



HL-LHC Collaboration meeting

WP3 satellite meeting

High Order Correctors status



M. Sorbi, M. Statera, G. Volpini
INFN Milano



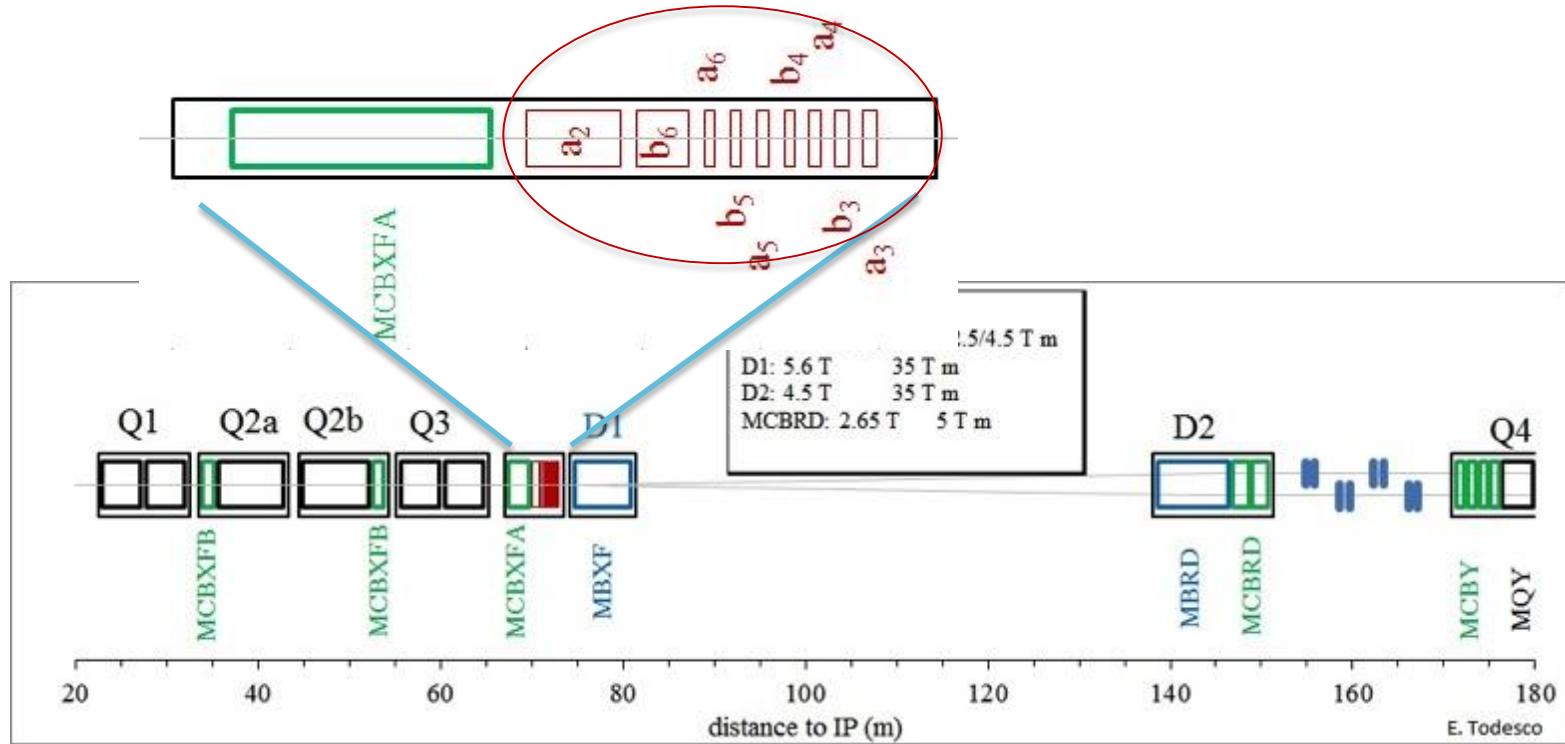
17 November 2016 – CEA Saclay

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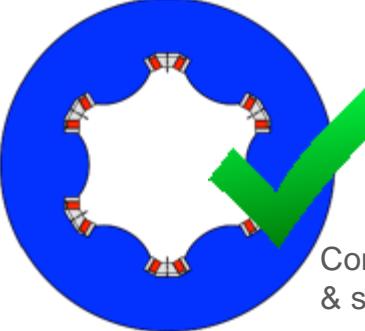
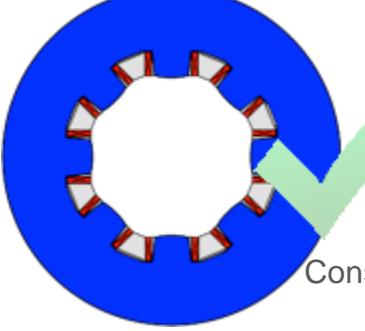
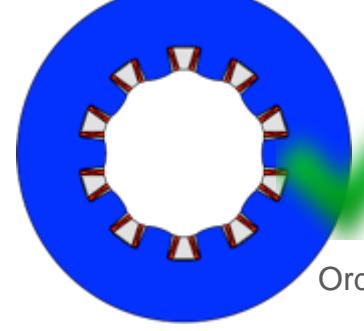
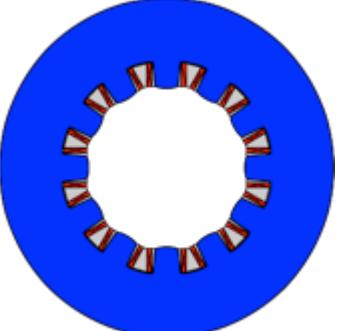
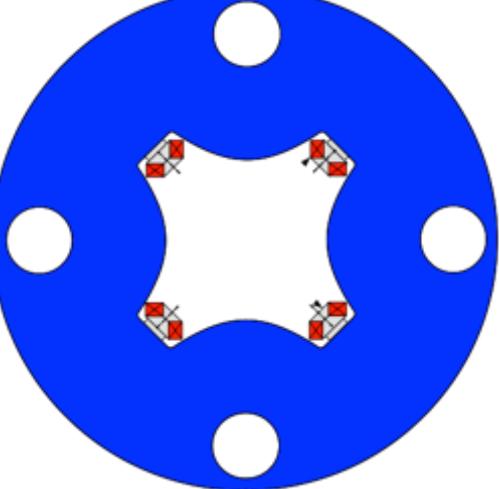
- Scope
- Status of work progress
 - first prototype construction and test
 - development of radiation hard coils
 - next prototypes design and production status
- Next activities

SCOPE

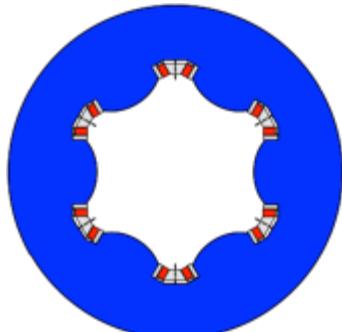
- The INFN-LASA follows the design, construction and test of the 5 prototypes of the high order (HO) corrector magnets for the HL interaction regions of HiLumi
- This activity is founded by INFN (Magix “activity”), and with an agreement CERN contributes for about 50%



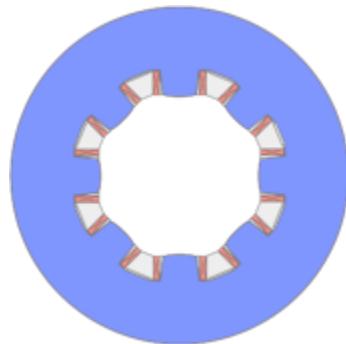
MAGNET ZOO (PROTOTYPES)

<p>OD=320 mm</p>  <p>Sextupole</p>	<p>OD=320 mm</p>  <p>Octupole</p>	<p>OD=320 mm</p>  <p>Decapole</p>
<p>Completed & successfully tested</p>		<p>Construction phase</p>
		<p>Ordering phase</p>
<p>OD=320 mm</p>  <p>Dodecapole</p>	<p>OD=460 mm</p>  <p>Skew quadrupole</p>	<p>Physical lenght:</p> <ul style="list-style-type: none">- 90-200 mm from 6-pole to 10-pole- 430 mm 12-pole normal- 840 mm 4-pole skew <p>Conductor type: NbTi Peak field on cond.: 2-3 T Operating current: 120-180 A -> 105 A Margin on load line: > 40%</p>
		

