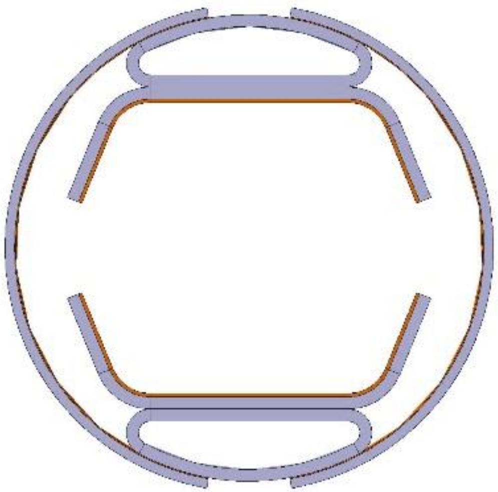
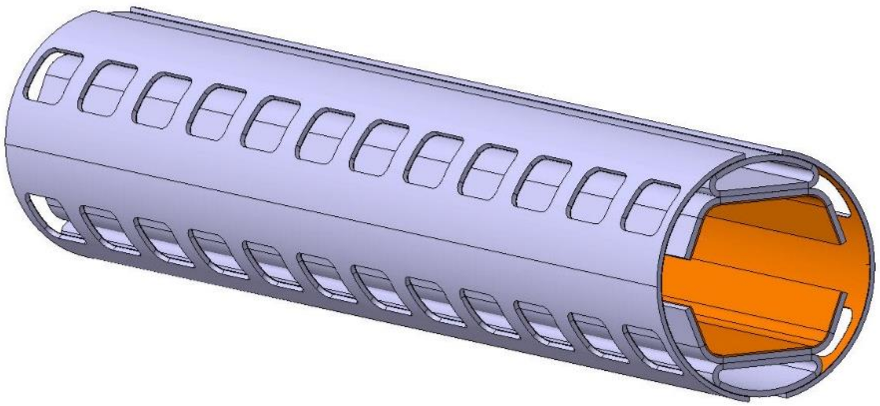
FCC-hh beam screen design

Marco Morrone
Cedric Garion

with inputs from Ignasi Bellafont





FCC week
Crowne Plaza Brussels Le Palace
24-28 June 2019

Outline

- Beam screen design
  - Recent design evolution at a glance
- Mechanical behaviour
  - Quench analysis
  - Beam screen supports
- Thermal behaviour
  - Temperature profile due to S.R.
  - Heat load to the cold bore by radiation and conduction
- Conclusions

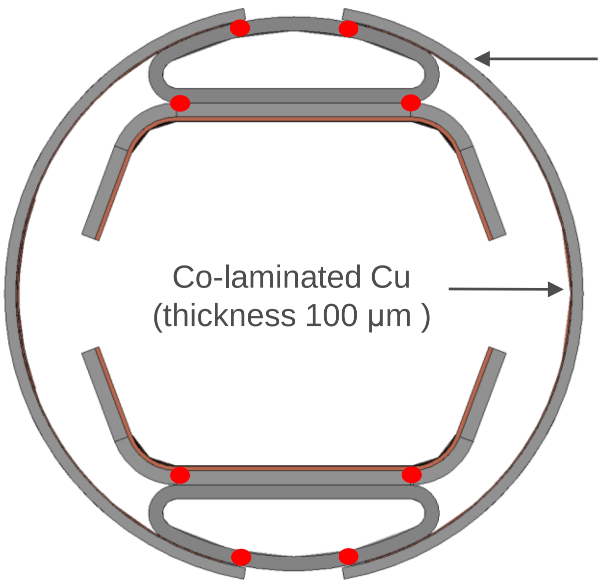
Outline

- Beam screen design
  - Recent design evolution at a glance
- Mechanical behaviour
  - Quench analysis
  - Beam screen supports
- Thermal behaviour
  - Temperature profile due to SR
  - Heat load to the cold bore by radiation and conduction
- Conclusions

Beam Screen Design

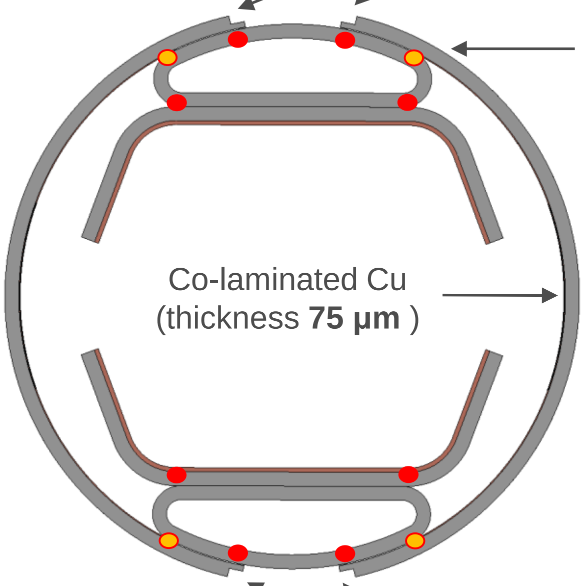
Recent design evolution at a glance

Former version



● Welding points (0.5 mm wide)

Updated version



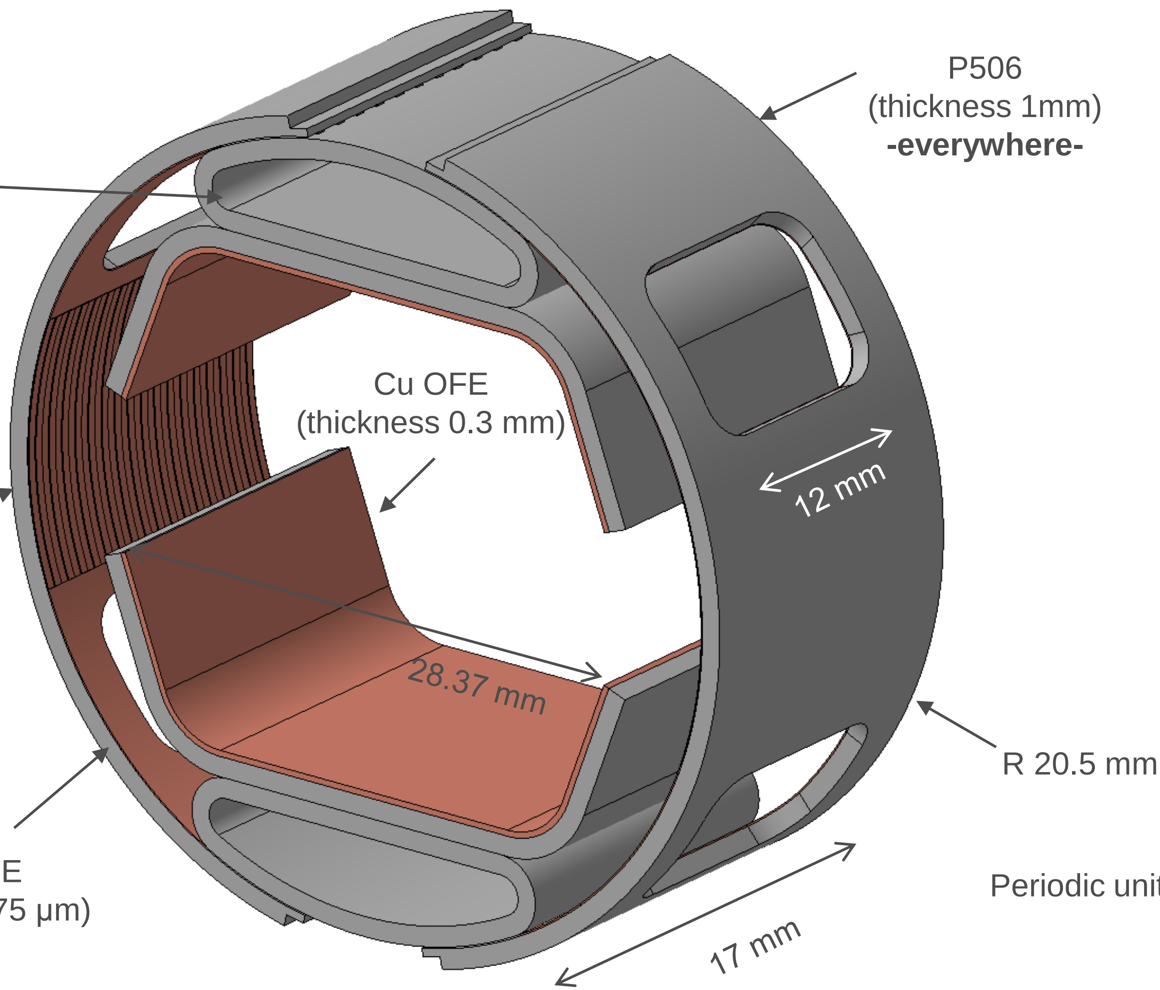
● Welding points (0.5 mm wide)

