Status of the Activity for the Construction of the HL-LHC Superconducting High Order Corrector Magnets at LASA-Milan

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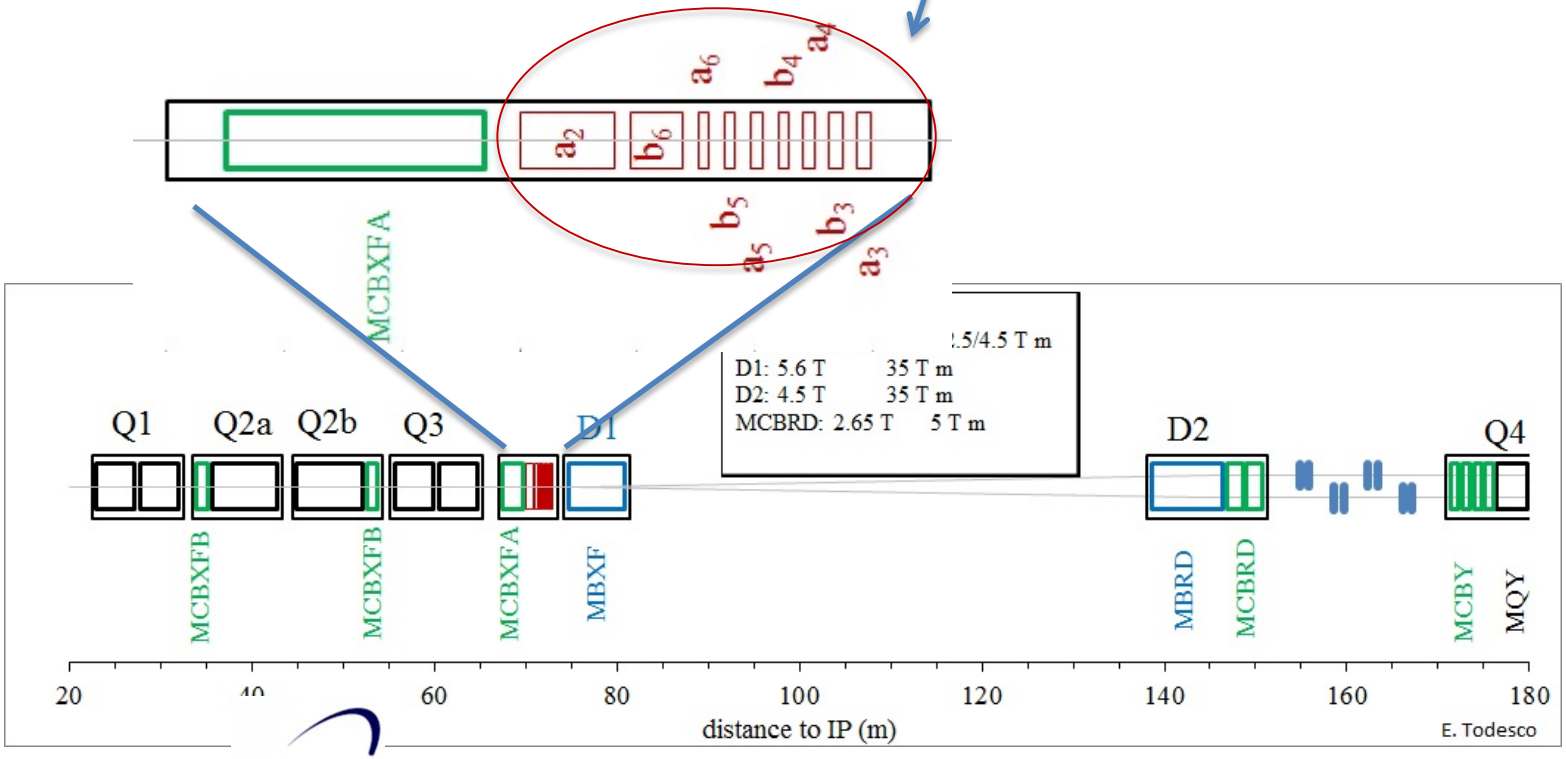
Mon-Mo-Or1

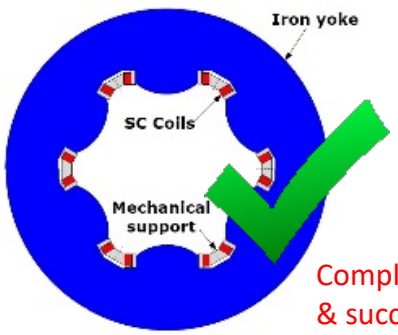
Scope

- The INFN-LASA follows the design, construction and test of the 5 prototypes of the <u>high order (HO)</u> corrector magnets for the interaction regions of HL-HiLUMI
- This activity is founded by INFN (Magix "activity"), and with an agreement CERN contributes for about 50%



