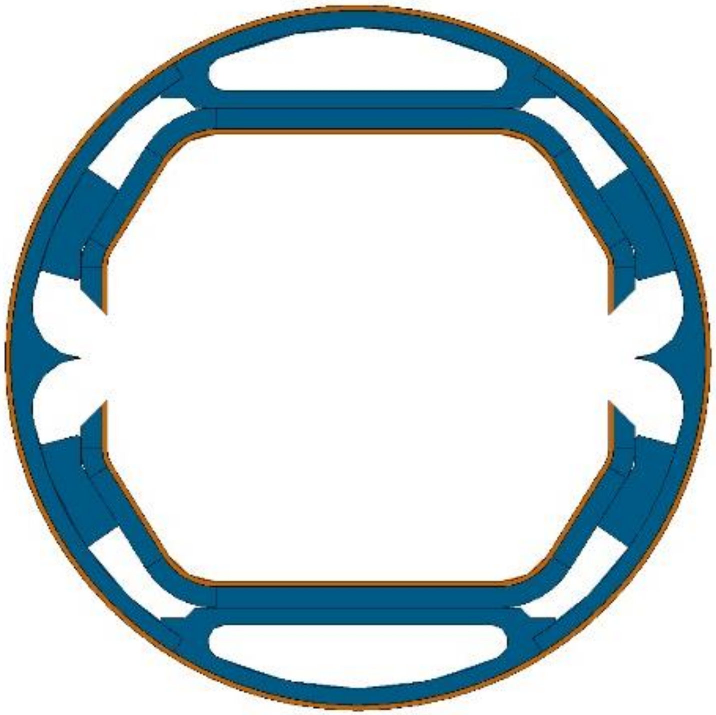
CERN

FCC-hh beam screen design

EuroCircol task 4.5

Javier Fernandez Topham



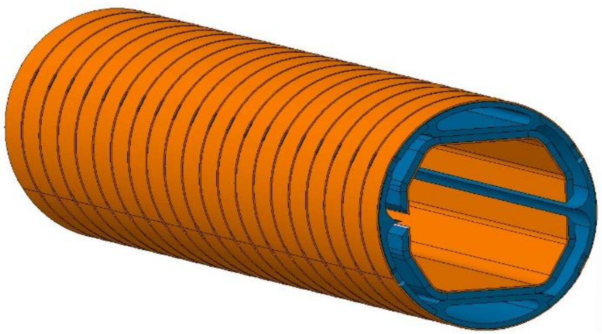
Outline

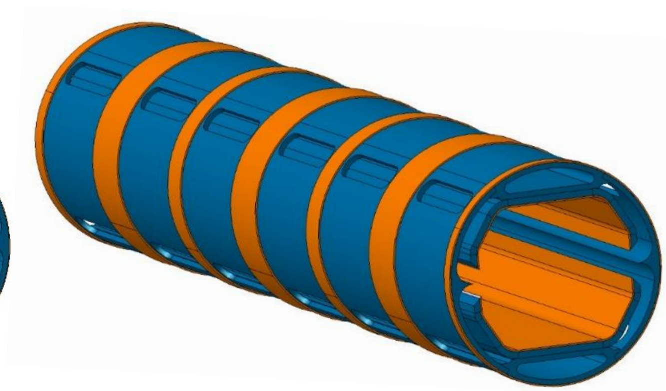
- New BS design
  - Geometry updates
- Mechanical design
  - Quench analysis
- Thermal study
  - Thermal model with updated SynRad data
  - Temperatures profile with SynRad data
  - Heat load from beam screen to cold bore
- Comparative
- Conclusions
- Next steps

Beam Screen Design

Beam screen design updates

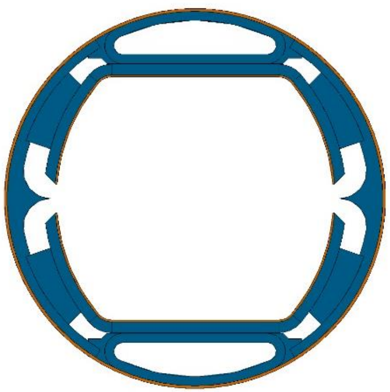
Orsay 09/2015 3th WP4 meeting	Geneva 06/2016 4th WP4 meeting	Barcelona 11/2016 5th WP4 meeting

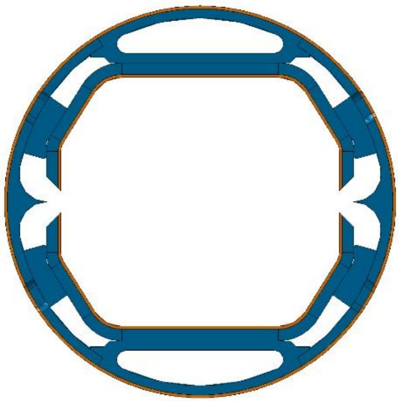


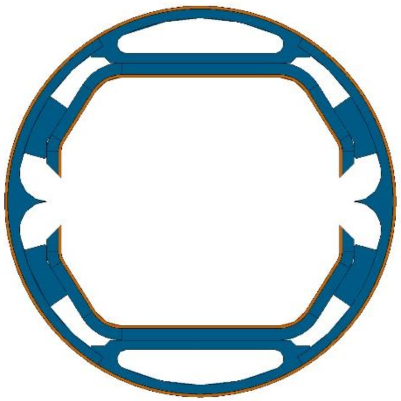


GOALS

- Improve pumping capacity
- Keep thermal and mechanical behaviour

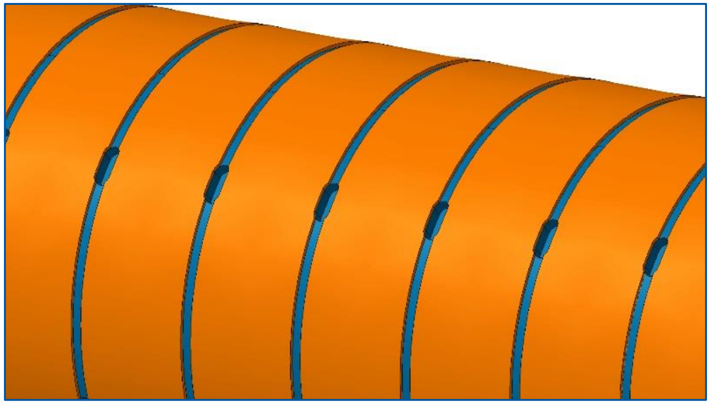




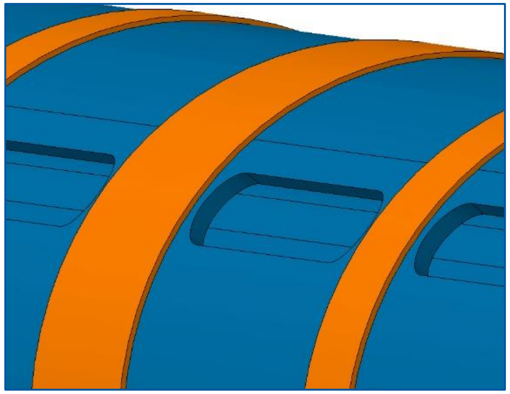


Beam Screen Design

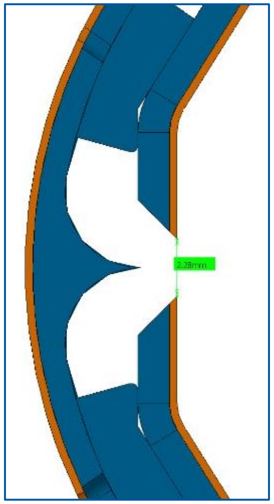
Pumping capacity



Pumping slots length: 1.5 mm

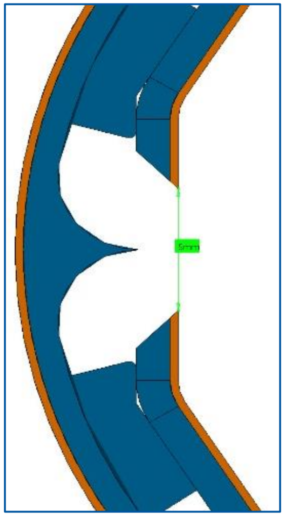


Pumping slots length: 23.75 mm



Deflector gap: 2.5 mm

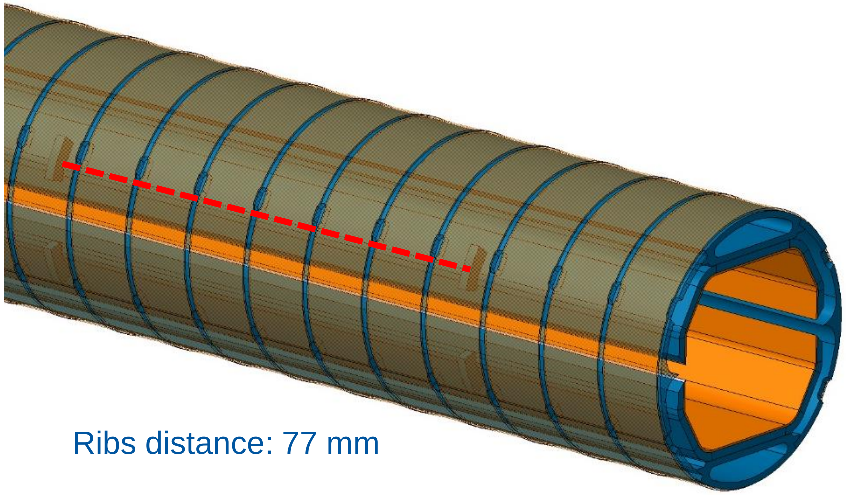
Increasing pumping slots length and deflector gap, pumping speed will be improved.