● New welding points (0.5 mm wide)

Beam Screen Design

Recent design evolution at a glance

Updated version

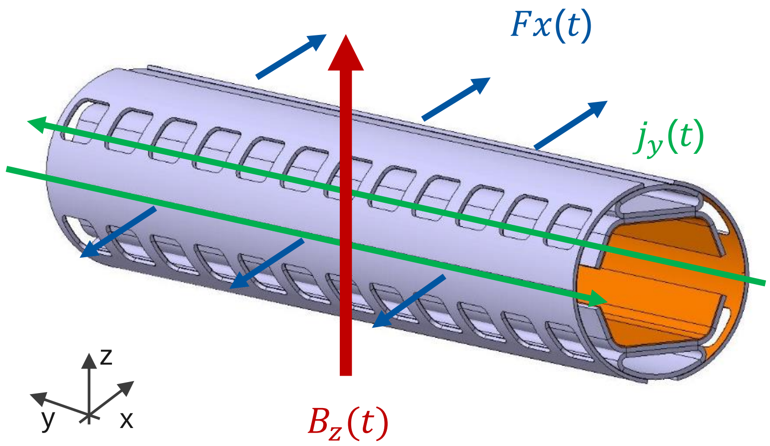


Outline

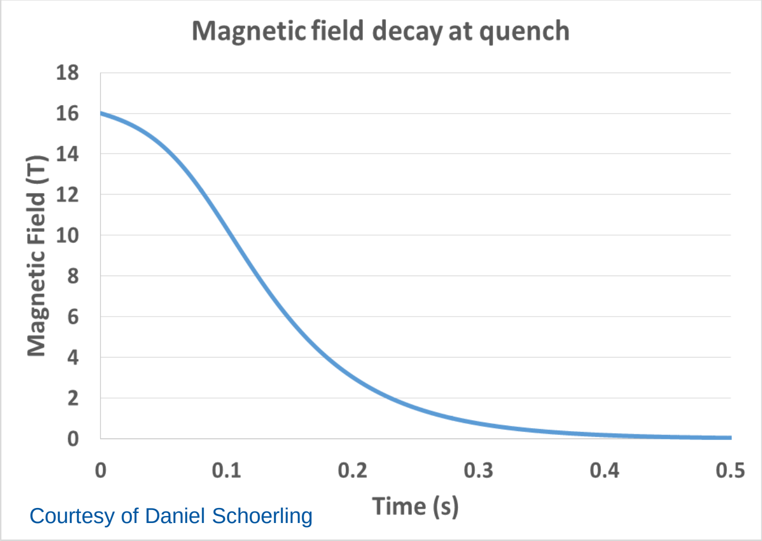
- Beam screen design
  - Recent design evolution at a glance
- Mechanical behaviour
  - Quench analysis
  - Beam screen supports
- Thermal behaviour
  - Temperature profile due to SR
  - Heat load to the cold bore by SR and the supporting system
- Conclusions

Mechanical behaviour

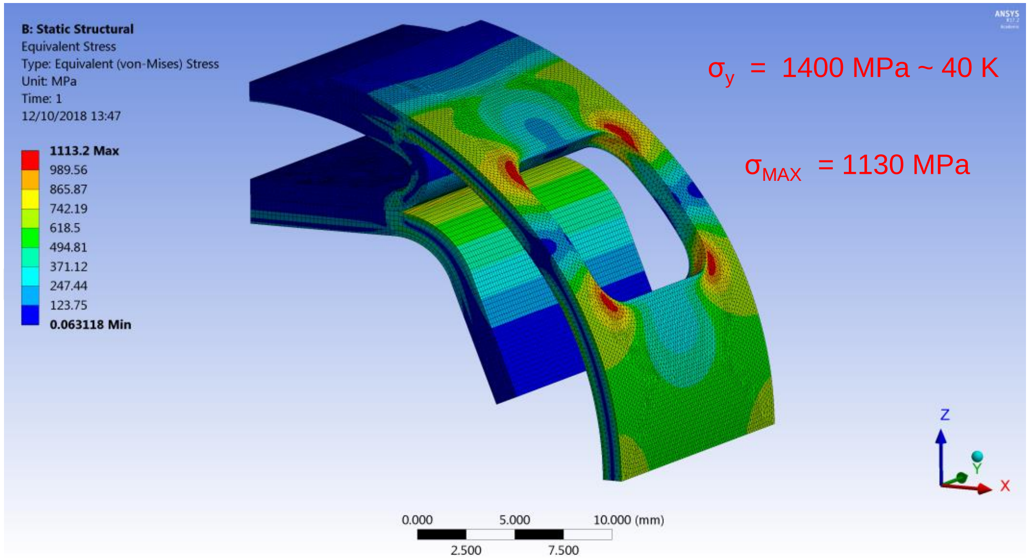
Quench analysis



- Variation of magnetic field at quench (resistive transition of the magnet) produces currents along the beam screen.
- These currents generate Lorentz forces that might endanger the mechanical integrity of the beam screen.
- 3D simulations have been carried out taking into account the Joule effect coupling with the magnetic field $(\rho C_p \frac{\partial T}{\partial t} - \nabla(k\nabla T) = Q_e = JE)$.



