Triplet workshop highlights...
...and MQXFS01 test update

P. Ferracin

on behalf of the MQXF collaboration

4th HL-LHC Technical Coordination Committee (TCC) meeting
CERN
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Acknowledgments

- CERN
  - A. Ballarino, H. Bajas, M. Bajko, B. Bordini, J.C. Perez, S. Izquierdo Bermudez, P. Fessia, C. Fichera, P. Grosclaude, M. Guinchard, M. Juchno, F. Lackner, L. Oberli, H. Prin, J. Rysti, E. Rochepault, S. Sequeira Tavares, E. Todesco, G. Vallone
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- FNAL
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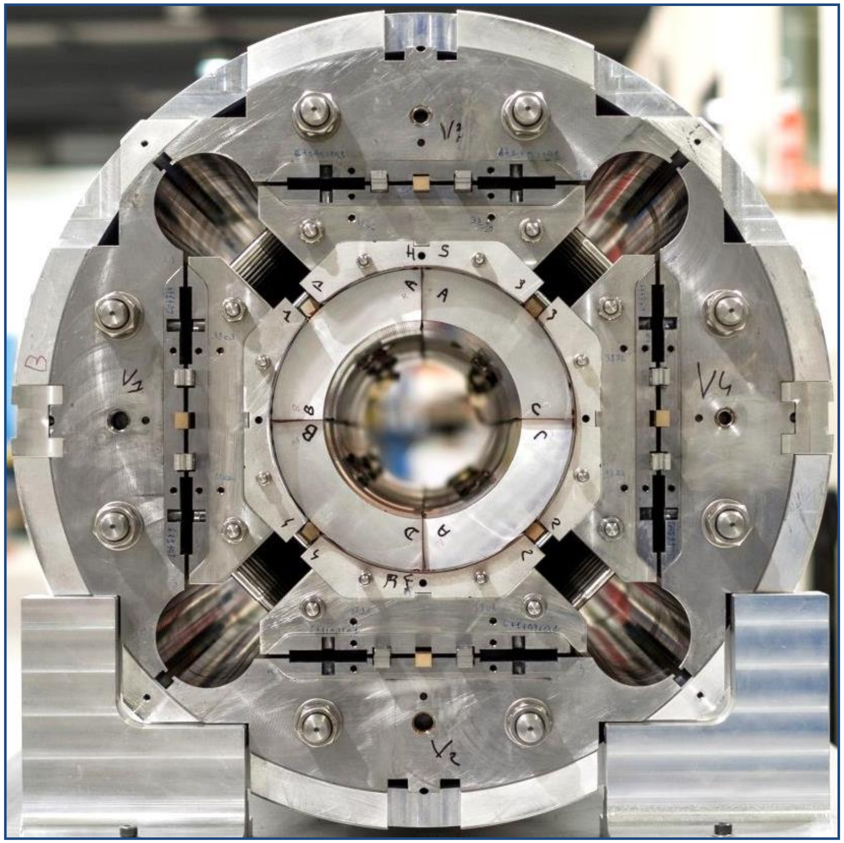
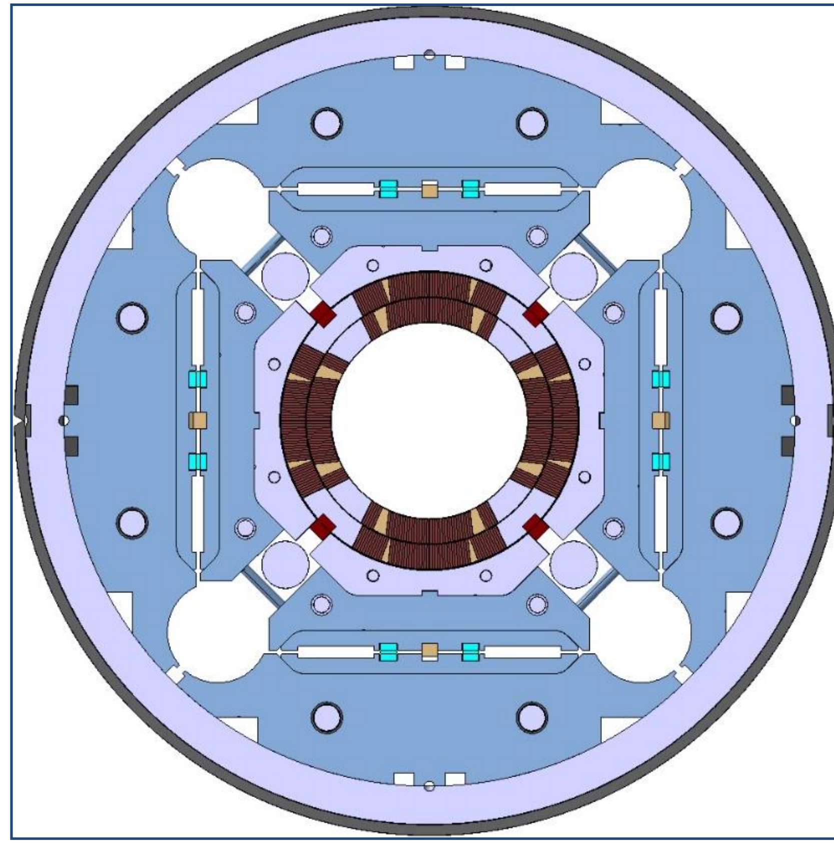
- LBNL
  - D. Cheng, D.R. Dietderich, R. Hafalia, M. Marchevsky, H. Pan, G. Sabbi, X. Wang
- CEA Saclay
  - H. Felice
- LASA
  - V. Marinozzi, M. Sorbi
- Tampere Univerisity of Technology
  - T. Salmi

