



# Status of the short nested orbit corrector MCBXFB prototype

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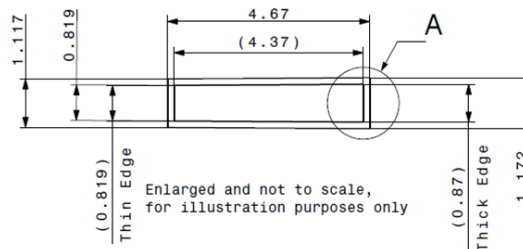
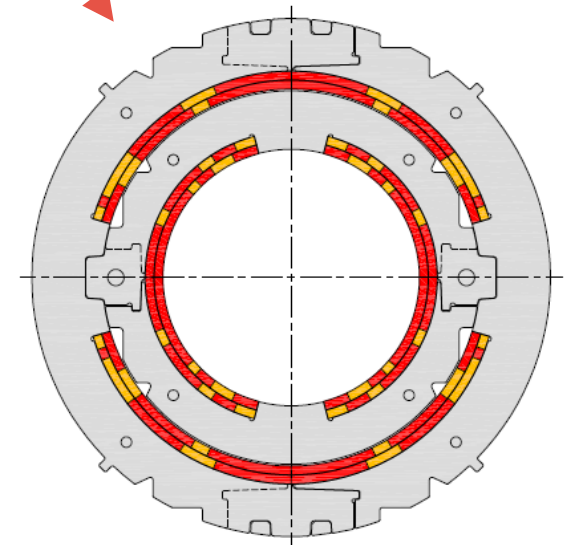
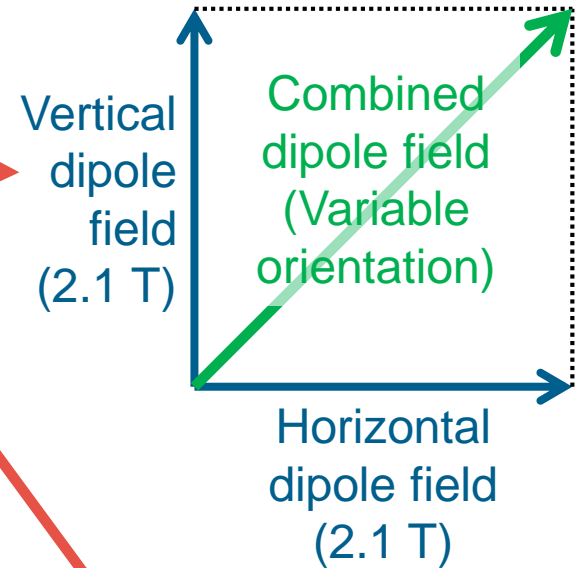
# Outline

- Final magnetic design
- Final mechanical design
- Short mechanical model
- Prototype fabrication
- Conclusions

# Magnet and cable specifications

## MCBXFB Technical specifications

<b>Magnet configuration</b>	Combined dipole (Operation in X-Y square)
<b>Integrated field</b>	2.5 Tm
<b>Minimum free aperture</b>	150 mm
<b>Nominal current</b>	< 2500 A
<b>Radiation resistance</b>	35 MGy
<b>Physical length</b>	< 1.505 m
<b>Working temperature</b>	1.9 K
<b>Iron geometry</b>	MQXF iron holes
<b>Field quality</b>	< 10 units (1E-4)
<b>Fringe field</b>	< 40 mT (Out of the Cryostat)

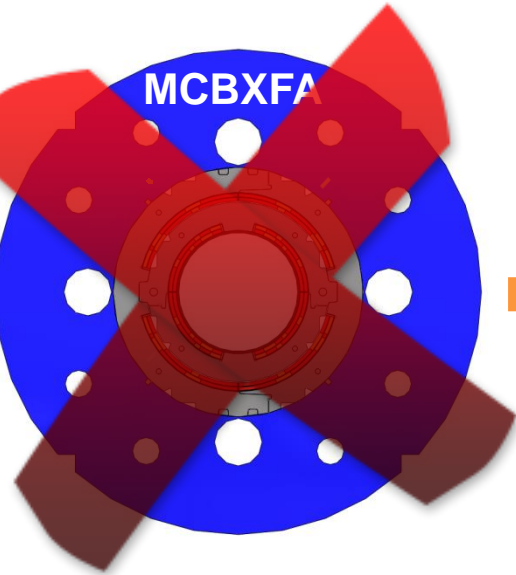
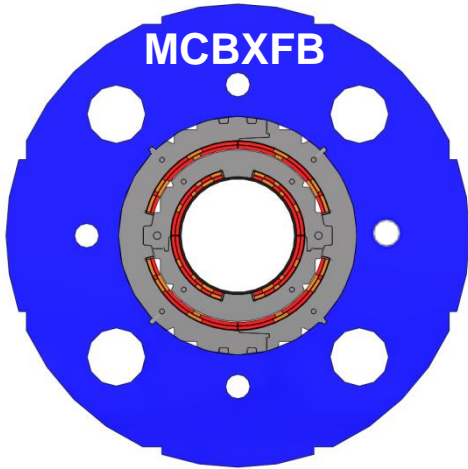


## Cable Parameters

<b>No. of strands</b>	18
<b>Strand diameter</b>	0.48 mm
<b>Cable thickness</b>	0.845 mm
<b>Cable width</b>	4.37 mm
<b>Key-stone angle</b>	0.67°
<b>Cu:Sc</b>	1.75

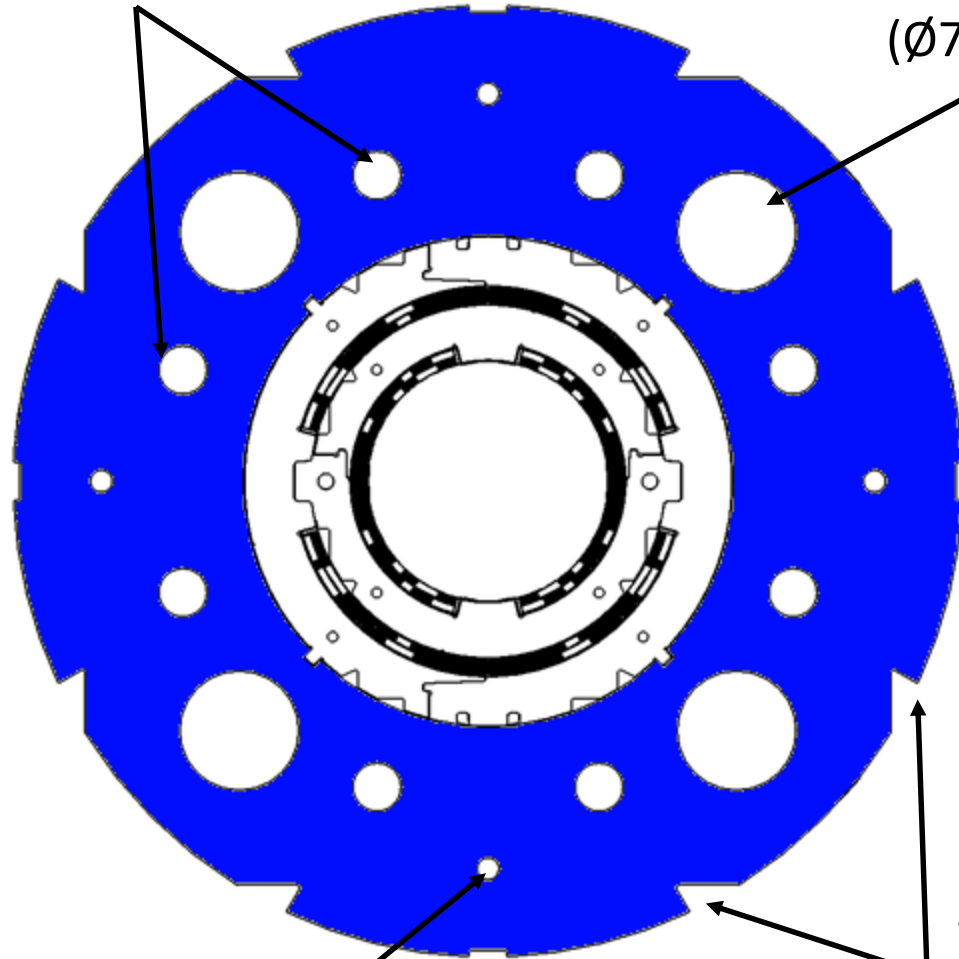
# Final iron geometry

PREVIOUS DESIGNS



Rod holes

Cooling channel  
( $\varnothing 77$  mm)

