MQXFB test updates

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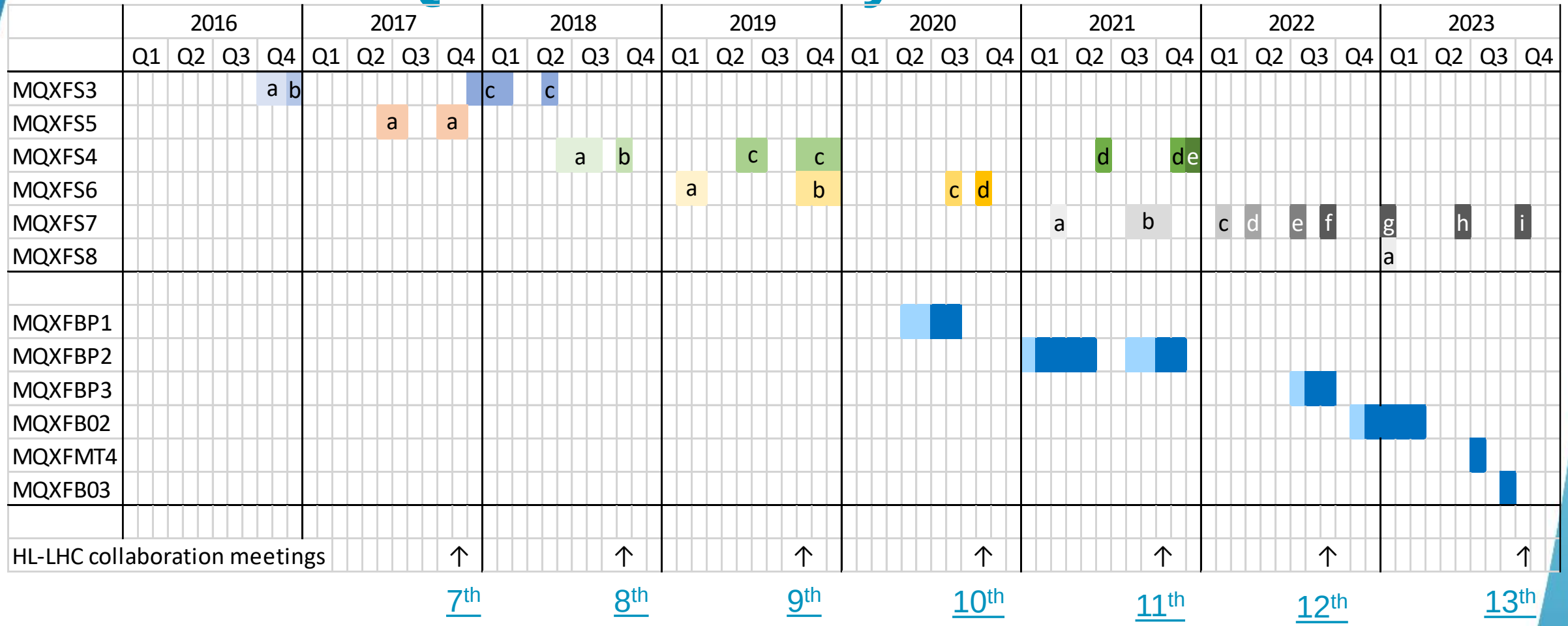
2023.09.27

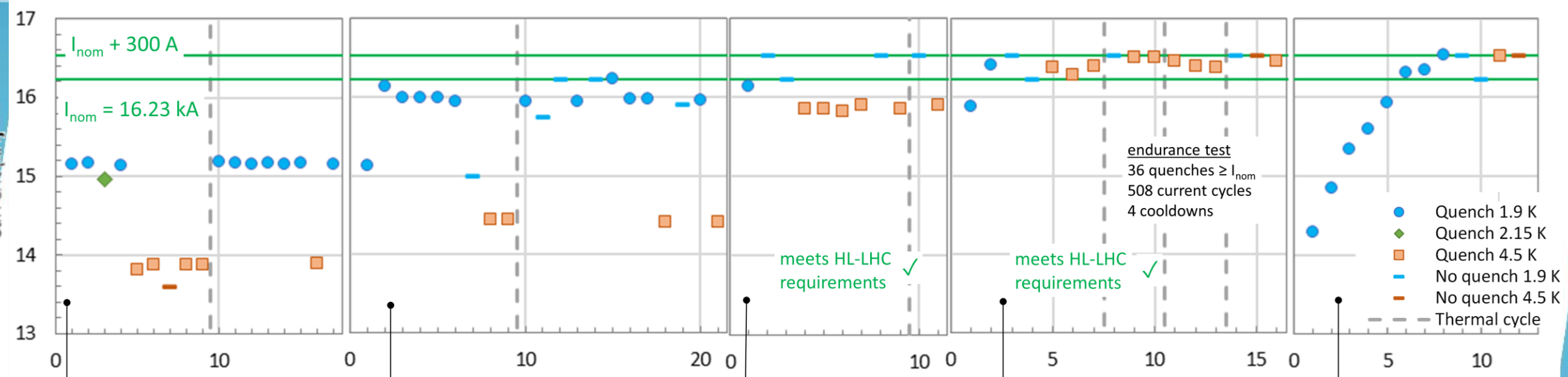
MQXF test history at CERN



Focus of today's talk: MQXFB02, MQXFMT4, MQXFB03

Overview of all MQXFB full length magnets

Natural quench history at 20 A/s of the first 5 MQXFB magnets (standalone test cold mass / cryostat configuration)



MQXF**BP1**
May 2020 – Sept. 2020
limited at 15.17 kA at 1.9 K
limited at 13.85 kA at 4.5 K
disassembled for destructive examinations of limiting coil

MQXF**BP2**
Jan. 2021 – Dec. 2021
limited at 15.95 kA at 1.9 K
limited at 14.45 kA at 4.5 K

MQXF**BP3**
Jul. 2022 – Oct. 2022
reached target at 1.9 K
limited at 15.85 kA at 4.5 K
(improved cold mass assembly)

MQXF**B02**
Nov. 2022 – Mar. 2023
reached target at 1.9 K
limited at 16.40 kA at 4.5 K
(improved magnet assembly)

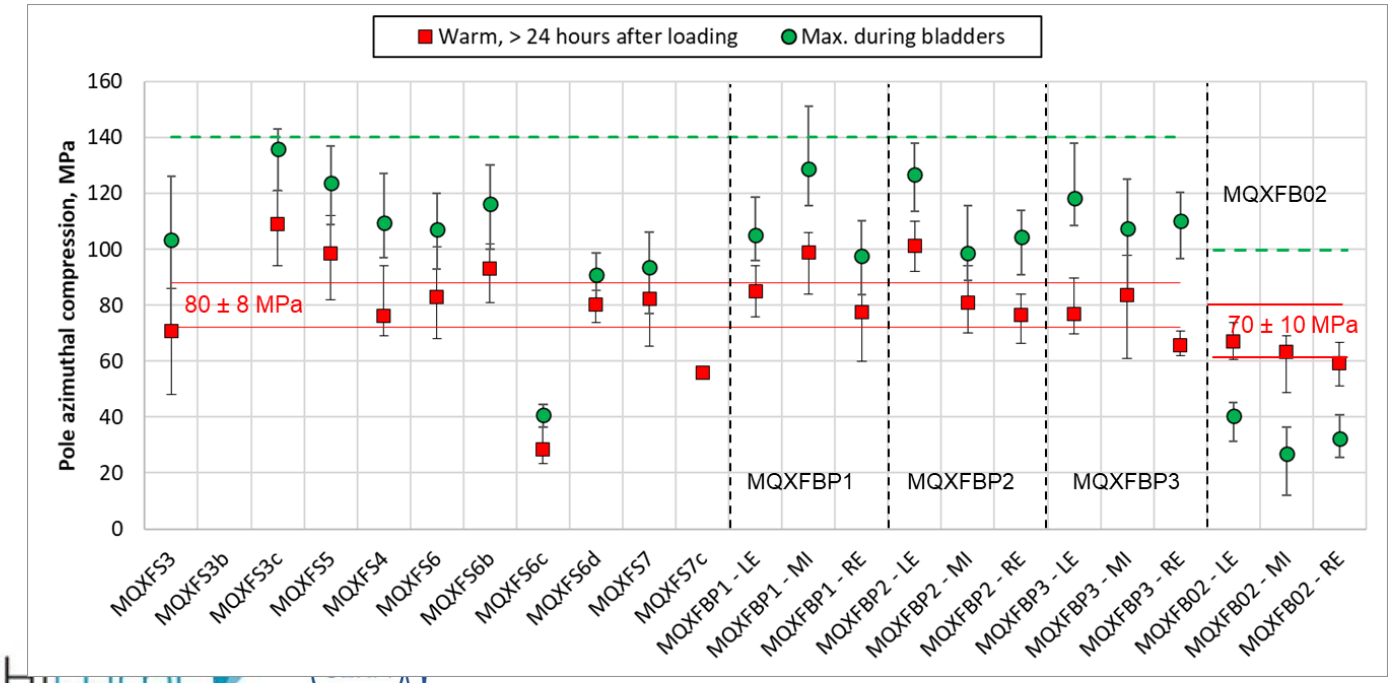
MQXF**B03**
Sept. 2023
reached target at 1.9 K and 4.5 K
(improved coils)

