MQXF status and plans

Paolo Ferracin and Giorgio Ambrosio
on behalf of the MQXF collaboration

6th HL-LHC Collaboration Meeting
14-16 November 2016
Paris

Acknowledgments

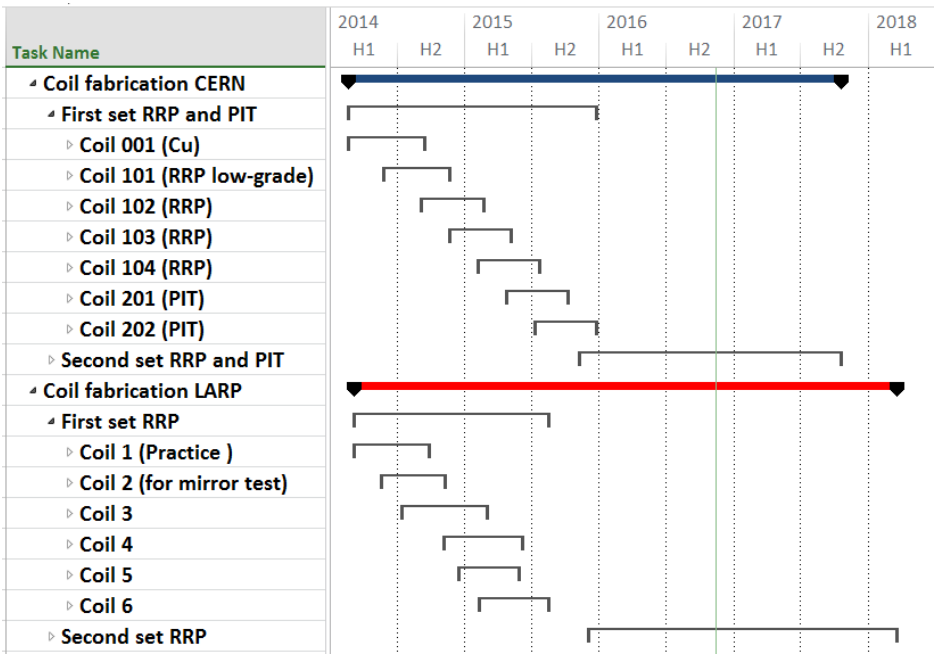
- CERN
  - A. Ballarino, H. Bajas, M. Bajko, B. Bordini, J.C. Perez, S. Izquierdo Bermudez, P. Fessia, C. Fichera, P. Grosclaude, M. Guinchard, P. Hagen, F. Lackner, H. Prin, E. Rochepault, S. Sequeira Tavares, E. Todesco, G. Vallone
- BNL
  - M. Anerella, A. Ghosh, J. Muratore, J. Schmalzle, P. Wanderer
- FNAL
  - G. Ambrosio, R. Bossert, G. Chlachidze, L. Cooley, E. Holik, S. Krave, F. Nobrega, I. Novitsky, S. Stoynev, T. Strauss, M. Yu,
- LBNL
  - D. Cheng, D.R. Dietderich, R. Hafalia, M. Marchevsky, H. Pan, I. Pong, E. Ravaioli, G. Sabbi, X. Wang
- CEA Saclay
  - H. Felice
- LASA
  - V. Marinozzi, M. Sorbi
- Tampere Univerisity of Technology
  - T. Salmi

Outline

- Short model program
- LARP prototype program
- CERN prototype program

Short model program
Coil fabrication

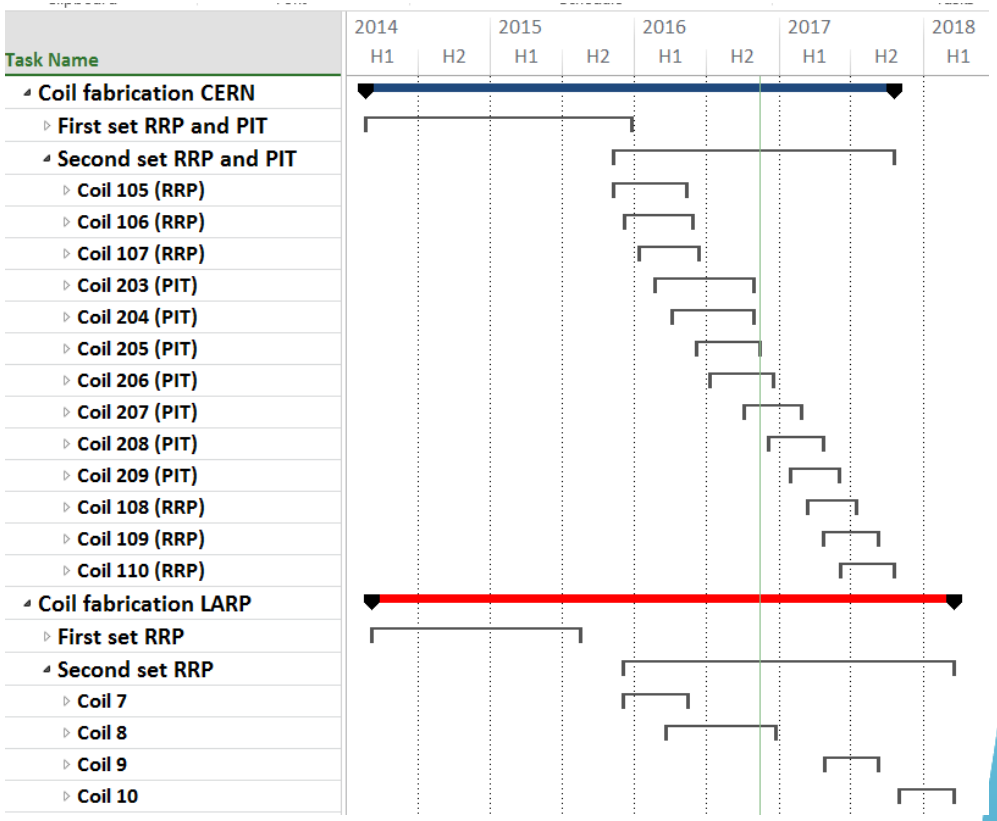
- 1st generation coils: **13**
  - CERN: **7**
    - 1 Cu and 1 low-grade
    - 3 RRP 132/169 and 2 PIT
  - LARP: **6**
    - All RRP 108/127
- Available for test: **9**
- **1** tested in MQXFSM1
  - Coil 2
- **4** tested in MQXFS1
  - 103,104,3,5
- **4** to be tested in MQXFS2
  - 102 (splice issue)
  - 201- 202 (low J_c and RRR)
  - Coil 6



Short model program
Coil fabrication

- 2st generation coils: **17** planned
  - CERN: **11**
    - RRP: 3, 132/169 and 1, 108/127
    - PIT 5 (no barrier) and 2 (barrier)
  - LARP: **6**
    - RRP 3, 132/169 + 2, 144/169 +1, 108/127
- **Proposal**: 2 LARP coils fabricated by CERN with LARP components

- Available for test: **17**
- **4** tested in MQXFS3
  - 105,106,107,7
- **4** to be tested in MQXFS5
  - 203,204,205,206
- **4** to be tested in MQXFS4
  - 9,108,109,110
- **4** to be tested in MQXFS6
  - 207,208,209,8

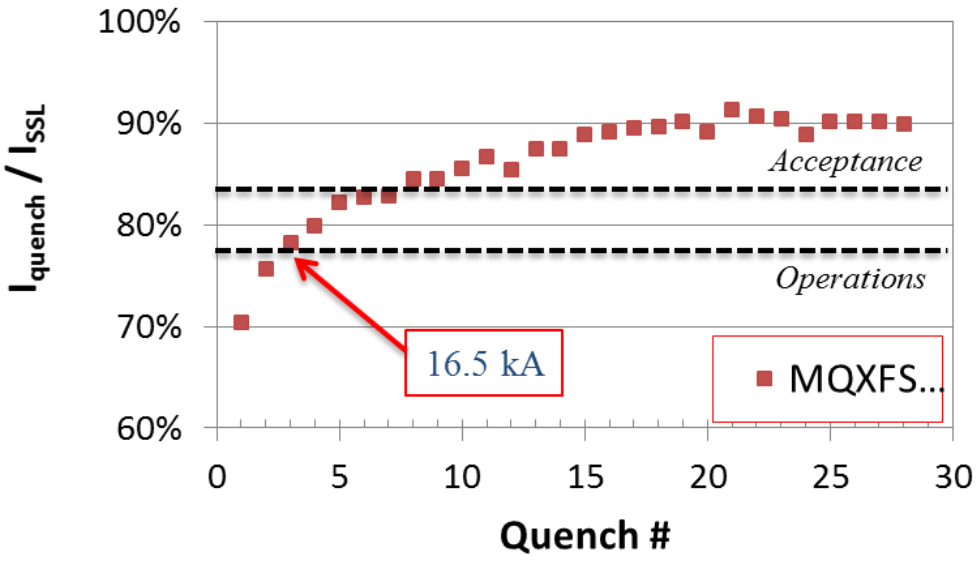


Short model program
Coil fabrication

- Summary
  - **22** coils fabricated from early 2014
    - **14** by CERN
    - **8** by LARP
  - **8** coils to be fabricated by end of 2017
    - **6** by CERN
    - **2** by LARP
  - Total
    - **30** coils

