HiLumi
HL-LHC PROJECT

MT25
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Detailed magnetic and mechanical design of the nested orbit correctors for HL-LHC

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Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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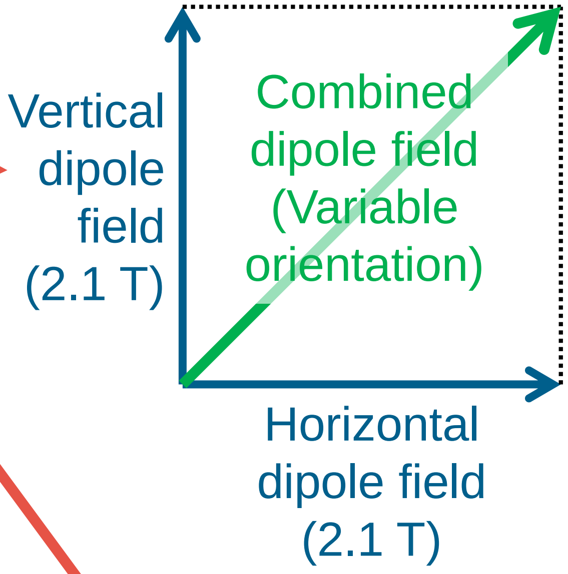
Outline

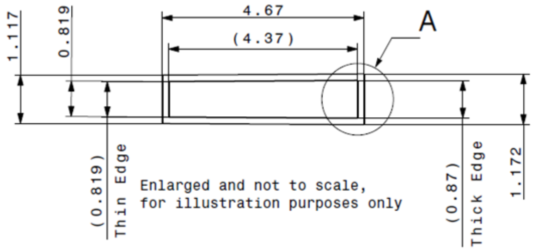
- Final magnetic design.
- Measurement of cable Young modulus.
- Final mechanical design.
- Short mechanical model.
- Conclusions.

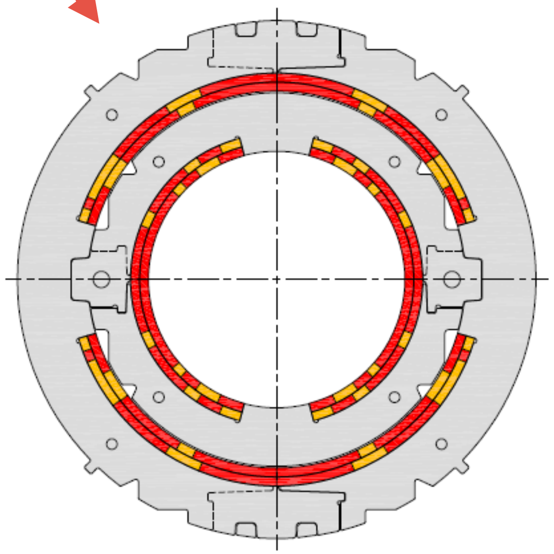
Magnet and cable specifications

MCBXFB Technical specifications	
Magnet configuration	Combined dipole (Operation in X-Y square)
Integrated field	2.5 Tm
Minimum free aperture	150 mm
Nominal current	< 2500 A
Radiation resistance	40 MGy
Physical length	< 1.505 m
Working temperature	1.9 K
Iron geometry	MQXF iron holes
Field quality	< 10 units (1E-4)
Fringe field	< 40 mT (Out of the Cryostat)



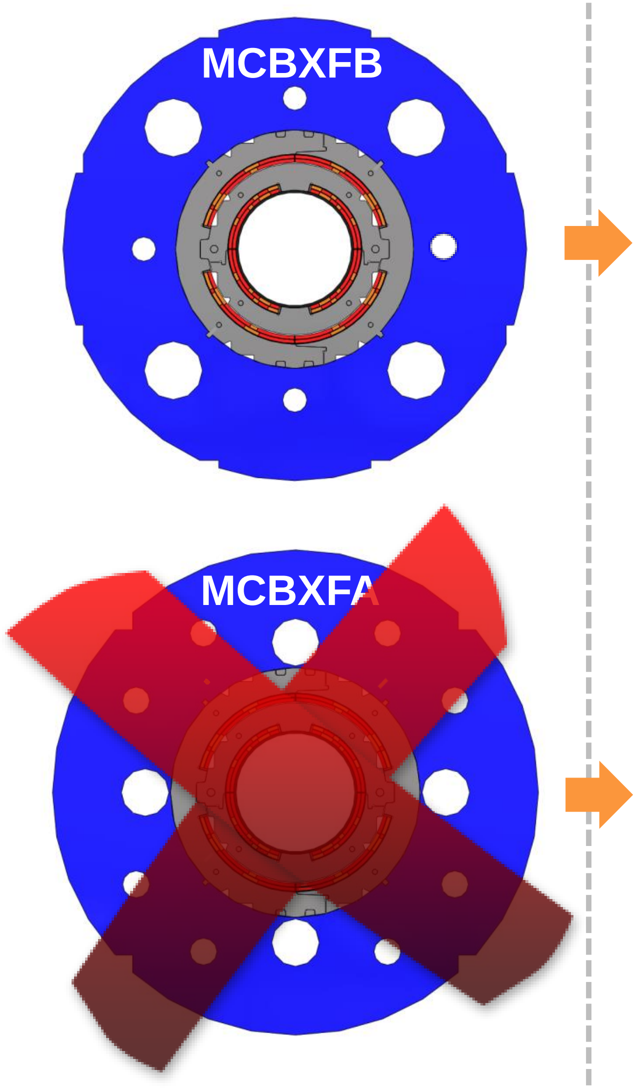
Cable Parameters	
No. of strands	18
Strand diameter	0.48 mm
Cable thickness	0.845 mm
Cable width	4.37 mm
Key-stone angle	0.67º
Cu:Sc	1.75

