HiLumi HL-LHC PROJECT

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Assembly of MQXFBP1 prototype, the Nb_3Sn Q2 quadrupole for HL-LHC

F. Lackner, P. Ferracin

On behalf of the MQXFB collaboration

22nd – 27th of September 2019

CERN

US HL-LHC AUP

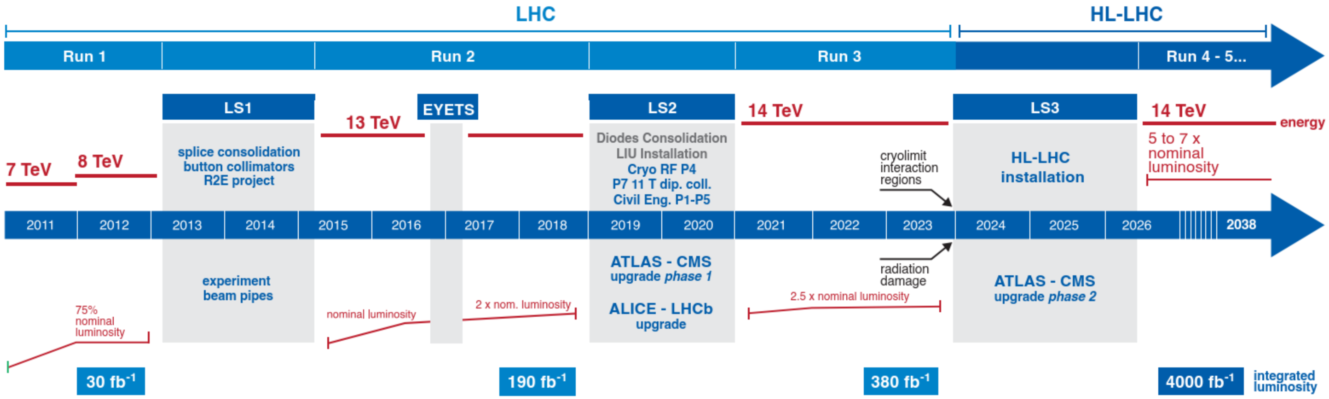
Acknowledgments

- CERN
  - A. Ballarino, H. Bajas, M. Bajko, B. Bordini, N. Bourcey, J.C. Perez, S. Izquierdo Bermudez, S. Ferradas Troitino, L. Fiscarelli, J. Fleiter, M. Guinchard, O. Housiaux, F. Mangiarotti, A. Milanese, P. Moyret, H. Prin, R. Principe, E. Ravaioli, T. Sahner, S. Sequeira Tavares, E. Takala, E. Todesco

- US Accelerator Upgrade Project (AUP)
  - BNL: M. Anerella, P. Joshi, J. Muratore, J. Schmalzle, P. Wanderer
  - FNAL: G. Ambrosio, M. Baldini, J. Blowers, R. Bossert, G. Chlachidze, L. Cooley, S. Krave, F. Nobrega, V. Marinozzi, I. Novitsky, C. Santini, S. Stoynev, T. Strauss, M. Yu
  - LBNL: D. Cheng, M. Marchevsky, H. Pan, I. Pong, S. Prestemon, G. Sabbi, G. Vallone, X. Wang
  - NHMFL: Lance Cooley