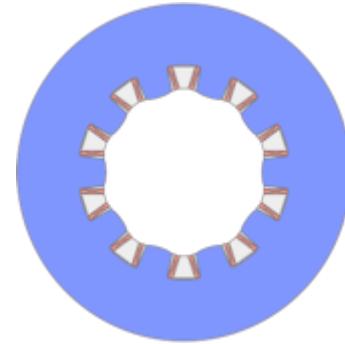
THE 6-POLE



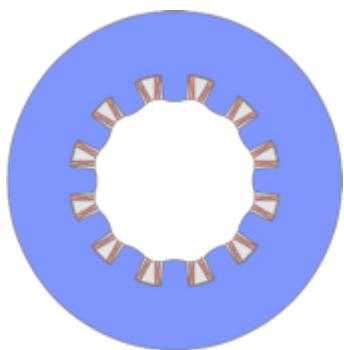
Sextupole



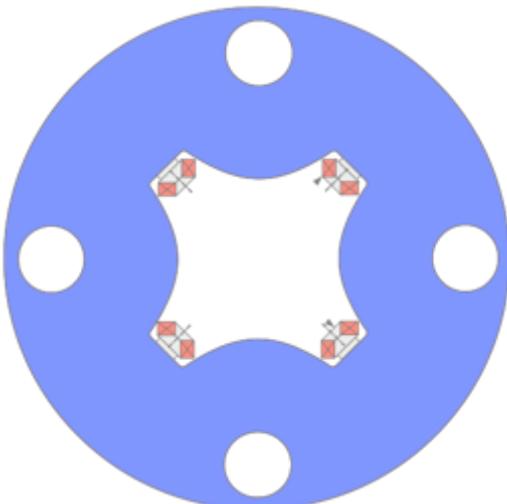
Octupole



Decapole



Dodecapole



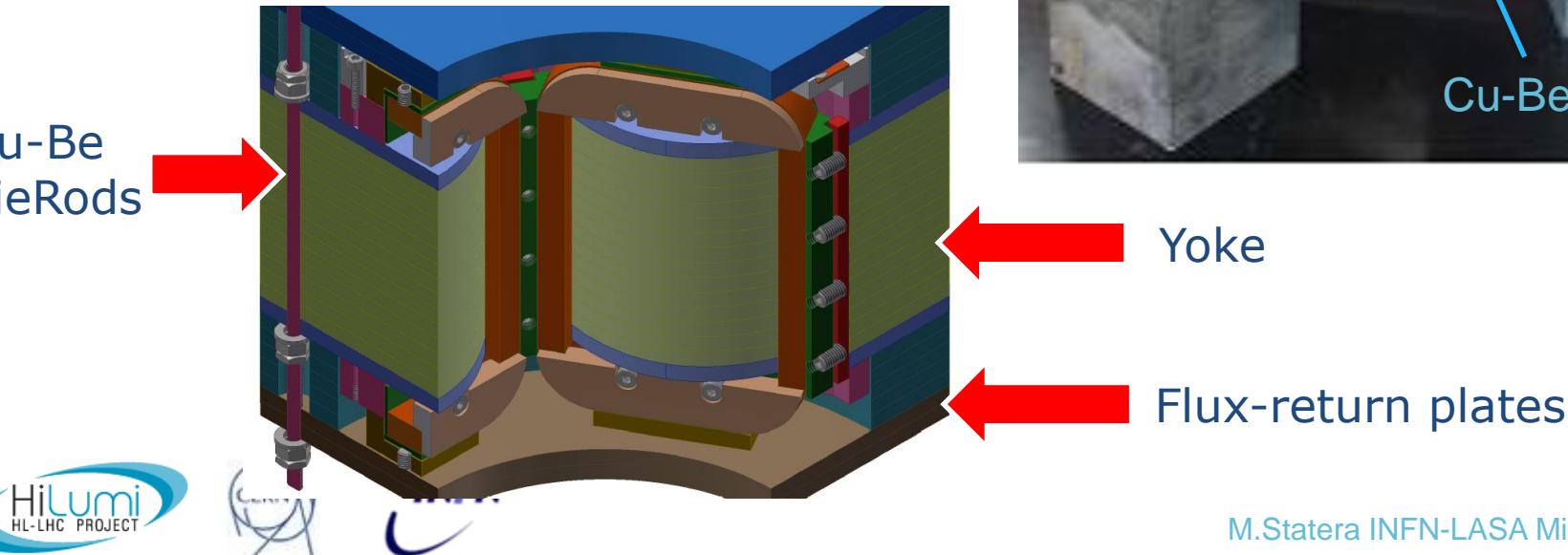
Skew quadrupole

6-POLE ASSEMBLY

Assembly procedure:

- Assembly frame
- Iron lamination insertion
- Coil installation
- Electrical connection
- Magnetic yoke closing (return flux)

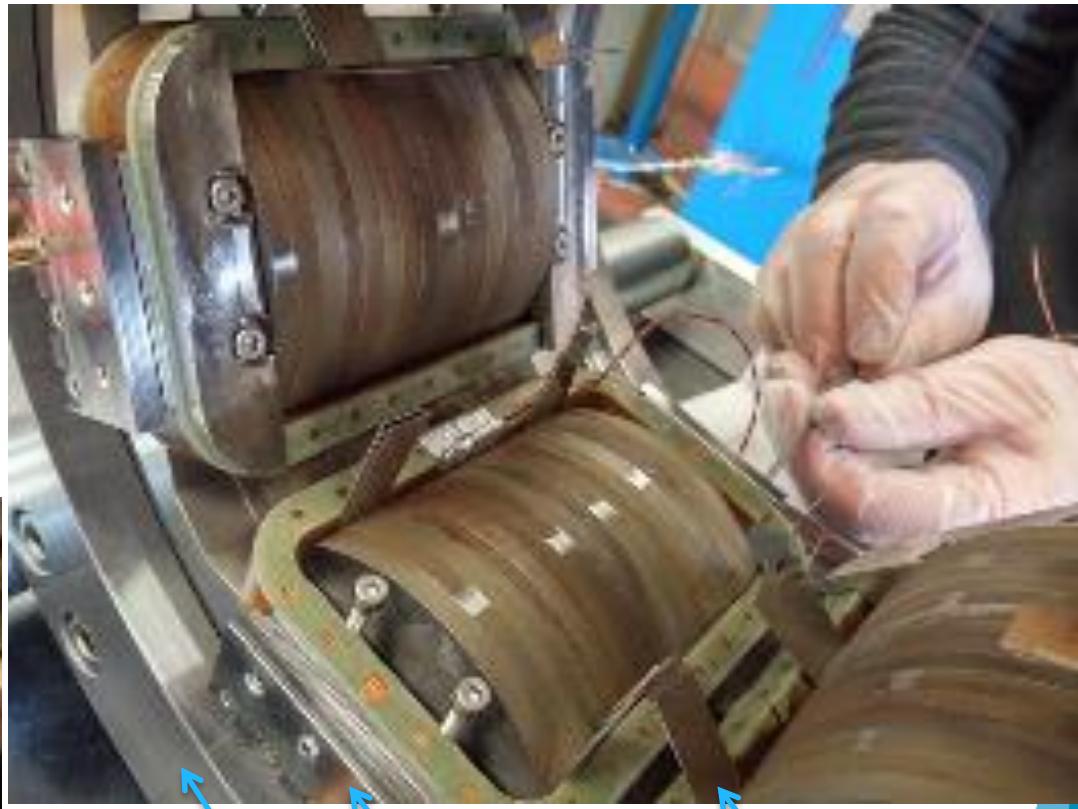
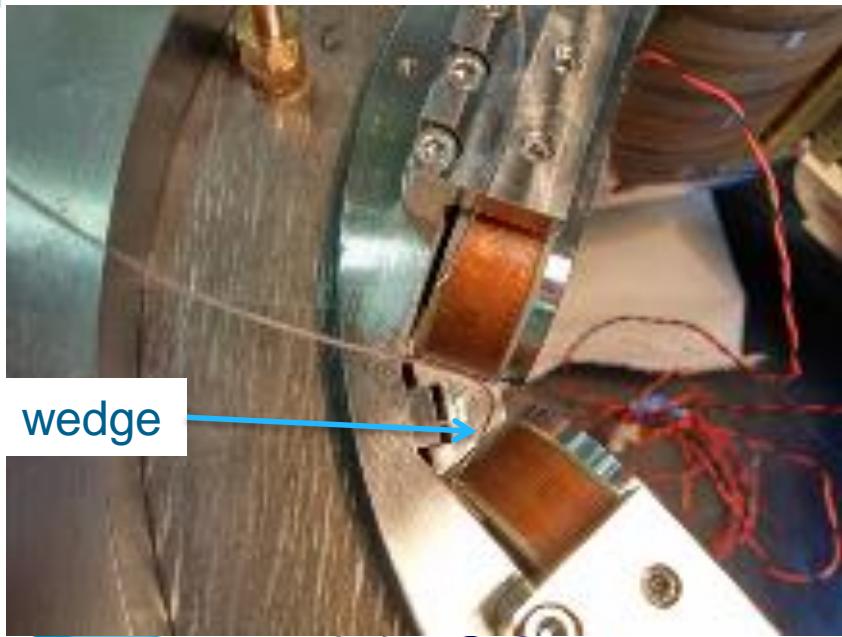
Procedure in view of series production (in industry)