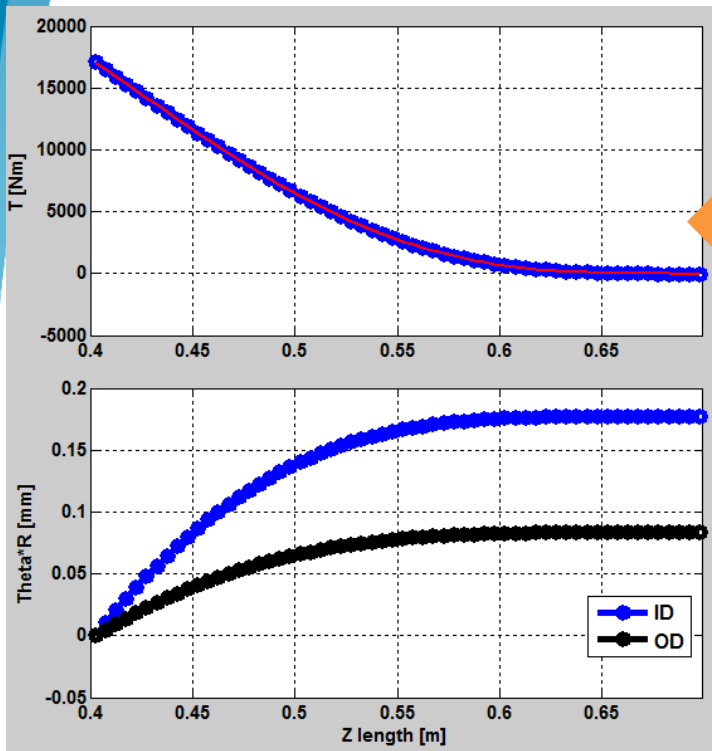


Holes for elastic pins

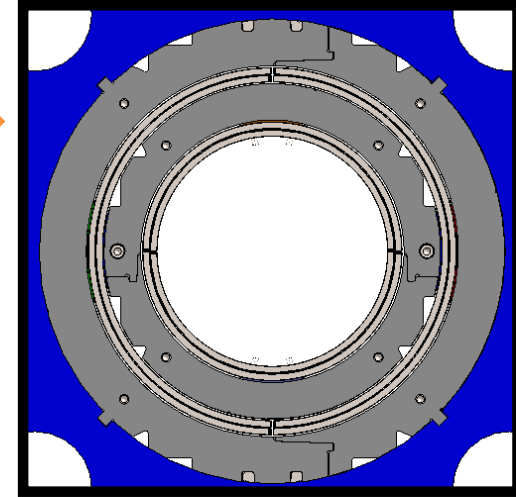
Welding housing

Support & Handling

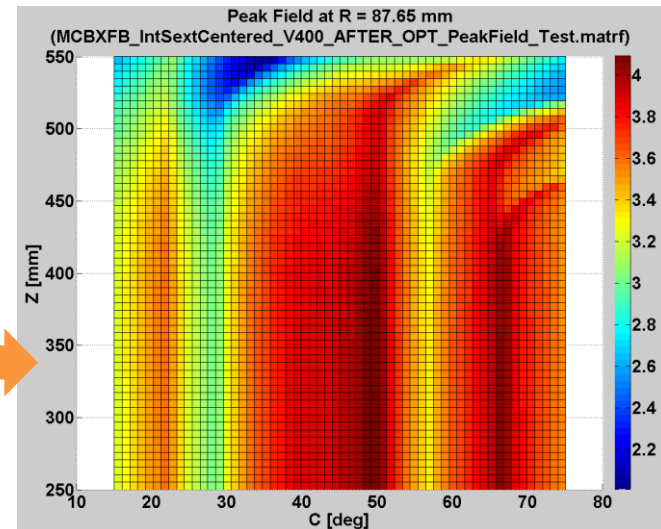
# Detailed magnetic design: Torque and peak field at coil ends



- 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 ( $45^\circ$  orientation)
- Peak field is always at the straight section.



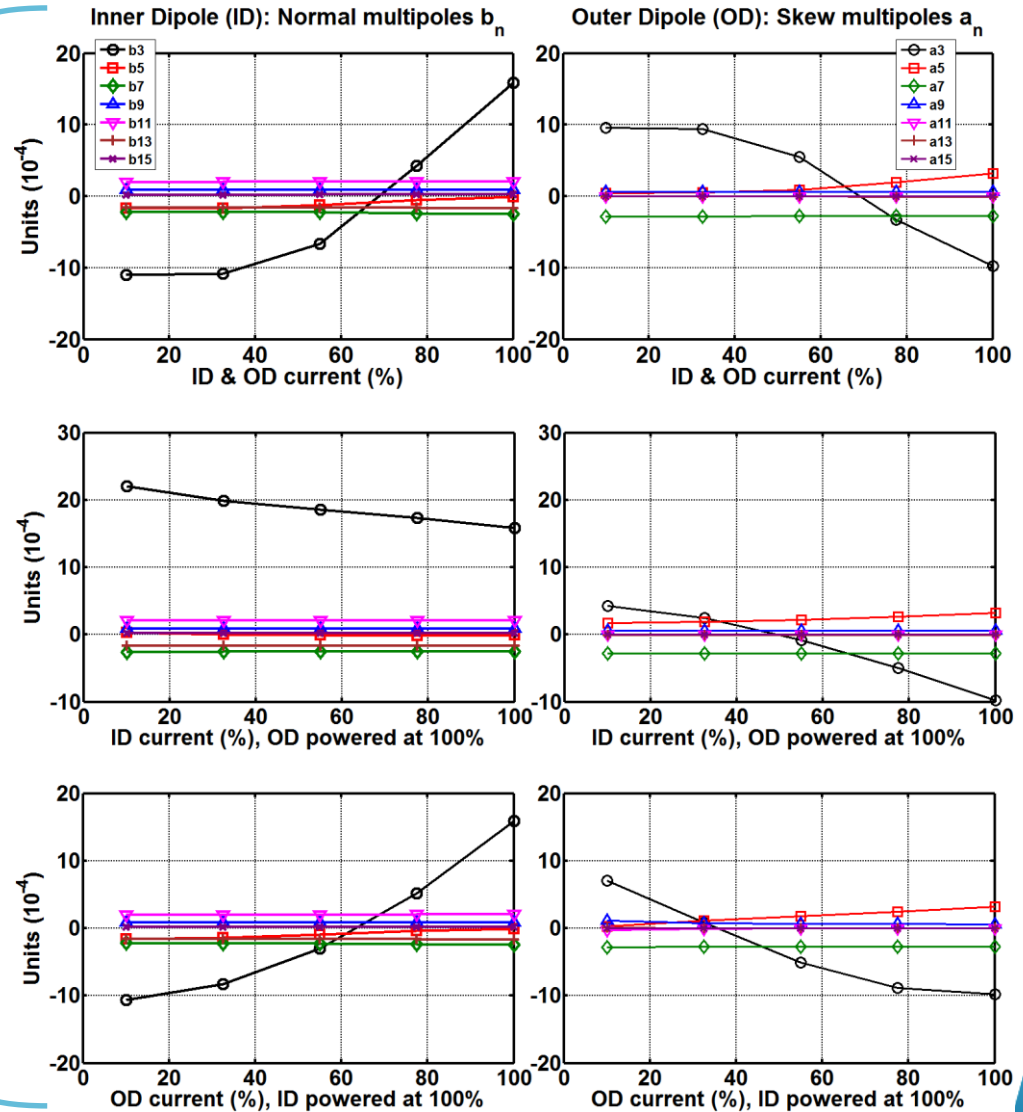
# Detailed magnetic design: Computation strategy and field quality

