Summary of MQXF short model test results

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On behalf of the MQXF collaboration: CERN, BNL, FNAL, LBNL

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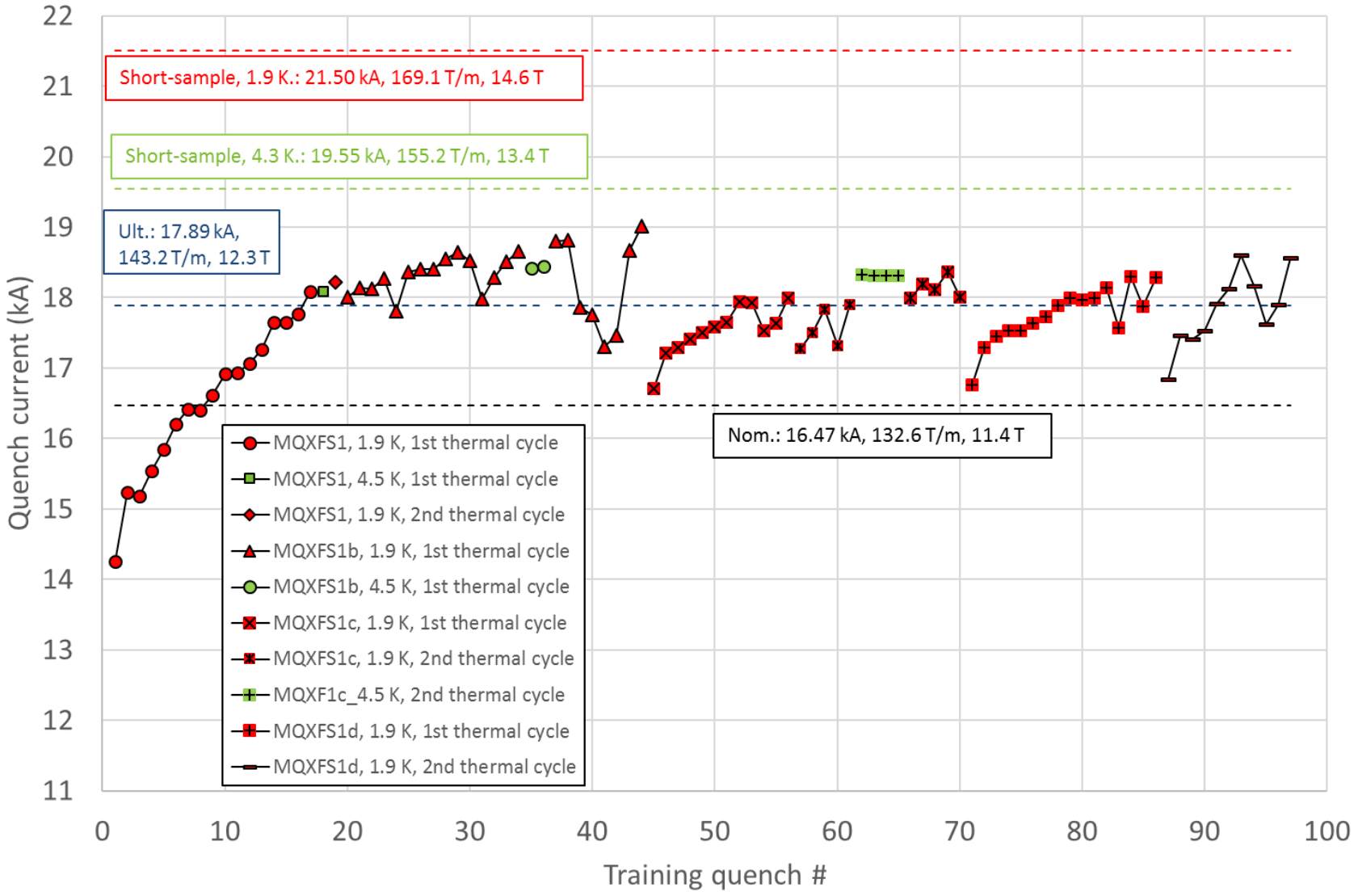
Summary of MQXF short models

Magnet	Version	Coils				Changes
MQXFS1	a	3	5	103	104	--
	b					+25% az pre-stress
	c					+65% long pre-stress
	d					SS shell welded
MQXFS3	a	7	105	106	107	--
	b					+ long pre-stress
	c	8				Coil change, + az pre-stress
MQXFS5	a	203	204	205	206	--
MQXFS4	a	108	109	110	111	--
	b					+ beam screen

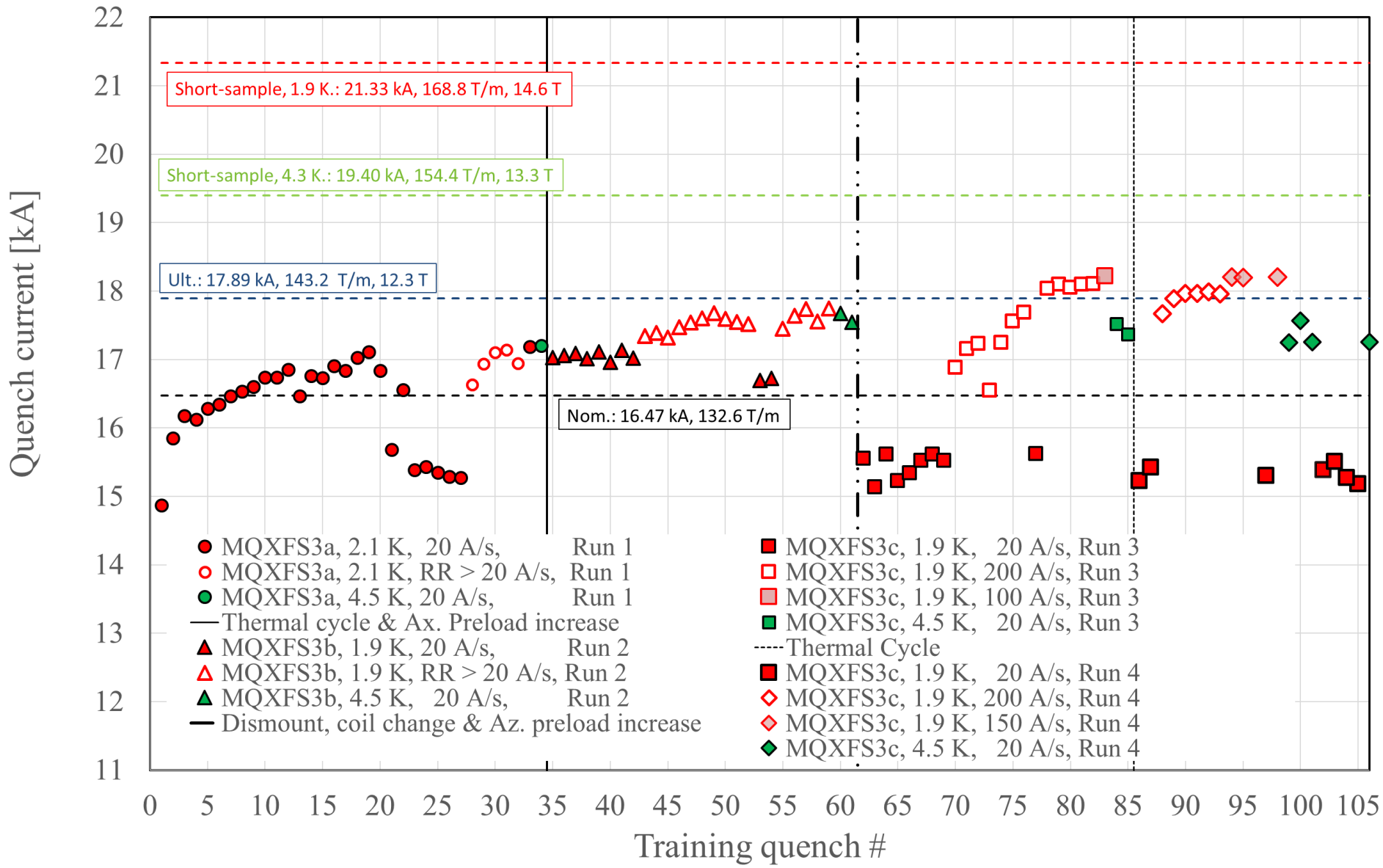
MQXFS1 training

- First short model tested
- 3rd fastest training to nominal current, 2nd fastest to ultimate
- Detraining probably due to pre-stress increases
- Reached 19 kA



