Advancement on MCBXFB prototype

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8th HL-LHC Collaboration Meeting – 18th October 2018

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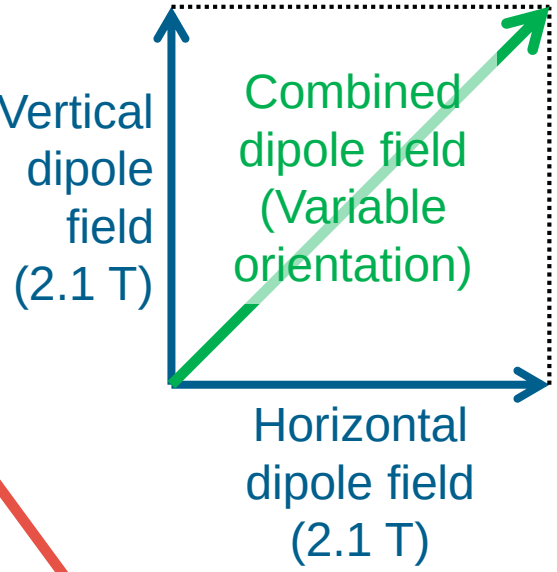
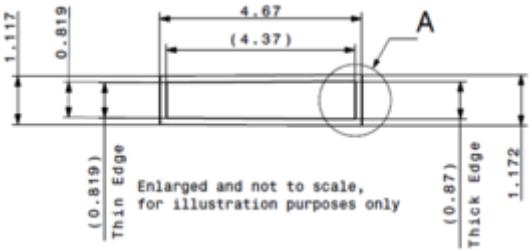
- Inner dipole (ID) coil fabrication.
- Outer dipole (OD) coil fabrication.
- Magnet structure components.
- Inner dipole assembly and collaring.
- Short mechanical model: Cold test.
- Inner dipole cold test.
- Documentation & planning.
- Conclusions.

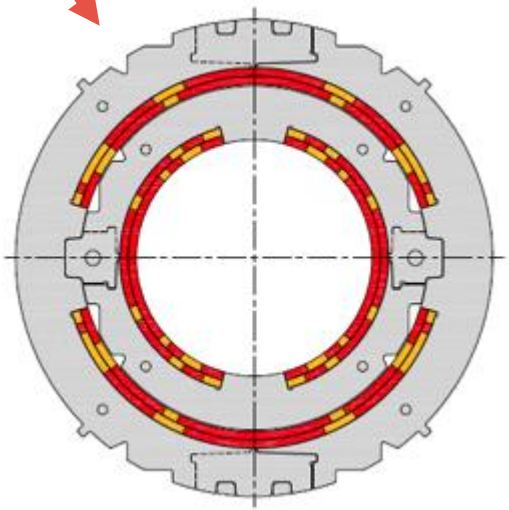
Magnet and cable specifications

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	35 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





Last HL-LHC Collaboration Meeting reminder

- Final magnetic and mechanical designs were presented.
- Short mechanical model results validated the feasibility of the assembly. Test results were in good agreement with simulations.
- The tooling for the fabrication of the inner dipole coils was commissioned.
- The parts for the first coil were procured and first coil was being wounded.
- Design of the tooling for the outer dipole coil was ongoing.

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ID coil winding

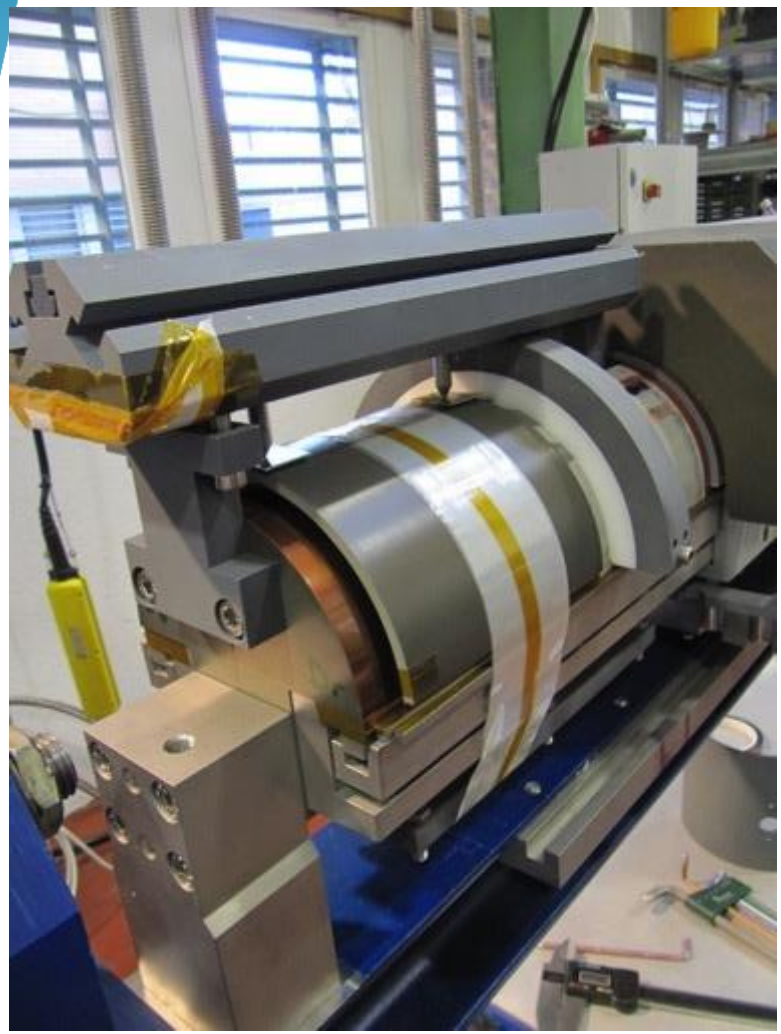
- **Three ID coils** have been produced. First coil took 14 weeks, third one only 7 weeks.
- **End spacers** produced by 3-D printing in stainless steel. Deformations are large (up to 1.5 mm), but spacers can be used with EDM cuts. Insulated with glass fiber tape impregnated with binder (acetone as solvent).
- **Copper wedges** insulated with glass fiber sleeves glued with binder at the ends.
- **Cable** is very flexible. Some problems with insulation: some breaks, dispersion in thickness (118-131 microns).
- **Tooling** concept was valid, although some modifications were necessary: more arc supports, longer lateral pushers, etc.
- **Winding tension** is decreasing while the turns are increasing. We start with 4.5 kg and finish with 3.5 kg.
- **Coil length** deviation is below 1 mm on each side. In most cases, only few tenths.
- The **inclination angle** of the cable with the mandrel is far from nominal (about 60 deg), reaching even 90 deg at some moments during the winding.