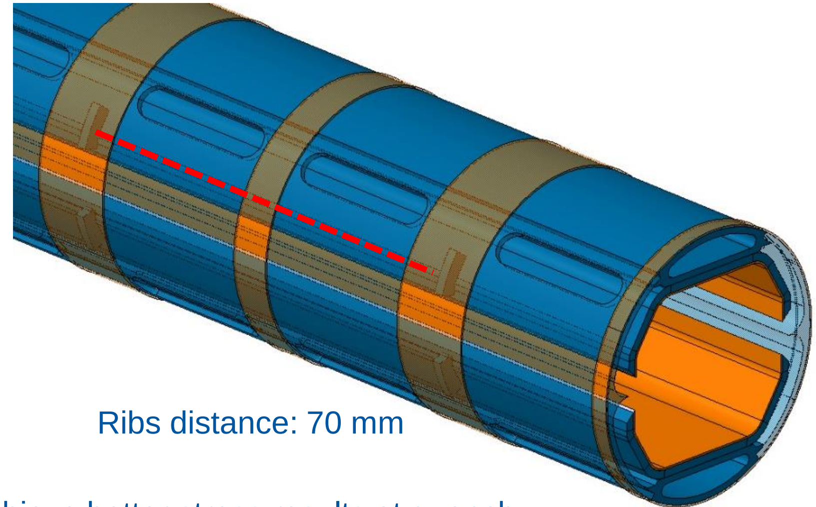
Deflector gap: 5 mm

Beam Screen Design

Mechanical and thermal design



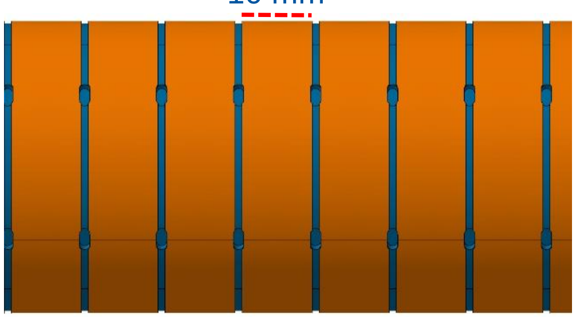
Ribs distance: 77 mm



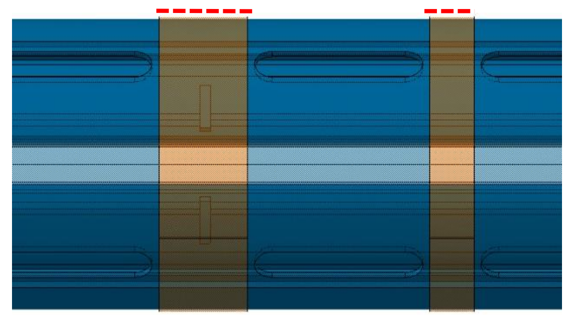
Ribs distance: 70 mm

Ribs distance has been decreased 7 mm in order to achieve better stress results at quench.

10 mm



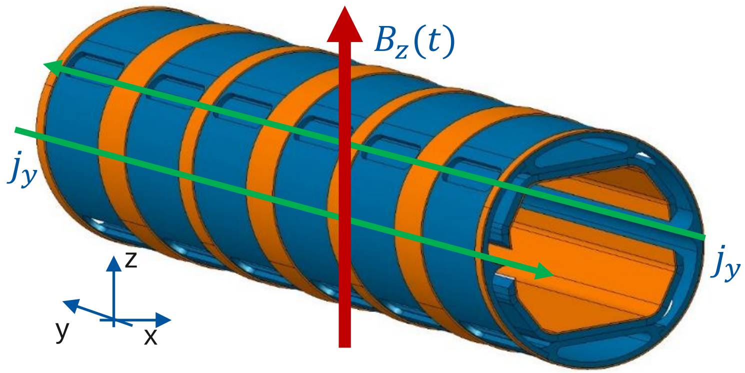
12.5 mm 6.25 mm



Bigger copper strips width on ribs area to distribute better heat loads.

Mechanical Design

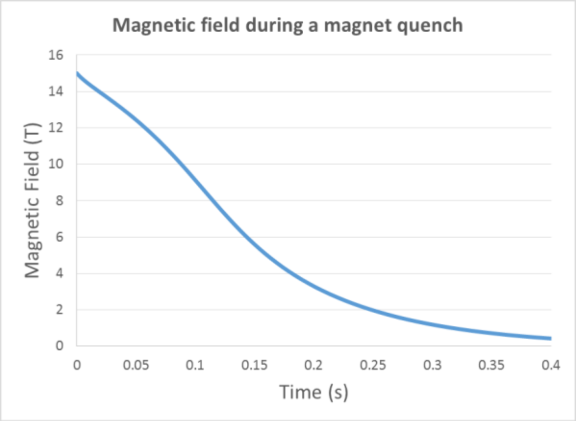
Magnet quench

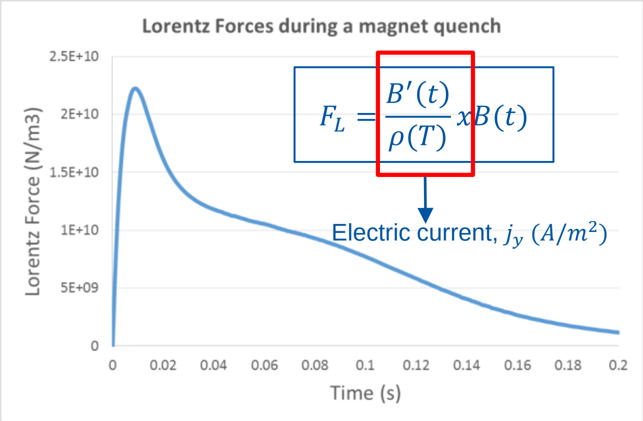


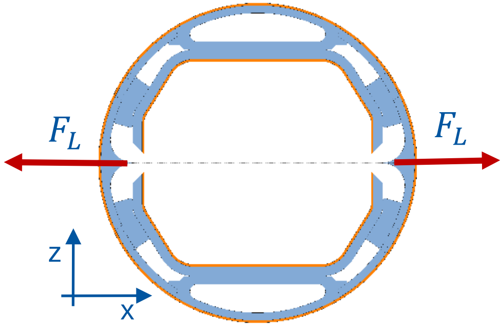
Variation of magnetic field at quench produces currents all along the beam screen.

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 ($\rho C_p \frac{\partial T}{\partial t} - \nabla(k \nabla T) = Q_e = JE$).

