High Luminosity LHC

Orbit Corrector Status

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GOBIERNO DE ESPAÑA

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

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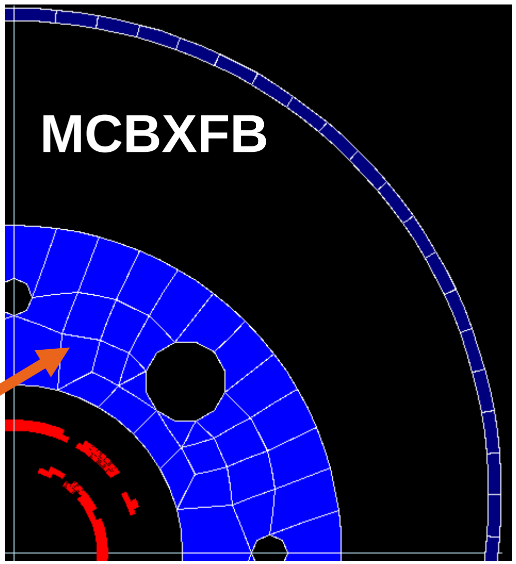
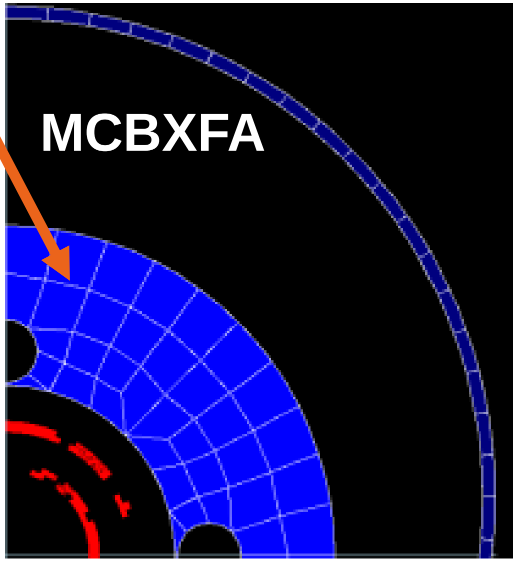
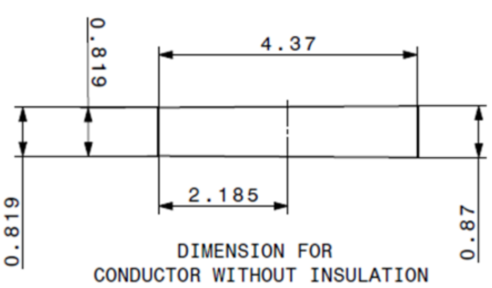
MCBXFB Technical specifications	
Magnet configuration	Combined dipole (Operation in X-Y square)
Integrated field	2.5 Tm
Minimum free aperture	150 mm
Nominal current	< 2500 A
Radiation resistance	50 MGy
Physical length	< 1.505 m
Working temperature	1.9 K
Iron geometry	MQXF iron holes
Field quality	< 10 units (1E-4)
Fringe field	< 40 mT (Out of the Cryostat)

Same cross section and coil ends but different irons



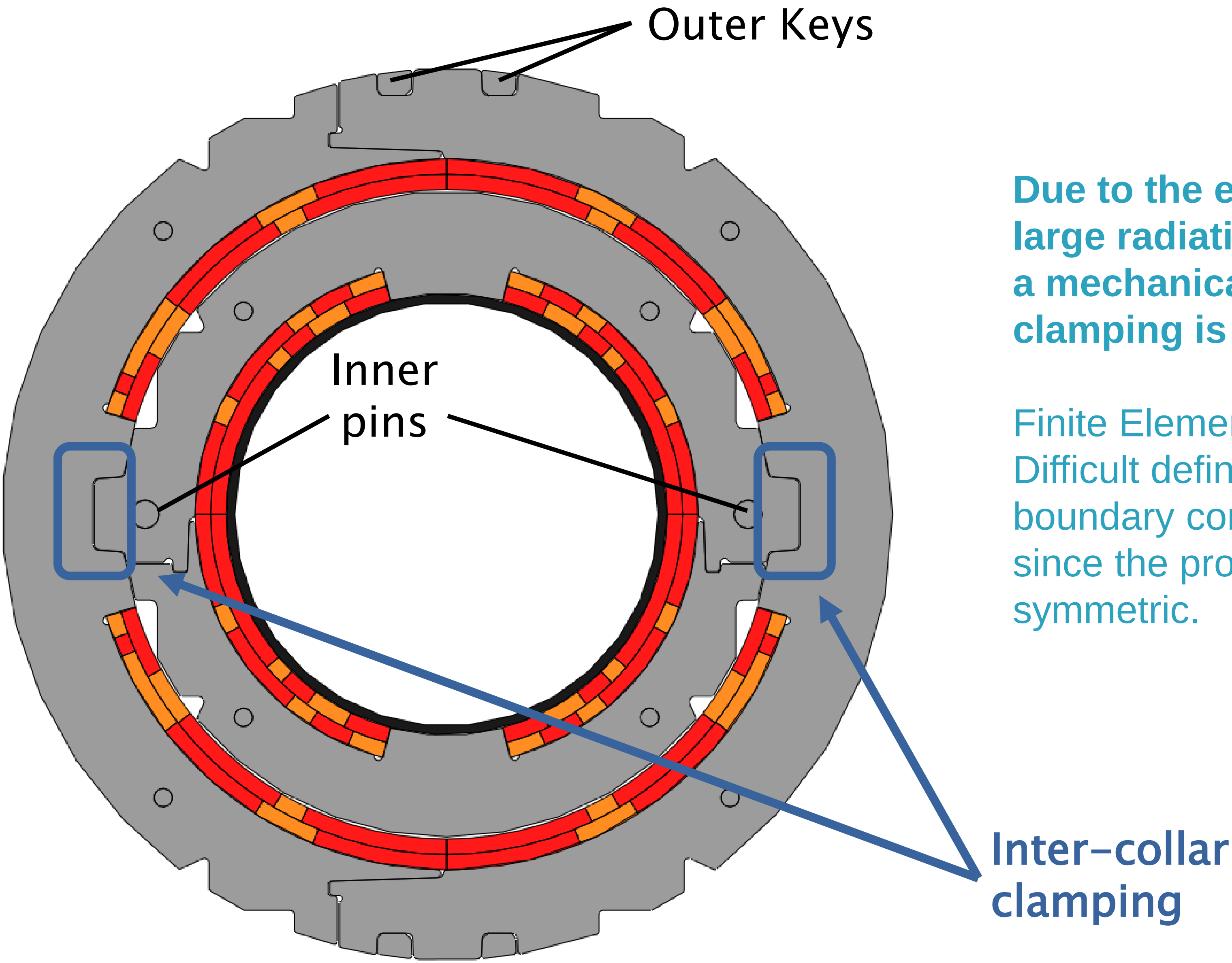




Cable Parameters	
No. of strands	18
Strand diameter	0.48 mm
Cable thickness	0.845 mm
Cable width	4.37 mm
Key-stone angle	0.67º
Cu:Sc	1.75

