# SC magnet study

## Ptolemy General Meeting

## INFN-LNGS Gran Sasso, 27th June 2023

Santiago Sanz, Joseba Bastarrarena, Gustavo Sarmiento (SUPRASYS)

Matteo Tropeano, Gianni Grasso (ASG)

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

SUPRASYS

ASG SUPERCONDUCTORS

# Location

- SUPRASYS is located in the landmark building of Avenue Lehendakari Aguirre 11, in Bilbao, Spain.
- 15 minutes by car from the Airport.


SUPRASYS S.L.

VAT: B95890893

www.suprasys.es

+34 946 855 837

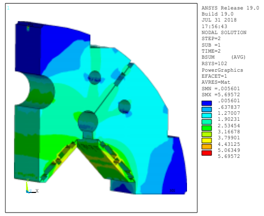
admin@suprasys.es

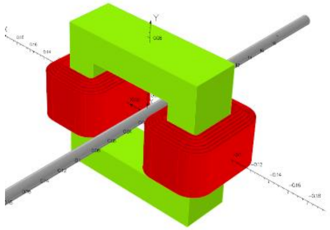
Av. Lehendakari Aguirre, 11. Planta 7
Dpto.7, E-48014 Bilbao (Spain)

# Technology based

## Electromagnetic systems

- Superconducting, resistive and permanent magnets
- Kickers & septa

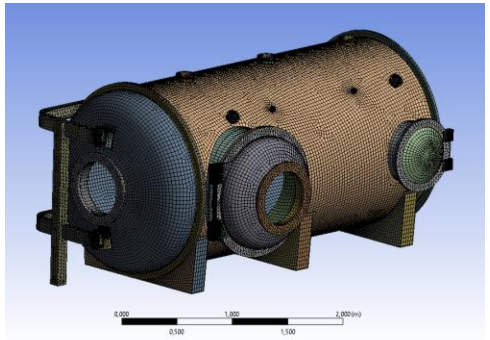




## Multiphysics analysis

- Thermal, structural, electromagnetics and CFD

- ANSYS™
- OPERA™.
- CST Studio™
- OpenFOAM®



## Cryogenics, Vacuum & Superconductivity

- Cryostat & vacuum chambers
- Cryogenic rotary joints
- Superconducting power applications

## Laboratory instrumentation and testing

- Thermometry
- Magnetic measurements
- Strain gauges measurements
- Control and acquisition systems
- Quench detection and protection

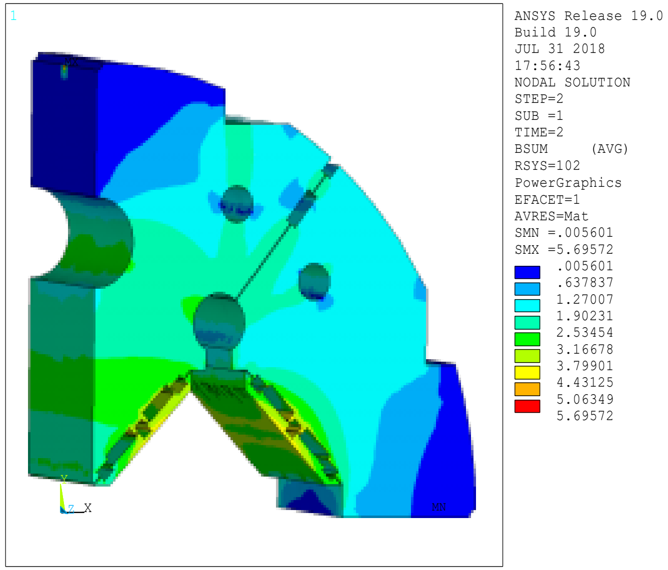
# Resources

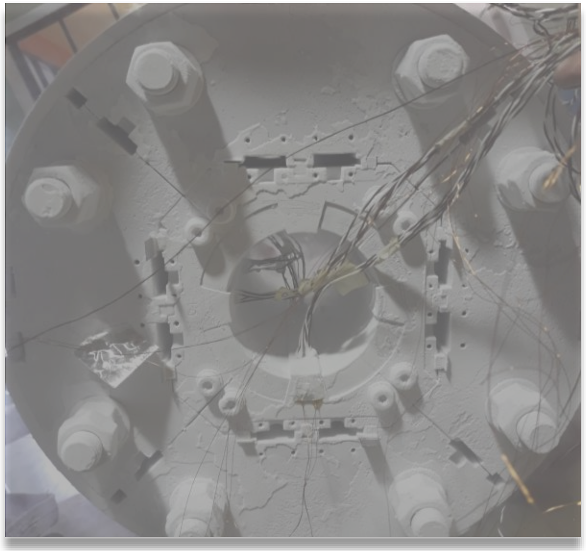
- ANSYS 19.2 Mechanical Maxwell 3D, Ansys Mechanical Enterprise and Emag.
- OPERA Simulation Software 2021
- SolidWorks Professional 2018
- OpenFOAM
- Draftsight 2020
- Simulia CST Studio 2022

# Relevant contributions

## ❑ Technical support for QUACO Phase II

- Magnet conceptual and detailed design of a first-of-a-kind magnet for CERN Hi-Lumi LHC Upgrade
- Multiphysics FEM simulations including structural and EM FEM analysis
- Mock-up design and testing (including strain gauges measurements at 77 K)

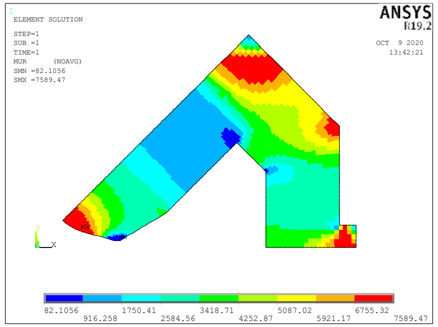


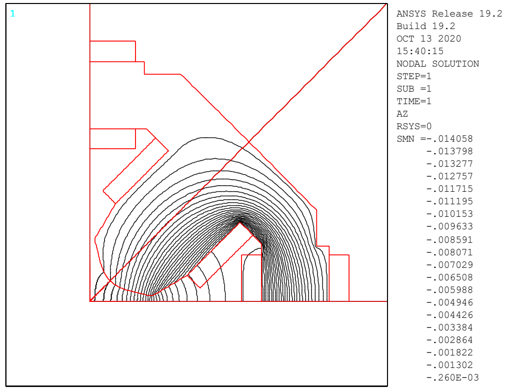



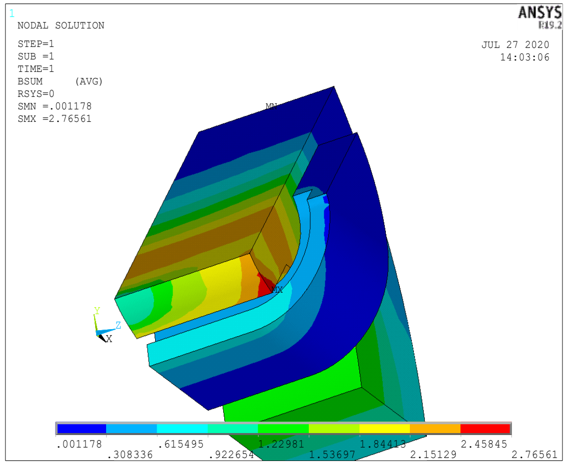
# Relevant contributions

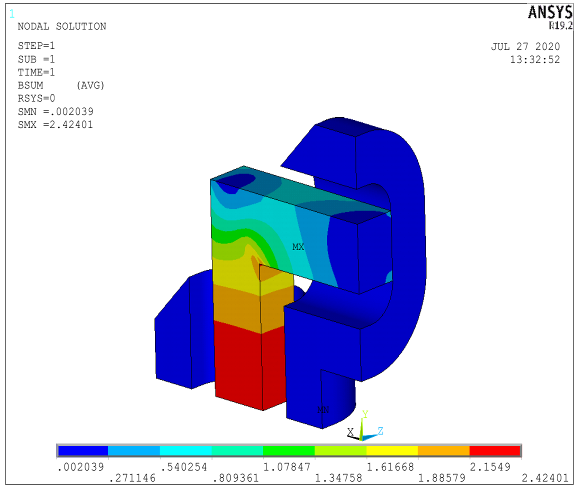
❑ **Conceptual design, EM calculations and optimization of accelerator magnets**

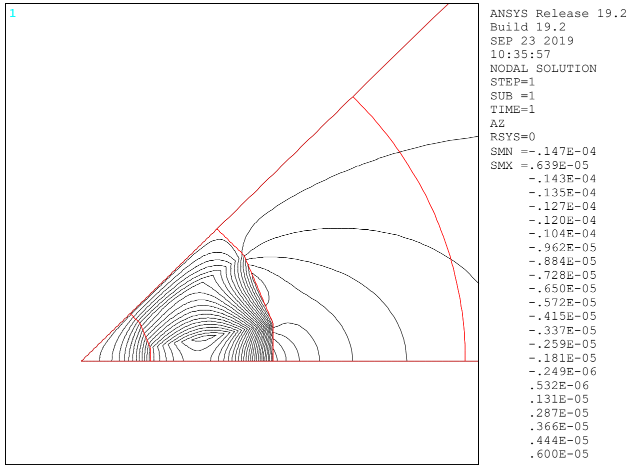
- Different type of magnets, for example:
- Combined magnets (quad + steerer) magnets
- Steerer magnets
- Quadrupole Permanent magnets
- Pulsed magnets