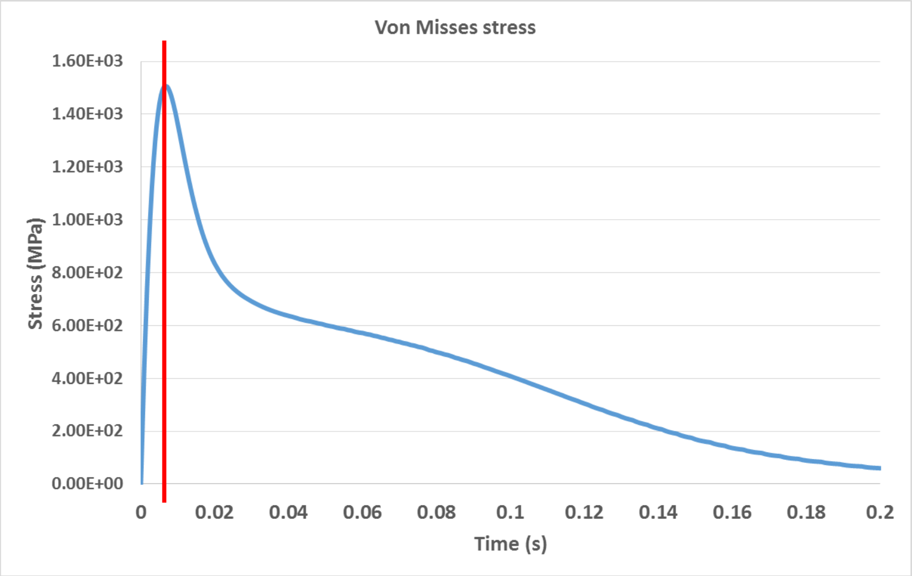


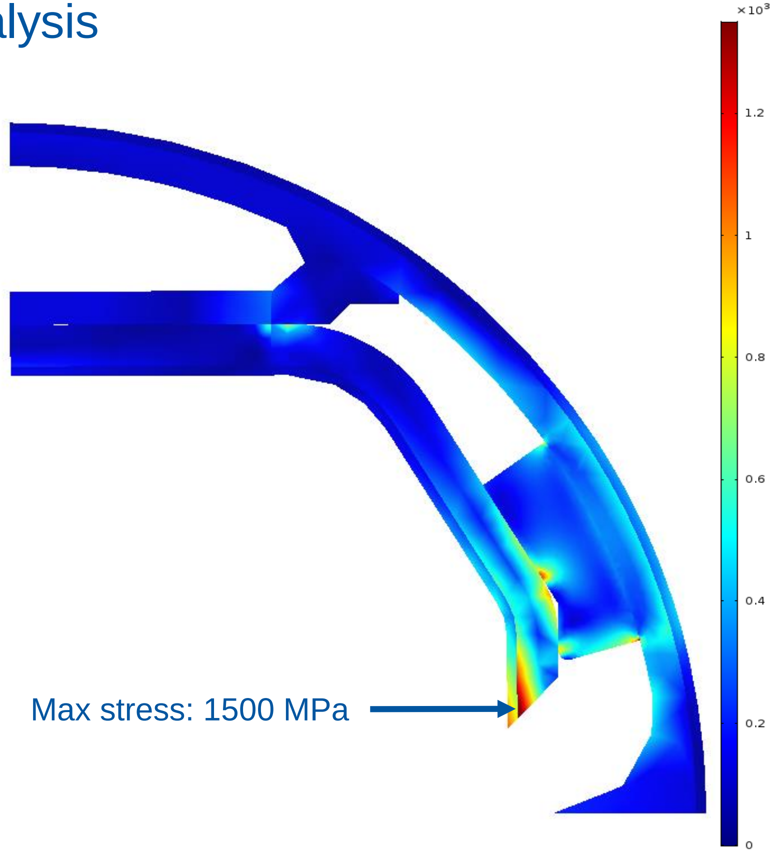


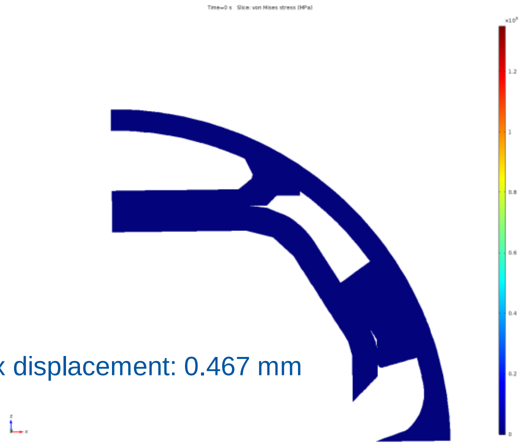


Mechanical Design

Stress analysis



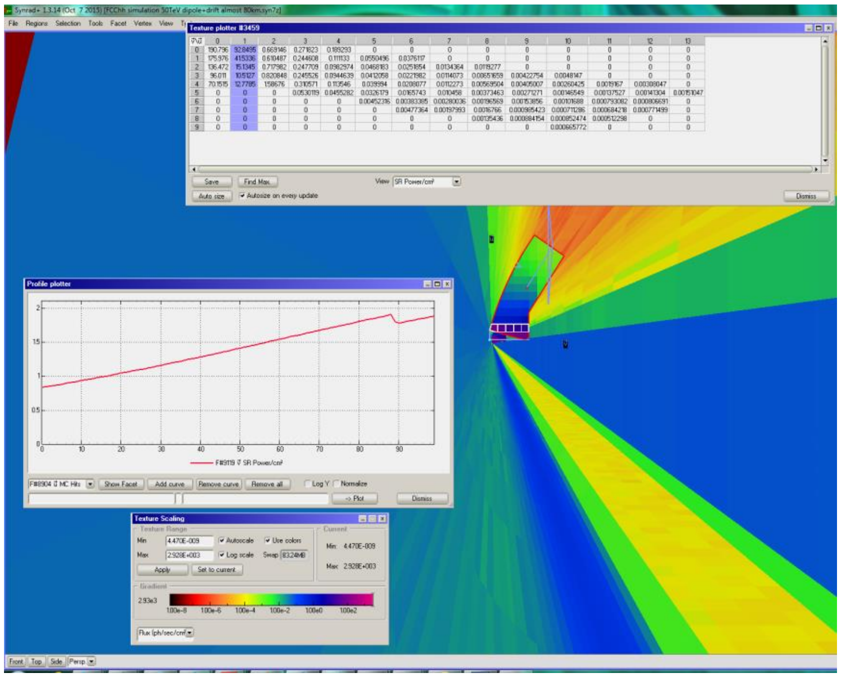


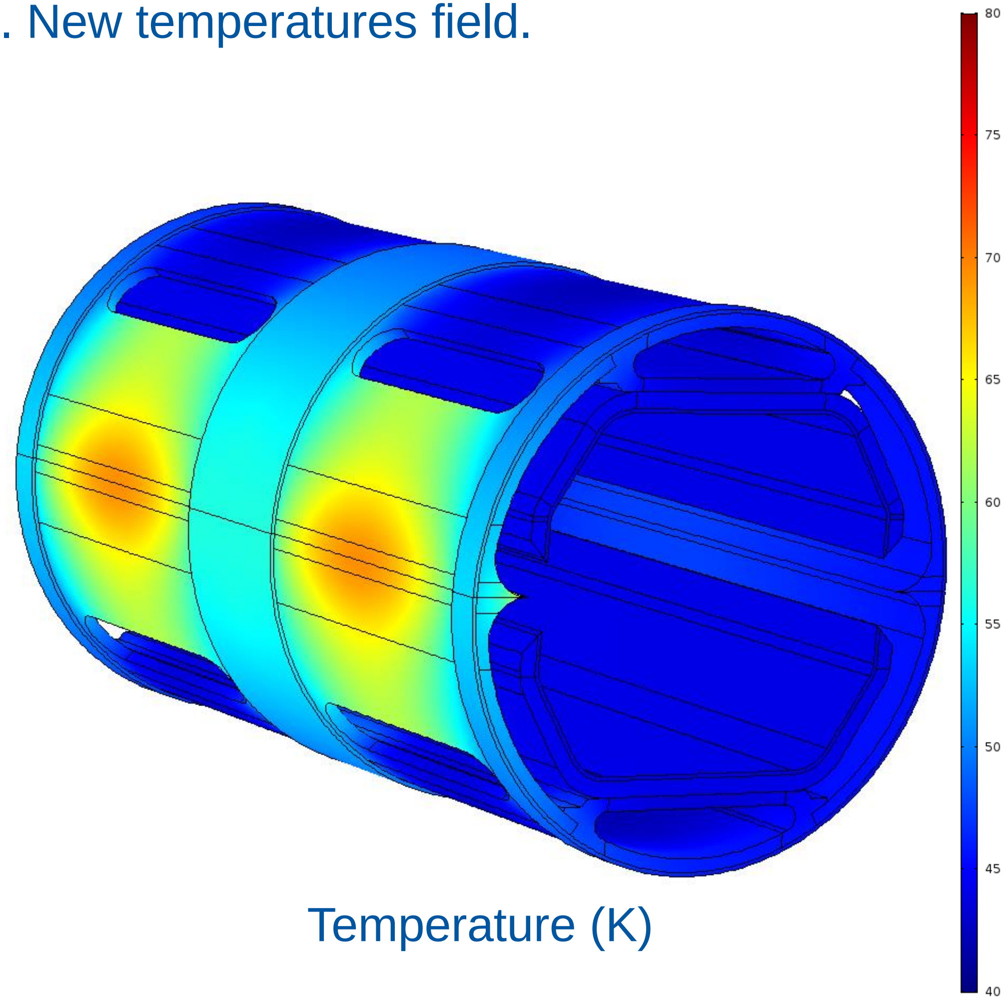


The maximum stress reached at highest Lorentz force (0.008 secs) is 1500 MPa (Yield strength at 50 K: 1350 MPa), so the material will plastify during magnet quench.

Thermal analysis

New SynRad data. New temperatures field.