For details of the differences between the assemblies see the presentation by Susana Izquierdo Bermudez

MQXFB02

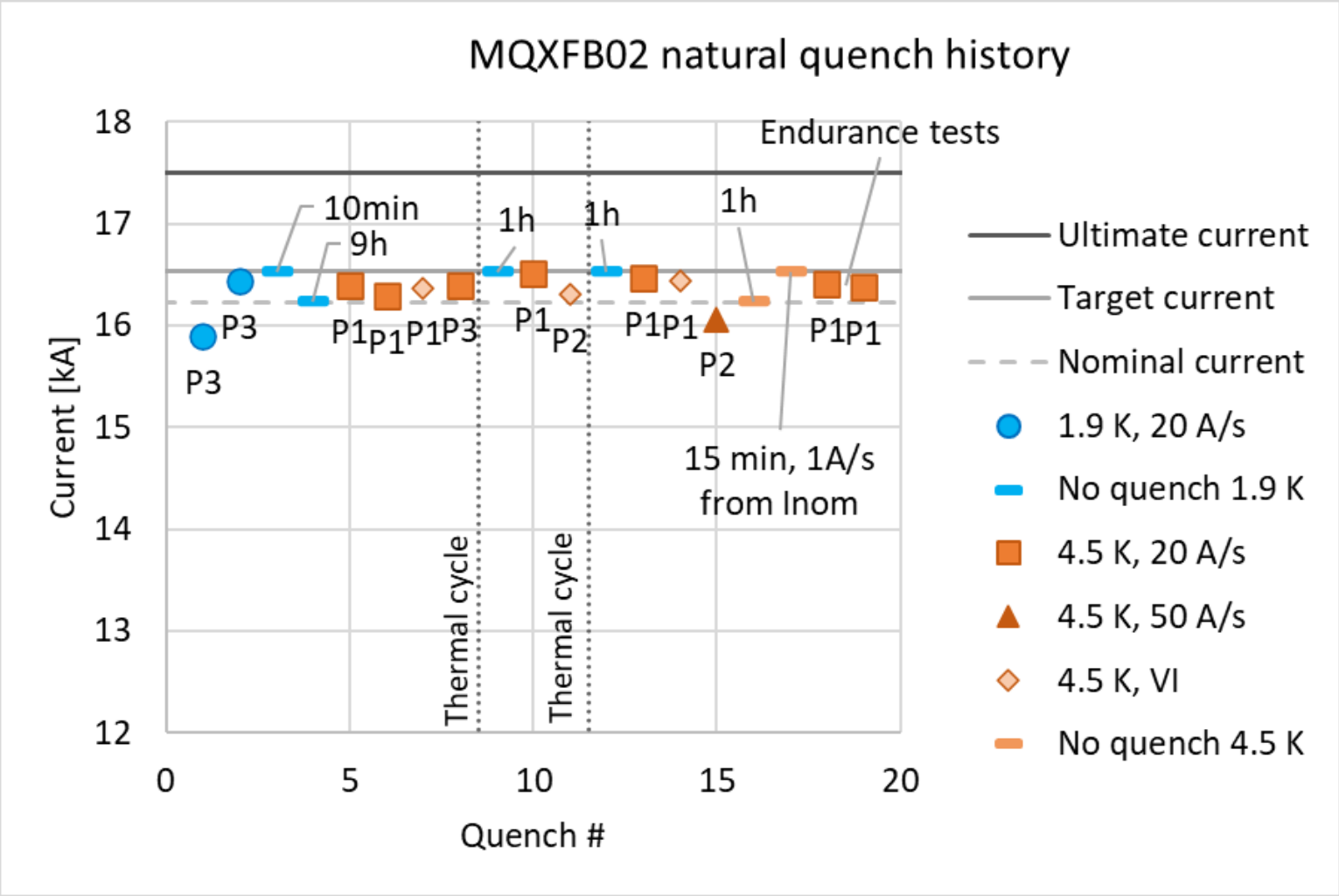
MQXFB02 – Magnet features

- Optimized **procedure of bladder and key loading**, based on stretching the outer structure via additional bladders in the cooling hole channels
  - It **eliminates the overshoot of coil azimuthal stress during loading** (+30 MPa, as high as +50 MPa), and minimizes peak stress in the coils, which is now during the insertion of the keys and not during bladder operations.
  - MQXFB02 has optimized welding and magnet assembly procedures, but the coils were fabricated before the stop of the production in spring 2021



Slide courtesy S. Izquierdo Bermudez

MQXFB02 quench plot



At nominal temperature 1.9 K

- Reached target current in 2 quenches
- No retraining after thermal cycle

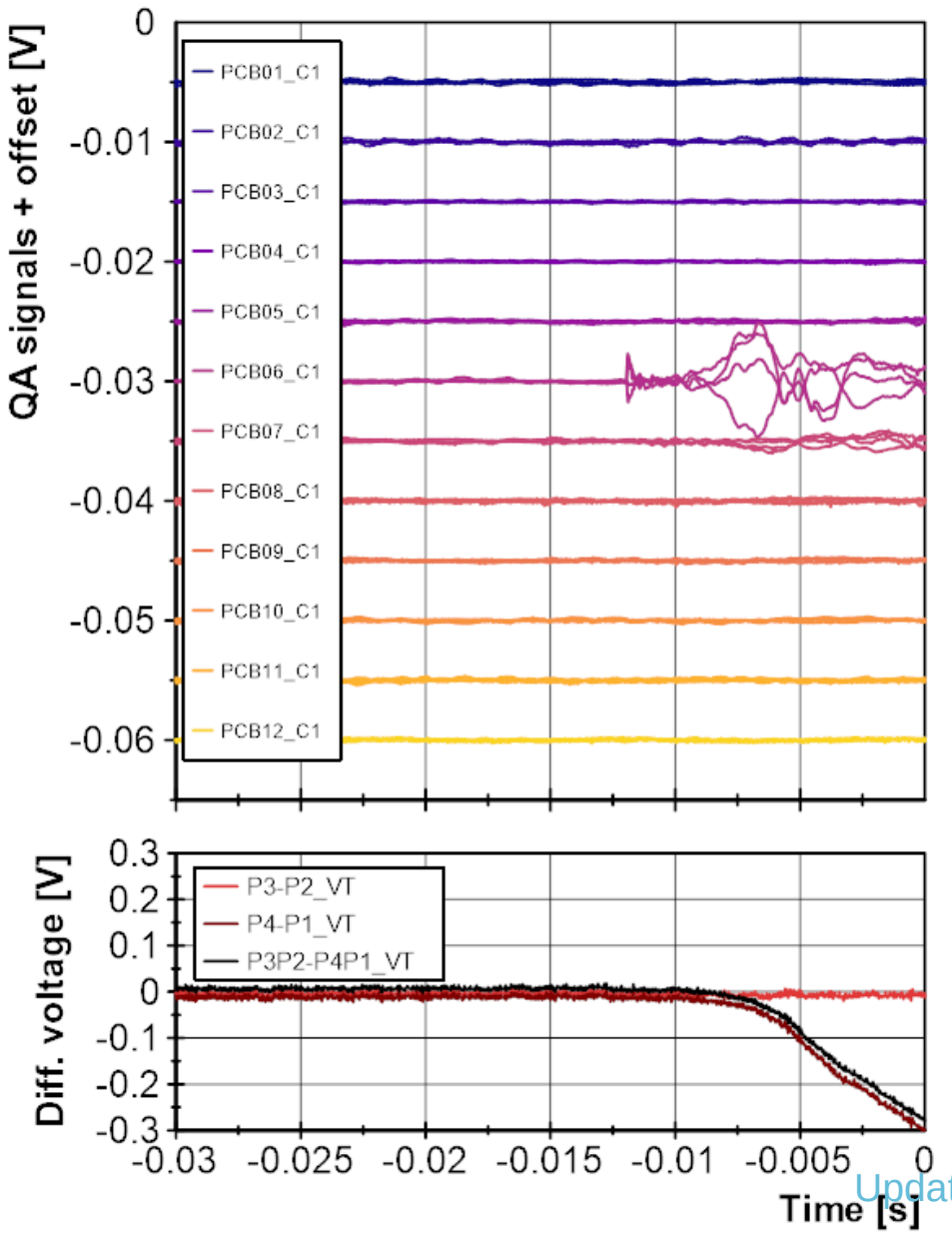
At 4.5 K:

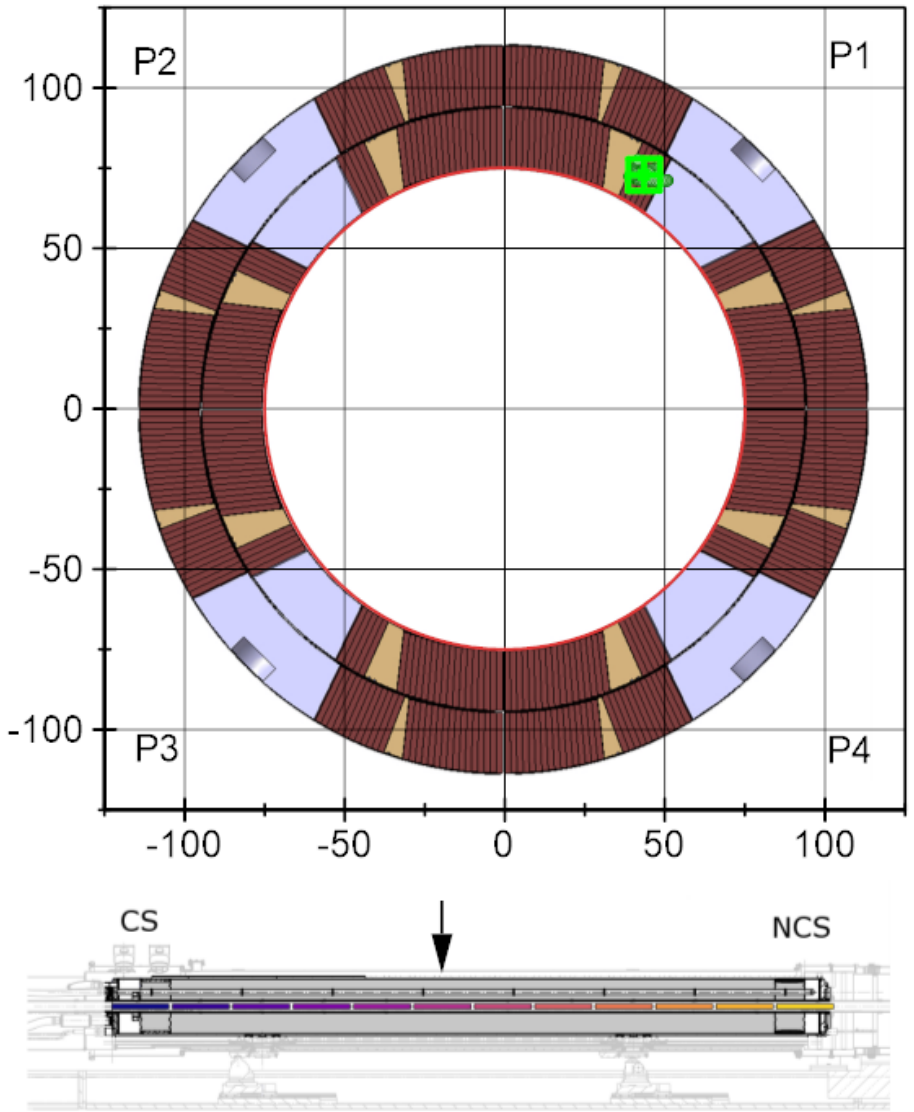
- All quenches at 20 A/s (except #8) are in the same location
- The three VI quenches are in different locations

Full test report in EDMS 2795008

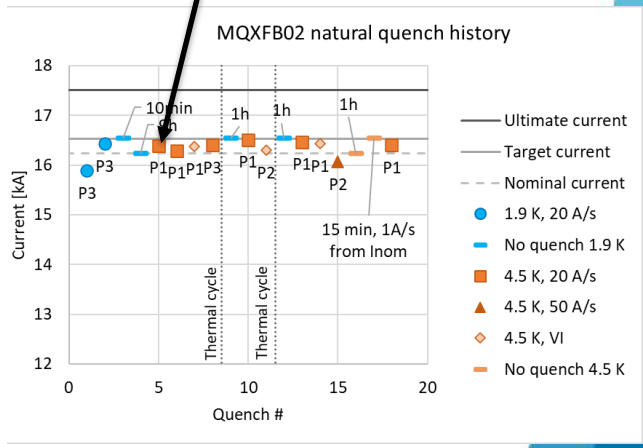
Note: the VI quenches have an "effective ramp rate" of less than 1 A/s (5 min plateau every 100 A, ramps at 1 A/s)

