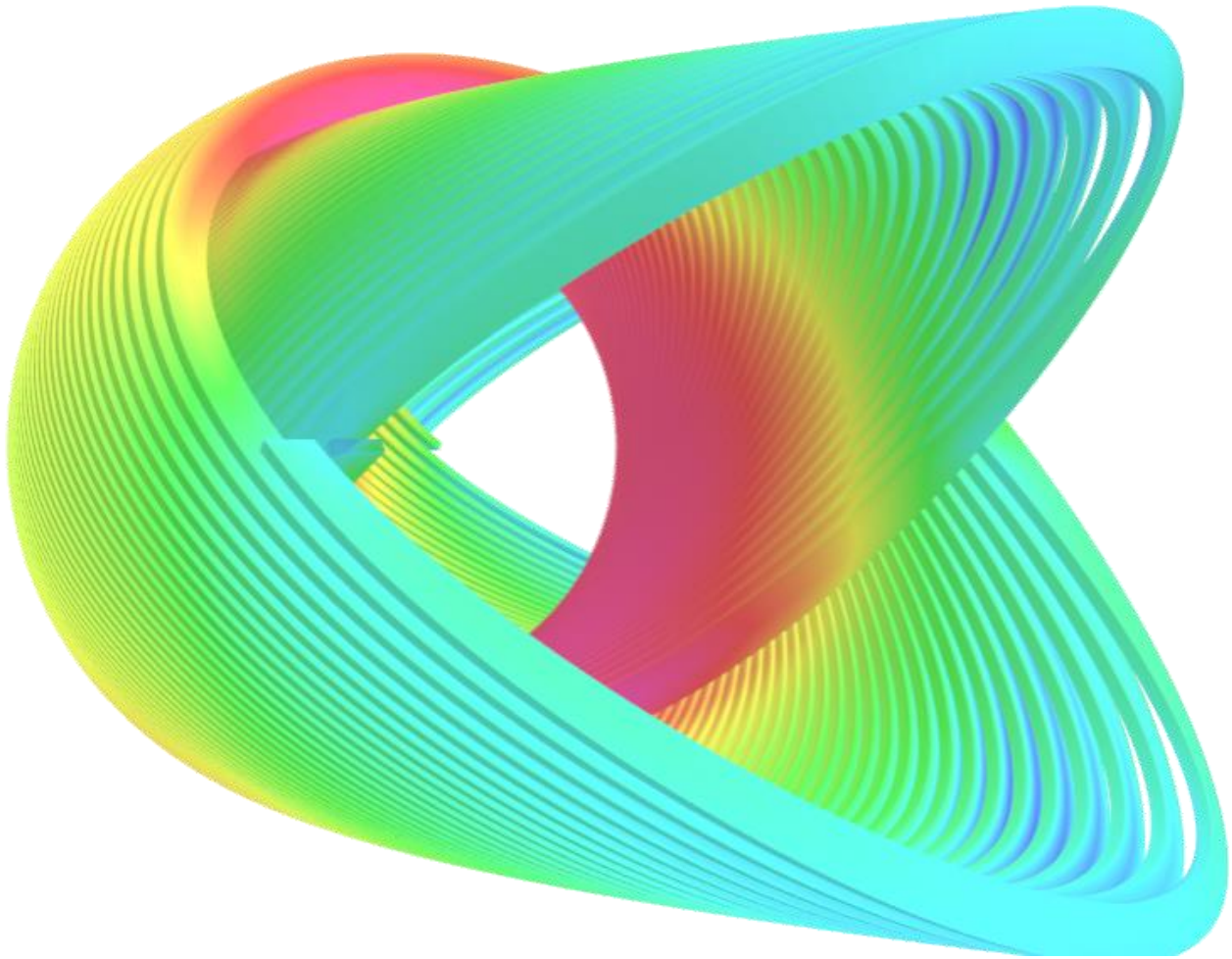
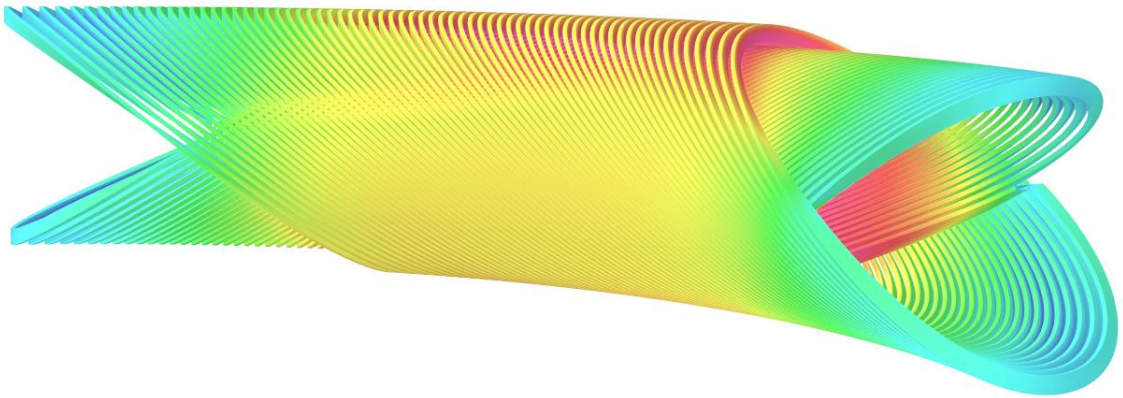
Fusillo

Update

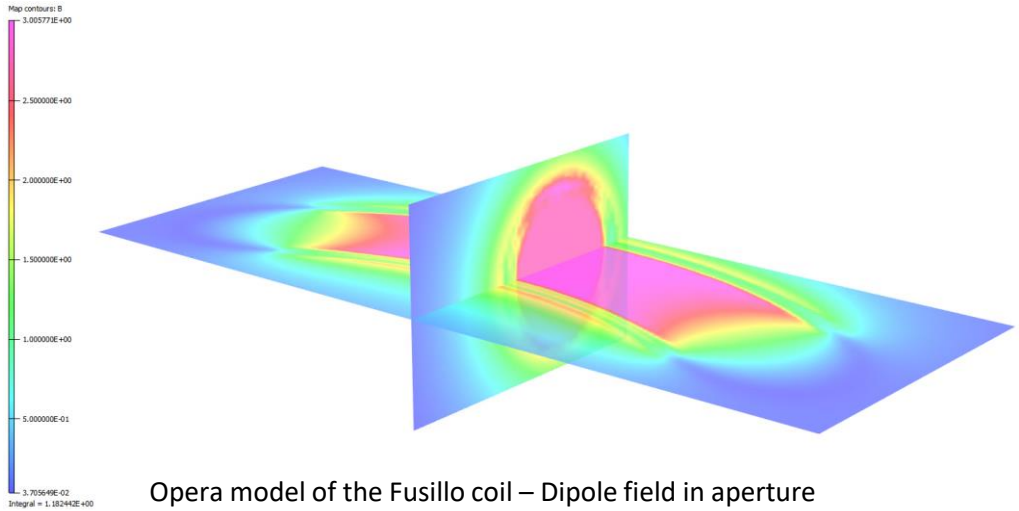


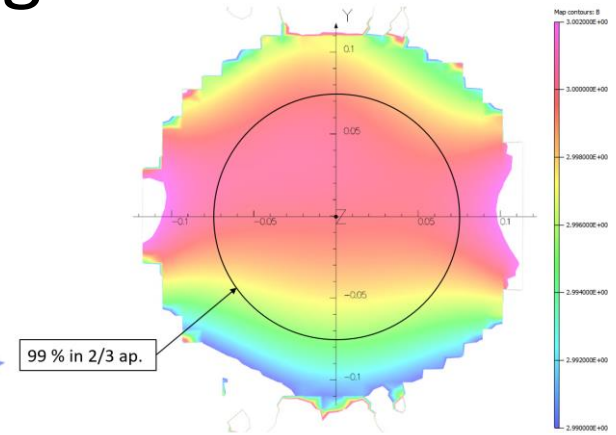


Opera model of the Fusillo coil – Magnetic field on conductor

Ariel Haziot Status of ROXIE for CCT 28.07.2022
Project includes also A. Foussat, G. Kirby, and D. Tommasini

