High Order Corrector update

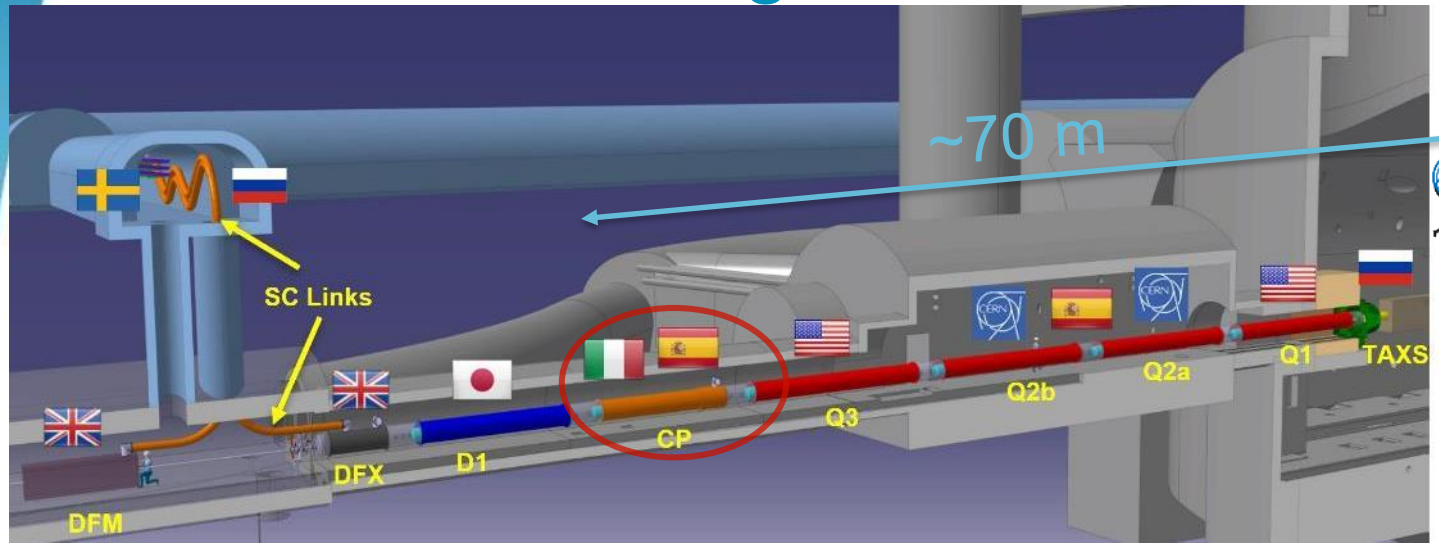
Marco Statera
on behalf of the LASA team
INFN Milano – LASA
Emma Gautheron
CERN

12th HL-LHC Collaboration meeting
Uppsala – Sep 19h 2022

OUTLINE

- Scope: the High Order Correctors magnets
- Overview on HO Correctors
- The test station and selected results
- Integration
- Schedule
- Conclusions

THE LOW BETA SECTION and the High Order Correctors



By H. Prin

SCOPE - High Order Correctors

The INFN-LASA followed the design, construction and test of the 5 prototypes of the High Order (HO) corrector magnets for the HL interaction regions of HL-LHC. KE2291

The INFN-LASA follows the series production of the HO corrector magnets for the HL interaction regions of HL-LHC. KE3085

Deliverables are the magnets, i.e. active part (coils) with iron yoke and support structure, plus the vertical tests. Integration in the cold mass corrector package is done at CERN

ADDENDUM No. 2 KE3085/TE/HL-LHC
to
FRAMEWORK COLLABORATION AGREEMENT KN3083
between
THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)
and
Istituto Nazionale di Fisica Nucleare (the "Institute")
concerning

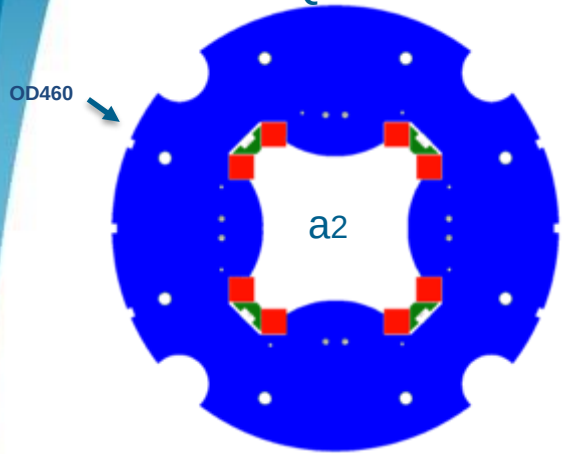
Collaboration in design, procurement and testing of the high-order orbit corrector superconducting magnets in the framework of the High Luminosity upgrade for the LHC at CERN

