MQXF Short Models
Status and Plans

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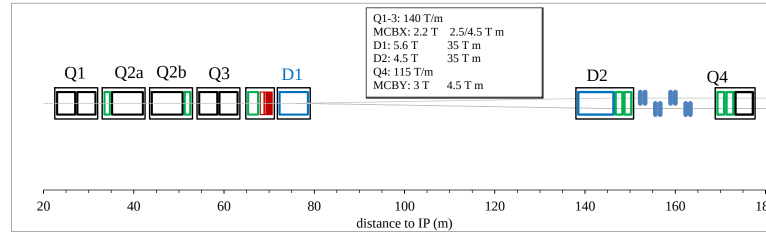
4th Joint HiLumi LHC-LARP Annual Meeting
November 17-21, 2014
KEK, Tsukuba

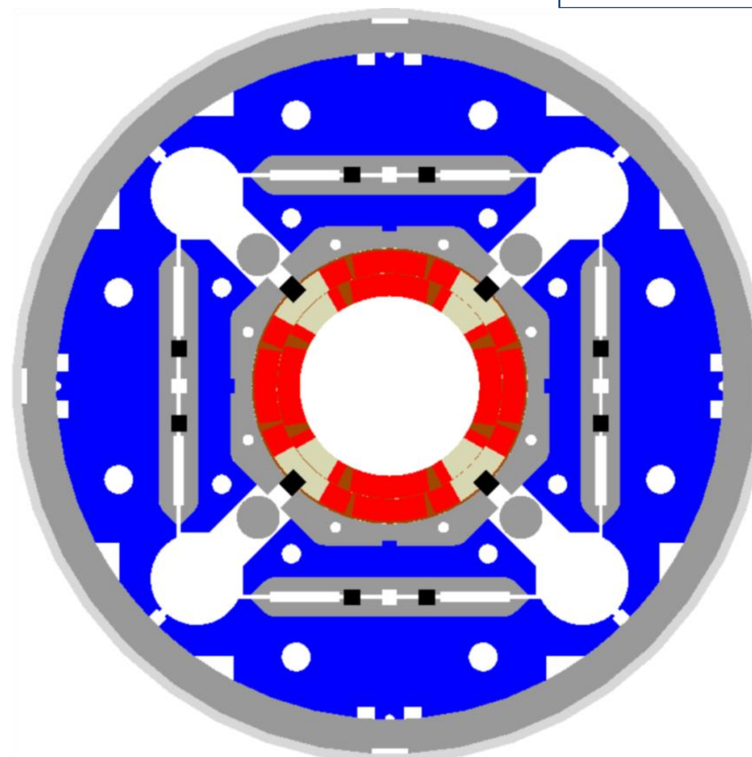
Overview of MQXF design

- Target: 140 T/m in 150 mm coil aperture
- To be installed in 2023 (*LS3*)



by E. Todesco

- Q1/Q3 (by US LARP collaboration)
  - 2 magnets with 4.0 m of magnetic length within 1 cold mass
- Q2 (by CERN)
  - 1 magnet of 6.8 m within 1 cold mass, including MCBX (1.2 m)



- Baseline: different lengths, same design
  - Identical short model magnets SQXF

Outline

- Strand, cable, insulation
- Coil design and fabrication
- Support structure
- Quench protection
- Planning

Conclusions from Daresbury meeting (14/11/2013)

- MQXF: fully integrated CERN - LARP program
  - Same magnet design, different lengths
- Conductor and cable
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    - Several mitigation option under investigation
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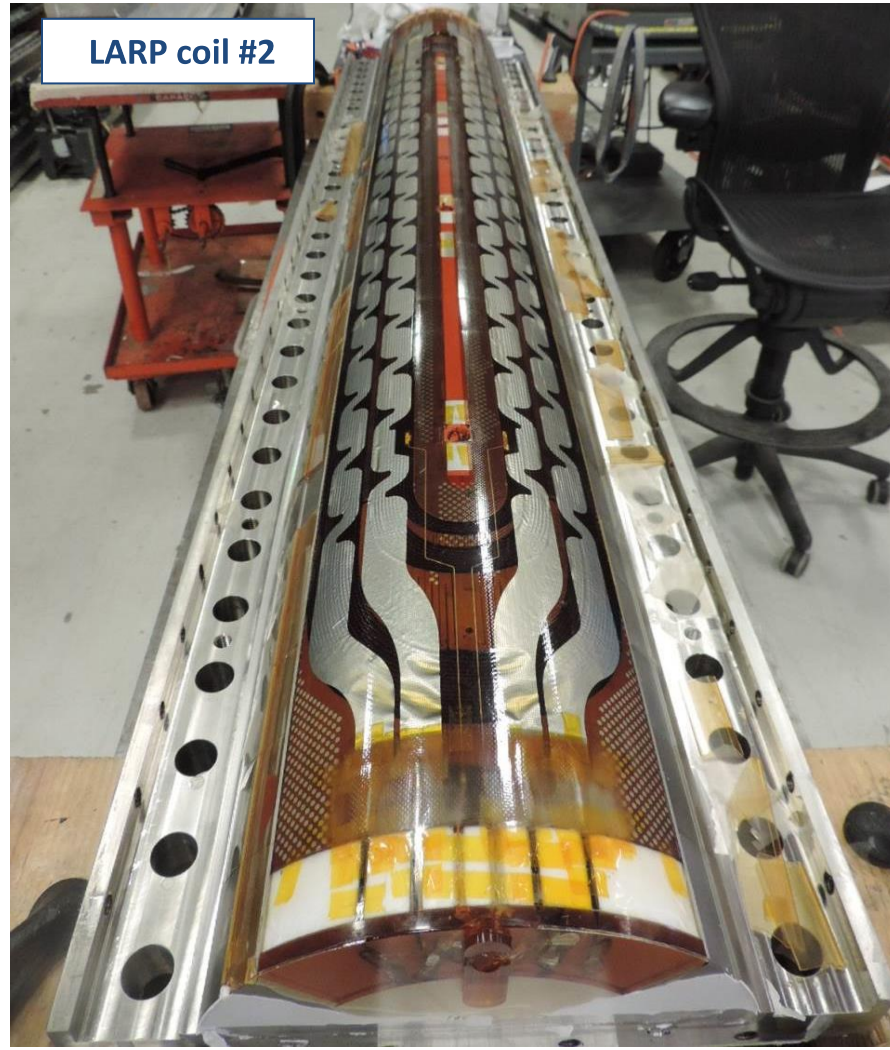
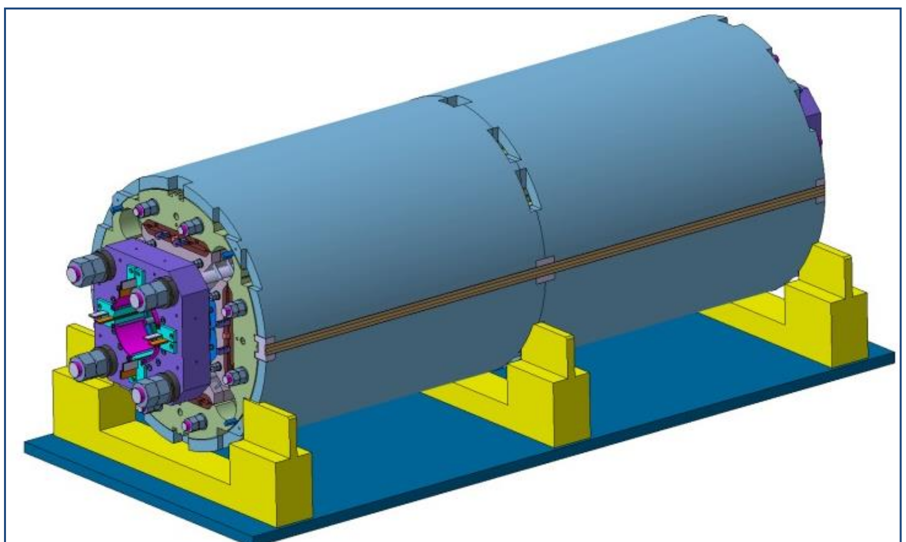
Integrated program
Exchangeable coils (almost identical)



Integrated program
2 identical support structures

- One at CERN, one shipped to LBNL
- Same CAD model and same fabrication companies