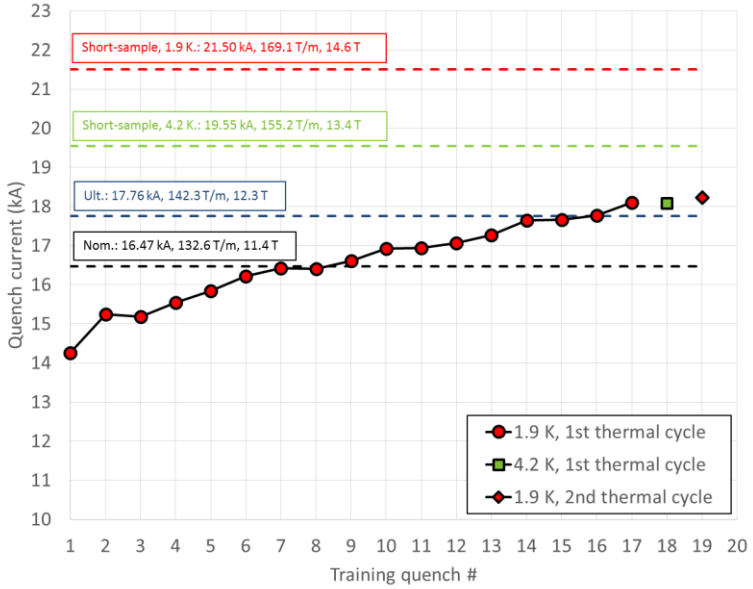
Short model program
Magnets status

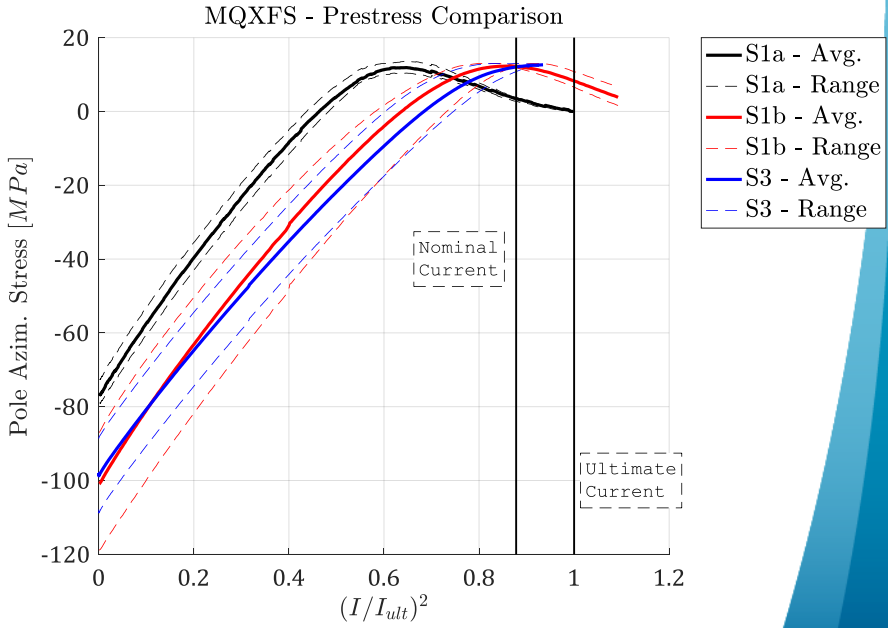
- **MQXFSM1**
  - Tested at FNAL in May 2015
  - Coil **2**
  - **Successfully demonstrated** coil & parts design, and coil fabrication process



Short model program
Magnets status

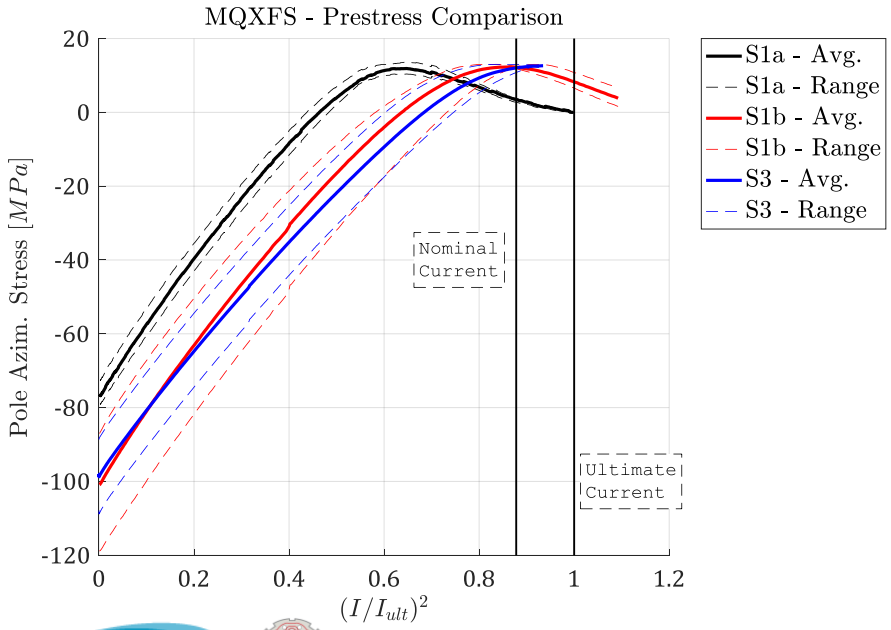
- **MQXFS1a**
  - Tested at FNAL in April 2016 with coils **3,5,103,104**
  - Demonstrated **temperature margin** and **excellent memory**
  - Exceeded **ultimate current**
  - Quenches distributed on the pole turn
    - Training was stopped to increase azimuthal preload

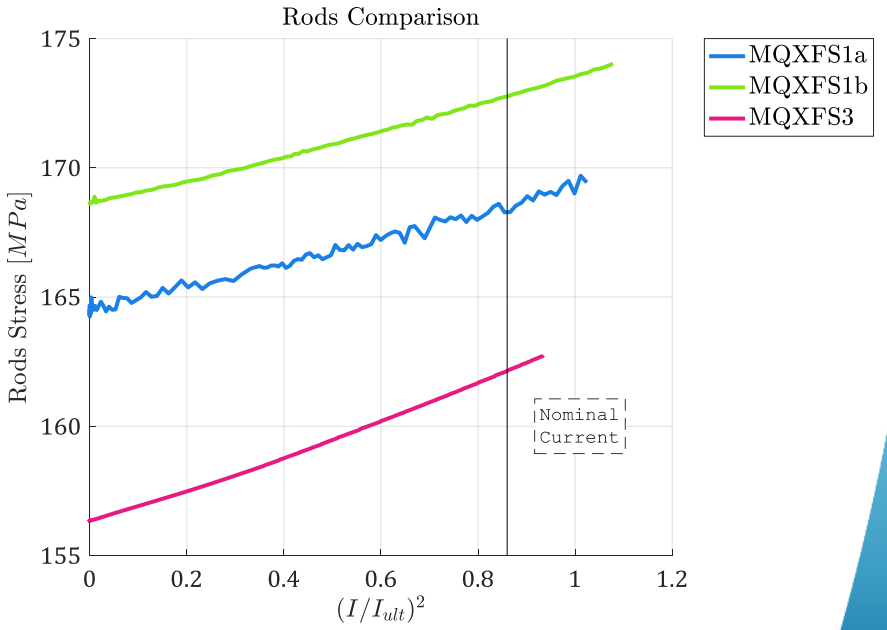




Short model program
Magnets status

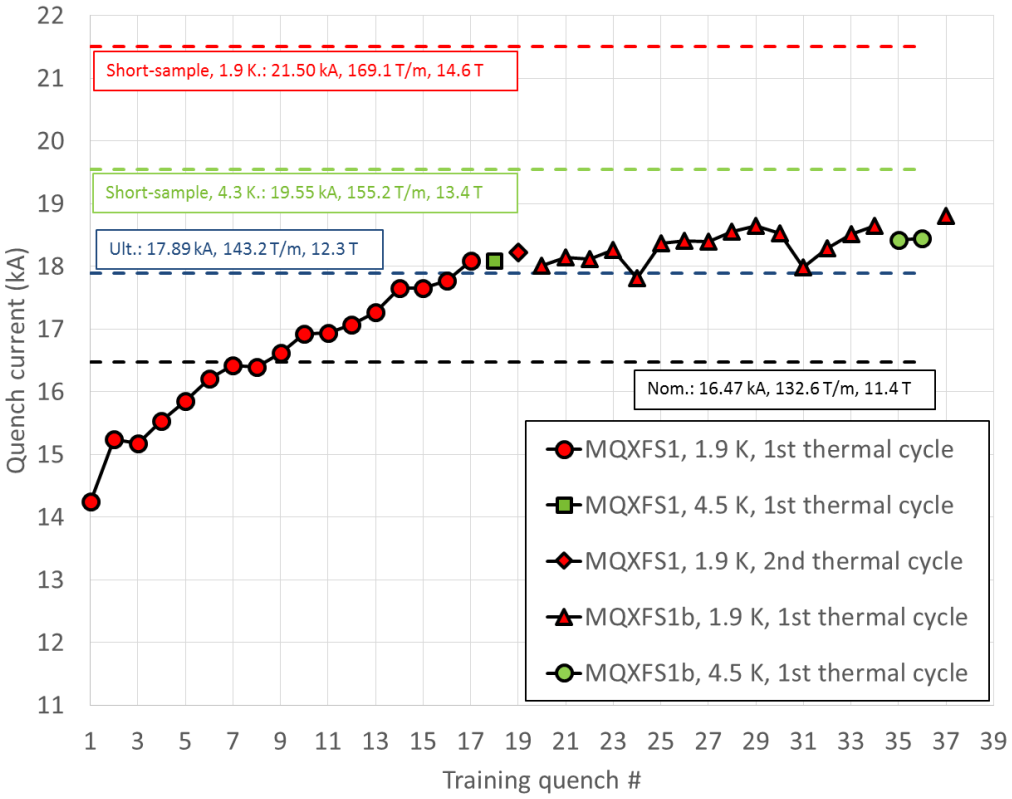
- **MQXFS1b**
  - Re-loaded at LBNL in summer 2016
  - Azimuthal coil pre-load increased by **20 MPa**
    - From **80 to 100 MPa**
  - Shift of pole **strain plateau**
  - Axial pre-load unchanged, still ½ of e.m. force (1.2 MN)
    - Same approach in HQ (but with 0.8 MN)





