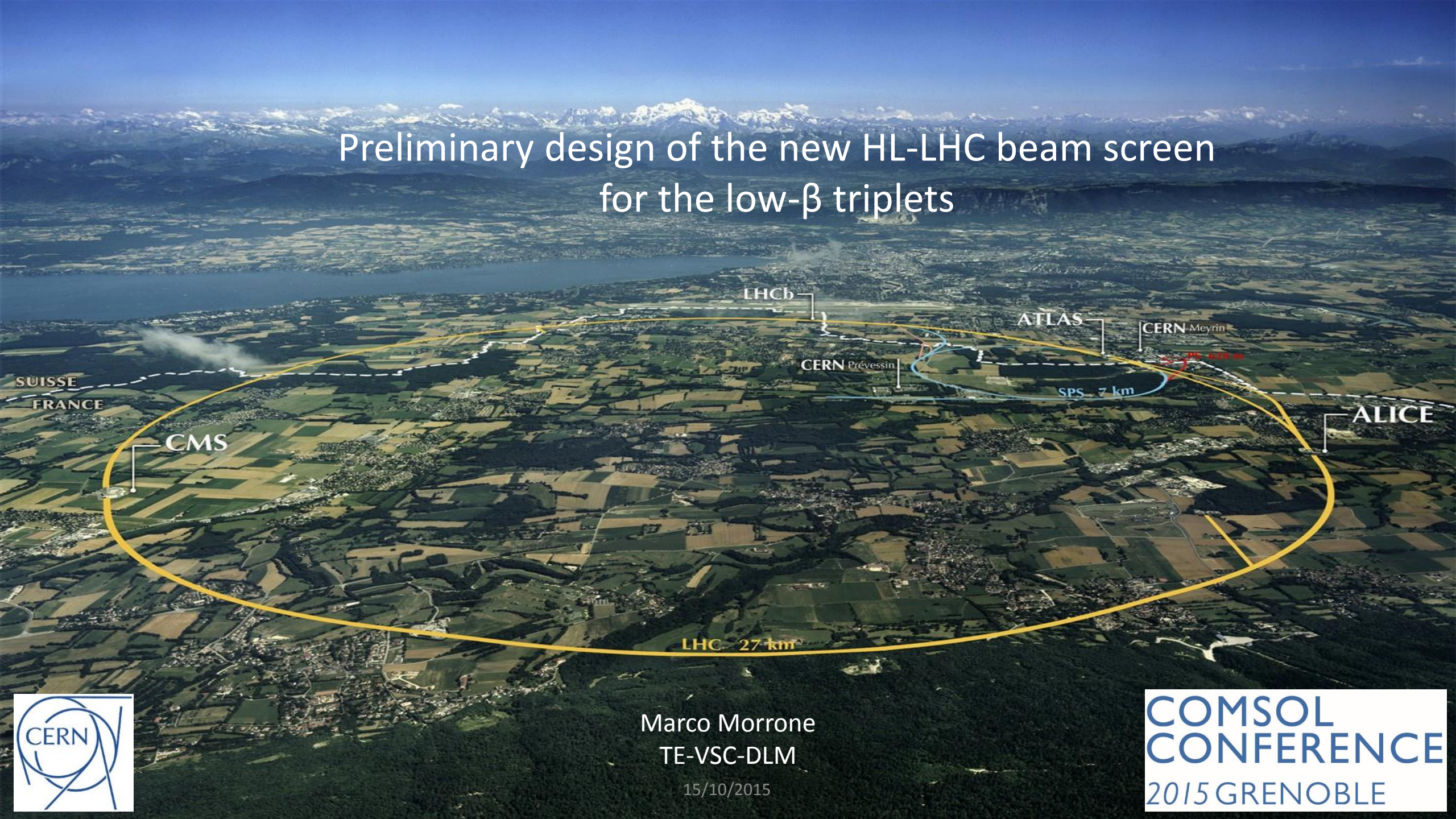
Preliminary design of the new HL-LHC beam screen for the low-β triplets



Marco Morrone
TE-VSC-DLM

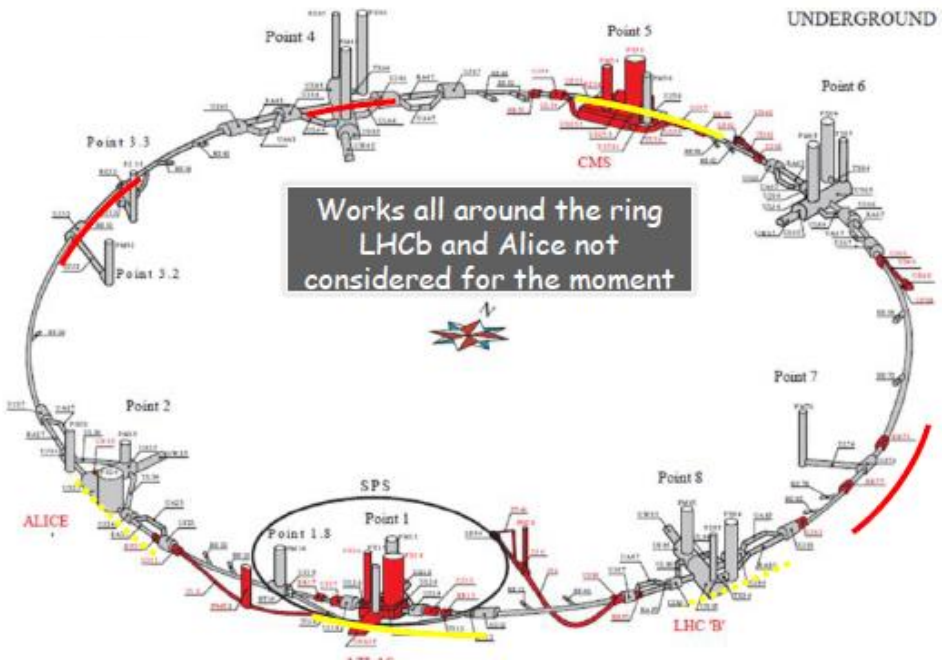
15/10/2015

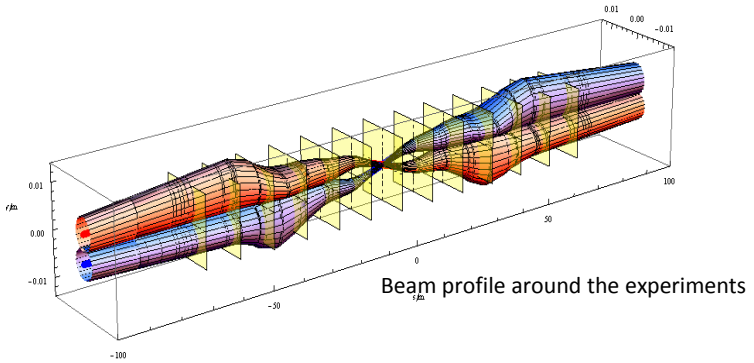
COMSOL CONFERENCE 2015 GRENOBLE

Contents

The HL-LHC Project

Major intervention on more than 1.2 km of the LHC





Beam profile around the experiments

- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- …

→ Smaller beam size at the interaction points.

Functional requirements - functional study

The HiLumi-LHC (HL-LHC) upgrade calls for a new tungsten-based shielding system to lower the debris coming from atomic collisions towards the cold masses of the superconducting triplet magnets (point 1 and 5).

Therefore, the new beam screen has to ensure:

-Thermal shielding of the cold bore from beam induced heat loads
(1 W of heat on CB = 1kW of cooling energy, Grobner)

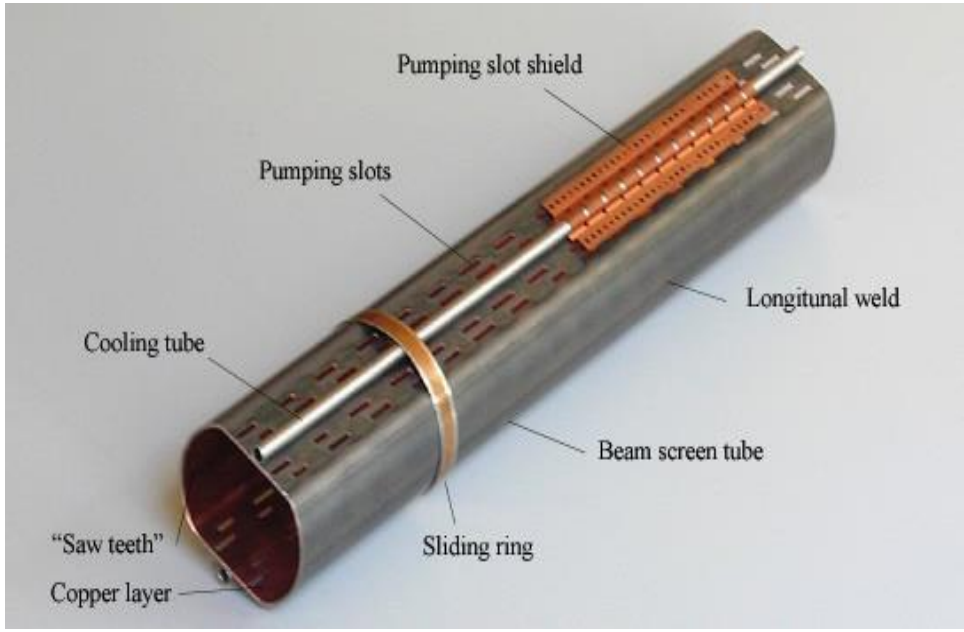
-Vacuum stability

-Mechanical resistance to magnet quench

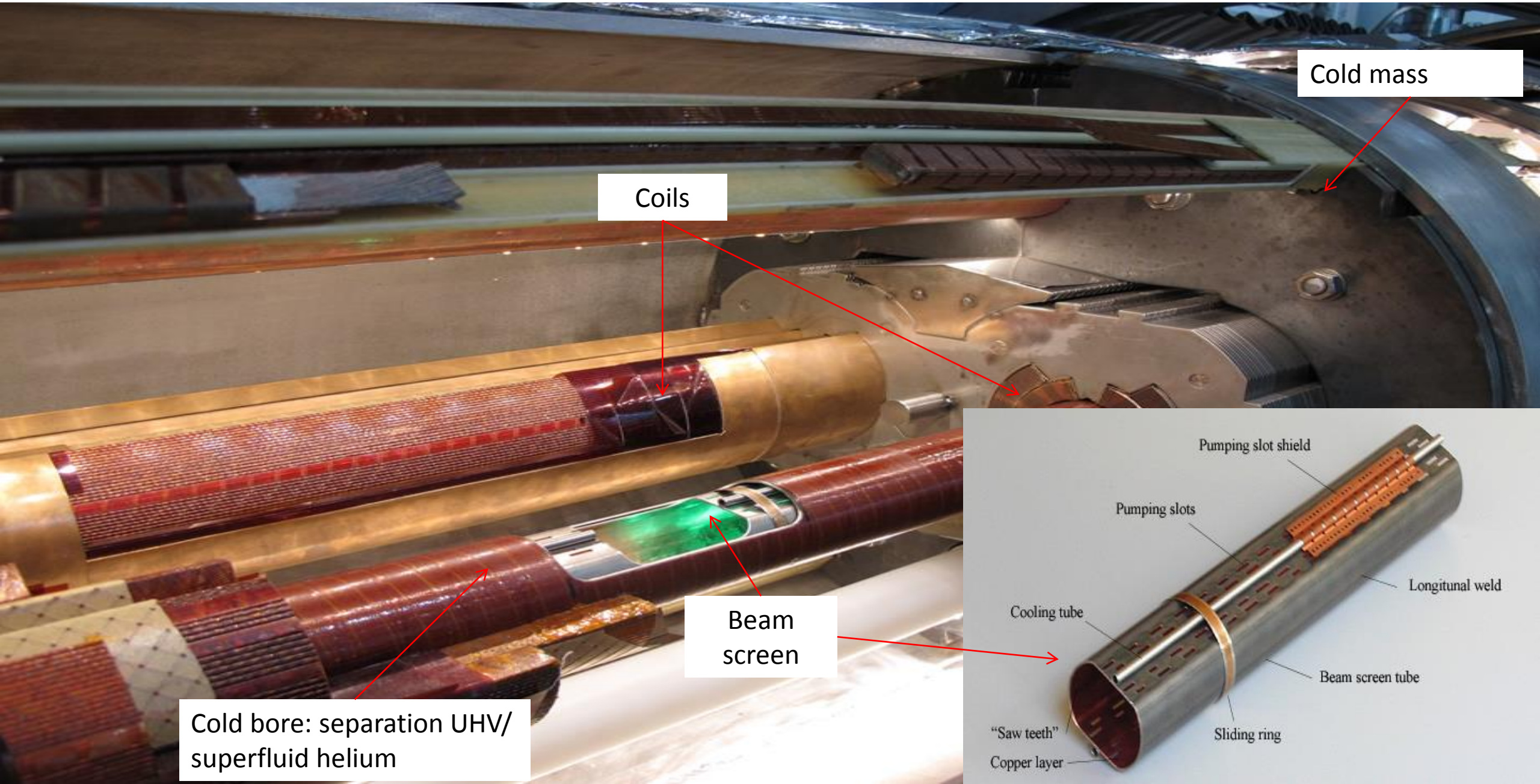
-Temperature in operation conditions between 40 and 60 K