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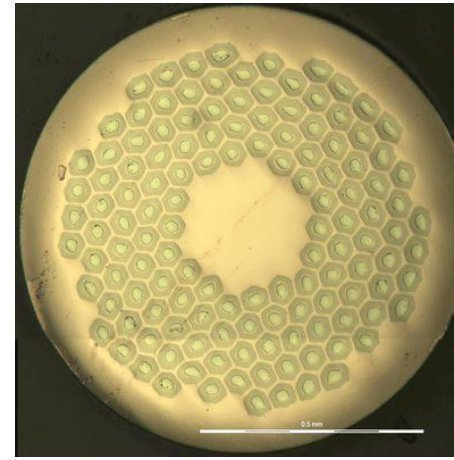
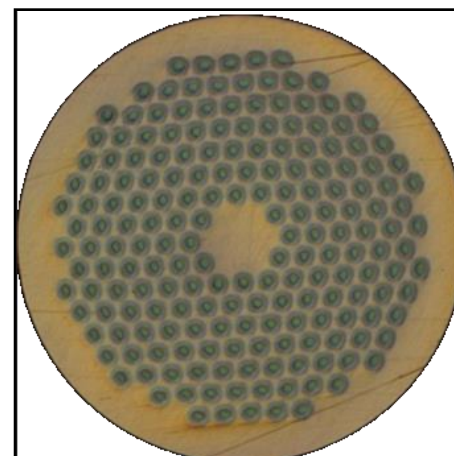
MQXF strand
(from CERN technical specification document)

- **0.85 mm** strand
- Filament size **<50 µm**
  - OST 132/169: 48-50 µm
  - Bruker PIT 192: 42 µm
- Cu/Sc: **1.2 ± 0.1** → 55% Cu
- Critical current at 4.2 K and 15 T
  - **361 A** at 15 T

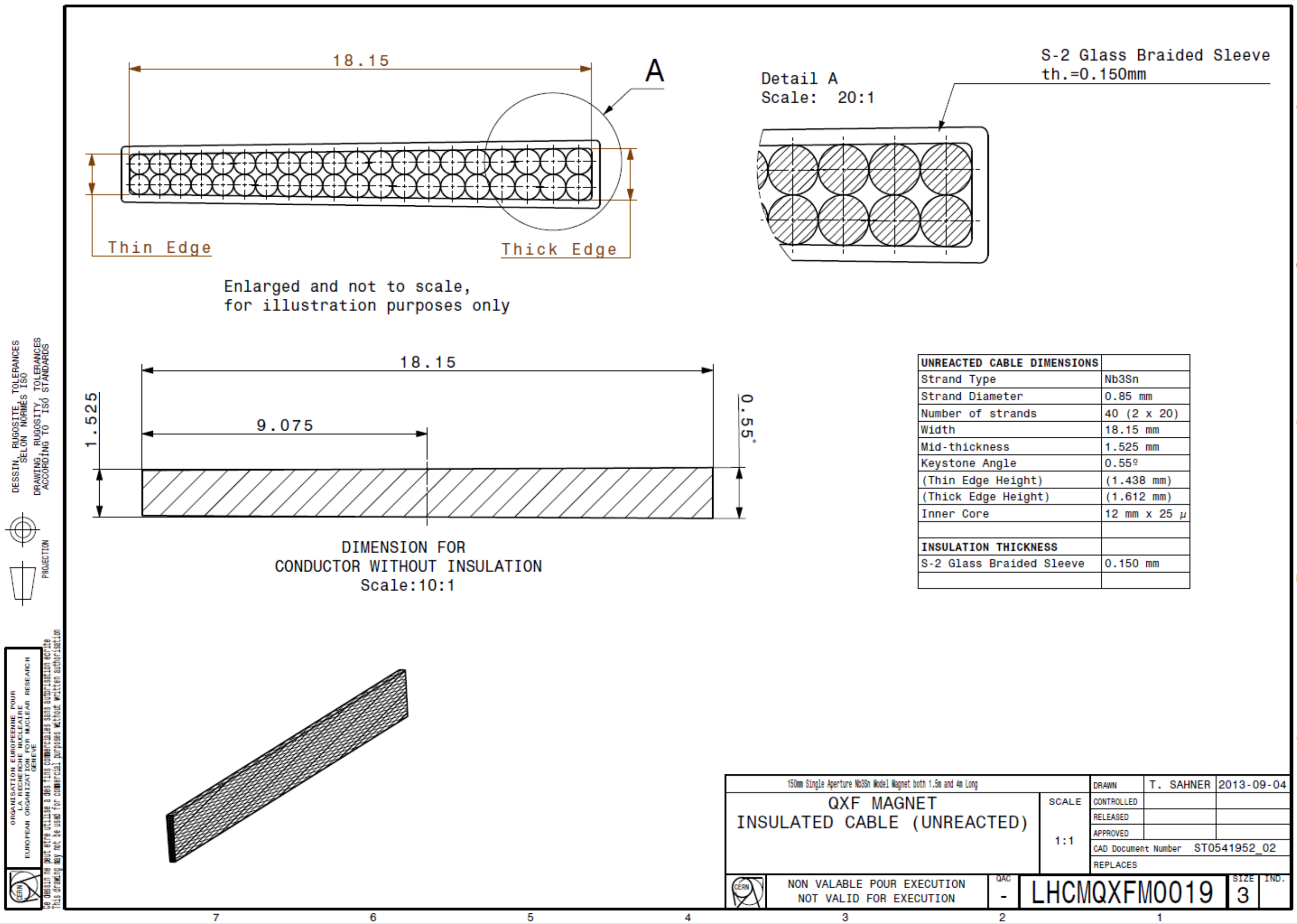
OST RRP strand, 132/169



Bruker PIT strand, 192



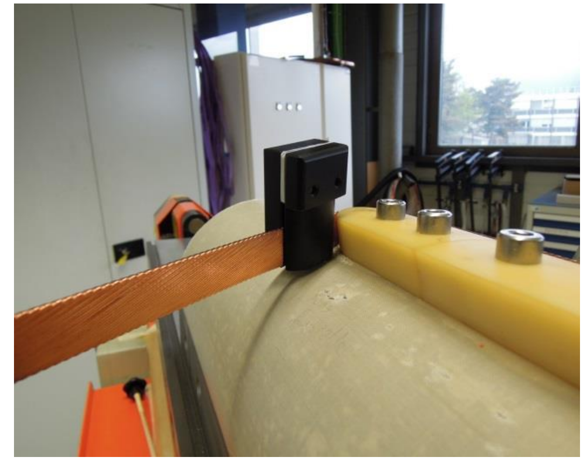
MQXF baseline cable and insulation

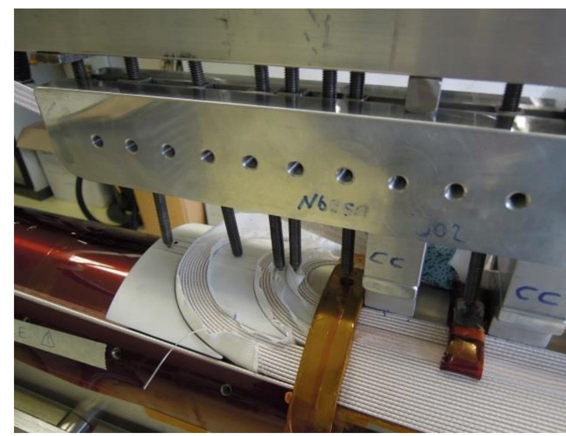


UNREACTED CABLE DIMENSIONS	
Strand Type	Nb3Sn
Strand Diameter	0.85 mm
Number of strands	40 (2 x 20)
Width	18.15 mm
Mid-thickness	1.525 mm
Keystone Angle	0.55º
(Thin Edge Height)	(1.438 mm)
(Thick Edge Height)	(1.612 mm)
Inner Core	12 mm x 25 μ
INSULATION THICKNESS	
S-2 Glass Braided Sleeve	0.150 mm

Cable mechanical stability and windability

- In general (45 winding tests)
  - all RRP and PIT cables are **stable in the favorable direction**
    - Cable wound clock-wise around the pole (inner layer condition)
  - all RRP and PIT cables are **unstable in the unfavorable direction**
- All RRP and PIT cables can be wound with the **tool** and/or with the binder
- The feed-back from the winding team about the stability of the insulated RRP cable during winding of first MQXF short model coils is **extremely positive**





From close-out of conductor review

- Optimize **margin** by all means
  - Design goals shall be conservative
- Keep **2** strand **suppliers**
  - Promote a substantive development program with BEAS
- Confirm that the following **specs** are correct:
  - Strand I_c: 361 A at 4.2 K and 15 T
  - RRR: 150 on virgin strand/100 on extracted strand
- RRP
  - Go ahead with 132/169 lower Sn content; final decision in one year for series production contract (back up being 108/127)
  - Consider proposal to reduce keystone angle
- PIT
  - Reduced keystone angle is a must