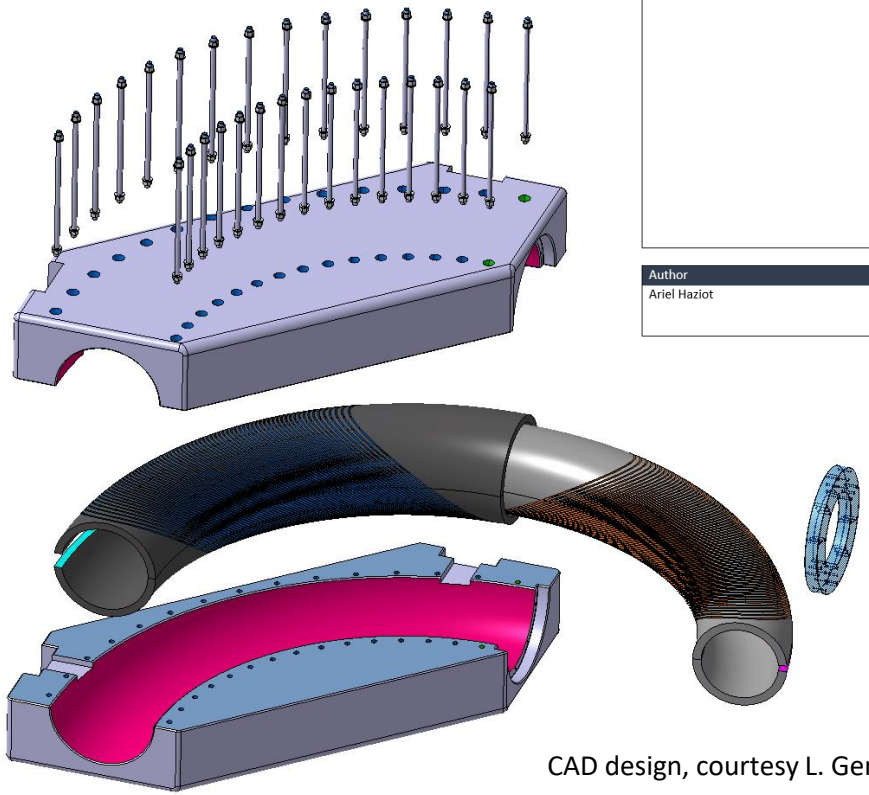
General overview of the magnet





Opera model of the Fusillo coil – Dipole field in aperture

Magnet specifications	Values
Free aperture	230 mm
Curvature radius	1.0 m
Angle between coil ends	90°
Central field amplitude	3.00 T
Peak field	3.50 T
Margin on the load line	40 %
Field homogeneity	0.1 % in 2/3 of the aperture
Strand	LHC type 2, 0.825 mm, 1.90 Cu:Sc
Number of turns	84



CAD design, courtesy L. Gentini

PROJECT **Fusillo**

Functional specifications of the Fusillo demonstrator

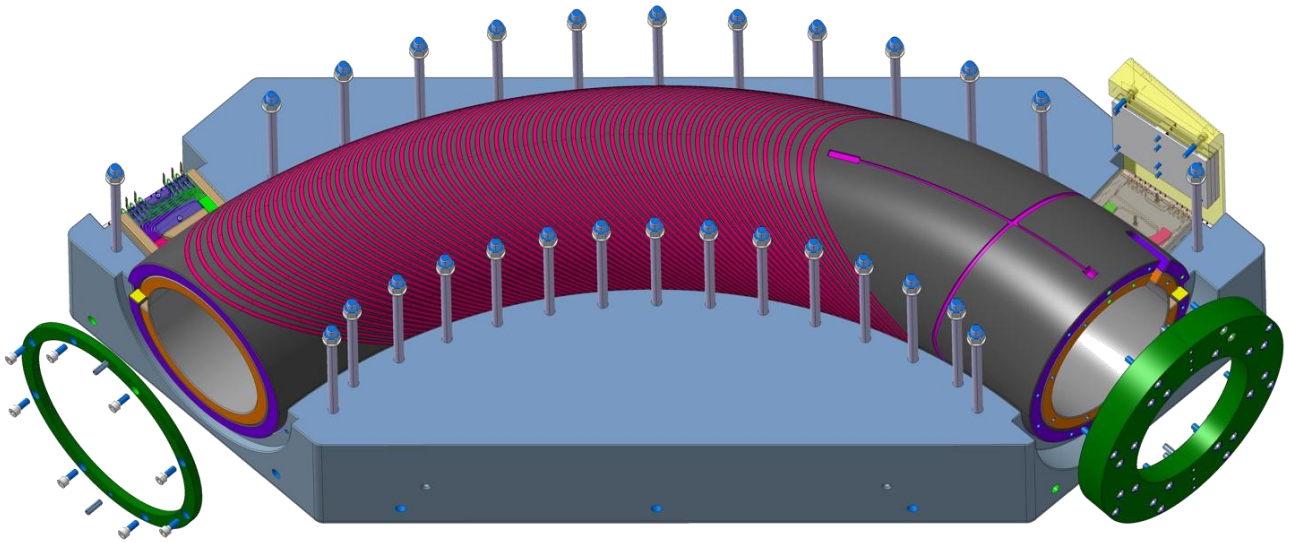
The Fusillo project consists in the design, construction, and test of a curved CCT (Canted Cosine Theta) dipole magnet demonstrator with a large aperture and small radius of curvature for future use in compact accelerators.

This document presents the functional specifications of this demonstrator.

Author	Revisions	
Ariel Haziot	Arnaud Devred	Stephan Russenschuck
	Arnaud Foussat	Davide Tommasini
	Glyn Kirby	

Specifications of Fusillo

- Type: Curved CCT dipole
- Central field: 3 T
- Curvature radius: 1 m
- Angle between magnet ends: 90°
- Free aperture: 230 mm



CAD design, courtesy L. Gentini, E. Urrutia

Cable parameters

Cable Parameters	Values
Type of cable	Rope type
Conductor	0.825 mm Nb-Ti strand
Wire insulation	Polyimide tape (25 µm) with FEP glue (2.5 µm) overlapping: 52 ± 2 %; t: 70 µm insulation: 5000 V DC
Insulated wire diameter	0.97 mm
Assembly	7 wires, helicoidal twist Pitch 45 ± 2 mm
Cable diameter	2.91 mm
Cable insulation (optional)	Glass fibre braid, S2, 66 Tex, ens. 493 covering: 70 %; t: 145 µm
Insulated cable diameter	3.2 mm

Table 2. Cable baseline parameters.

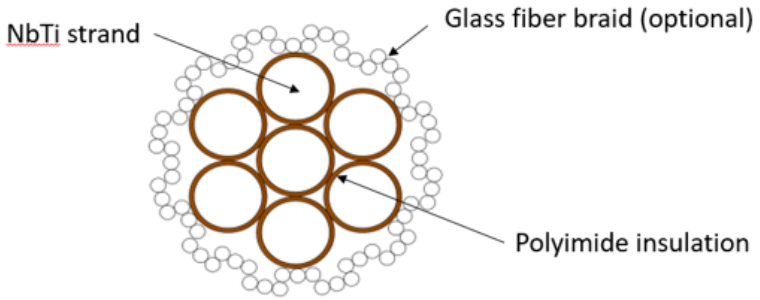
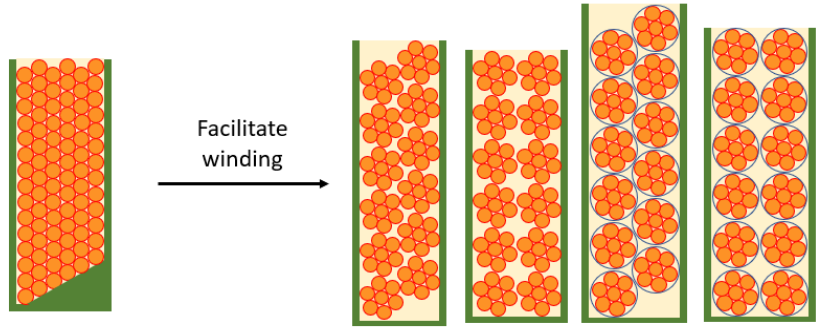
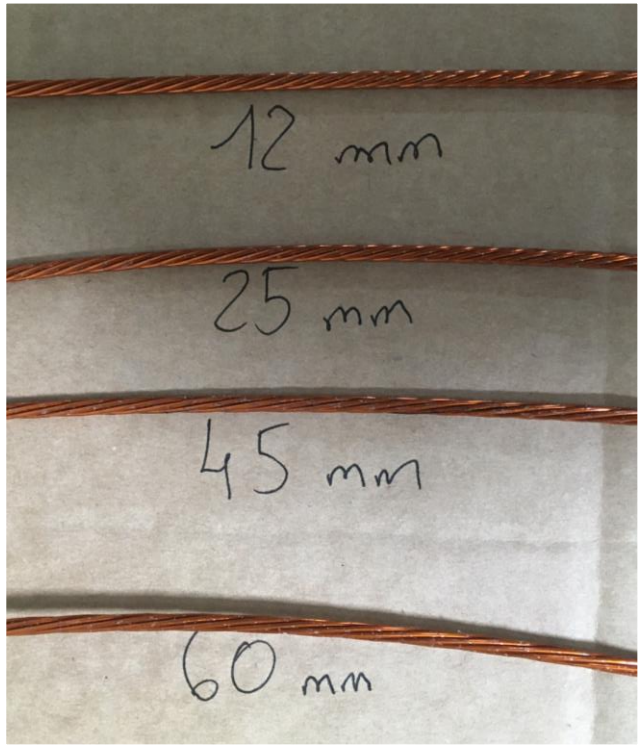


Figure 3. Cross section of the superconducting rope with 7 insulated Nb-Ti strands and a glass fibre braid.





Different pitches of twisting

66 Tex, pitch 1.75 mm, 3.12 - 3.15

33 Tex, pitch 1.75 mm, 3.0 mm

33 Tex, pitch 1.35 mm, 3.0 mm

33 Tex, pitch 0.83 mm, 3.1 mm

Inner/Outer layer parameters

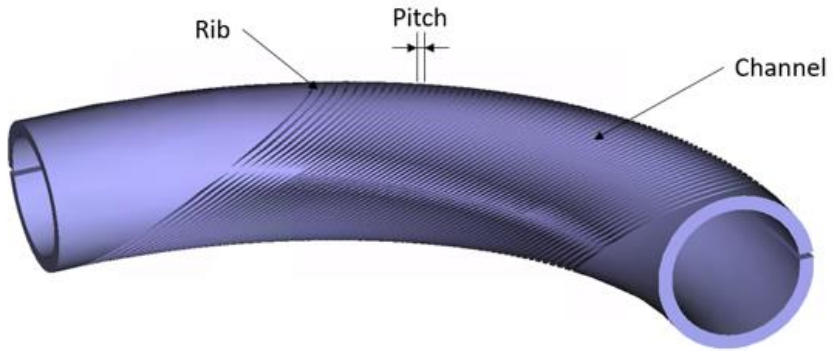


Figure 4. Fusillo inner former showing different parameters: rib, channel, and pitch.