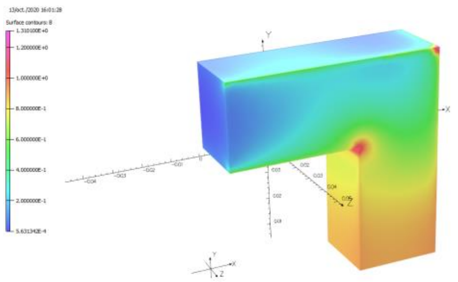


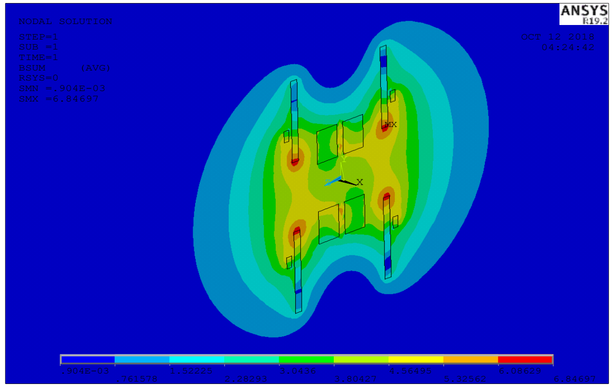



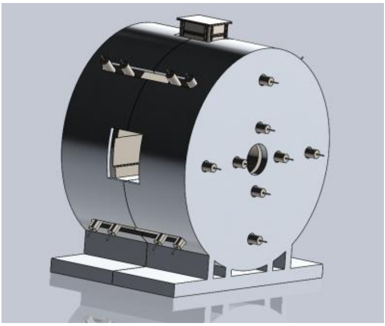



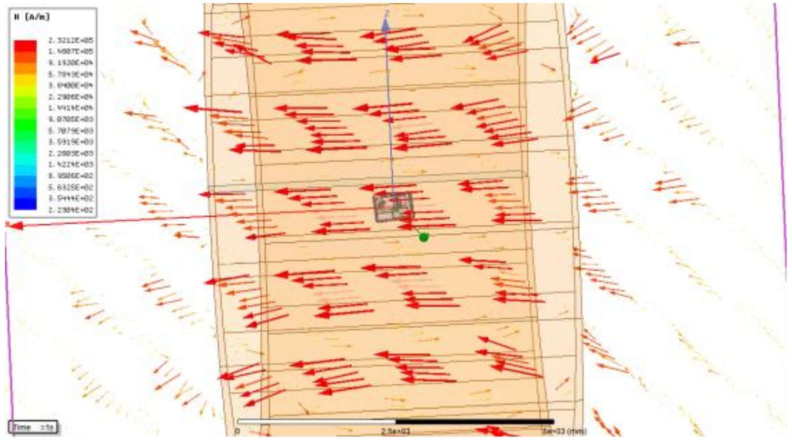
# Relevant contributions (fusion):

❑Superconducting magnet feasibility study for UKAEA




- Magnetic design.
- Mechanical design.
- Quench analysis.
- Transitory analysis.

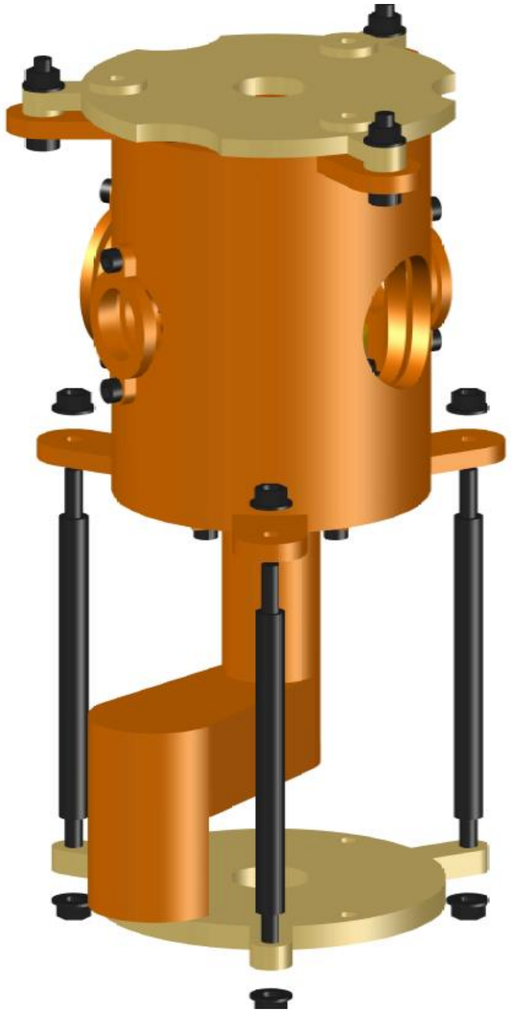




❑EM studies for ITER

# Relevant contributions

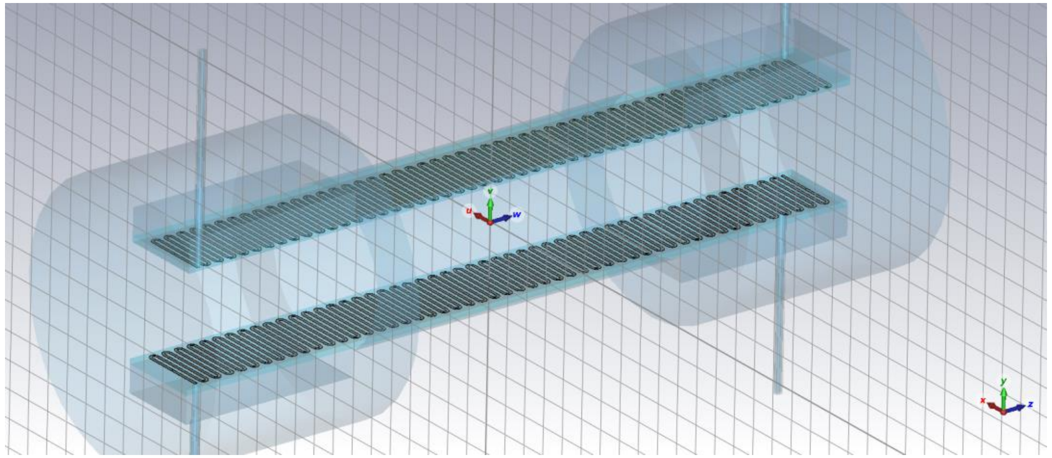
**Customized Penning ion trap.**
**Universidad de Granada.**

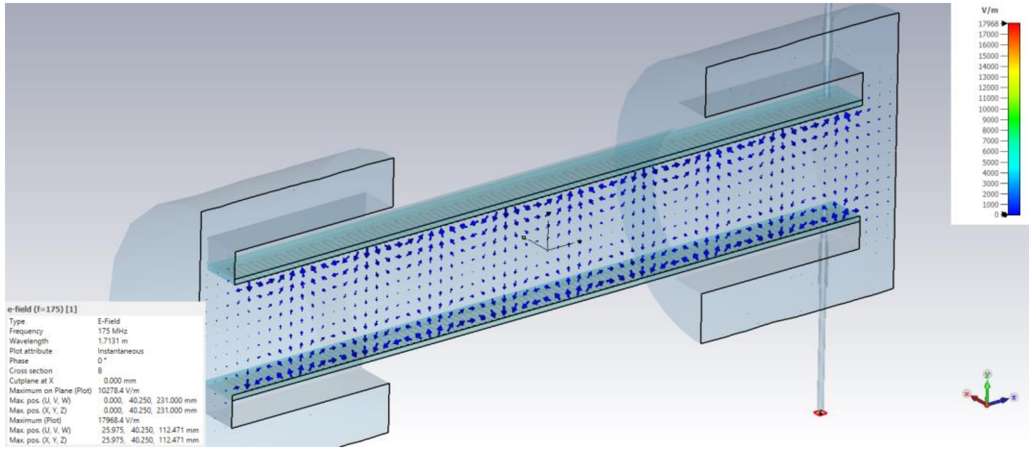


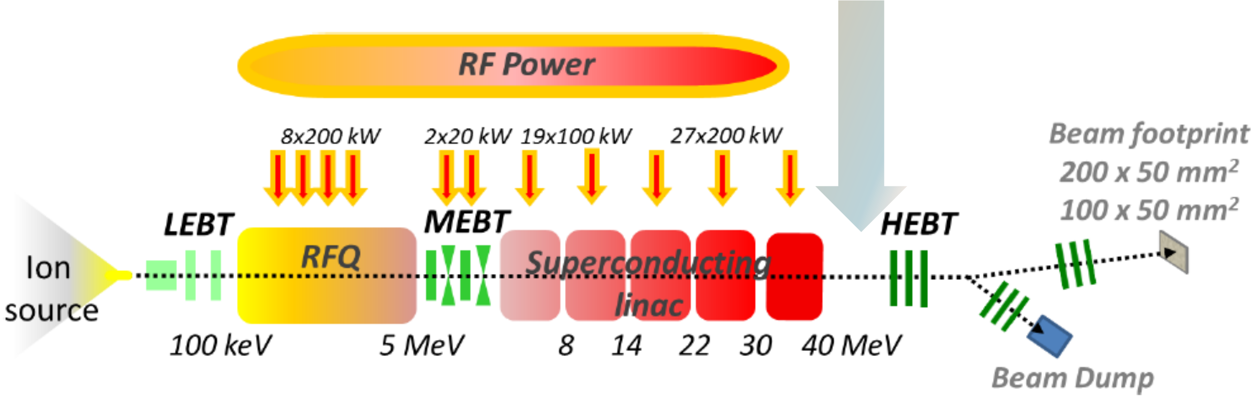
**Preliminary design by the University of Granada**

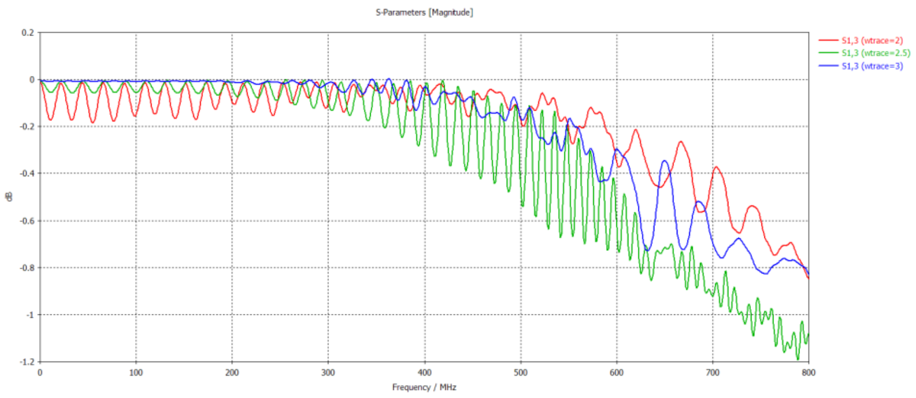
# R&D projects: DONES-EVO

- Design and experimental test for a single bunch extraction system in IFMIF-DONES.