6-POLE ASSEMBLY

Coil assembly

- coil-yoke alignment
- 0.6 mm gap
- spacers



frames rotates

longitudinal setting

spacers

6-POLE TEST

VERTICAL TEST @ LASA FEB 2016

- magnet qualification
- training
- transfer function
- ramp rate sensitivity
- dynamic inductance
- re-cooling time



SUPER AND FERRIC: THE FIRST HL-LHC COMPONENT IS READY

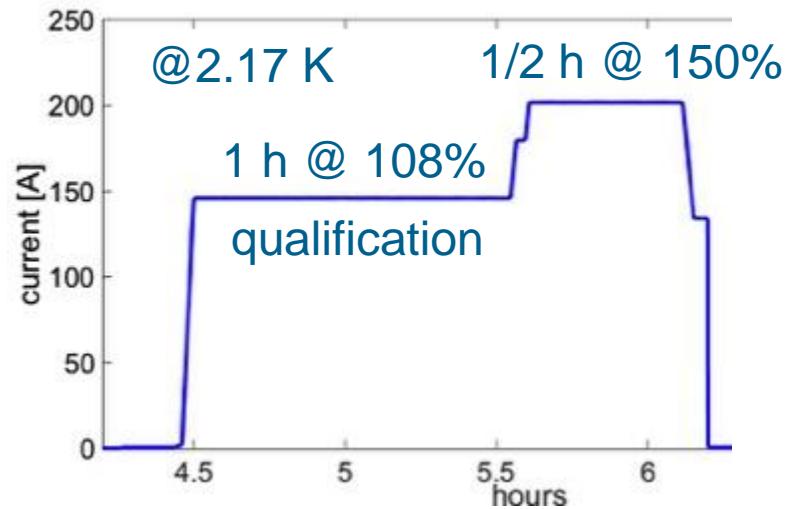
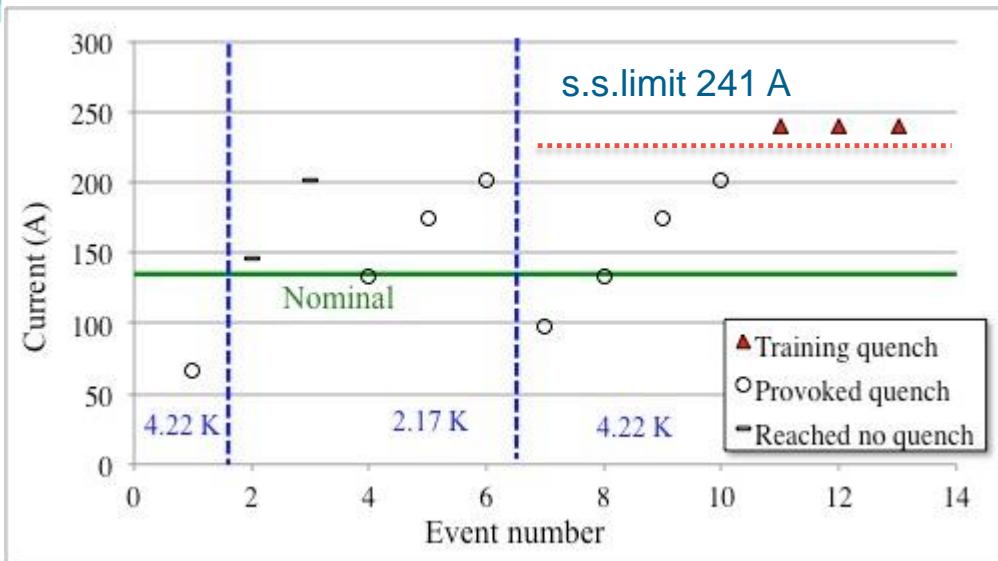
Although the actual installation phase in the tunnel will only start in 2024, the first magnet – a sextupole – of the High-Luminosity LHC (HL-LHC) is ready and working according to specifications. This first component is also rather unique as, unlike the superconducting magnets currently used in the LHC, it relies on a “superferric” heart.

CERN Bulletin Issue n. 11-12, March 2016

6-POLE TEST

QUALIFICATION TESTS

- cooling at 22.5 K/h
- test @ 2.17 K (1h @134.4 A i.e. 108% nominal current)
- no-training
- Limit test @ 4.2 K

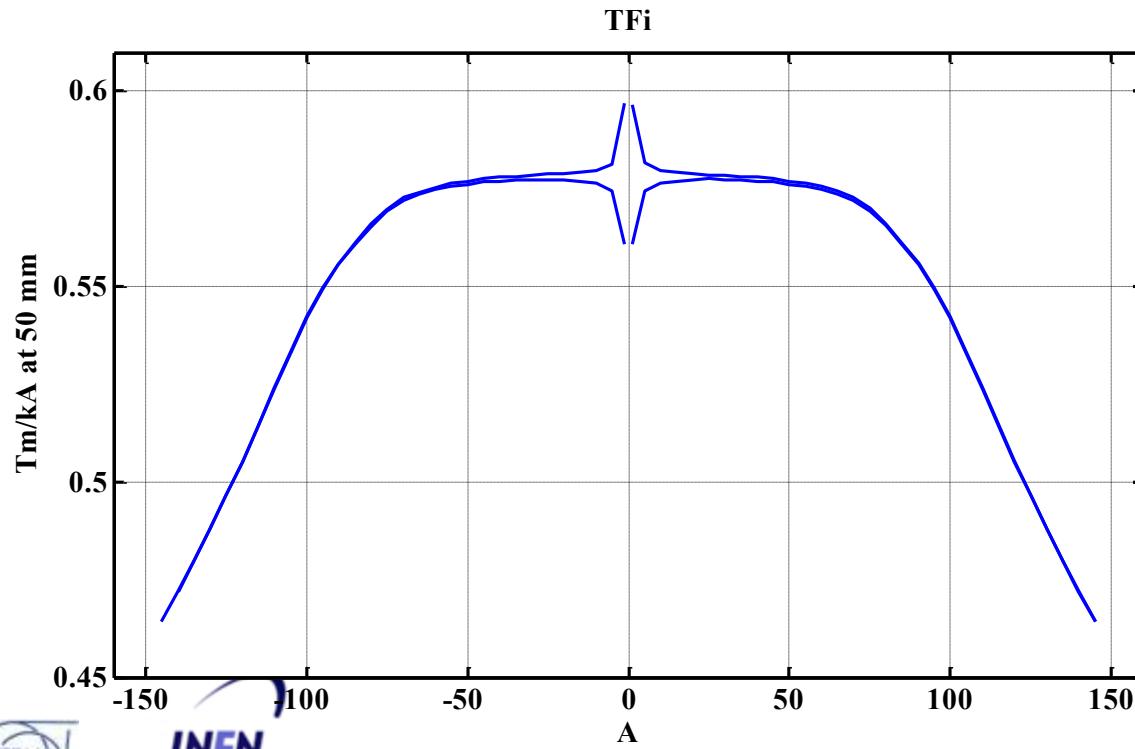


- provoked quench
- 3 «natural» quenches @ 241 A, i.e. **97%** of s.s. limit @4.2 K

6-POLE TEST

MAGNETIC MEASUREMENTS

- Transfer function at 134 A : 0.47 Tm/kA (nominal 0.468)
- Harmonic content sum: ~15 units (nominal < 100 units)
- Low influence of transfer function for iron saturation, also at low current



6-POLE TEST

MAGNETIC MEASUREMENTS

NON I INFAR - cryogenic

- sum of measured components
 - 15.3 UNITS at room temperature
 - 13.4 UNITS at cryogenic temperature
- maximum sum of simulated components:
 - 4.5 UNITS
- field measurements by CERN by
 - Andrea Musso TE-MSC-MDT
 - Hugo Bajas TE-MSC-TF
 - Carlo Petrone TE-MSC-MM
 - Lucio Fiscarelli TE-MSC-MM