Mechanical Design

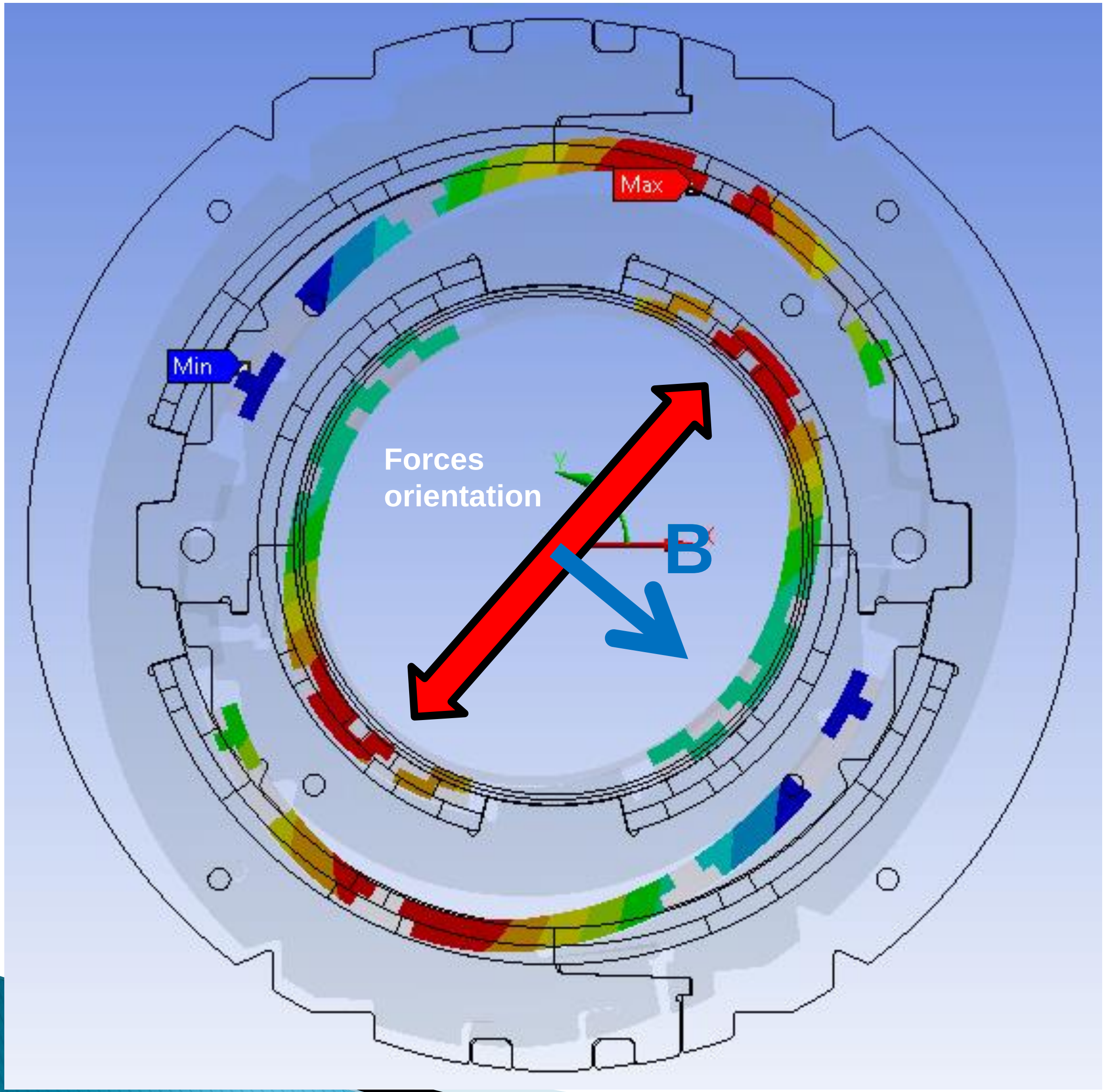
2D Mechanical Design: Basics



Due to the expected large radiation dose, a mechanical clamping is required.

Finite Element Analysis: Difficult definition of boundary conditions since the problem is not symmetric.

