First prototype of the long orbit nested corrector for HL-LHC

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ASC – 26th Oct 2022

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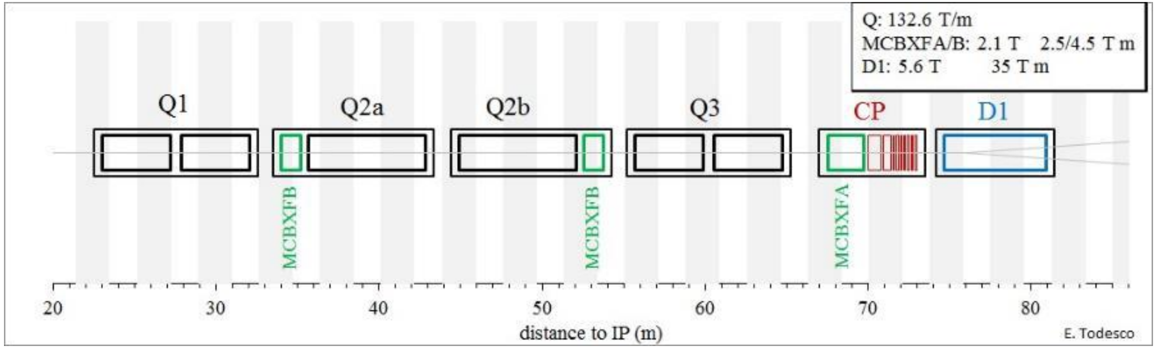
- Electromagnetic calculations
- Mechanical design
- Prototype fabrication
- Conclusions

HL-LHC orbit correctors

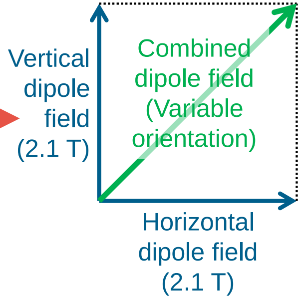


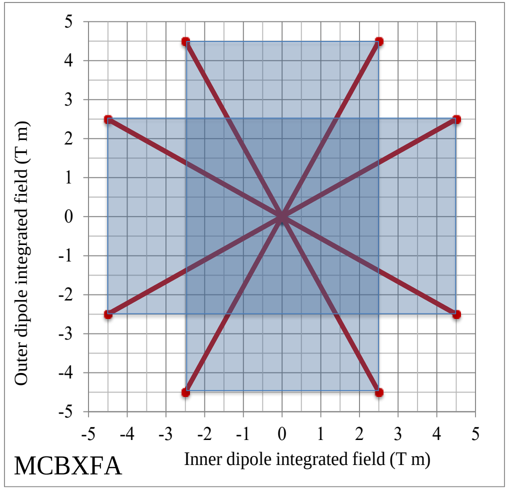
- MCBXF are **nested** dipole H/V correctors, the closest ones to the interaction point:
  - 150 mm single aperture, **NbTi technology**
  - Two magnet lengths with the **same cross section**:
    - Type A (2.5 m long): 1 prototype + 6 series (2 of them: spares)
    - Type B (1.5 m long): 2 prototypes + 12 series (4 of them: spares)
- **CIEMAT deliverable**: "bare" magnets
  - Powering tests done at CERN & FREIA
  - Integration in cold mass at CERN

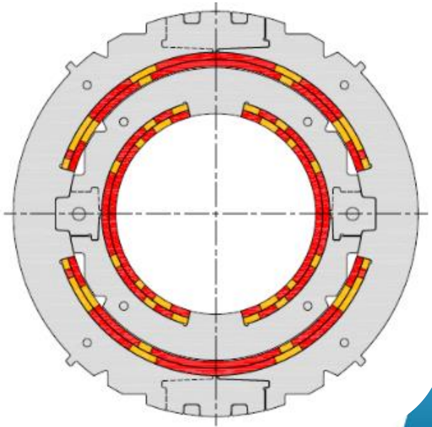
MCBXFB ready to test at SM18 (CERN courtesy)

Magnet layout

MCBXF Technical specifications	
Magnet configuration	Combined dipole (Operation in X-Y square)
Integrated field	4.5 (A) / 2.5 (B) Tm
Minimum free aperture	150 mm
Nominal current	< 2000 A
Radiation resistance	35 MGy
Physical length	< 2.5 (A) / 1.505 (B) m
Working temperature	1.9 K
Iron geometry	D1 (A) / MQXF (B) iron holes
Field quality	b3 < 20 units (1E-4), b5 < 7, the rest < 5
Fringe field	< 40 mT (Out of the Cryostat)







