Electron-Ion Collider User Group Meeting 2023

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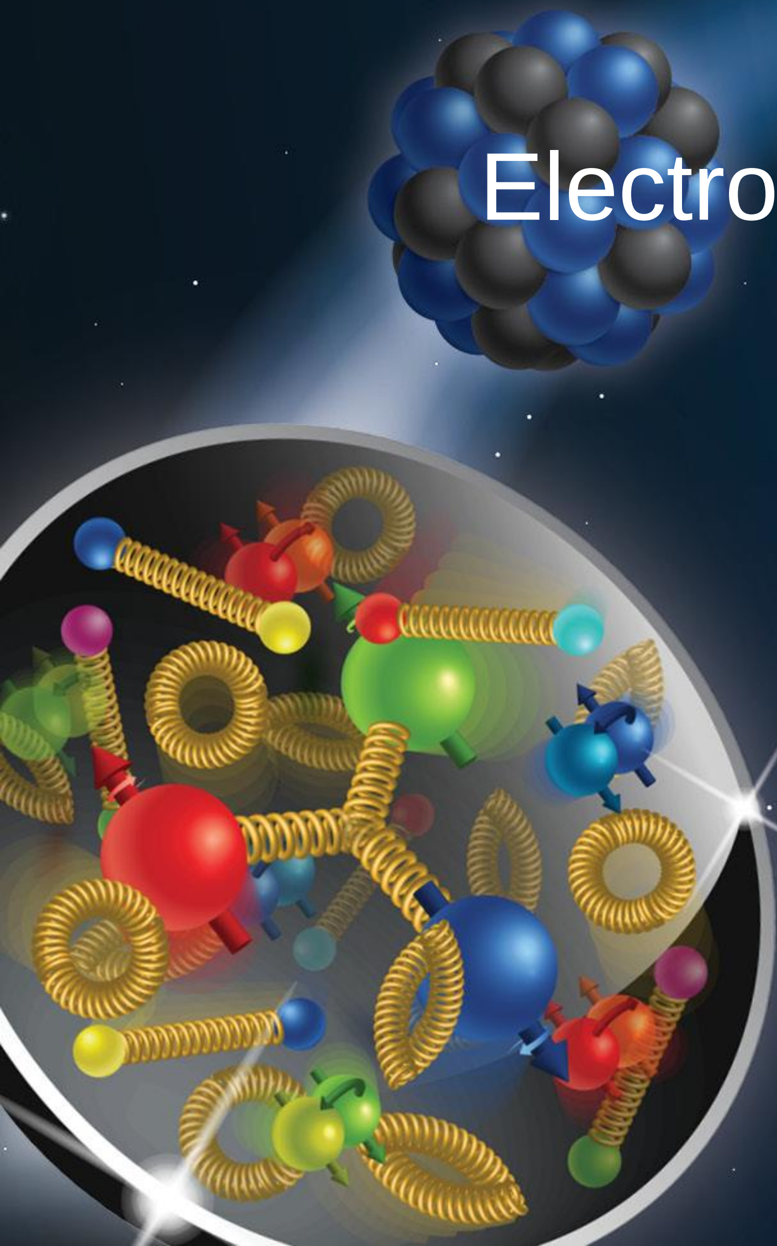
On Behalf of EIC Detector Magnet team

Status of MARCO Solenoid

July 27, 2023



Outline

- ePIC Detector Solenoid (MARCO) Overview
- MARCO Magnet Specifications
- Status of the Design
- 3D Magnetic Design Results
- Conductor definition
- Mechanical Design
- Cryogenic Design
- Magnet Assembly
- Conclusions

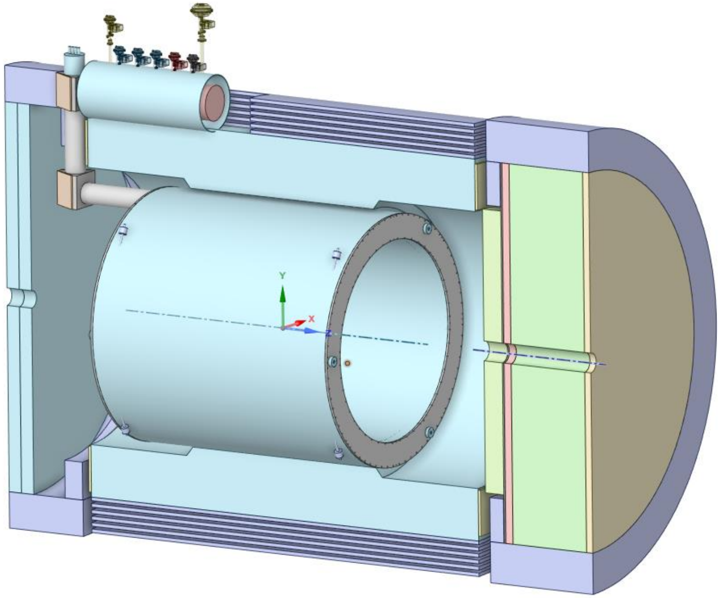
MARCO

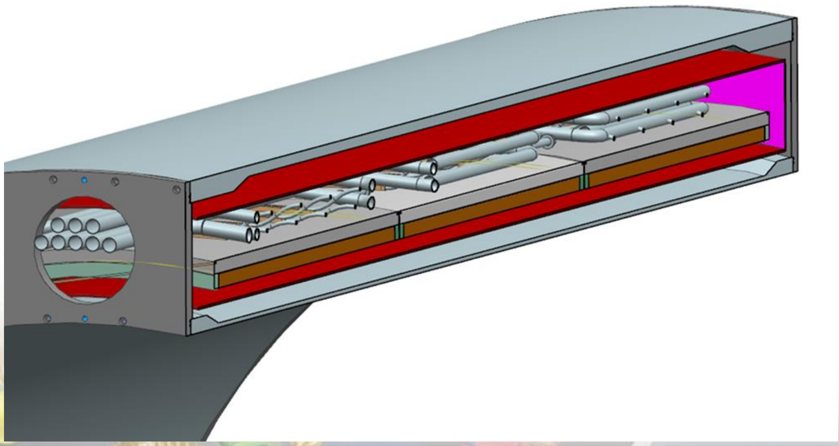
***MA**gnet with **R**enewed **CO**ils*

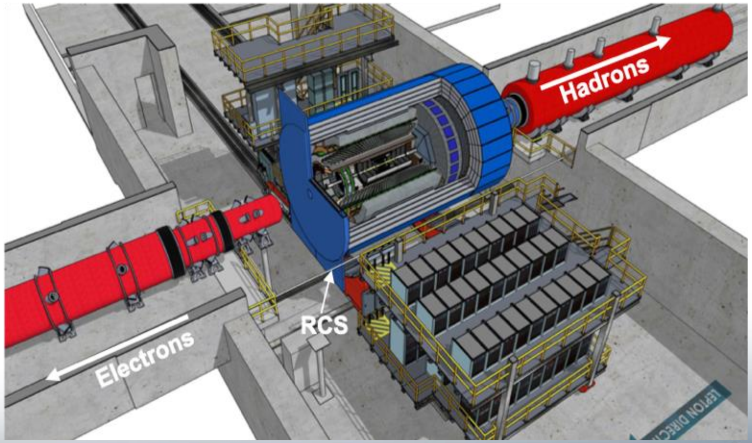
ePIC Detector Solenoid (MARCO) Overview

Superconducting Detector Solenoid

- 3.5 m long coil, 2.84 m room temperature bore diameter
- 2 T on-axis field
- Operating Temperature 4.5 K
- Conductor: Copper Cladded, Rutherford Cable made with NbTi superconducting strands