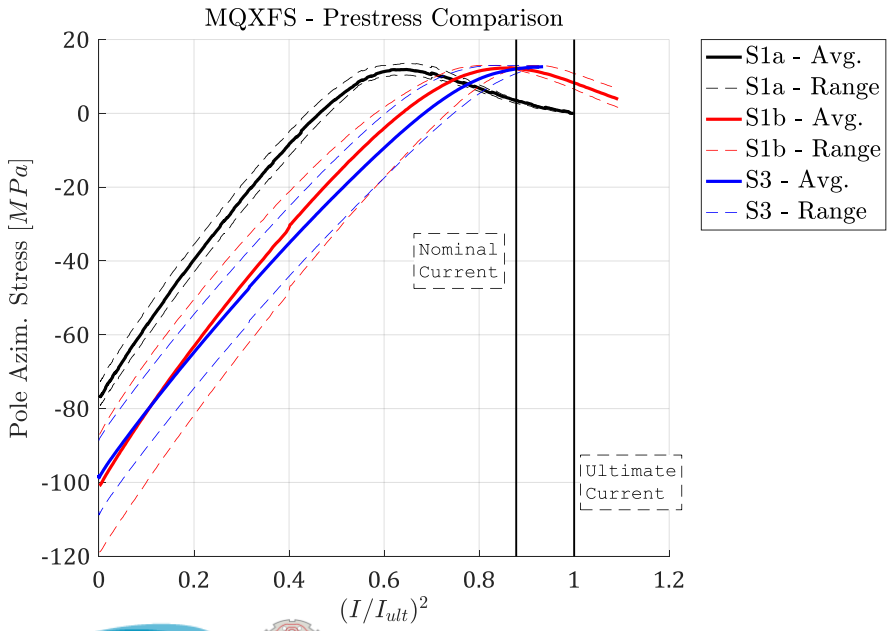
Short model program
Magnets status

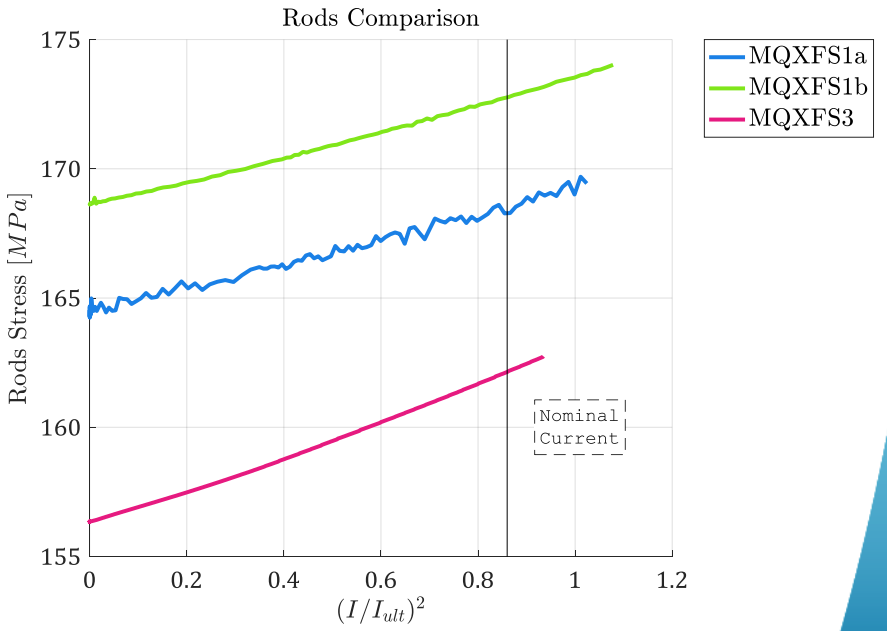
- **MQXFS1b**
  - Again, **good memory**
  - Stably **above ultimate**
    - Only 1 quench below
  - **87%** of I_{ss} at **1.9 K**
  - **95%** of I_{ss} at **4.5 K**
  - **Slower** training than MQXFS1a
  - Quenches in the **ends**



Short model program
Magnets status

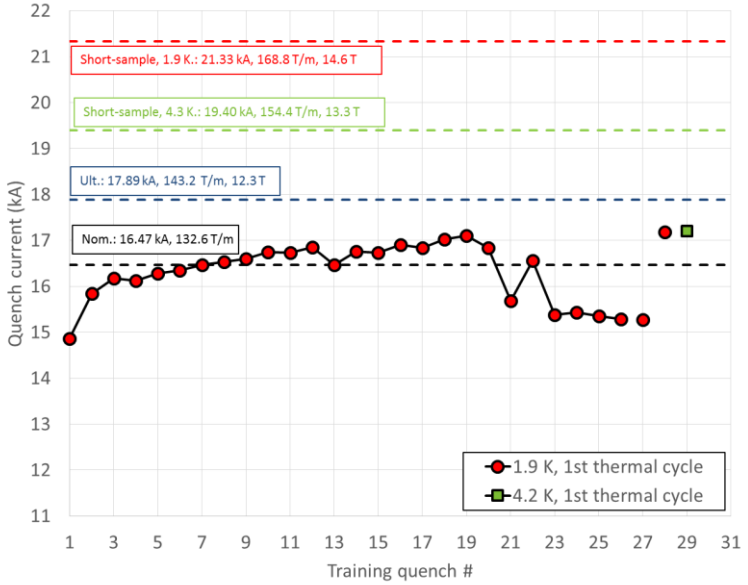
- **MQXFS3**
  - Tested at CERN in October 2016 with coils **105,106,107,7**
  - Same **azimuthal pre-load** as MQXFS1b
  - Similar **axial pre-load** as MQXFS1b
    - ½ of e.m. force (1.2 MN)

