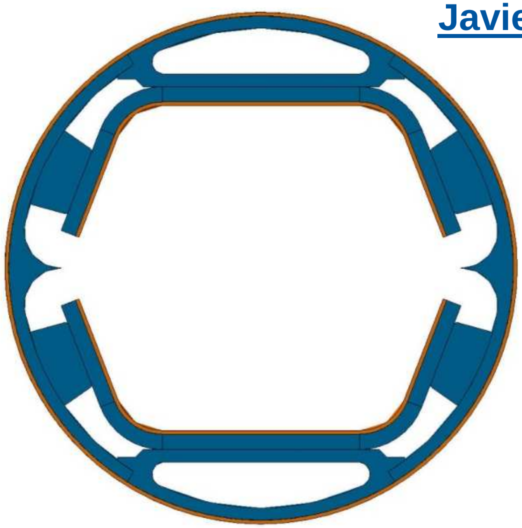
CERN

FCC-hh beam screen design

3rd FCC week, Berlin

Javier Fernandez Topham[1], Cedric Garion[2]

(1) CIEMAT, (2) CERN



EuroCirCol WP4

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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A key to New Physics

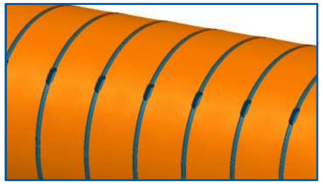
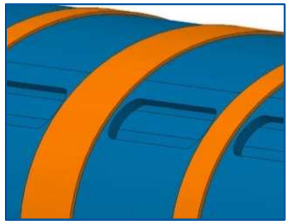
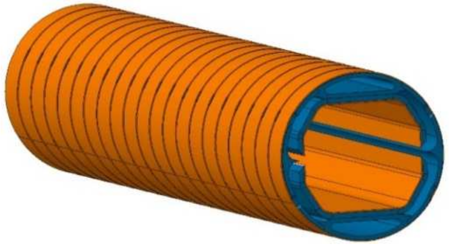
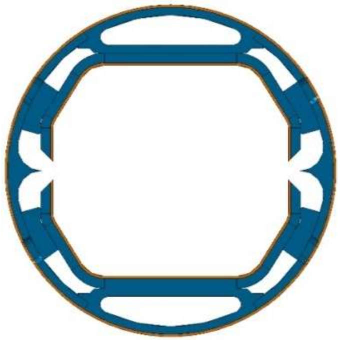
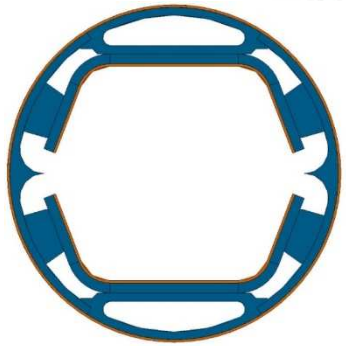
CERN

Outline

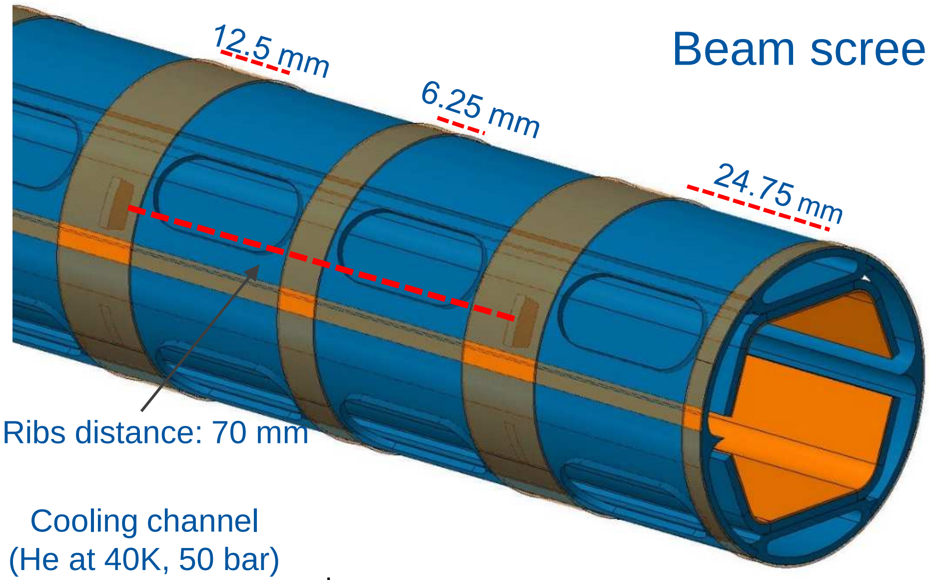
- Beam screen design
  - Beam screen evolution
  - Beam screen geometry
- Mechanical behaviour
  - Quench analysis
  - Mechanical effects of CLIQ system
- Thermal management
  - Temperature profile
  - Thermal stress
  - End dipole absorber
  - Heat transferred to cold bore
- Conclusions
- Next steps

Beam Screen Design

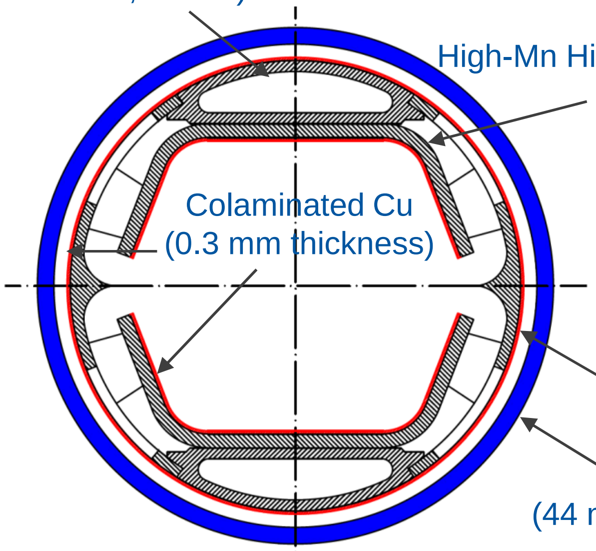
Beam screen evolution

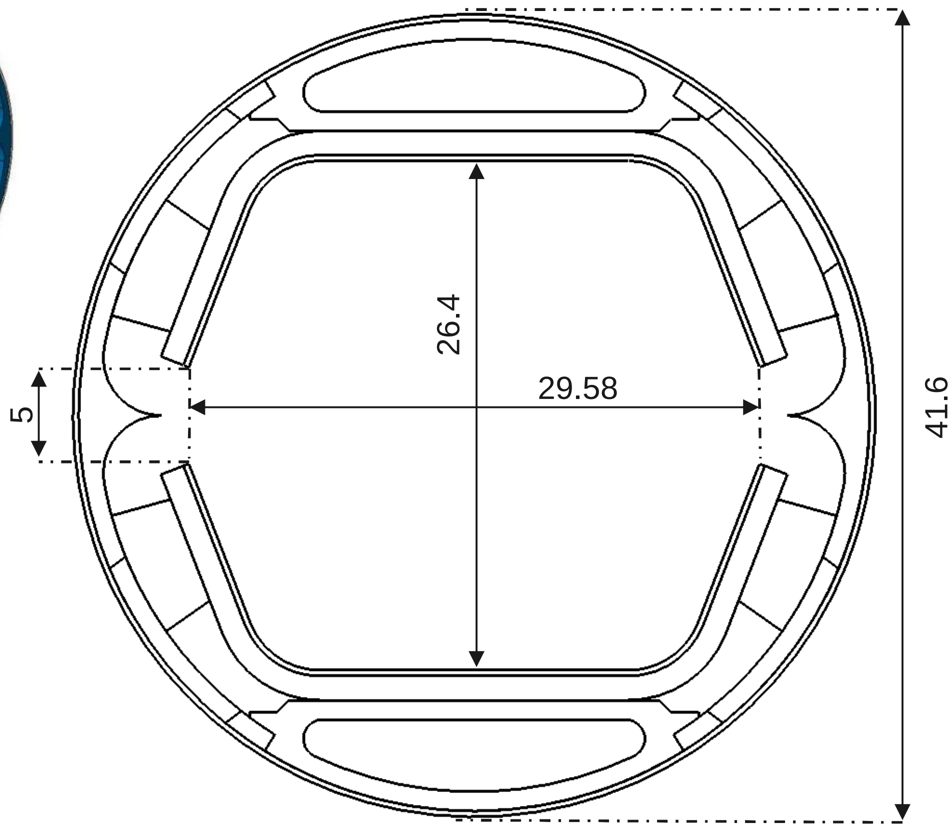
FCC week Rome 04/2016		FCC week Berlin 05/2017
	1. Bigger pumping holes in order to increase pumping efficiency.	
	2. Copper strips optimized and adapted to the new pumping hole size.	
	3. Inner chamber geometry changed to achieve better mechanical and vacuum results and ease manufacturing.	

Beam Screen Design



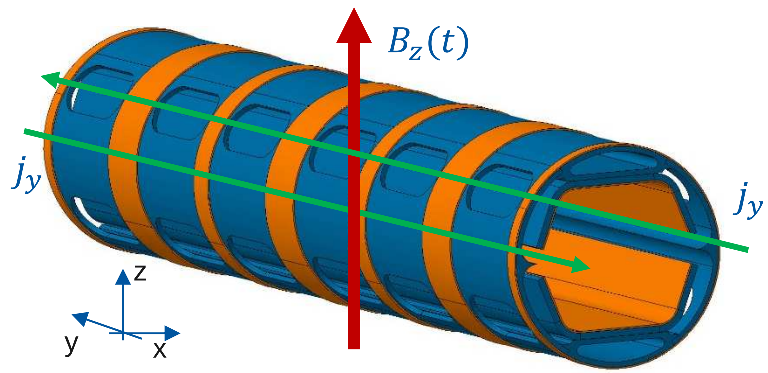
Beam screen geometry





Mechanical Design

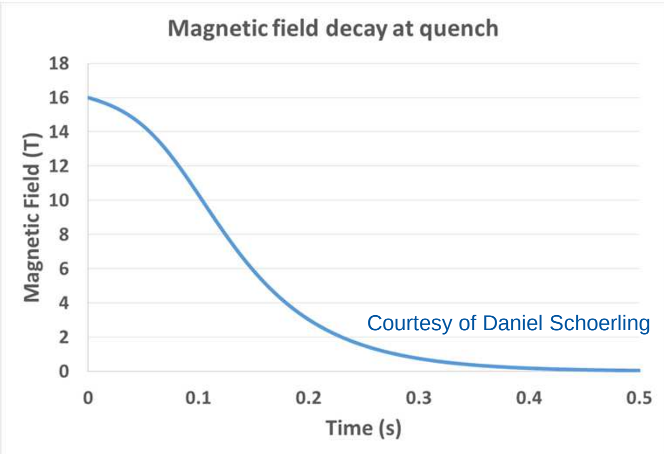
Magnet quench

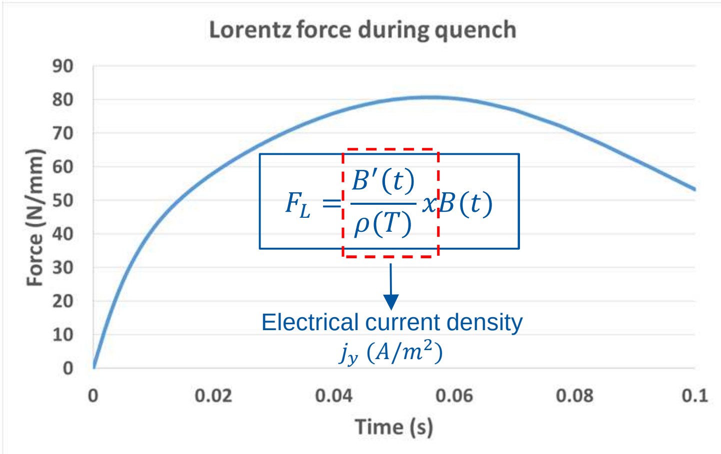


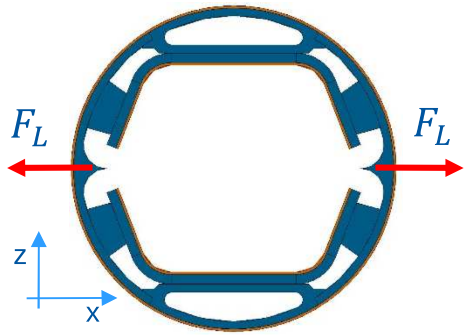
Variation of magnetic field at quench produces currents all along the beam screen.