-Lowering beam impedance

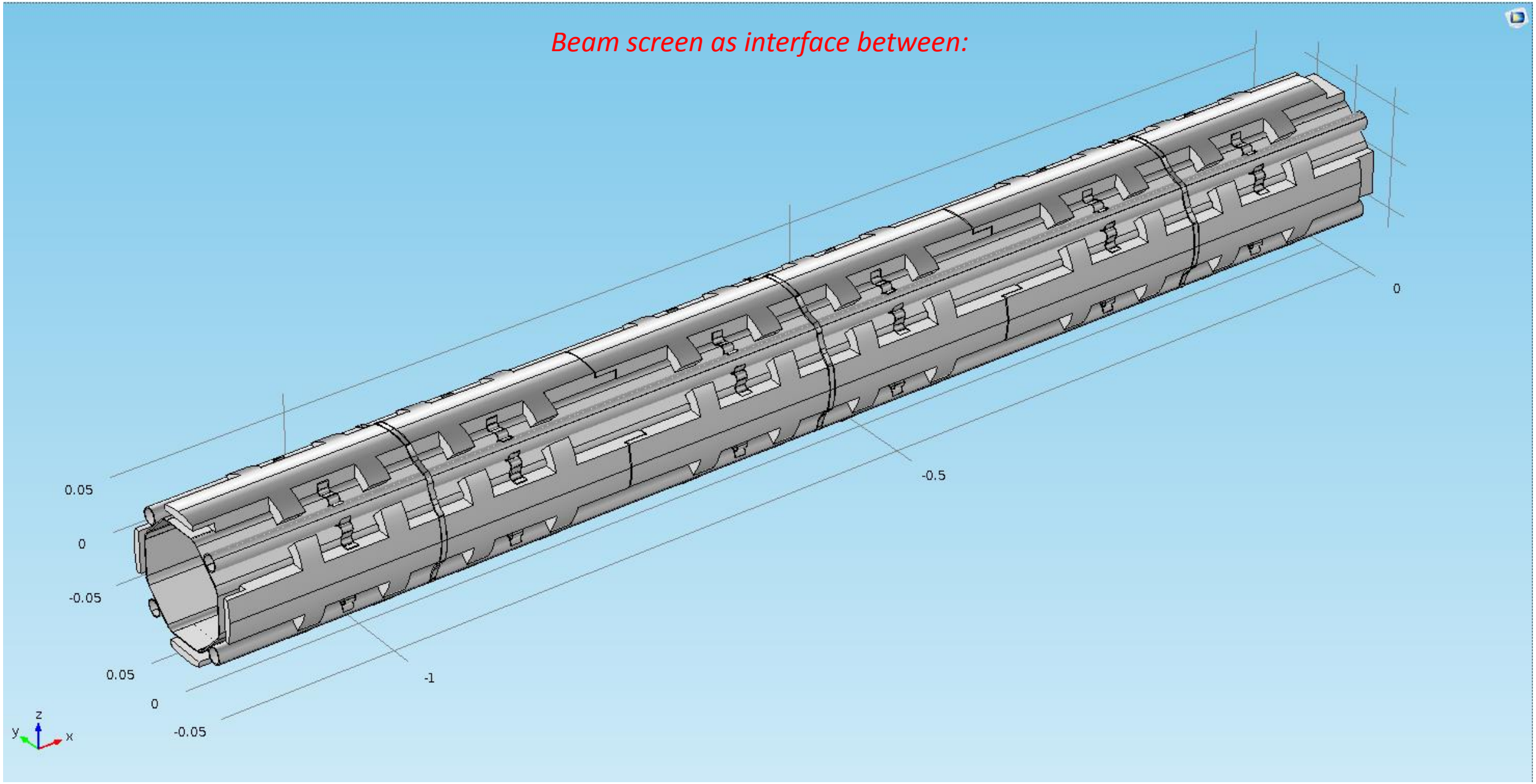
-Compliancy with beam optical requirements



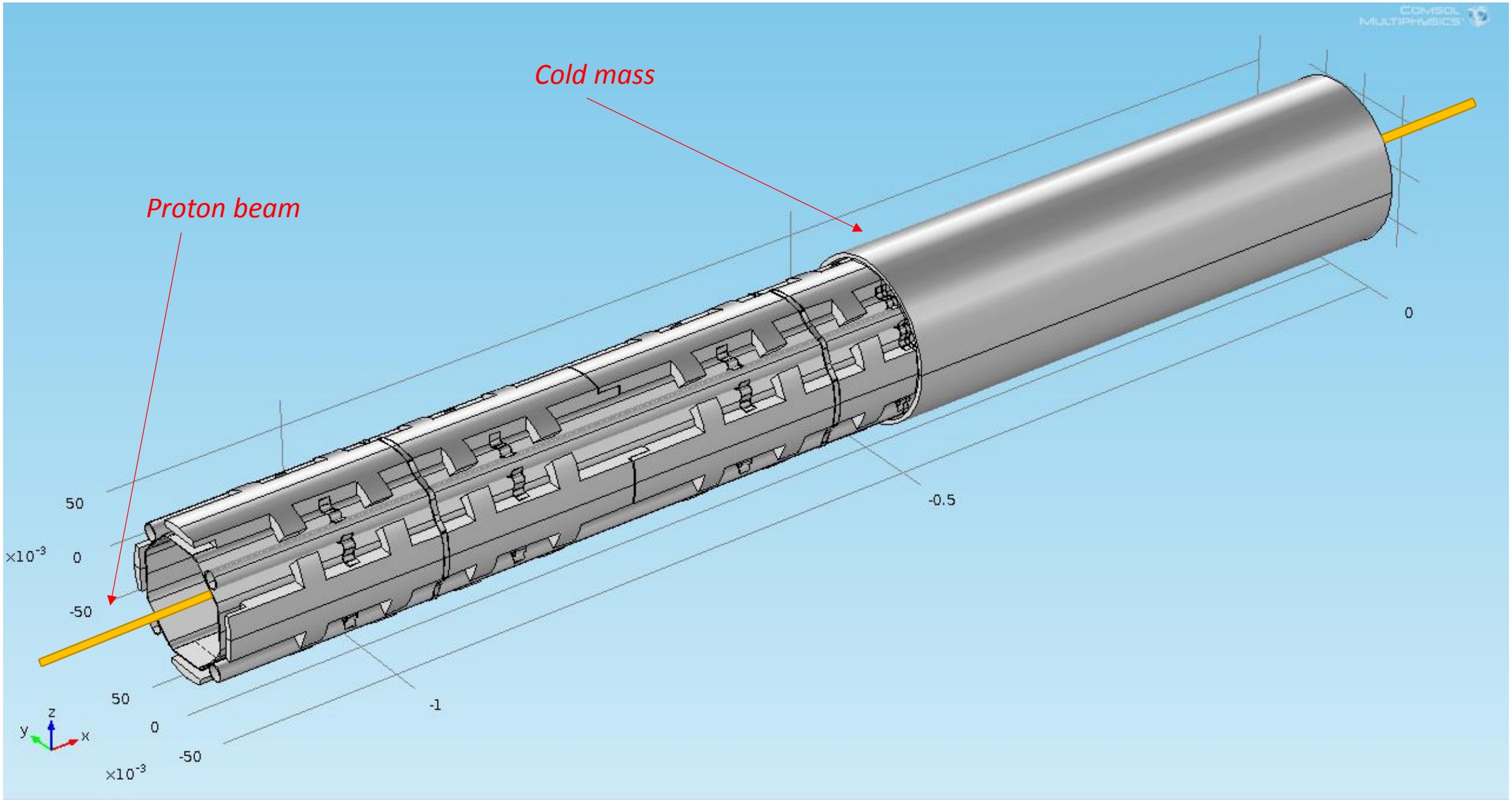
Functional requirements – current BS



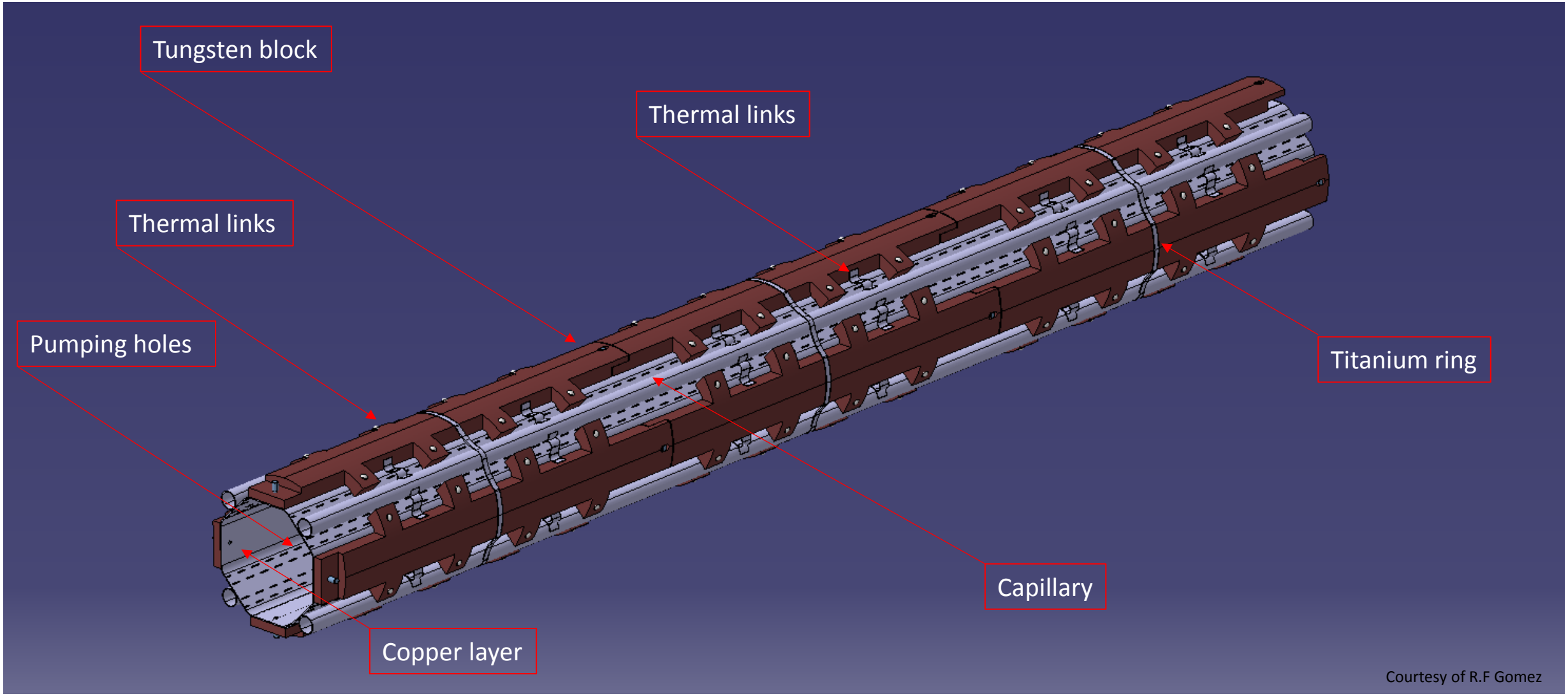
Functional requirements – new BS concept



Functional requirements - new BS concept



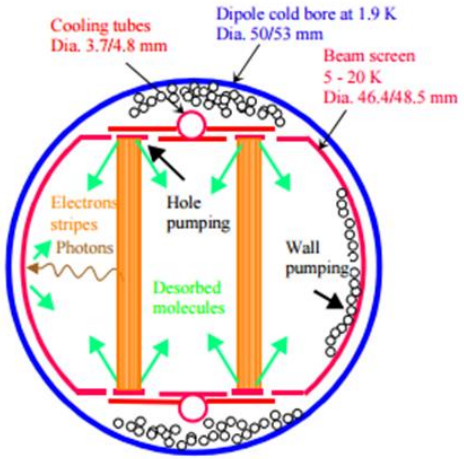
Functional requirements – new BS concept