First nested superconducting accelerator magnet with mechanical torque locking

Up to **147 kNm/m** ¡¡~**250 times** **the electric *Porsche Taycan Turbo S* motor torque in a A-type magnet!!**

Magnet layout

MCBXF Technical specifications	
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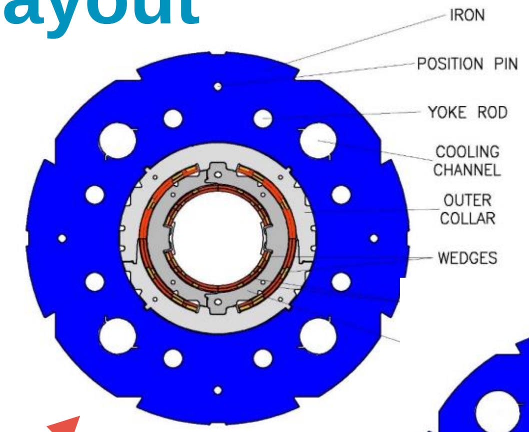
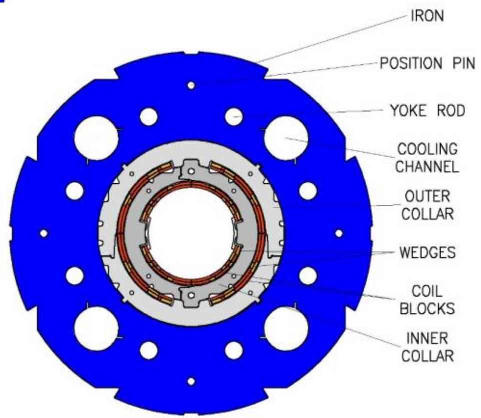
Minimum free aperture	150 mm
Nominal current	< 2000 A
Radiation resistance	35 MGy
Physical length	< 2.5 (A) / 1.505 (B) m
Working temperature	1.9 K
Iron geometry	D1 (A) / MQXF (B) iron holes
Field quality	< 10 units (1E-4)
Fringe field	< 40 mT (Out of the Cryostat)



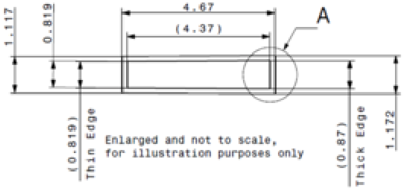
MCBXFA



MCBXFB

Cable fixed as an input data

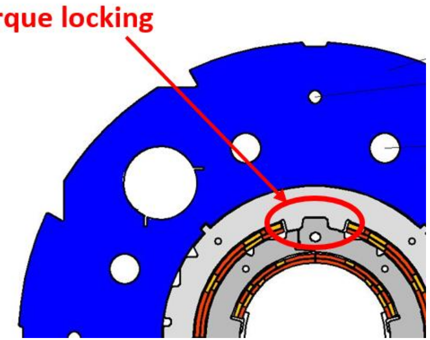
Cable Parameters	
No. of strands	18
Strand diameter	0.48 mm
Cable thickness	0.845 mm
Cable width	4.37 mm
Key-stone angle	0.67º
Cu:Sc	1.75

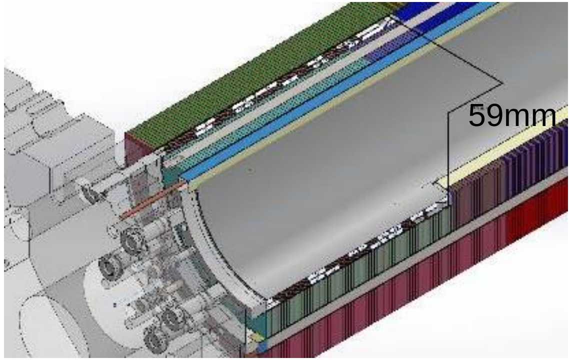


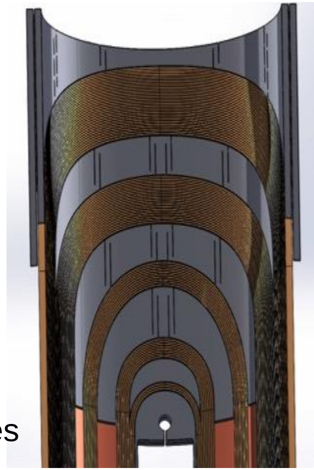
- Insulated with a braided glass fiber sleeve
- High number of turns: impregnated coils