MQXFB02 quench localization

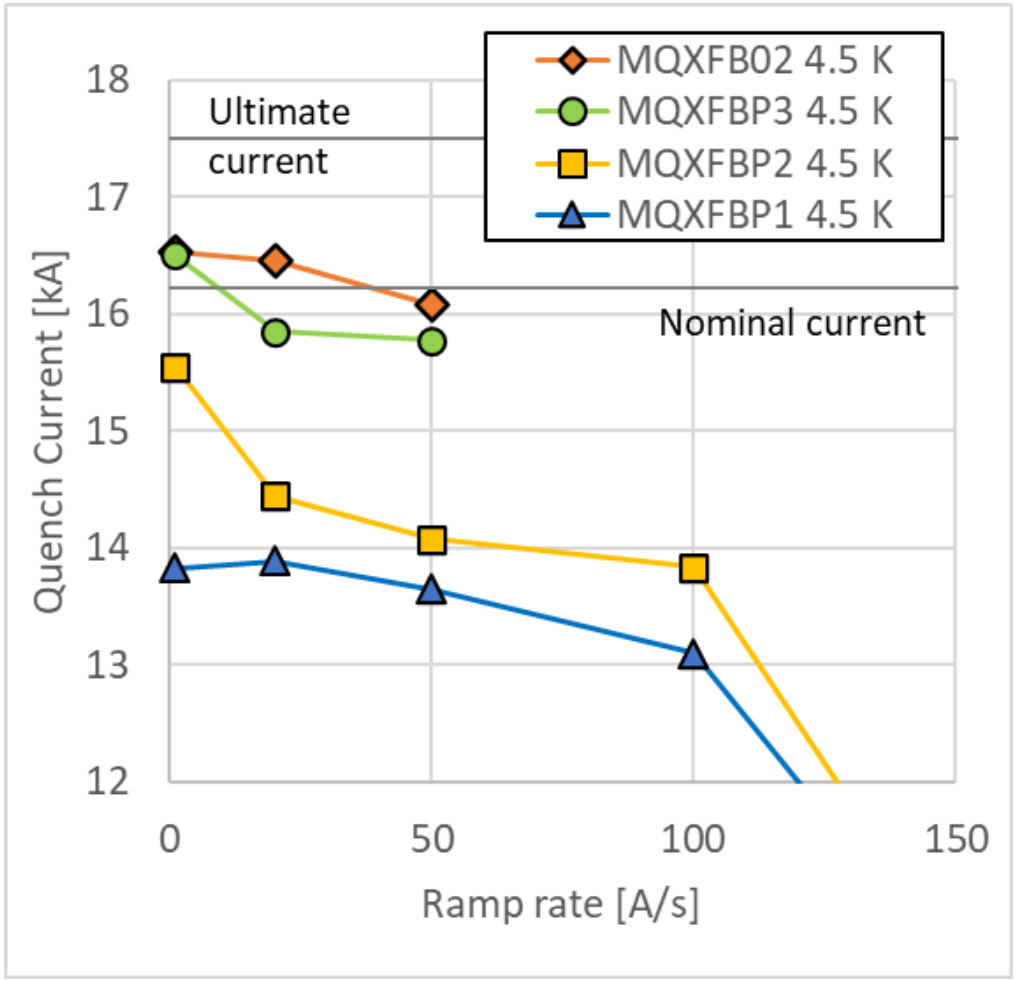


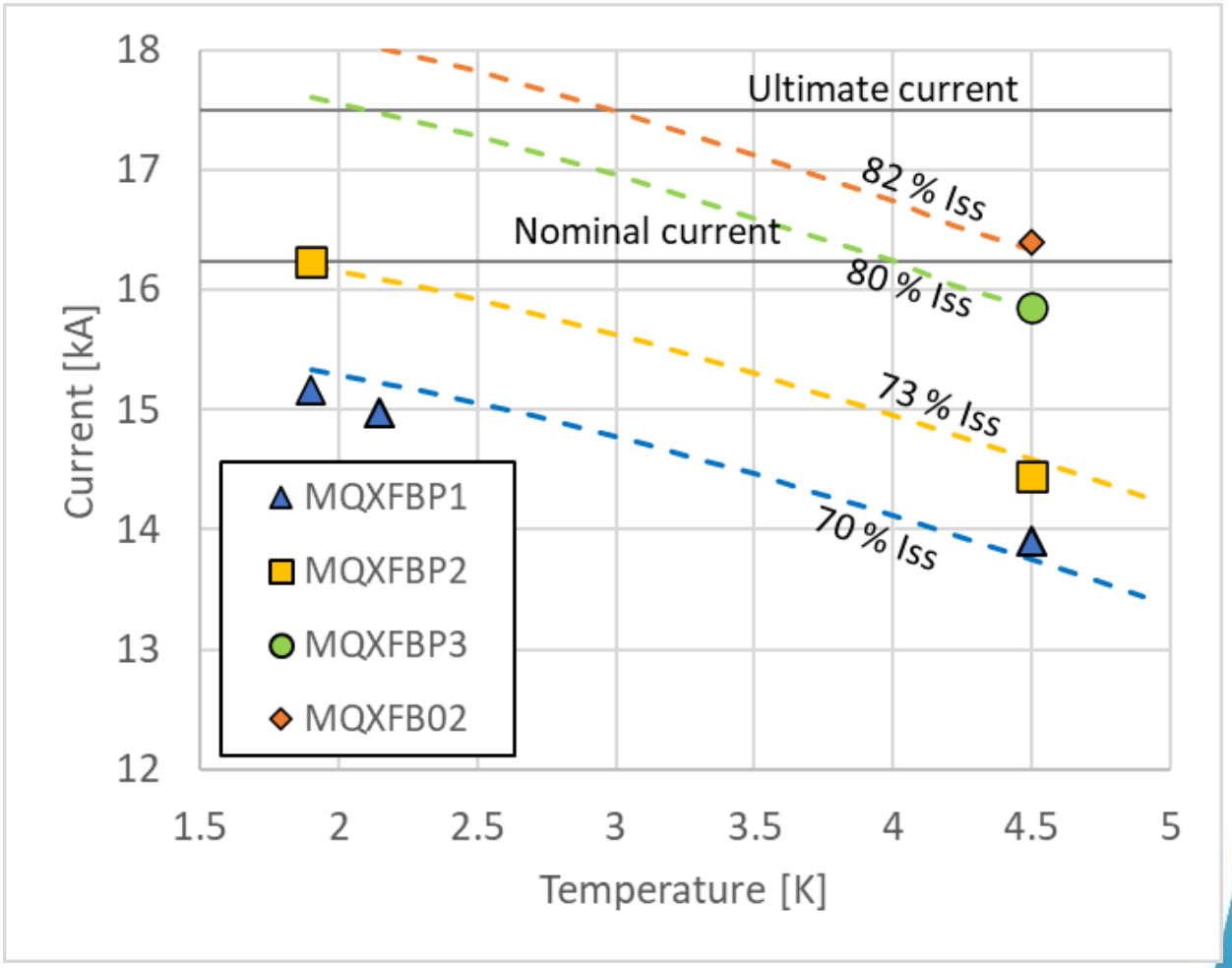


Example: this quench



Ramp rate and temperature dependency

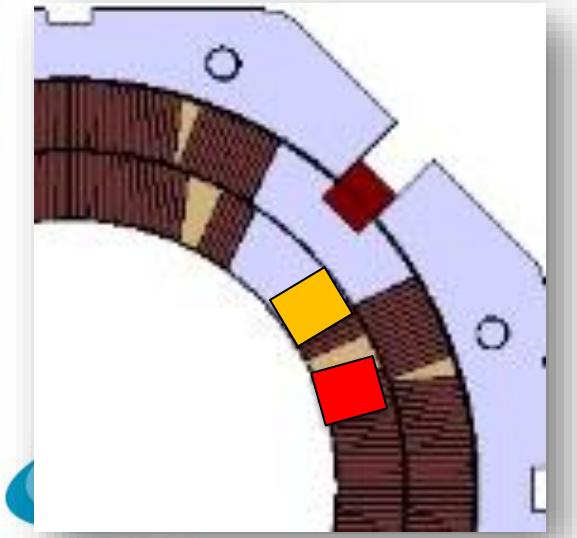




BP3 and B02 did not quench at 1.9 K.

Quench locations (excluding training)

	1.9 K			4.5 K		
MQXF…	VI	20 A/s	50 A/s	VI	20 A/s	50 A/s
BP1	P3.A	P3.B		P3.A	P3.A	P3.B
BP2	P1 P1	P1	P1	P1	P1	P1
BP2 trim	---	P3		P2	P3	
BP3	---	---	---	P3 P3	P4	P4
B02	---	---	---	P1.A P1.B P2.A	P1.A	P2.B



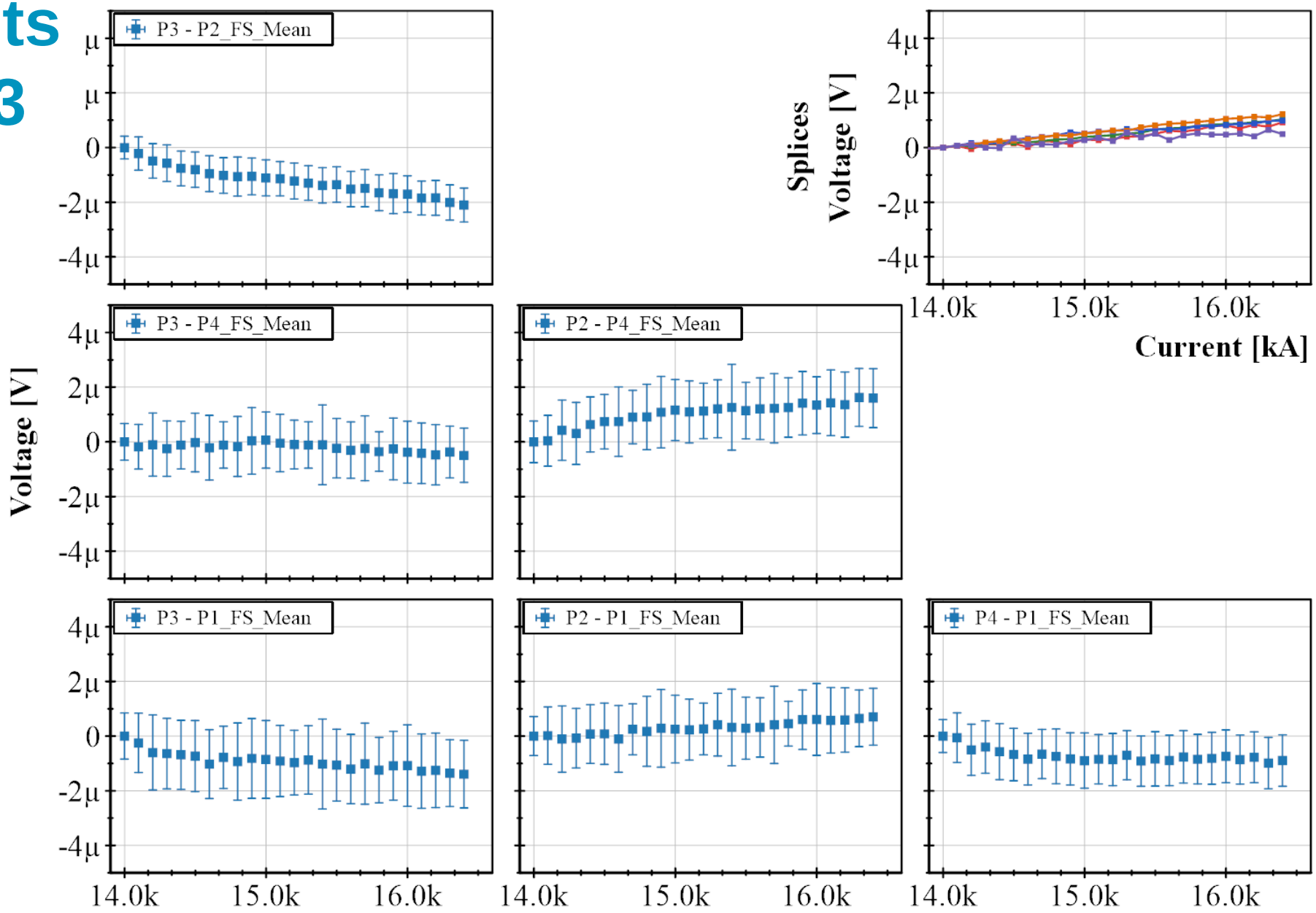
Color indicates where the quench happened in the cross section
Text indicates coil number, and an identifier if several quench locations in the same coil