30th Nov 2017

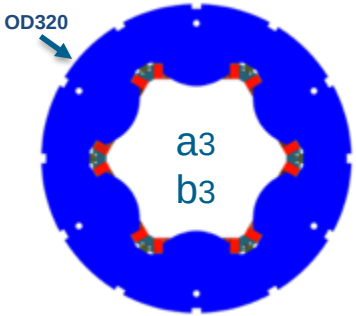
54 S.C. High Order Corrector magnets

HO Corrector Magnets Zoo

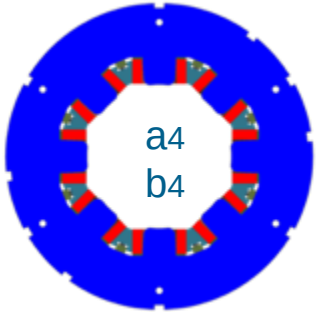
MQSXF



MCSXF



MCOXF



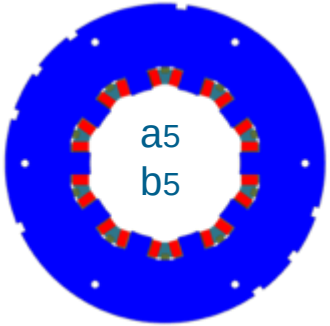
Design
Construction & Test

- 5 protoptypes
- 54 series magnets

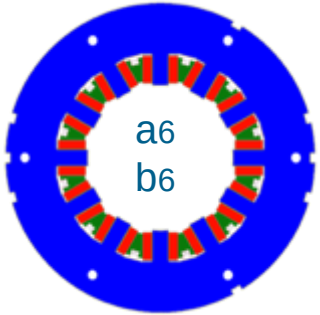
6P 8P 10P +50% Bdl

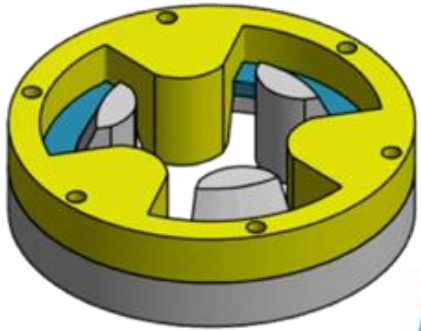
Prototypes tested 2016-2020
NbTi SuperFerric design
Geometrical lengths:
200 mm - 265 mm
12P, S4P: 540 mm – 580 mm

MCDXF



MCTXF





Round Coil Superconducting Magnet
MgB_2demonstrator

Superferric Design

NbTi superconding coils

- Racetrack
- Insulation by S2 glass reinforced material

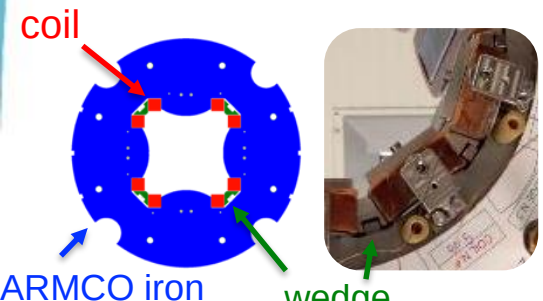
Superferric design

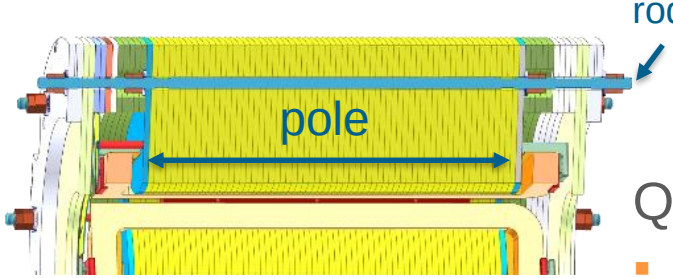
- Compact and modular
- Strong contribution of the iron poles
- Field quality influenced by the shape of the poles

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	

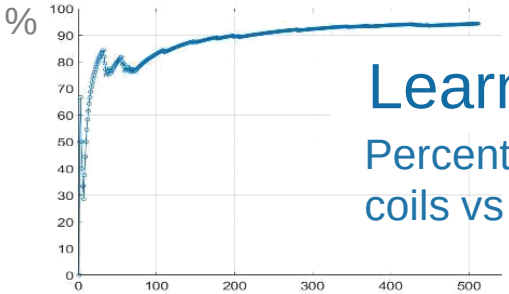
	Batch	Serial	TEST
M10	1a	1	
		2	
	1b	3	
		4	
	2	5	
		6	
		7	
		8	
	3	9	
		10	
		11	
		12	
M12	1a	1	
	1b	2	
	2	3	
		4	
	3	5	
		6	
M13	1a	1	
	1b	2	
	2	3	
		4	
	3	5	
		6	