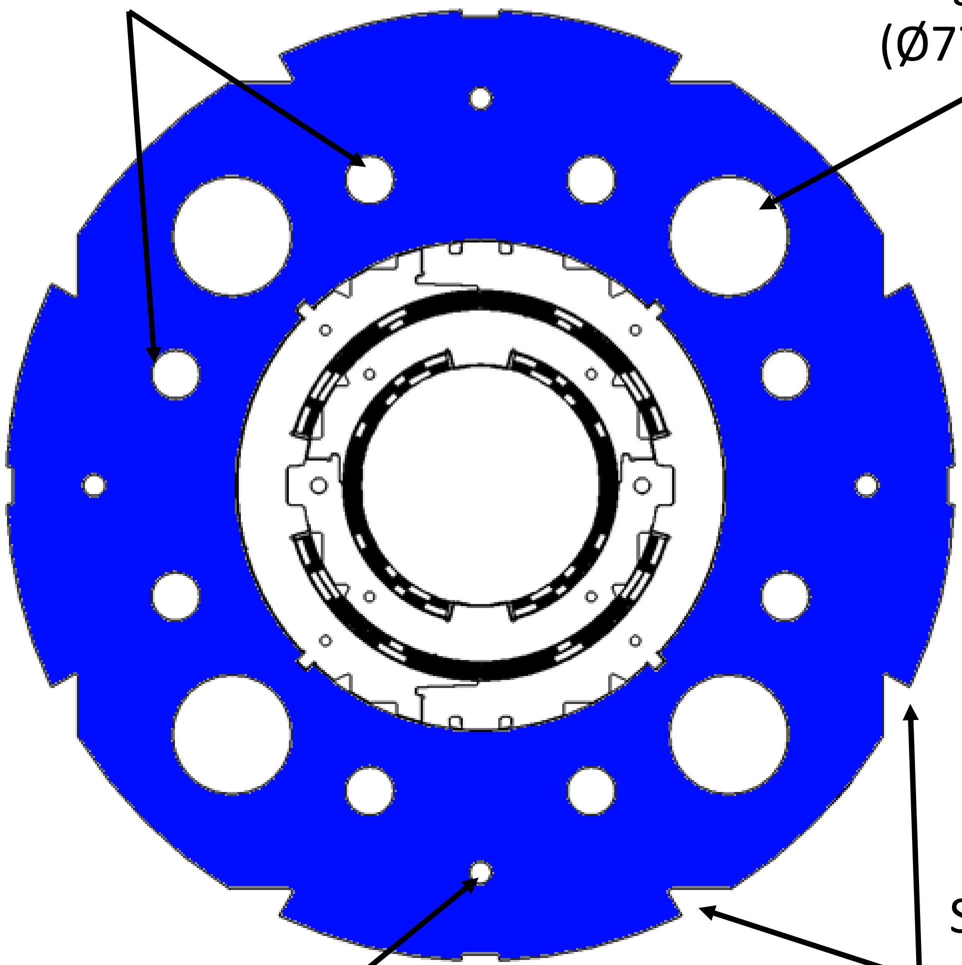




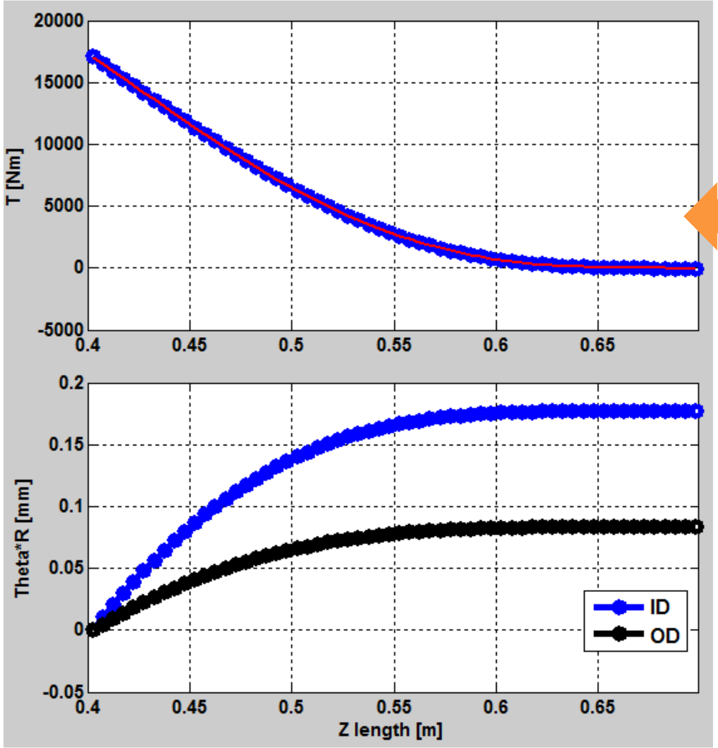
Detailed magnetic design: Final iron geometry

PREVIOUS DESIGNS

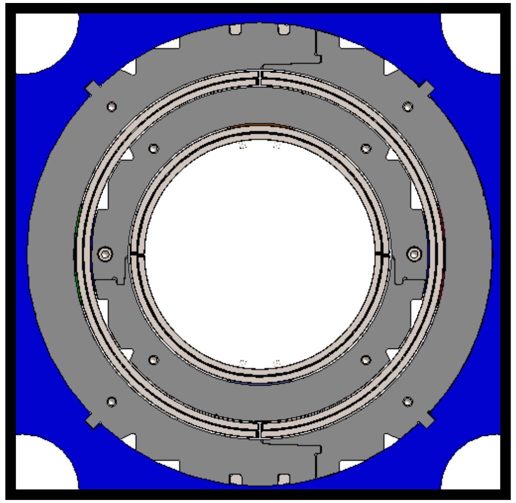




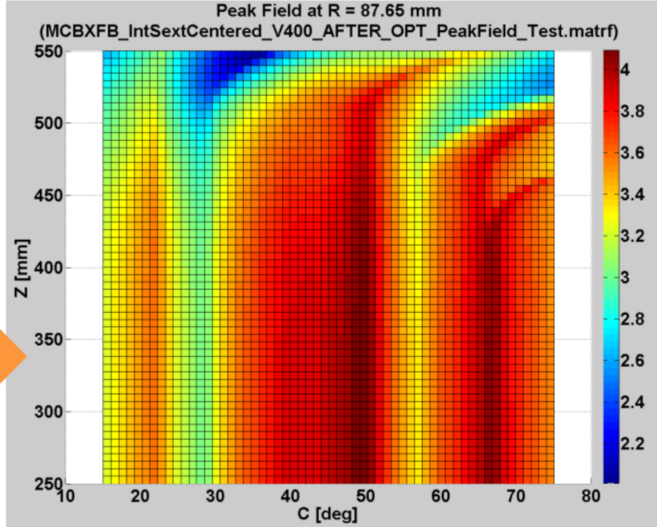
Detailed magnetic design:
Torque and peak field at coil ends



- Torque cannot be azimuthally locked at coil ends.
- Coil ends should be shortened to improve the torque clamping.
- Look out endspacers not to be too slender.



- Field is not aligned with coil poles at nominal current (45º orientation)
- Peak field is always at the straight section.



