WP3 - Q4 magnets for HL-LHC

J.M. Rifflet, M. Segreti, E. Todesco

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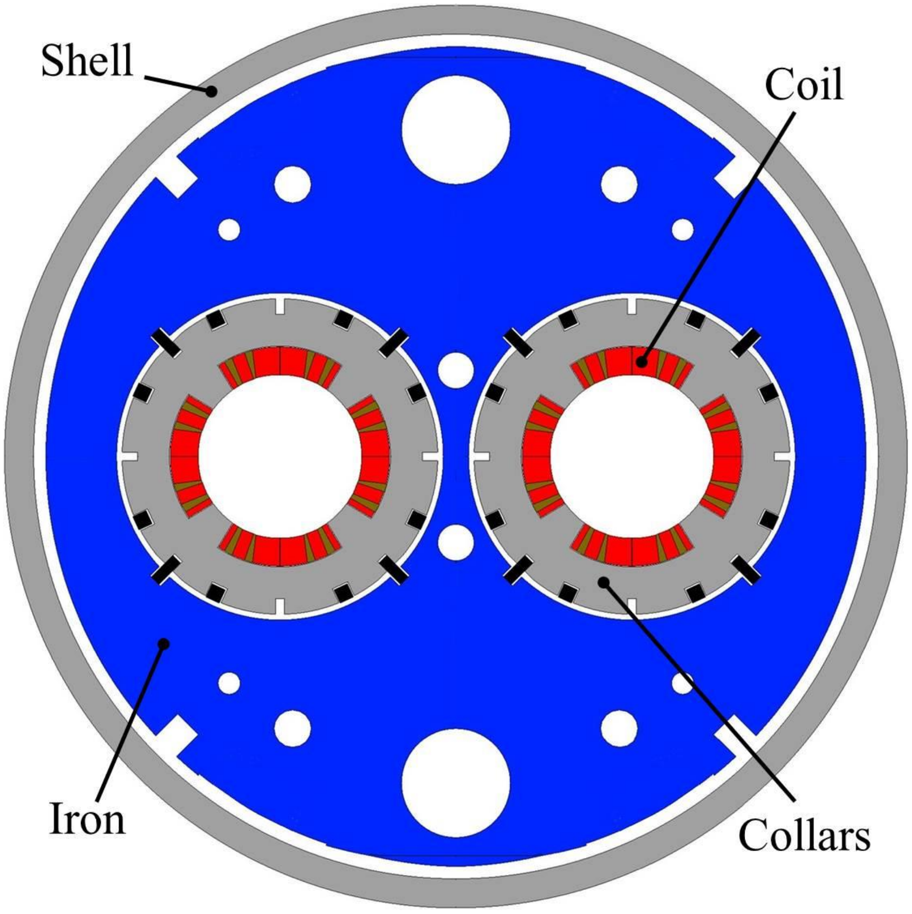
This work is continued under the collaboration agreement CERN / CEA KE2275/TE

Previous magnetic design using MQ cable

Parameters
1 layer
3 conductor blocks (octant)
14 turns (8 + 4 + 2)

Aperture = 90 mm
Integrated gradient = 440 T
Magnetic length = 3.83 m
Nominal gradient = 115 T/m
Loadline margin = 20 %
Temperature = 1.9 K
Nominal current = 15650 A
Stored energy = 0.73 MJ
Differential inductance = 2 × 2.9 mH



Field quality and unbalanced regime

0 % Nominal current

Current	Gradient	Normal relative multipoles (× 10^{-4}) in the left aperture								
(A)	(T/m)	b1	b3	b4	B5	b6	b7	b10	b14	b18
15650	120	5.50	0.00	0.21	0.27	0.00	0.03	0.00	1.55	-0.23
Current	Gradient	Normal relative multipoles (× 10^{-4}) in the right aperture								
(A)	(T/m)	b1	b3	B4	B5	b6	b7	b10	b14	b18
15650	120	-5.50	0.00	0.21	-0.27	0.00	-0.03	0.00	1.55	-0.23