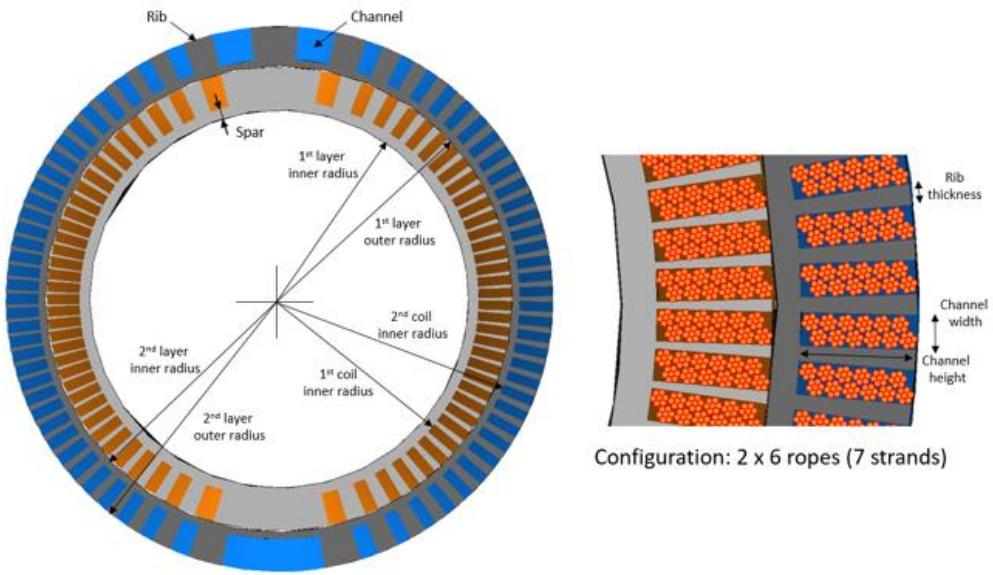


Figure 5. Cross section at the centre of the Fusillo formers showing some important parameters: rib, channel, spar, and radii.

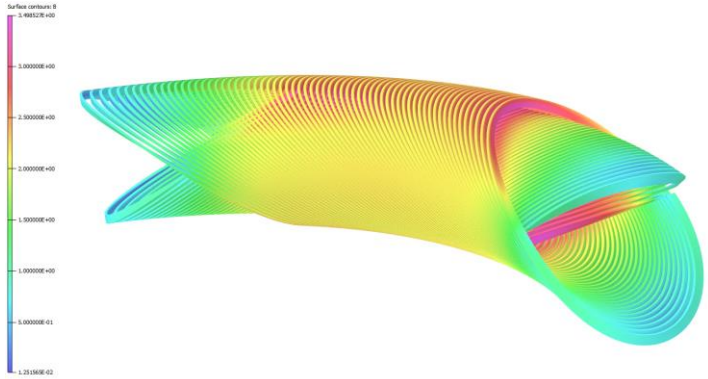
Former Parameters	Values	
	Inner layer	Outer layer
Curvature radius	1.0 m	
Angle between coil ends	90°	
Minimum free aperture	230 mm	
Pitch (-33/-20/-10/10/20/33 turns)	20 / 10 / 6.38 / 6.38 / 10 / 20 mm	
Skew angle (dipole)	30°	
Number of channel turns	66	
Minimum curvature radius	49.7 mm	70.5 mm
Channel (width x height)	5.88 x 20.15 mm	
Minimum rib thickness	0.5 mm	
Spar	6.75 mm	5 mm
Space between formers	0.2 mm	
Coil inner radius (centre)	123.00 mm	148.35 mm
Former inner radius (centre)	116.25 mm	143.35 mm
Former outer radius (centre)	143.15 mm	168.50 mm
Taper	5 mm (± 2.5 mm from centre)	
Number of ropes per channel	12	
Number of turns per layer	84	
Former material	Aluminium 6082-T6	

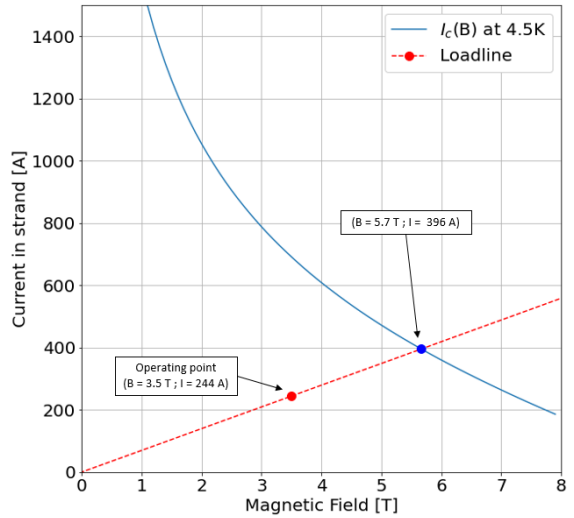
Table 3. Former parameters for inner and outer layers. Radii are reported at the centre of the magnet.

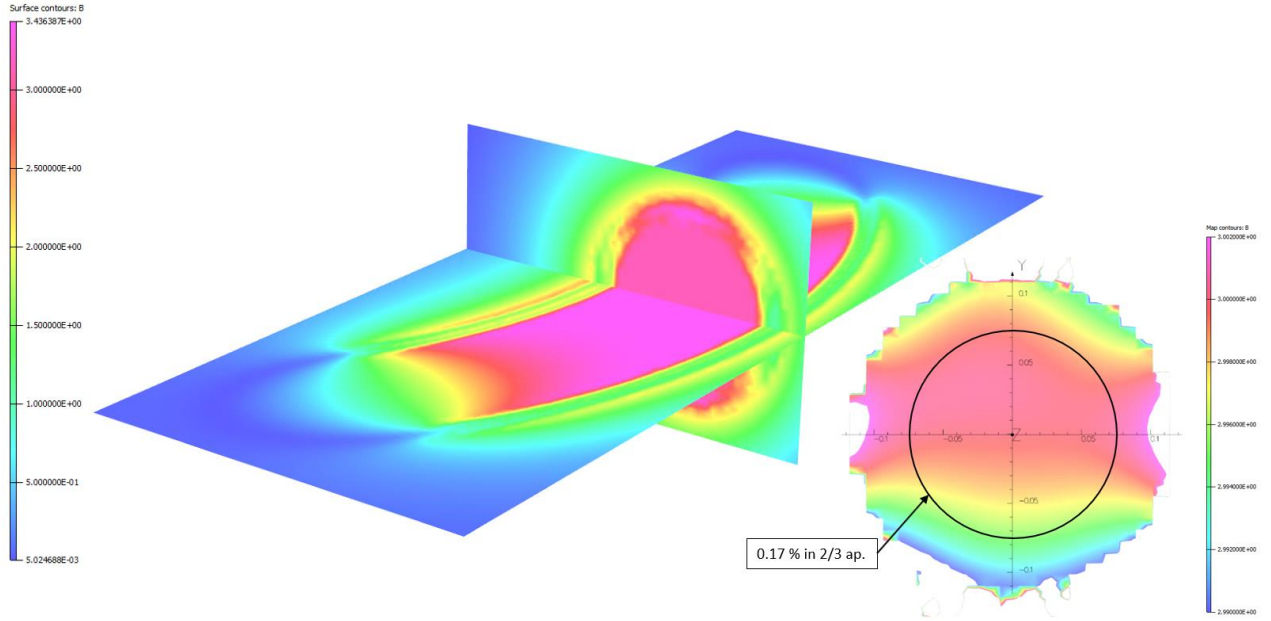
Magnetic design

Parameter	Value
Nominal field in aperture	3.00 T
Field integral	2.958 Tm
Peak field on conductor	3.500 T
Nominal current in wire	244.46 A
Load line margin at nominal field	38.6 %
Temperature margin at nominal field	1.5 K
Inductance	12.36 H
Stored energy	369.14 kJ
Total conductor (wire) length	15.57 km

Table 4. Magnet parameters at nominal current.