Courtesy of Daniel Schoerling

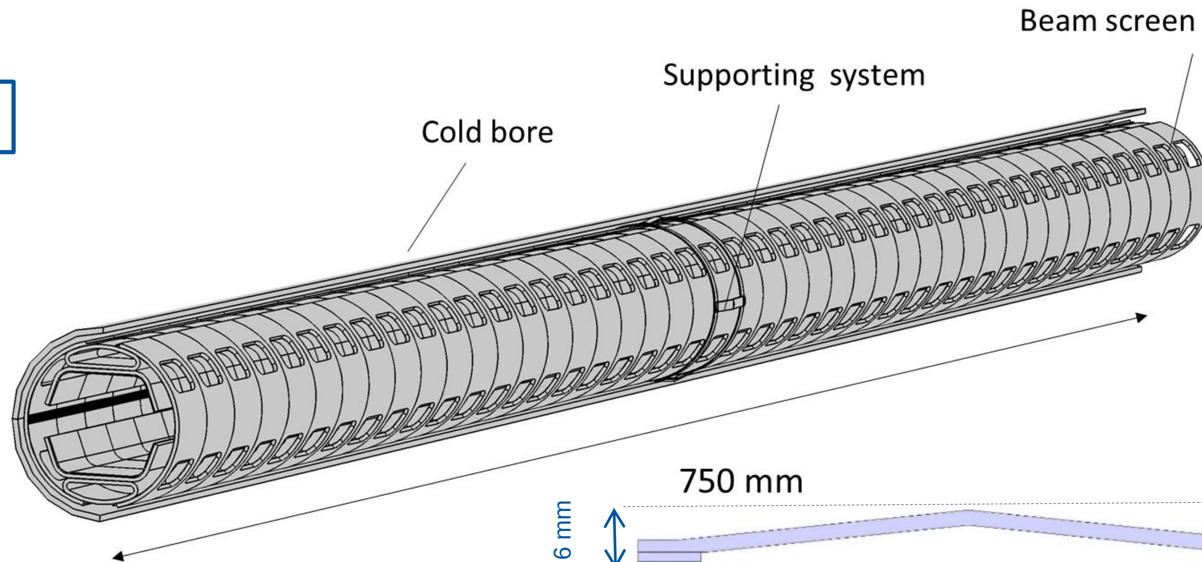


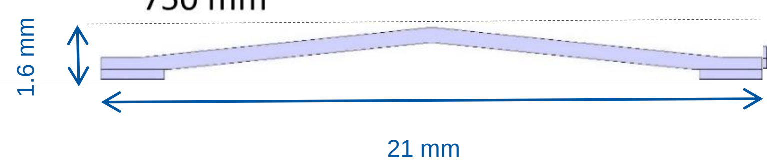
Von Mises stress when the highest forces are induced

Beam Screen Design

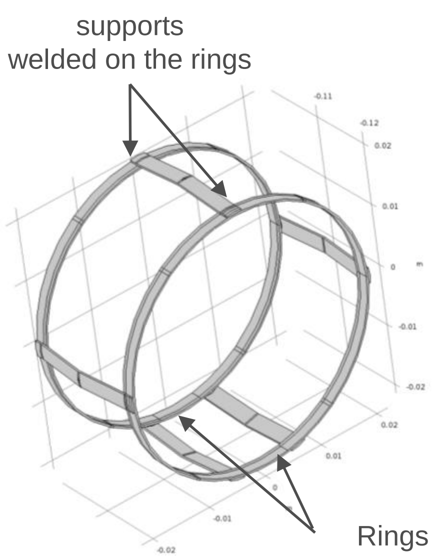
Beam screen supports

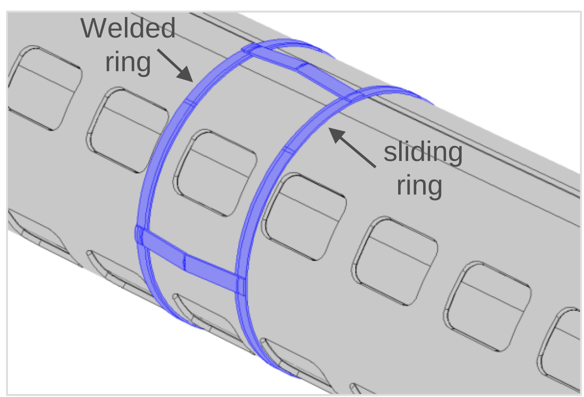
Beam screen supports



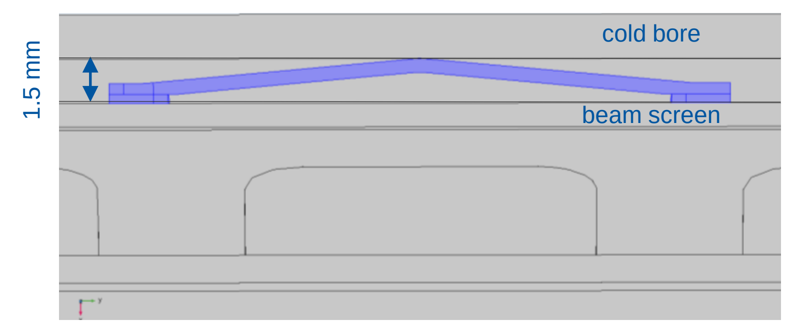


Before insertion → pre-stress insertion 0.1 mm





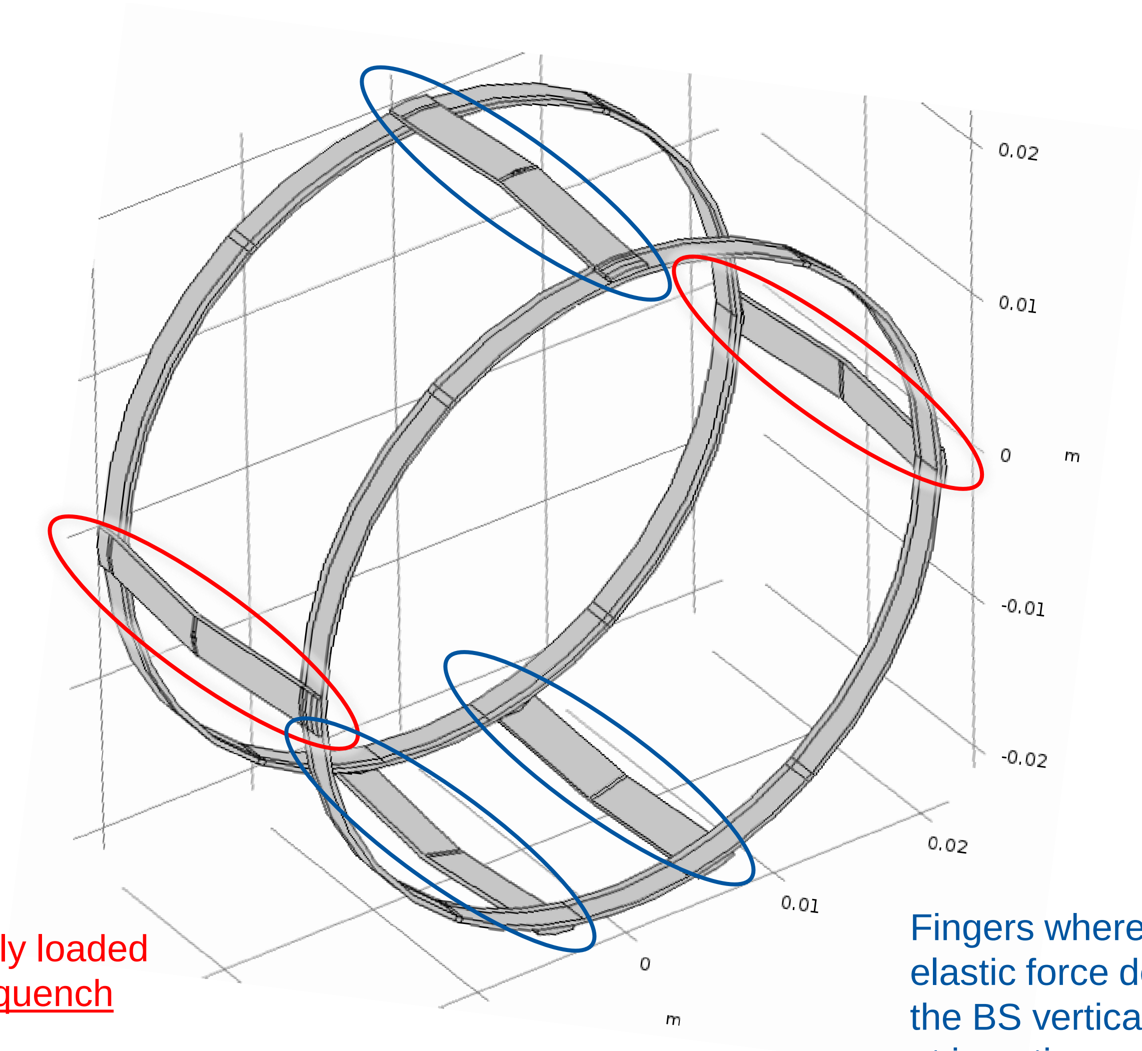
Rings welded as two half shells on the BS