These currents produce Lorentz forces that have to be correctly withstand by the beam screen.

This 3D simulation has been carried out taking into account 'Joule effect' coupling magnetic field and temperatures ($\rho C_p \frac{\partial T}{\partial t} - \nabla(k \nabla T) = Q_e = JE$).

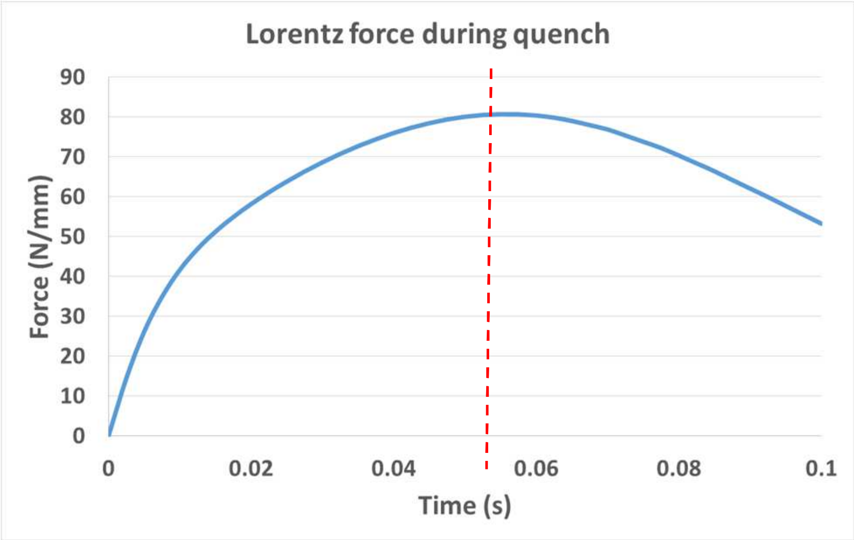


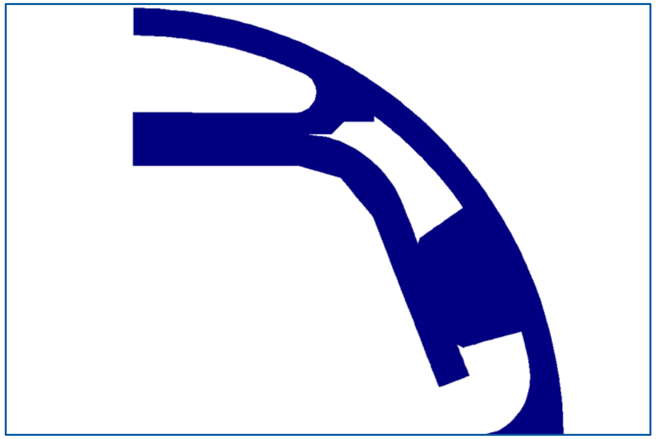




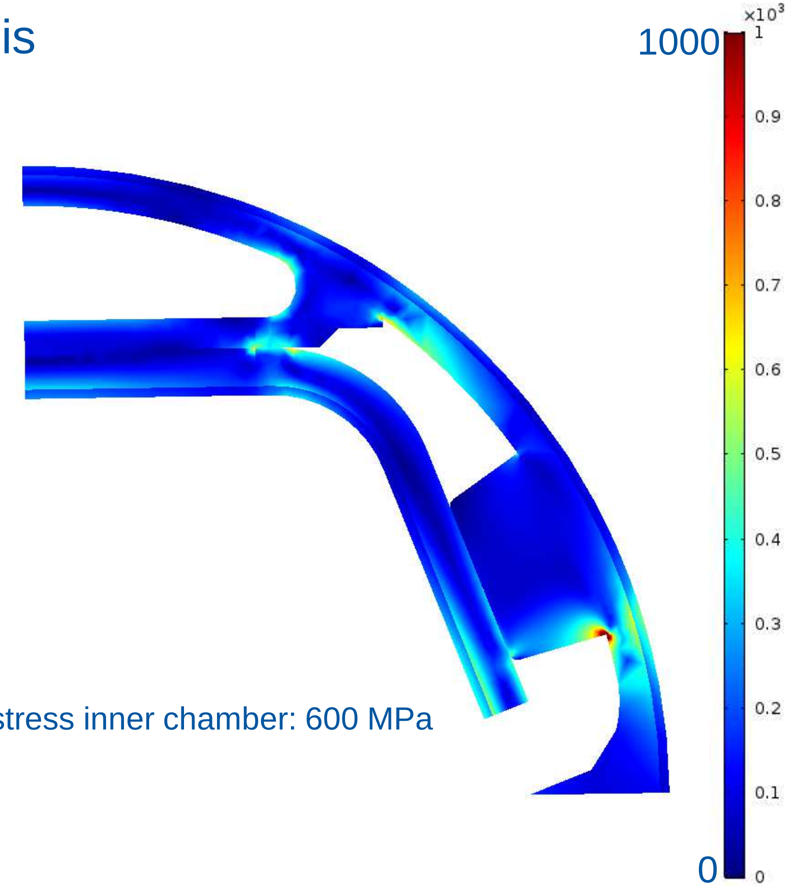
Mechanical Design

Stress analysis





Max displacement exterior beamscreen: 0.275 mm

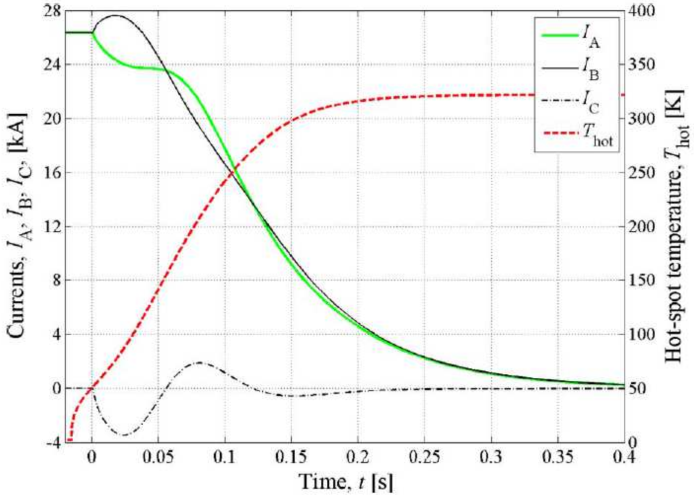


Max stress inner chamber: 600 MPa

Von Mises Stress (MPa)

Maximum stress reached at highest Lorentz force (0.055 secs): 550 MPa. No yield limit exceeded (1350 MPa at 50K).

CLIQ analysis

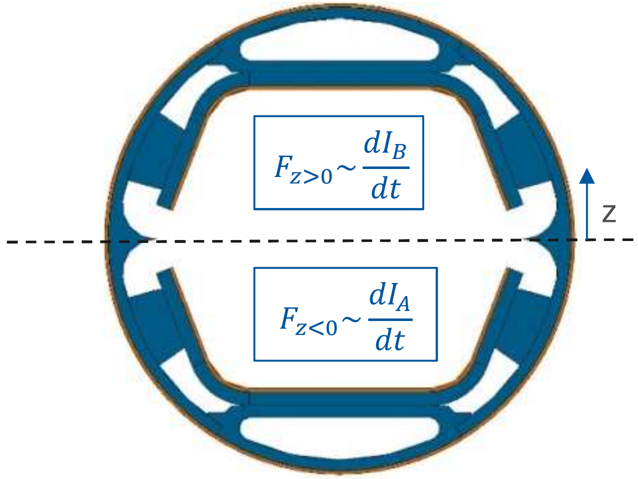


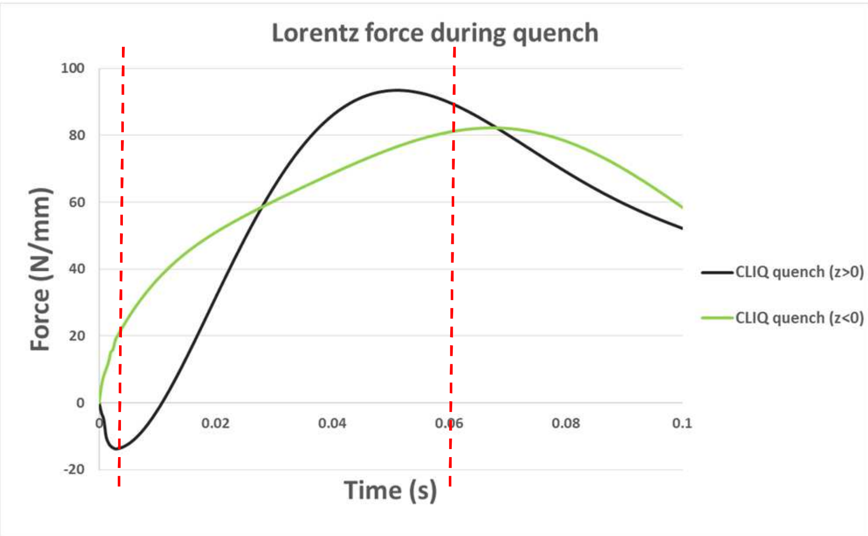
Different intensities on dipole coils (I_A, I_B) during quench. [1]