Magnet zoo (prototypes)

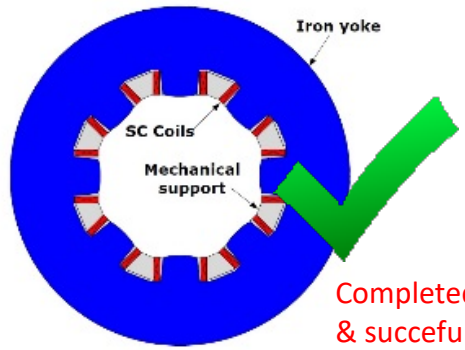
OD=320 mm



Completed
& succefully tested

Sextupole

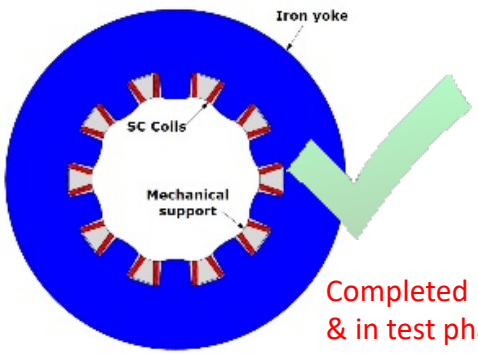
OD=320 mm



Completed
& succefully tested

Octupole

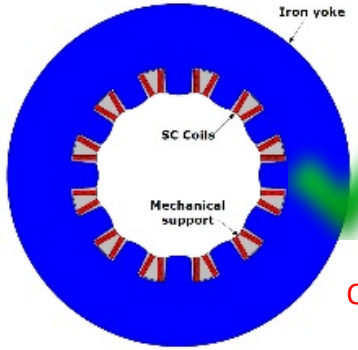
OD=320 mm



Completed
& in test phase

Decapole

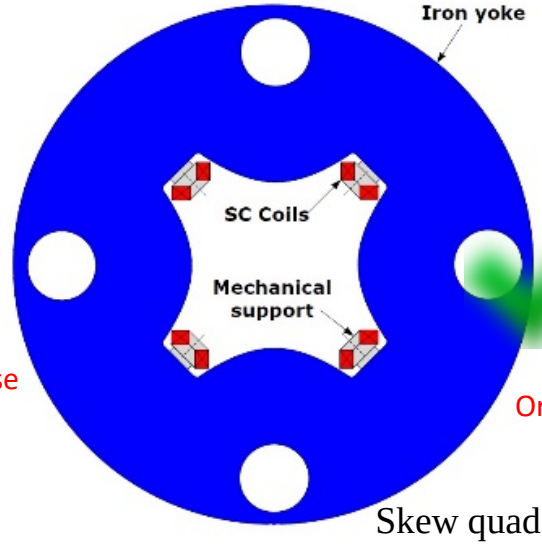
OD=320 mm



Ordering phase

Dodecapole

OD=460 mm



Ordering phase

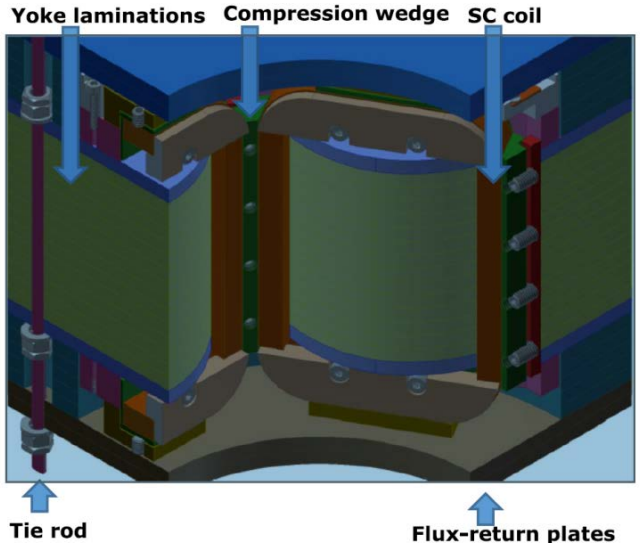
Skew quad

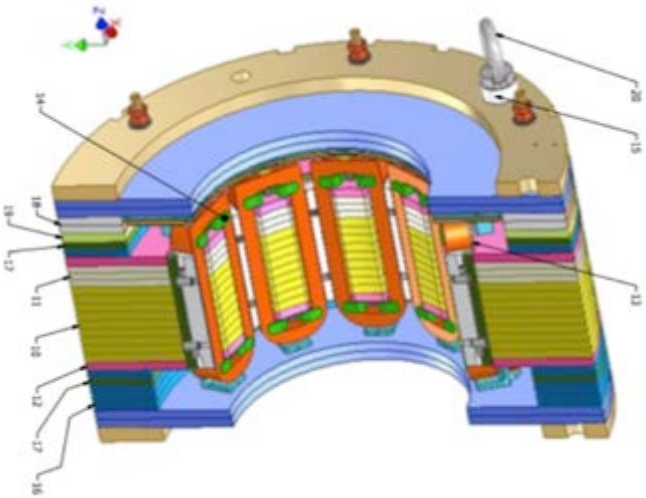
Physical lenght:
- 90-120 mm from 6-pole to 10-pole
- 430 mm 12-pole normal
- 840 mm 4-pole skew

Conductor type: NbTi
Peak field on cond.: 2-3 T
Operating current: 105-180 A
Margin on load line: 50-60%

Electromagnetic Design I

- The design is based on superferric configurations.
- Large bore aperture (150 mm)
- Nb–Ti coils operating in a static superfluid He bath at 1.9 K.
- Large margin on load line (about 60%, corresp. to $\Delta T \approx 4.5$ K).