ID coil winding

ID coil binder

- A **custom binder** from CTD (1.1) with butanone as solvent.
- Applied with a **brush**, controlling applied weight by zones.
- The mould is assembled at the winding machine. Delicate process to avoid cables loosening.
- It is necessary both for the inner and outer layer. For the inner layer, we use the same mould with **fillers** replacing the outer layer.
- **Curing** at 120ºC during 18 hours and slow cooling. Heating using resistors.
- The **coil length** increases because of the pressure applied by the mould. Elongation is larger in the inner layer. Large dispersion, from few tenths up to 3.5 mm. This behaviour is not well understood yet.
- As expected, the **coil is rigid enough** to be manipulated during the next steps of the fabrication.

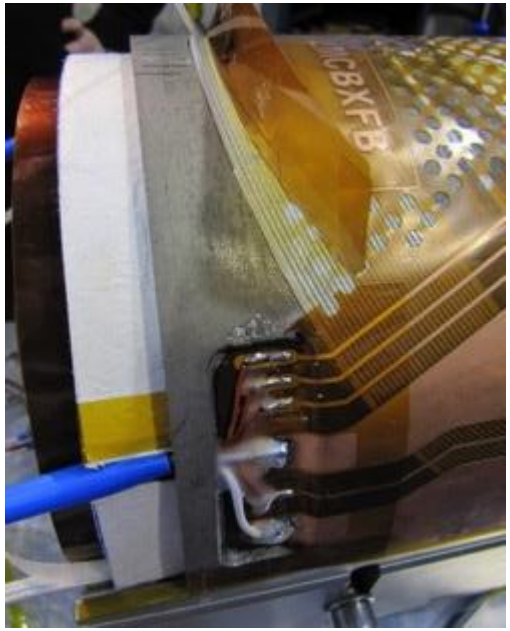
ID coil binder

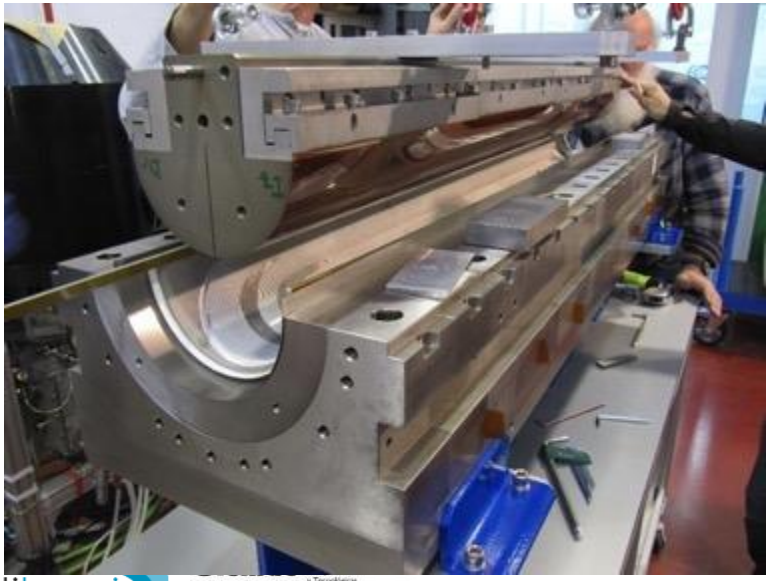


ID coil impregnation

- The **impregnation mould assembly procedure** is cumbersome because of the coil instrumentation (Quench heater and 8 voltage taps).
- The mould is introduced in a **custom vacuum chamber** to ease vacuum processing. Heating is by resistors.
- Resin is **CTD-101K**.
- First coil was **spoilt** because some silicone spacers were too tight during assembly. When warmed up, they pushed the loading plates away.
- Since the insulated cable thickness is below minimum nominal size, the cables are relatively loose in azimuthal direction. There is a thin layer of resin on the loading plates, which means that the shim thickness will need to be above nominal.

ID coil impregnation

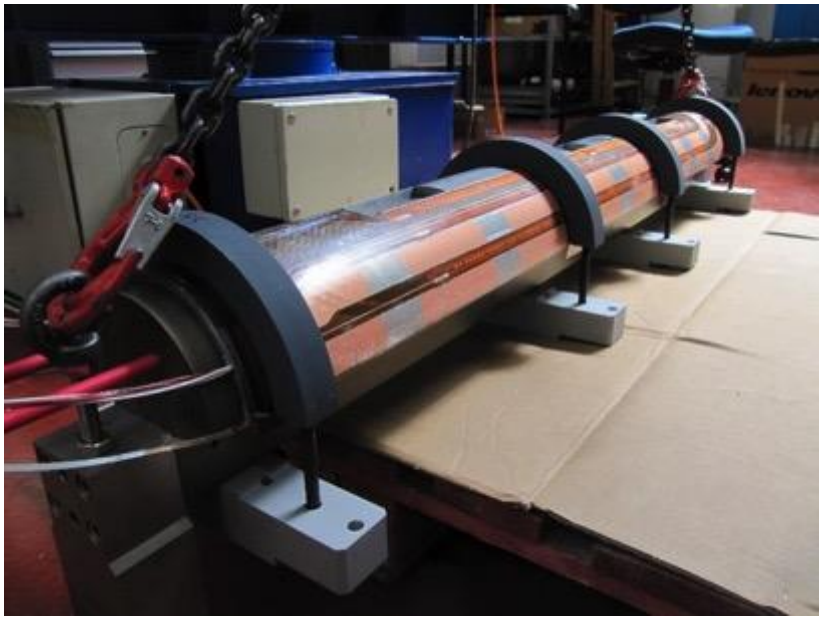




ID coil quality control

- **Electrical measurements** are made on each coil. The template is similar to those used at 927 workshop. We measure the resistance, insulation and self-inductance. The self-inductance is measured with a frequency sweep to detect short-circuits, due to the large number of turns.
- The **geometry** is measured with the coil clamped on the winding mandrel at a CMM.

Inductance [mH]		Impedance Analyzer 4192A			
		NO short Circuit		Short circuit between V1 and V5	
Measures made		Ls	D	Ls	D
Frequency	0,1 KHz	16,200	0,3350	16,210	0,3380
	1 kHz	15,750	0,0530	15,750	0,0540
	10 kHz	19,220	0,0340	19,210	0,0400
	100 kHz	-2,214	0,4970	-2,040	0,6210
	Resonance 1 [KHz]	22,030		22,040	
	20 kHz	79,480	0,2242	77,100	0,2840
	30 kHz	-16,110	0,0765	-16,060	0,1040
	40 kHz	-5,400	0,0630	-5,410	0,0860
	50 kHz	-2,464	0,0983	-2,480	0,1300
	60 kHz	-1,028	0,2660	-1,060	0,3330
	70 kHz	0,028	16,7000	-0,059	9,6800
	80 kHz	1,212	1,1800	0,865	1,7260
	90 kHz	-1,330	3,2400	-0,916	3,8650
	Resonance 2 [KHz]	69,720		70,620	
	Resonance 3 [KHz]	88,050		87,830	