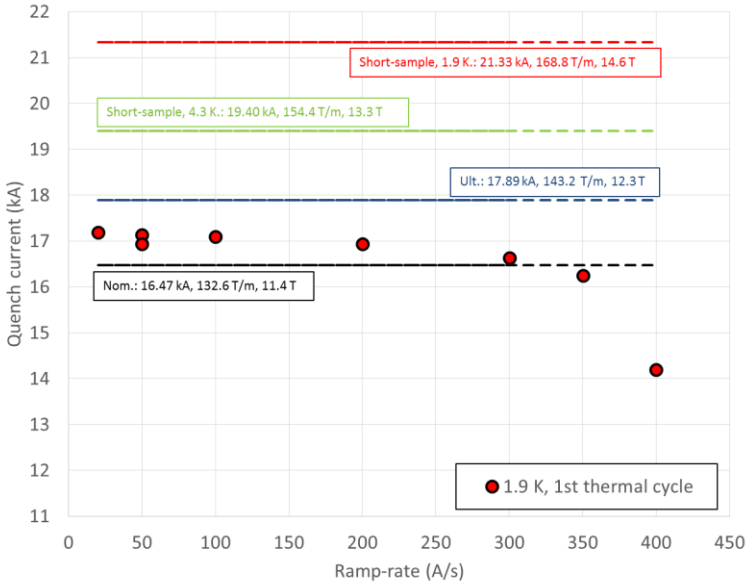




Short model program
Magnets status

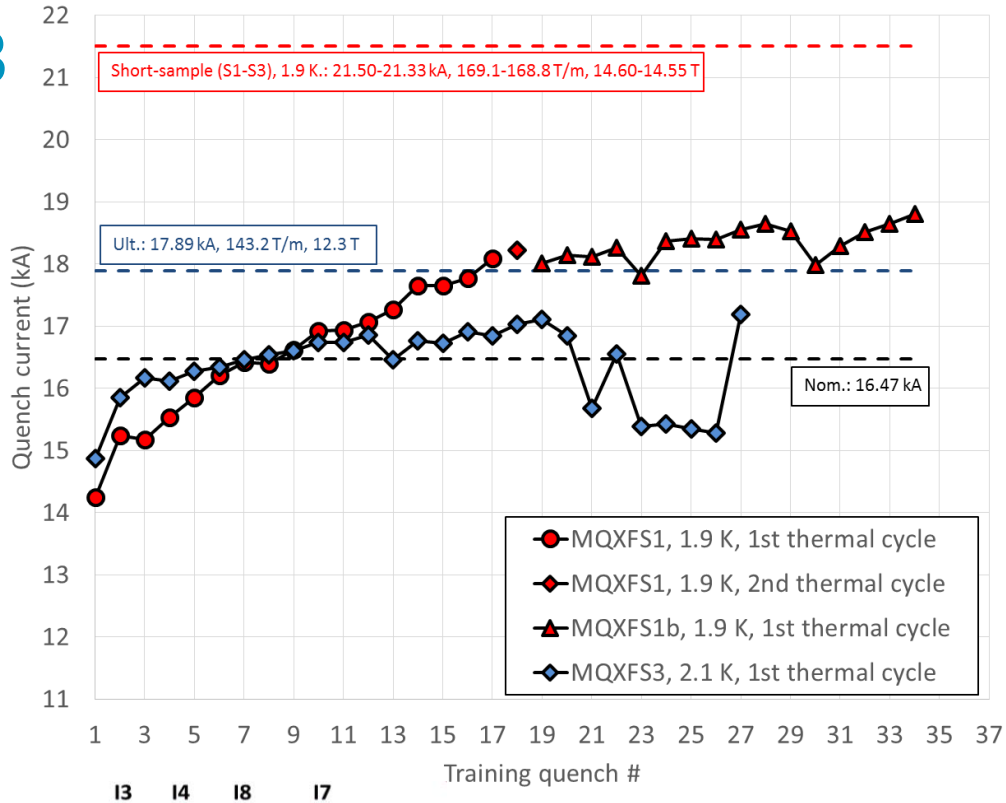
- **MQXFS3**
  - At nominal in 7 quenches
  - Training mainly in the ends and coil 105
  - Detraining after quench 19 and plateau in coil 7
  - Full recovery after high ramp-rate quenches
    - **81%** of I_{ss} at **1.9 K** and about **89%** of I_{ss} at **4.5 K**

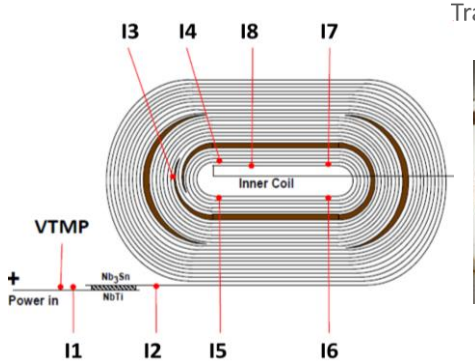


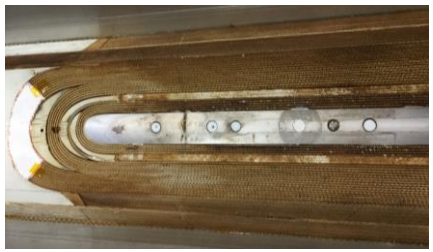


Short model program
Magnets status

- **MQXFS1b** vs. **MQXFS3**
  - Very **similar** axial and azimuthal **pre-load**
    - wrt MQXFS1, same axial, +20 MPa azimuthal
  - **Similar training** slope
    - Although at different current level
      - …but 1b not virgin
    - Slower than MQXFS1a
  - **Similar quench** locations
    - End region, I3I4 segment

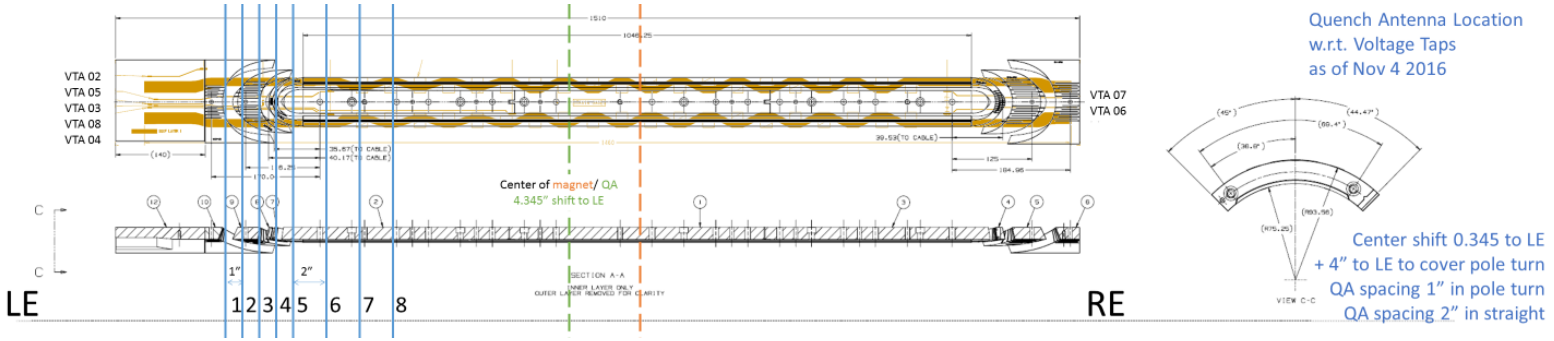






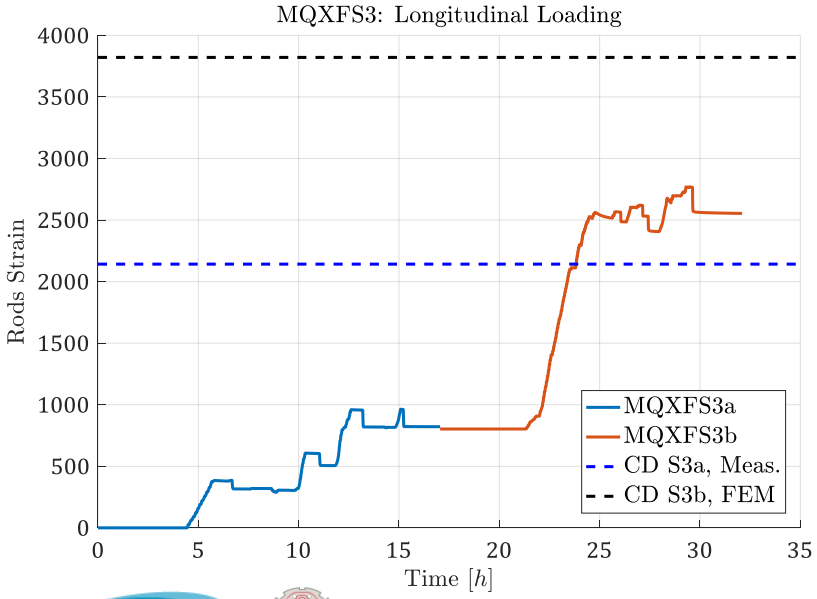
Short model program
Plans for MQXFS1 and MQXFS3 (I)

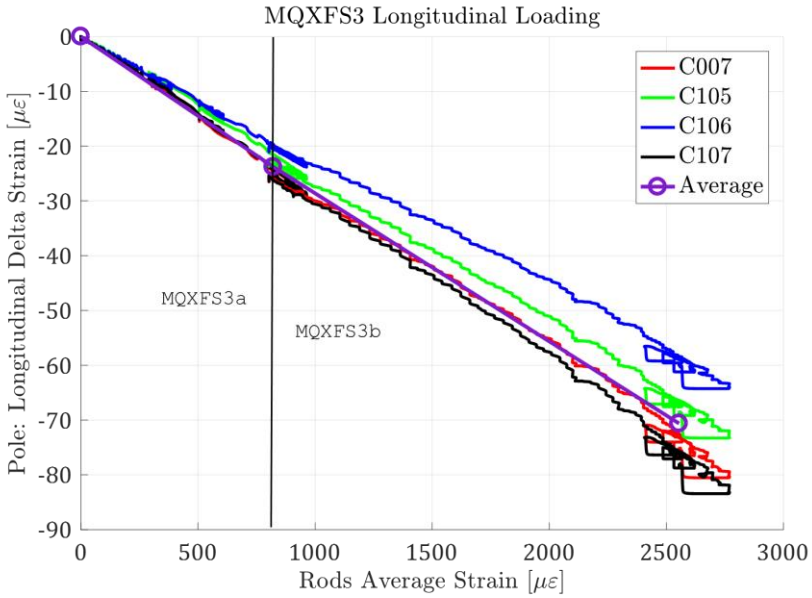
- **Analysis** in progress
  - More detailed analysis with **quench antenna** in MQXFS1b
    - Adjusted quench antenna to pinpoint quench locations
  - Comparison of **HQ03 and MQXF** pre-loading levels
    - **Strain gauges** measurements
      - Pole strain plateau levels
    - **Finite element model**
      - Ratio between axial load and e.m. forces
      - Contact pressure between coil and end parts
      - Model of the LE
  - Check for differences between MQXFS1a/1b/3a



Short model program
Plans for MQXFS1 and MQXFS3 (II)