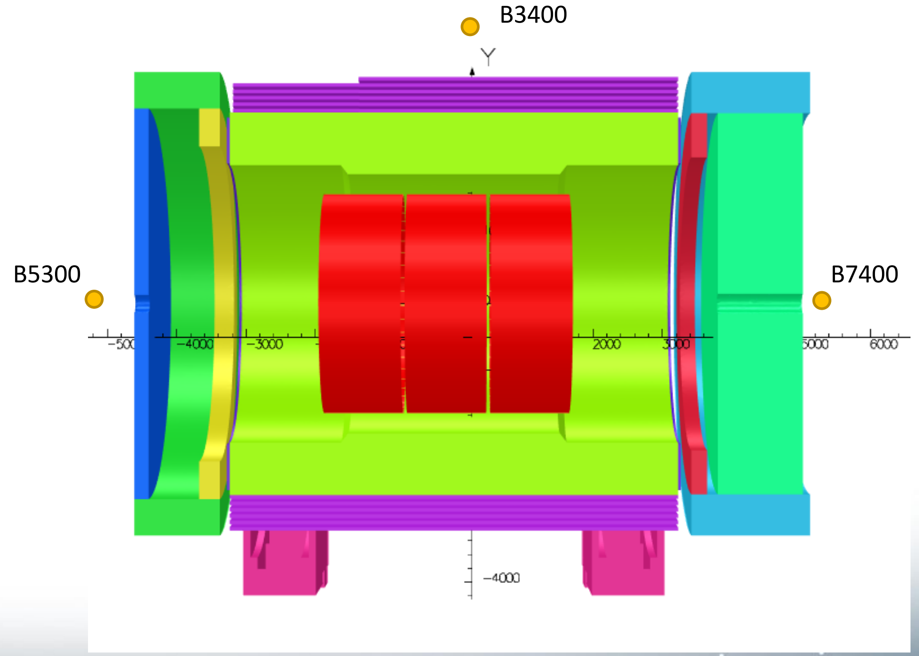


MARCO Magnet Specifications

Parameter	Value
Coil length	3512 mm
Warm bore diameter	2840 mm
Cryostat length	< 3850 mm
Cryostat outer diameter	< 3540 mm

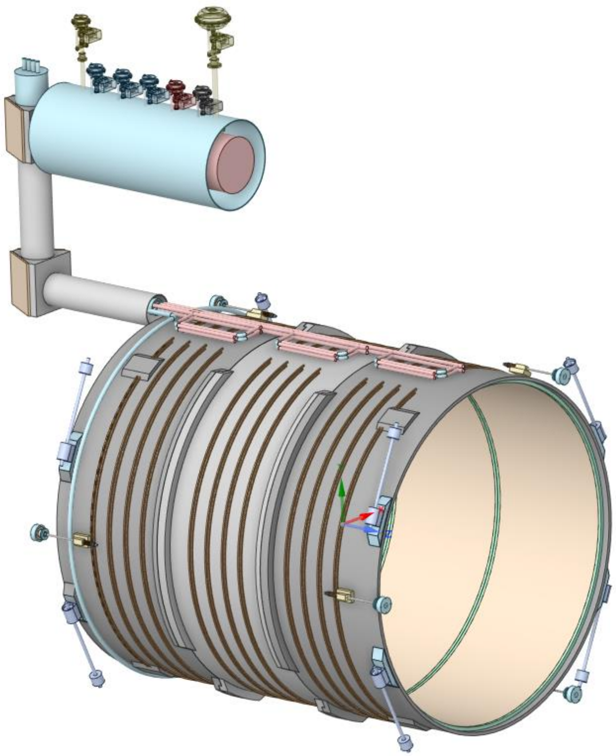
Parameter	Value	Comment
B5300 (B @ Z= -5300 mm)	< 10 G	**Stray field requirement is based on IR magnet location**
B7400 (B @ Z= 7400 mm)	< 10 G	
B3400 (B @ R= 3400 mm)	< 10 G	

Parameter	Value	Comment
Central Field B_0	2.0 T	**Magnetic Field Properties**
Lowest operating field	0.5 T	
Field Uniformity in FFA	12.5 % ± 100 cm around center 80 cm radius	
Projectivity in RICH Area	< 0.1 (mrad@30GeV/c) < 10 T/A/mm² From Z = 180 cm to 280 cm	



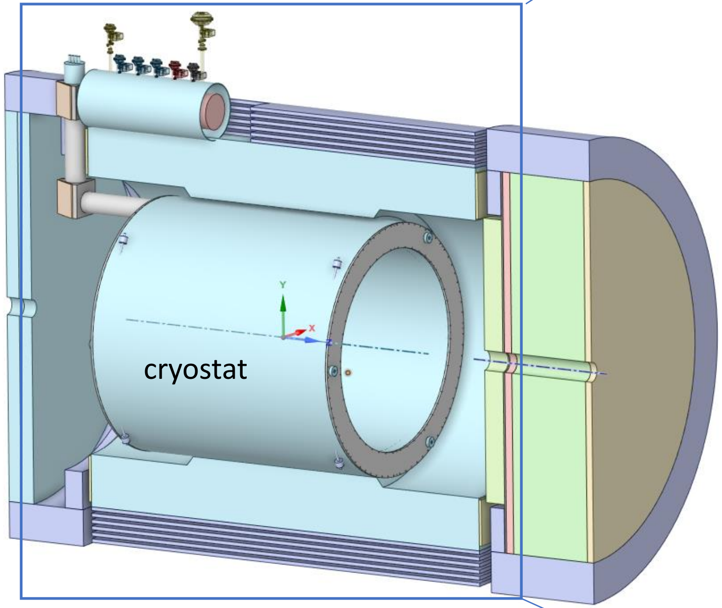
Status of the Design

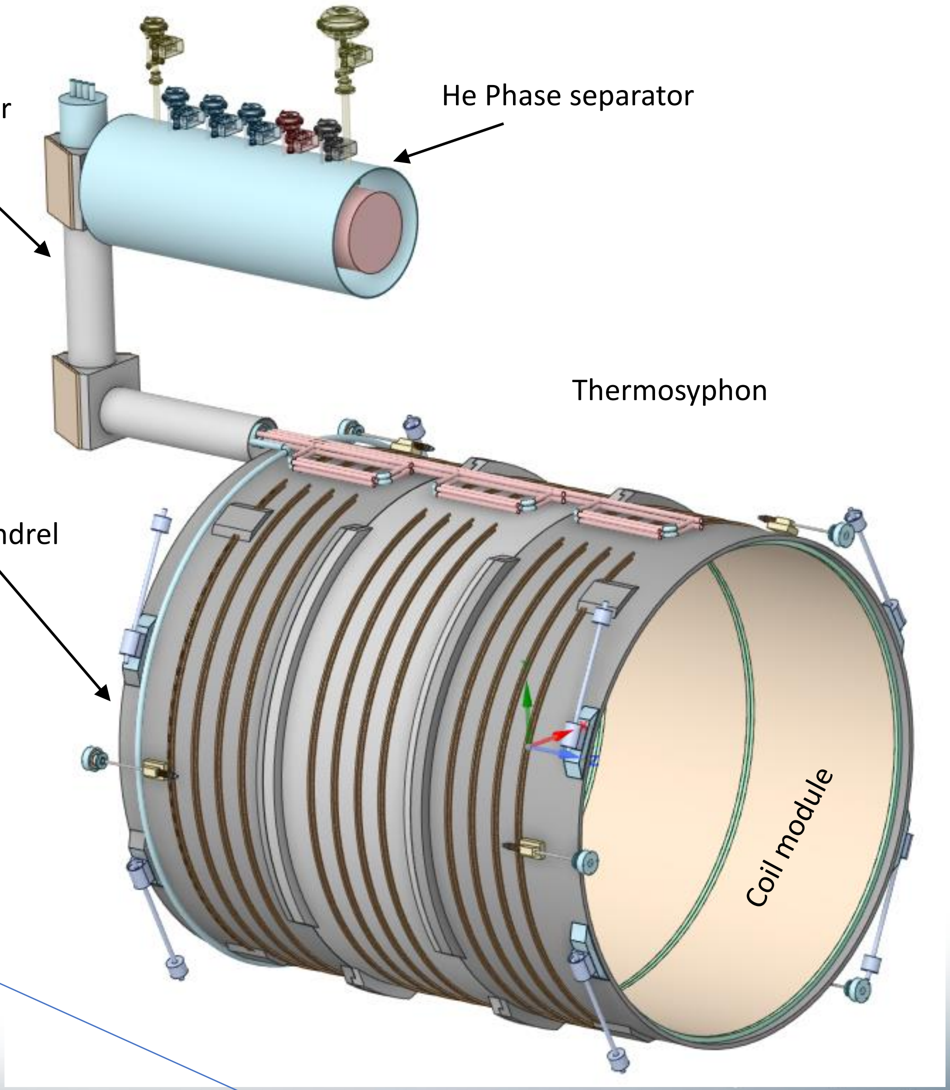
MAGNETIC Design	COMPLETED
CONDUCTOR Design	COMPLETED
MECHANICAL Design	FINALIZING
CRYOGENICS Design	FINALIZING
DEFAULT SCENARIO	FINALIZING
DRAWINGS	FINALIZING