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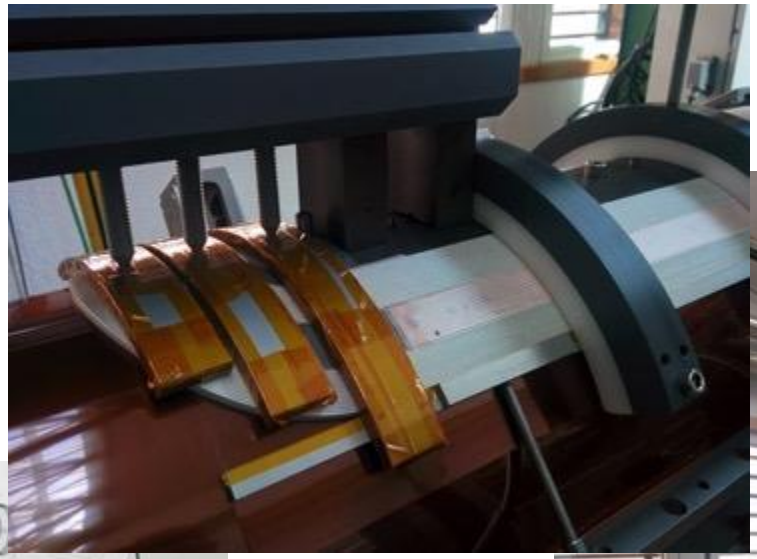
OD coil fabrication

- The winding and binding **tooling** is already commissioned. Some parts of the impregnation mould are not finished yet.
- Winding of the **first OD coil** is on-going.



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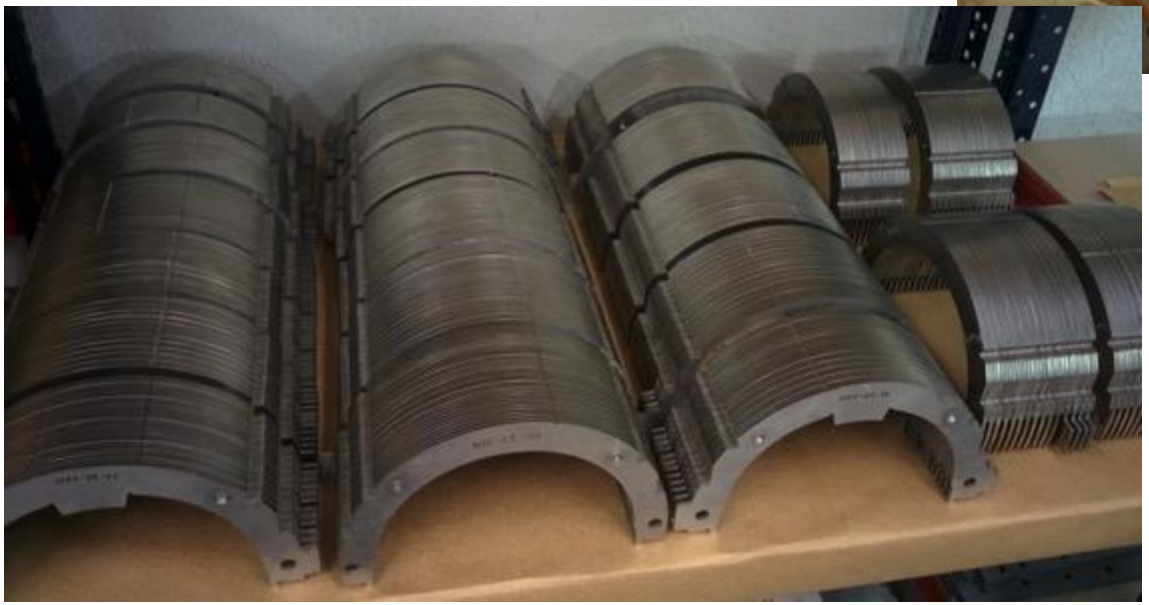
Ground insulation and collaring shoe

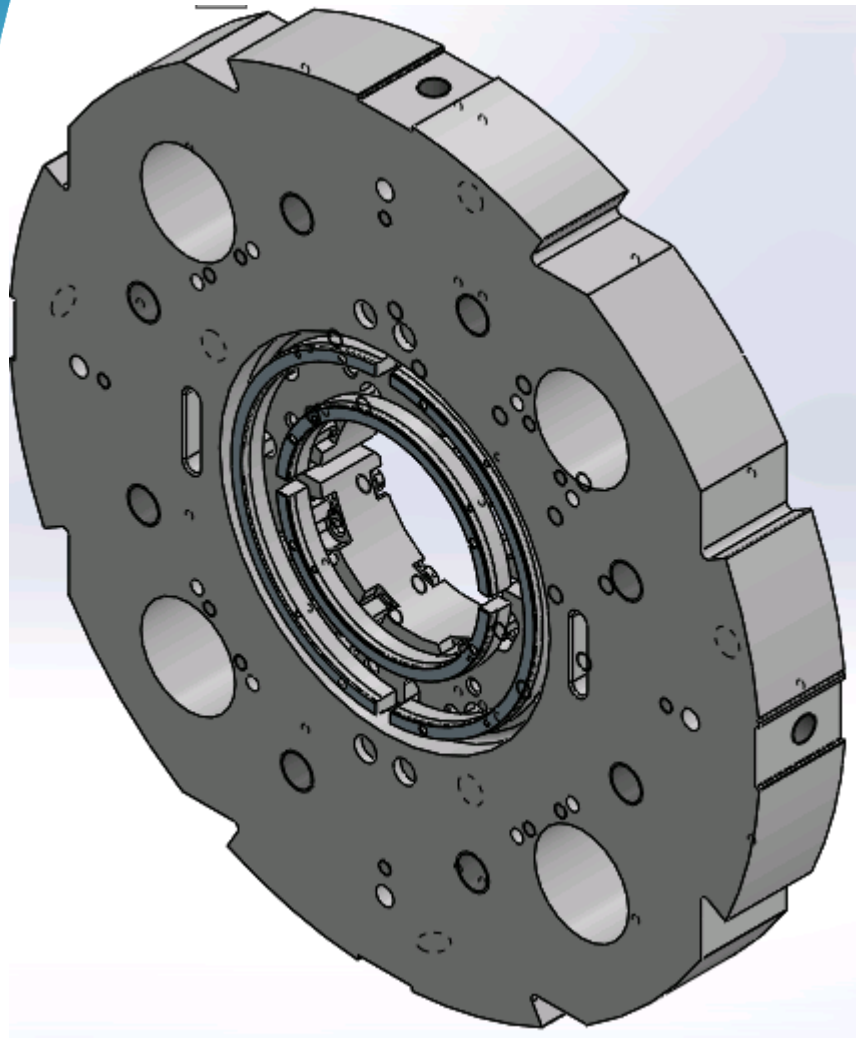
- Ground insulation have been pre-formed by 120ºC heating during 2 hours.
- Collaring shoes have been laser-cut and pre-formed with a custom tooling.

Collars

- All **ID collars** have been machined and instrumented (CERN).
- ID collar packages were assembled using a custom tooling.
- Most of **OD collars** are already machined (laser+EDM).
- OD collars are being instrumented at CERN.



Iron yoke & endplates



- All the iron laminations (232 units) have been fabricated:
  - Laser cutting
  - EDM cutting
  - Black oxide for surface protection
- Endplates: Currently in production.