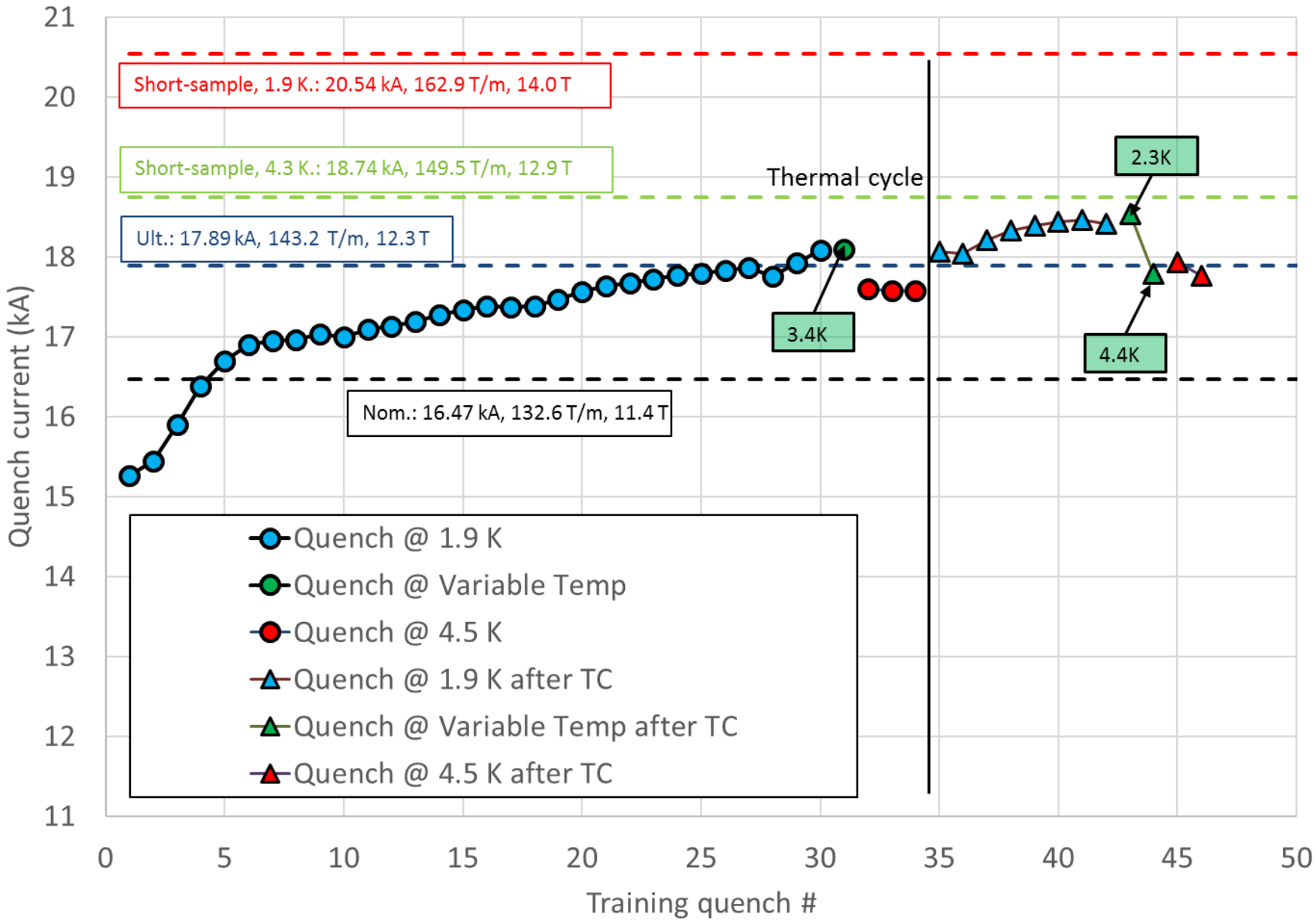
MQXFS3 training

- Large detraining in one coil (7) after ~20 quenches
- Limitation bypassed by high ramp rate quenches
- Coil change in 3c: 7→8, new limiting coil: 106.
- 3c reached ultimate current only at high ramp rates
- Quenches at 4.5 K at same or higher current than 1.9 K



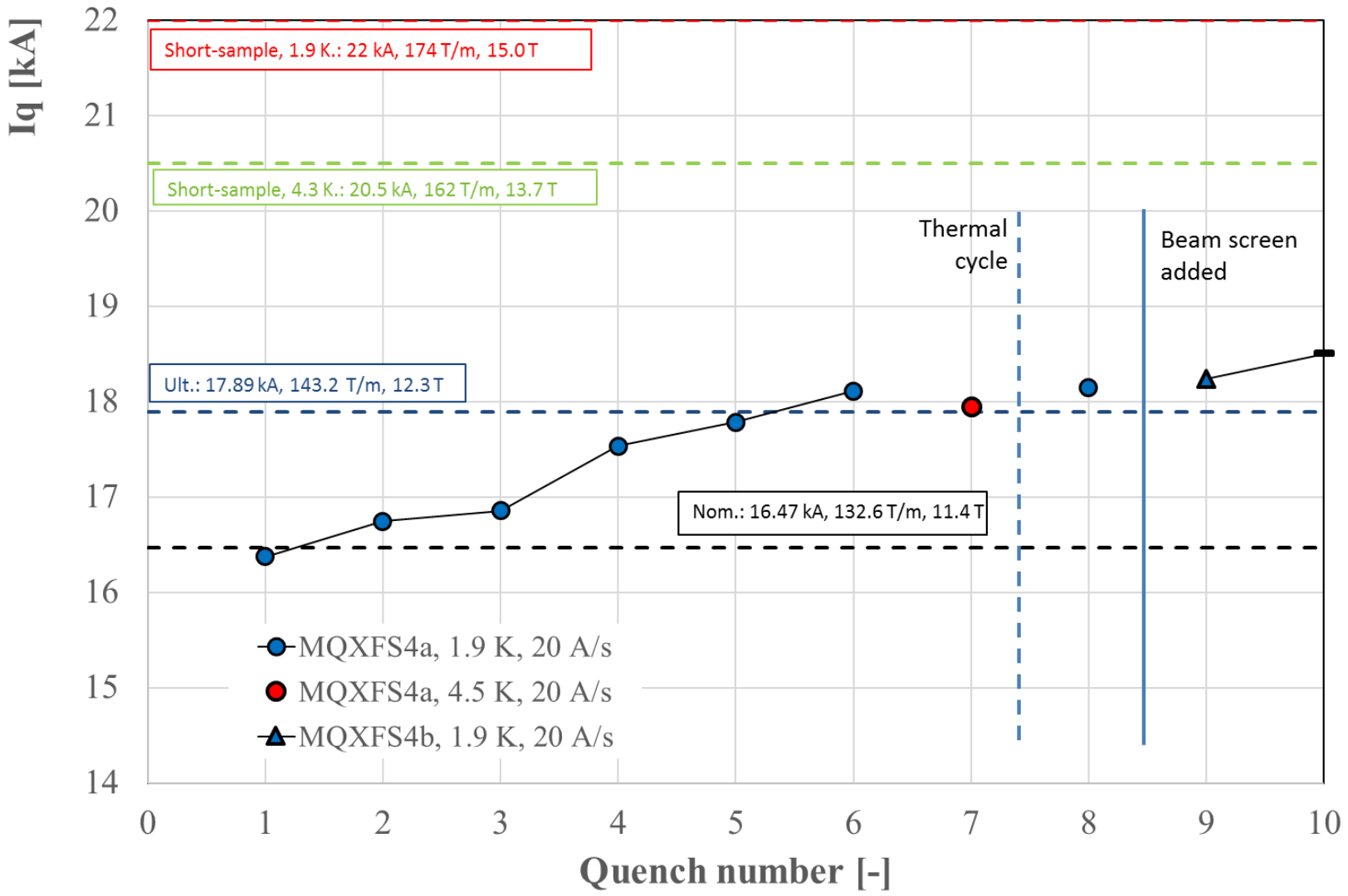
MQXFS5 training

- Magnet with PIT conductor
- 2nd fastest to nominal, 3rd to ultimate
- No detraining and perfect memory after a thermal cycle