Functional requirements – design criteria

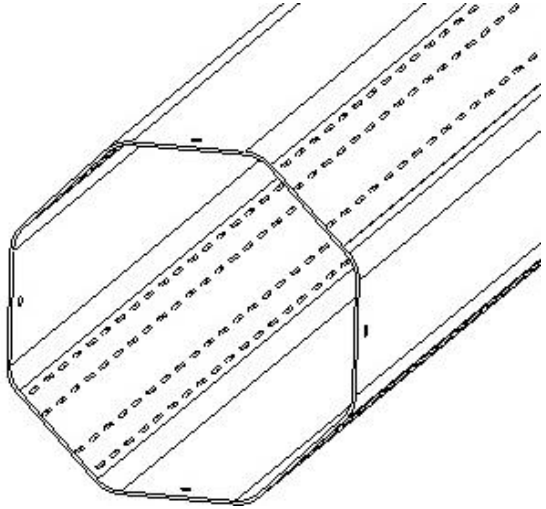
Normal operation conditions

Vacuum stability



Courtesy of V. Baglin

Holes = 4% surface coverage



Thermal

Fourier Law 1D

Cross section thermal link

Temperature difference

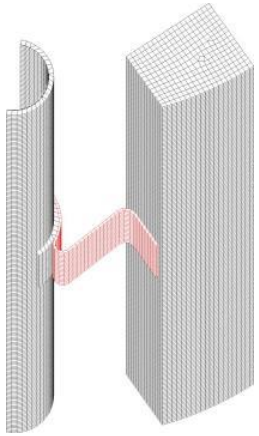
$$Q = \lambda S \frac{\Delta T}{L}$$

Heat flux

Thermal conductivity

Thermal link length

- Q = 2W/ tungsten block of 40cm
- λ = 1000 W/K/m
- ΔT= 5 K
- L ≅ 25 mm



Considering 4 links

$S = 10\ mm^2$/ link

dim= 20 * 0.5 mm

Worst-case scenario

Magnet quench

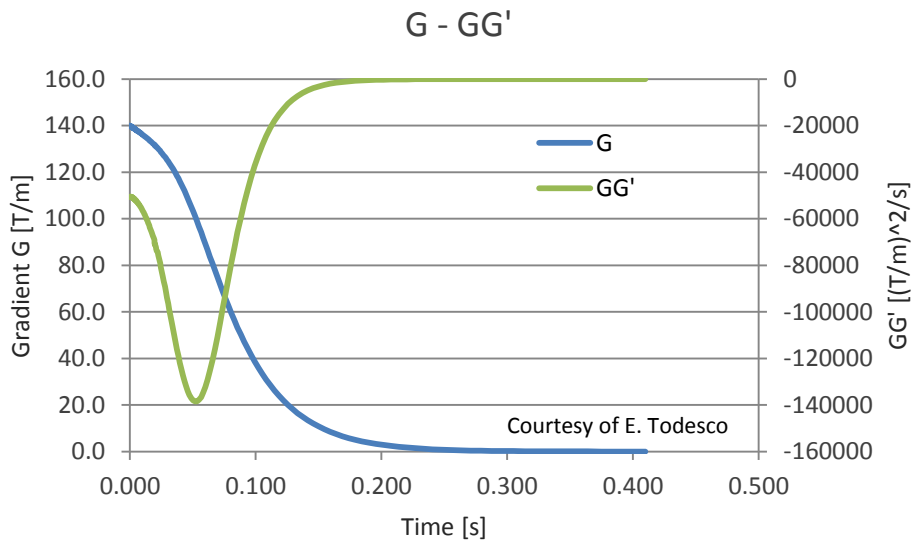
Resistive transition of the magnet

Specific force

Magnetic gradient

$$\vec{f} \propto \frac{G\dot{G}}{\rho}$$

Electrical resistivity



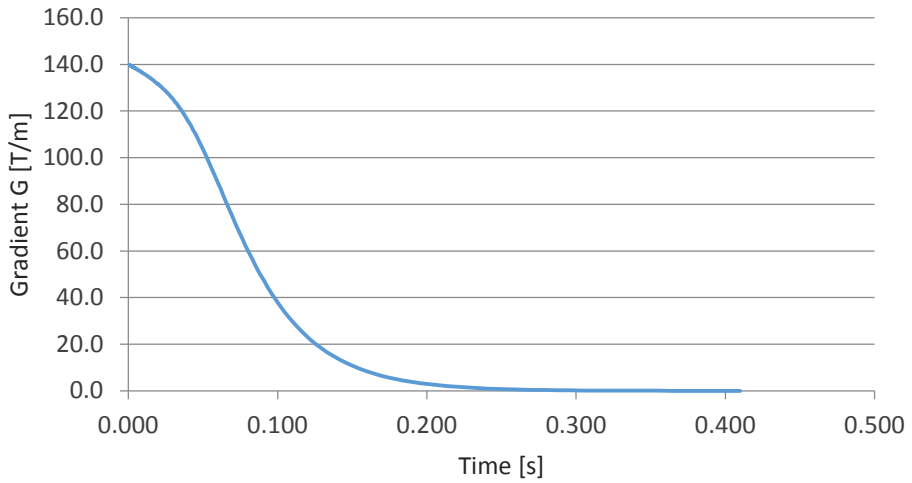
→ Lorentz forces are maximum after 0.5 ÷ 0.6 s.