Reminder: design fine-tuning (MCBXFB01)

- First two B-type prototypes performed **long training** with each torque inversion**: quenches located at coil ends.**
- The inner coil end of the first B-type series magnet MCBXFB01 was **shortened by 118 mm** to **reduce the unlocked length** at coil ends.
- In addition, **endspacers** legs were enlarged to increase the rigidity at the transition from the straight section to the coil heads.
- This successful fine-tuning of the design is implemented in A-type magnets.






Prototypes

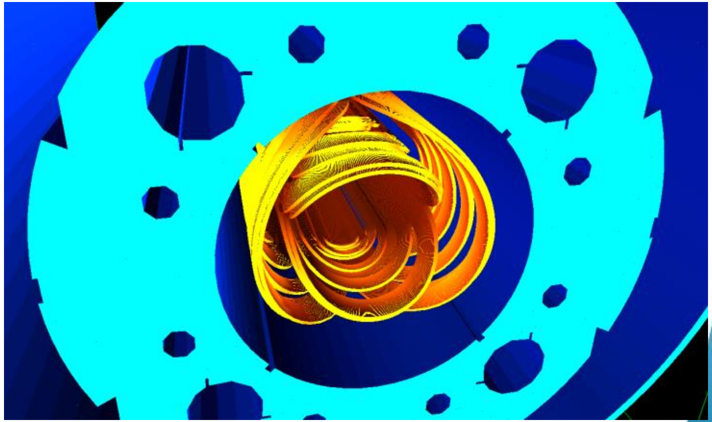

Series

Electromagnetic calculations

MCBXFA / MCBXFB

Parameter	ID	OD	Units
Nominal individual field	2.12 / 2.36	2.12 / 2.24	T
Field integral	4.5 / 2.5	4.5 / 2.5	Tm
Nominal current	1617 / 1755	1353 / 1435	A
Ultimate current	1737 / 1855	1457 / 1545	A
Pole length	1828 / 828	1828 / 828	mm
Coil length	2224 / 1224	2342 / 1342	mm
Differential inductance at nominal current	101.3 / 52.5	234.1 / 125.4	mH
Stored magnetic energy at nominal current	132.7 / 81.1	224.8 / 136.7	kJ
Stored magnetic energy at ultimate current	153.1 / 93.5	257.8 / 138.5	kJ

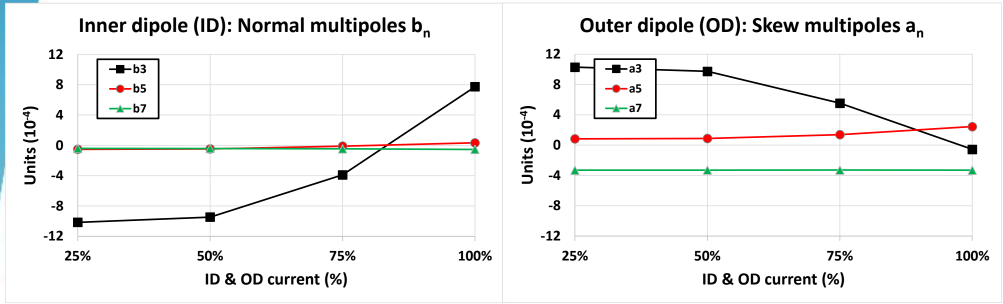
- Electromagnetic calculations performed with Xroxie.
- Challenging because of: high number of conductors, magnet length and lack of symmetry.



