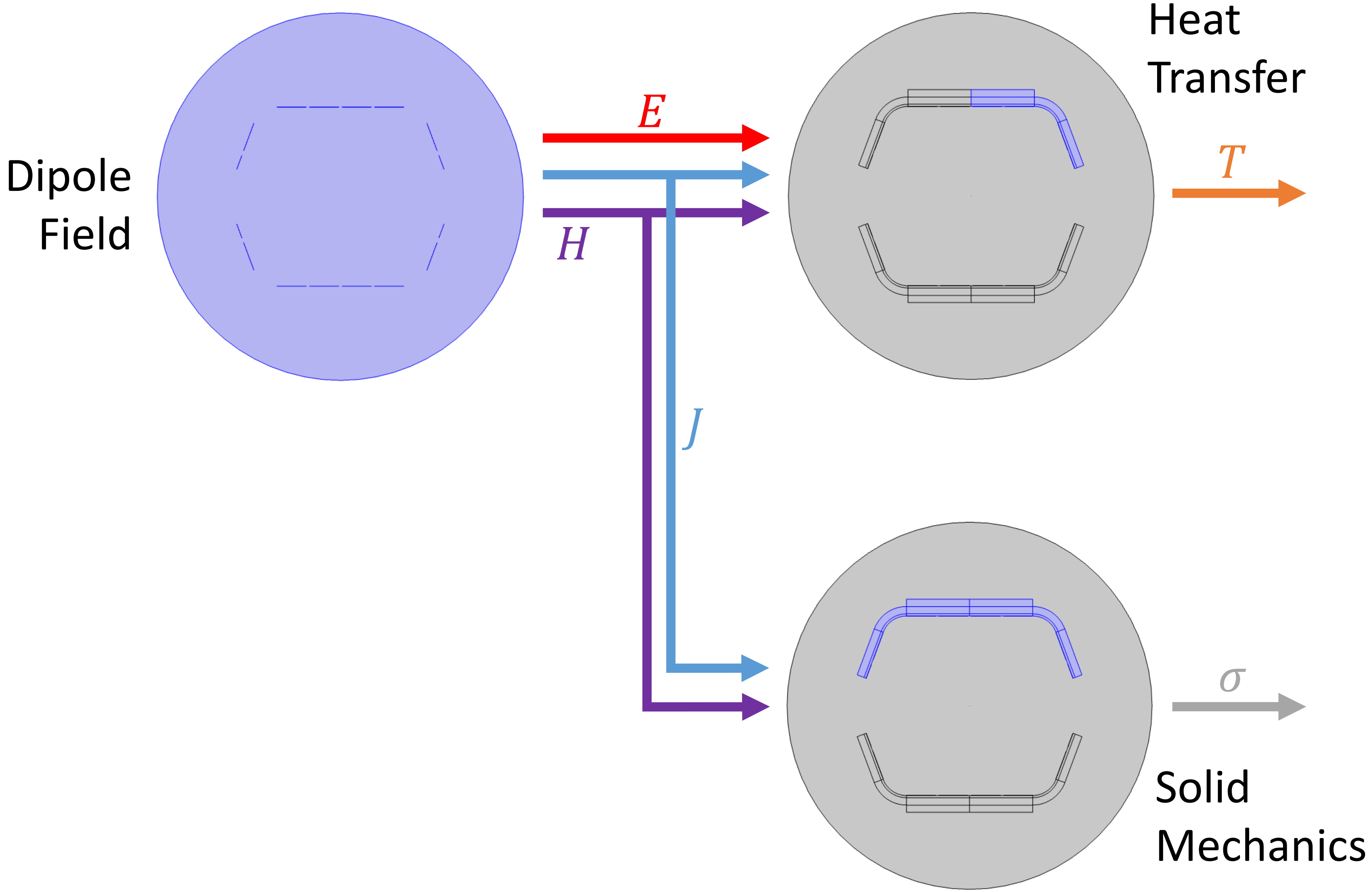
Multiphysics Interface



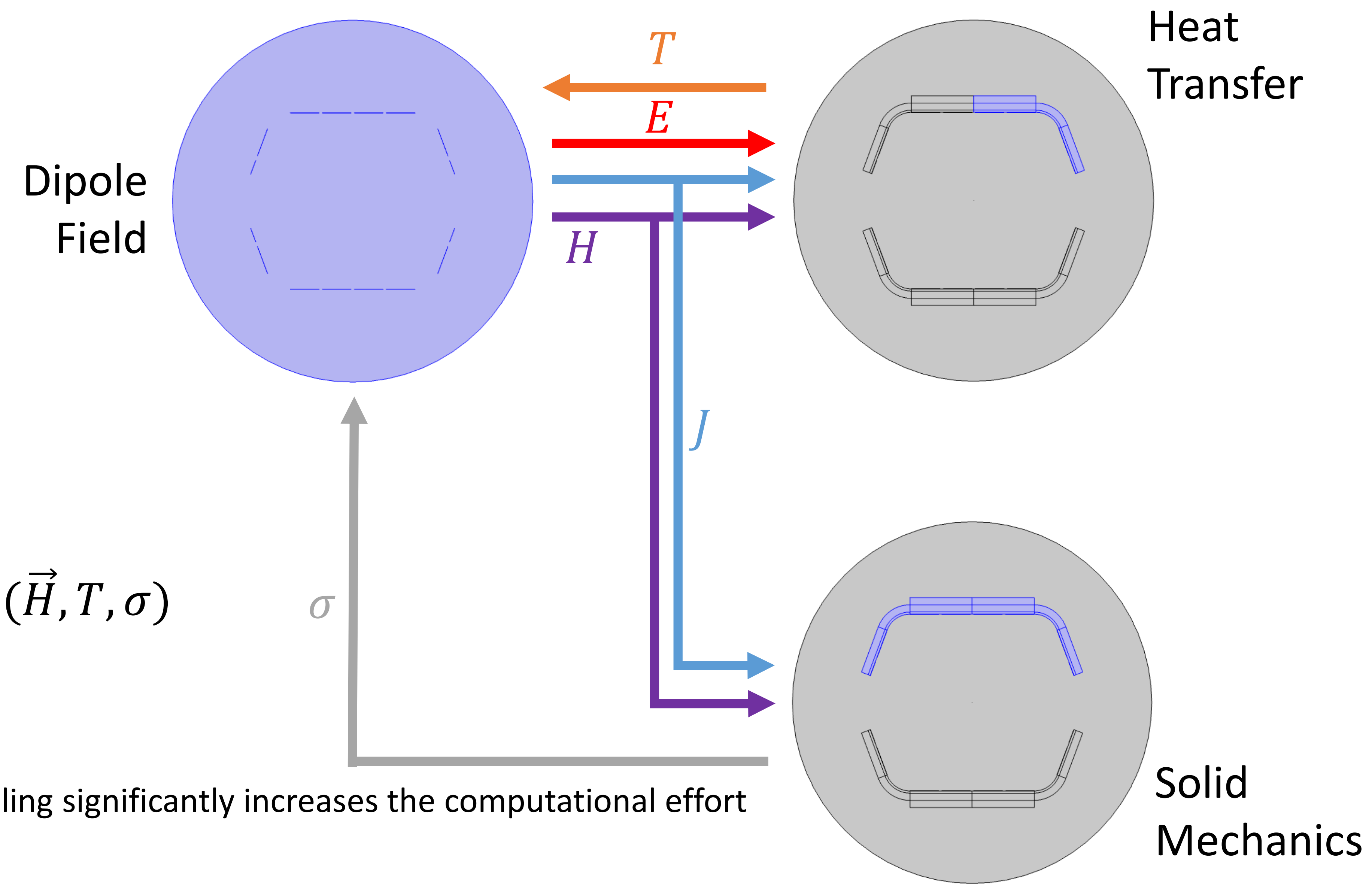
Multiphysics Interface



Multiphysics Interface



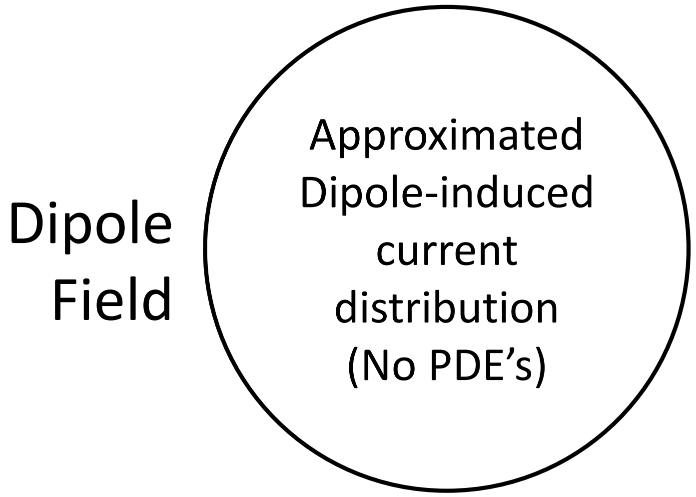