After insertion

Beam Screen Design

Beam screen supports



Later fingers highly loaded during a magnet quench

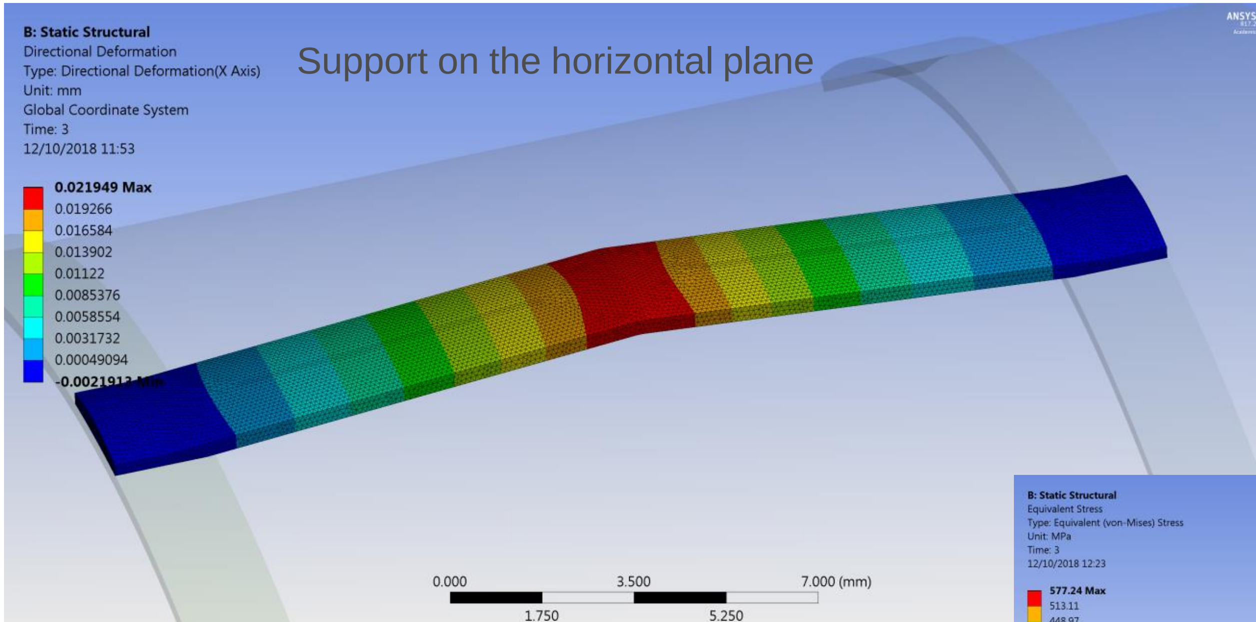
Fingers where the elastic force determines the BS vertical position at insertion

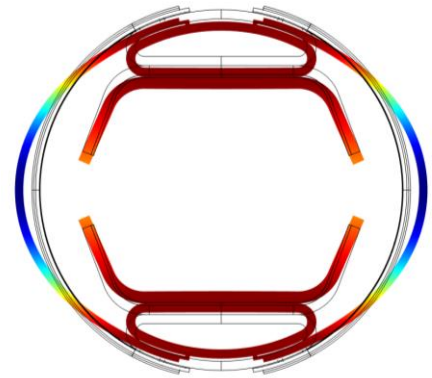
Mechanical behaviour

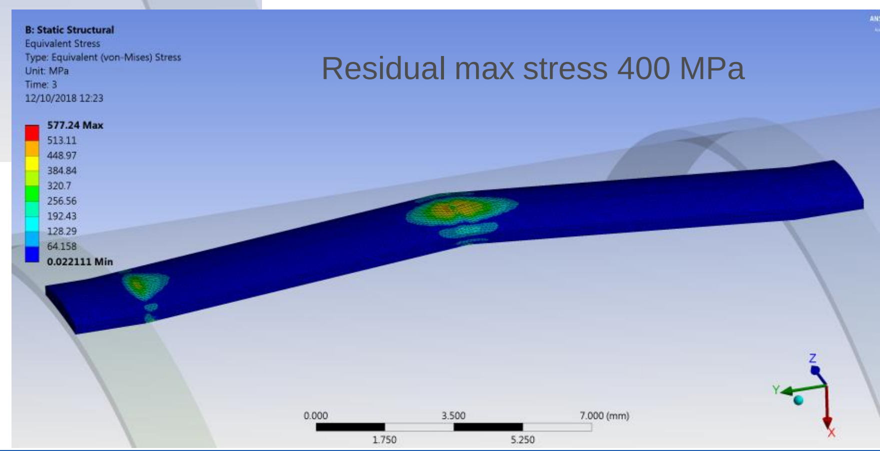
Beam screen supports at magnet quench

Maximum BS displacement Δx=0.65 mm

Residual deformation **20 µm** < 100 µm of pre stress







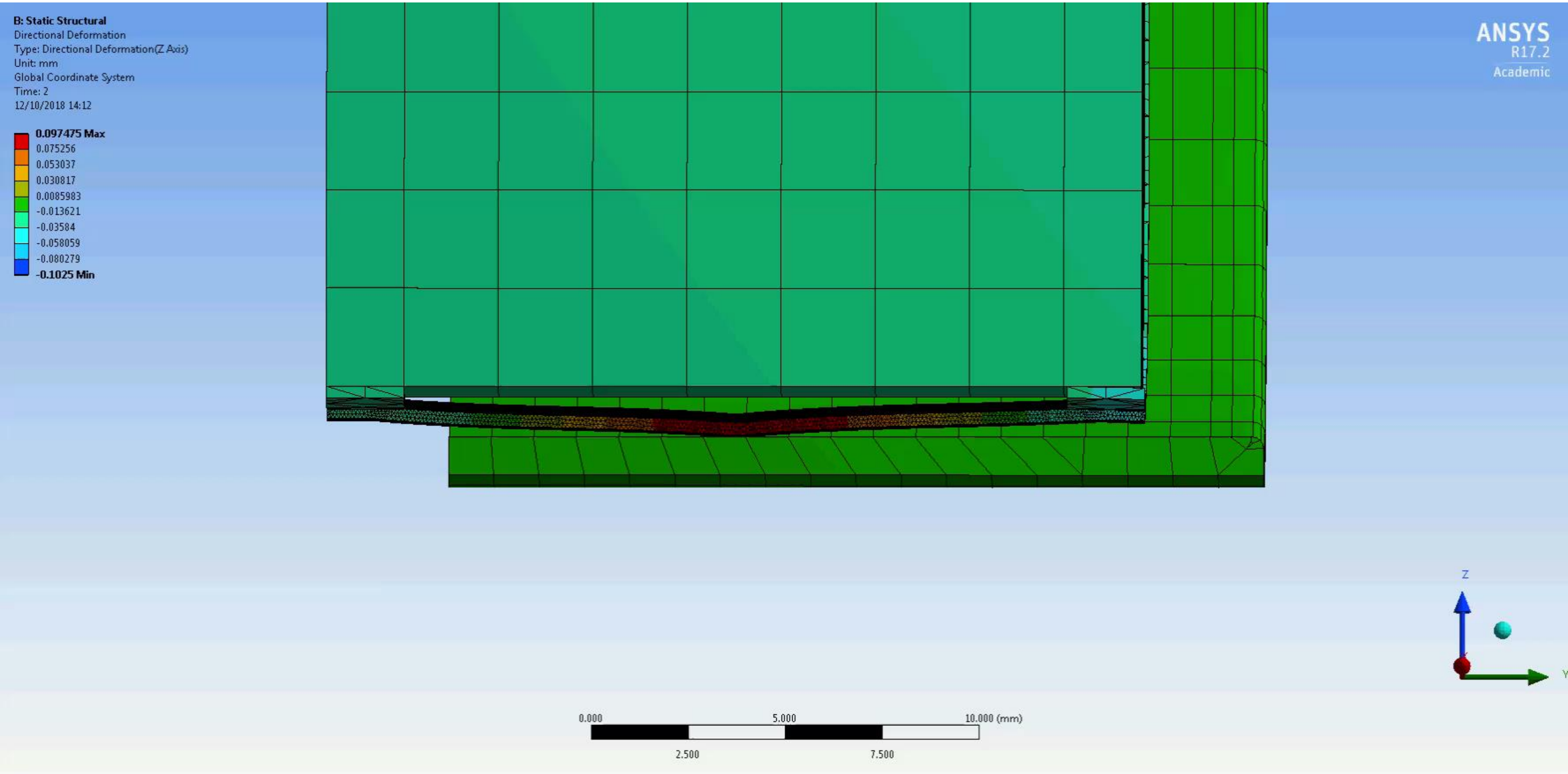
Optimisation of the beam screen supports to withstand a magnet quench with reduced plastic deformation