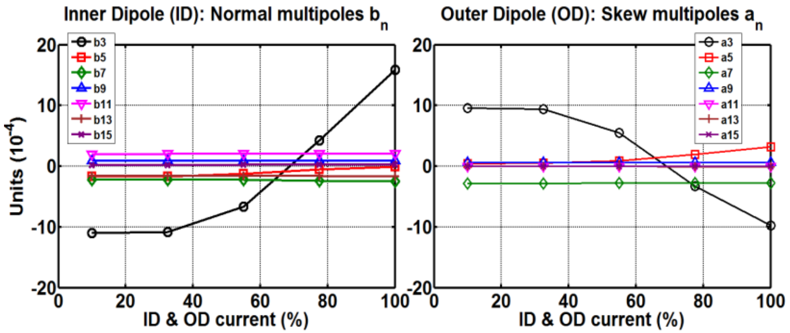
- Nominal currents of A-type magnet are lower:
  - Less iron saturation (smaller iron holes)
  - Larger ratio of straight cross section to coil end length

Magnetic field quality (I)

MCBXFA



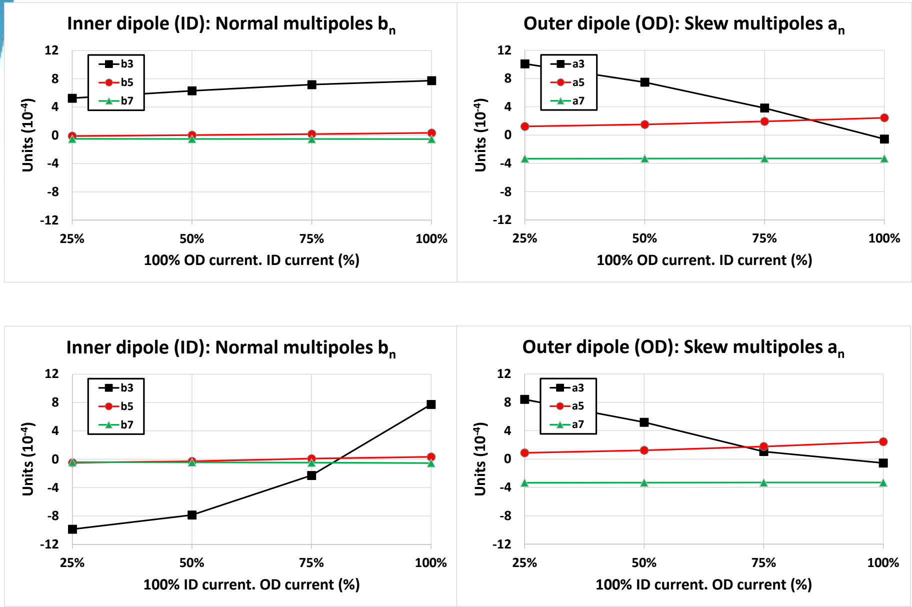
MCBXFB



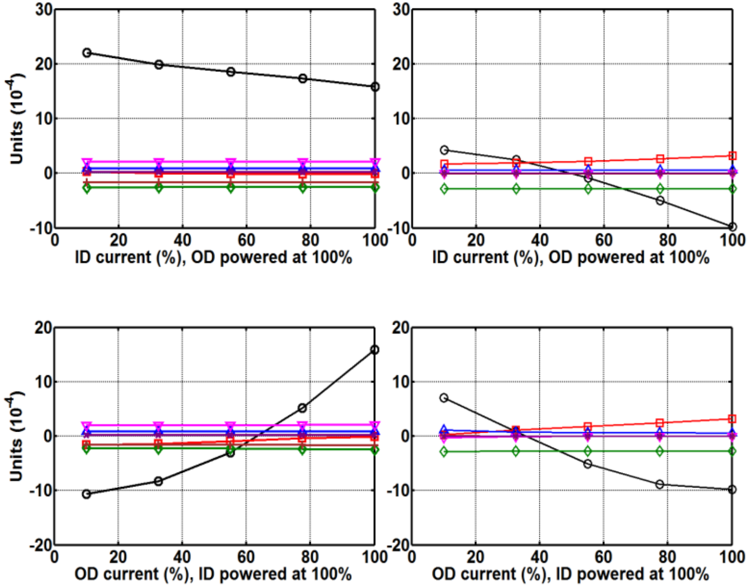
- There are many **powering scenarios**.
- In the case of powering both dipoles with the same current, the effect of **saturation** is clearly visible. However, A-type magnet is much less sensitive.

Magnetic field quality (II)

MCBXFA



MCBXFB



- The iron saturation is mainly due to the outer dipole.
- A-type magnet features better field quality in any powering scenario.