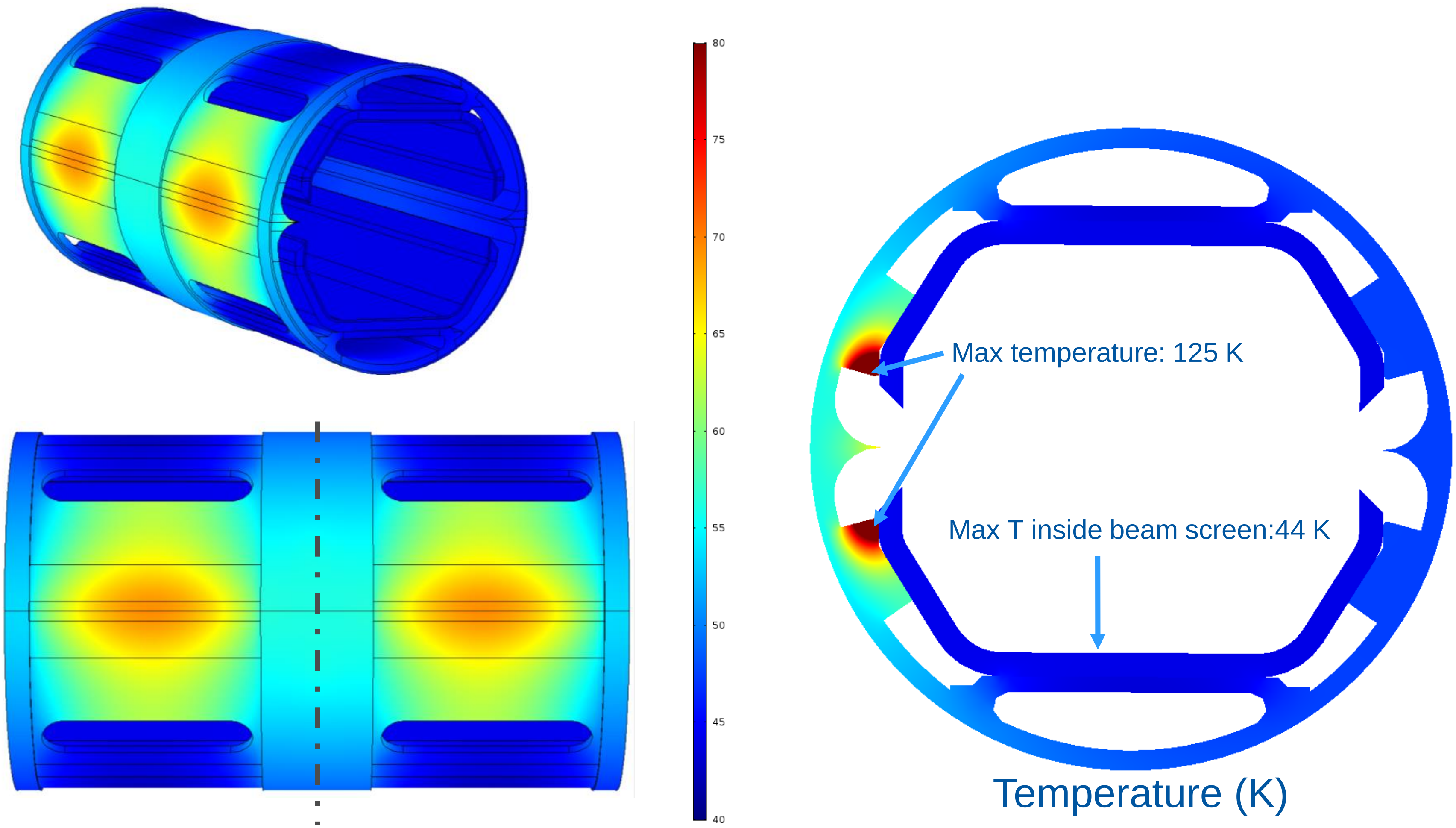




The inner beam screen temperature remains at 44 K, inside the temperature range allowed (between 40 K - 60 K).

Thermal analysis

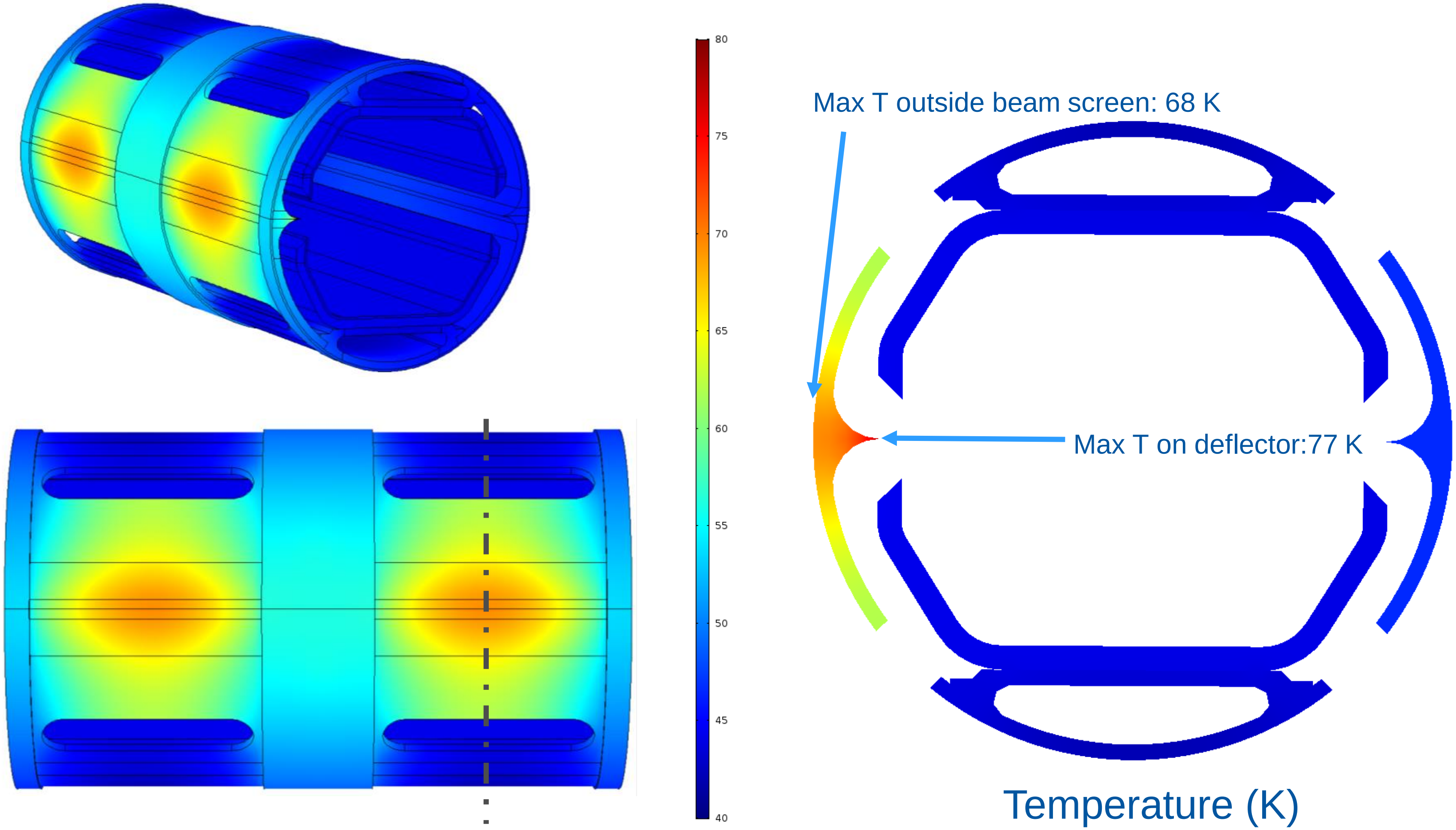
Temperature profile



The inner beam screen temperature remains at 44 K, inside the temperature range allowed (between 40 K - 60 K).

Thermal analysis

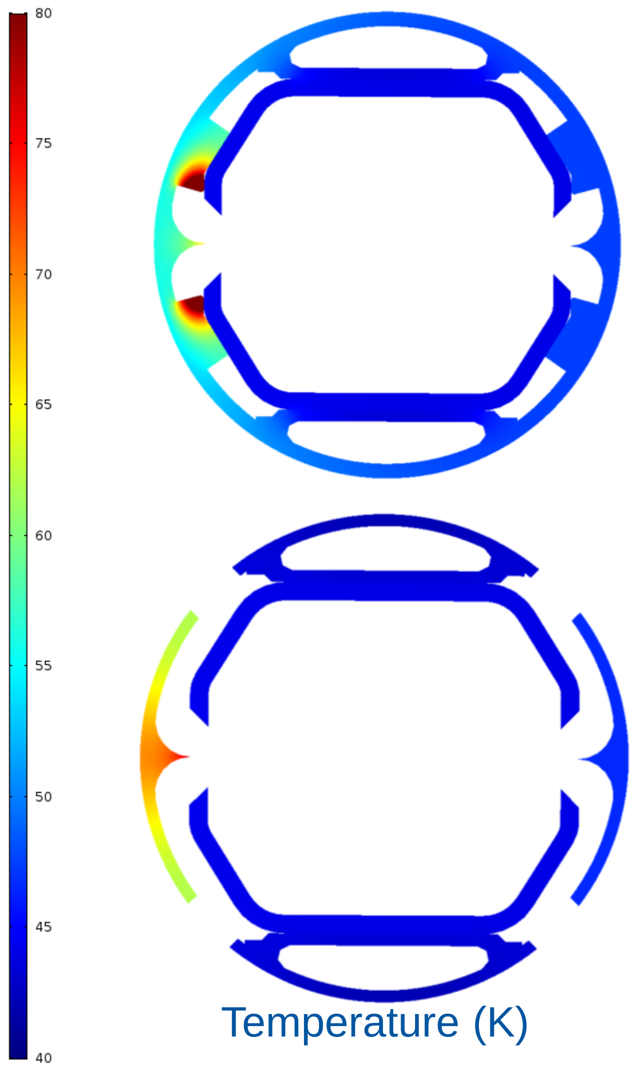
Temperature profile



The inner beam screen temperature remains at 44 K, inside the temperature range allowed (between 40 K - 60 K).

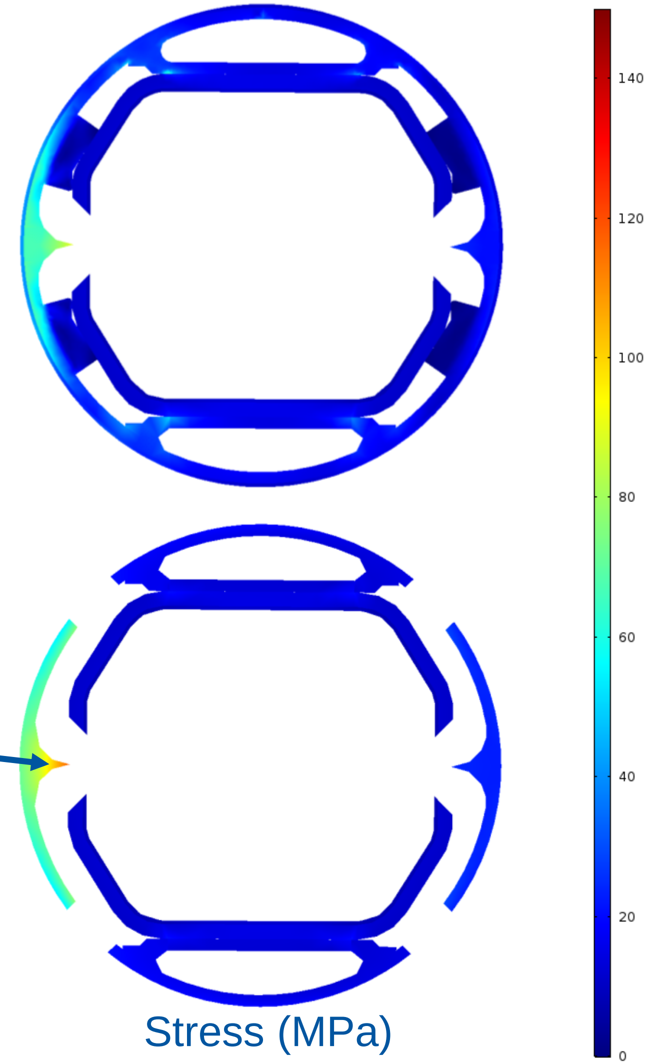
Thermal analysis

Thermal stress



Temperature (K)