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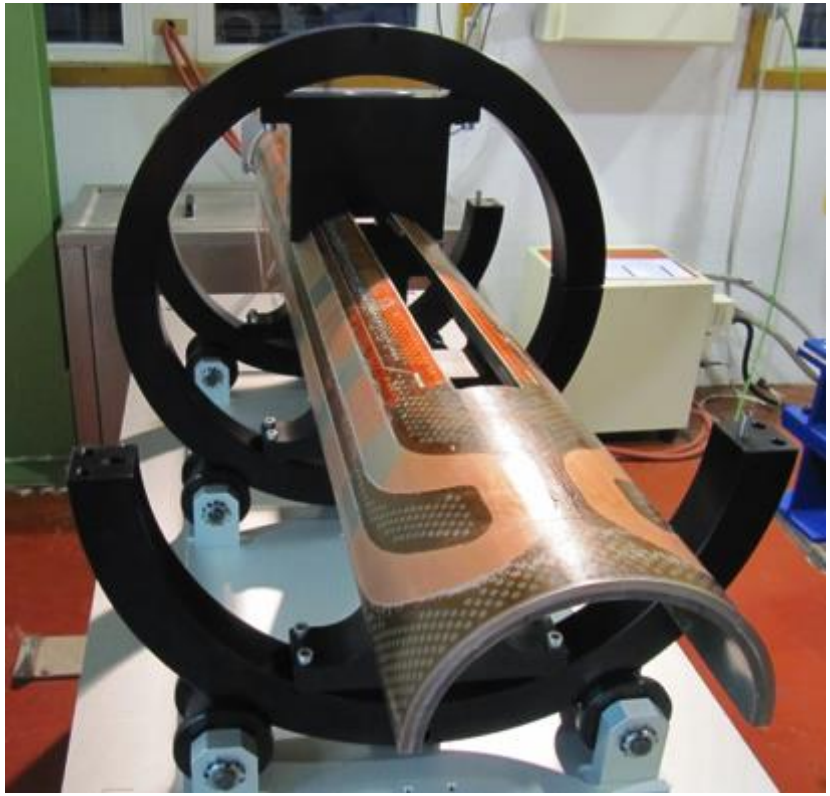
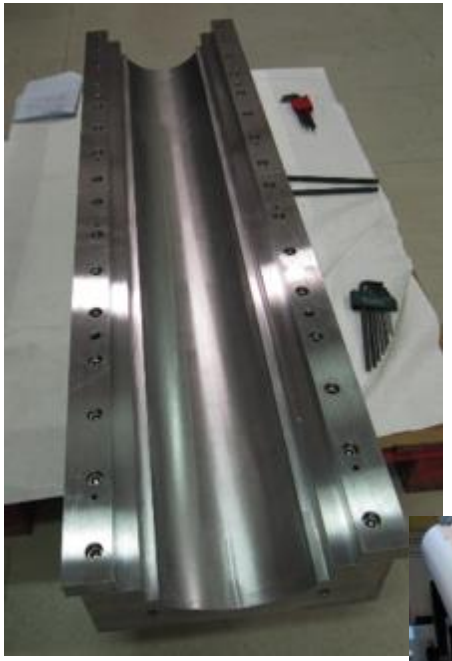
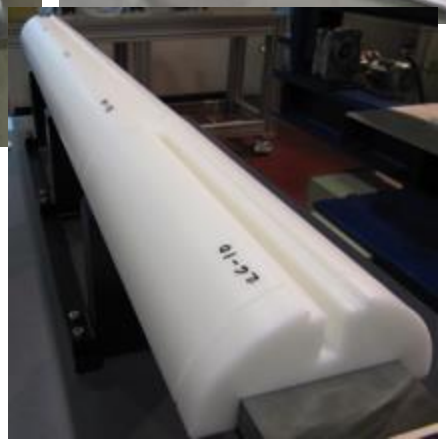
Inner dipole assembly

- Last week (9th Oct), assembly of the inner dipole was performed.
- The required assembly tooling and collaring cradles were previously commissioned.

