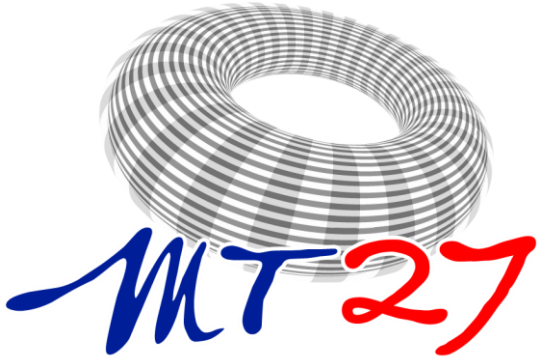


Nov. 15-19, 2021
Fukuoka, Japan

The HL-LHC High Order Correctors Series Production and Powering Tests Status

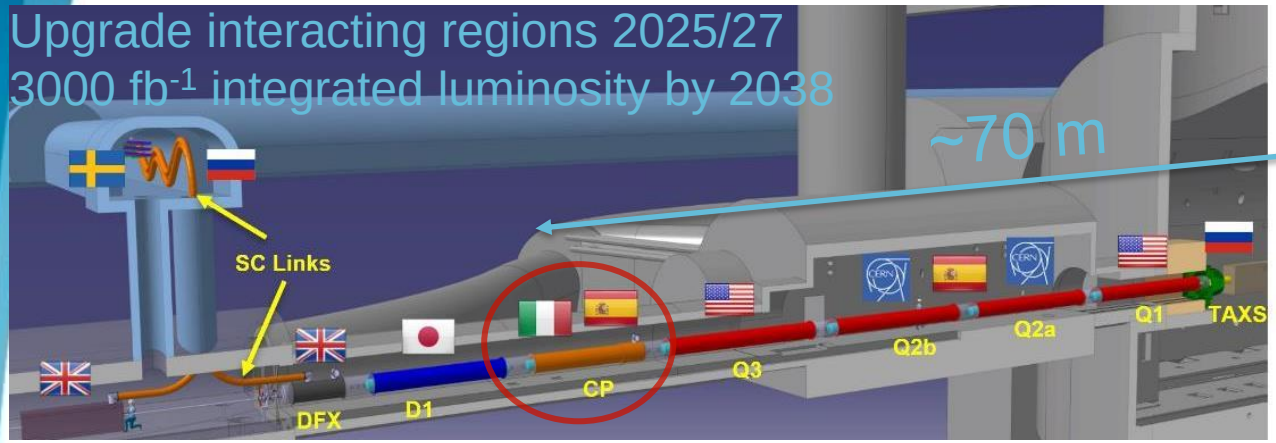
Marco Statera
on behalf of the LASA team
INFN Milano - LASA

27th International conference on Magnet technology
Fukuoka, Nov 17h 2021

OUTLINE

- The High Order Correctors magnets
- Status of the series production
- The test station and test results
- Conclusions

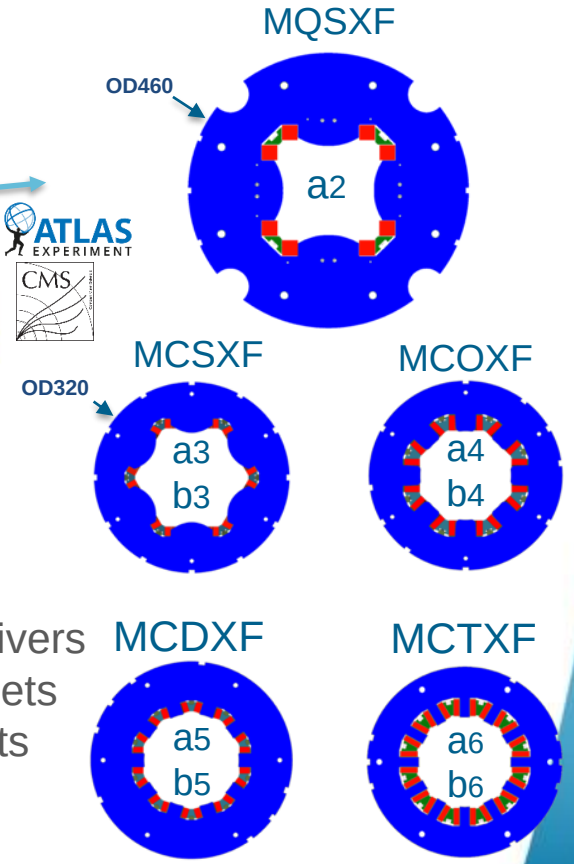
The Low Beta Section and the HO Correctors