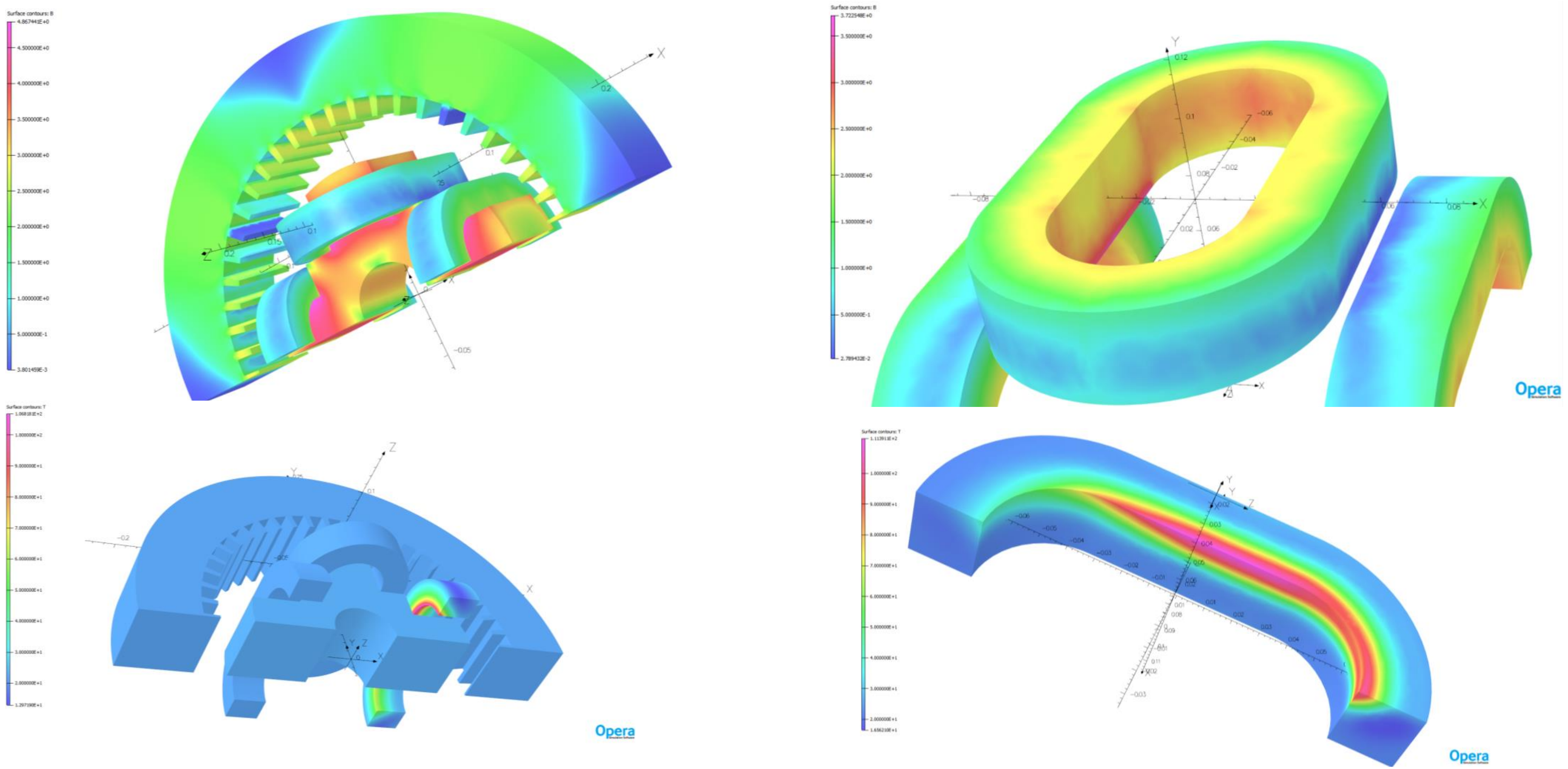






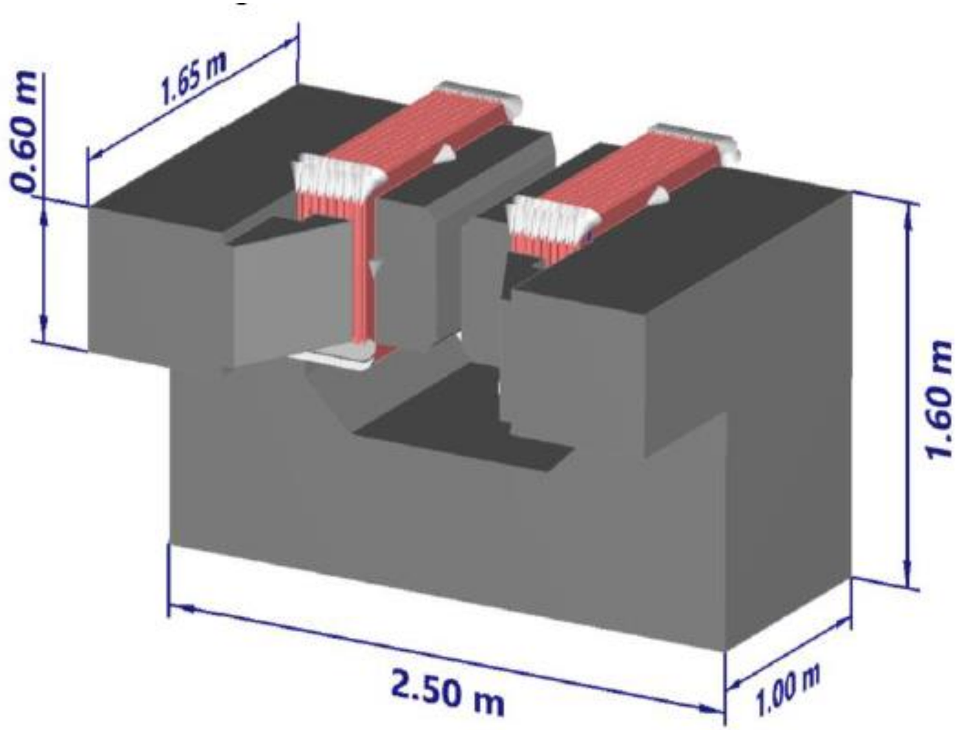



# R&D projects: HIVOMOT




- Conceptual design of a 2 MW partially SC motor at 2700 rpm for aviation
- EM and quench analysis

# PTOLEMY Full-Scale Prototype at LNGS




2.1. Magnet

| | |
|---|---|
| B field (nominal): | 1 T |
| Pole Gap: | 12 cm |
| $N \cdot I$: | 96000 Amp-turns |
| Iron core cross-section: | $0.6 \times 1.0$ m$^2$ |

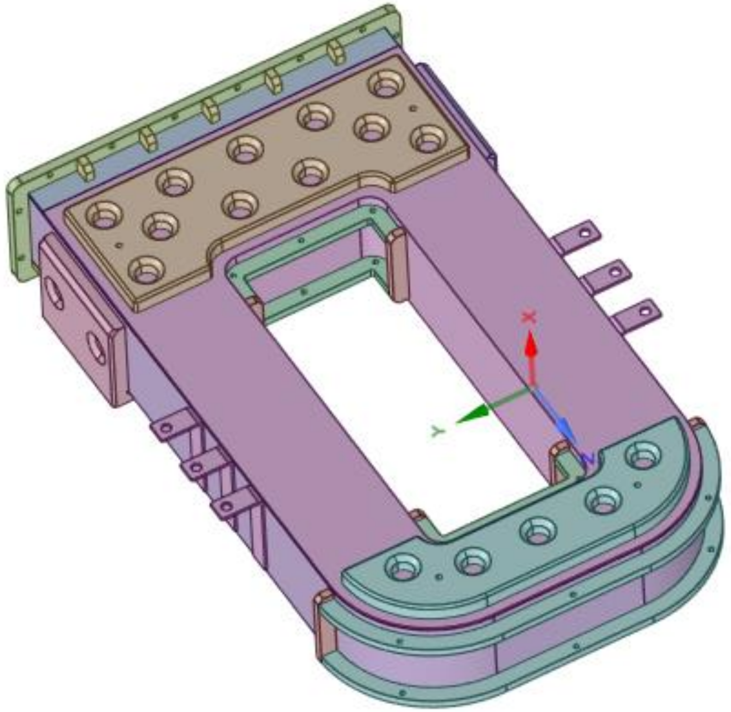
2.2. Coil

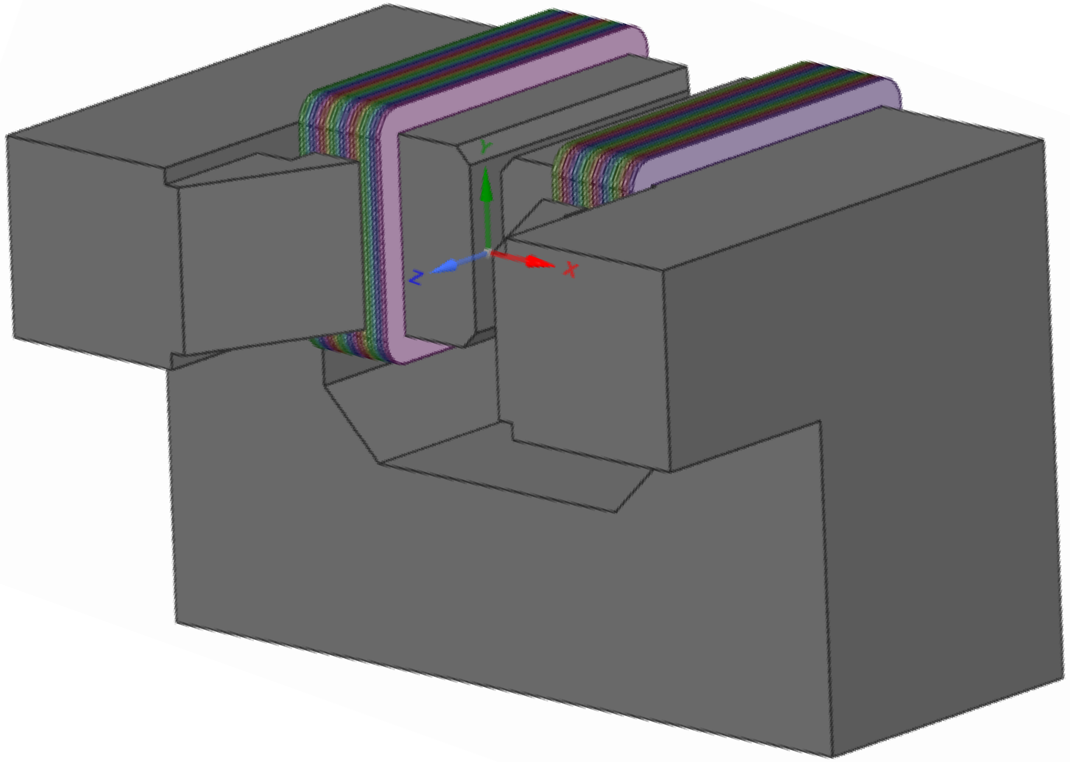
8 pairs each pole with 120-turn each running at 50 A as shown below.