HARMONIC

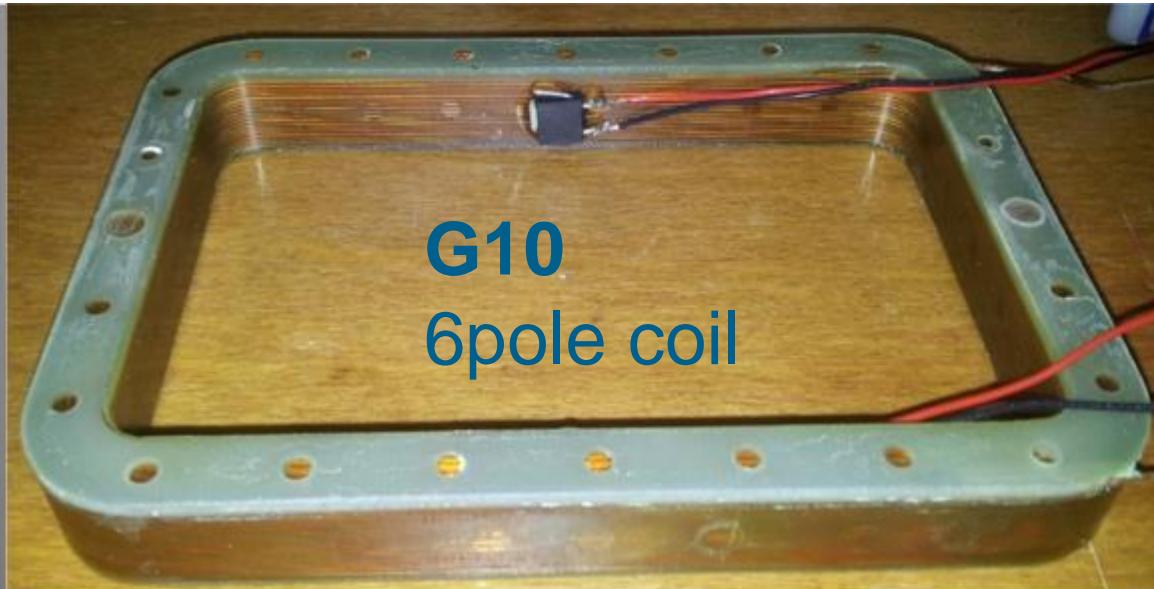
COILS TECHNOLOGIES

- G10 coils installed in the sextupole
- radiation hardness 24-35 MGy
- new materials and technologies
- 4 coils tested
- tensile shear test to validate materials

test coil	material	features
TC5	ULTEM™ polyetherimide (PEI) 3D print	low mechanical properties
TC6	DURATRON® PEI + short fiber	bulk – no thin layers
S8	G10	low radiation hardness
	BTS2 Bismaleimide Triazine resin – S2 glass laminate reinforced	same technology of G10