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**

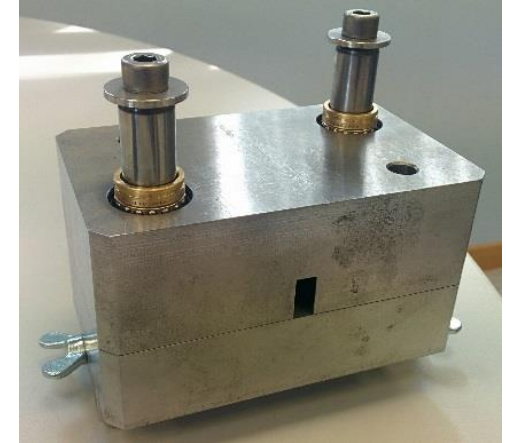
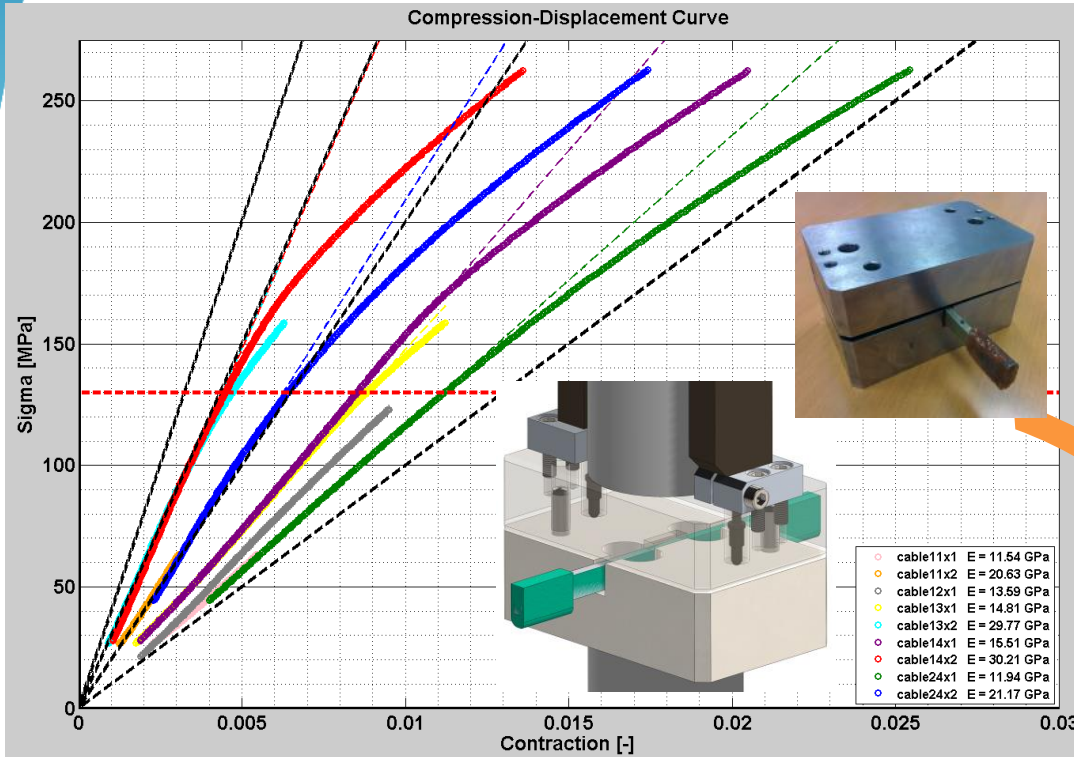


# Outline

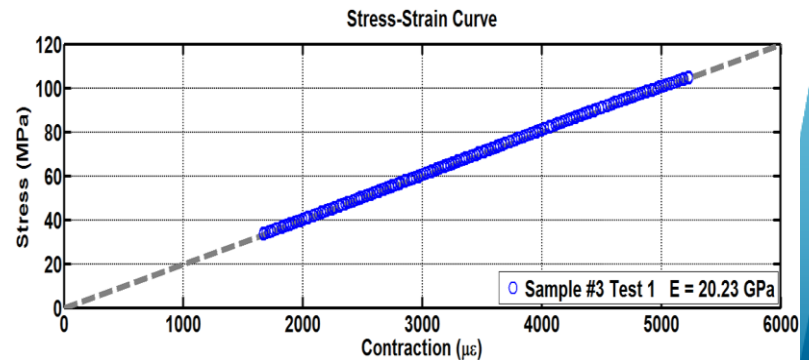
- Final magnetic design
- **Final mechanical design**
- Short mechanical model
- Prototype fabrication
- Conclusions

# Measurement of cable Young's modulus

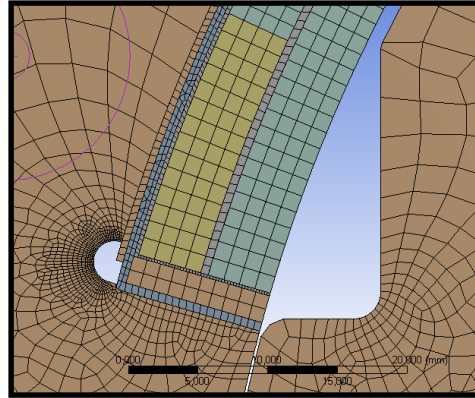
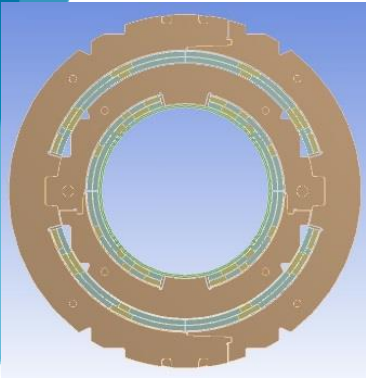
After improving the tooling, the tests confirm that Young's modulus of the cables is close to **20 GPa**.



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



# Mechanical design update (I)

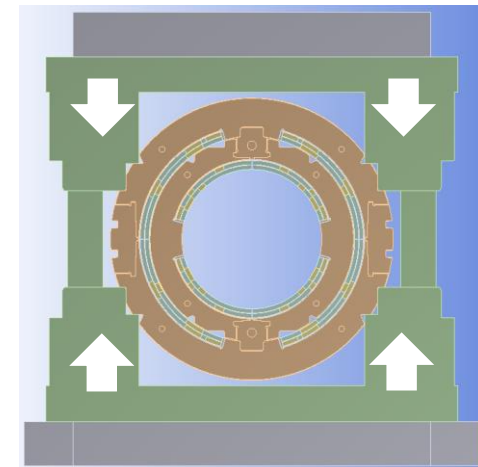
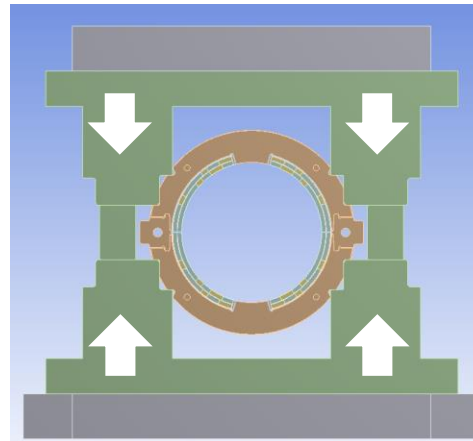


- ▶ The new cable rigidity (20 GPa) has been included in the mechanical model.
- ▶ An additional 0.1 mm of interference is necessary to achieve the same coil pre-compression than before:
  - Inner dipole: 0.35 mm instead of 0.25 mm.
  - Outer dipole: 0.45 mm instead of 0.35 mm.