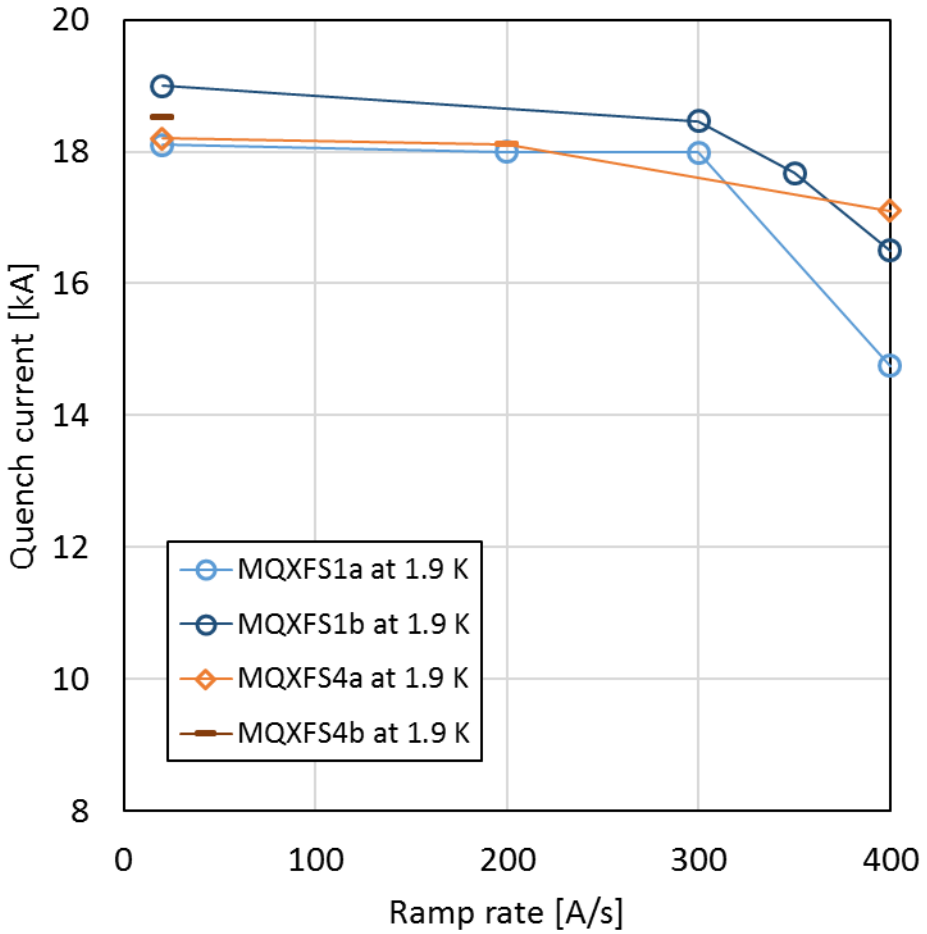


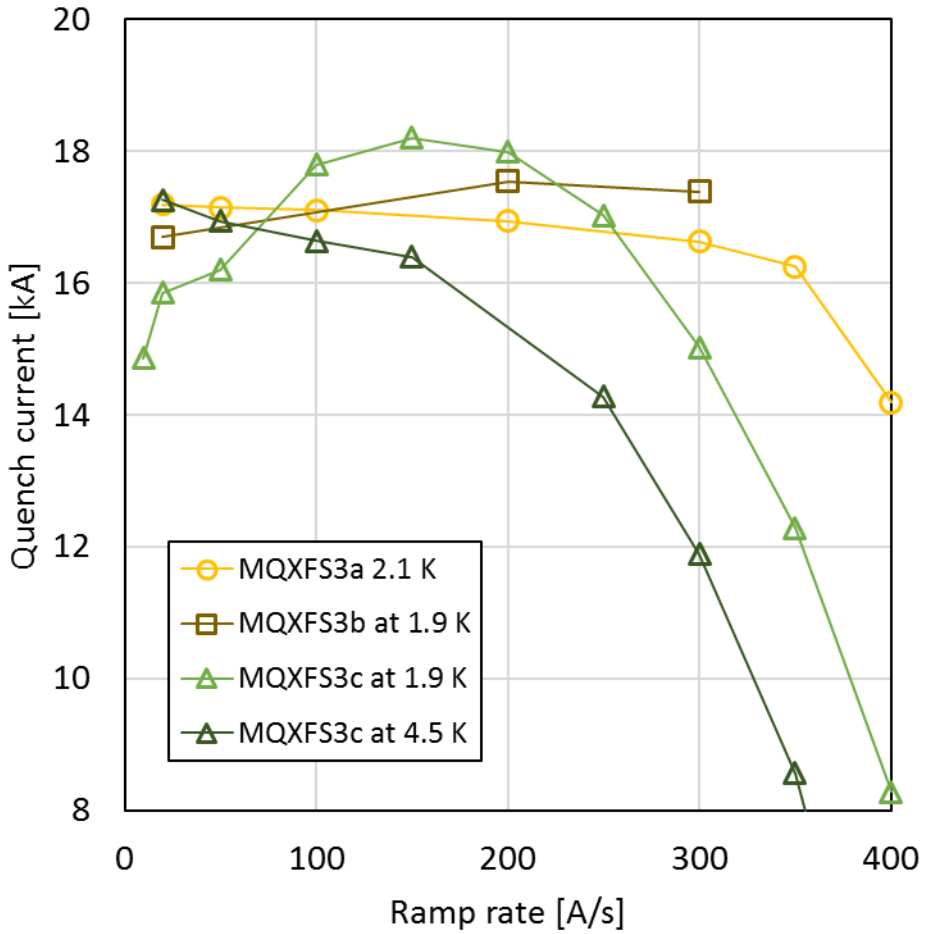
MQXFS4 training

- Fastest training to nominal & ultimate current
- No detraining and perfect memory, after TC and also after adding beam-screen
- Reached 18.5 kA



Ramp rate studies

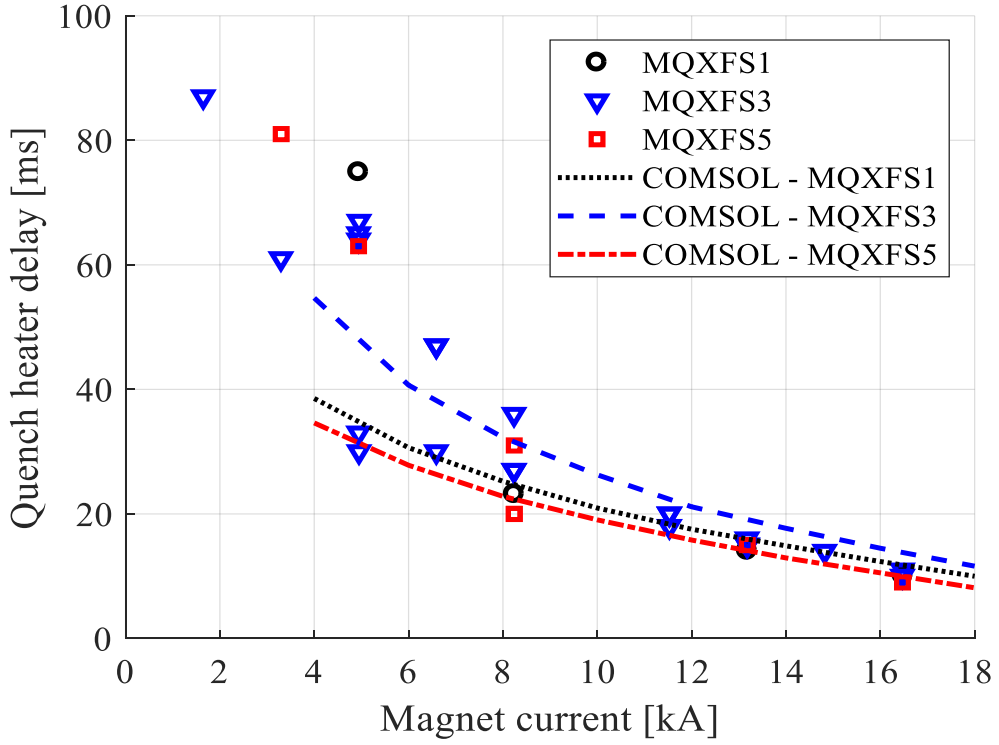




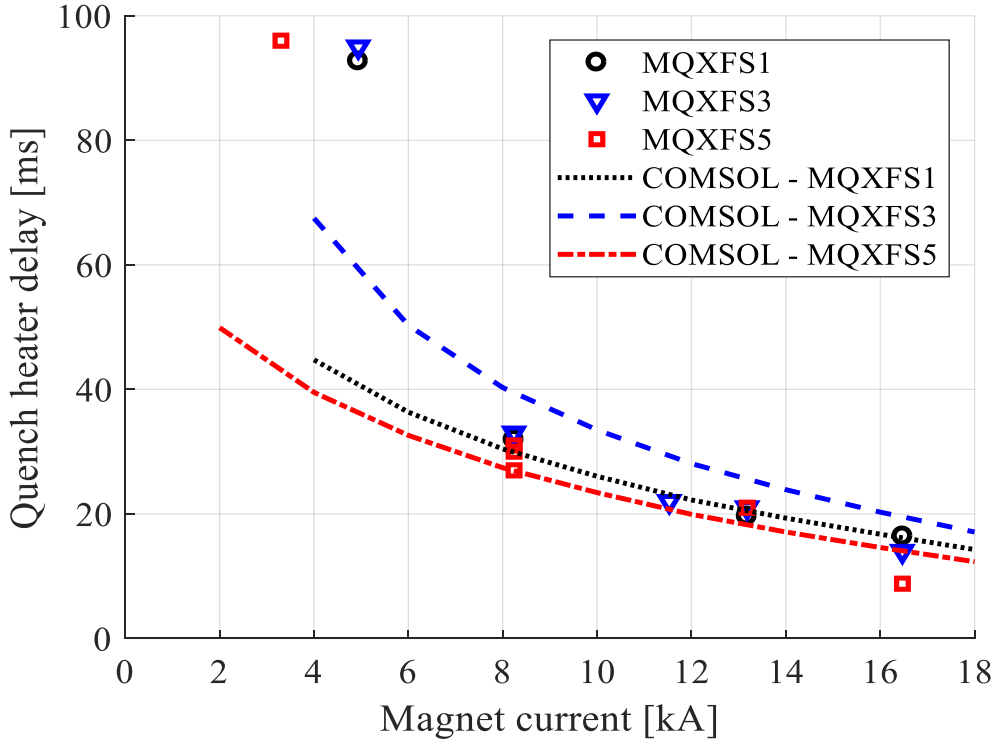
MQXFS1 and 4 show a flat ramp rate dependency up to 300-400 A/s
MQXFS3 show signs of progressive degradation