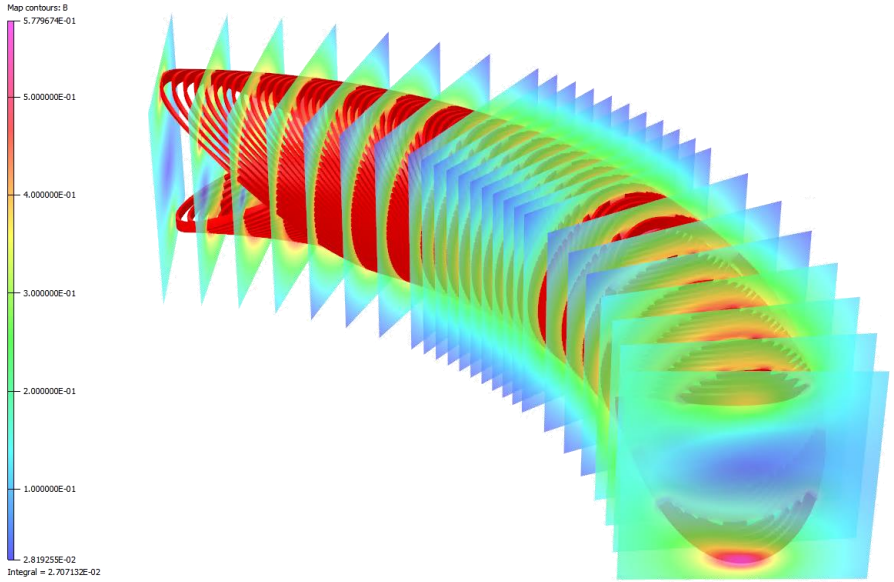


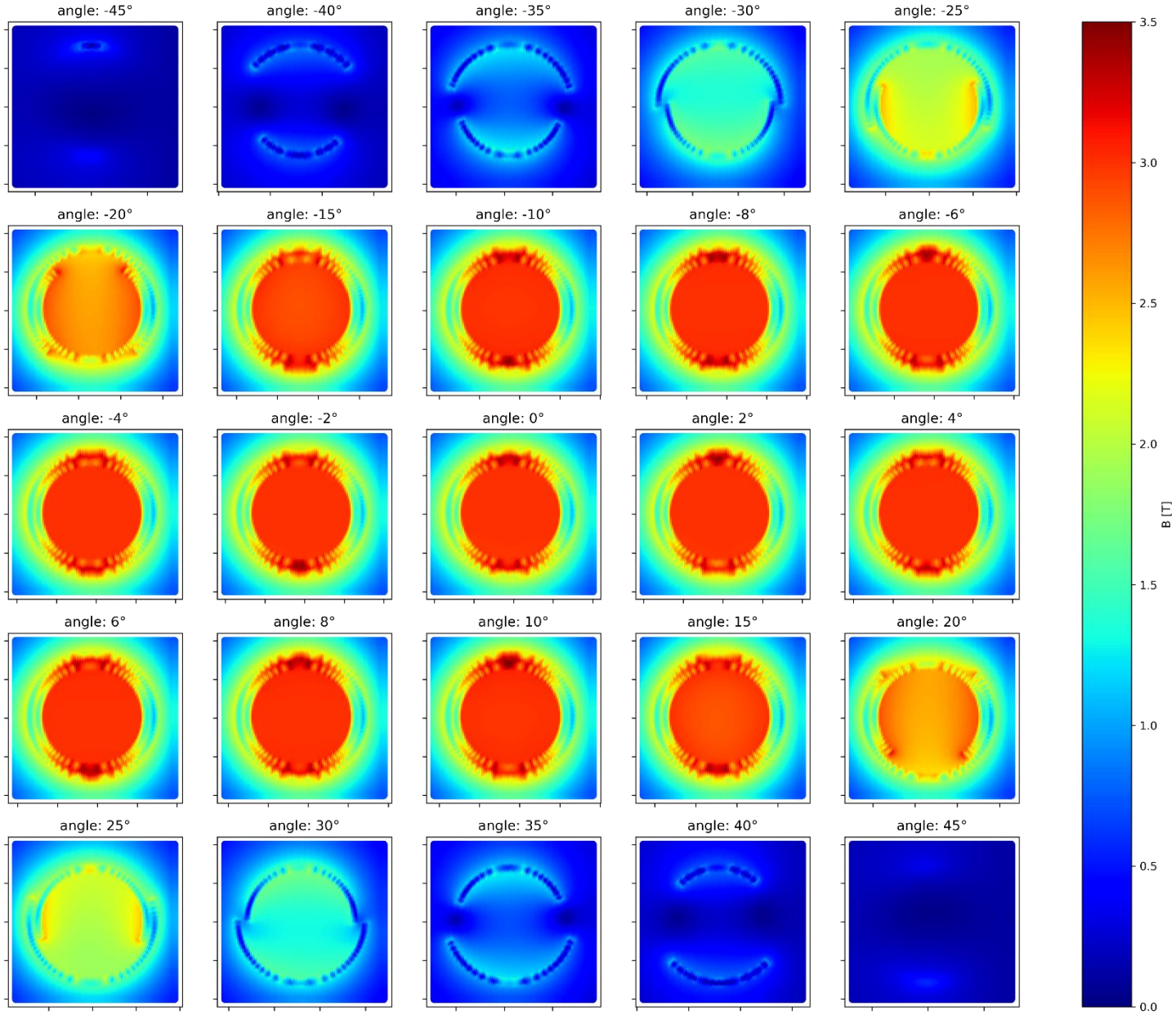




Magnetic design

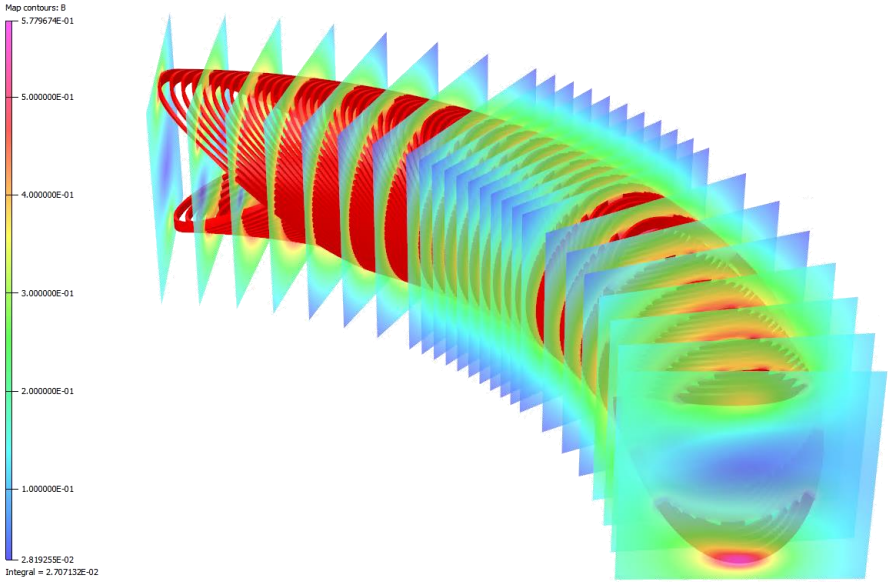
Cross section, magnetic flux B

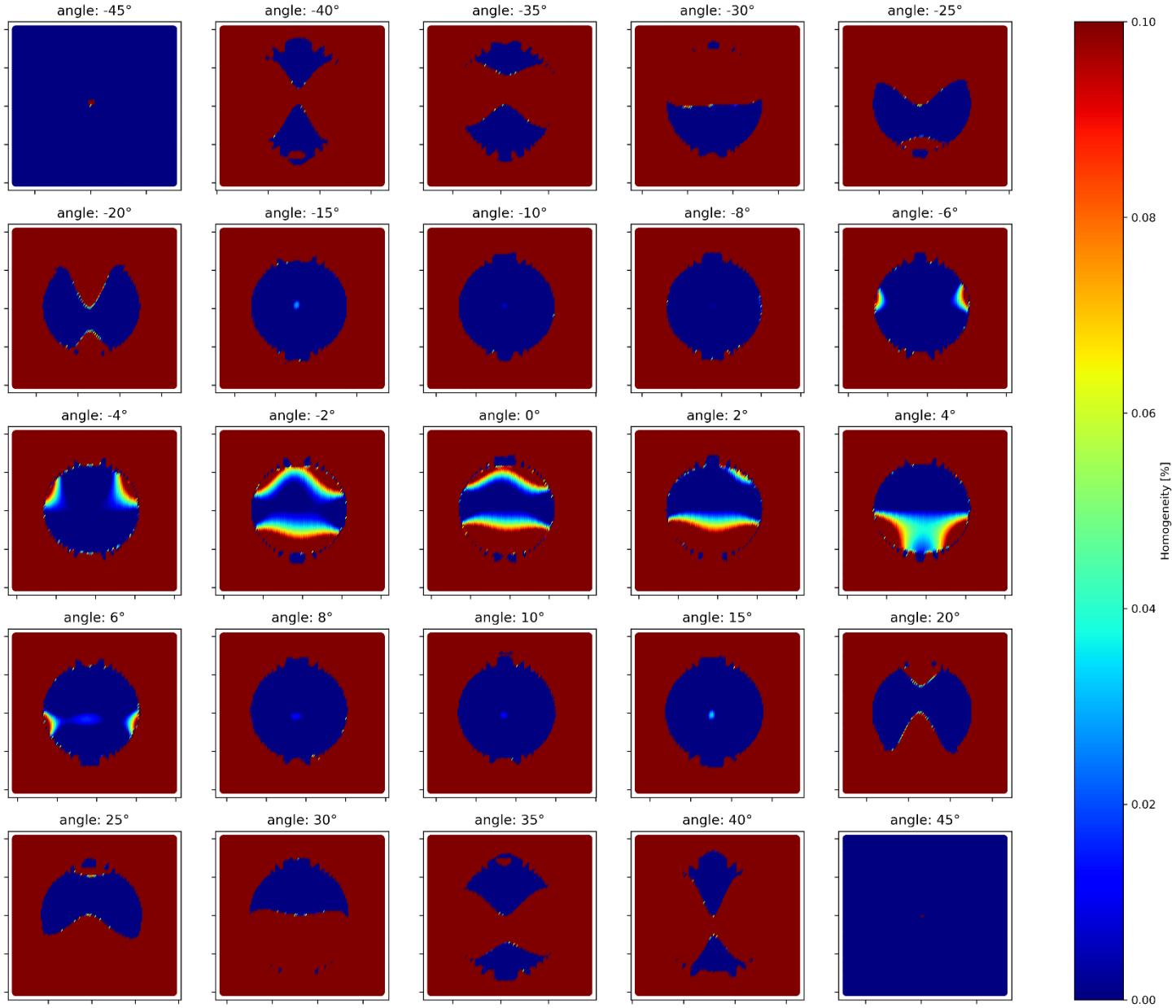




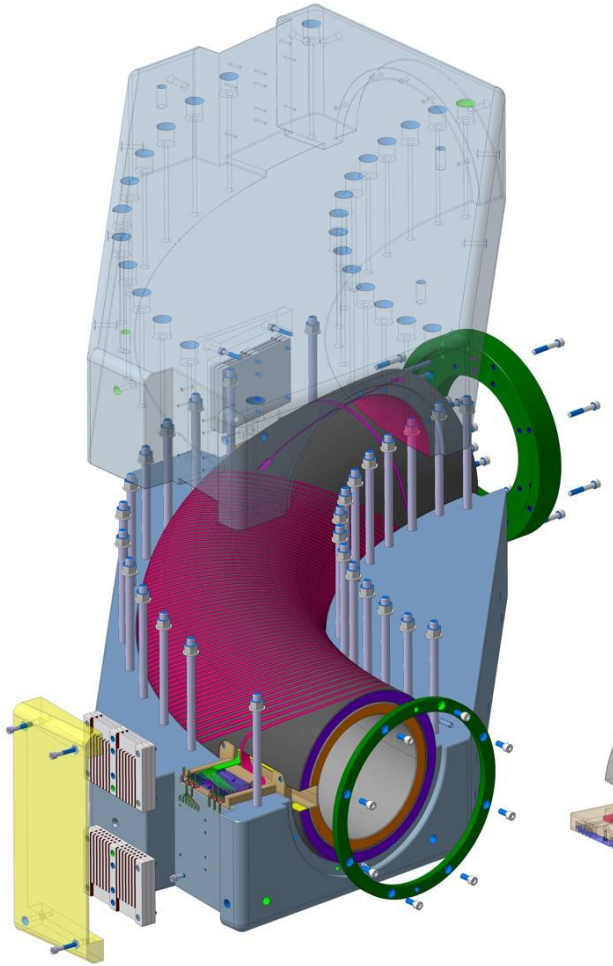
Magnetic design

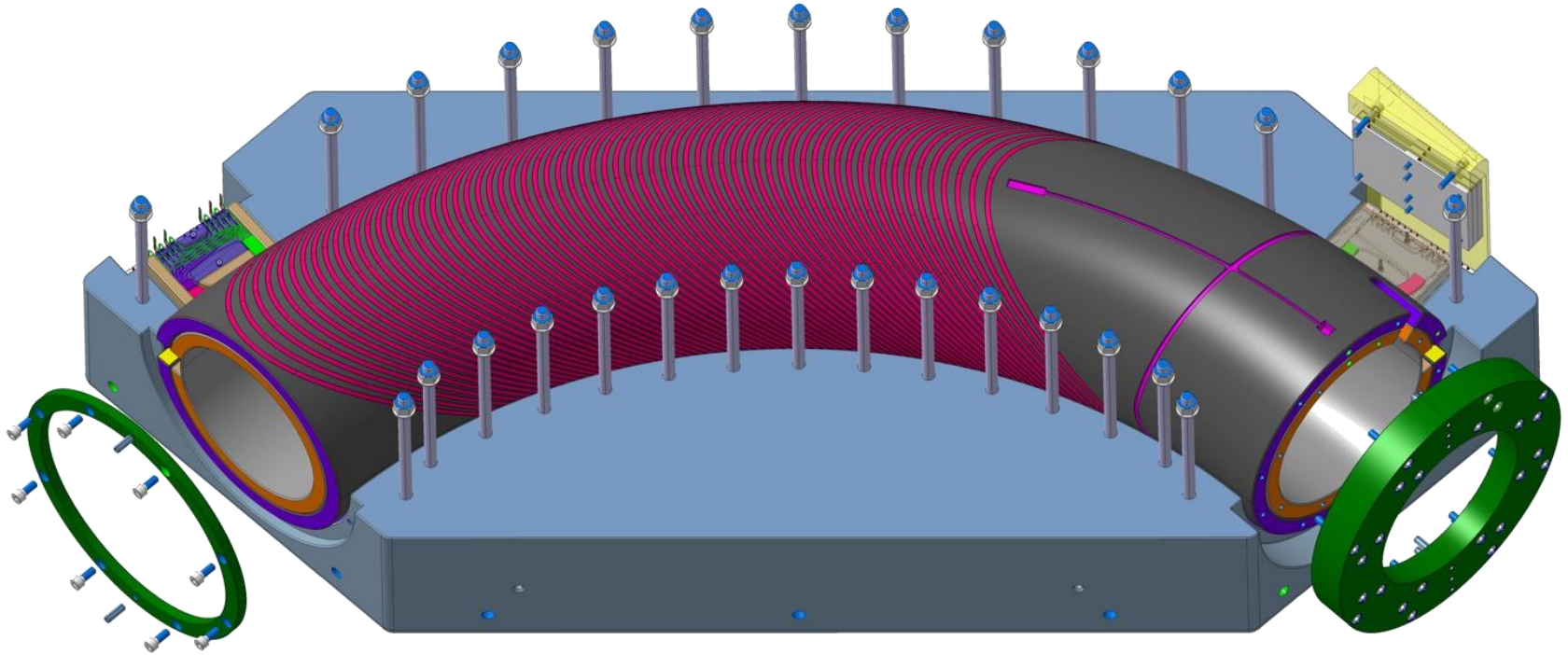