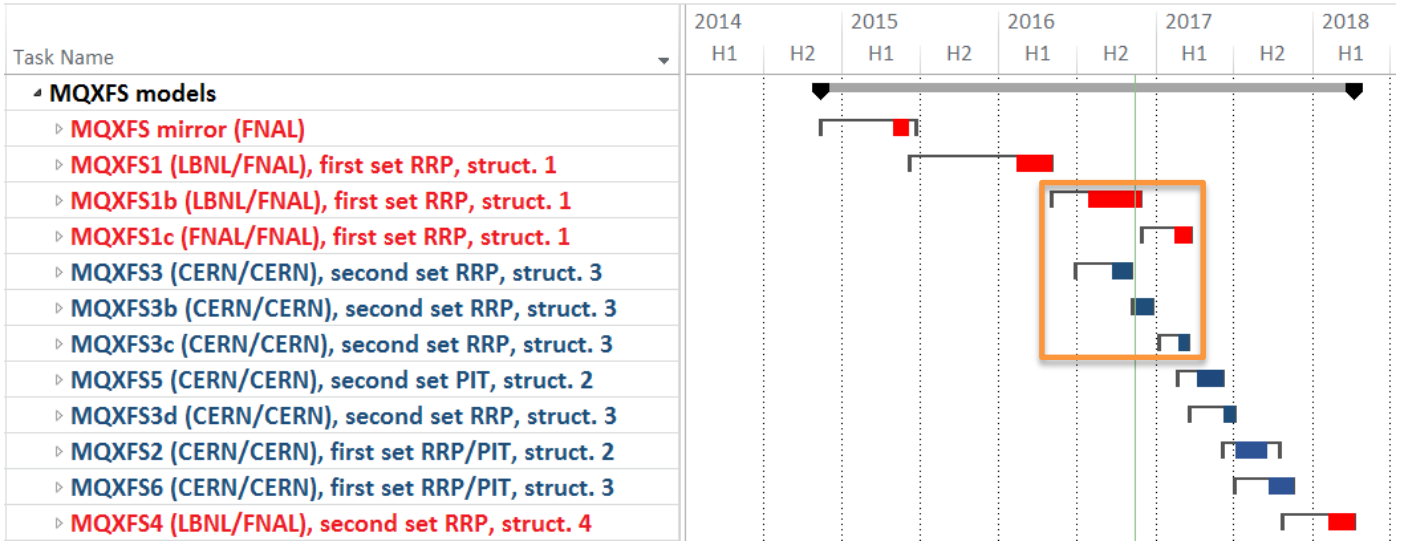
- **MQXFS3b**
  - Retest with **axial pre-load increased**
    - Pre-load increased by about a factor two at cold last Friday
      - No need of disassembly
  - Insertion of a **new quench antenna** with 40 mm long coils
  - Test expected in December 2016





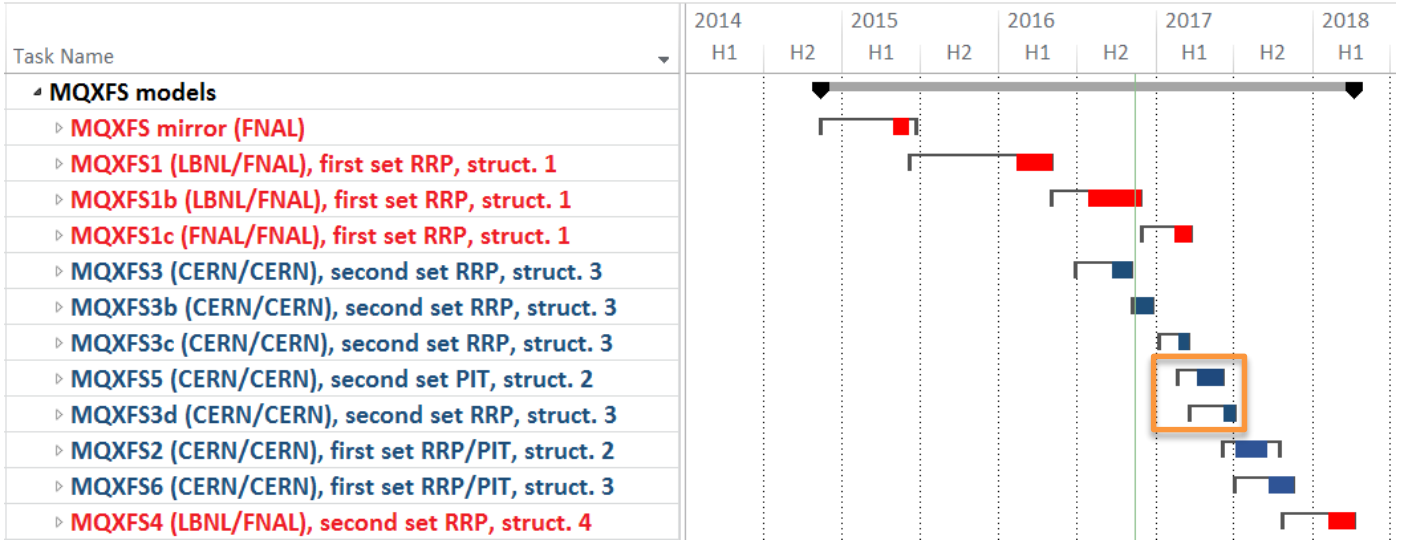
Short model program
Plans for MQXFS1 and MQXFS3 (III)

- **MQXFS3c**
  - Full disassembly and coil visual inspection
  - Reassembly and re-loading with higher azimuthal pre-stress
    - Depending on 3b test and visual inspection
- **MQXFS1c** (currently stainless steel shell test)
  - Increase of axial pre-load under consideration



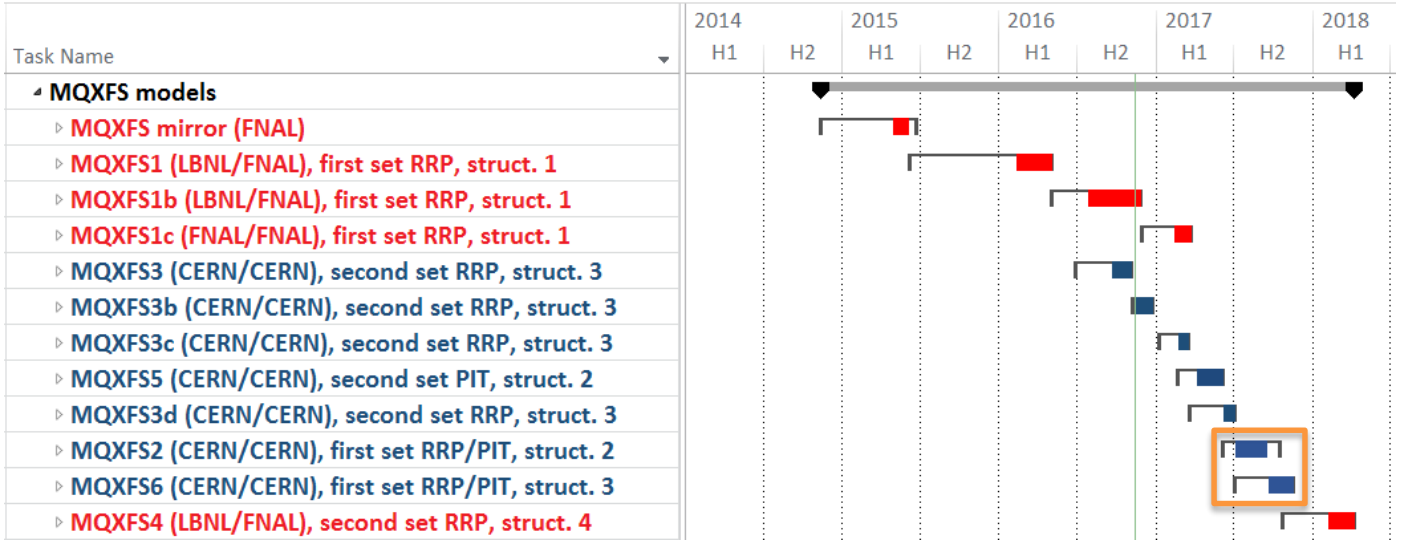
Short model program
Upcoming tests (I)

- **MQXFS5**
  - Test of four PIT coils (203,204,205,206) with 2nd generation cable design
    - Strand without bundle barrier
- **MQXFS3d**
  - Stainless steel shells test



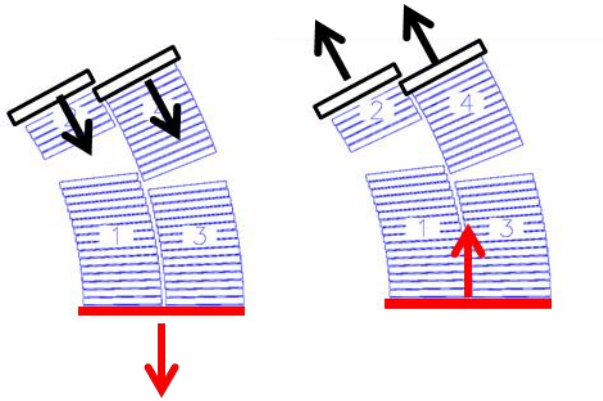
Short model program
Upcoming tests (II)

- **MQXFS2**
  - Test of 3 non conform 1st generation coils
    - 102 (RRP, splice issue), 201-203 (PIT, low J_c and RRR)
    - Together with coil 6
- **MQXFS6**
  - Test of PIT strand with bundle barrier (208,209)
    - Together 207 (PIT no barrier) and 108 (RRP)



Short model program
Upcoming tests (III)