Mechanical behaviour

Beam screen supports at insertion

Weight: 2.16 kg/m

Vertical displacement: -32 µm

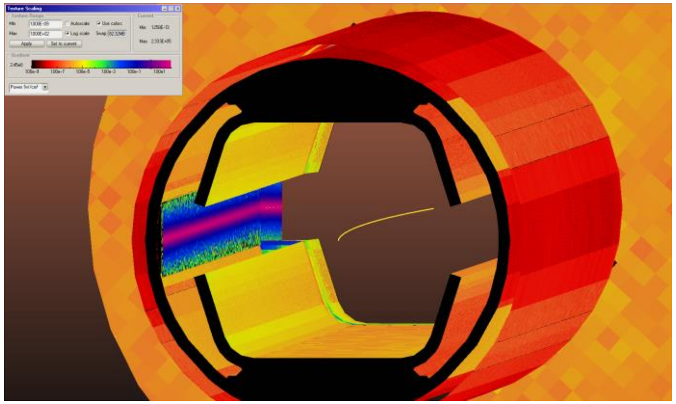


Outline

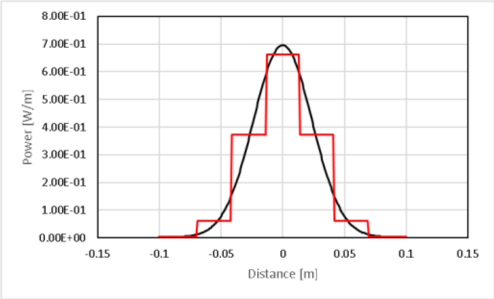
- Beam screen design
  - Recent design evolution at a glance
- Mechanical behaviour
  - Quench analysis
  - Beam screen supports
- Thermal behaviour
  - Temperature profile due to SR
  - Heat load to the cold bore by radiation and conduction
- Conclusions

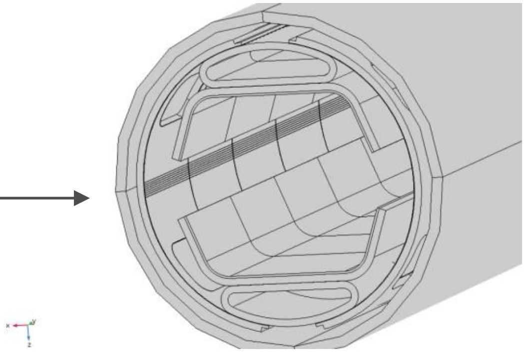
Thermal behaviour

Temperature profile due to S.R.