Cross section, homogeneity at 0.1% from central point on magnetic flux By

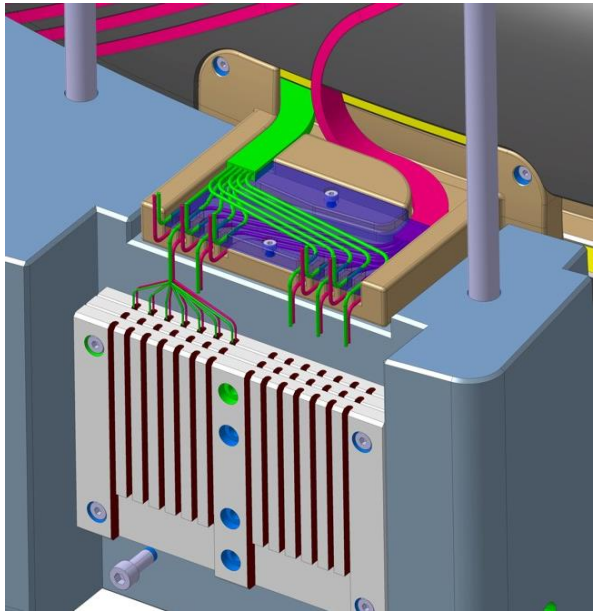




CAD design

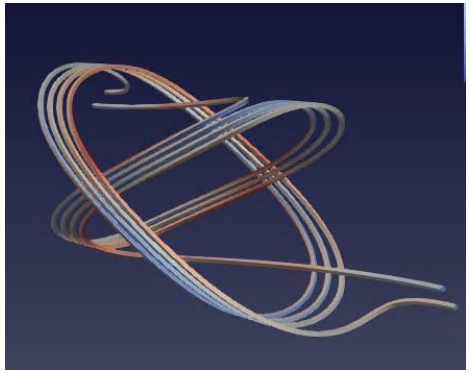






CAD design, courtesy L. Gentini, E. Urrutia

Design workflow today



Coil geometry

(Given by Rat today but hoping to shift to ROXIE in the future)