First installation of a superferric magnet in a collider

HOC: compensate for field quality errors of the main final focusing quadrupoles in the Interaction Regions

INFN LASA delivers 54 series magnets and vertical tests



Superferric Design

NbTi superconding coils

- Racetrack
- Insulation by S2 glass reinforced material

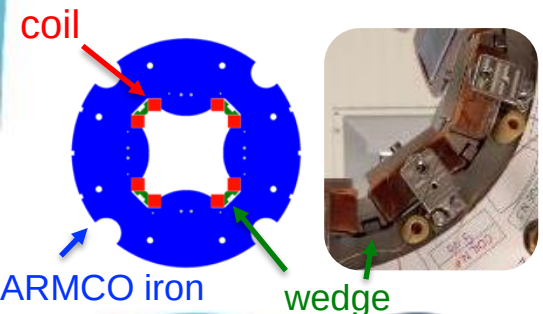
Superferric design

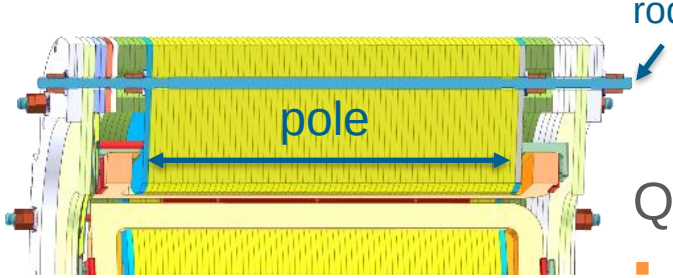
- Compact and modular
- Strong contribution of the iron poles
- Field quality influenced by the shape of the poles

constraints

- Longitudinal dimension
- Quench protection
- Small dimension: 84kN series production (6 families)

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

Status of Production

Produced magnets

	Batch	Serial	TEST
M06	1a	1	
		2	
	1b	3	
		4	
	2	5	
		6	
		7	
		8	
	3	9	
		10	
		11	
		12	
M08	1a	1	
		2	
	1b	3	
		4	
	2	5	
		6	
		7	
		8	
	3	9	
		10	
		11	
		12	

	Batch	Serial	TEST
M10	1a	1	
		2	
	1b	3	
		4	
	2	5	
		6	
		7	
		8	
	3	9	
		10	
		11	
		12	
M12	1a	1	
	1b	2	
	2	3	
		4	
	3	5	
		6	
M13	1a	1	
	1b	2	
	2	3	
		4	
	3	5	
		6	

