MQXF Short model test results CERN
(also He gas intermediate test)

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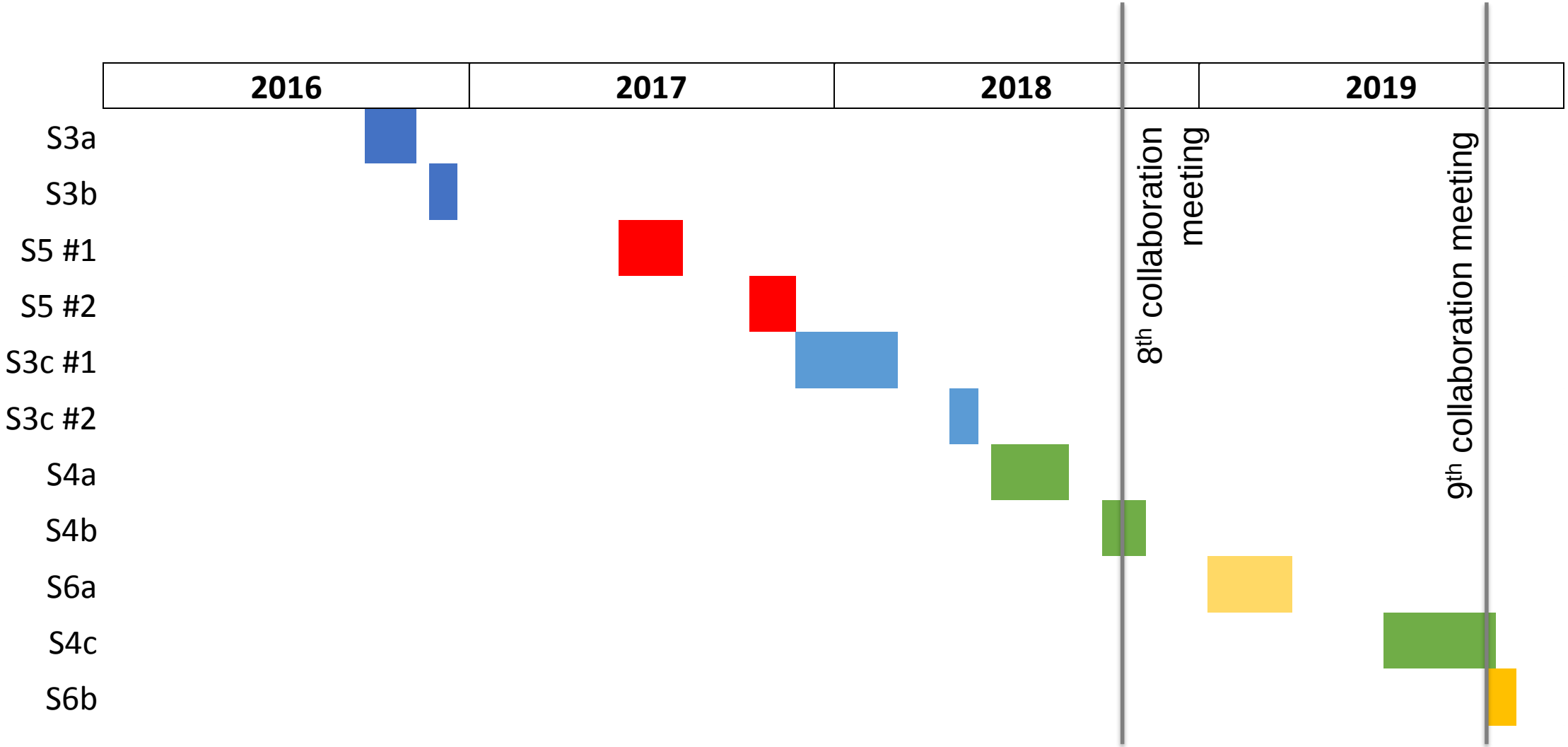
Thanks to support throughout the section, group and project.

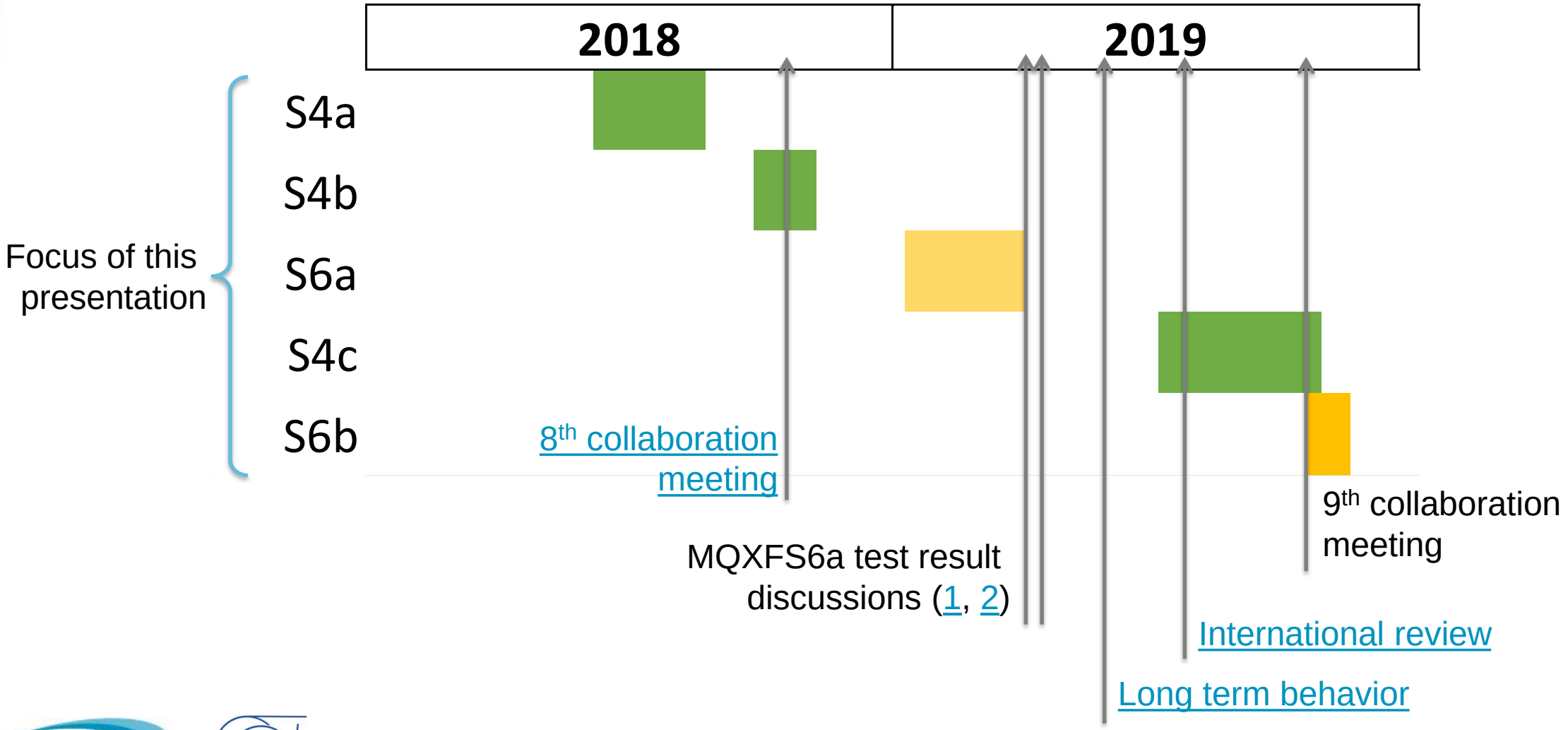
2019/10/16, 9th HL-LHC Collaboration Meeting

MQXF short model tests at CERN



(Note that magnet test duration includes preparation at warm)

MQXFS presentations since 8th coll.meeting



Summary of tests of CERN's short models

Magnet	Number of cool downs	Reached nominal?	Reached ultimate?	Maximum quench integral [MA²s]	# high current cycles §	# QH firings
S3a-b	2*	Yes (7 Q)	No (61 Q)	30.4 (~280 K)	101	112
S3c	2	Yes¶ (8 Q)	Yes¶ (16 Q)	40.3 (>400 K)	113	95
S5	2	Yes (4 Q)	Yes (28 Q)	26.6 (~230 K)	85	97
S4a-b-c	5	Yes (1 Q)	Yes (5 Q)	30.6 (~280 K)	55	89
S6a	1	Yes¶ (12 Q)	No (23 Q)	18.5 (~120 K)	28	26
S6b						

Nominal current: 16.5 kA
Ultimate current: 17.9 kA
Max. target current: 18.5 kA

§: only current cycles above 80% of nominal current (13.2 kA)
*: S3a → S3b had a change of pre-stress
¶: only at non-nominal ramp rate

Outline

- MQXFS4a—c → the last RRP short model
- MQXFS6a—b → the last PIT short model
- (Also He gas intermediate test)

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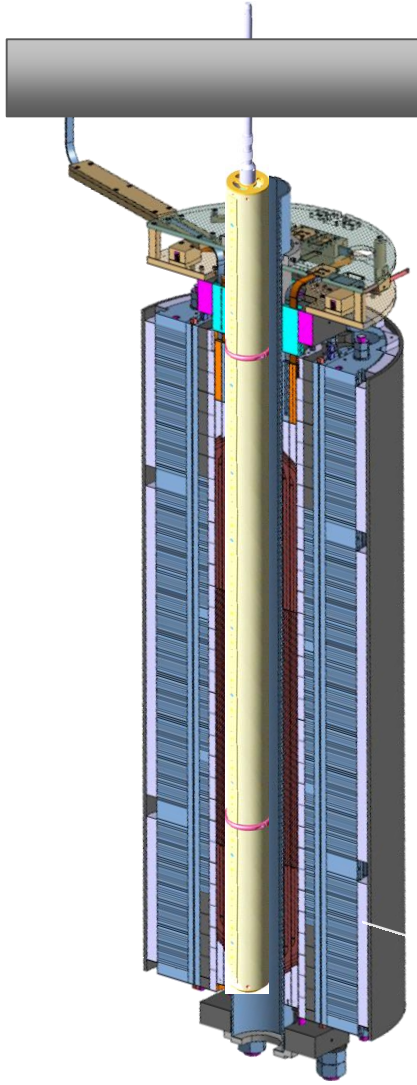
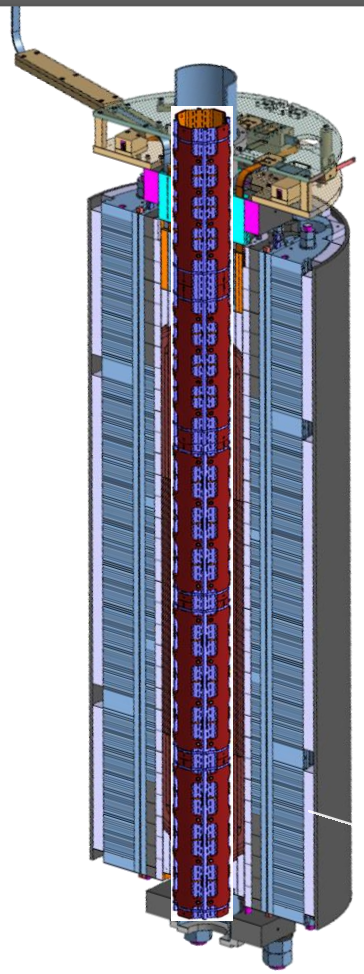
S4 history