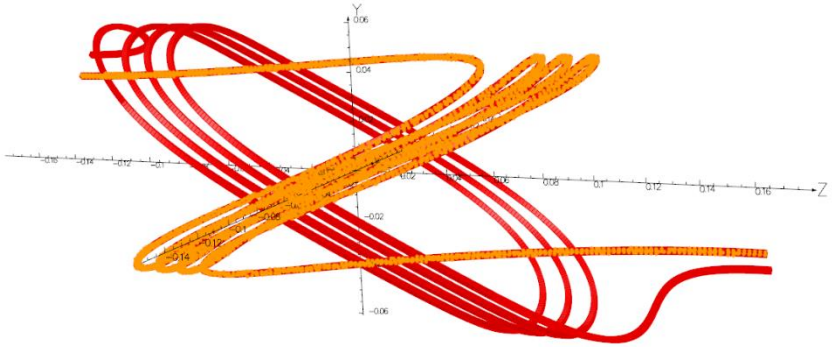
Opera Simulation Software

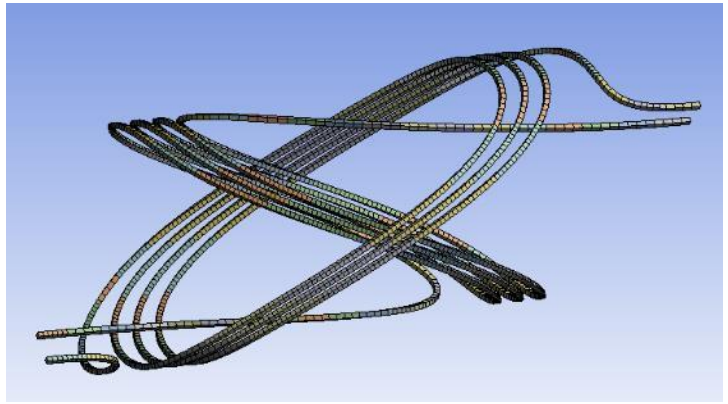
mesh centroids

Force field

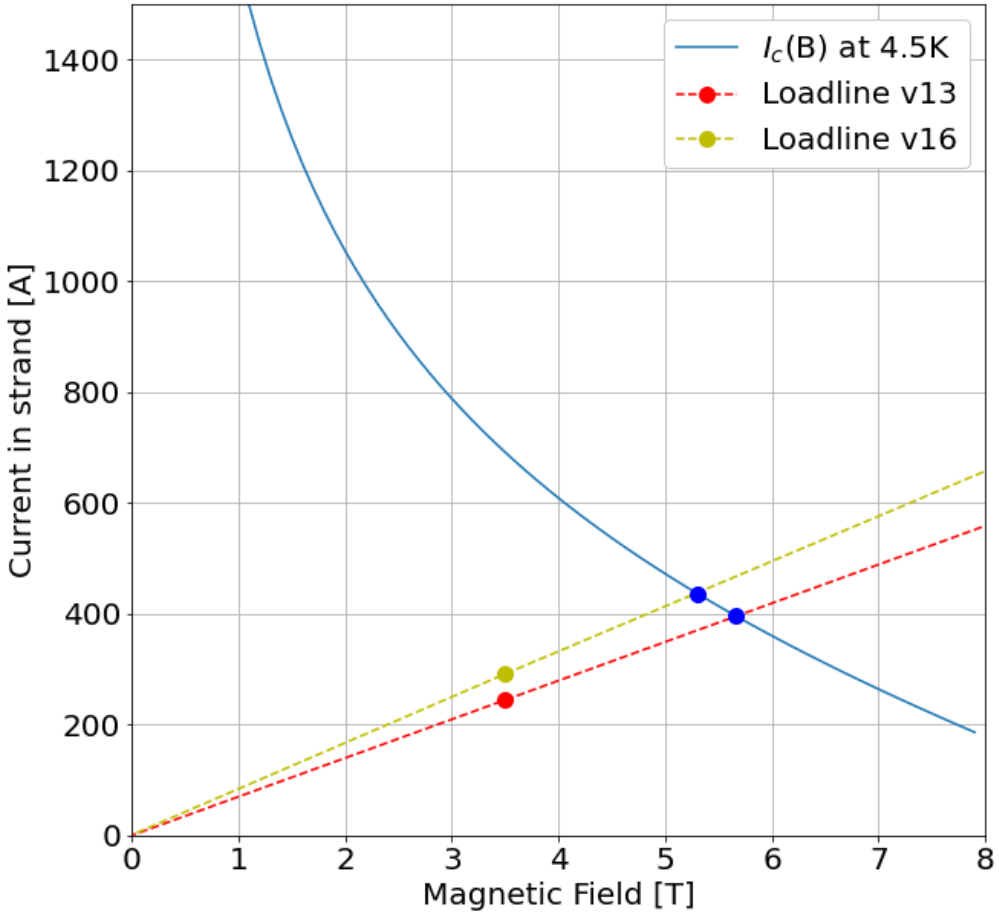
Ansys

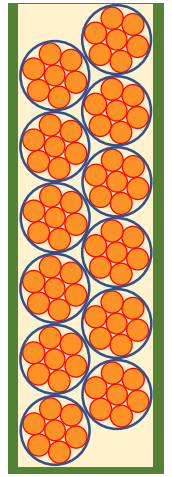
Mechanical model



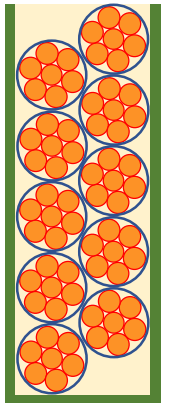


New design





V13
12 ropes



V16
10 ropes

	V13	V16
Operating conditions	244.457 A 3.5 T	291.546 A 3.551 T
Intersection with load line	395.7 A 5.7 T	435.8 A 5.3 T
Short sample	61.8 %	67.0 %


To be continued…

Resistive CCT program

Goal

Build/test mini resistive CCTs powered by pulses:

- Measure a **straight** CCT and a **curved** CCT with different corrections.
- Test the assembly of a 3D printed formers made of **multiple parts**.
- Develop magnetic measurement methods.

Low cost, easy and rapid way to test and validate new exotic designs on CCT magnets (combined functions, curvature, field correction…)

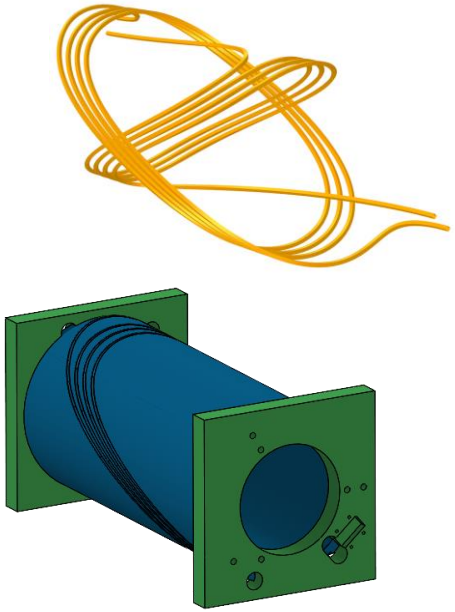
It offers also a laboratory for new measurements technics: magnetic and mechanic.

List of coils

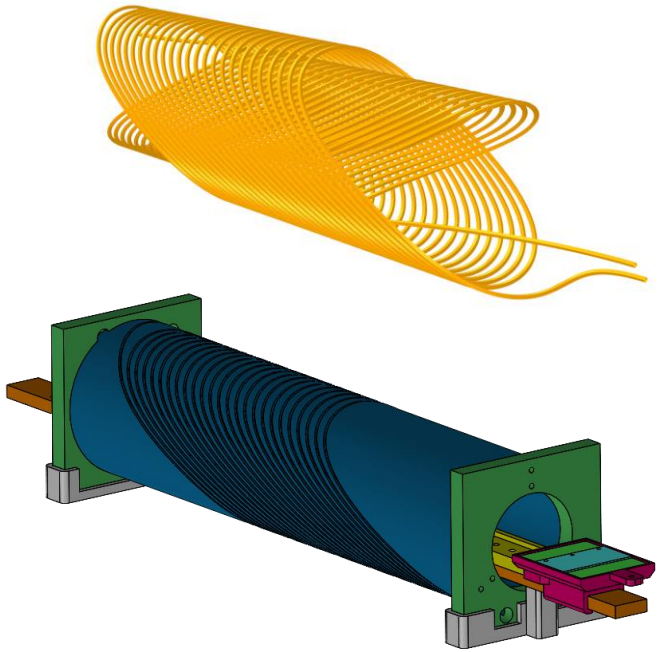
#	Type	Material	Aperture	Layer	Turn	Min rib thick.	Conductor	Cond. length	Inductance	Status
R1	Short Dipole	Accura 25	80 mm	2	6	3.8 mm	2.1 mm Cu	4.16 m	0.009 mH	Done
R2	Straight dipole	Accura 25	80 mm	2	23	3.8 mm	2.1 mm Cu	25.3 m	0.133 mH	Done
R3	Curved dipole	Accura 25	80 mm	2	23	2.0 mm	2.1 mm Cu	25.3 m	0.133 mH	Done
R4	Curved dipole (fully corrected)	Accura 25	80 mm	2	26	2.0 mm	2.1 mm Cu	25.3 m	0.133 mH	Design
R5	Curved dipole (quad corr.)	Accura 25	80 mm	2	26	2.0 mm	2.1 mm Cu	25.3 m	0.133 mH	Concept