Overview

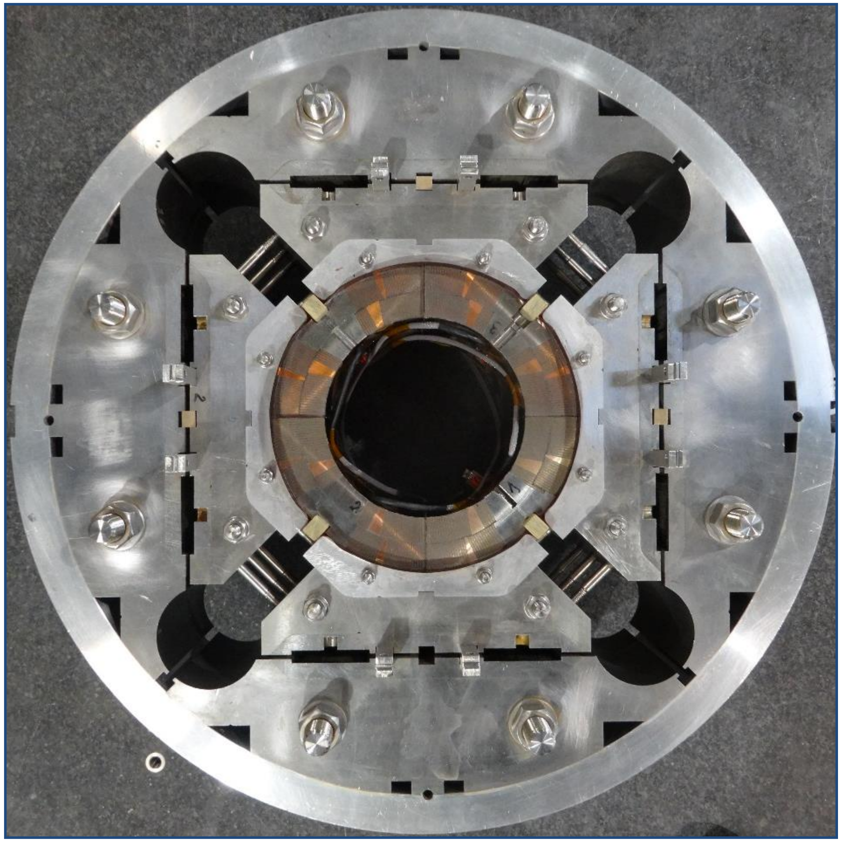
- **"MQXF Workshop on Structure, Alignment, and Electrical QA"**
  - *https://indico.cern.ch/event/478951/*
  - *2 to 4 February 2016 in conf. room 927*
  - *About ~20-30 participant per day*
    - *8 from the US +2 in video-meeting*
- General agreement among participants about the effectiveness of the format
  - List of action items defined
- 1 hour in morning and afternoon for discussion/summary

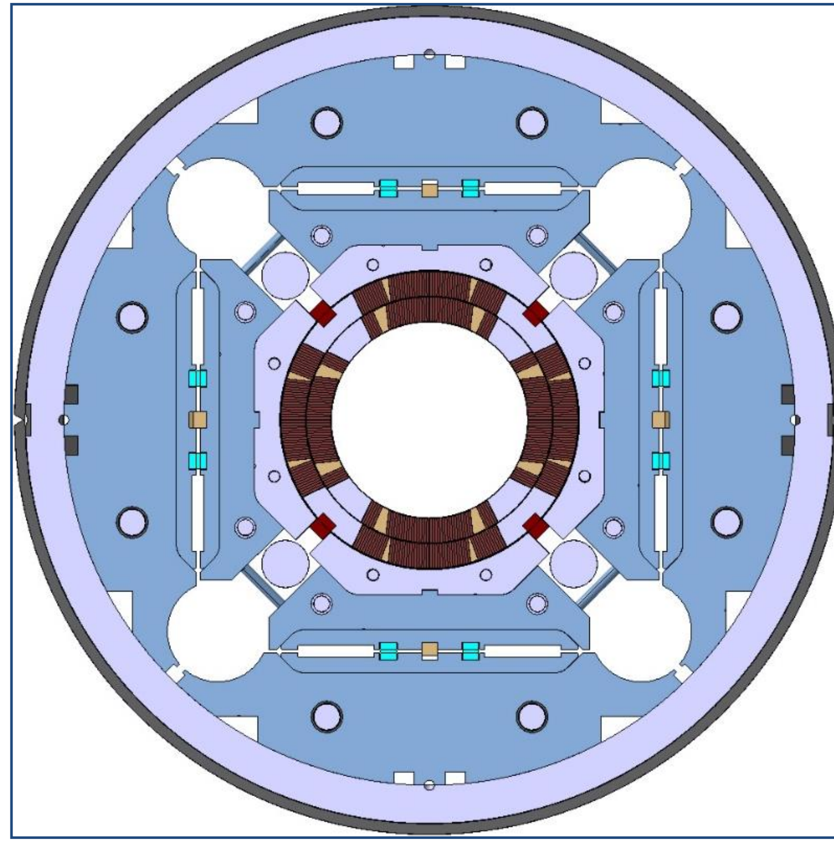
Overview of MQXF design





Overview of MQXF design





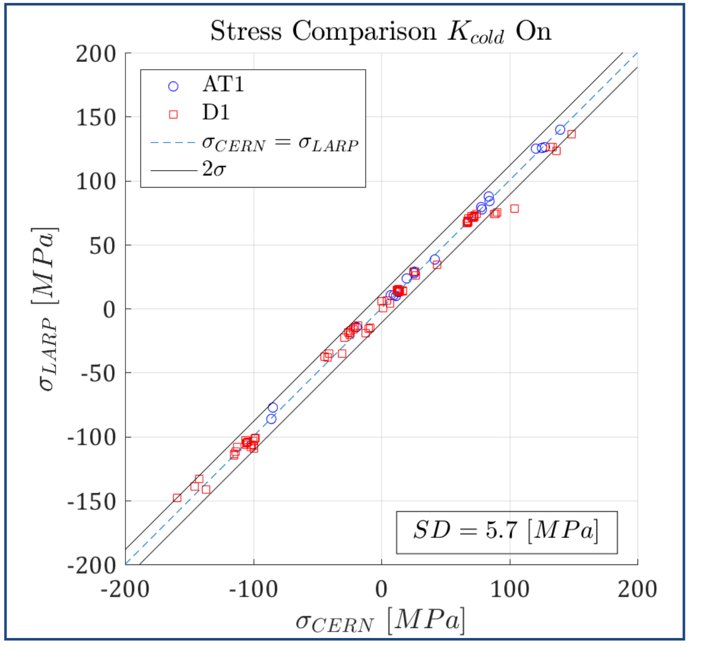
Day 1

- Analysis of mechanical performance of short models with dummy and real coils
  - Strain gauge data and FE model
- Review of assembly process of short model