Preliminary study

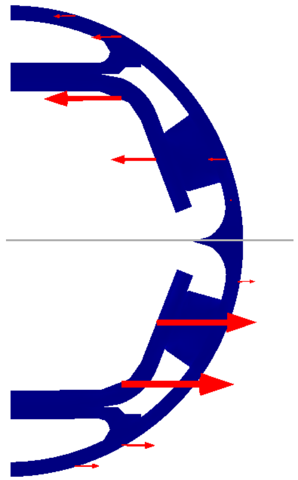
$$B'(t) \sim \frac{dI}{dt}$$

$$F \sim B'(t)$$

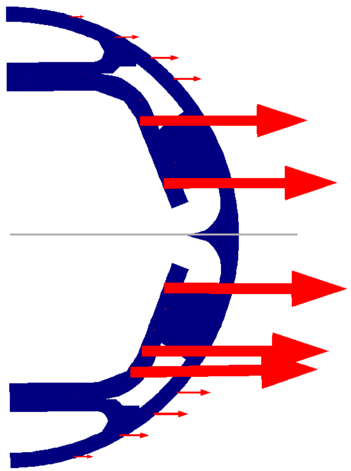




Inner copper layer force ($\sim 90\%$ total force on beamscreen)



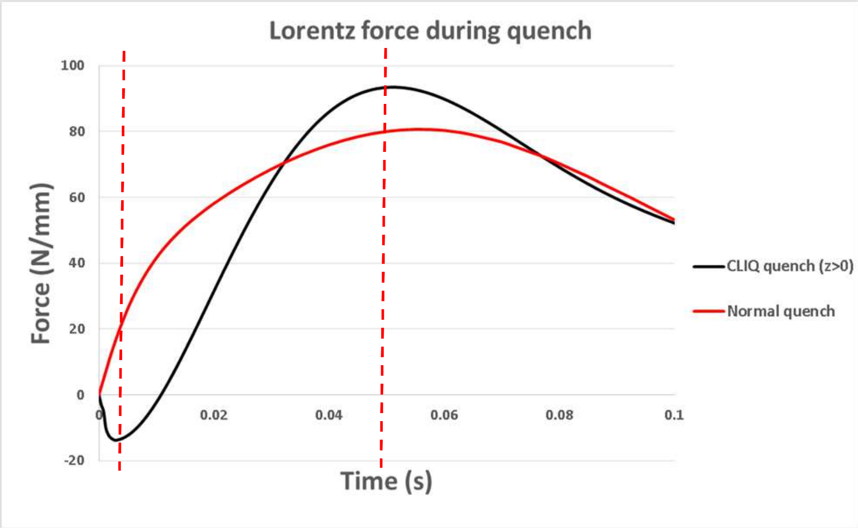
Lorentz Force 0.004 s

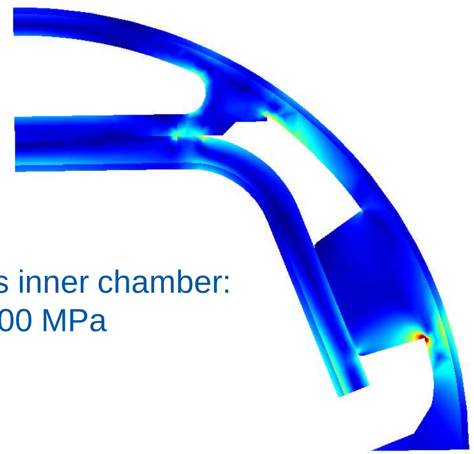


Lorentz Force 0.06 s (max total force)

[1] Design Study of a 16-T Block Dipole for FCC. IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 26, NO. 3, APRIL 2016

CLIQ comparative

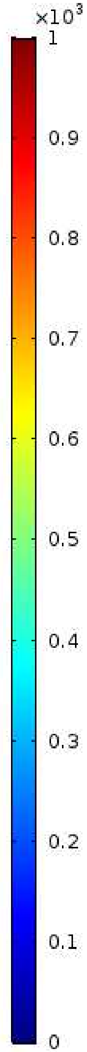




Max stress inner chamber:
600 MPa

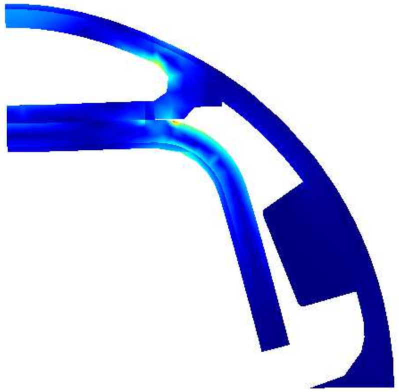
Normal quench at 55 ms

1000



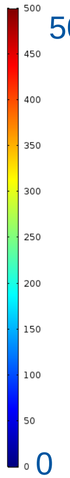
0

Von Mises Stress (MPa)



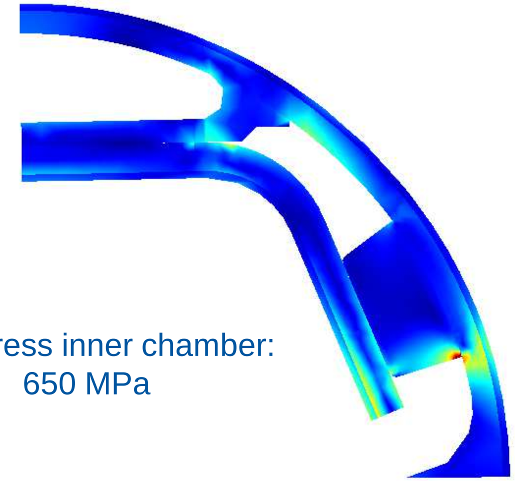
CLIQ quench at 4 ms

500



0

Von Mises Stress (MPa)



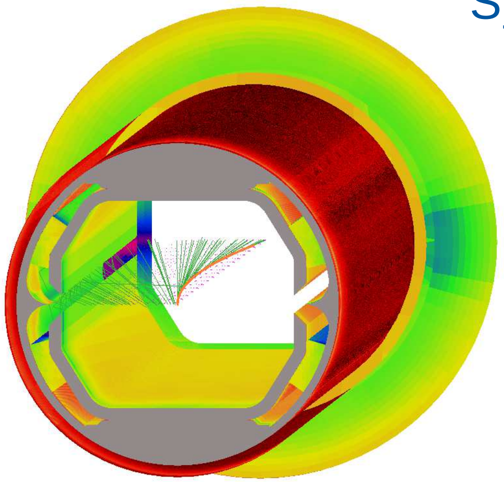
Max stress inner chamber:
650 MPa

CLIQ quench at 50 ms

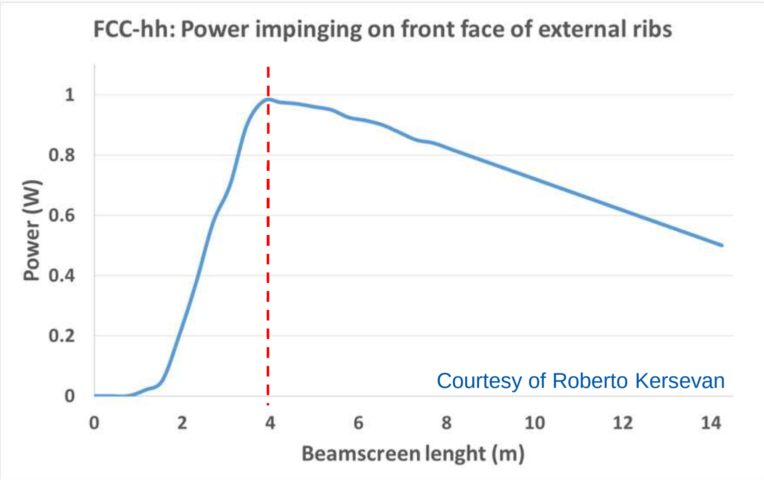
Expected maximum stress slightly higher than in normal quench. Weld line between internal screen and cooling channel is now significantly stressed, further studies are needed in order to ensure its integrity.