Protection studies - QH

High field QH

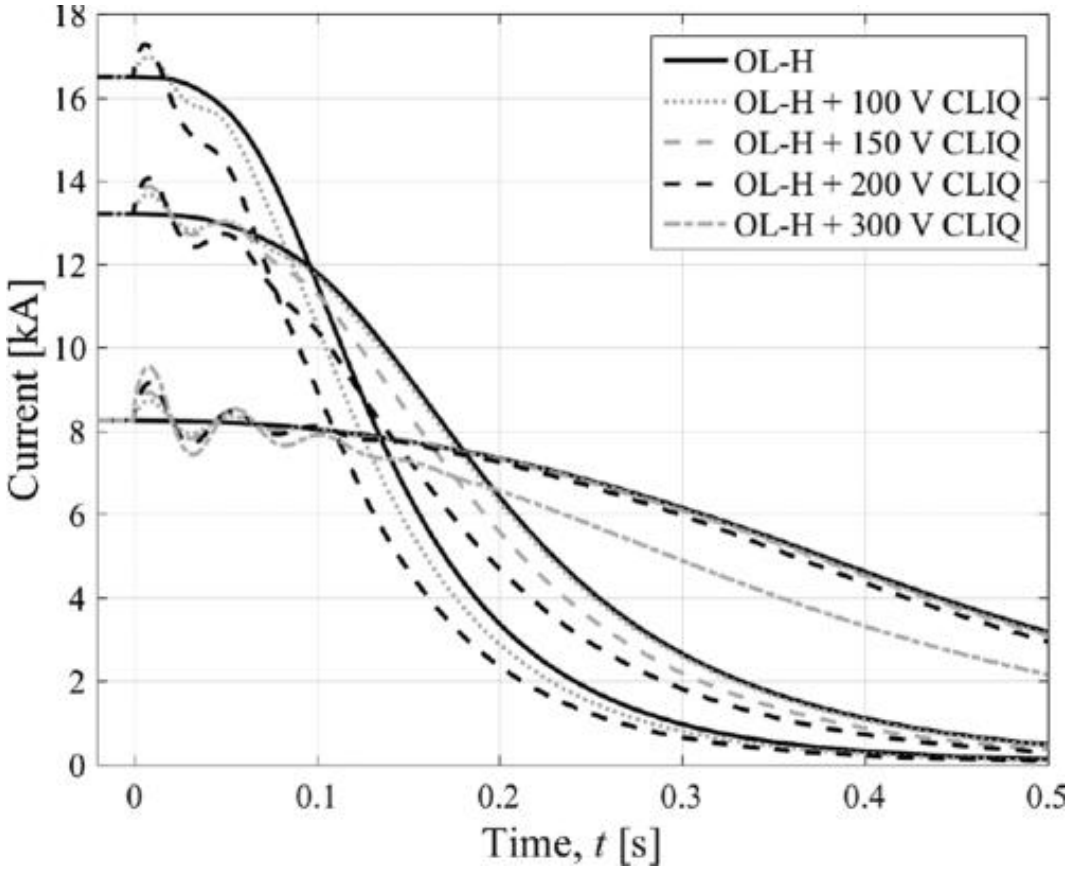


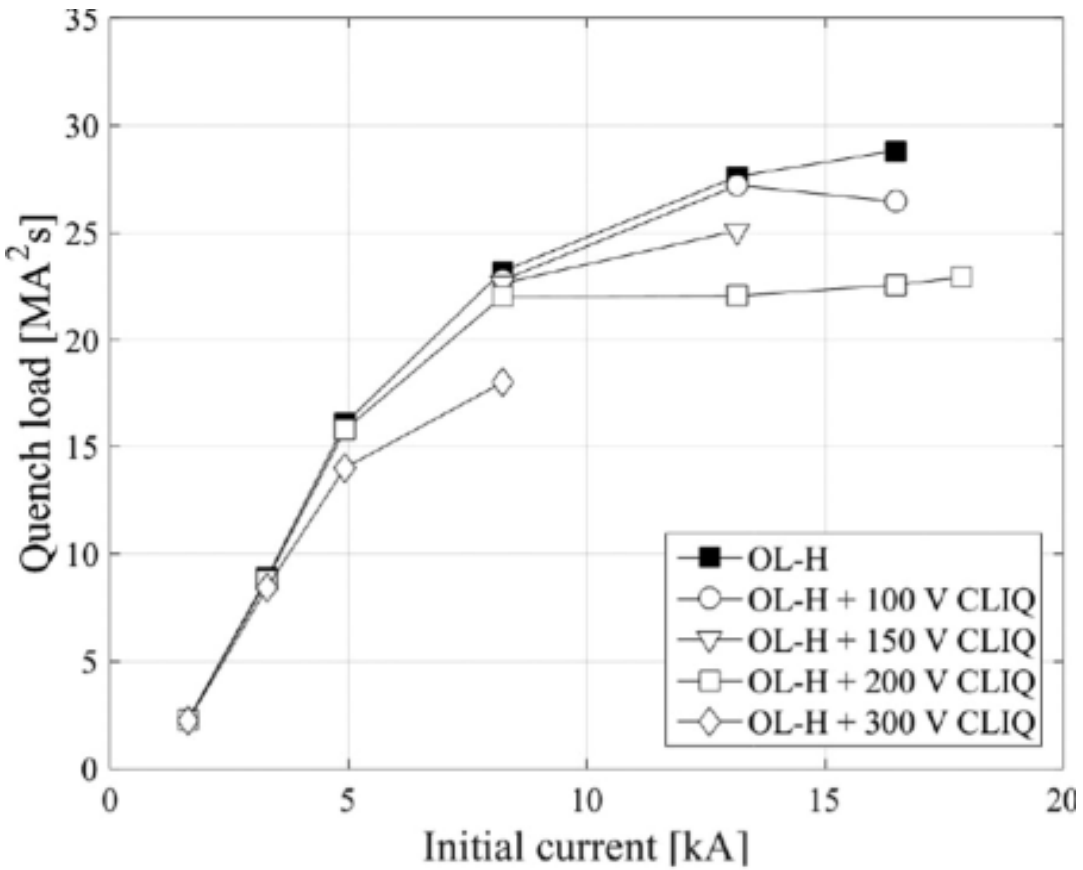
Low field QH



Report on Quench Protection Tests: MQXFS5 by S. Izquierdo Bermudez *et al*. EDMS Nr: 1891255