| | |
|---|---|
| Total winding length $L_{avg}$ = | 3.712 m. |
| Conductor net cross-section: | $120 \times 11 \times 0.83 = 1095.6$ mm$^2$ |
| Resistance per coil: | 0.91 Ohm |
| Current density: | $j = 50/(11 \times 0.83) = 5.48$ A/mm$^2$ |
| Coil cross-section area: | $0.3 \times 0.08$ m$^2$ |

# Direct implementation of SUPRAPOWER concept

- First attempt was to consider cryostat and coils manufactured for SUPRAPOWER project



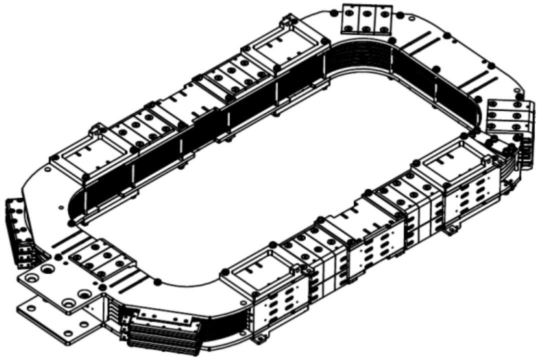



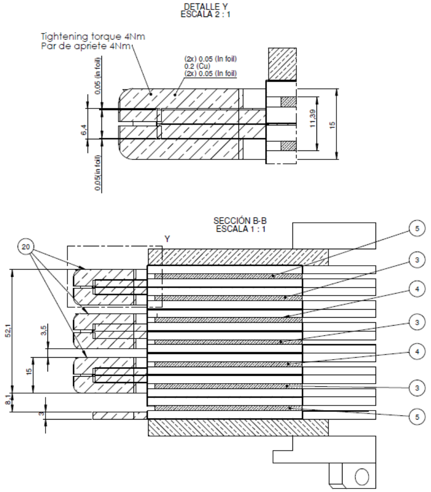

Mag_LNGS configuration

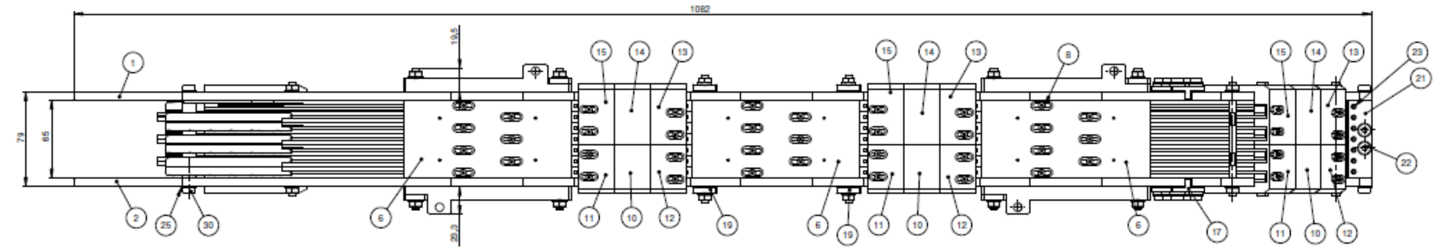
# Suprapower coil

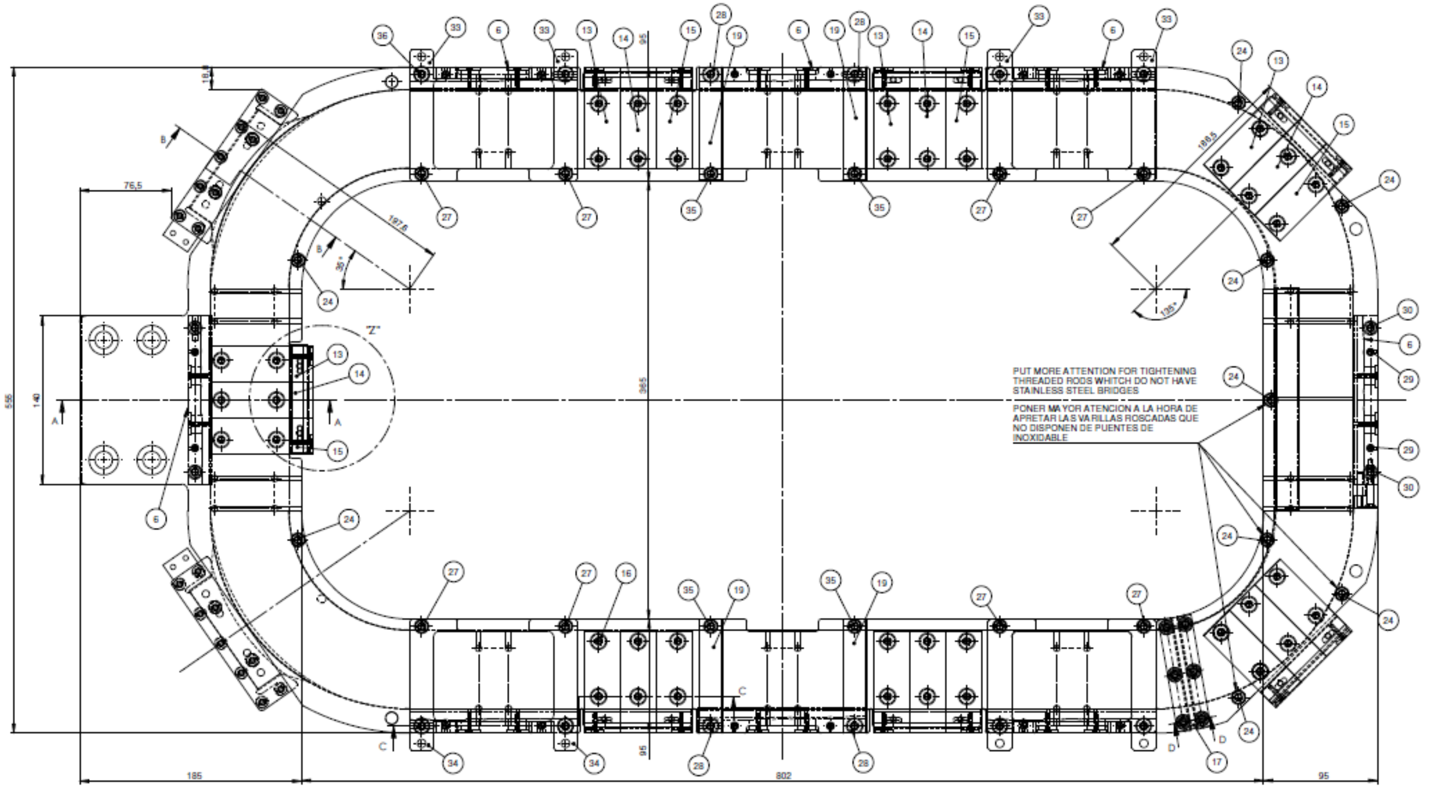
SUPRAPOWER coil is based in a stack of double pancakes, racetrack form, with a mechanical structure.