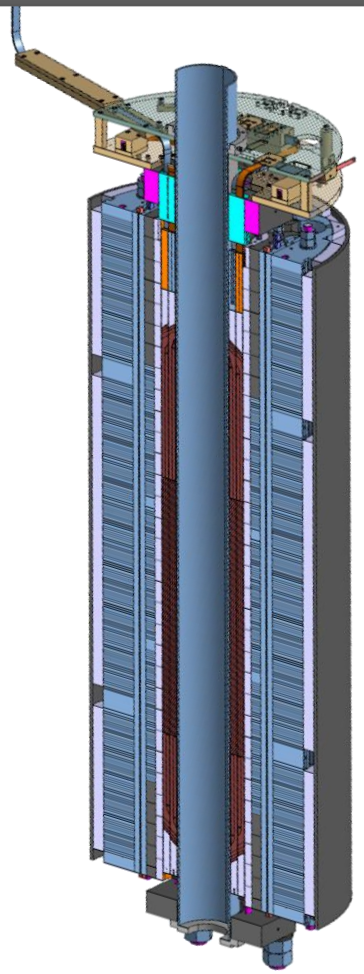
Past	Present	Future ?



S4a
With MM shaft
Standard program



S4b
With beam screen (BS)
Protection studies



S4c
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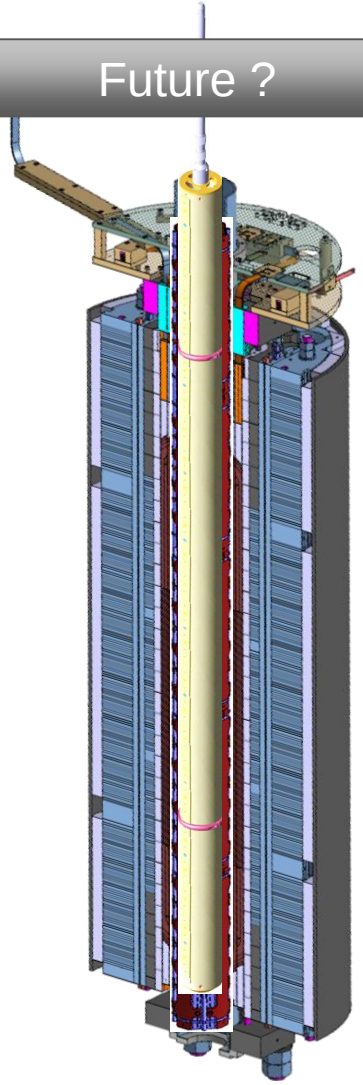
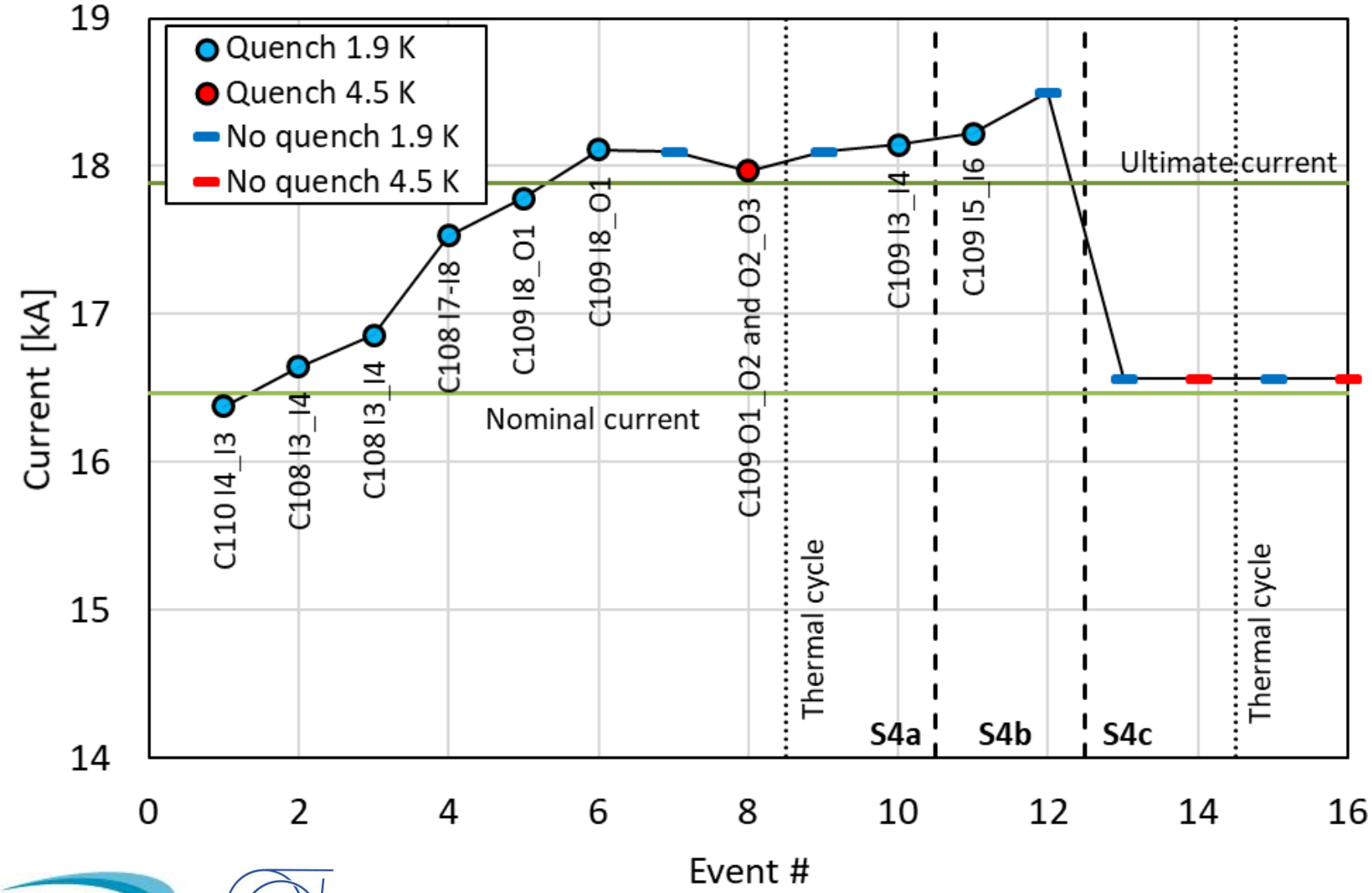
Endurance & HV



S4d
With BS & MM shaft
Special Mag. Meas.