	Batch	Serial	TEST
M04	1a	1	
	1b	2	
	2	3	
		4	
	3	5	
		6	

Legend
done/tested re-test
ongoing re-assembly
Test ongoing

Last produced magnets delivered to LASA

Coils

Production completed

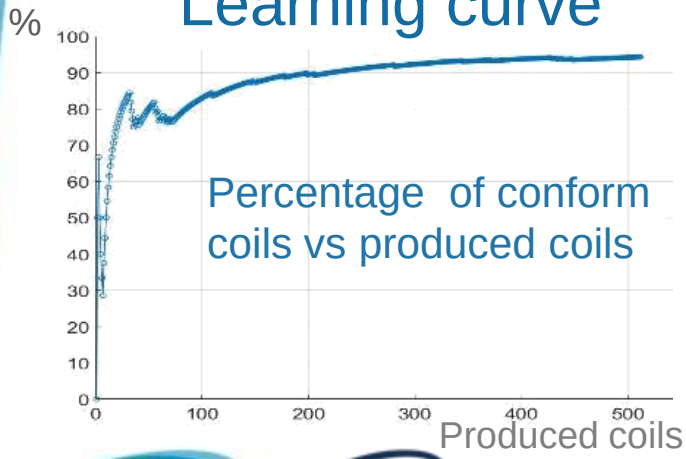
Produced coils 508

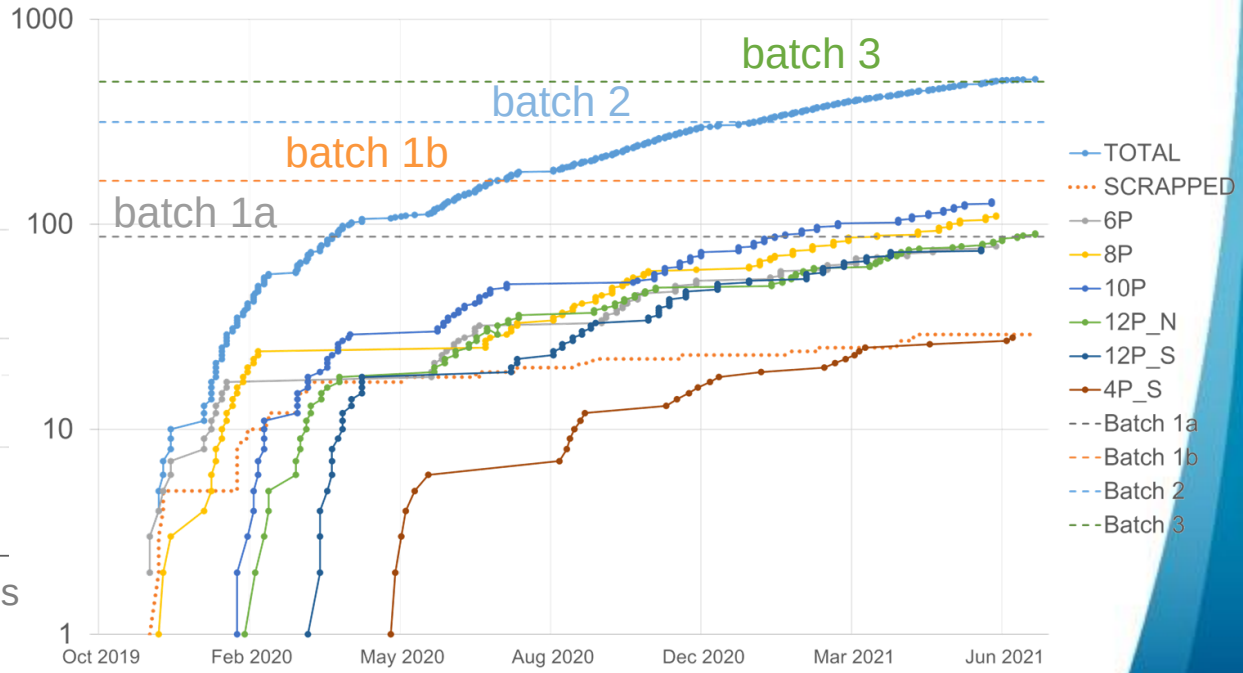
- 29 NC (6%)
- 11 spares

TUE-PO1-720-01 by M. Prioli

Magnet	6P	8P	10P	12P-N	12P-S	4P
Produced coils	78	110	129	88	75	28
NC (total 29)	3	4	6	13	1	2