Max stress: 115 MPa

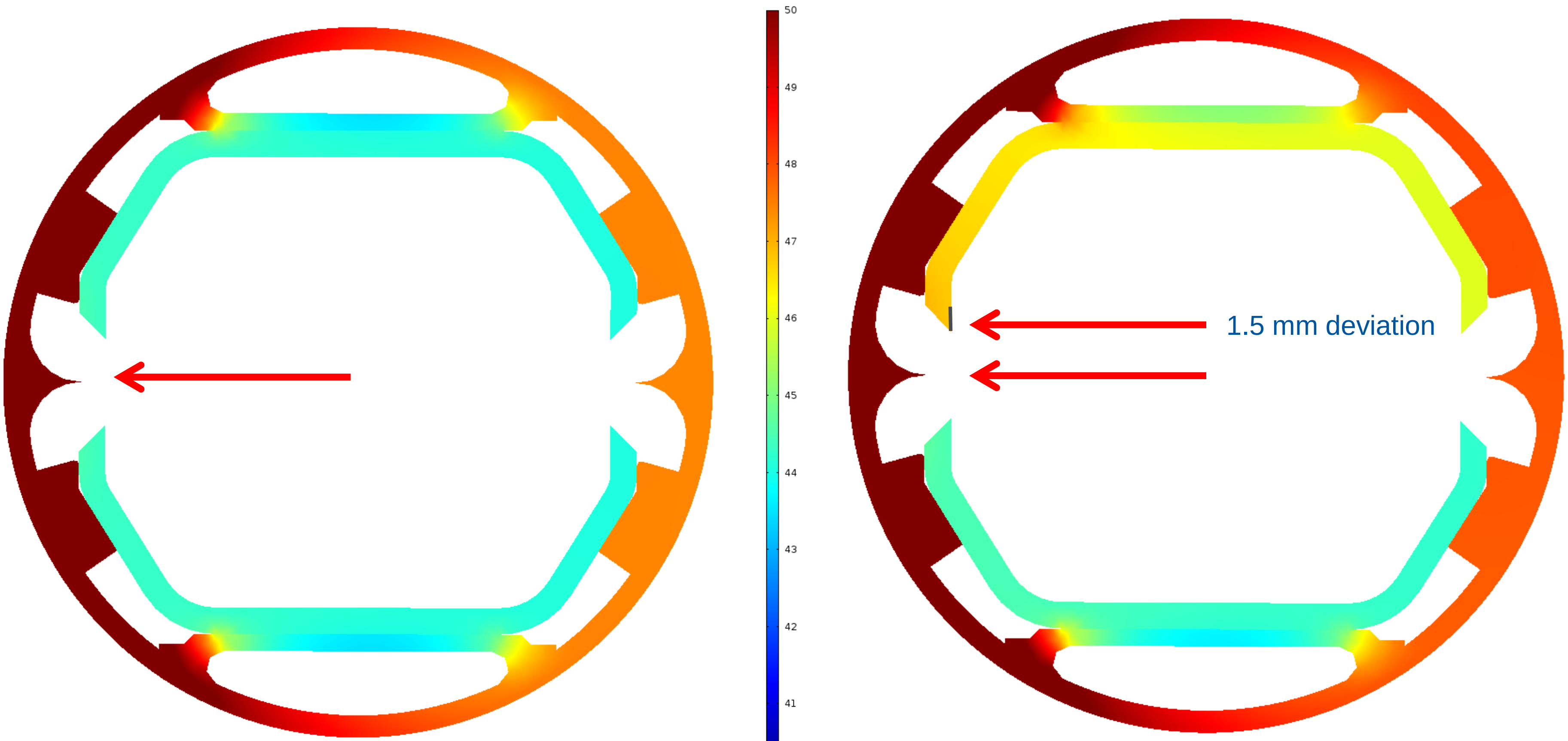


Stress (MPa)

Max stress reached (115 MPa) below yield strength (~1200 MPa).

Thermal analysis

Temperature profile

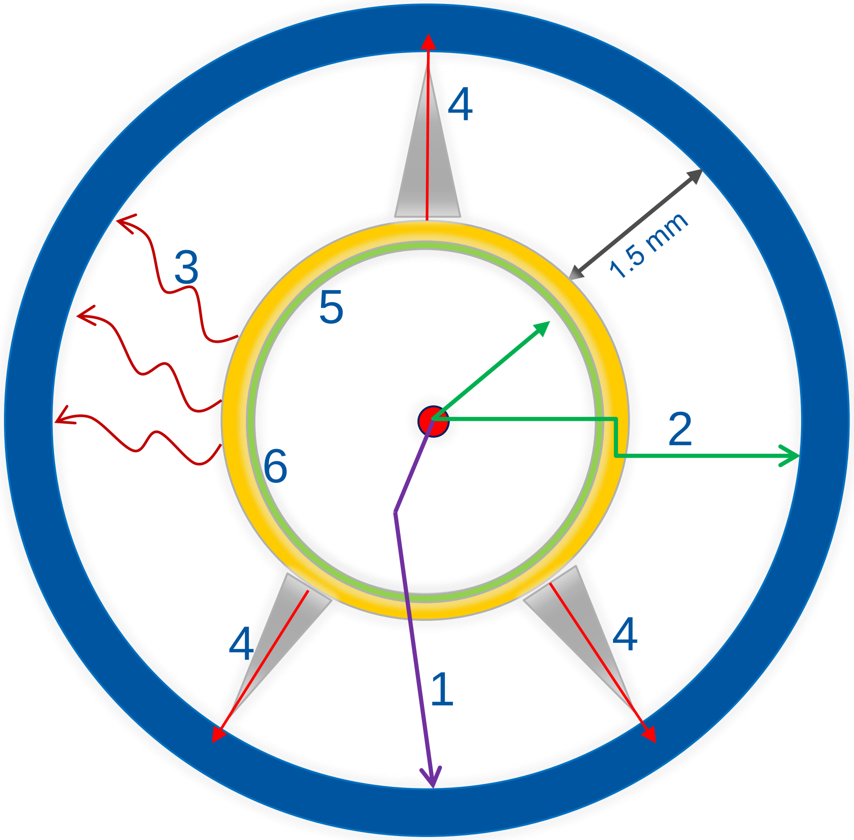


Max T inside beam screen: 44 K

Max T inside beam screen: 46.8 K

Temperature (K)