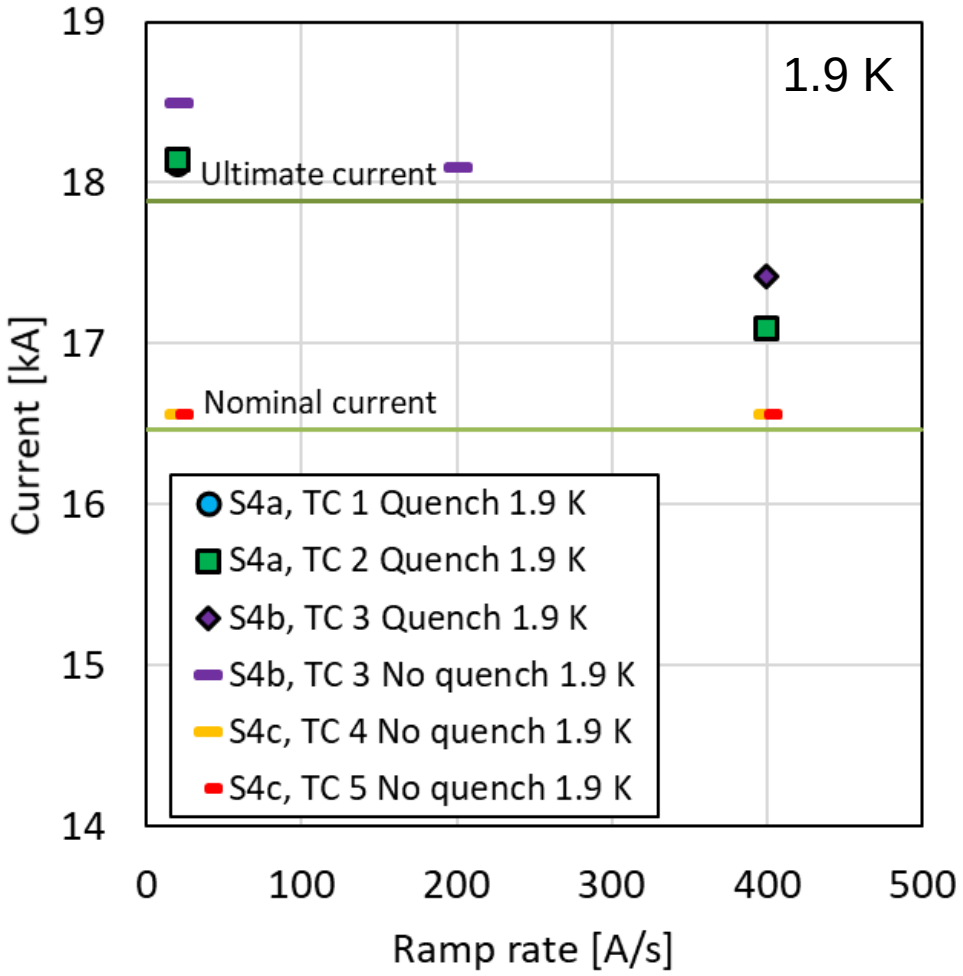
S4 training

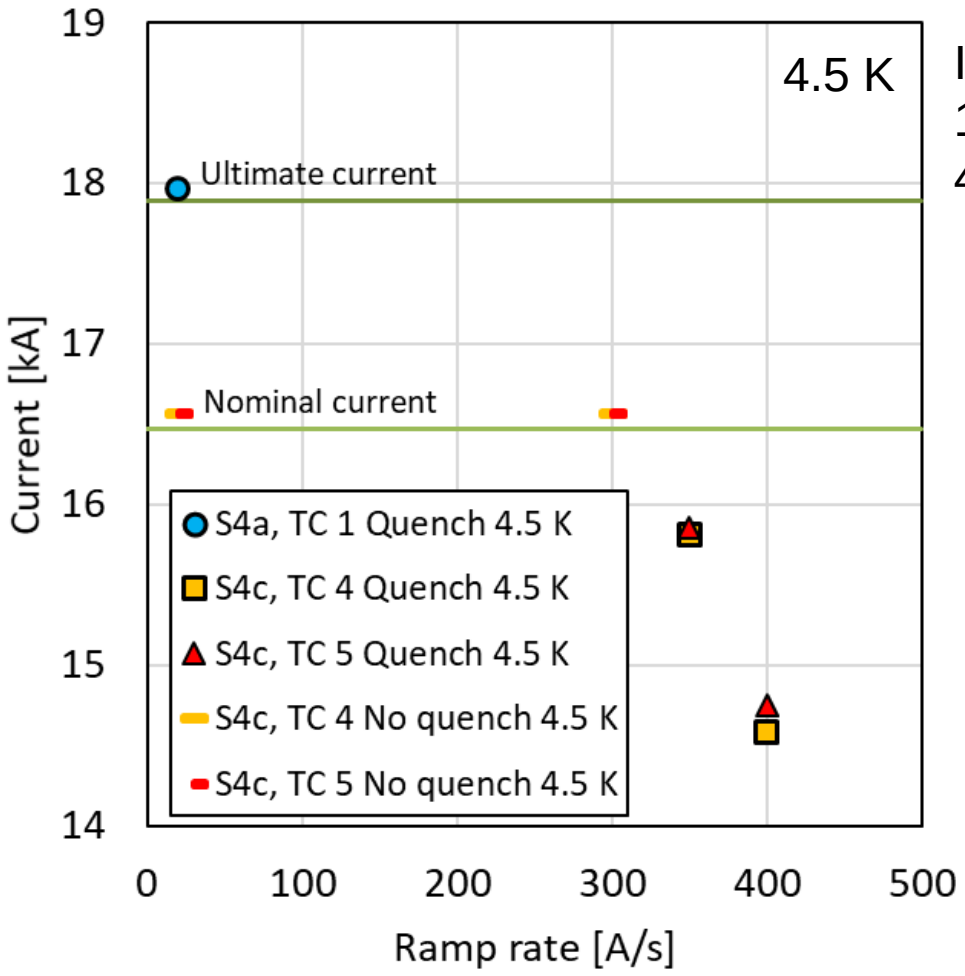


Short sample limits:
1.9 K: 21.5 kA
4.5 K: 19.7 kA

No degradation observed up to nominal current after 5 cool downs

S4 ramp rate studies 1/2

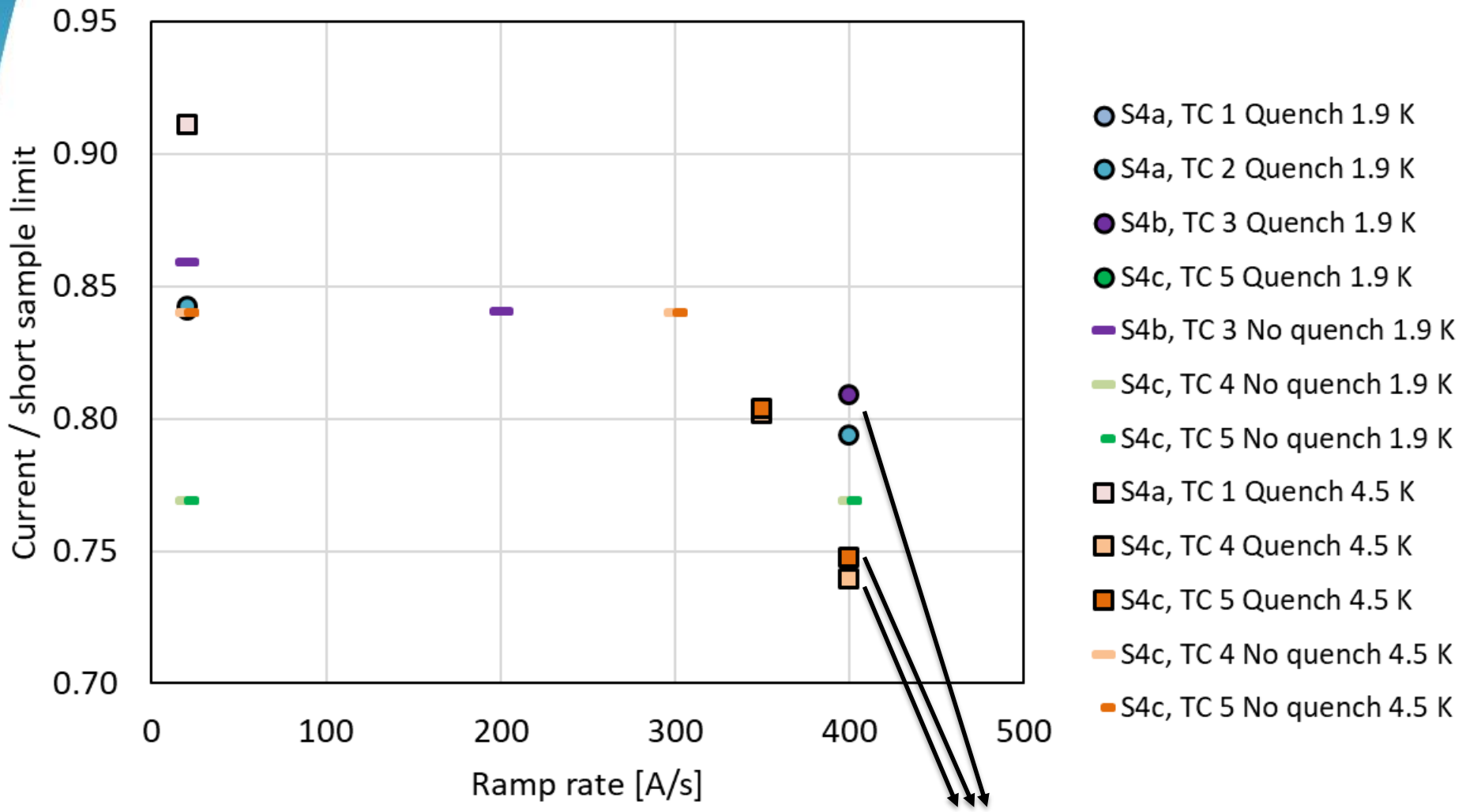




Iss:
1.9 K: 21.5 kA
4.5 K: 19.7 kA

Very large margin: reaching nominal current at 4.5 K, 300 A/s

S4 ramp rate studies 2/2



Location: 109 I2I3, 111 I3I2

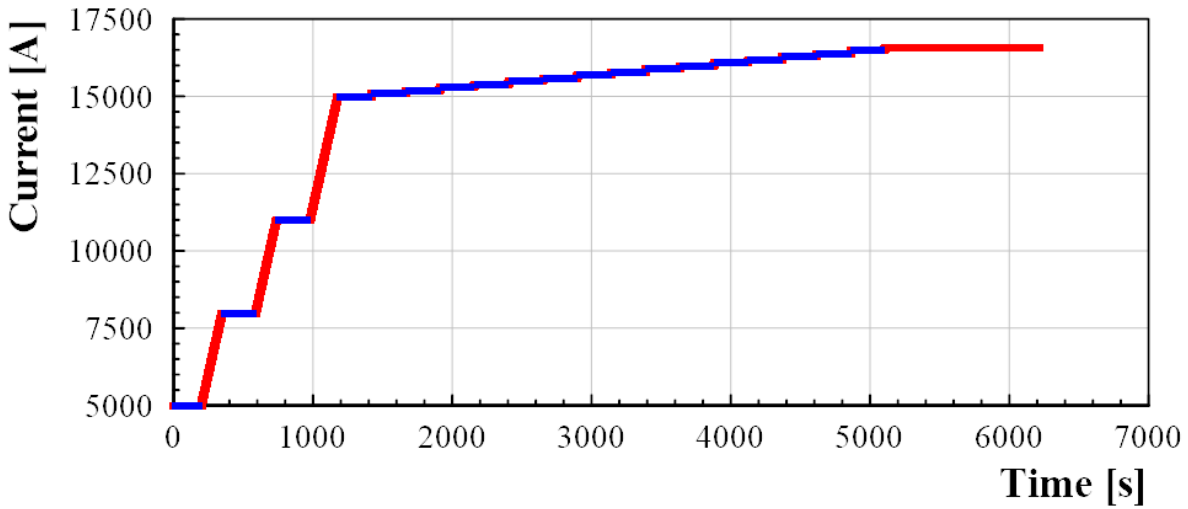
Iss:
1.9 K: 21.5 kA