- **MQXFS4**
  - Second RRP 2nd generation magnet, as S3
    - **Reproducibility**
  - Test of **pole/mid-plane shims** to correct allowed harmonics
  - 1st test of **laminated structure** by LARP



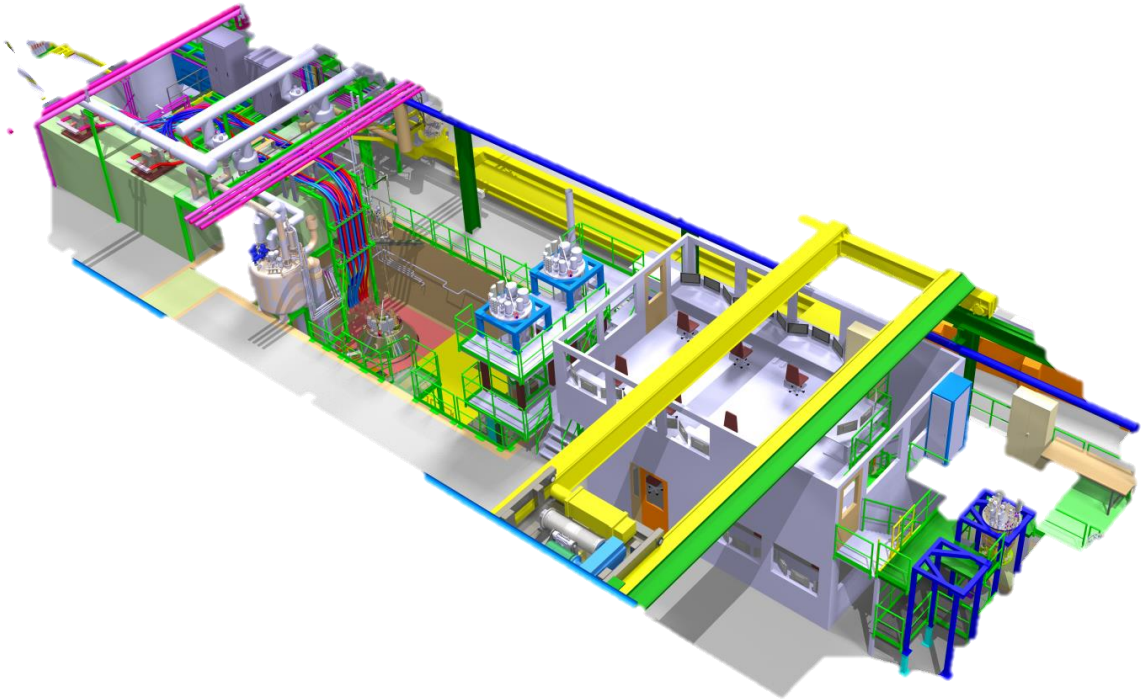
Task Name	2014 H1	2014 H2	2015 H1	2015 H2	2016 H1	2016 H2	2017 H1	2017 H2	2018 H1
MQXFS models									
MQXFS mirror (FNAL)									
MQXFS1 (LBNL/FNAL), first set RRP, struct. 1									
MQXFS1b (LBNL/FNAL), first set RRP, struct. 1									
MQXFS1c (FNAL/FNAL), first set RRP, struct. 1									
MQXFS3 (CERN/CERN), second set RRP, struct. 3									
MQXFS3b (CERN/CERN), second set RRP, struct. 3									
MQXFS3c (CERN/CERN), second set RRP, struct. 3									
MQXFS5 (CERN/CERN), second set PIT, struct. 2									
MQXFS3d (CERN/CERN), second set RRP, struct. 3									
MQXFS2 (CERN/CERN), first set RRP/PIT, struct. 2									
MQXFS6 (CERN/CERN), first set RRP/PIT, struct. 3									
MQXFS4 (LBNL/FNAL), second set RRP, struct. 4									

Short model program Summary

- **MQXFS1**
  - LARP 3: 108/127, first generation cable
  - LARP 5: 108/127, first generation cable
  - CERN 103: 132/169, first generation cable
  - CERN 104: 132/169, first generation cable
- **MQXFS2**
  - LARP 6: 108/127, first generation cable
  - CERN 102: 132/169, first generation cable
  - CERN 201: PIT 192, first generation cable
  - CERN 202: PIT 192, first generation cable
- **MQXFS3**
  - LARP 7: 108/127, second generation cable
  - CERN 105: 132/169, second generation cable
  - CERN 106: 132/169, second generation cable
  - CERN 107: 132/169, second generation cable
- **MQXFS4**
  - LARP 9: 144/169, second generation cable, with shift for field quality adjustment
  - CERN 108: RRP 108/127, second generation cable, with shift for field quality adjustment
  - CERN 109: 132/169, second generation cable, with shift for field quality adjustment
  - CERN 110: 132/169, second generation cable, with shift for field quality adjustment
- **MQXFS5**
  - CERN 203: PIT 192, second generation cable
  - CERN 204: PIT 192, second generation cable
  - CERN 205: PIT 192, second generation cable
  - CERN 206: PIT 192, second generation cable
- **MQXFS6**
  - CERN 207: PIT 192, second generation cable
  - CERN 208: PIT 192 (with barrier), second generation cable
  - CERN 209: PIT 192, (with barrier) second generation cable
  - LARP 8: 144/169, second generation cable

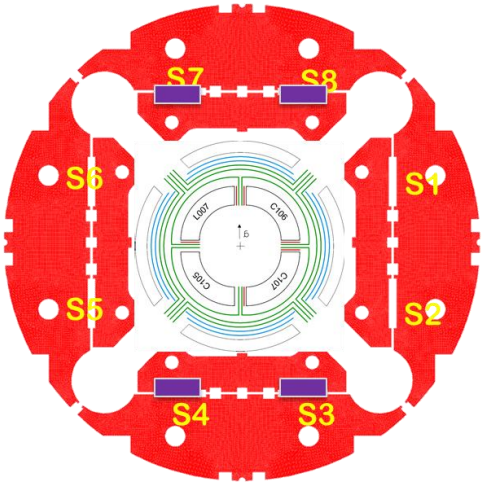
Short model program
Plan for tests

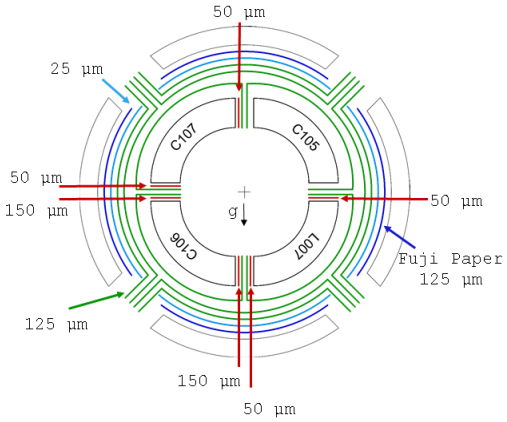
- Test schedule defined relying on
  - **CERN CLUSTER D** station available in 2017 for MQXFS by ~Feb.
  - **FNAL test facility** (MQXFS4)
- Also, 3.5 structures available and 2 trained teams for assembly and loading



Short model program
Field quality

- Good prediction of effect of **corrective strategies**
  - Magnetic shims
  - Coil shims during coil pack assembly to compensate for coil size differences
- **Saturation effect** well reproduced
- Still, field errors mainly due to differences in **coil size**
  - To be pointed out: **MQXFS5** is the only model with 4 coils with the same strand, cable, parts, and fabricated in the same lab





Short model program
Quench protection

- MQXFS1 tests confirmed strategy and validated **outer layer heater** simulations
  - Very good agreement with outer Layer heaters data
  - Inner layer delays are longer than in simulations

- MQXFS3
  - Outer layer heaters perform as expected.
  - Two inner layer heater strips were lost. Investigations needed to understand the source of the problems.
  - Quench integral studies indicate that the heaters effectively quench the magnet.