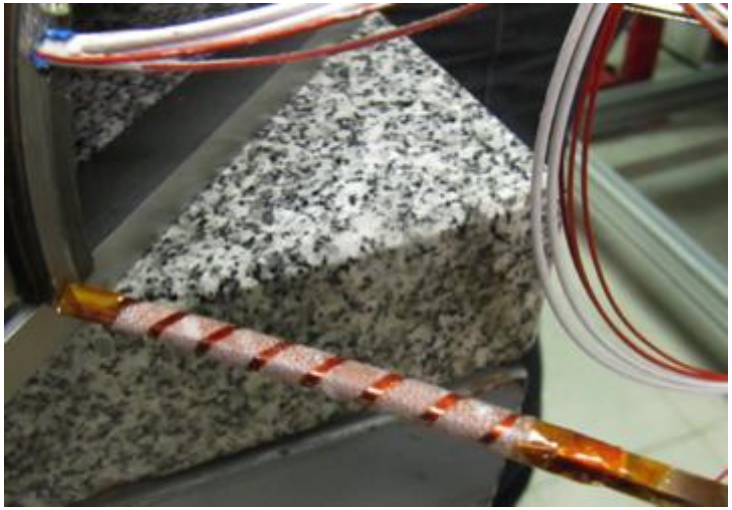


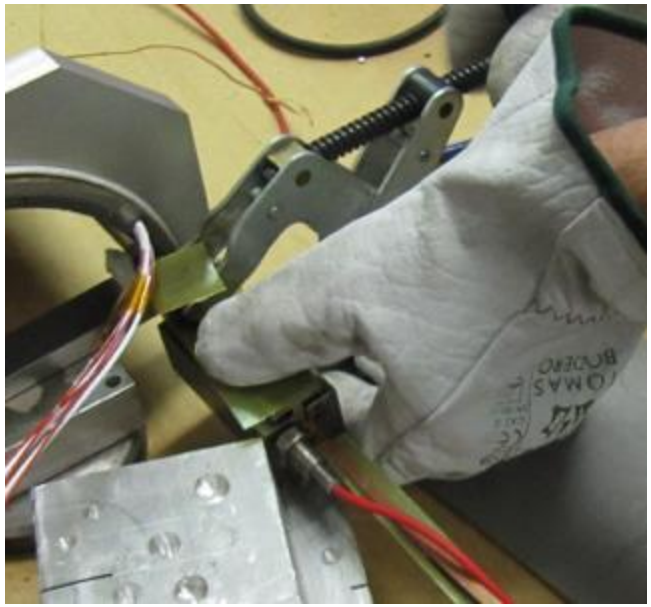




Inner dipole assembly

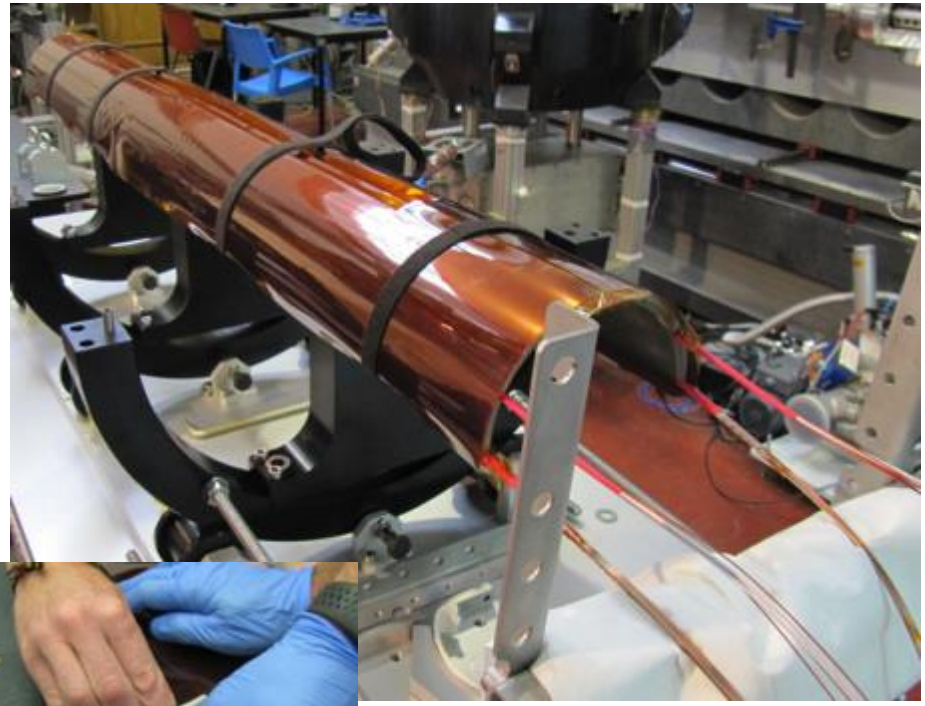
- Current lead tinning and stabilization using 1.5 mm thick copper plate.
- Current leads and instrumentation wires insulation.

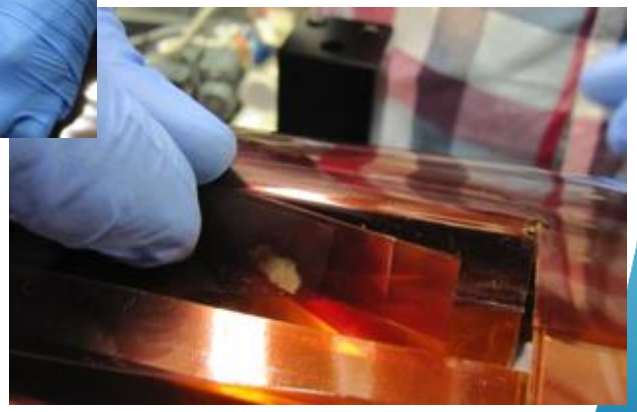




Inner dipole assembly

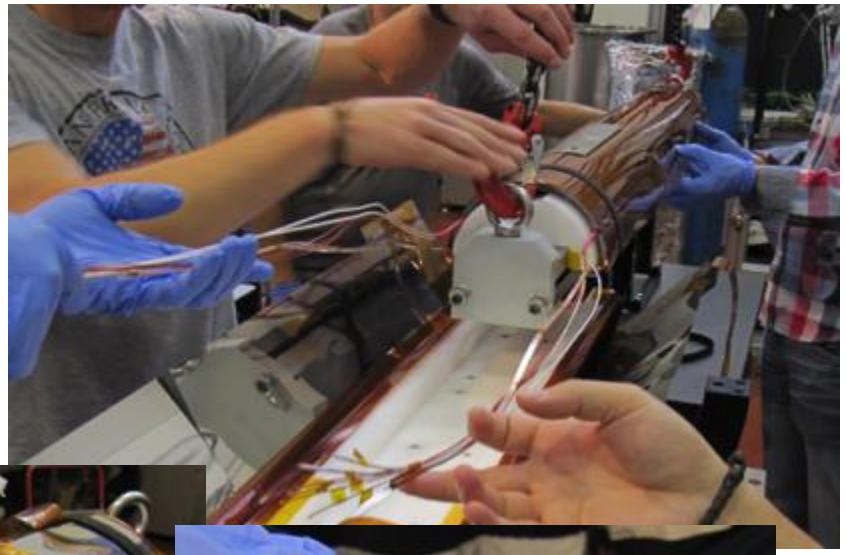
- Ground insulation: Pre-bending was enough to assemble properly the five different layers.
- Pole pocket needed to be manually bent again in order to ease the operation.
- Nominal interference (0.35 mm) was increased by additional 0.2 mm shimming in order to compensate CMM measurements on coils.

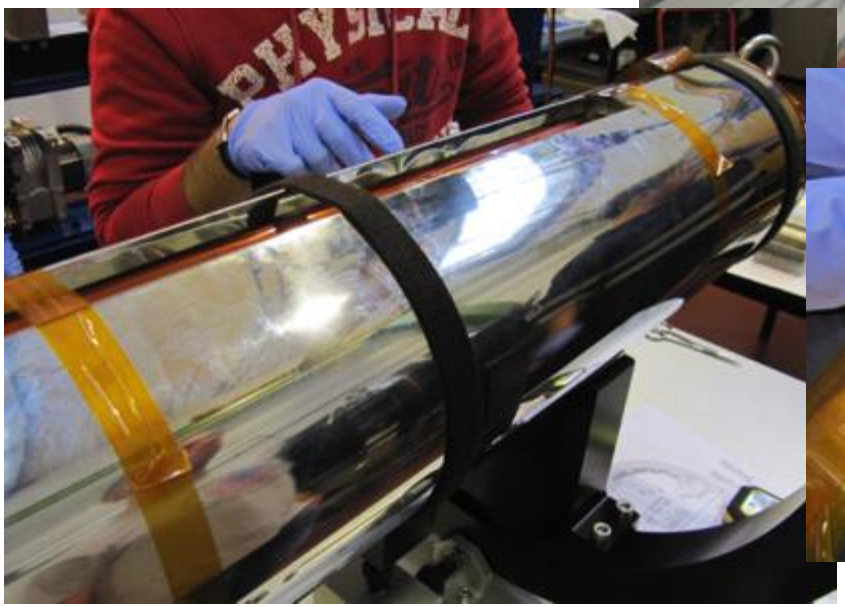


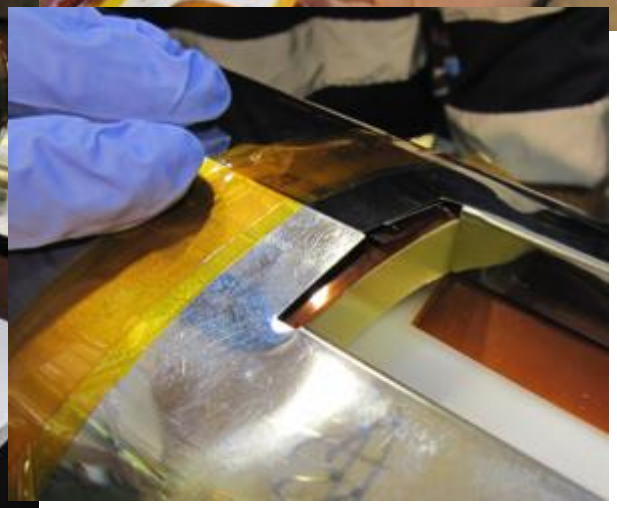


Inner dipole assembly

- After ground insulating both coils, collaring shoes were assembled around them.
- They fit well although strong clamping is necessary to keep them in position.

