



MQXFA Status

*Giorgio Ambrosio,
with contributions from
the whole MQXFA team*



Acknowledgement

- **US HL-LHC Accelerator Upgrade Project (AUP)**
 - **BNL:** K. Amm, M. Anerella, A. Ben Yahia, H. Hocker, P. Joshi, F. Kurian, J. Muratore, J. Schmalzle, P. Wanderer
 - **FNAL:** G. Ambrosio, G. Apollinari, M. Baldini, J. Blowers, R. Bossert, R. Carcagno, G. Chlachidze, J. DiMarco, S. Feher, S. Krave, V. Lombardo, C. Narug, A. Nobrega, V. Marinozzi, C. Orozco, T. Page, S. Stoynev, T. Strauss, M. Turenne, D. Turrioni, A. Vouris, M. Yu
 - **LBNL:** D. Cheng, P. Ferracin, L. Garcia Fajardo, E. Lee, M. Marchevsky, M. Naus, I. Pong, S. Prestemon, K. Ray, G. Sabbi, G. Vallone, X. Wang
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- **CERN: HL-LHC Project**
 - G. Arnau Izquierdo, A. Ballarino, M. Bajko, C. Barth, N. Bourcey, B. Bulat, M. Cruovizier, A. Devred, H. Felice, S. Ferradas Troitino, L. Fiscarelli, J. Fleiter, M. Guinchard, O. Housiaux, S. Izquierdo Bermudez, N. Lusa, F. Mangiarotti, A. Milanese, A. Moros, P. Moyret, C. Petrone, J.C. Perez, H. Prin, R. Principe, E. Ravaioli, T. Sahner, S. Sgobba, P. Tavares Coutinho Borges De Sousa, E. Todesco, J. Ferradas Troitino, R. Van Weelderren, G. Willering

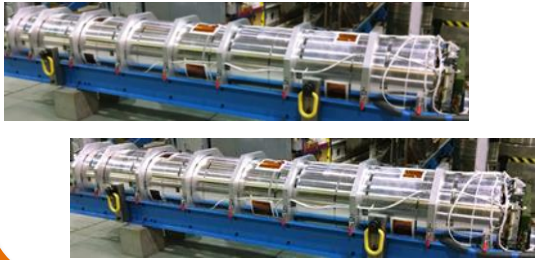
MQXFA (AUP 302.2) Deliverables

■ 20 Magnets

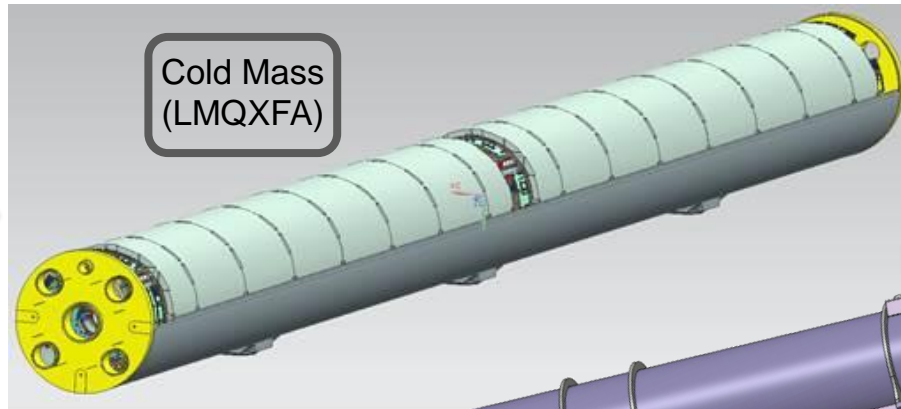
- 16 magnets for 8 Q1/Q3 to be installed in LHC tunnel
- 4 magnets for 2 Q1/Q3 commissioning spares
- (assuming: 4 re-assemblies = post test re-work)
- (assuming: 1 damaged during handling or shipment)



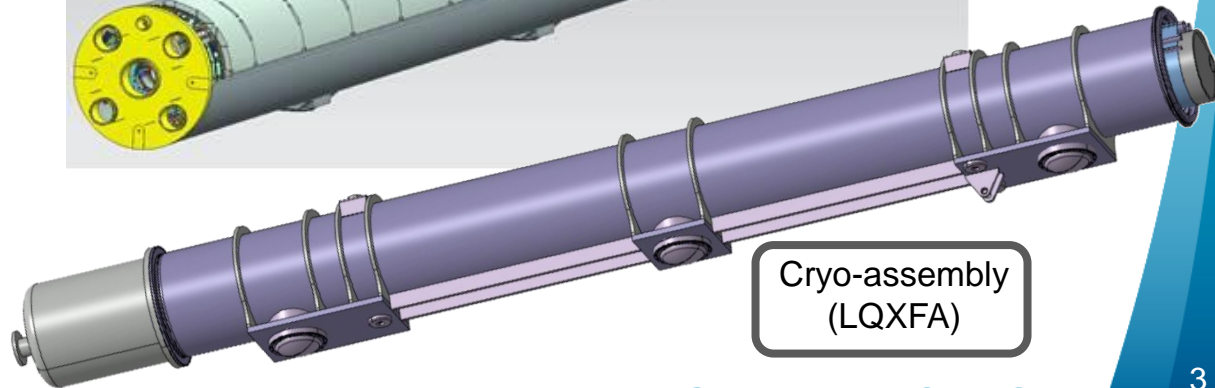
Magnet
(MQXFA)