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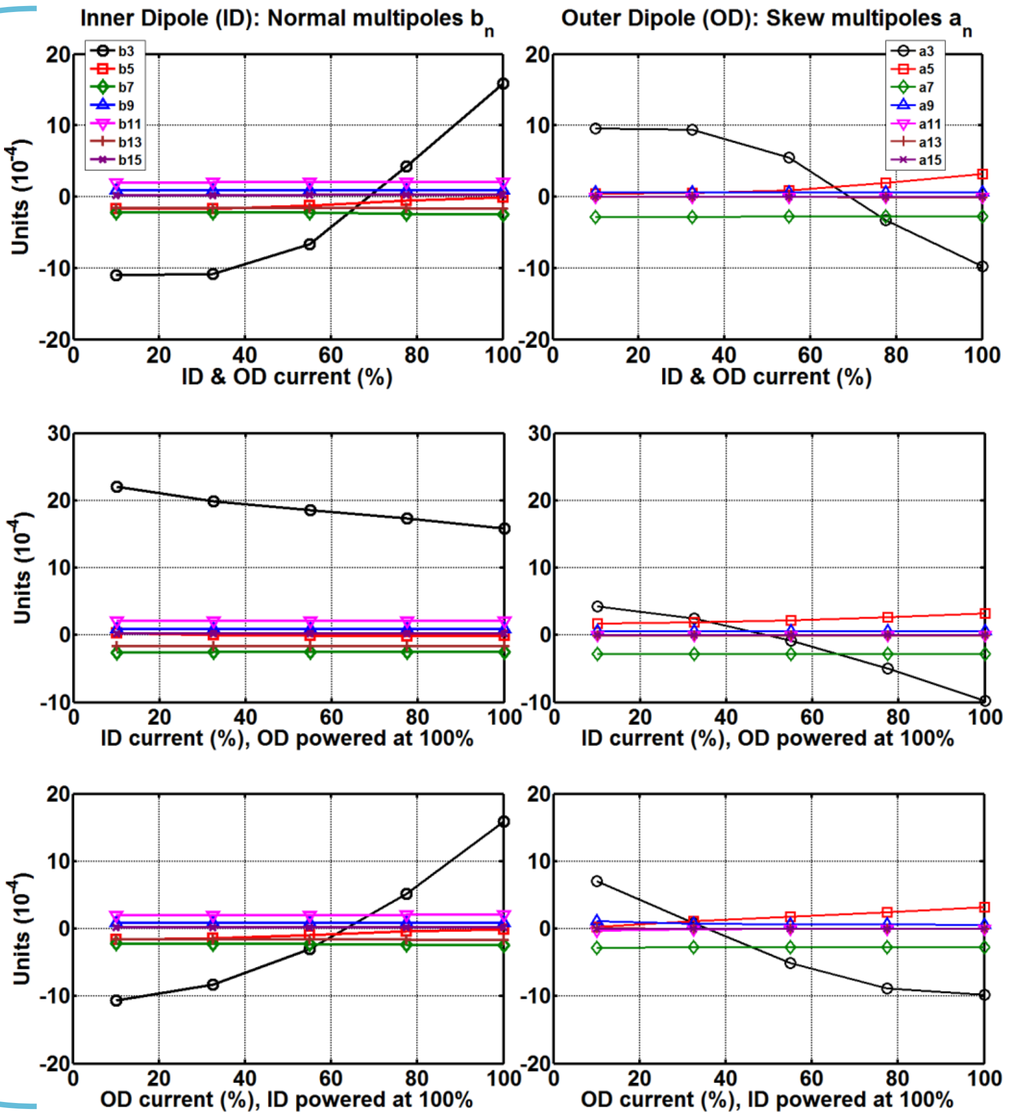
Detailed magnetic design: Computation strategy and field quality

Optimization needed for any powering scenario (infinite cases)

Each case takes like an hour to compute (3D iron)

Reduced to only **three** powering scenarios



The optimization is performed without iron.
The objectives are shifted to take it into account.

< 10 units required

Outline

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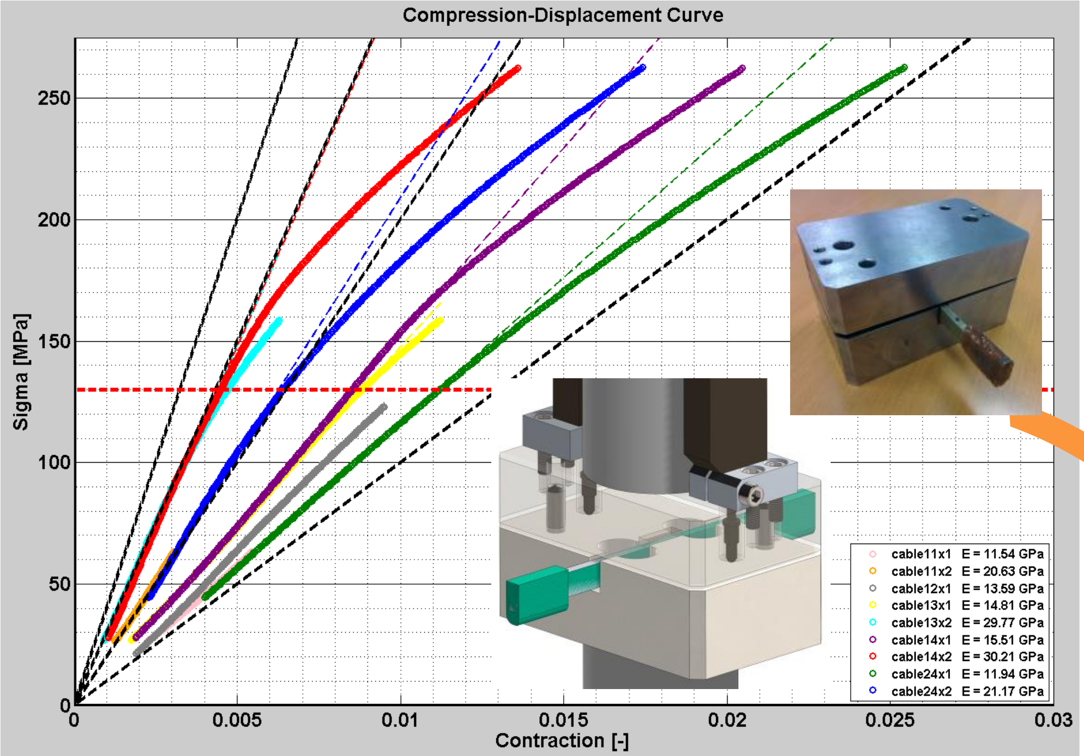
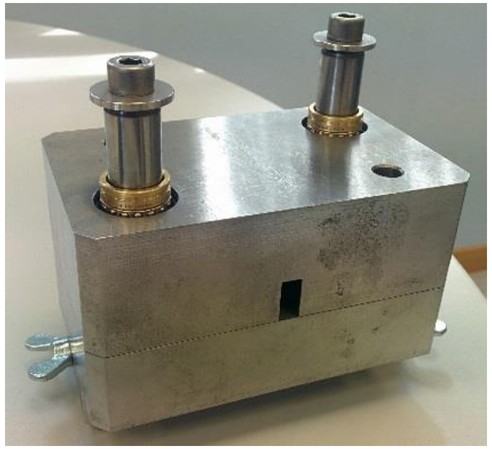
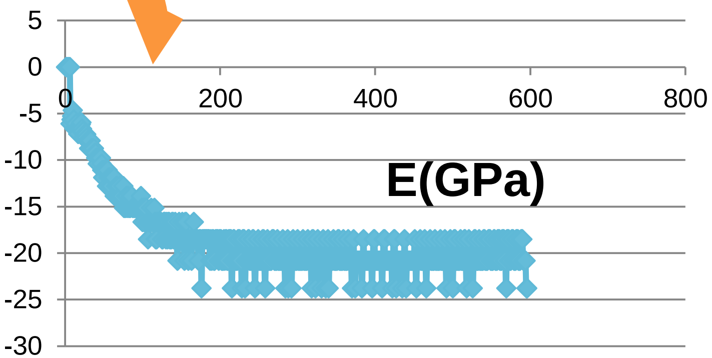
- Measurement of cable Young modulus.
- Final mechanical design.
- Short mechanical model.
- Conclusions.

Measurement of cable Young modulus



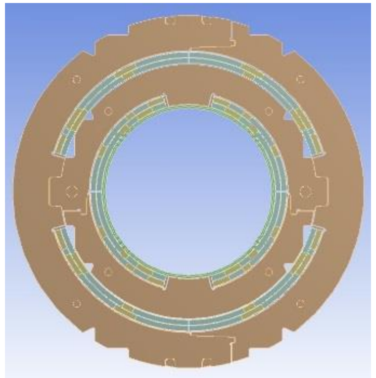
After improving the tooling, the tests confirm that Young modulus of the cables is close to **20 GPa.**

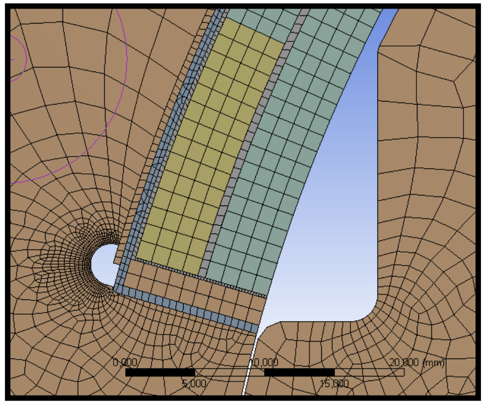




Custom tooling was used to obtain the Young modulus of ten-cable stack impregnated samples. First results showed half the expected rigidity.