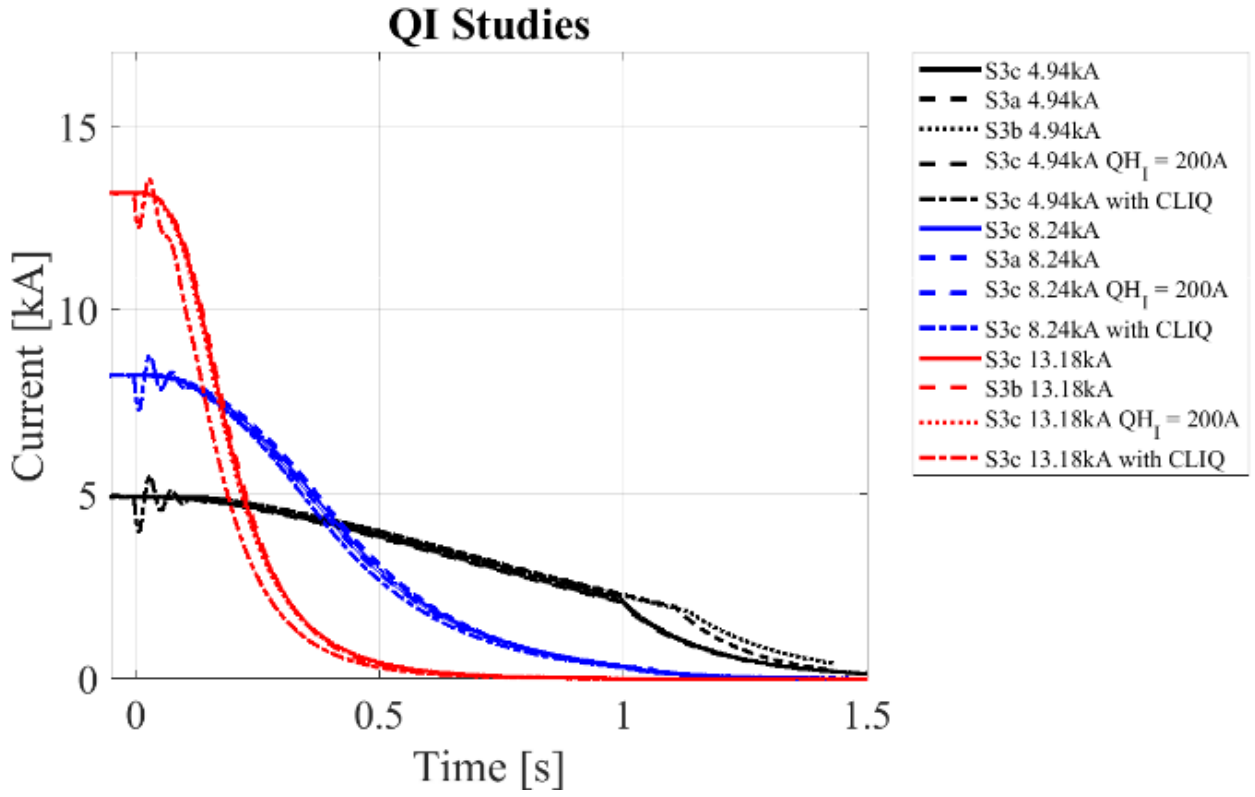
MQXFS1 Protection studies - CLIQ

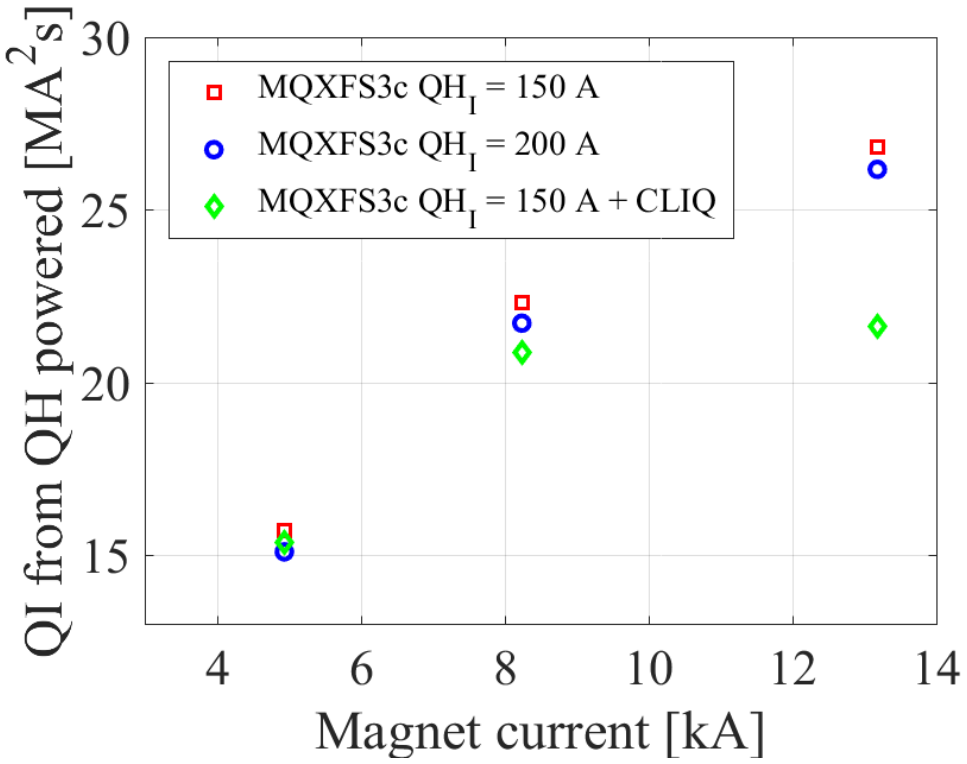




Quench Protection Performance Measurements in the First MQXF Magnet Models by E. Ravaioli *et al*.
doi: 10.1109/TASC.2018.2793900

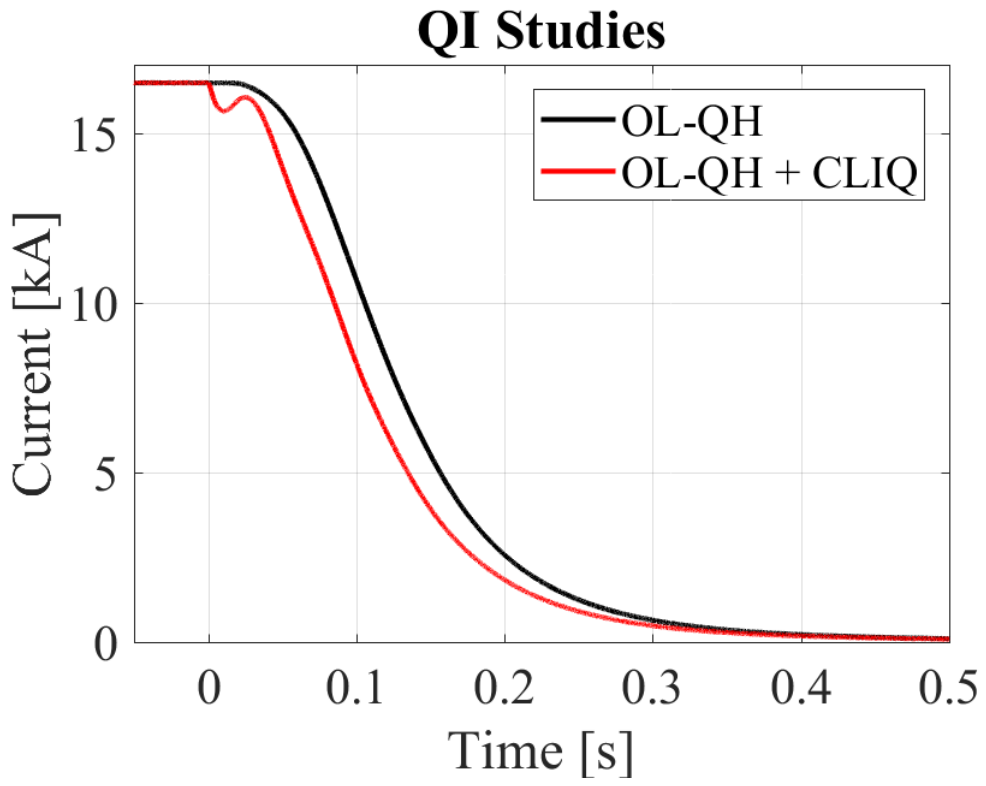
MQXFS3 Protection studies - CLIQ

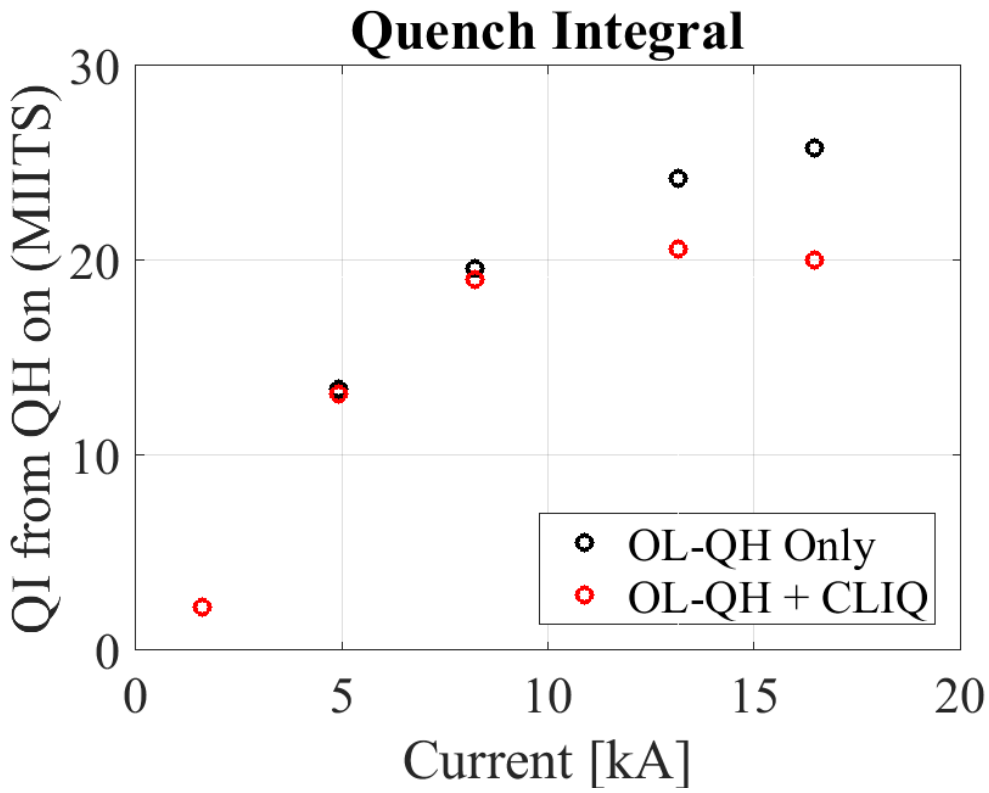




Report on Quench Protection Tests: MQXFS3 by S. Izquierdo Bermudez *et al*. EDMS Nr: 1836709

MQXFS5 Protection studies - CLIQ





Report on Quench Protection Tests: MQXFS5 by S. Izquierdo Bermudez *et al*. EDMS Nr: 1891255

Electrical insulation (HV) tests

	Reception (warm, air)		After LHe (warm, air/He)		In LHe		Test station
	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	
EDMS 1963398	3680 V	3680 V	368 V	460 V	1840 V	2300 V	
1a--d	1000	1000	1000	1000	1000	1000	Fermilab
3a	3700	3000			1500	2300	HFM
3b	-	-	3000	1000	1500	2300	HFM
5_1	3700	3000			1500	1000	Cluster D
5_2	-	-	3000	1000	1000	1000	Cluster D
3c_1	3700	3000	3700	3000	1000	1000	Cluster D
3c_2	-	-	1000	1000	1000	1000	Cluster D
3c_3	-	-	3700	500/1000	800	1100	Cluster D
4a	3700	3000	1000	1000	950	1800	Cluster D
4b	-	-	1000	500	1500	1880	HFM

Chronological order

EDMS

Target >> EDMS	Target = EDMS	Target < EDMS	Target not reached

Details on MQXFS5 HV tests

	Reception (warm, air)		After LHe (warm,air/He)		In LHe		Test station
	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	
EDMS 1963398	3680 V	3680 V	368 V	460 V	1840 V	2300 V	
1a--d	1000	1000	1000	1000	1000	1000	Fermilab
3a	3700	3000			1500	2300	HFM
3b	-	-	3000	1000	1500	2300	HFM
5_1	3700	3000			1500	1000	Cluster D
5_2	-	-	3000	1000	1000	1000	Cluster D
3c_1	3700	3000	3700	3000	1000	1000	Cluster D
3c_2	-	-	1000	1000	1000	1000	Cluster D
3c_3	-	-	3700	500/1000	800	1100	Cluster D
4a	3700	3000	1000	1000	950	1800	Cluster D
4b	-	-	1000	500	1500	1880	HFM