	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 10 produced magnets delivered to LASA in Oct 2021
Produced coils 508

- 29 NC (6%)
- Spares delivered to CERN except 4P



Learning curve

Percentage of conform coils vs produced coils

Test 1

date	Magnets
Jul 2020	**MQSXFP1c MCDXF01**
Nov 2020	**MCDXF02 MCOXF01 MCSXF01 MCTXF01**
Jan 2021	**MCDXF03 MCOXF03 MCSXF03 MCTXF2**
Mar 2021	**MCOXF02 MCOXF04 MCSXF02 MQSXF2**
Mar-Apr 2021 CERN	**MCDXF02b MCDXF04 MCSXF01b MCDXF05 MCDXF06 MCSXF04 MCDXF01b MCTXF1**

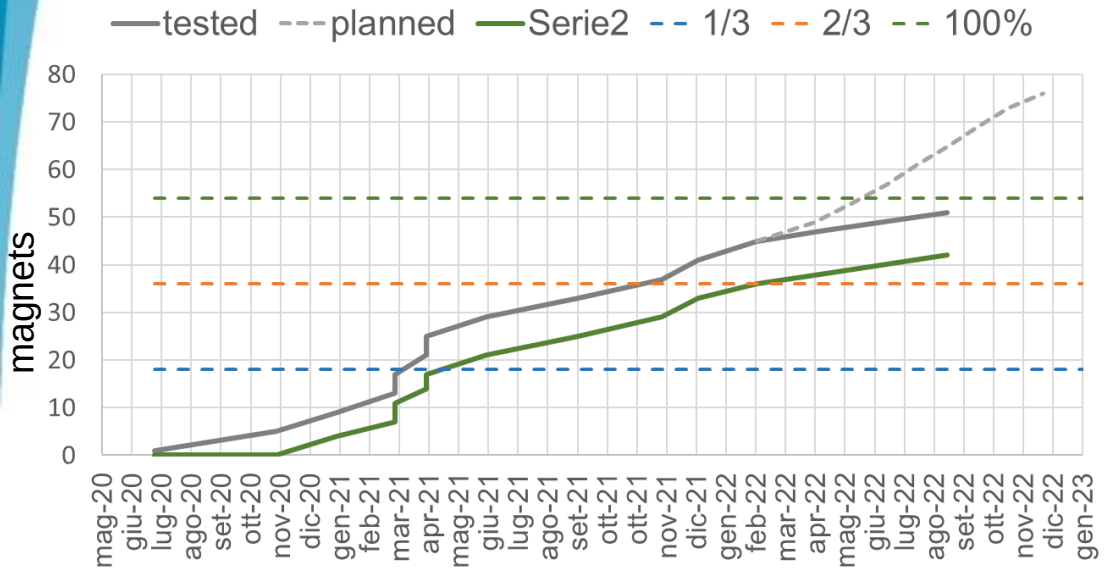
date	Magnets
Apr 2021 CD5	**MQSXF1 MCSXF05 MCTSXF1 MCTSXF2**
Jun 2021 CD6	**MCOXF04b MCOXF07 MCSXF06 MQSXF3**
Sep 2021 CD7	**MCDXF07 MCDXF08 MCSXF07 MCTXF3**
Nov 2021 CD8	**MCOXF05 MCOXF01b MCSXF08 MCTXF4**
Dec 2021 CD9	**MCOXF08 MCOXF06 MCSXF09 MQSXF1b**
Feb 2022 CD10	**MCTSXF3 MCTSXF4 MCSXF10 MQSXF5**

date	Magnets
Apr 2022 CD11	**MCTSXF6 MCTXF5 RCSM 2 coils**
Jul 2022 CD12	**MCDXF09 MCOXF09 MCSXF11 MCTXF6**
Sep 2022 CD13	**MCTXF6 MCOXF10 MCSXF12 MQSXF4**
Oct 2022 CD14	**MCDXF10 MCOXF11 MCDXF11 MQSXF6**
Nov 2022 CD15	**MCOXF12 MCDXF12 MCTXF4***

