SPPC Beam Screen Design

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Outline

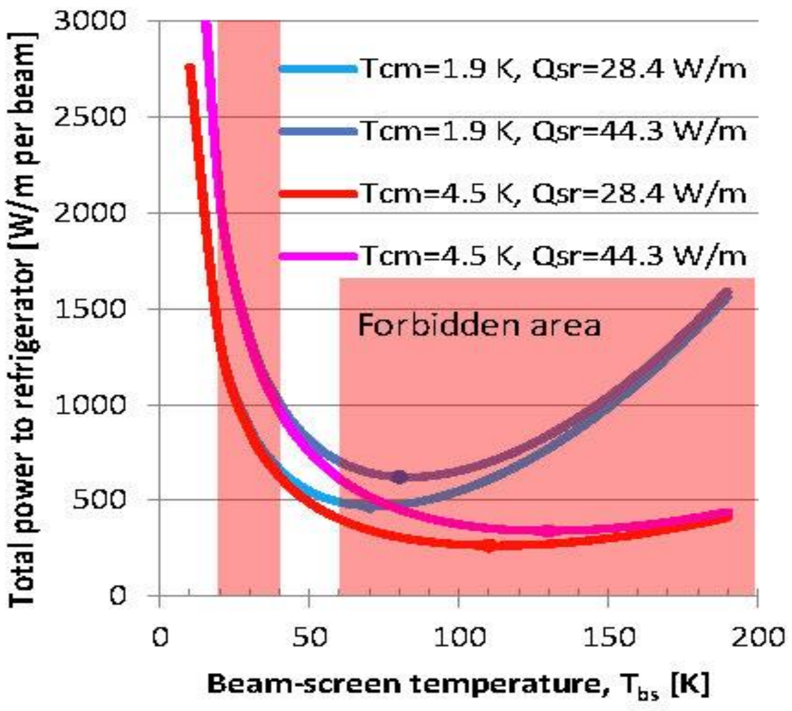
- ☐ Beam screen issues for Future Hadron Collider
- ☐ FCC beam screen design
- ☐ SPPC beam screen design
- ☐ Conclusion and next

Beam screen issues for Future Hadron Collider
Synchrotron radiation

	LHC(27km)	FCC(100km)	FCC(83km)	SPPC(54km)
P_{SR} in W/m	0.2	28.4	44.3	57

Synchrotron radiation => Photo-electrons => Accelerated by the successive particle bunches => Multipacting => Buildup of electron cloud

- **desorbs gases**
- **cause beam instabilities, emittance growth, even beam loss, and poor lifetime**
- **heat the surfaces**

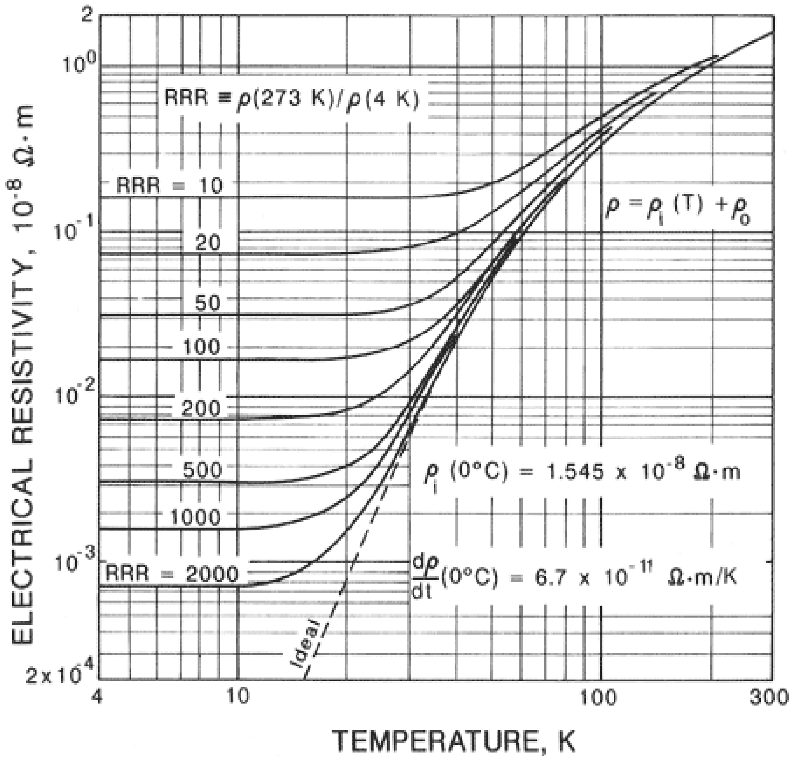


Philippe Lebrun & Laurent Tavian, Beyond the Large Hadron Collider: a first look at cryogenics for CERN future circular colliders, 25th International Cryogenic Engineering Conference and the International Cryogenic Materials Conference in 2014, ICEC 25–ICMC 2014

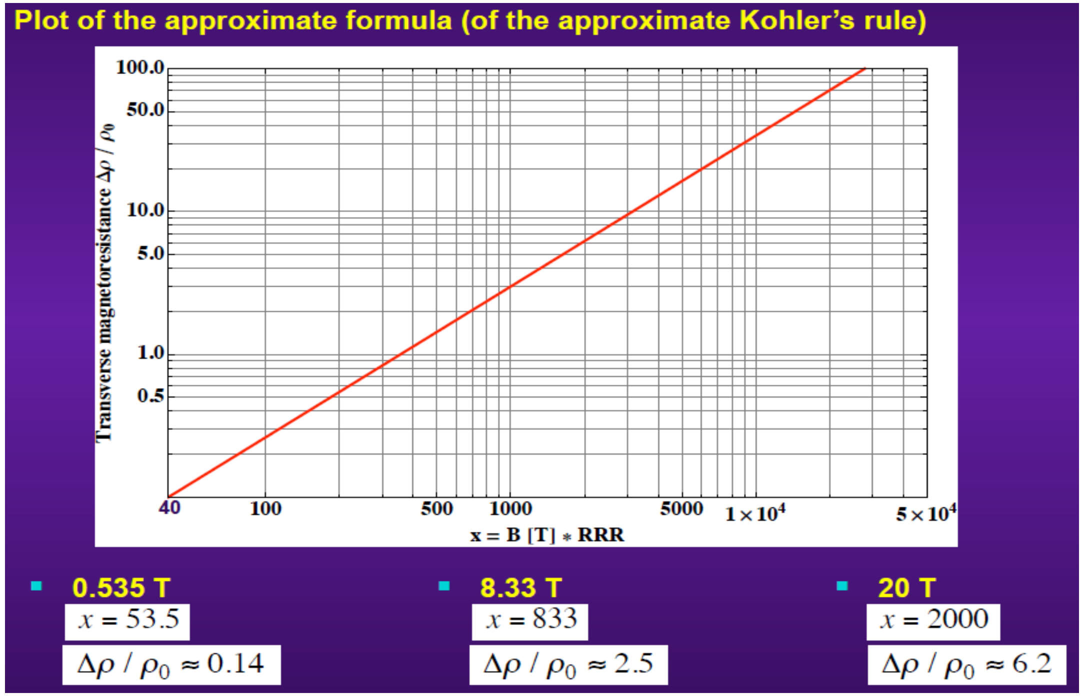
Beam screen issues for Future Hadron Collider Impedance

Beam stability requires low transverse impedance.

Copper resistance depends both on the temperature and magnetic field.



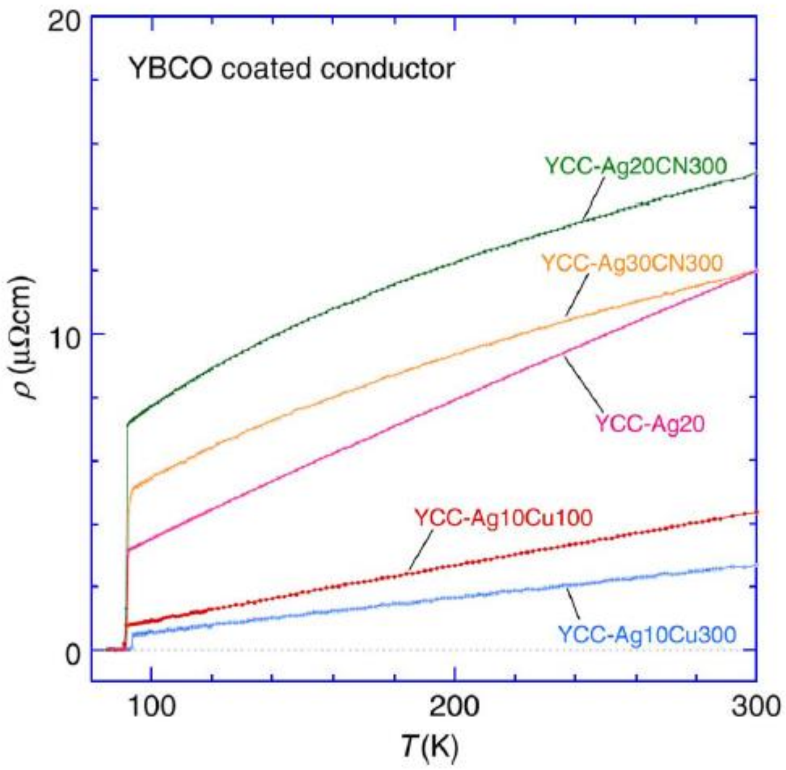
http://www.copper.org/resources/properties/cryogenic/