Electromagnetic Design II

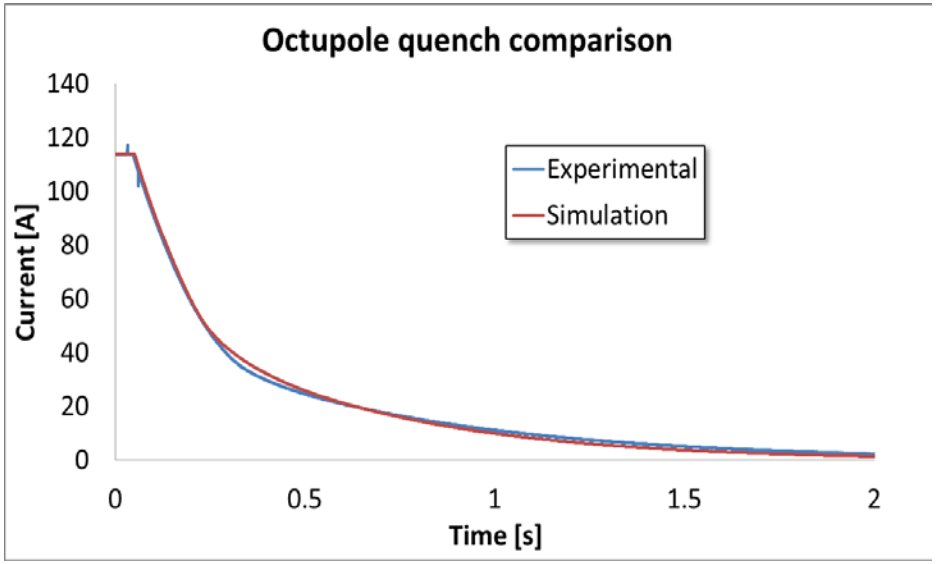
- The detailed 3D design of all magnets completed, to fulfill the requirements

Magnet order	Type	Integr. field at r=50 mm	Magnetic Length	Coil Peak Field	Magnetic stored energy	Operating Current	Turn per coils
		T·m	m	T	kJ	A	-
Quadrupole	S	1.016	0.671	3.53	36	182	754
Sextupole	N,S	0.064	0.140	2.14	1.2	132*	216*
Octupole	N,S	0.046	0.099	2.06	1.1	**105**	228
Decapole	N,S	0.026	0.097	1.73	0.5	**105**	228
Dodecapole	N	0.086	0.471	1.44	7.8	**105**	432
Dodecapole	S	0.017	0.089	1.44	~0.9	**105**	~172

* Value of the sextupole prototype, to be scaled for the series production.

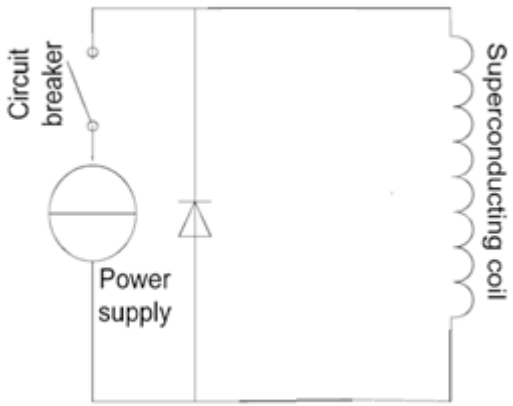
Quench Protection I

- The scope was:
  - T_{max} < 250 K (for safety reason)
  - ΔV_{max} < 300 V (to limit the magnet test at room temp. to 2 kV)
- The protection study has been executed with the code QLASA
- Comparison between calculation and prototype tests validate the results.