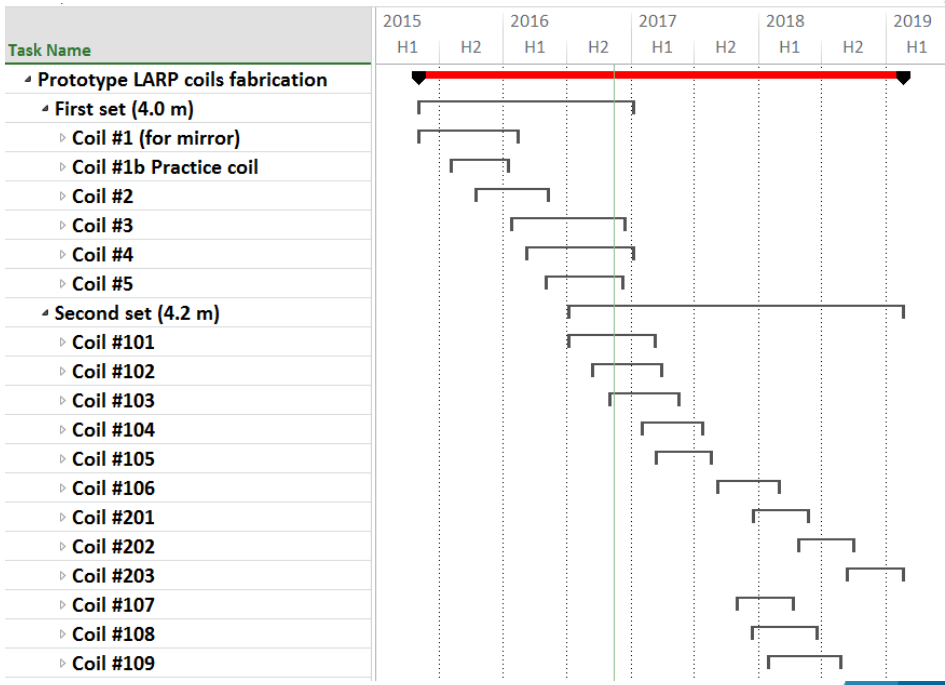
- CLIC test in progress in MQXFS1b

Outline

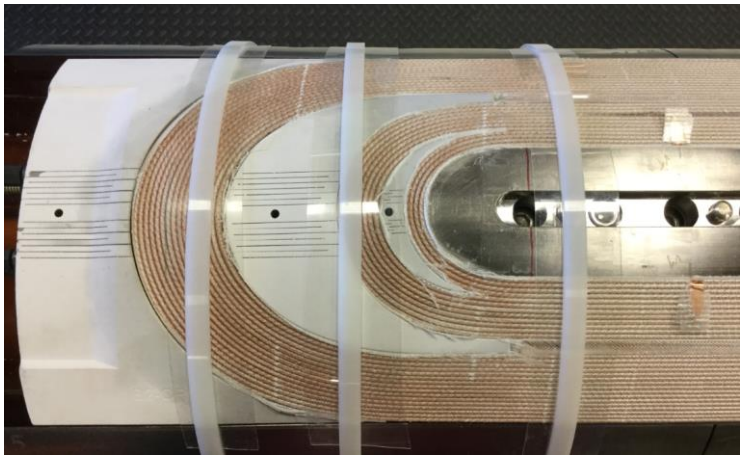
- Short model program
- **LARP prototype program**
- CERN prototype program

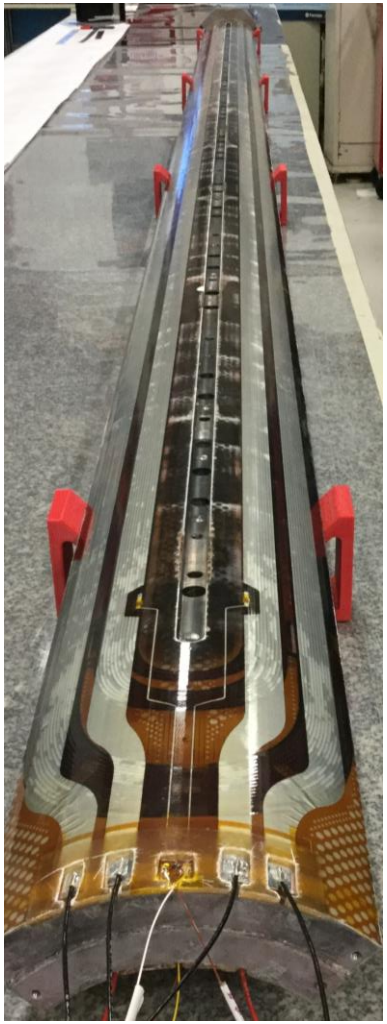
LARP prototype program
Coil fabrication

- Coils for practice & mirror: **2** coil, 4-m long, completed
  - Coil 01 for mirror (1st generation cable)
  - Coil 01b practice (1st generation cable)
- Coils for MQXFA1: **4** coils, 4-m long, ~completed
  - Coil 02 (1st generation cable)
  - Coil 03,04,05 (2nd generation cable)
- **12** Coils for MQXFA2-3 & for practice of BNL W&C line (4.2 m long)
  - **9** W&C at FNAL
    - 6 R&I at FNAL
    - 3 R&I at BNL
  - **3** W&C, R&I at BNL



LARP prototype program
Coil fabrication



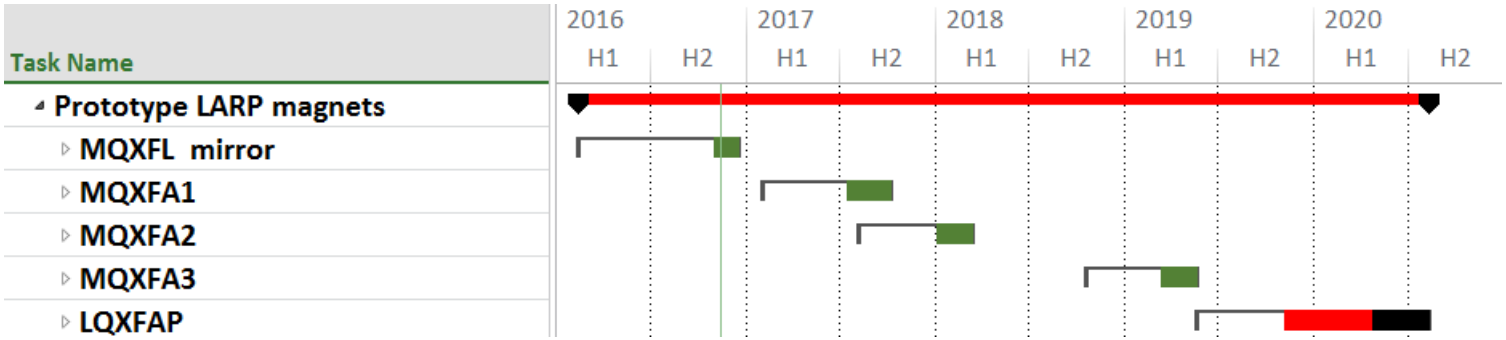


LARP prototype program
Coil test

- **MQXFPM1**
  - Vertical Test Facility @ BNL commissioned in September-October 2016
  - Test results at 1.9 K
    - **First quench**: 14387 A, **65%** of I_{ss} (22.1 kA)
      - Outer layer mid-plane block
    - **Second quench**: 16040 A, **73%** of I_{ss}
      - Inner layer pole turn straight section
  - Replacement of IGBT blown at discharge of quench 2 in progress
  - Training resuming this week

LARP prototype program
Prototype plans

- **MQXFA1** (4 m long)
  - Test in summer 2017 with coils **02,03,04,05**
- **MQXFA2** (4.2 m long)
  - Test in early 2018
- **MQXFA3** (4.2 m long)
  - Test in early 2019
- **Prototype cold mass**: end of 2019, early 2020



LARP prototype program
Support structure

- **MQXFA1** structure
  - All parts by early December, mech. model in January
- **MQXFA2** structure
  - Procurement cycle has started.

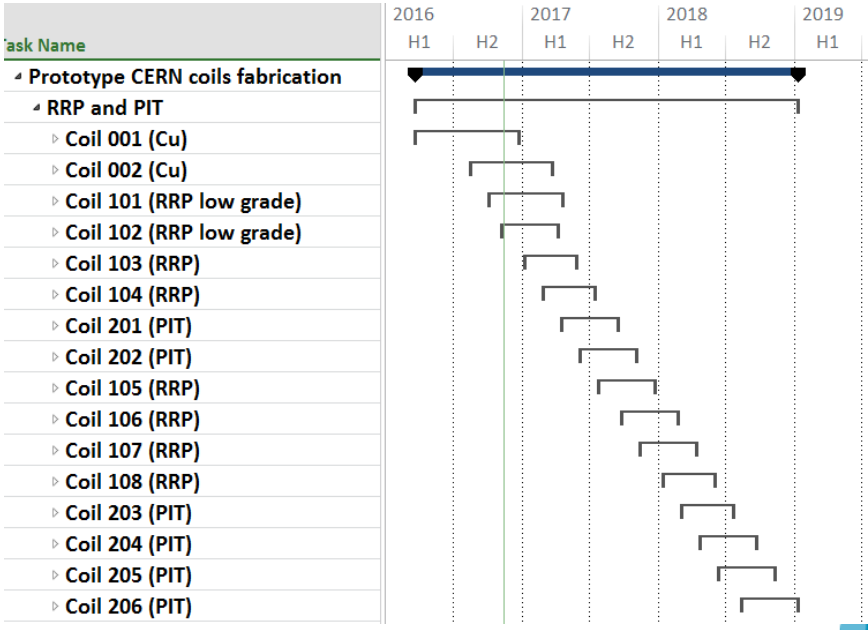
- **MQXFA3** structure
  - Under discussion: procurement of thin laminations
    - possibly provided by CERN (exchange with other parts)
  - In the meantime, practice with MQXFS4

Outline

- Short model program
- LARP prototype program
- **CERN prototype program**

CERN prototype program
Coil fabrication

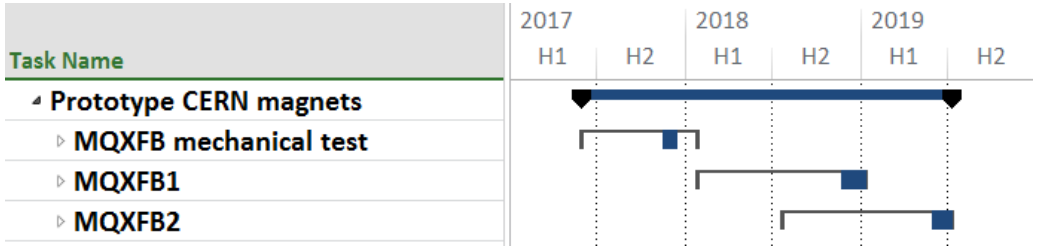
- **2** coils with Cu cable and **1** with low grade Nb_3Sn **wound and cured**
  - 4^{th} coil with low grade Nb_3Sn being wound
- **1** Cu coil **reacted**
  - 10 m long oven site acceptance test passed
- **1** Cu coil being **prep for impregnation**
- Then, **6** RRP and **6** PIT coils to be produced