Thermal and mechanical requirements are guaranteed

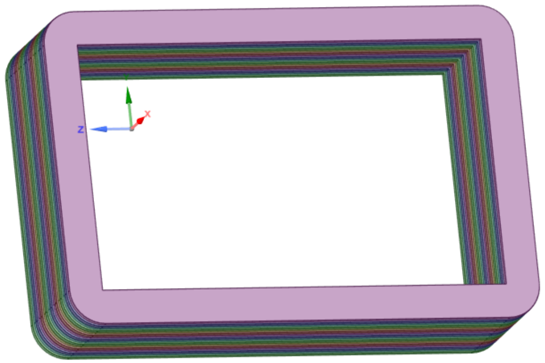


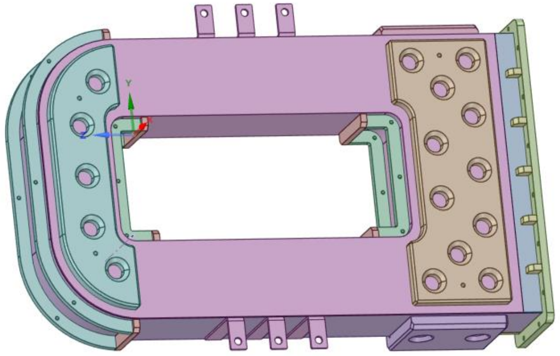


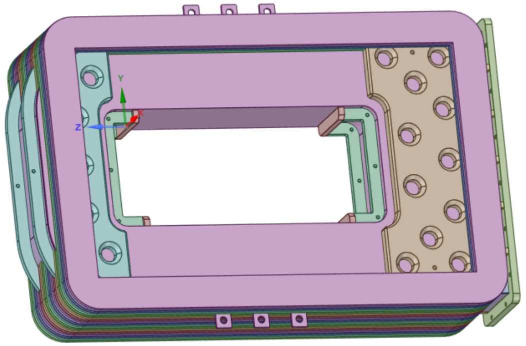



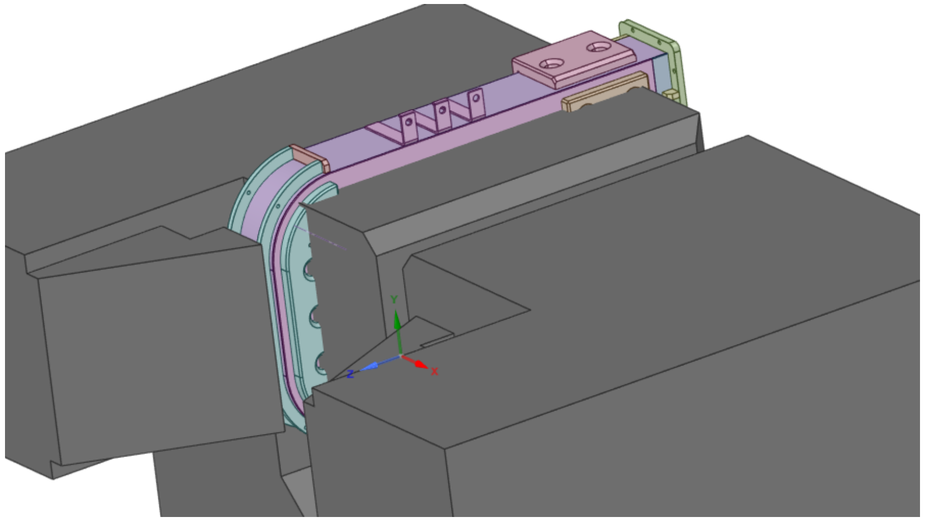
# SUPRAPOWER coil + Mag_LNGS







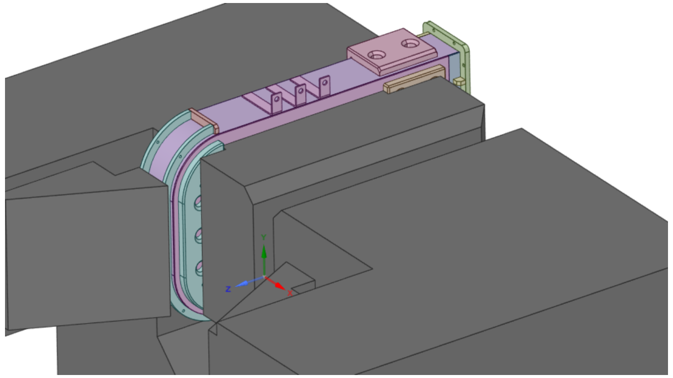
- Superconducting coils require a cryostat to keep cryogenic operation conditions.
- Suprapower cryostat plus superconducting coils, occupied more internal space than resistive coils (of ancient design)

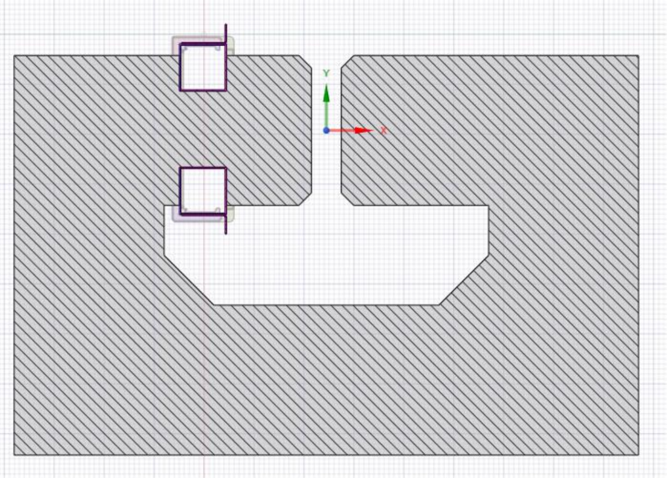


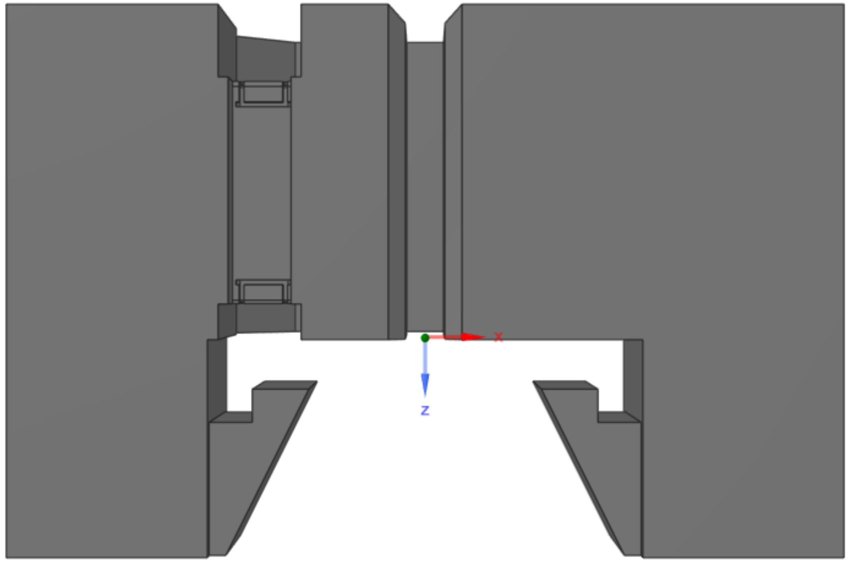
# Iron pole adaptation is required

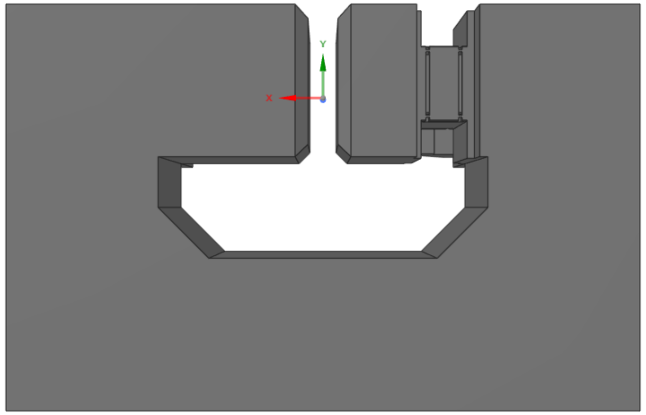
- A direct implementation of original cryostat and coils requires iron coils reduction.

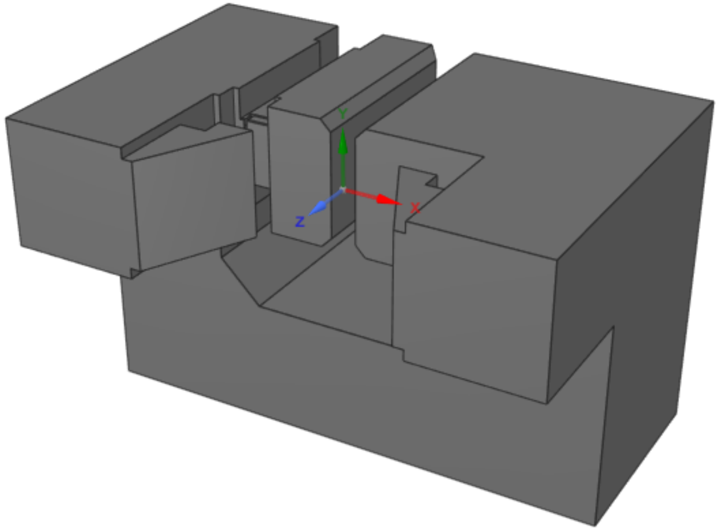
- Magnetic performance is analysed with such modification