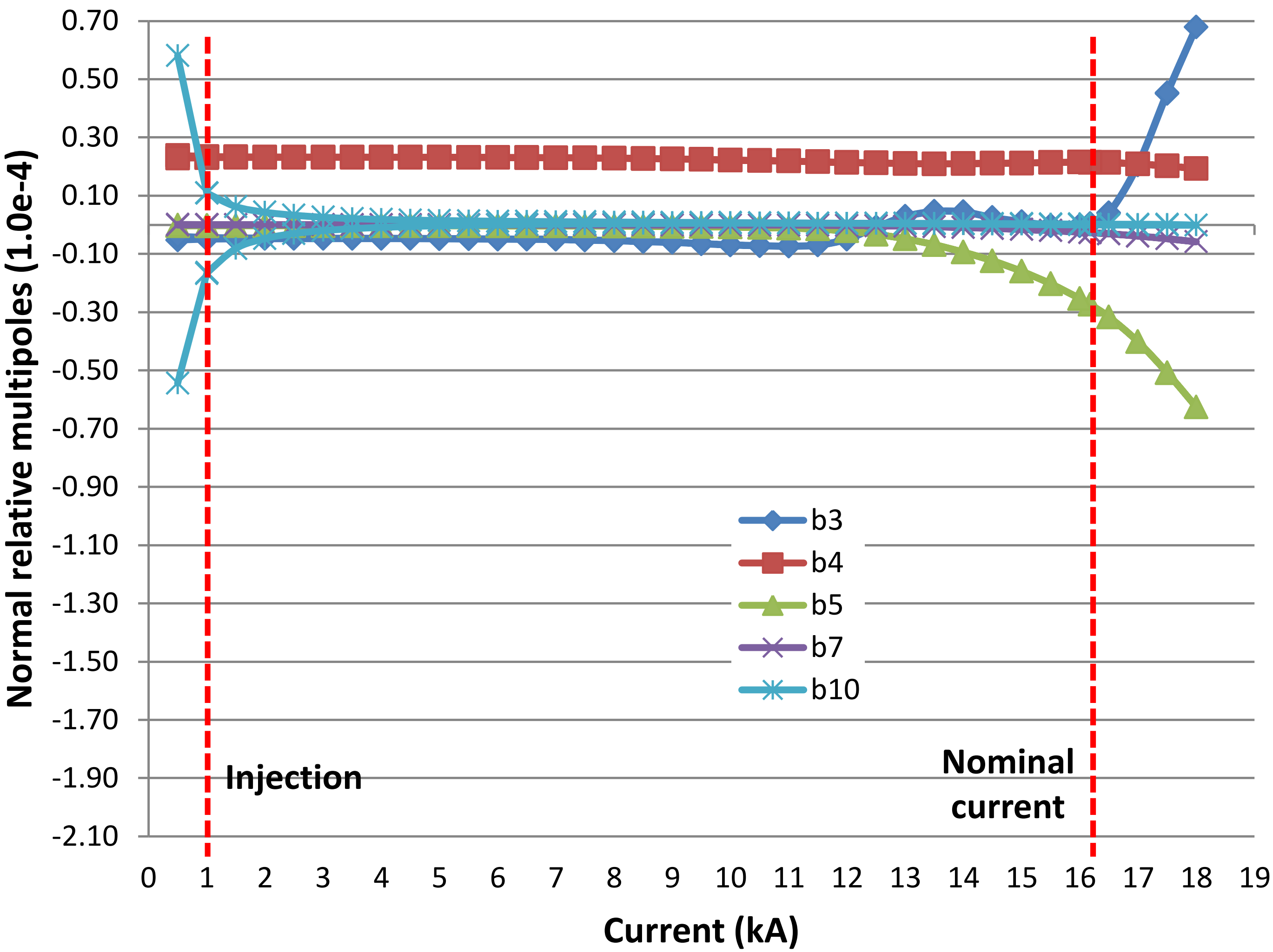
20 % unbalanced

Current	Gradient	Normal relative multipoles (× 10^{-4}) in the left aperture								
(A)	(T/m)	b1	b3	b4	b5	b6	b7	b10	b14	b18
15650	120	5.56	-0.19	0.17	0.28	0.00	0.03	0.00	1.55	-0.23
Current	Gradient	Normal relative multipoles (× 10^{-4}) in the right aperture								
(A)	(T/m)	b1	b3	b4	b5	b6	b7	b10	b14	b18
12520	96	-0.23	-0.07	0.26	-0.04	-0.31	0.00	0.00	1.55	-0.23

50 % unbalanced

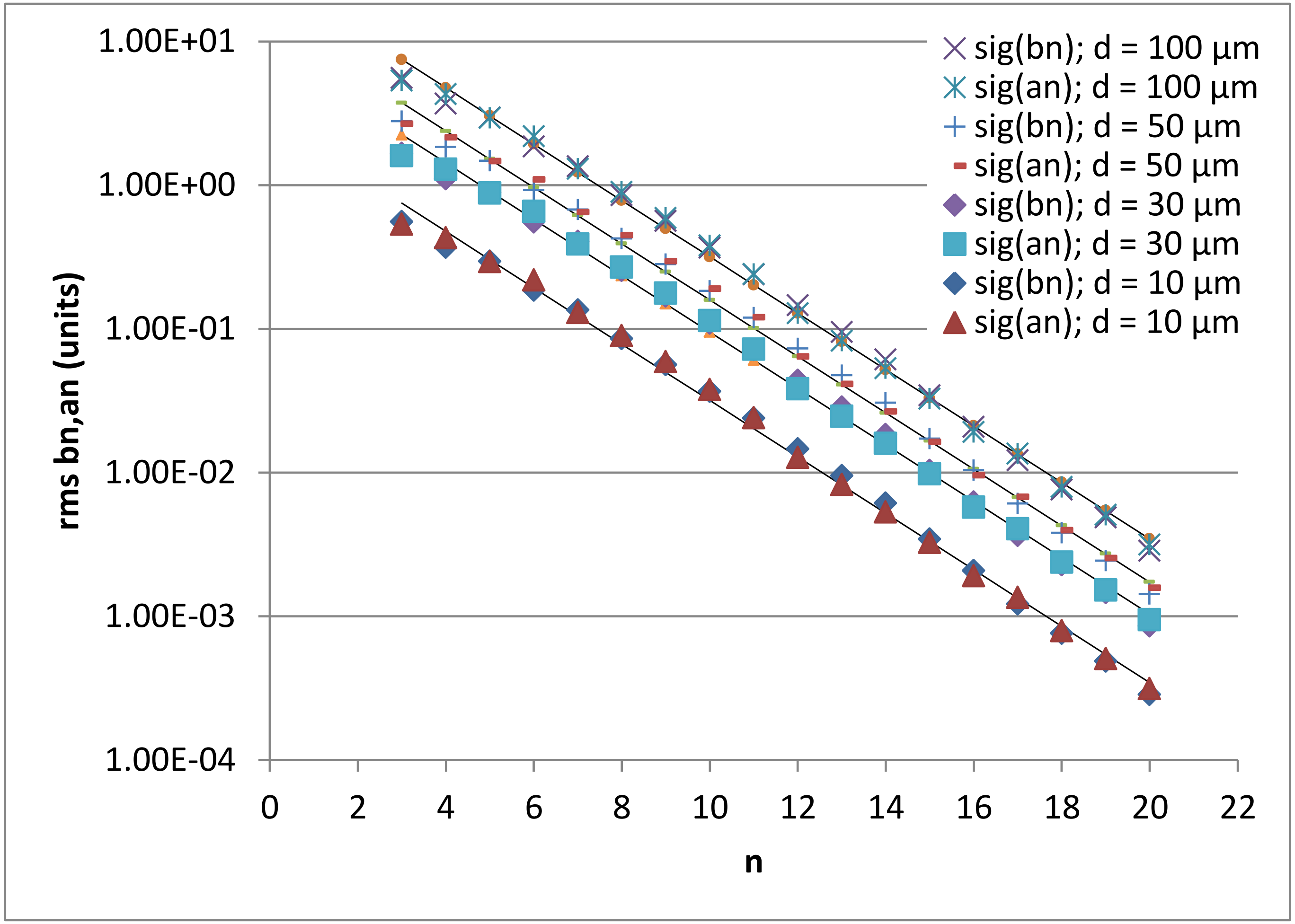
Current	Gradient	Normal relative multipoles (× 10^{-4}) in the left aperture								
(A)	(T/m)	b1	b3	b4	b5	b6	b7	b10	b14	b18
15650	119	3.32	-0.92	-0.03	0.22	-0.02	0.02	0.00	1.55	-0.23
Current	Gradient	Normal relative multipoles (× 10^{-4}) in the right aperture								
(A)	(T/m)	b1	b3	b4	b5	b6	b7	b10	b14	b18
7825	60	-2.88	**-1.64**	0.90	-0.22	-0.40	-0.01	0.01	1.55	-0.23