- ▶ This is coherent considering coil smeared-out properties.

40 GPa Cable blocks + 130 GPa copper wedges  $\cong$  70 GPa Coil  
20 GPa Cable blocks + 130 GPa copper wedges  $\cong$  50 GPa Coil

- ▶ Stress distribution is checked at the different load steps.

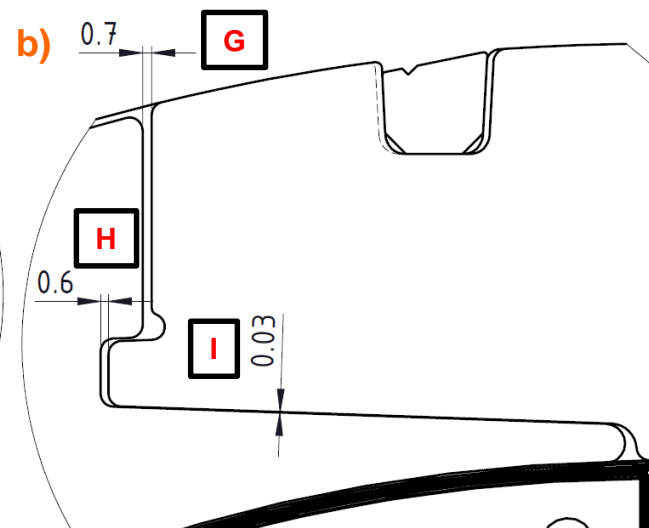
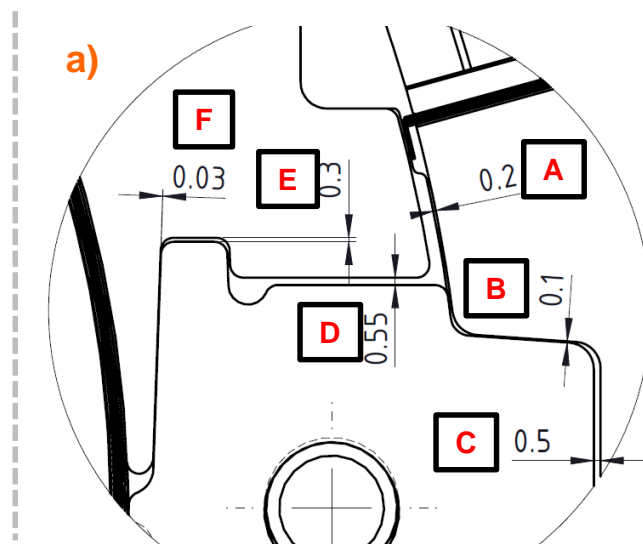
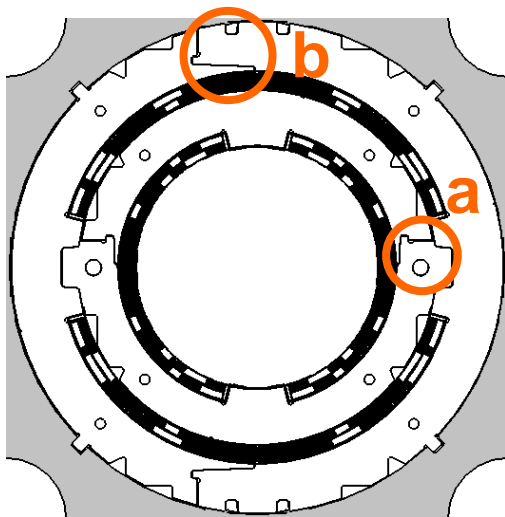


# Mechanical design update (II)

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

- ▶ Motivation: There is no previous experience in nested collaring structures.
- ▶ Undesired contact between parts could spoil the assembly.
- ▶ Too large gaps could spoil the field quality or cause clattering during operation.

All values in mm

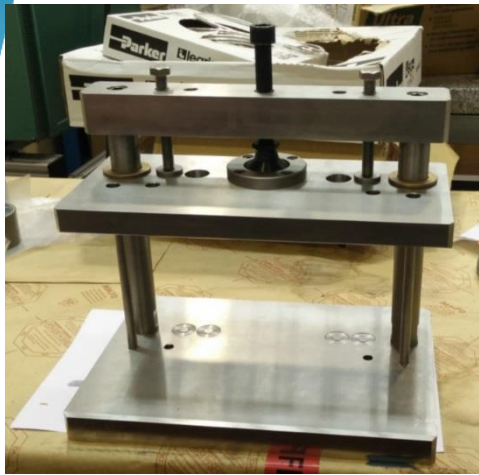


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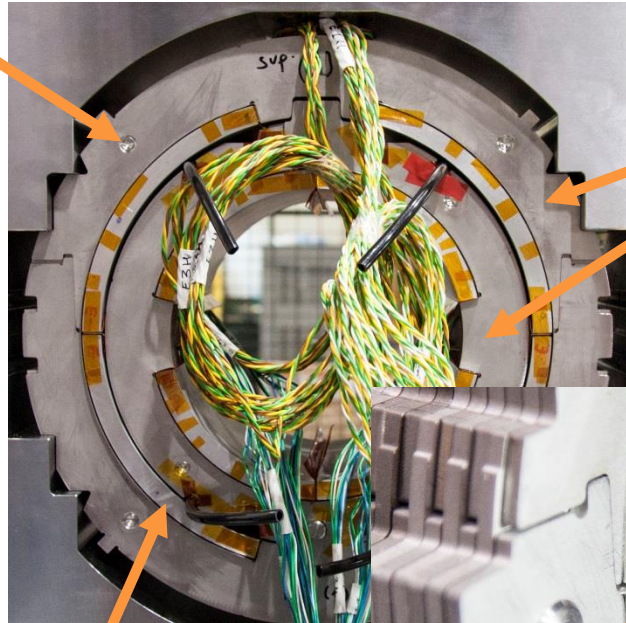
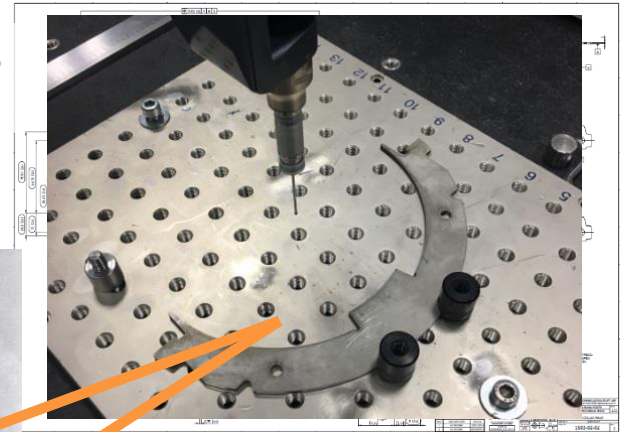


# Short mechanical model: Fabrication

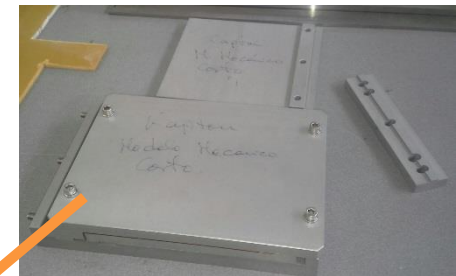


Collar packaging tool (ID & OD)

Collars  
(Laser + EDM)