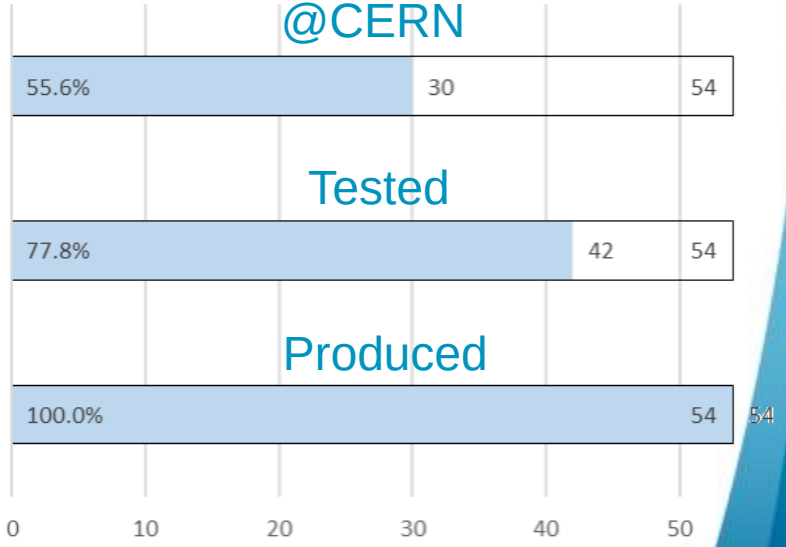
21 magnets tested since last Collaboration Meeting and one MgB2 Round Coil Superconducting Magnet

Test 2

- Cooled magnets 55
- Compliant magnets 42

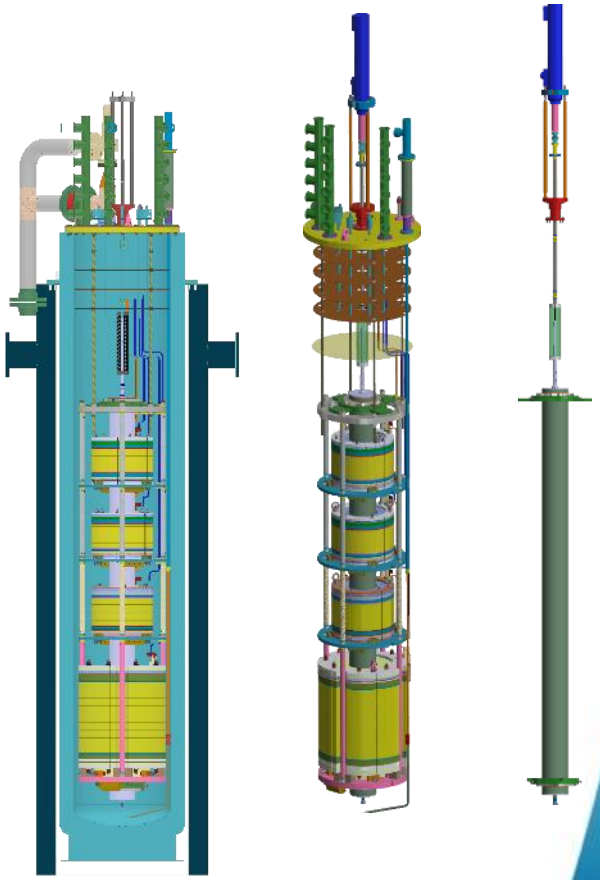


- Delivered to CERN 55%
- MM all magnets except one 8@CERN and others @LASA



The test station

- Four HO correctors cooled
  - Each magnet powerd individually
  - Magetic 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

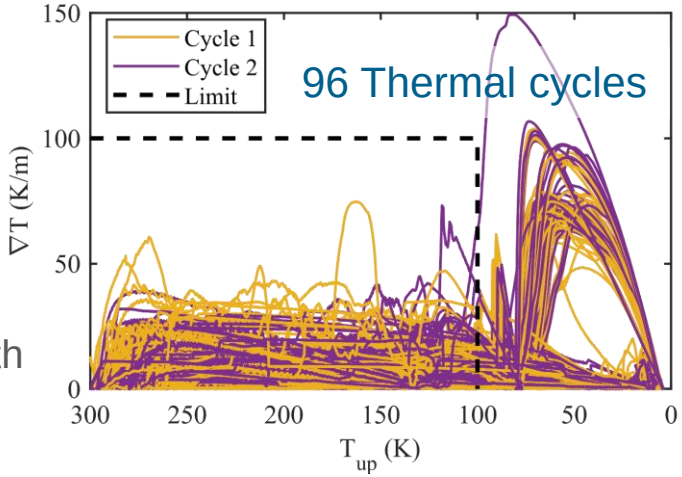
Powering (M. prioli)

- Training (both polarities)
- Endurance test 1h at ultimate

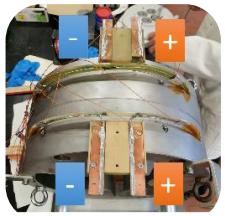
Magnetic field measurement
(E. De Matteis, S. Mariotto)