Quench Protection II

- Study has been performed to avoid dump resistor for energy extraction (to simplify the circuit)
- Results: all magnets fulfill the requirements except the Quadrupole



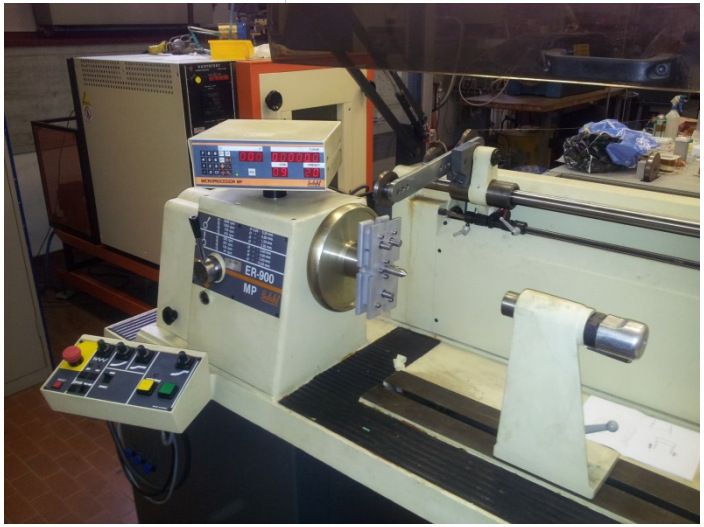
Max voltage & hot spot temperature without dump resistor

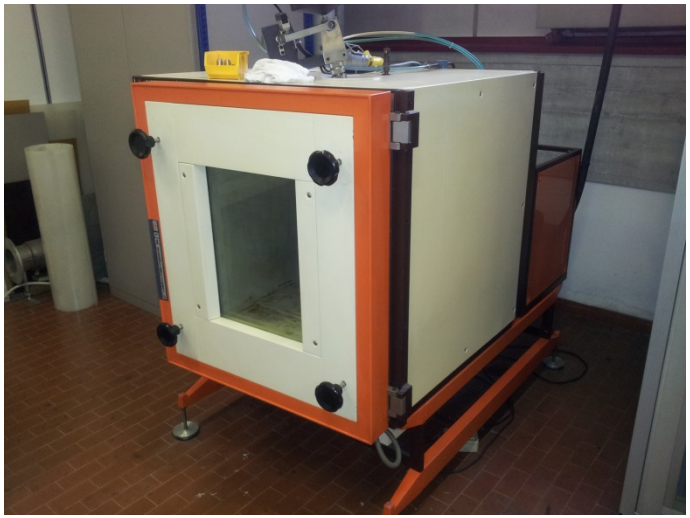
	4-pole	6-pole	8-pole	10-pole	12-pole-N
V-max (V)	**633**	135	70	36	251
T-max (K)	132	164	131	122	147

- With a R_{dump} = 1.5 Ω (grounded in the middle), the Quadrupole V-max goes to 287 V

Prototyping I

- The prototyping of 6-pole, 8-pole and 10-pole has followed the same procedure:
  - Winding & Impregnating the S.C. coils at LASA
  - Test of single coil in LHe (to validate coil costruction)
  - Ordering of the mechanical components of the magnets
  - Assembling of the components & coils at LASA
  - Quality Assurance tests
  - Powering test of the magnet in LHe and He-II