Field quality



All below one unit

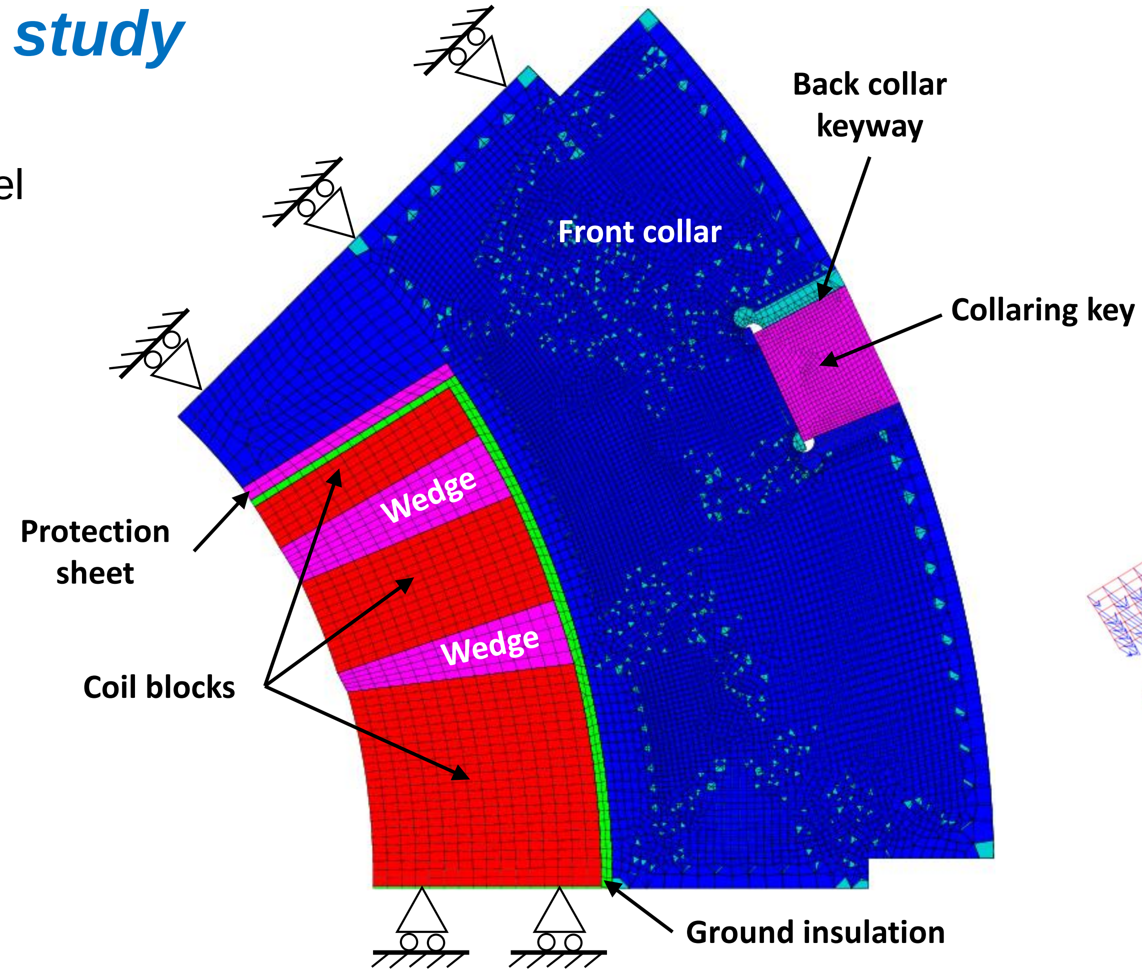
Random geometric field errors

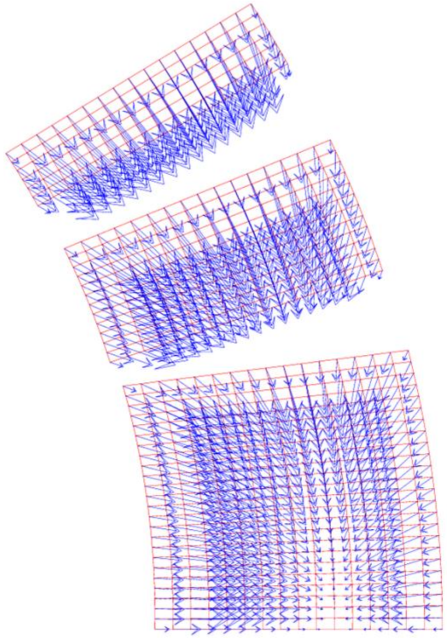


d	alpha	beta
[µm]	[1/µm]	[-]
100	0.2899	0.6366
50	0.2900	0.6366
40	0.2899	0.6366
30	0.2898	0.6366
20	0.2897	0.6366
10	0.2901	0.6366
Average	0.2899	0.6366

Mechanical study

Mechanical model
CAST3M
Elastic-plastic



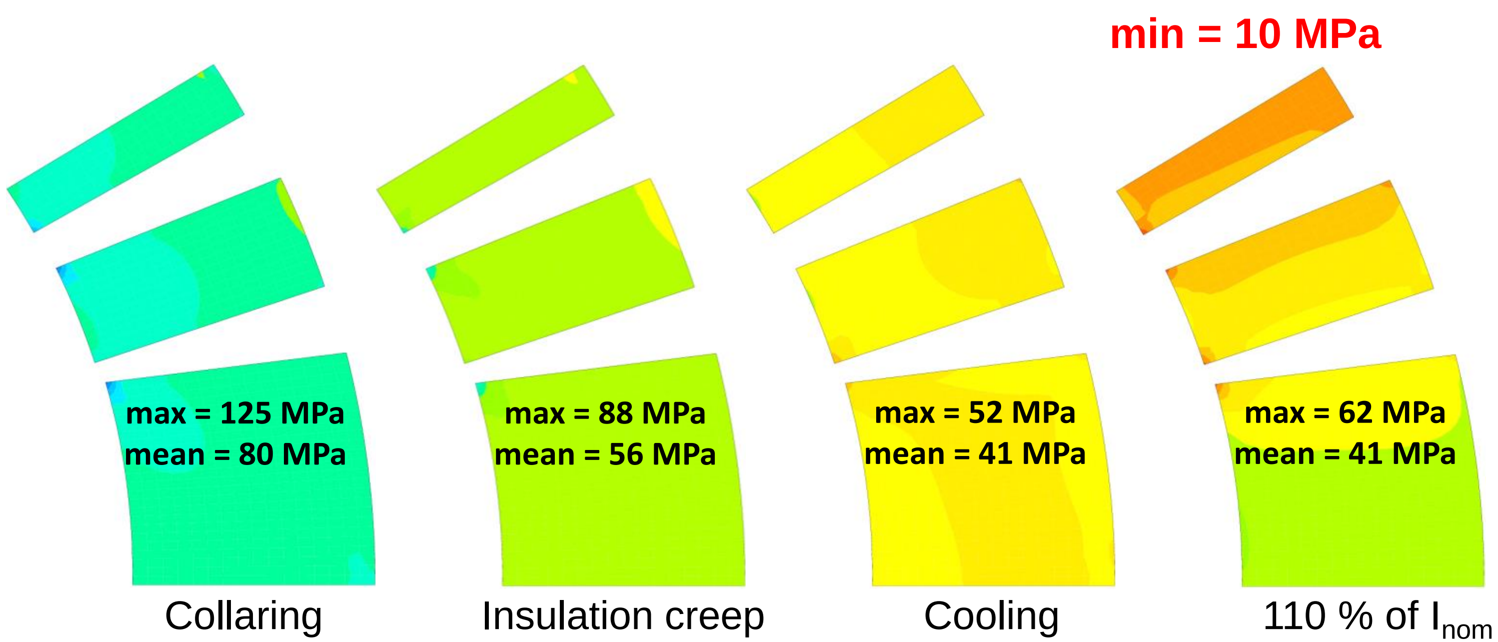


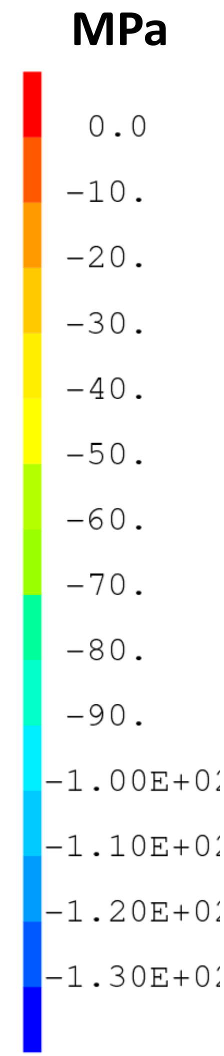
Simulation :

- Collaring (key)
- Insulation creep (30 %)
- Cooling
- Energisation at 110 % of I_{nom} → Magnetic forces are computed at each coil node