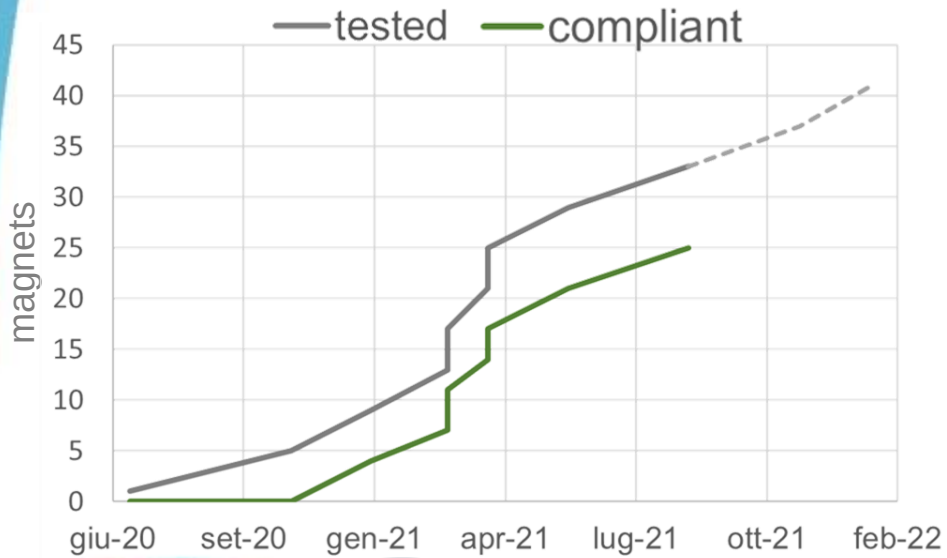
Learning curve

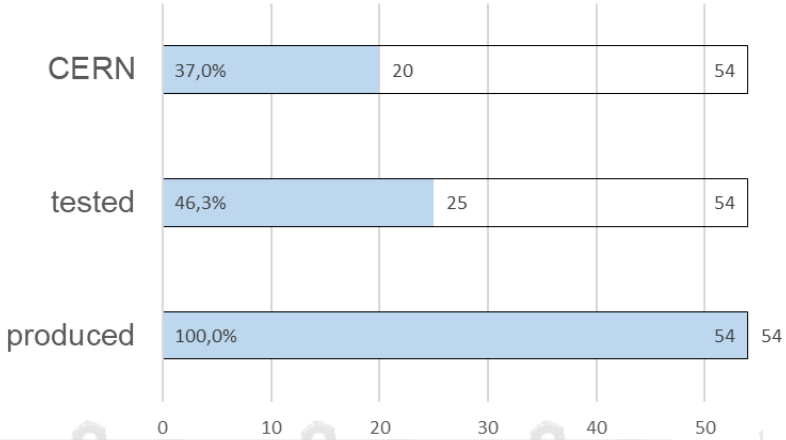


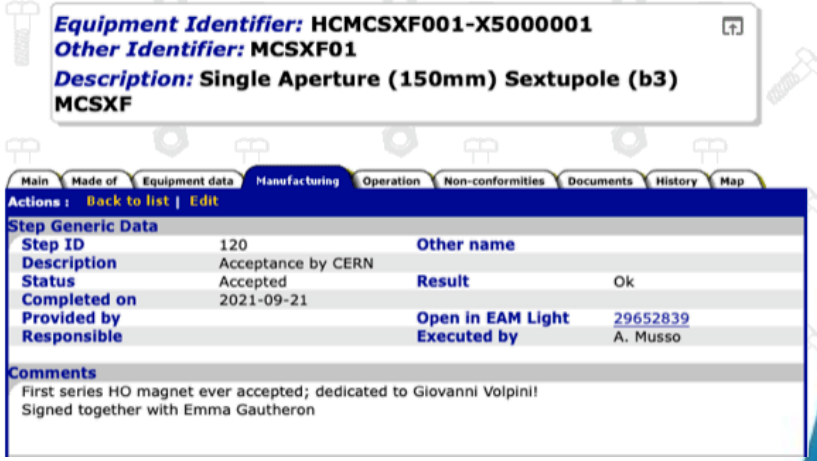


Test

Cooled magnets: 29
Compliant magnets: 25
Expected 29 compliant within 2021
Delivery to CERN within summer 2022

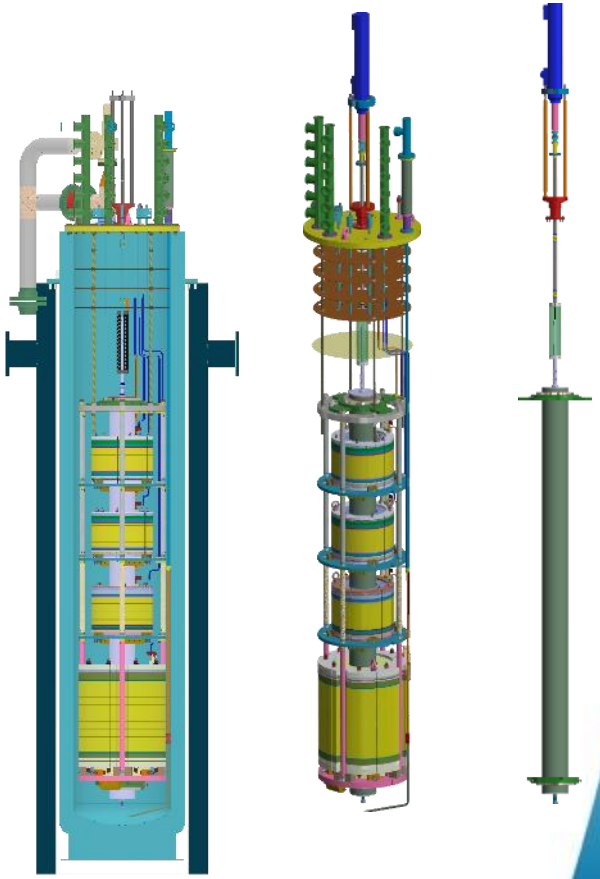






The Test Station

- Four HO correctors cooled
  - Each magnet powerd individually
  - Magnetic Measurements
- New power converter 600 A
  - Dump resistance 1 Ω or 1.5 Ω
  - IGBT polarity switch by LASA
  - IGBT for quench protection
- Field probe for the series
  - Each magnet measured individually
  - No cross talk