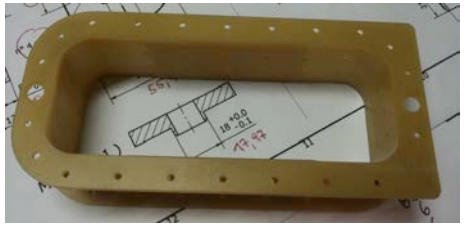


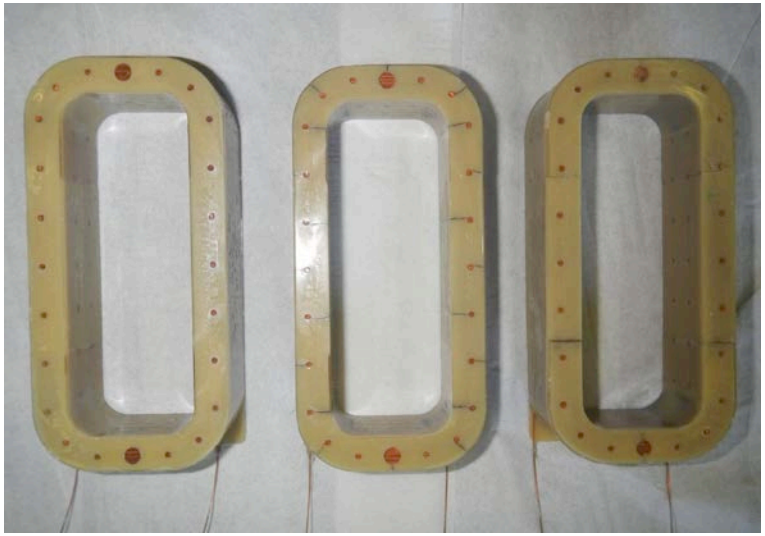
Prototyping II
Coil production

Different solutions tested and validated in the magnets.

Insulating materials compliant with the design radiation dose of 25 MGy

Casing and ground insulation in Duratron (PEI, 30% glass fiber)



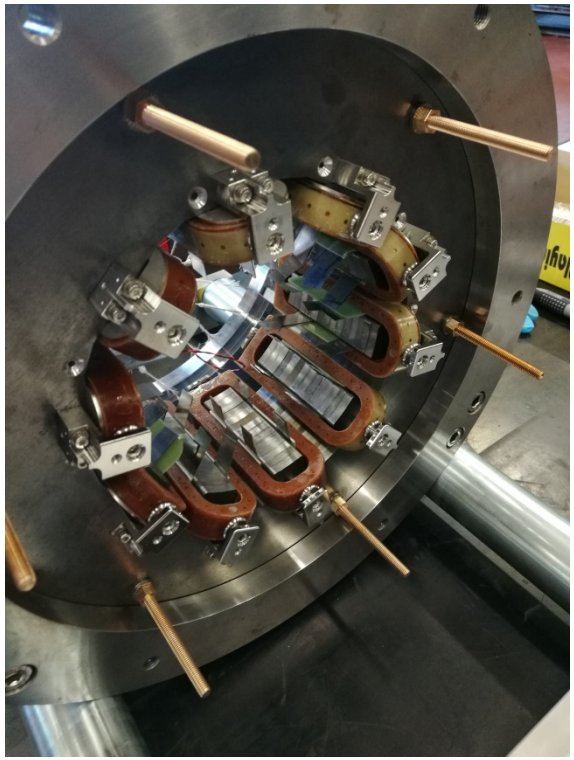


Solution full in BTS2 (resin S2 laminate) or hybrid BTS2/Duratron

Prototyping III
Mechanics

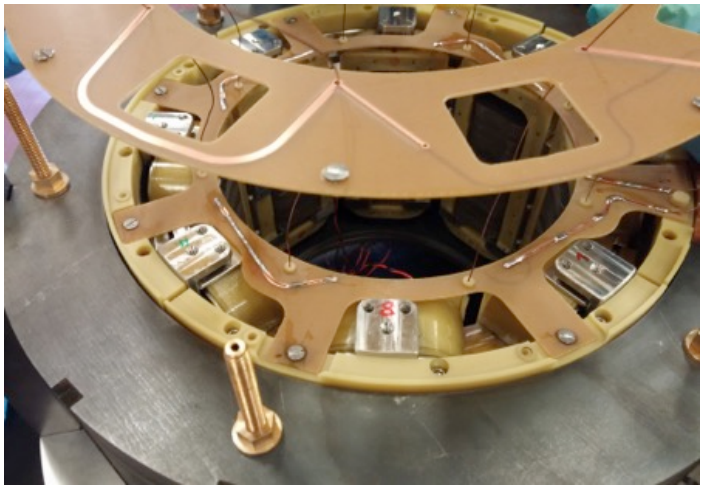
- The iron laminations have been precisely machined by wire electro-erosion, with torerance of +/-0.03 mm

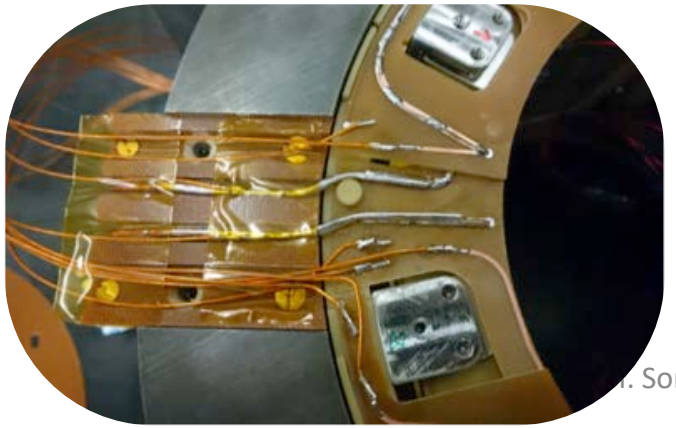
The external alignments grooves allows to align the laminations with an external rectified tool