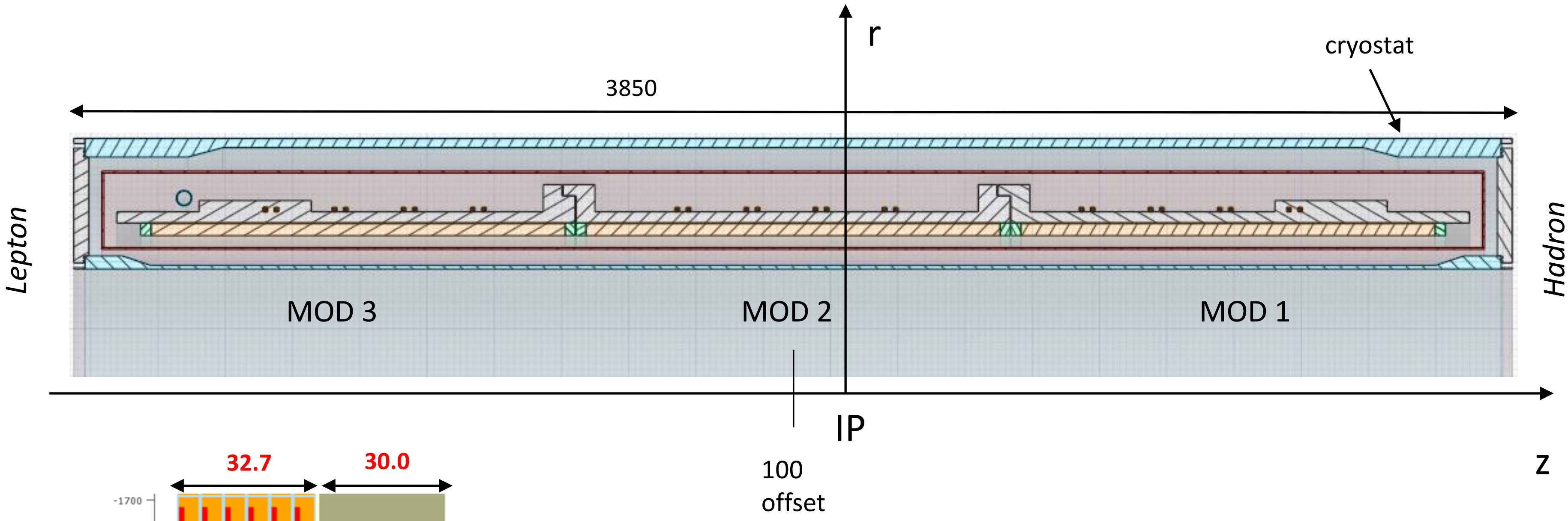
We are on schedule for the DOE Review in Nov. 2023

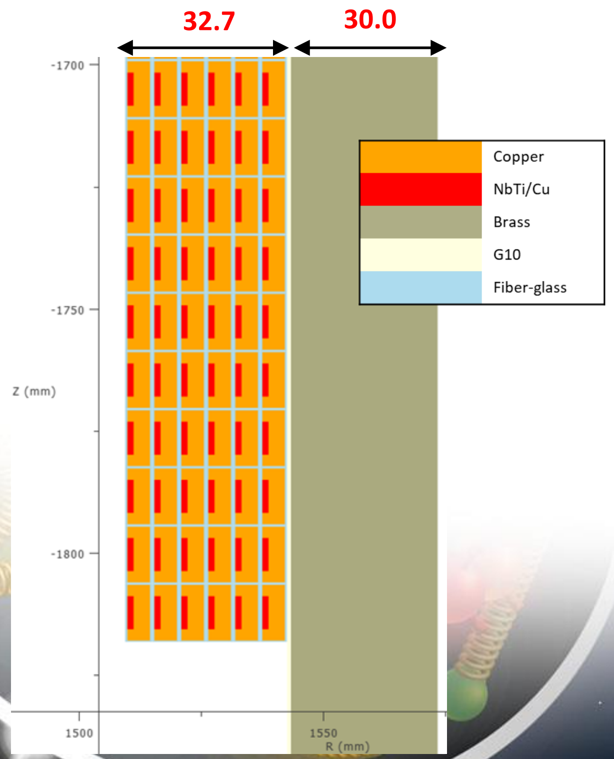
Status of the Design





Magnet Design – Cold Mass





- 3 modules
- 6 layers
- 1668 turn

Cold mass average thickness = 63.7 mm

Interaction Length Limits

TRANSPARENCY
for the transverse momentum

Mean range

$$\Delta x = \int 1/S(E)dE$$

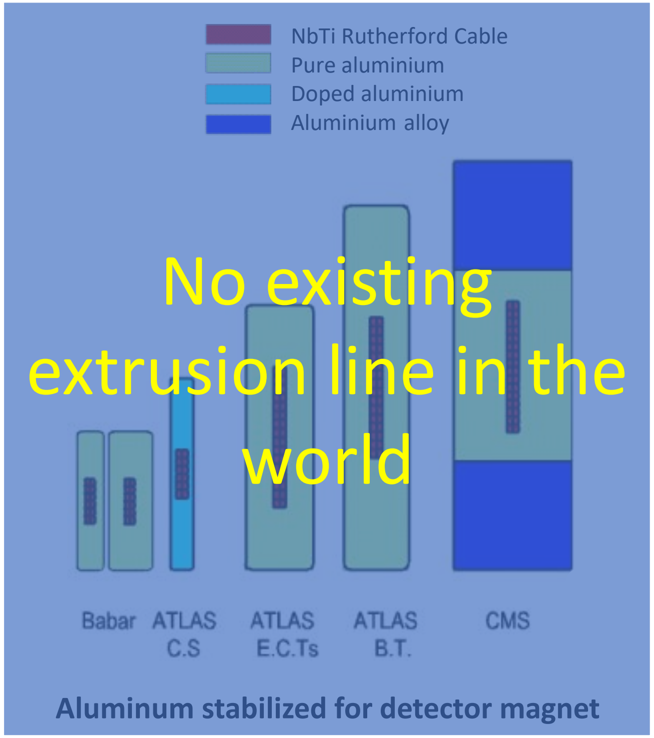
$S(E) = dE/dx \propto \rho Z/A$ (Bethe equation)

Stabilizer material for conductor

Copper $\rho \frac{Z}{A} = 4124 \frac{kg}{m^3}$

Aluminium $\rho \frac{Z}{A} = 1350 \frac{kg}{m^3}$

3x less stopping power with the same coils dimensions and NbTi fraction in the cable if Aluminum is used



Conclusions from Workshop on Superconducting Detector Magnets @ CERN, 12/14 Sept 2022

