Construction and Power Test of the Superferric Skew Quadrupole for HL-LHC

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INFN Milano - LASA

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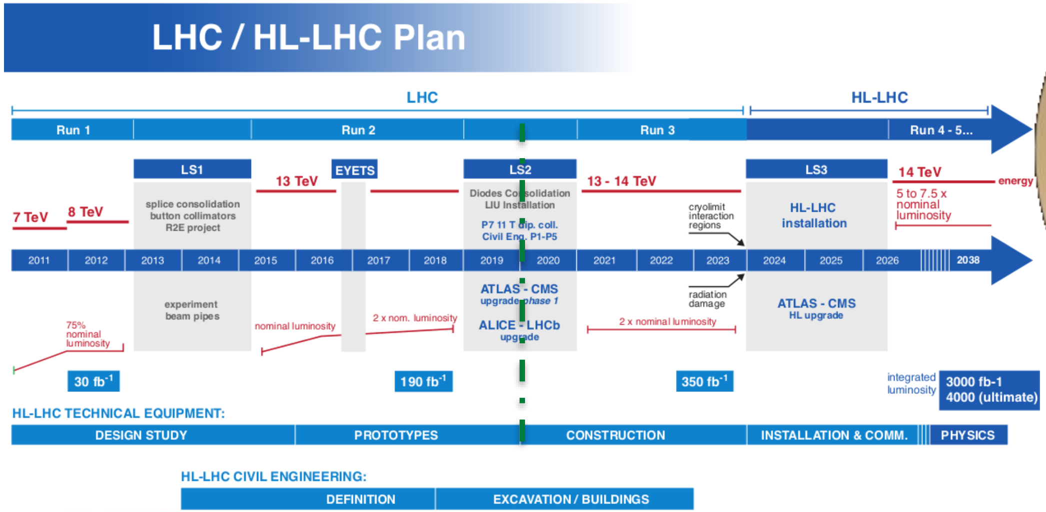
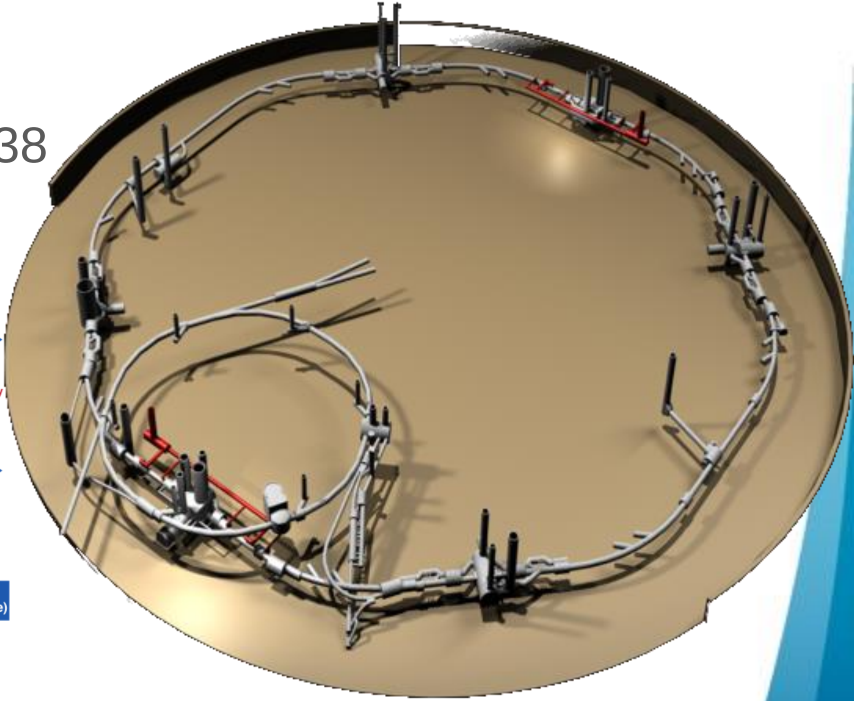
OUTLINE

- Scope: the High Order correctors magnets
- Design
- Construction and power test
- Electrical failure
- Second assembly and power test
- Conclusions

High Luminosity LHC

- **LHC** integrated luminosity 300 fb^{-1} by 2023
- **HL LHC**
  - upgrade interacting regions 2024/26
  - 3000 fb^{-1} integrated luminosity by 2038