Day 1	**02/02/2016**			**MQXFS design and structures**	
		08:30	00:30	Overview short model design and structures	Ferracin
		09:00	00:30	Short model assembly and lessons learned at LBNL	Cheng
		09:30	00:30	Short model assembly and lessons learned at CERN	Bourcey
		10:00	00:30	Coffee break	
		10:30	00:30	Overview of FE models and updates	Pan
		11:00	00:30	CERN and LARP strain gauge systems	Guinchard
		11:30	00:30	Discussion	
		12:00	***01:30***	*lunch*	
				MQXFS design and structures	
		13:30	00:30	Analysis of loading and cool-down of MQXFSD	Vallone
		14:00	00:30	Analysis of loading and cool-down of MQXFS1	Pan
		14:30	00:30	Overview of stress uniformities and comparison with FE models	Vallone
		15:00	00:30	Strain measurements and FE analysis: plans for prototypes	Vallone
		15:30	00:30	Coffee break	
				MQXF Prototype structures	
		16:00	01:00	Tolerance analysis	Pan
		17:00	00:30	Requirements and feedback from LARP structure review	Carcagno
		17:30	00:30	Discussion	
		18:00			

Day 1 findings and action items

- CERN/LARP meas. differences: **±10 MPa**
- Uniformity
  - Shell stress : **±10 MPa**
  - Dummy coil stress : **±10 MPa**
  - Real coil stress : **±17 MPa**
- Prototypes instrumentation defined (mainly on shell)



- Trying to converge on CERN system
- Agreement on assembly procedure
  - We are moving from thick to thin iron laminations
- Tolerance analysis in progress

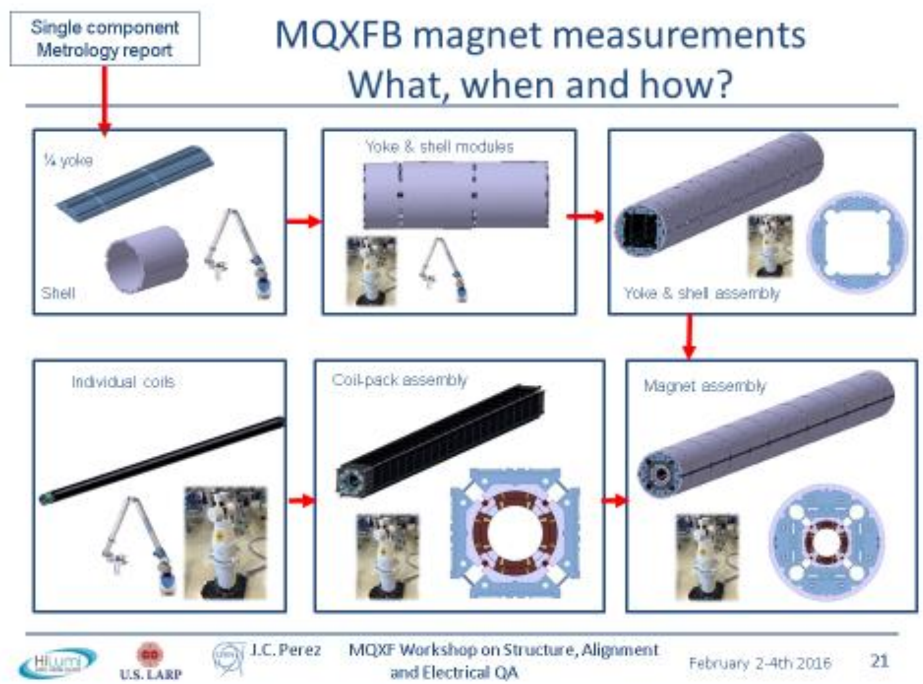
Day 2

- **Prototype** design and assembly
- **Alignment**

Day 2	**03/02/2016**			**MQXF Prototype Structures**	
		08:30	01:00	MQXFA design, assembly plans & tooling	Cheng
		09:30	01:00	MQXFB design, assembly plans & tooling	Perez
		10:30	00:30	Coffee break	
		11:00	00:30	Options for modifications to parts and procedures	Anerella
		11:30	00:30	Discussion	
		12:00	***01:30***	*lunch*	
				MQXF Alignment	
		13:30	01:00	Plan for mechanical alignment measurements	Cheng
		14:30	01:00	Plan for mechanical alignment measurements	Perez
		15:30	00:30	Coffee break	
		16:00	00:30	MQXFA cold mass assembly steps	Vouris
		16:30	00:30	MQXF bus-bar routing	Prin
		17:00	01:00	Discussion	
		18:00			

Day 2 findings and action items

- Review of prototype design and assembly procedure
- Magnetic measurements before coil-pack insertion
- Alignment
  - Mandatory to check all steps
  - Start working on the mech.-magn. probe
  - Define some reasonable values based on previous experience
  - WP3-WP2 meeting on this to be called
- Bus-bar in or out?



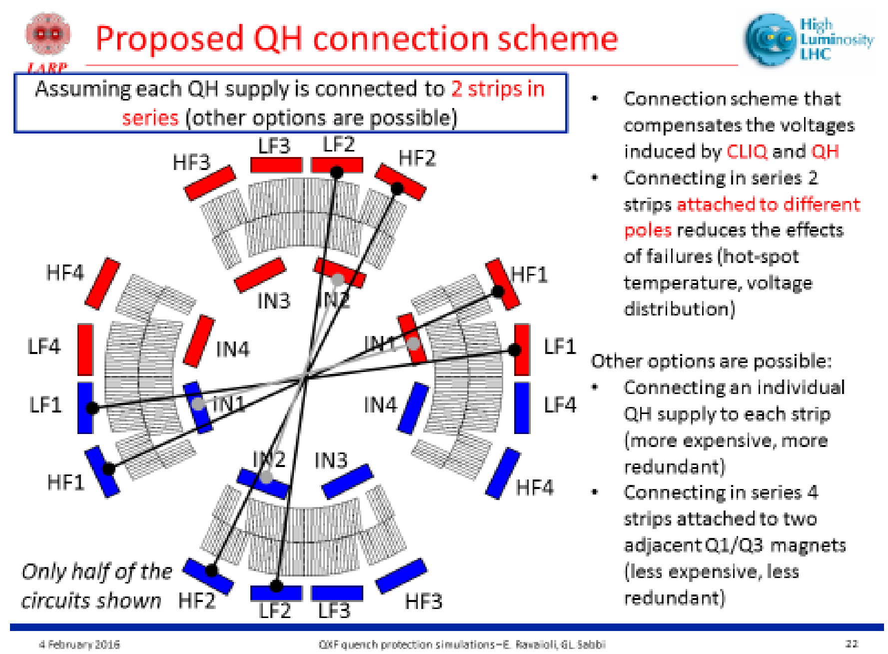
Day 3

- **Quench protection and electrical QA**

Day 3	**04/02/2016**			**QP and Electrical QA**	
		08:30	00:30	Options for triplet circuit	Wollmann
		09:00	00:30	QP simulations - heaters only	Ambrosio
		09:30	01:00	QP simulations - with CLIQ	Ravaioli
		10:30	00:30	Coffee break	
		11:00	01:00	Discussion	
		12:00	01:30	*lunch*	
				QP and Electrical QA	
		13:30	01:00	High voltage withstand levels	Rodriguez Mateos
		14:30	00:30	Electrical tests on coils and components	Ambrosio
		15:00	00:30	Impulse testing of coils and magnets: present experience and future plans	Marchevsky
		15:30	00:30	Coffee break	
		16:00	01:00	Discussion	
		17:00			