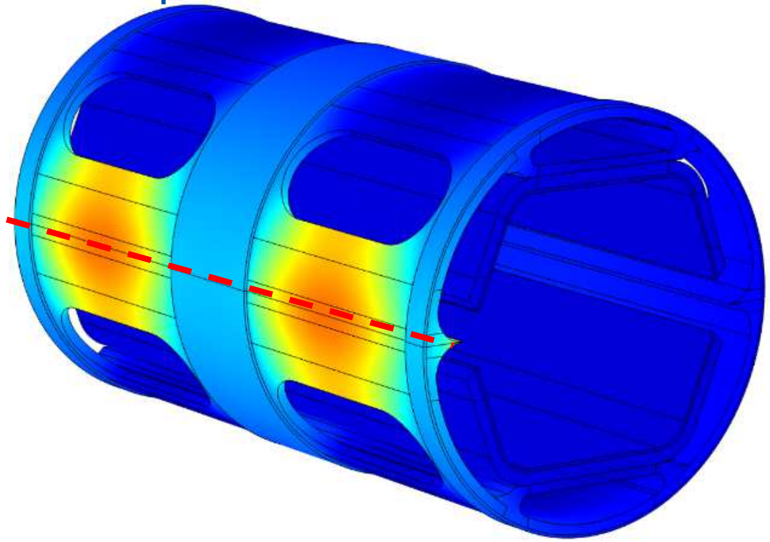
Thermal analysis

Synchrotron radiation impact

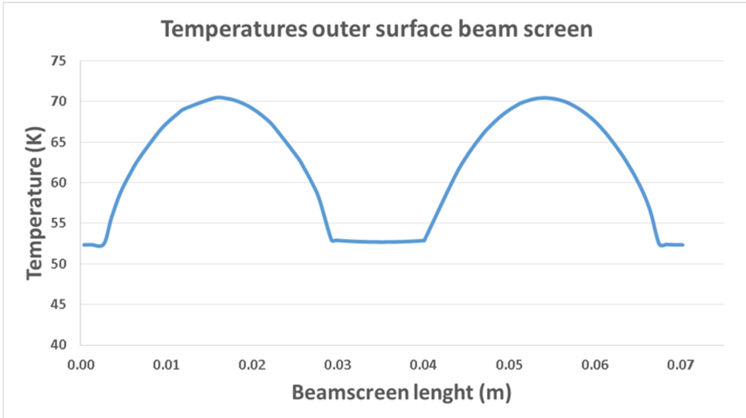


Synchrotron radiation power ~ 32 W/m
Beam intensity: 0.5 A, 50 TeV



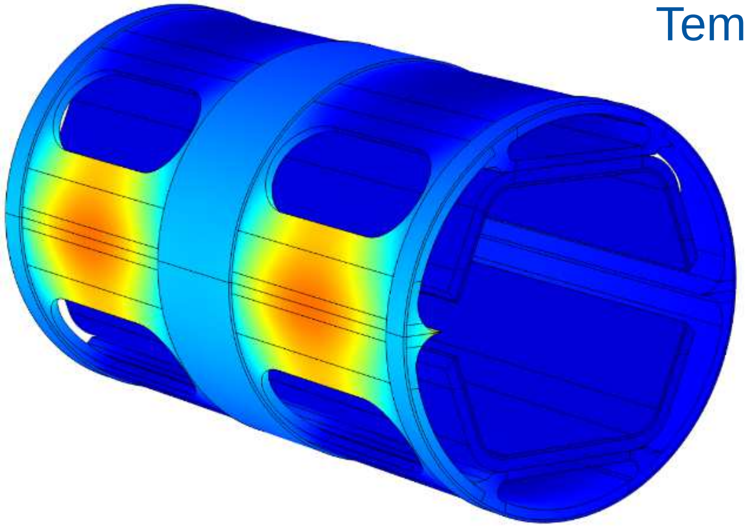


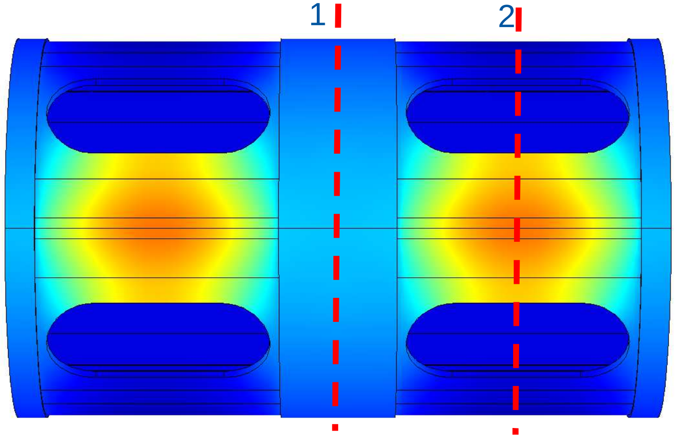
Temperature field produced by synchrotron radiation during beam nominal behaviour.



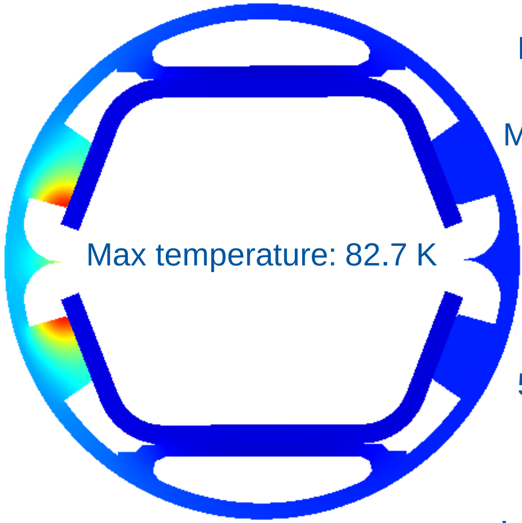
Thermal analysis

Temperature profile





Section 1

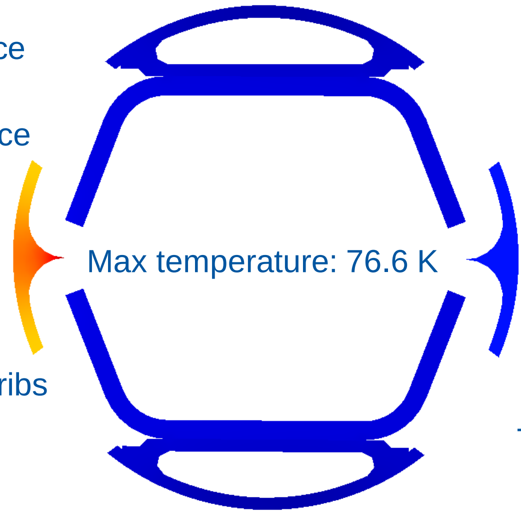


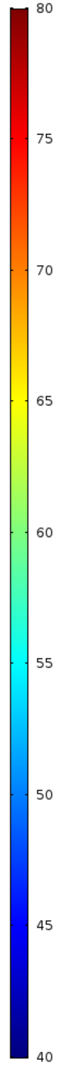
Max temperature inner surface
43.9 K

Mean temperature inner surface
43.7 K

51% SR power absorbed by ribs

Section 2





80

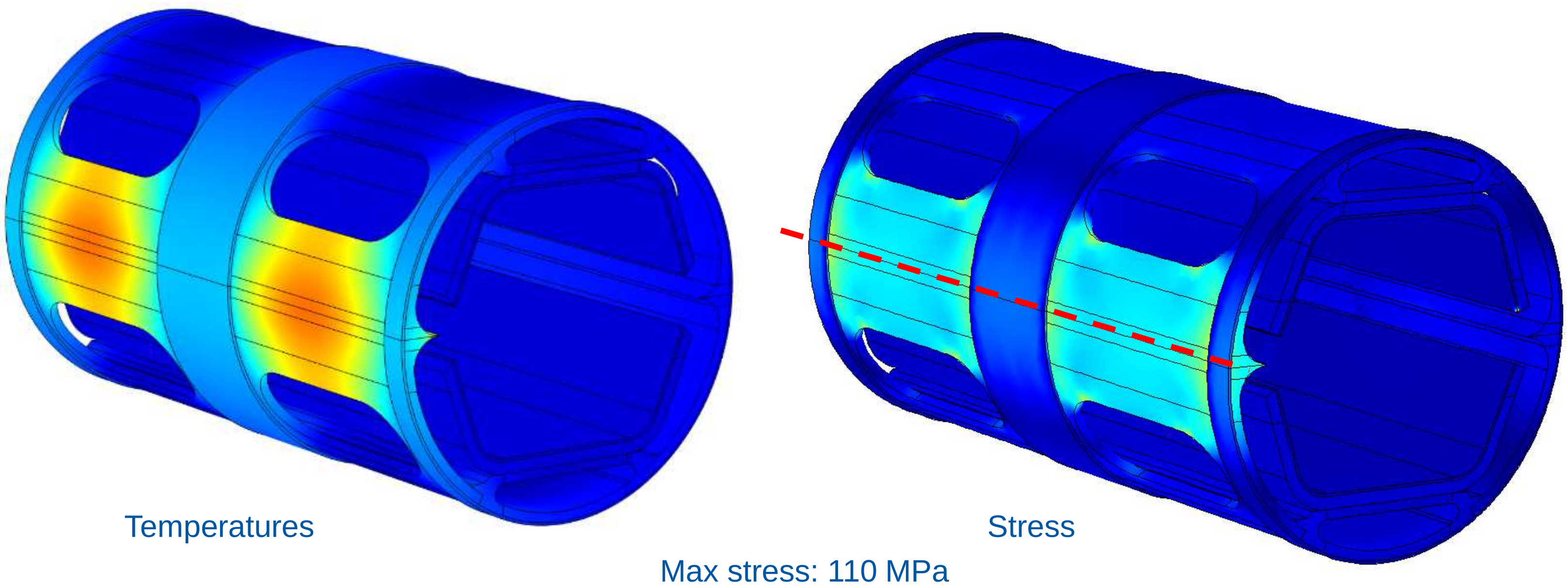
40

Temperature (K)

Inner beam screen temperature remains inside the temperature range allowed (between 40 K - 57 K).

Thermal analysis

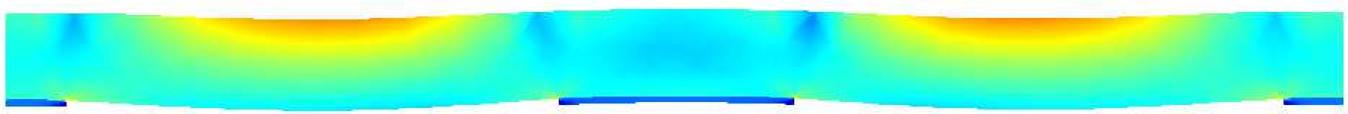
Thermal stress



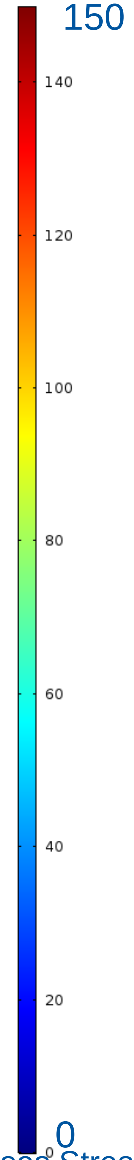
Temperatures

Stress

Max stress: 110 MPa



Max displacement: 0.01 mm



Von Mises Stress (MPa)

Similar thermal expansion coefficient for both stainless steel and copper avoid high stress values.
Overall deformation of beam screen will be assessed.

Thermal analysis

End dipole absorber

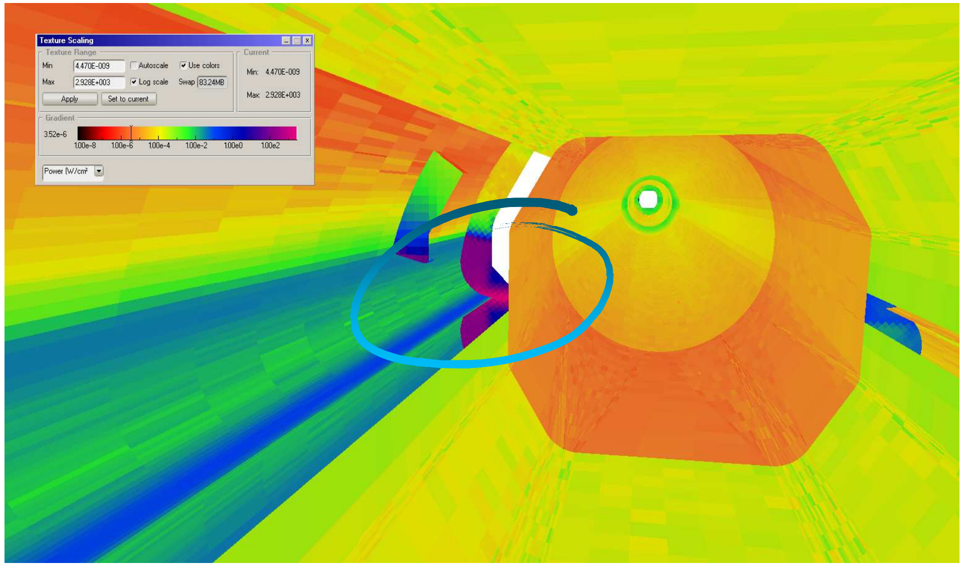
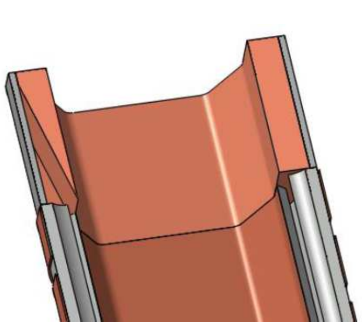
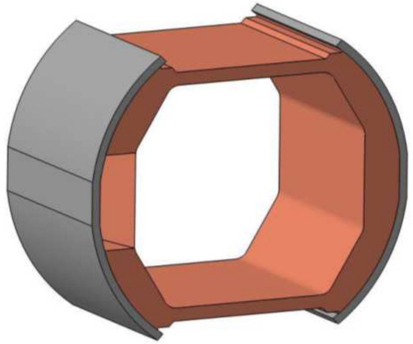