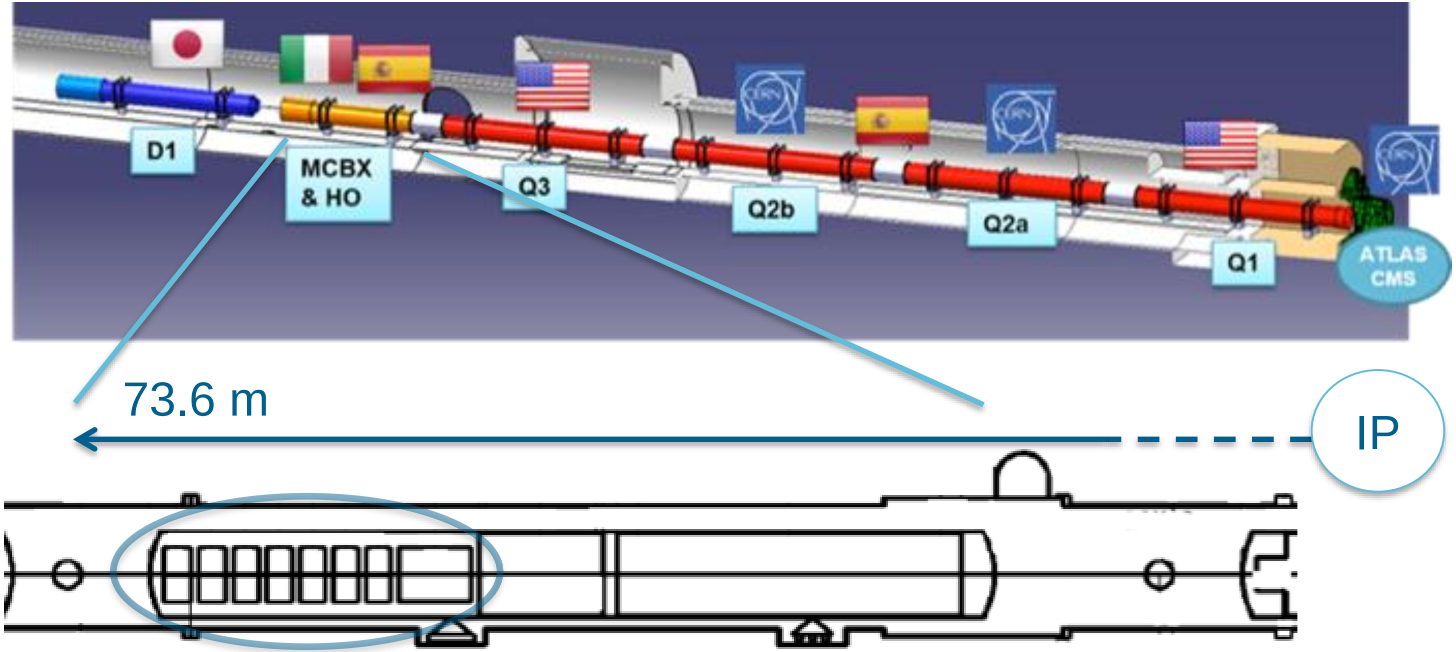




CERN courtesy

THE LOW BETA SECTION

and the High Order Correctors



b3 b4 b5 b6 a2

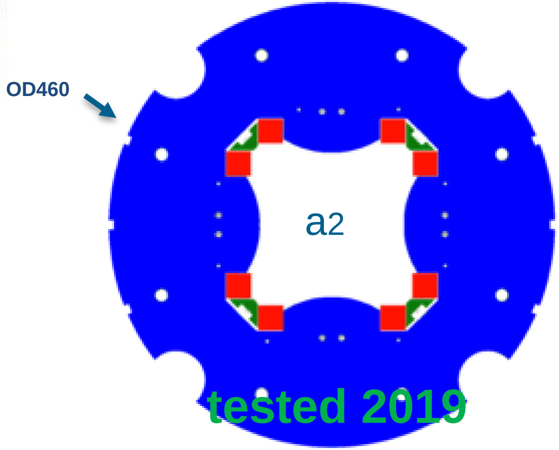
a3 a4 a5 a6

by P. Fessia

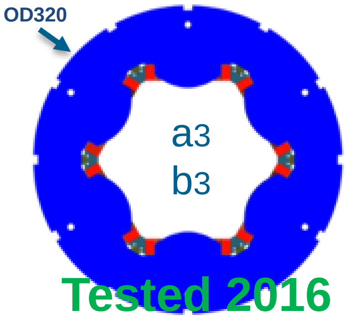
HO CORRECTOR MAGNETS ZOO

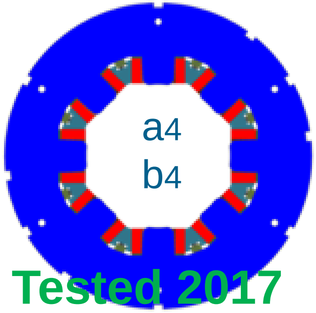
MCSXFP1

MCOXFP1

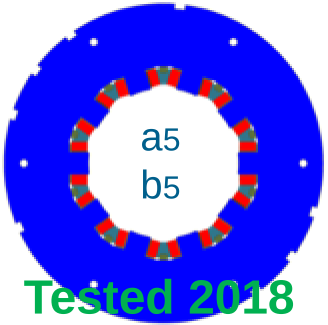


MCQSXFP1



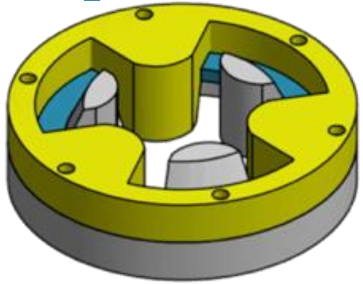


MgB_2 demonstrator



MCDXFP1

MCTXFP1



S. Mariotto
Tue-Af-Po2.18-06

design construction test
5 protoptypes
54 series magnets

HiLumi HL-LHC PROJECT INFN

SUPERFERRIC DESIGN

NbTi superconding coils

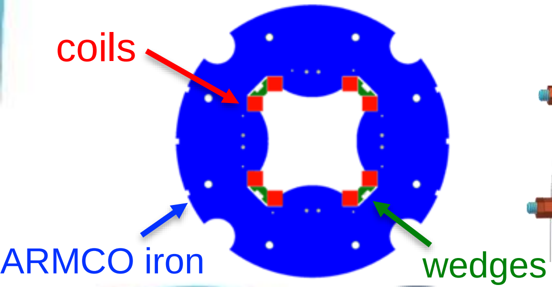
- Racetrack
- Insulation by S2 glass reinforced material

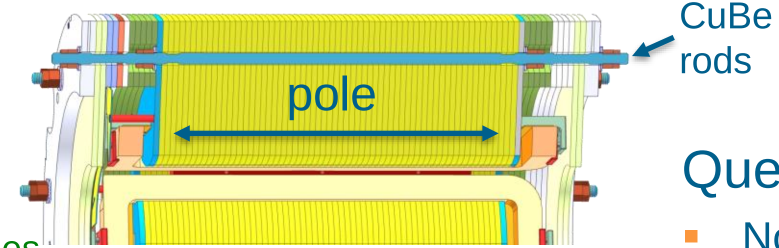
Superferric design

- Compact and modular
- Strong contribution of the iron poles
- Field quality influenced by the shape of the poles

constraints	
	• Longitudinal dimension • Quench protection • Small dimension: 84kN series production (6 magnets)

magnet	Ic @ 4.2 K	Margin @4.2 K	Margin @1.9K
4P S	315.5 A	42.3 %	57.1 %
6P	225.5 A	53.4 %	>60 %
8P	230.2 A	54.4 %	>60 %
10P	255.7 A	58.9 %	>60 %
12P N	232.6 A	54.9 %	>60 %
12P S	230.2 A	54.4 %	>60 %