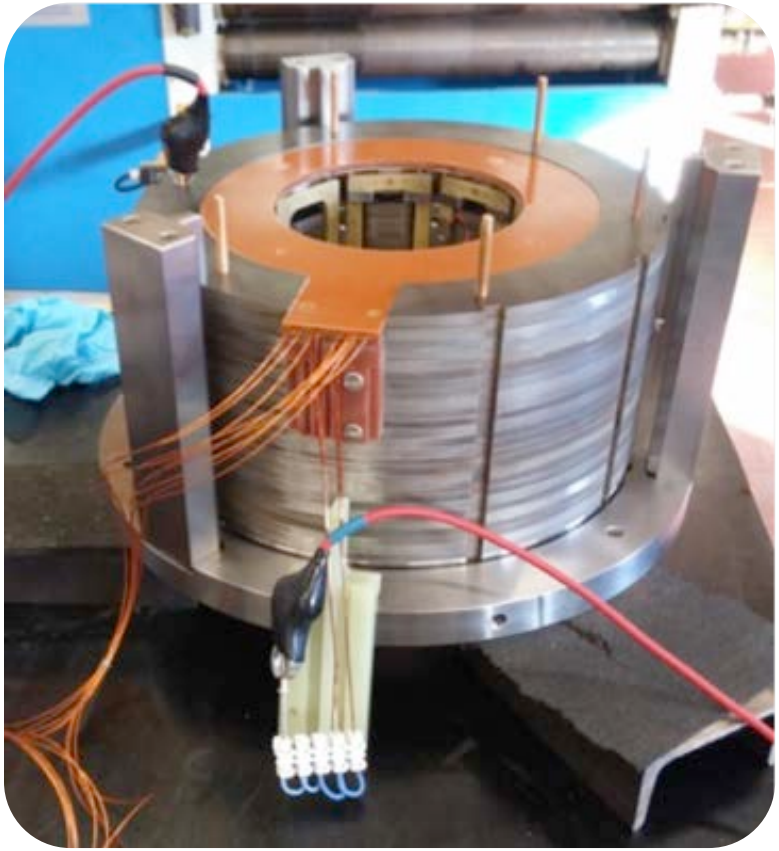


Prototyping IV
Electrical Connections

- The soldering of coil & voltage taps connections is performed on Cu tracks on 2 separate Arlon disks.