Multiphysics Interface

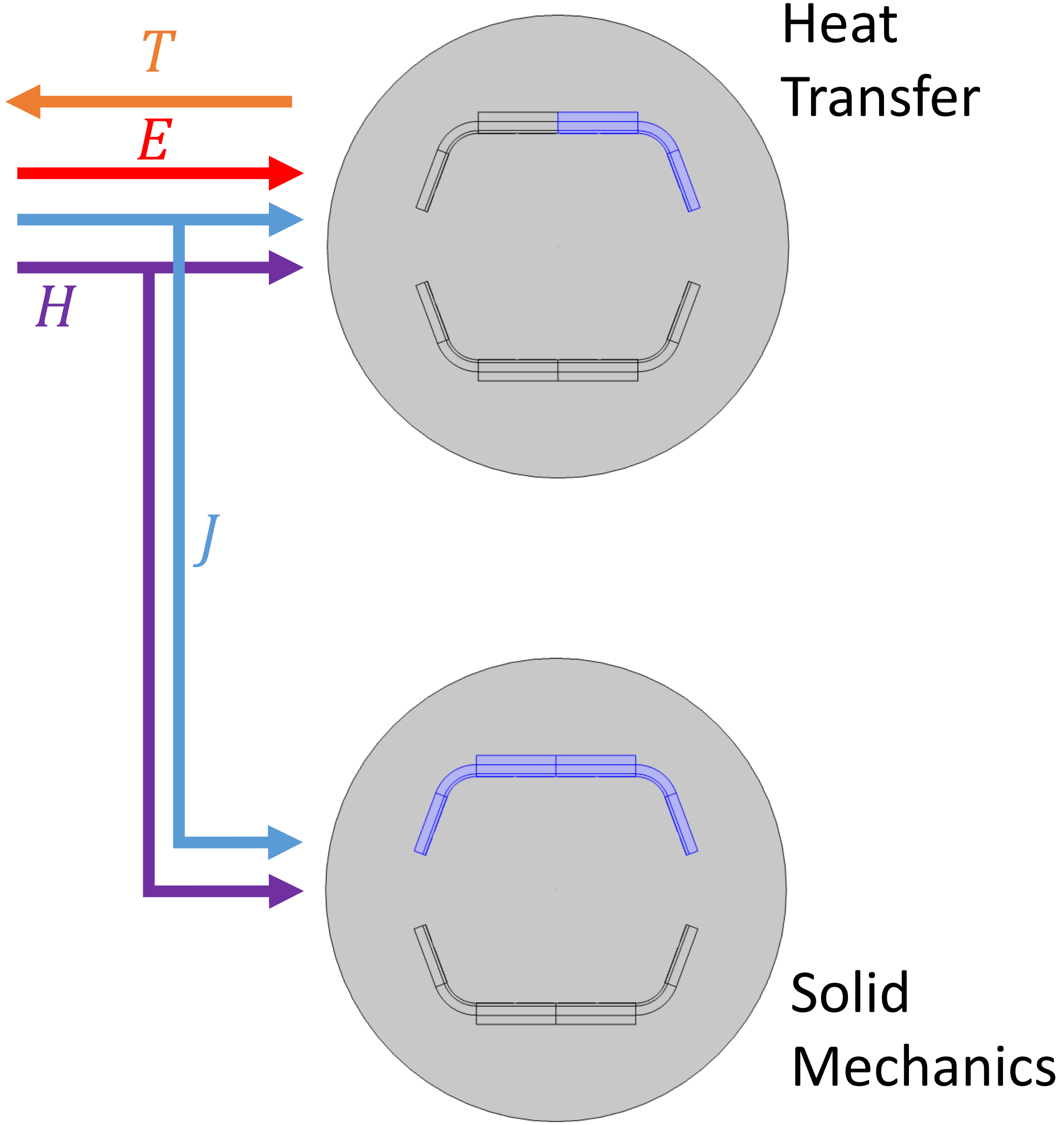


$$J_c = f(\vec{H}, T, \sigma)$$

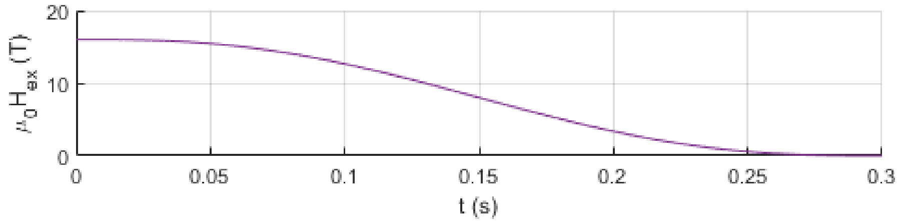
Bilateral coupling significantly increases the computational effort