Mechanical study

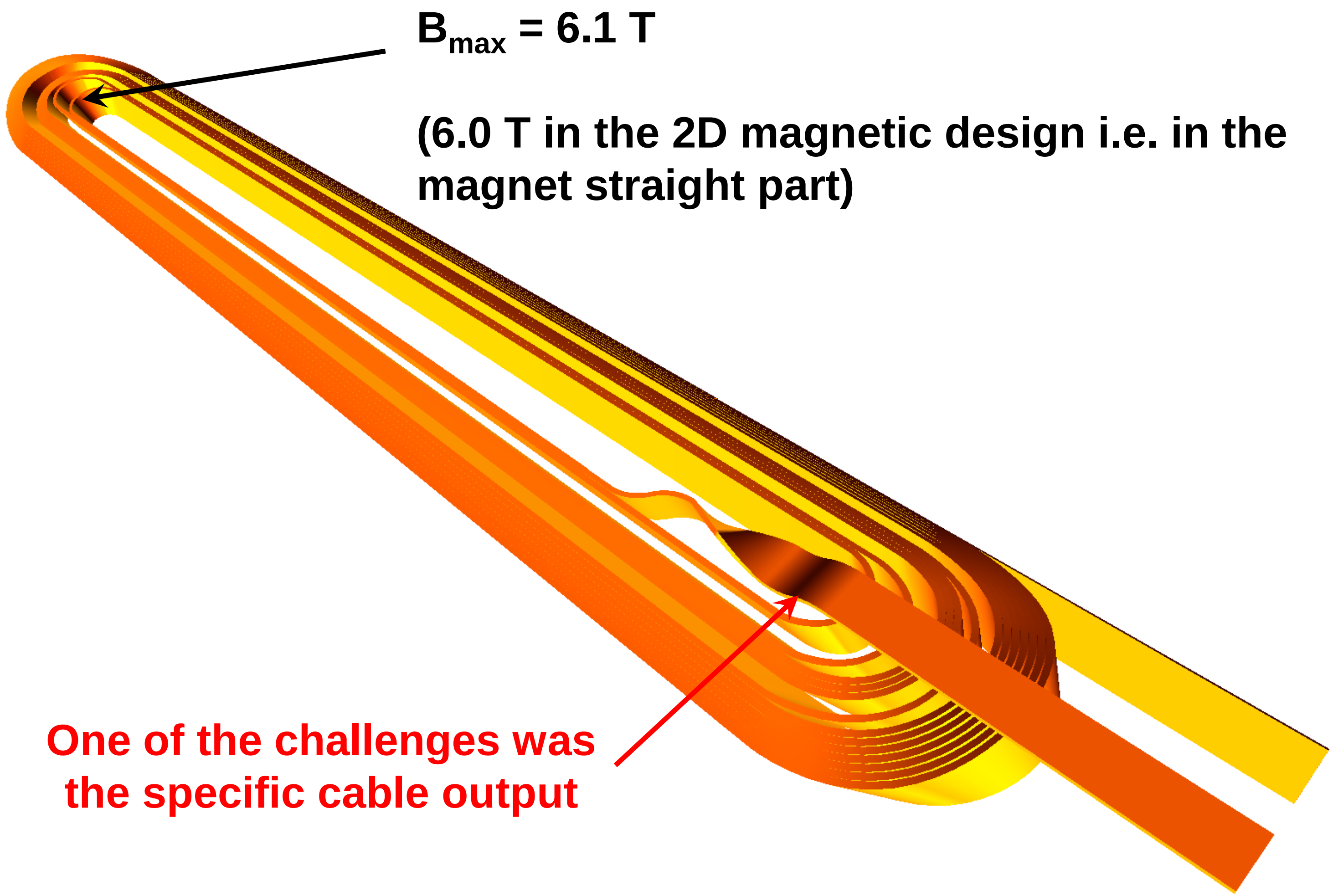
A self-standing collar solution as mechanical structure is validated