Inner layer pole turn is an “old friend” across all MQXFB so far

B02 has a bit more variety in quench location

V-I measurements MBXFB02, CD 3

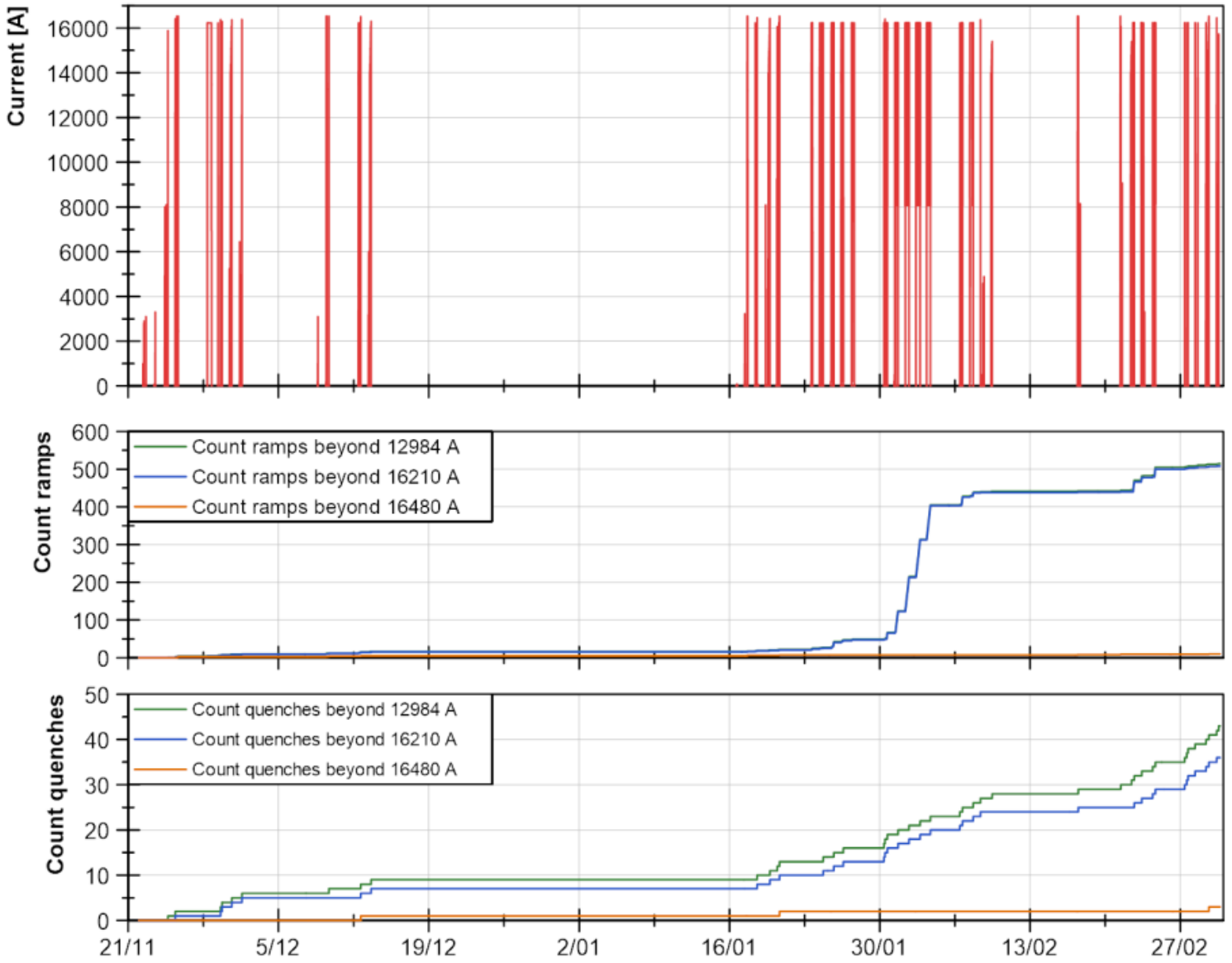
- The V-I measurements are always a challenge in keeping the noise low.
- Where for prototype BP1 and BP2 a clear voltage buildup was measured, this was not the case for B02.



MQXFB02 endurance tests

- 515 cycles beyond 80% Inom
- 508 cycles up to Inom
- 43 quenches above 80% Inom
- 36 quenches at or above Inom