Mechanical design update (I)





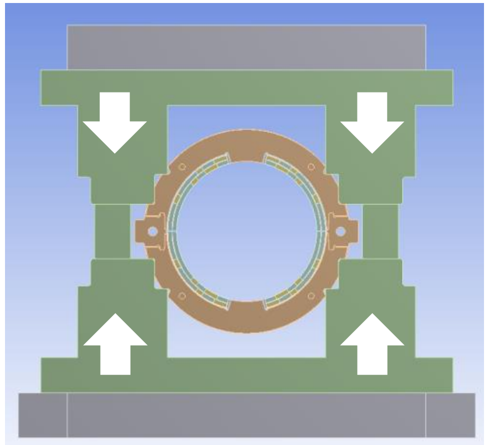
- The new cable rigidity (20 GPa) has been included in the mechanical model.
- An additional 0.1 mm of interference is necessary to achieve the same coil pre-compression than before:
  - **Inner dipole: 0.35 mm** instead of 0.25 mm.
  - **Outer dipole: 0.45 mm** instead of 0.35 mm.

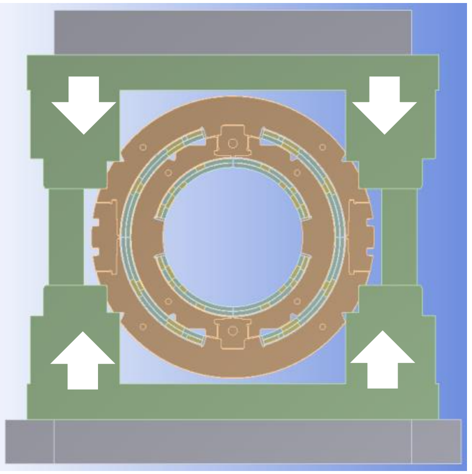
- This is coherent considering coil smeared-out properties.

40 GPa Cable blocks + 130 GPa copper wedges ≅ 70 GPa Coil

20 GPa Cable blocks + 130 GPa copper wedges ≅ 50 GPa Coil

- Stress distribution is checked at the different load steps.



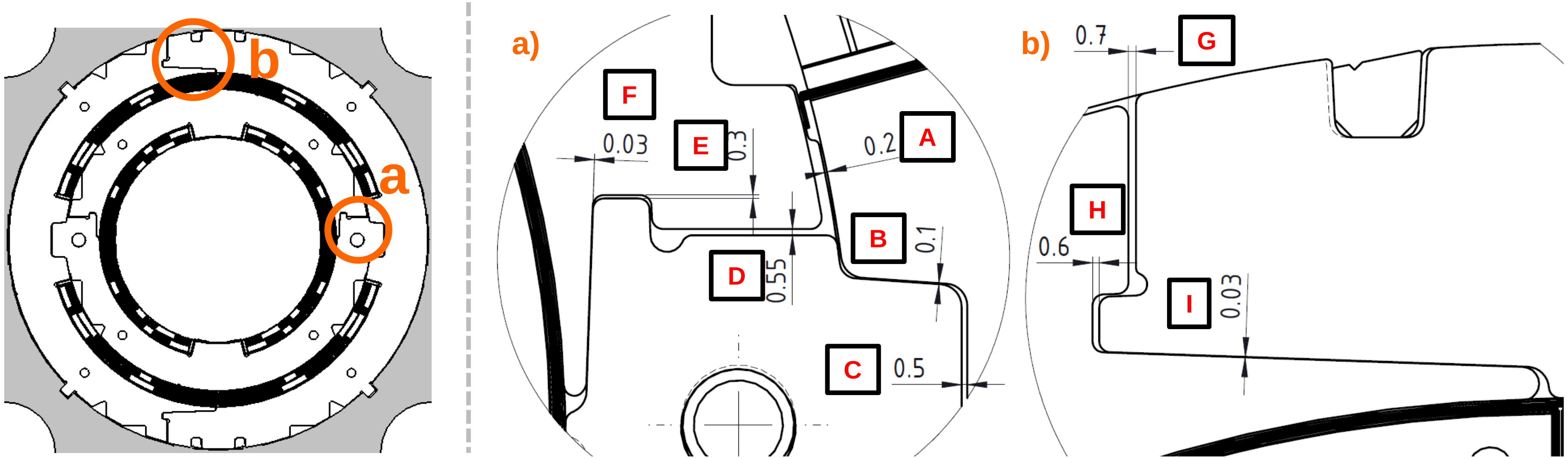


Mechanical design update (II)

Gap	Original gap	ID Press	ID Spring Back	Before OD Press	OD Press	OD Spring back	Cool-down	108% Power.
A	0,2	-	-	opens	0,13	opens	opens	0,08
B	0,1	-	-	opens	0,08	0,08	0,085	contact
C	0,5	-	-	opens	0,47	opens	opens	0,4
D	0,55	0,42	opens	opens	opens	opens	opens	opens
E	0,3	0,18	opens	opens	opens	opens	opens	opens
F	0,03	≅0,03	contact	contact	contact	contact	contact	contact
G	0,7	-	-	opens	0,55	opens	opens	opens
H	0,6	-	-	opens	0,45	opens	opens	opens
I	0,03	-	-	contact	contact	contact	contact	°contact

All values in mm

- **Motivation: There is no previous experience in nested collaring structures.**
- **Undesired contact between parts could difficult/prevent the assembly.**
- **Excessive gaps could spoil the field quality or cause clattering during operation.**