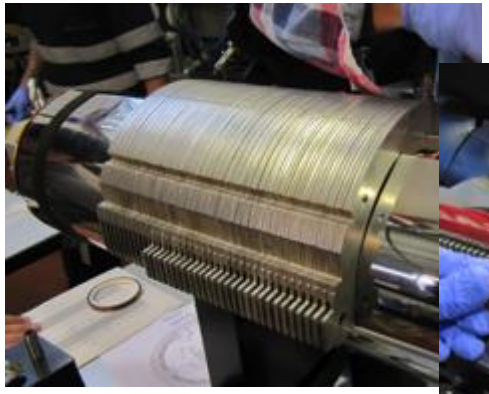


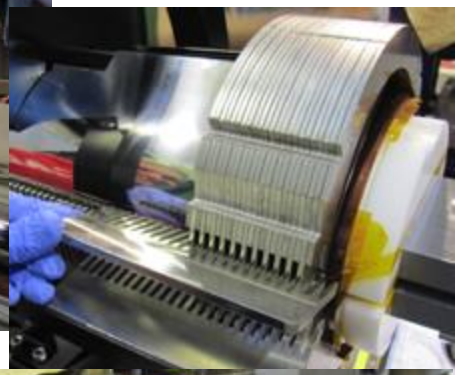


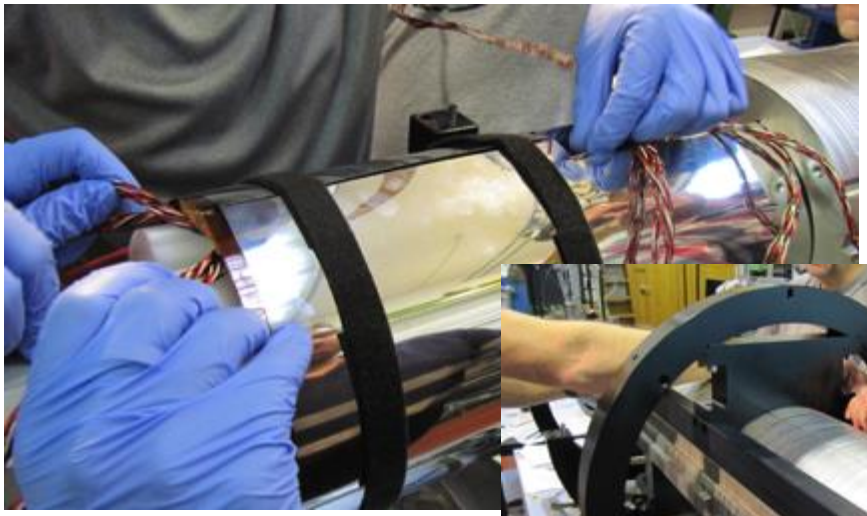


Inner dipole assembly

- Collar packets fit well and strain gauges connectors could be extracted through a dedicated housing in the collapsible mandrel.
- Two laminations were removed from the straight section to compensate longer than nominal collar packets.