Multiphysics Interface





$$J_c = f(\vec{H}, T)$$



Current approximation

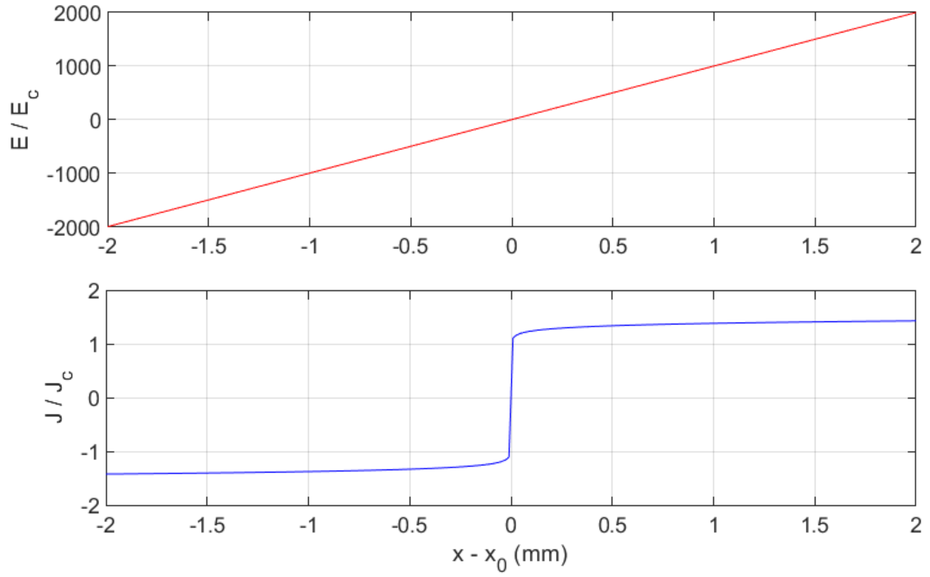
- Now E, J and H can be found directly from H_{ex}