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- Final magnetic design.
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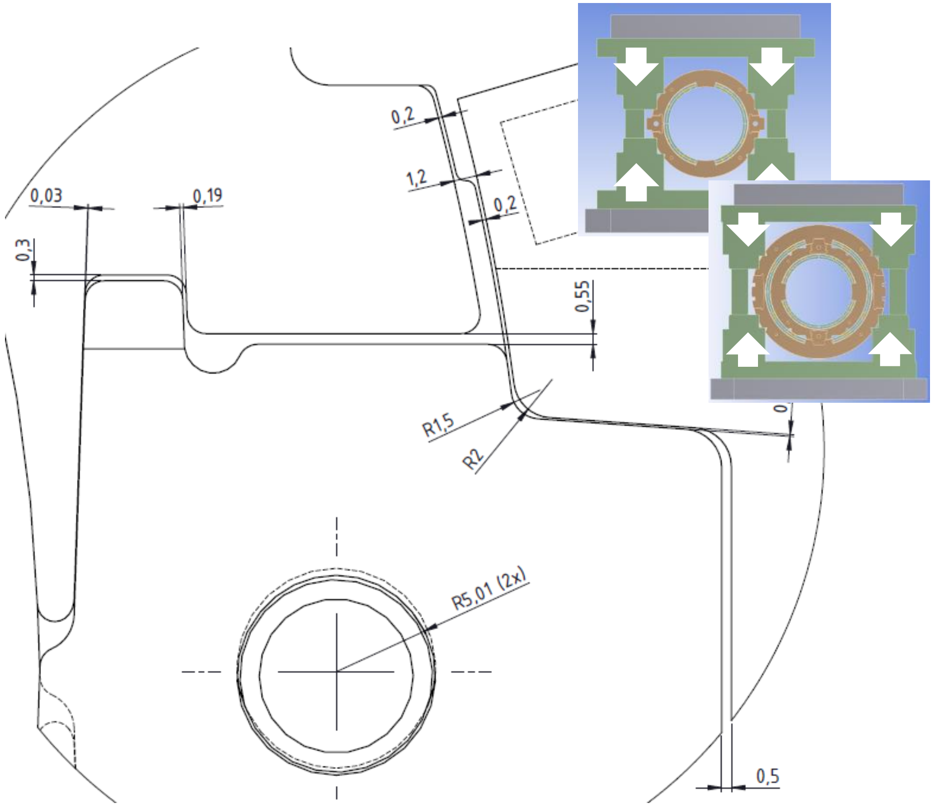
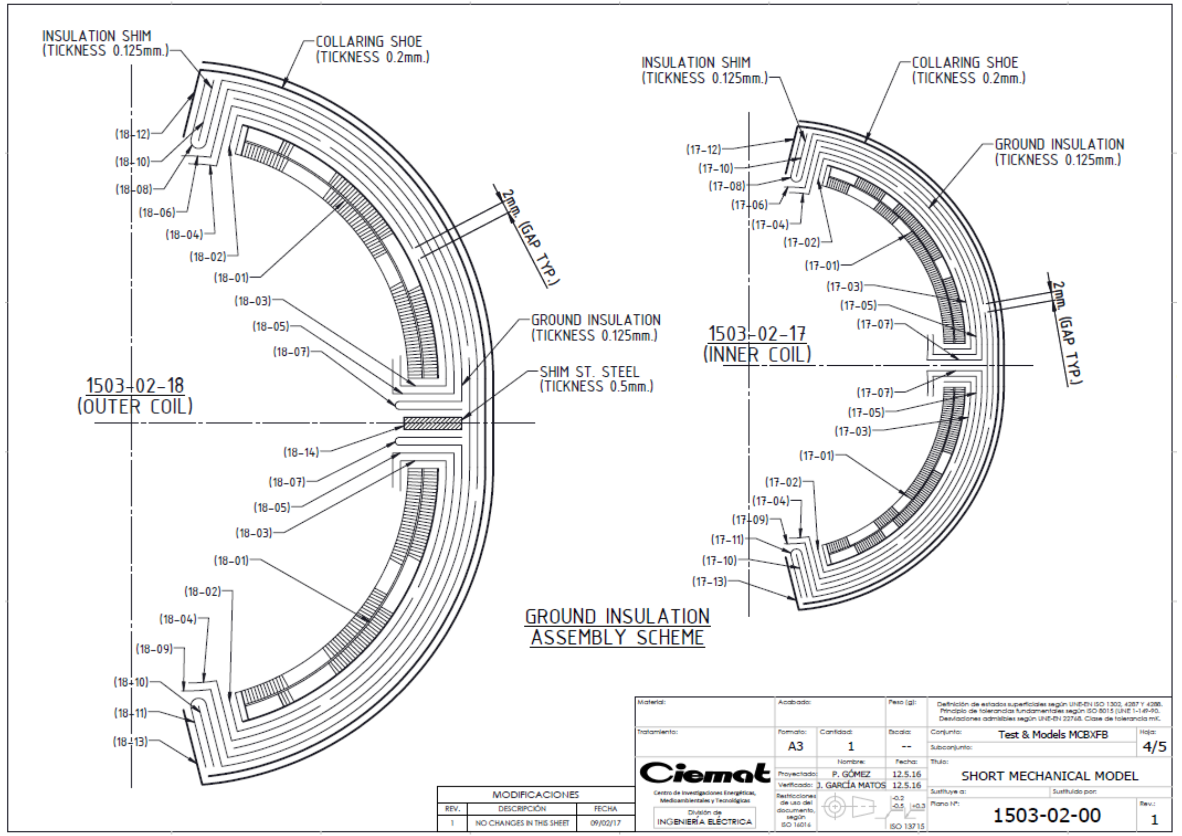
- Short mechanical model.
- Conclusions.

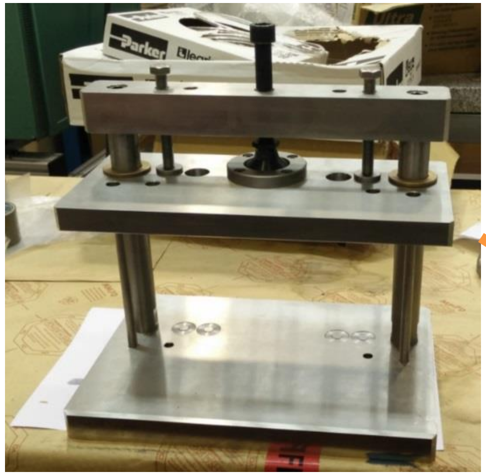
Short mechanical model: Motivation





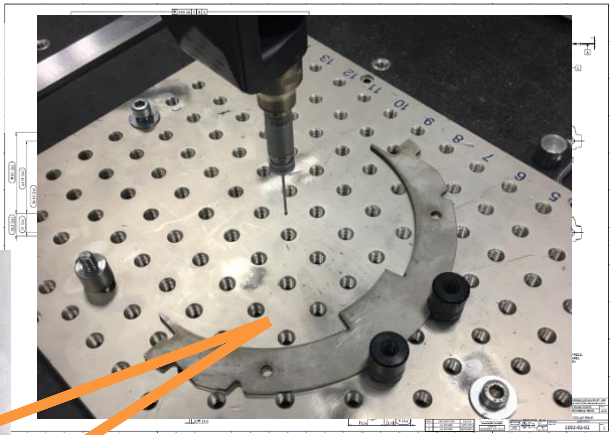
- A short mechanical model, as close as possible to the real magnet, becomes essential to:
  - Validate the assembly process of the nested dipoles: feasibility, gaps, ground insulation, collaring shoes...
  - Test part of the tooling to be used in the prototype assembly.
  - Validate the FE mechanical model.