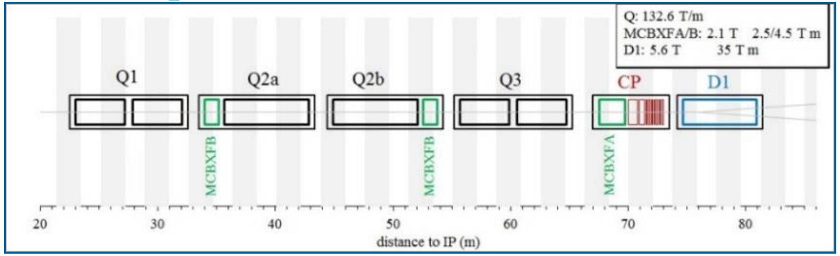
From LHC to HL-LHC

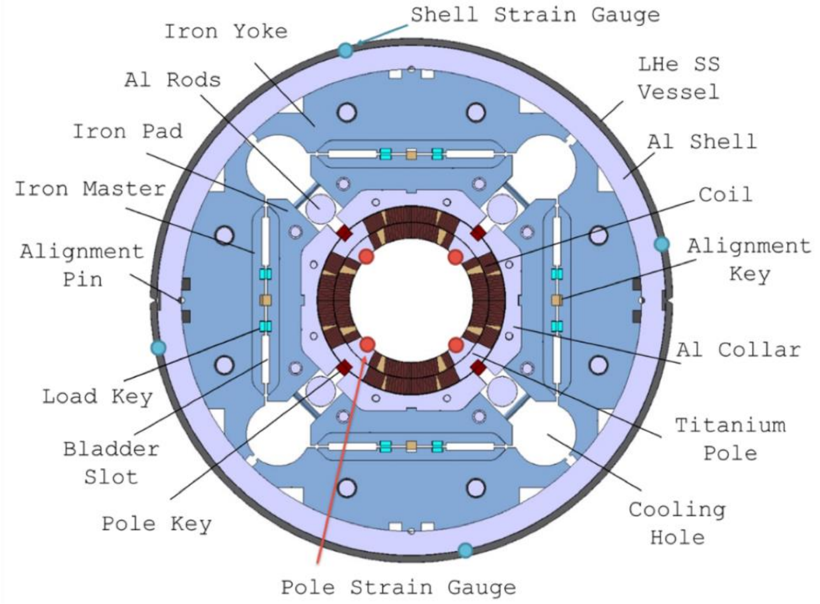
- LHC
  - Integrated luminosity of 300 fb^{-1} by 2023
    - About 2.5 $\times 10^{16}$ proton-proton collisions
- HL-LHC
  - Upgrade the Interaction Region in 2024-2026
  - 3000 fb^{-1} integrated luminosity in following ~12 years



HiLumi low-β quadrupole MQXF

- Target
  - G_{nom}=132.6 T/m, 11.4 T B_{peak_nom}
    - Corresponds to 14 Tev in LHC
  - G_{ult}=143.2 T/m, 12.3 T B_{peak_ult}
- Q1/Q3 (by AUP)
  - 2 magnets MQXFA with 4.2 m
    - Series: 20 magnets
- Q2a/Q2b (by CERN)
  - 1 magnet MQXFB with 7.15 m
    - Series: 10 magnets
- Different lengths, same design
  - Identical short models