Aluminium  
dummy coils



Kapton bending  
tooling

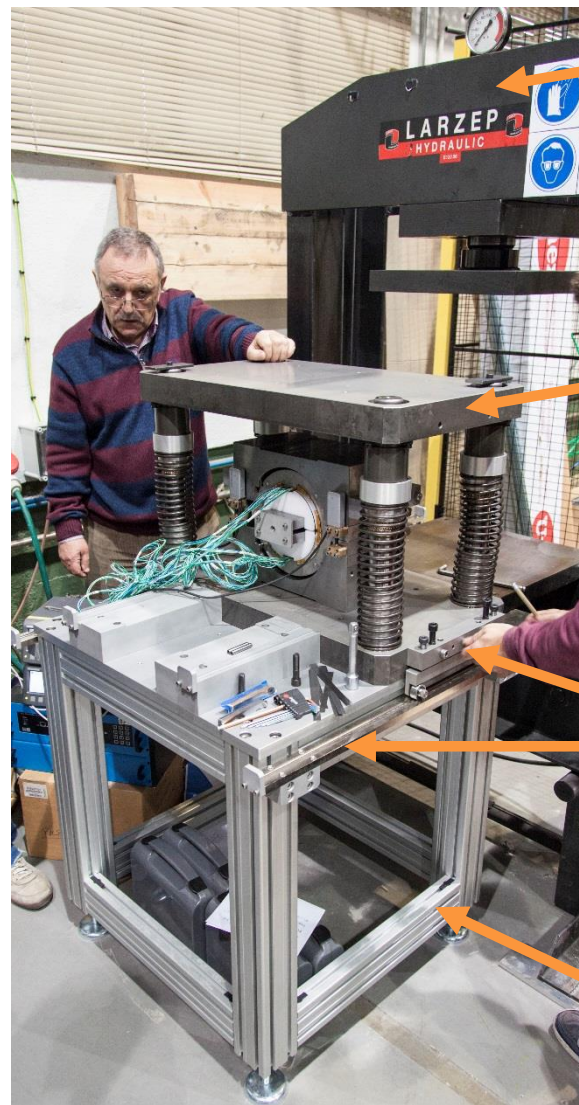
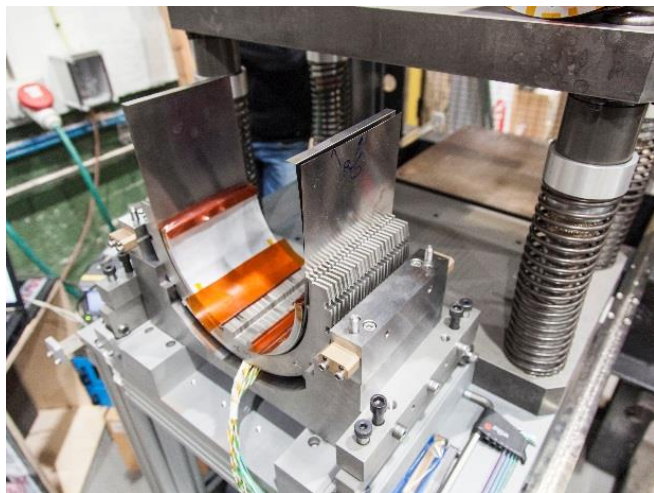


Handling scissors (ID & OD)



Collaring shoe  
preforming  
tooling

# Short mechanical model: Assembly

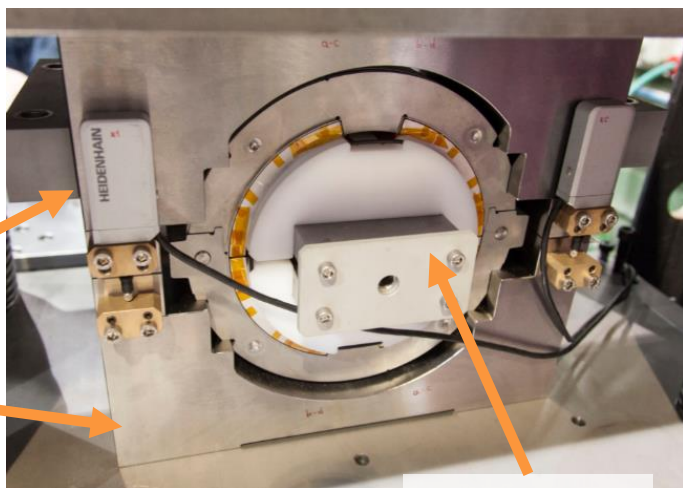


120 Ton press  
refurbished and  
calibrated

Alignment  
cage

Handling/sliding  
system

Support/assembly  
table

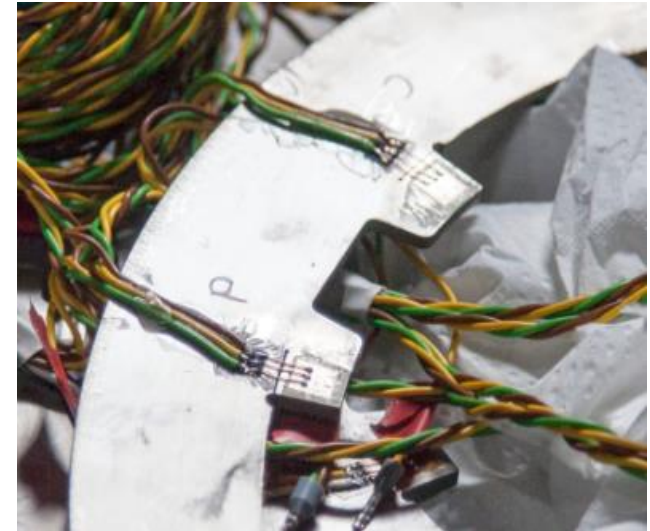
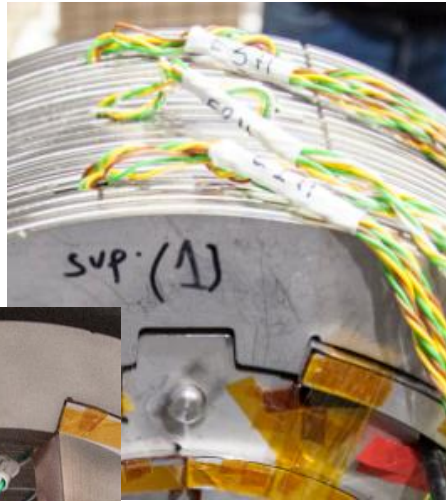


Inner  
collapsible  
mandrel

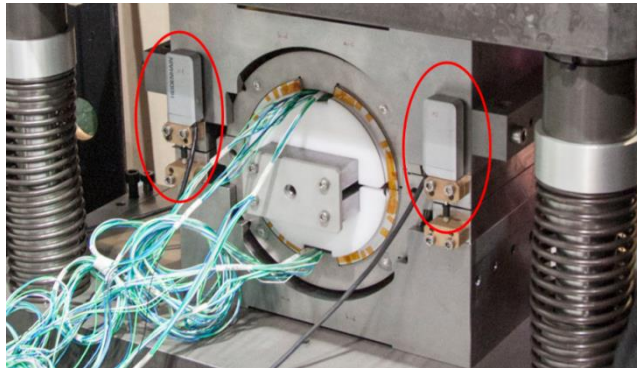
dles  
s

# 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

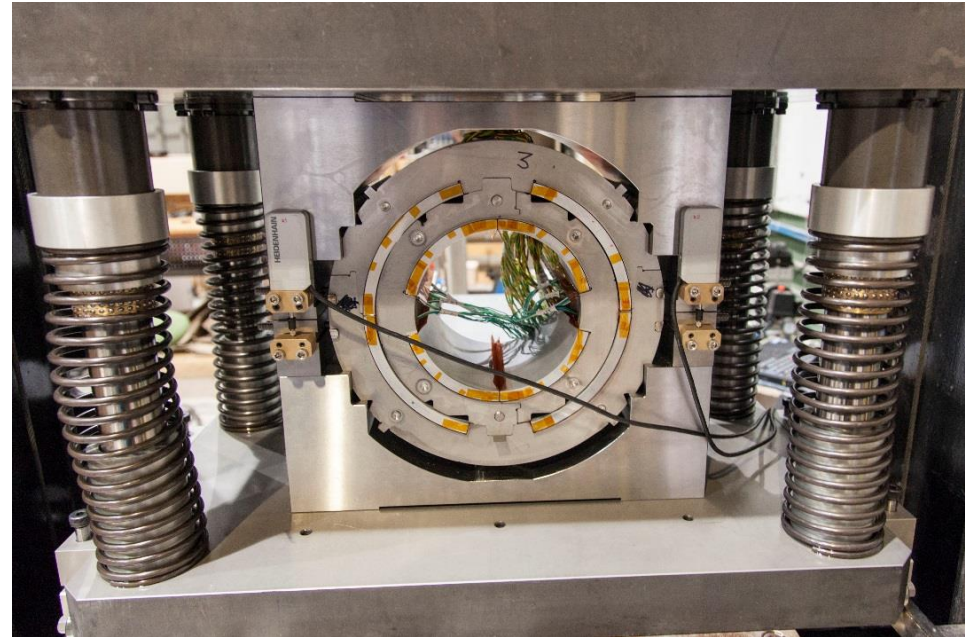


- Very good **agreement** between calculations and measurements when the pins are inserted and afterwards (spring-back).
- The collapsible mandrel is easily extracted.