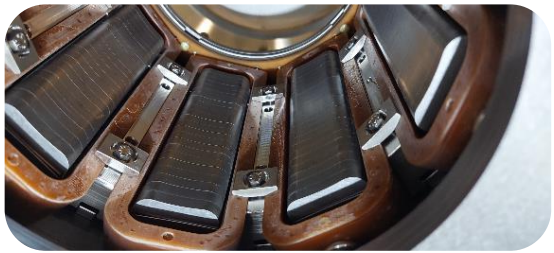
Test Results

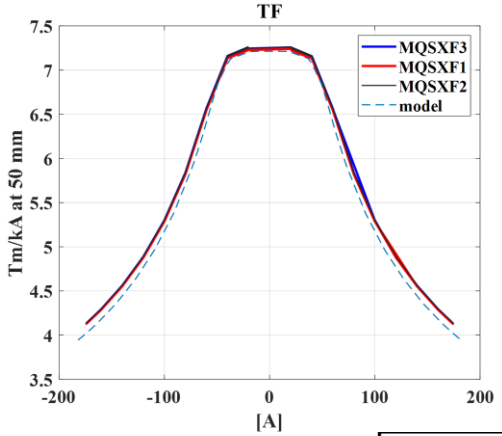
Training (both polarities)
Endurance test 1h at ultimate
Magnetic field measurement

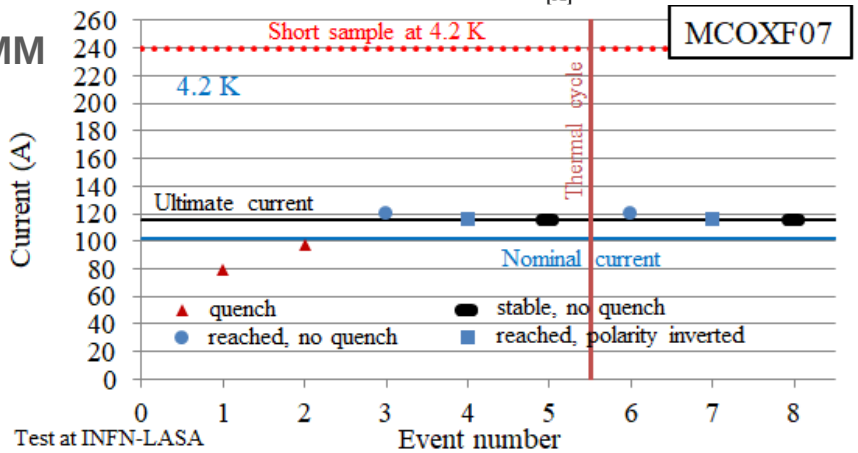
- Field integral 1% to 3% wrt simulations
- Field integral reproducibility <0.1%
- Field quality high reproducibility
- Transfer function very good agreement with simulations, high reproducibility