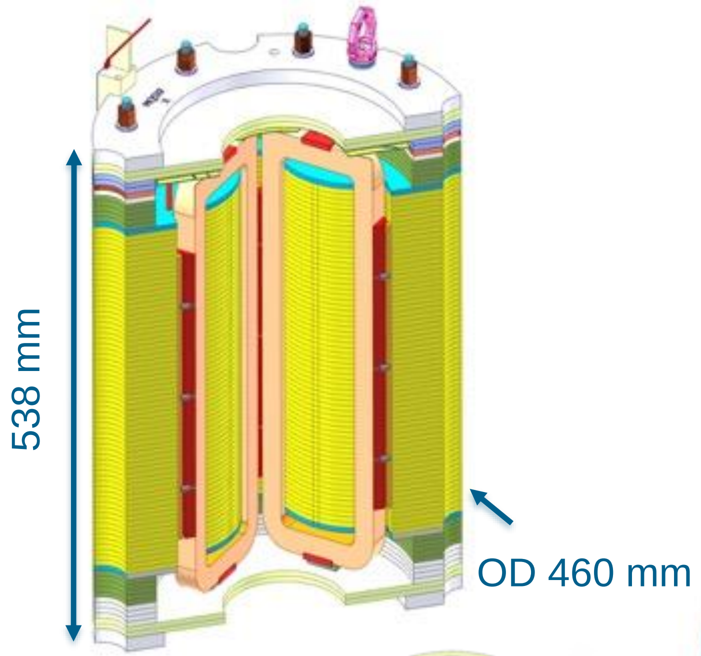
Quench protection

- No energy extraction (but 4P)
- 60% margin @ 1.9 K

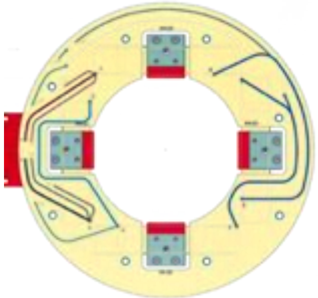
MCQSXFP1

length	538 mm
integrated field @ In @ r50 mm	0.700 Tm
magnetic length	401.1 mm
energy @Inom	30.8 kJ
harmonics	B6= -30 U at low current B6= 30 U at I_{op} B10= -8 U ÷ -12 U

- I_{nom}= 182 A
- COILS
  - 754 windings
  - 815 m of Φ 0.7 mm NbTi

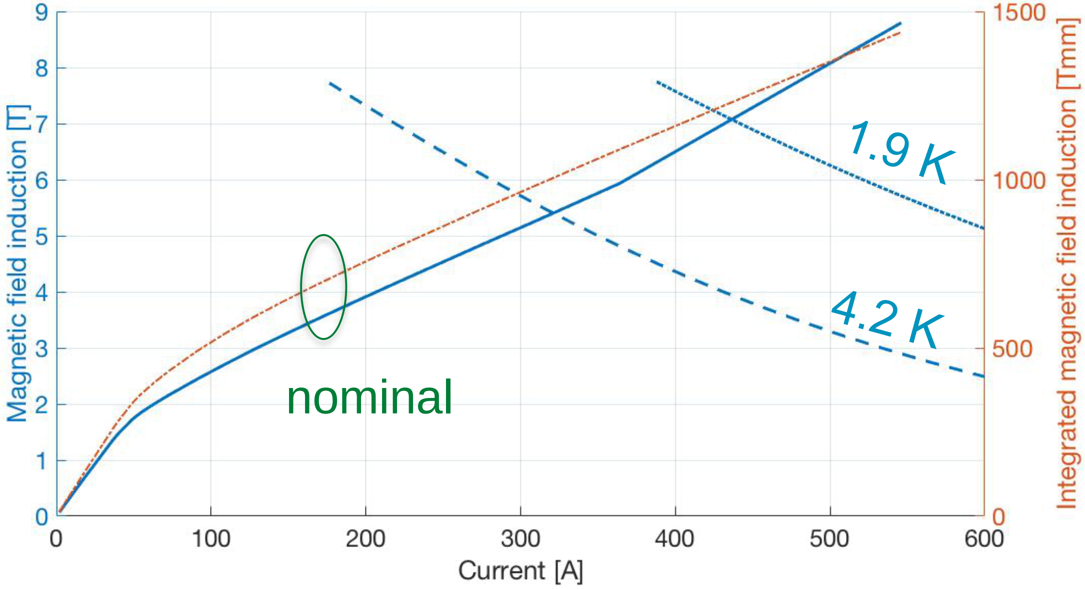


connections on a PCB board (Arlon N85)

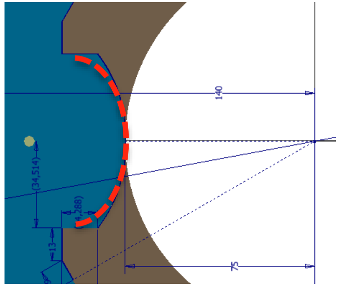


EM DESIGN

- nominal current 174 A - field integral 0.7 Tm
- ultimate current 197 A



modifed ideal pole shape (wire EDM laminations)

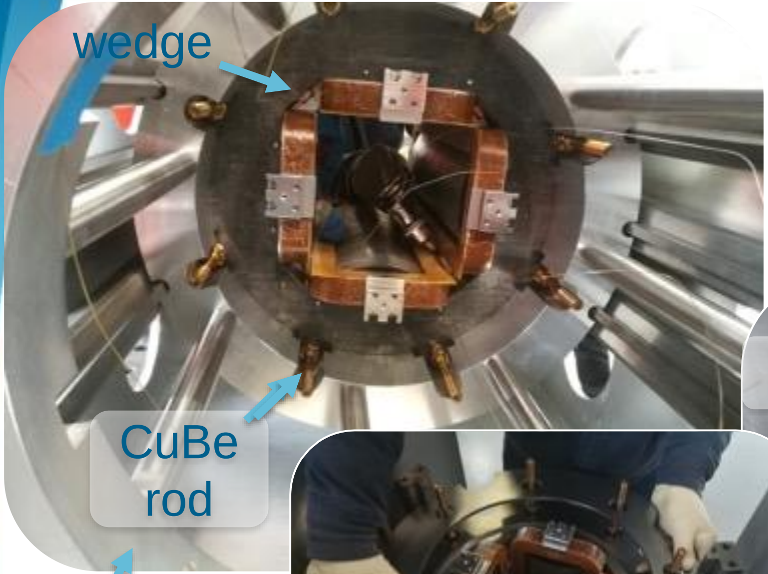


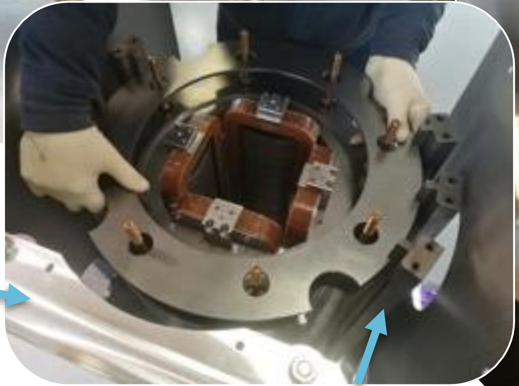
QUENCH protection
OPERA + QLASA
1.5 Ω dump ressitor
ground in the middle
max temperature 145 K
max voltage 235 V