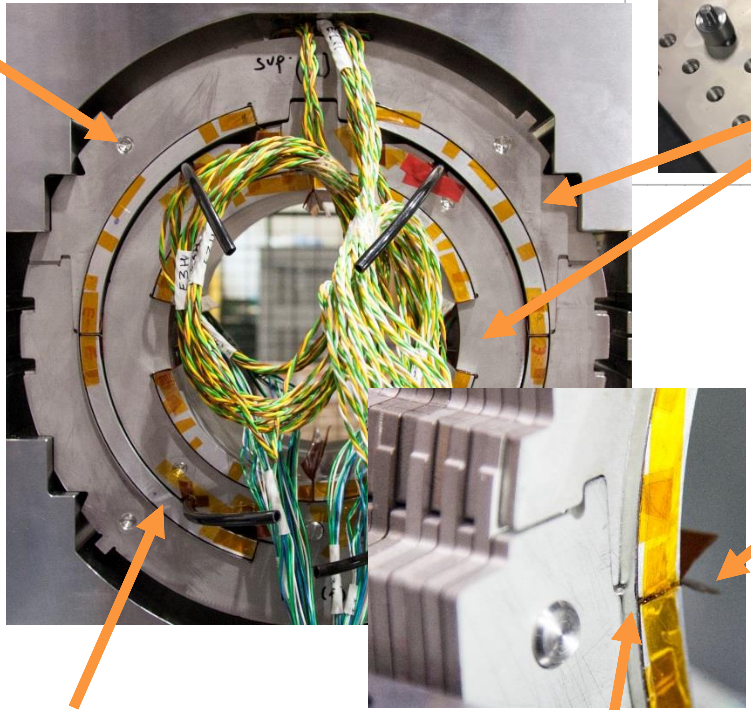
Short mechanical model: Fabrication

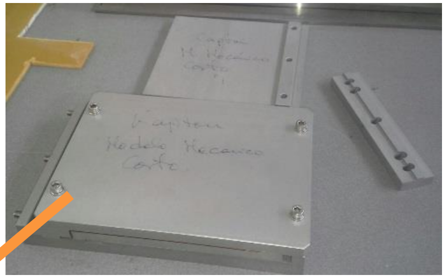


Collar packaging tool (ID & OD)

Collars
(Laser + EDM)



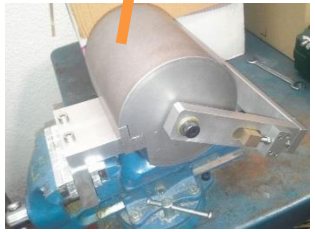




Kapton bending
tooling

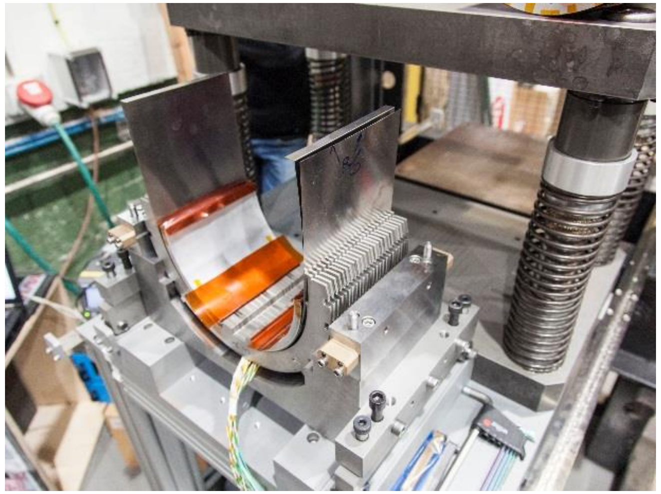
Aluminium
dummy coils

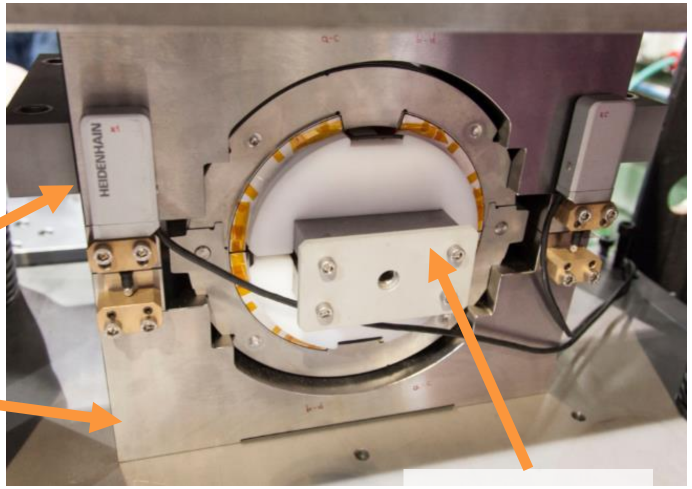
Handling scissors (ID & OD)

