
CERN

FCC-hh beam screen studies and cooling scenario

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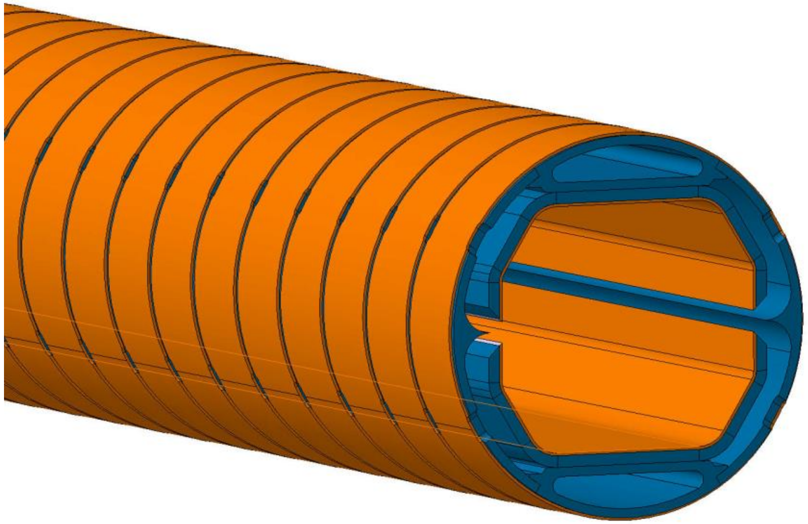
With material of C. Kotnig, L. Tavian and R. Kersevan

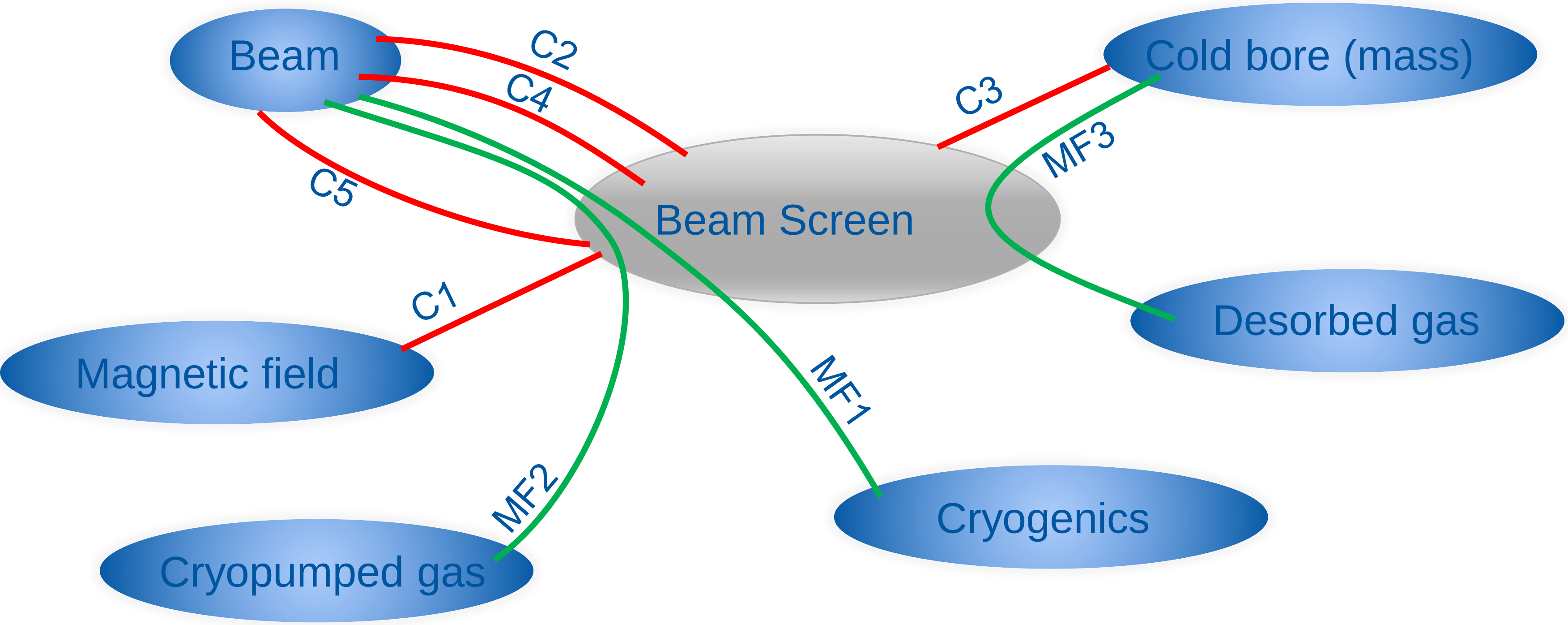


Cross section and 3D model of the beam screen

Outline

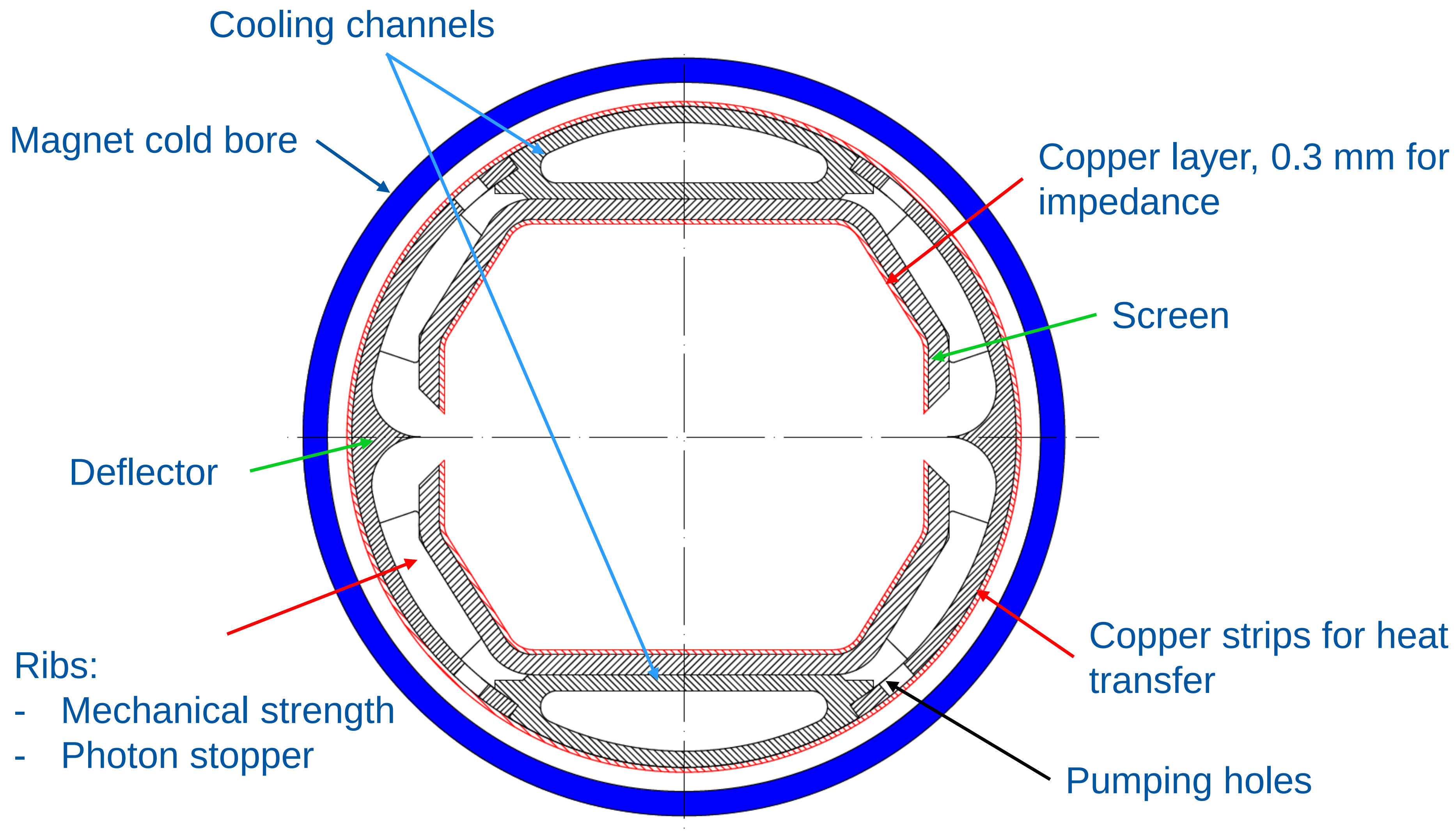
- Beam screen functions and concept
- Vacuum study
- Thermal study
  - Nominal heat transfer
  - Off-plane beam heat transfer
- Cooling of the beam screen
- Mechanical design
  - Internal pressure in cooling channel
  - Quench model & mechanical behaviour
  - Material properties
- Prototyping
- Summary