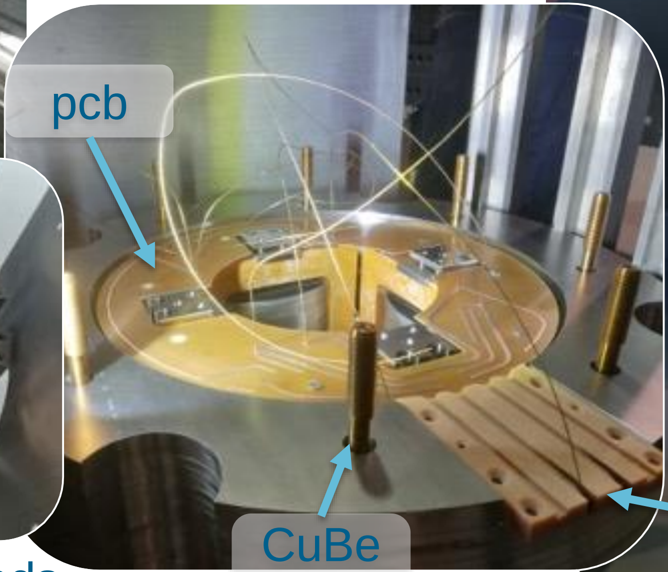
Assembly

Saes Rial Vacuum

Dec. 2018

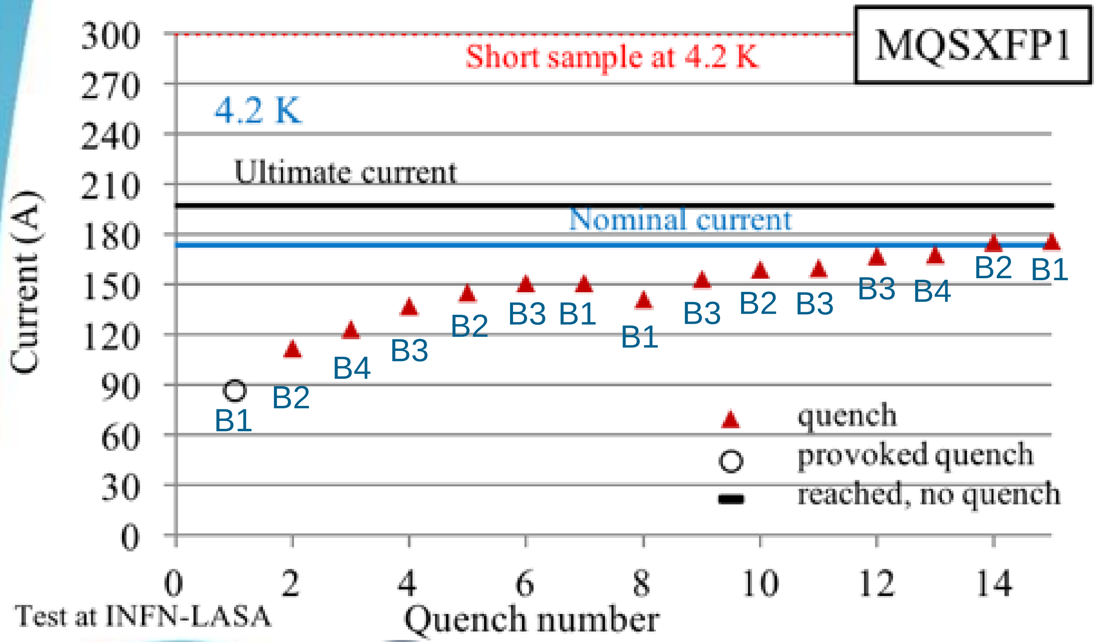




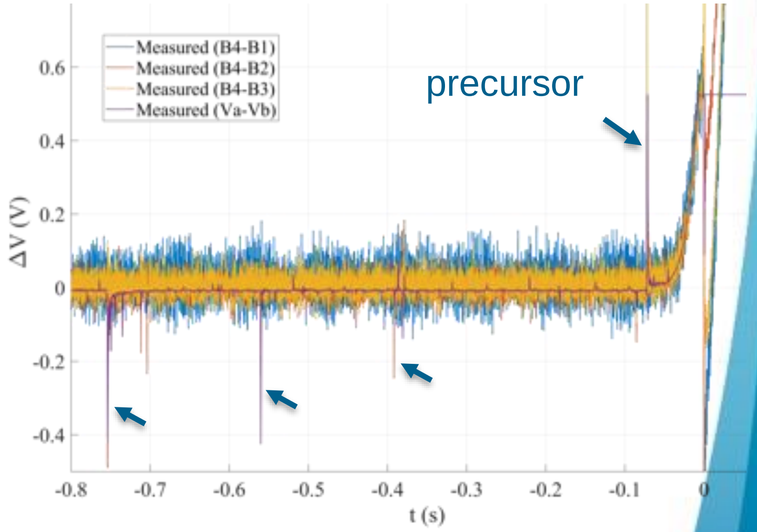


First Cooldown and Energization

- Training up to nominal



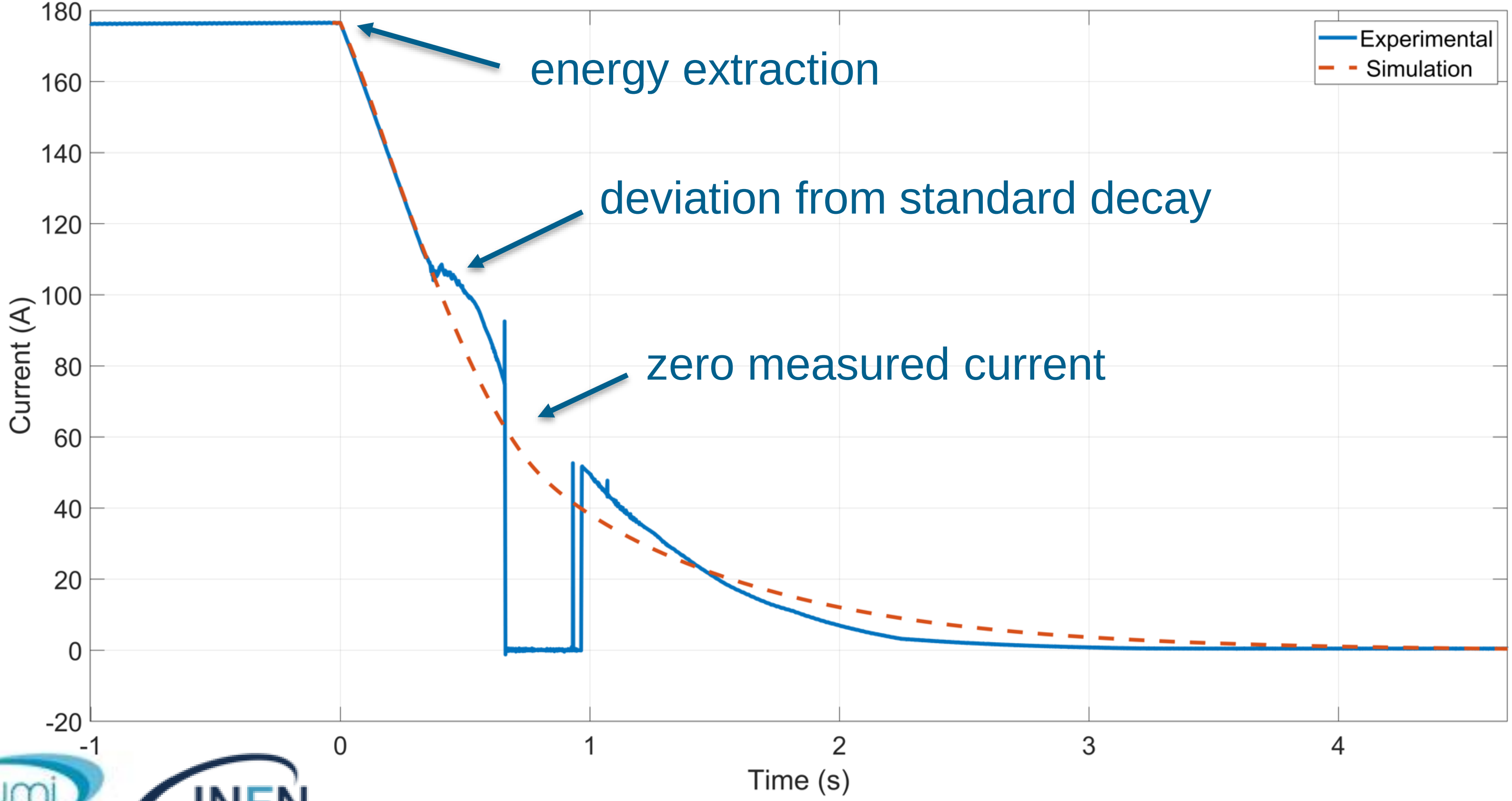
- Electrical problem