COILS TECHNOLOGIES

- no training but ULTEM coil
- $I/I_c > 90\%$



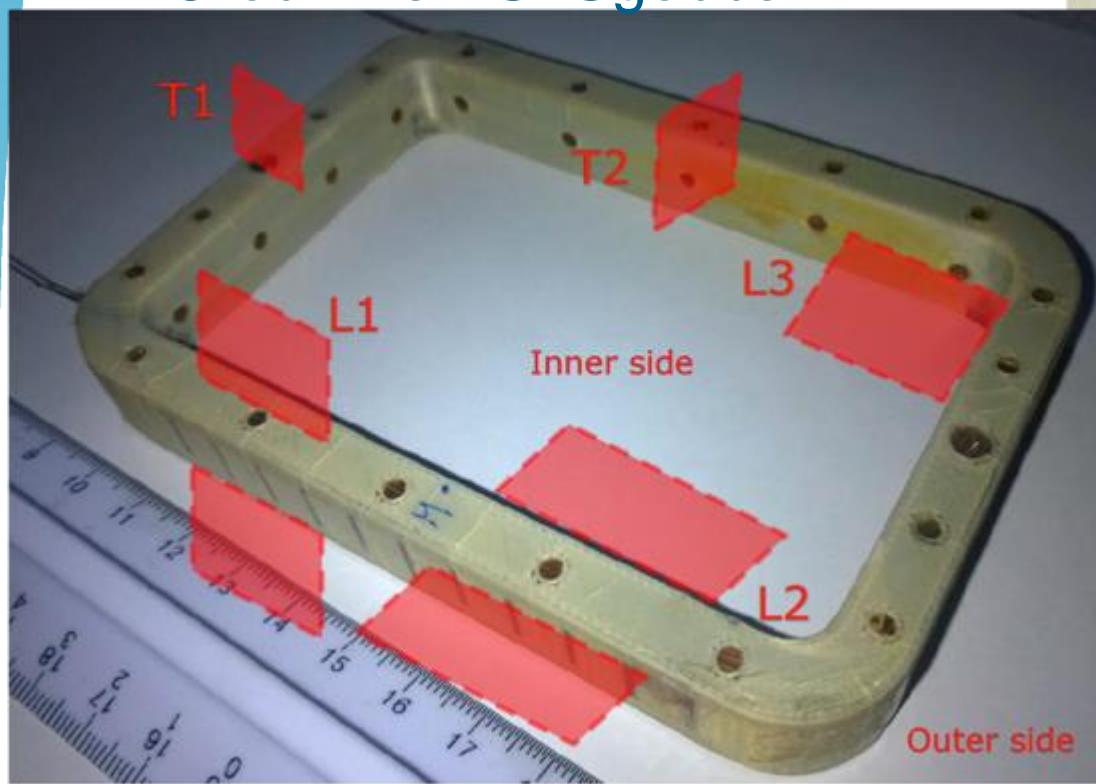
WINDING QUALITY

TC5 ULTEM™

@CERN

edms n. 1554721

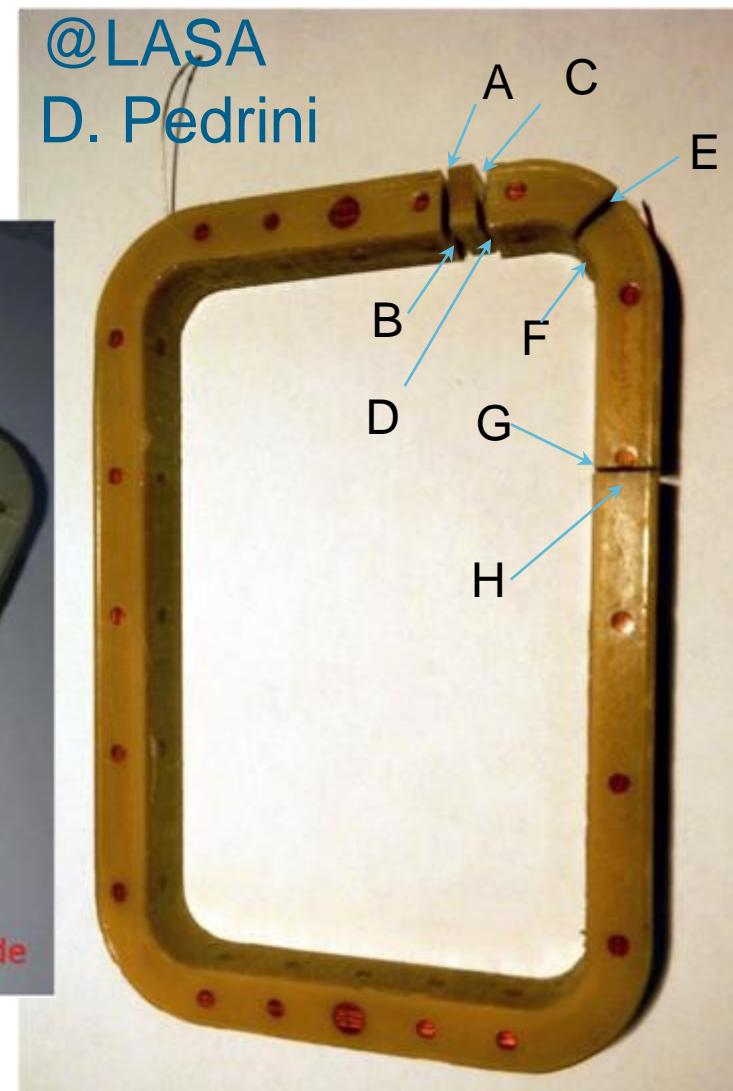
M. Crouvizier S. Sgobba



TC6 DURATRON®

@LASA

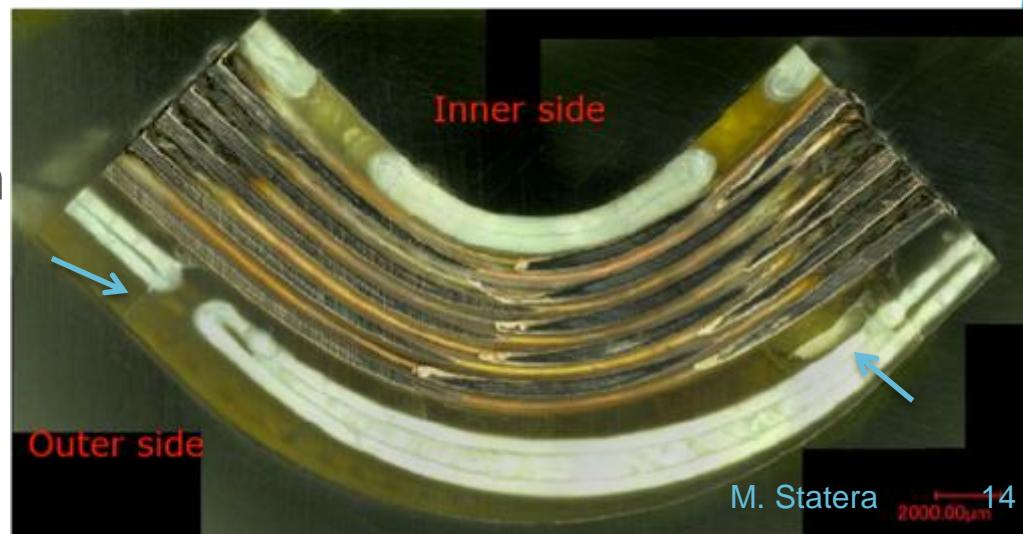
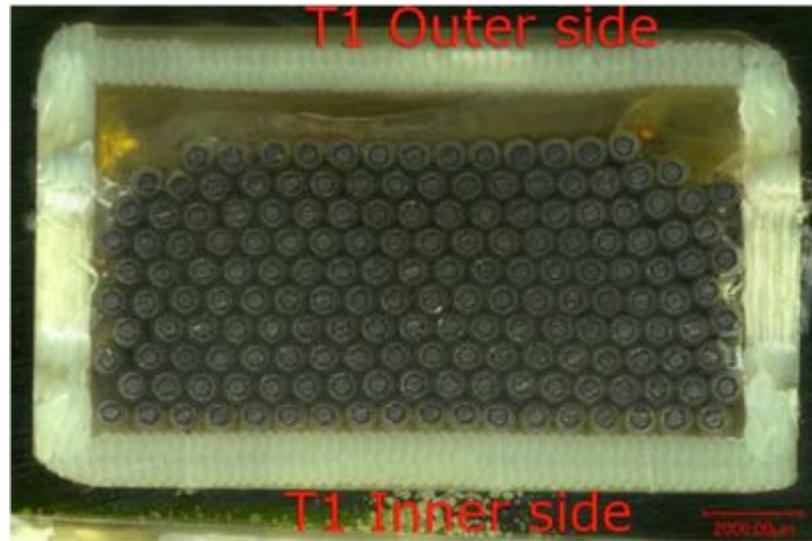
D. Pedrini



M. Statera

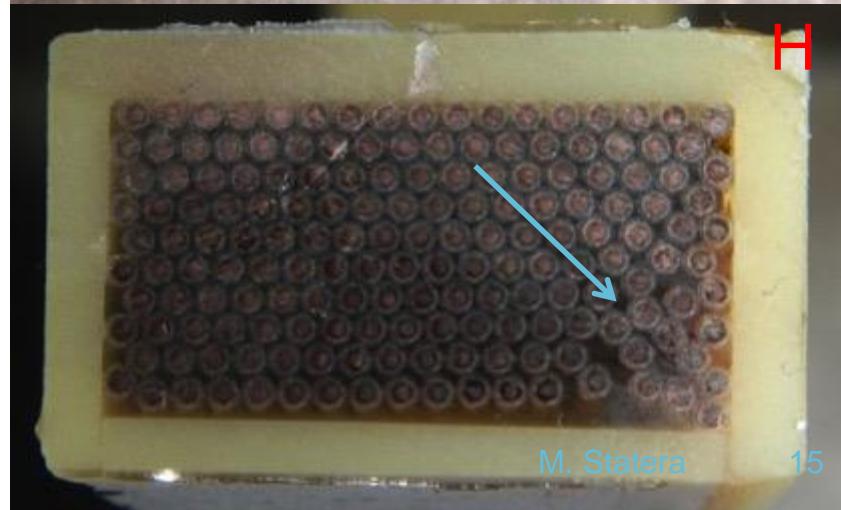
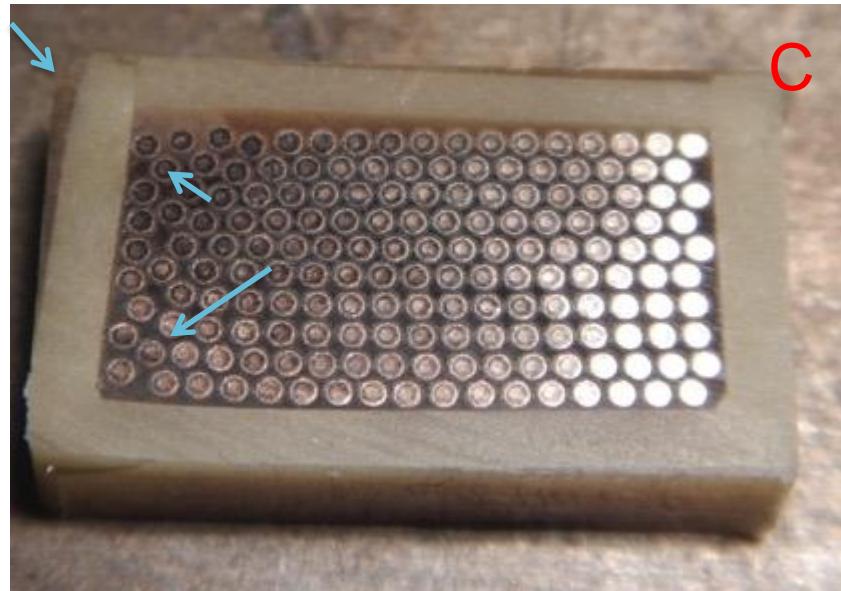
TC5 ULTEM™ TRANSVERSE CUTS

- quite symmetric arrangement
 - dimensions not optimized
- outer resin thickness (coil specific)
- cracks
 - perpendicular to surface
 - stops in the area between Ultem™ and glass fiber surrounding the wires



TC6 DURATRON[©]

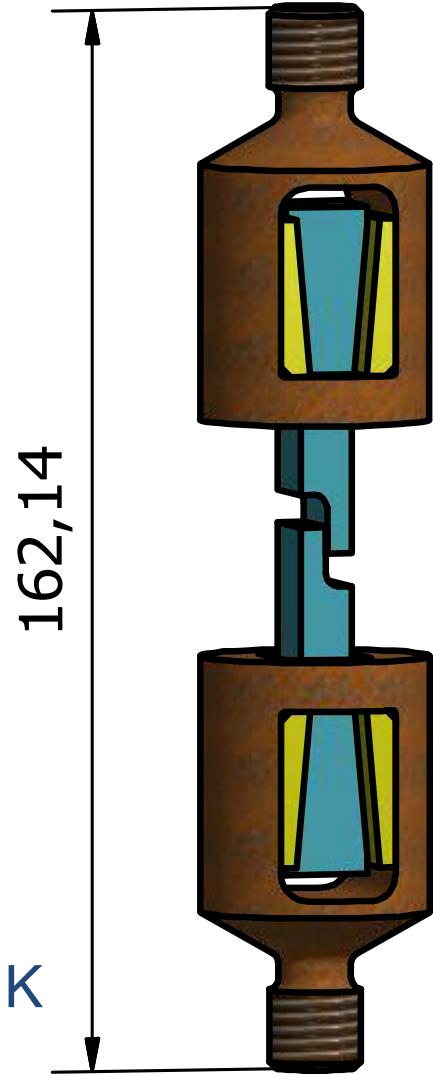
- thin section (few mm)
 - no resin detaching
 - 1 void wires-duratron
- stacking not perfect
 - inner dimension not optimized
- duratron deformation during impregnation