CERN prototype program
Coil fabrication

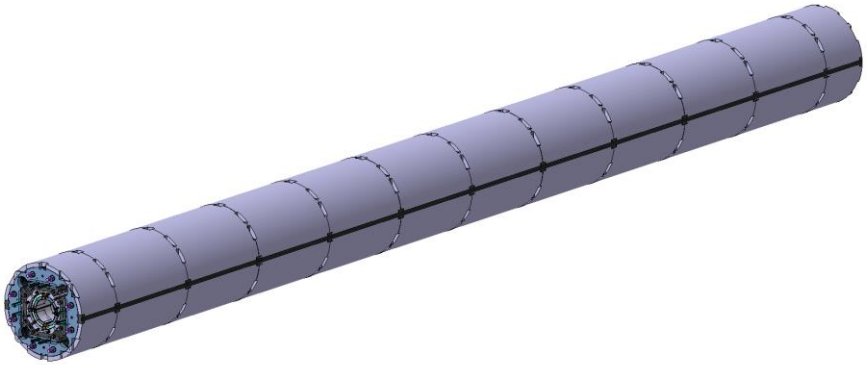
CERN prototype program
Prototype plans

- **MQXFB mechanical test**
  - Cool-down of cold-mass with practice coils by end 2017
- **MQXFB1**
  - Test by end 2018
- **MQXFB2**
  - Test in mid 2019



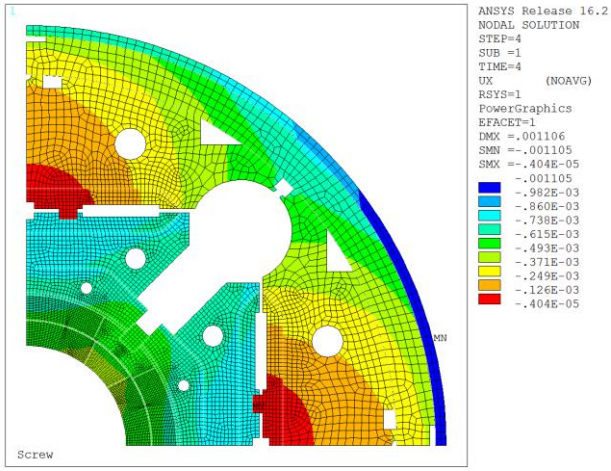
CERN prototype program
Prototype plans

- Support structure for **MQXFB mechanical test and MQXFB1** expected by March 2017
- Material for components for **MQXFB2** procured

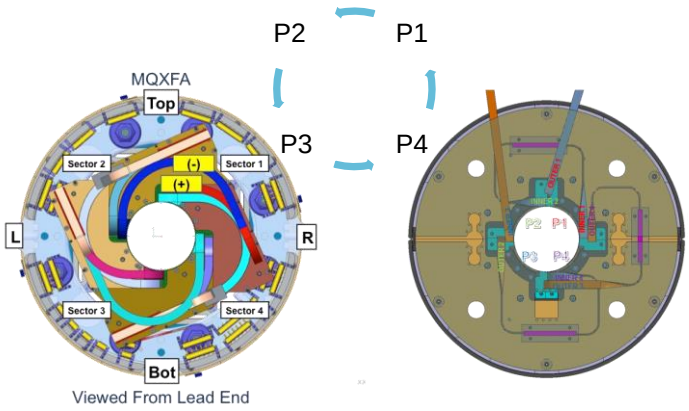


Additional items addressed since last CM (I)

- **Stainless steel shell**
  - Further finite element analysis
  - General agreement to set as a tension target after welding 50 ± 50 MPa



- **Connection box and powering scheme**
  - Two different connection box designs but same coil sequence
    - e**P1**i-i**P4**e-i**P2**e-e**P3**i



Additional items addressed since last CM (II)

- **Voltage withstand levels**
  - Agreement on the values to be met for the acceptance of a MQXF cold mass

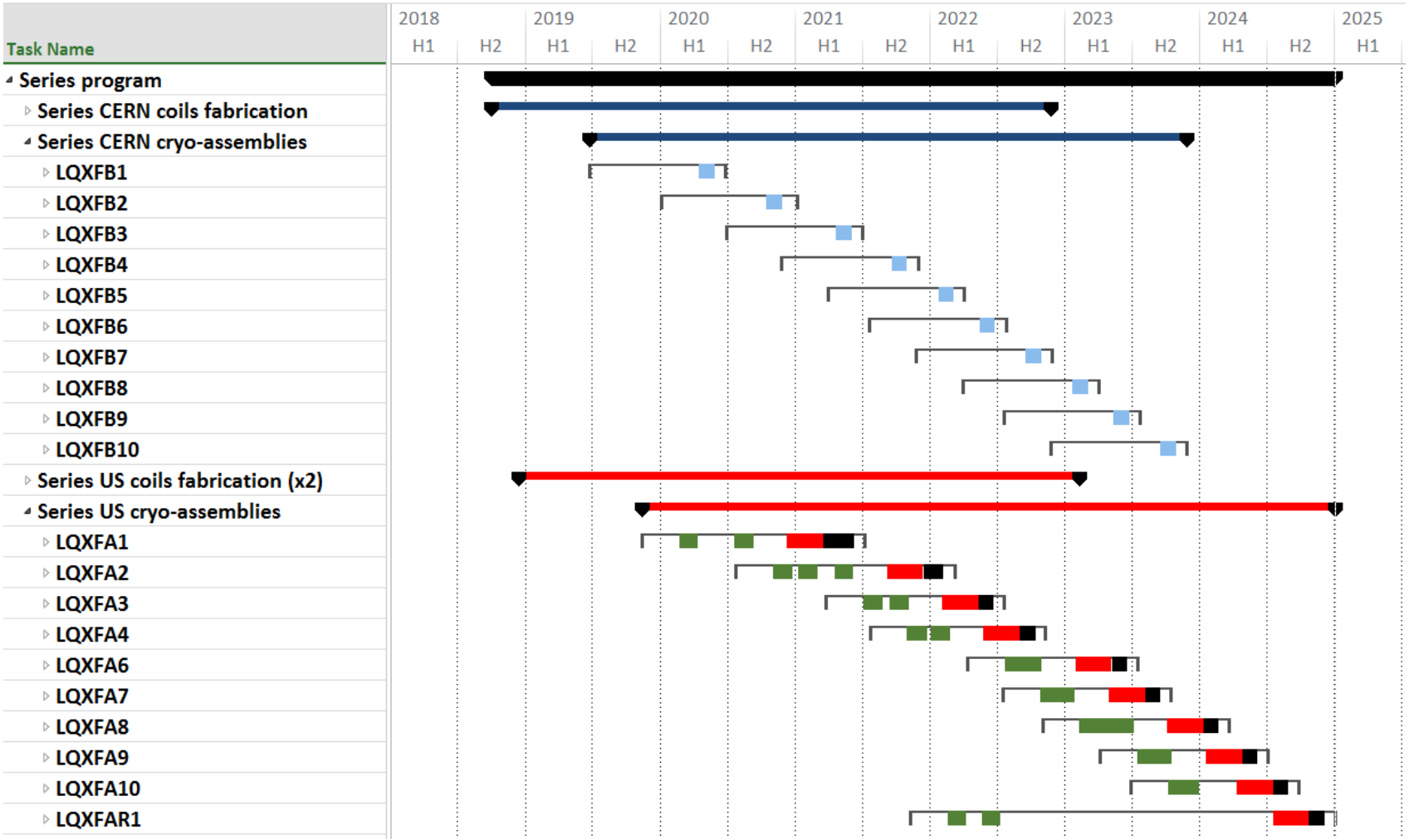
By F. Rodriguez Mateos

Circuit Element	Expected Vmax [V]	V hi-pot	I hi-pot [µA]	Minimum time duration [s]
Coil to Ground at RT *	n.a.	3 kV	10	30
Coil to Quench Heater at RT *	n.a.	3 kV	10	30
Coil to Ground at cold **	520	1.5 kV	10	30
Coil to Quench Heater at cold **	900	2.3 kV	10	30

* Room Temperature conditions refer to air at 20±3 °C and relative humidity lower than 60%

** Cold conditions refer to nominal cryogenic conditions (superfluid helium)

And finally, series production



Appendix

Schedule
Q2 series

- Coil fabrication
  - 75-80 days per coil
  - 1 coil every 3 weeks (winding 3 weeks, reaction 3 weeks)
  - 50 coils fabricated in 4 years
- Cryo-assemblies
  - About 1 year from coil-pack assembly to “ready for installation”
  - 3 cryo-assemblies per year
    - Imposed by time required to fabricate 5 coils
  - 10 cryo-assemblies fabricated in 4.5 years