5, 1st run: tests Coil-Gnd at cold OK at 500, 1000 V. Then failed at 1500 V, but tested again at 1000 V OK

5, 2nd run: tests Coil-Gnd at cold OK at 500, 1000 V. Did not try to go beyond that

Target >> EDMS	Target = EDMS	Target < EDMS	Target not reached

Details on MQXFS3c, run 3 HV tests

	Reception (warm, air)		After LHe (warm,air/He)		In LHe		Test station
	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	
EDMS 1963398	3680 V	3680 V	368 V	460 V	1840 V	2300 V	
1a--d	1000	1000	1000	1000	1000	1000	Fermilab
3a	3700	3000			1500	2300	HFM
3b	-	-	3000	1000	1500	2300	HFM
5_1	3700	3000			1500	1000	Cluster D
5_2	-	-	3000	1000	1000	1000	Cluster D
3c_1	3700	3000	3000	1000	1000	1000	Cluster D
3c_2	-	-	1000	1000	1000	1000	Cluster D
3c_3	-	-	3700	500/1000	800	1100	Cluster D
4a	3700	3000	1000	1000	950	1800	Cluster D
4b	-	-	1000	500	1500	1880	HFM

3c, 3rd run: testing up to the EDMS recommended value did not show the defective quench heater found at our own target value (1 kV).

For this run we also tested the coil-QH insulation in gaseous helium at 80, 150 and 280 K.

Target >> EDMS	Target = EDMS	Target < EDMS	Target not reached

Details on MQXFS4 HV tests

	Reception (warm, air)		After LHe (warm,air/He)		In LHe		Test station
	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	Coil-Gnd	Coil-QH	
EDMS 1963398	3680 V	3680 V	368 V	460 V	1840 V	2300 V	
1a--d	1000	1000	1000	1000	1000	1000	Fermilab
3a	3700	3000			1500	2300	HFM
3b	-	-	3000	1000	1500	2300	HFM
5_1	-	-	3000	1000	1000	1000	Cluster D
5_2	-	-	3000	1000	1000	1000	Cluster D
3c_1	3700	3000	3700	1000	1000	1600	Cluster D
3c_2	-	-	3700	1000	1000	1000	Cluster D
3c_3	-	-	3700	500/1000	800	1100	Cluster D

4a: tests at cold failed to reach the EDMS target value. Maximum reached was 900 V coil-ground and 1700 V coil-QH.

4b: after changing test facility and upgrading the auxiliary leads for CLIQ, the maximum voltage reached was 1140 V coil-ground and 1400 V coil-QH

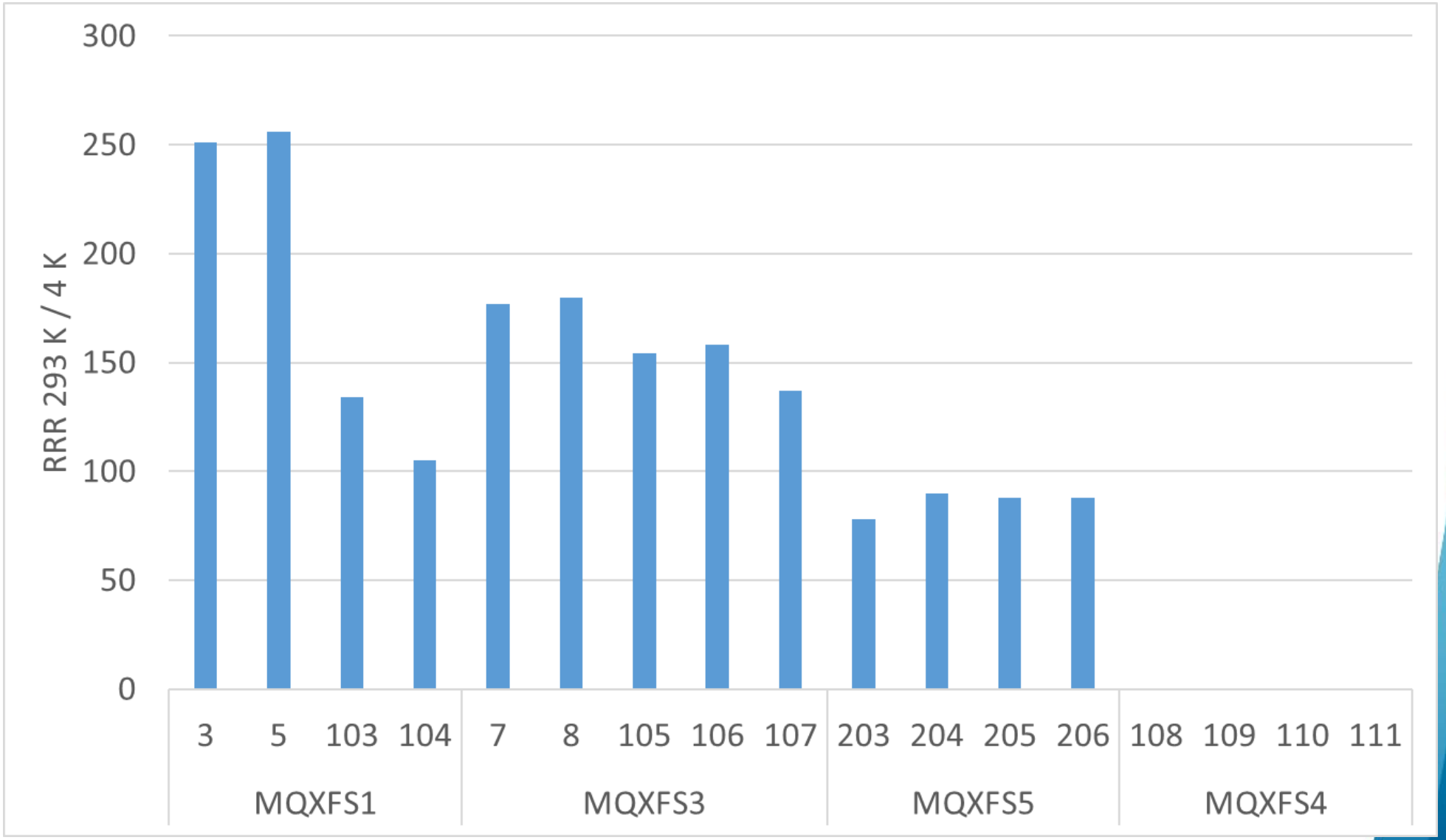
Breakdown in coil-QH at 1880 V happened after ~25 s of maintaining the voltage