TENSILE SHEAR STRENGTH

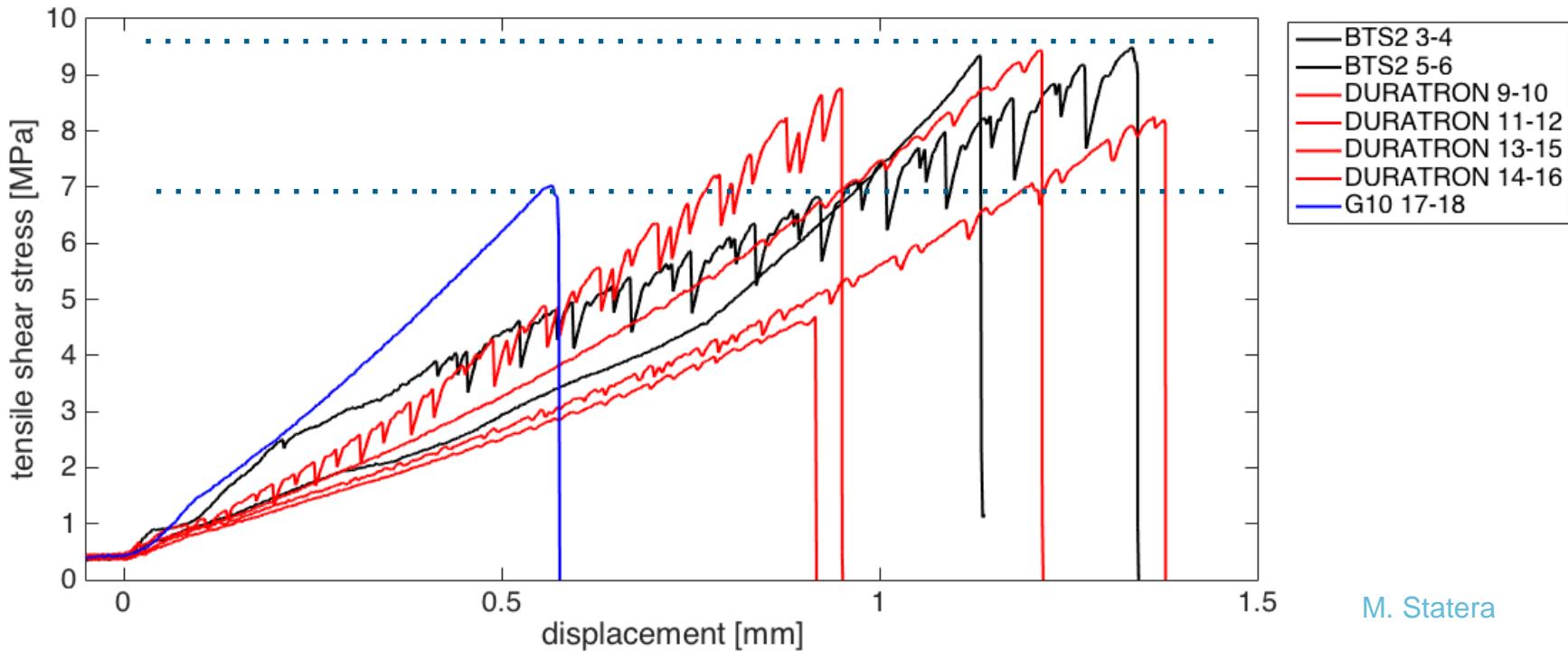
- compare the CTD101K adhesion
 - G10
 - DURATRON[©]
 - BTS2
- glued area: 4 mm x 15 mm
- inspired to tensile shear test
 - ISO 4587: Adhesives -- Determination of tensile lap-shear strength of rigid-to-rigid bonded assemblies
 - ASTM D3165-07: Standard Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies

The BTS2 material to prepare the specimens is kindly supplied by Dr Nakamoto and his team at KEK

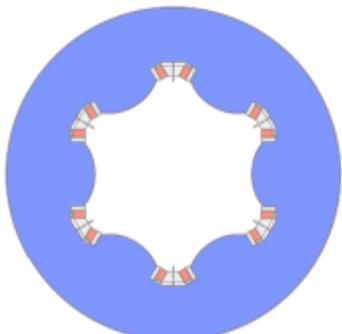


SHEAR STRENGTH RESULTS

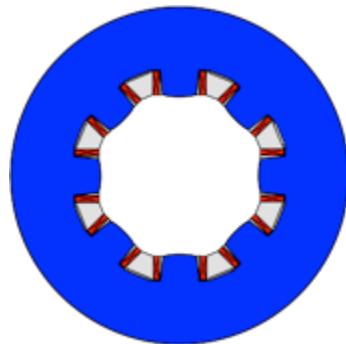
- room temperature tests
1 G10, 2 DURATRON[©] and 2 BTS2
- cooled at 77 K and then tested at room temperature
2 DURATRON[©] and 2 BTS2
- the measured values are comparable
- no systematic resin detaching