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	-
<b>0.2</b>	<b>40</b>	<b>106</b>	<b>108</b>
<b>Spring-back</b>	-	<b>72</b>	<b>74</b>

# Short mechanical model: Outer collaring test

- Very good **agreement** of average measurements and calculated ones, when the keys are inserted and afterwards.
- 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.
- The assembly is **repeated** two times and measurements were balanced. We think that the assembly procedure was not right the first time.



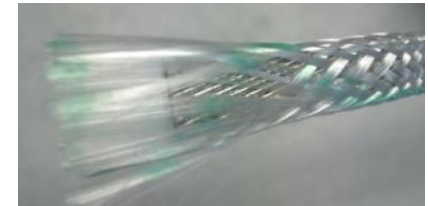
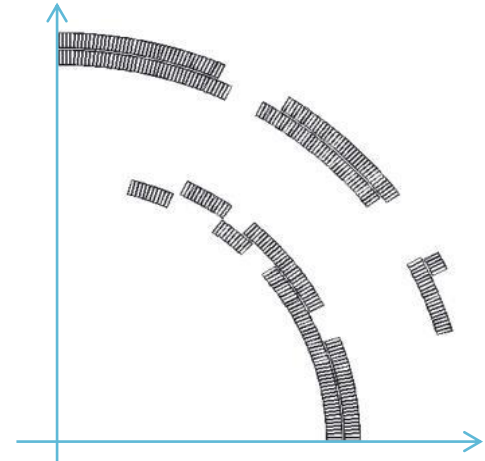
Gap [mm]	Press force [ton]	Average stress measured [MPa]	Average stress simulated [MPa]
0.5	33	76	-
0.4	38	90	-
0.3	40	105	-
<b>0.2</b>	<b>40</b>	<b>124</b>	<b>110</b>
Spring-back	-	89	81

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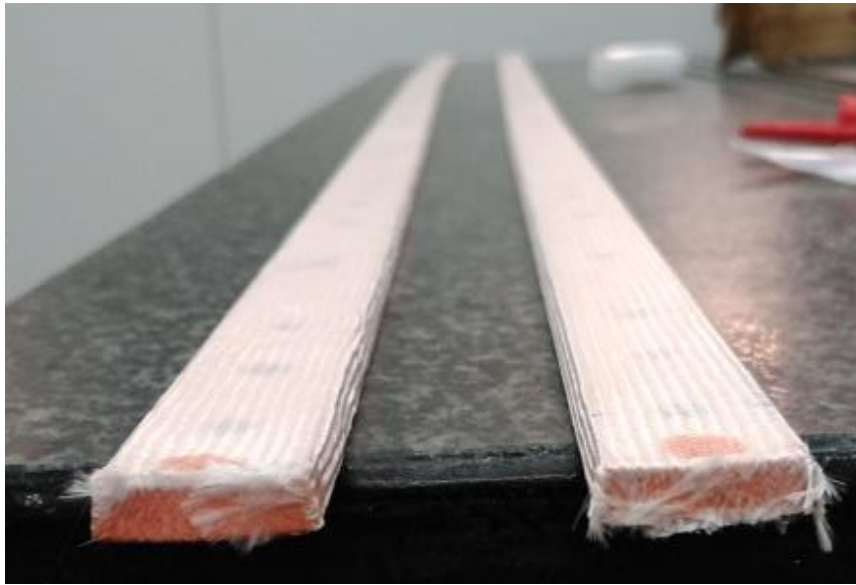
# Manufacturing concept and coil fabrication remarks

- Double pancake coils of small NbTi cable with large aperture lead to large number of turns: **fully impregnated coils**.
- Cable should be insulated with **glass-fibre** to ease the impregnation (CTD 101K).
- CTD **binder** 1.1 will be used to allow double pancake winding. It is compatible with the resin.
- **Coil pre-stress** will be provided by self-supported stainless steel collars.
- **Iron yoke** will be laminated and will not provide additional mechanical support.
- MCBXF are **2-in-1 magnets**, given the inner/outer dipole configuration, so tooling is thought to be used in both magnets if possible, in order to reduce production costs.