→ Maximum GG' = 140000 $T^2/m^2/s$

Mechanical design - structural study during quench

1

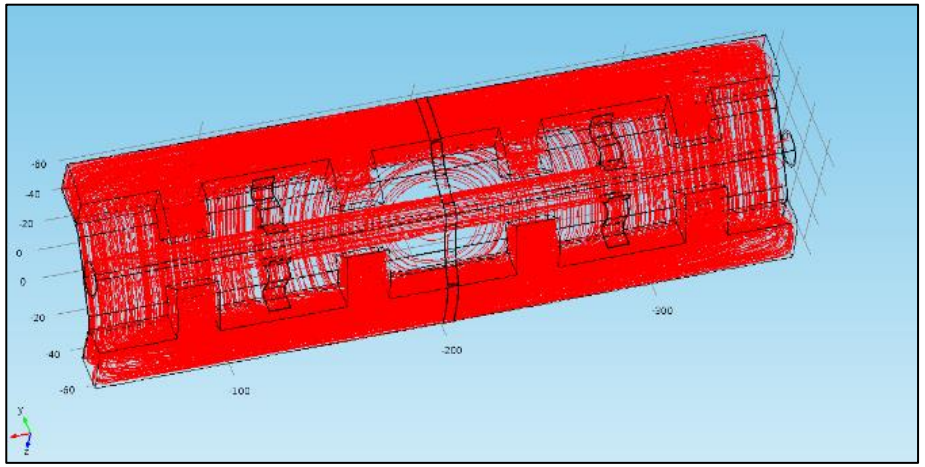
Magnet quadrupole gradient decay



2

Eddy currents

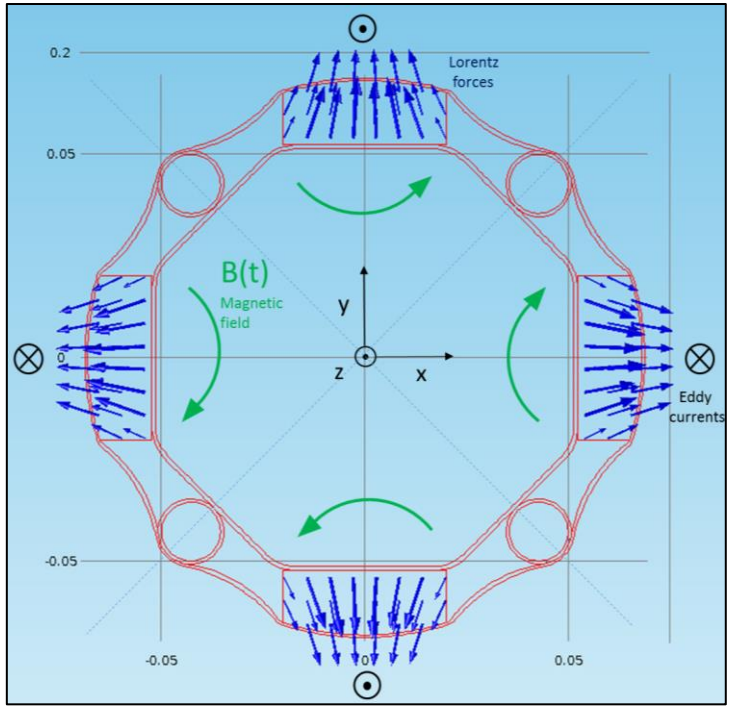
Ohm's law: $j_z = E_z/\rho$



3

Force distribution

Laplace's law: $f_v = j \wedge B$



Maxwell equations

rot E$=-\partial \mathbf{B}/\partial t$

B: magnetic field

E: electric field

j: current density

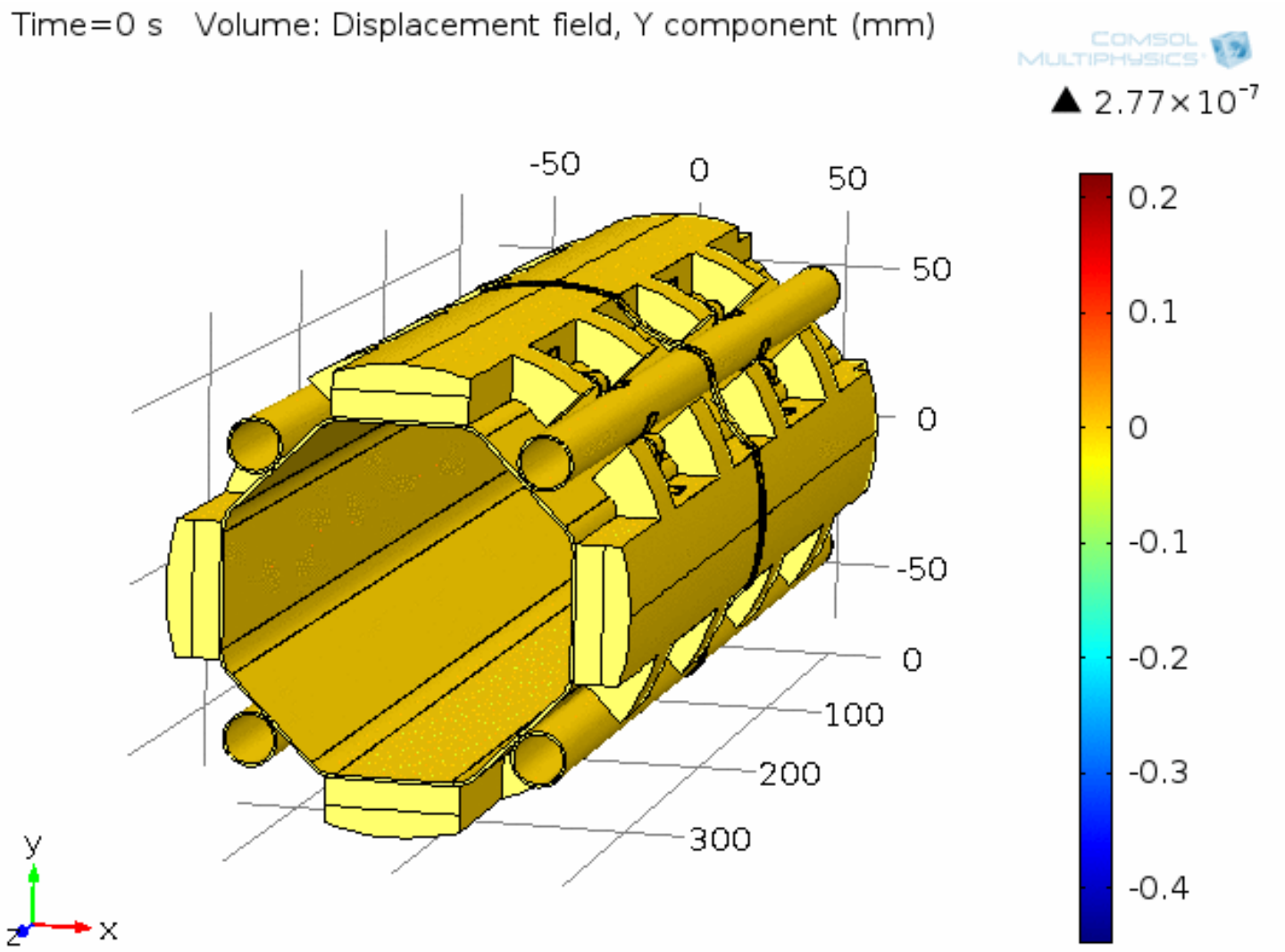
ρ: electrical resistivity

→ Electrical field: $\mathbf{E} = 1/2.G'.r^2.\cos(2\varphi).\mathbf{z}$

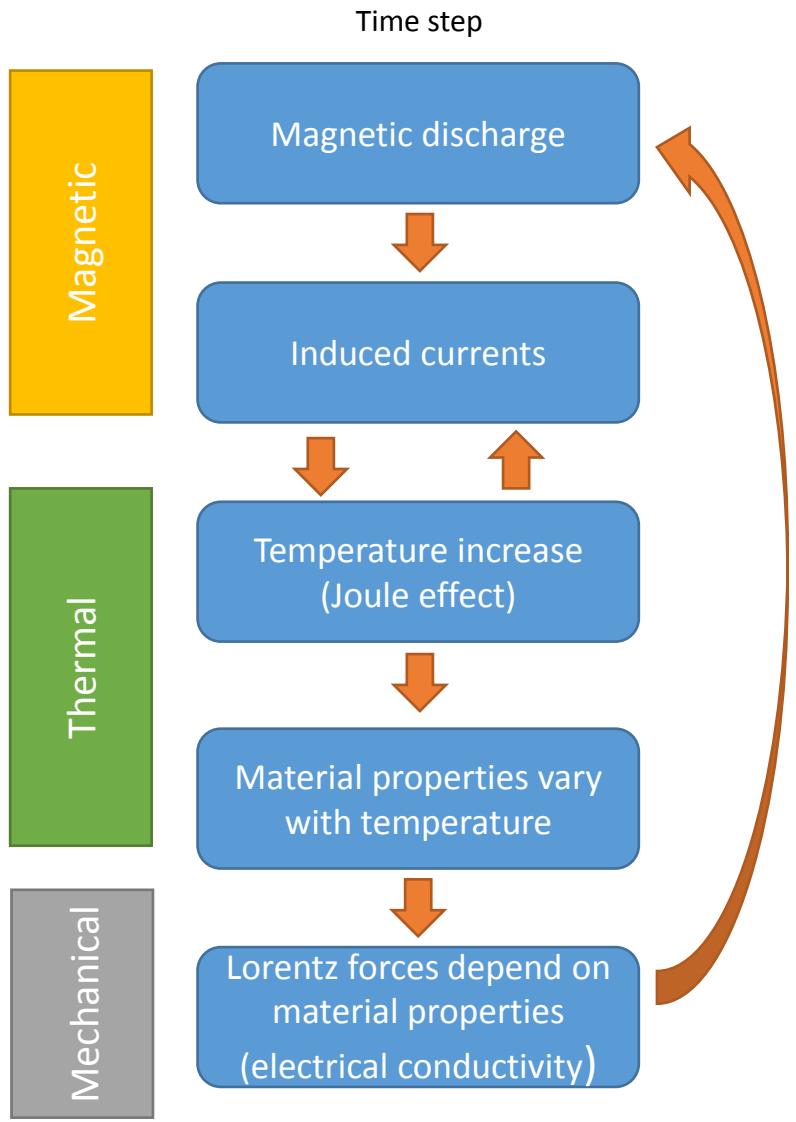
→ Current density: $j_z = 1/2.G'.r^2.\cos(2\varphi)/\rho$

→ Specific Laplace's force: $\mathbf{f} = 1/2.G.G'.r^3.\cos(2\varphi)/\rho.(\sin(2\varphi)\mathbf{e_\theta} - \cos(2\varphi)\mathbf{e_r})$

Mechanical design - structural study during quench

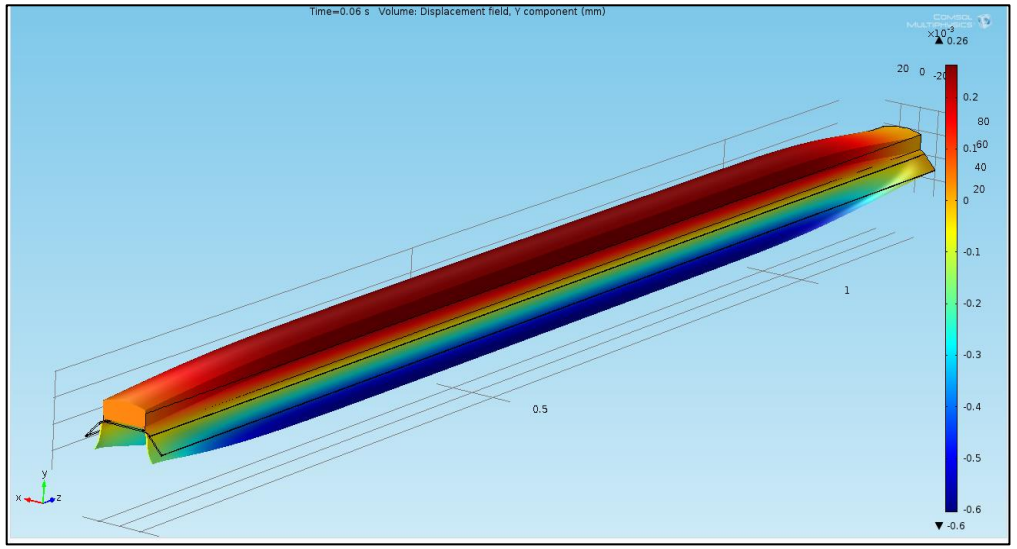


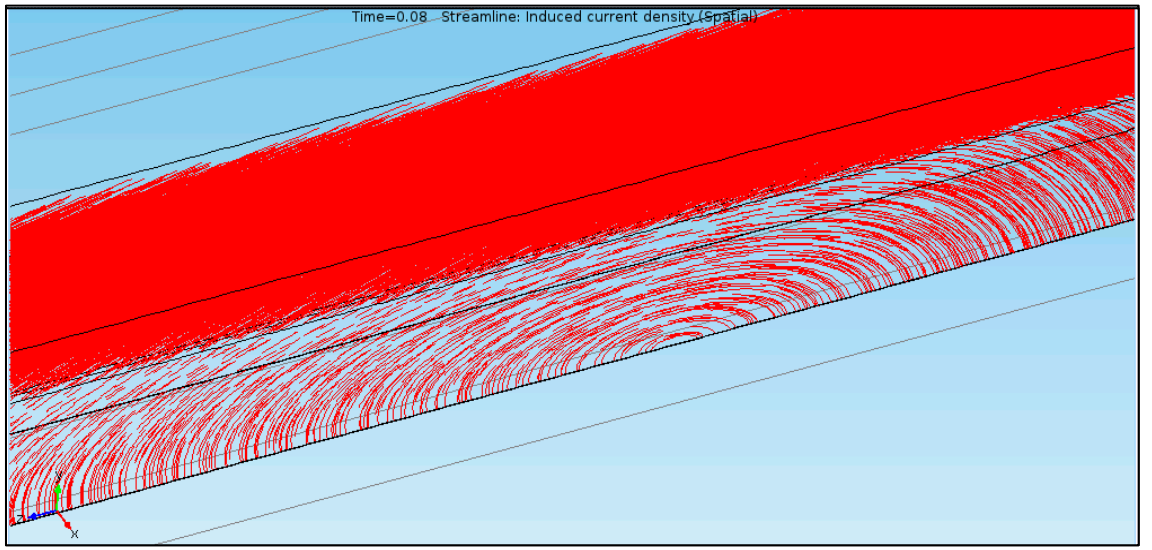
Multiphysics problem



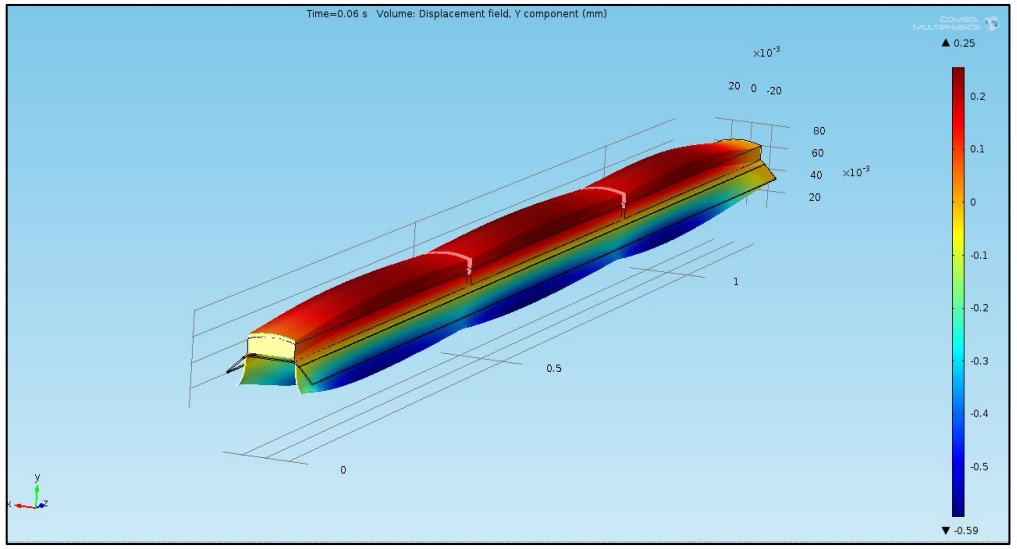
Mechanical - structural study during quench