Detailed discussion in WED-OR3-702-04 by E. De Matteis

Quenched coil recostruction via MM by S. Mariotto

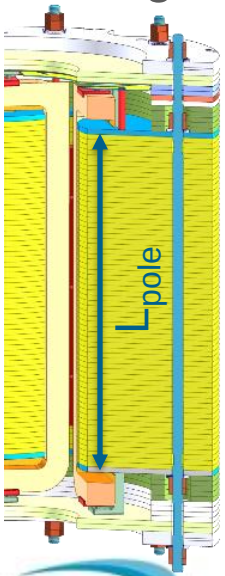


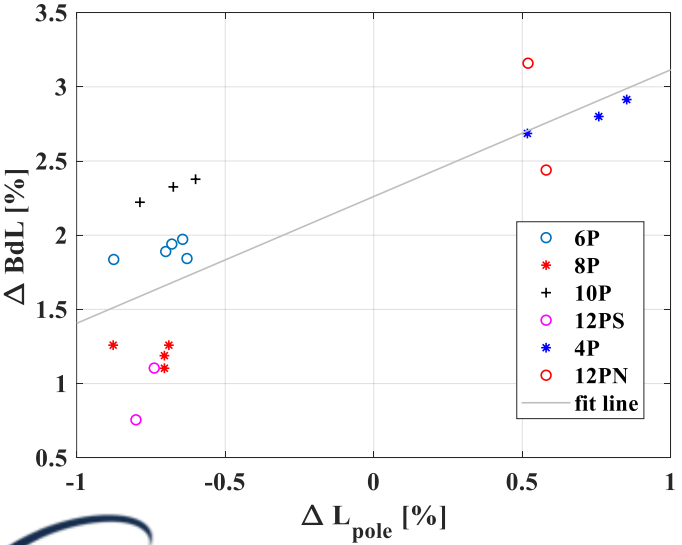


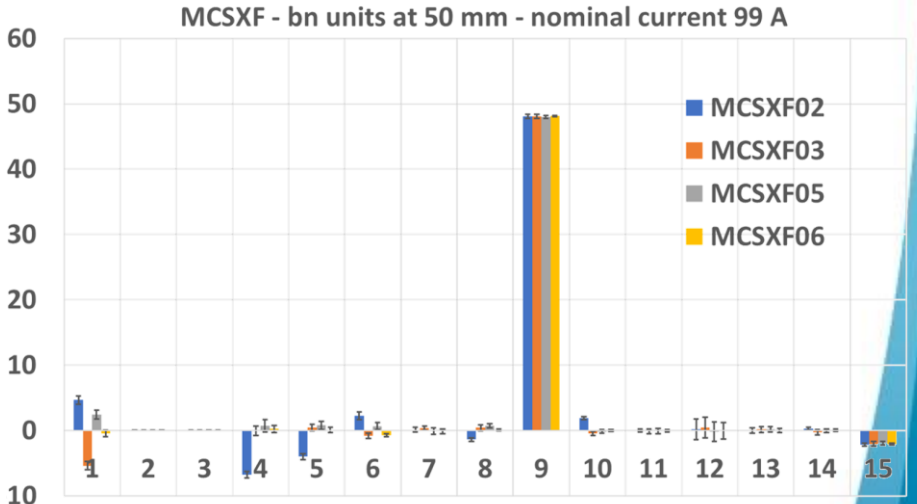


Repeatability

- Pole length variability < 0.5% per family
- Clear correlation between field integral (BdL) and pole length
- Same family, same region
- High repeatability in field quality