4.5 K: 19.7 kA

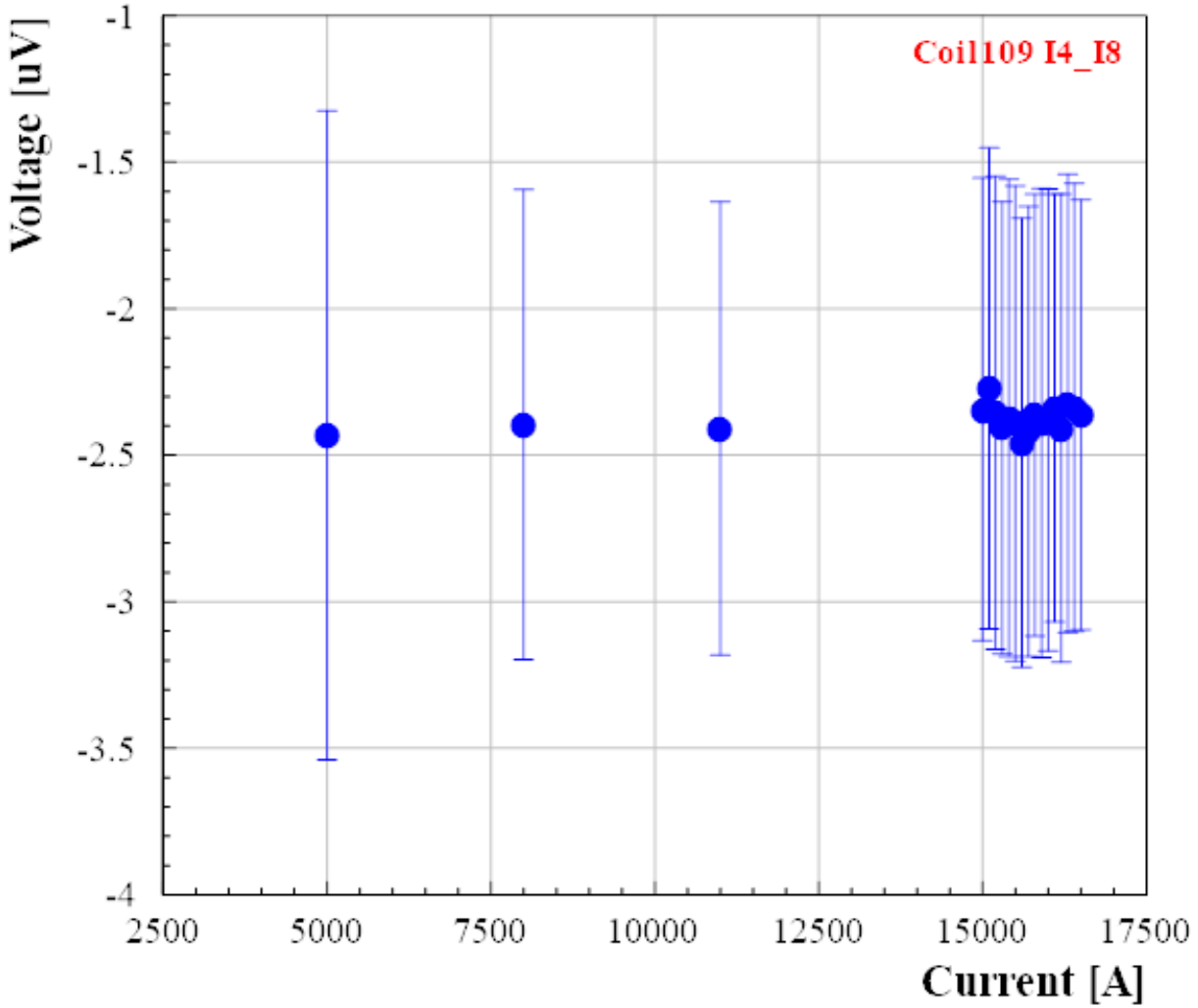
Difficult to extract conclusions between 1.9 and 4.5 K test due to all the physics involved: cooling, heating, strain, superconductor effects…

To be checked with ramp rate studies at higher currents at 1.9 K during cool down 6

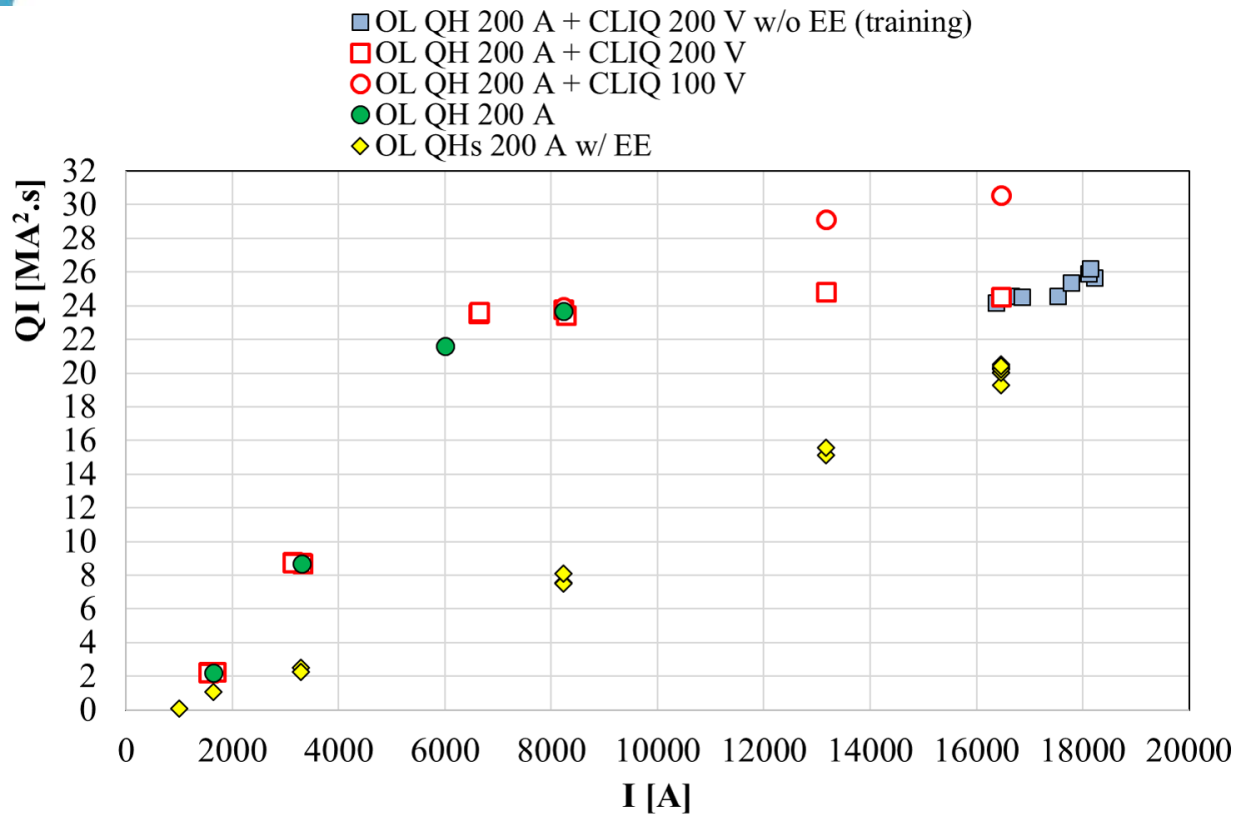
S4 VI measurements at 4.5 K

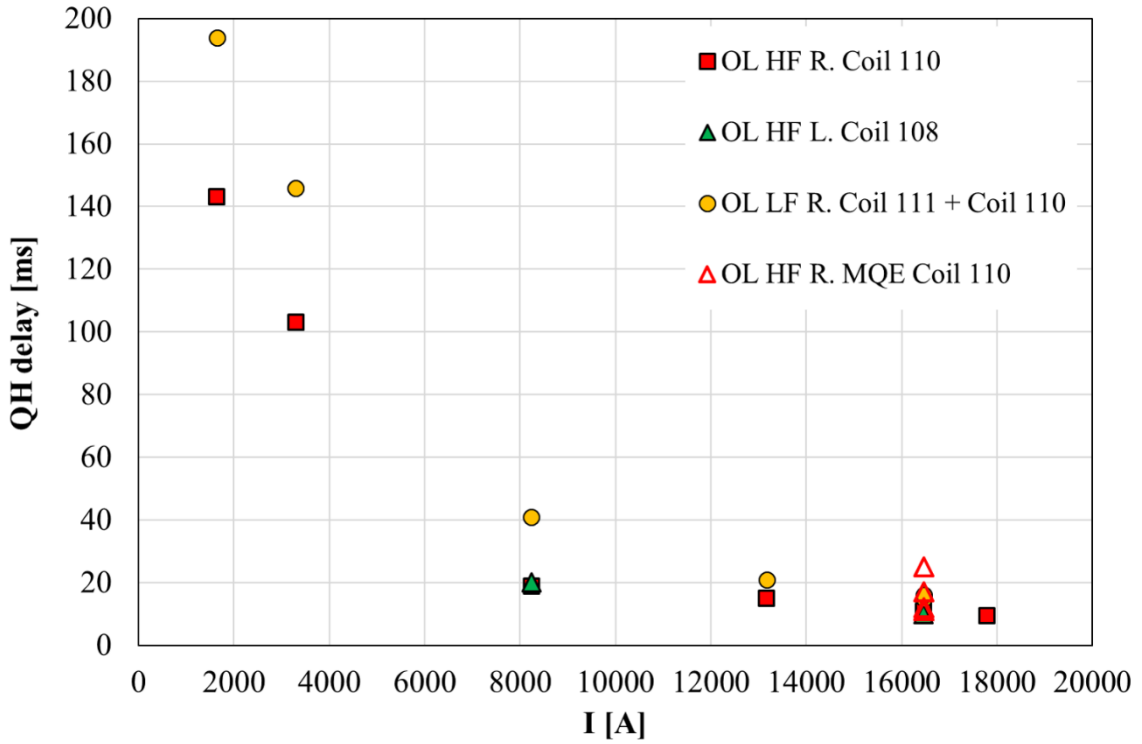
No early transition is observed up to 16.57 kA at 4.5 K (57% I/I_c, 84% I/I_{ss}), in any of the measured segments