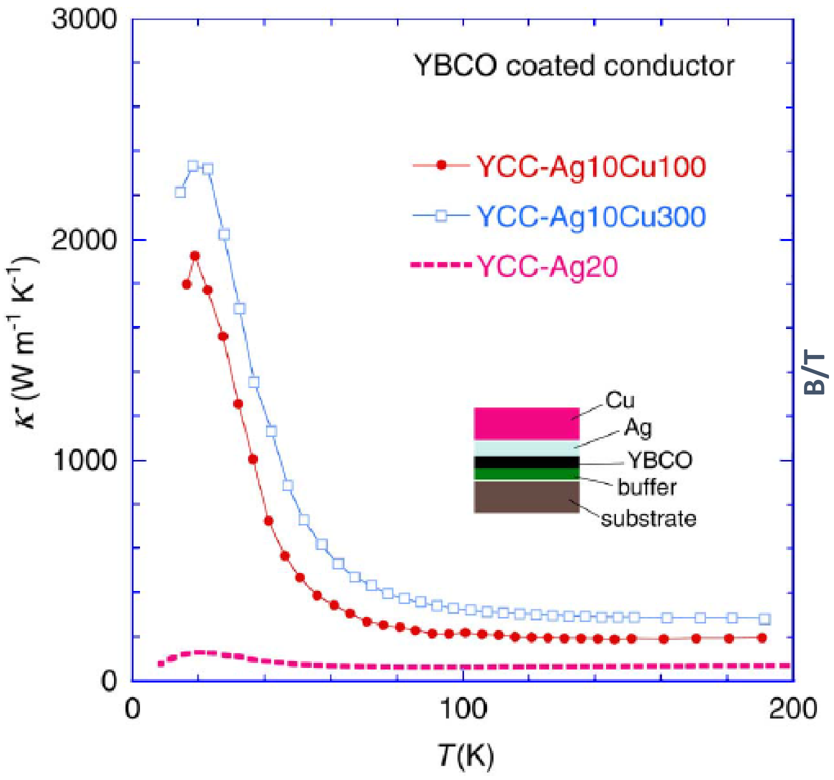
$$\Delta\rho = \rho(B) - \rho_0$$

E. Metral, "Beam Screen Issues," in Proc. HE-LHC10, 14–16 October 2010

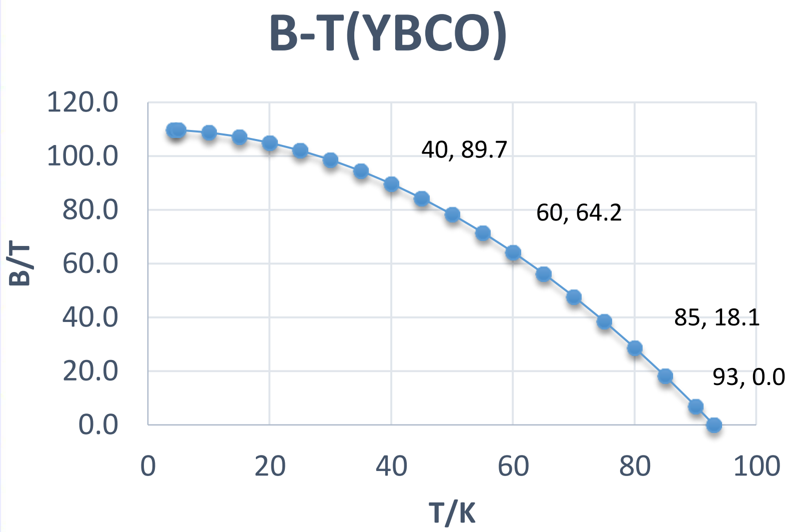
Some properties of YBCO



Electrical resistivity with temperature



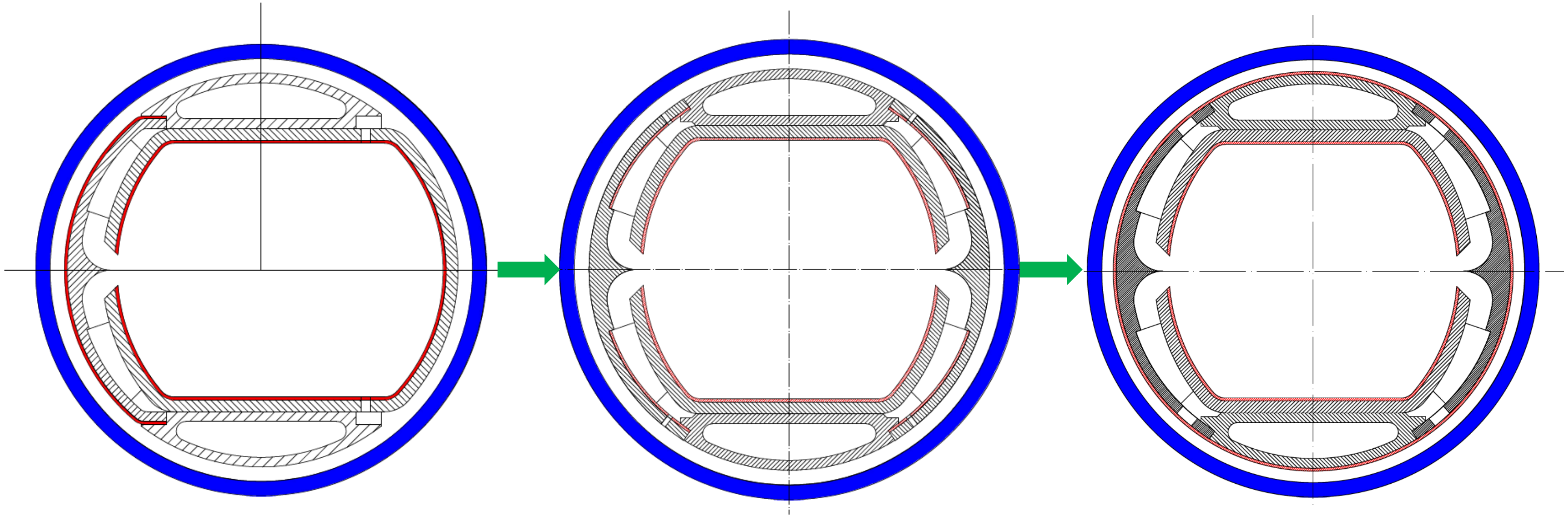
Thermal conductivity with temperature



Critical magnetic field with temperature

Naito T, Fujishiro H, Yamamura Y. Thermal Conductivity of YBCO Coated Conductors Reinforced by Metal Tape[J]. IEEE Transactions on Applied Superconductivity, 2011, 21(3): 3037-3040.
Golovashkin A, Ivanenko O, Kudasov Y. Low temperature measurements of H c2 in HTSC using megagauss magnetic fields[J]. Physica B-condensed Matter, 1992, 177(1): 105-108.

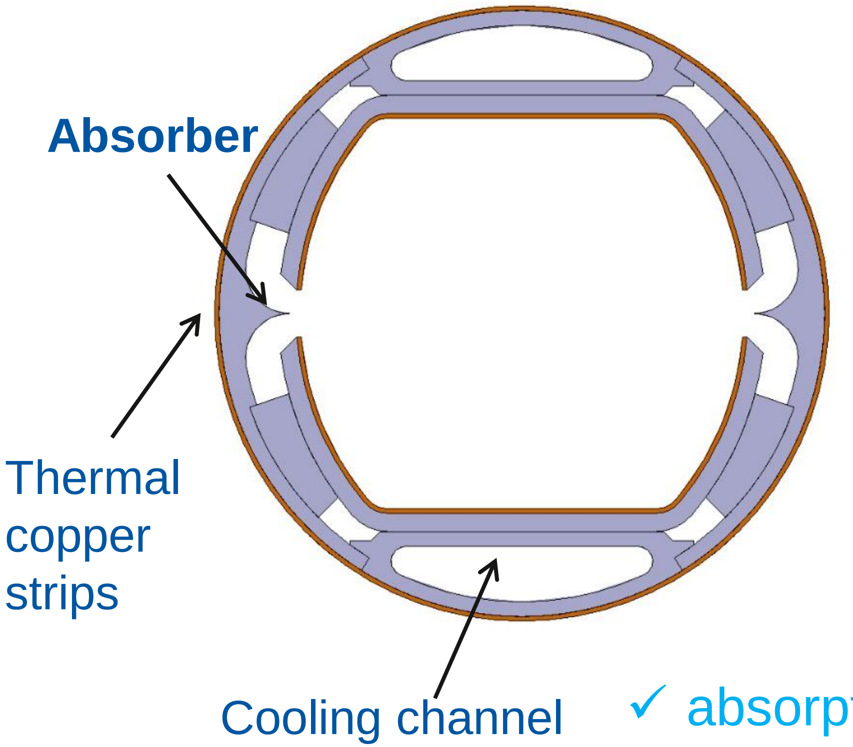
FCC beam screen design updates

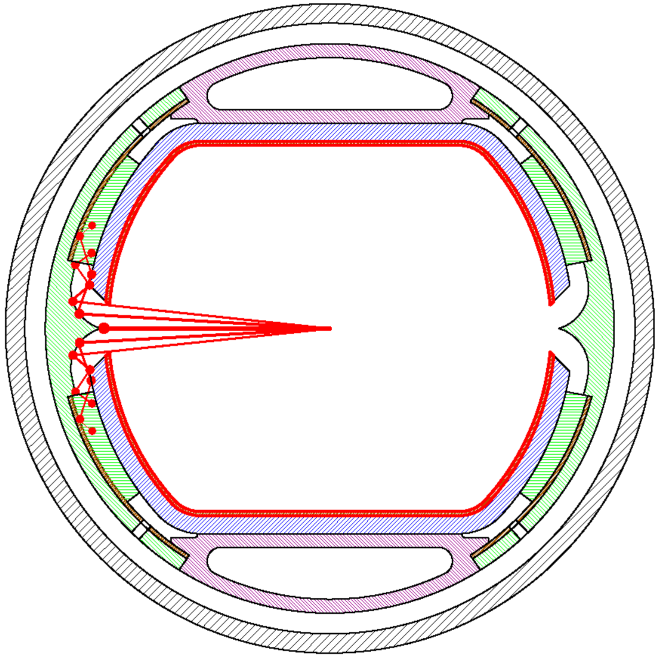


- Symmetrical design
  - → Better impedance
  - → Pumping holes hidden by the screen
- Thermal copper coating on the outer side
- Bigger pumping holes – no constraint for the distribution