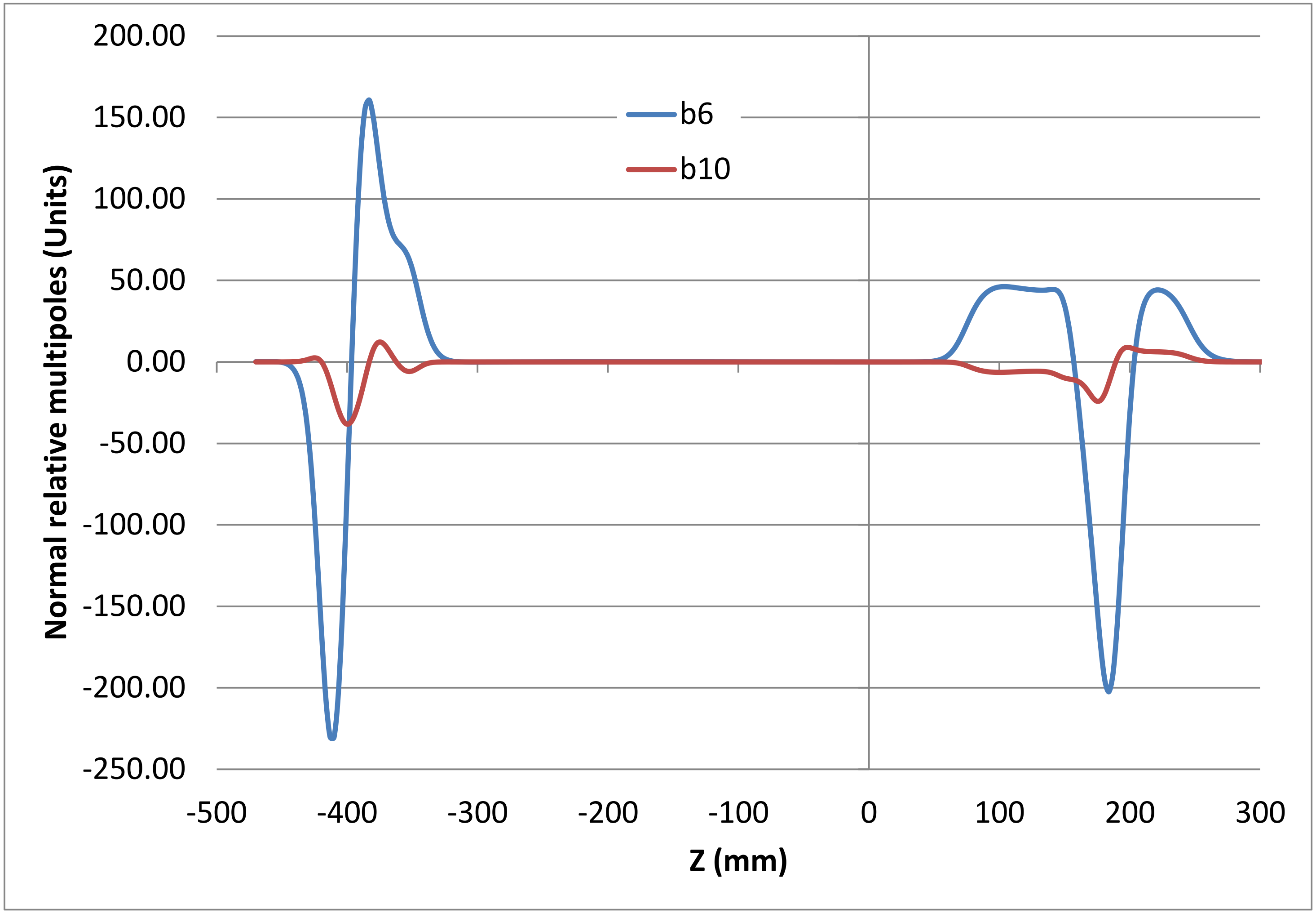


Azimuthal stress distribution in coil at each main step

Previous coil ends using MQ cable



Previous coil ends using MQ cable



Q4 MAGNETS FOR HL-LHC

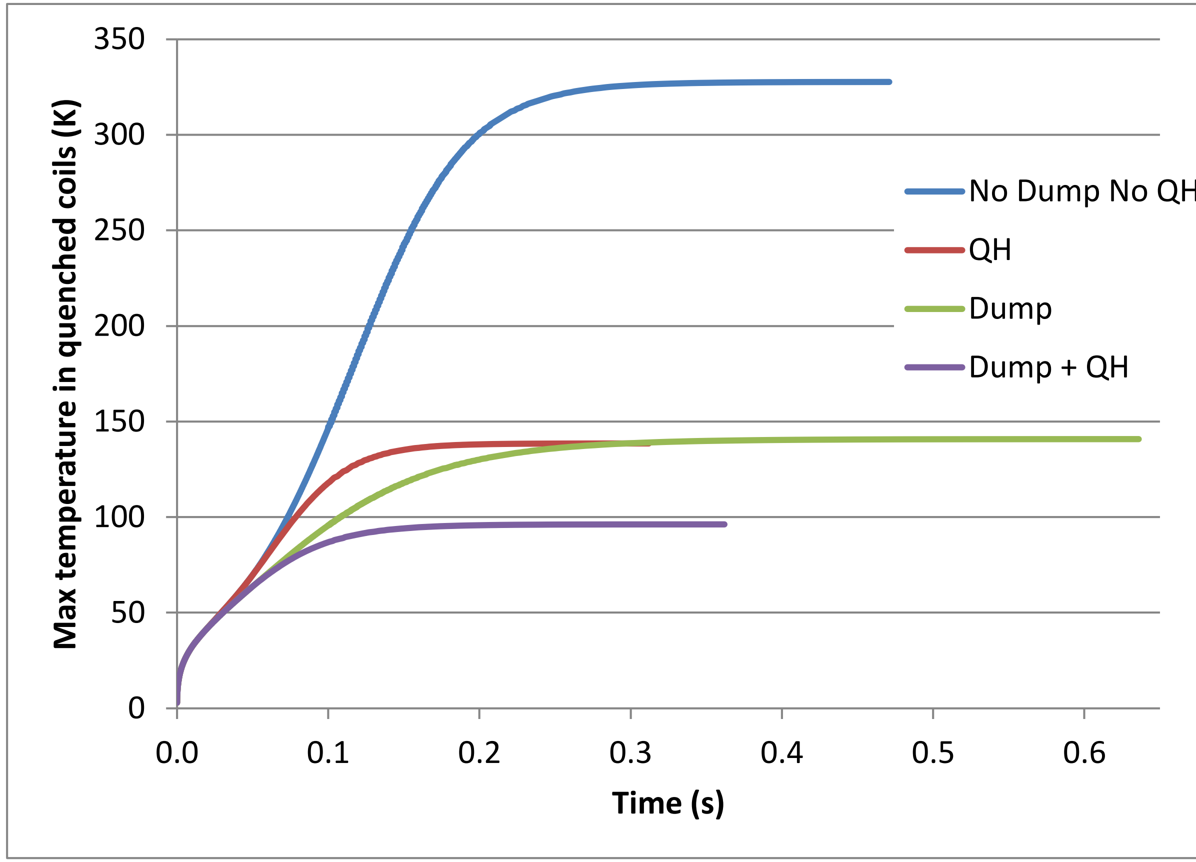
Protection

Specifications

Max hot spot temp = 250 K
Max voltage to ground = 500 V

Voltage detection = 0.1 V
Time detection = 10 ms

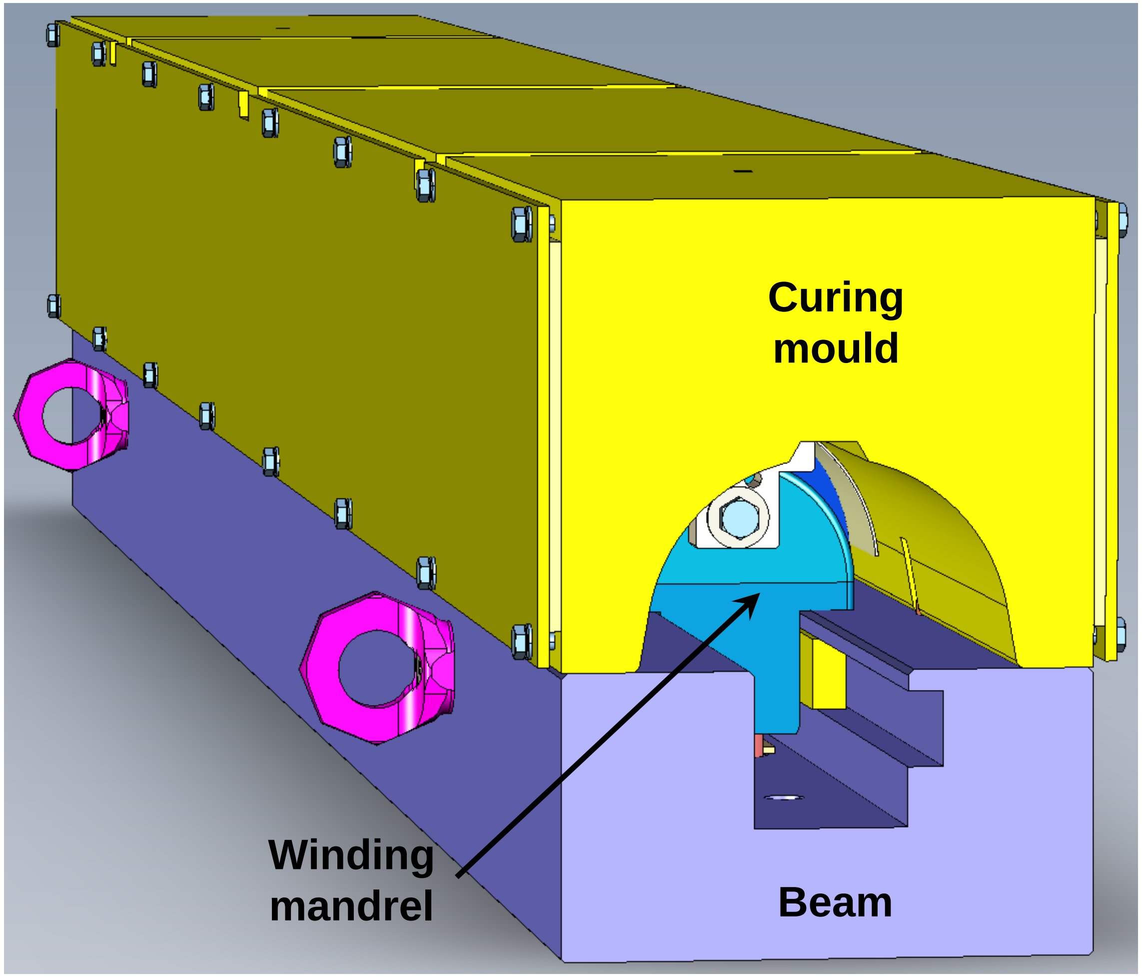
Dump resistor = 32 mΩ
QH time of activation = 40 ms