Day 3 findings and action items

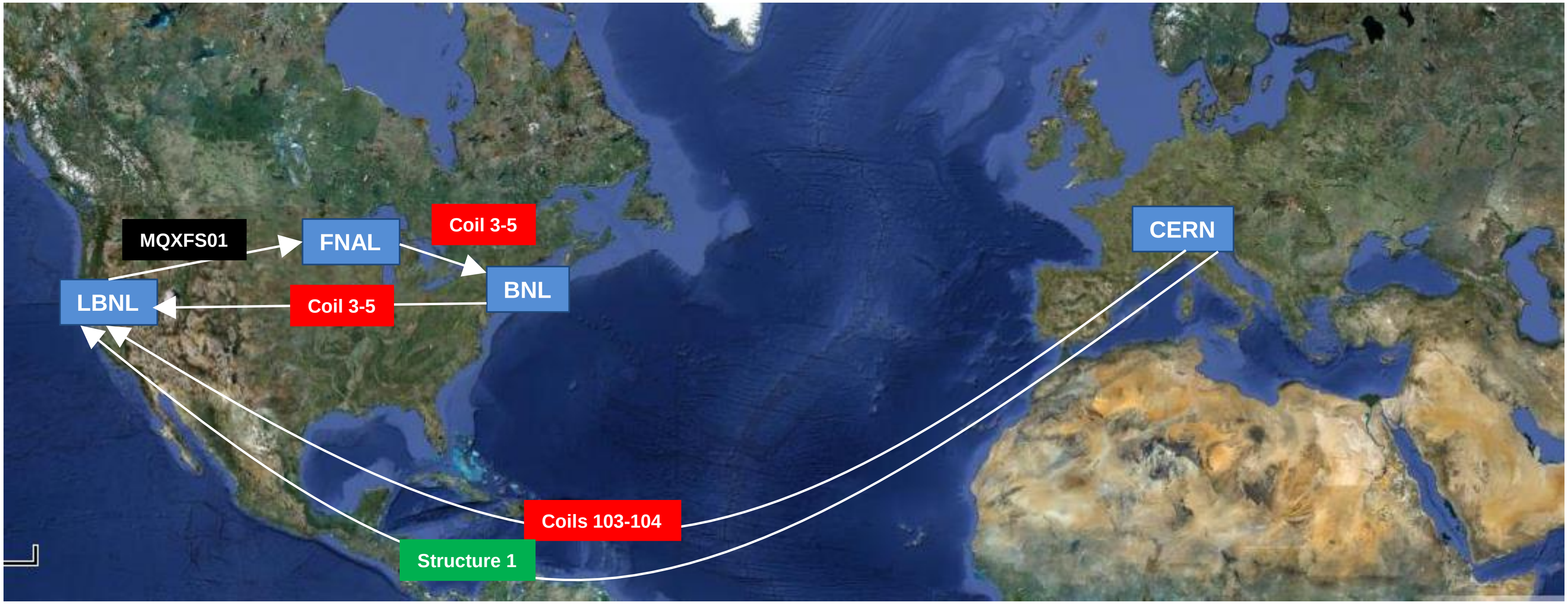
- Triplet circuit
  - Baseline today: 2 circuits with energy extr.
  - General agreement on removing energy extr. and going to 1 circuit
- CLIQ
  - Proposal, accepted
    - 1 or 2 Power supply, not important
    - No energy extraction
    - 6-CLIQ, 4 warm diodes strings
    - QH connection scheme →
  - The plan is to check CLIQ as soon as possible
    - MQXFS1b, MQXFS2,



Update on MQXFS01 test

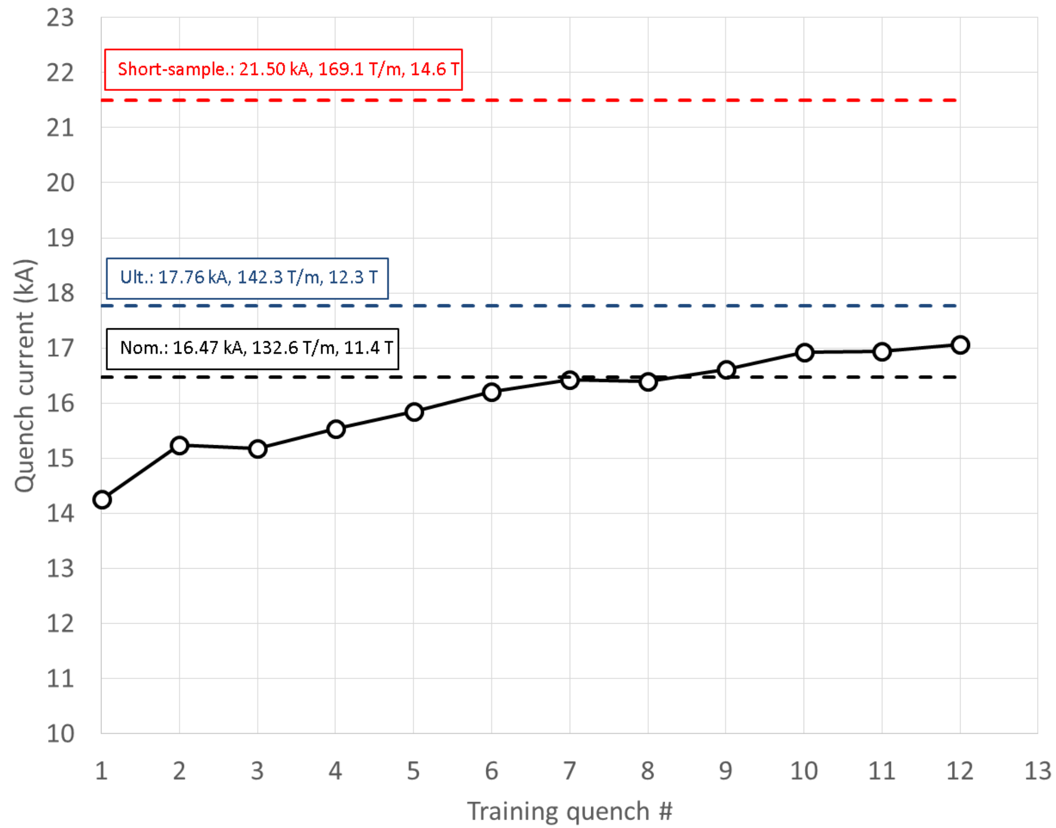
- Test at FNAL in progress: quench performance, mechanical behaviour, field quality, quench protection