$$B = \mu_0 H_{ex}$$

$$E = -\frac{\partial B}{\partial t}(x - x_0)$$

$$\vec{J} = \frac{1}{\rho}\vec{E}$$

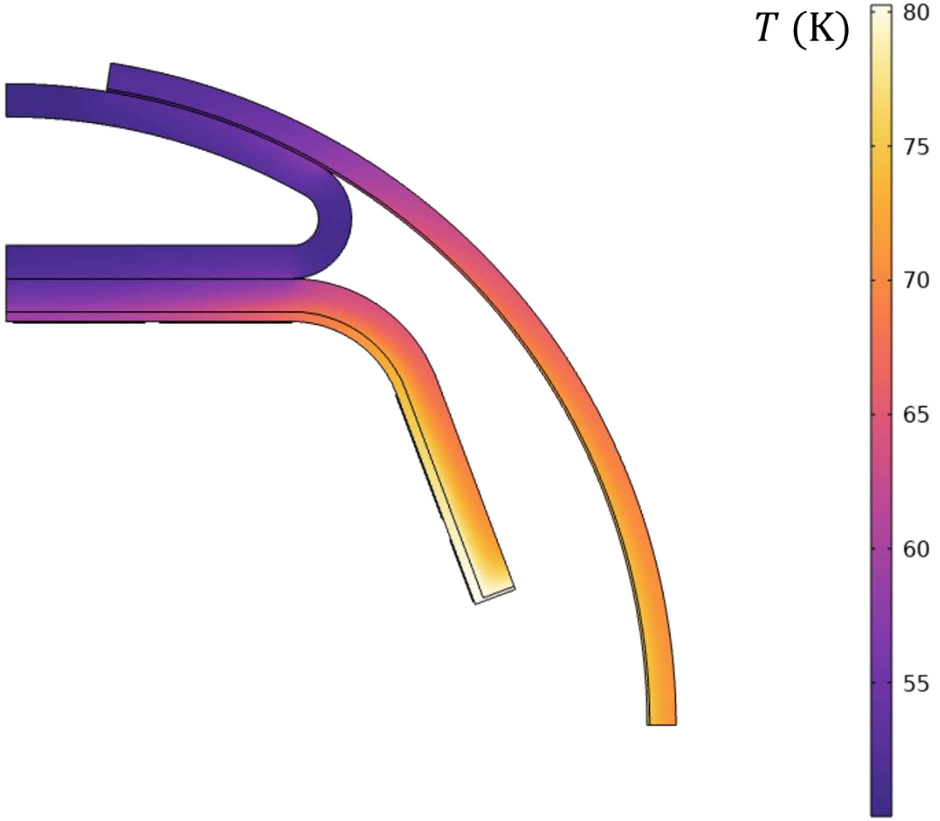
$$\rho_{sc} = \left| \frac{E_c}{J_c(\vec{H}, T, \sigma)} \left(\frac{E}{E_c}\right)^{1 - \frac{1}{N(\vec{H})}} \right|$$

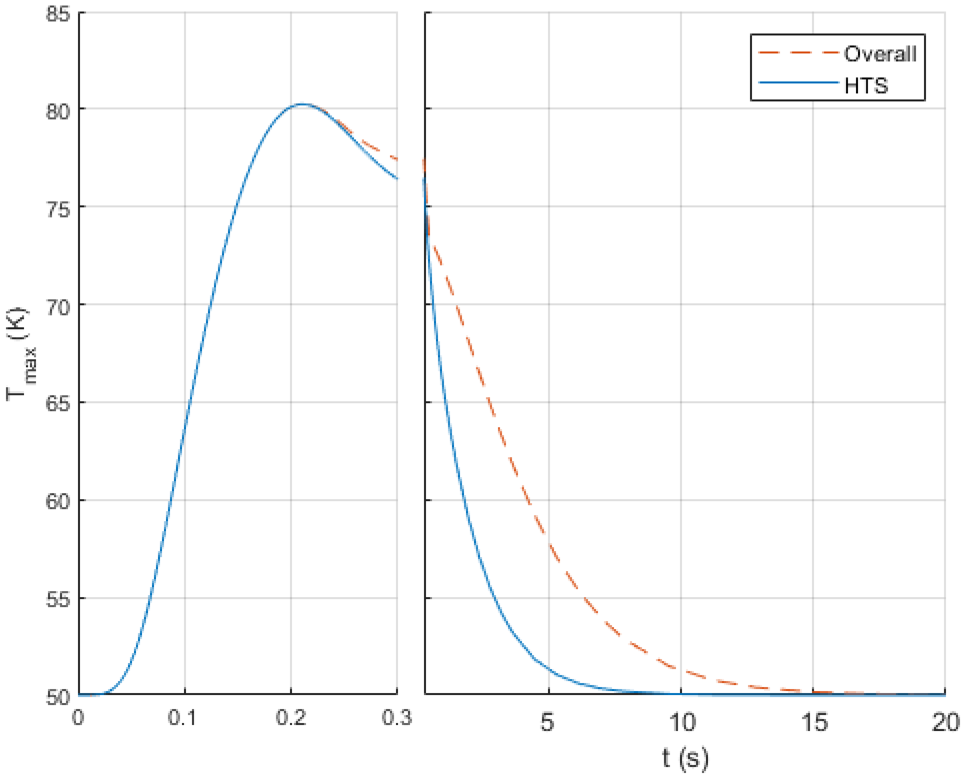


Dipole Field

Approximated Dipole-induced current distribution (No PDE's)