Cold Mass
(LMQXFA)



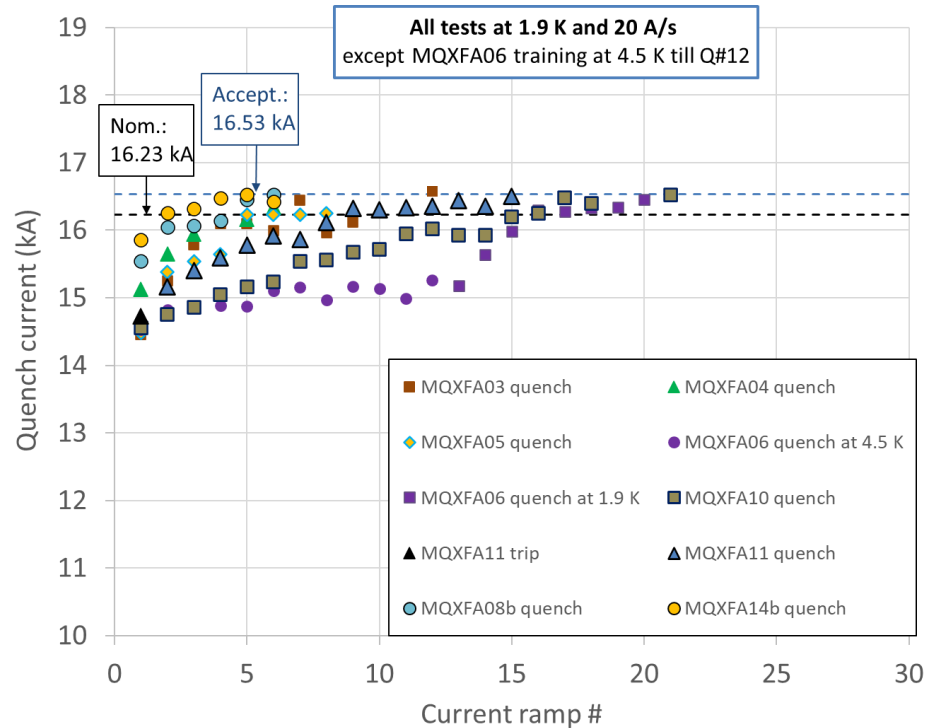
Cryo-assembly
(LQXFA)



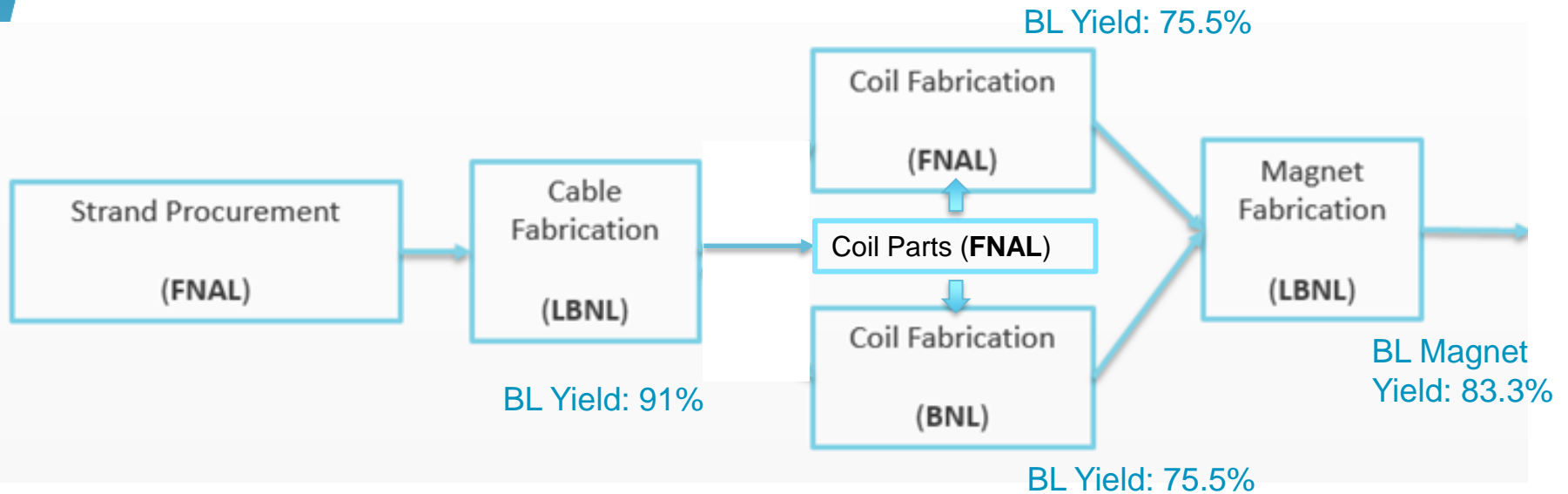
The Big Picture

MQXFA magnets

- Tested: 11
- Met Requirements: 8 →
- Did not meet requir.: 3
- Waiting for test: 1
- Being assembled: 2