Slide from C. Garion

FCC beam screen design





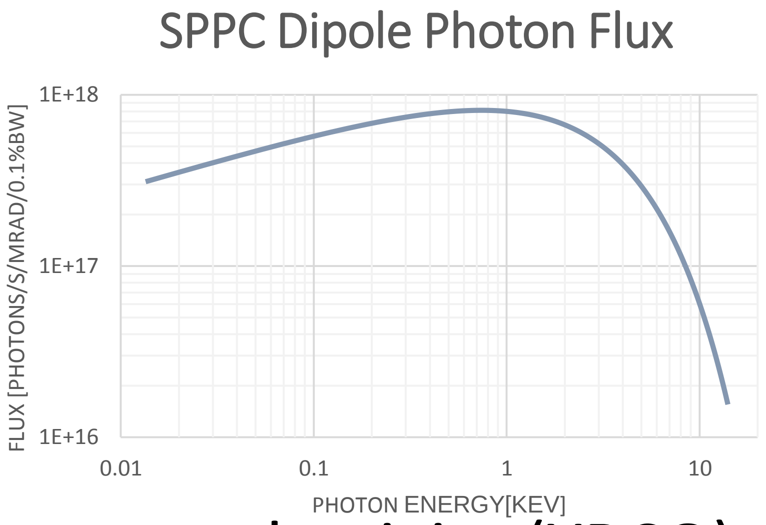
- ✓ absorption of synchrotron radiation
- ✓ avoids photo-electrons
- ✓ helps with beam vacuum

Claudio Kotnig, FCC Beam Screen cooling, FCC Design Meeting 12.11.2015, C. Garion ,FCC-hh beam screen design EuroCircol task 4.5

SPPC beam screen design

- Synchrotron radiation power: 57W/m! **=>need absorbers!**

	E(TeV)	I(A)	Γ（ph/m/s）	P_{SR} (W/m)
SPPC	35.6	1	4.24E+17	57.6
FCC（20T）	50	0.5	1.68E+17	35.6
FCC（16T）	50	0.5	1.39E+17	24.6
LHC	7	0.584	8.53E+16	0.2

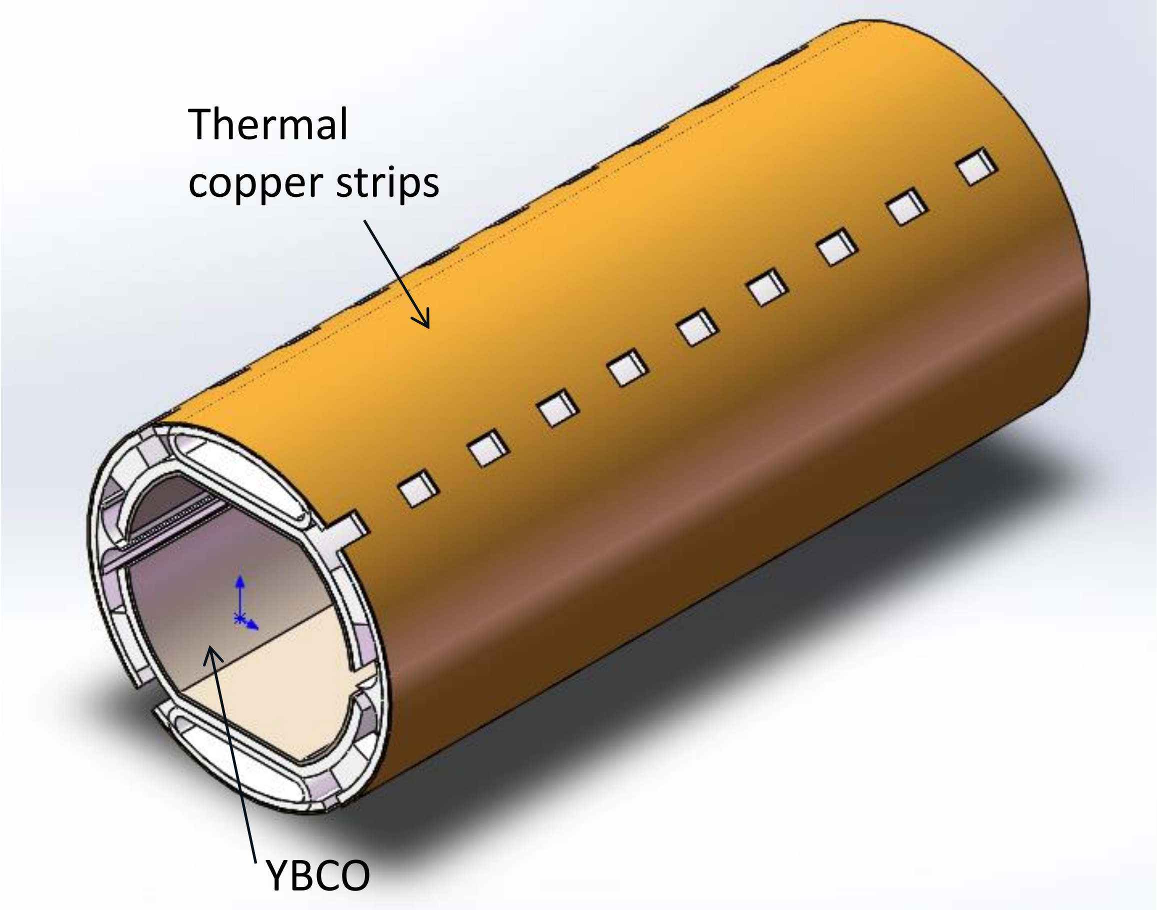


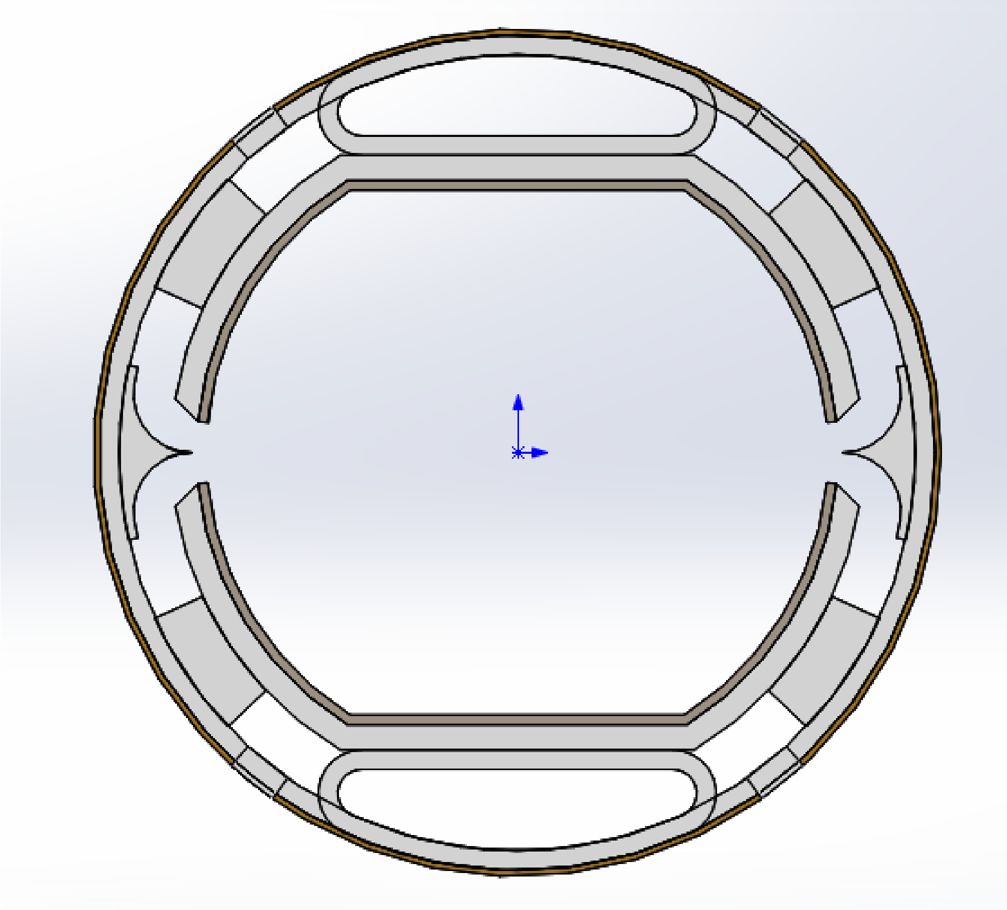
- Impedance => high temperature superconductivity (YBCO)

Resistive wall loss on Cu layer	
	P(mW/m)
LHC	85.32
SPPC（50K）	479.69
FCC（16T 50K）	122.04
FCC（20T 50K）	123.45

SPPC beam screen design

- SPPC beam screen will use FCC novel structure and coat YBCO on inner surface of beam screen. The work temperature is 60-80K.