S4 protection studies



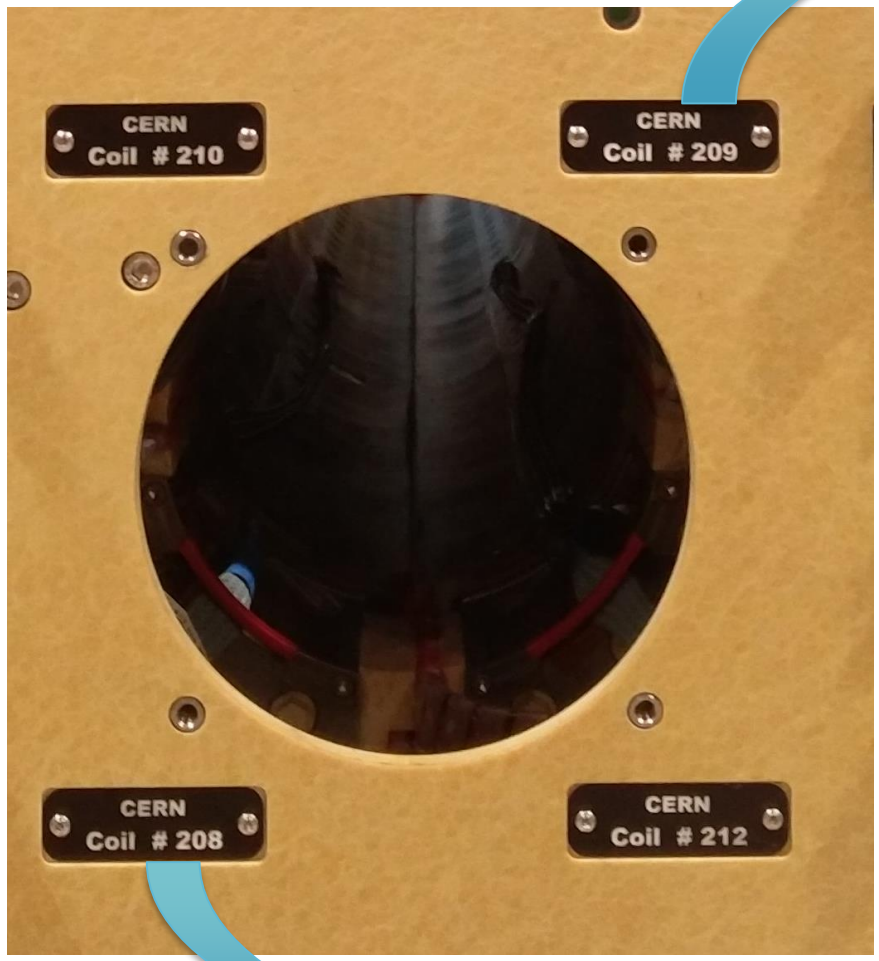


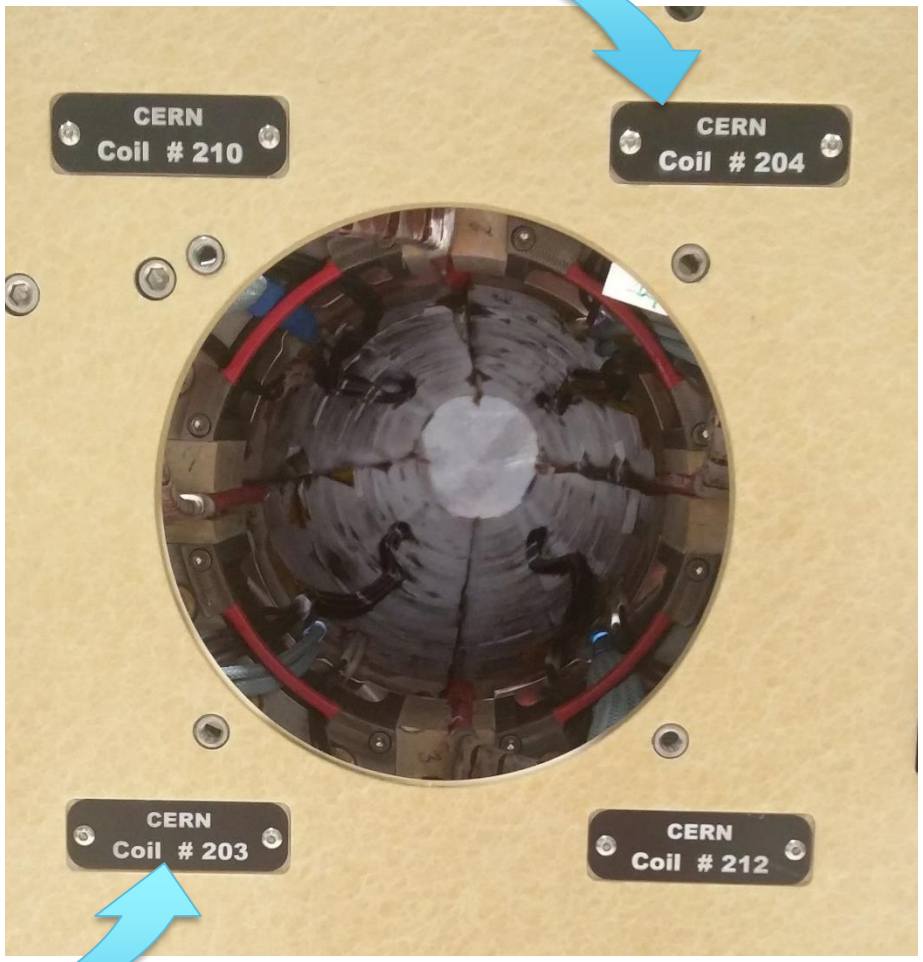
Over 50 provoked quenches with different CLIQ and QH parameters. Full report in preparation

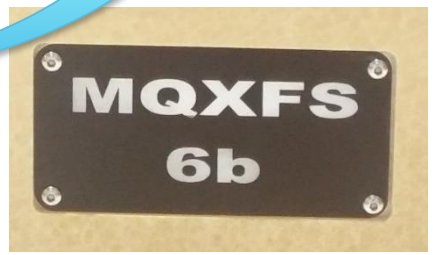
Outline

- MQXFS4a—c → the last RRP short model
- MQXFS6a—b → the last PIT short model
- (Also He gas intermediate test)

S6 history

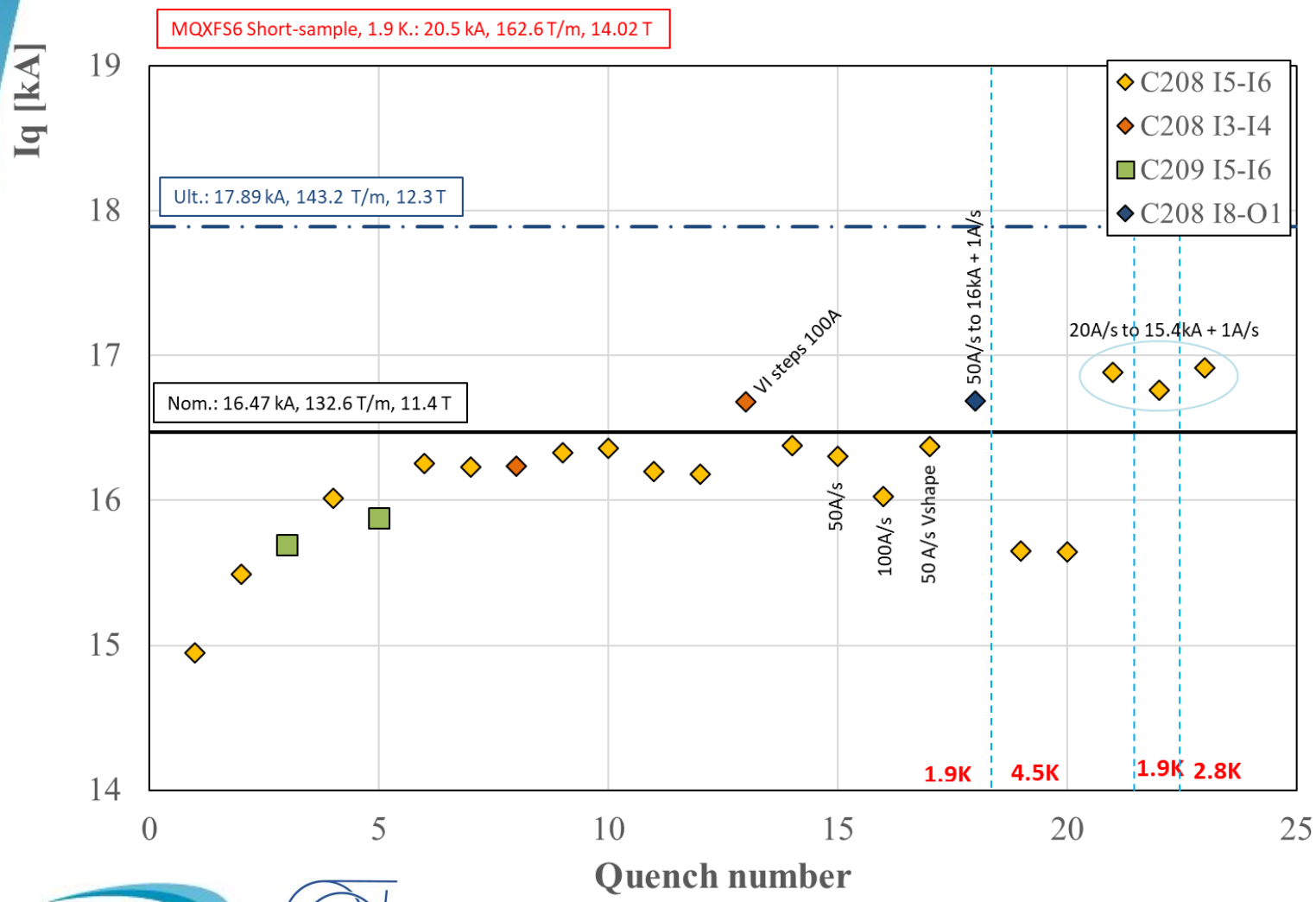




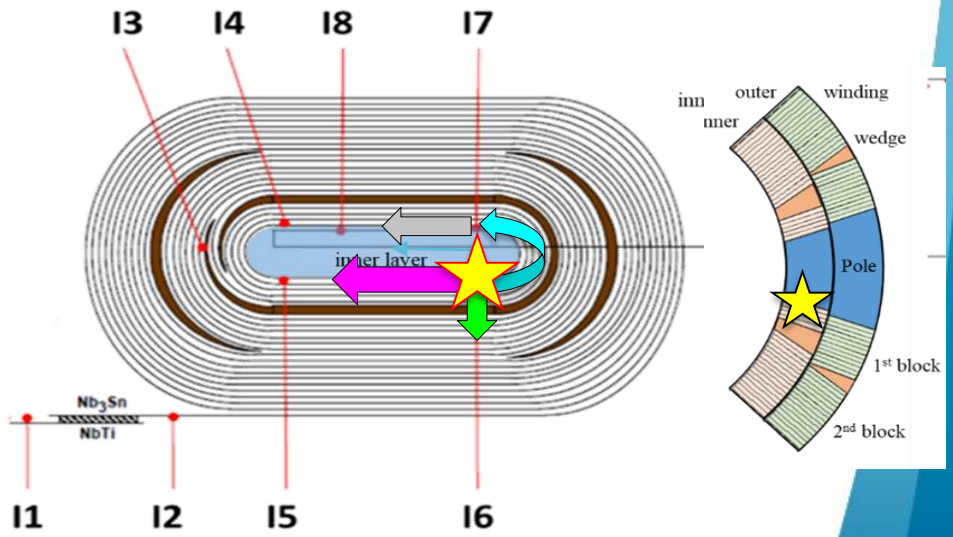


Coil 204 and 203 (from S5) replace coils 209 and 208, respectively.
All the rest stays the same