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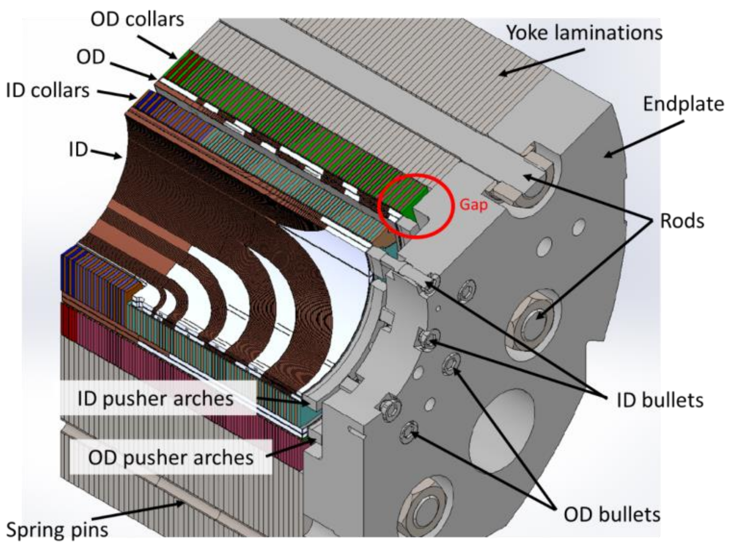
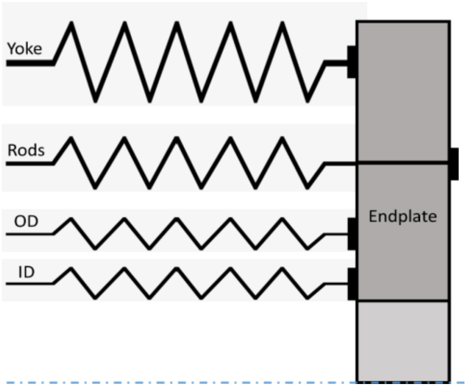
Mechanical design

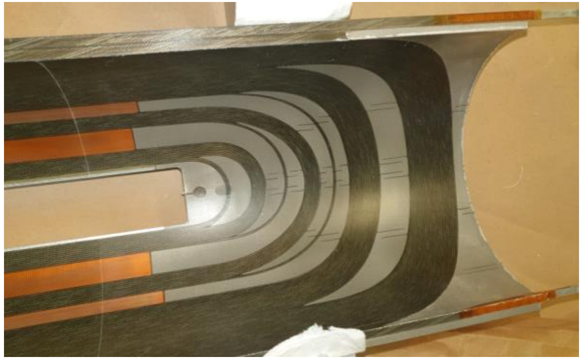
- **Axial Lorentz forces** are lower wrt B-type magnets: 15% for inner dipole and 11% for outer dipole.
- **Torque** is about 13% lower than in B-type magnets.
- Two 70-mm-thick **endplates** compress the iron and holds the axial Lorentz forces: elastic model based on four coupled springs.
- Eight 28-mm-diameter **rods** hold the endplates. Expected maximum force is about twice the Lorentz forces, that is a stress about 60 MPa at the rods.