We will not be able to use Aluminum stabilized conductors for long long time

Interaction Length Limits

	Thickness/Nuclear interaction length			
Material	BaBAR 1.4 T	ATHENA SOCRATE	Marco 1.5 T (4 layers)	Marco 2T (6 layers)
Al	0.382	0.650	0.113	0.113
Cu	0.011	0.170	0.114	0.166
SS/Brass	0.000	0.417	0.136	0.181
NbTi	0.007	0.020	0.003	0.008
G10			0.009	0.028
Total	**0.400**	**1.258**	**0.372**	**0.468**

By R. Rajput-Ghoshal

We can have a magnet working at 2T with essentially the same transparency as BaBAR

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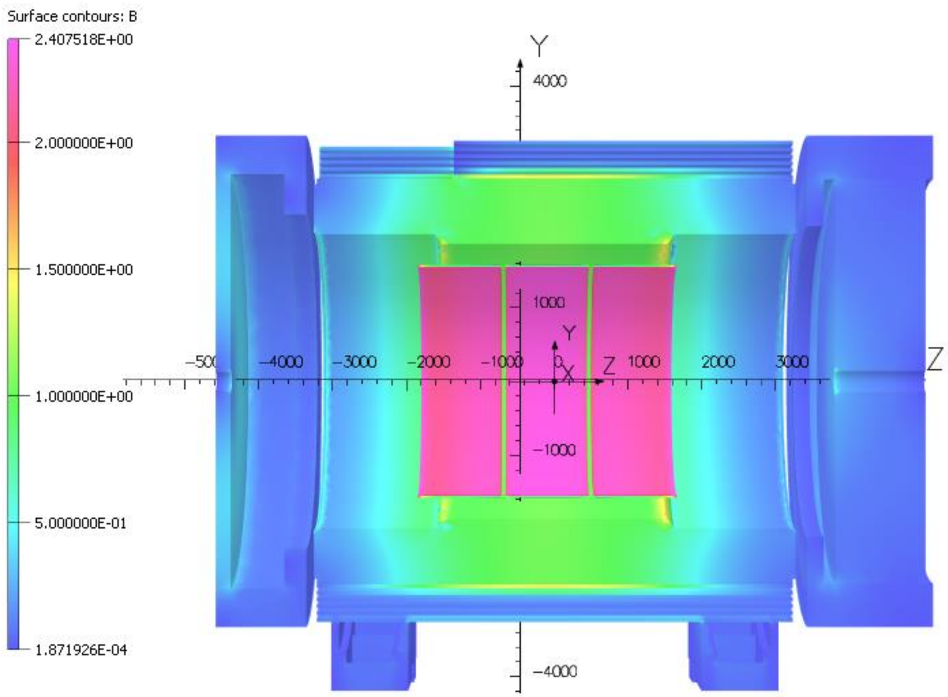
Magnetic Design Results

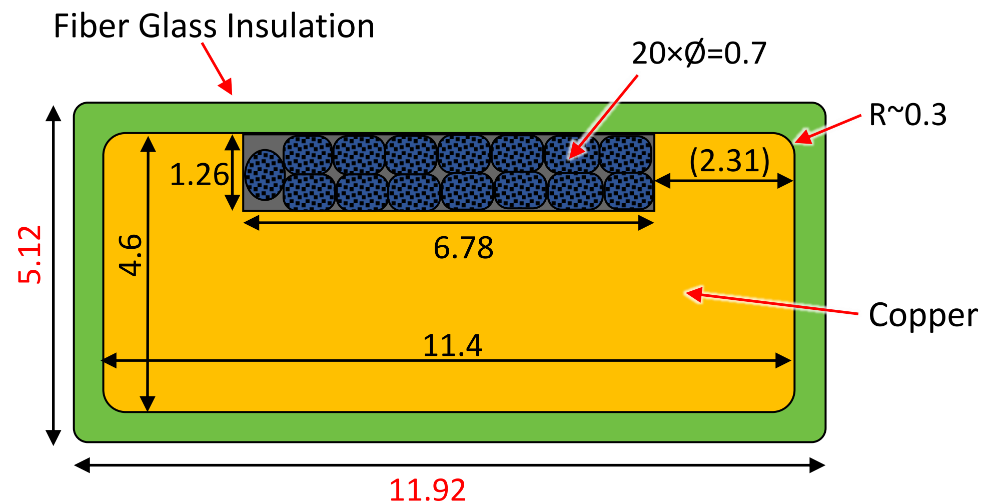
Parameter	V7.6.2.2.10 3D	Units
Current	**3924**	**A**
# turns	1668	
B_0	**2.000**	**T**
Homogeneity	**12.7**	**%**
Projectivity	**3.28**	**Tmm²/A**
Bpeak (MOD 3)	2.671	T
Energy	**45.010**	**MJ**
Inductance	5.846	H
Fz MOD 1	11.88	MN
Fz MOD 2	57.5	kN
Fz MOD 3	-11.97	MN
Fz tot	**-32.4**	**kN**
Fr Tot	**112**	**N**
B5300	**15.3**	G
B7200	**10.9**	G
B3400	**2.4**	G



Fringe field will be compensated with local shielding around the focusing magnet

Conductor Design

	Parameters	Values	Units
Strand	Strand diameter	0.7	mm
	Cu/NbTi	1.3	
	Ic @ 2.6T & 4.7K	> 680	A
	Filament diameter	< 30	µm
	RRR Cu	> 80	
Cable	NbTi strands	20	
	Transposition pitch	50	mm
Channel	RRR Cu	> 100	
	Copper section (Final)	43.7	mm²
Conductor	Nominal current	3924	A
	RRR conductor	> 100	
	Temp. margin @ 2.6T & 4.7K	2.5	K
	Hot spot Temperature	71.4	K
	$\sigma_{0.2\%}$ @ 293K	> 165	MPa
	Unit length	1.05	km
	Total length	18.9	km