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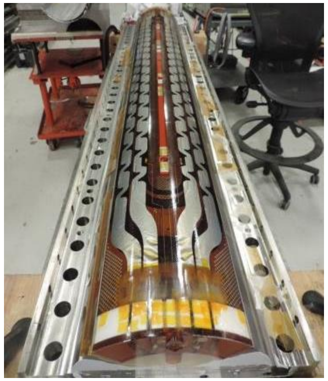
Coil fabrication status

LARP coil #1
completed

LARP coil #2
completed



LARP coil #3
Prep. for impregnation at BNL

CERN coil #001 (Cu)
completed

CERN coil #101 (Low-grade)
Prep. for impregnation

CERN coil #102
Being reacted

Electrical checks

- LARP **MQXF short model coil 1** passed all baseline electric checks

Hipot Checks

Actual / Target

(< 1 uA leakage)

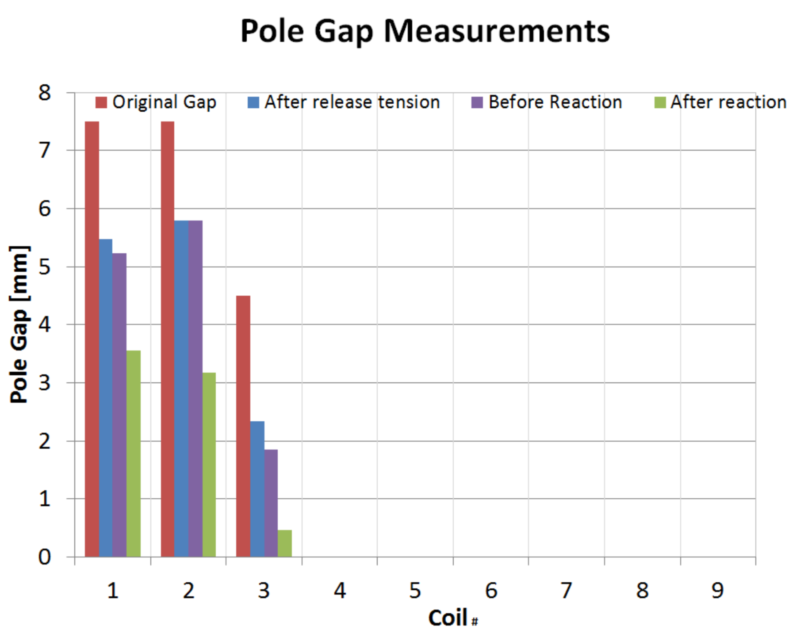
SQXF01	Coil	PHA01	PHA02	PHB01	PHB02	PHB03	PHB04	LE IL Endshoe	RE IL Endshoe
PHA01	2000 / 2000								
PHA02	2000 / 2000								
PHB01	2000 / 2000								
PHB02	2000 / 2000								
PHB03	2000 / 2000								
PHB04	2000 / 2000								
LE IL Endshoe	1200 / 1200	1000 / 1000	1000 / 1000						
LE OL Endshoe	1200 / 1200			1000 / 1000	1000 / 1000	1000 / 1000	1000 / 1000	600 / 600	
RE IL Endshoe	1200 / 1200	1000 / 1000	1000 / 1000						
RE OL Endshoe	1200 / 1200			1000 / 1000	1000 / 1000	1000 / 1000	1000 / 1000		600 / 600
Pole	500 / 500								

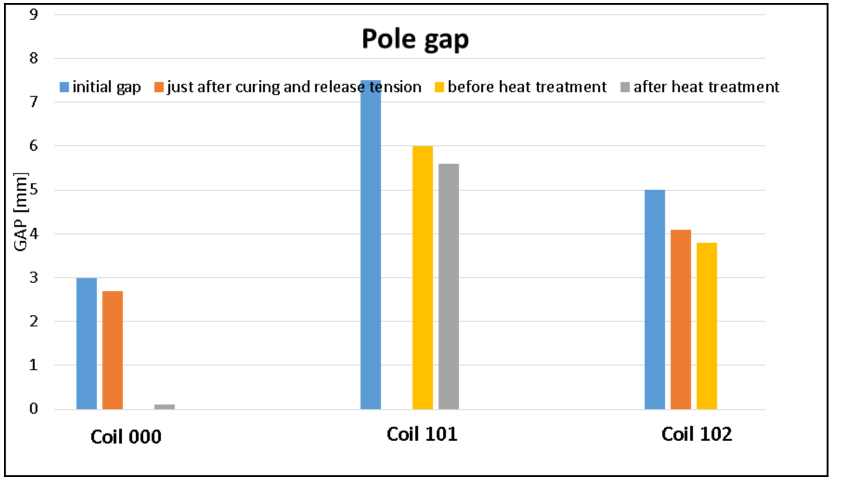
- **4 LARP HQ03 coils** (22,23,24,26) that went into the magnet passed 100% with no hipot trips or lost Vtaps prior to magnet assembly

Coil axial contraction (pole gaps reduction)

- 1.7-2.2 mm from
  - winding tension relaxation
- 1.7-2.6 mm from
  - Heat treatment

- 1.2-1.5 mm from
  - winding tension relaxation
- Almost no contraction in coil 2 during reaction
  - Low grade, 3 cycles





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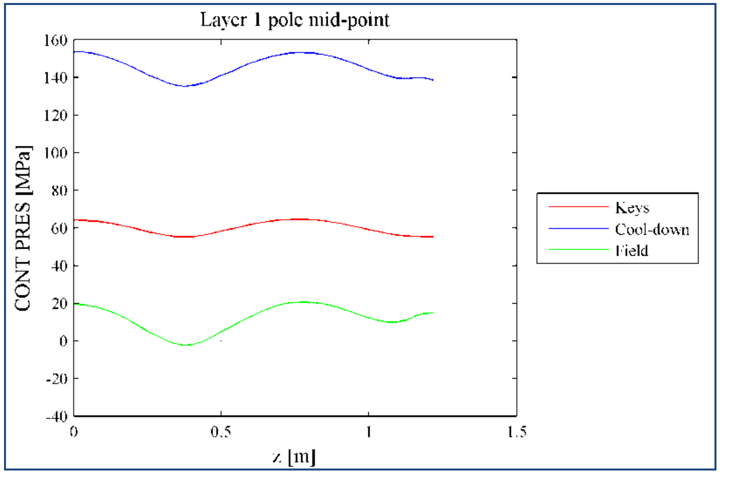
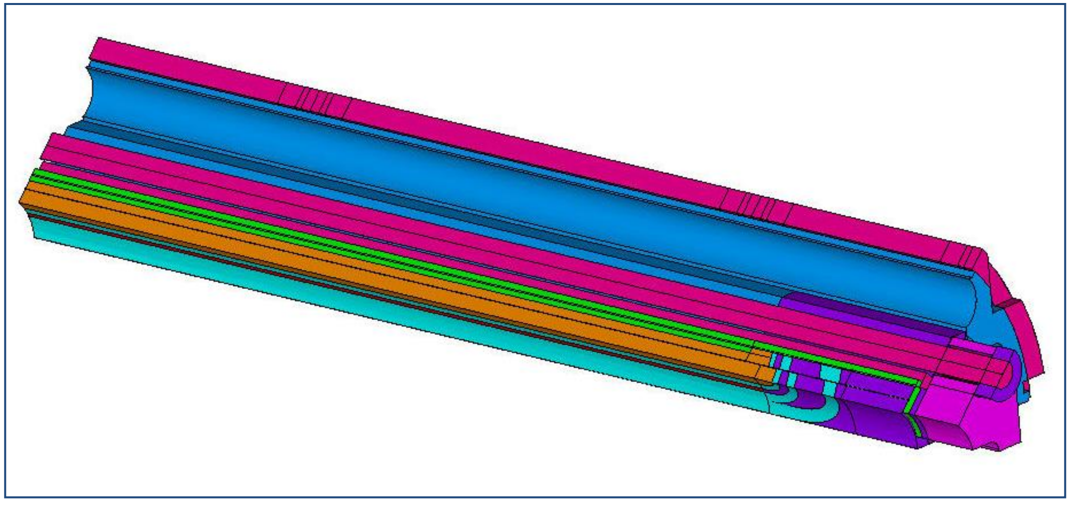
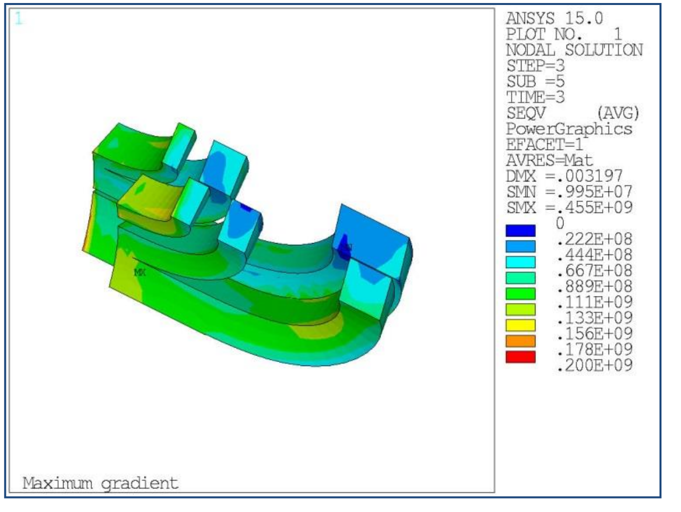
3D finite element model