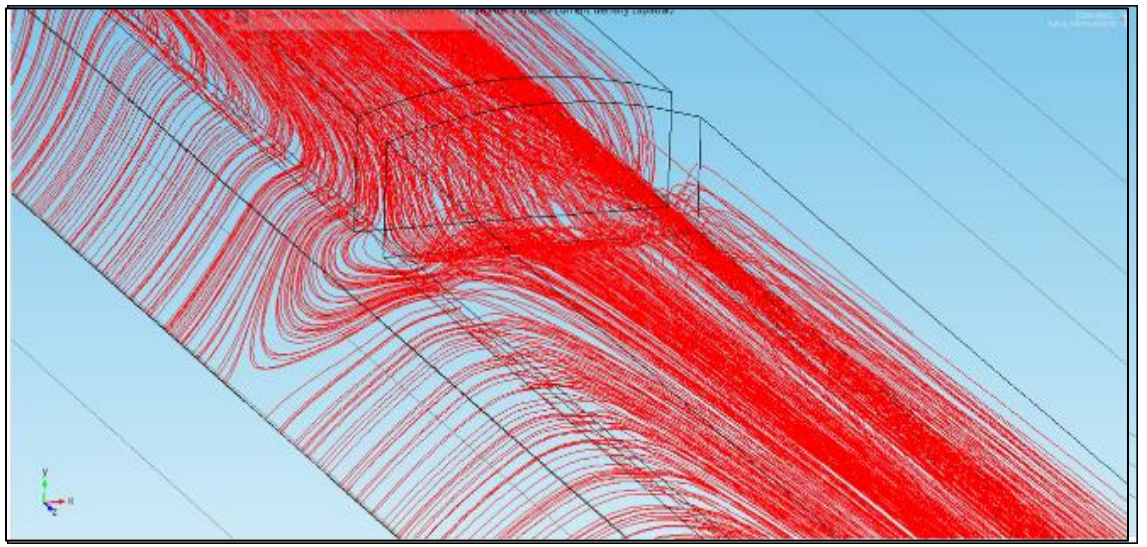
Fy = 2.79 · 10 ^{5} N @ 0.06 sec



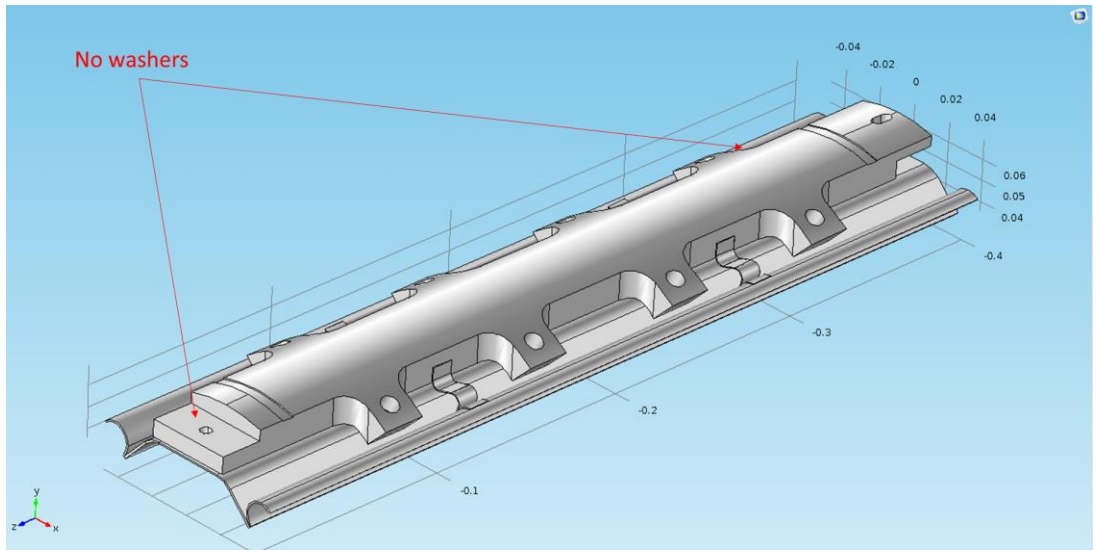


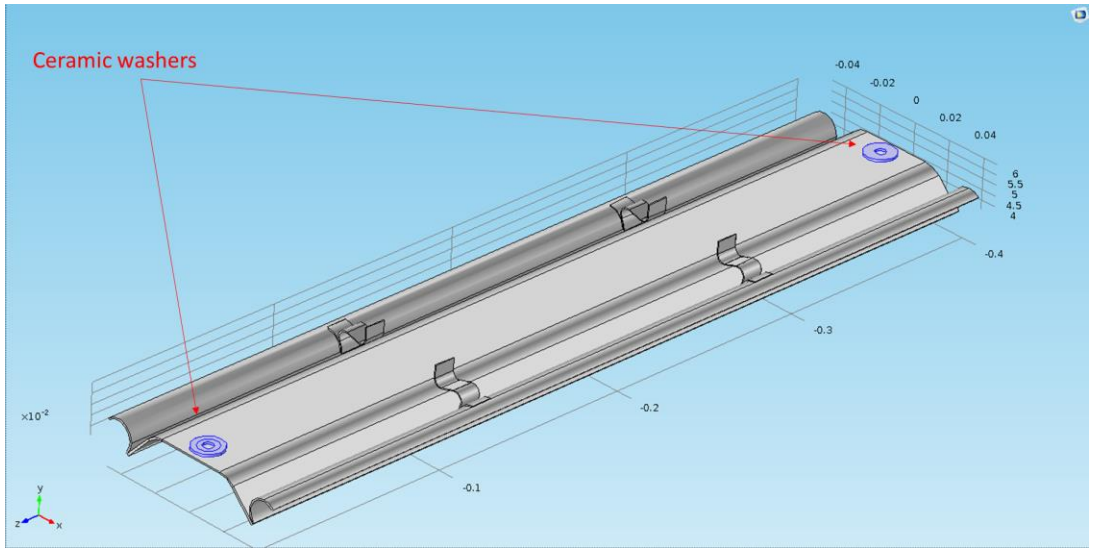
Fy = 2.42 · 10 ^{5} N @ 0.06 sec

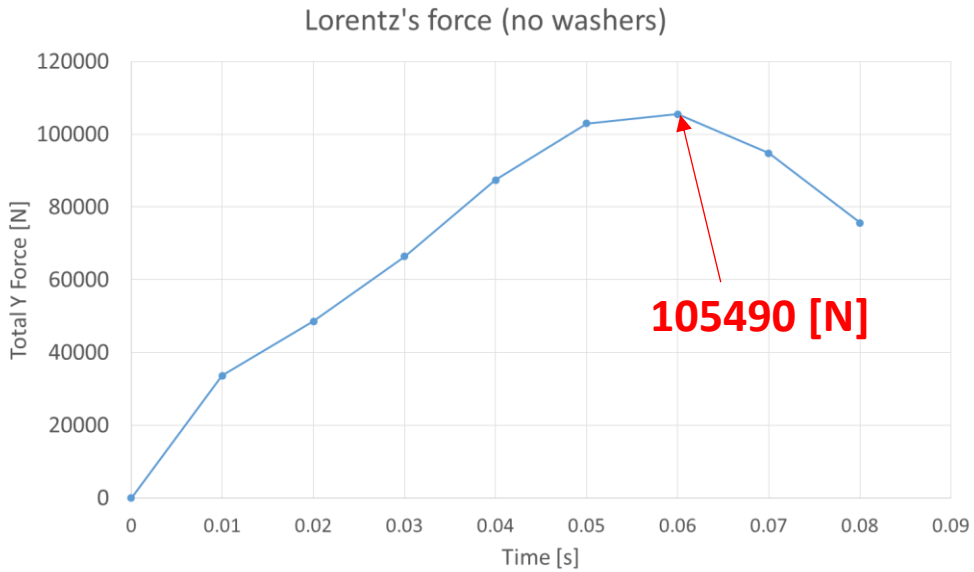


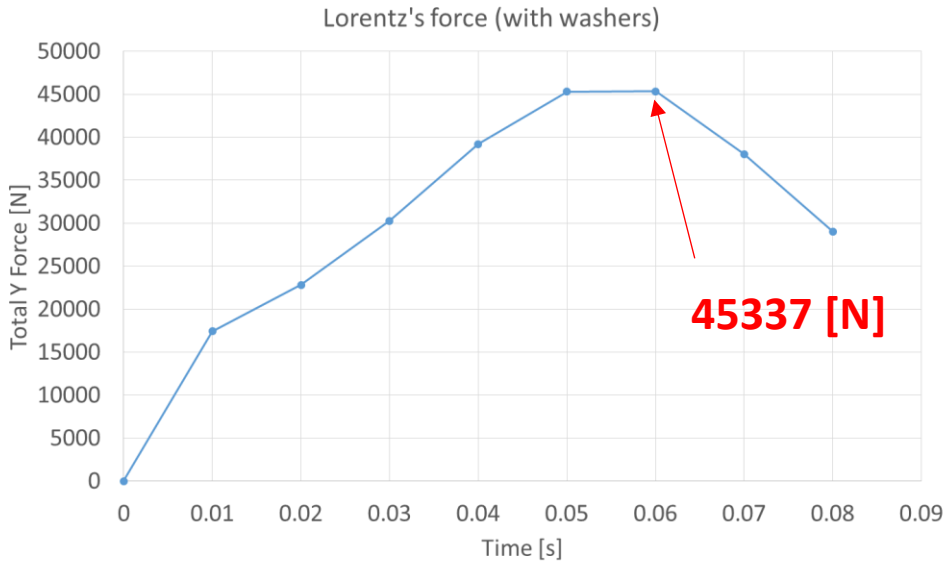


Mechanical - structural study during quench



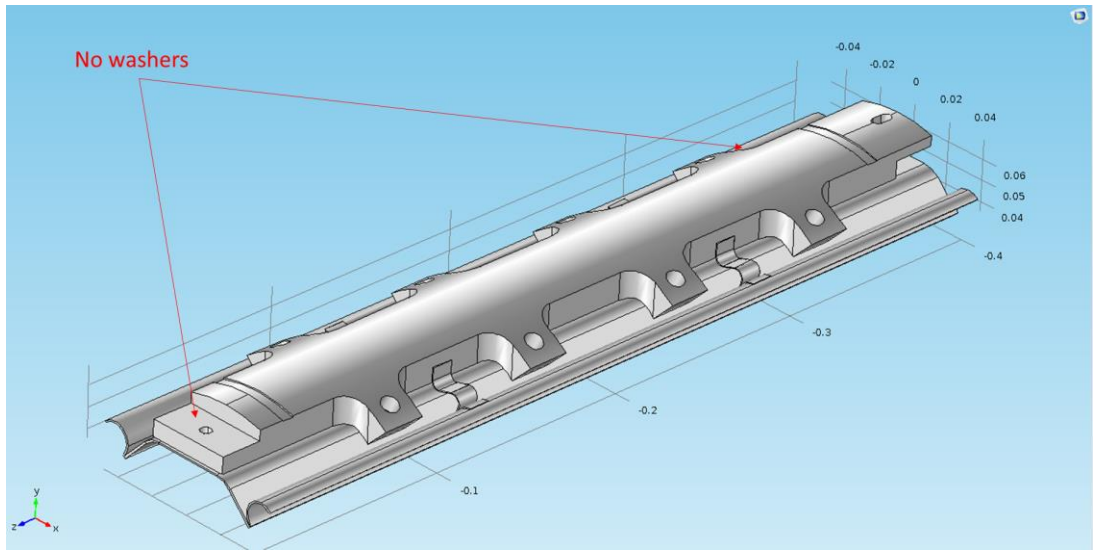