Beam Screen functions



MF1 : Intercept beam induced synchrotron power and transfer it to cryogenic cooling fluid
MF2 : Hide the cryopumped gas from beam induced photon impingement
MF3 : Provide sufficient pumping speed of desorbed gas toward the cold bore
C1: Withstand the Lorentz's forces during a quench
C2: Fulfil impedance requirements
C3: Minimise the heat loads to the cold bore
C4: Mitigate electron cloud
C5: Maximize the beam aperture

Beam screen concept


Cooling channels

Magnet cold bore

Copper layer, 0.3 mm for impedance

Screen

Deflector

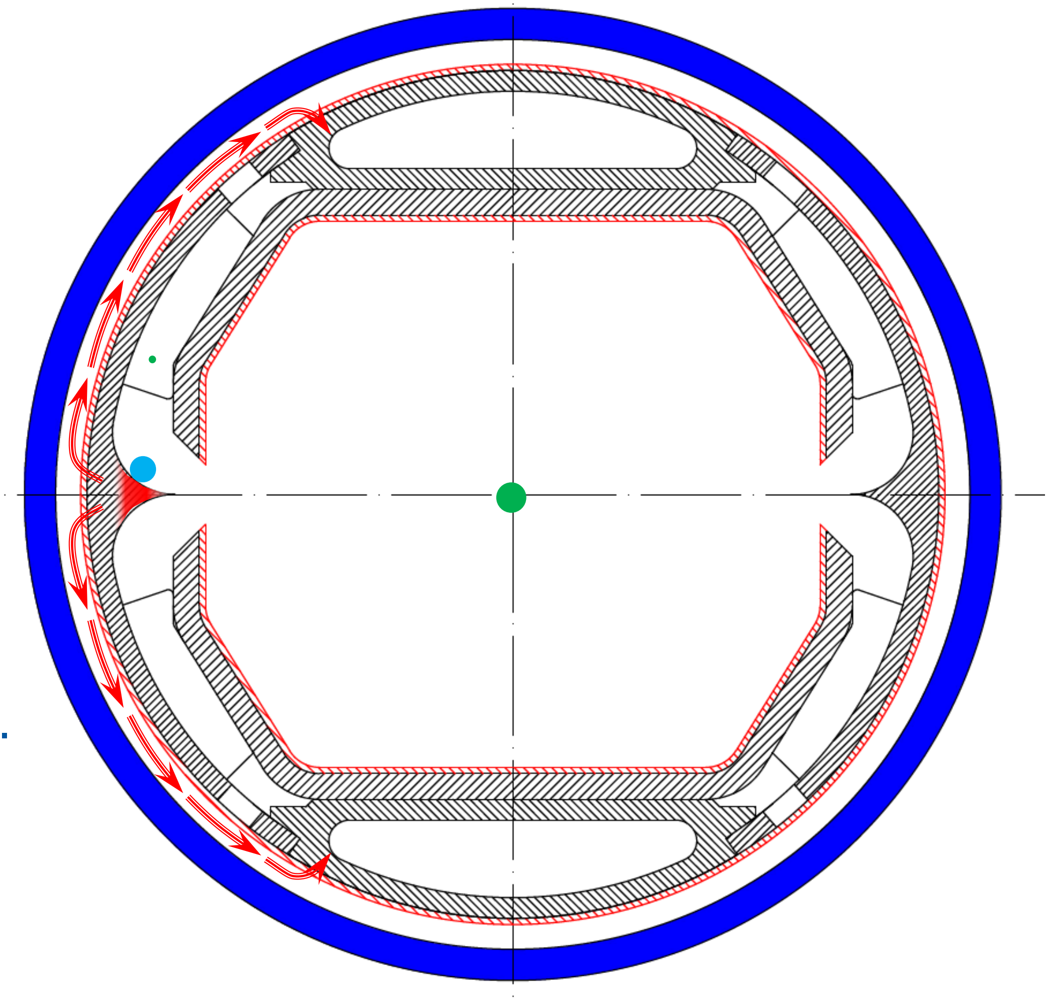
Copper strips for heat transfer

Ribs:
- Mechanical strength
- Photon stopper

Pumping holes

Beam screen concept - Principle

1. Photons are channelled in the antechamber and stopped onto the ribs.
2. Photondesorpted gas is channelled in the antechamber and pumped through pumping holes.
3. Synchrotron radiation power is deposited mainly on the deflector tip and is transferred to the cooling circuit by the external copper.



Design – Main dimensions

Cold bore diameter: 44/47 mm

Beam screen wall:

- 1.25 mm P506 (high-Mn high-N st. steel)
- 0.3 mm copper

Nominal aperture:

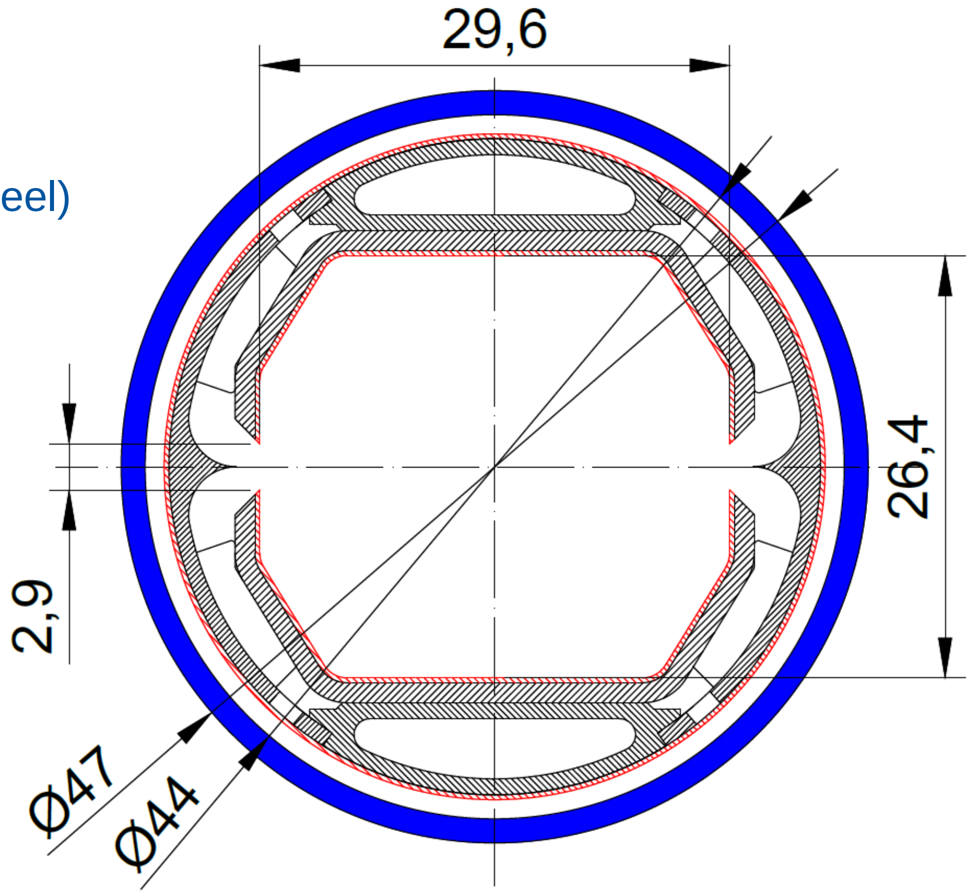
- H:~ 29.6 mm
- V:~26.4 mm

Slit height: ~ 2.9 mm

Cooling channel:

- Thickness 1 mm
- Internal 53.58 mm^2
- Hydraulic diameter: 5.61 mm

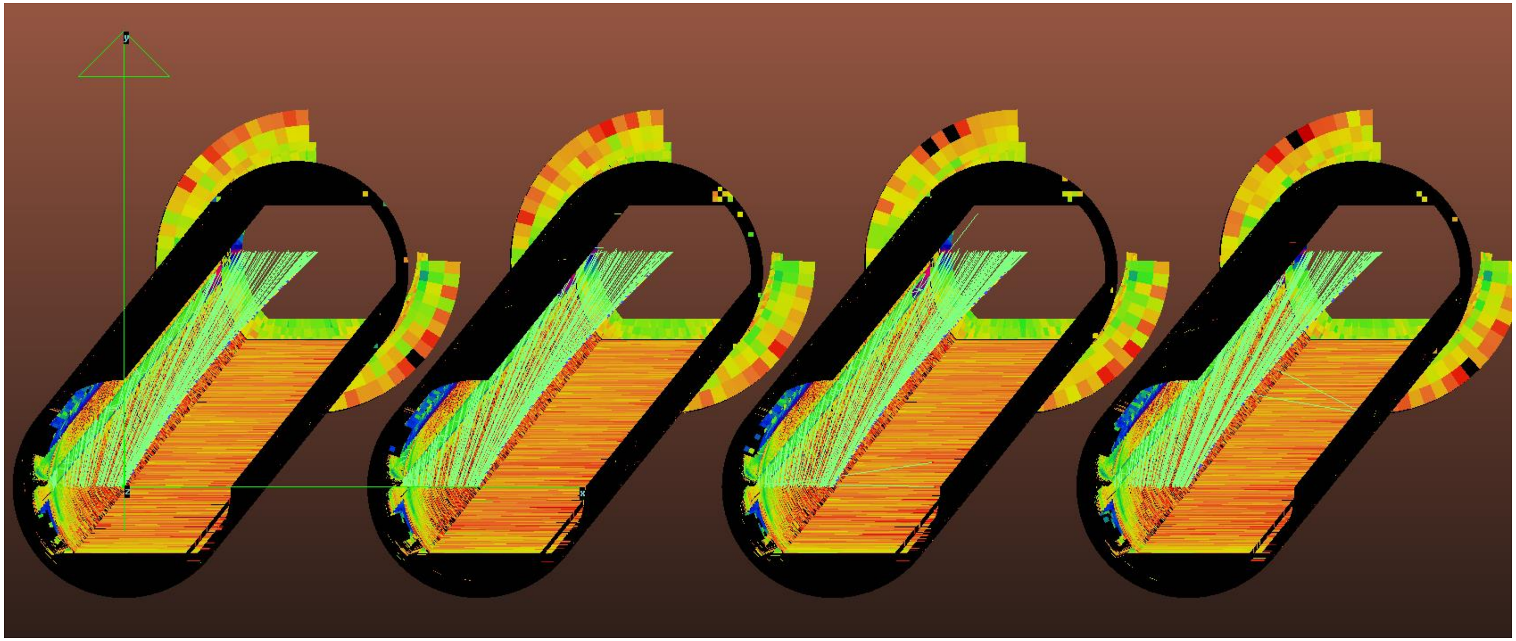
Copper for heat transfer: 0.3 mm



Vacuum performance

Vacuum is driven by photodesorption. The vacuum simulations are done in two steps:

1. Simulation of the flux and power distribution of the synchrotron light (Synrad)

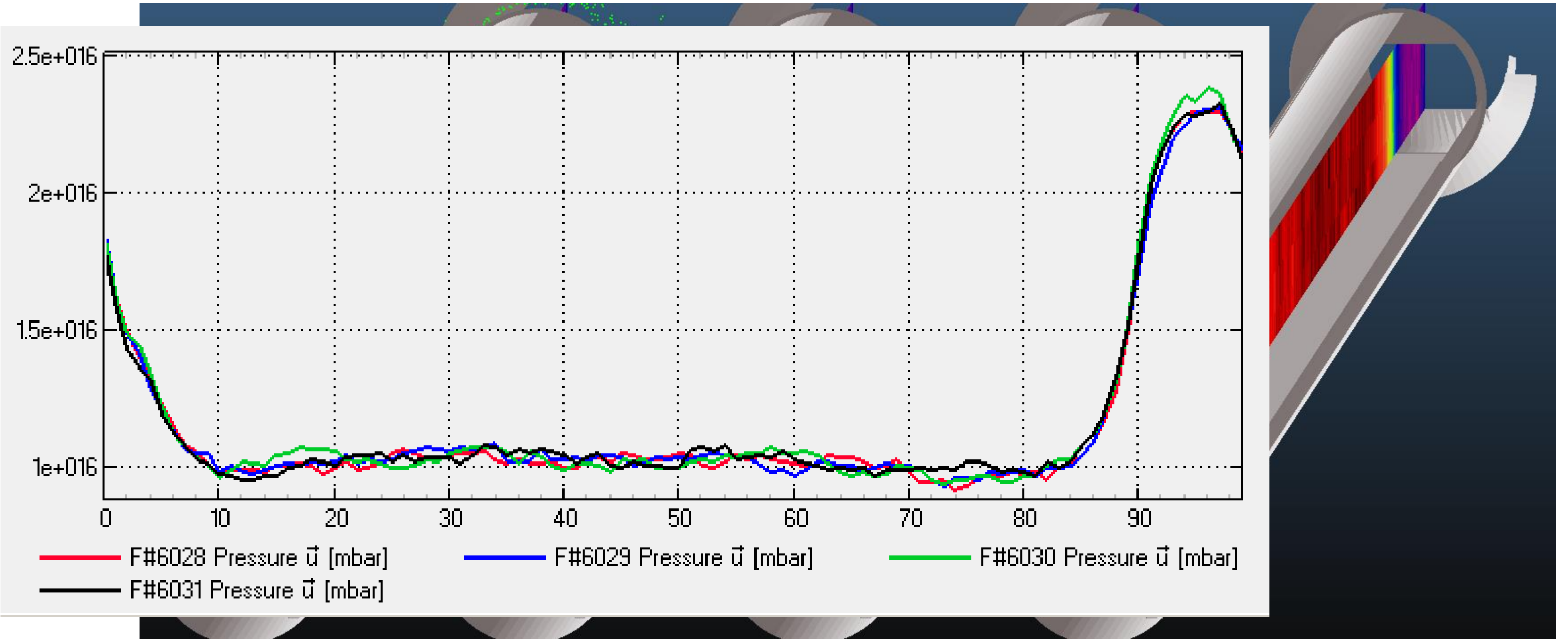


Synchrotron radiation (SR) ray-tracing model, showing 4x 14.3 m-long dipoles followed by a 1.65 m-long drift section (for interconnect, BPM block, etc..) on a bigger diameter, to minimize SR flux on it. The angle of incidence, photon energy, and surface roughness are taken into account during ray tracing.