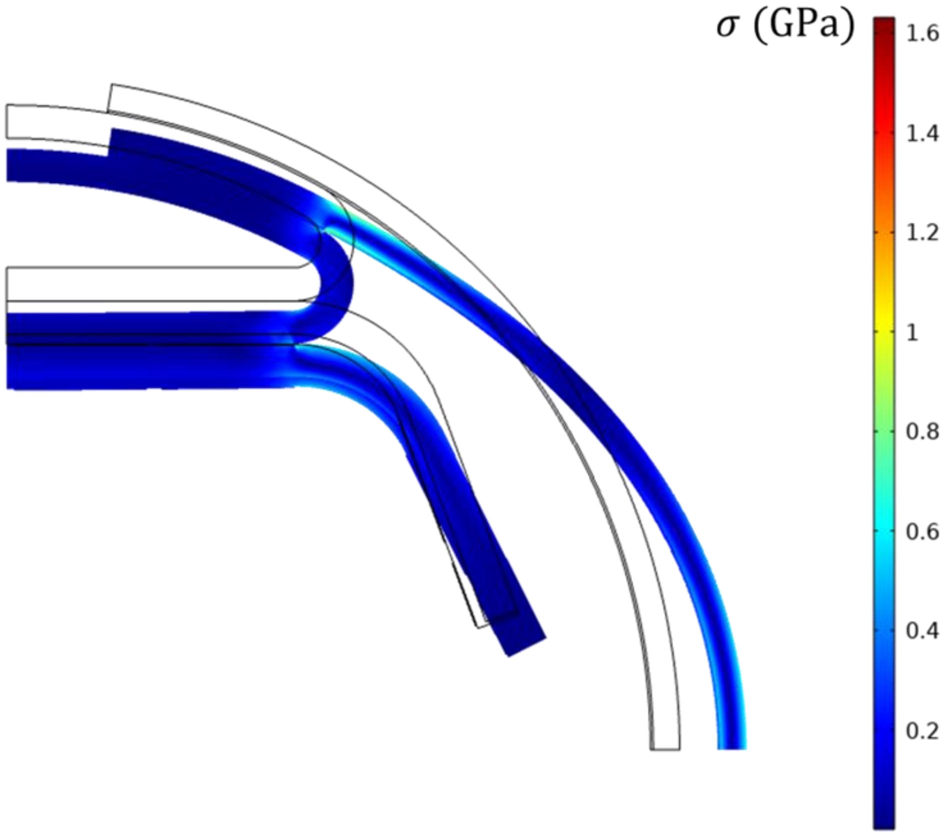
Quench Results: Thermal

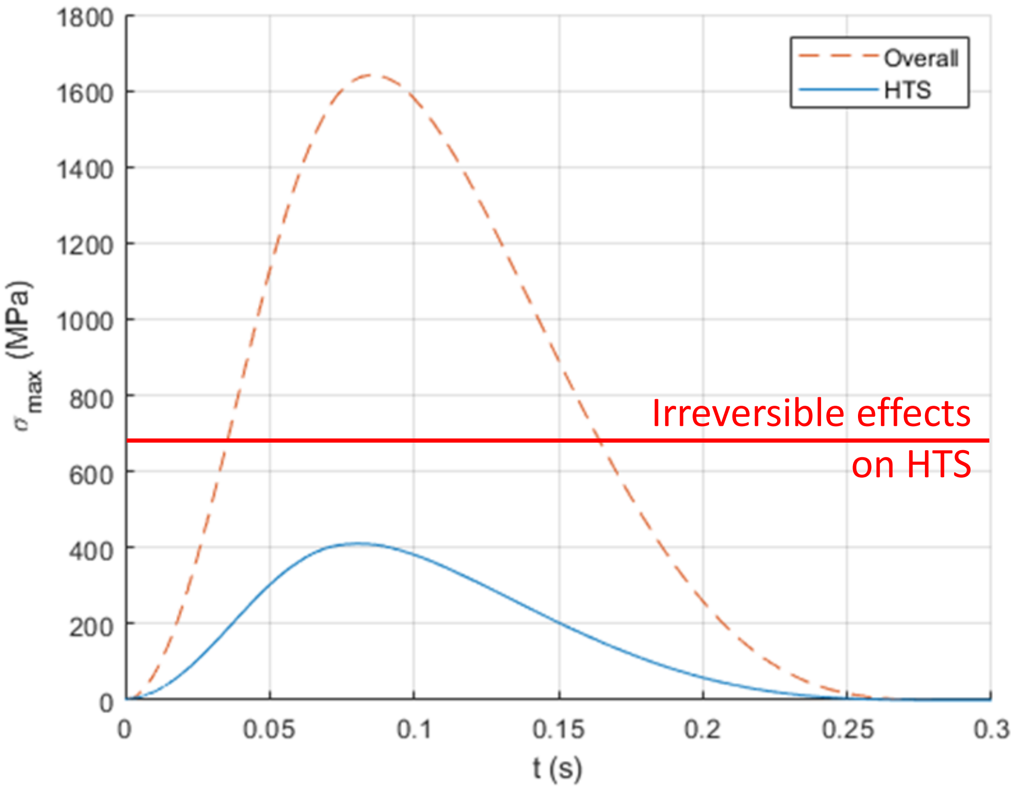




Significant temperature shift, but still below T_c

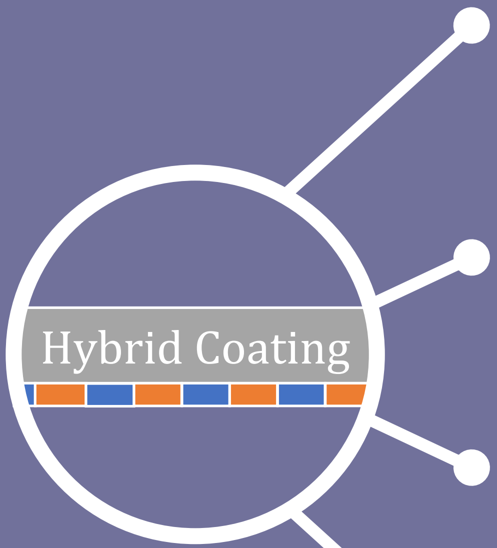
Quench Results: Mechanical





Significant strain, but still not enough to damage HTS

Summary and Conclusions



The beam screen of particle accelerators requires a **low surface impedance** and **high field quality** coating to preserve the orbit of the particle beam. The coated beam screen must endure the thermomechanical loads during regular operation and in the event of a magnet quench.