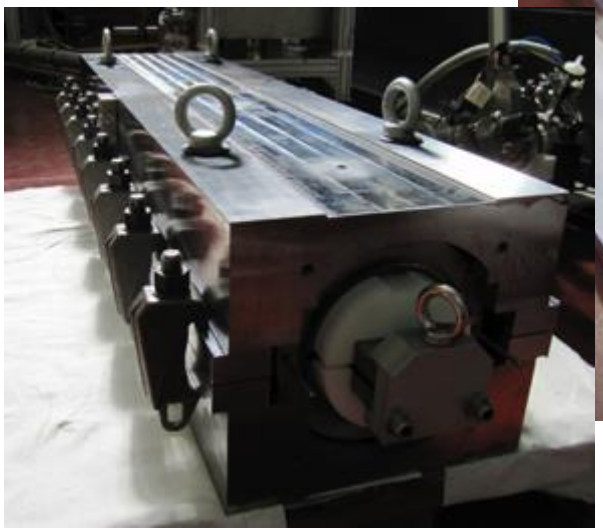


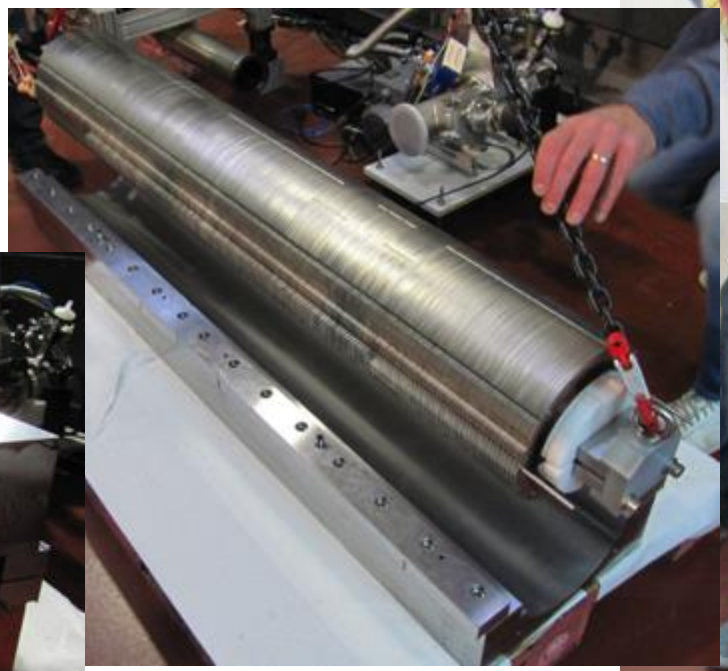


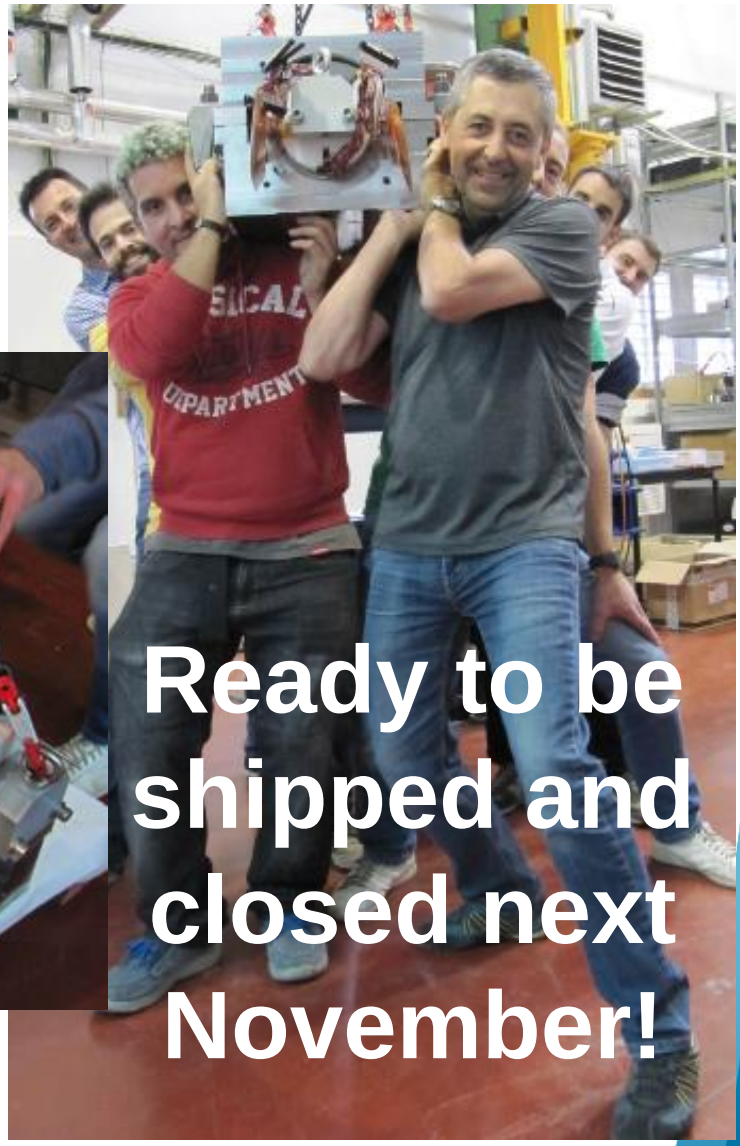


Inner dipole assembly

- Finally the pre-collared dipole was placed inside its collaring cradles.
- Some pressure is applied with clamps to prevent undesired movements during transportation.







Ready to be shipped and closed next November!

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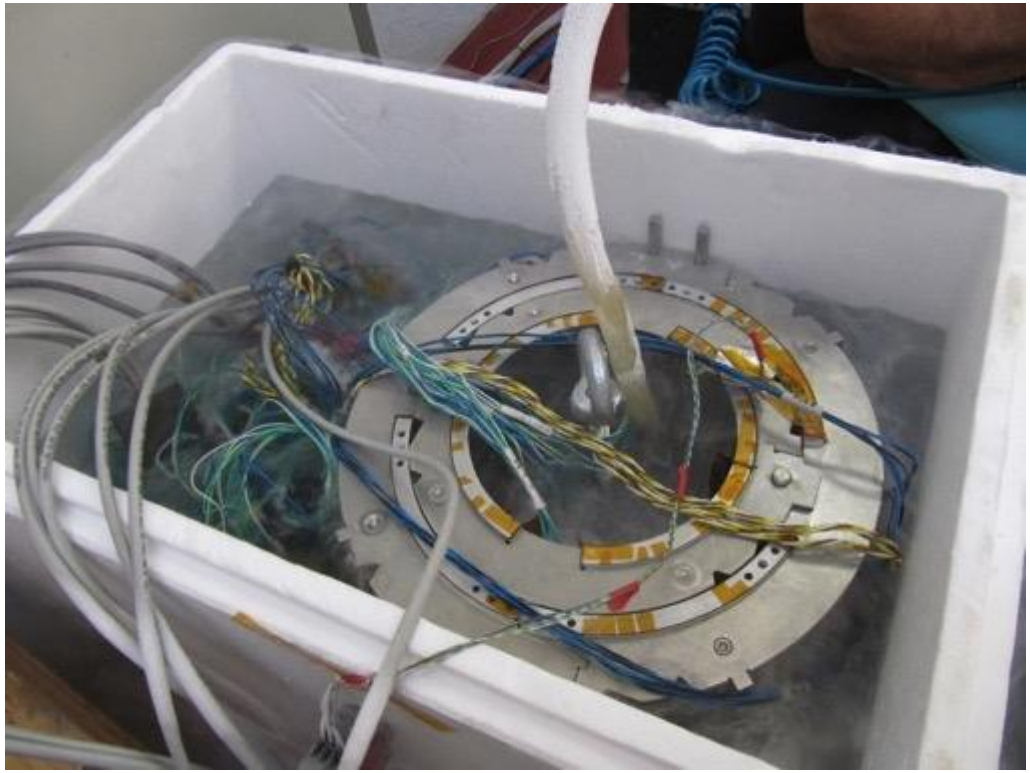
Short mechanical model: cold test

- The short mechanical model has been cooled down in a liquid nitrogen bath. Average measurements are very close to FEM results (250 με).



ID-edge	OD-edge	ID-center	OD center	Average
359	197	230	228	254

Measured deformations at collar noses from room to liquid nitrogen temperature (με)

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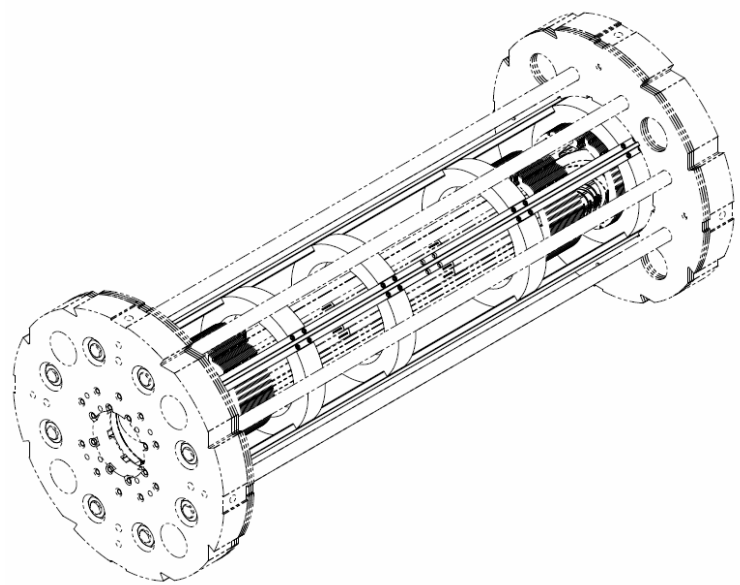
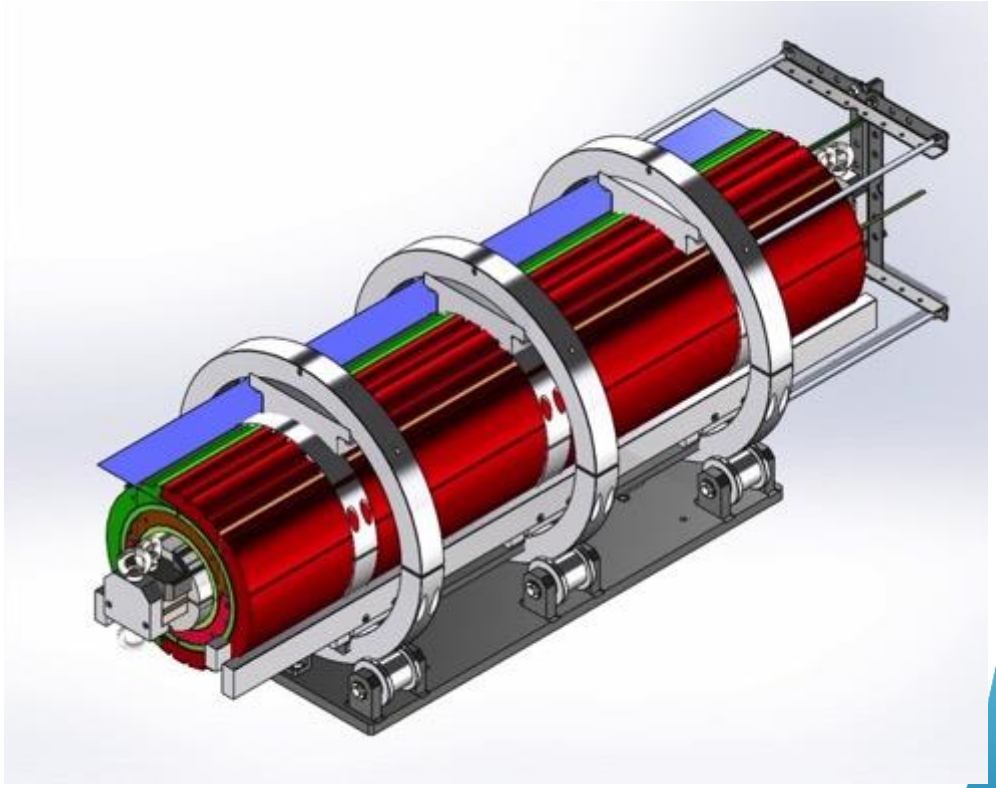
Inner dipole cold test