*image by Ignasi Bellafont

100 W (19% of the absorbed power in the dipole)
Points with almost **3000 W/cm²**

Preliminary end absorber design

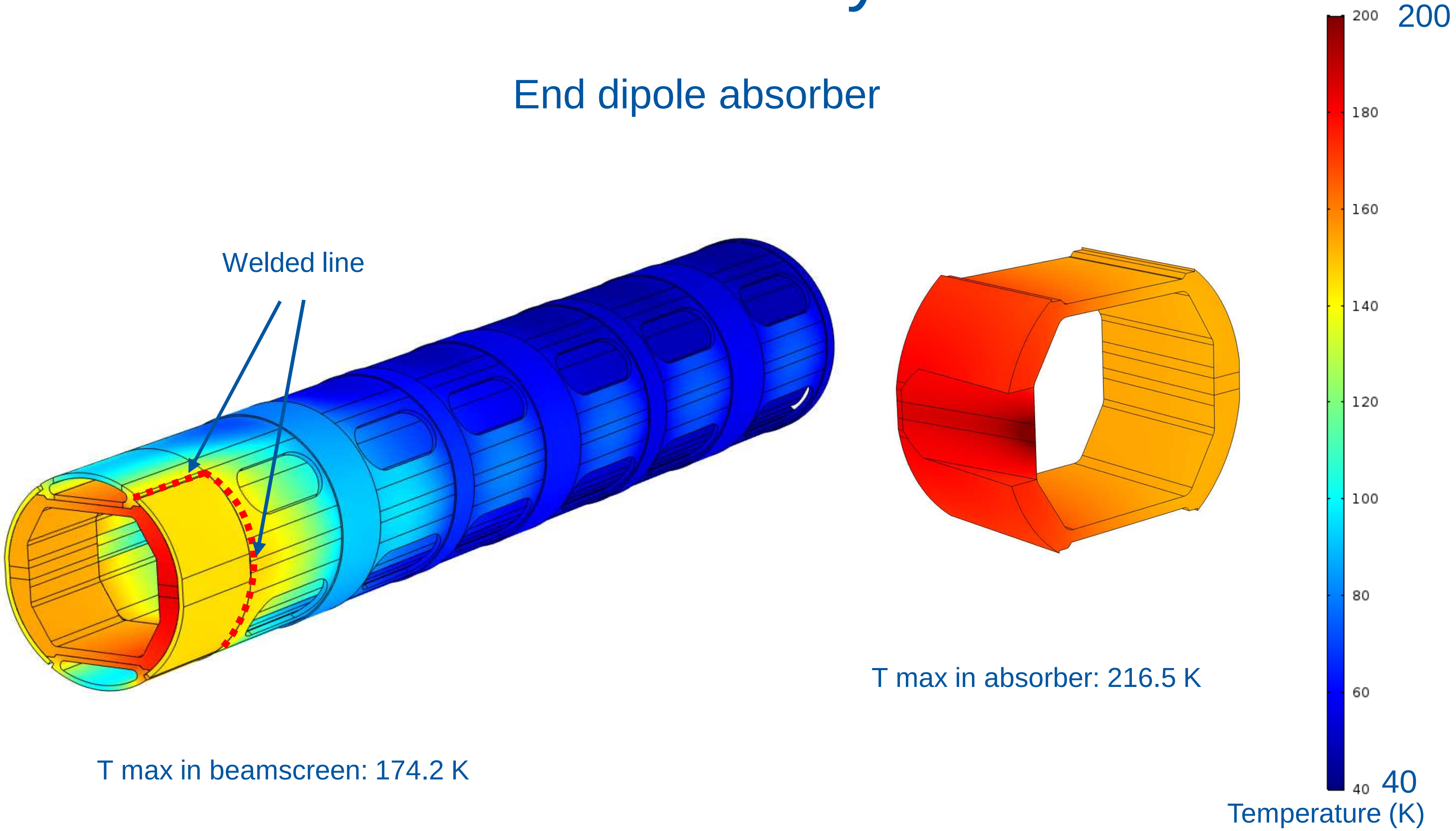




Due to the high SR density at the end of the dipole, an absorber has been designed in order to reduce as much as possible power density in this area.

Thermal analysis

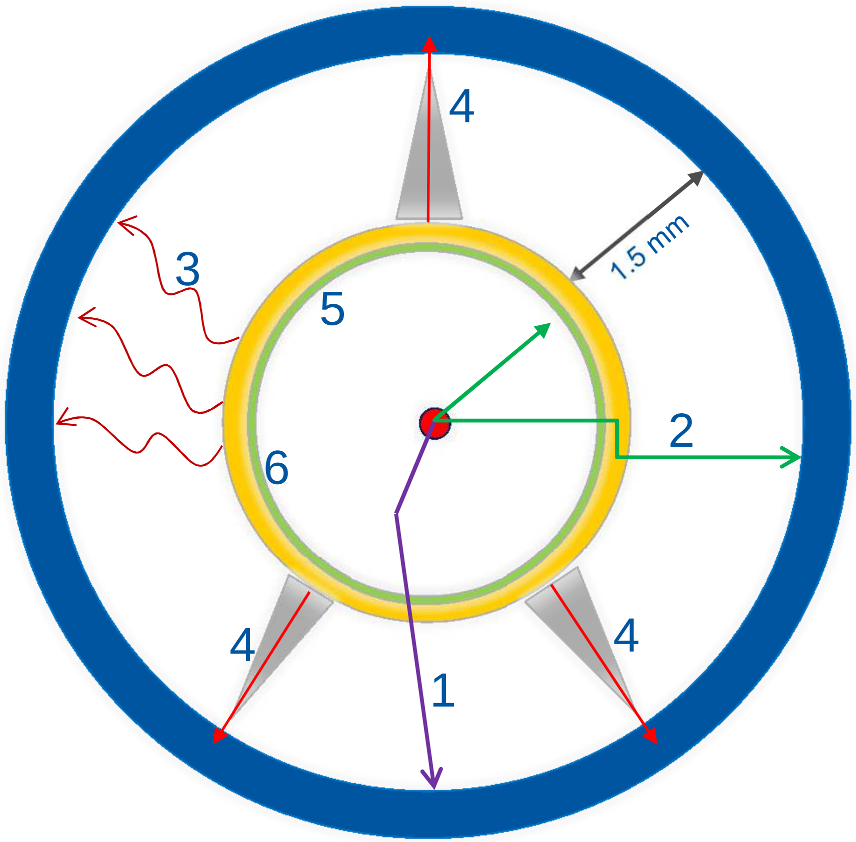
End dipole absorber



First simulations show that temperatures in the absorber reach very high values due to the SR stopped at the end of the dipole. Further studies including different designs, with different cooling scheme, will be carried out

Thermal analysis

Heat transferred to cold bore



1 • Nuclear scattering: 191 mW/m

2 • Synchrotron radiation: 2.4 mW/m

3 • Thermal radiation: 2.3 mW/m

4 • Beam screen supports: 25 mW/m

5 • ~~Image currents~~

6 • ~~Electron cloud effect~~

Max power allowed: 300 mW/m

Total thermal load transferred to cold bore: 220.7 mW/m

Conclusions

Mechanical design

- Simulations during a magnet quench have been done taking into account the Joule effect and using 3D massive finite element model. At quench conditions, beam screen mechanical behaviour remains under yield limit.
- CLIQ discharge produces different Lorenz forces distribution on beam screen, nevertheless, beam screen mechanical behaviour remains similar than in normal quench.

Thermal analysis

- Taking into account synchrotron radiation impact during nominal behaviour, temperatures, as well as thermal stress in the new beam screen, remain on the range allowed (with similar results than in the previous model).
- Synchrotron radiation impact at end dipole absorber has been analyzed. High temperatures reached makes necessary to study in deep this area. Further studies of the end absorber and of the beam screen extremities in a more general way will be carried out.
- Main types of heat transfer from beam screen to cold bore has been studied. First estimations indicate that heat load remains below the limit.

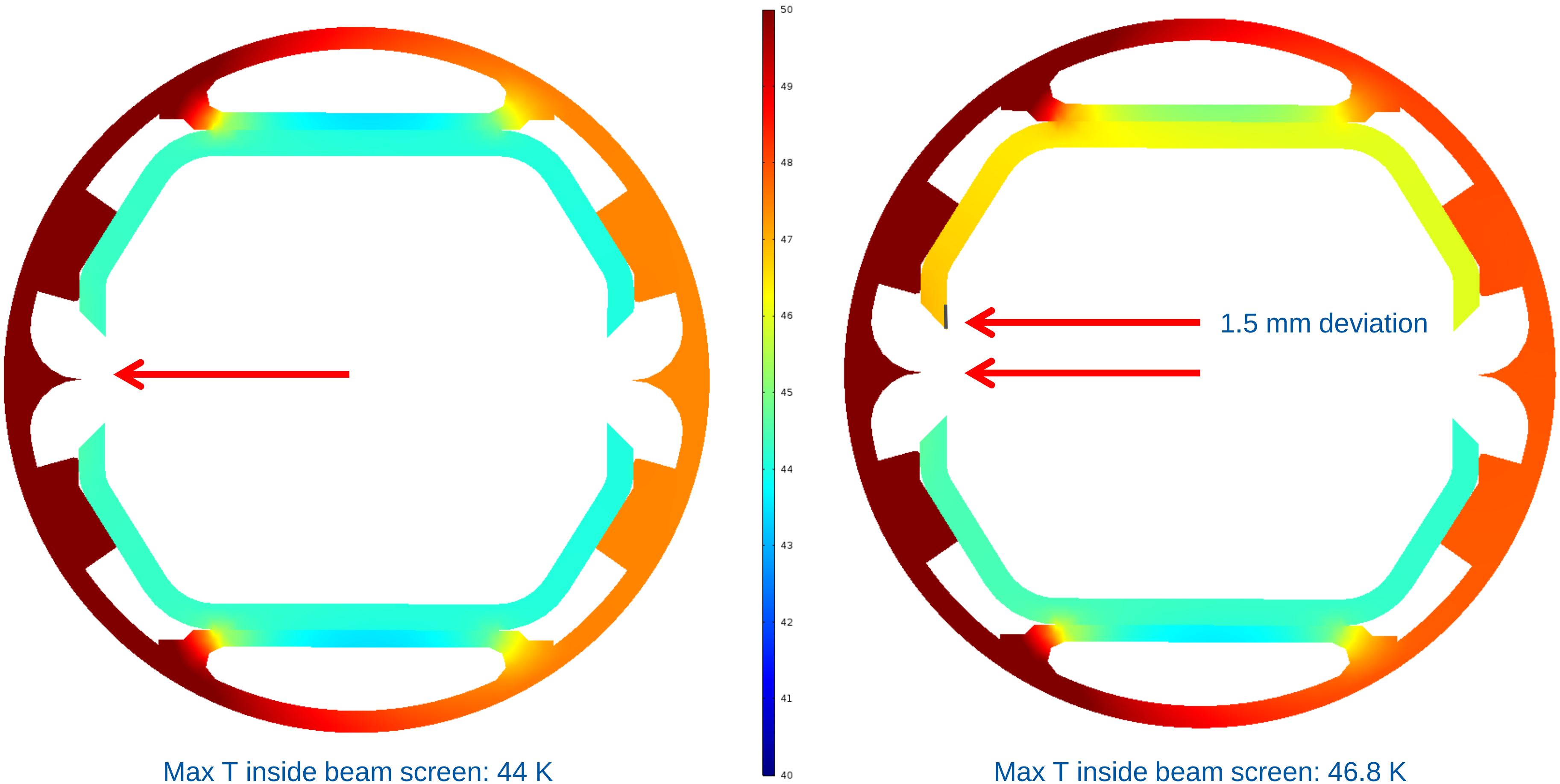
Next steps

- Check mechanical behaviour of beam screen on future geometry updates.
- Beam screen thermal analysis with future SynRad data.
- Detailed study of end dipole absorber as well as beam screen extremities.