A **multiphysics interface** accounting for **beam- and dipole-induced effects** in the beam screen is used to calculate the current distribution in the beam screen and the emerging **Lorentz Forces** and **Joule Heating**

J_c and R_s of REBCO take into account **material properties from commercially available coated conductors** and include aspects such as superconductor **anisotropy and creep**

Simulation results show **negligible thermomechanical effects during regular operation** and **tolerable mechanical stresses and temperature shift in the event of a dipole magnet quench.**

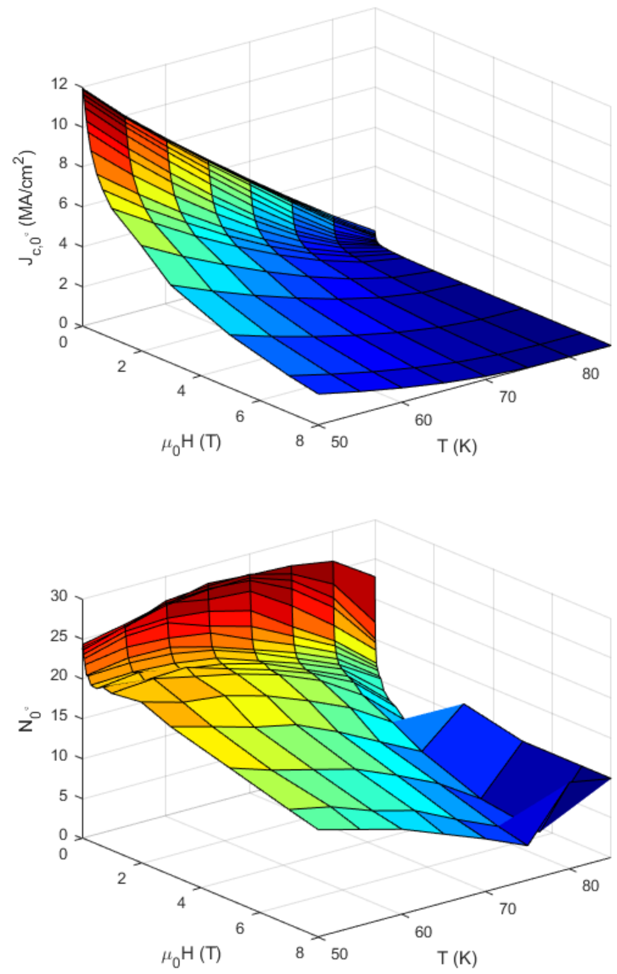
Thank you!