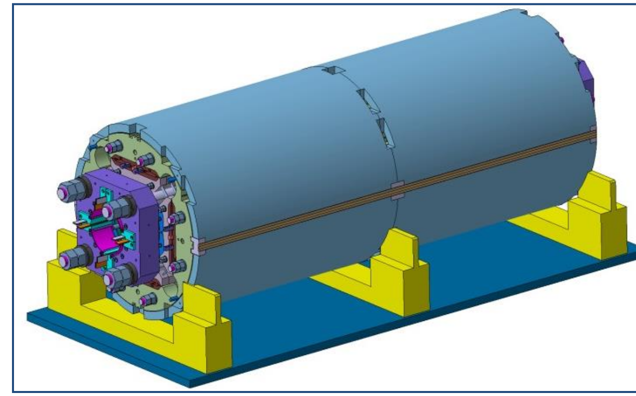
- Full 3D mechanical analysis completed
  - Effort to reduce coil σ variation
    - ±10 MPa expected due to shell segmentation (50%) and shell cut-outs (50%)

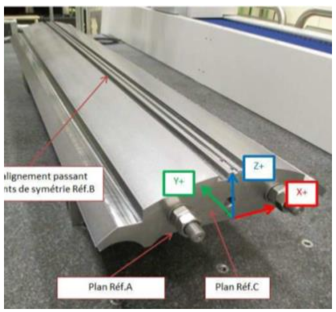


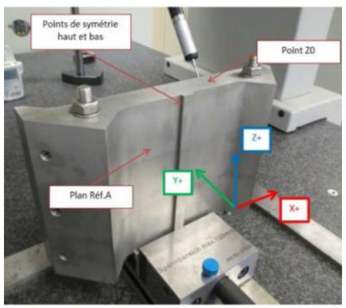


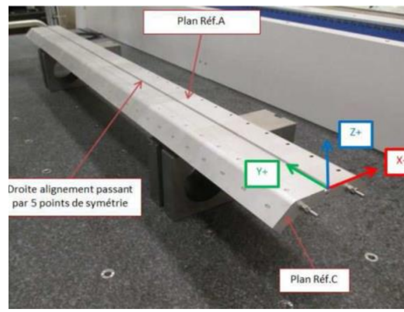


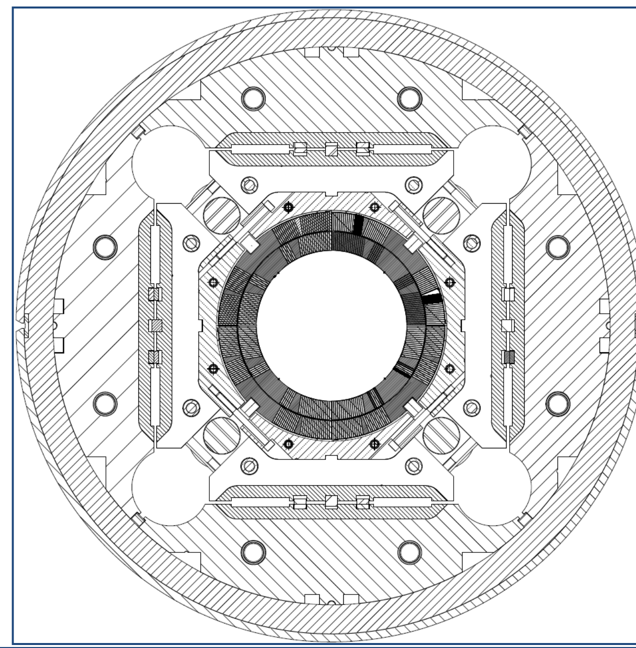
2 identical short model structures fabricated