Event n.13 **B4**

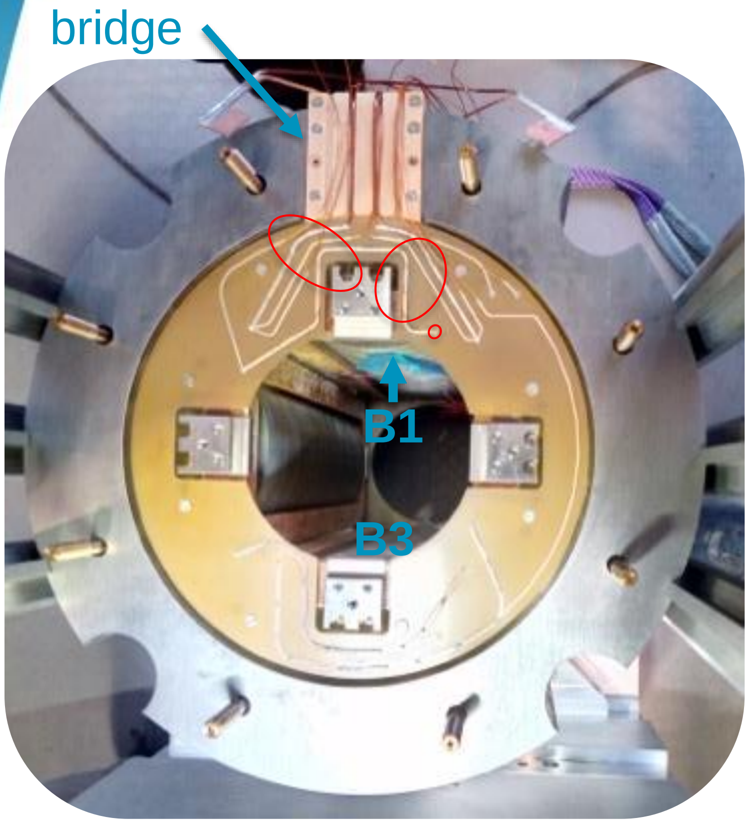
- Precursor
- Recovered transitions in different coils

Event n.15



Current (A)
Time (s)
Experimental
Simulation
energy extraction
deviation from standard decay
zero measured current
180
160
140
120
100
80
60
40
20
0
-20
-1
0
1
2
3
4