- 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

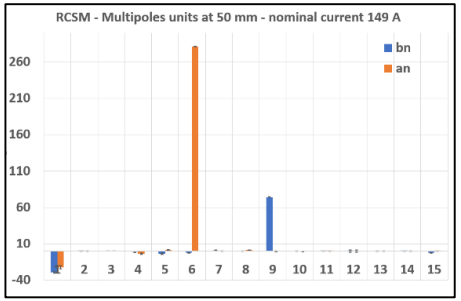
Quenched coil recostruction via Magnetic Measurements (S. Mariotto)



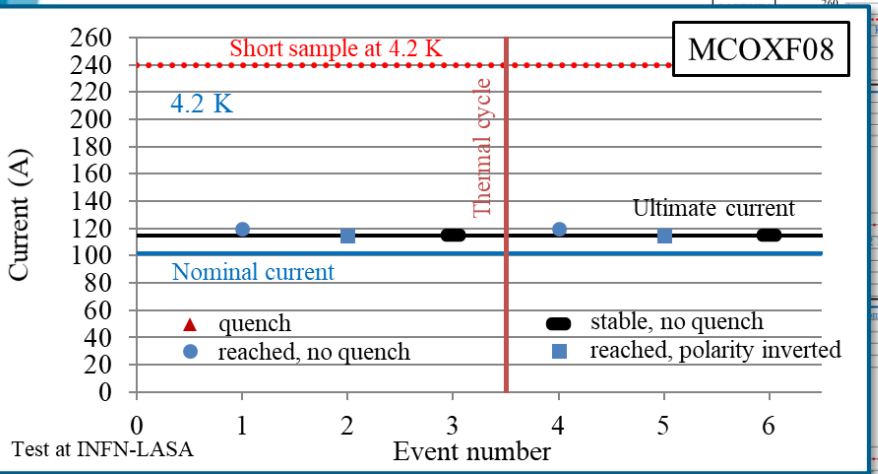
Roud Coil Superconducting Magnet
2 MgB_2 coils
Reached 230 A (1.5 I_{nom})