S6a training



- Coils 210 and 212 reach above nominal current without quench
- All quenches except two in same coil (with low RRR)
- One limiting location: coil 208 I5-I6 (pole turn)



Full overview of the S6a test:
https://indico.cern.ch/event/811284/

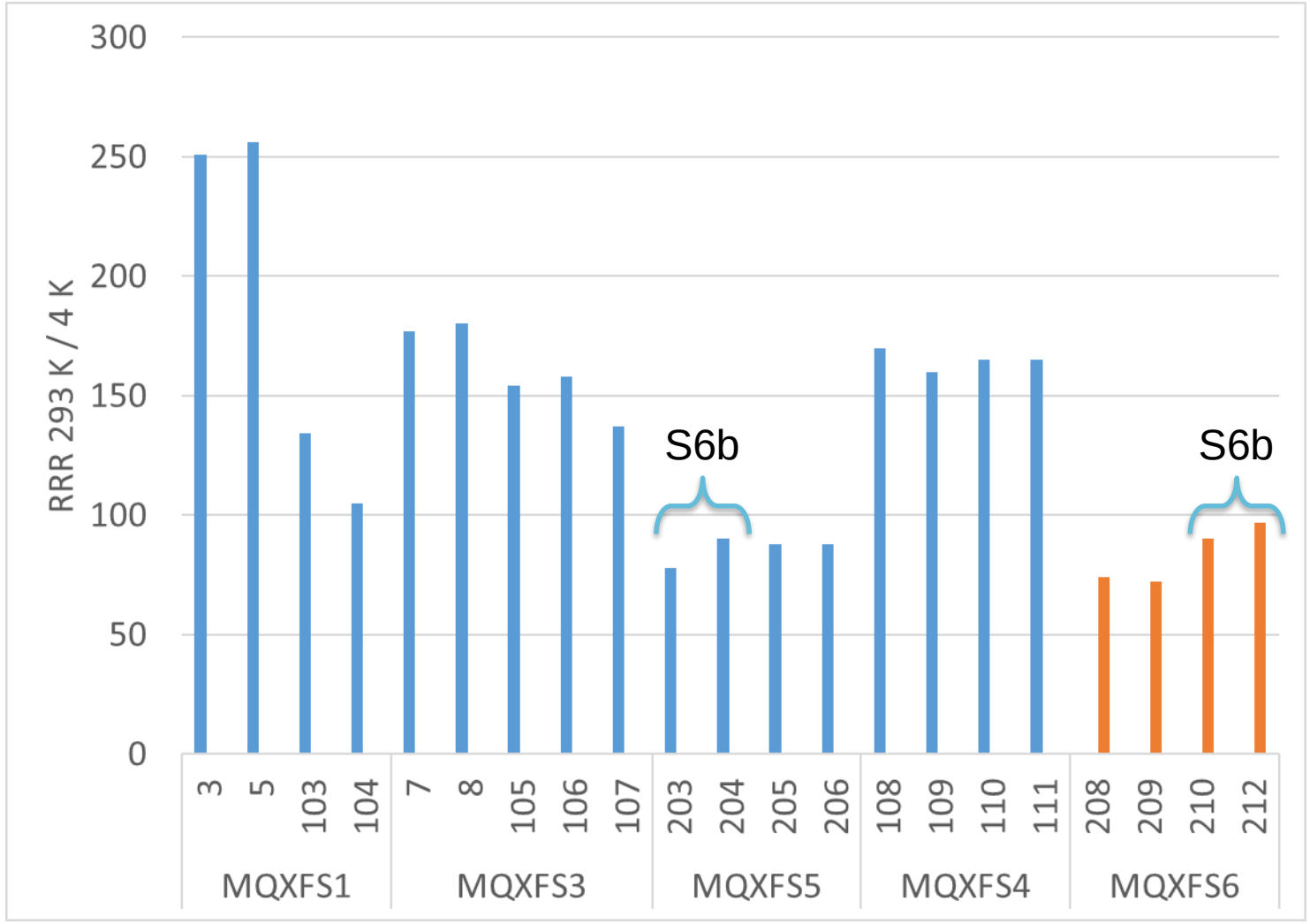
More details on the limiting sector:
https://indico.cern.ch/event/808872/

RRR (293 K / 4 K) of all MQXFS coils

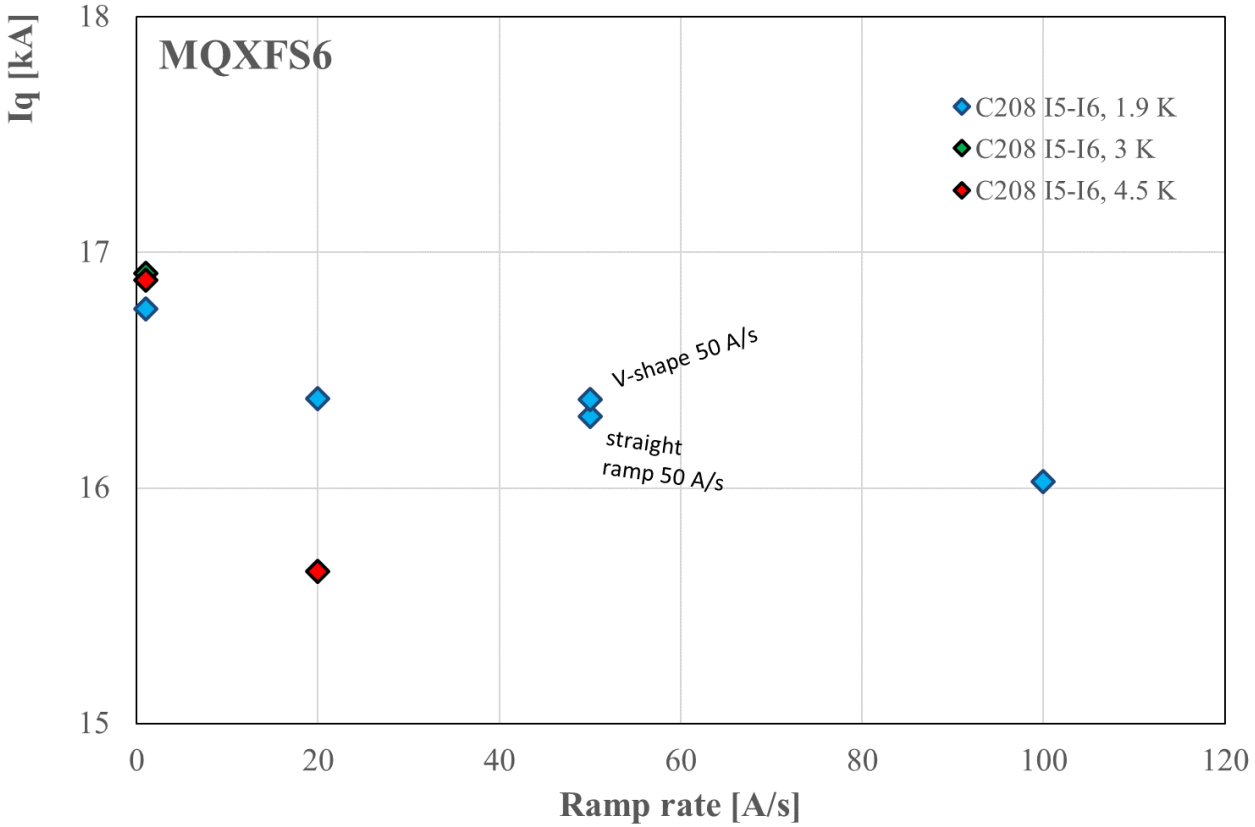
Lowest measured RRR in coil 208 and 209 (70-74).