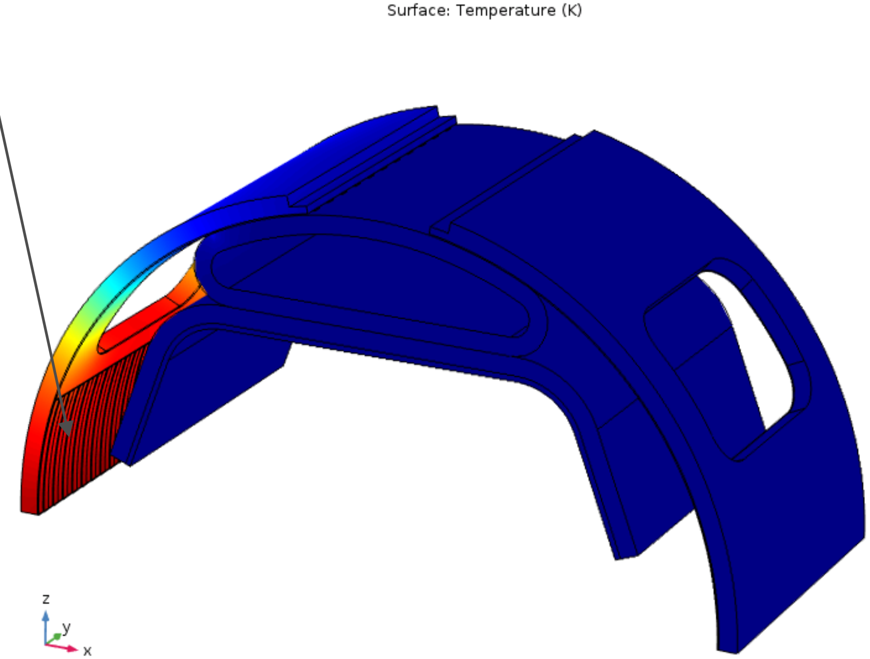


Max **synchrotron radiation** power ~ 42 W/m
Beam intensity: 0.5 A, 50 TeV

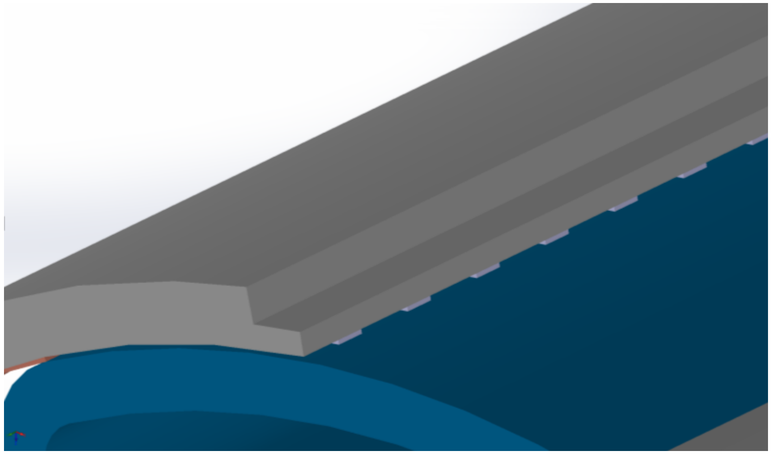




Heat load deposited according to a Gaussian distribution on the saw-teeth



Half beam screen has been modelled because of symmetry

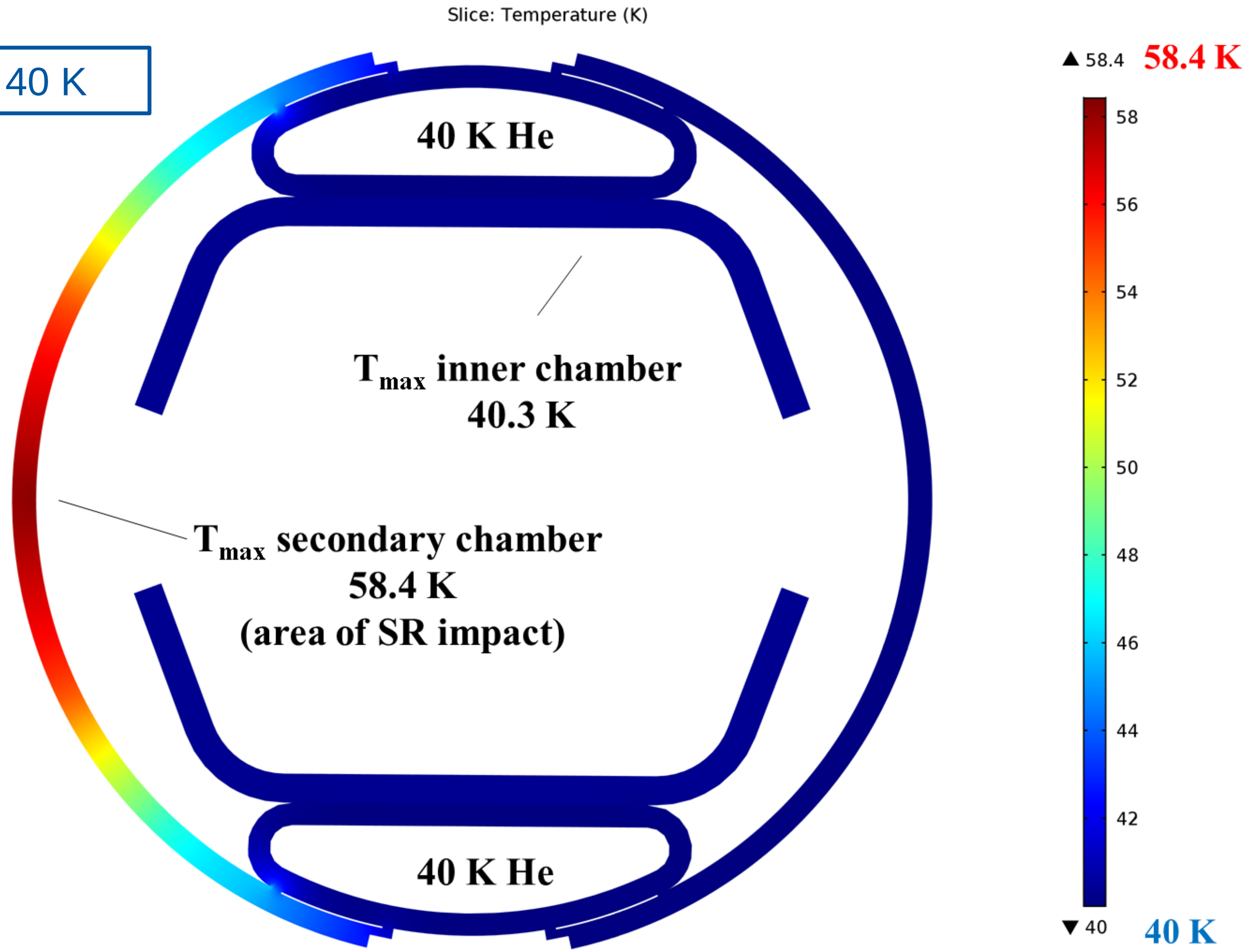


Thermal contacts (bonded) according to the spot welding pattern

Thermal behaviour

Temperature profile due to S.R.