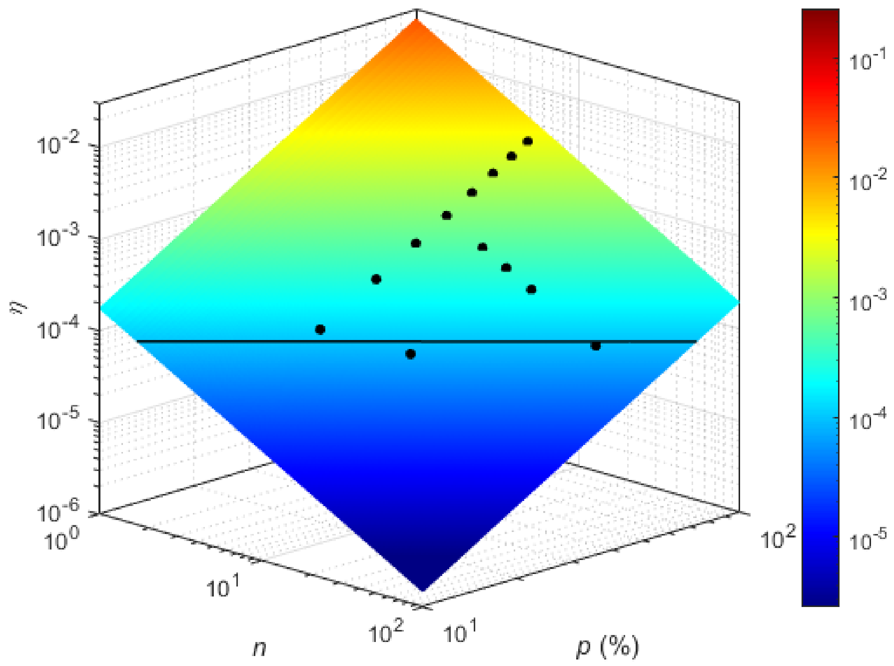
gtelles@icmab.es

Backup Slides

gtelles@icmab.es

Backup Slides



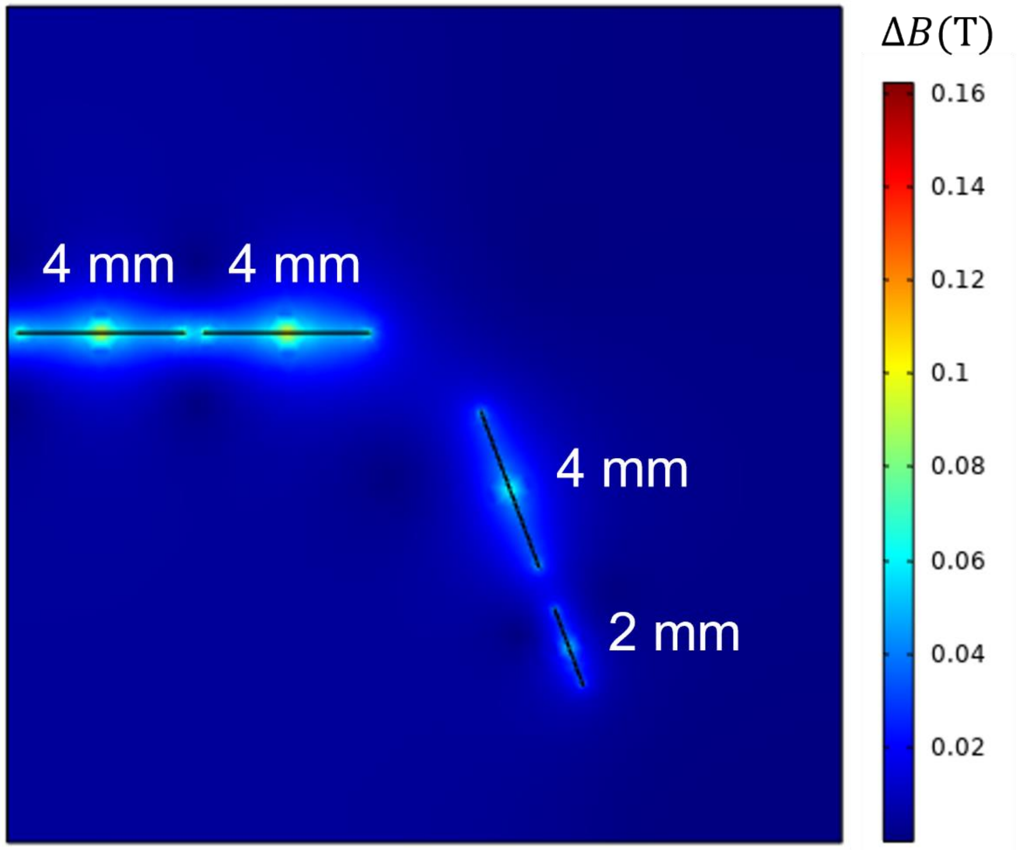


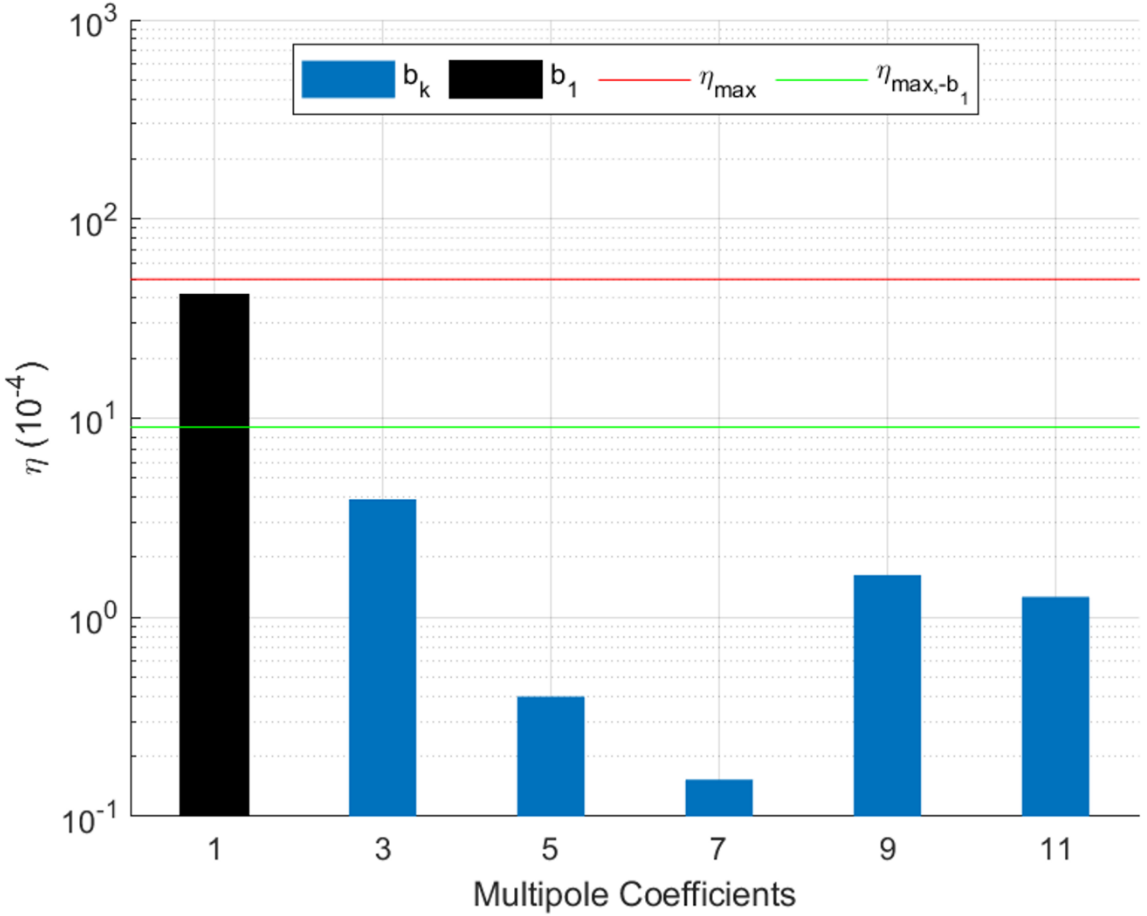
G T Telles *et al* 2023 *Supercond. Sci. Technol.* **36** 045001