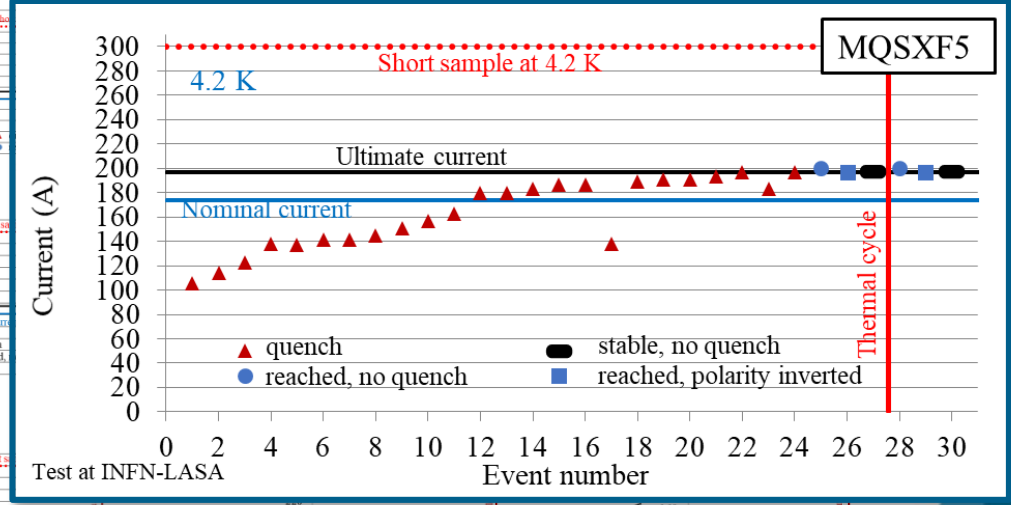


By R. Valente
M. Statera

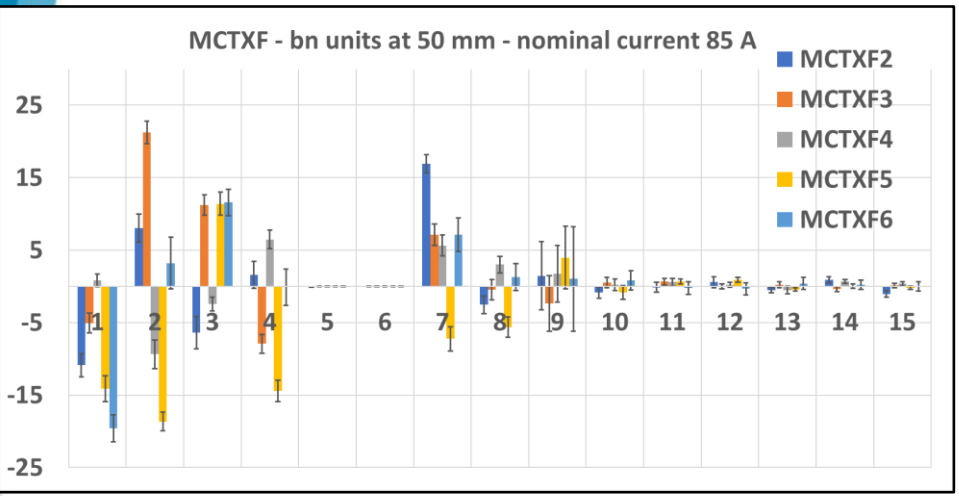


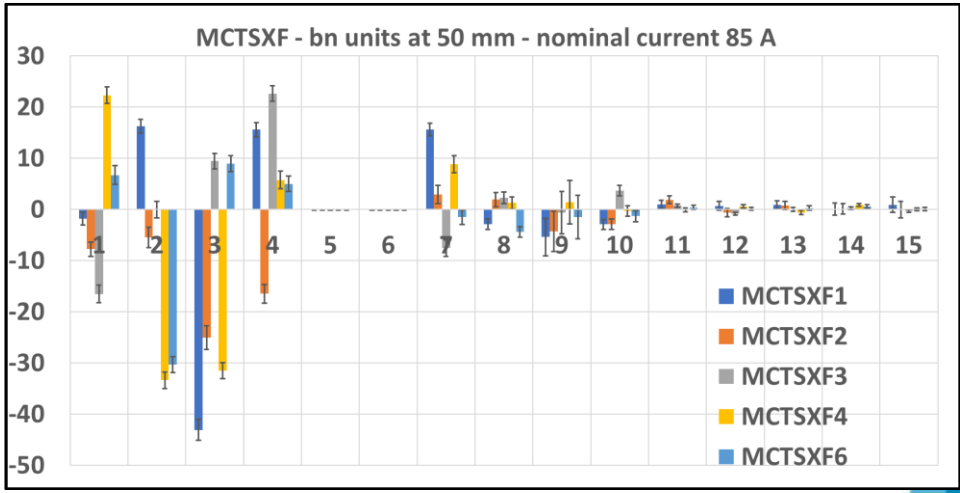
Training


MCOXF08
Short sample at 4.2 K
4.2 K
Thermal cycle
Ultimate current
Nominal current
quench
reached, no quench
stable, no quench
reached, polarity inverted
Current (A)
Event number
Test at INFN-LASA


MQSXF5
Short sample at 4.2 K
4.2 K
Ultimate current
Nominal current
Thermal cycle
quench
reached, no quench
stable, no quench
reached, polarity inverted
Current (A)
Event number
Test at INFN-LASA