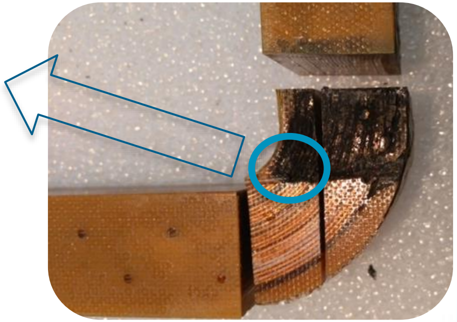
Damaged Coil



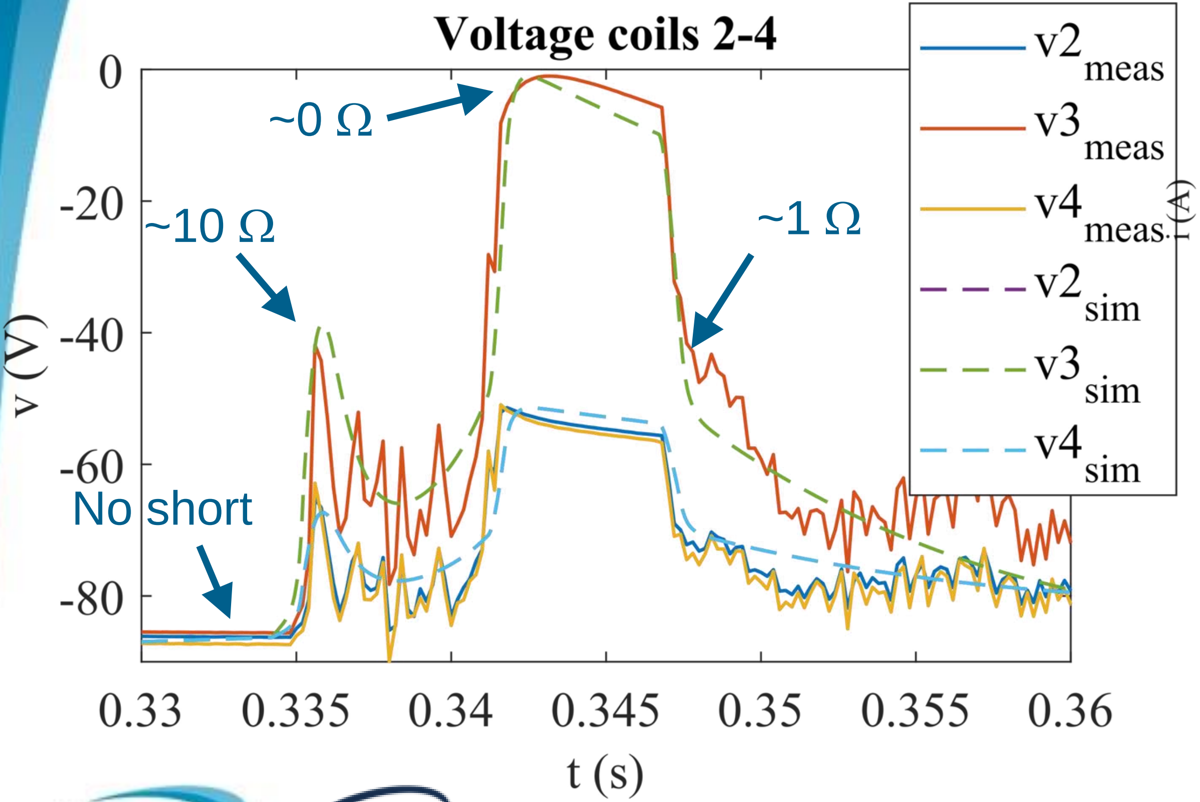
Numerical Model

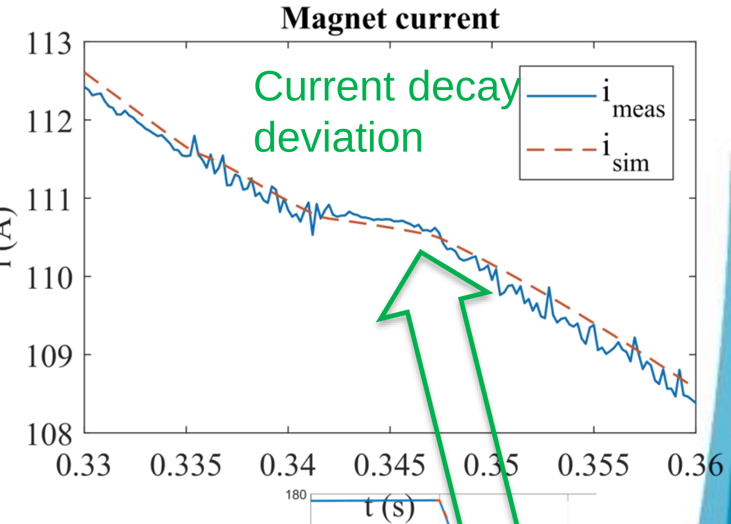
- Numerical model implemented in LTSpice, Netlist forma (M. Prioli)
- Coil 1 split into two parts:
  - Coil 1A**: 7 high-field layers** bypassed by a short-circuit
  - Coil 1B: 19 layers normally in series with the rest of the circuit
- Mutual inductance matrix (5 x 5) computed in Opera (S. Mariotto)
- Quench originated in the high-field zone (Coil 1A)
  - The resistance is not evenly distributed between coil 1A and coil 1B
  - Simulated distribution is 37% for coil 1A and 63% for coil 1B
- The **short resistance** is a variable
  - It is initially high (~10 Ω), then decreases due to a local welding (~0 Ω) then increases (~1 Ω)

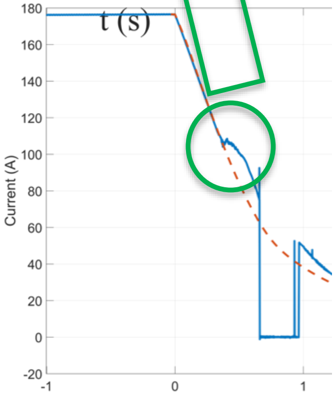
- Discharges between output wire and windings
- Inner layers not damaged