Vacuum performance

Vacuum is driven by photodesorption. The vacuum simulations are done in two steps:

1. Simulation of the flux and power distribution of the synchrotron light (Synrad)
2. Simulation of the photon stimulated desorption and gas density (Molflow+)



Molflow+ calculation of the H_2 density profiles derived from the previous ray-tracing; The plot shows the 4 density profiles along each section after an integrated photon dose equivalent to 1h of beam at 50 TeV and 500 mA; The specification is $< 2 \cdot 10^{14}$ H_2/m^3; The density bumps correspond to the drift sections, where no BS with pumping slots has been assumed; **Cold bore temperature is 1.9 K** (60 K for the beam screen);

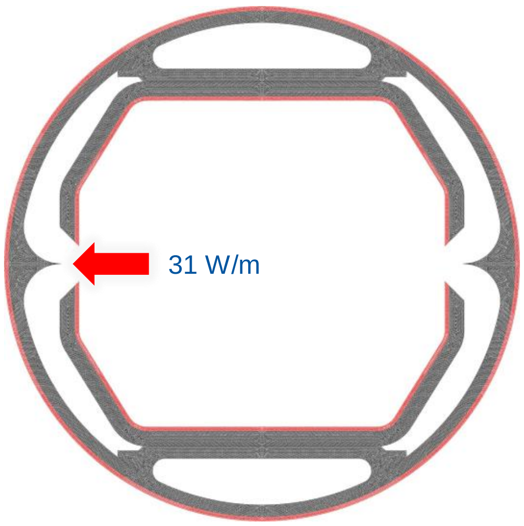
[R. Kersevan, I. Aichinger, Thursday AM]

Thermal analysis

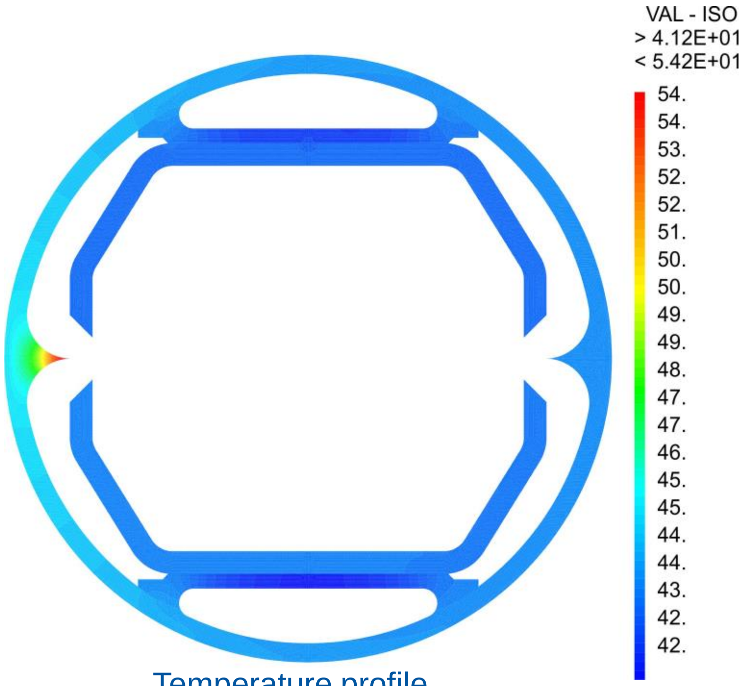
Nominal behavior

Model:

- 2D massive model
- Heat deposition of 31 W/m centrered w.r.t. beam screen
- Heat deposition field based on SynRad simulation
- Thermal conductivity of copper estimated at 50 K and under 16T ~ 700 W.m^{-1}.K^{-1} (need to be measured)
- Thermal conductivity of stainless steel at 50 K ~ 6 W.m^{-1}.K^{-1}
- Convection coefficient of 150 W.K^{-1}.m^{-2}



Model



Temperature profile

Local temperature increase (reflector tip)

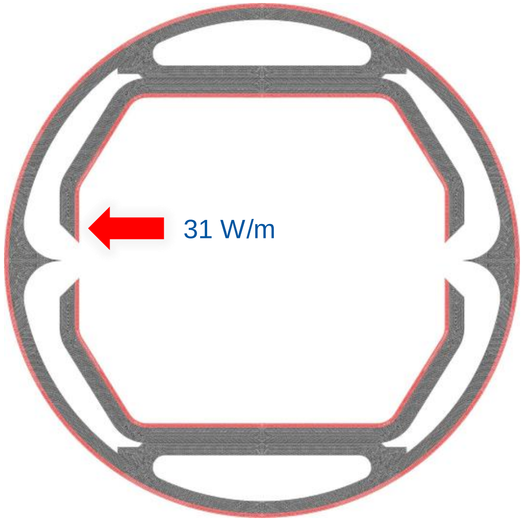
Screen temperature a few K (<3K) higher than the helium temperature

Thermal analysis

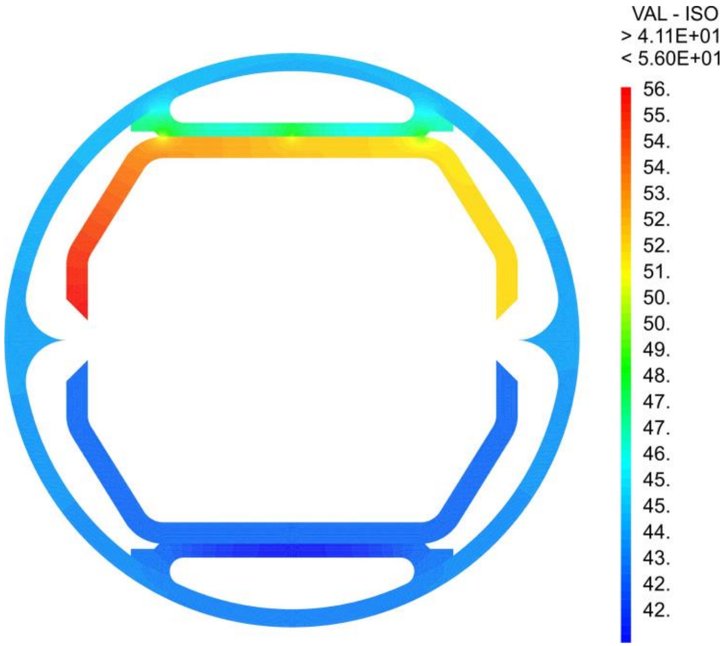
Off-plane beam behavior

Model:

- 2D massive model
- Heat deposition of 31 W/m on one beam screen edge
- Thermal conductivity of copper estimated at 50 K and under 16T ~ 700 W.m^{-1}.K^{-1} (need to be measured)
- Thermal conductivity of stainless steel at 50 K ~ 6 W.m^{-1}.K^{-1}
- Convection coefficient of 150 W.K^{-1}.m^{-2}

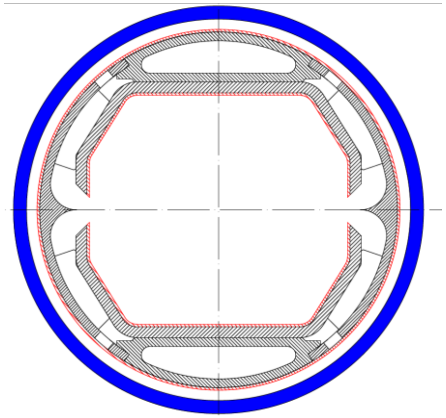


Model



Temperature profile

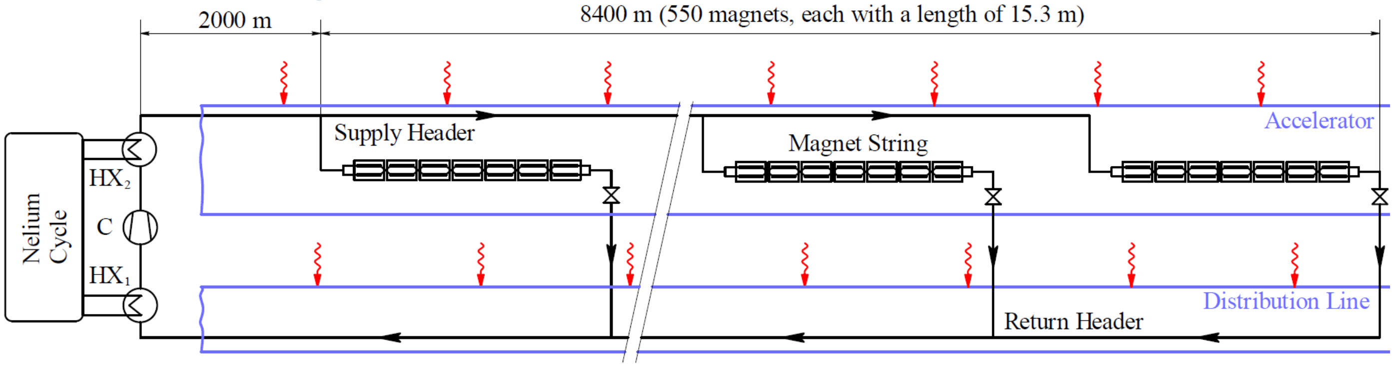
Cooling of the beam screen



Hydraulic parameters:

$A_{\text{cooling tube}}$: 53.7 mm^2
A_{tot}: 107 mm^2
D_{hyd}: 5.6 mm

FCC cryogenic flow scheme for the beam screen circuit:



1. Control Valves → valves, but minimize necessary amount
2. Flow direction → counter flow scheme
3. Assembly scheme → assembly scheme HX1 - C – HX2 – MS - V
4. Supply pressure → supply pressure 50 bar

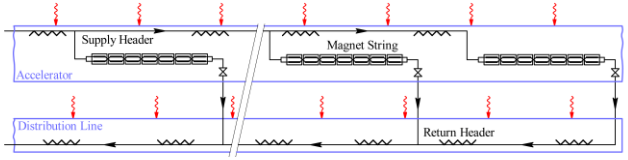
[C. Kotnig, L. Tavian, poster 145]

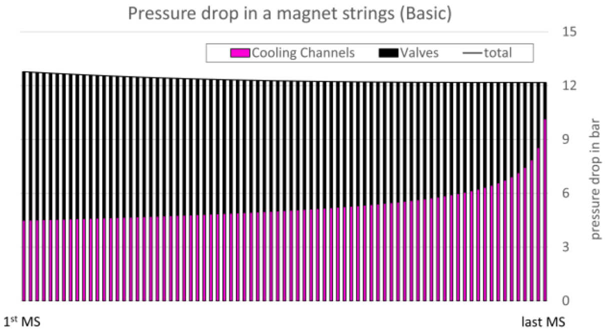
Cooling of the beam screen

Different scenarios and corresponding pressure losses in magnet strings (7 magnets)

Basic:

Supply header used to cool the thermal screen

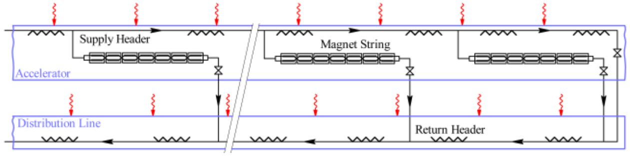


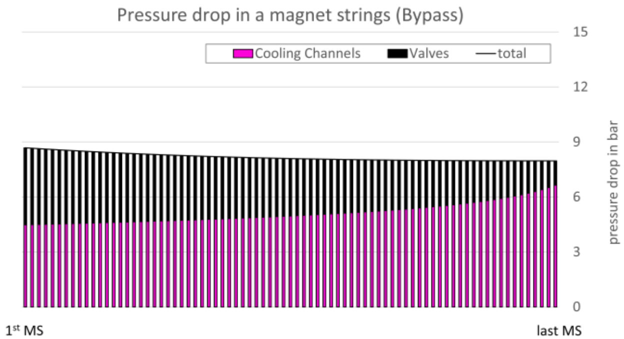


$\Delta p_0 \approx 13$ bar

Bypass:

- Supply header used to cool the thermal screen
- Bypass valve at the extremity

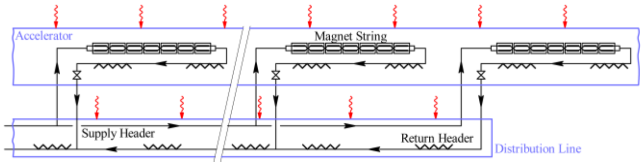


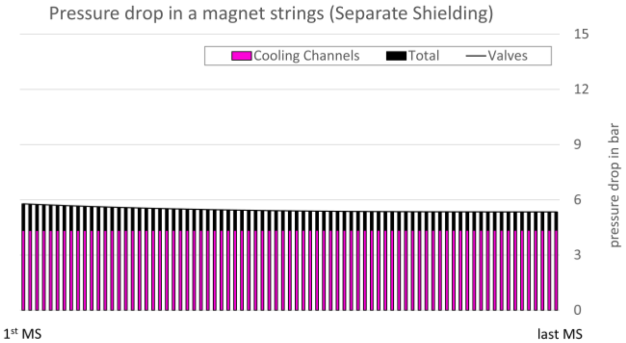


$\Delta p_0 \approx 9$ bar

RH-Shield:

Return header used to cool the thermal screen





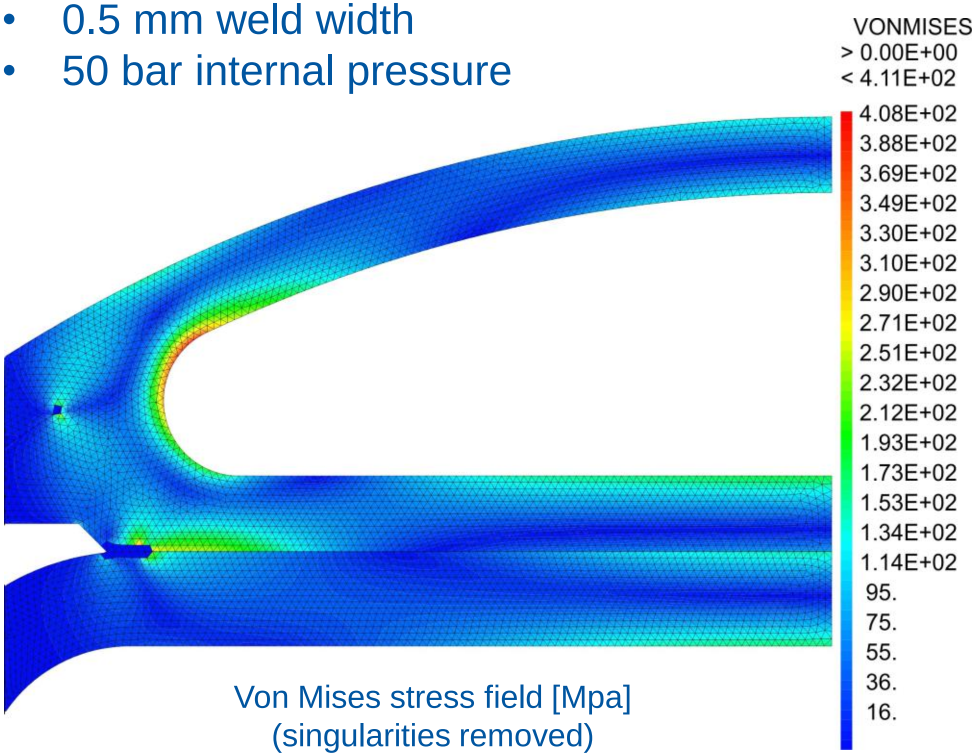
$\Delta p_0 \approx 6$ bar

The separate shielding scheme is the preferable choice to minimize the pressure drop and therefore the necessary power consumption for cooling magnet strings of reasonable lengths.