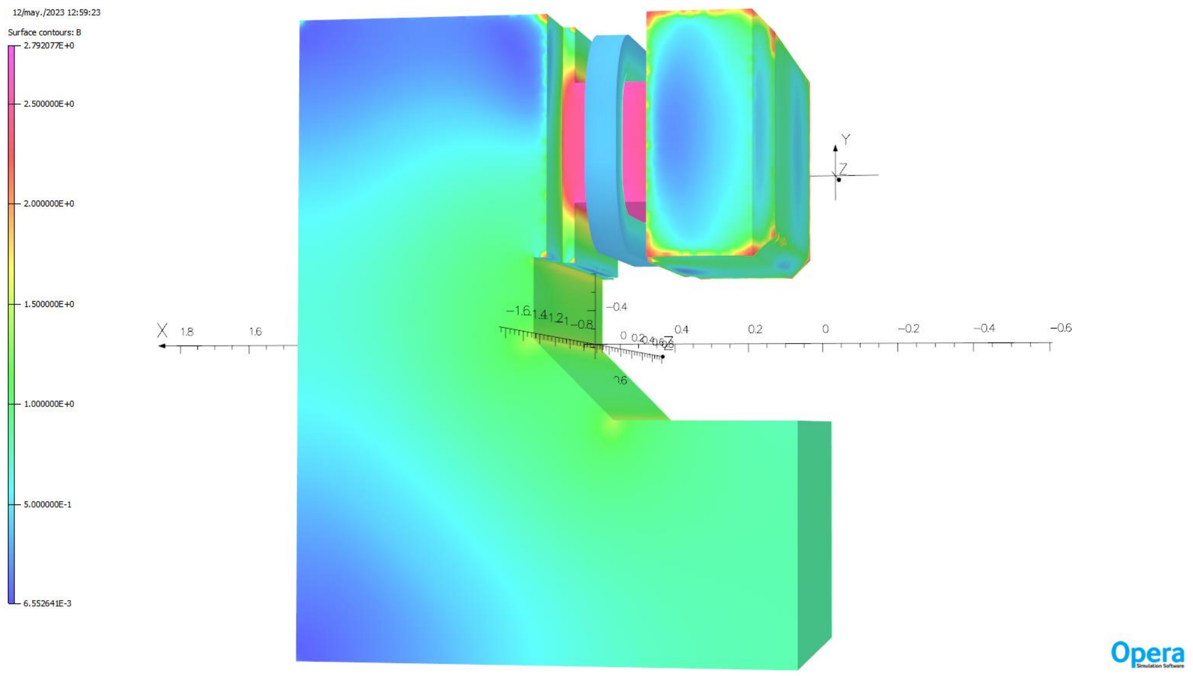


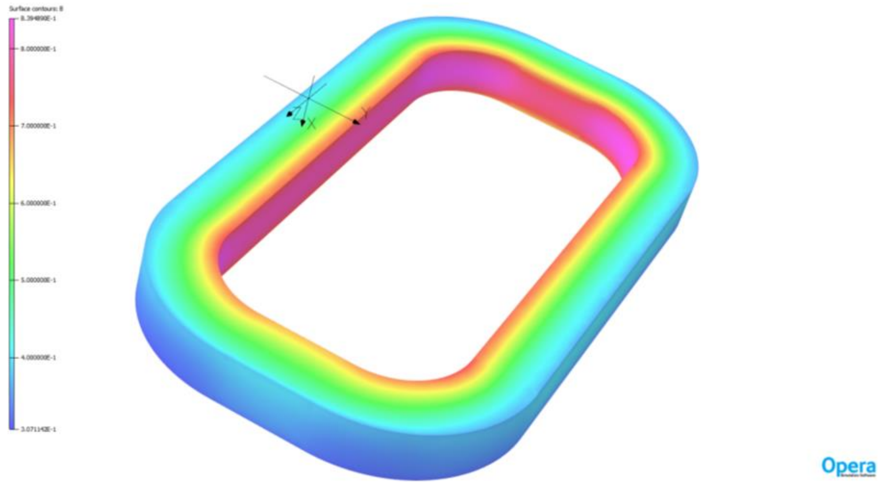




# EM Simulations with reduced iron yoke

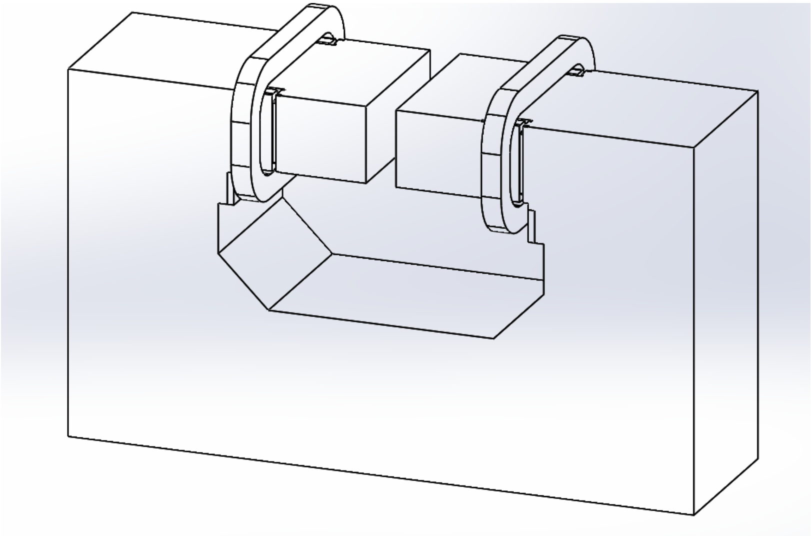
- Iron yoke is reduced to leave space for the SUPRAPOWER cryostat and coil
- Iron inside the coil bore is totally saturated
- Magnetic field  in the good field region (20 cm x 20 cm x 60 cm) of airgap is 0.5 T.
- SC coil suffers a peak magnetic field in superconductor of 1.2 T

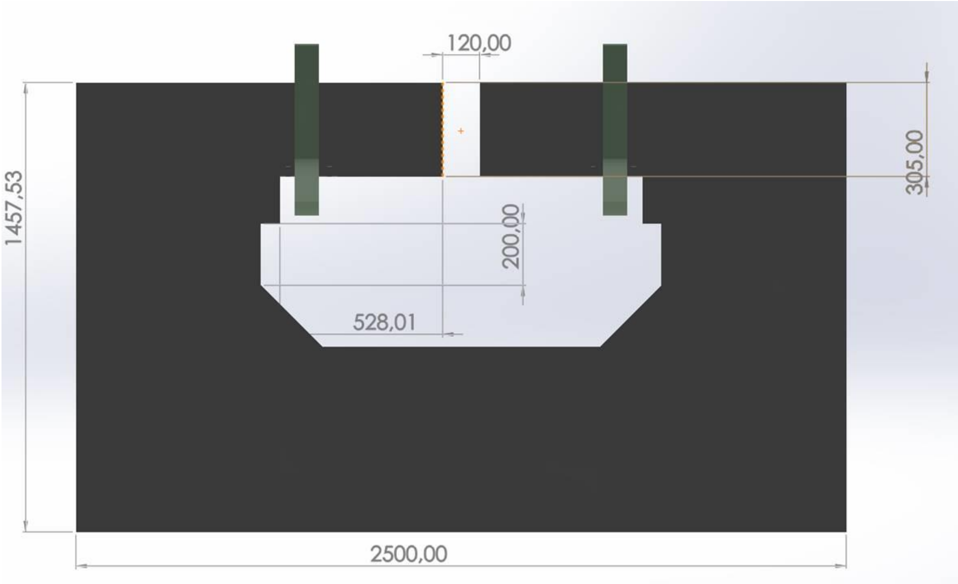


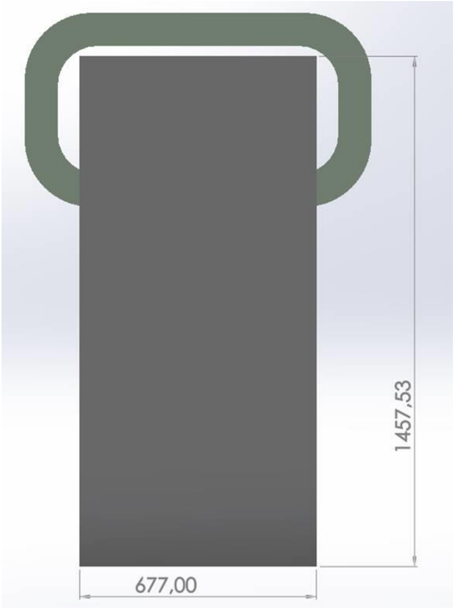



# New reduced  iron yoke to improve the design

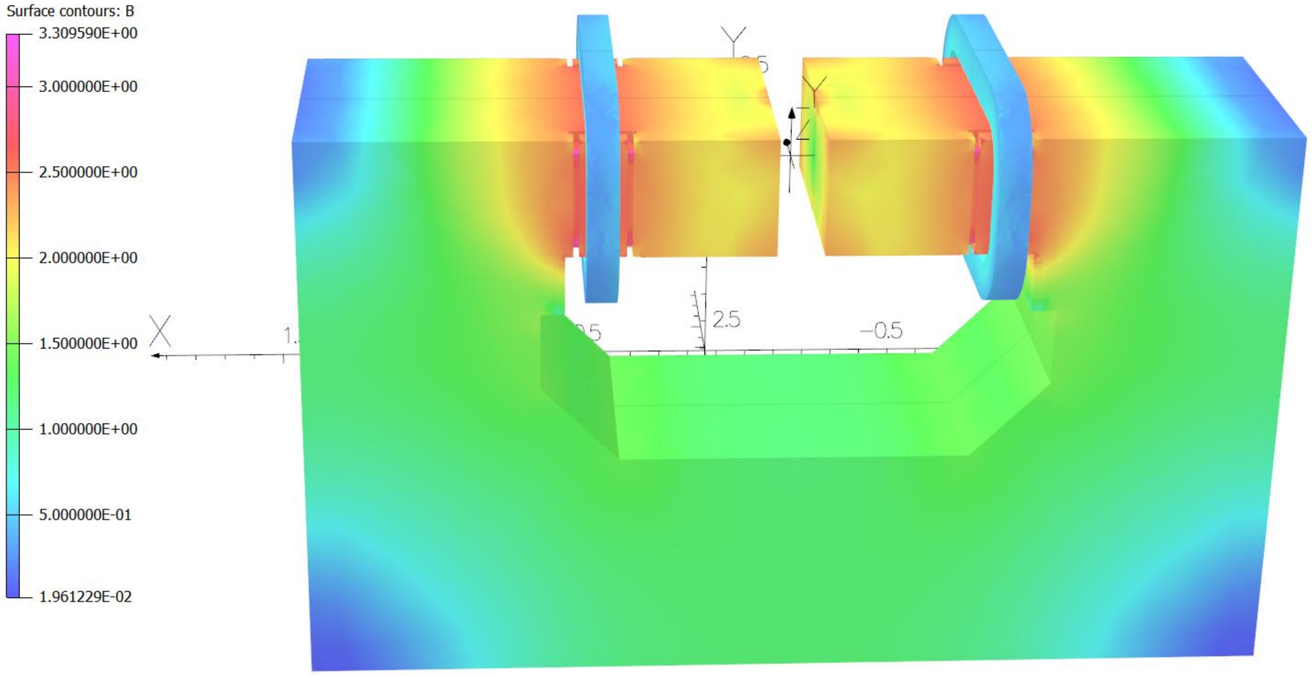
- Keeping Suprapower coils size
- Reducing the effective iron mass