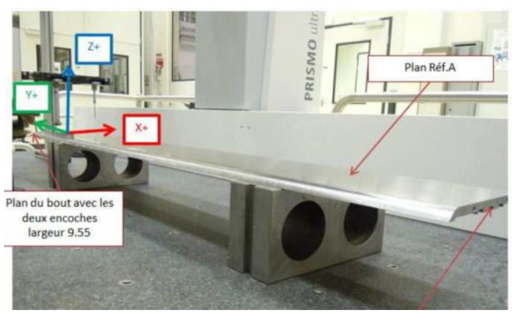




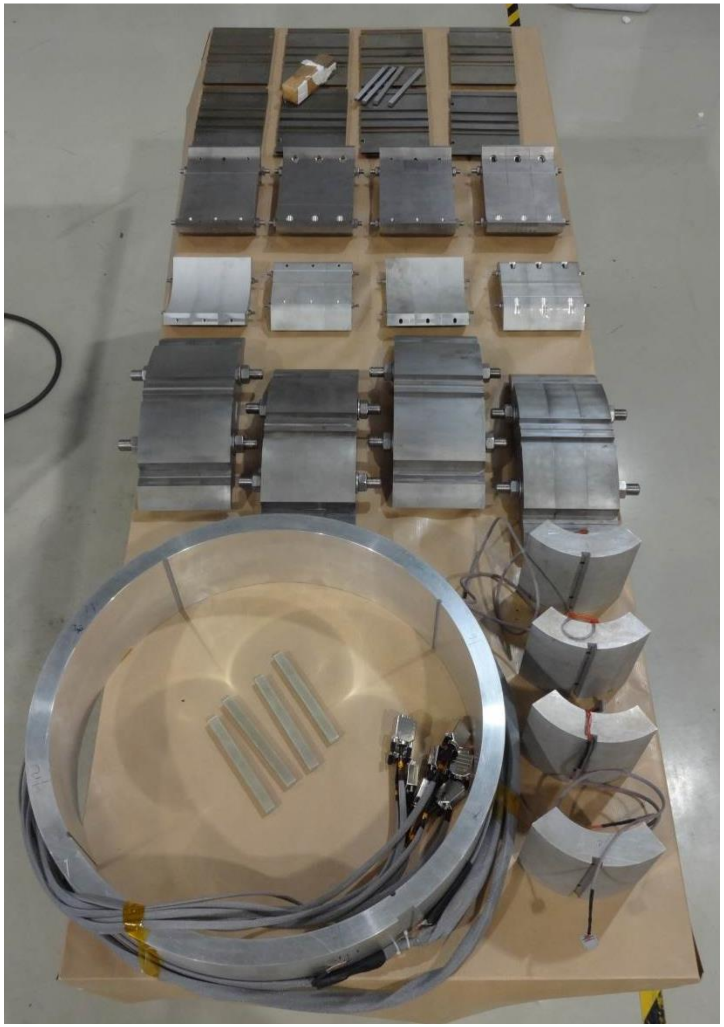


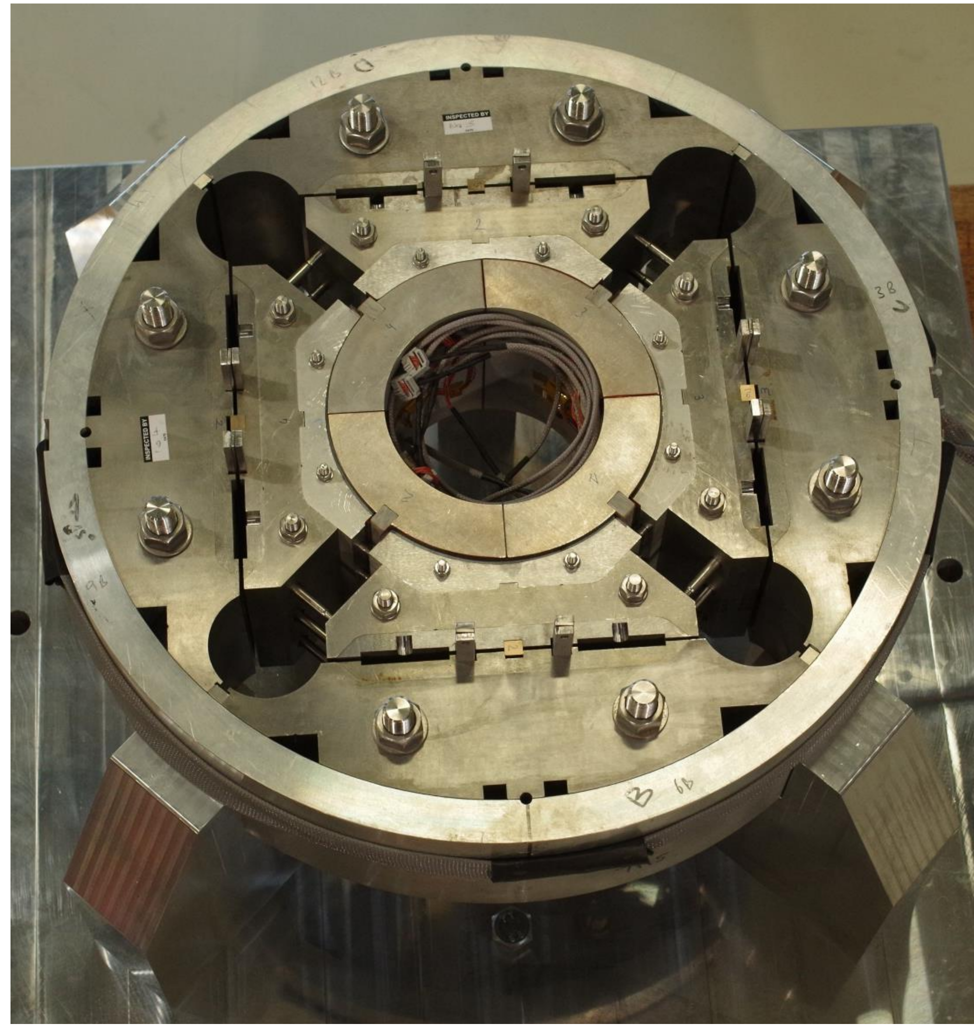




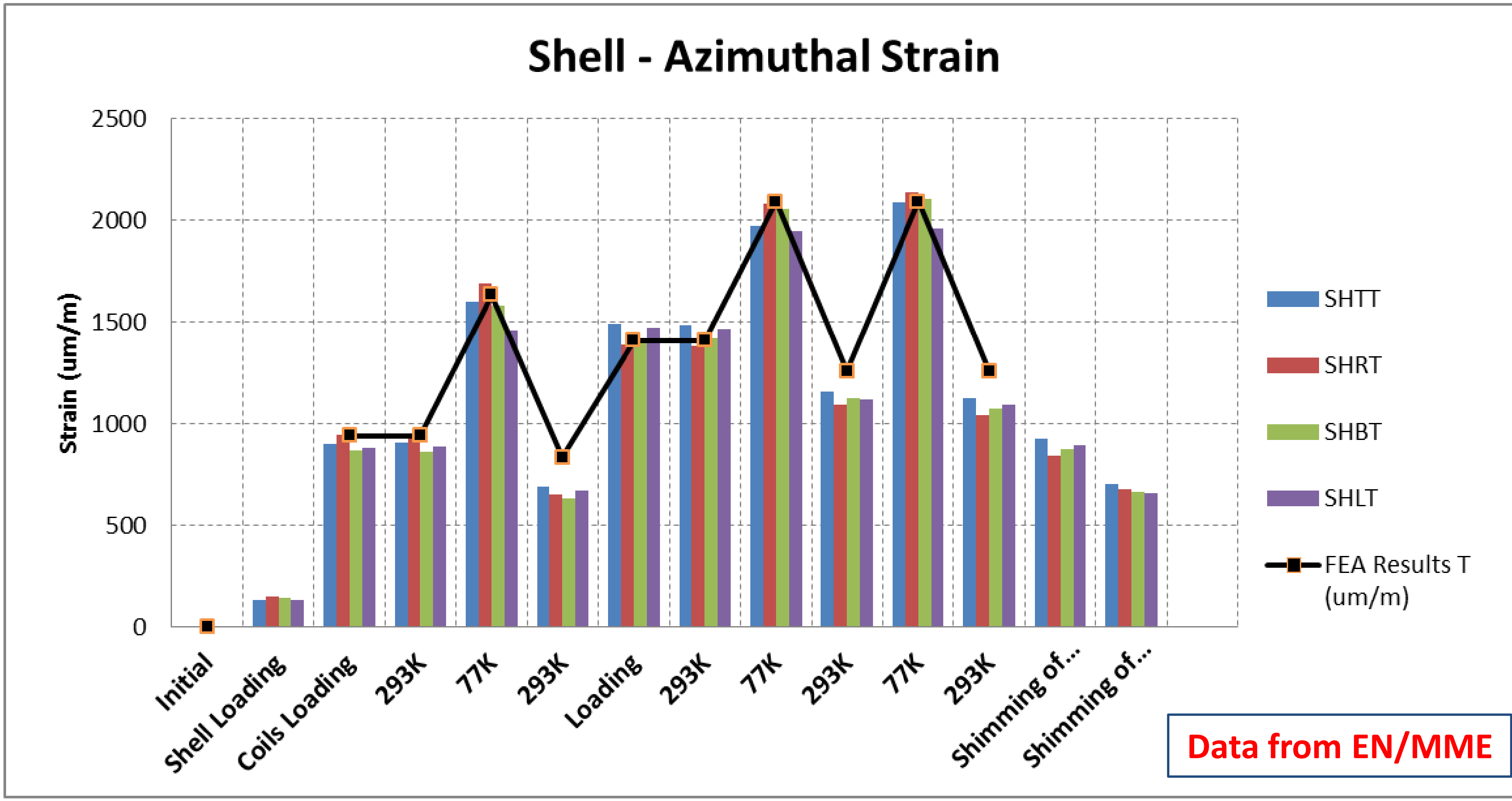


150 mm mock-up assembled, pre-loaded and cooled-down to 77 K (twice)





Loading and cool-down of 150 mm mock-up



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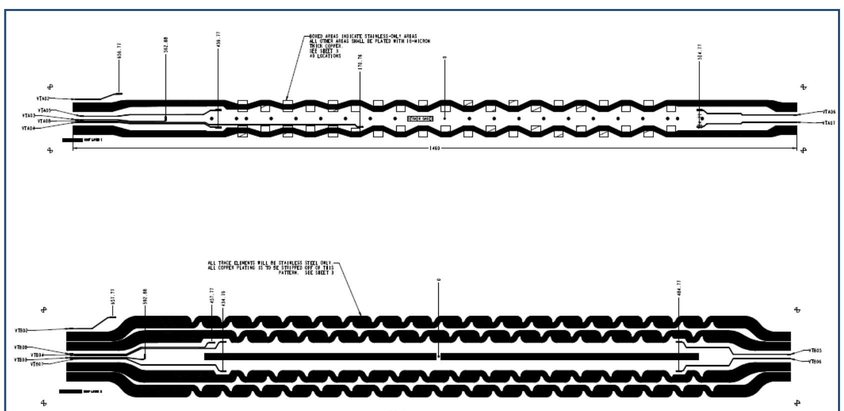
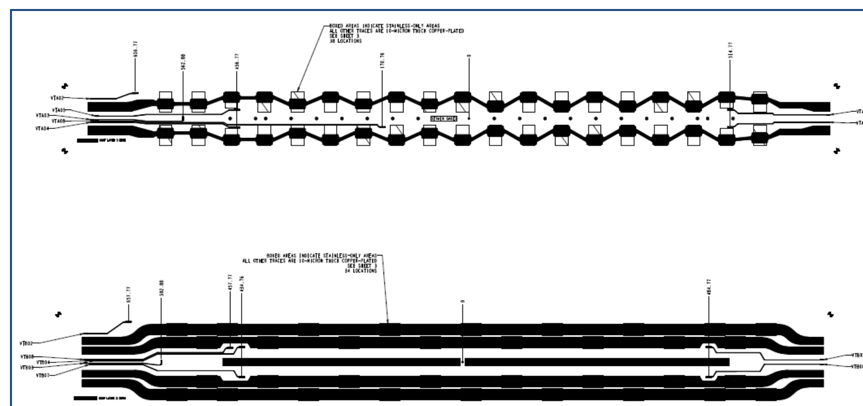
Quench protection

- Protection studied in the case of 2 magnets in series (16 m) protected by one dump resistor (48 mΩ, 800 V maximum voltage)
  - Voltage threshold: 100 mV
  - Validation time: 10 ms
  - Protection heaters on the outer and on the inner layer
- **Hot spot T : ~260 K**