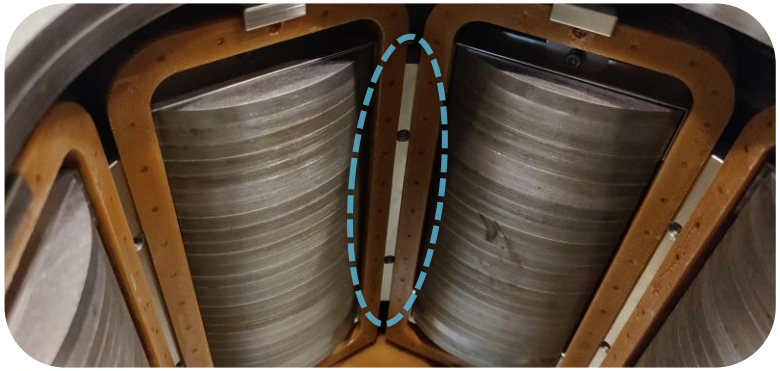
Measured at LASA

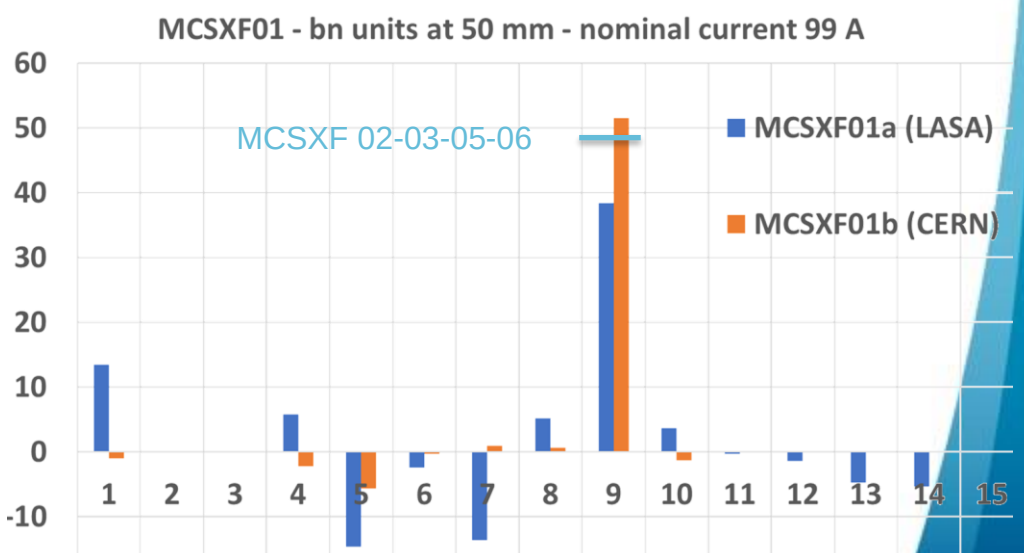
Optimized probe designed by CERN

Re-assembled Magnets

- Two assembly of the same magnet
- First measurements using preliminary system (probe/mechanics)
- Different mechanical setups (non optimized probes)
- Compatible with measuerements by optimized probe

Detailed discussion in WED-OR3-702-04
by E. De Matteis

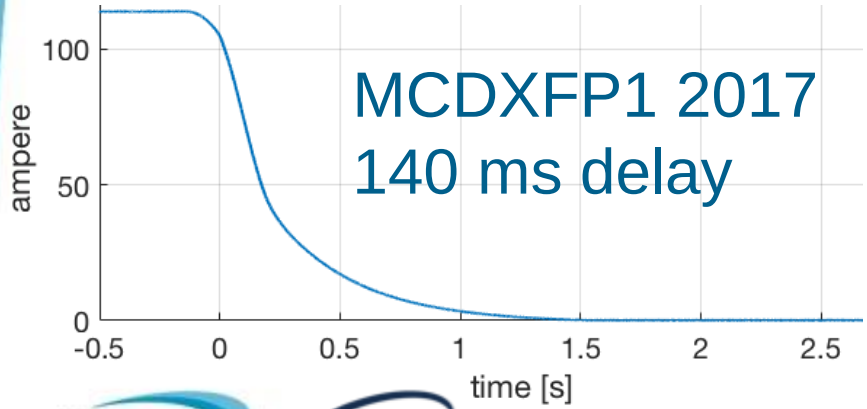




Quench protection and simulations

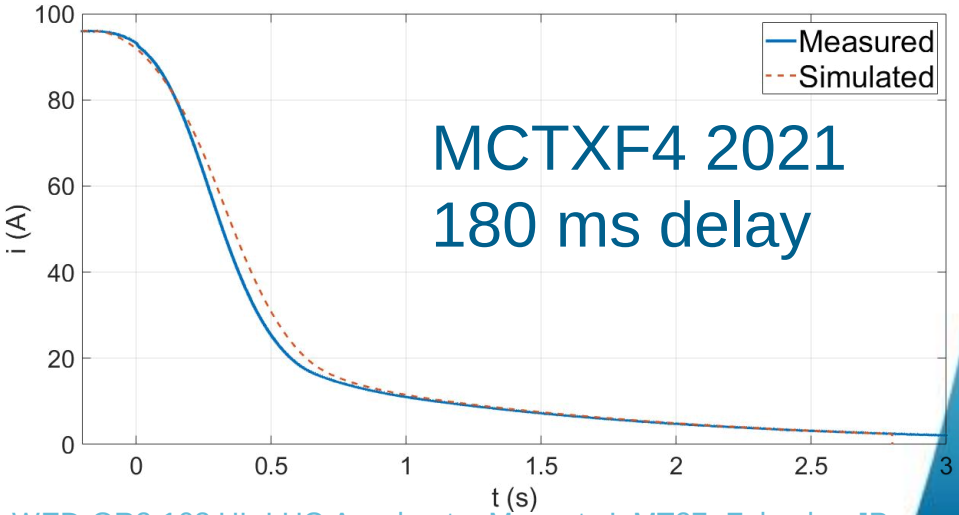
Protection in LHC

- Measuring current
- Time range 60-180 ms
- No energy extraction (but quadrupole)