Status Summary



Component	Status	Actual yield	Yield in Baseline
Strand procurement	98% complete	-	-
Cable fabrication & insulation	98% complete	95.5%	91%
Coil fabrication	96% complete	88.7%*	
Coil yield due to magnet integration & test	-	84%**	
Total coil yield	-	74.5%	75.5%
Magnet assembly	~50% complete		
Magnet yield after vertical test	11 tests	82.8%**	83.3%



*,** see backup slides for notes

Conductor Procurement & QC

- Conductor delivery:
 - ~98% conductor received (out of 260 km, including LARP proc.)
 - Last shipment (40 km) expected in October 2023
 - Some spools that were reworked received extra lubricant, and impacted cable stability (see next slide)
- Strand verification 98% complete
- Cable qualification 100%
- Witness Sample tests ~94%

Cable Fabrication & Insulation

- Cable Fabrication & Insulation Status:
 - Fabricated: 111 (+ 4 from LARP)
 - To be fabricated: 2
- Cable yield:
 - Yield is **95.5%** (4 rejected, 2 on-hold), vs. 91% assumed in Baseline
 - Some cables (5) were on-hold because of strand lubrication issue causing cable mechanical instability
 - Coil fabrication teams (at FNAL and BNL) were able to fix all popped strands in 3 cables and fabricate 3 coils

Coil Fabrication at FNAL & BNL

- Coil fabrication is **96% complete** (out of 106 coils)

	Coils at FNAL*	Coils at BNL	Total	Baseline
Accepted after fabr.	42	41	83	
In Fabrication	2	5	7	
Rejected	4	3	7	
On Hold	6	3	9	
Total	54	52	106	106
Fabrication Yield			88.7%	

	After Integration	After Vertical Test	Total	Baseline
Rejected	2	3	5	
On Hold	5	0	5	
Accepted after Test			32	80
Integration & Test Yield** ¹			84.0%	
TOTAL Coil Yield			74.5%	75.5%

¹Assuming to use some coils on hold



More details on **Thursday** in
MQXFA fabrication status and schedule

MQXFA Structure Proc. & Magnet Assembly

- Procurement of main parts is complete
- Two assembly lines at LBNL are fully operational
 - staggered mode
- 15 magnets have been assembled
 - 11 tested (8 successful, 2 reworked, 1 to be reworked)
 - 2 disassembled for NCRs
 - 1 preload adjustment based on lessons learned from MQXFA13
 - 1 ready for test (MQXFA07b)
- Assemblies of MQXFA16 and MQXFA17 are in progress.

More details on **Thursday** in [MQXFA, magnet assembly and preload](#) by Dan Cheng