Configurations	Max temperature (K)	Max voltage to ground (V)
No Dump No QH	**328**	412
QH	139	68
Dump	141	500
Dump + QH	96	500

CAD

3D models of all components, tooling and accessories for coil fabrication were ready (end-spacers, copper wedges, beam, mandrel, curing mould…)



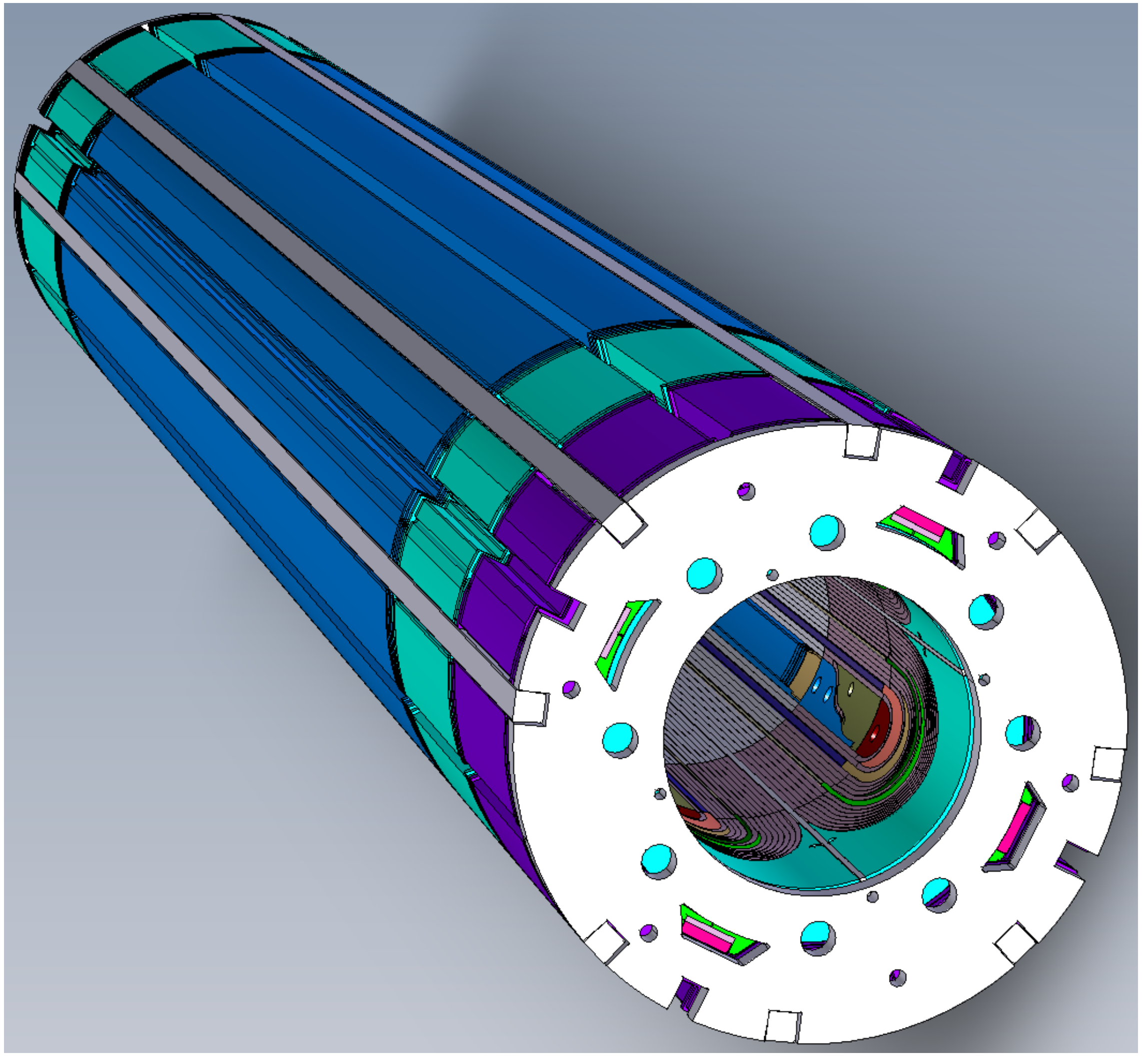
Q4 MAGNETS FOR HL-LHC

CAD

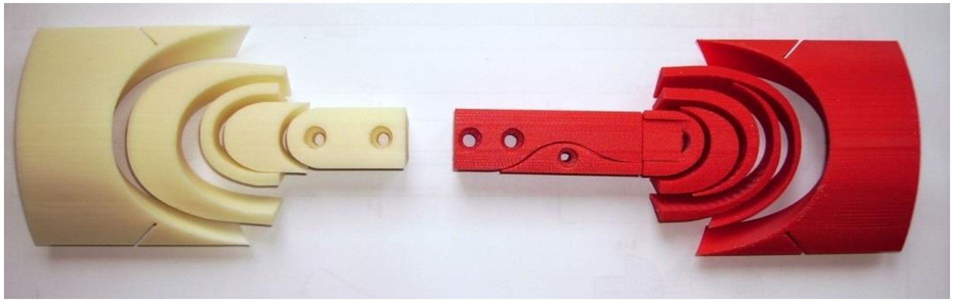
3D model of the single aperture short-model was ready up to the collared coils

The internal connection between coils was defined

The geometry of the yoke outer diameter is still to be defined with CERN (to take into account the correctors integration in the cold mass)

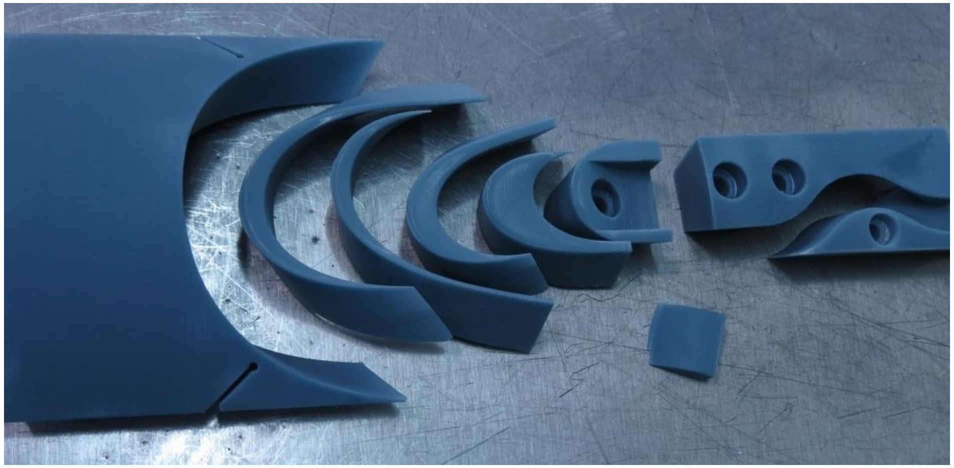


Winding trial



The Cern routine allowed to obtain rapidly the CAD of end-spacers from ROXIE output files

A first set of plastic end-spacers was 3D printed at the design office



A second set was printed at Cern with Bluestone composite material which can survive the curing temperature