MQXFS1

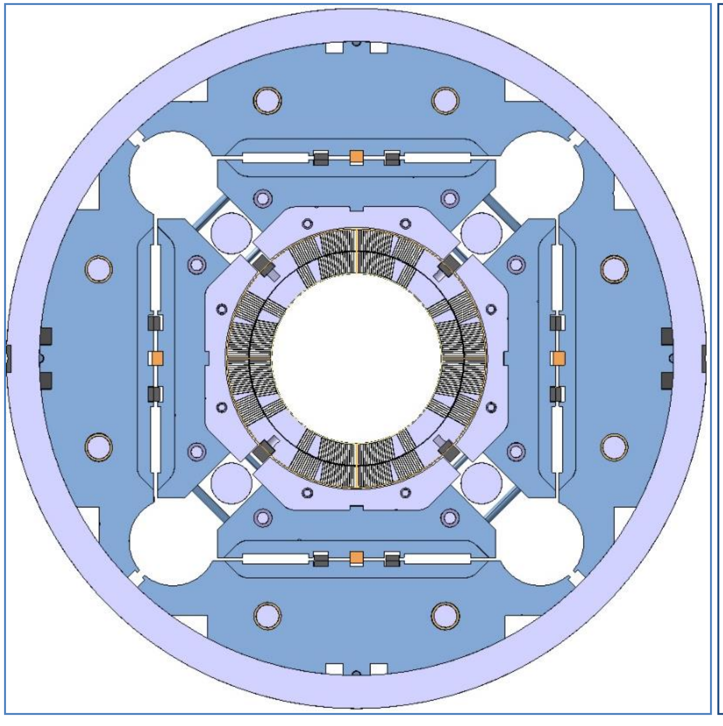

MQXFS01
FNAL
Coil 3-5
BNL
LBNL
Coil 3-5
CERN
Coils 103-104
Structure 1

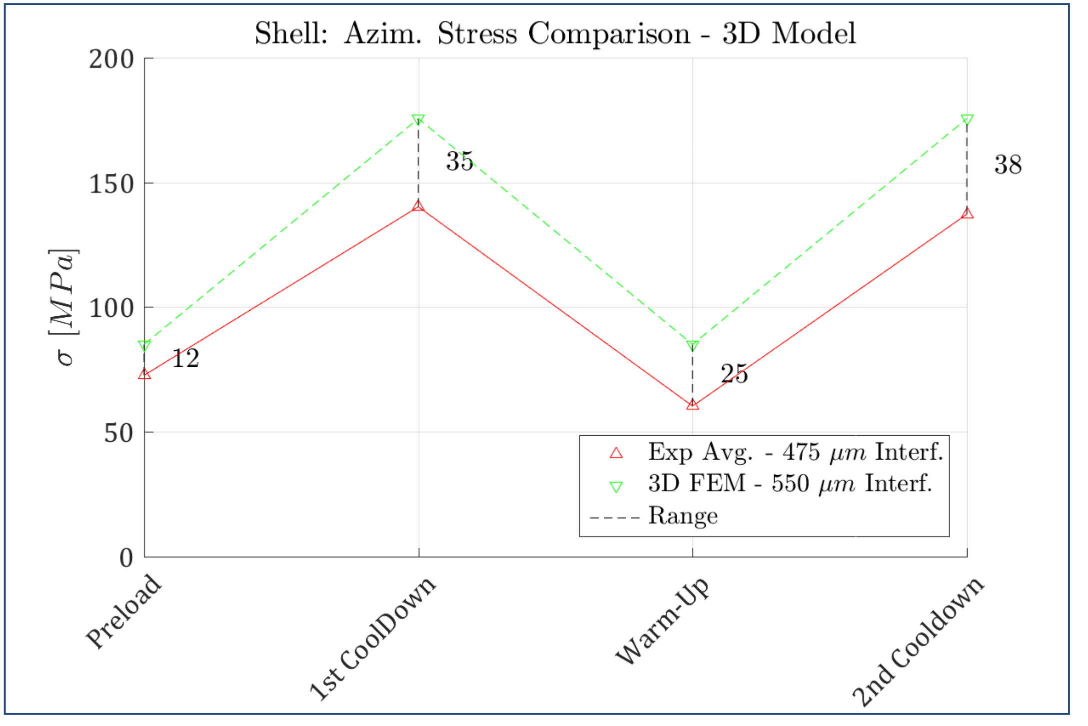
Training

- First quench at 66% of I_{ss}
- G_{nom} in ~7 quenches
- All coils involved
  - Mainly CERN 103 (weakest)
- Pole turn quenches
  - High field area
- 45 min at nominal during magn. meas.