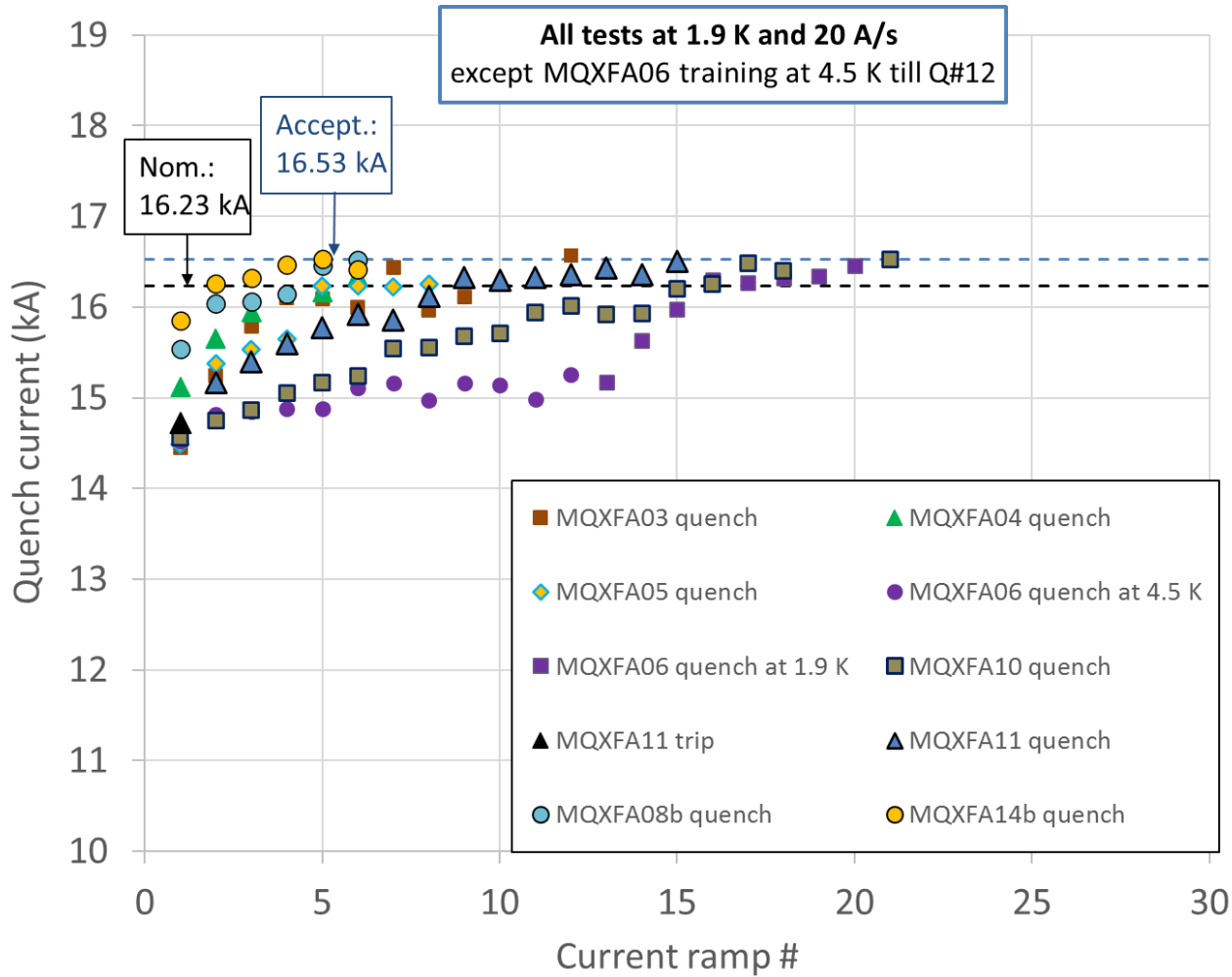
Two MQXFA assembly lines at LBNL



MQXFA shell-yoke assembly in process

MQXFA Vertical Test (by 302.4)

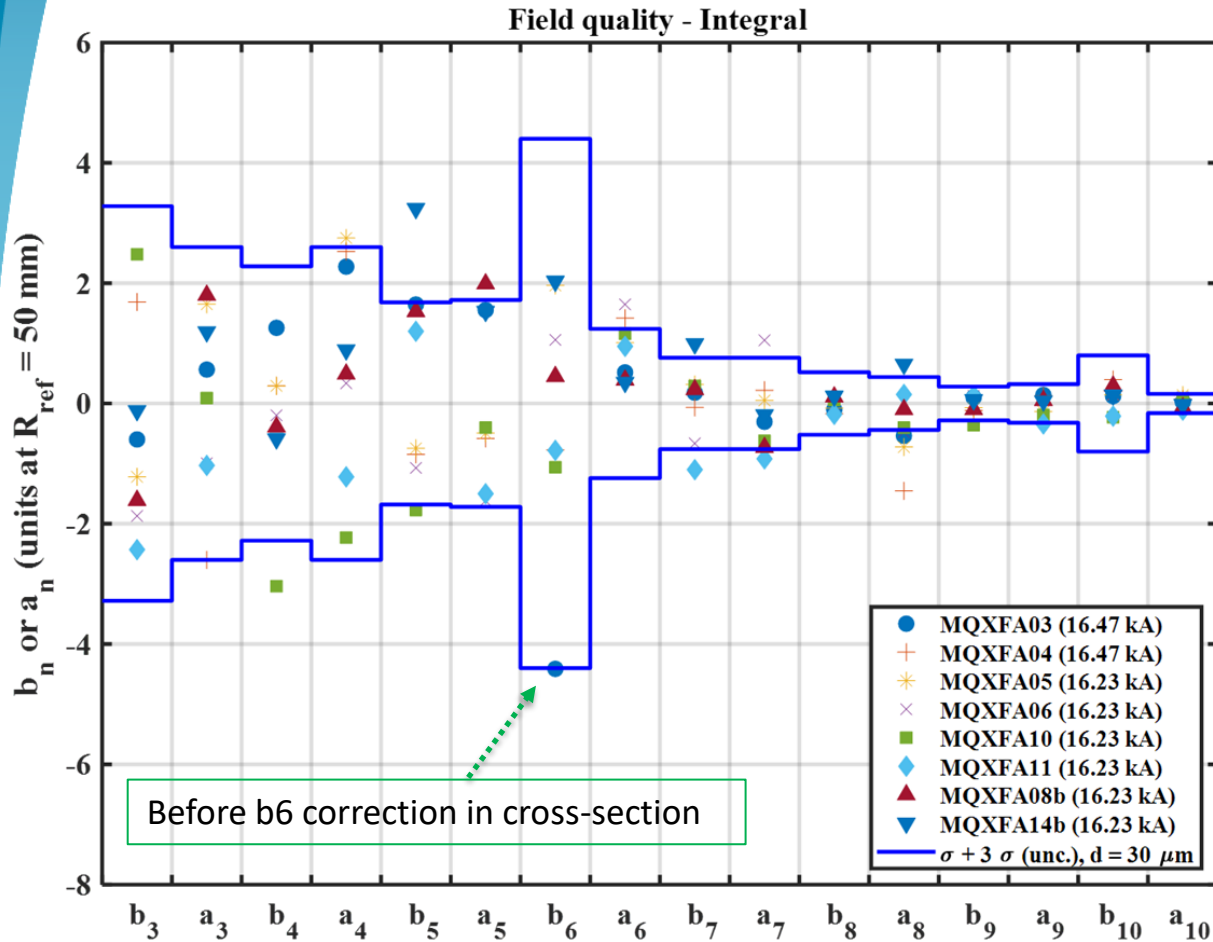
8 magnets met requirements out of 11 tests