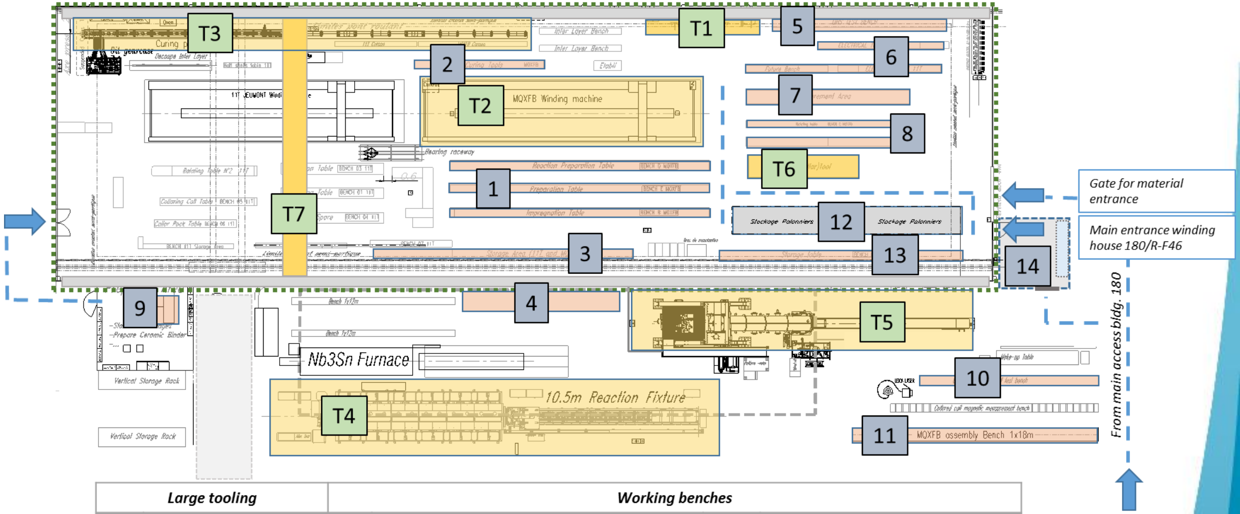




MQXFB production at CERN

- Work carried out in the shadow of the 11T dipole fabrication
- The Large Magnet Facility has started to produce first MQXFB coils in 2016 (Cu, low grade Nb_3Sn)
- Infrastructure, procedures, QA/QC were continuously improved
- The coil production for 1st prototype started in 2017
- Currently the production is resumed after major non-conformities on coils for the second prototype