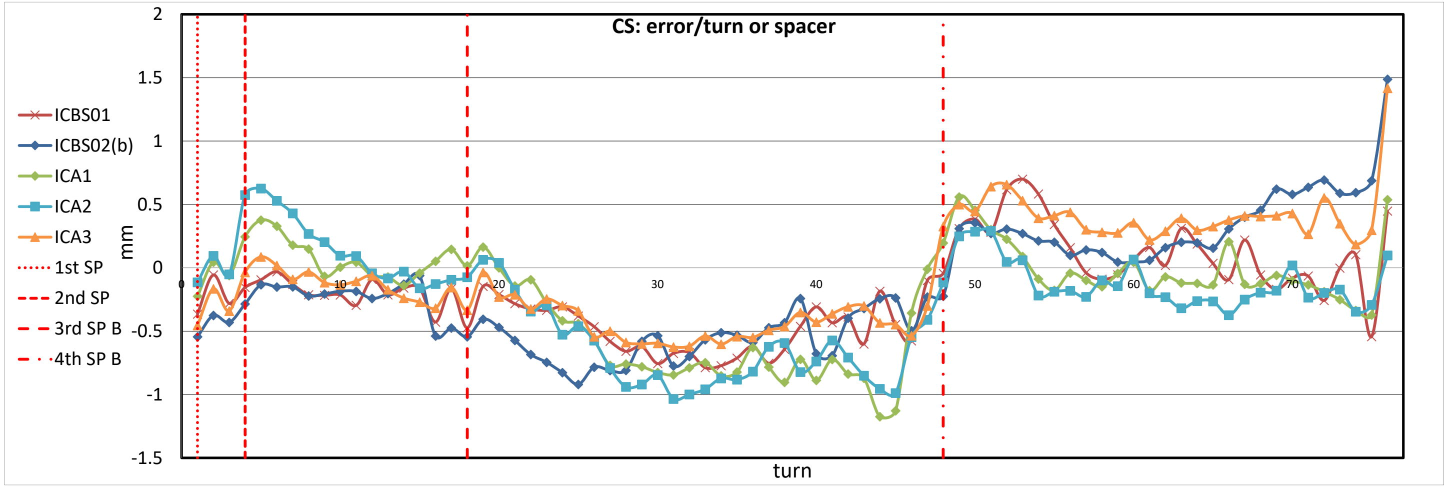
MCBXFA prototype fabrication

- The **longest** magnet ever produced at CIEMAT.
- **Assembly** will be done at CERN (lab 927)
- We use the same **fabrication techniques** that are being used for the B-type coils:
  - Binder application after each layer winding
  - Vacuum impregnation with CTD-101K



First finished inner coil

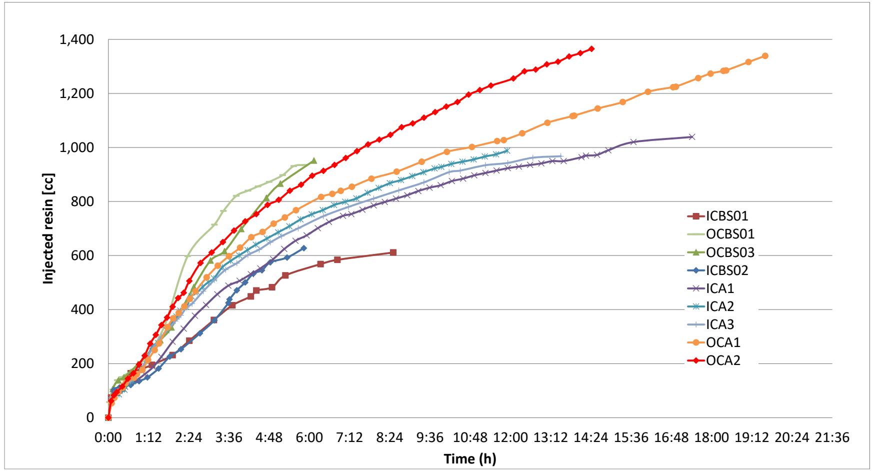
MCBXFA prototype: winding



- No significant differences in cable **position** at coil ends wrt B-type coils.
- Large **sagitta** at straight section: tight tolerance for support arcs instead of increasing winding tension.

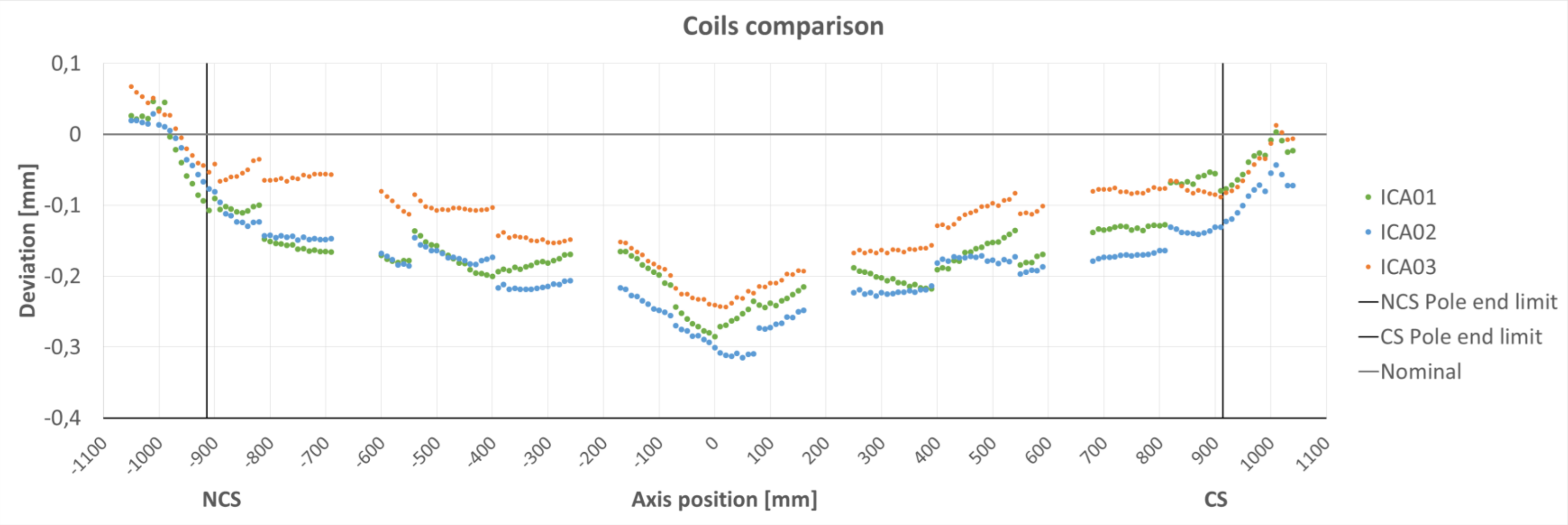
MCBXFA prototype fabrication: impregnation