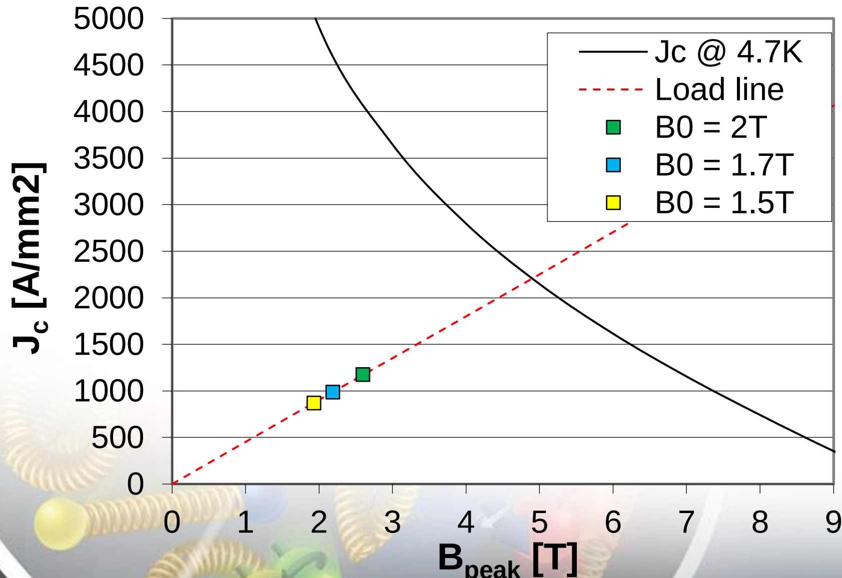
Dimensions are in mm

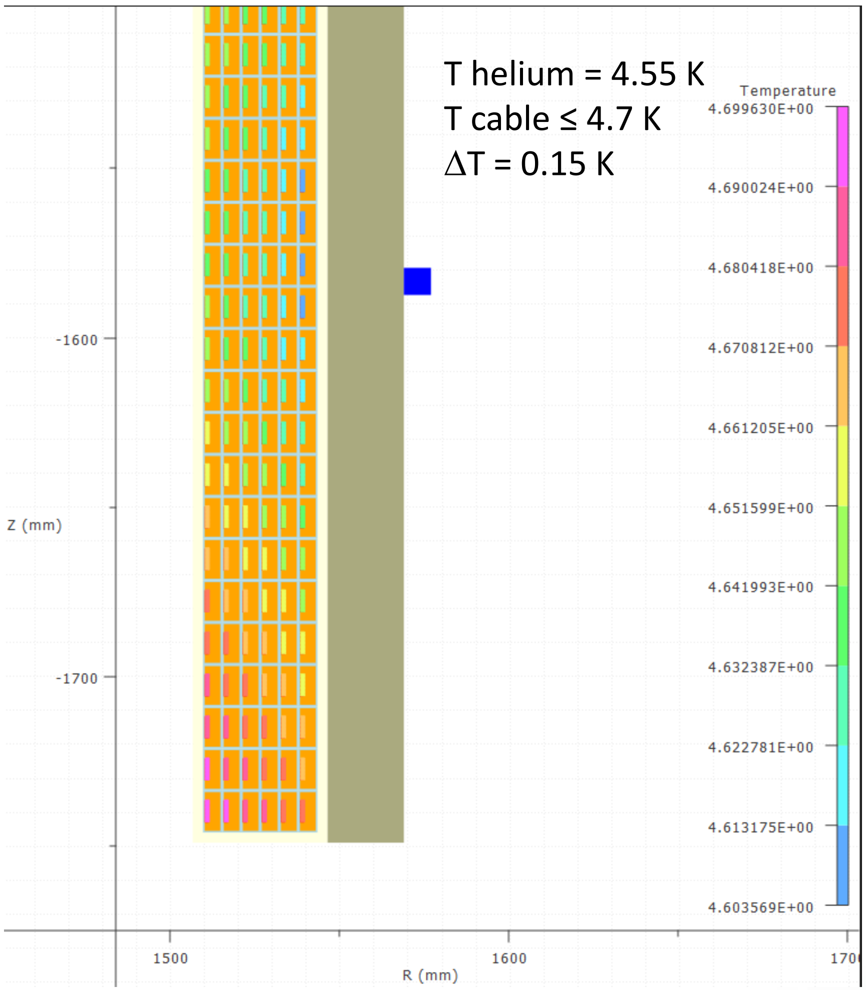
Order of conductor samples put in place based on these specifications

- ***First samples in October 2023***
- ***Contacting labs to test them***

Conductor Margins

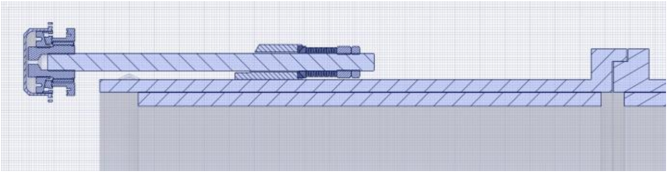
B_0	1.5 T	1.7 T	2.0 T	Units
Current	2900	3296	3924	A
B_{peak}	1.925	2.187	2.602	T
Temp. margin	**3.1**	**2.9**	**2.5**	**K**
Enthalpy margin			**7.4**	**kJ/m³**
Load line margin	60.6	55.3	46.8	%
$I / Ic(T_m, B_{peak})$	17.3	21.3	28.8	%





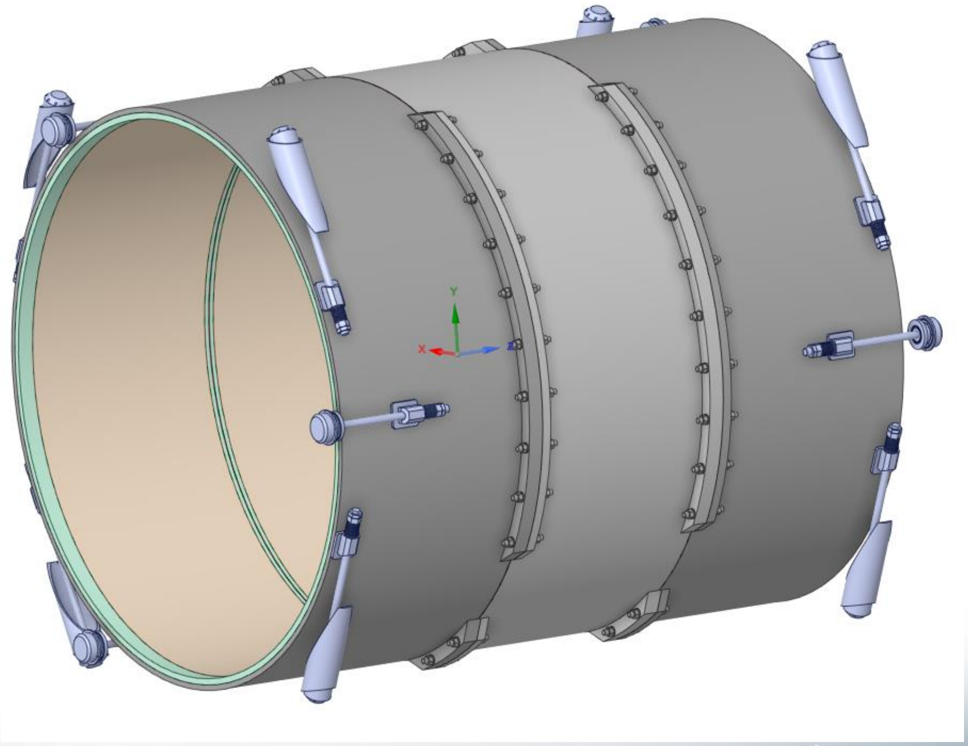
CMS works at 1.8K of margin

Mechanical Design



Finalizing the detailed design

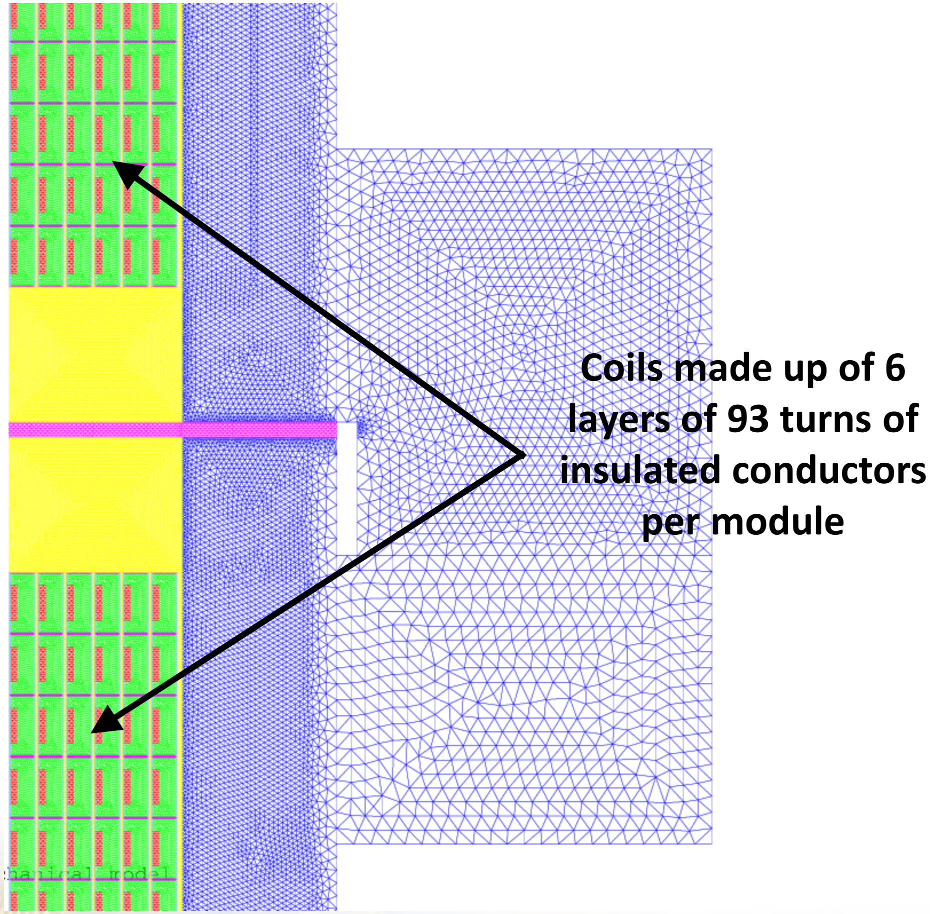
- Mandrel design completed
- Tie-rods finalizing
- 2D Model ready
- 3D Model finalizing