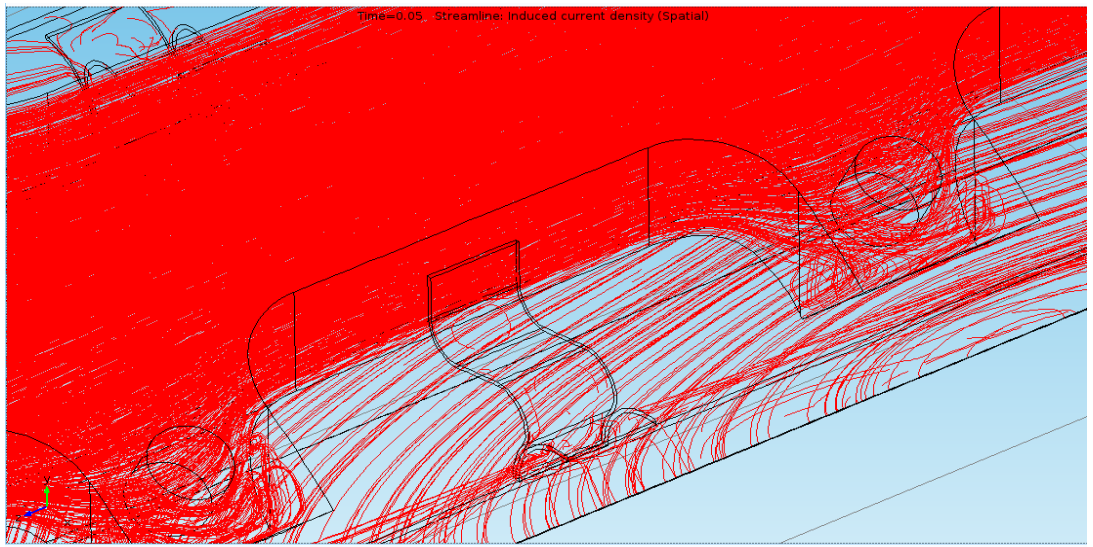


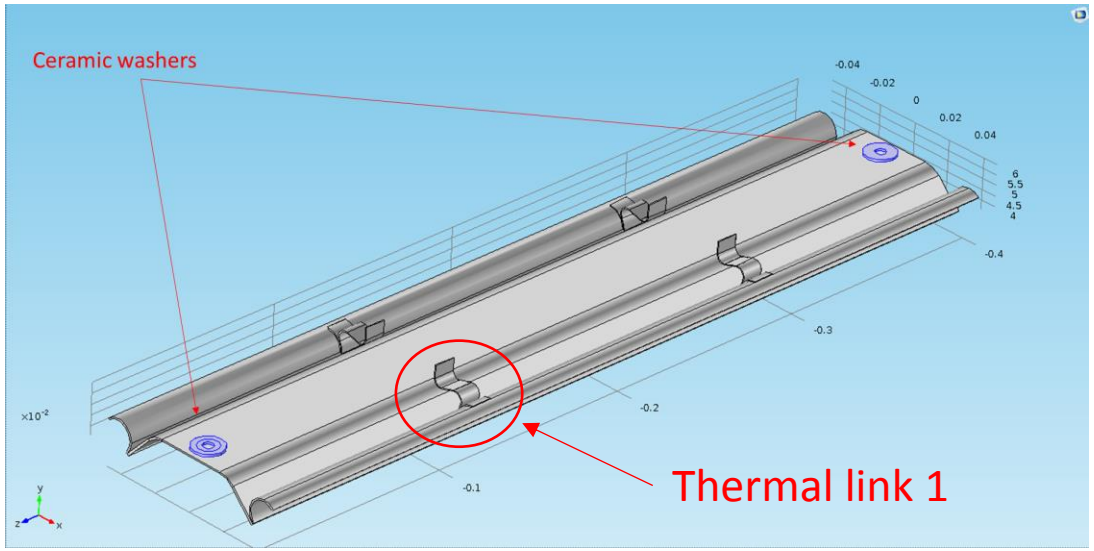


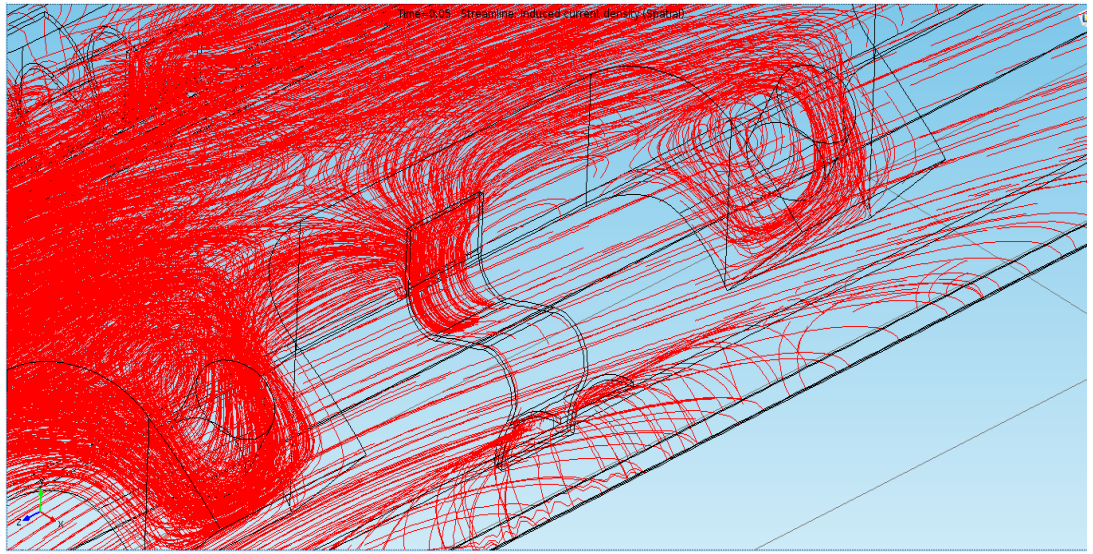
Mechanical - structural study during quench

T.L. S shape
COPPER MADE





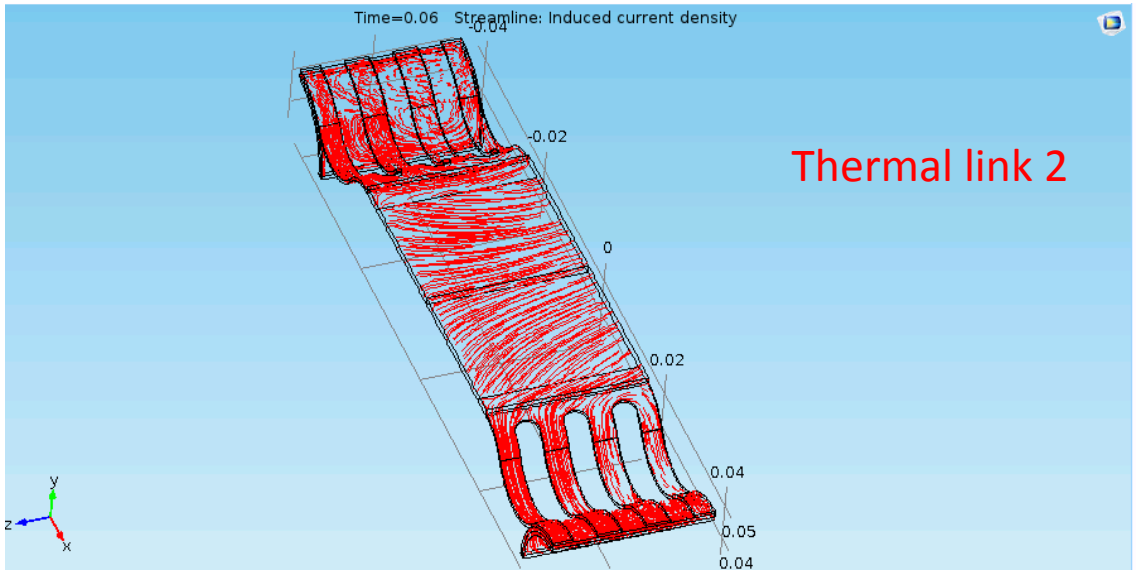


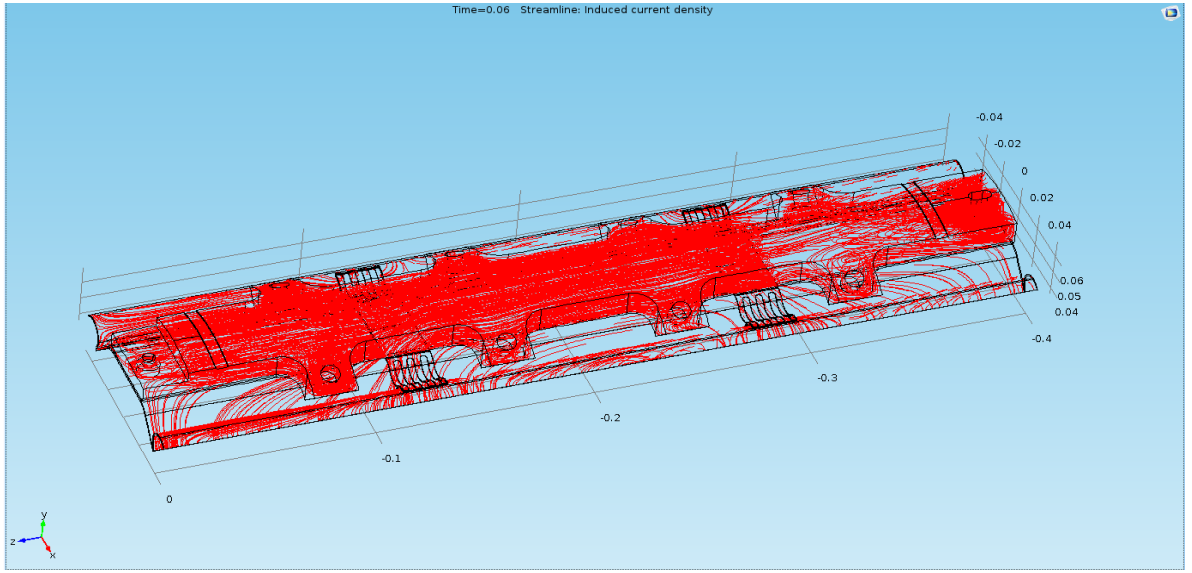


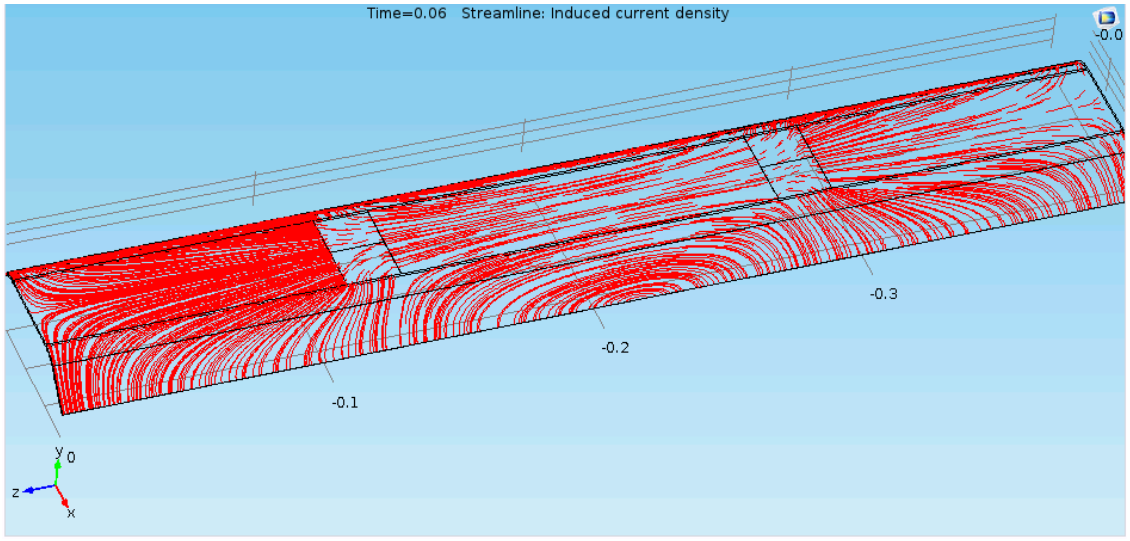
Mechanical - Thermal study during quench