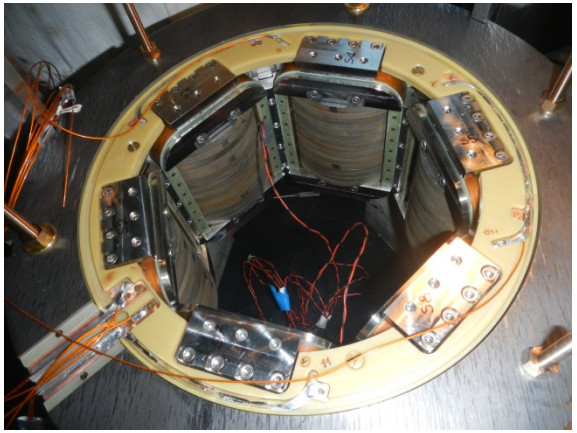




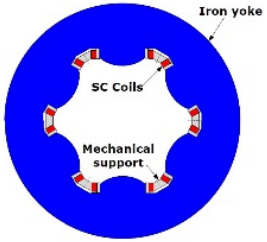


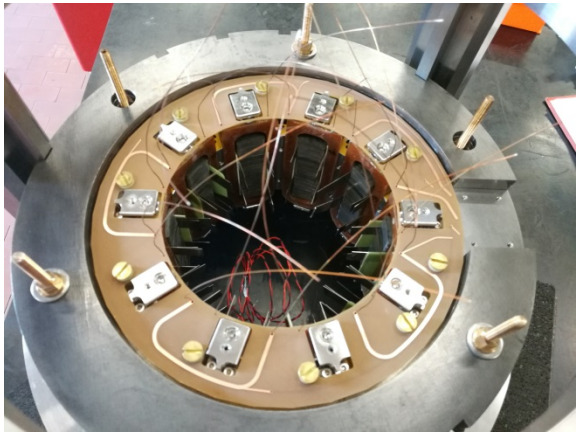
Prototyping V

- Three of the five magnets have been completed

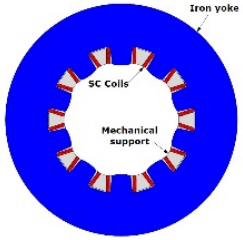


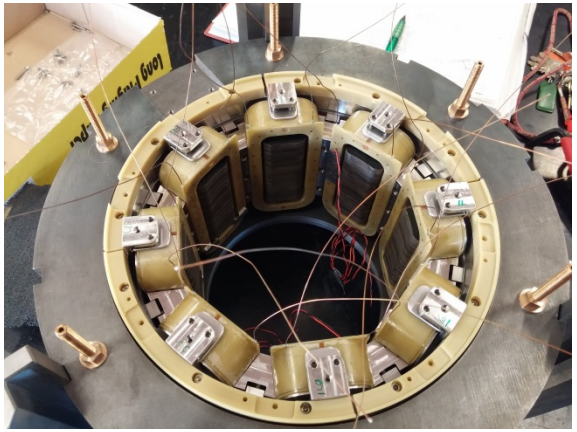
6-pole
Completed
Tested



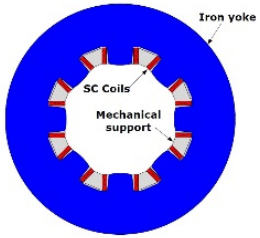


10-pole
Completed
To be tested

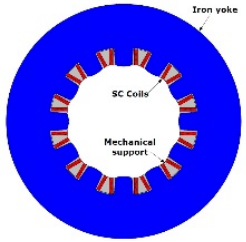


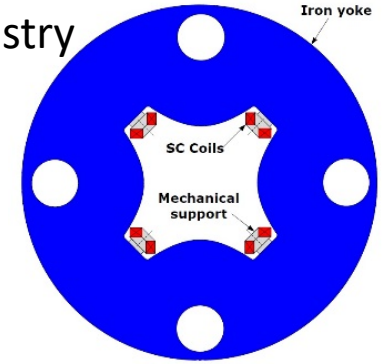


8-pole
Completed
Tested



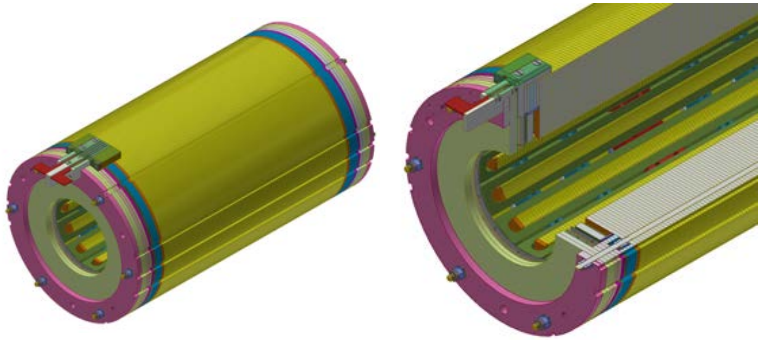
12-pole & 4-pole
Assigned to industry

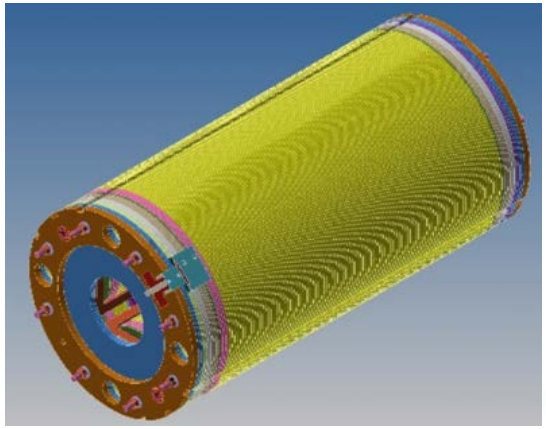


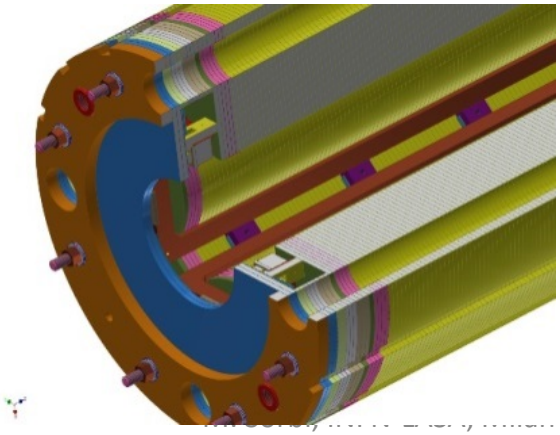


Prototyping VI

- 12-pole and 4-pole have larger dimensions
- Coils cannot built at LASA
- Construction has been assigned to industry after a tender
- Completition in 2018







Technical Specification

for the construction of two prototypes of superconducting magnets – Quadrupole skew and Dodecapole normal – of the High Order Correctors for the High Luminosity upgrade of LHC (HiLumi – LHC) and of the Special Toolings for Winding and Impregnation

(Author: Massimo Sorbi, Marco Statera)

Summary
This technical specification concerns the manufacture of a superconductor quadrupole and a superconducting dodecapole, prototypes of two High Order (HO) Correctors for the High Luminosity upgrade of LHC (HL – LHC). It concerns also the supply of the Special Toolings for Winding and Impregnation of the superconducting coils. It includes all information for allowing selected firms to provide a technical and economical offer.