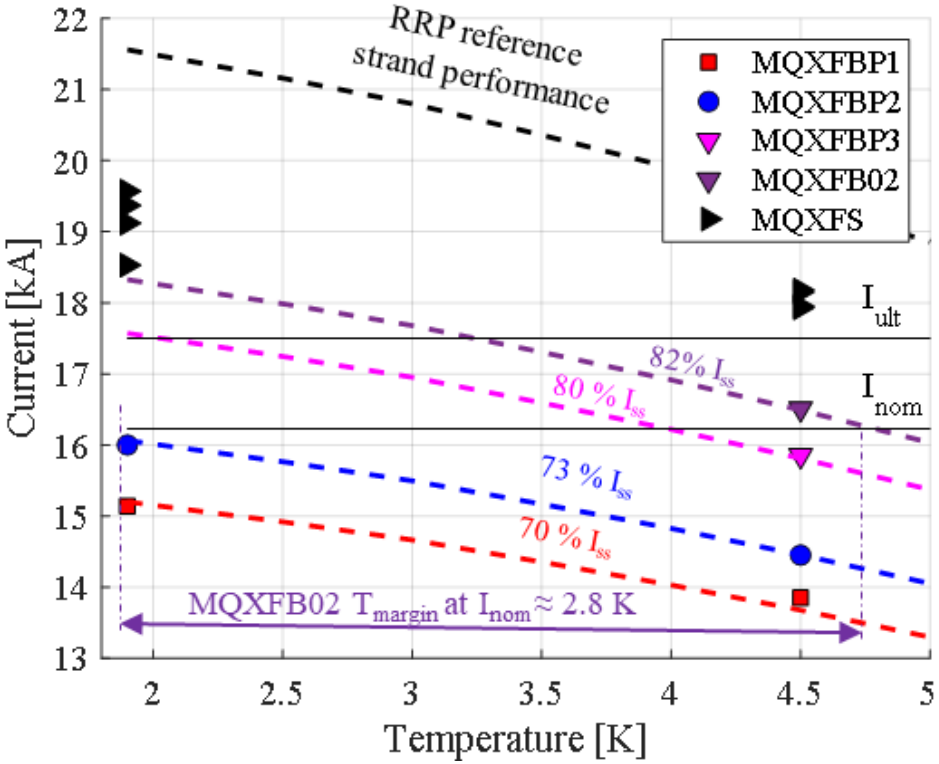
- 60 QH firings
- 61 CLIQ firings



Conclusion MQXFB02

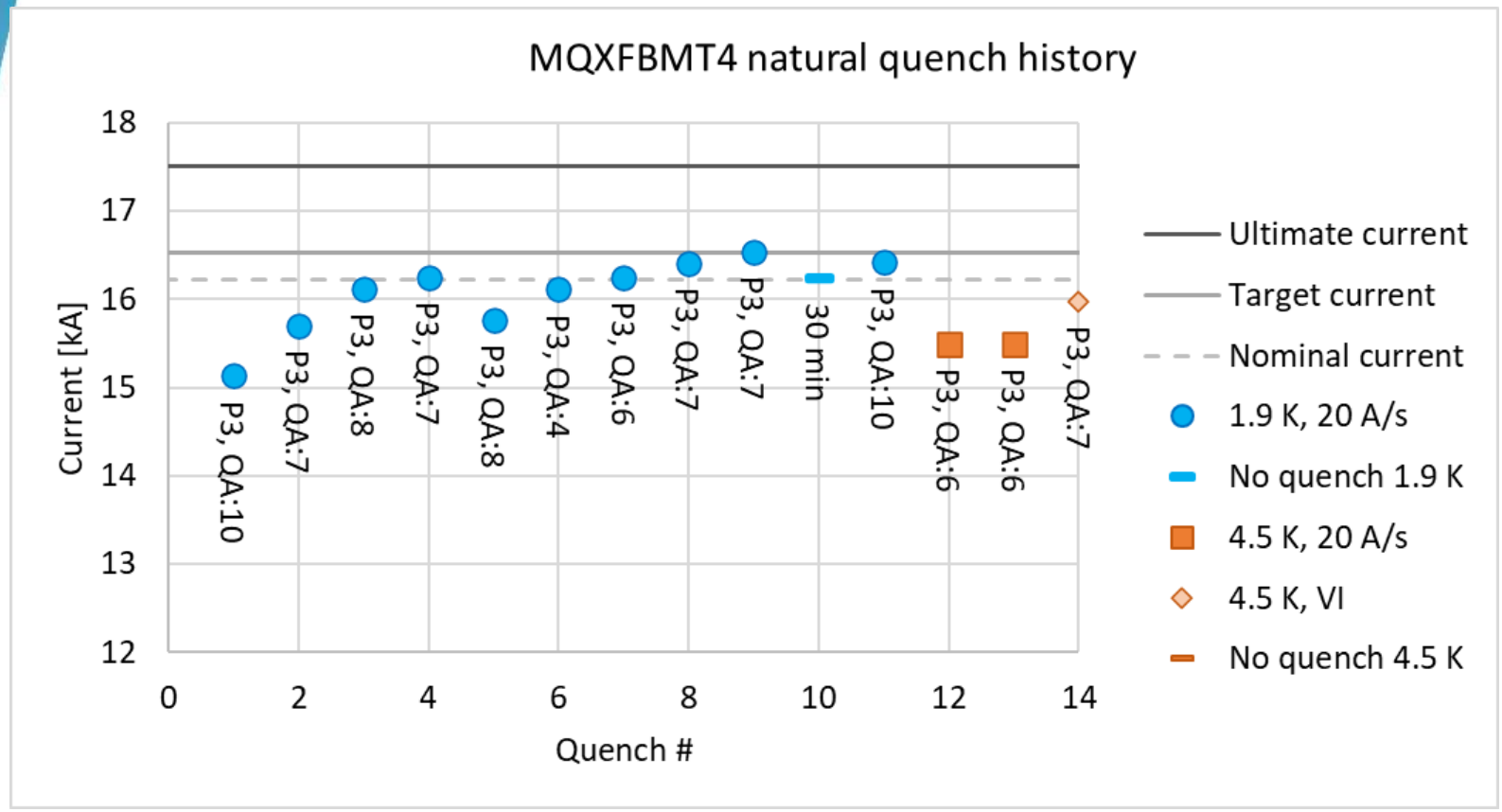
- Good performance over 3 cool downs
- No quenches in the coil ends
- Limited in the straight part in the middle of the magnet, (like P1, P2 and P3),at around 82 % of short sample at 4.5 K.
- Important: No change in this performance limit during 3 cool downs and many quenches and powering cycles.

Stable performance with 2.8 K margin at 7TeV operation!



MQXFBMT4

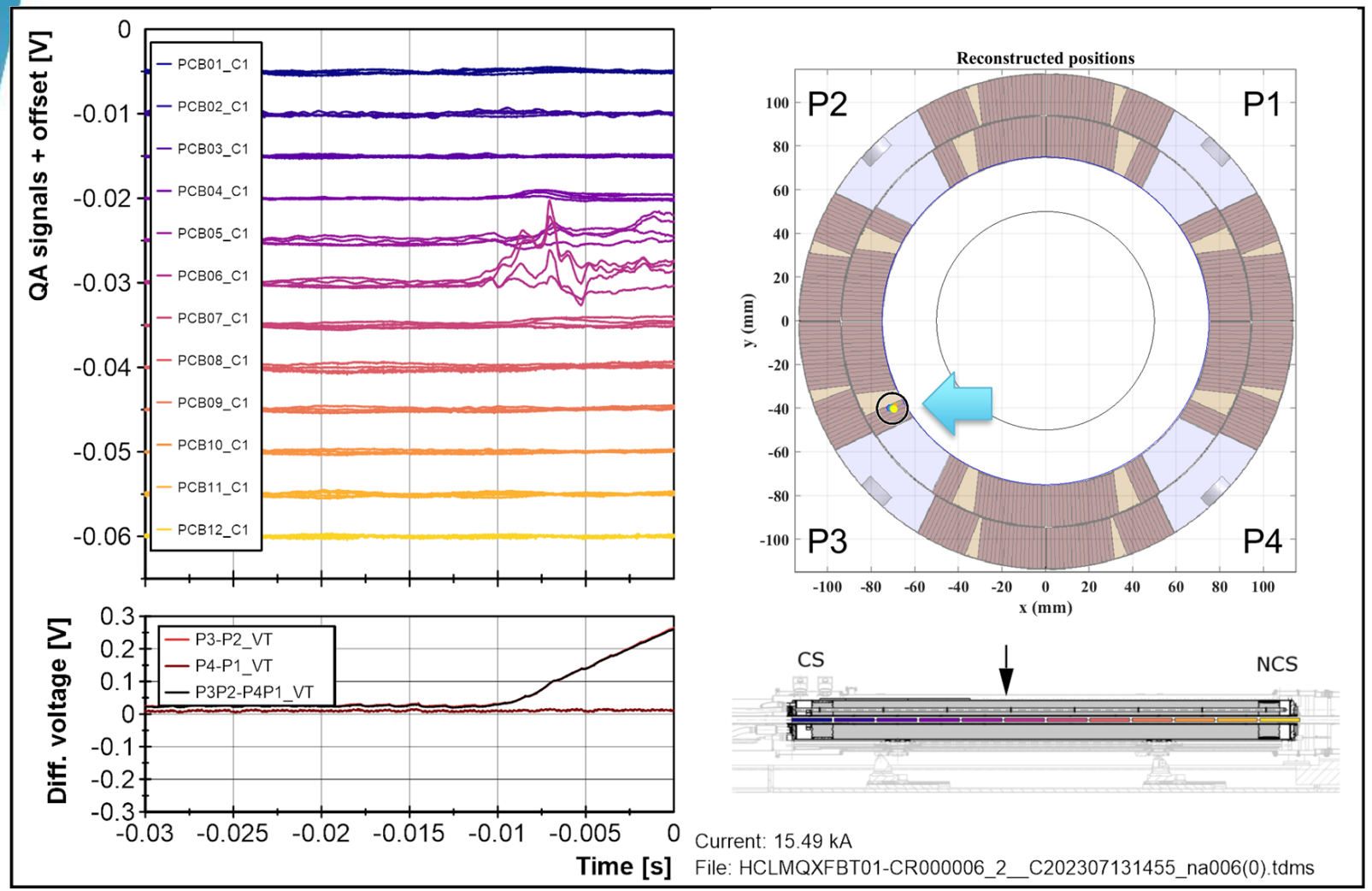
MQXFBMT4 quench plot



- All quenches in the new coil, but in different longitudinal location
- Training significantly slower than previous magnets
- After 10 quenches at 1.9 K, we went to 4.5 K to check the performance. We had a repetitive quench level and location.
- Training of this magnet at 1.9 K was not finished due to time constraints

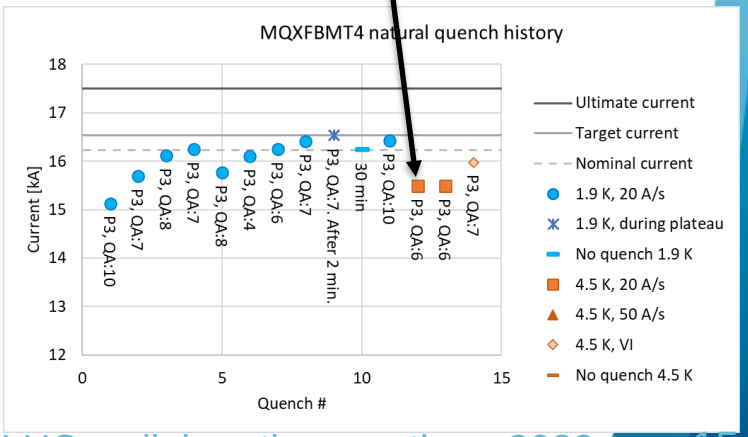
Note: the VI quenches have an “effective ramp rate” of less than 1 A/s (5 min plateau every 100 A, ramps at 1 A/s)