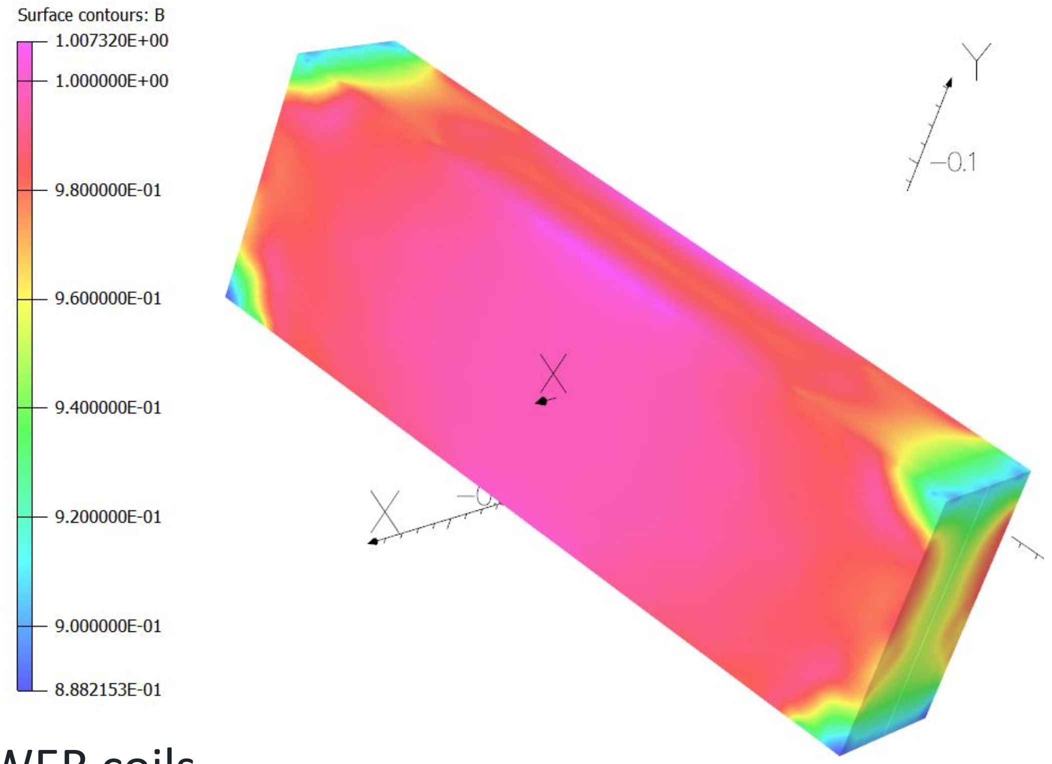


# Design with new reduced iron yoke




Good field region 20 cm x 20 cm x 60 cm in the airgap



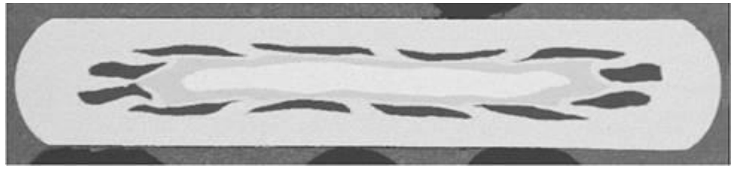

- This preliminary design keeps the size of the SUPRAPOWER coils
- It is more efficient in terms of iron yoke mass

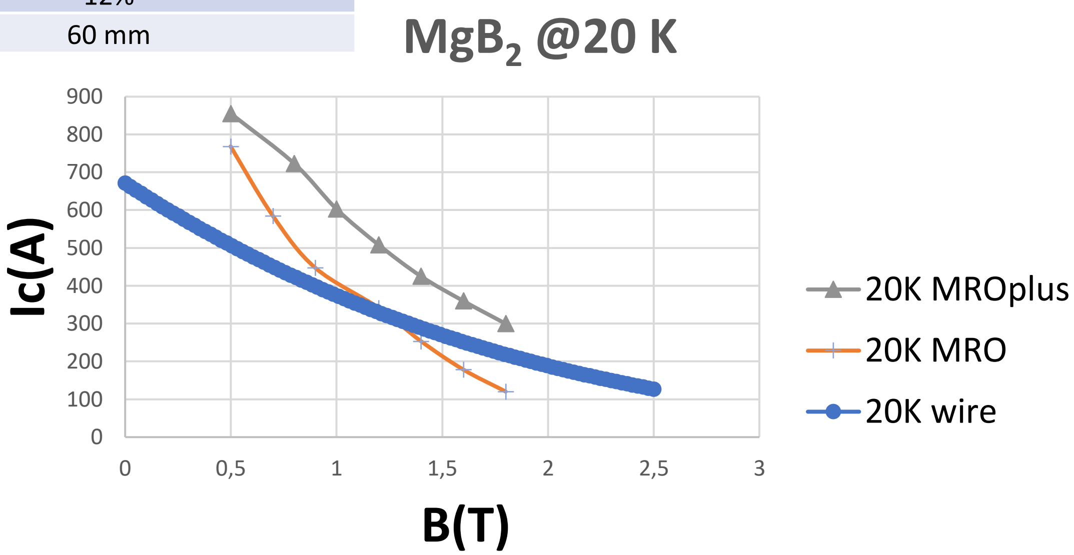
# SUPRAPOWER design adaptation

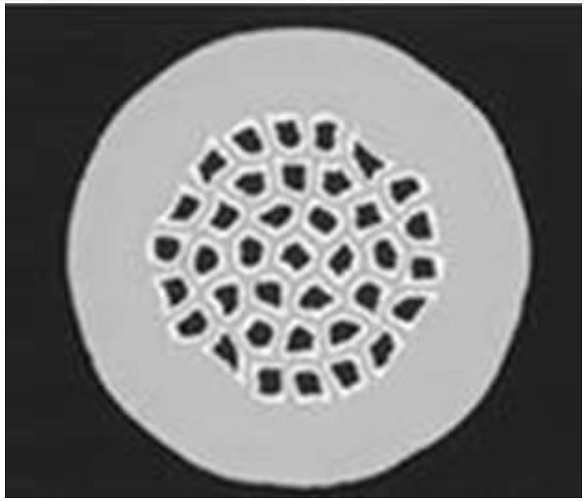
- New existing $MgB_2$ tapes and wire with better performance
- SUPRAPOWER design adaptation admits both configurations
- Coils size increased

| ID | Feature | Value | Note |
|---|---|---|---|
| 1 | Overall copper plated conductor diameter [mm] | 1 mm | |
| 2 | Overall Area [$mm^2$] | 0.78 $mm^2$ | |
| 3 | $MgB_2$ area [$mm^2$ and %] | 0.09 $mm^2$ - 12% | |
| 4 | Monel area [$mm^2$ and %] | 0.36 $mm^2$ – 46% | |
| 5 | Nickel area [$mm^2$ and %] | 0.12 $mm^2$ – 15% | |
| 6 | Niobium area [$mm^2$ and %] | 0.10 $mm^2$ – 13% | |
| 7 | Copper area [$mm^2$ and %] | 0.11 $mm^2$ – 14% | |
| 8 | Copper plated conductor Fill Factor [%] | 12% | |
| 9 | Twist pitch [mm] | 85 | Clockwise |
| 11 | Minimum bending radius [mm] | 100 | Corresponding to a Ic value degradation of 2% with respect to a non-bent sample. |
| 12 | Maximum allowable strain [%] at room temperature. | 0.28 | Same as above |
| 11 | Number of filaments | 37 | |

| Wire MRO - MROPlus | |
|---|---|
| Overall bare conductor dimensions [mm] | 3.67 X 0.65 mm |
| Overall Area [$mm^2$] | 2,2 $mm^2$ |
| Doped $MgB_2$ area [$mm^2$ and %] | 0,26 $mm^2$ - 12% |
| Ni area [$mm^2$ and %] | 1,39 $mm^2$ – 63% |
| Iron area [$mm^2$ and %] | 0,22 $mm^2$ – 10% |
| Copper area [$mm^2$ and %] | 0,33 $mm^2$ – 15% |
| Fill Factor [%] | 12% |
| Minimum bending radius | 60 mm |

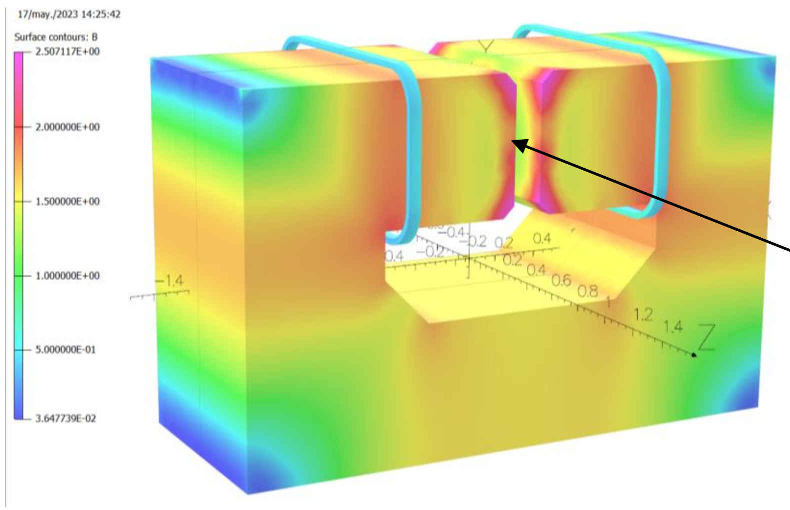




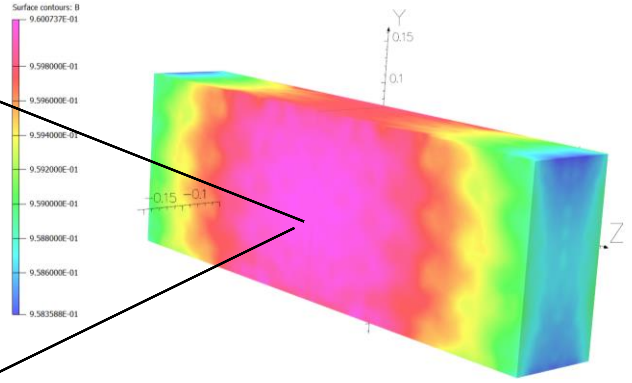



# SUPRAPOWER design adaptation

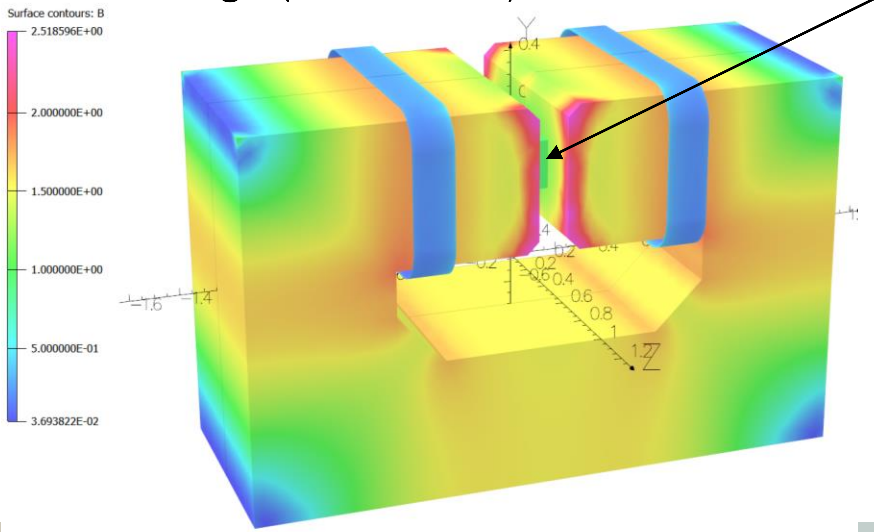
Tape design (MRO class)