TABLE OF CONTENT

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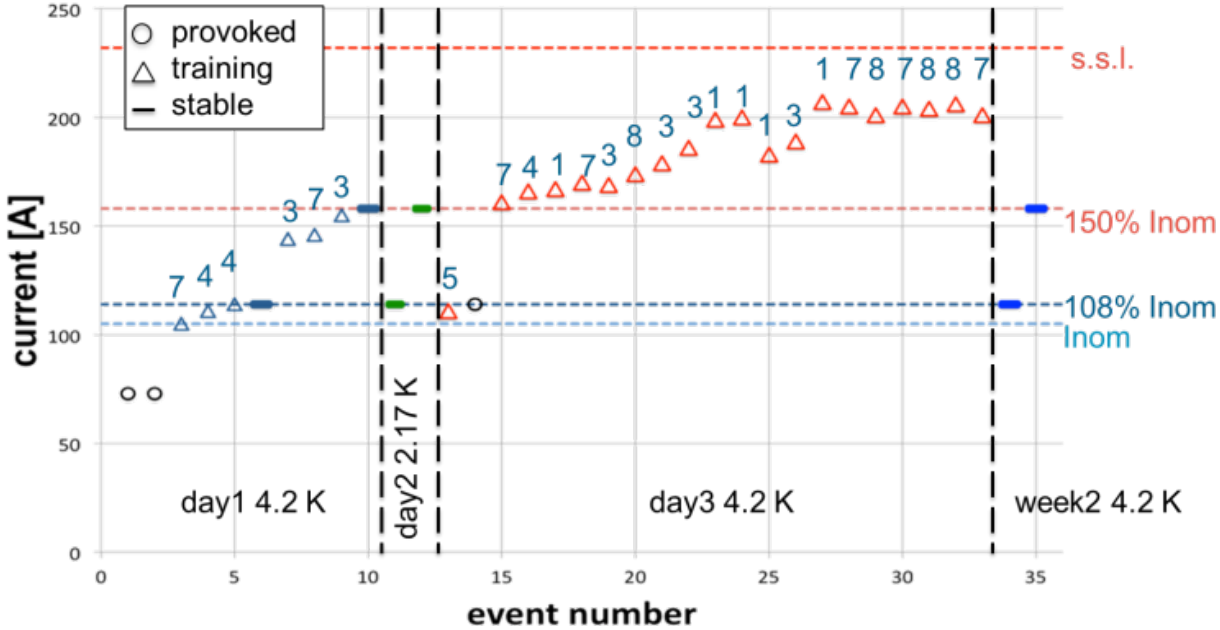
Powering Test

- The magnet is inserted in a vertical cryostat for test in LHe and He II (2.2 K)
- Scope of tests:
  - To reach nominal and ultimate current (108% of nominal) and stay for 1 h
  - Verify limiting current (@ 4.2 K)
  - Verify memory on training after thermal cycle
- 6-pole tested in Feb. 2016: excellent results already reported last year (97% of s.s.l.)
- 8-pole tested in May 2017
- 10-pole test in Sept. 2017
- 12-pole and 4-pole in 2018

Summary of Powering Test of 8-pole



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- Reached required performance with 3 quenches
- Proved to have stable operation at ultimate current (108% of nominal) and at 150% of nominal.
- Slow training towards short sample and reached 90% of s.s.l. after ~20 quenches.

Conclusions

- The prototyping of the 5 high order corrector magnets of HL-LHC is ongoing at INFN- LASA (Milan).
- The first prototype, the sextupole, was completed and tested in 2016.
- The octupole, completed and tested in 2017: it reached required performance.
- The decapole is completed and powering test is in progress
- No substantial issues have been identified in magnet constructions.
- The dodecapole and skew-quadrupole construction has been assigned to industry.
- The completion and test of the magnets is expected in May 2018 (dodecapole) and in September 2018 (skew-quadrupole).

To **Giovanni Volpini** (1963-2016), who initiated, worked and leaded this activity at LASA & CERN