MQXFA magnet being moved to vertical test station at BNL 10

More details on **Wednesday** in **Test Production testing summary of the MQXFA magnets** by Anis Ben Yahia; and in **Field quality and integrated gradient in MQXFA magnets and LQXFA/B01** by Joe Di Marco.

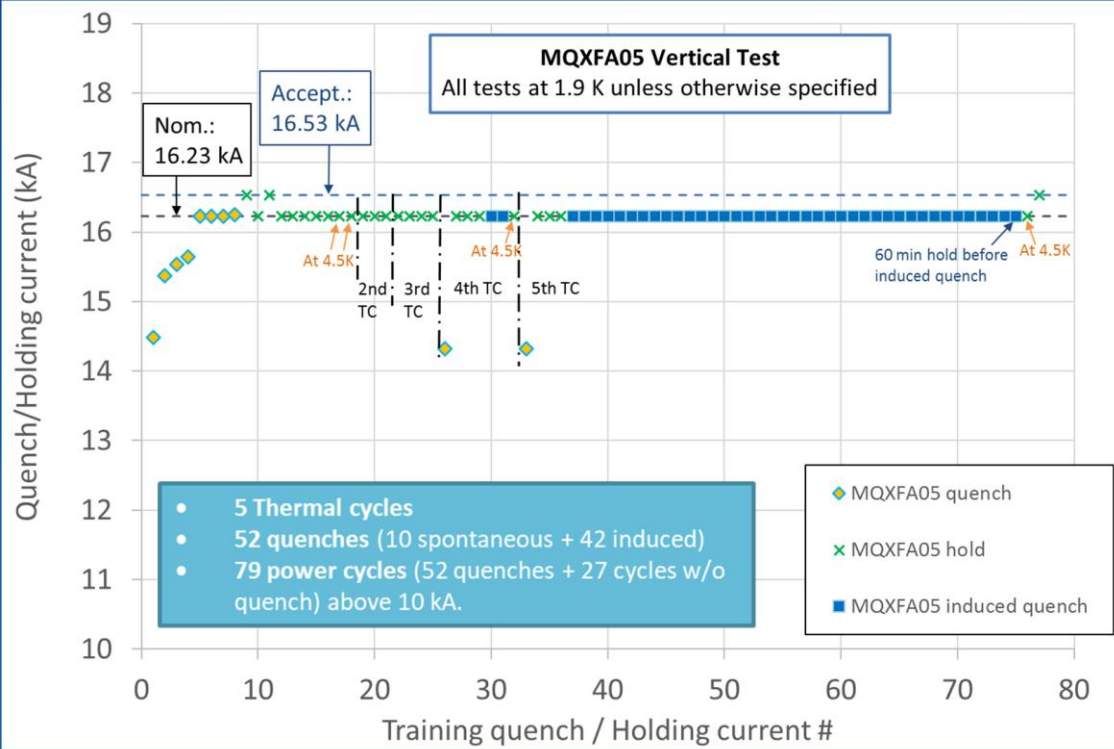
MQXFAs Integral Harmonics at Nominal Curr.



b_6 correction introduced in one coil on MQXFA04 and all subsequent coils:
125 μm shift toward midplane