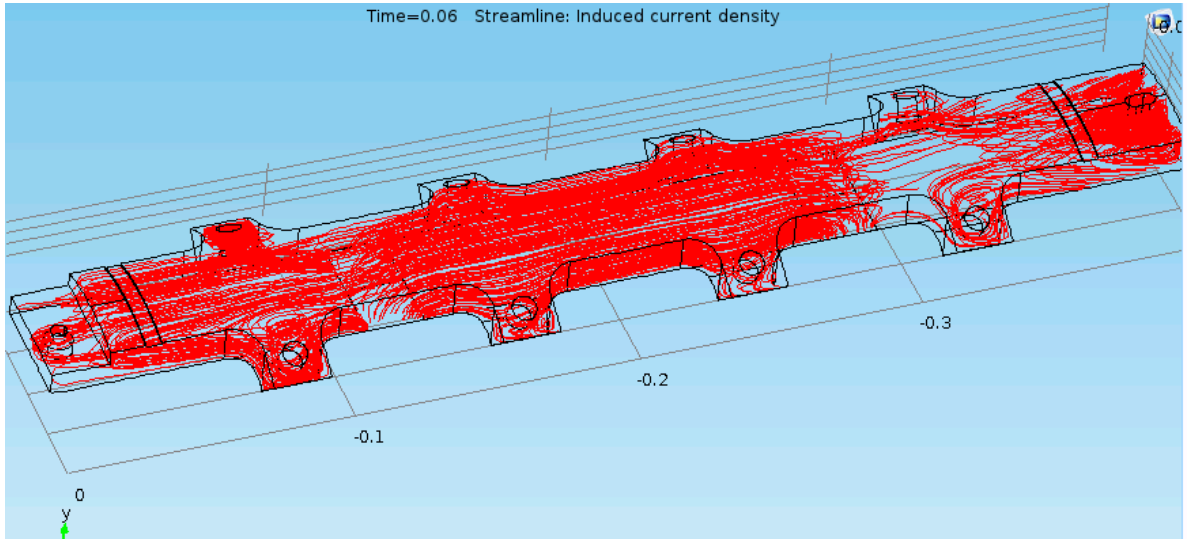
Thermal links

T.L. wing shape
COPPER MADE



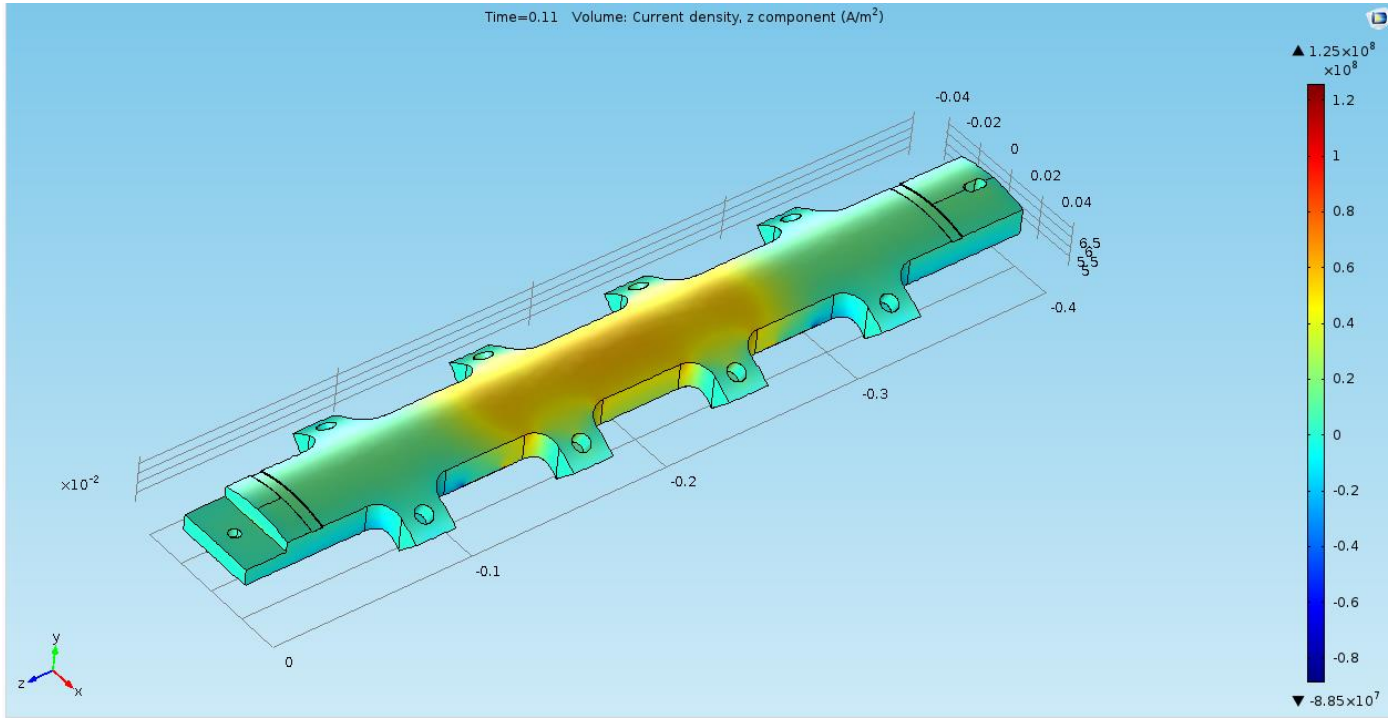


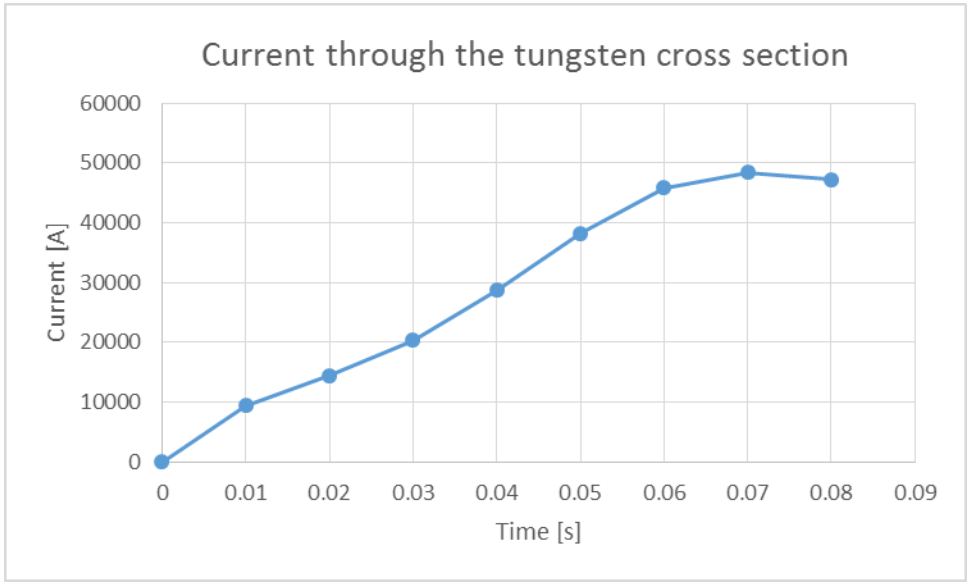




Thermal- Thermal study during quench

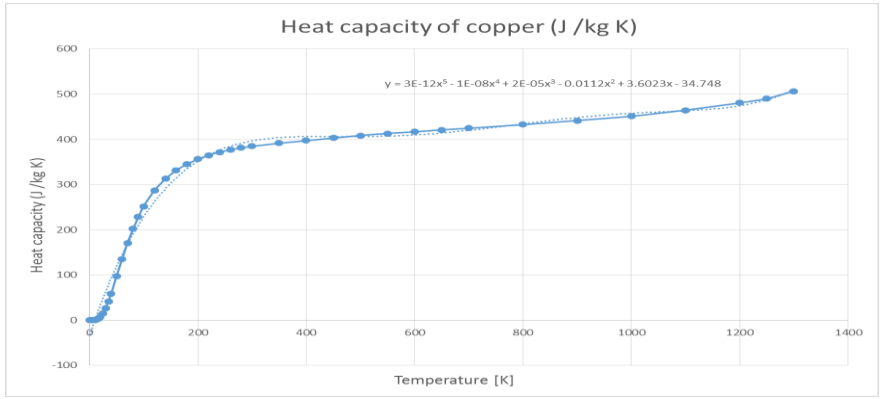
Current density [A/m^2]