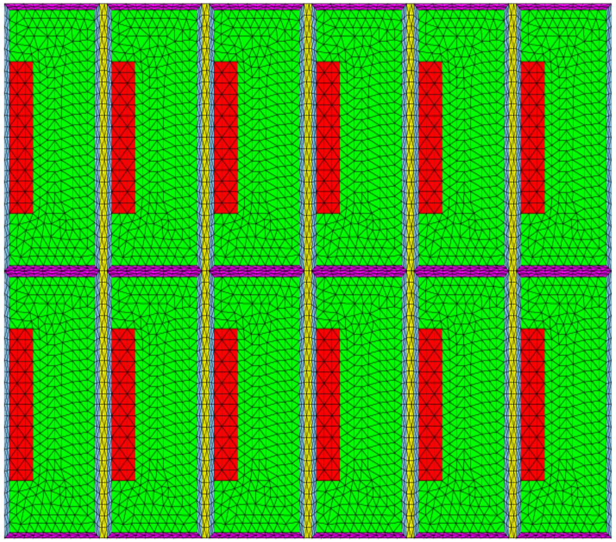


MECH Design includes

- Nominal CASE
- How to transport the magnet
- Tolerances

Magnetic Design 2D Results



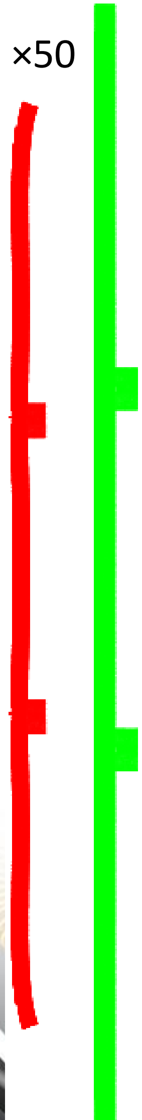


Each insulated conductor is composed of:

- **Superconducting cable (in red) where magnetic forces are calculated for energization simulation**
- **Cu stabilizer (in green)**
- **Horizontal (in pink) and vertical (in blue) conductor insulation made of glass fiber**

Magnetic Design 2D Results

Deflection

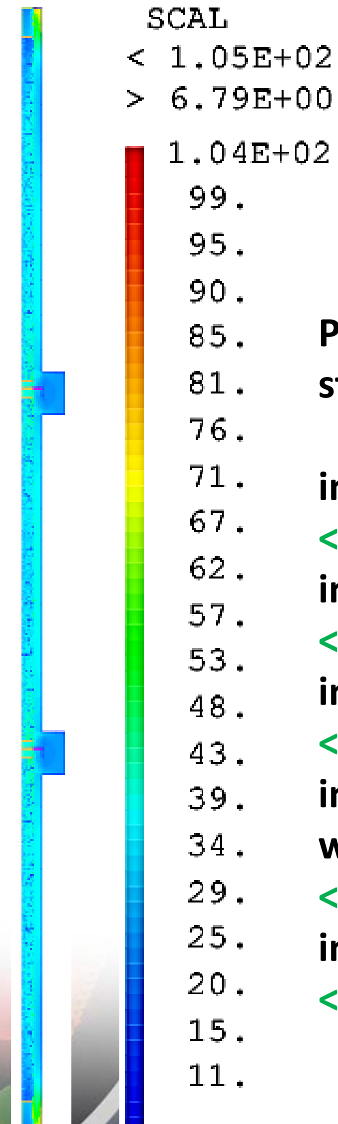


Dr max = -5.89 mm

Dz max (top) = -6.61 mm

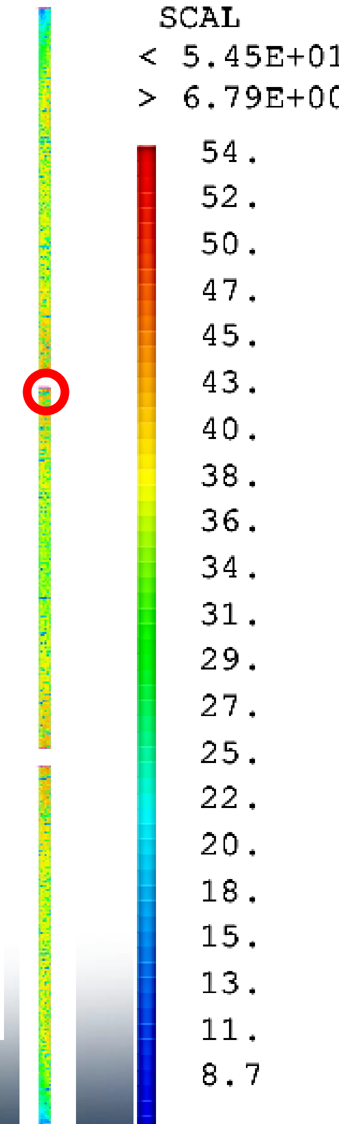
Dz max (bottom) = 6.61 mm

Brass avoid separation btw coils and mandrel during cool-down



Peak Von Mises stress (MPa):

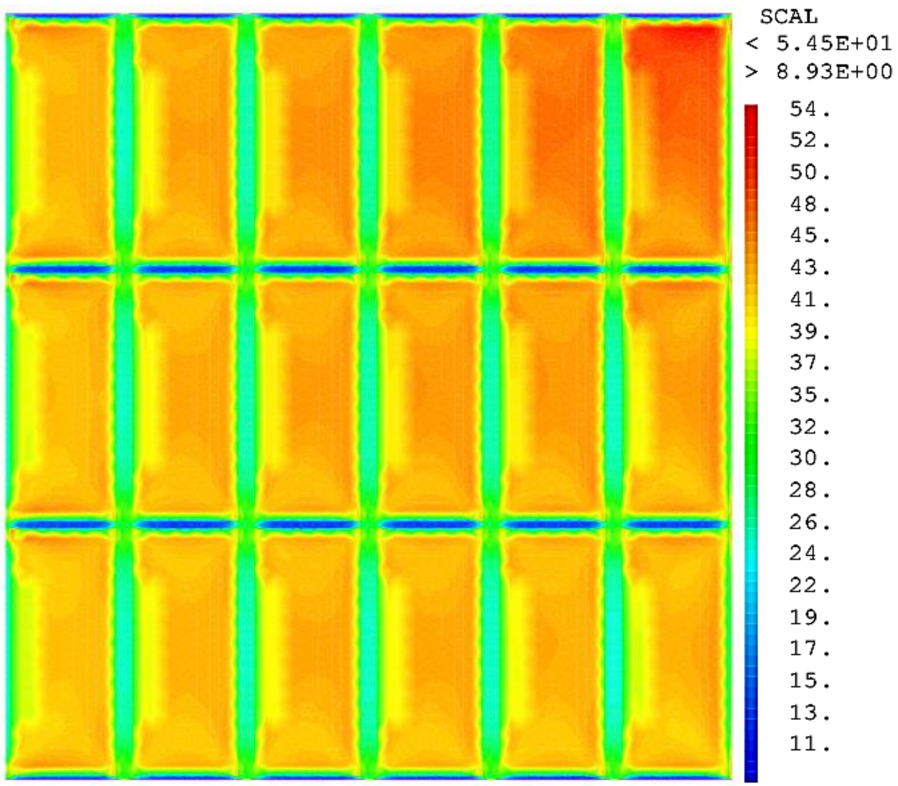
in coils = 55
< 133
in ground ins. = 53
< 198
in coil wedges = 84
< 198
in inter-module wedges = 54
< 198
in structure = 105
< 345