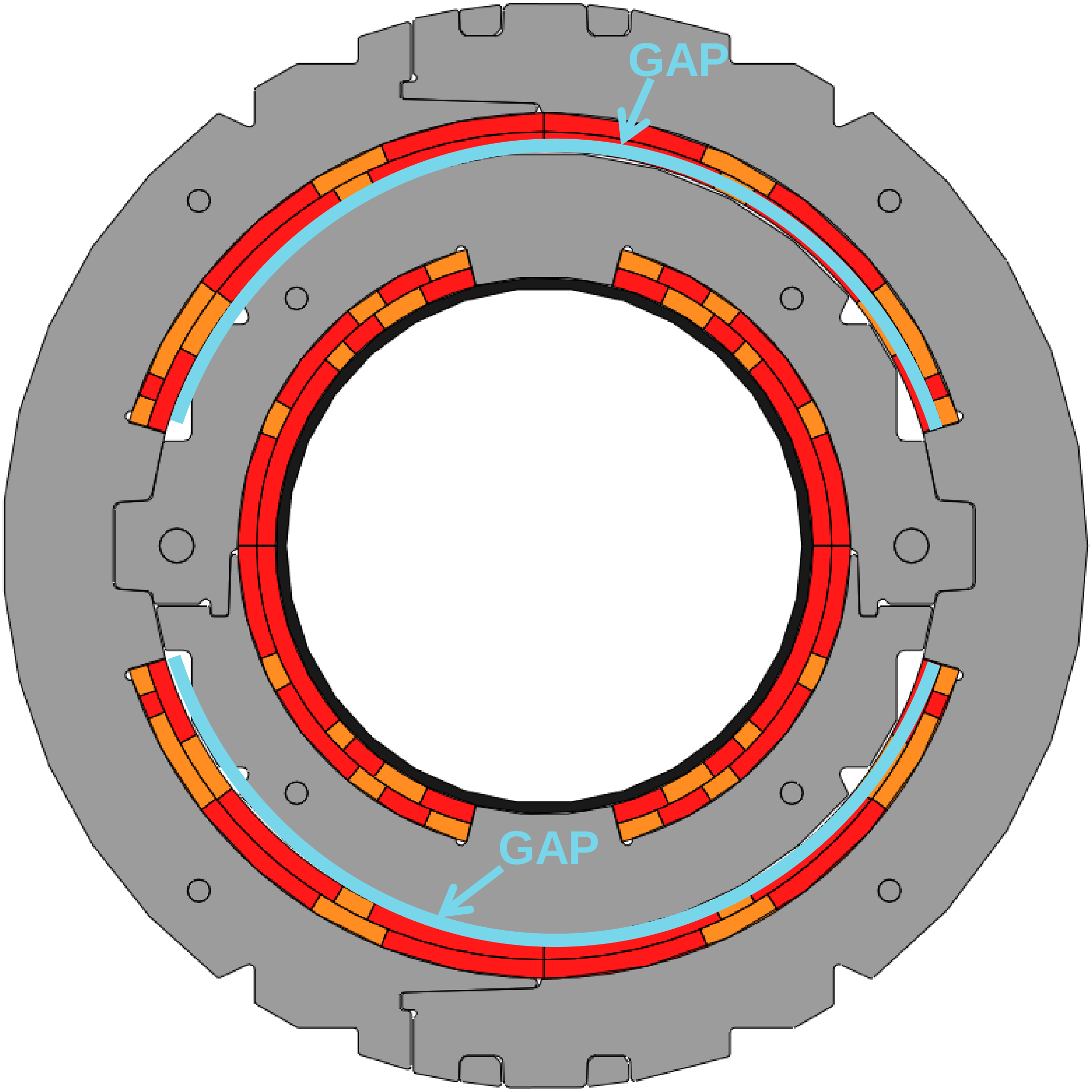
2D Mechanical Design: Support Structure Deformation



- **Large aperture leads to large radial deformations:**
  In a beam, the sag is proportional to the fourth power of the distance between supports
  (~ magnet aperture).

- **Variable orientation of the Lorentz forces** could trigger a quench with such large deformations.

2D Mechanical Design: Support Structure Deformation



The action of an external shell or increasing the outer collars thickness do not reach the inner coils, given the assembly gap between inner collars and outer coils.

The only way to decrease the inner dipole deformation is to increase inner collars thickness.

⇩

Self Supporting collars:

- Inner collar outer diam.= **230 mm** (Thickness = **27 mm**)
- Outer collar outer diam. = **316 mm** (Thickness = **33 mm**)

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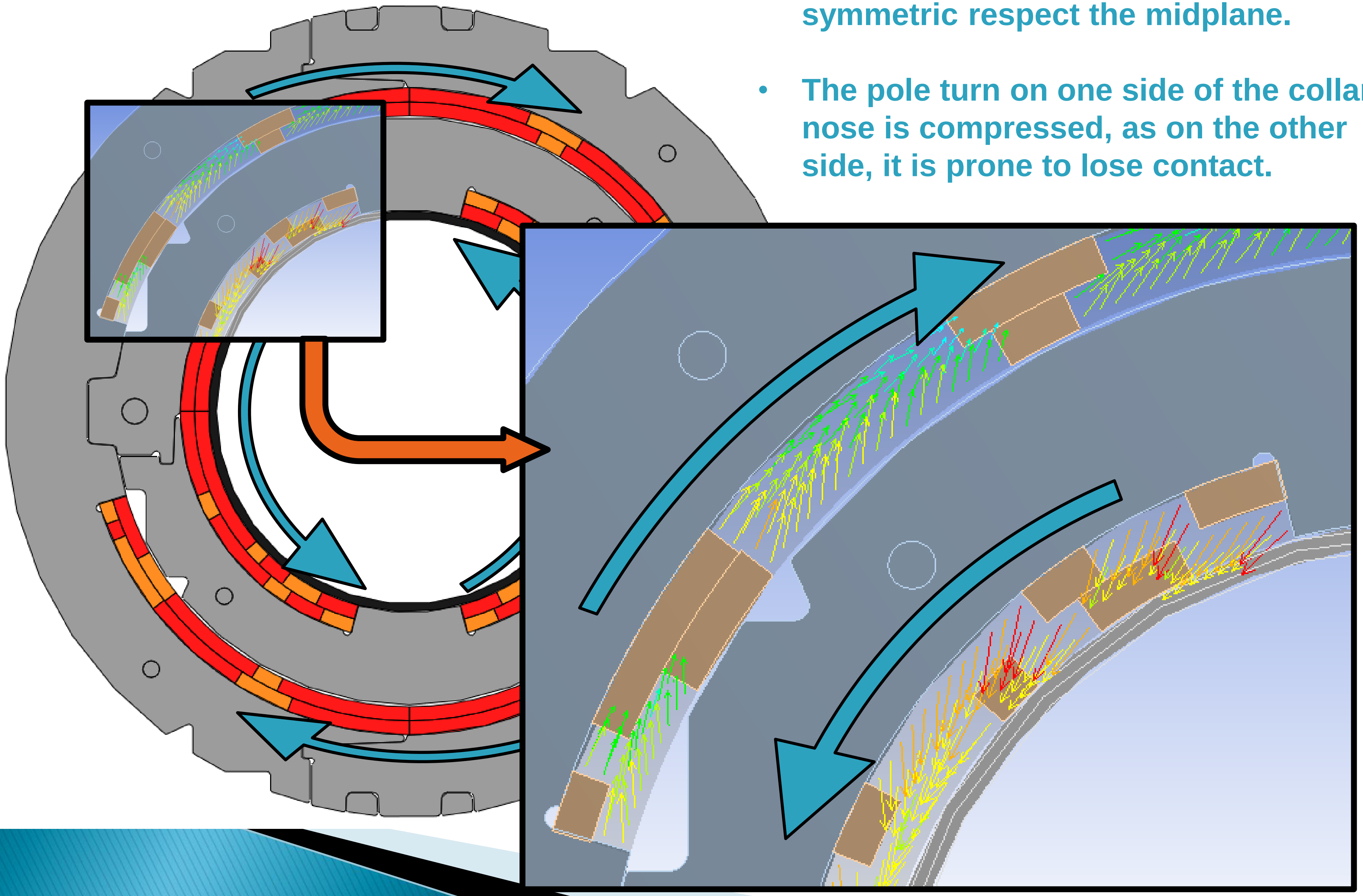
Differences between the axis of the elliptical shape of the coils:

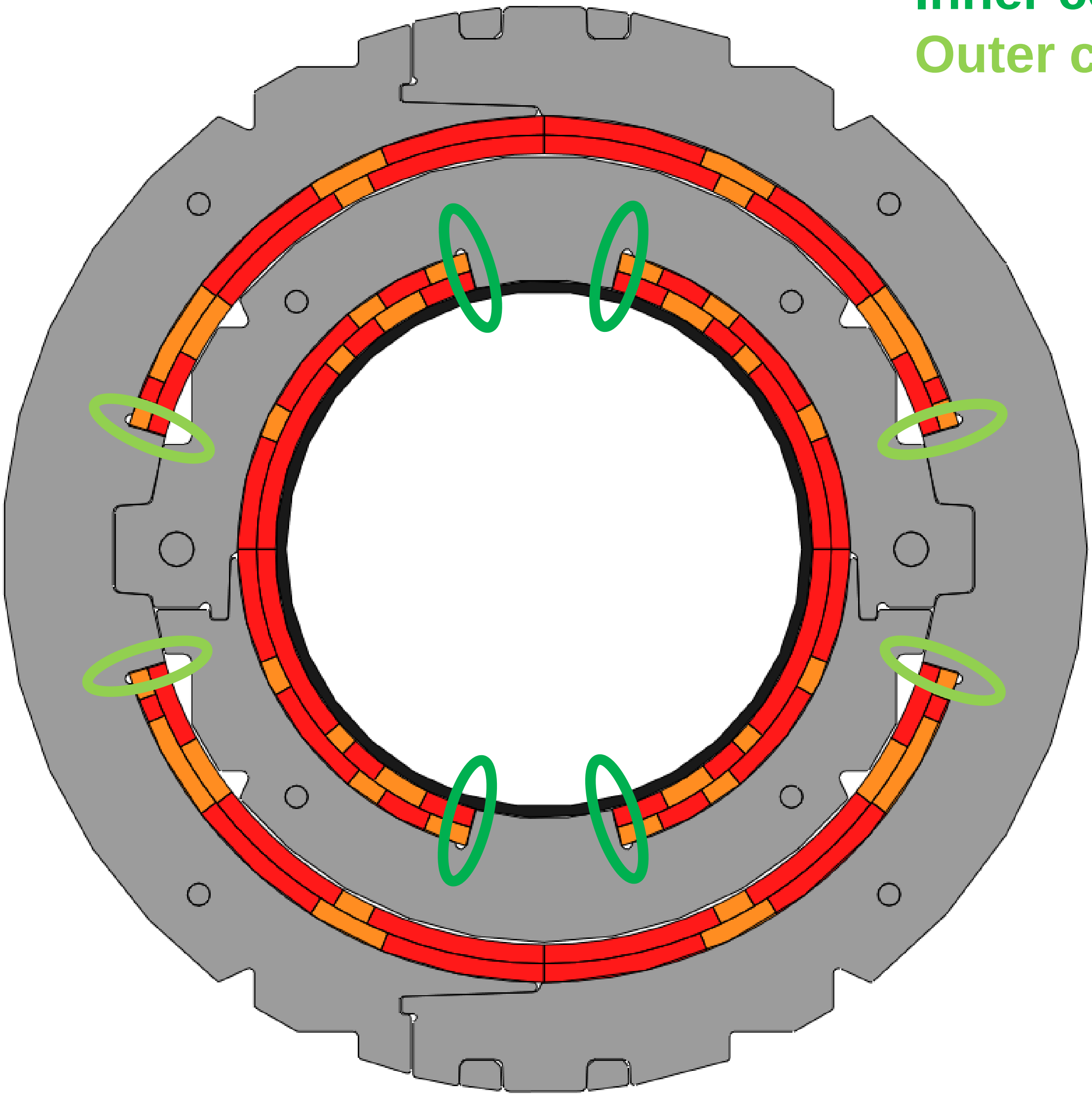
- Inner dipole = 0.6 mm
- Outer Dipole = 1 mm

2D Mechanical Design: Azimuthal Coil Deformations



- Azimuthal coil displacements are not symmetric respect the midplane.
- The pole turn on one side of the collar nose is compressed, as on the other side, it is prone to lose contact.