MQXFBMT4 quench localization



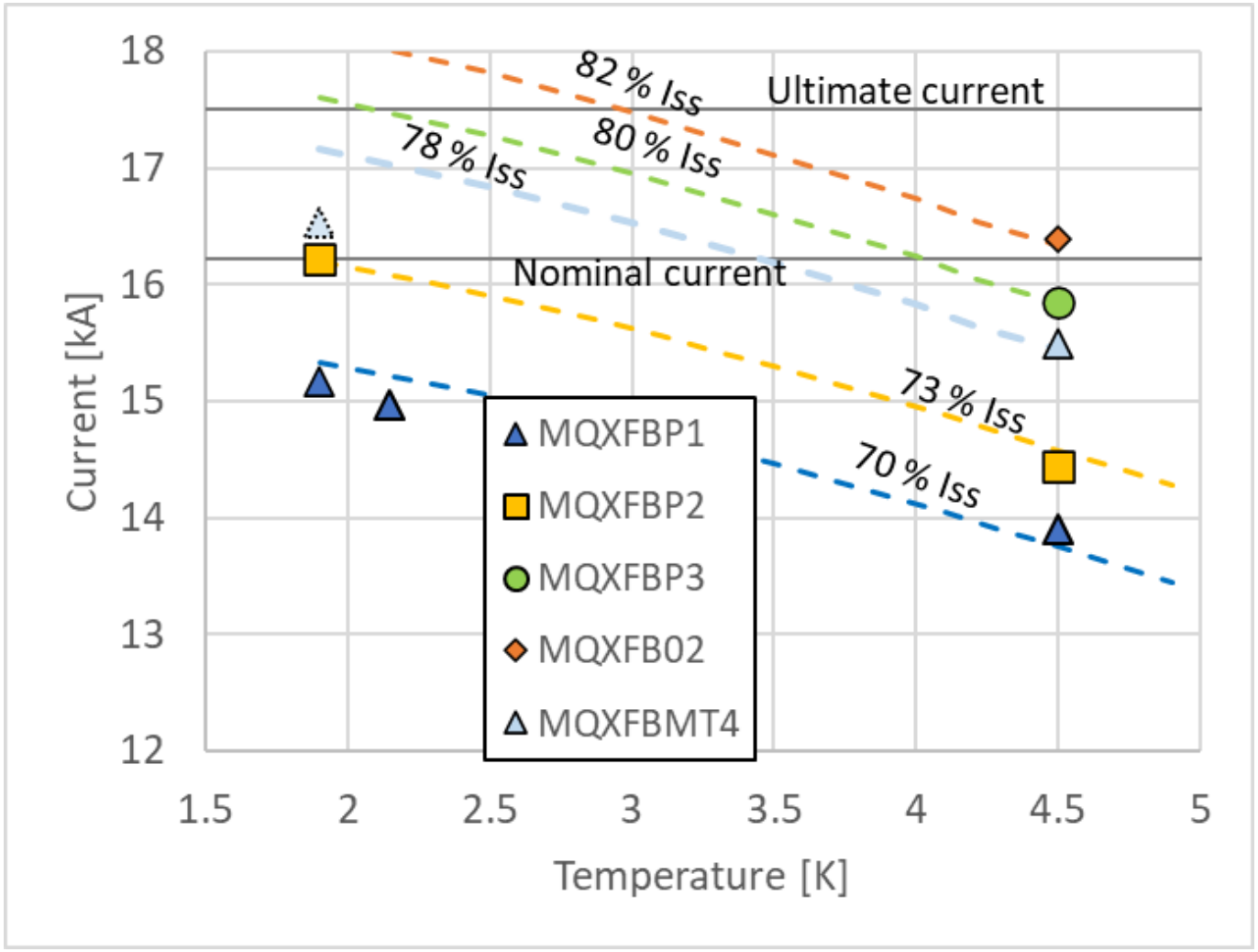
- Example localization for one of the 4.5 K quenches.
- Coil limit in the straight part of the magnet, around Quench Antenna 6.

Example: this quench



Temperature dependency, compared to previous magnets

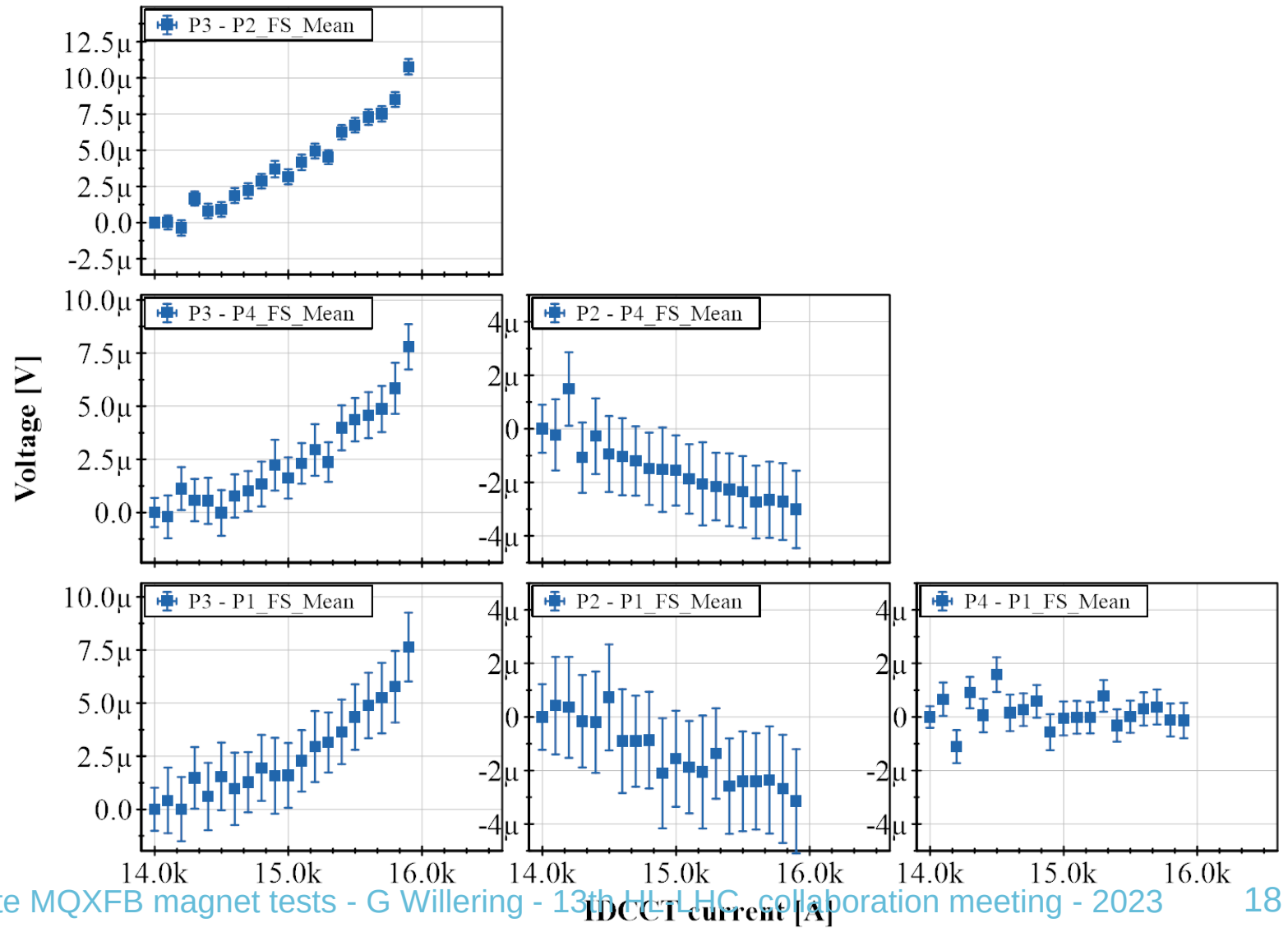
- Dashed lines show the short sample limit at different levels of reduction
- As mentioned before, training of MQXFBMT4 at 1.9 K was not finished due to time constraints