4a	3700	3000	1000	1000	950	1800	Cluster D
4b	-	-	1000	500	1500	1880	HFM

Target >> EDMS	Target = EDMS	Target < EDMS	Target not reached

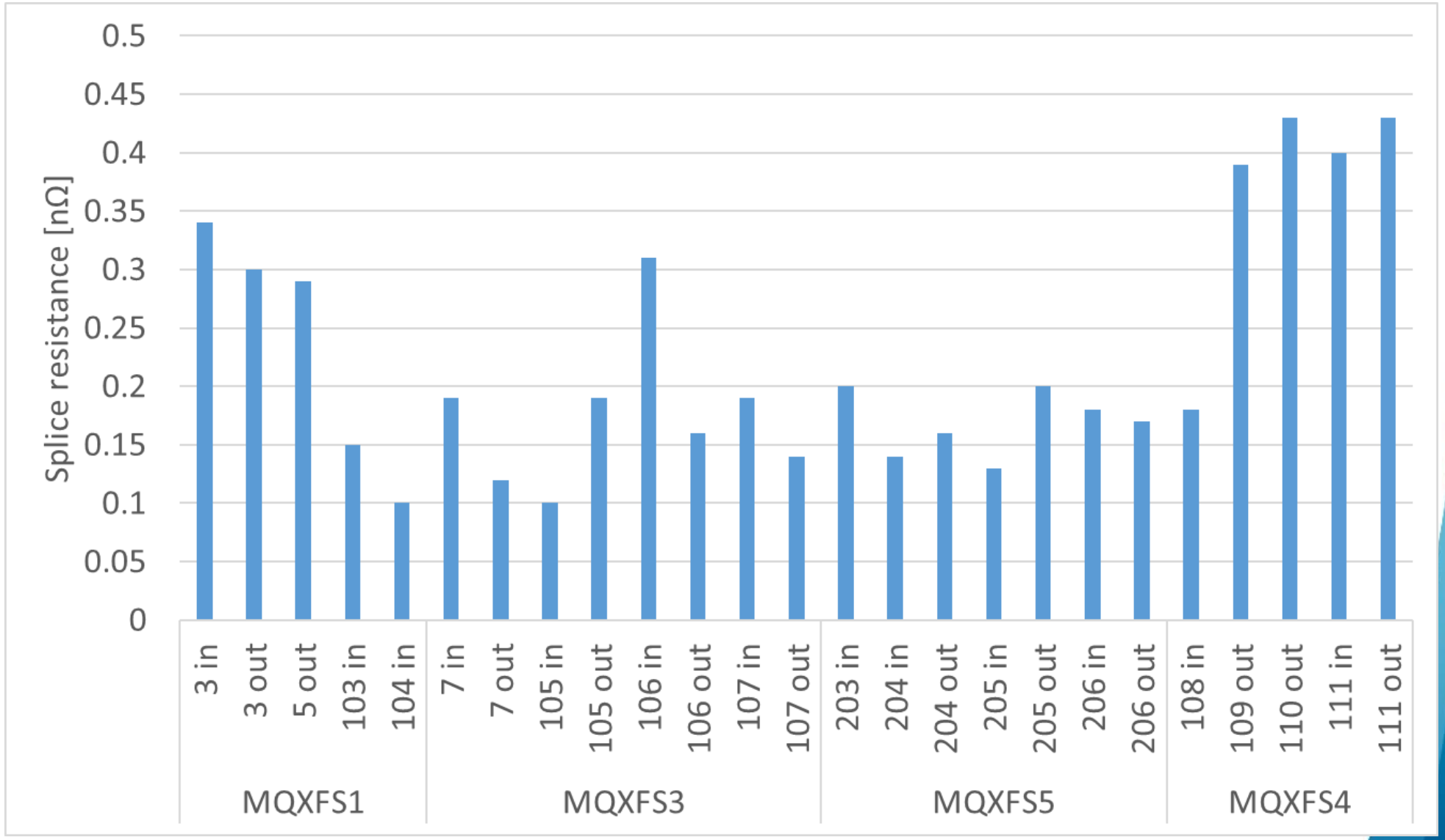
RRR

- MQXFS1 and 3 above specs (100)
- MQXFS5 below specs (PIT without bundle barrier)
- MQXFS4 will be measured next week



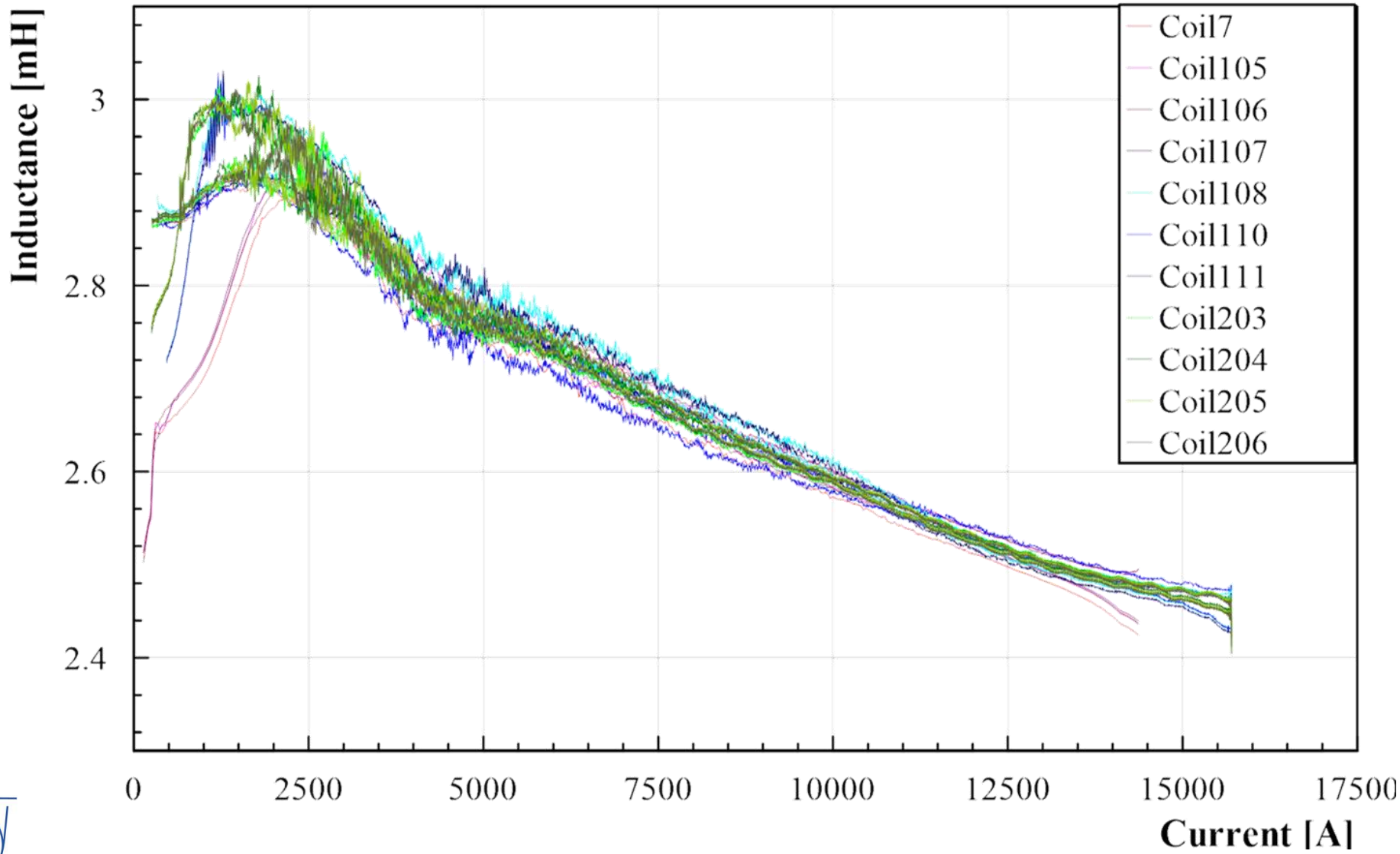
Splices resistance

- Splices resistance well below 1 nΩ specification

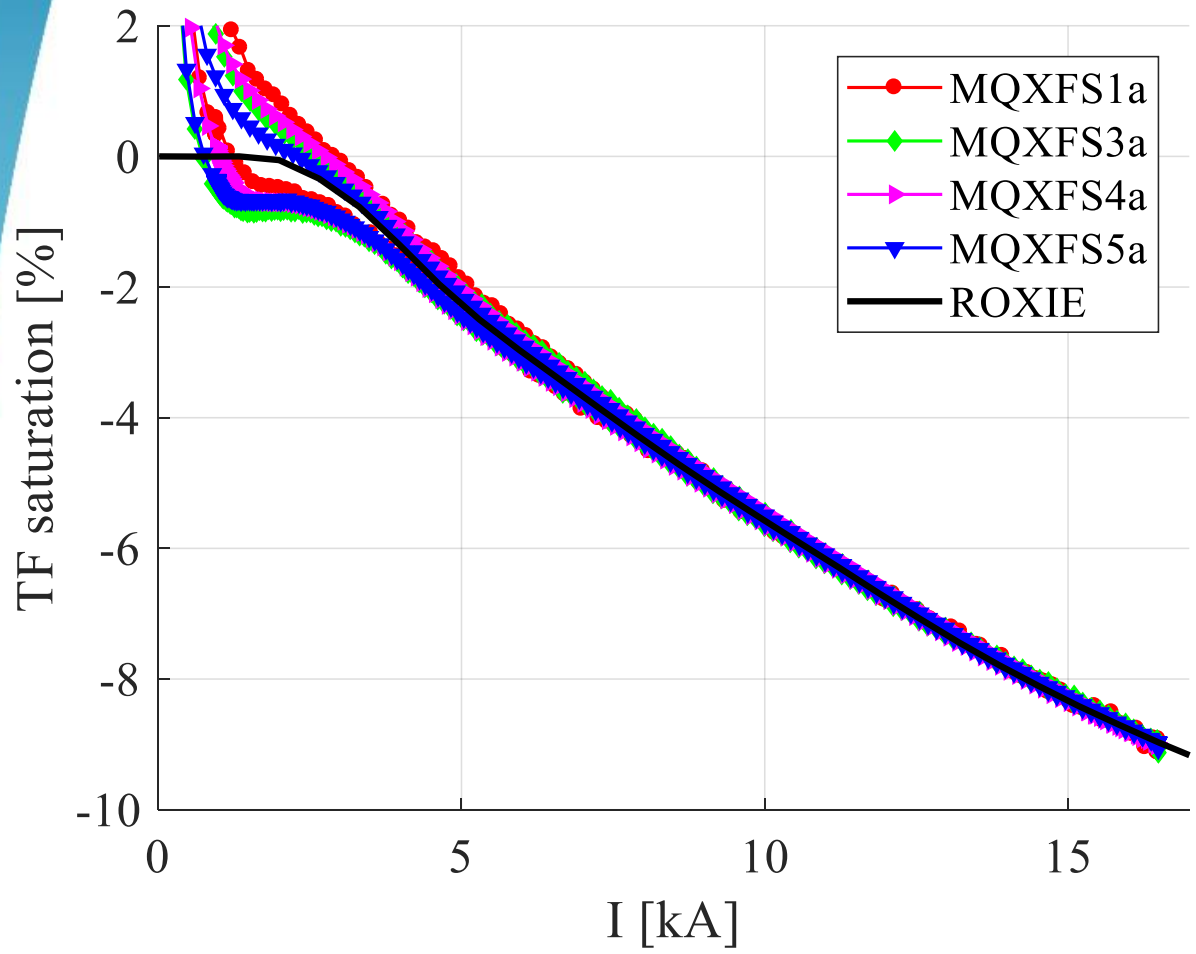


Coils' inductance

- All coils inductance the same above ~2500 A



Transfer function



- Decrease on the transfer function by ∼ 9 % from injection to nominal current due to iron saturation, in agreement with expectations.
- Main field at nominal current is within 15 units the expected value for all measured magnets.