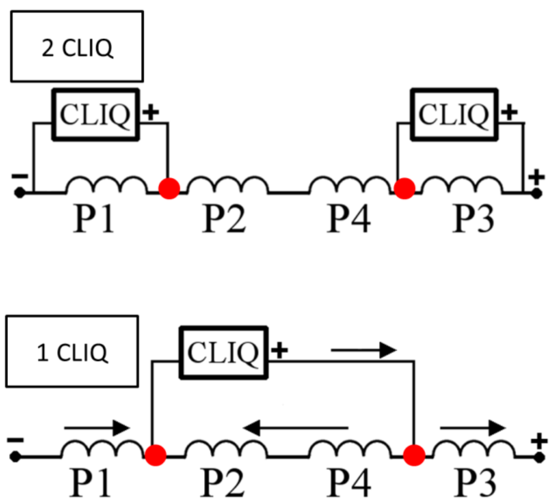


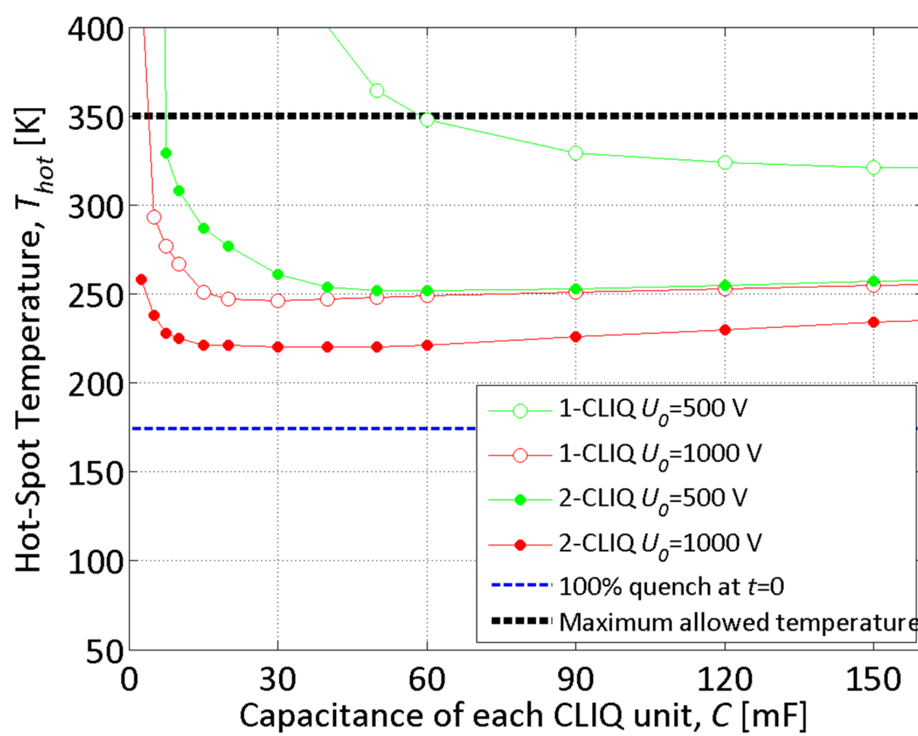


Quench protection
CLIQ

- MQXF configuration to be tested in HQ03

Simulation results – I_0 = 17.3 kA (I_{nom})





MQXF

Magnetic Length 6.8 m
Self-inductance 70 mH
Nominal current 17.3 kA

Quadrupole magnet for the **LHC high luminosity upgrade** (US-LARP collaboration)

For each studied configuration a minimum capacitance is needed to protect the magnet

As expected performance of 2-CLIQ-500 V similar to 1-CLIQ-1 kV

Assumptions: no QH; no EE; RRR=140; 10 ms detection time

Protecting a Full-Scale Nb3Sn Magnet with CLIQ, the New Coupling-Loss Induced Quench System 11 August 2014 1

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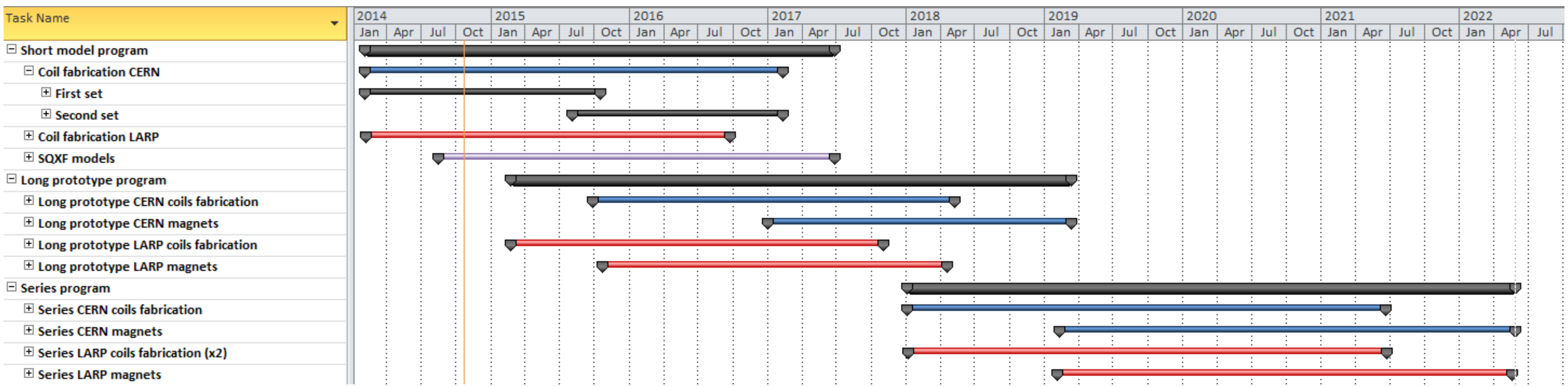
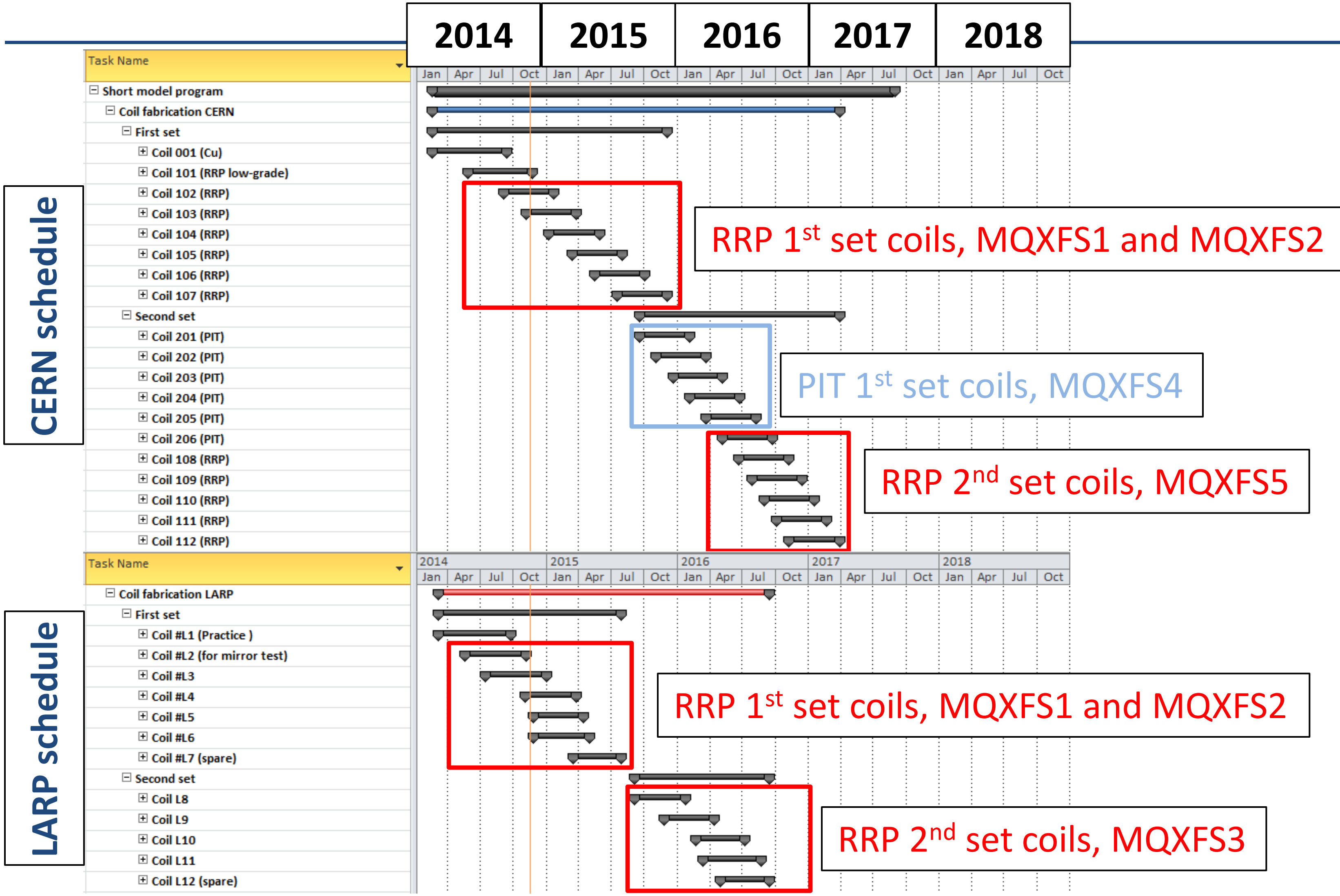
MQXF project schedule