Good field region 20 cm x 20 cm x 60 cm in the airgap




Wire design (1 mm class)

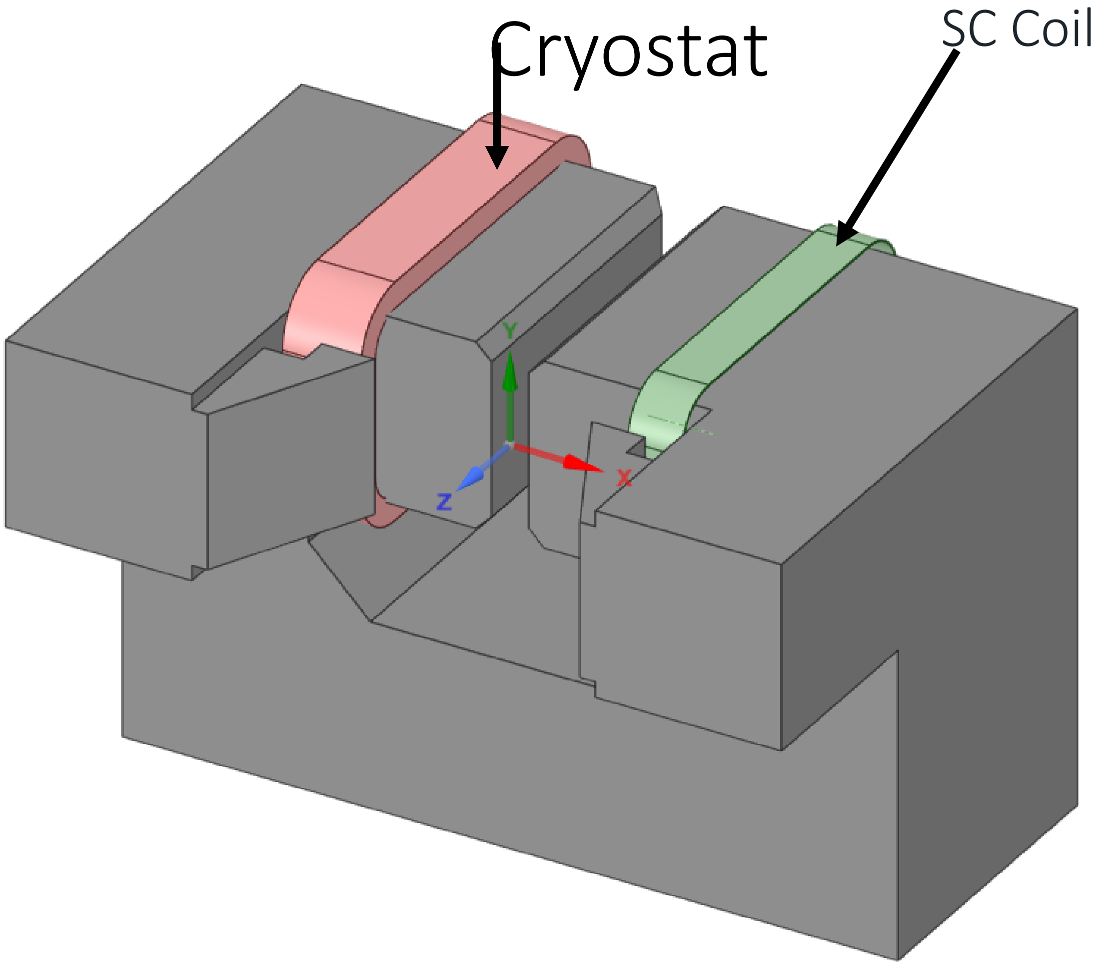


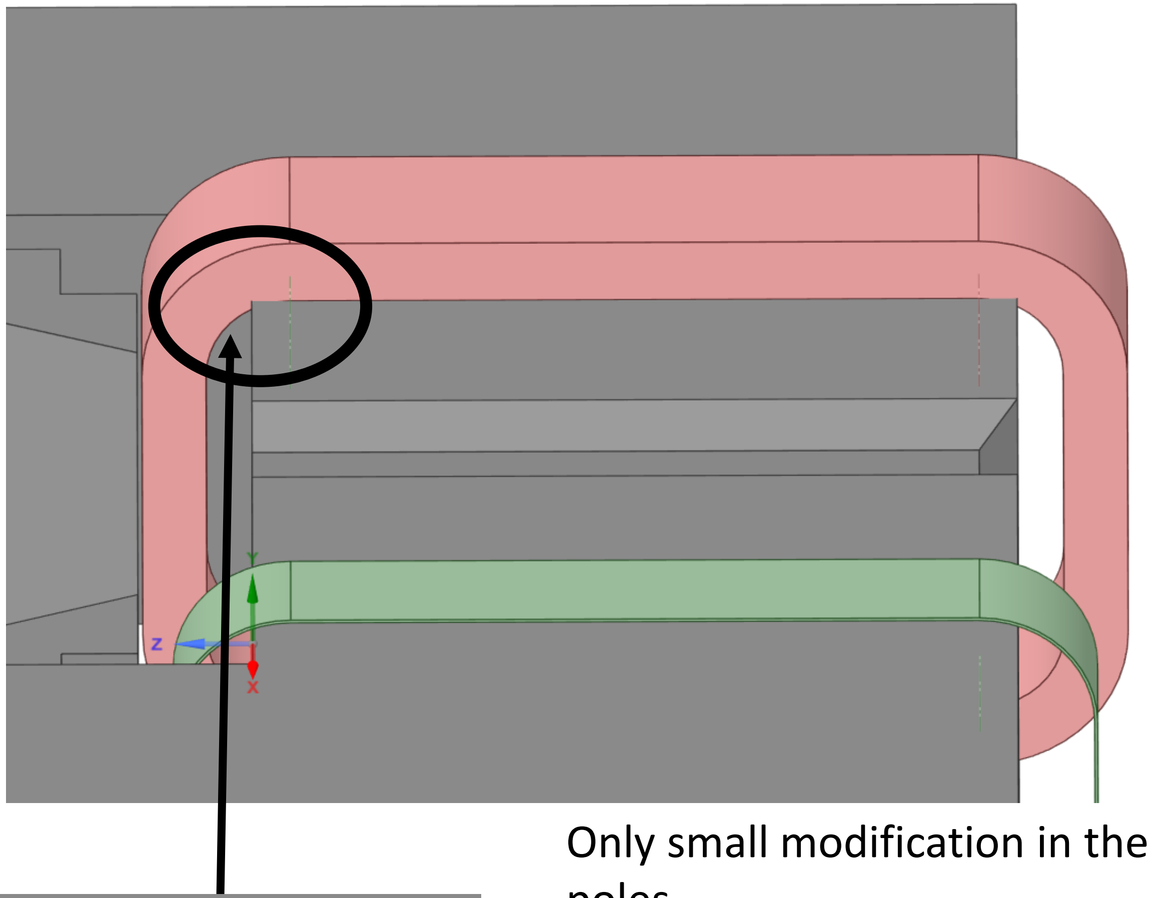

Preliminar designs considering MRO tape and wire resulting:

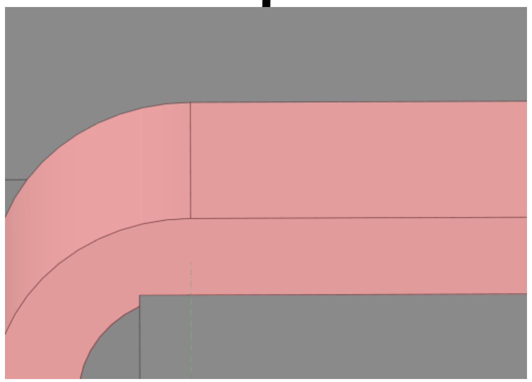
- both superconductors are implemented in two quite similar coils
- Performance is compatible with requeriments
- There is room to enhance the magnetic flux density in the airgap, above 1 T

| Coil design | MRO Tape with 7 DPs | Wire design |
|---|---|---|
| Operating current | 95 A | 120 A |
| Magnetic field in the airgap | 1 T | 1 T |
| Peak magnetic field in superconductor | 0.61 T | 0.52 T |
| H coil | 53 mm | 170 mm |
| W coil | 26 mm | 3.72 mm |
| Turns | 560 | 436 |
| Total length | 2 km | 1.6 km |

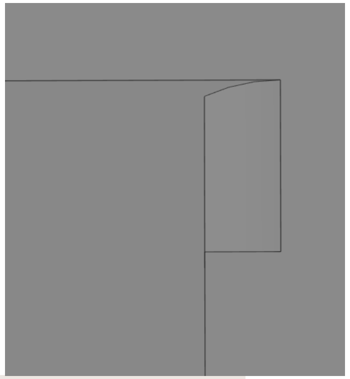
# Efficient cryostat adaptation into existing iron yoke



Only small modification in the poles



# Conclusions

- Original design in SUPRAPOWER obliges a modification of the iron yoke that inabilities to reach 1 T in the airgap
- Reducing the iron yoke, is possible to achieve specification
- A comparison between new class $MgB_2$ superconductors has been done, obtaining two possible conceptual design, compatible with requirements (1 T in the good field region)
- Both designs offer the potentiality of enhance the magnetic flux in airgap
- Further improvement is possibly by optimizing the iron yoke size

# Future works

- SUPRAPOWER design adaptation for an optimized configuration
  - EM optimization
  - Engineering design adaptation
- Material supply and manufacturing
- Assembly
- Testing
  - Factory
  - Final site

# Thank you for your attention!

**Santiago Sanz Castillo**
Director de Tecnología y Cofundador
CTO & Cofounder
santiago.sanz@suprasys.es
T +34 946 85 58 37
M +34 647 40 36 80
www.suprasys.es
Avda. Lehendakari Aguirre, 11, 7º Dpto. 7
48014 Bilbao (Spain)

**Gustavo Sarmiento Muñoz**
Director General y Cofundador
CEO & Cofounder
gustavo.sarmiento@suprasys.es
T +34 946 85 58 37
M +34 668 71 33 34
www.suprasys.es
Avda. Lehendakari Aguirre, 11, 7º Dpto. 7
48014 Bilbao (Spain)