2D Mechanical Design: Azimuthal Coil Deformations



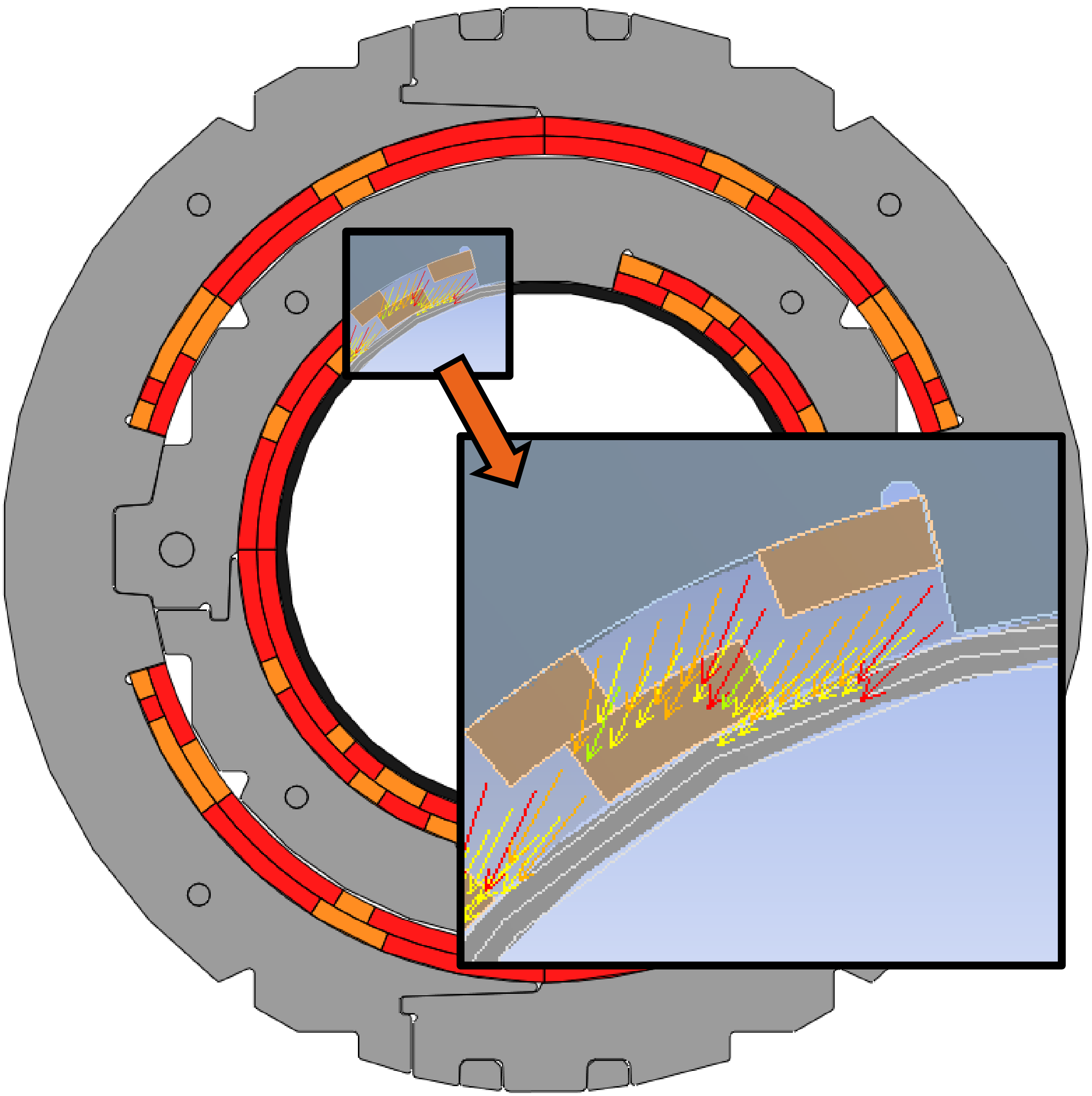
Inner collar interference = 0,25 mm
Outer collar interference = 0,35 mm

Interference between collar nose and the pole turn is introduced.

With the values presented:

- **Coils edges remains under compression at every powering scenario.**
- **The stresses are not too high through the different assembly and operation stages.**

2D Mechanical Design: Radial inward forces



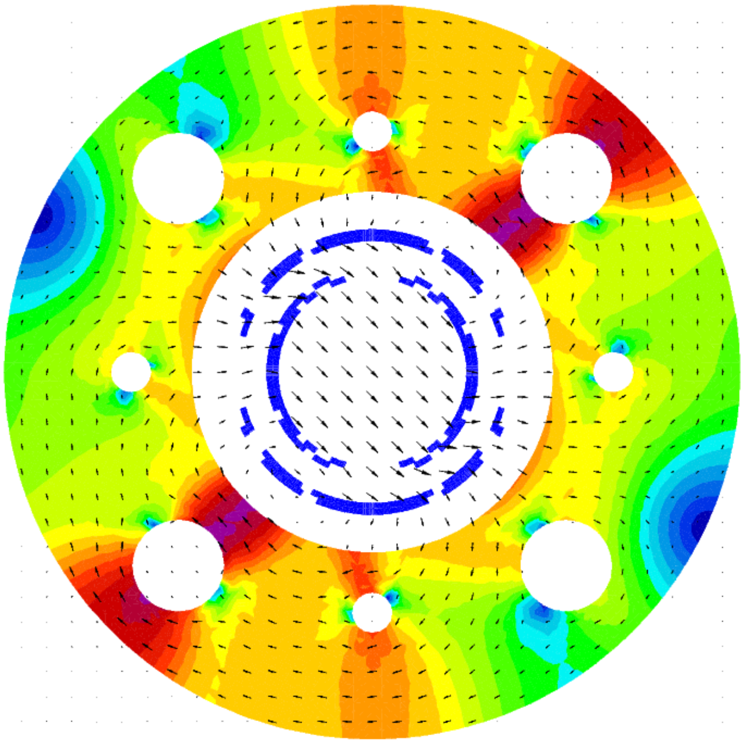
Due to the nested dipole configuration, inner coils tend to deform into the aperture (0,1 mm without friction).

Some space (3 mm radially) is kept for a titanium tube to be inserted if necessary.

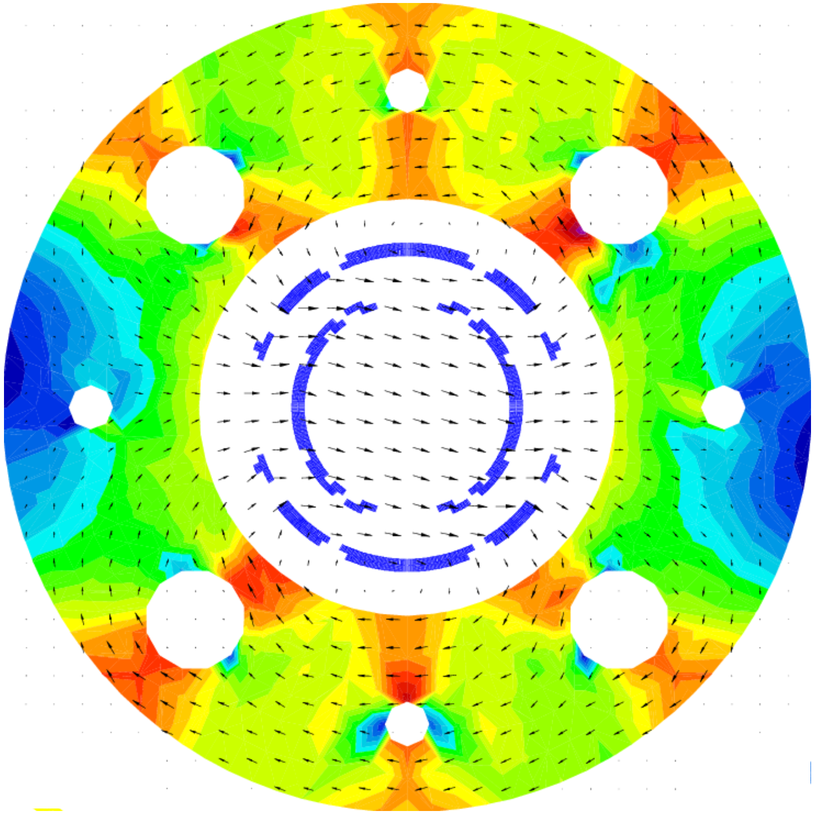
This solution was initially conceived for a 3 T design that was finally discarded because of the high stresses.