Production layout – Large Magnet Facility

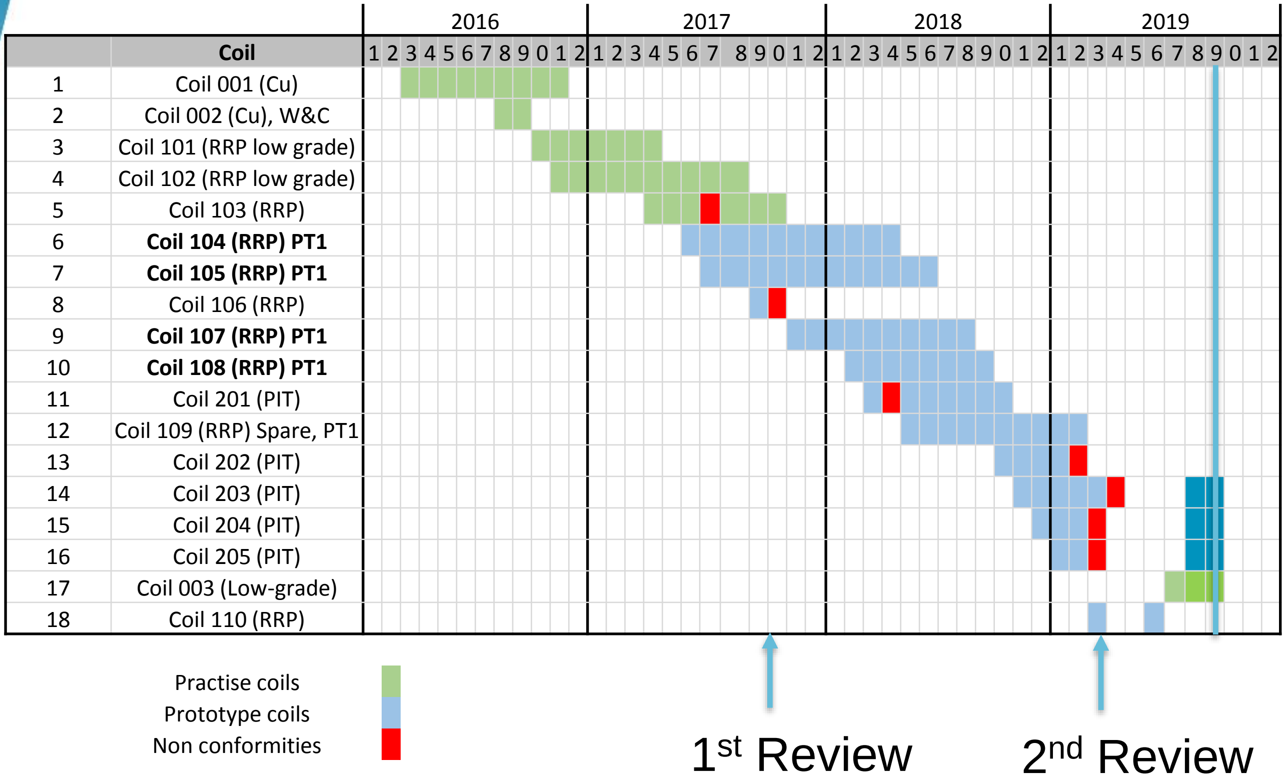


Large tooling		Working benches			
T1	Spooling bench	1	Reaction and impregnation fixture assembly/disassembly	8	Ground insulation preparation
T2	Winding machine	2	Curing tooling	9	Copper wedge preparation
T3	Curing press	3	Coil storage area	10	Impregnation preparation bench
T4	Reaction furnace	4	Coil storage rack	11	Magnet assembly/coil pack insertion
T5	Vacuum impregnation system	5	Quench heater QC	12	Lifting girder storage
T6	Coil pack assembly	6	Electrical QC of coils	13	Interlayer preparation
T7	Gantry crane (15 tons)	7	Geometrical QC	14	Access (SAS)

Overview on progress

- **Full validation of tooling** (coil fabrication, coil pack and magnet assembly), implementation of identified sources for improvement (2015 - 2016)
- **Test assembly based on practice coils in 2017 – 2018** (Copper and low grade Nb_3Sn)
- **Iterative improvements applied on procedures + tooling is still ongoing**
- **Production of prototype coils (6 RRP, 3 PIT)**
- **Assembly and loading of 1st prototype magnet** (2019)
- **Procedure update prior PT2** coil fabrication

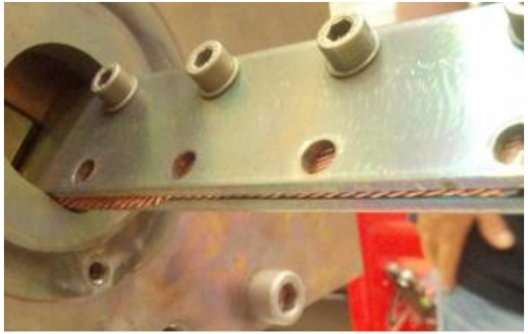
Production rate 2016 - 2019



- No show stopper during the start up phase of the practice coils and dummy assembly
- No non-conformities on tooling and machines
- Production rate comparable to the one of short model coils
- Due to major NC's a 2nd review of procedures was launched in spring 2019

NCs during coil fabrication for PT1

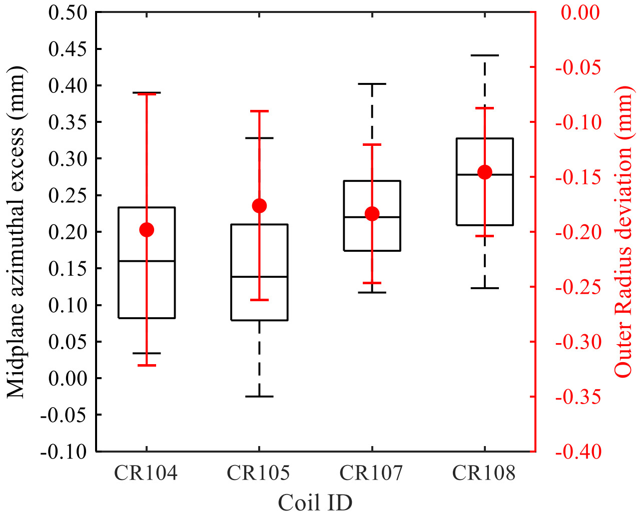
- CR103, 07/2017: NC during RHT due to a non verified tooling to support lead ends. Coil impregnated but rejected
  - Action item: No tooling adaptation without prior approval



- CR106, 09/2017: NC during winding due to interchange of IL and OL reel. IL unwound, OL used for short model.
  - Action item: Checklist and cable reel measurements