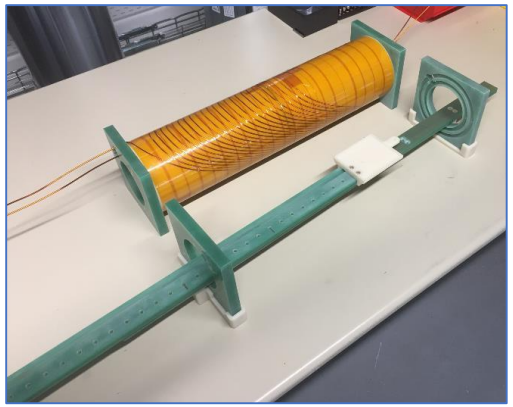
Resistive CCT program

Short Straight - R1

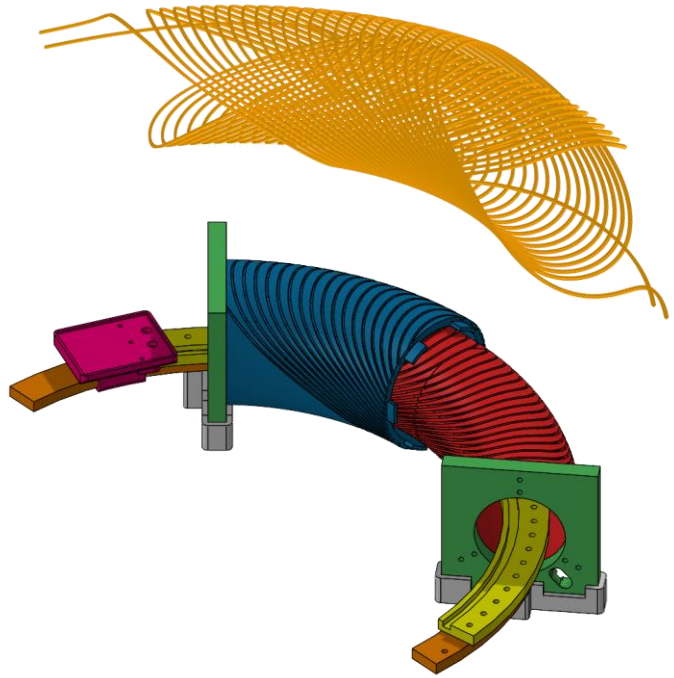


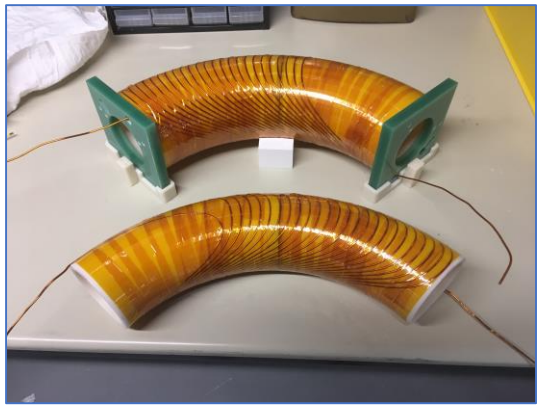
Long Straight - R2





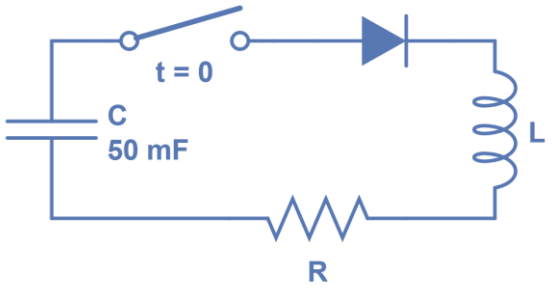
Long Curved R3





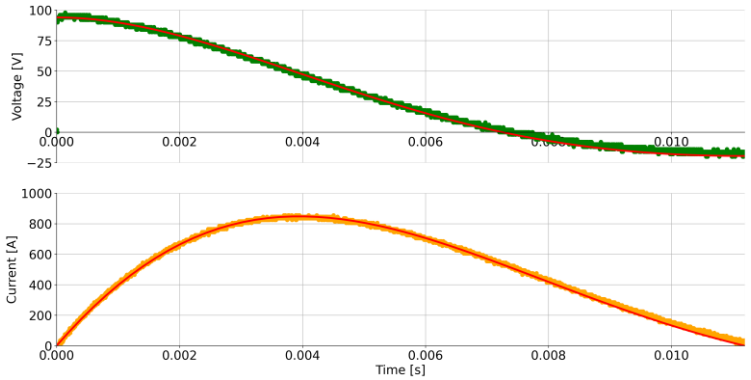
Resistive CCT program

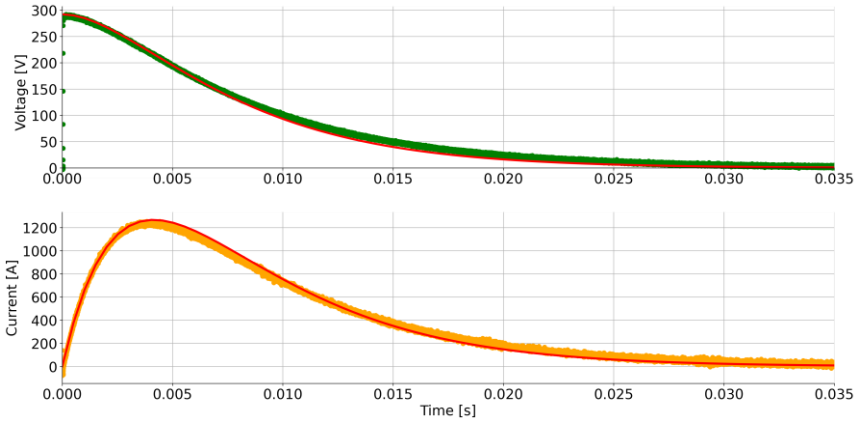
Powering



- **Pulse power unit** from CLIQ (50 mF, up to 500V)
- Different regime depending on L & R:
  - **Under damped regime:** $i(t) = B_2 e^{-\alpha t} sin(\omega_d t)$
  - **Over damped regime:** $i(t) = A_1 (e^{s_1 t} - e^{s_2 t})$
- **Temperature raise**

$$m\, C_p\, \Delta T = R\, I_{RMS}^2\, \tau$$



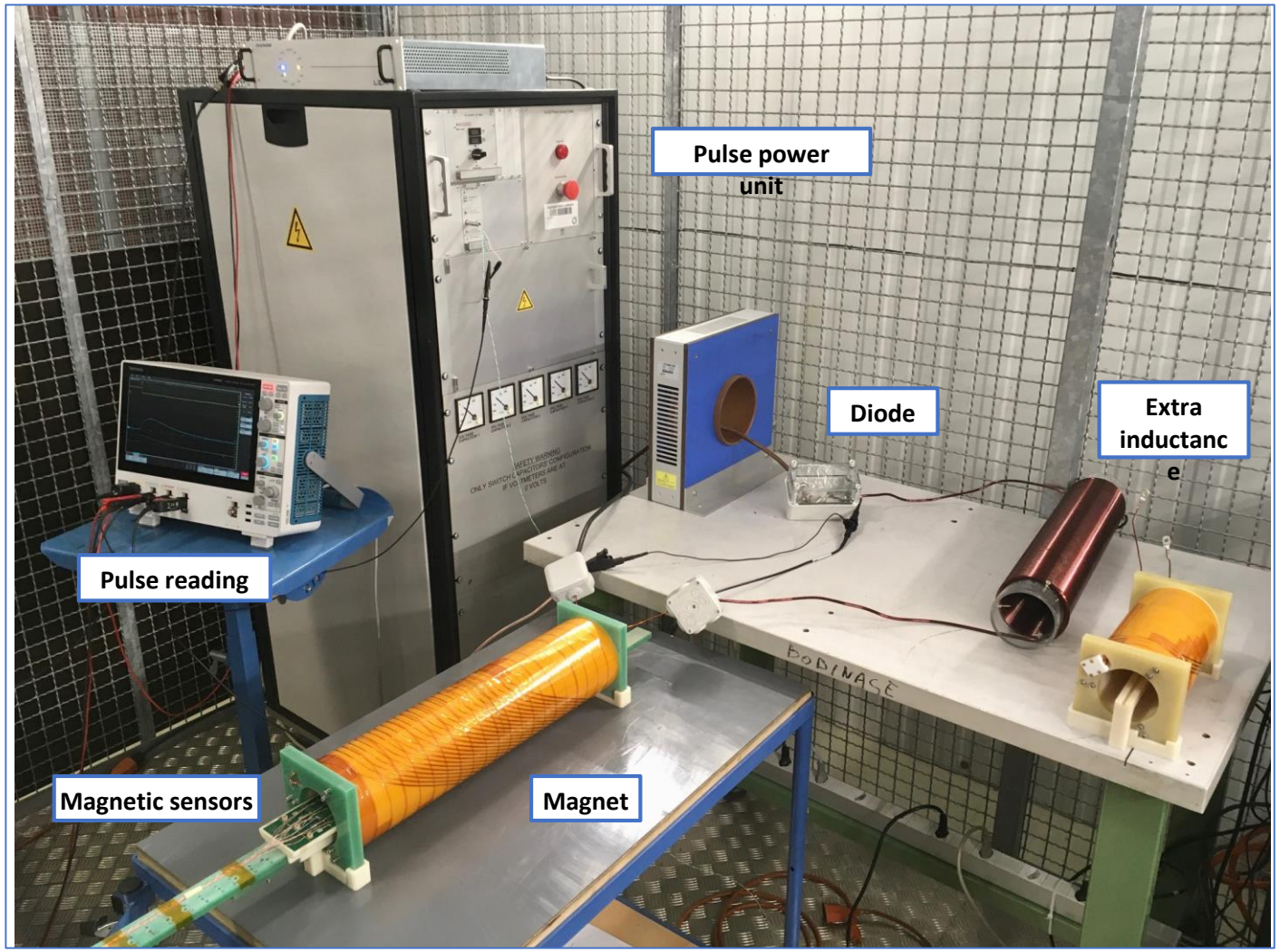


#	Type	Inductance	Resistance	Capacitance	Voltage	Max Current	Pulse time	Temperature raise		Comments
R1 + L	Dipole + Solenoid	0.210 mH	50 mΩ	50 mF	100 V	944 A	11.0 ms	1.2 K	0.0 K	Under damped regime
				50 mF	200 V	1888 A	11.0 ms	4.6 K	0.1 K	