Thermal load to cold bore



1 • Nuclear scattering: 46 mW/m

2 • Synchrotron radiation: 2.4 mW/m

3 • Thermal radiation: 2.33 mW/m

4 • Beam screen supports: 49 mW/m

5 • ~~Image currents~~

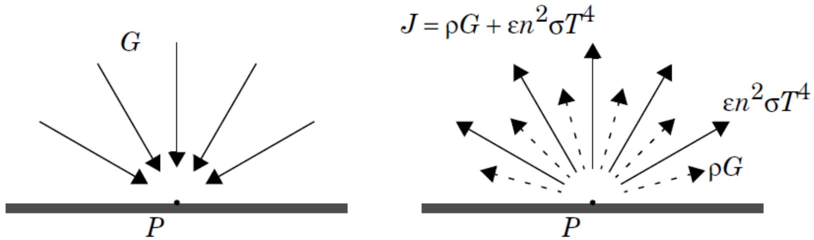
6 • ~~Electron cloud effect~~

Max power allowed: 100 mW/m

Total thermal load transferred to cold bore: 99.73 mW/m

Thermal load to cold bore

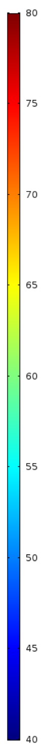
Radiation

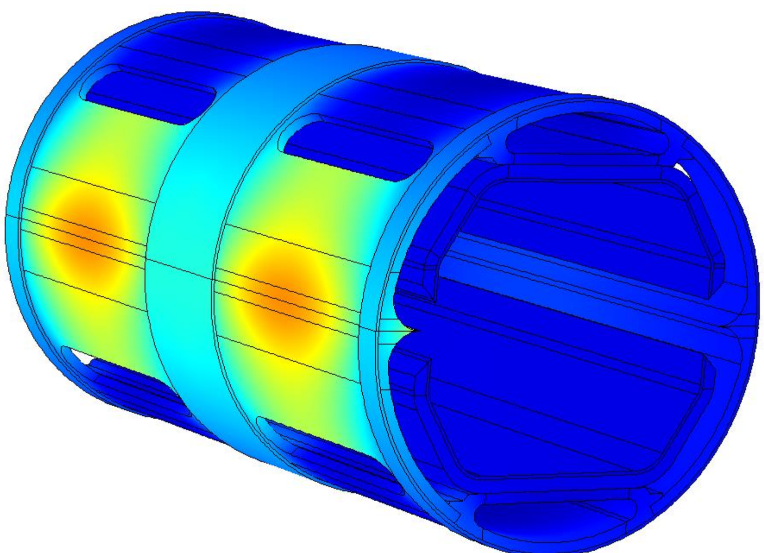


$$q = \varepsilon(G - n^2\sigma T^4)$$

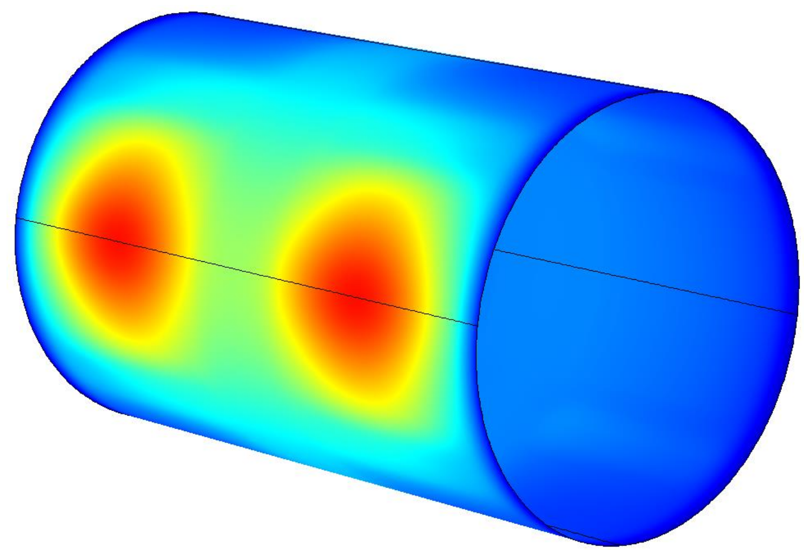
$\varepsilon = 0.1$
$n = 1$
$\sigma = 5.670373 \cdot 10^{-8}\ Wm^{-2}K^{-4}$

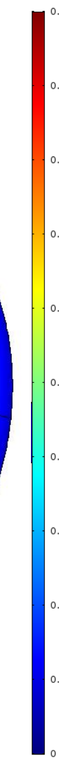
All surfaces are diffuse grey surfaces: No dependency on the radiation wavelength and angle between surface normal and the radiation direction.





Temperature (K)





Radiosity (W/m2)

Total radiation heat: 2.33 mW/m

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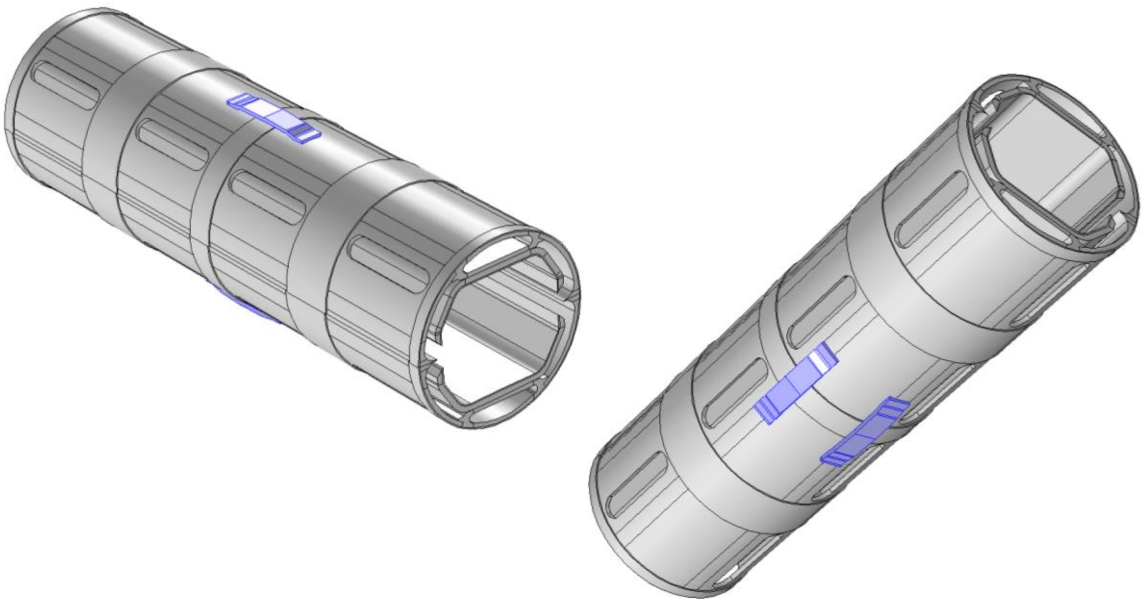
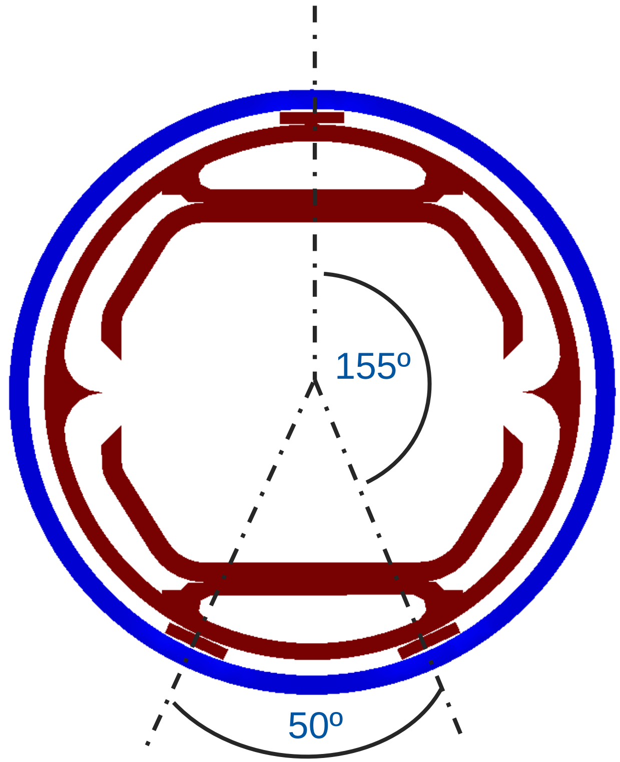
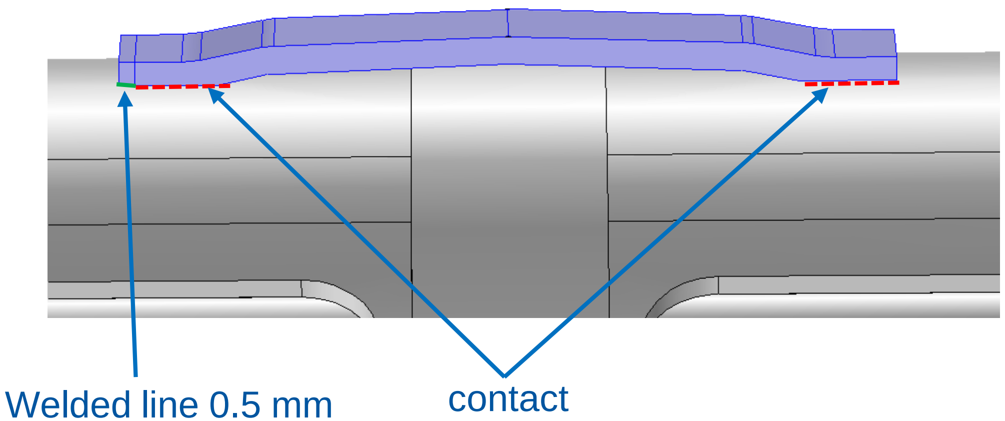
EuroCircol WP4 meeting, Barcelona
8th November 2016

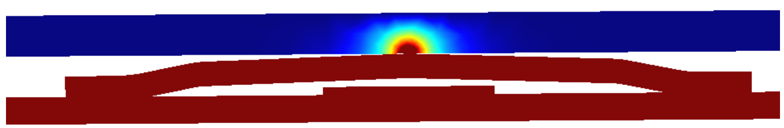
Thermal load to cold bore

Beam screen supports









Total contact heat: 49 mW/set

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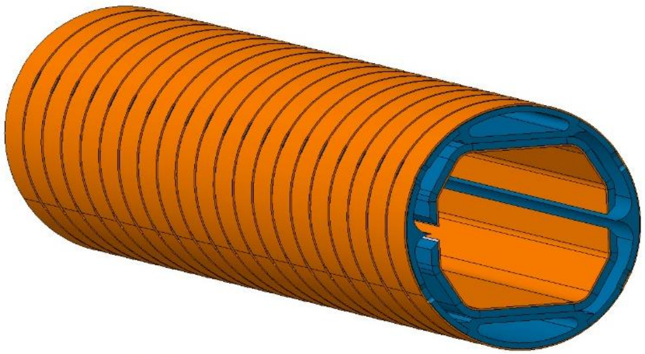
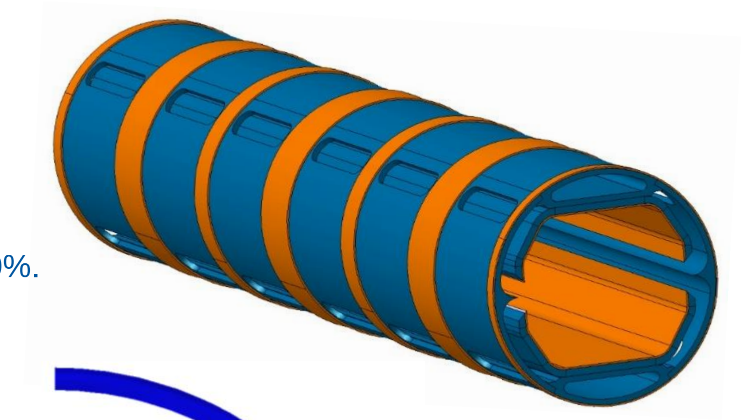
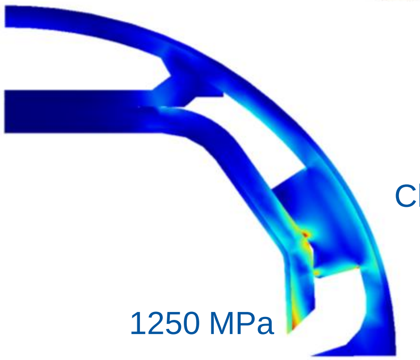
BS comparative

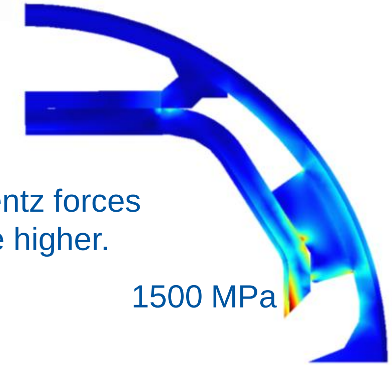




Amount of copper reduced 70%.