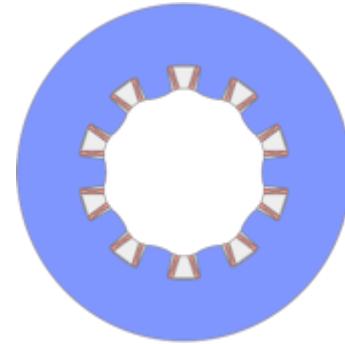
THE 8-POLE



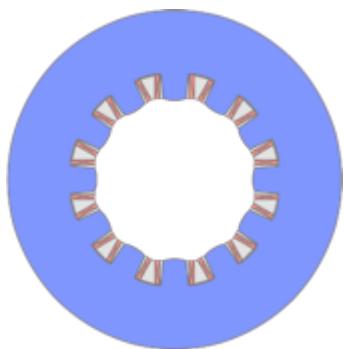
Sextupole



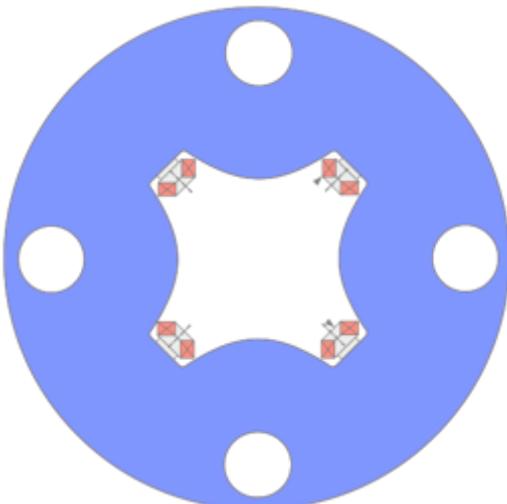
Octupole



Decapole



Dodecapole

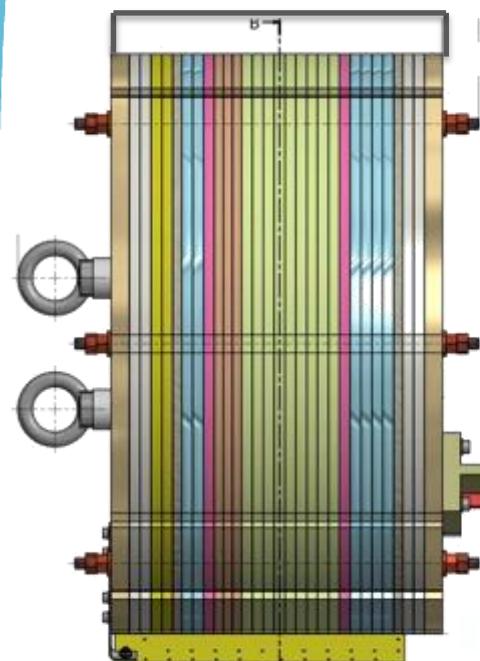


Skew quadrupole

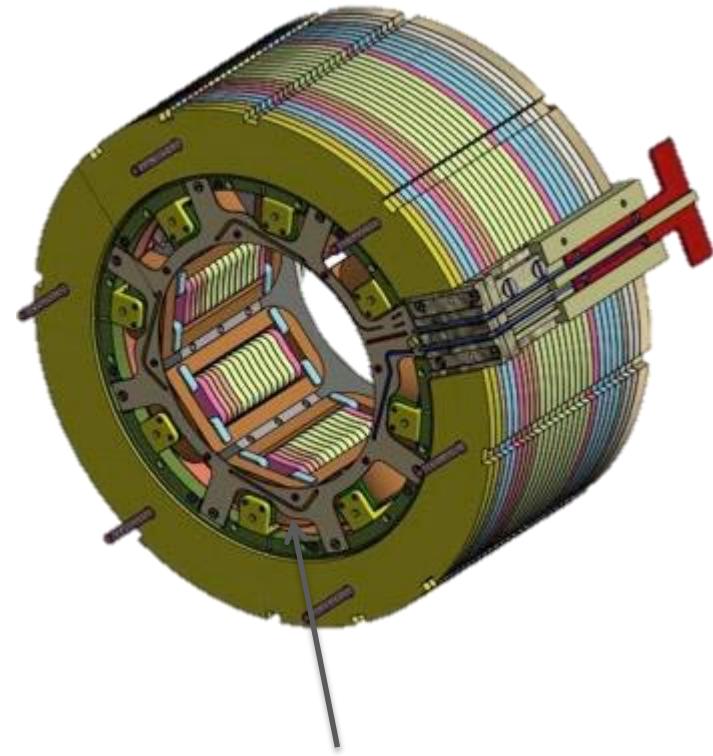
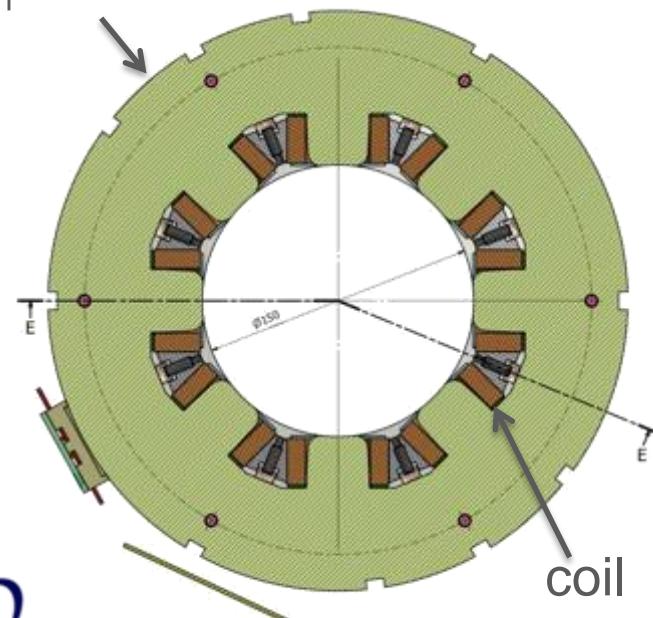
8-POLE

- designed
 - transfer function 0.435 Tm/kA
 - harmonic content sum < 15
- procurement ongoing

183 mm



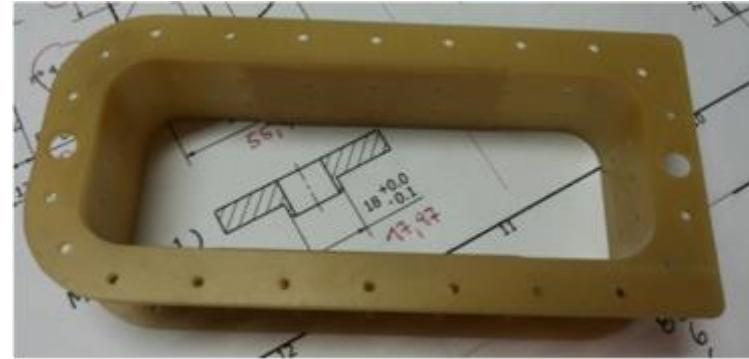
$\phi 320 \text{ mm}$



ELECTRICAL CONNECTIONS
printed boards to improve high voltage insulation:

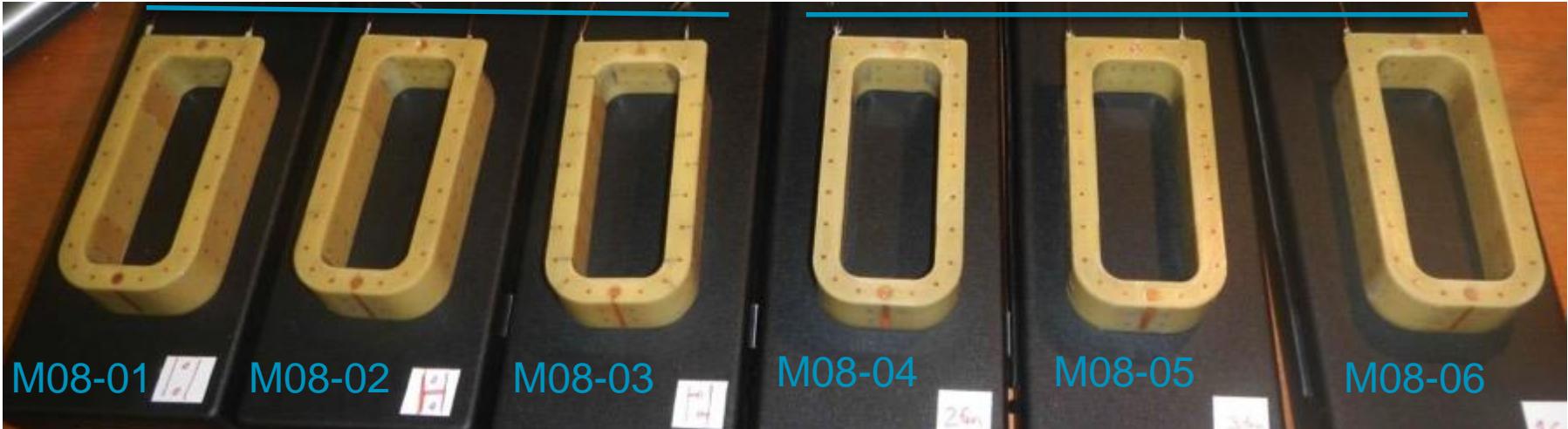
8-POLE: COILS

- test coil produced 01÷03
- production ongoing
first batch produced 04÷06
- single coil cryogenic test
- M08-01 tested M08-02 and M08-03 thermal cycle