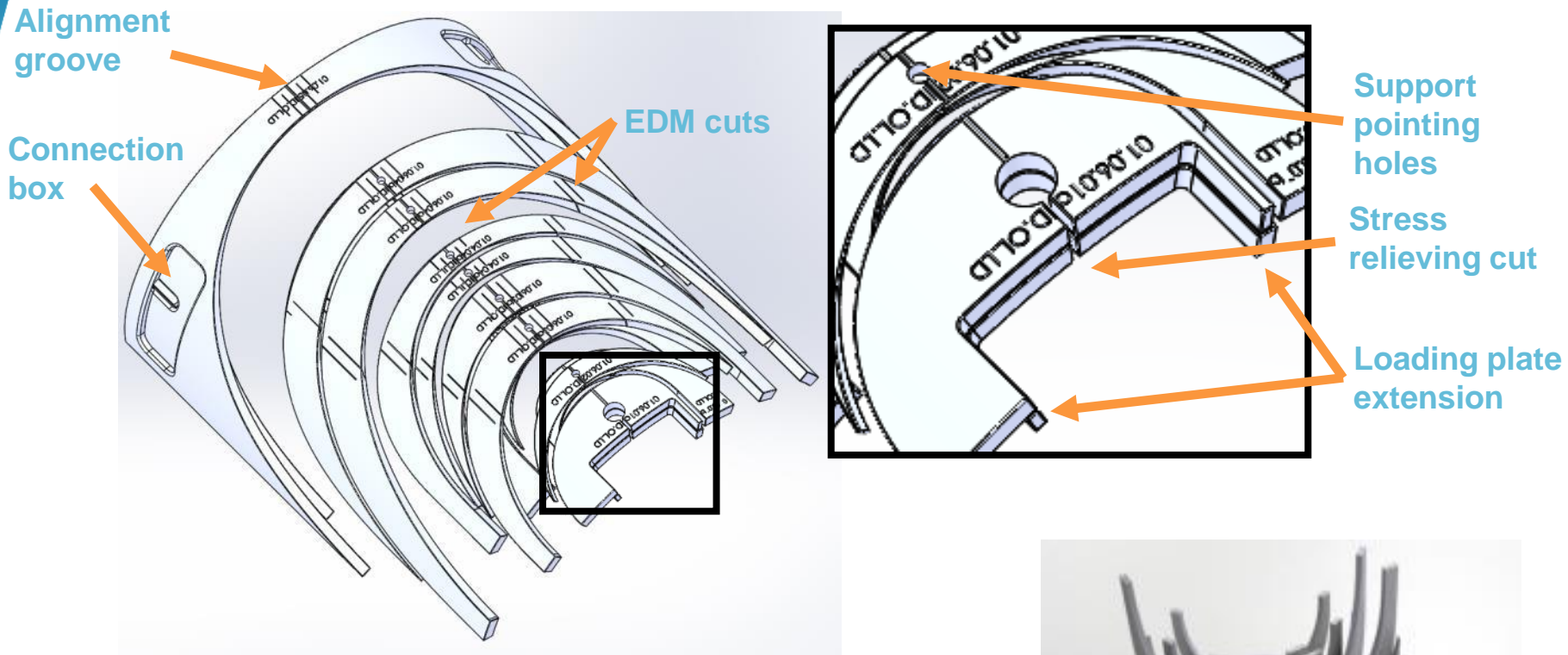


# Fabrication of coil parts: cable and wedges

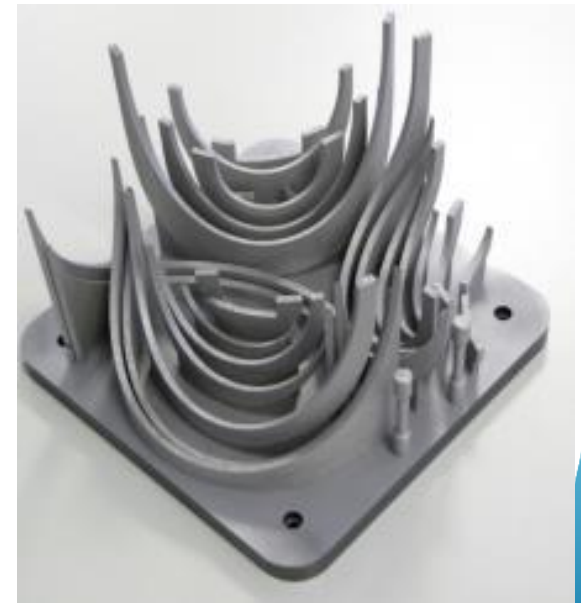
- **66TEX933** fiberglass is woven around the cable, which is compatible with the resin and close to the nominal thickness of 135 micron (131 micron measured on ten-stack).
- Each coil cross section needs 5 different wedges to provide a good field quality. They are produced by machining in parts of approximately 300 mm length. So each coil needs **30 parts**.



# Fabrication of coil parts: End spacers

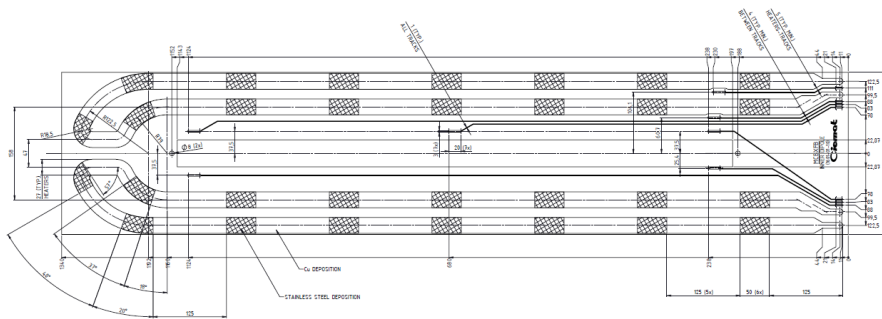


- There are **58 different end spacers per magnet!!**
- Produced by 3D printing, several improvements and add-ons have been introduced after the first tests.
- Large deformations (up to +/- 2 mm): EDM cuts are introduced.



# Coil Fabrication: Quench heaters

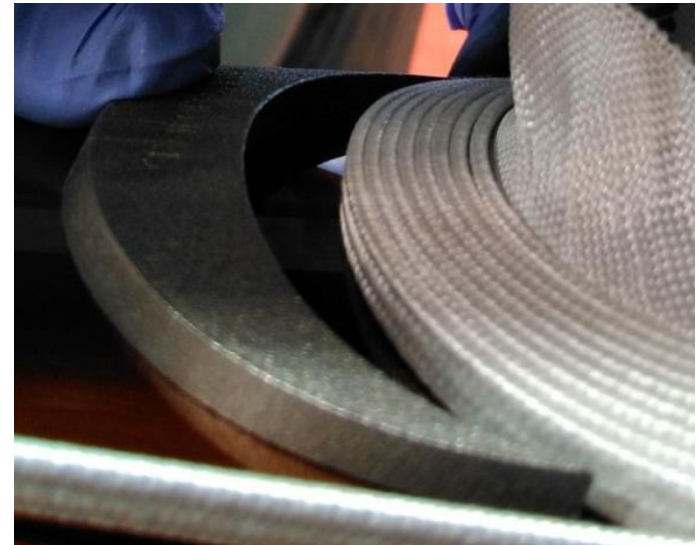
- Quench simulation with CIEMAT code **SQUID**, based on finite difference method.
- Baseline strategy is: short magnet is self-protected, long one is protected by dump resistor.
- Heaters are being implemented in the short prototype for **validation**. If successful, they will be likely implemented instead dump resistor.
- Heaters produced by **927** team.
- One **voltage tap** per cable block and at both sides of the layer jump.



	Current	Dipole	Protection	Tmax (K)	Vmax (V)	Energy dissipated in magnet (kJ)
MCBXFA	Nominal	Inner	Heaters ON	126	393	121
			Heater OFF	242	389	121
			Dump resistor 0.3 ohm	65	480	5
		Outer	Heaters ON	133	643	215
			Heater OFF	284	618	215
			Dump resistor 0.3 ohm	106	441	26
	110% nominal	Inner	Heaters ON	154	519	146
			Heater OFF	274	504	146
			Dump resistor 0.3 ohm	80	528	9
		Outer	Heaters ON	160	847	260
			Heater OFF	322	798	260
			Dump resistor 0.3 ohm	141	485	46
MCBXFB	Nominal	Inner	Heaters ON	129	234	72
			Heater OFF	177	235	72
			Dump resistor 0.3 ohm	50	480	2
		Outer	Heaters ON	137	383	129
			Heater OFF	211	376	129
			Dump resistor 0.3 ohm	65	441	7
	110% nominal	Inner	Heaters ON	154	311	88
			Heater OFF	198	308	88
			Dump resistor 0.3 ohm	57	528	3
		Outer	Heaters ON	163	504	156
			Heater OFF	243	489	156
			Dump resistor 0.3 ohm	79	485	11

# First winding and binding test

- About 60 m of cable were used.
- Cable **did not lay down** at the coil ends as expected. Coil is a bit shorter than nominal.
- All **tooling** worked relatively well.
- Some minor **improvements** were implemented:
  - Regulation of the height of the cable exit from the spool.
  - Additional arcs for cable clamping during winding.
  - Narrower glass fiber tape for insulation of end-spacers.
  - Fiber glass for end-spacer insulation is impregnated with binder.