Magnetic Design

2D Final Magnetic Design: Iron saturation

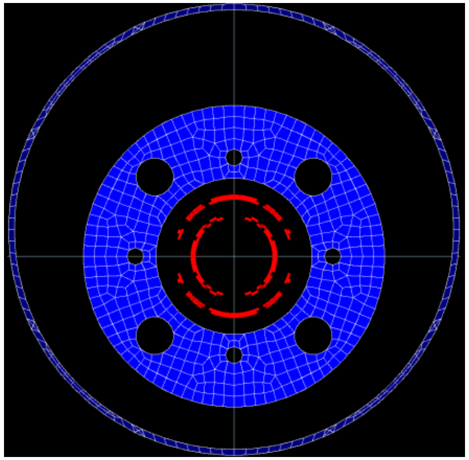


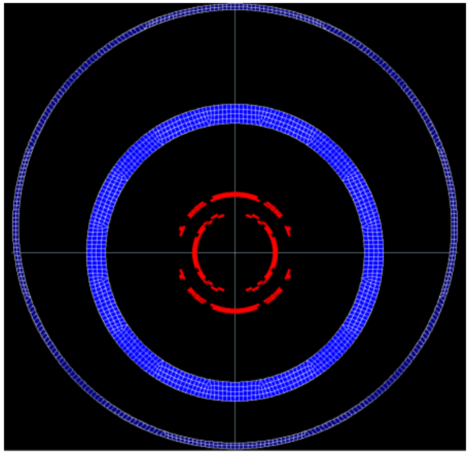
- **Iron saturation causes the variation of sextupoles with the current (up to 40 units in the worst case)**
- **The difficulty comes because the field changes in two ways depending on the powering scenario: orientation and intensity.**

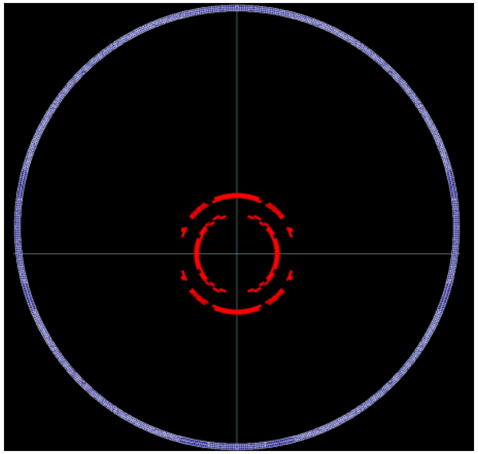


2D Final Magnetic Design: Iron geometry

- **Different yoke configurations have been checked: full iron with holes, ring, no iron at all.**







… but they do not meet the fringe field requirement:
Dipole field decays with $1/r^2$.

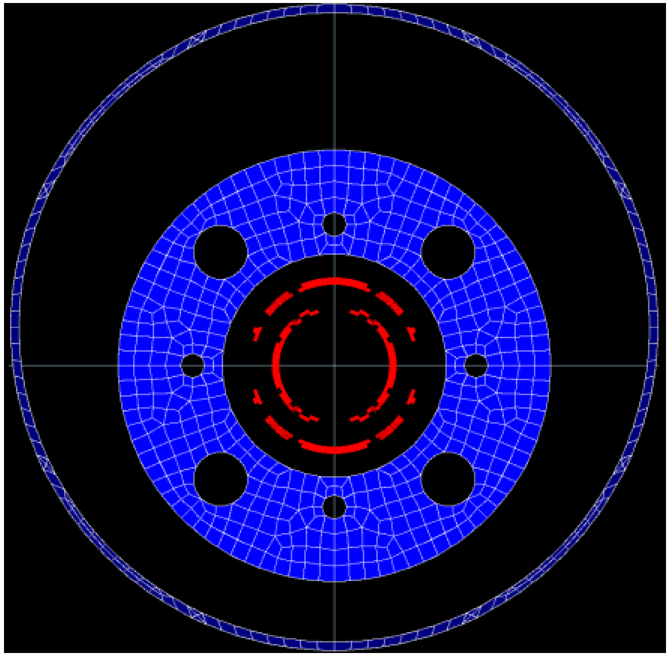
- **Therefore, we have to choose between:**
  - **High fringe field or**
  - **High variation of the multipoles with the current.**

2D Final Magnetic Design

Inner Dipole (ID) & Outer Dipole (OD) parameters	Units	ID	OD
Nominal field	T	2.11	2.23*
Nominal Field (Combined)	T	3.07	
Nominal current	A	1600	1470
Coil peak field	T	4.13 (ID)	
Working point	%	50.1	
Inductance/m	mH/m	46.77	99.1
Stored energy/m	KJ/m	59.87	107
Aperture	mm	156	230
Iron yoke Inner Diam.	mm	316	
Iron yoke Outer Diam.	mm	614	
Torque	10^5 Nm/m	1.2	
Max fringe field, 20 mm out of the cryostat	mT	29	
Total number of turns	-	139	187
Cable length needed for each pole/coil	m	362	485
Magnetic length	m	1.185	1.121
Mechanical length	m	1.505	2.508