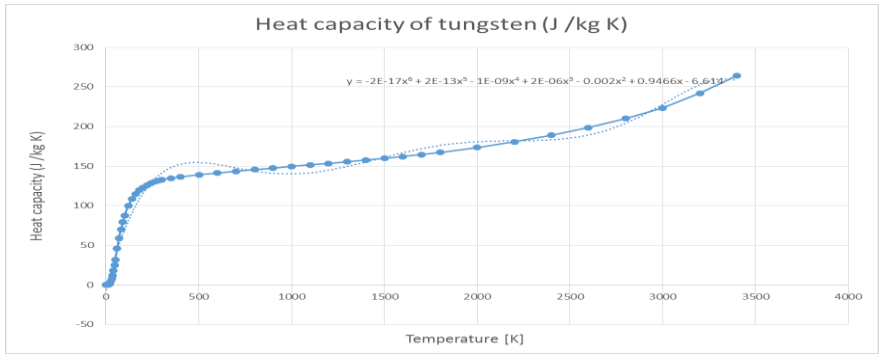


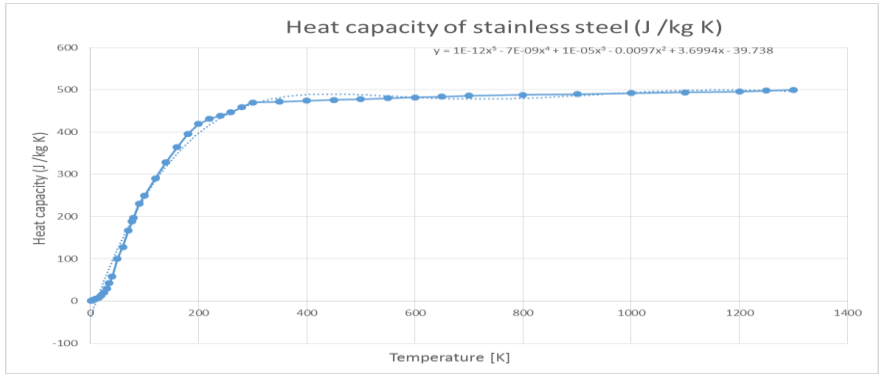


Thermal- Thermal study during quench

BS material heat capacity

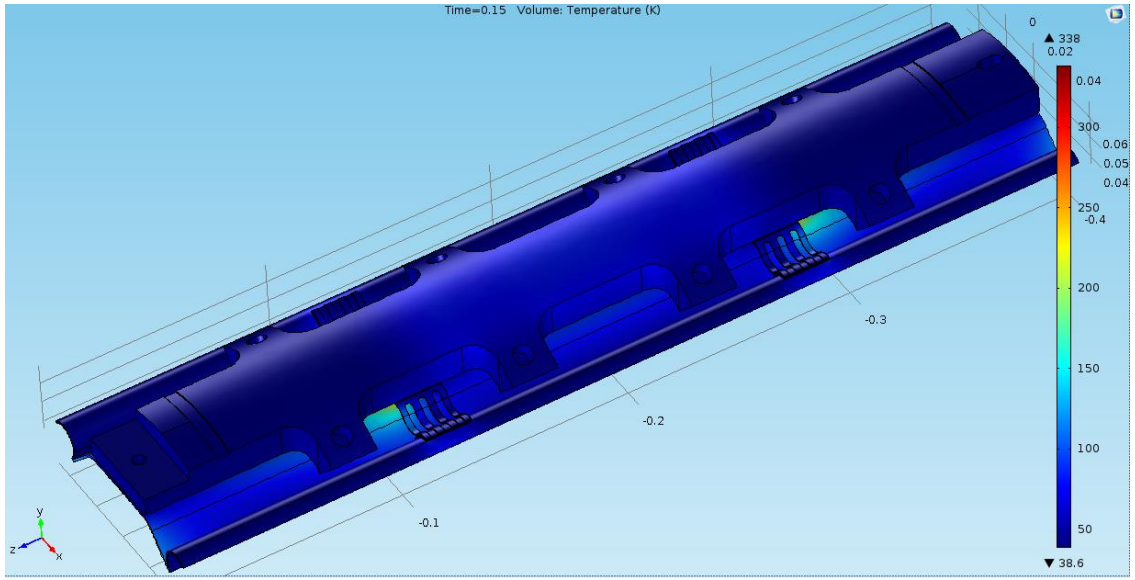




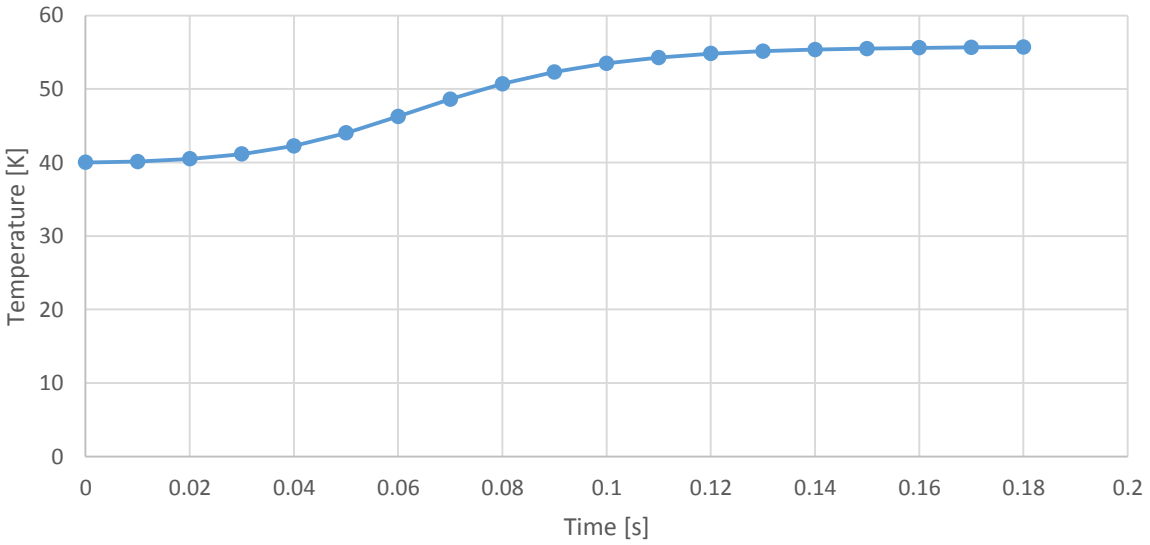


$$Q = mc\Delta T$$

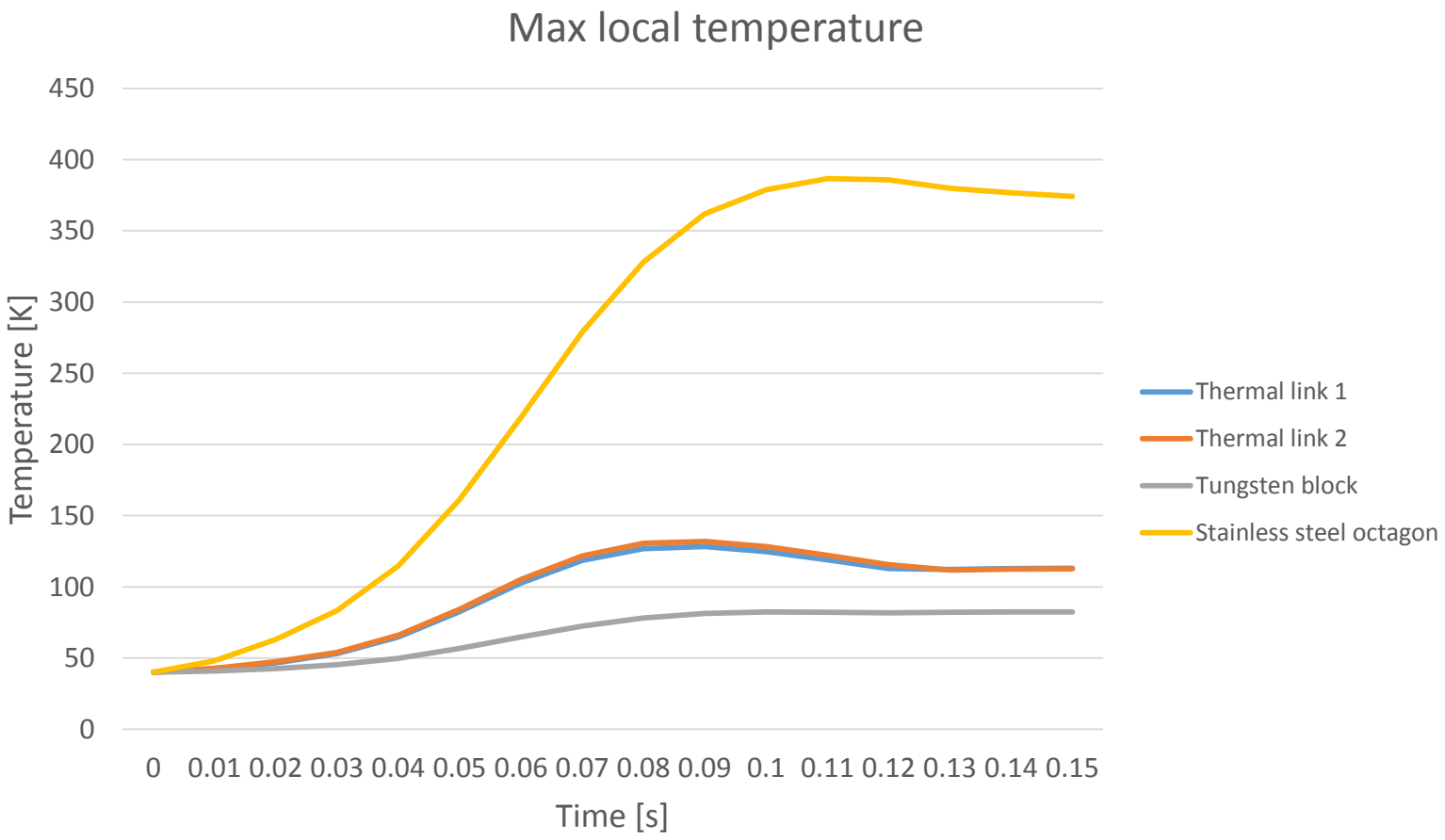
$$Q = RI^2$$

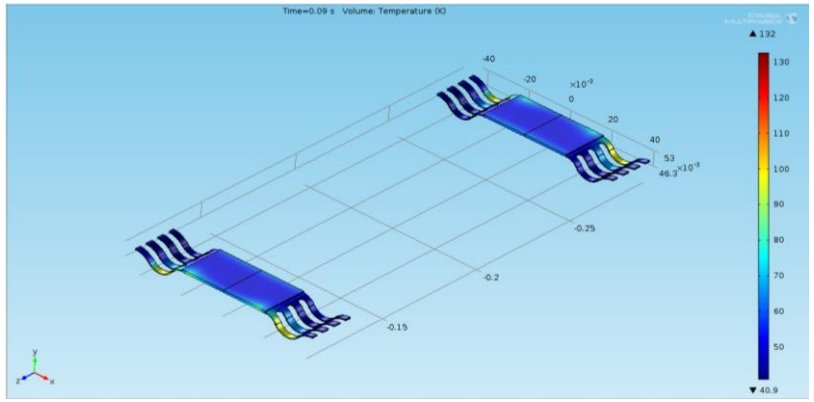


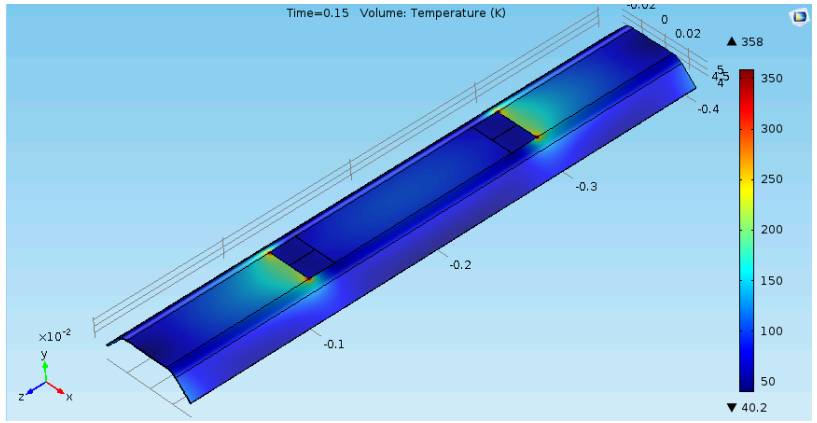
Average temperature increase due to the eddy currents on the HL beam screen

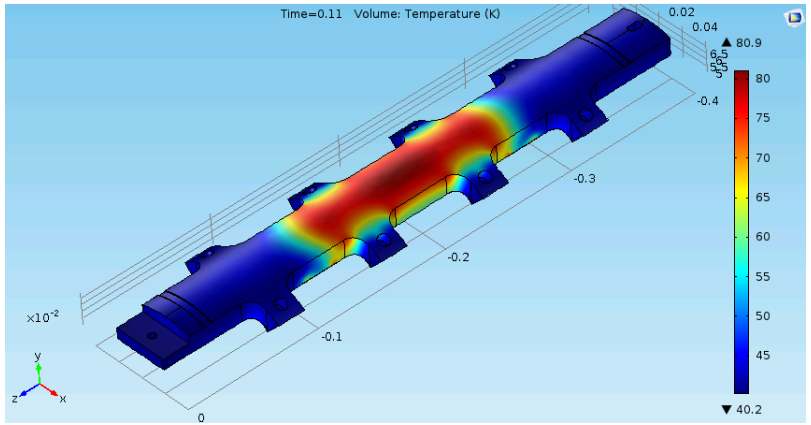


Thermal- Thermal study during quench



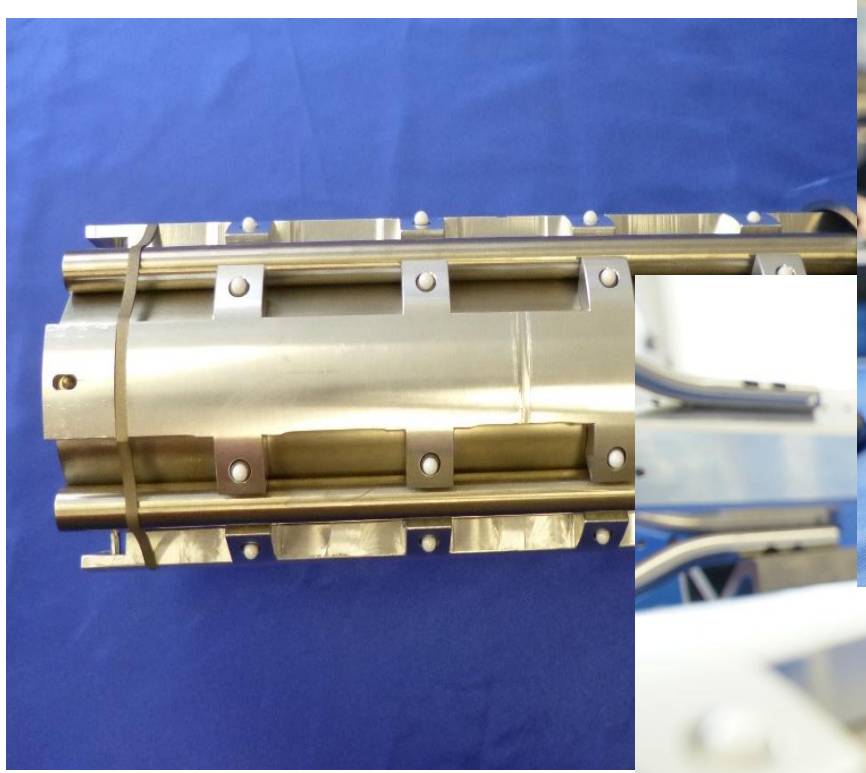


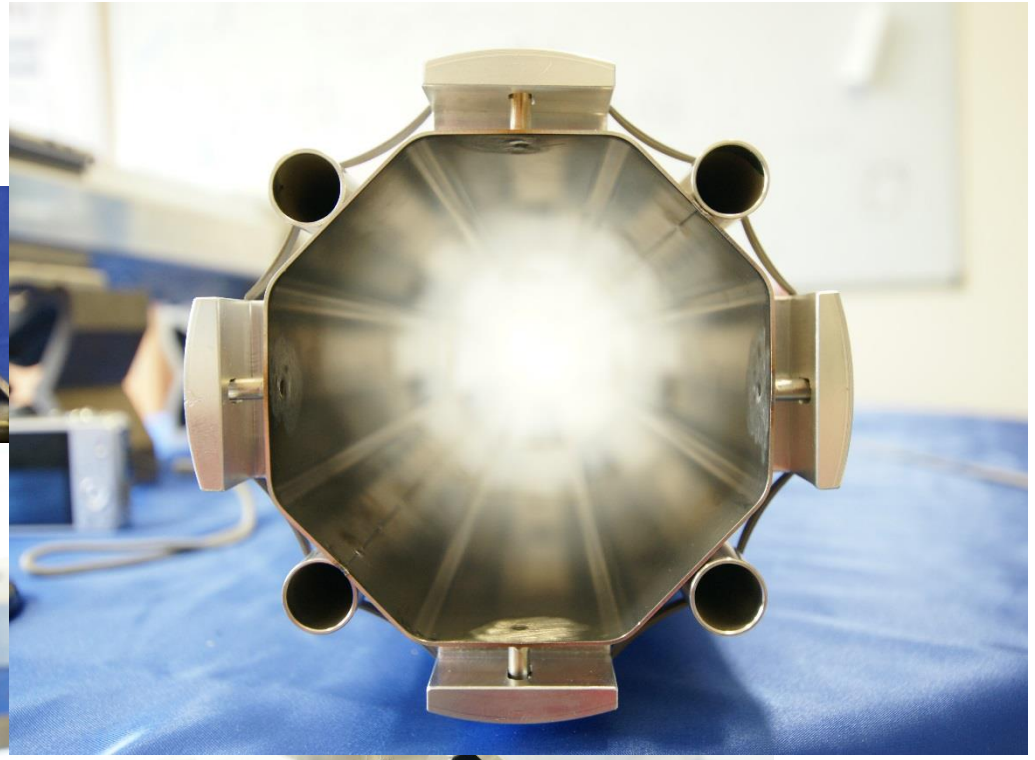


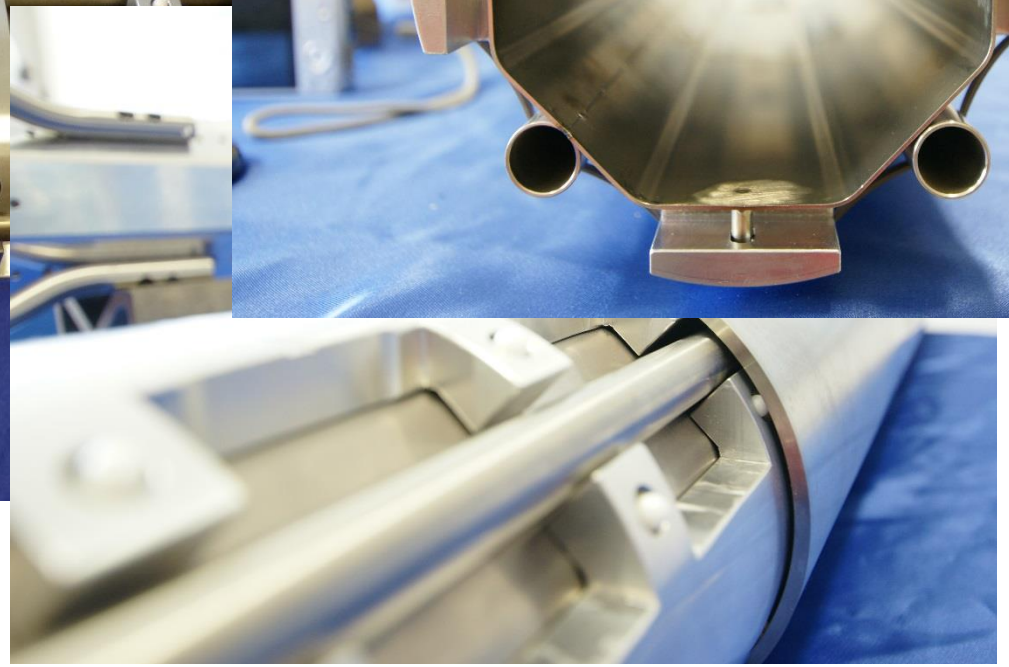


Prototyping and next steps

Assessing tolerances and mounting of the first BS prototype







Next steps

- Design optimisation
- Peeling test
- Experimental test for the heat transfer and magnet quench


Thanks for your attention !