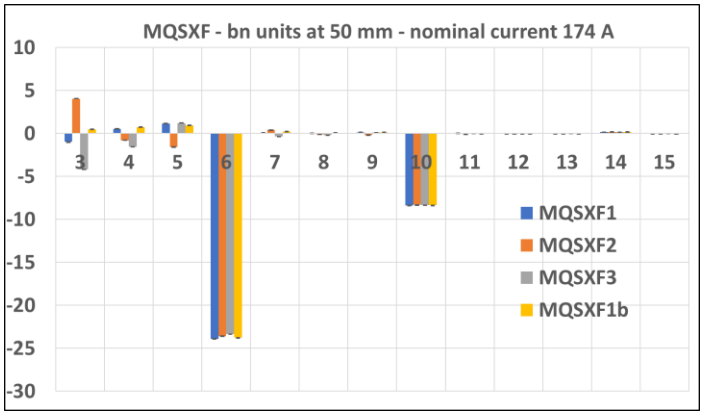
MM results 1

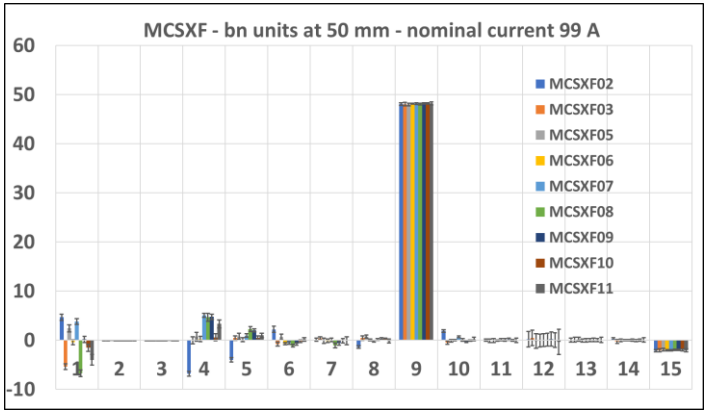


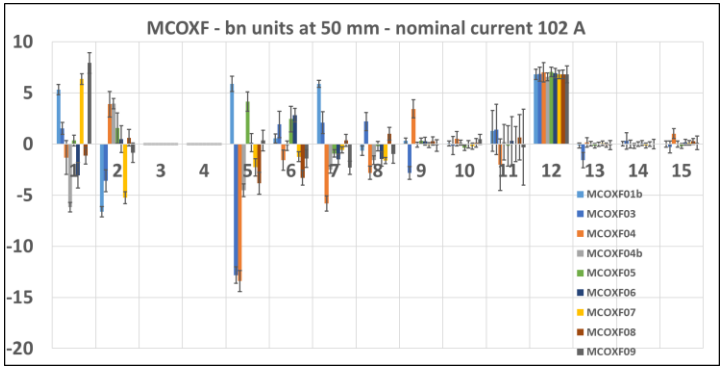


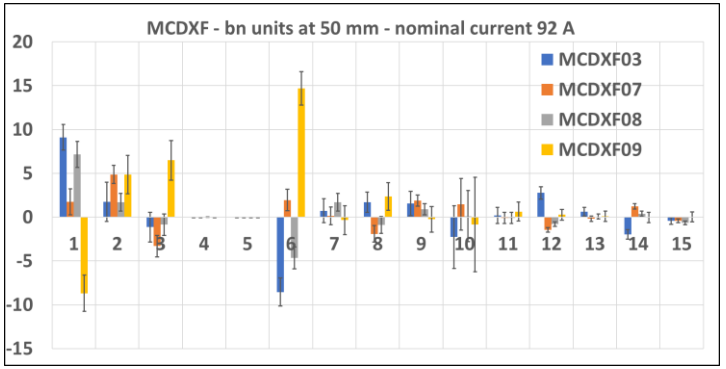
- Very reproducible
- Monitor of assembly quality over time

MM results 2

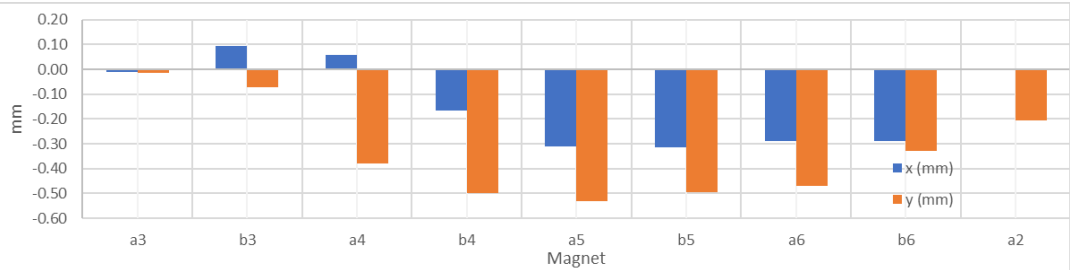

MQSXF - bn units at 50 mm - nominal current 174 A
MQSXF1
MQSXF2
MQSXF3
MQSXF1b


MCSXF - bn units at 50 mm - nominal current 99 A
MCSXF02
MCSXF03
MCSXF05
MCSXF06
MCSXF07
MCSXF08
MCSXF09
MCSXF10
MCSXF11


MCOXF - bn units at 50 mm - nominal current 102 A
MCOXF01b
MCOXF03
MCOXF04
MCOXF04b
MCOXF05
MCOXF06
MCOXF07
MCOXF08
MCOXF09


MCDXF - bn units at 50 mm - nominal current 92 A
MCDXF03
MCDXF07
MCDXF08
MCDXF09

Integration



Mechanical integration

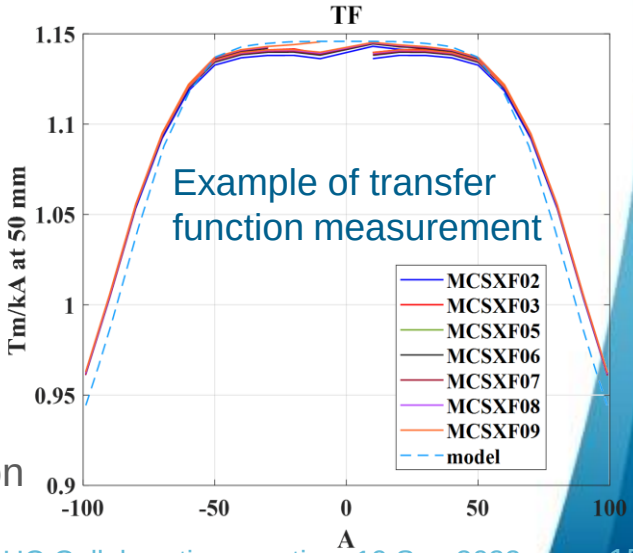
Assembly in b.180 by H. Prin

Alignment measurement by C. Petrone

Field Description of the LHC (FiDeL) model

Transfer function of LHC magnets by several effects by A. Chmielinska, L. Fiscarelli