Assembly of inner coil impregnation mould



- Challenging assembly because of **tight tolerances**.
- Long time for **resin injection** into A-type coils:
  - Viscosity and pot life is very sensitive to temperature: it is a factor of two from 60 to 50 degrees.
  - The impregnation mould of the first long coils was too tightened: torque control of 120 Nm in the next ones.

MCBXFA prototype fabrication: finished coils



- Arc coil length is checked with CMM. Very good uniformity in inner dipole coils. Slightly below nominal because of resin contraction after curing.
- Outer dipole coils will be measured next week.

Conclusions

- **Long nested correctors** are also part of CIEMAT contribution to HL-LHC.
- The **fine-tuning** of the design performed on short magnets is also applied to the long ones.
- A-type magnets feature **better field quality** because iron saturation is smaller.
- Prototype **components** are produced at CIEMAT.
- **Impregnation** of long coils is slow and must be carefully monitored to control the viscosity and pot life.
- Final step is the **magnet assembly** in collaboration with CERN starting in mid-November. Powering test is foreseen in December.

HiLumi
HL-LHC PROJECT

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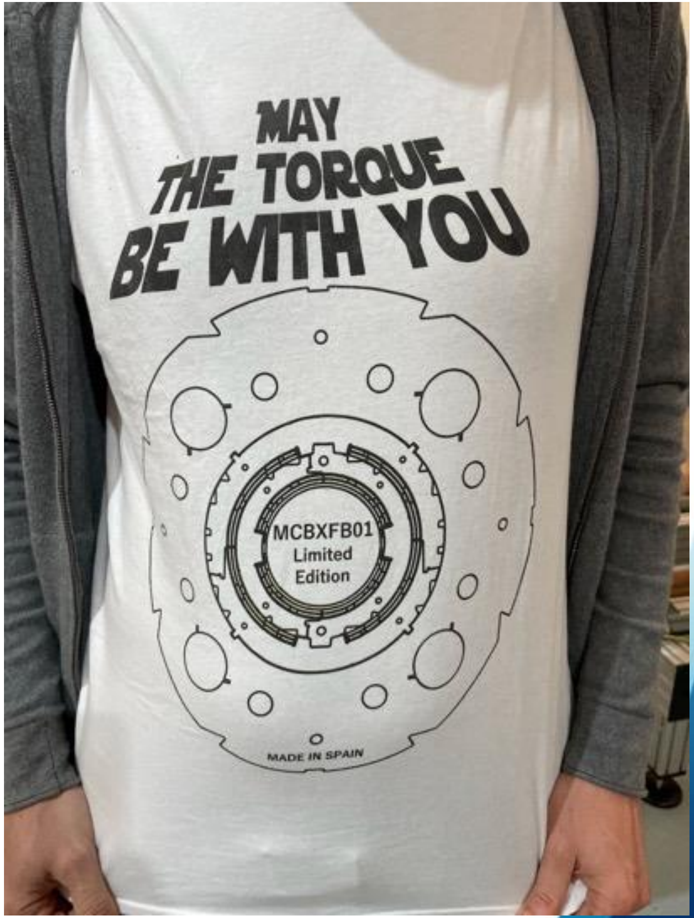

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