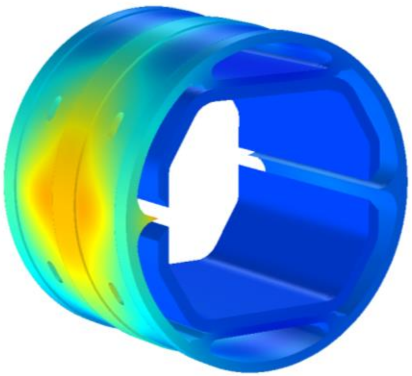


1250 MPa



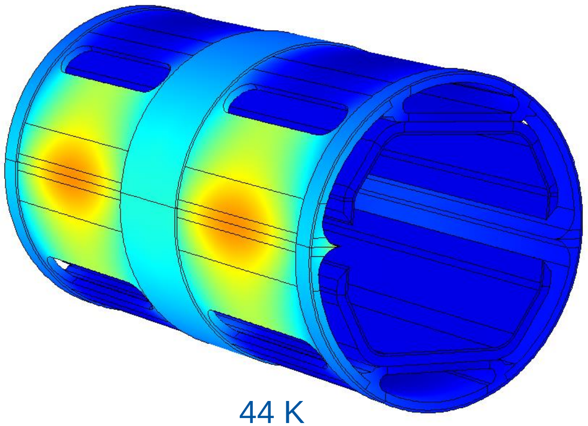
1500 MPa

Change on deflector gap produces higher Lorentz forces and lower inertia moment, so that, stress are higher.



47 K

Inner copper layer temperature reduced 3K thanks to the isolation produced by bigger pumping slots.



44 K

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Conclusions

Geometry update

- In order to optimize pumping capacity, outer beam screen geometry and deflector gap have been re-design.
- The aim of this new design has been, not only increase pumping capabilities, but also meet as much as possible mechanical and thermal targets.

Mechanical design

- For the new geometry mechanical 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 reach locally plasticity.

Thermal analysis

- Taking into account synchrotron radiation during nominal behaviour, the temperatures as well as the thermal stress in the new beam screen remain on the range allowed (with similar results than in the previous model).
- All types of heat transfer from beam screen to cold bore has been studied. First estimations indicate that heat load is slightly lower than the limit.

Next steps

- Optimize ribs.
- Optimize beam screen supports.
- Analyse synchrotron radiation impact on the dipole end cover
- Beam screen thermal analysis with future SynRad data.
- Check mechanical behaviour of beam screen on future geometry updates.

THANK YOU FOR YOUR ATTENTION

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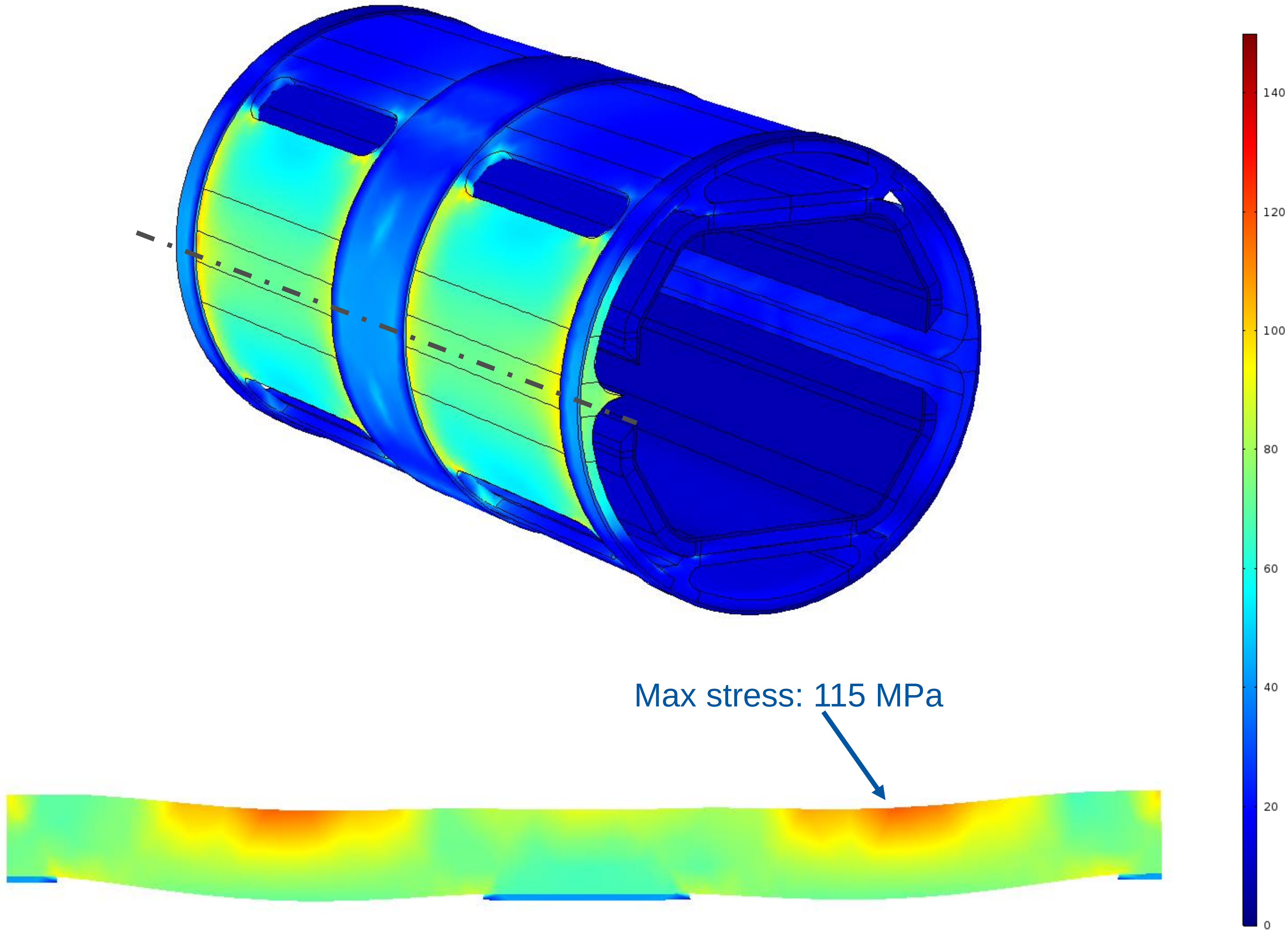