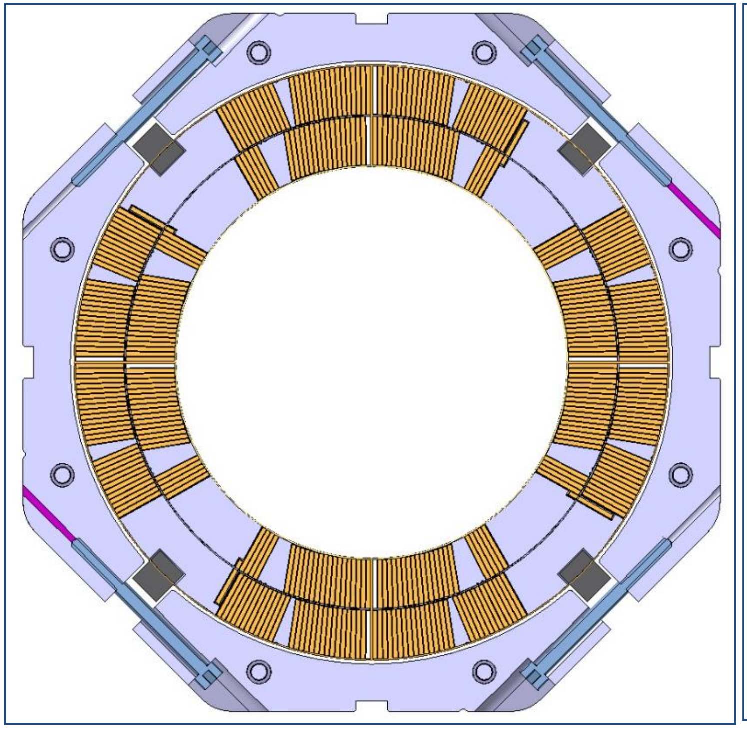


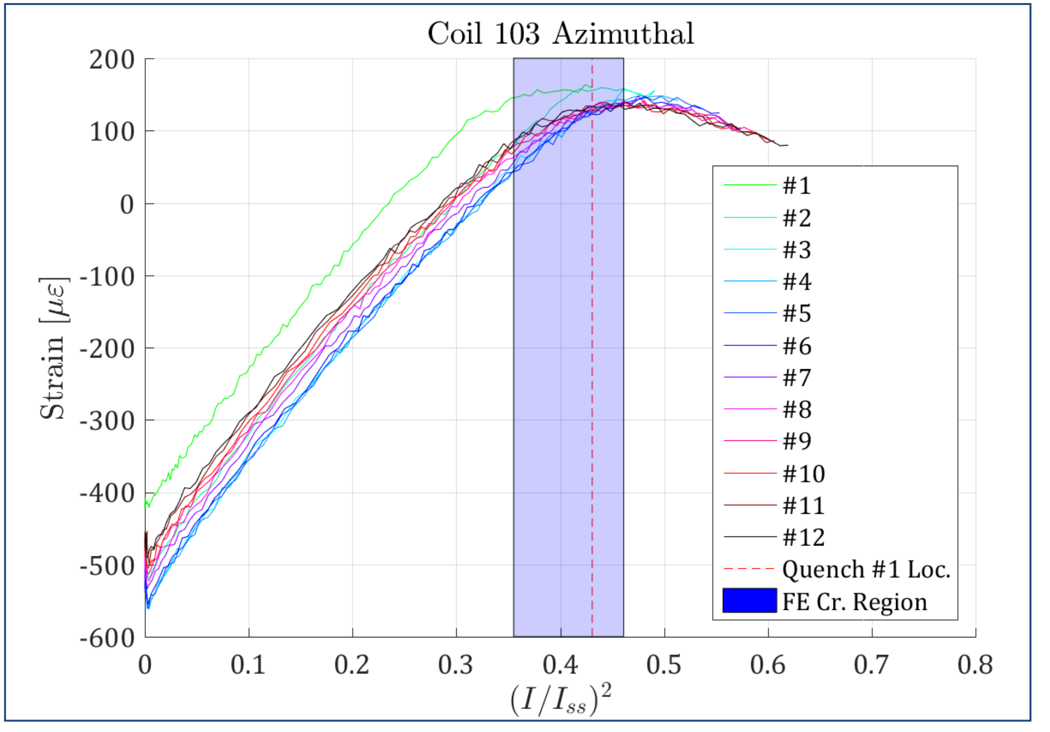
Shell stress: meas. vs. target



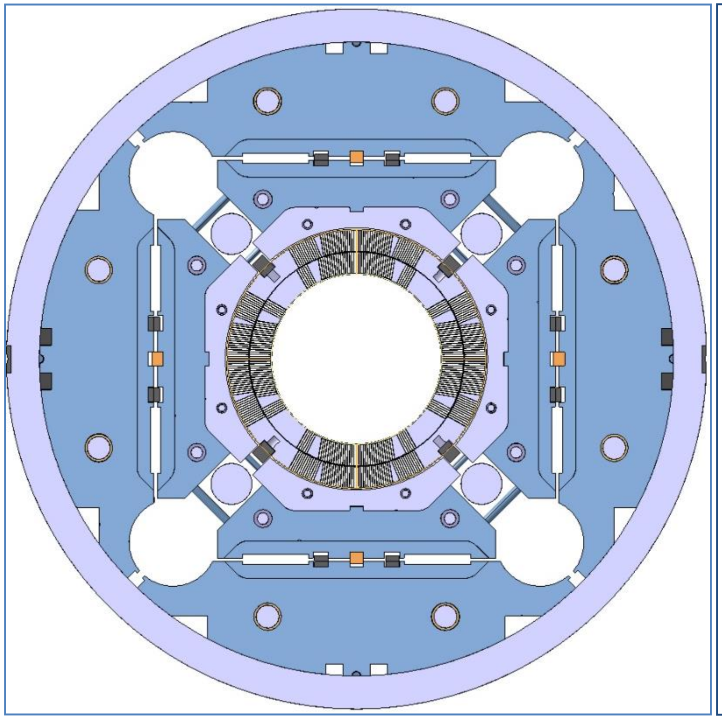


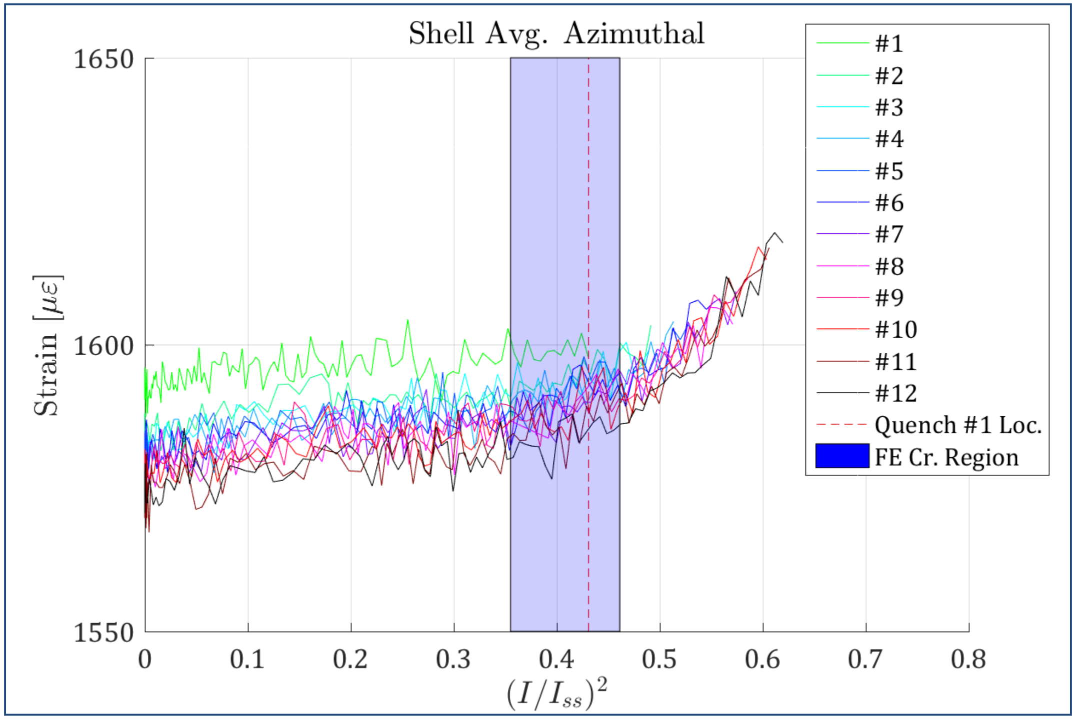
Coil unloading





Shell stress increase





The HQ02 case

TABLE I
HQ02 PARAMETERS

Parameters	Units	
Restacked Rod Process (RRP) strand diameter	mm	0.778
Number of strands in the cable		35
Nominal reacted bare cable dimension	mm	15.002
Nominal reacted bare cable mid-thickness	mm	1.44
Nominal S2-glass sleeve insulation thickness	μm	100
S2-glass sleeve insulation thickness @ 7 MPa	μm	86
Nominal keystone angle	deg	0.75
Short sample current I_{ss} at 4.5 K / 1.9 K	kA	16.5 / 18.3
Short sample gradient at 4.5 K / 1.9 K	T/m	186 / 205

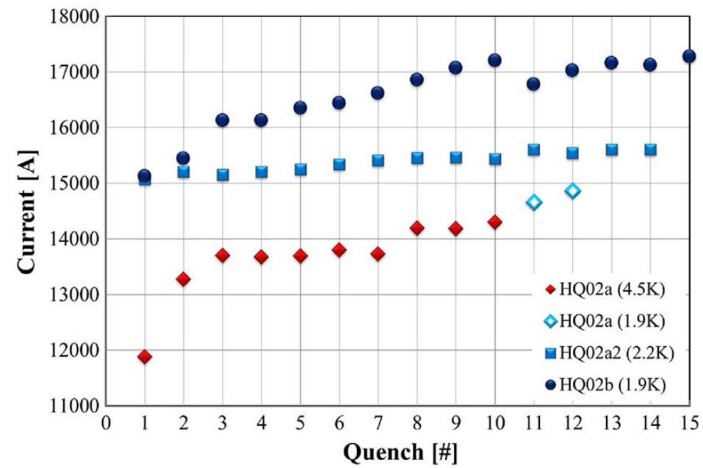


Fig. 3. HQ02a and b first training comparison at different temperatures. The benefit of the increased pre-stress between both assemblies is visible.

Appendix

Day 1

- Instrumentation prototype/series
  - Possible scenario for strain gauges
    - Prototype
      - Al shell equipped with SG, removed before ss shell welding
      - SS shell equipped with SG
      - Temporary smaller bore tube to allow for SG on coils
    - Series
      - Al shell equipped with SG, removed before ss shell welding
      - SS shell equipped with SG
      - No coil SG
- Converge on 1 SG system?
  - Work in progress to converge on CERN system

Day 1

- Yoke-shell sub-assembly: simplified procedure, with yokes temporary “bolted” to the shell or traditional yoke keys?
  - The yoke keys (gap keys) are important to ensure "protection" of the coil pack in case of bladder failure. With gap keys in and shell slightly pre-tensioned there is no risk of the top yoke to collapse on the coil pack
  - It seems that the yoke key would better define the dimension of the yoke-shell sub-assembly

Day 1

- Packing factor of yoke laminations
  - Historically the axial rigidity of the structure was assumed to be provided by the yoke behaving as a solid piece since everything else is segmented
    - If we reduce the compaction of the yoke laminations, don't we compromise this rigidity?
  - To be checked with Rob the 98% level and about possible alternatives (slots in laminations)

- The coil sequence is defined (we use the one assumed on MQXFS1)