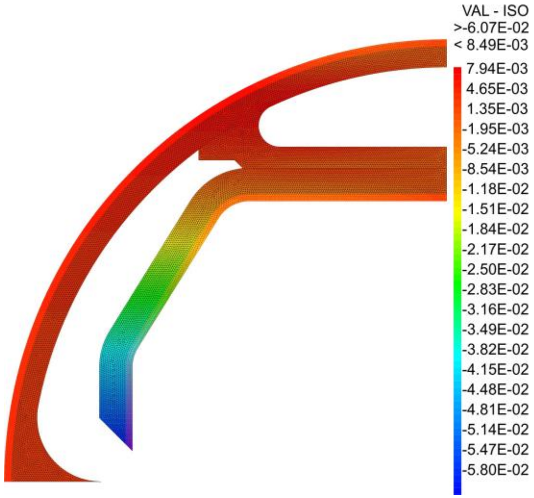
Mechanical analysis

Internal pressure in the cooling channels

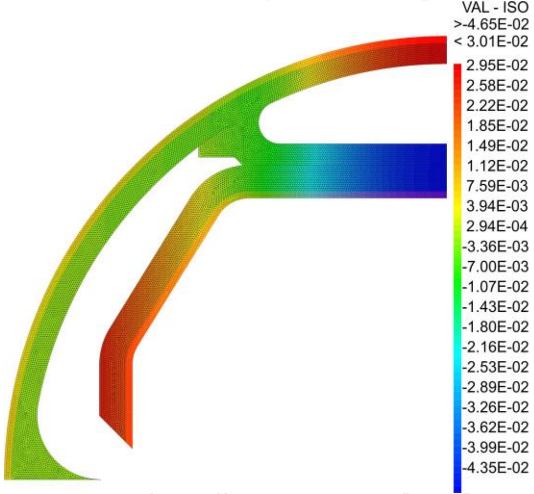
- Cooling channel thickness: 1 mm
- 0.5 mm weld width
- 50 bar internal pressure



Von Mises stress field [Mpa]
(singularities removed)



Horizontal displacement [mm]



Vertical displacement [mm]

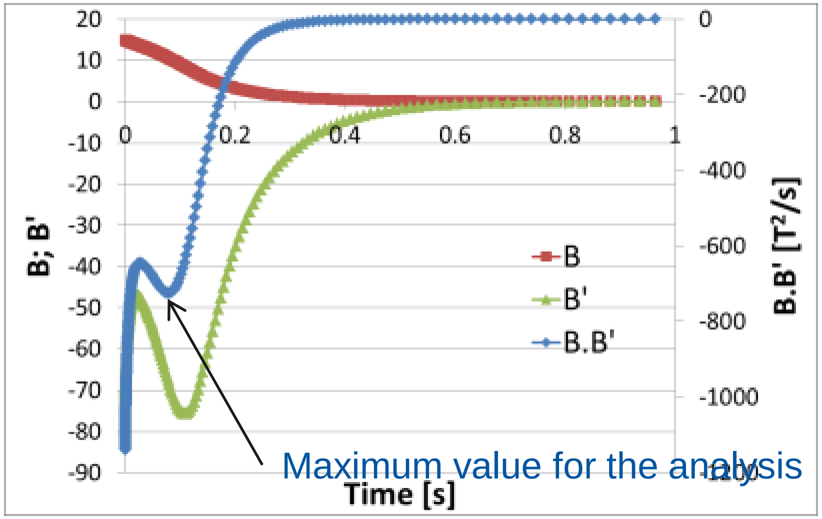
→ OK for nominal operation.
→ Pressure test to be checked.

Mechanical analysis

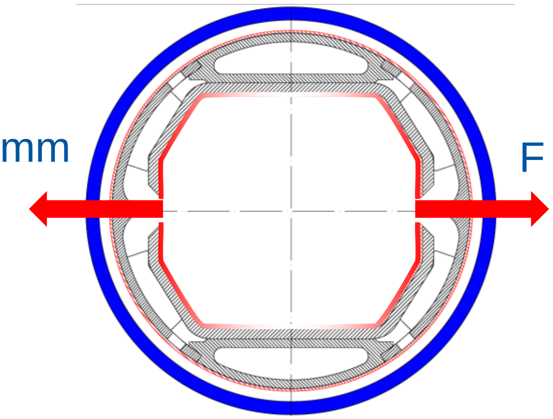
Magnet quench

Model:

- Quarter of beam screen, solid elements
- Electrical conductivity of copper estimated at 50 K and under 16T
- Heat dissipation by Joule effect taken into account
- Eddy currents in the reflector
- Static analysis
- Lorentz force driven by the parameter B.B’ ~ -725 $T^2.s^{-1}$



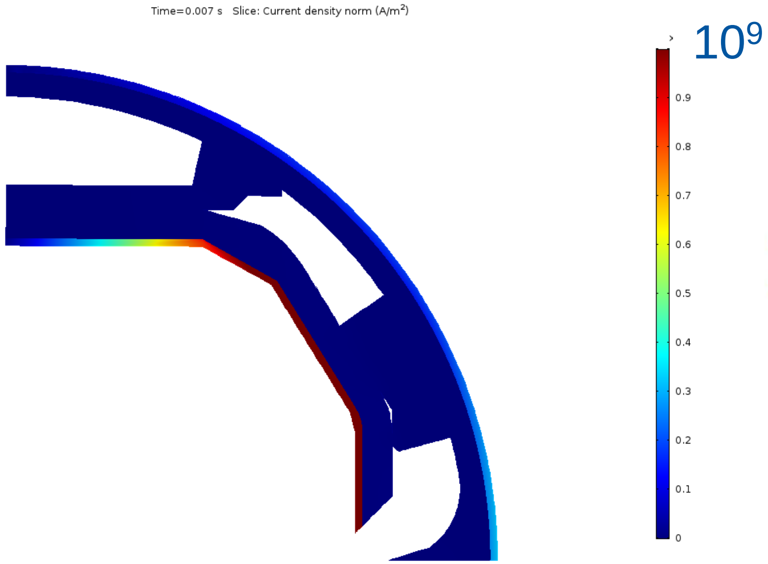
Maximum value for the analysis



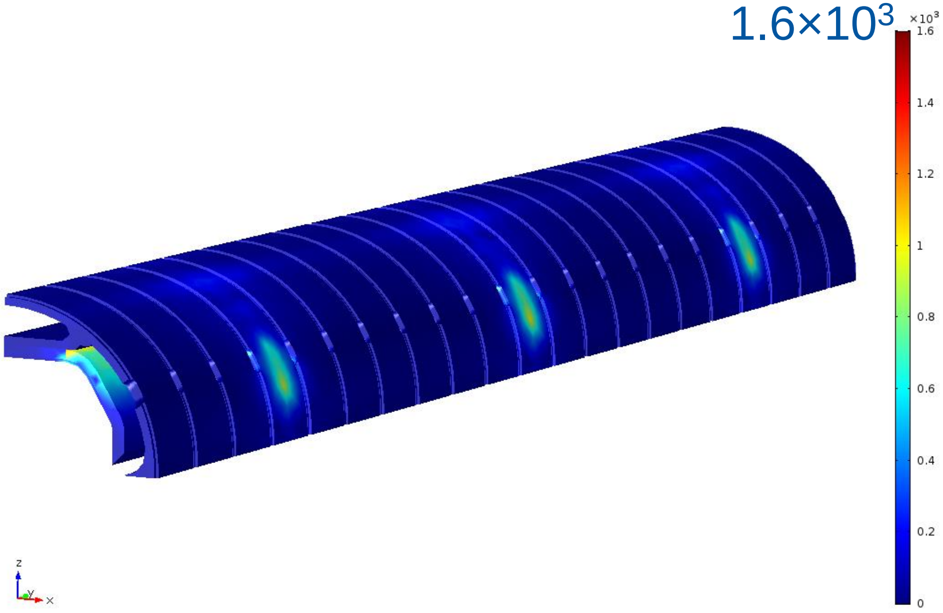
Lorentz forces

Mechanical analysis

Magnet quench



Current density [A/m^2]



Von Mises stress in the beam screen [MPa]

Current density in the external copper much lower than on the inside.
Even if the model has to be refined, results of the beam screen behaviour during a quench are promising. Space between the ribs has to be optimized.