Backup Slides

$p = 89\%$ → low Z_s

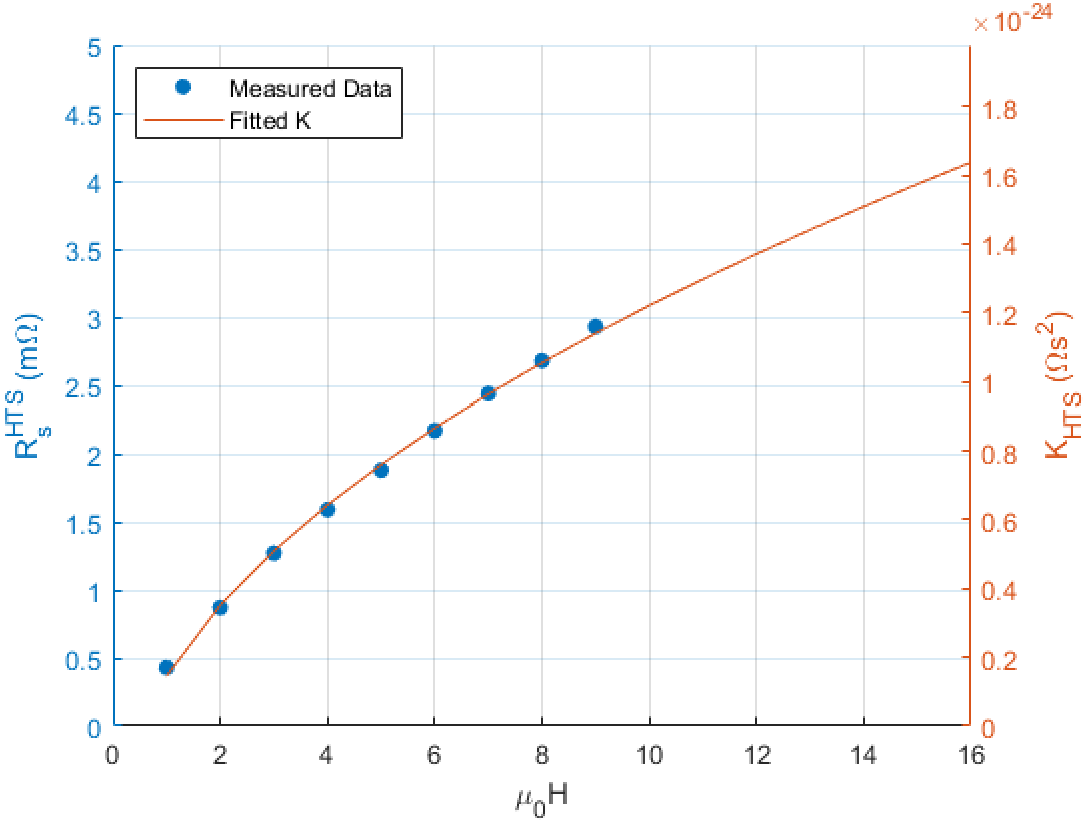
$n = 4$ → low b_k

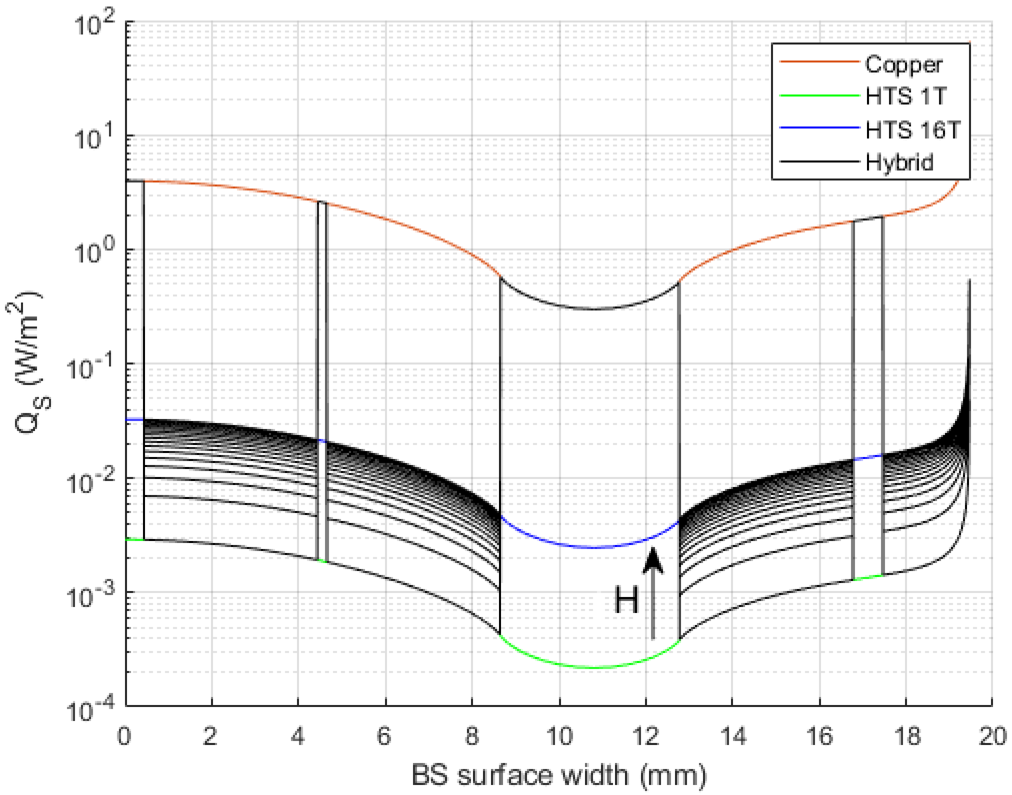




Widths = 2 and 4 mm, which are commercially available and therefore do not require further striation. Making the coating production process chaper, easier and faster.

Backup Slides





Backup Slides