SPPC beam screen design-main dimensions

Cold bore diameter: 48/51 mm

Beam screen wall:

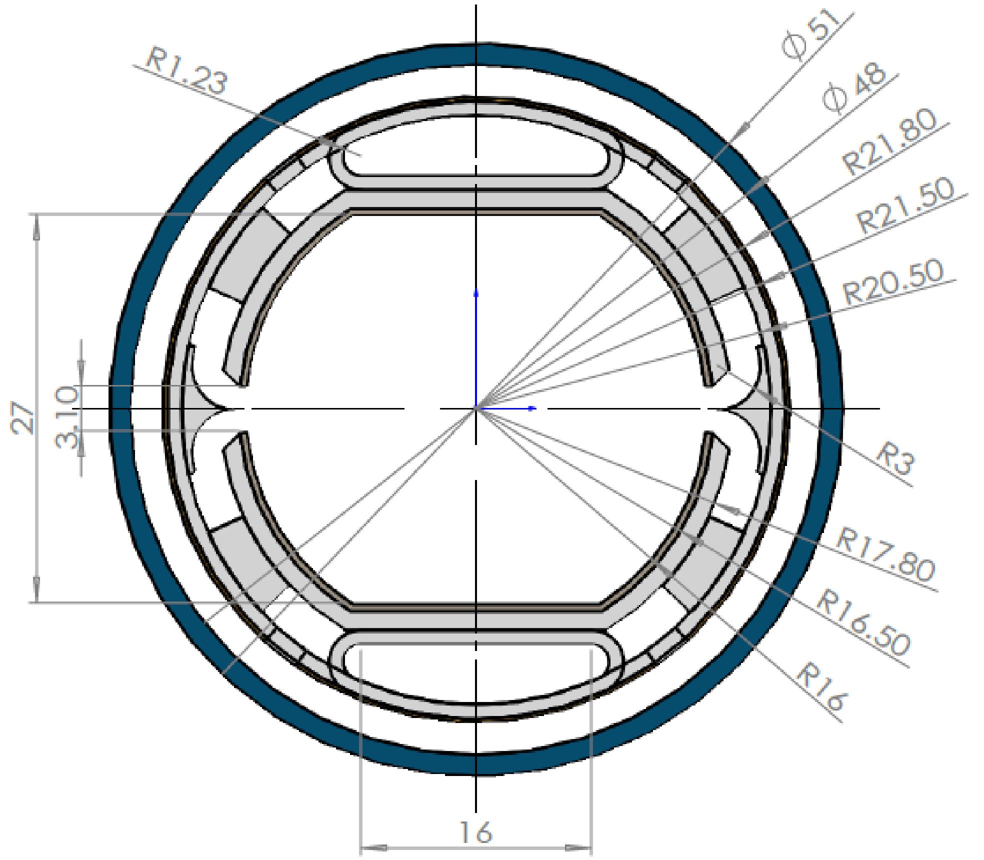
- 1.3 mm stainless steel
- 0.5 mm YBCO

Slit height: 3.1 mm

Cooling channel:

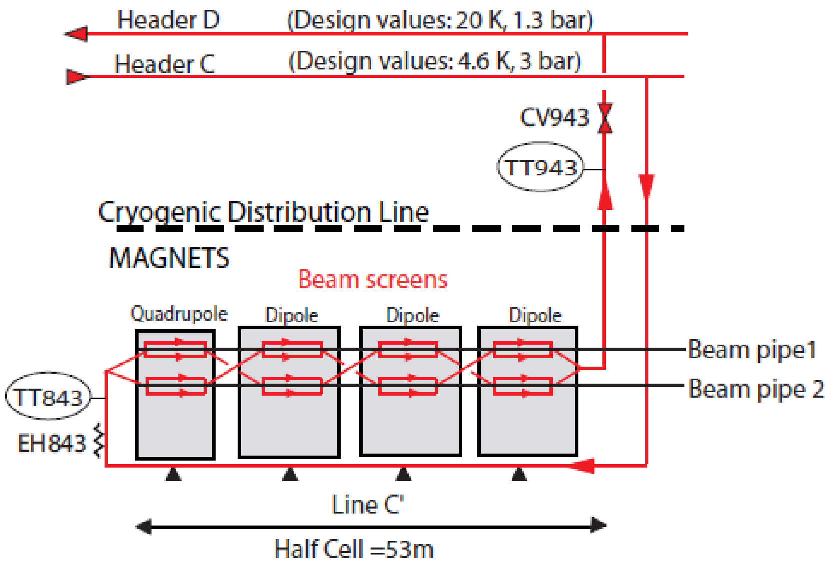
- Thickness 1 mm
- Internal 63.47 mm^2
- Hydraulic diameter: 1.58 mm

Copper for heat transfer: 0.3 mm



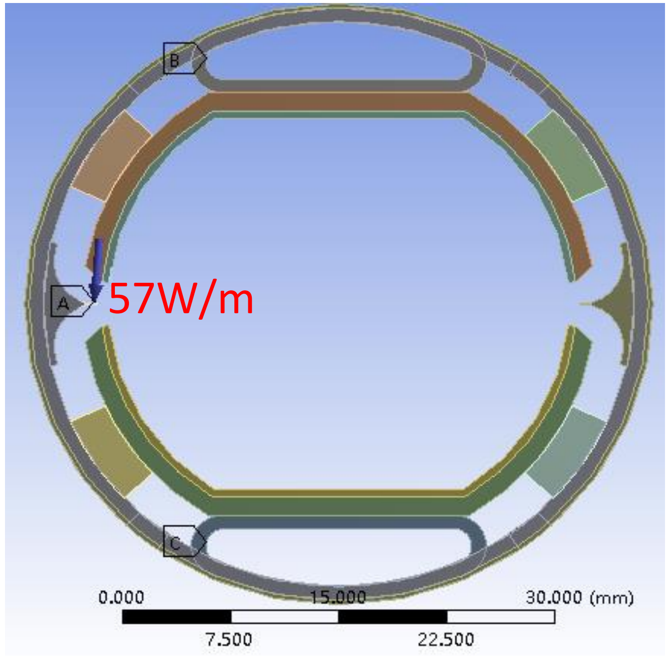
Cooling fluids

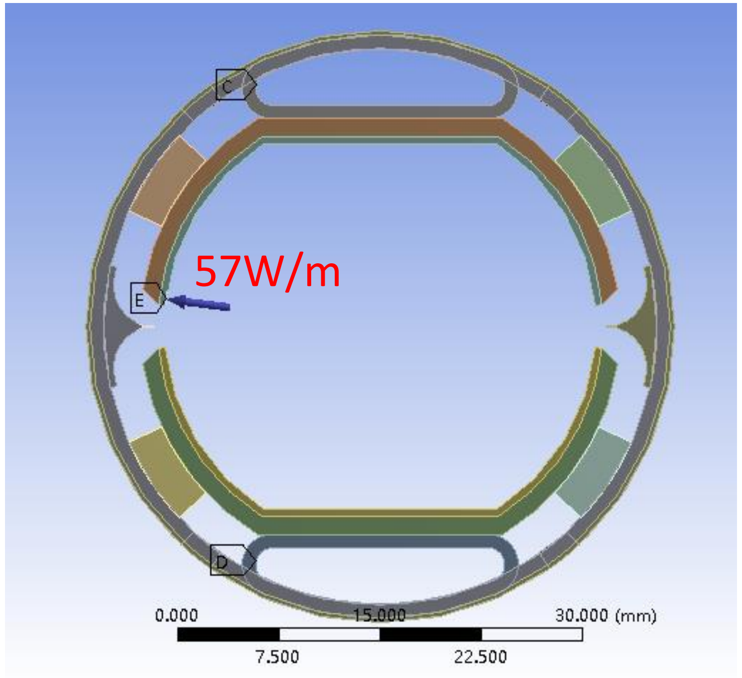
	Cryogens	P_{SR}(W/m)	Temp(K)	P(MPa)	Cp(J/g/K)	Length(m)	ΔT(K)	ρ(kg/m³)	S(mm²)	V(m/s)	Mass flow(g/s)
SPPC	Neon	57	60	3.0	1.511	53	20	143.38	63.47	5.49	49.98
SPPC	Nitrogen	57	65	0.5	2.000	53	15	860.46	63.47	0.92	50.35
SPPC	Oxygen	57	60	0.3	1.673	53	20	1282.40	63.47	0.55	45.14
SPPC	Helium	57	60	3.0	5.328	53	20	22.57	63.47	9.90	14.18
LHC	Helium	1	5	0.3	6.854	53	15	117.50	10.75	0.2	0.26
FCC	Helium	31	40	3.0	5.513	53	20	33.34	53.58	4.17	7.45



Bradu B, Vinuela E, Gayet P. Example of cryogenic process simulation using EcosimPro: LHC beam screen cooling circuits[J]. Cryogenics, 2013: 45-50.