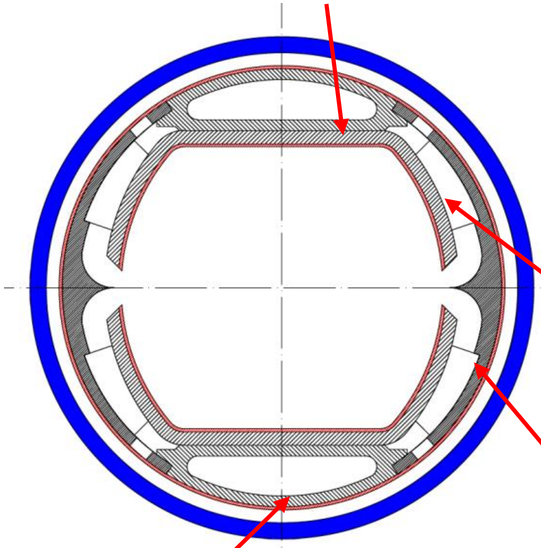
Prototypes

Series vs first prototypes

Sub-component manufacturing:

Series

Beam screen wall:
- P506, 1.25 mm
- copper colamination, 0.3 mm



Reinforcement:
- P506
- punching

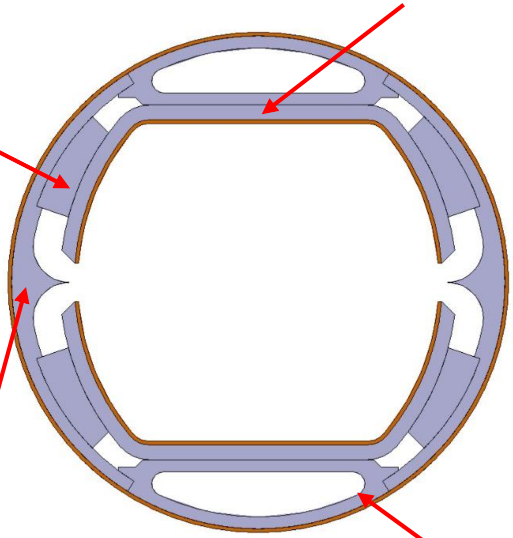
Cooling channel:
- P506 stainless steel
- Extruded

Reflector:
- P506 stainless steel
- Extruded + finishing

1st prototype

Beam screen wall:
- 304L, 1. 5 mm
- copper electrodeposition, 0.05 mm

Reinforcement:
- 304L
- Laser cutting

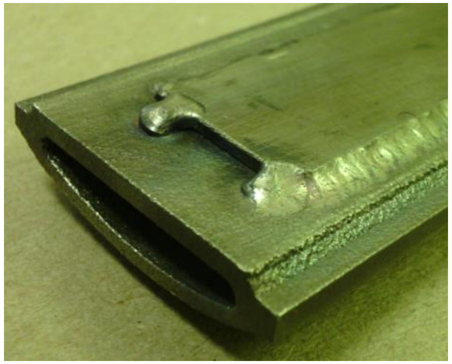


Reflector:
- 304,
- Machined + forming + finishing

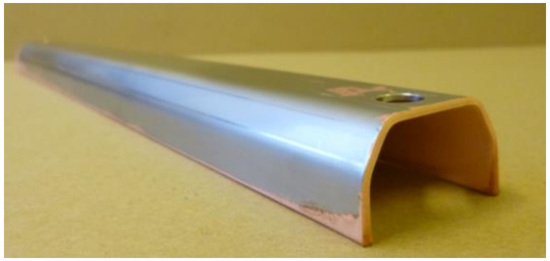
Cooling channel:
- 316L,
- 3D printed + machined