The tooling and accessories for the winding trial were fabricated at CEA

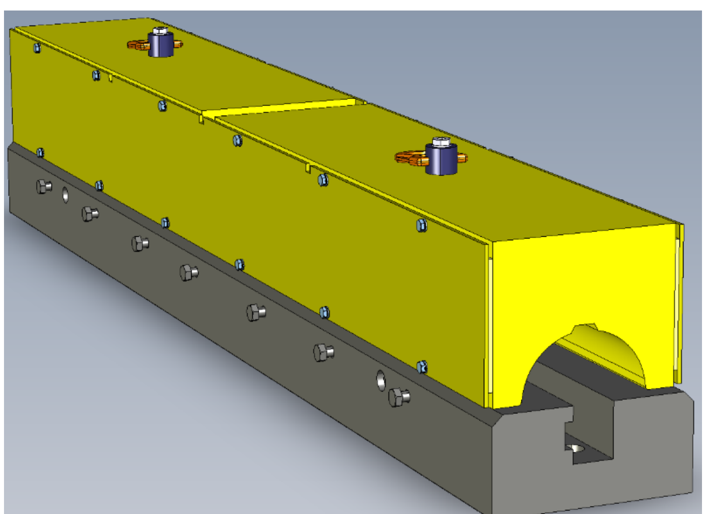
The tooling and accessories for the winding & curing trial was ready

Winding trial

A winding trial performed during the first half of January 2015 validated the geometry of the end-spacers

40 m of insulated cable were received from Cern. This length was sufficient to make two 700-mm long mockups

2nd winding trial + curing trial was ready to be performed. **But STOPPED!**



Why it is necessary to change the magnetic design (E. Todesco)

New elements

- Spring 2015: cost and schedule review
  Large cost of 18 kA power converters – 4.5 MCHF (0.5 MCHF each, compared to ~1 MCHF for building the magnet)

- Spring 2015: beam dynamics simulations
  a "light" magnet with 3 mH inductance, even with a top class power converter gives for Q4 a tuneshift contribution equivalent to the contribution of the whole triplet

Additional elements

- 18 kA poses problems for test station
- Ancillary equipment to bring 16 kA to the tunnel are also a overhead

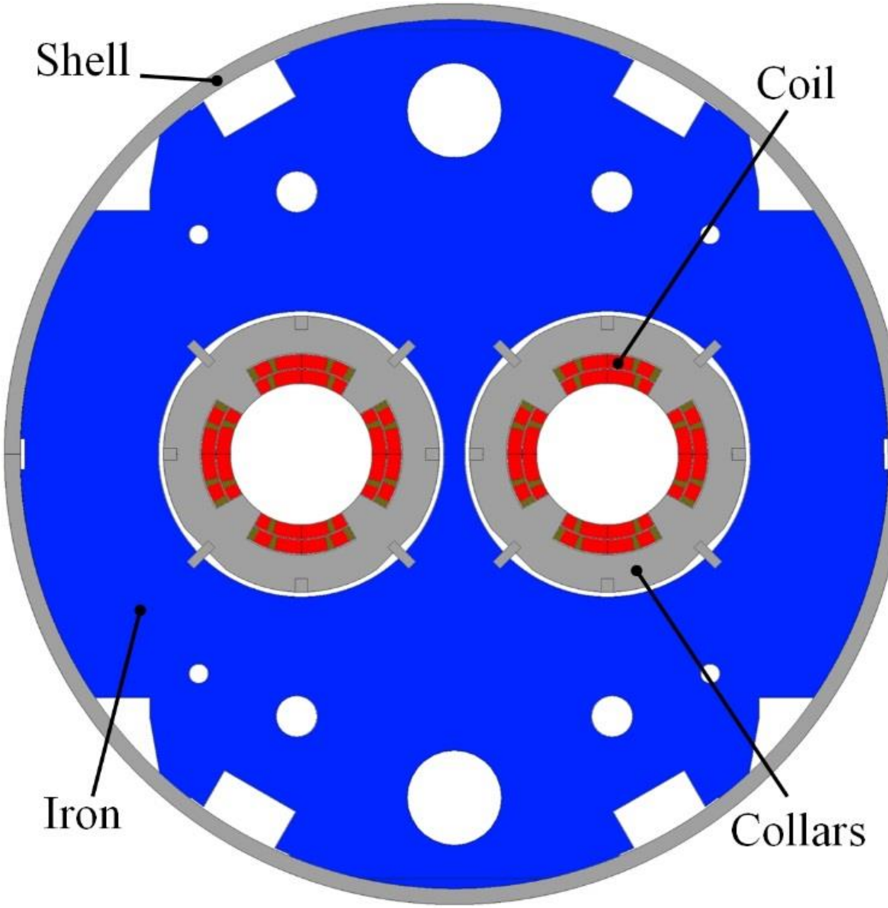
This gave reasons to propose a change of design

- First discussion between CERN and CEA-Saclay in July 2015
- New baseline in August, proposal validated in September with the **use of 2 layers of MQM cable for the magnetic design**

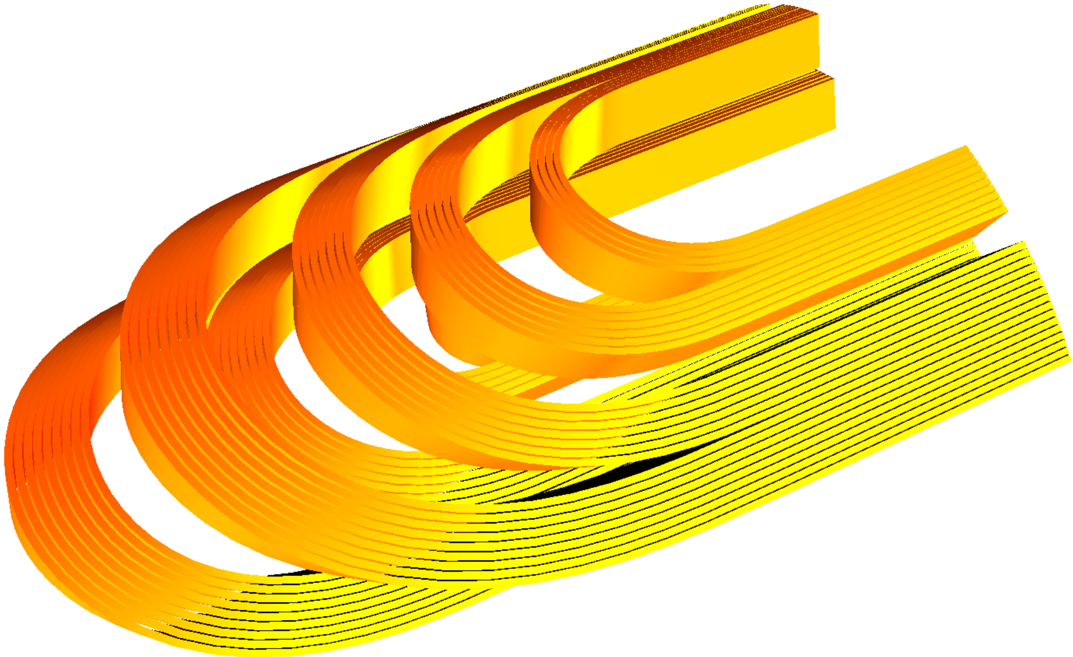
Updated magnetic design using 2 layers of MQM cable

Since August

Aperture = 90 mm (unchanged)
Integrated gradient = 440 T
Magnetic length = 3.67 m
Nominal gradient = 120 T/m
Loadline margin = 20 %
Temperature = 1.9 K
Nominal current = 4590 A
Stored energy = 0.81 MJ
Differential inductance = 2 × 37.5 mH



Updated coil ends using 2 layers of MQM cable



For now, optimization of the return end is quasi finished.
Lead end optimization to be done.