Max stress: 115 MPa
140
120
100
80
60
40
20
0

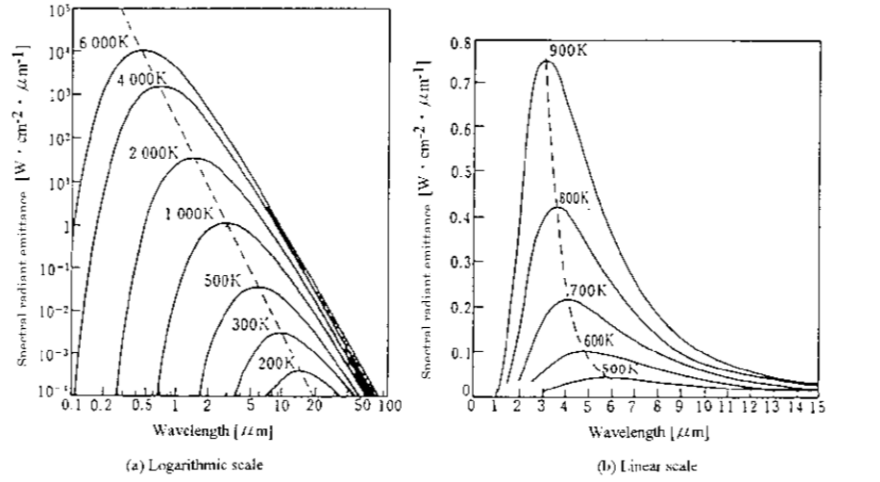


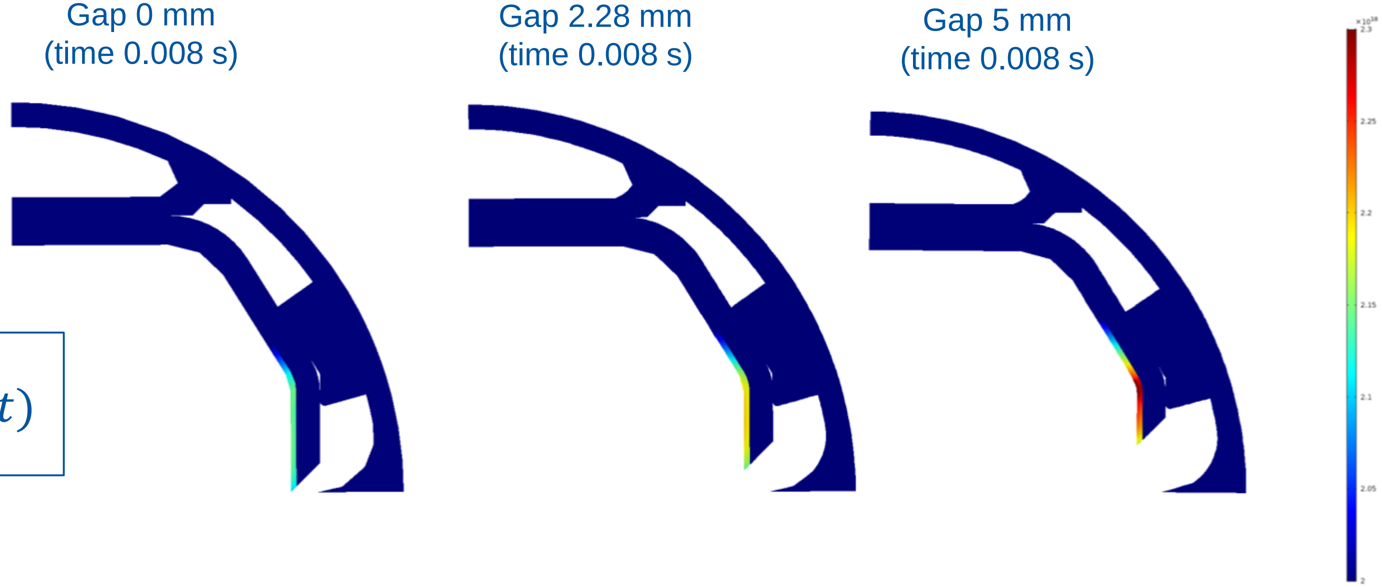
Fig. 6.2 Spectral radiant emittance of a blackbody

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

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

Gap 0 mm (time 0.008 s) | Gap 2.28 mm (time 0.008 s) | Gap 5 mm (time 0.008 s)

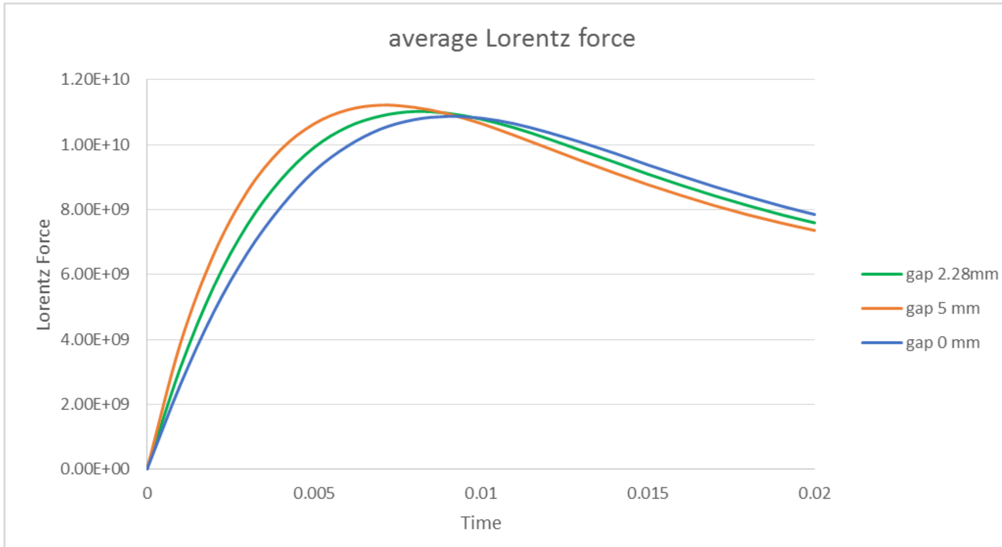


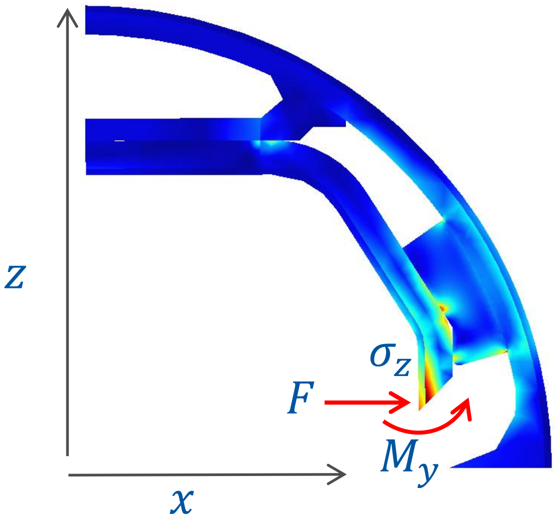
Lorentz force range: 2E10 – 2.3E10 N/m3

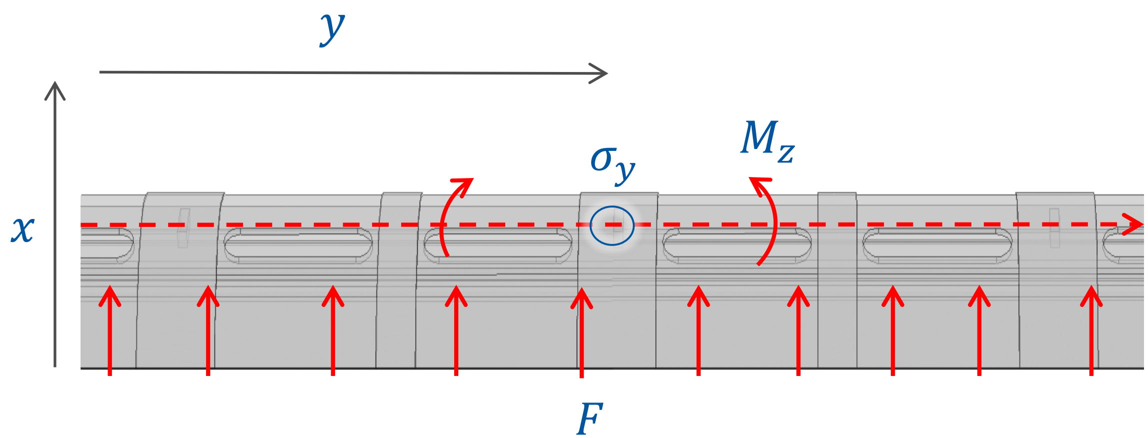
$$F_L = \frac{B'(t)}{\rho(T)} x B(t)$$

$B(t) \rightarrow B'(t) \rightarrow j \rightarrow b(t) \rightarrow B(t)$ ⇒ $B(t) - b(t)$

Lenz law: The direction of current induced in a conductor by a changing magnetic field, due to Faraday's law of induction, will be such that it will create a field that opposes the change that produced it.







$$\sigma_{y2.5} = \frac{M_z \cdot y}{I_y}$$

$$\sigma_{z2.5} = \frac{M_y \cdot z}{I_z}$$

High Lorentz force

Gap deflector change

$$\sigma_{y5} = \frac{\uparrow M_z \cdot y}{I_y \downarrow}$$

$$\sigma_{z5} = \frac{\uparrow M_y \cdot z \downarrow}{I_z \downarrow}$$

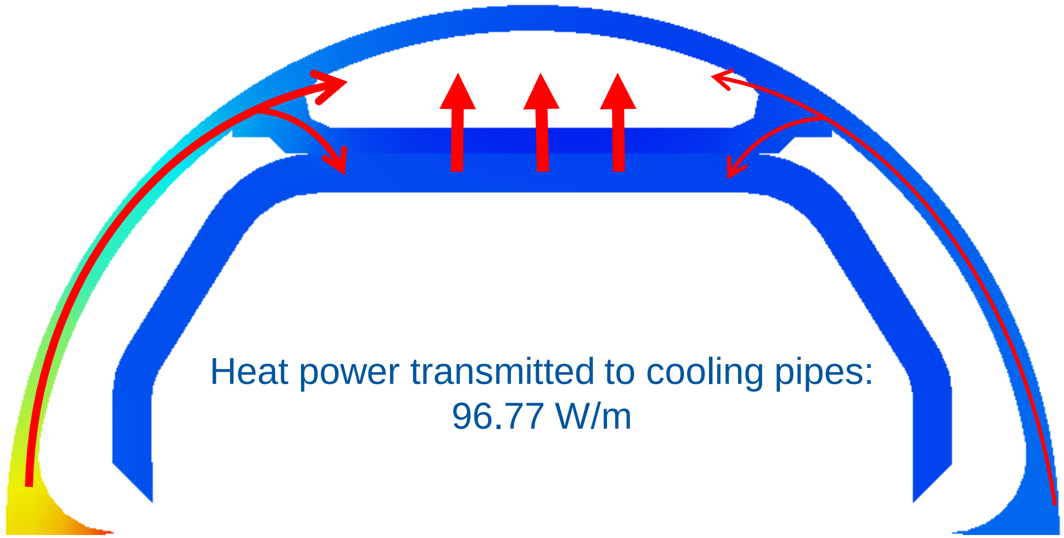
$$\sigma_{y2.5} < \sigma_{y5}$$

$$\sigma_{z2.5} < \sigma_{z5}$$

$$\sigma_x \approx 0$$

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

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



Pumping holes isolate beam screen sides, so that, inner beam screen layer remains cooler than in the previous geometry.