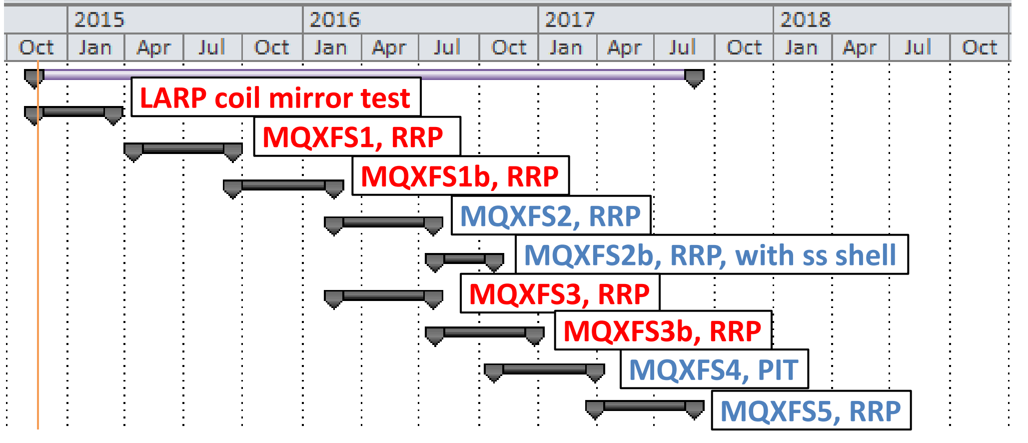
- Short model program: *5 CERN-LARP models*, **2014-2017**
  - Coil fabrication started in 03/2014
  - First magnet test (SQXF1) in 08/2015 (3 LARP coils, 1 CERN coil)
- Long model program: *2 (CERN) + 3 (LARP) models*, **2015-2018**
  - Coil fabrication starts in 2015: 02 (LARP), 10 (CERN)
  - First magnet test in 11/2016 (LARP) and 07/2017 (CERN)
- Series production: *10 (CERN) + 10 (LARP) cold masses*, **2018-2022**
  - Coil fabrication starts in 01/2018
  - First magnet test in 10/2019

CERN and LARP short coil fabrication schedule



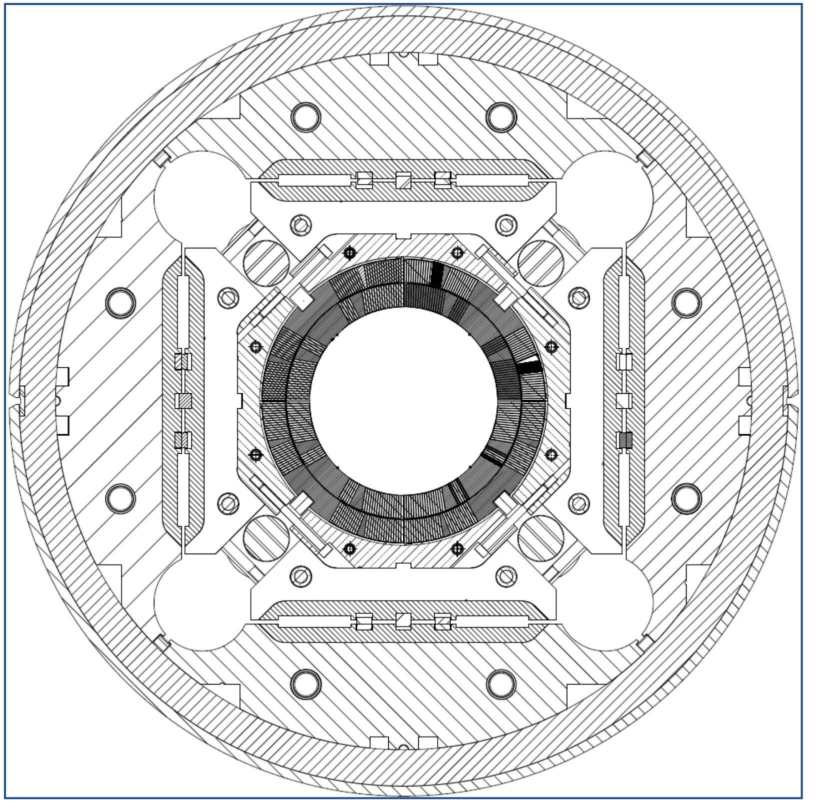
MQXFS test plan

- 1st set of RRP coils
  - First **LARP coil mirror test** in 12/2014 (Dedicated structure)
    - No mirror test for CERN coil
  - First magnet test (**MQXFS1**) in 08/2015
  - Then **MQXFS1b** (LARP), **MQXFS2** (CERN), **MQXFS2b** (CERN) in 2015-2016
  - Test of LHe containment in MQXF2b
    - In 2015 first welding test with CERN structure and aluminium dummy coils
- 2nd set of coils
  - LARP RRP: **MQXFS3** and **MQXFS3b** (2016)
  - CERN PIT and RRP: **MQXFS4** and **MQXFS5** (2016-2017)
  - Room temp. assembly of 2-magnets in 1-cold-mass in 2017