Magnetic shims used to correct low order harmonics

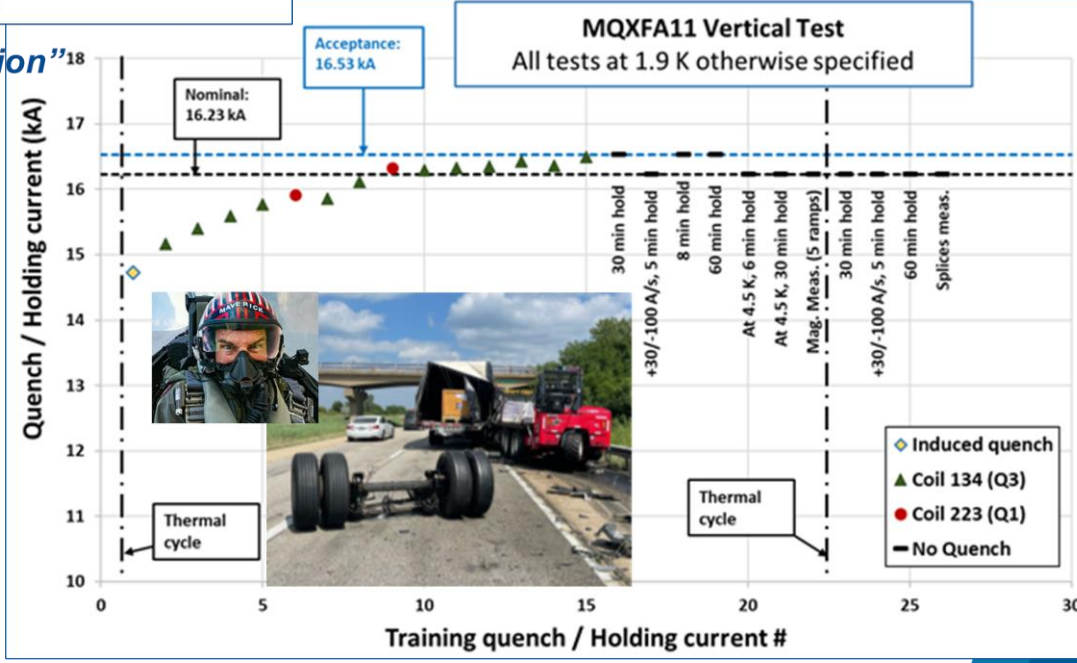
More details on **Wednesday** in **Field quality and integrated gradient** in MQXFA magnets and LQXFA/B01 by Joe Di Marco.



“Endurance” & “Resilience” Demonstrations

MQXFA05 “Endurance Demonstration”

More details on **Wednesday** in **Test Production testing summary of the MQXFA magnets** by Anis Ben Yahia.

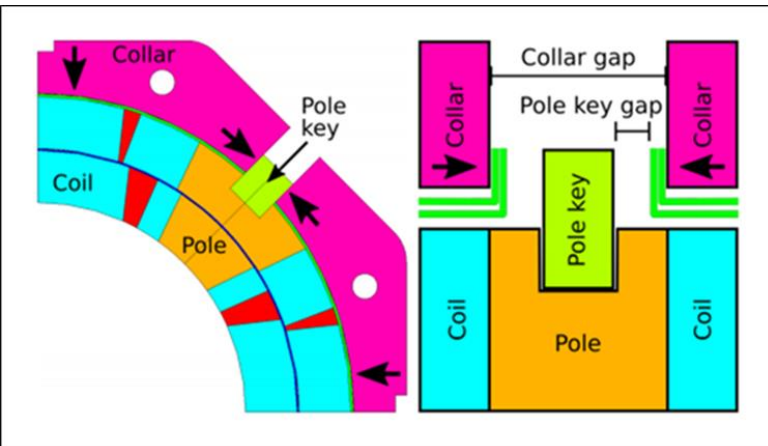


MQXFA11 “Resilience Demonstration”

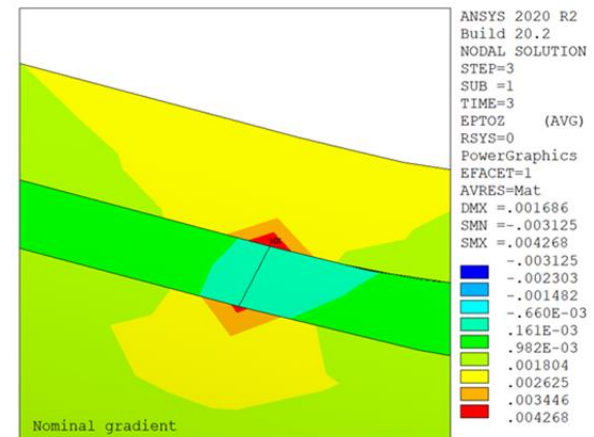


Lessons Learned from MQXFA07/08 NCR

- MQXFA07 and MQXFA08 non-conformity analyses are complete (AUP doc-4293 & 4776; EDMS# 2777612)
 - “Smoking gun” (broken Nb_3Sn filaments) was found through metallographic analysis by CERN team
- Lessons learned:
 - Asymmetry during assembly may be looked-in by prestress
 - 2D asymmetry may cause poor preload in the ends
 - COVID restrictions contributed to these issues
- All causes have been addressed for future magnets



Closed pole key gap in a coil may lead to poor longitudinal preload in the ends of that coil at edge to end-spacer transition