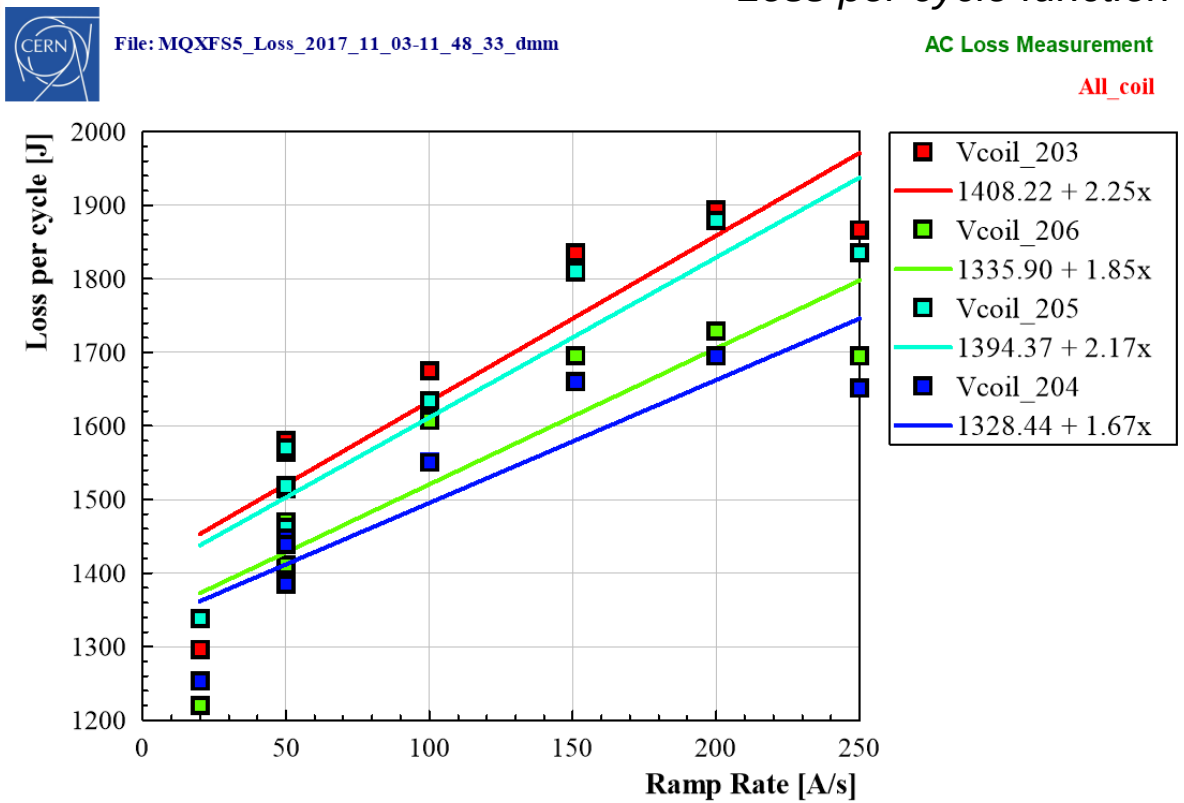
Transfer function at nominal current

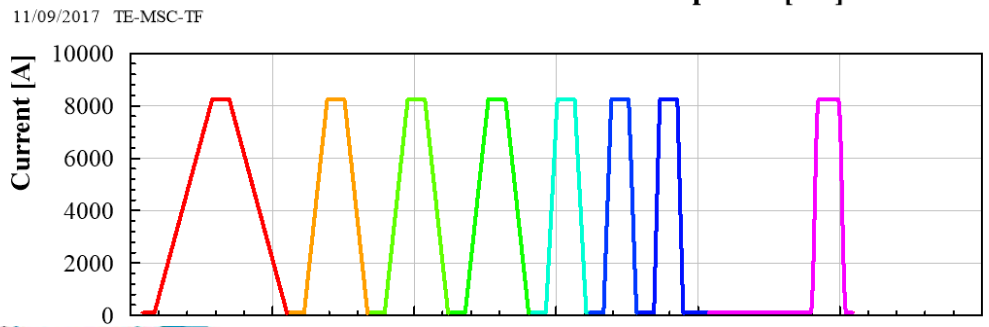
	ROXIE	MEASUREMENTS	DIFF TO ROXIE
	T/m/kA	T/m/kA	Units
MQXFS1a	8.134	8.145	14
MQXS3a		x	x
MQXS4a		8.13	-5
MQXS5a		8.146	15

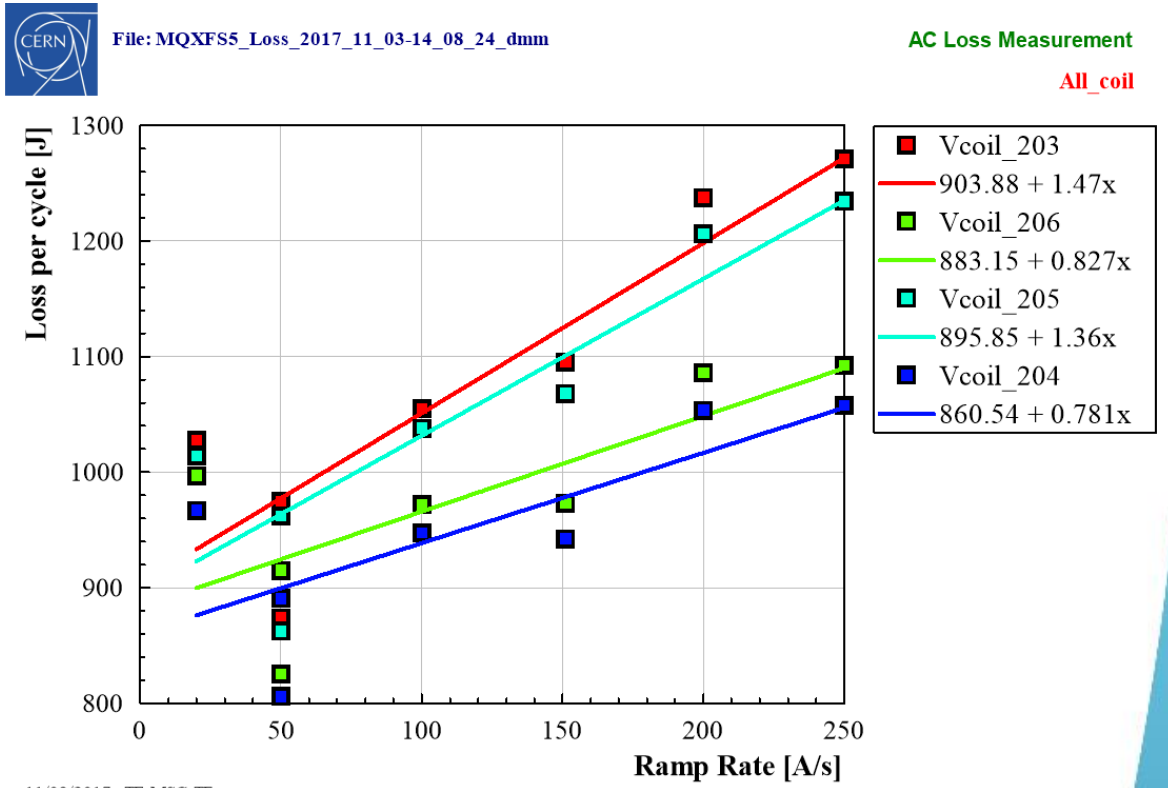
Courtesy S. Izquierdo Bermudez

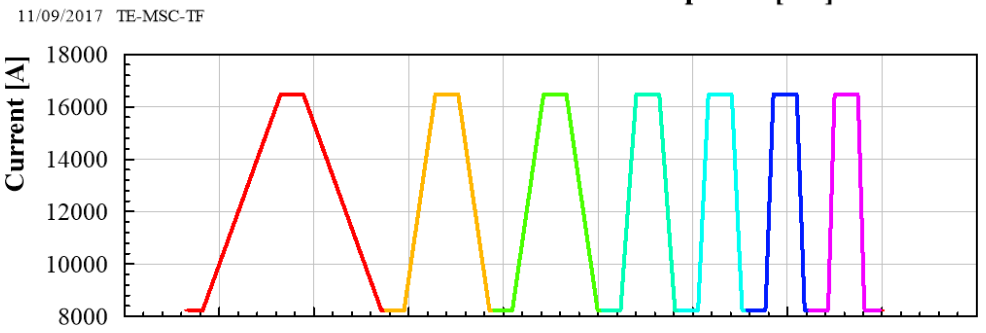
MQXFS5 AC losses

Loss per cycle function of ramp rate (4 coils)









Conclusions

- Ten versions of four MQXF short models tested
- Training behavior has improved after iterations, adjusting the manufacturing & assembly processes
  - Last model tested reached nominal current in one quench, and ultimate in 5
- Extensive protection studies performed MQXFS1, 3, 5 (ongoing on 4), results are consistent with models and provide confidence in the protectability of the full-length magnet
- Electrical insulation target test levels were not defined at the time of MQXFS1, 3a-c and 5. 3a and 3b tested OK almost to the target levels. MQXFS4 passed this test at warm but not in LHe
- Other characteristics: RRR (except in MQXFS5), splice resistance, coils inductance, transfer function are reproducible and within specifications

HiLumi HL-LHC PROJECT

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