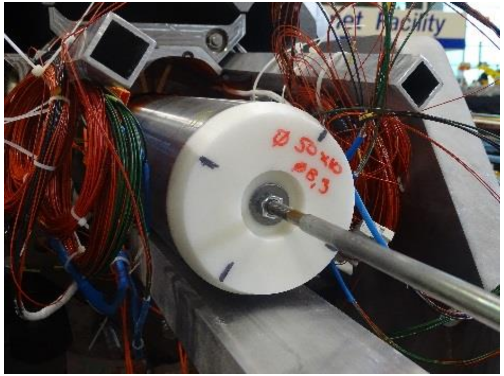
Metrological inspection

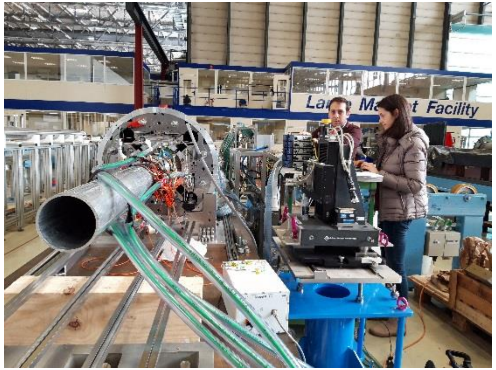
- The inspection is carried out by a FARO Arm and consists of measuring 37 transversal cross sections of the coil spaced by 200 mm along its length
- Three coil features are measured : Outer radius, pole, mid-planes
- Alignment with CAD dimensions allows to compute azimuthal excess of both coil branches



Coil ID		CR104	CR105	CR107	CR108
Midplane excess	Max (mm)	0.390	0.328	0.402	0.441
	Q75% (mm)	0.233	0.210	0.270	0.328
	Median (mm)	0.160	0.139	0.220	0.278
	Q25% (mm)	0.082	0.079	0.174	0.209
	Min (mm)	0.034	-0.025	0.117	0.123
Outer Radius	Average (mm)	113.178	113.200	113.192	113.230
	Std deviation (mm)	0.123	0.086	0.063	0.058

MQXFBP1 insertion of coil pack and loading

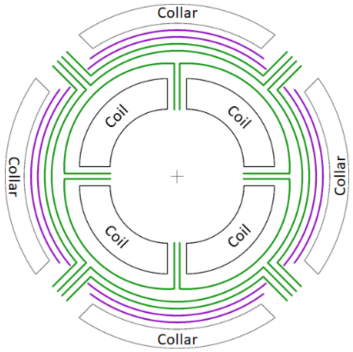




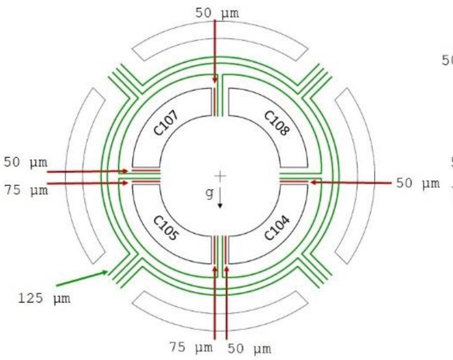
- **Insertion of coil pack**
- **Insulated cold bore tube insertion** into the coil pack
- **Warm magnetic measurements**, coil pack reopened for inspection due to observed high a4 harmonic, excellent repeatability during reassembly
- Local harmonic a4 disappeared after loading operation, very good field quality at RT
- **Lifting tests of coil pack**, single and double coil assembly were successful carried out
- **Electrical QC** in agreement with specified acceptance criteria's