  - A change has major implication on the design of the connection box
- We need to measure the mechanical properties of “Rad-hard G10”

- We need to continue the analysis of measurement performed with vs. CMM measurements

Day 1

- Mechanical model / SG data
  - Verify numbers of axial pre-load with ss rods
- Check the possibility for LARP to procure an additional LE end-plate compatible with 33 mm axial rods.
- Check coil stress with stainless steel shell
  - coil stress uniformity along z should improve
- Check strain gauge vs. model during bladder operation
  - Plot coil stress vs shell stress with bladders inflated
- Include end-plates screws in the model to verify it thread can handle the load
- Investigate stress in coil 5
  - Measurements indicate much higher stress
- Perform tolerance analysis on dummy coil case and check with measurements data
- Investigate impact of “Azimuthal tolerances”
- “Check on MQXFS01 the impact of temperature gradient during warm up on coil peak stress (observed in HQ)

Day 2

- MQXFA
  - It was suggested to remove the pad/collar bolts after the coil-pack assembly
  - General agreement that we perform magnetic measurements before bladders operation
    - To be checked is before or after coil-pack insertion
      - Preliminary computations indicates that the harmonics do not change in or out the yoke-shell
  - Check rigidity of insertion table
  - The reference for alignment is the slot of the left-right yokes

Day 2

- Requirements
  - The key points to focused right now is voltage thresholds and cold mass design (interfaces)
  - What about splice resistance and splice VT?

Day 2

- MQXFB
  - We need from Rob size of “channels” in the yoke thick laminations
    - This would remove the requirements of 98% of packing factor and allowed a tight compaction of the yoke laminations
- Alignment
  - MQXFA
    - Mandatory to check the yoke-shell sub-assembly: length, straightness, parallelism
  - MQXFB
    - Start working on the mech-magn probe
  - Obtain from WP2 some alignement budget number
    - We can start with “0.5 mm”

Day 2

- MQXFA cold mass
  - Check support point before rotation
  - Check the twist of the shell
  - Check with project office about PED
  - Target for welding requirement: 50-100 MPa
- Bus bar routing
  - Check 150 cm^2 free area of Lhe; is this compatible with internal bus bar option?