MCDXFP1 2017
140 ms delay

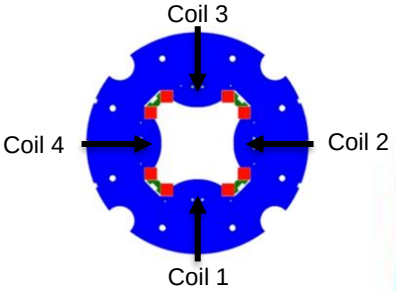
- Modeled and tested on prototypes
- Crosscheck on series magnets
- Simulia opera 3D, QLASA, STEAM (QLASA,Ltspice)

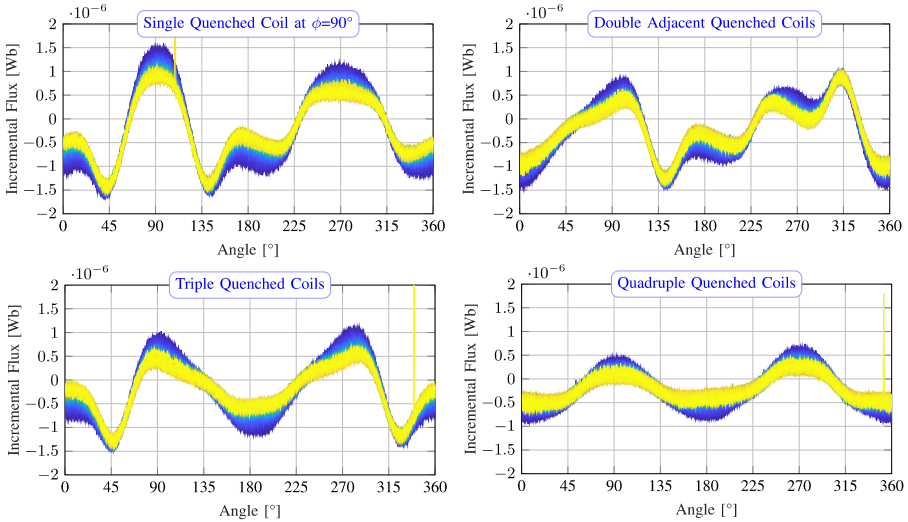


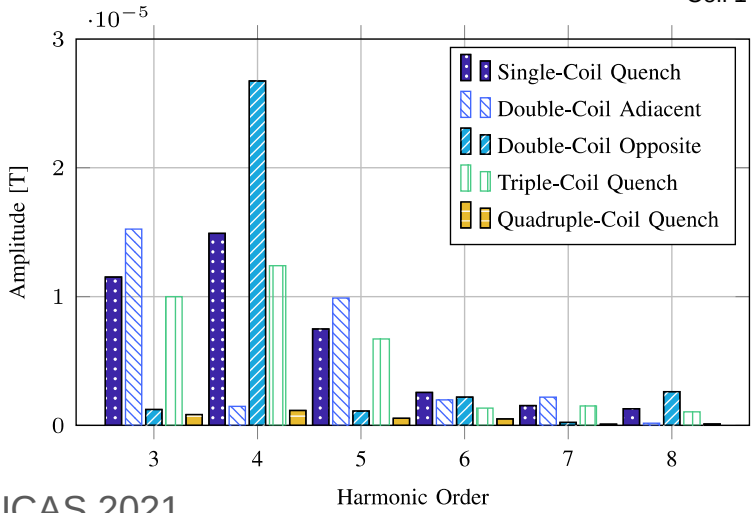
MCTXF4 2021
180 ms delay

New Method for Quench Localization

- For the series magnets, no info on the quenched coil
- Reliable **innovative quench localization** method based on MM of superconducting residual magnetization
- Experimental evidence of multi-coil quench **modeled and reproduced**







By S. Mariotto, presented @ EUCAS 2021
"Innovative Method for Quench Localization in Superconducting High Order Magnets

Conclusions

- HO Correctors series production
- 54 magnets delivered to LASA (6 families)
- Vertical tests ongoing
  - Field quality and transfer function within specs
  - High repeatability and reliability
  - Innovative quench localization method developed
- 20 magnets delivered at CERN
- All HO Correctors tested and delivered to CERN within Summer 2022

INFN LASA

Istituto Nazionale di Fisica Nucleare

Laboratorio Acceleratori e Superconduttività Applicata

LASA team

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THANK YOU