Shimming plan for the MQXFB

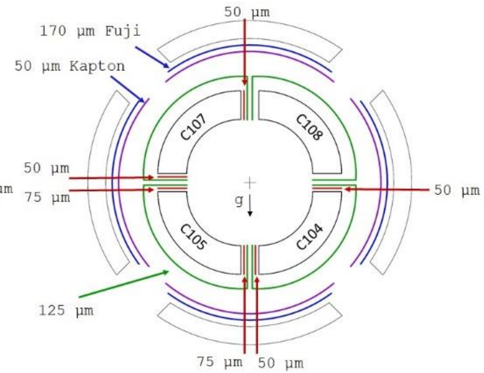
Courtesy: E. Takala



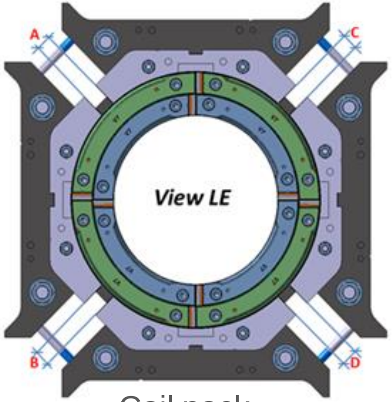
- Nominal shimming plan



- Shimming of PT1

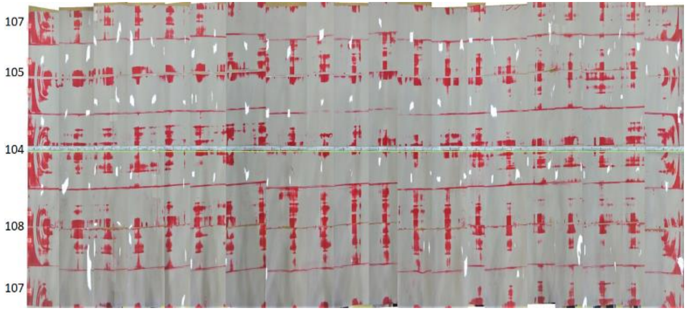


- Shimming including pressure sensitive thin film



- Coil pack

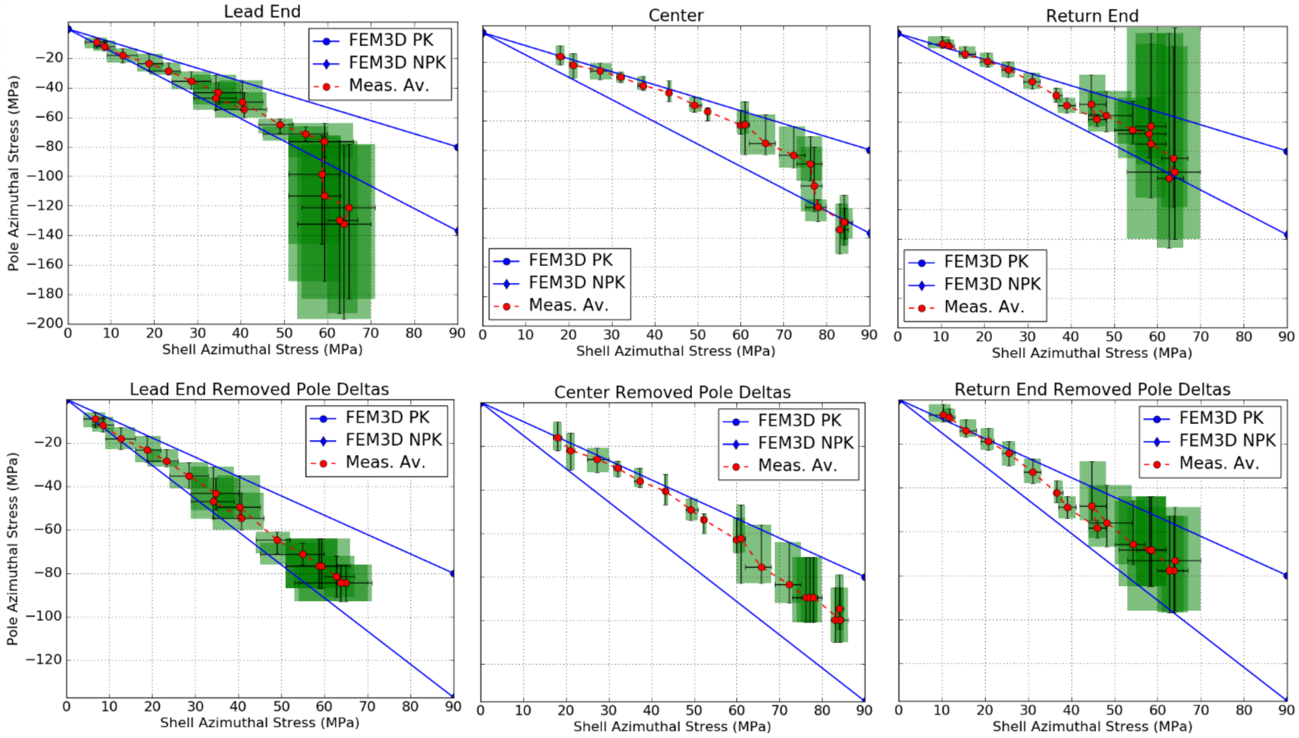
- Shimming plan according to coil metrology
- Assembly of coil pack based on pressure sens. film
  Allows to identify initial conditions for loading and verification of uniform closure of coil pack
- The pole key clearance intercepts part of the stress seen by the coil