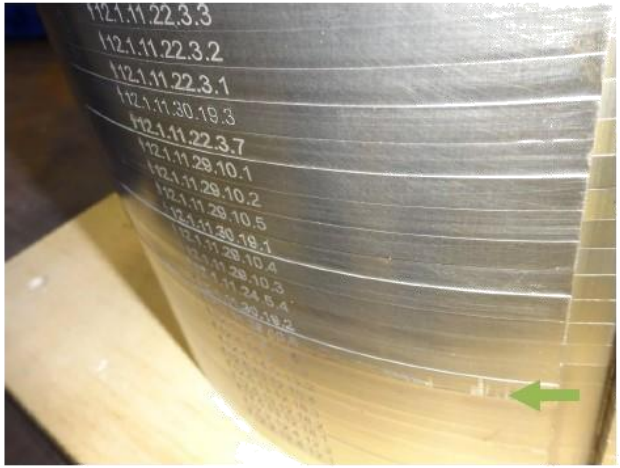
Geometric, DC magnetization, saturation, residual magnetization

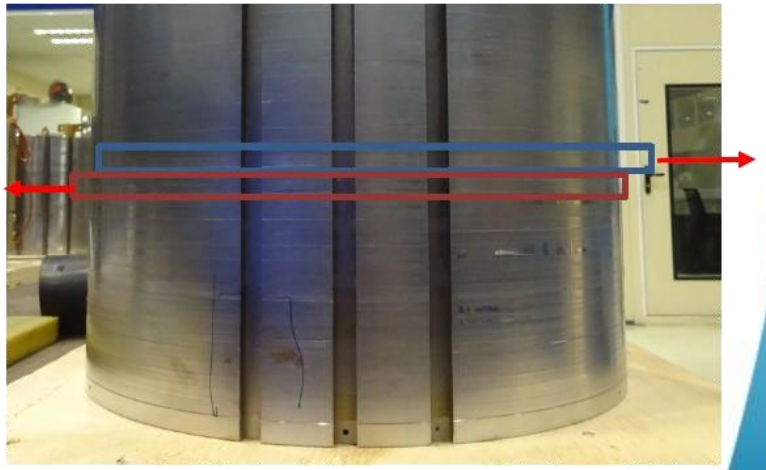


NCs and challenges

- Updated design to improve robustness of coil positioning (wedges) ok
- Handling has to be monitored

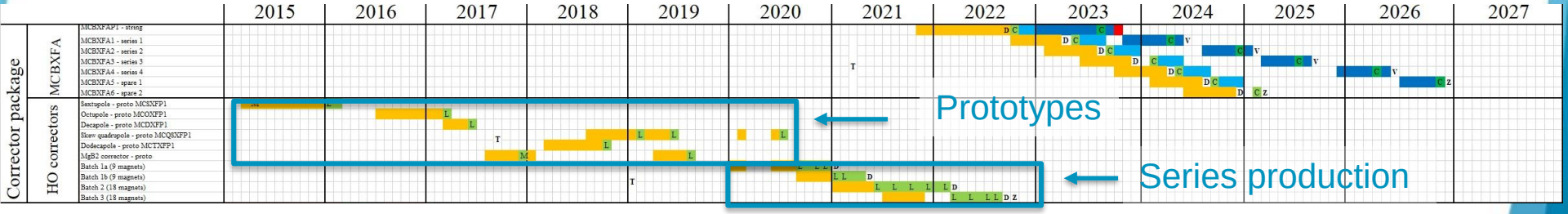
EDMS 2649775
MCTXF1b test ongoing





Schedule

- Delays in testing due to covid restriction
- Delays in testing due cryogenic maintenance and safety update
- Expected end of testing at LASA Dec 2022



Conclusions

- All magnets assembled
- 75 % of the series magnets have been tested
- About half of the magnets at CERN
- Cold mass preparation ongoing
  - Alignement has been measured
- All HO Correctors tested and delivered to CERN within Jan 2023

INFN LASA

Istituto Nazionale di Fisica Nucleare

Laboratorio Acceleratori e Superconduttività Applicata

THANK YOU

LASA team
F. Broggi, M. Dam, E. De Matteis,
S. Mariotto, A. Paccalini, A. Palmisano,
A. Pasini, D. Pedrini, L. Imeri,
A. Leone, M. Prioli, M. Sorbi, S. Sorti,
M. Statera, M. Todero,
R. Valente
CERN E. Gautheron, E. Todesco