Short prototype manufacturing

3D printed cooling channel



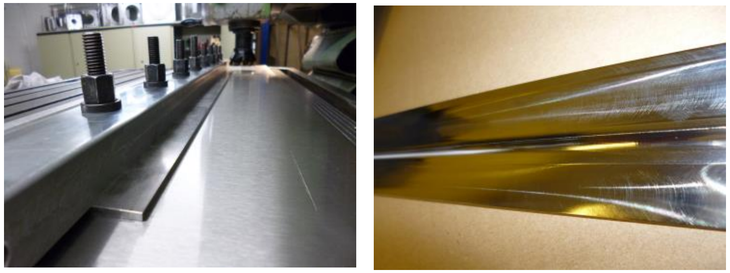
Copper coated screen



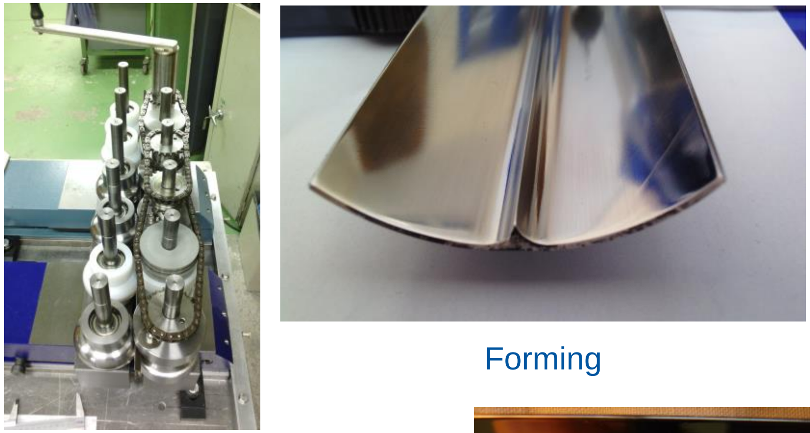
Machining

Welding and machining

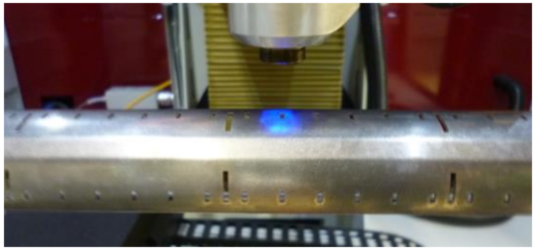
Deflector manufacturing



Milling



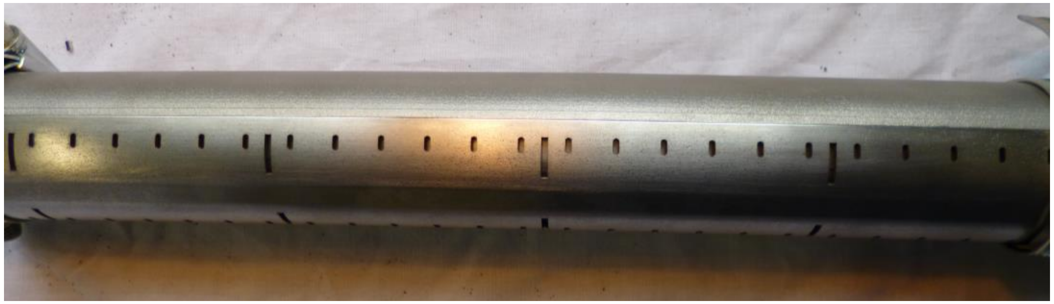
Forming



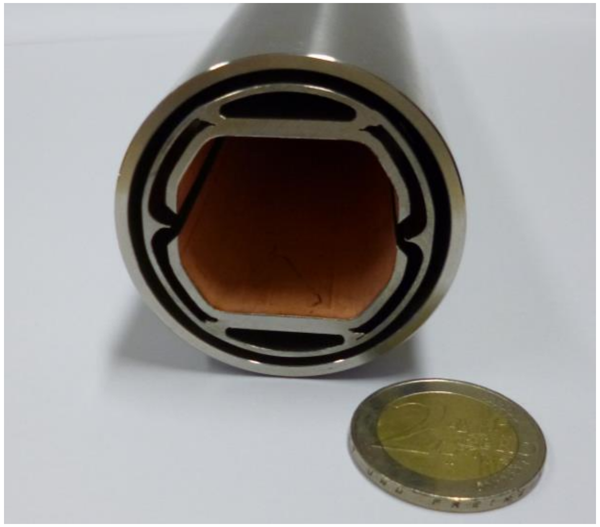
Laser cutting

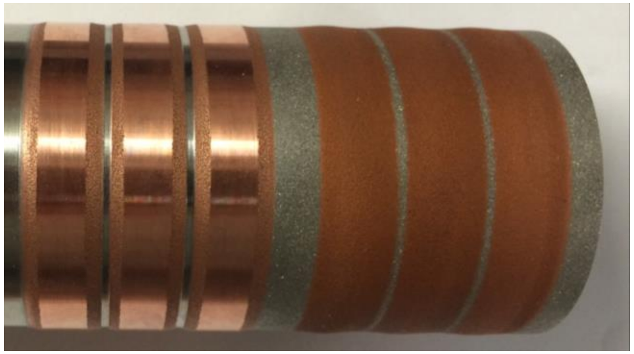
Polishing

Short prototype manufacturing



Assembly and welding



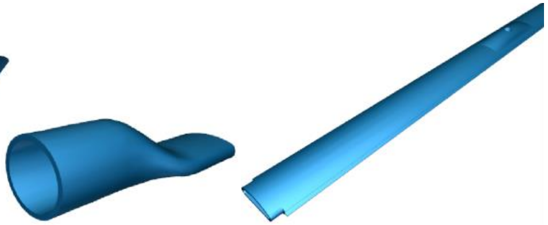


Copper coating

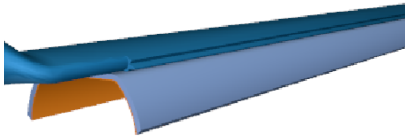
Long prototype to be installed at Anka

Assembly:

~ 40 cm long



Transition and special central pieces



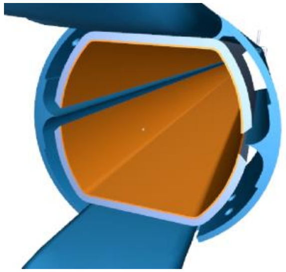
Cooling channel: Powder → 3D printing → Machining → Welding

Beam screen wall: Sheet → Forming → Coating → Machining

→ Welding →

Reflector: Flat bar → Machining → Forming → Cutting → polishing

→ Welding →



Reinforcement: Sheet → Cutting → Welding → Coating

Conclusion and next steps

A beam screen design has been proposed. It relies on an antechamber to channel the synchrotron radiation and localize the photodesorption.

Thermal, mechanical and cryogenic aspects have been studied. No showstopper has been identified until now.
A more detailed analysis (3D model, singularities, Joule heating) will be carried out.
An optimization of the slit and deflector lip geometries will be done.

First short prototypes, ~ 30 cm long, have been manufactured. Main manufacturing techniques have been validated and will be used for the production of a 2 m long prototype.

2 m long prototype, to be installed and tested at Anka, will be manufactured by the end 2016.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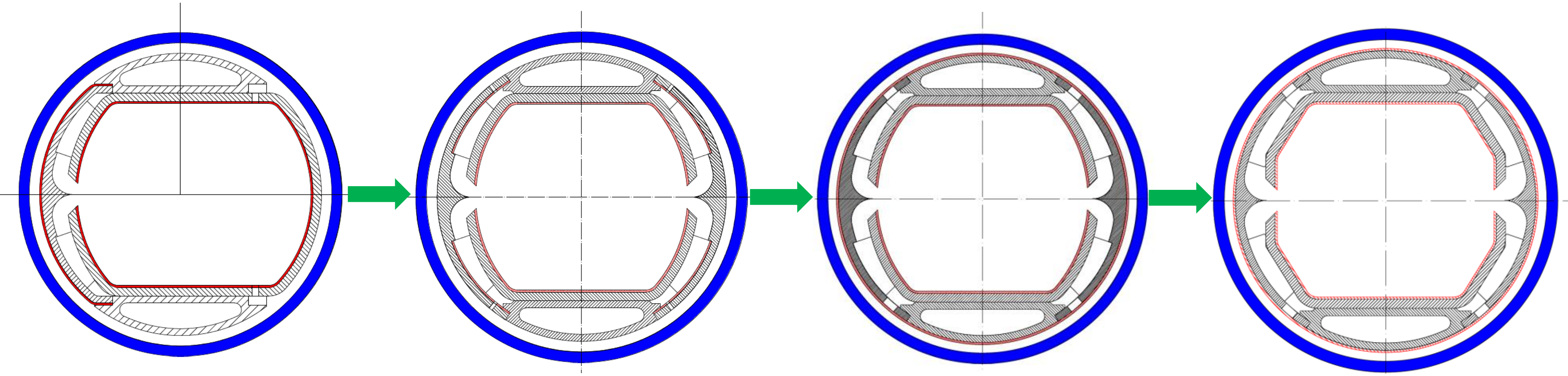
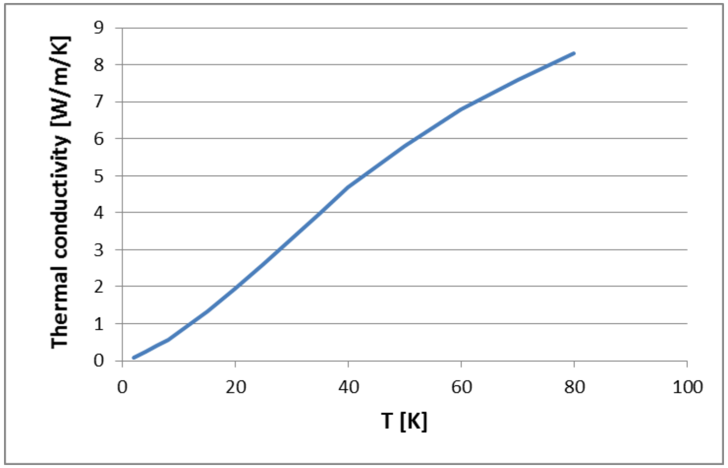
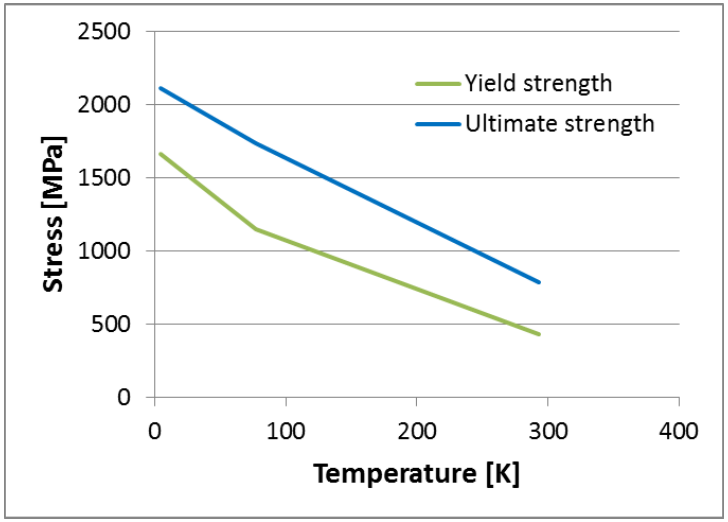
Design Updates



- Symmetrical design
  - → Better impedance
  - → Pumping holes hidden by the screen
- Thermal copper coating on the outer side
- Bigger pumping holes – no constraint for the distribution
- Polygonal shape of the screen

Material properties





P506 properties

<u>Stainless steel*:</u>

Electrical resistivity (50 K) ~ 5.10^{-7} Ω.m

Thermal conductivity (50 K) ~ 6. $\mathrm{W.m^{-1}.K^{-1}}$

<u>316LN:</u>

Yield strength:

σ_y (4K)** ~ 860 MPa

σ_y (293 K) ~ 300 MPa

<u>P506 (high-Mn high-N austenitic stainless steel):</u>

Yield strength***:

σ_y (50K) ~ 1350 Mpa

Magnetic susceptibility ~3.10^{-3}

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*Jensen et al. Selected cryogenic data notebook, BNL, vol. 1

** Sa et al., Mechanical Characteristics of Austenitic Stainless Steel 316LN Weldments at Cryogenic Temperature, Fusion Engineering 2005

***Sgobba, S. and Hochörtler, G., A new non-magnetic stainless steel for very low temperature applications, Stainless Steel Science and Market, 1999; 2; 391-401