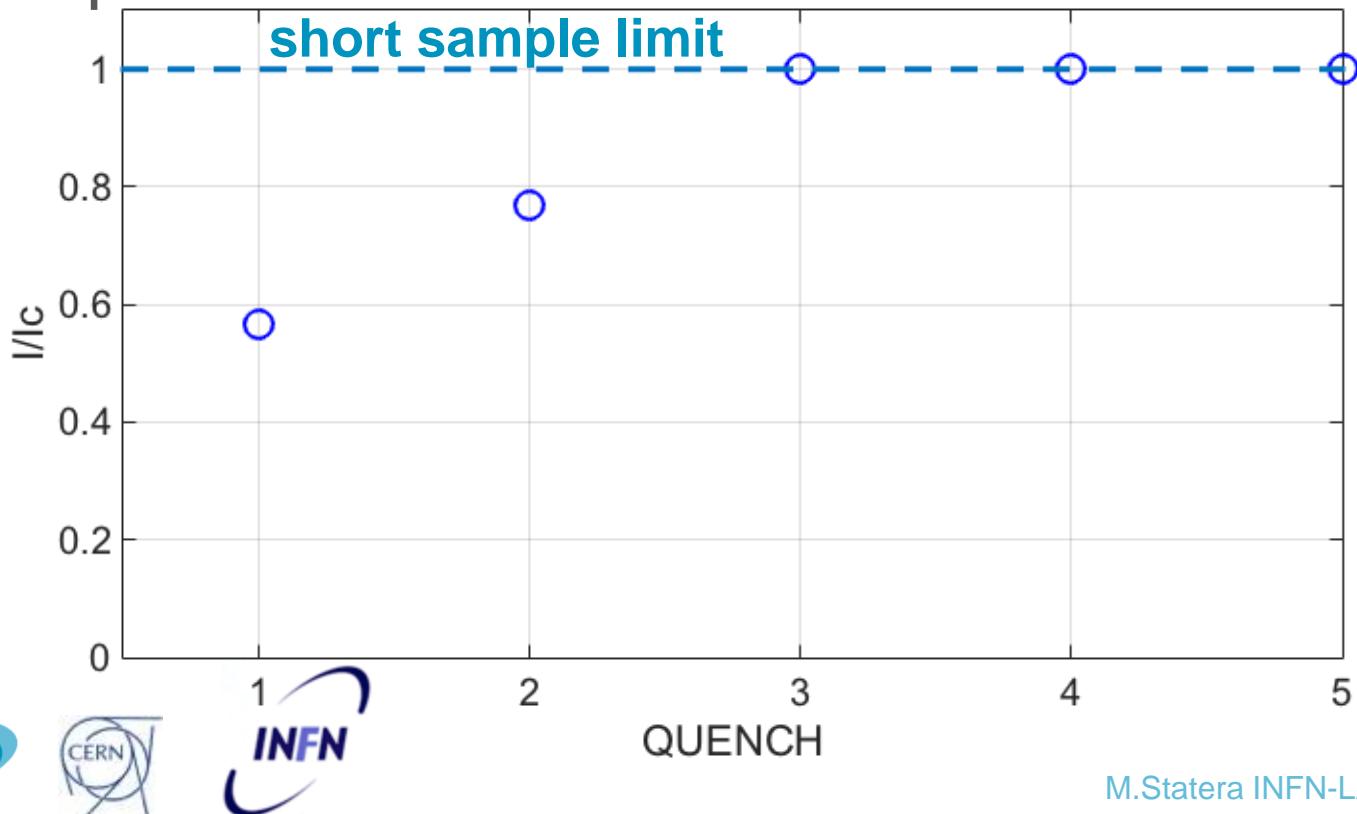
TEST COILS

FIRST BATCH

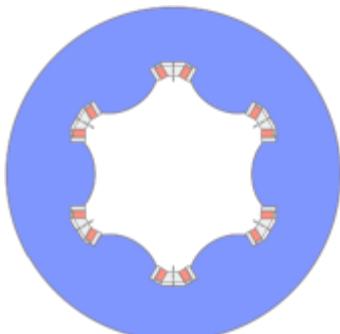


8-POLE: SINGLE COILS TEST

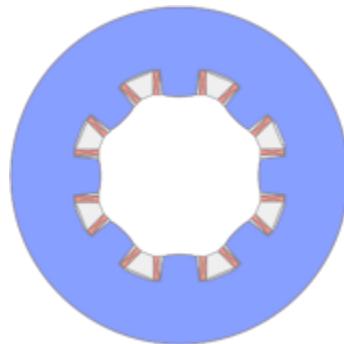
- M08-01 tested
- 1 h @ 114 A (ultimate current)
- training: 2 quenches before reaching short sample current



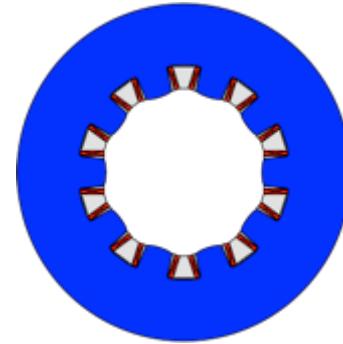
THE 10-POLE



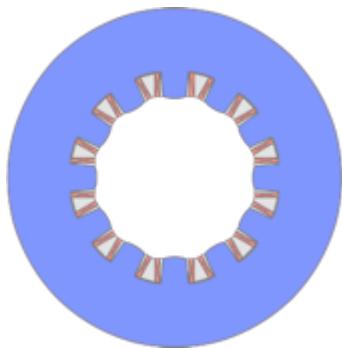
Sextupole



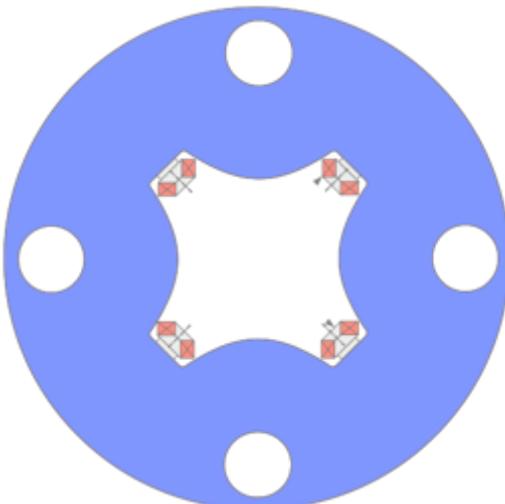
Octupole



Decapole



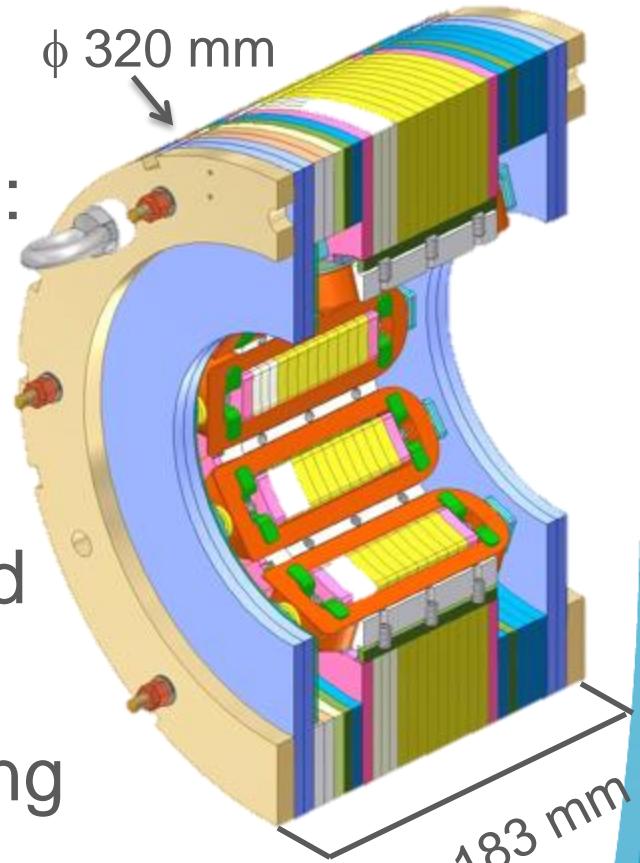
Dodecapole



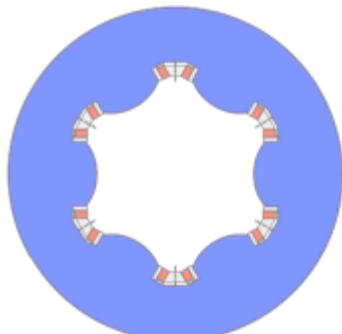
Skew quadrupole

10-pole

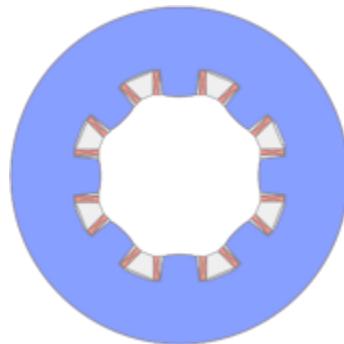
- preliminary Electromagnetic design:
 - transfer function 0.25 Tm/kA
 - harmonic content sum < 15
 - optimization is ongoing
- BTS2 technology for the coil ground insulation/case
- molds for coils: procurement ongoing
- started the procedure to acquire the mechanics (delivery 1Q-2017)



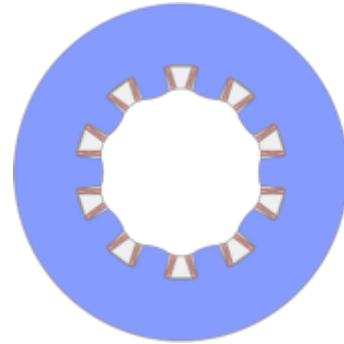
THE 12-POLE & 4-POLE



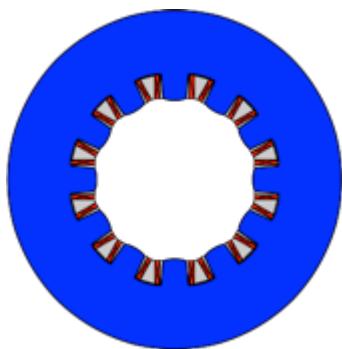
Sextupole



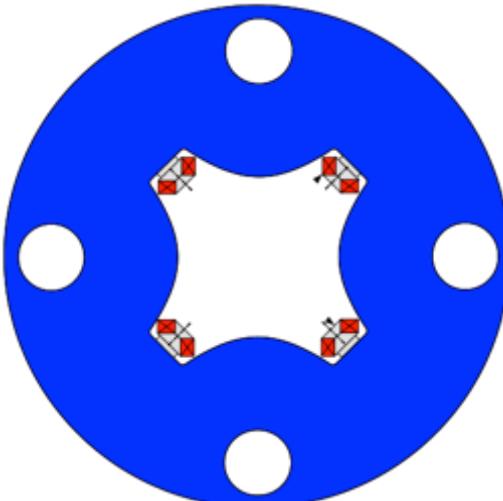
Octupole



Decapole



Dodecapole



Skew quadrupole

12-POLE & 4-POLE: NEXT STEPS

- the electromagnetic design will be finalized 1Q-2017 (12-pole and 4-pole)
- the 12-pole construction will follow the usual procedure (mechanicals “outside”, coil winding and assembly in “home”)
- The 4-pole entire construction will be entrusted to external firm (coil length ~1 m)

CONLUSIONS

- sextupole: built and successfully tested
- octupole: construction
- decapole:
 - refining electromagnetic design
 - procurement started
- dodecapole and quadrupole: design and construction start in 2017



THANK YOU

LASA team

F. Alessandria, G. Bellomo, F. Broggi, A. Paccalini,
D. Pedrini, A. Leone, V. Marzocchi, M. Quadrio, M. Sorbi,
M. Statera, M. Todero, G. Volpini, C. Uva