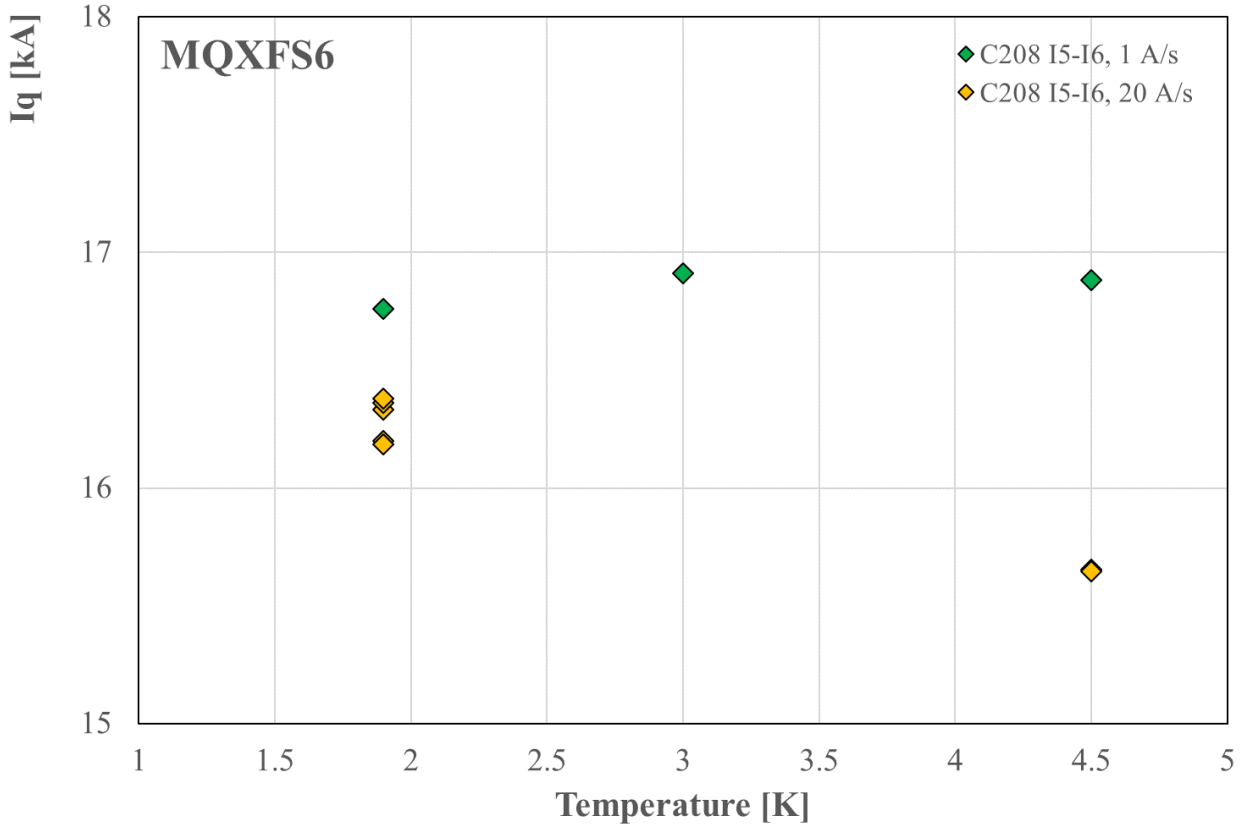
Coils 210 and 212 similar to those of MQXFS5 (also PIT cable).

Measured over warm up.



S6a ramp rate and temperature dependency

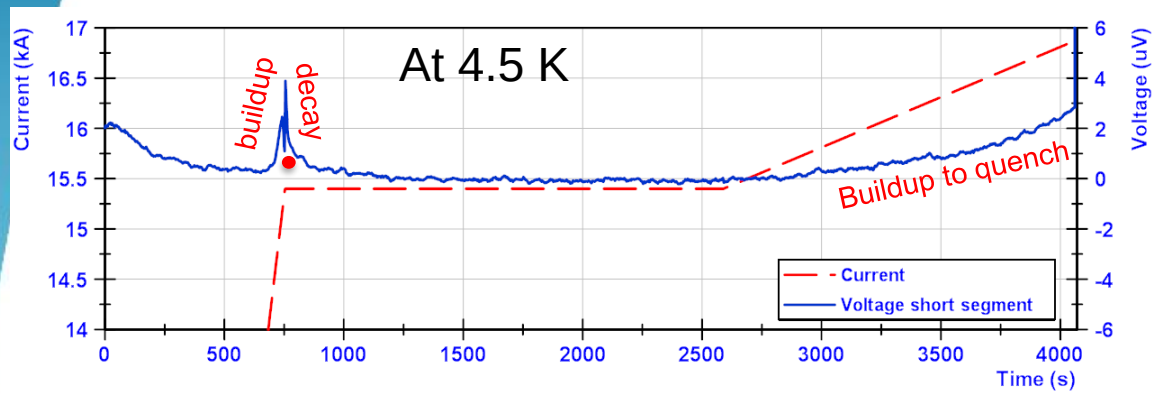


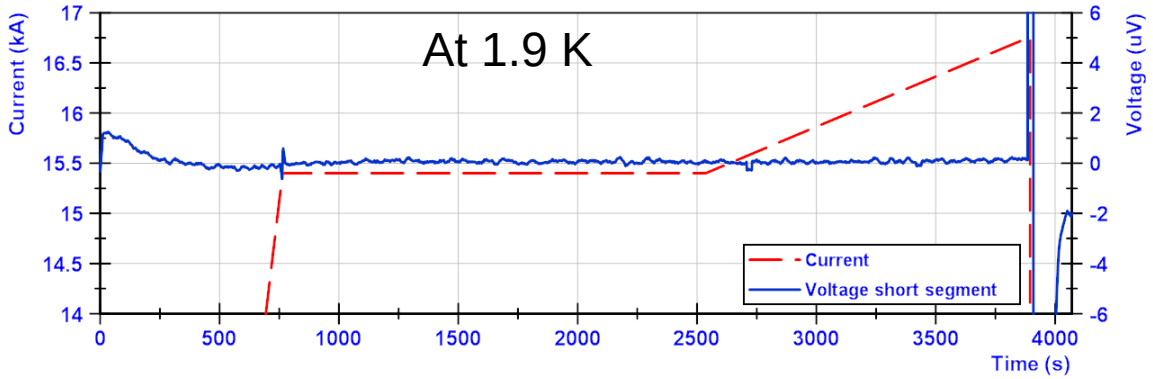


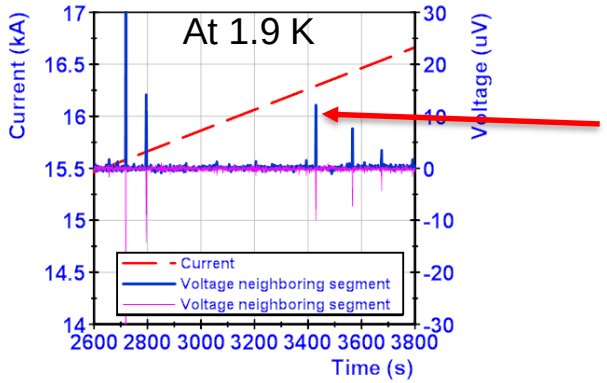
In a cycle with flattop, followed by a slow ramp of 1 A/s, the quench current was significantly higher than at 20 A/s.

Highest quench current not at 1.9 K, but at around 3 K. Even 4.5 K higher quench current (at low ramp rate) than at 1.9 K.

S6a V-I measurements on quenching location







At 4.5 K
- We stop ramping just before quench.
- Voltage was building up, but decays in short time
- When ramping slowly at 1 A/s later, voltage builds up again until quench.
- Clear sign of current redistribution effect.

At 1.9 K
- Same current cycle
- Too far from local critical surface to see any voltage buildup.

Why quenches at 1.9 K at a current lower than 4.5 K without voltage buildup?
- Spikes in voltages, only seen at 1.9 K, suggest self-field instabilities that quench the magnet.

S6a → S6b and plans

- Two low RRR coils have been replaced
- S6b tests will start next week
  - Standard tests (quench, holding current, ramp rate)
  - Magnetic measurements
  - Protection studies

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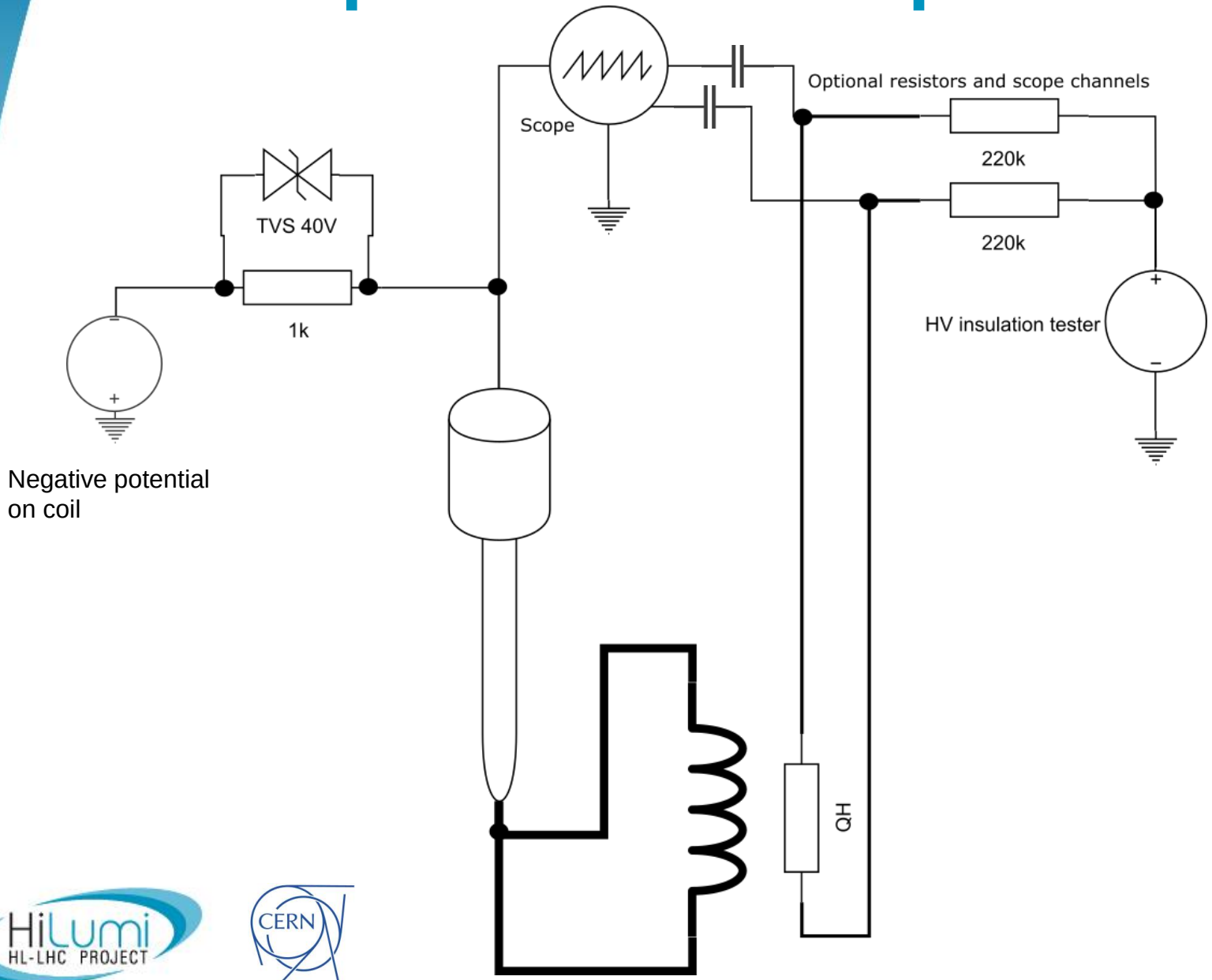
Electrical insulation tests in liquid helium