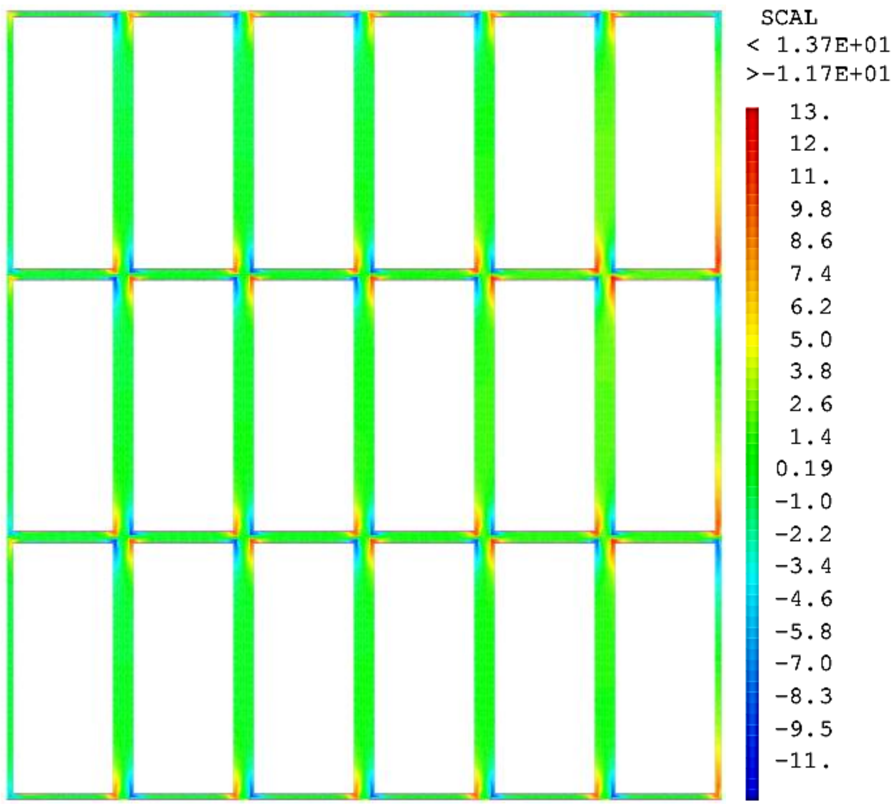
Von Mises stress distribution in coils (MPa)

Peak stress localized at the top side of the central coil

Magnetic Design 2D Results

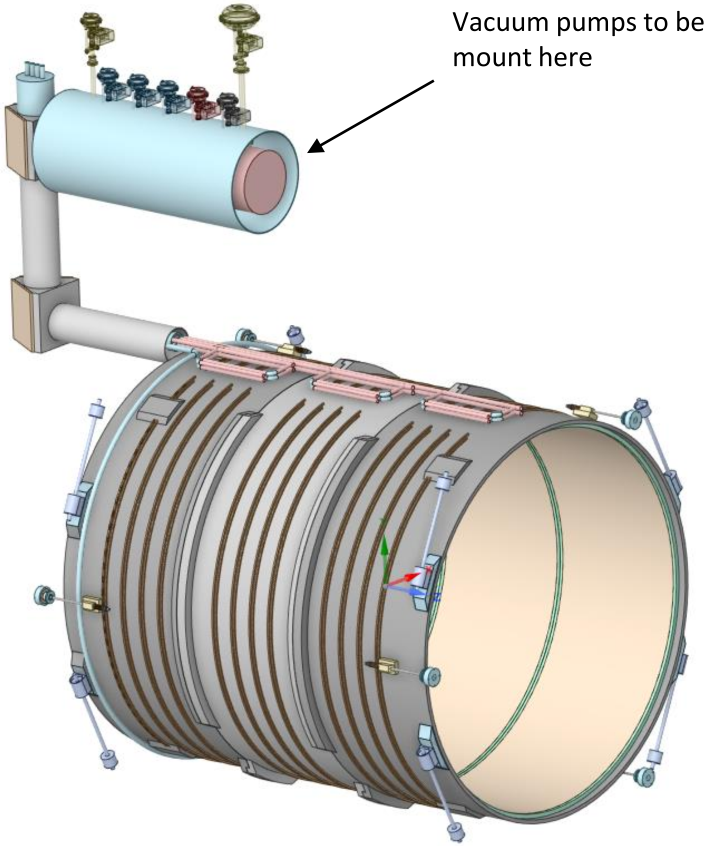


Peak Von Mises stress (MPa):
in supercond. cable = 50 < 150
in Cu stabilizer = 55 < 133
in glass fiber ins. = 49 < 198