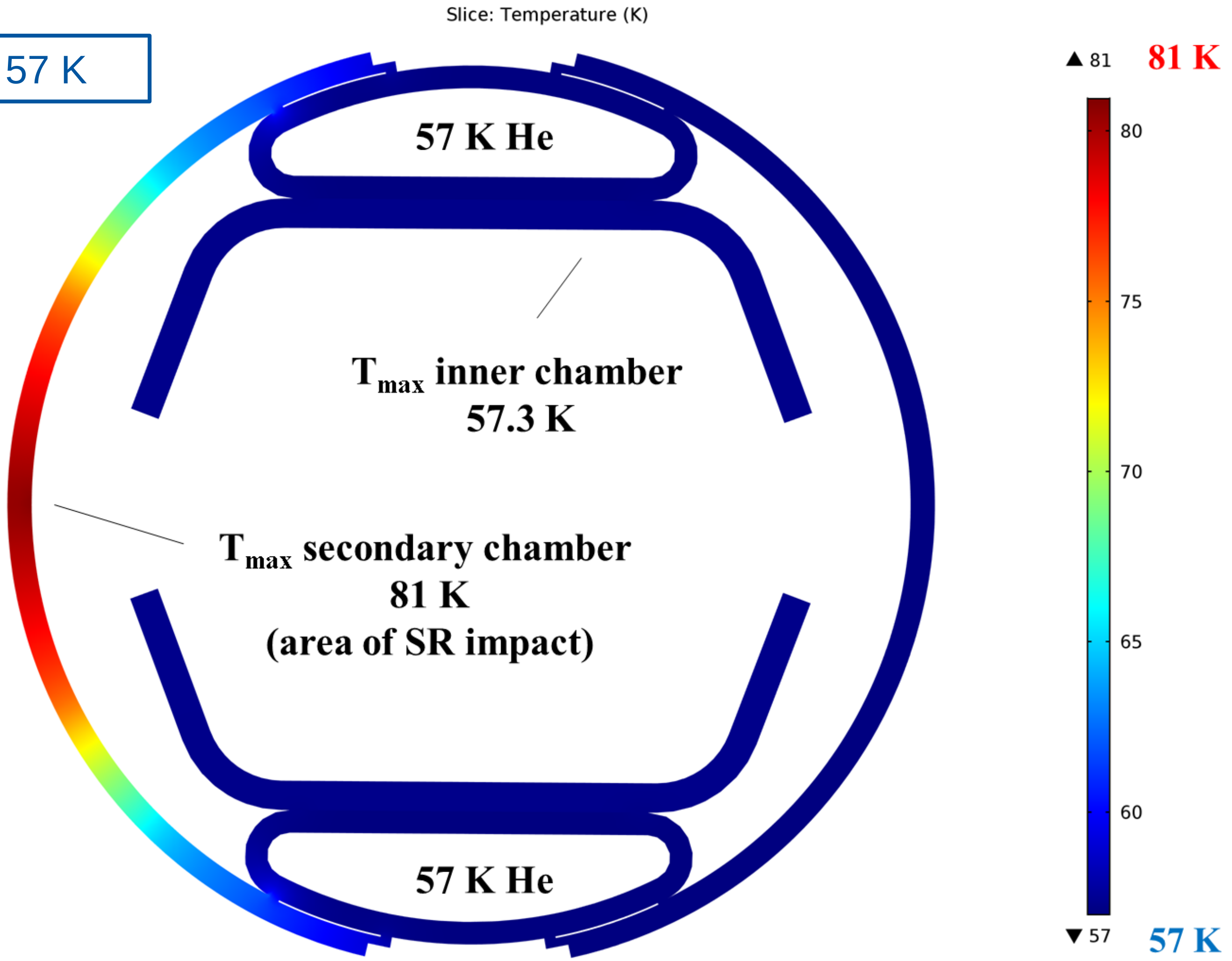
Base temperature 40 K



Thermal behaviour

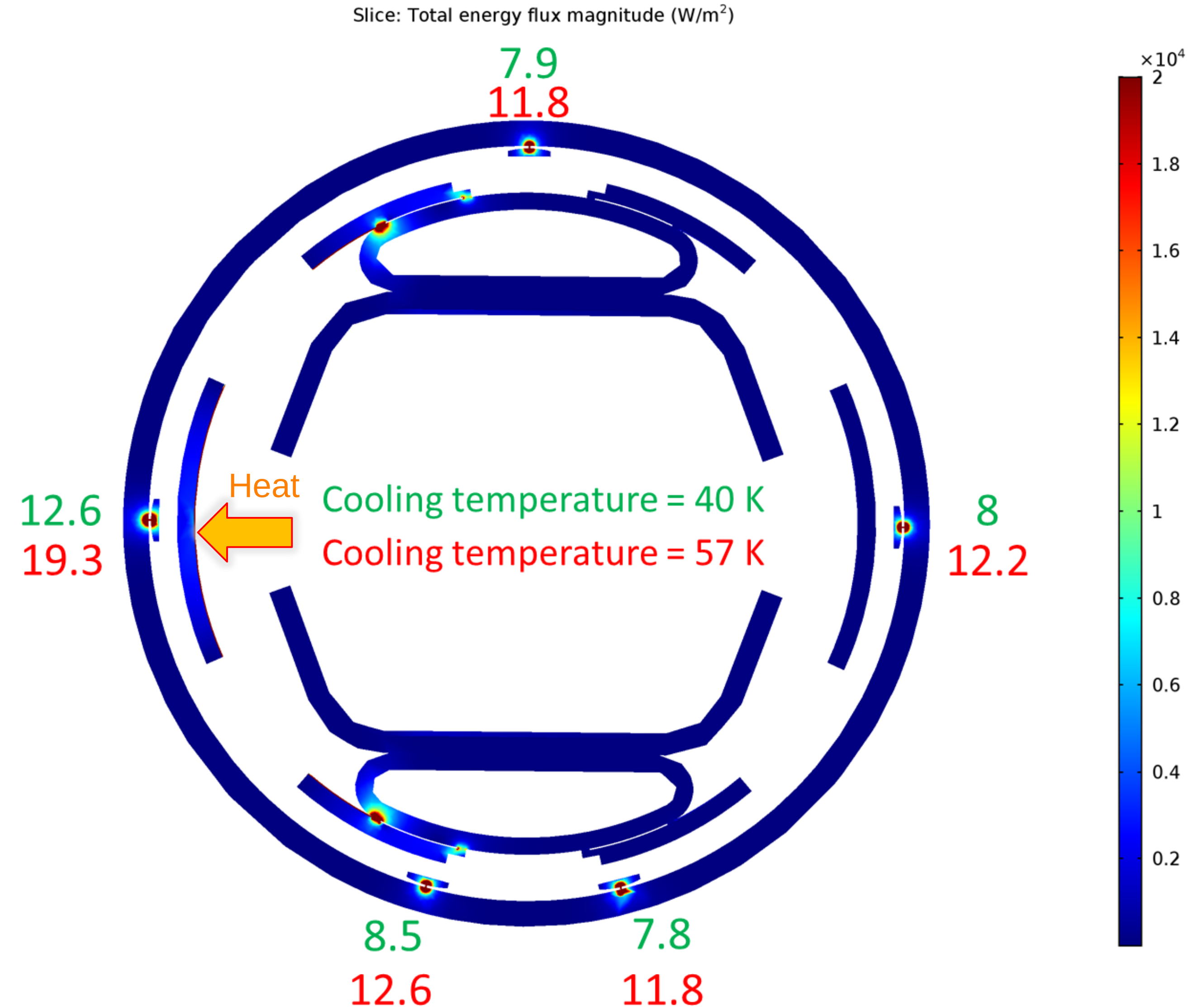
Temperature profile due to S.R.

Base temperature 57 K



Thermal behaviour

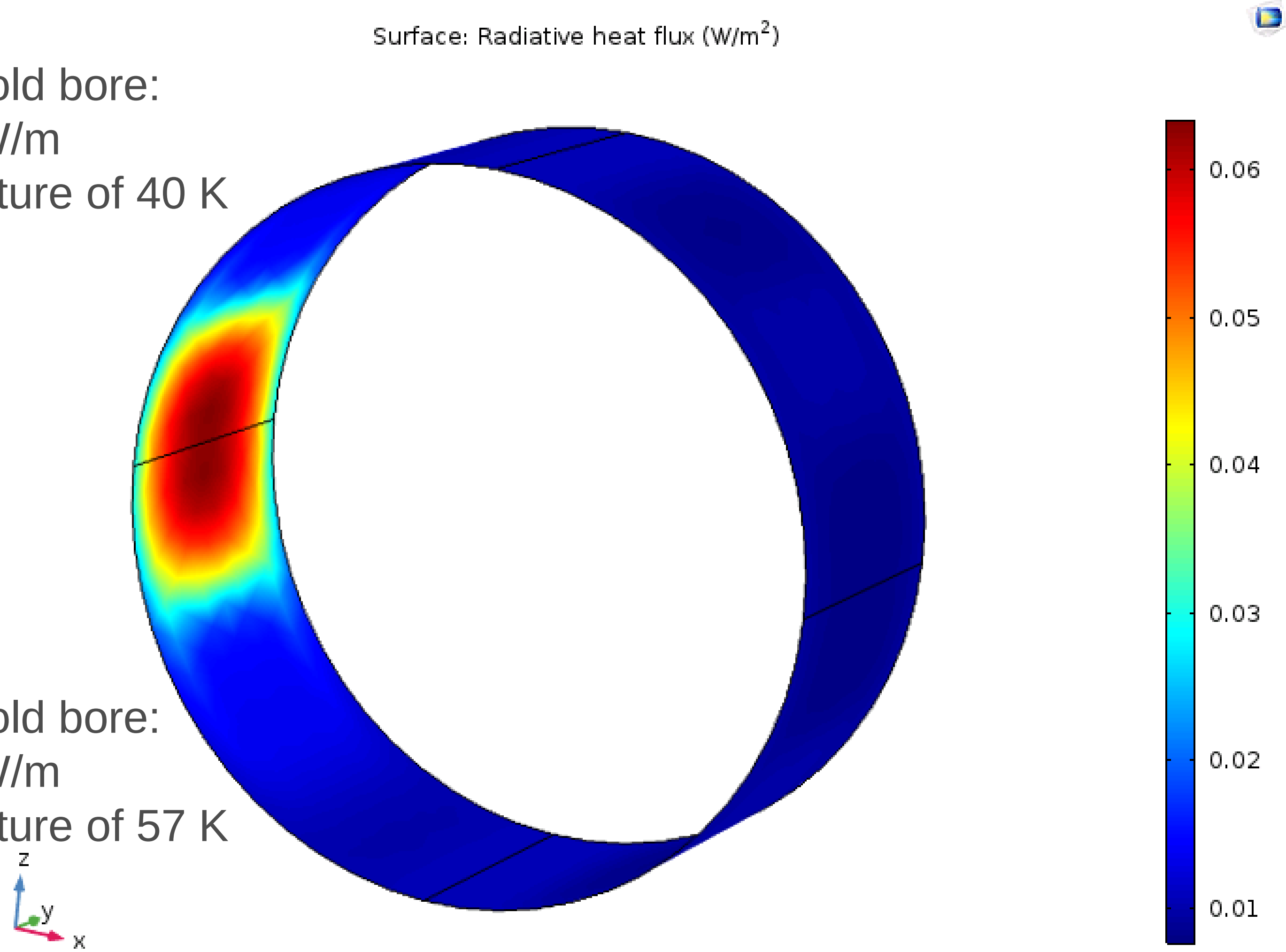
Heat load to the cold bore by conduction [mW/m]



Thermal behaviour

Heat load to the cold bore by thermal radiation

Heat to the cold bore:
2.95 mW/m
@ base temperature of 40 K



Heat to the cold bore:
8.84 mW/m
@ base temperature of 57 K

Summary of the heat loads @ 57 K
(worst case scenario)

Heat source	Value [mW/m]	Ratio [%]
Nuclear scattering	178	69.8
Conduction through supports	67.7	26.5
Thermal radiation	8.9	3.5
Leaked SR power	0.5	0.2
TOTAL	255.1	100

< of the 300 mW/m threshold!