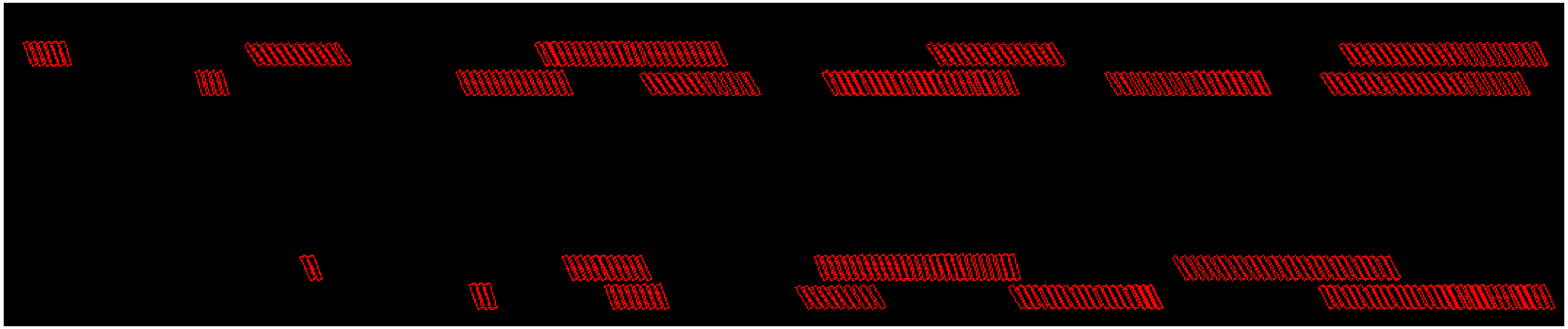
Whole iron option is chosen:

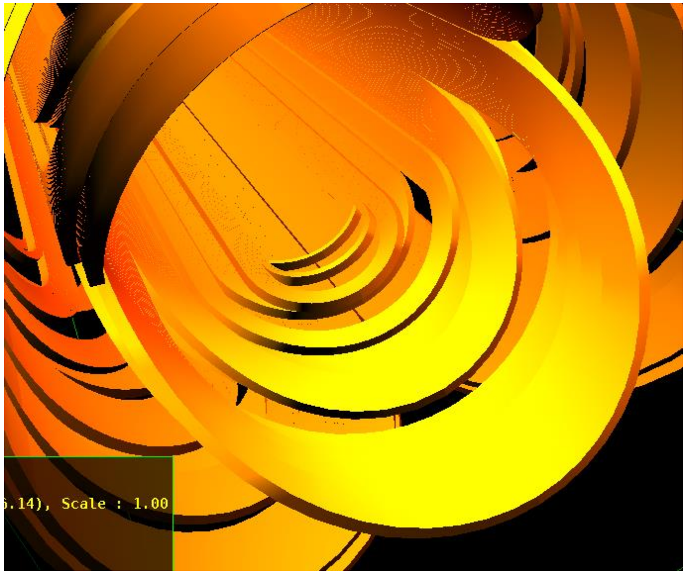
- It meets fringe field requirement.
- It has smaller Lorentz forces.



* Higher field necessary to compensate the longer coil end at the outer dipole.