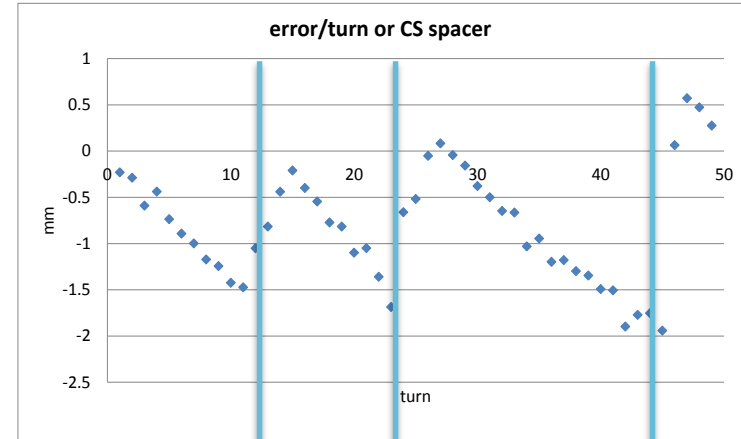
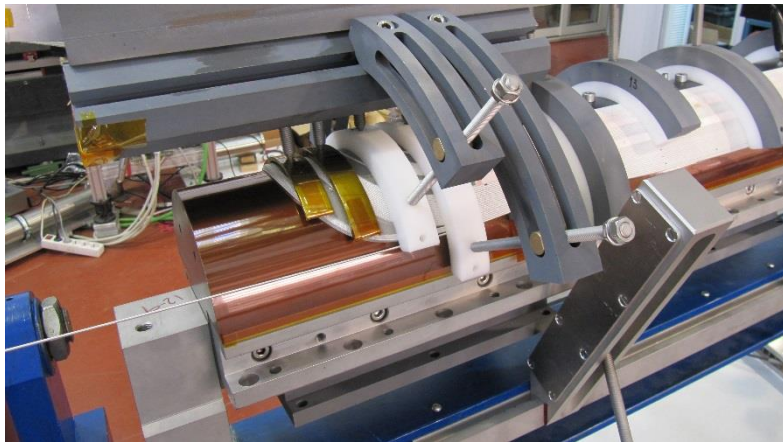
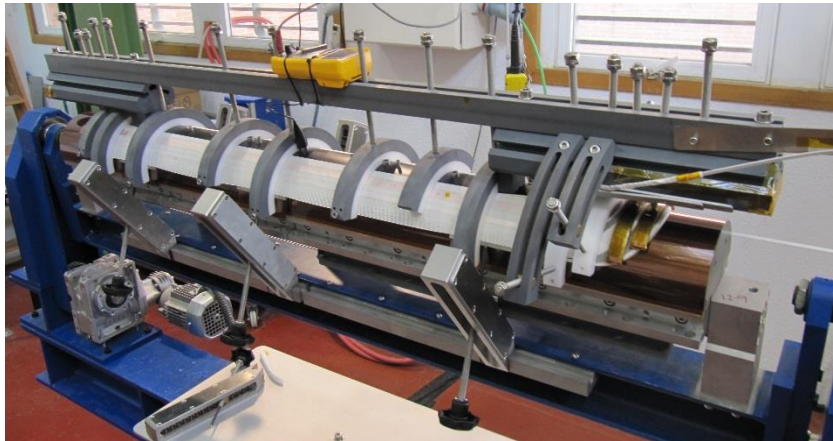


# First coil winding

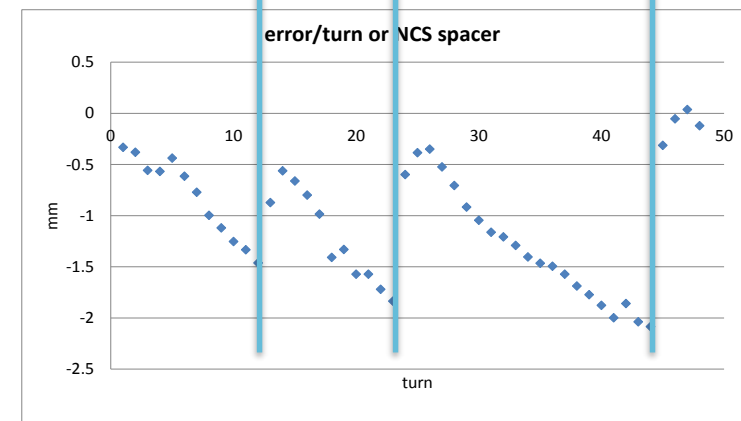
- The cable has been partially unwound twice, due to some problems with a voltage tap and end spacers.
- Cable is very flexible, so unwinding is not a problem.



# First coil winding



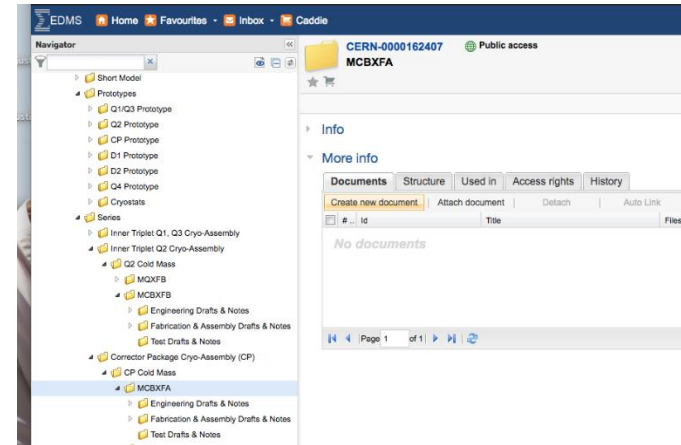
Spacers



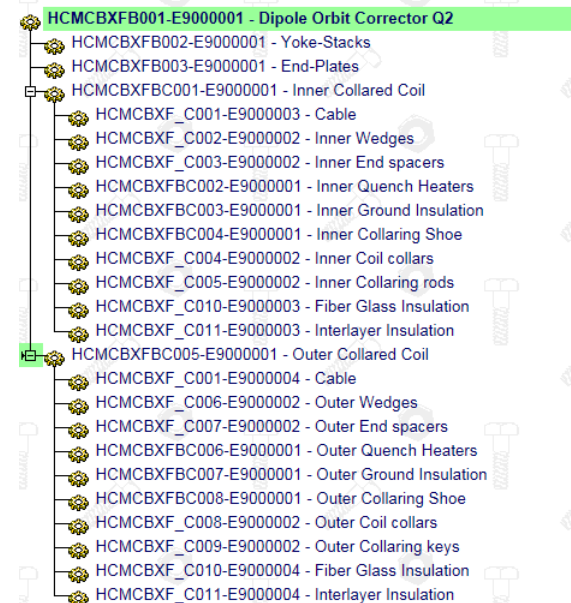
Longitudinal position at coil ends is shorter than nominal. Few tenths of mm at the first turn after an end spacer, up to 2 mm at the last turn before an end spacer. Both ends behave in the same way.

# Quality Control

- The structure at **EDMS** has been created.
- The equipment codes for **CDD** storage have been created. About 500 drawings of the short mechanical model and the inner dipole tooling have been already sent to CDD team.
- The **MTF** equipment codes are also generated.
  - Equipment codes for CDD
    - LHCMCBXFA (MCBXFA magnet: 11 digits + 4 digits for drawing number)
    - LHCMCBXFAC (MCBXFA coil assembly & components)
    - LHCMCBXFB (MCBXFB magnet)
    - LHCMCBXFT (MCBXFA & B generic tooling)
      - LHCMCBXFT001\_E9001 (Pay-off machine)
      - LHCMCBXFT002\_E9002 (Take-up machine)
      - ...
    - LHCMCBXFMM (Short mechanical model)
    - LHCMCBXTMT (tooling for short mechanical model)
  - Equipment code for MTF
    - HCMCBXFA001-E9xxxxxx (E9:CIEMAT, MCBXFA magnet)
    - HCMCBXFAC001-E9xxxxxx (MCBXFA Inner collared coil)
    - HCMCBXFAC002-E9xxxxxx (MCBXFA Inner coil)
    - HCMCBXFAC003-CRxxxxxx (MCBXFA collared coil components).
      - The number 00X will increase by each different component
    - HCMCBXFA001-E9xxxxxx (MCBXFB magnet)
    - HCMCBXFAC001-E9xxxxxx (MCBXFB Inner collared coil)
    - HCMCBXFAC002-E9xxxxxx (MCBXFB Inner coil)
    - HCMCBXFAC003-CRxxxxxx (MCBXFB collared coil components).



## Assembly Tree



# Schedule

	Task	Date
<b>Design</b>	Detailed mechanical calculations	Done
	ID fabrication drawings	Oct-17
	OD fabrication drawings	Dec-17
<b>Fabrication</b>	Cable MCBXB H+V delivered (4 ID + 3 OD unit lengths)	Oct-17
	Winding machine ready	Jun-17
	First winding test	Sept-17
	First ID coil	Nov-17
	ID coils	Jan-17
	ID Collaring	Feb-18
	ID Magnet assembly	March-18
	OD coils	April-18
	OD Collaring	May-18
	Magnet Assembly	June-18
	<b>Test</b>	ID in vertical cryostat
Magnet prototype in vertical cryostat		July-18

# Conclusions

- Magnetic and mechanical design is finished.
- 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.
- First winding and binding tests have been successfully performed.
- First coil fabrication is ongoing.

# Thank you for your attention



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