THANK YOU FOR YOUR ATTENTION

Thermal analysis

Temperature profile



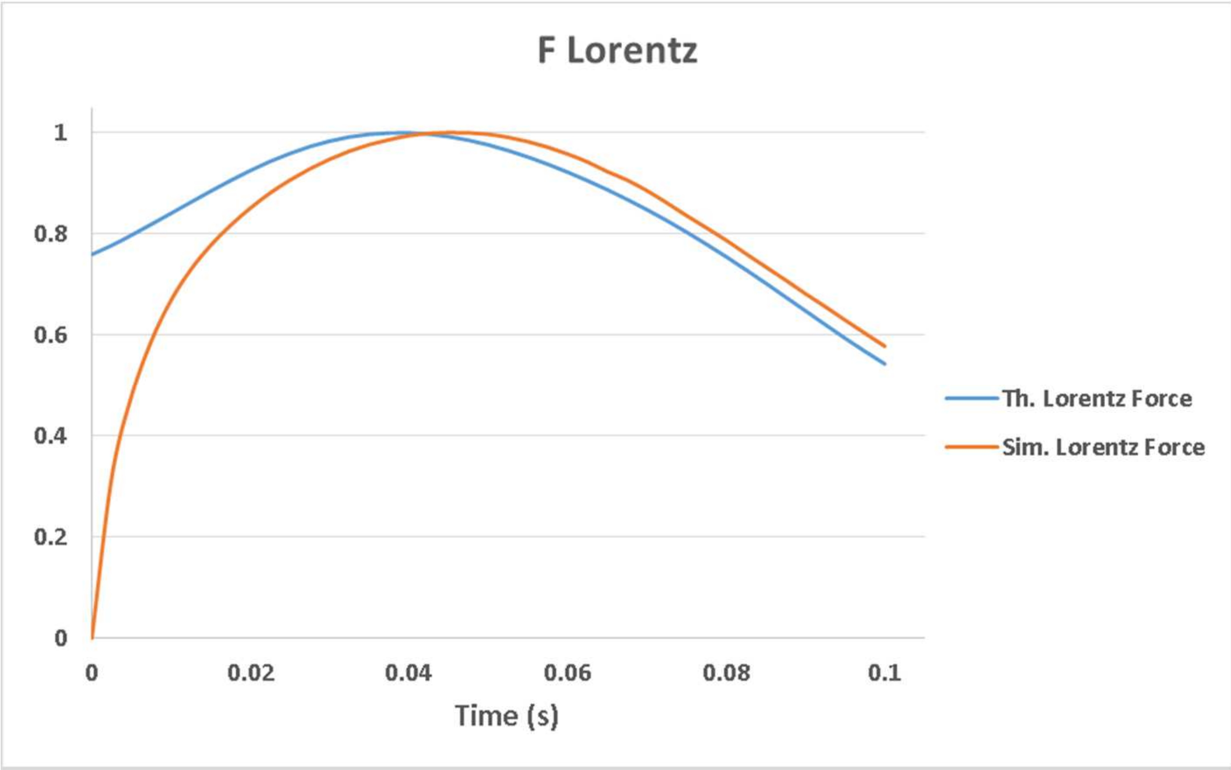
Max T inside beam screen: 44 K

Mean T inside beam screen: 43.7 K

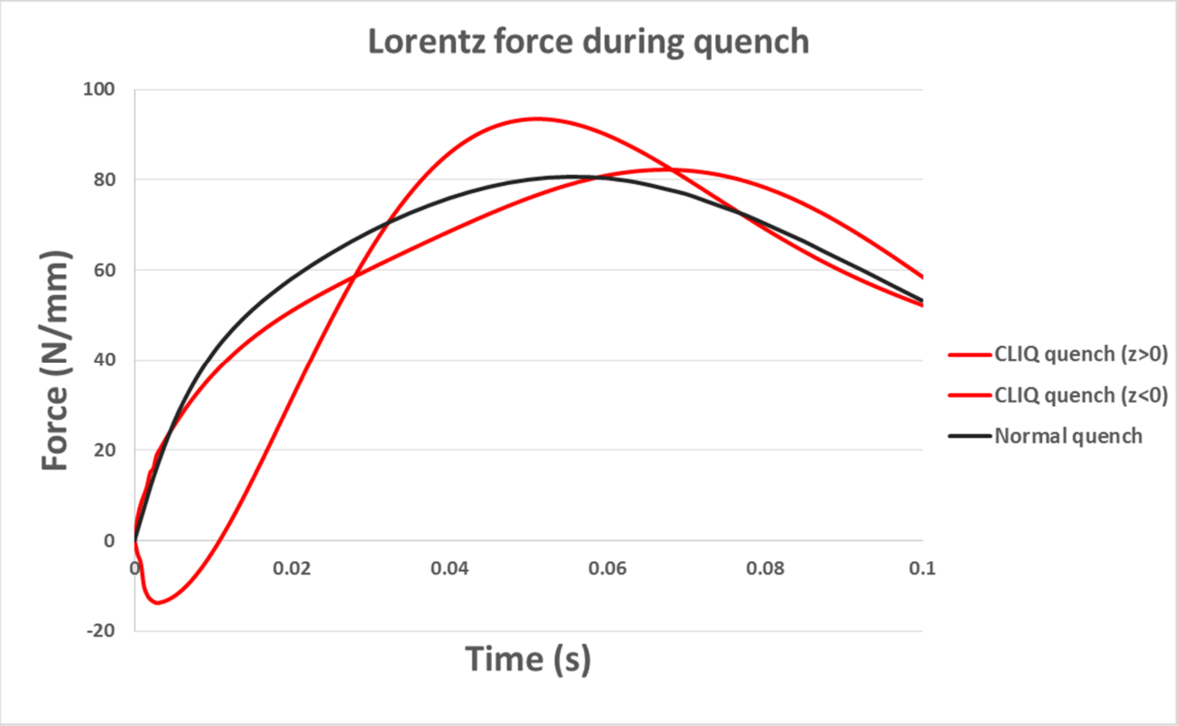
Temperature (K)

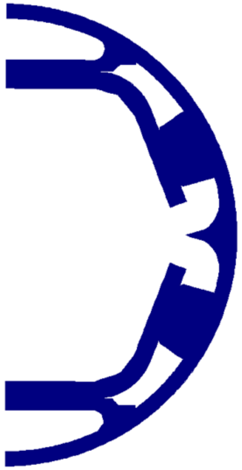
Max T inside beam screen: 46.8 K

Mean T inside beam screen: 46.1 K

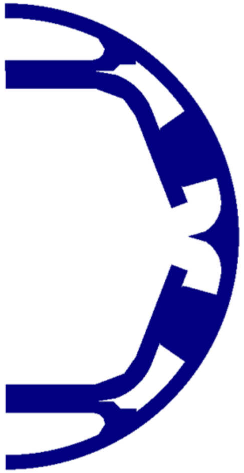

F Lorentz
1
0.8
0.6
0.4
0.2
0
0
0.02
0.04
0.06
0.08
0.1
Time (s)
Th. Lorentz Force
Sim. Lorentz Force