Day 3

- Initial discussion on alignment requirements
  - Herve' will send some reasonable values
  - We organize in the coming month a WP3-WP2 meeting on this
- Triplet circuit
  - Baseline today is with 2 circuits with energy extraction
  - There is a general agreement on the removing energy extraction from the baseline
  - Going from 2 to 1 circuit is still under discussions, but it seems also in this case that there is a general agreement on proposing 1 circuit for the circuit review
    - Would be good to have a proposal for the circuit review

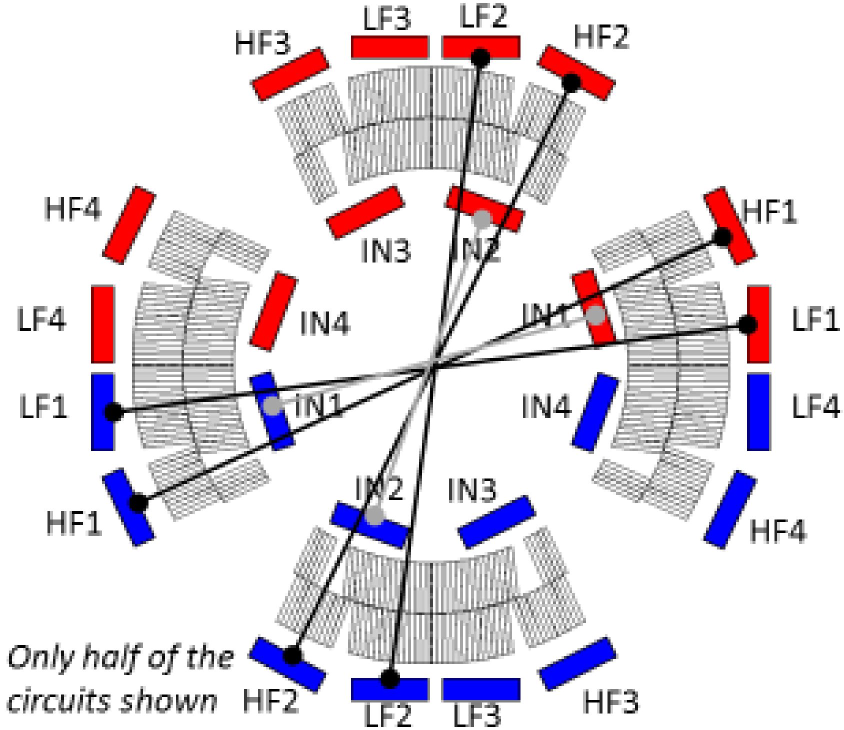
Day 3

- Protection with heaters
  - The baseline is OL quench heaters + CLIQ, with IL quench heaters for redundancy/back-up
- CLIQ
  - It looks like the worst case scenario in general is a hot spot temperature of 300-320K and a peak voltage
    - Peak voltage to ground: 520 V
    - Peak coil-to-QH voltage: 500 V
    - Peak mid-plane voltage: 500 V
    - Peak layer-to-layer voltage: 500 V
    - Peak turn-to-turn voltage: 50 V
  - Emanuele need to check the voltage in the hot spot
  - Mechanical force assessment of CLIC
  - Proposal, accepted
    - 1 or 2 Power supply, not important
    - No energy extraction
    - 6-CLIQ, 4 warm diodes strings
    - The QH connection scheme is the one shown in slide 22 of Ravaioli's talk (see next slide)
- Measure interfilament AC losses in strand
- Update diagram to reflect actual powering

Day 3

Proposed QH connection scheme

Assuming each QH supply is connected to 2 strips in series (other options are possible)



- Connection scheme that compensates the voltages induced by CLIQ and QH
- Connecting in series 2 strips attached to different poles reduces the effects of failures (hot-spot temperature, voltage distribution)

Other options are possible:

- Connecting an individual QH supply to each strip (more expensive, more redundant)
- Connecting in series 4 strips attached to two adjacent Q1/Q3 magnets (less expensive, less redundant)

4 February 2016 QXF quench protection simulations – E. Ravaioli, GL Sabbi 22

Day 3

- HVWL
  - It was requested to verify if we could reduce the maximum voltage in the CLIQ case (now 500 V)
  - The plan is to check CLIQ in MQXFS as soon as possible: MQXFS1b, MQXFS2, both in the summer
  - Change the QH connection according to previous slide in MQXFS1b
  - Design the test plan to manage the risk for test stations, for example evaluate the 80K high voltage test.
  - Let’s target the collaboration meeting to have a table of high voltage values, maybe even for the circuit review
  - We will try to test Maxim discharge test proposal in MQXFS1b or MQXFS2 (we could use HQ or LQ)

Train. Q#	Quench ramp rate	Ramp-rate profile	Current	Current	Iss	Grad_ss	Bpeak_ss	Iss %	emf %	Grad	Bpeak	Quench location	MIITS	Remarks
#	A/s	A/s	A	kA	kA	T/m	T	%	%	T/m	T			
1	20	20toQ	14249	14.249	21.5	169.08	14.60	66	44	116.1	10.0	Coil 5, A5A4	24.6	pole turn, LE
2	20	50to9; 20toQ	15238	15.238	21.5	169.08	14.60	71	50	123.5	10.6	Coil 3, A6A7	24.8	pole turn RE
3	20	50to10; 20toQ	15182	15.182	21.5	169.08	14.60	71	50	123.1	10.6	Coil 103, A4A5	23.7	pole turn LE
4	20	50to9; 20toQ	15540	15.540	21.5	169.08	14.60	72	52	125.8	10.8	Coil 103, A5A6	23.7	pole turn SS
5	20	50to9; 20toQ	15848	15.848	21.5	169.08	14.60	74	54	128.0	11.0	Coil 104, A8B8	23.8	Ramp
6	20	50to9; 20toQ	16209	16.209	21.5	169.08	14.60	75	57	130.7	11.3	Coil 103, A4A5	23.8	pole turn LE
7	20	50to9; 20toQ	16418	16.418	21.5	169.08	14.60	76	58	132.3	11.4	Coil 5, A6A5	24.17	pole turn SS
8	20	50to9; 20toQ	16399	16.399	21.5	169.08	14.60	76	58	132.1	11.4	Coil 103, A8B8	23.37	Ramp
9	20	50to9; 20toQ	16614	16.614	21.5	169.08	14.60	77	60	133.7	11.5	Coil 103, B8B6	24.38	pole turn ss
10	20	50to9; 20toQ	16920	16.920	21.5	169.08	14.60	79	62	136.0	11.7	Coil 103, A2A4	23.47	LE
11	20	50to9; 20toQ	16937	16.937	21.5	169.08	14.60	79	62	136.1	11.7	Coil 104, A5A6	22.06	pole turn ss
12	20	50to9; 20toQ	17067	17.067	21.5	169.08	14.60	79	63	137.1	11.8	Coil 103, A6A7	22.4	pole turn RE