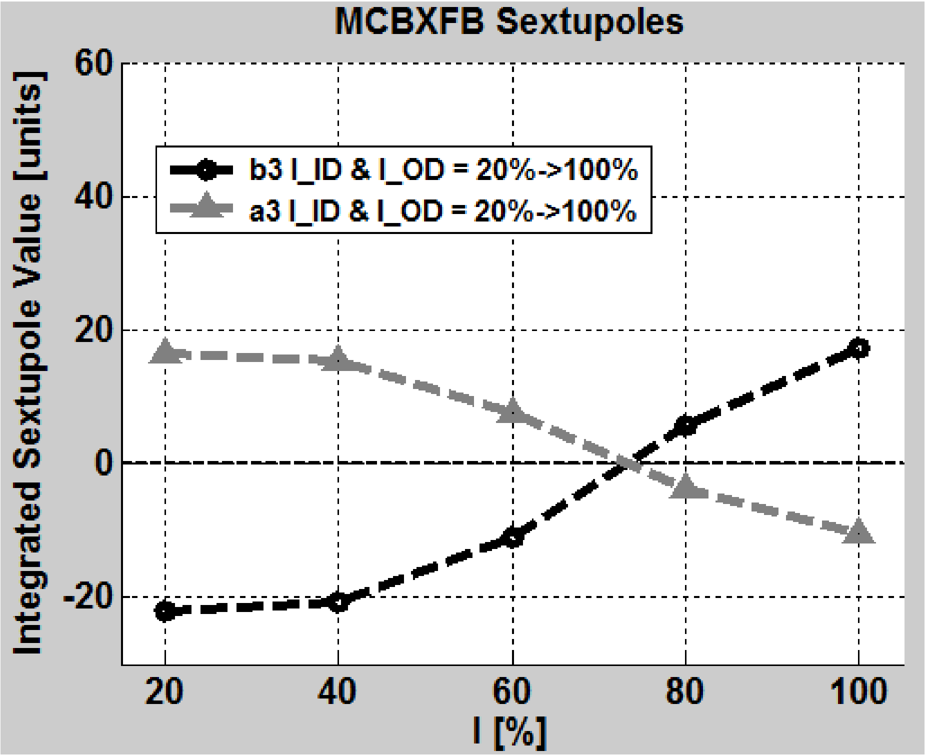
Coil ends

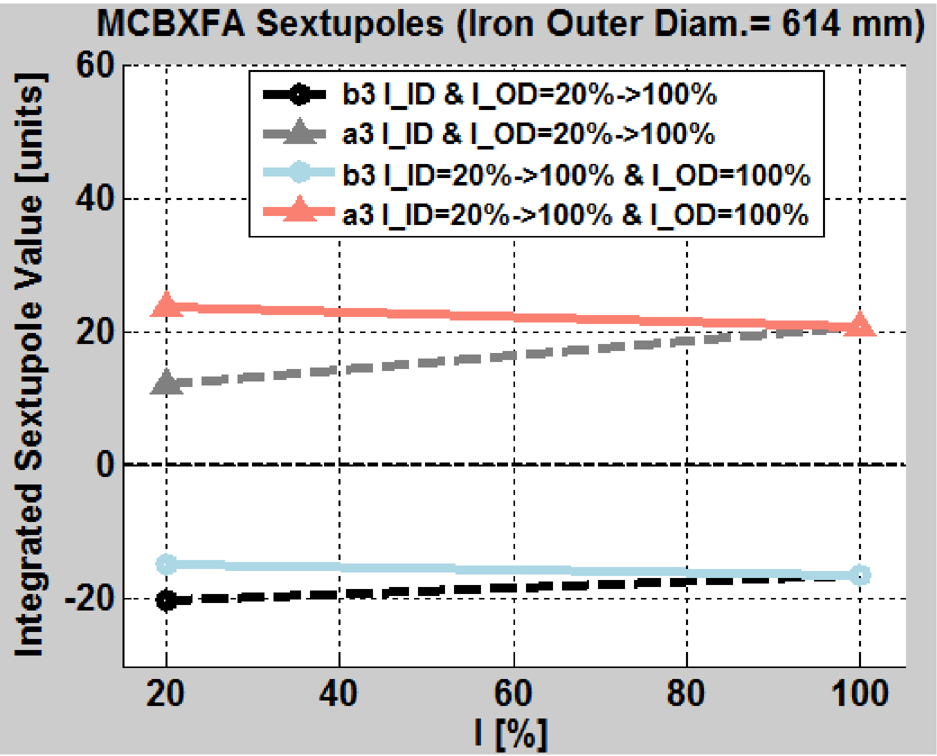




- Quite long: inner dipole coil end is about 200 mm long and outer one, 250 mm.
- Some additional end spacers to ease manufacturing.
- Peak field is very similar to straight section one.
- Torque at the coil ends cannot be hold by the collars: preliminary calculations show reasonable torsion stresses.

3D Magnetic Design





- It is not possible to centre the sextupole variation simultaneously on both magnets with the same cross section and coil ends.
- The effect of iron saturation is more significant for the outer dipole. It should be taken into account by the beam optics: outer dipole can be vertical or horizontal.

Final Magnetic Re-design (I)

- Concerning the cable dimensions:

Cable	Nominal	Measured	New design	Units
Thickness	0.845	0.851 @ 20 MPa 0.855 @ 5 MPa	0.860	mm
Insulation	0.150	0.131 @ 5 MPa	0.135	mm
Keystone angle	0.67	0.62	0.65	degree
Width	4.370	4.367 @ 5 MPa	4.370	mm

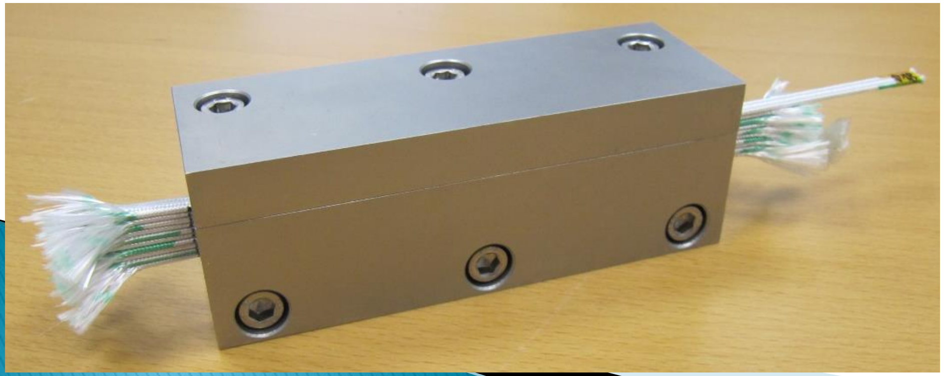
Final Magnetic Re-design (II)

- Concerning the ground insulation:
    - Five layers of 0.125 mm thick polyimide are planned as ground insulation. Two of these layers will reach the midplane for each coil, so there will be 4 layers between coils.
    - The interlayer insulation will be 2x0.28 D611 glass fiber foil. It should be checked if it can be sprayed with the new binding agents under test to ease manipulation.
- Concerning the multipole field optimization:
    - MCBXFA is more relevant for the accelerator expected operation, so it is decided to centre its sextupole variation.
    - Centring MCBXFB sextupole variations by means of shims at the midplane is worth to be studied.

Fabrication progress

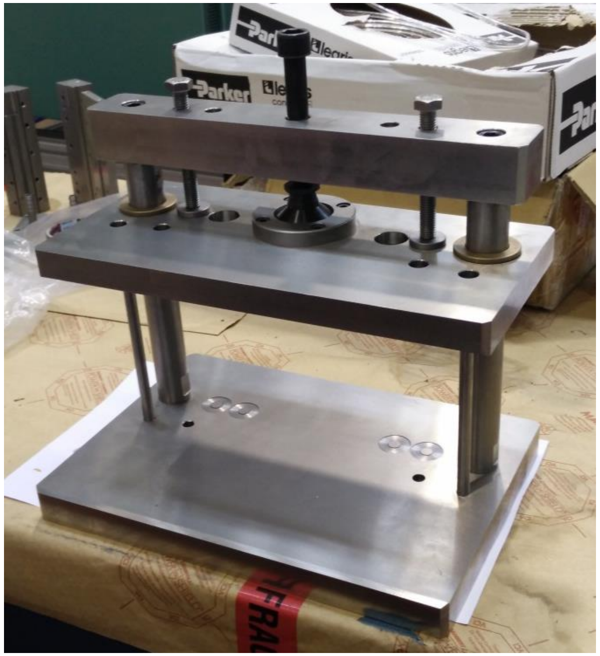
Preliminary tests: binding agents

- Two different binding agents from CTD have been tested so far: one needs catalyst, not the second one.
  - Visual inspection is fine.
  - The stack thickness slowly increases once the sample is extracted from the mould: fluency.
  - Mechanical tests are ongoing: 3-point flexion test, peeling.
- First samples have been impregnated with cyanate ester resin CTD422 (hard radiation resistance):
  - Visual inspection is fine.
  - Mechanical tests are ongoing: tensile stress, cross section cut.
- For the time being, this is the baseline technique for coil fabrication.



Short mechanical model

- A **short mechanical model** (150 mm long) is under preparation:
  - In a first approach, coils are replaced by aluminium shells.
  - Two sets of collars will be equipped with strain gauges to measure the stresses and check the mechanical calculations.



Conclusions

- Both magnetic and mechanical calculations are closed to be finished.
- Both short and long orbit correctors have been considered during the calculation stage.
- Next step is the quench simulation for both orbit correctors: the aim is to use a passive protection system.
- In parallel, validation tests on the binding agent and a short mechanical model are ongoing.
- The fabrication drawings of the tooling and magnet have been started.

Next activities

- Finish magnetic and mechanical detailed design (Nov'15).
- Short mechanical model (Dec'15).
- Magnet protection studies (Dec'15).
- Fabrication drawings of magnet and tooling (March'16).
- First coil (July'16)