CLIQ comparative

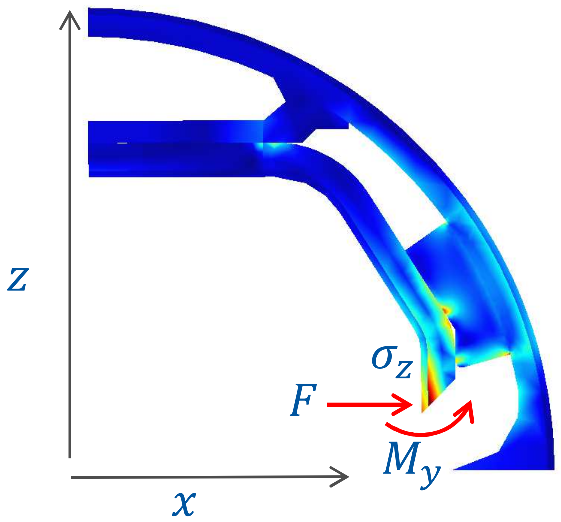


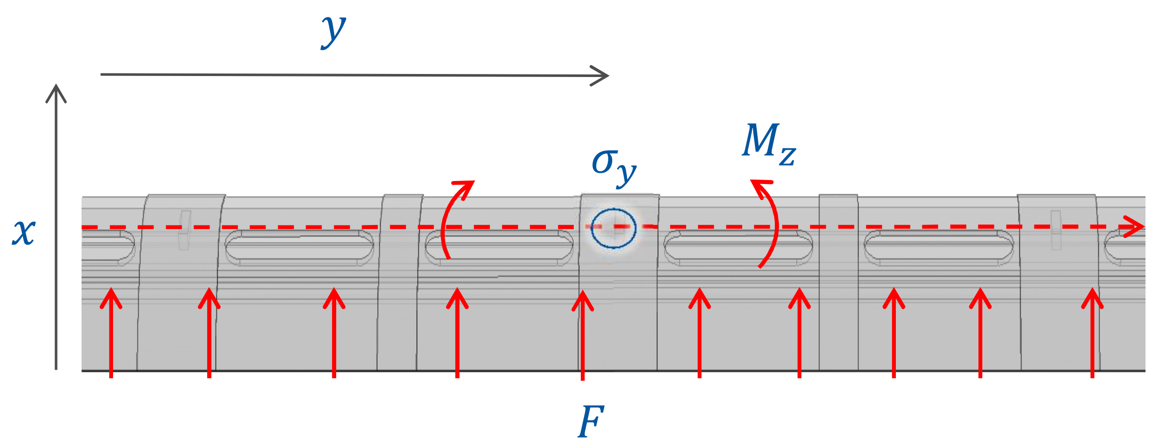


Normal quench



CLIQ quench





$$\sigma_y = \frac{M_z \cdot y}{I_y}$$

$$\sigma_z = \frac{M_y \cdot z}{I_z}$$

High Lorentz force → Gap deflector change

$$\sigma_y = \frac{\uparrow M_z \cdot y}{I_y}$$

$$\sigma_z = \frac{M_y \cdot z \downarrow}{I_z \downarrow}$$

$$\sigma_{y2.28} > \sigma_{y5}$$

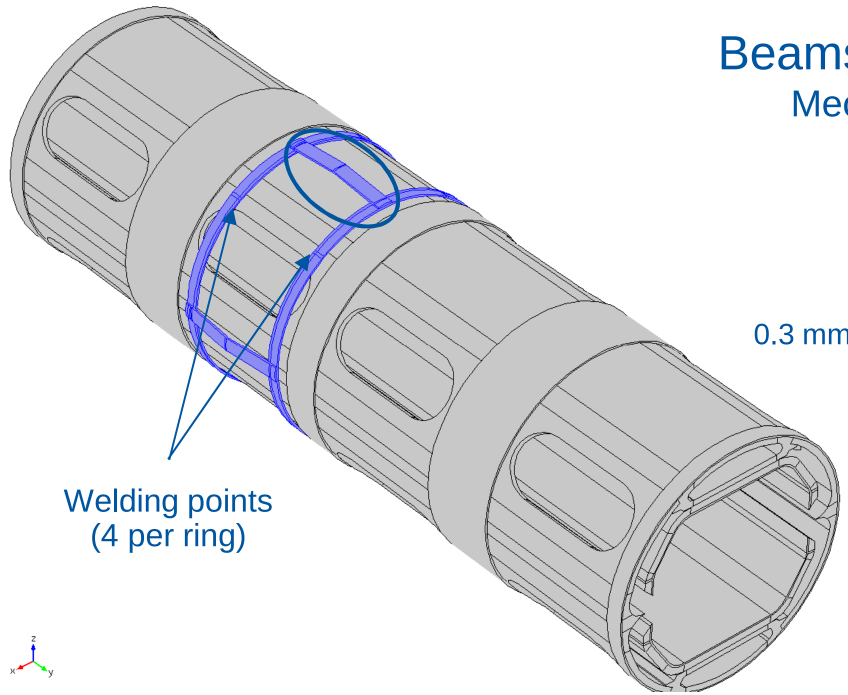
$$\sigma_{z2.28} > \sigma_{z5}$$

$$\sigma_x \approx 0$$

$$\sigma_{VM} = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}$$

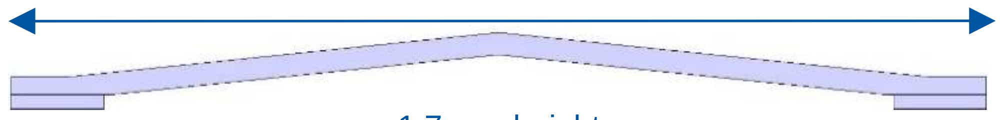
$$\sigma_{VM2.28} > \sigma_{VM5}$$

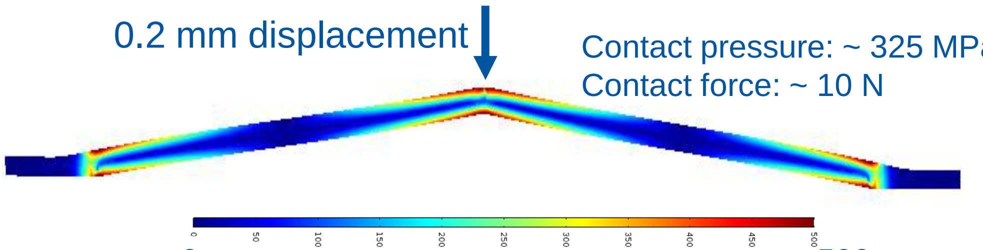
Thermal load to cold bore



Beamscreen supports.

Mechanical analysis





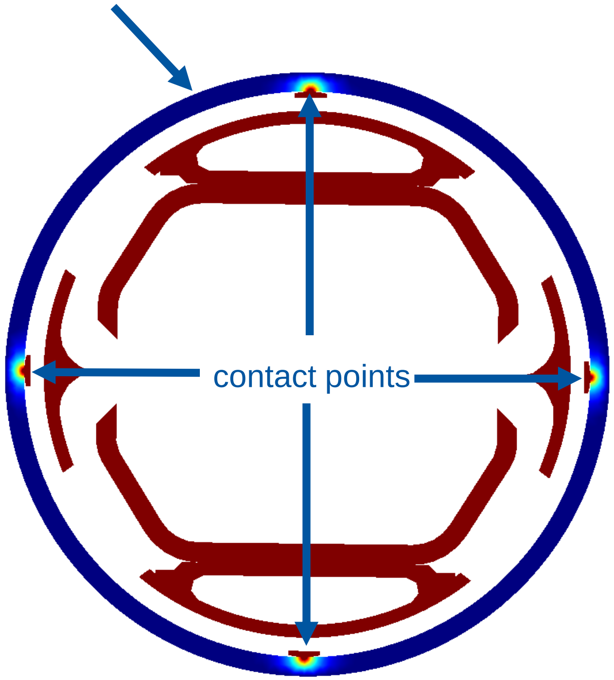
Mechanical behaviour acceptable

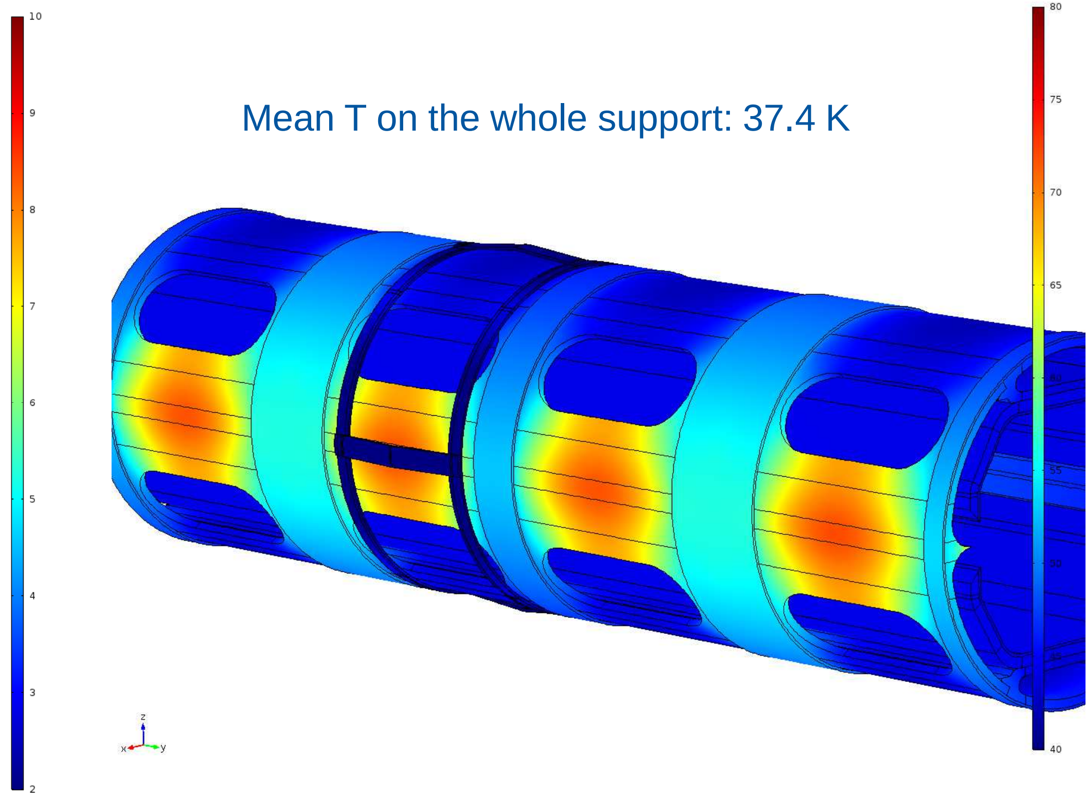
Thermal load to cold bore

Beamscreen supports.

Thermal analysis

Cold bore: 1.9 K





Total heat load transferred: 25 mW/set

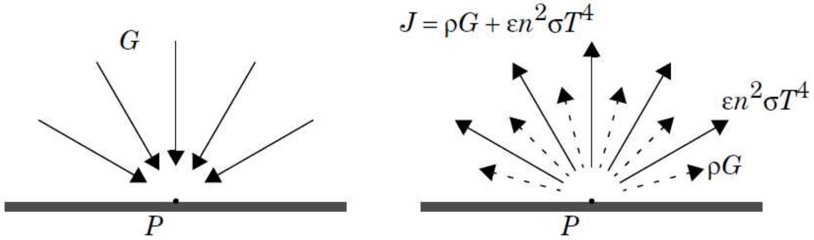
Assuming one set per meter: 25 mW/m

(beam screen alignment study in process)