- A first cold test with the inner dipole coils is foreseen. This test will validate the coil fabrication method.
- An intermediate support structure is necessary to align the collared inner dipole coils and the iron yoke and endplates.
- All the parts are under fabrication or finished.





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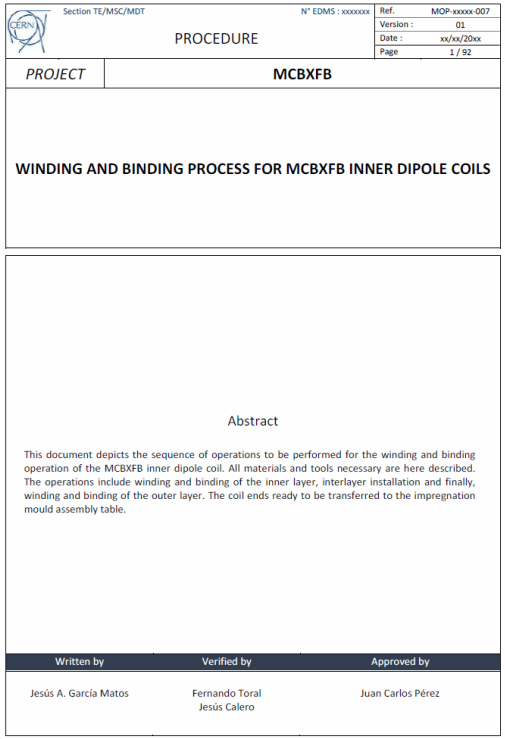
Documentation

- About 900 drawings, 95% finished.
- Procedure for inner coil winding and curing is under the last revision to be released (about 130 pages). Instrumentation and impregnation is 70% completed (about 120 pages). Inner dipole assembly has been also documented to allow promptly procedure writing.
- Hundredths of photographs have been included to ease the comprehension of the procedures.



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PROCEDURE

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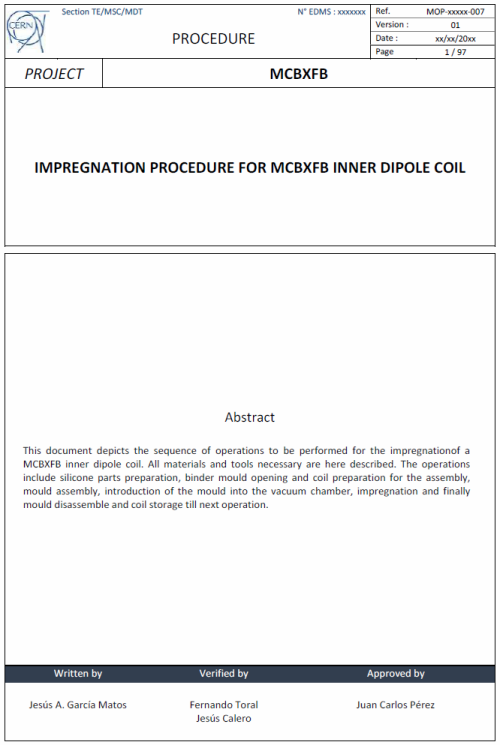
PROJECT: MCBXFB

WINDING AND BINDING PROCESS FOR MCBXFB INNER DIPOLE COILS

Abstract

This document depicts the sequence of operations to be performed for the winding and binding operation of the MCBXFB inner dipole coil. All materials and tools necessary are here described. The operations include winding and binding of the inner layer, interlayer installation and finally, winding and binding of the outer layer. The coil ends ready to be transferred to the impregnation mould assembly table.

Written by	Verified by	Approved by
Jesús A. García Matos	Fernando Toral Jesús Calero	Juan Carlos Pérez



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PROJECT: MCBXFB

IMPREGNATION PROCEDURE FOR MCBXFB INNER DIPOLE COIL

Abstract

This document depicts the sequence of operations to be performed for the impregnationof a MCBXFB inner dipole coil. All materials and tools necessary are here described. The operations include silicone parts preparation, binder mould opening and coil preparation for the assembly, mould assembly, introduction of the mould into the vacuum chamber, impregnation and finally mould disassemble and coil storage till next operation.

Written by	Verified by	Approved by
Jesús A. García Matos	Fernando Toral Jesús Calero	Juan Carlos Pérez

Prototype schedule

	Task	
Design	Detailed mechanical calculations	Done
	ID fabrication drawings	Done
	OD fabrication drawings	Done
Fabrication	Cable MCBXB H+V delivered (4 ID + 3 OD unit lengths)	Delivered
	Winding machine ready	Jun-17
	First winding test	Sept-17
	First ID coil	Jan-18
	3 ID coils	Jun-18
	ID Collaring	Oct-18
	ID Magnet assembly	Oct-18
	OD coils	Dec-18
	OD Collaring	Jan-19
	Magnet Assembly	Jan-19
Test	ID in vertical cryostat	Dec-18
	Magnet prototype in vertical cryostat	Mar-19

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Conclusions

- ID coils are finished and the inner dipole has been successfully assembled and pre-collared.
- Inner dipole shipment along with all the necessary tooling is expected in the next weeks. Collaring should take place in the first days of November.
- In parallel, the production of the OD coils has started.

Thanks for your attention