Thermal analysis

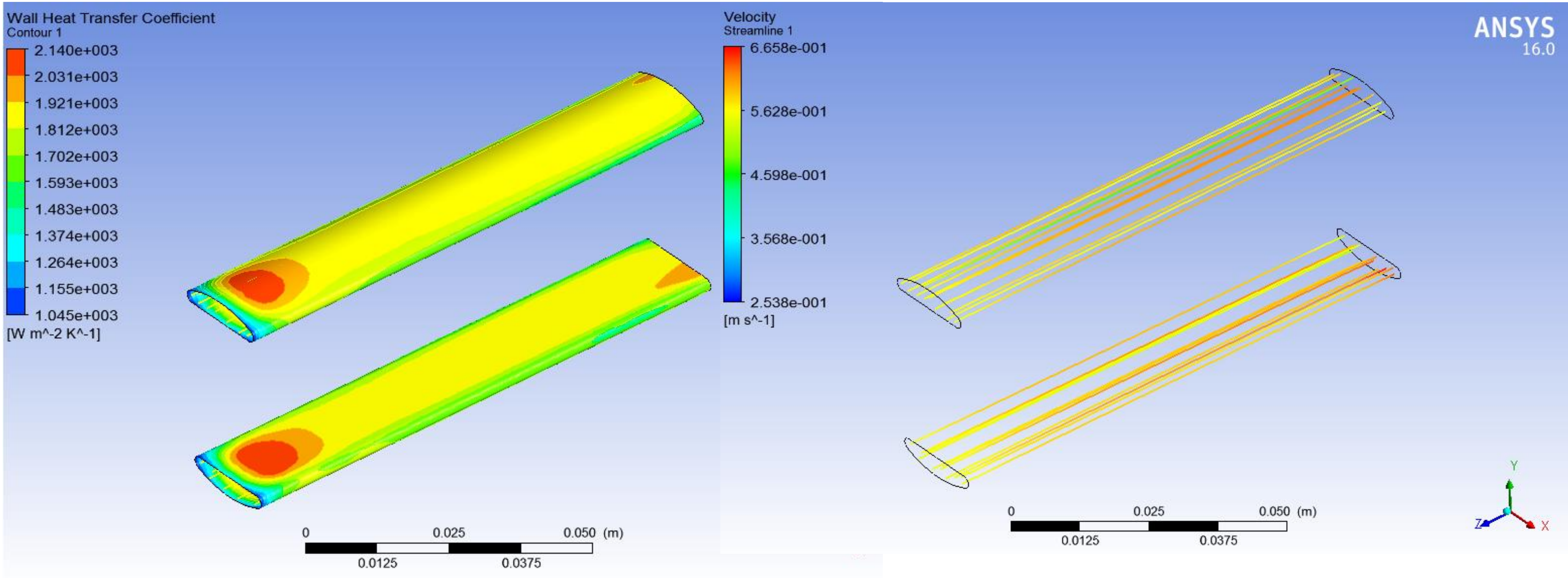




Thermal conductivity of copper at 60 K * ~ 600 $W.m^{-1}.K^{-1}$
Thermal conductivity of stainless steel at 60 K ** ~8 $W.m^{-1}.K^{-1}$
Thermal conductivity of YBCO at 60K *** ~ 400 $W.m^{-1}.K^{-1}$
Convection coefficient provided by CFX

*http://www.copper.org/resources/properties/cryogenic/
**Mchenry H. The Properties of Austenitic Stainless Steel at Cryogenic Temperatures[J]., 1983.
***Naito T, Fujishiro H, Yamamura Y. Thermal Conductivity of YBCO Coated Conductors Reinforced by Metal Tape[J]. IEEE Transactions on Applied Superconductivity, 2011, 21(3): 3037-3040.

Thermal analysis (Oxygen)



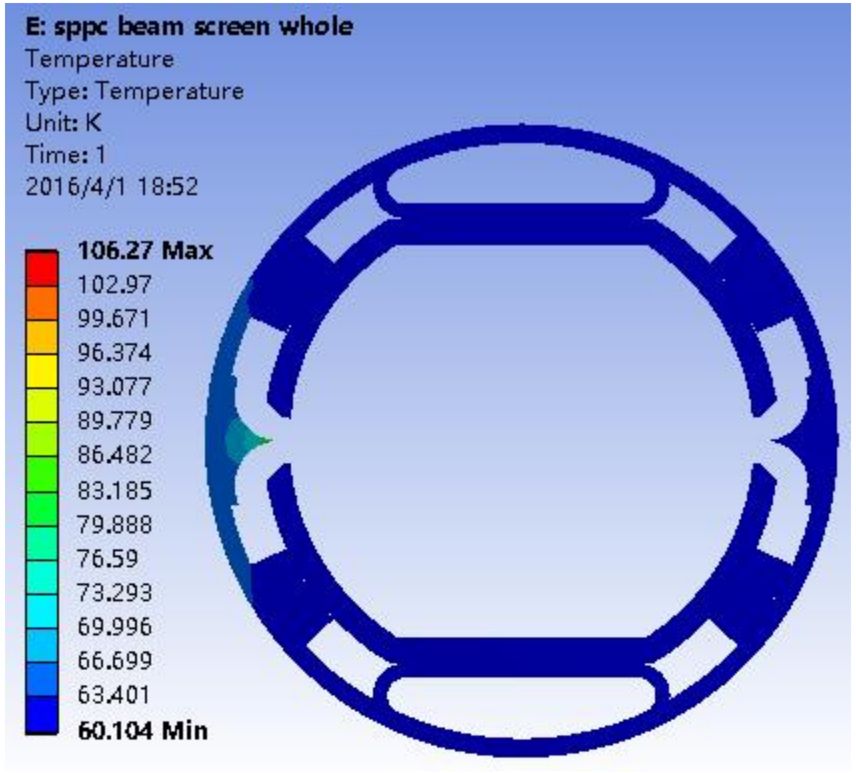
Properties of oxygen@$T = 60K, P = 0.3MPa$: $\rho = 1282.4kg/m^3 c_p = 1.673J/(g.K)$

$viscosity\ \mu = 649.84\mu Pa \cdot sconductivity\ k = 0.19418W/(m \cdot K)$

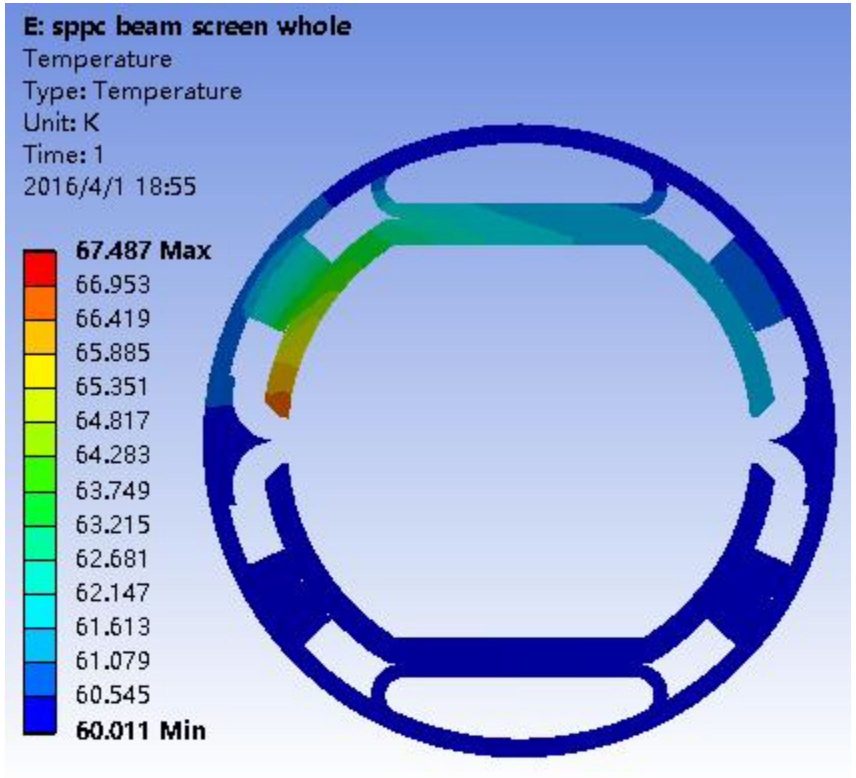
Boundary: Mass flow rate 45g/s

Data from http://webbook.nist.gov/chemistry/fluid/

Thermal analysis (Oxygen)