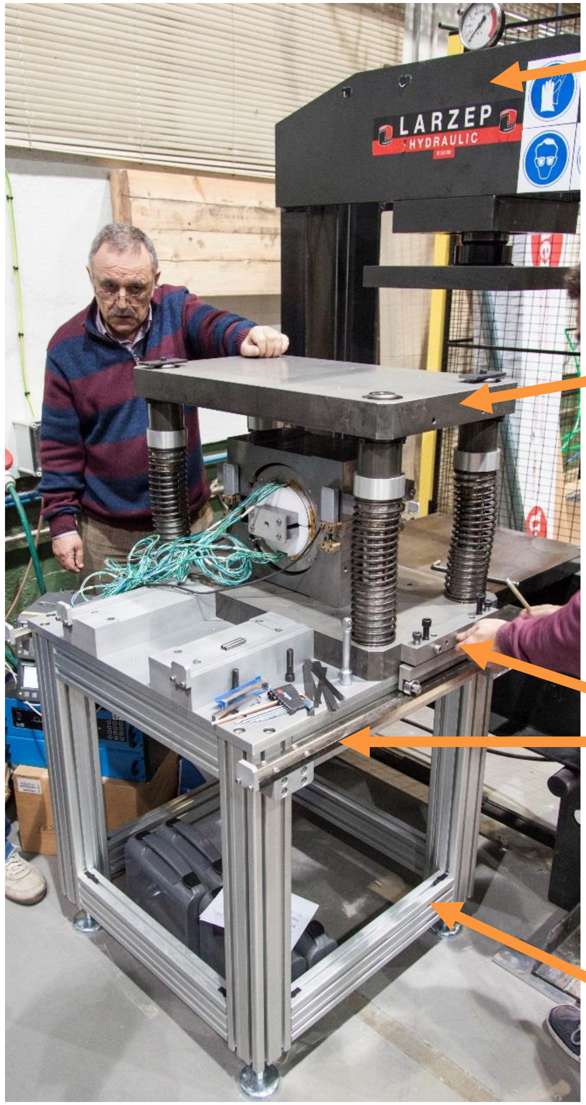


Collaring shoe
preforming
tooling

Short mechanical model: Assembly







120 Ton press refurbished and calibrated

Alignment cage

Handling/sliding system

Support/assembly table

Pressing craddles and stoppers

Inner collapsible mandrel

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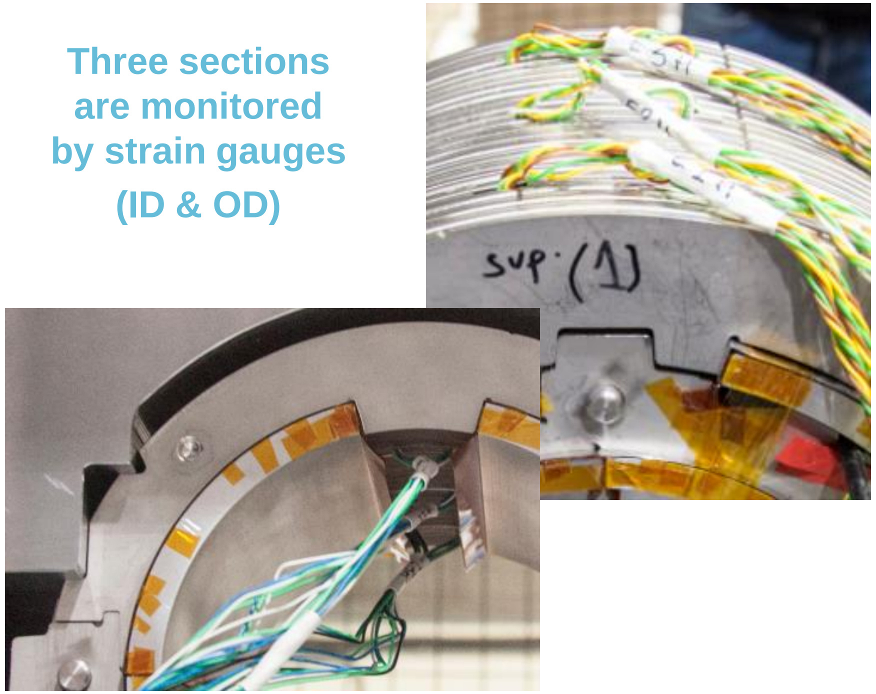
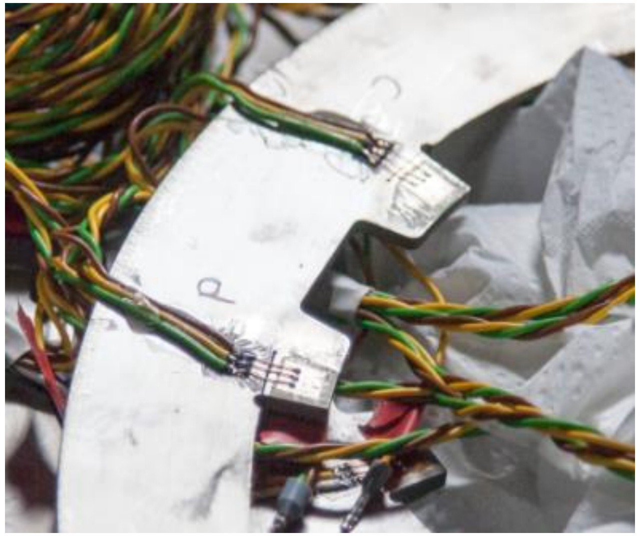
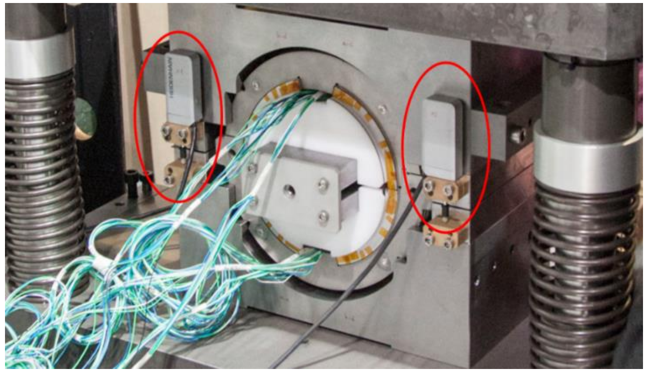
Short mechanical model: Instrumentation

Three sections are monitored by strain gauges (ID & OD)





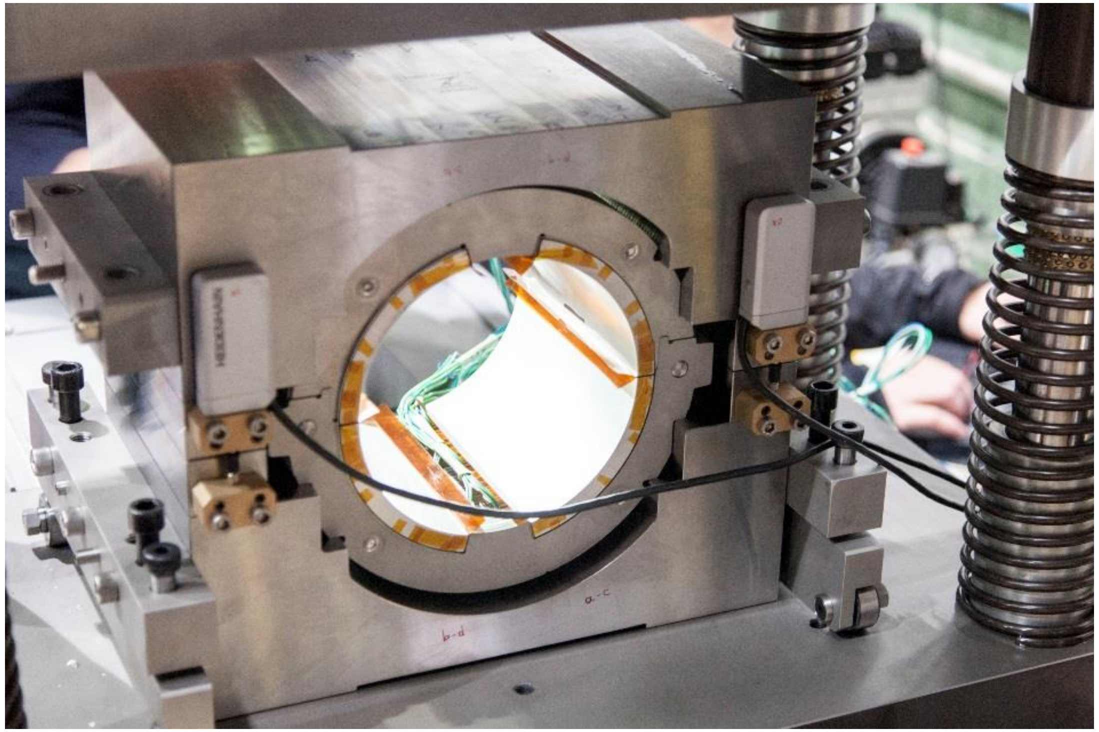
Four strain gauges per collar: on both sides of the collars and noses



Four displacement gauges: micrometric precision

All gauges configuration, installation, cabling and data acquisition have been developed in-house