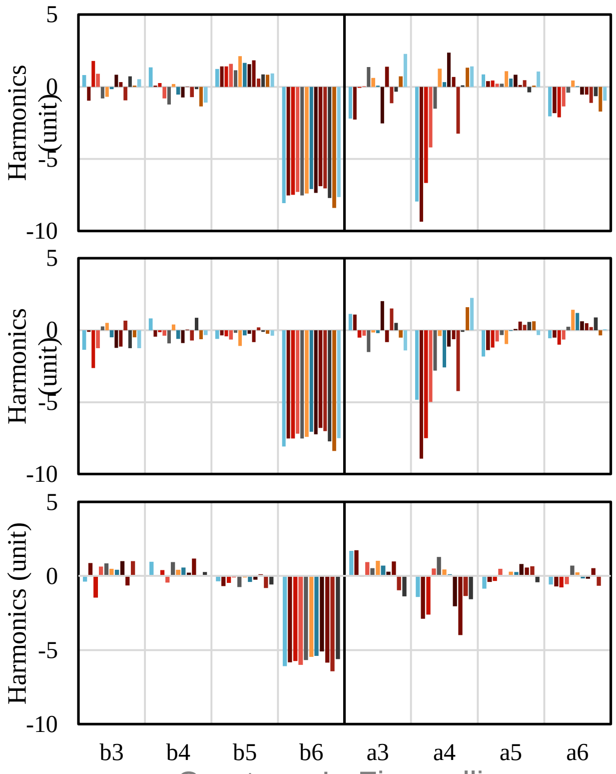
- Verifying the pole key gap

Loading of the first MQXFB prototype

Courtesy: E. Takala

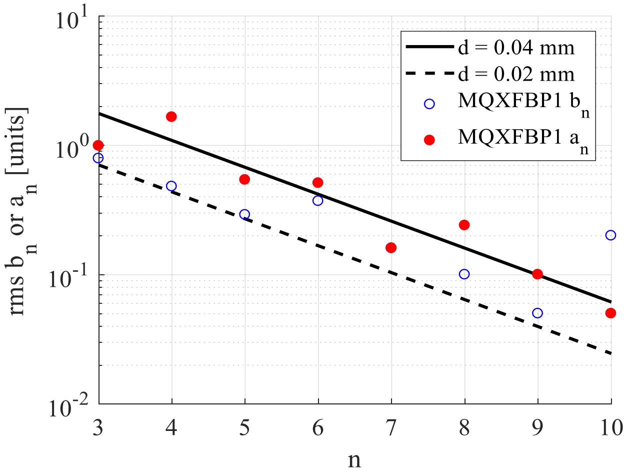


Warm magnetic measurements MQXFB



Courtesy: L. Fiscarelli

- **Magnetic measurement** scans for **(bn)** and skew **(an)** harmonics up to the order 6. Each bar represents one position along the magnet. Top: coil pack; Middle: coil pack after reassembly; Bottom: after loading. The reference radius is 50 mm