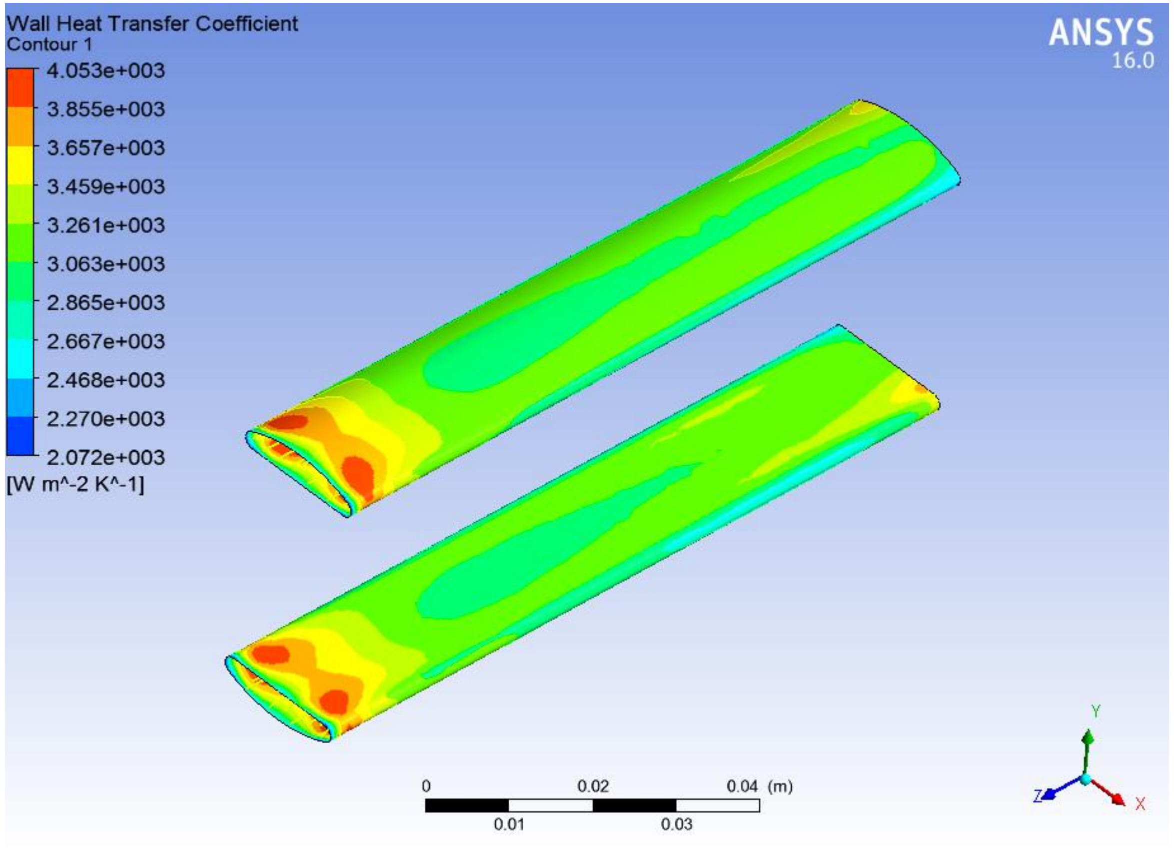


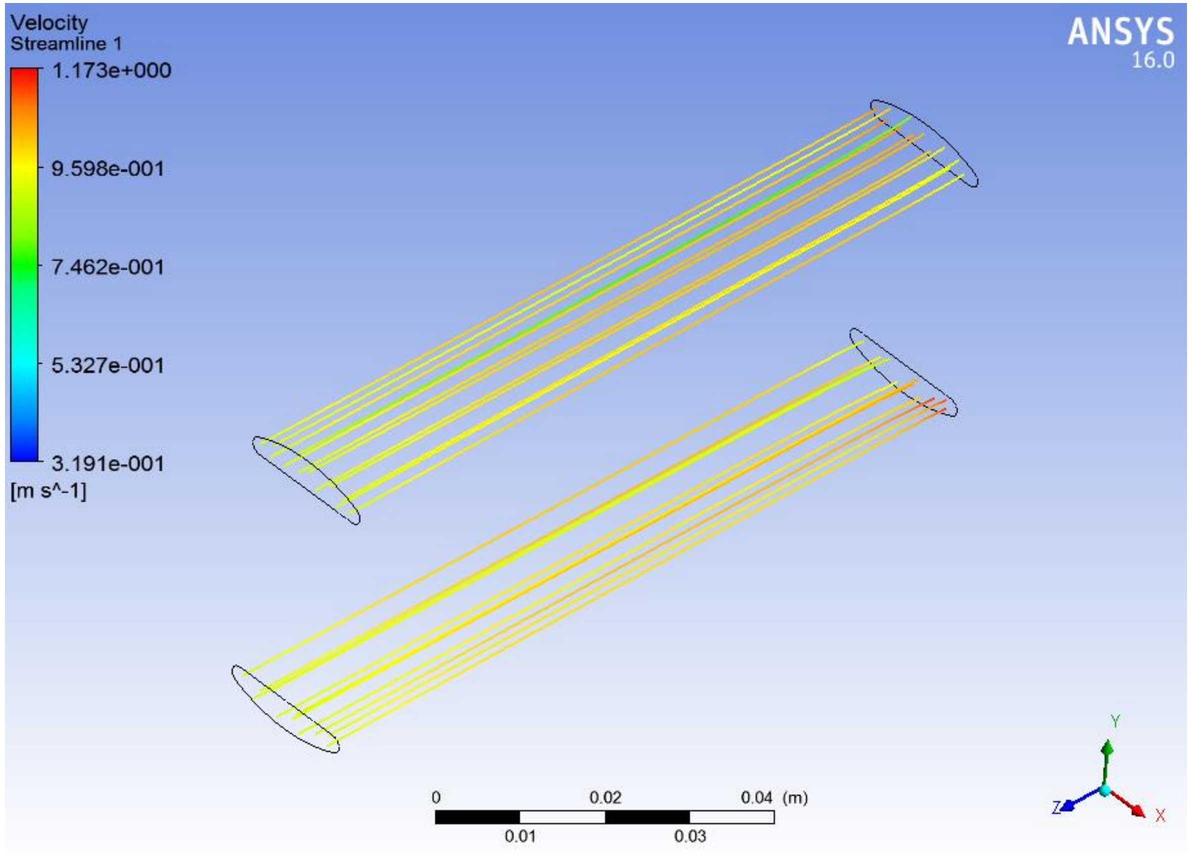
The max temperature is at the absorber tip. Most part is in the range of 60-63.4K.



The max temperature rise is about 7.5K. The YBCO can maintain its superconductivity.

Thermal analysis (Nitrogen)





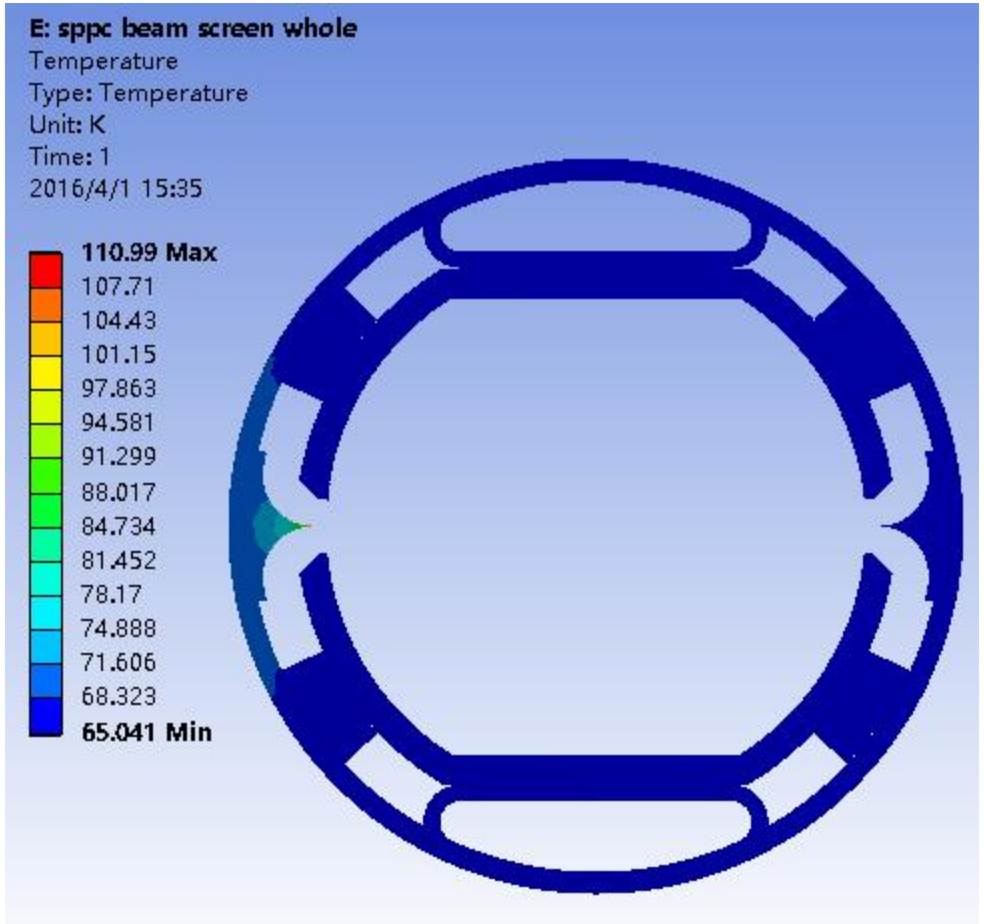
Properties of nitrogen@$T = 65K, P = 0.5MPa$: $\rho = 860.46kg/m^3 c_p = 2J/(g.K)$

$viscosity\ \mu = 282.02\mu Pa \cdot sconductivity\ k = 0.17357W/(m \cdot K)$

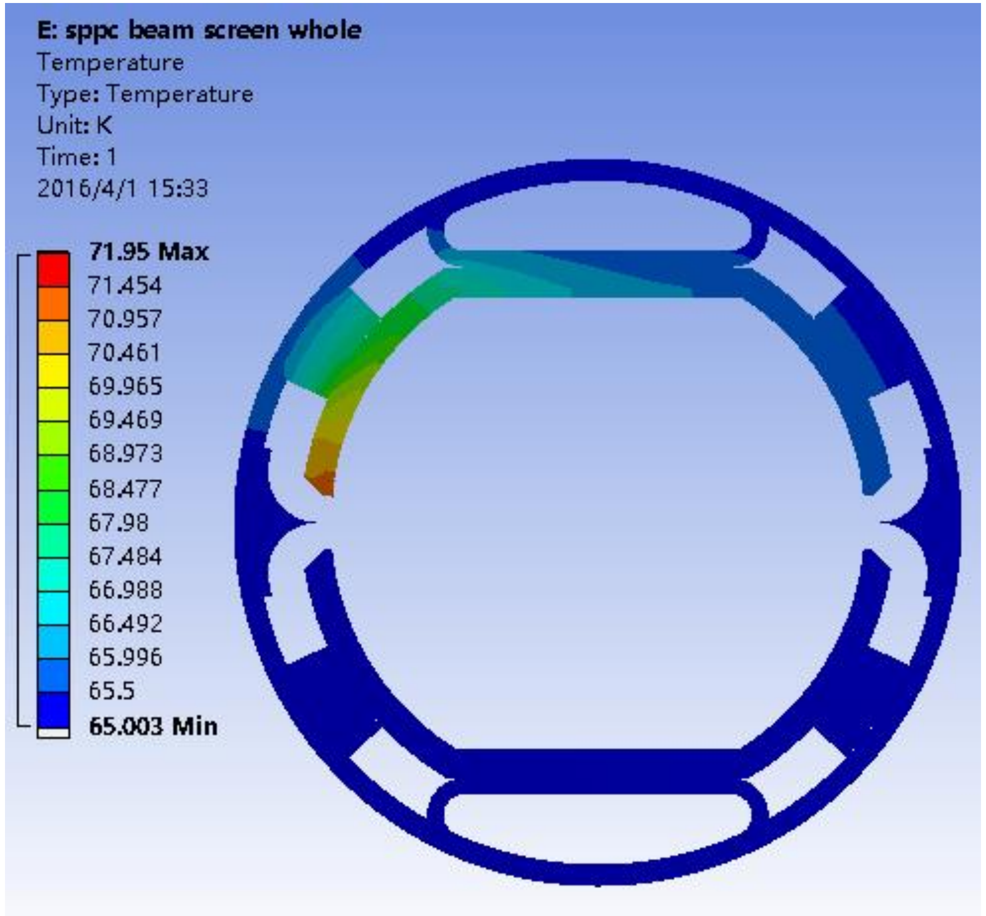
Boundary: Mass flow rate 50g/s

Data from http://webbook.nist.gov/chemistry/fluid/

Thermal analysis (Nitrogen)