Magnet	Test station	Magnet-Ground [kV]	Magnet-QH [kV]
S3a-b	HFM	1.5	2.3
S3c	Cluster D	1.0	1.1
S5	Cluster D	1.0	1.0
S4a	Cluster D	0.9	1.7
S4b	HFM	1.1	1.4
S4c	Cluster D	1.0	1.6
S6a	HFM	1.1	1.4
S6b	HFM		

No breakdown up to specified voltage level

In most cases, tests could not be done up to requirement (1.8 / 2.3 kV)

Special test setup from ELQA team



Problem:

- breakdown through test station wiring

Two improvements:

- Oscilloscope to detect if breakdown QH to ground or QH to magnet circuit
- Negative potential on magnet to reach higher QH to magnet voltage

First tested in MBHSP107 on October 4th

See more information in Jaromir Ludwin's presentation here

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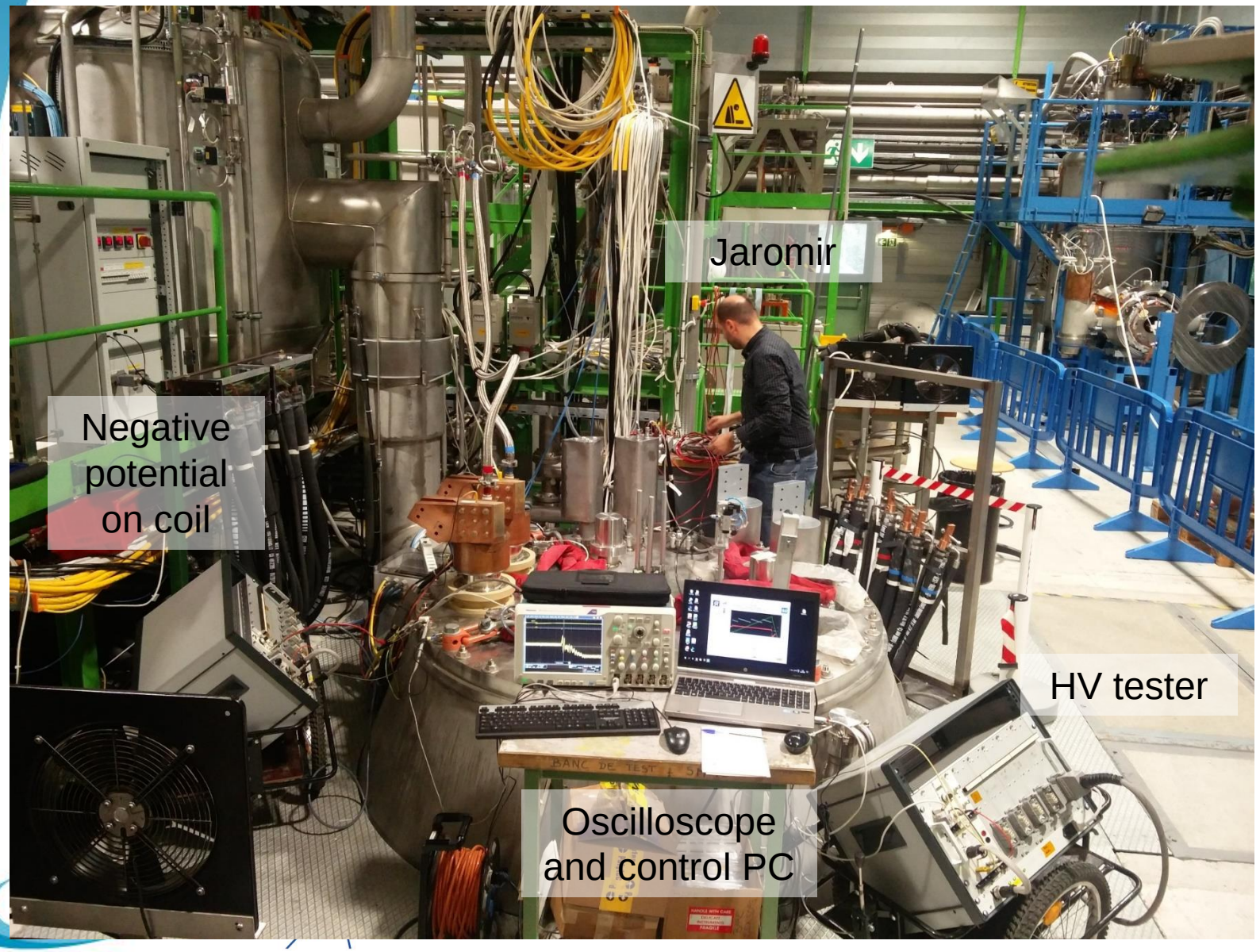

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S4c: HV tests in LHe with ELQA setup

	Old setup			New ELQA setup					
07-Oct-19	Megger			ELQA			ELQA		
	Result	Target	Comment	Result	Target	Comment	Result	Target	Comment
Magnet-ground	1015	1800		900	900	QH grounded			
Magnet-QH108	2260	2300	floating	1400	1400	Magnet grounded	2300	2300	magnet at -900V
Magnet-QH109	1710	2300	floating	1254	1400	Magnet grounded	2050	2050	magnet at -900V
Magnet-QH110	1910	2300	floating	1400	1400	Magnet grounded	2300	2300	magnet at -900V
Magnet-QH111	2300	2300	floating	1400	1400	Magnet grounded	2300	2300	magnet at -900V
			Pass						
			Breakdown (undefined)						
			Breakdown to ground						

- With the ELQA setup we could test up to 2.3 kV three of the four coils' QH
- Coil 109's QH cannot be tested up to 2.3 kV due to limit in the test station

S3c: GHe intermediate HV test

Test name	Magnet before cold test	Special at 1.9 K	Special at 80 K	Special at 150 K	Special at 300 K
Date	04-05-18	14/05/2018	15/05/2018	16/05/2018	18/05/2018
Place	SM18	SM18	SM18	SM18	SM18
T[K]	4.5	1.9	80	150	280
Ambient	He(L)	He(L)	He(G)	He(G)	He(G)
LP08-HF-Right	1105 V 30 s 5 nA 239 GΩ	Max: 1935V 30s_9,21nA_210GΩ	Max 200V	Max 200V	Max 200V
LP08-HF-Left					Max: 816V 30s 3nA 264GΩ
LP08-LF-Right			Max: 1834V 30s_0,23nA_2000GΩ	Max: 1025V 30s_0.98nA_1050GΩ	Max: 816V 30s 3.3nA 247GΩ
LP08-LF-Left				Max: 1025V 30s_1.05nA_976GΩ	Max: 813V 30s 3.5nA 232GΩ
C106-HF-Right		Max: 1119V 30s _ 3.38nA_ 331 GΩ	Max: 1834V 30s_0,23nA_2000GΩ	Max: 1020V 30s_2.8nA_365GΩ	Max: 814V 30s 2.6nA 312GΩ
C106-HF-Left				Max: 1120V 30s_3.06nA_366GΩ	Max: 815V 30s 4.3nA 189GΩ
C106-LF-Right			Max: 1629V 30s_0,9nA_1820GΩ	Max: 1023V 30s_0.47nA_2000GΩ	Max: 814V 30s 4.4nA 184GΩ
C106-LF-Left					Max: 814V 30s 4.8nA 171GΩ
C105-HF-Right				Max: 1025V 30s_0.73nA_1400GΩ	814 V, 30 s 16 nA 50 GΩ
C105-HF-Left		Max 1730V 30s _4.4 nA_ 393 GΩ	Max: 1629V 30s_1,83nA_892GΩ	Max: 1026V 30s_0.81nA_1270GΩ	
C105-LF-Right					
C105-LF-Left			Max: 1529V 30s_1,71nA_894GΩ	Max: 1222V 30s_1.65nA_741GΩ	
C107-HF-Right					814 V, 30 s 11 nA 77 GΩ
C107-HF-Left			Max: 1729V 30s_1,82nA_952GΩ	Max: 1020V 30s_1.28nA_797GΩ	
C107-LF-Right				Max: 1019V 30s_1.46nA_699GΩ	
C107-LF-Left		Max: 1934V 30s _ 3.78nA_ 512GΩ	Max: 1629V 30s_1,65nA_987GΩ	Max: 1025V 30s_0.67nA_1520GΩ	
Empty socket					(ramp) 906V 3nA 300GΩ

← Previously lost heater

80 K:
1.6-1.8 kV OK

150 K:
1.0-1.2 kV OK

280 K:
0.8-0.9 kV OK

Helium gas tests: no target voltage. Reported: maximum voltage reached

S4c: GHe intermediate HV test

- Target: coil-QH 850 V at 100 ± 20 K, ~1.3 bar
- Test passed at 90 K, 1.8-2 bar
  - Will be repeated to try to get to 1.3 bar

Conclusions

- Two short models (S5 and S4a-b-c) had very good performance
  - S4a-b-c: fastest training of all short models
  - Endurance tests ongoing on S4c. After 5 cool downs, we have not seen any signs of degradation up to nominal current
- Three short models (S3a-b, S3c, S6a) limited in specific locations
  - In general linked to coil rather than magnet
  - S6a: limitation in one coil, in one spot, probably with non-homogeneous degradation which triggers self-field instability and current redistribution
- One short model (S6b) to be tested soon
  - Re-test two coils from S6a and two from S5
  - Study PIT coil performance and magnet performance after coil replacement
- Electrical insulation tests:
  - At nominal operation conditions: difficult to test in the vertical test stations
  - At ~100 K: reached 850 V or above in two magnets (S3c, S4c)