Javier Fernandez Topham
Vacuum, Surfaces & Coatings Group
Technology Department

Thermal load to cold bore

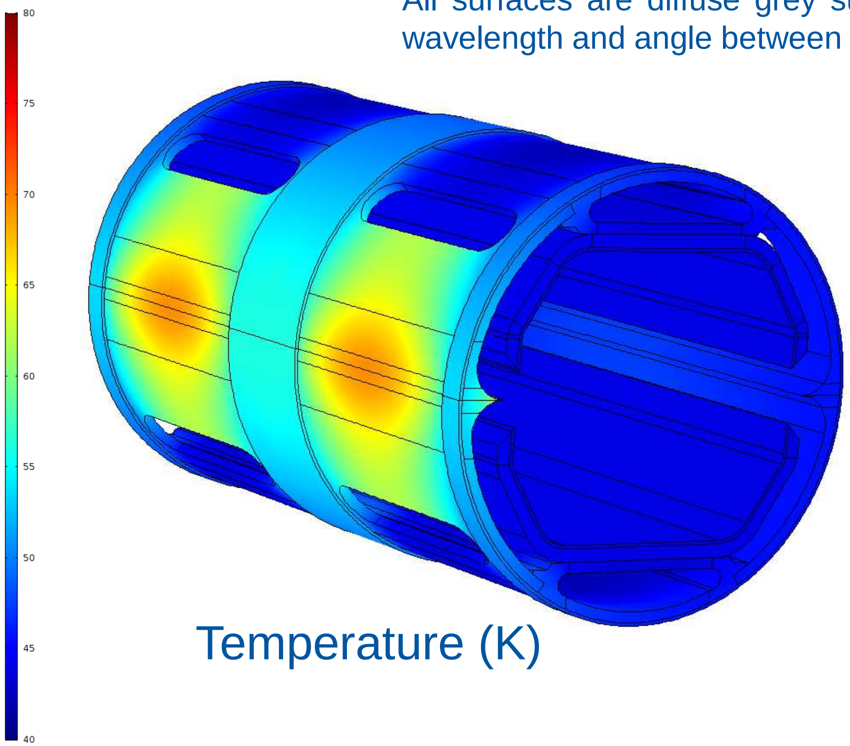
Radiation



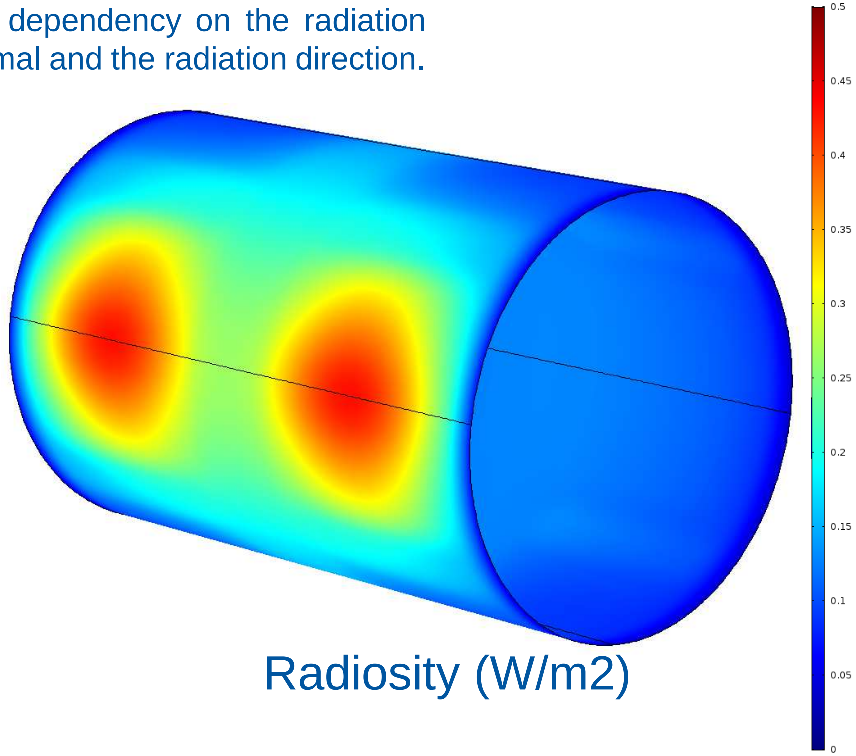
$$q = \varepsilon(G - n^2 \sigma T^4)$$

$\varepsilon_{cu} = 0.02$
$\varepsilon_{ss} = 0.07$
$n = 1$
$\sigma = 5.670373 \cdot 10^{-8}\ W m^{-2} K^{-4}$

All surfaces are diffuse grey surfaces: No dependency on the radiation wavelength and angle between surface normal and the radiation direction.



Temperature (K)



Radiosity (W/m2)

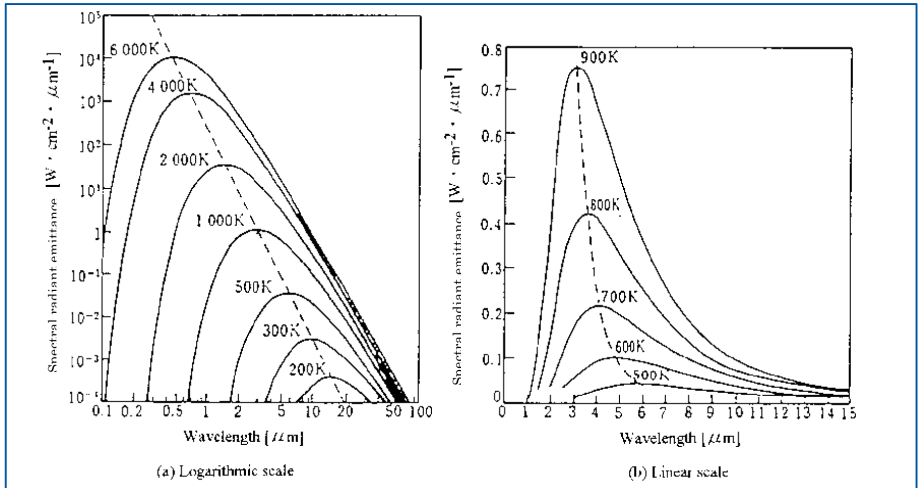


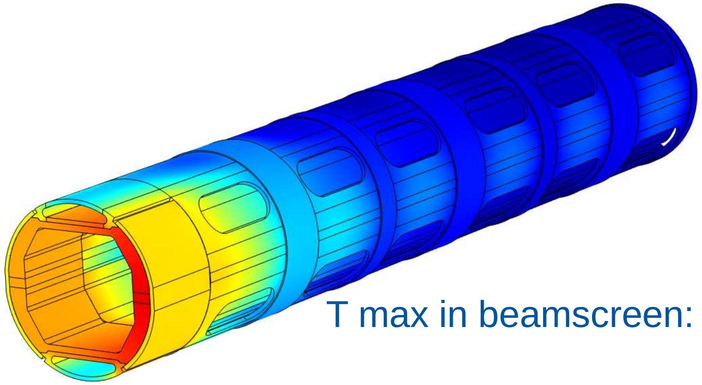
Fig. 6.2 Spectral radiant emittance of a blackbody

$$W_\lambda = \frac{c_1}{\lambda^5\left\{\exp\left(\frac{c_2}{\lambda T}\right) - 1\right\}}$$

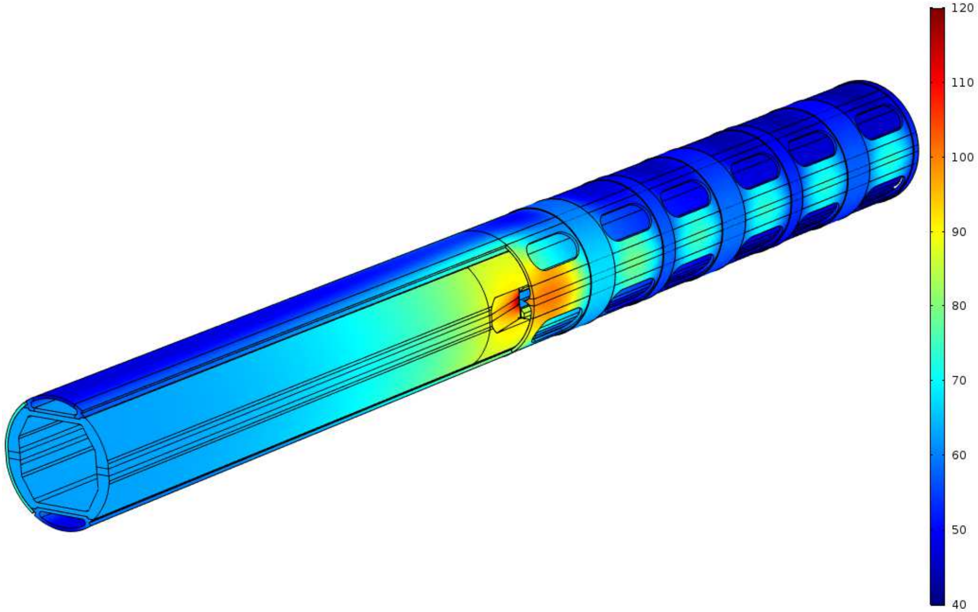
Emissivity of technical materials at low temperatures

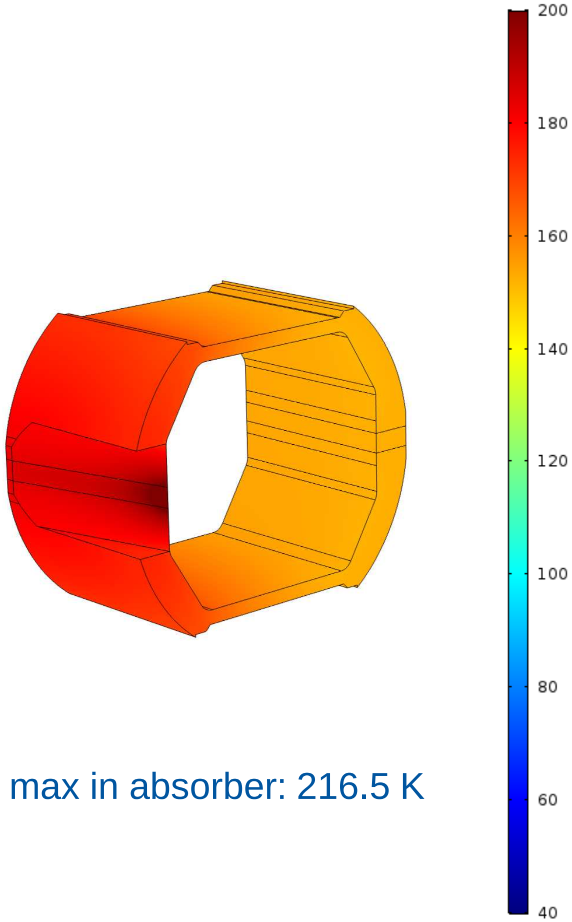
	Radiation from 290 K Surface at 77 K	Radiation from 77 K Surface at 4.2 K
Stainless steel, as found	0.34	0.12
Stainless steel, mech. polished	0.12	0.07
Stainless steel, electropolished	0.10	0.07
Stainless steel + Al foil	0.05	0.01
Aluminium, as found	0.12	0.07
Aluminium, mech. polished	0.10	0.06
Aluminium, electropolished	0.08	0.04
Copper, as found	0.12	0.06
Copper, mech. Polished	0.06	0.02

End dipole absorber



T max in beamscreen: 174.2 K



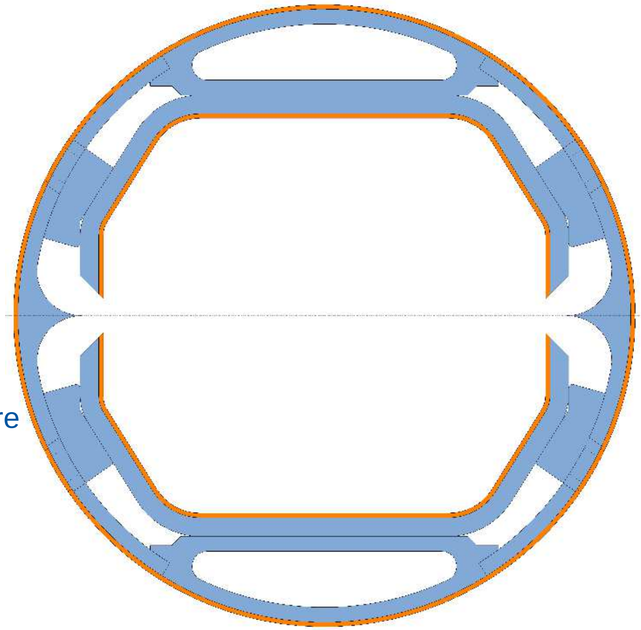


T max in absorber: 216.5 K

Temperature (K)

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.