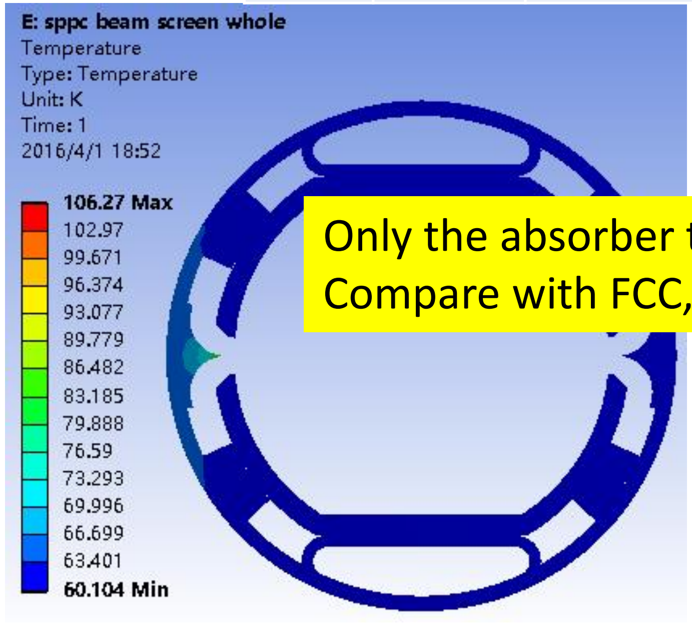
The maximum temperature is at the absorber tip.
Most part is in the range of 65-68.3K.

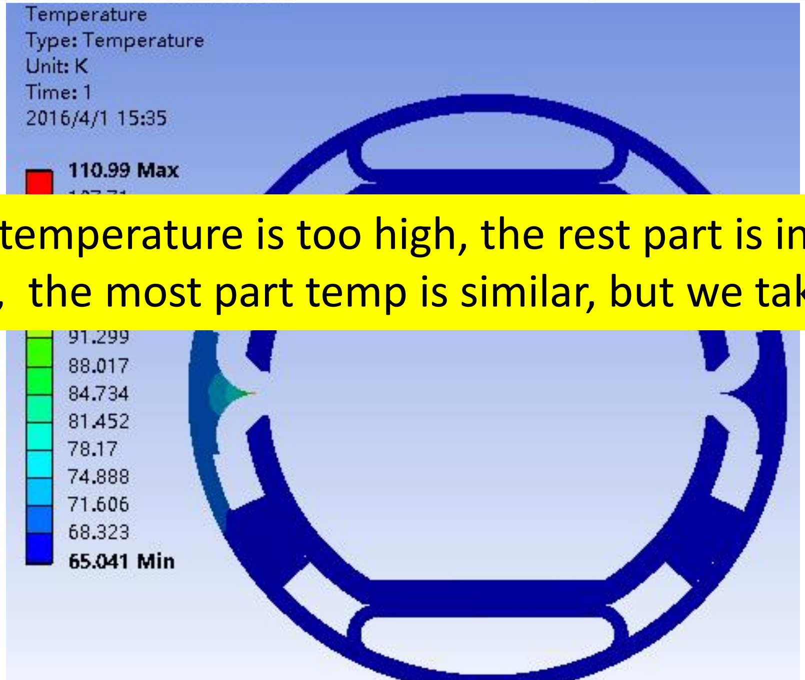


The maximum temperature rise is about 7K.
The YBCO can maintain its superconductivity.

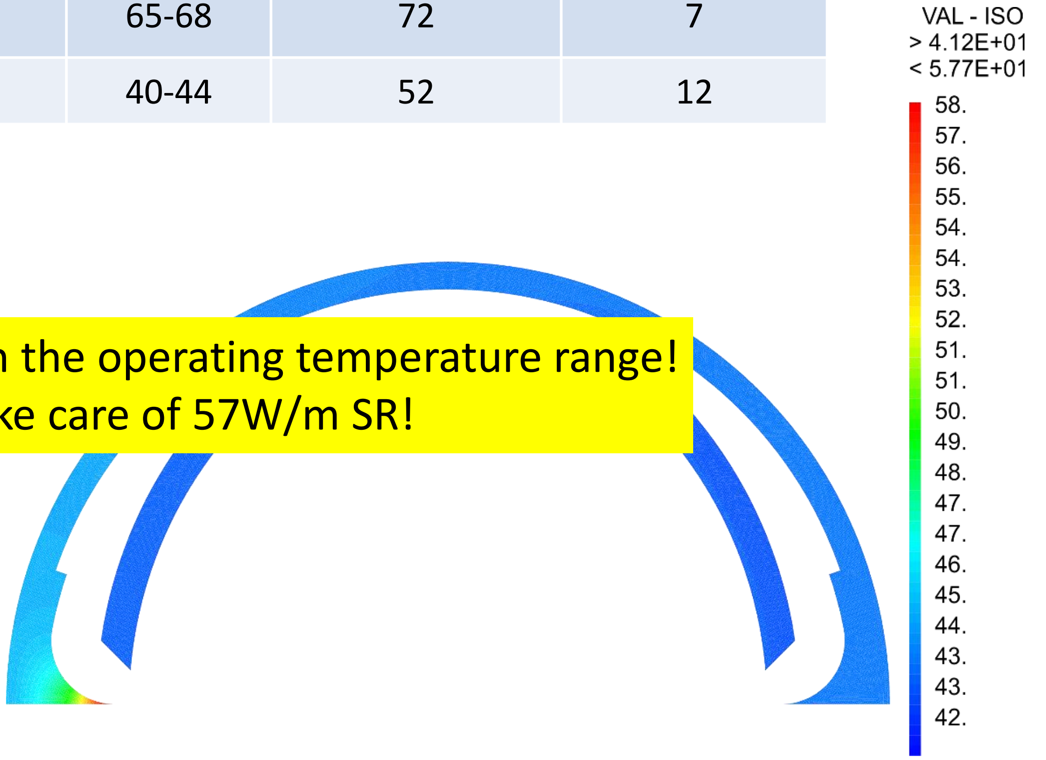
Thermal analysis results compare

	P_{sr} (W/m)	Coolant	Beam screen operating temp(K)	The maximum temp on tip (K)	Maximal temp difference(K)	Most part temp(K)	The maximum temp on tip (K)	Maximal temp difference(K)
				SR on the absorber			Missed	
SPPC	57	Oxygen	60-80	106	46	60-63	67	7
SPPC	57	Nitrogen	65-80	111	46	65-68	72	7
FCC	31	Helium	40-60	58	18	40-44	52	12





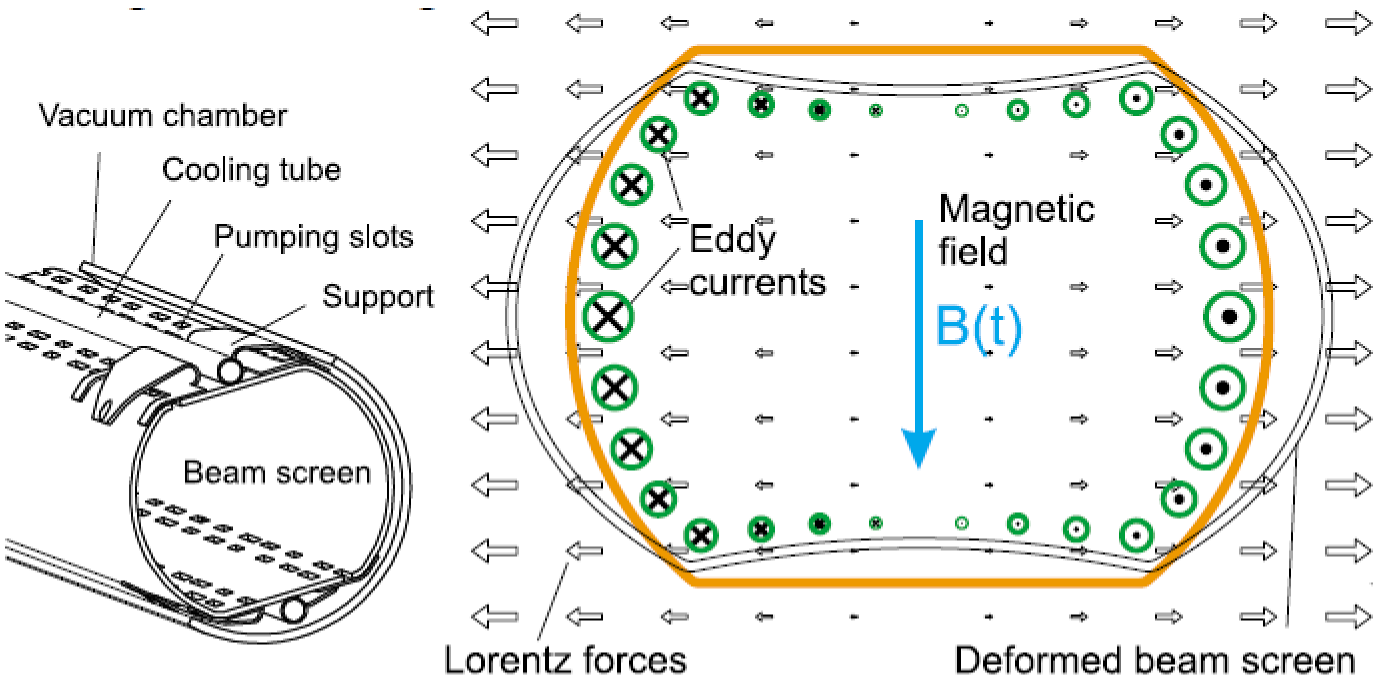
Only the absorber temperature is too high, the rest part is in the operating temperature range!
Compare with FCC, the most part temp is similar, but we take care of 57W/m SR!