Outline

- Beam screen design
  - Recent design evolution at a glance
- Mechanical behaviour
  - Quench analysis
  - Beam screen supports
- Thermal behaviour
  - Temperature profile due to SR
  - Heat load to the cold bore by radiation and conduction
- Conclusions

Conclusions

Beam screen design

- The thickness of the P506 outer shell has been increased to **1 mm** (from 0.8 mm) while its copper thickness has been reduced to **75 µm** (from 100 µm). **Two welding lines** have been added on the outer shell. The outer diameter of the beam screen remains unchanged, i.e. 41 mm.

Mechanical behaviour

- During a magnet quench, the mechanical behaviour of the beam screen remains elastic, the **maximum deformation** along the horizontal plane is **0.65 mm**.
- **Supports** have been designed to ensure a good alignment of the beam screen while **minimizing the permanent deformation** due to a quench.

Thermal behaviour

- The **synchrotron radiation** heat load leads to a maximum temperature of **81 K**.
- The **highest heat load** to the cold bore due to **SR by thermal radiation** is **8.9 mW/m**.
- The **highest heat load** to the cold bore **through the supporting system** is **67.7 mW/m**.

Future plans

- Magnet quench test at 1.9 K.

References

- Thermo-mechanical behaviour of the FCC-hh beam screen, M. Morrone, C. Garion. CERN Technical report, EDMS number 2166499.

- Bellafont, I., M. Morrone, L. Mether, R. Kersevan, C. Garion, V. Baglin, P. Chiggiato, and F. Perez. "Design of the FCC-hh beam screen vacuum chamber." Physical Review Accelerators and Beams (2019). Under Review.

Thank you for your attention

Spare slides

Mechanical Design

Material properties

Copper

Mechanical properties

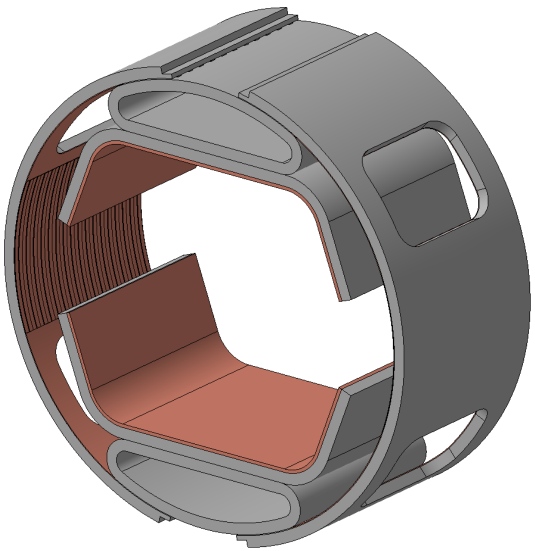
- Density, ρ = 8700 (Kg/m^3)
- Young's modulus, E = 110 (GPa)
- Poisson's ratio, v = 0.35

Magnetic properties

- Relative permittivity, ε = 1
- Relative permeability, μ = 1
- Resistivity changes with temperature

Thermal properties

- Thermal conductivity, k = 700 (W/(m·K))
- Heat capacity changes with temperature
- Coefficient thermal expansion, α = 17E-6 (1/K)



P506 (high-Mn high-N austenitic stainless steel)

Mechanical properties

- Density, ρ = 7850 (Kg/m^3)
- Young's modulus, E = 205 (GPa)
- Poisson's ratio, v = 0.28

Magnetic properties

- Relative permittivity, ε = 1
- Relative permeability, μ = 1
- Resistivity, ρ = 5E-7 (Ω·m)*

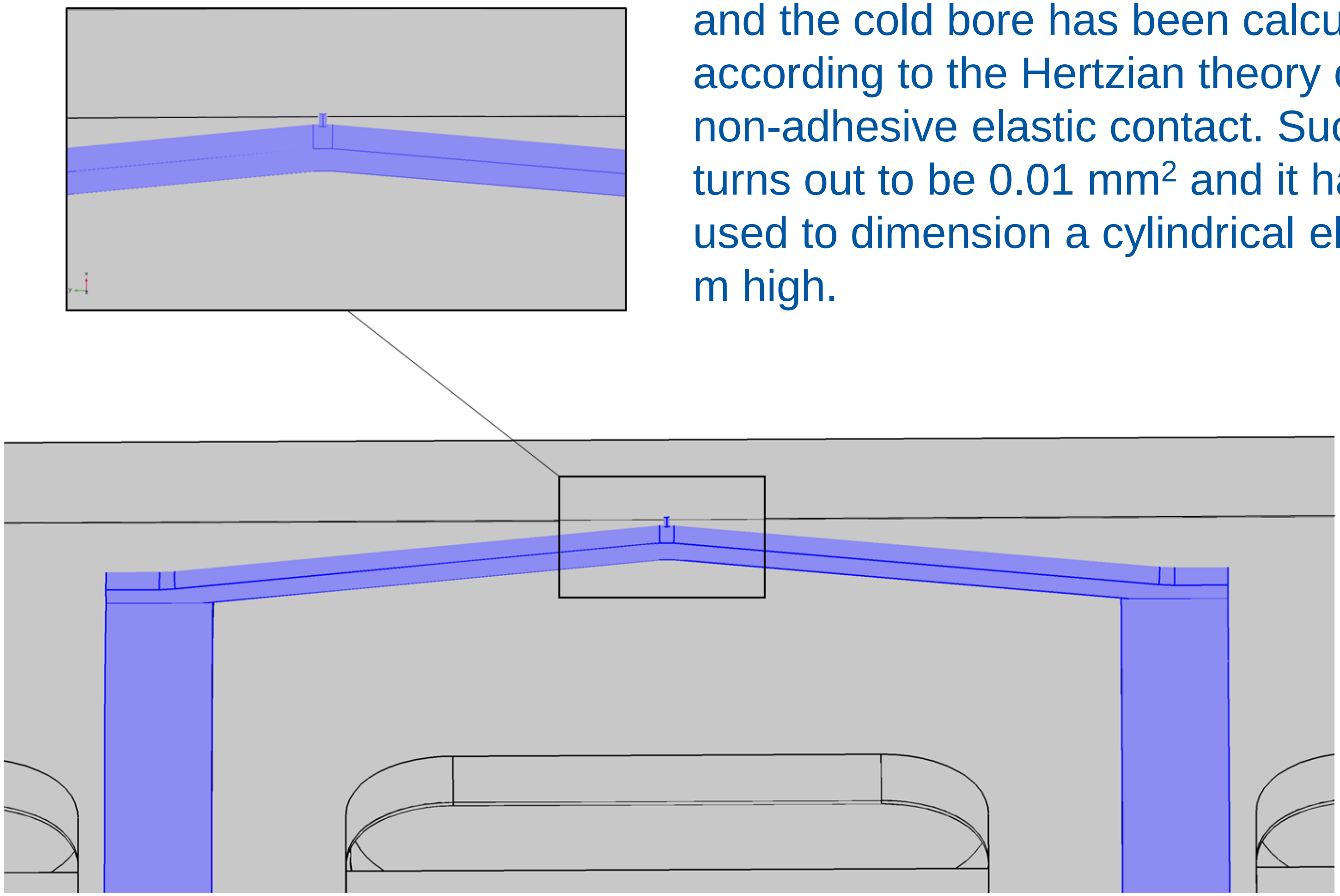
Thermal properties

- Thermal conductivity, k = 5 (W/(m·K))
- Heat capacity changes with temperature
- Coefficient thermal expansion, α = 12.3E-6 (1/K)

* Due to the high value of stainless steel resistivity, and its small variation with temperature, it has been considered constant with temperature.

Thermal behaviour

Temperature profile due to S.R.



The contact area between the elastic finger and the cold bore has been calculated according to the Hertzian theory of non-adhesive elastic contact. Such area turns out to be 0.01 mm^2 and it has been used to dimension a cylindrical element 0.1 m high.