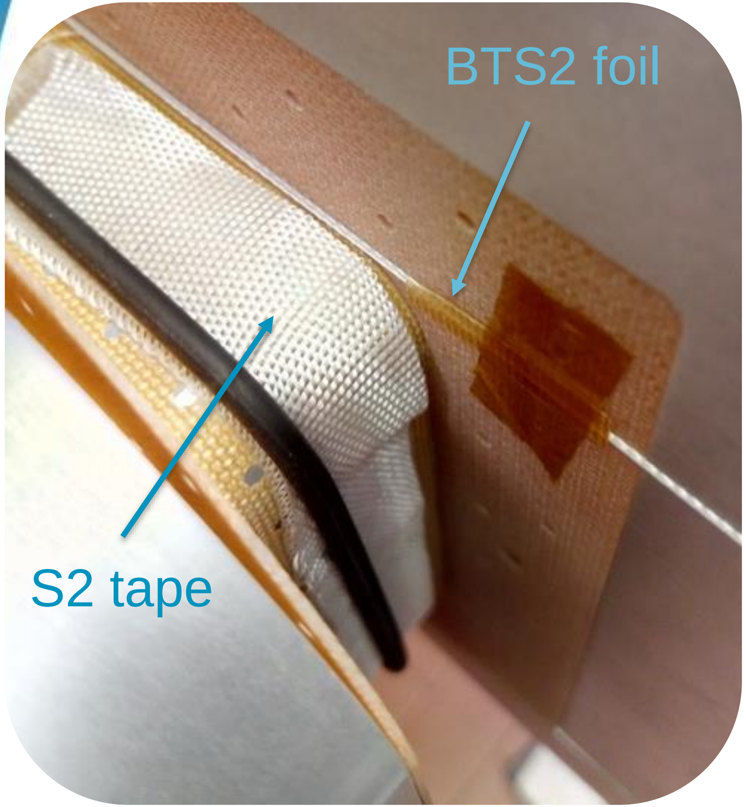
Numerical Model: Results



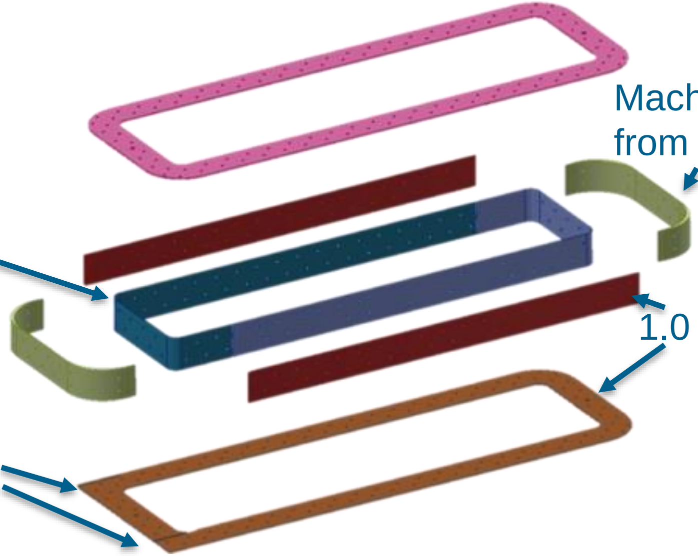




Two New Coils



- all coils compliant
- the 2 new coils installed

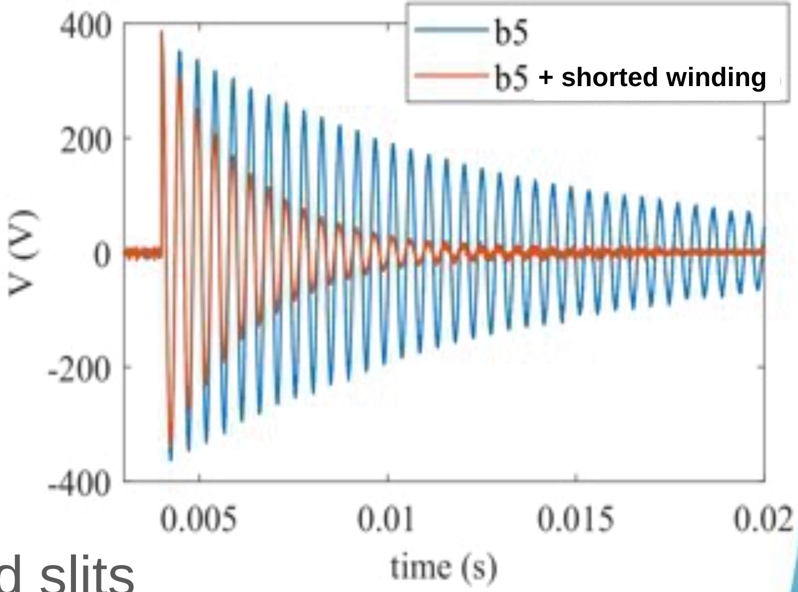


Second Assembly Assessment

Coil

- Geometry
- HV ground insulation (2,5 kV)
- Wire-wire insulation, turns

All coils are compliant



Magnet

- Laminations' profiles and slits
- Alignment of the assembly
- HV ground insulation of the magnet (up to 2 KV)