Lessons Learned from MQXFA13 NCR

- MQXFA13 investigation is in progress
 - metallographic analysis to be performed at CERN
- **Main suspect: Small arc-length in the ends of all coils caused low pre-load and high strain in the ends.**
 - Limiting coil had smallest arc-length of all tested coil
- Preventive actions:
 - Increased the maximum allowable stress during preload: from 110 to 120 MPa
 - Target for minimum loading key size based on coil dimensions

More details on **Thursday** in **MQXFA, magnet assembly and preload** by Dan Cheng

Plans and Schedule

- Plans for magnet assembly:
 - MQXFA07b is at BNL for test
 - MQXFA15 preload adjustment in a couple of weeks after MQXFA16 is complete
 - MQXFA16 & MQXFA17 have high priority for test in CA05
 - MQXFA13b and MQXFA12b after them
 - MQXFA09 was retired
 - 2 coils and structure reused in other magnets

- Working Schedule

- August update:

Magnet Assembly	P6 Schedule	
P6 Label	Start	Finish
MQXFA-16	8-Aug-23	11-Oct-23
MQXFA-17	20-Sep-23	22-Nov-23
MQXFA-18	15-Dec-23	23-Feb-24
MQXFA-19	2-Feb-24	5-Apr-24
MQXFA-20	15-Mar-24	17-May-24
MQXFA-21	26-Apr-24	1-Jul-24
MQXFA-22	10-Jun-24	13-Aug-24
MQXFA-23	23-Jul-24	25-Sep-24
MQXFA-R3	16-Oct-24	26-Dec-24
MQXFA-R4	27-Nov-24	11-Feb-25

Conclusions

- The fabrication of MQXFA magnets by US-AUP is at peak production rate.
 - Strand procurement, Cable fabrication, Coil fabrication are almost complete
 - Magnet assembly is close to 50% complete
- Cable yield is higher than starting assumption, whereas coil yield is lower. Baseline was changed accordingly.
- Three magnets out of eleven did not meet requirements during vertical test. Lessons were learned and changes implemented.
- Last magnet to be completed around beginning of 2025

Back up Slides



Status Summary

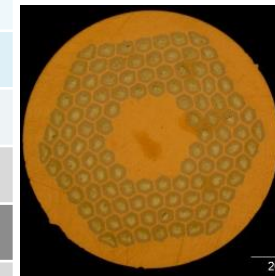
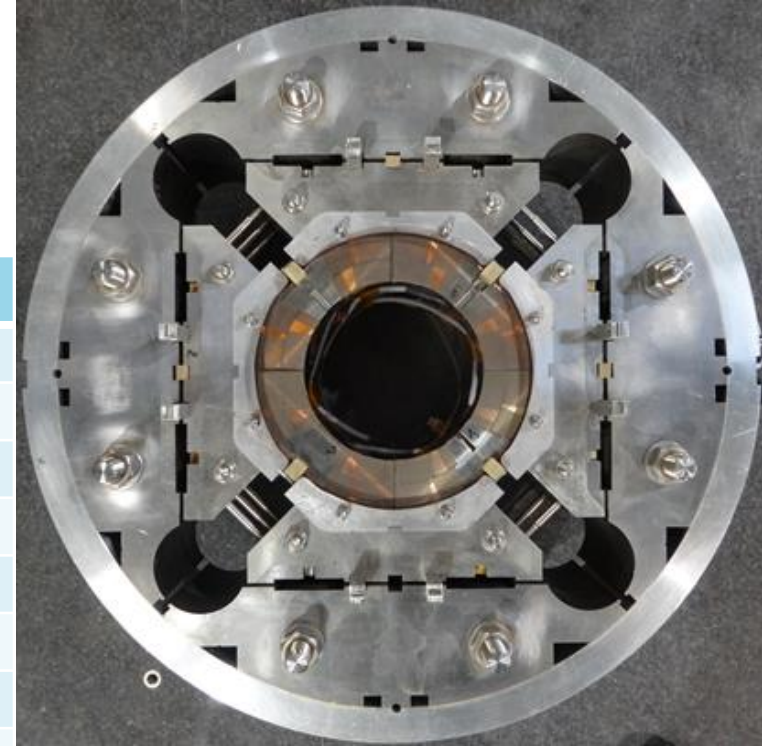
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*The actual yield includes the sum of the probabilities of using coils on hold (i.e. 2 coils with 50% probability of being used = 1 coil approved for use).