Short mechanical model: Inner collaring test

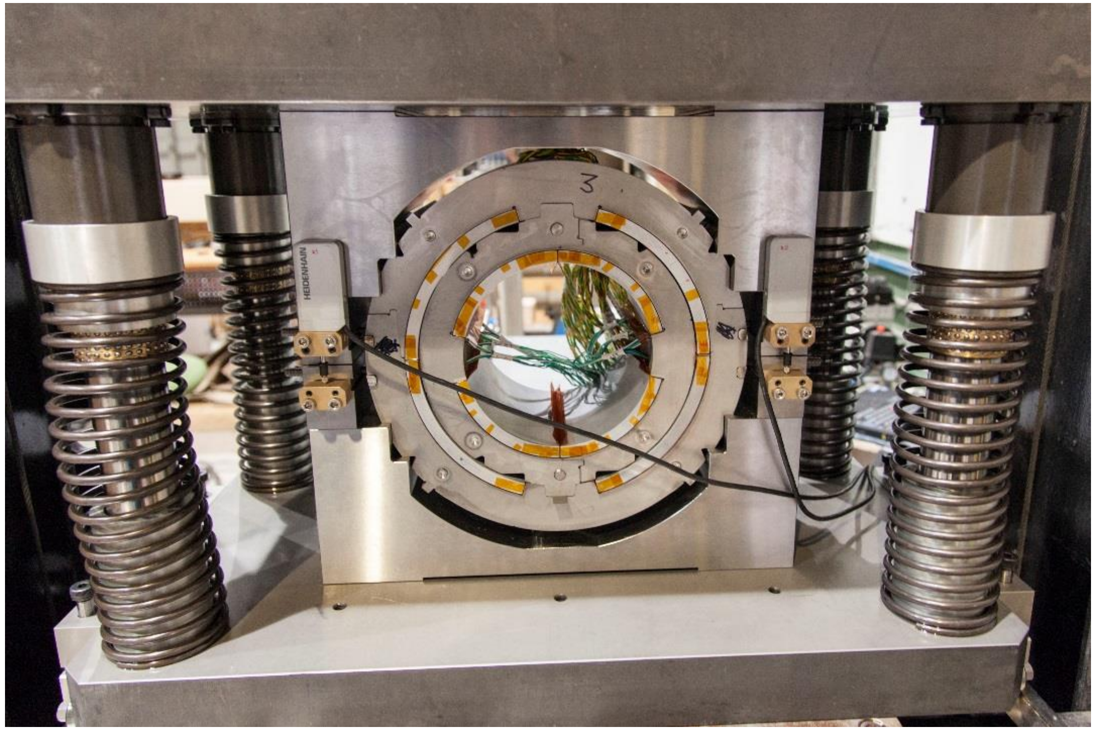


Gap [mm]	Press force [ton]	Average stress measured [MPa]	Average stress simulated [MPa]
0.5	26	52	-
0.4	34	71	-
0.3	40	90	-
0.2	**40**	**106**	**108**
Spring-back	**-**	**72**	**74**

- **At the minimum gap of 0.2 mm, expected stress at the collar nose was about 108 MPa, very close to the average of the measurements of the gauges (106 MPa).**
- **When the pressure is relieved, the inner dipole is left in its "spring-back" position. Calculated strain is 74 Mpa and the average of all measures is 72 MPa.**
- **The collapsible mandrel is retired without effort from the inner dipole aperture.**

Short mechanical model: Outer collaring test

- At the minimum gap of 0.2 mm, expected stress at the collar nose was about 110 MPa, not far from the average of the measurements (124 MPa). However, gauges in the lower half measured about twice the pressure of the upper ones.
- The coils have not tried to collapse inwards. Gaps are correct.
- Strain gauges show the same unbalance at the “spring back” position. However the average is 89 MPa, very close to the 81 MPa expected from the simulation results.
- The assembly is repeated two times and measurements were balanced. We think that the assembly process was not right the first time.



Gap [mm]	Press force [ton]	Average stress measured [MPa]	Average stress simulated [MPa]
0.5	33	76	-
0.4	38	90	-
0.3	40	105	-
0.2	**40**	**124**	**110**
Spring-back	**-**	**89**	**81**

Conclusions

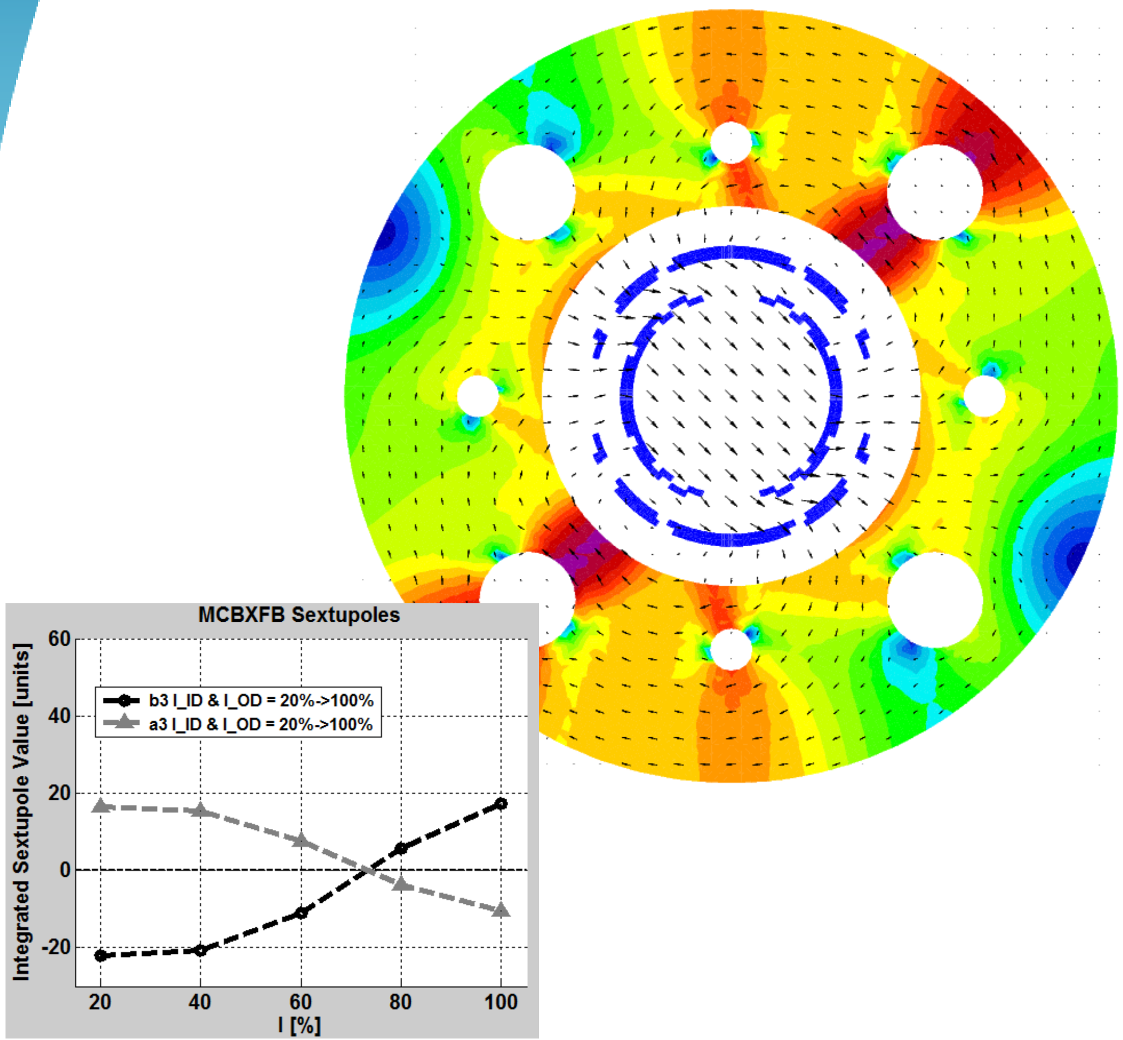
- Final 3D magnetic design is achieved with a specific optimization approach taking into account three different powering scenarios.
- Mechanical results are updated with the measured Young modulus of the cable blocks. Each load step has been simulated and stress distribution is valid.
- A short mechanical model has been produced and successfully tested to validate the feasibility of the assembly. Test results are in good agreement with simulations.
- The design and fabrication of tooling has been already started. Production of the first prototype is ongoing. Winding of first coil will be done next month.

Thank you for your attention

Back-up slides

MT24(II): Magnet conceptual design

Iron Saturation



Self-supporting collars

1 Inner collar outer diameter = 230 mm (Thickness = 27 mm)
Outer collar outer diameter = 316 mm (Thickness = 33 mm)

3 Interference