R2/R3 + L	Dipole 2 parts + Solenoid	0.342 mH	170 mΩ	50 mF	100 V	437 A	13.0 ms	0.3 K	0.0 K	Over damped regime
				50 mF	200 V	873 A	13.0 ms	1.4 K	0.0 K	
				50 mF	300 V	1310 A	13.0 ms	3.1 K	0.1 K	
				50 mF	400 V	1747 A	13.0 ms	5.5 K	0.1 K	

Resistive CCT program

Measurement setup



Acknowledgement

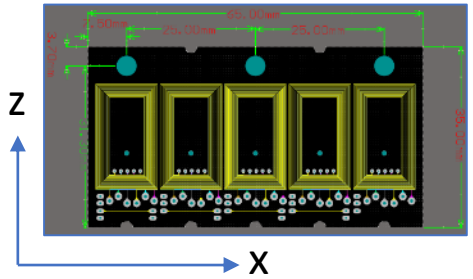
CAD:	J.S. Rigaud
3D printing:	R. Gavaggio
Manufacturing:	927 and 180 workshops
Conductor:	M. Dumas (NCM)
Winding & assembly:	J.S. Rigaud
3D printed support:	A. Carlon Zurita (SCD)
Power supply:	D. Carrillo (MPE-MP)
Test set-up:	F.O. Pincot & P.A. Contat

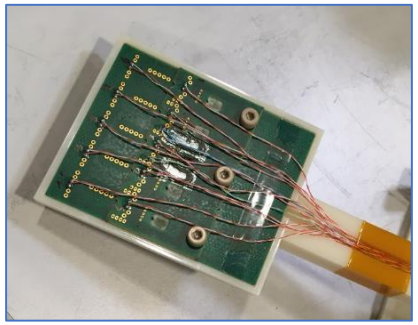
Resistive CCT program

Measurements

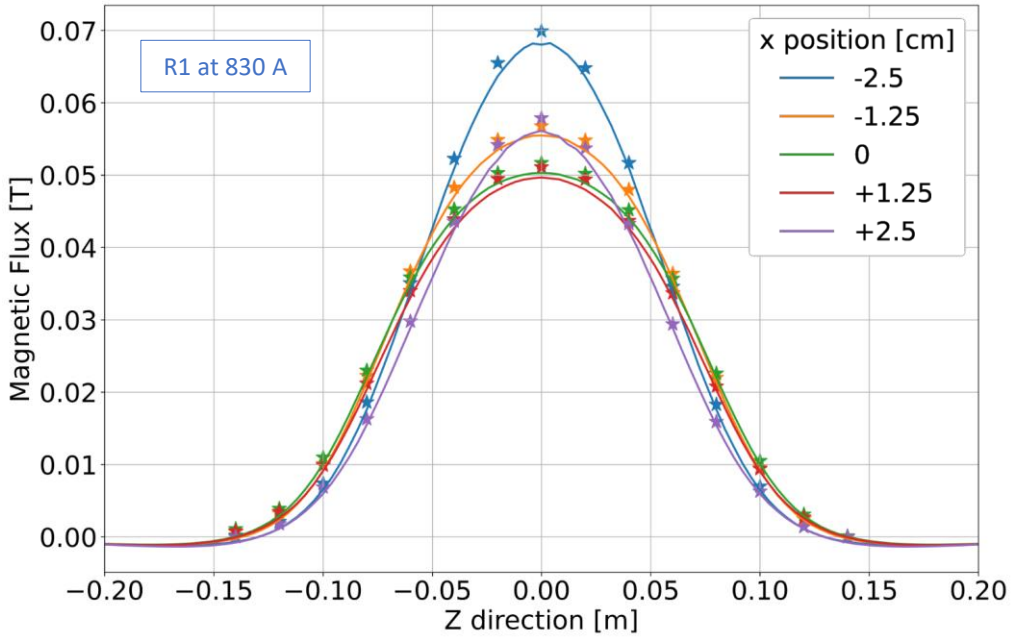
(with C. Petrone and M. Pentalla from MSC- TM)

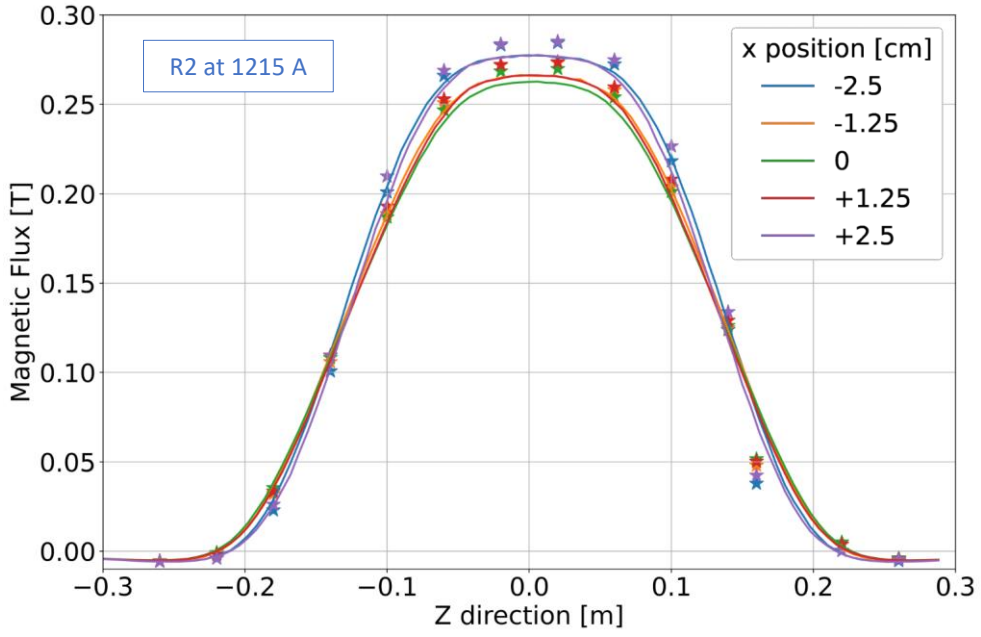
- **Array of 5 pickup coils** aligned in x direction and translating in the z direction on a rail.
- **Very good agreement** between measures and simulations for both R1 and R2.





PCB with pickup coils





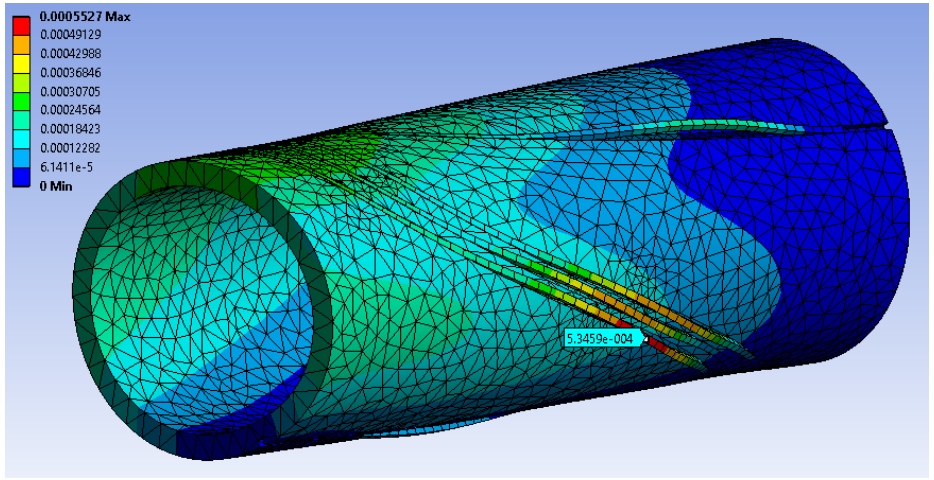
Resistive CCT program

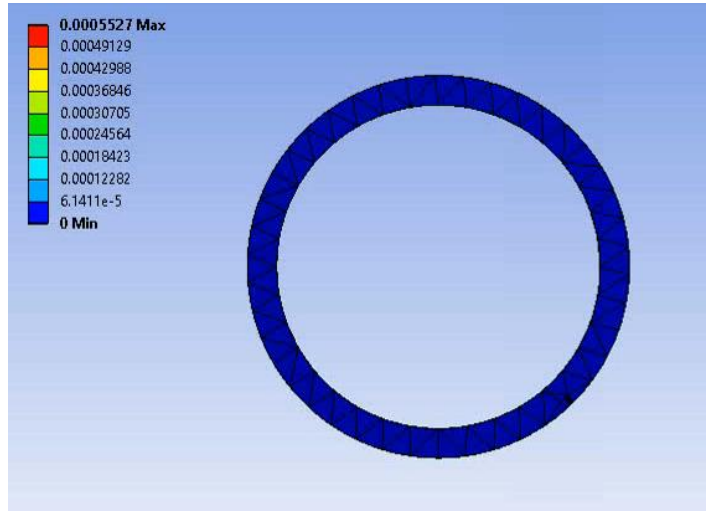
Finite element analysis - Results

Res 250 inner former, no case, 3000 A

Simulation inputs

- Geometry: Inner coil (copper) + inner former (PP), truncated before ends
- Mesh: 5 mm long on coil (435 elem)
- Contact: sides and bottom frictional (0.1)
- Constraints: fixed displacement on former end and coil ends
- Forces: Lorentz forces on coil, 3000 A, from Opera





Max deformation

Coil: 5.5e-4 m

Former: 3.0e-4 m

Max stress

Coil: 78 MPa

Former: 3.5 MPa