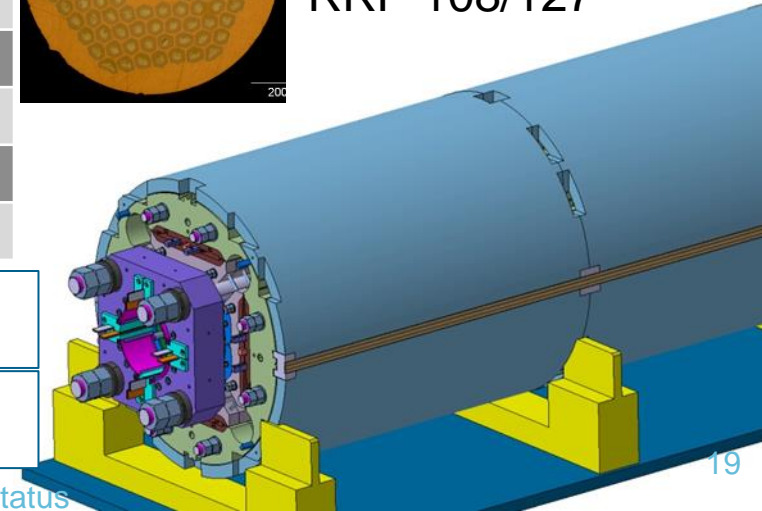
**MQXFA07 and MQXFA08 coils and magnets were fabricated under Covid restrictions. AUP project was re-baselined assuming that 66% of MQXFA07 and MQXFA08 limited performances were due to the impact of Covid restrictions. These issues assumed to be Covid impact were not included in the actual yield.

MQXFA/B Design

PARAMETER	Unit	MQXFA/B
Coil aperture	mm	150
Magnetic length	m	4.2/7.15
N. of layers		2
N. of turns Inner-Outer layer		22-28
Operation temperature	K	1.9
Nominal gradient	T/m	132.2
Nominal current	kA	16.23
Peak field at nom. current	T	11.3
Stored energy at nom. curr.	MJ/m	1.15
Diff. inductance	mH/m	8.26
Strand diameter	mm	0.85
Strand number		40
Cable width	mm	18.15
Cable mid thickness	mm	1.525
Keystone angle		0.4



Nb₃Sn Conductor
RRP 108/127



P. Ferracin et al., "Development of MQXF, the Nb₃Sn Low-β Quadrupole for the HiLumi LHC" IEEE Trans App. Supercond. Vol. 26, no. 4, 4000207

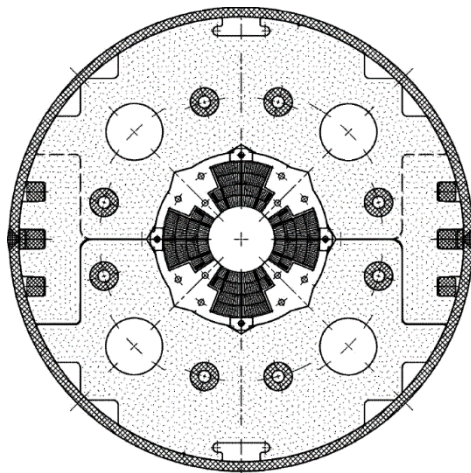
G. Ambrosio et al., "First Test Results of the 150 mm Aperture IR Quadrupole Models for the High Luminosity LHC" NAPAC16, FERMILAB-CONF-16-440-TD

Low- β quadrupole magnets from LHC to HL-LHC

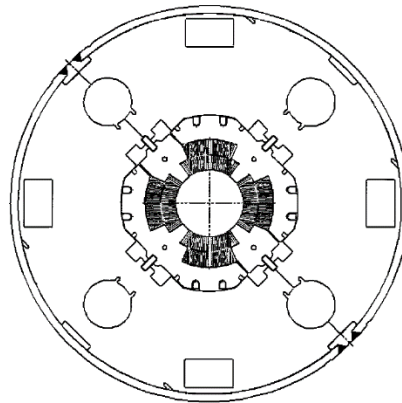
- Cold mass OD from 490/420 to **630 mm**
- More than double the aperture: from 70 to **150 mm**
- **~4 times** the e.m. forces in straight section
- **~6 times** the e.m. forces in the ends

State of the art quadrupoles at the time of LHC construction

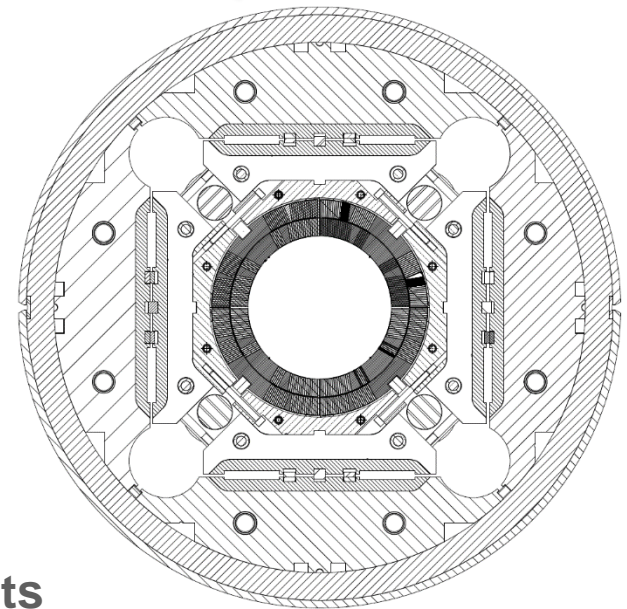
MQXA



MQXB



MQXF



Same scale for all 3 plots