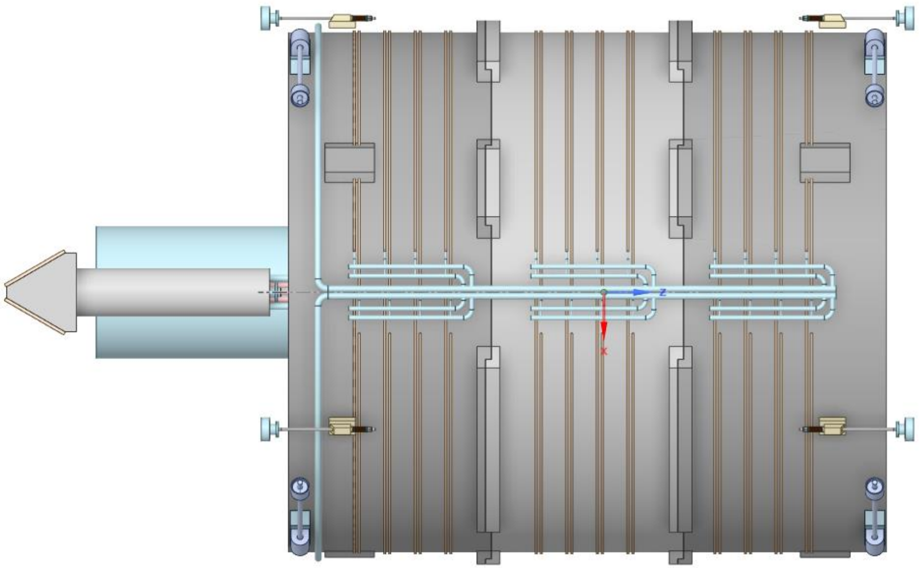


Peak Sigma RZ stress (MPa) in conductor insulation:
14 = 14

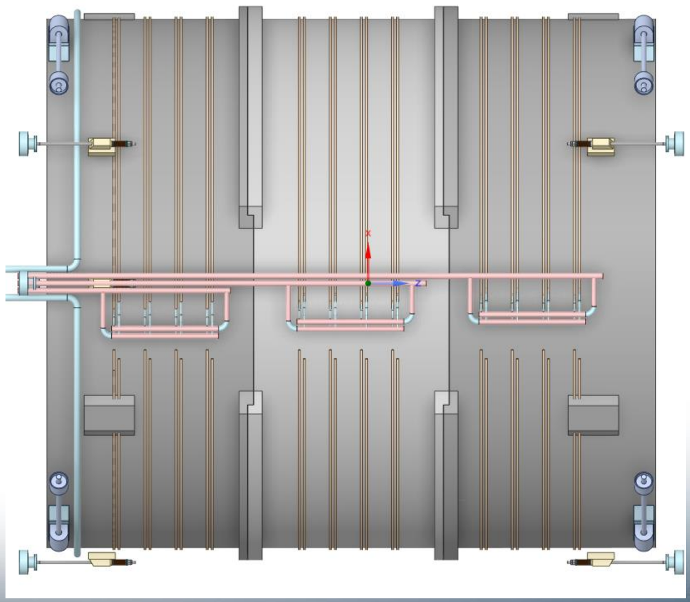
Cryogenics Design



Bottom view



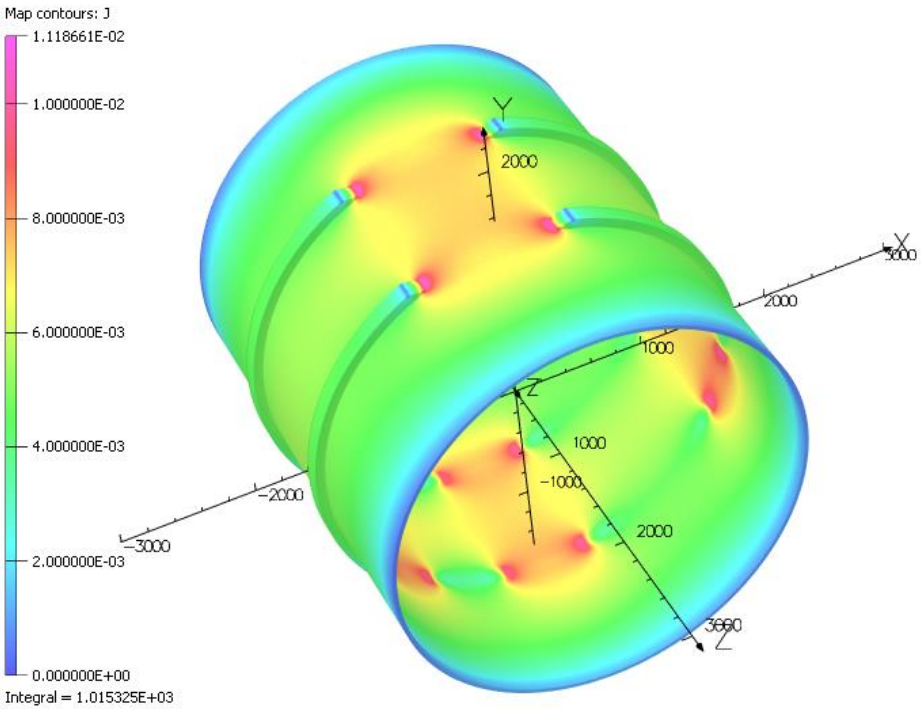
Top view



2 thermosiphons (main + spare)
Phase separator design finalizing
Thermal screen design finalizing

Ramp-up / Ramp-down

Parameter	V7.6.2.2.10	Units
Current	3924	A
Inductance	5.846	H
Ramp	**1**	**A/s**
Power	3.642	W
Eddy current	-1015.32	A
R mandrel (P/I^2)	3.516	μΩ
M mandrel	3.570	mH
L mandrel*	2.346	μH
k	0.964	



Magnet can be ramped-up/down to full field at 1 A/s → 1h15 min

Full 3D Thermal Analysis ongoing to know how long it takes to cool it down (estimated 8 days from room temperature)

Other On-going Activities

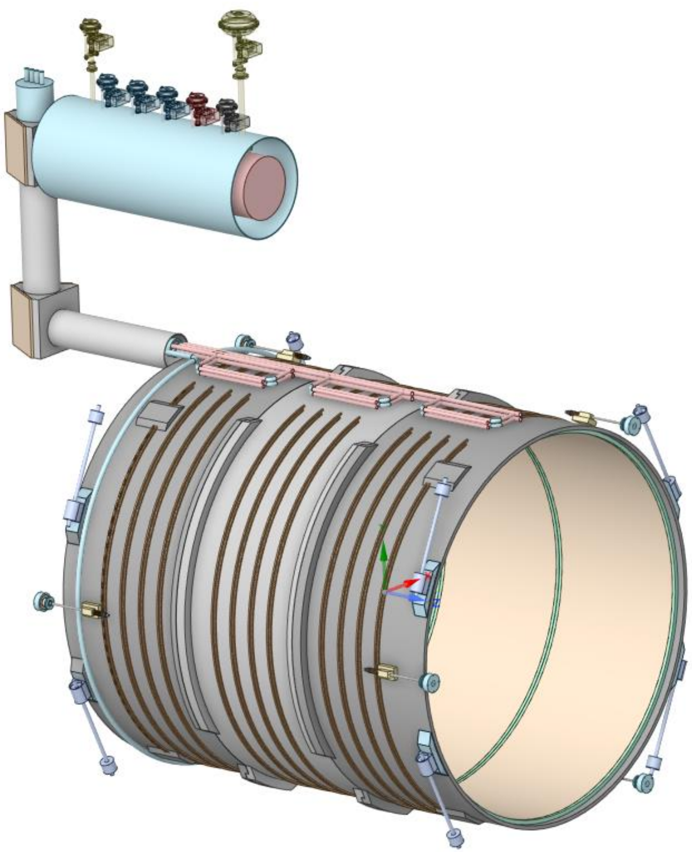
Tolerances
→ Monte Carlo simulation to study the effect of tolerances and the robustness of the design

Protection
→ Finalizing the QUENCH simulations
→ Finalizing the protection circuits
→ Expected hot-spot temperature < 100 K

Sensors
→ List completed
→ Finalizing the positions

FMEA Analysis
→ Ongoing for all components

Drawings
→ Updated daily



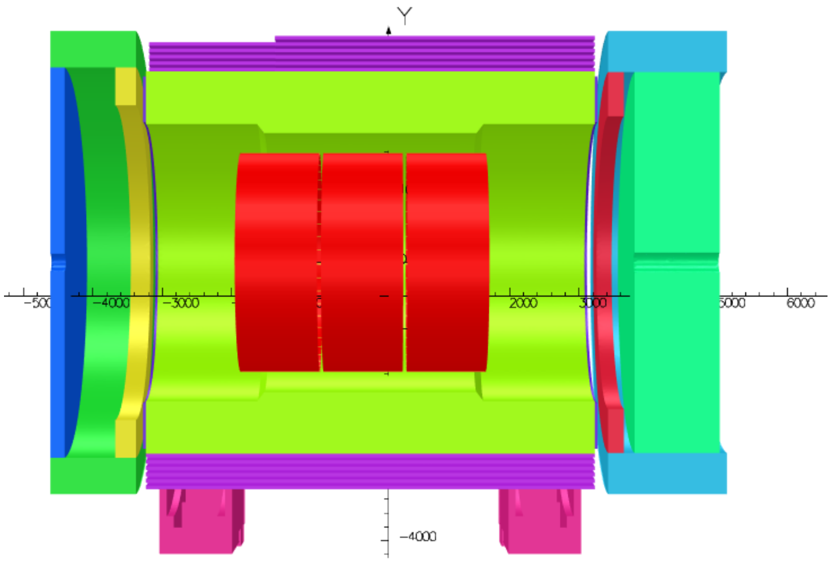
Conclusions

Superconducting Detector Solenoid
3.5 m long coil, 2.84 m room temperature bore diameter
2 T on-axis field

Conductor sample in production

Robust mechanical design

Magnet design is full of redundancies to make it work for more than 30 years



Working hard to deliver the design for the Final Review in Oct 5/6!

How we work

- Collaboration of Jefferson Lab, CEA Saclay and Brookhaven National Lab
- 30% Design done as in-kind contribution by CEA Saclay in collaboration with Jefferson Lab Magnet Group
- BNL provides subject matter expert information on infrastructure and integration
- 60% design done as contract with CEA Saclay augmented with Jefferson Lab work and further in-kind contributions of CEA Saclay
- 90% design work is in progress in collaboration with CEA Saclay
- Expectation is that vendor contract may follow similar pattern for vendor oversight.
- Further discussions ongoing on international engagement on magnet construction phase.
- October 5/6 Final Review