Cold test of the single aperture short model

- The baseline is that the test of the single aperture short model will be done at CEA-Saclay.
- The solution considered is to use the 8 m vertical cryostat. Cost and labor assessment is in progress
- Cern will provide the magnetic measurements system

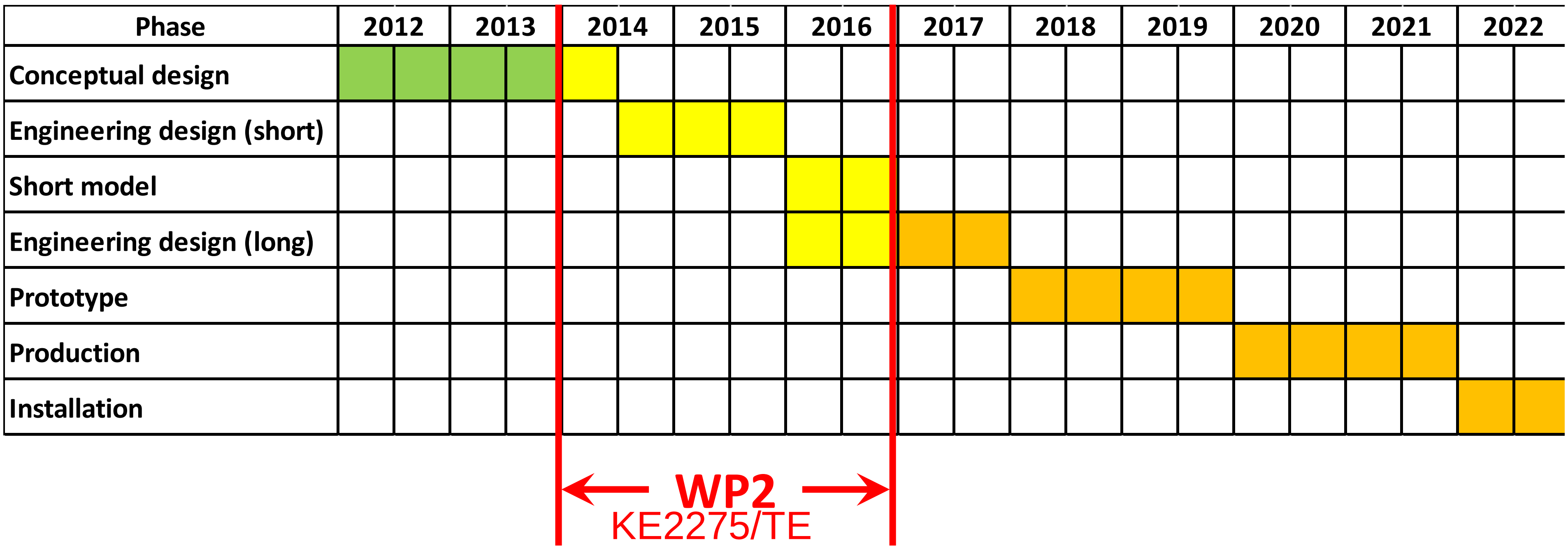
Quaco : New H2020 project (Pre-Commercial Procurement)

- Proposal submitted to EC in April 2015 for funding R&D for HiLumi
- Co-funding (70%) of design, engineering and fabrication of 2 Q4 quadrupole by 2 European firm
- Total contract value: 6.6 M€; max EU contribution: 4.6 M€
- Grant agreement signature : November, 23rd 2015
- Start : January 2016 (to be confirmed). 42 months

- Partners : CERN, CEA, CIEMAT, NBCJ. Leader = CERN (launch tenders on behalf of all partners

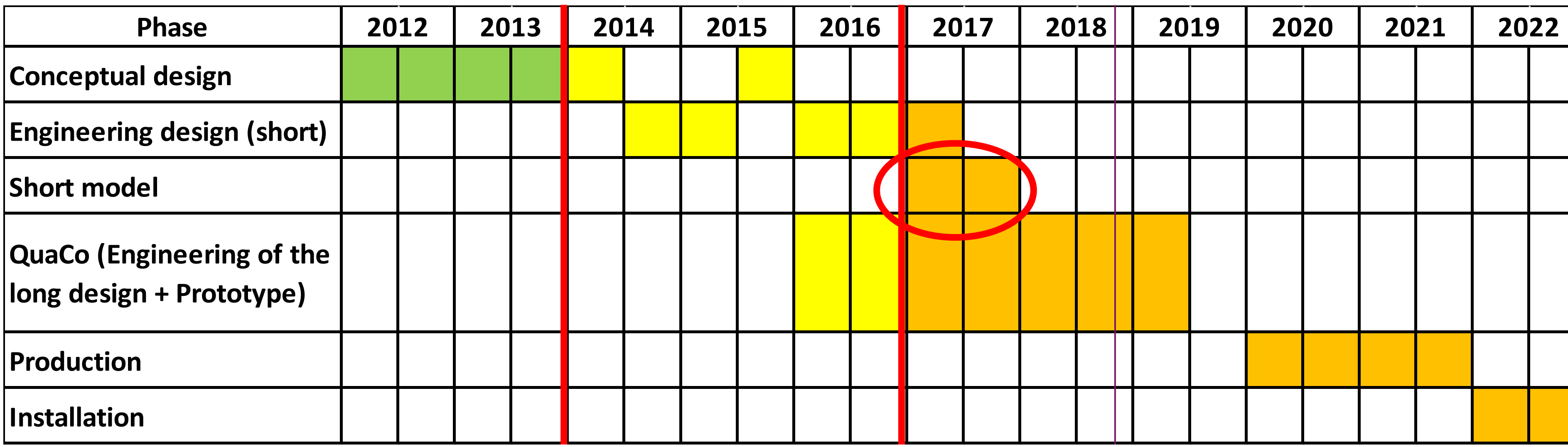
- 3 phases
  - Design (2-4 months); at least 3 contractors
  - Prototype development (10 months)
  - Pilot fabrication (max 22 months); 2 “first of a kind” by 2 contractors

Previous Q4 production for HL-LHC (January 2015)



CEA/CERN
collaboration
agreement

Actual Q4 production for HL-LHC (new design + QuaCo)



With the new magnetic design using MQM cable, the fabrication and test of the short model single aperture is reported to end of 2017/ early 2018

Conclusion

- The design of Q4 with MQ (Outer Dipole) cable was nearly finished in June 2015
- Low inductance → difficulties of magnet powering → change of cable → use of MQM cable
- The new design is in progress. It is estimated that about 1 additional year is necessary to finish and test the short model.

- A new funding approach is used for prototyping phase: PCP
- 2 “first of a kind” pilots will be built within the QUACO PCP framework. This will prepare for the small series production

we seek to hire a short term contract engineer for this project
if you know somebody interested, do not hesitate to put us in contact

Thanks for your attention