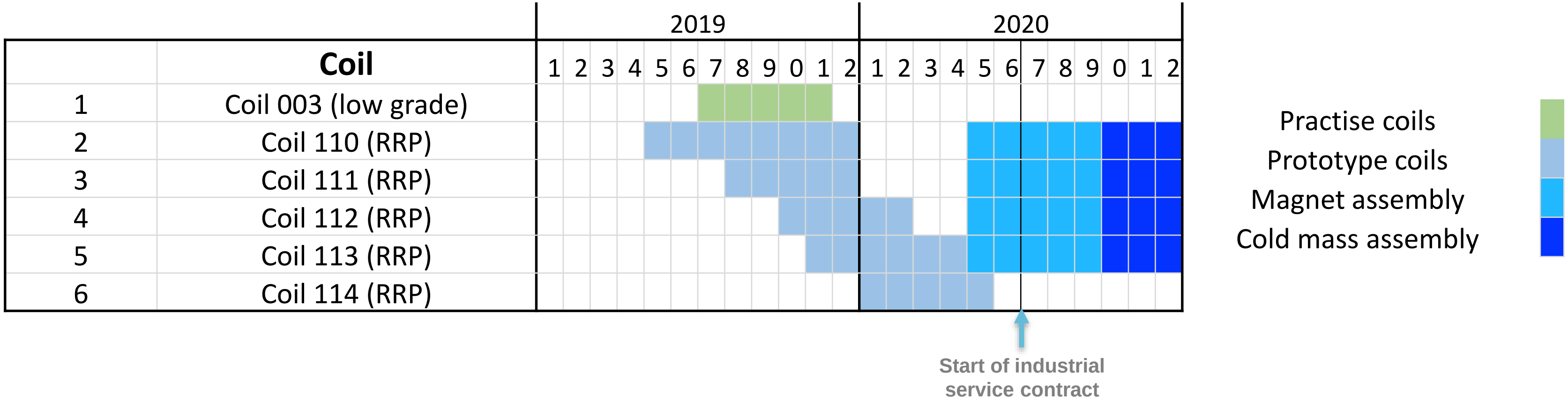


- Harmonics computed over the 13 segments in straight section, corresponds to a precision of 0.02-0.04 mm in the position
- Equivalent to performance observed for the LHC dipole magnets

Status: LMF finishing area, 11T and MQXFB

Towards middle of 2020

- Coil fabrication & magnet assembly for second RRP prototype



- Production of 4 + 1 RRP **coils** for the **2nd prototype** until **May 2020**
- Assembly of yoke pack and **magnet** until **Sept. 2019**
- Cold mass manufacturing and **delivery** for **cryostating** in **Dec. 2020**
- Based on the concept of one production line and subsequent to the termination of the 11T contract: **Launching an industrial service contract in July 2020**

Conclusion

- **Coil fabrication launched** in **02/2016** starting with practice coils
- **6 RRP and 3 PIT coils so far impregnated**
- **First magnet assembly** carried out with **practice coils** in 2018
- **First prototype (RRP) assembled** and loaded successfully in 2019, now in the finishing area and soon assembled into a cryostat. Cold test foreseen in early 2020
- **NC coils** (**4 rejected, 3 in quarantine**), increase of QC
- In line with critical non conformities in **2019 a debugging of procedures** and MIP
- **Production of one practice coil** was launched in 07/2019 to validate findings and procedure improvements
- 2nd Magnet assembly based on test coils currently ongoing for training and development of procedures

HiLumi
HL-LHC PROJECT

MT 26
International Conference on Magnet Technology
Vancouver, Canada | 2019

Thank you !

CERN
US HL-LHC AUP