procedures validated
- second assembly
- coil replacement

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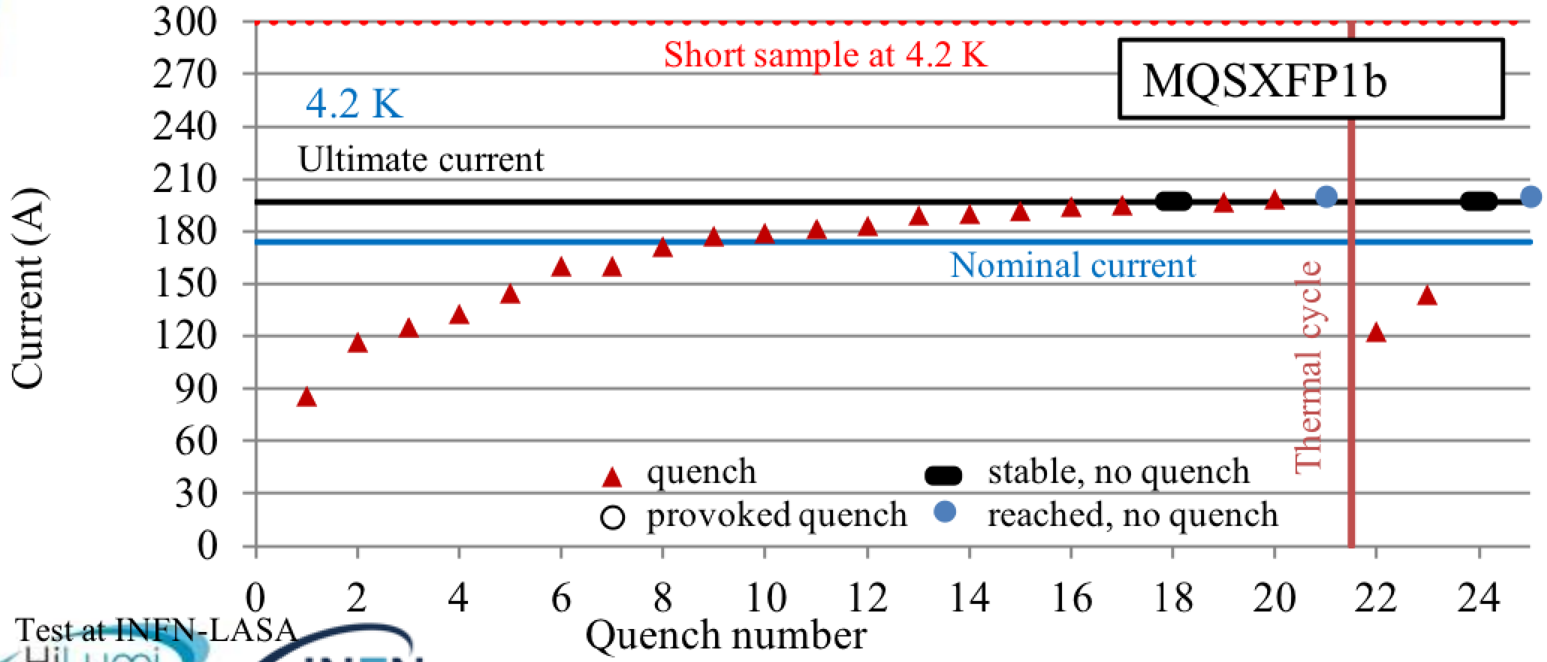
Power Test

Most quenches in new coils

Good stability after reaching 200 A (> I_{ult} 197 A)

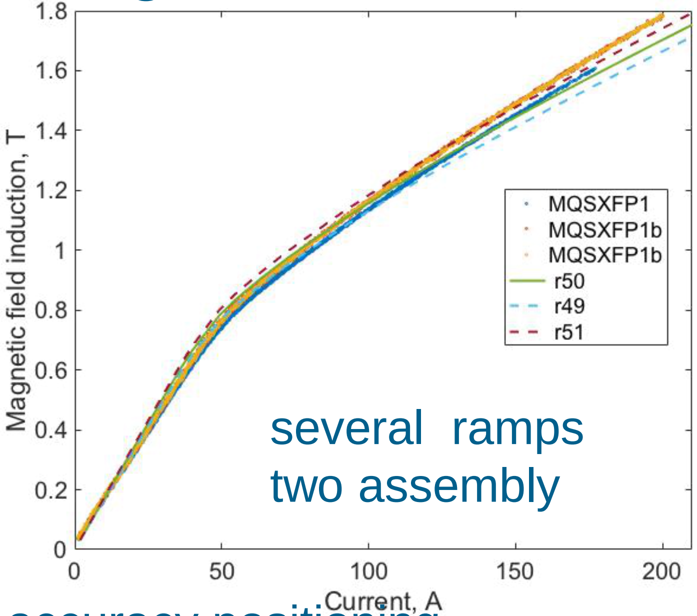
Stable 1 h @ ultimate after thermal cycle



Test at INFN-LASA

MAGNETIC FIELD AND INDUCTANCE

Single Hall Probe

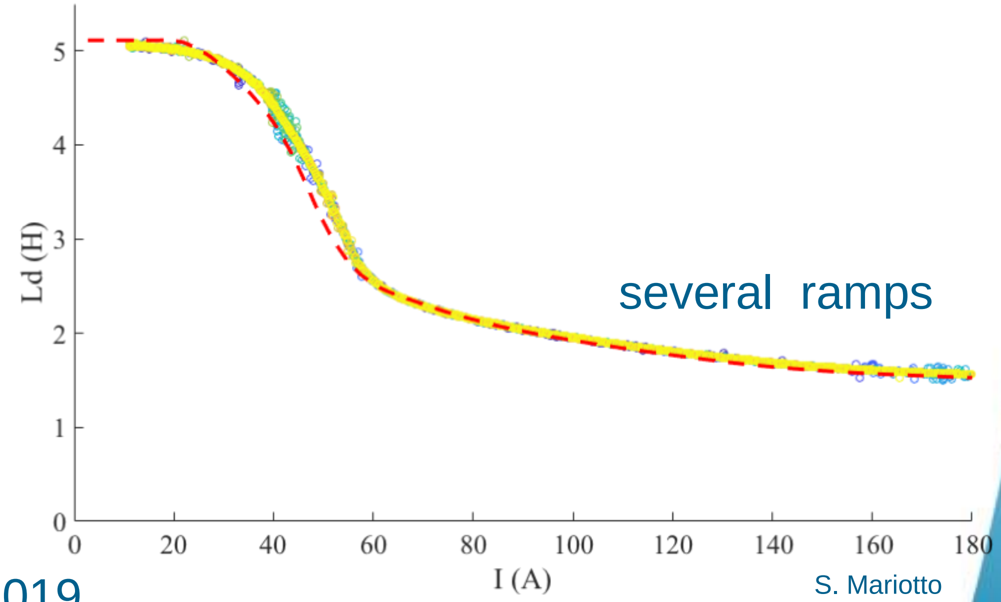


Low accuracy positioning

Field quality measurement at LASA in 2019

Dinamic inductance

measured during current ramps



S. Mariotto

Conclusion

- The HL-LHC skew quadrupole corrector magnet was successfully designed and assembled
- First power test had an electric failure
  - The fault has been identified
  - A mitigation was applied even if all the non damaged coils are compliant, also for series production
  - New quality test introduced
- Second assembly power test showed good results: ultimate current reached, stabiliity test (1 h @ultimate), good quench memory
- Procedures validated
- All High Order Correctors protoypes tested

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SAES Rial Vacuum M. Canetti, F. Gangini

RODOFIL A. Zanichelli

THANK YOU

Ph. by G. Fornasier