FCC data from: C. Garion ,FCC-hh beam screen design EuroCircol task 4.5

The mechanical behavior

The beam screen needs to resist the induced Lorentz forces during a resistive transition (quench) of the magnet.

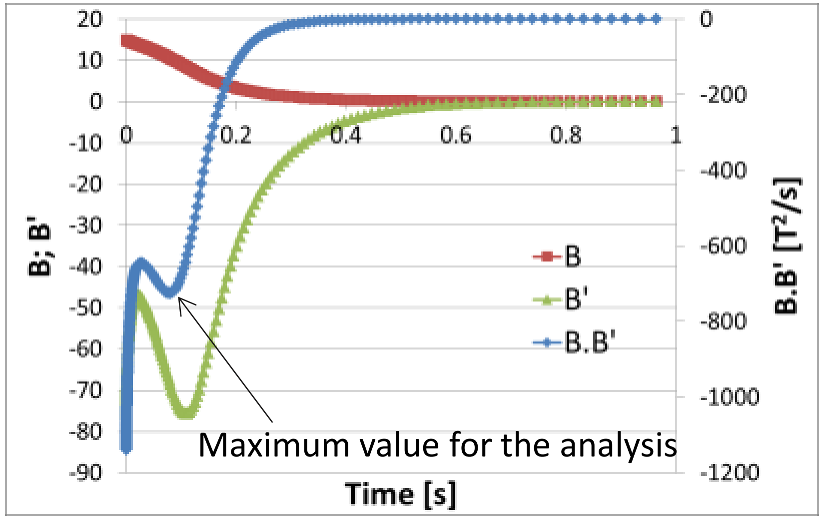


Eddy currents, Lorentz forces and deformations of a beam screen in a dipole field during quench.

Rathjen C. MECHANICAL BEHAVIOUR OF VACUUM CHAMBERS AND BEAM SCREENS UNDER QUENCH CONDITIONS IN DIPOLE AND QUADRUPOLE FIELDS[J]., 2002.

Mechanical analysis

Magnetic field decay* during a quench [E. Todesco]. BB'~725 $T^2.s^{-1}$



Max Lorentz forces are given by**:

$$F_{max} = r^2 \left[\frac{t}{\rho_{ss}} + \frac{\Delta_1}{\rho_{sc}} + \frac{\Delta_2}{\rho_{cu}}\right] B\dot{B}\ N/m$$

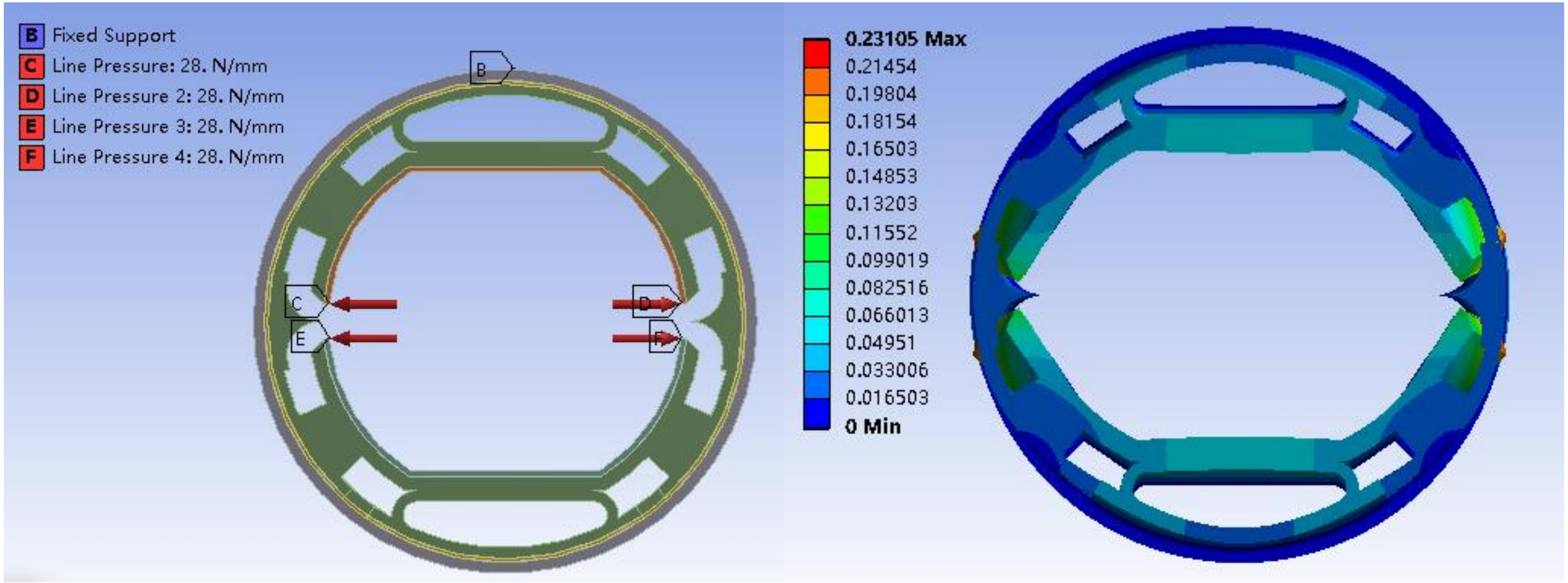
r: the radius of the beam screen.
t,Δ_1,Δ_2: the thicknesses of stainless steel, superconductor and copper.
ρ_{ss} , ρ_{sc}, ρ_{cu}: the specific electric resistances of stainless steel, superconductor and copper.

YBCO superconductivity break down (100-150K)***: $\rho \sim 1 \times 10^{-6} \Omega \cdot m$
Copper at 70K****:$\rho \sim 2 \times 10^{-9} \Omega \cdot m$
Stainless steel *****: $\rho \sim 5 \times 10^{-7} \Omega \cdot m$

$F_{max} \sim 28\ N/mm$

*C. Garion ,FCC-hh beam screen design EuroCircol task 4.5
**Karliner M, Mityanina N, Persov B. LHC beam screen design analysis[J]., 1994.
***Tokudome M, Doi T, Tomiyasu R. Fabrication of YBa2Cu3O7 thin film on cube-textured Cu tape[J]. Journal of Applied Physics, 2008, 104(10).
**** http://www.copper.org/resources/properties/cryogenic/
*****Mchenry H. The Properties of Austenitic Stainless Steel at Cryogenic Temperatures[J]., 1983.

Mechanical analysis



Simplified Model

Maximum displacement: ~ 0.213mm
It is acceptable.

YBCO Young's Modulus*: 88.54 GPa;

Stainless steel at 77K Young's Modulus**: 214GPa; Poisson's Ratio:0.278.

*Tokudome M, Doi T, Tomiyasu R. Fabrication of $YBa_2Cu_3O_7$ thin film on cube-textured Cu tape[J]. Journal of Applied Physics, 2008, 104(10).

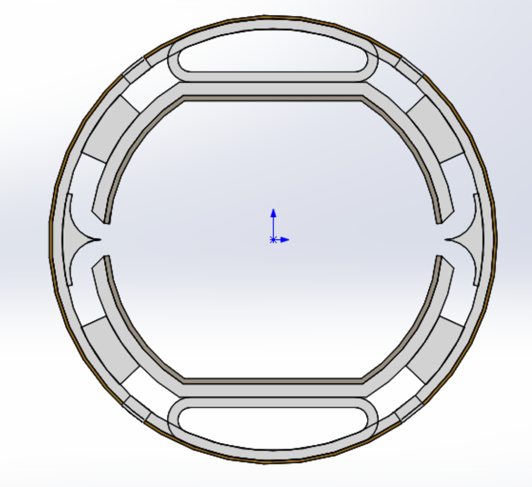
**Mchenry H. The Properties of Austenitic Stainless Steel at Cryogenic Temperatures[J]., 1983.

Mechanical analysis compare

$$F_{max} = r^2 \left[\frac{t}{\rho_{ss}} + \frac{\Delta_1}{\rho_{sc}} + \frac{\Delta_2}{\rho_{cu}} \right] B\dot{B}\ N/m$$

	T (K)	r(mm)	t(m)	Δ_1(m)	Δ_2(m)	ρ_ss(Ω.m)	ρ_sc(Ω.m)	ρ_cu (Ω.m)	$B\dot{B}$ (T^2.s^{-1})	F(N/mm)
FCC	40–60	15.0	1.25E-03	0	3.00E-04	5.00E-07	1.00E-06	1.00E-09	725	49
FCC	40–60	18.0	1.25E-03	0	3.00E-04	5.00E-07	1.00E-06	1.00E-09	725	71
SPPC	60–80	16.0	1.30E-03	2.00E-04	3.00E-04	5.00E-07	1.00E-06	2.00E-09	725	28
SPPC	60–80	20.5	1.00E-03	0	3.00E-04	5.00E-07	1.00E-06	2.00E-09	725	46

Under the same BB'~725 T^2.s^{-1} conditions, Lorentz forces generated on SPPC beam screen are a little more than half of FCC's. The main reason is material electrical resistivity is higher than FCC's because of our beam screen higher operating temperature.



Conclusion and next

- ✓ Beam screen can operate at 60-80K cooled by liquid oxygen, at 65-80K cooled by liquid nitrogen.
- ✓ Higher operating temperature can reduce the Lorenz forces on the structure during magnet quenches.
- ✓ YBCO may solve the wall resistance problem (need to check)
- ➢ Test material properties at low temperature and under high magnet field
- ➢ Refine mechanical analysis
- ➢ Manufacture prototypes
- ➢ Check if the vacuum OK between 60-80K

Thanks for your attention!

Reference

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