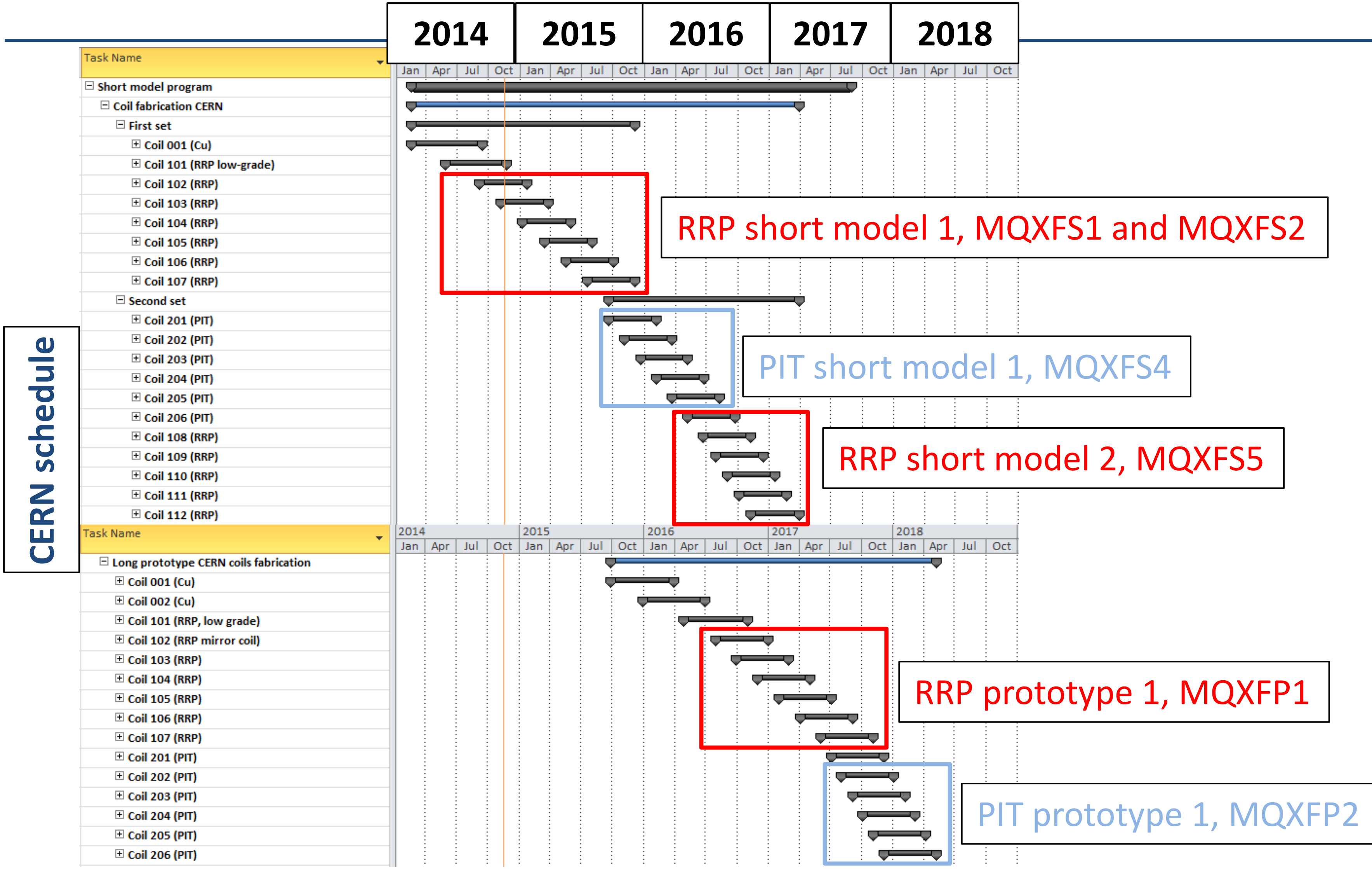
Single coil test with MQXF structure

- 1 Nb_3Sn coil and 3 dummy coils made of Cu (material tbd)
- If successful, excellent tool for long coils, especially for CERN
- Possible scenario
  - First test in 2015 with CERN coil 102 and CERN structure
    - Test by LARP



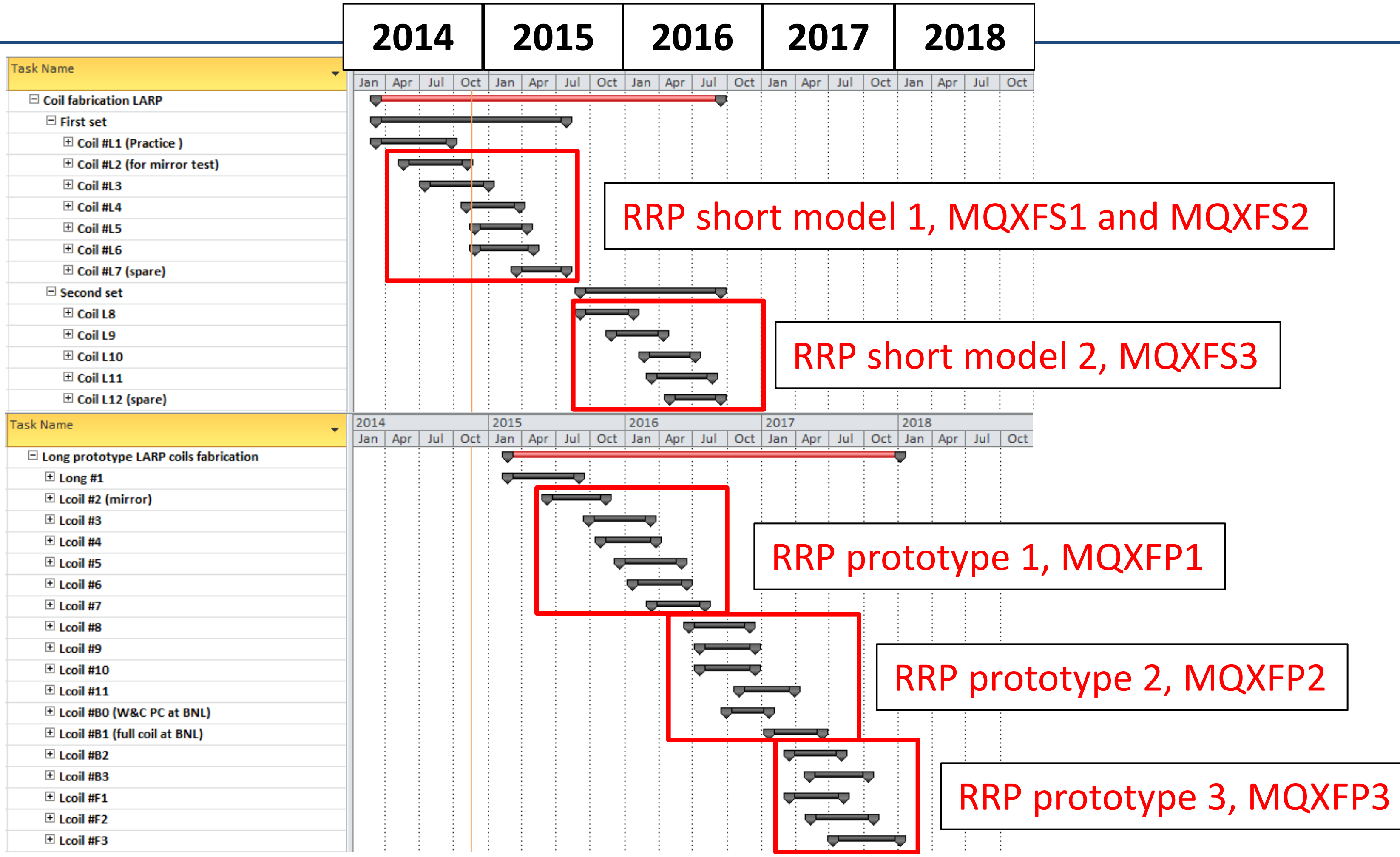
Appendix

CERN coil fabrication schedule



LARP coil fabrication schedule

LARP schedule



Close-Out of MQXF Cable Review

5-6 November 2014

Introduction

- Critical and important project; unique opportunity to make higher performance, space effective accelerator magnets using Nb_3Sn
- Enthusiastic transatlantic team, bringing a new generation
- Good communication between Hi-Lumi and LARP
- Great recent progress
- It has to move from an R&D effort to a construction project!

Overall/schedule - 1

- Design goals shall be conservative because Nb_3Sn accelerator magnet technology is still not sufficiently matured and impregnated Nb_3Sn coils operated at 1.9 K are prone to self-field instabilities
- Therefore: optimize margin by all means, such as: increasing length, revisiting Cu-to-non-Cu ratio, and so on.
- Make use of model/prototype phase for finalizing specifications essential for success, including of acceptance criteria

Overall/schedule - 2

- Keep 2 strand suppliers; if one supplier has less maturity, it will require more resources

- Schedule is challenging; there should be some clearly defined articulations and decision points between the phases

- Address plan B

Technical specs

- Not complete at this time
  - Relationship of superconductor properties to magnet performance has not been clearly defined
- Add requirement on strand cleanliness and surface conditions (especially for bare copper strands)
- Clarify billet/unit length approval
- Benefit from model/prototype program to confirm that the following specs are correct:
  - strand I_c: 361 A at 4.2 K and 15 T
  -RRR: 150 on virgin strand/100 on extracted strand
- Address R_a and R_c on cable

RRP

- Go ahead with 132/169 lower Sn content; final decision in one year concerning series production contract (back up being 108/127)
- Consider proposal to reduce keystone angle

PIT

- Promote a substantive development program with BEAS to optimize strand properties and establish performance baseline for series production
- In the meantime, CERN should go ahead with RRP for model magnet production and should optimize phasing of strand/cable deliveries between RRP and PIT.
- Reduced keystone angle is a must.

QA/QC

- Must be finalized during model/prototype phase
- Level of verification measurements can be based upon ITER experience
- Promote development of in-line video quality control of cable (in particular, at the thin edge)
- Better identify qualification plans including specific cryogenic tests such as: “local” measurements, full-size conductor tests and magnet tests
- For series productions: all acceptance tests should have criteria; requirements should be identical for LARP and Hi-Lumi

Conclusion

1. Are the Functional or Technical Specification for conductor strand and cable adequate to the scope of the MQXF ?
Incomplete
Are they sufficiently developed and reasonably finalized ?
incomplete

2. Does the design of strand and cable meet the specifications in terms of minimum Ic, maximum allowed degradation, minimum RRR, maximum Deff, stability request, cable size, and unit length ?
I_C and minimum RRR have to be revisited
D_{eff} is not critical around 50 μm

3. Assess the likelihood of meeting – with adequate margin – the chosen specifications and requirements based on the decade long experience acquired by LARP in cables and magnet construction and the most recent experience in Europe.
Very optimistic, needs more optimization

4. Is the plan for two types of strand architecture (RRP and PIT) correctly managed inside the program?
PIT needs more support

5. Is the procurement schedule, with associated QA and test plan, credible and adequate for the prototyping phase (where applicable) and for the construction phase?
No yet, need to better articulate the different project phases and the decision points