Ramp rate dependency, compared to previous magnets

MQXFBMT4 VI measurements

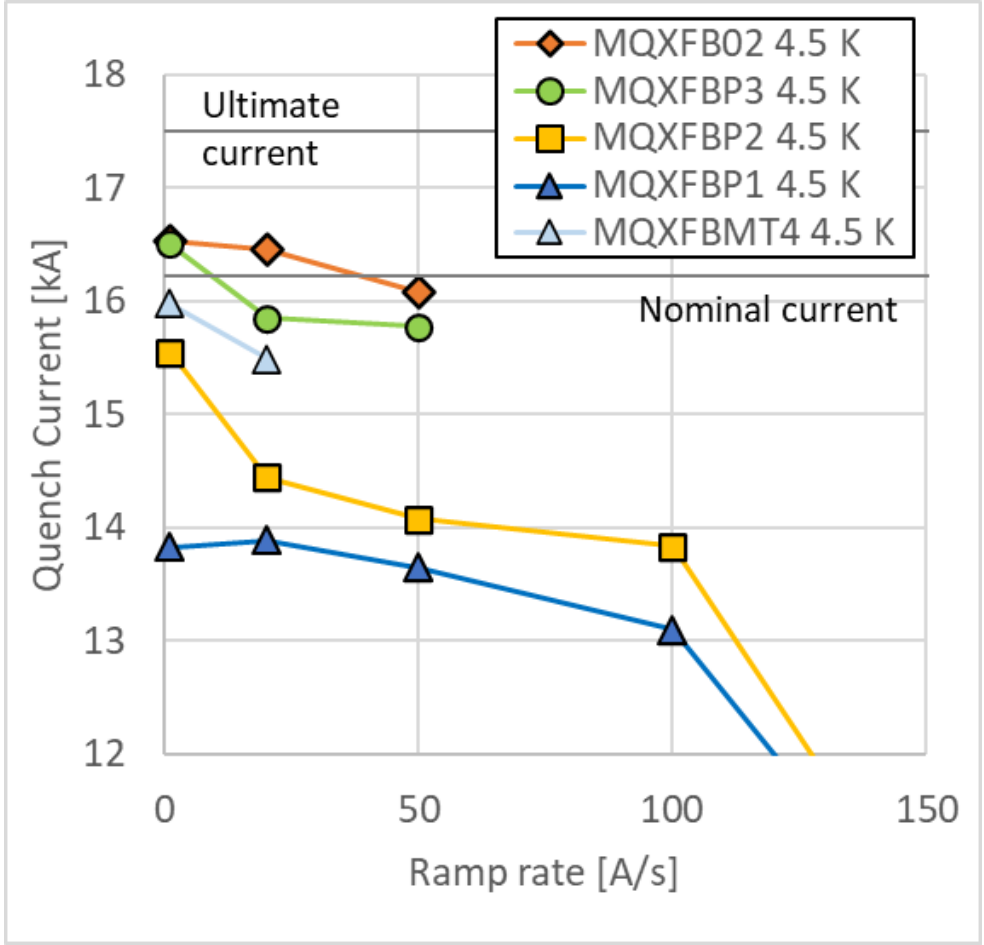
- V-I measurements analysis done in differential mode (P3 – P2, etc)
- Coil P3 shows a voltage buildup of around 7-10 uV at 16.9 kA



Conclusion MQXFBMT4

- The performance of the 3 earlier used coils was not impacted by reassembling them. No quenches in those coils.

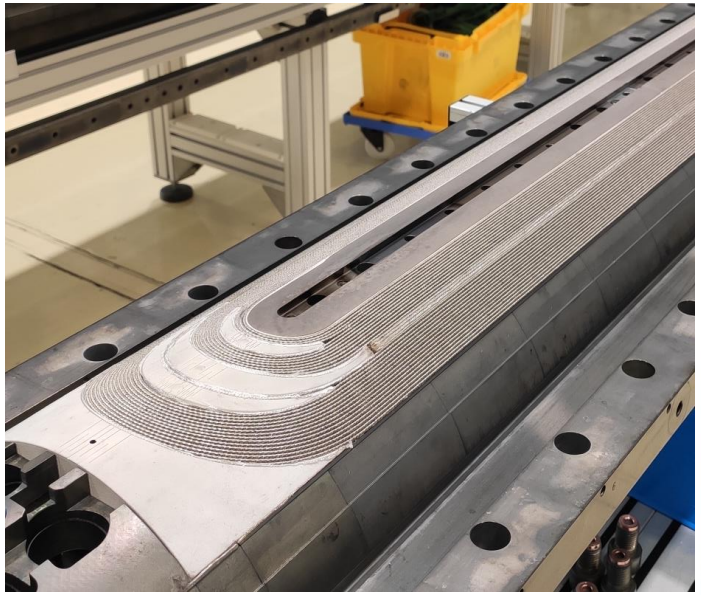
- The new coil (P3) showed a conductor degradation during training, 4.5 K performance limits and V-I measurements. The location was in the center of the magnet, identical to earlier prototypes.

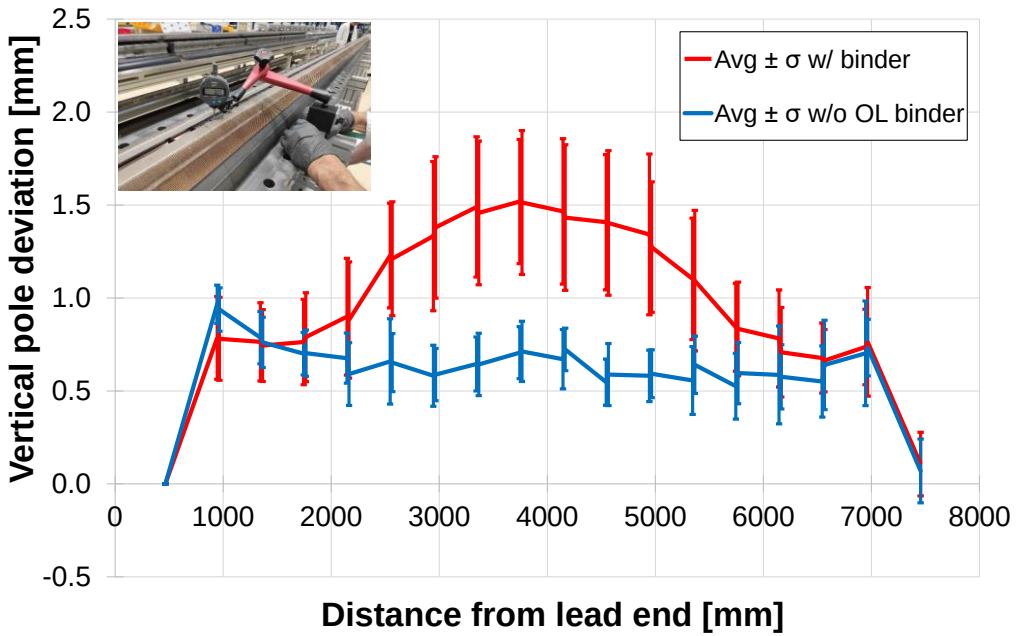


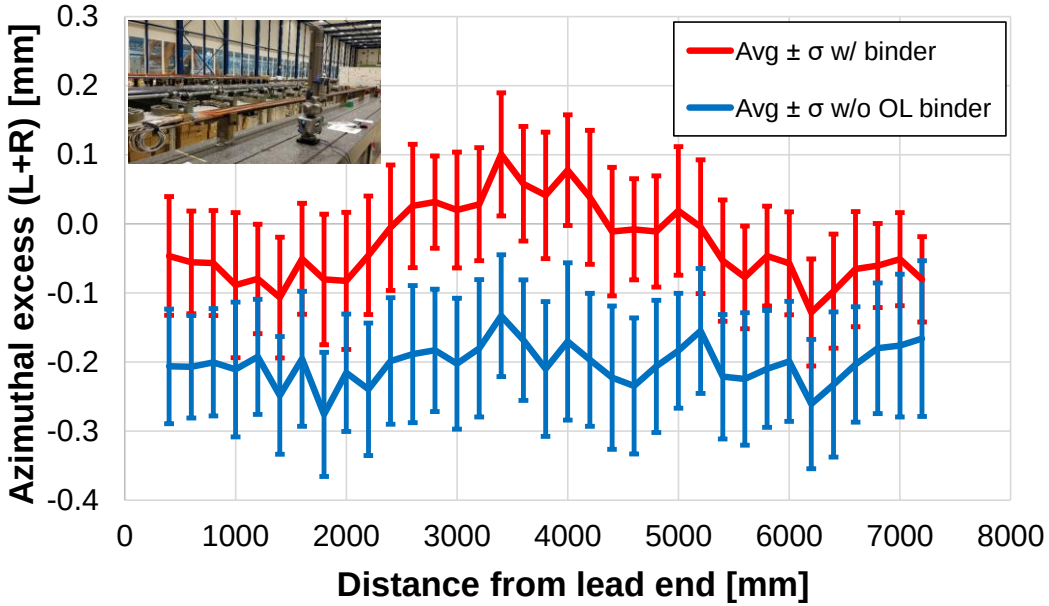
MQXFB03

MQXFB03 has new generation coils

- Modifications aimed at reducing the friction between coil and reaction mold
  - Pole gap increase
  - Partial compensation of the curing cavity
  - **Removal of the ceramic binder from the outer layer of the coil**
- New generation coil measurables point to a coil which is more ‘relaxed’ after RHT
  - No coil ‘hump’ after reaction
  - No bigger coil azimuthal size towards the middle after impregnation
  - More homogeneous torque required to close the impregnation fixture

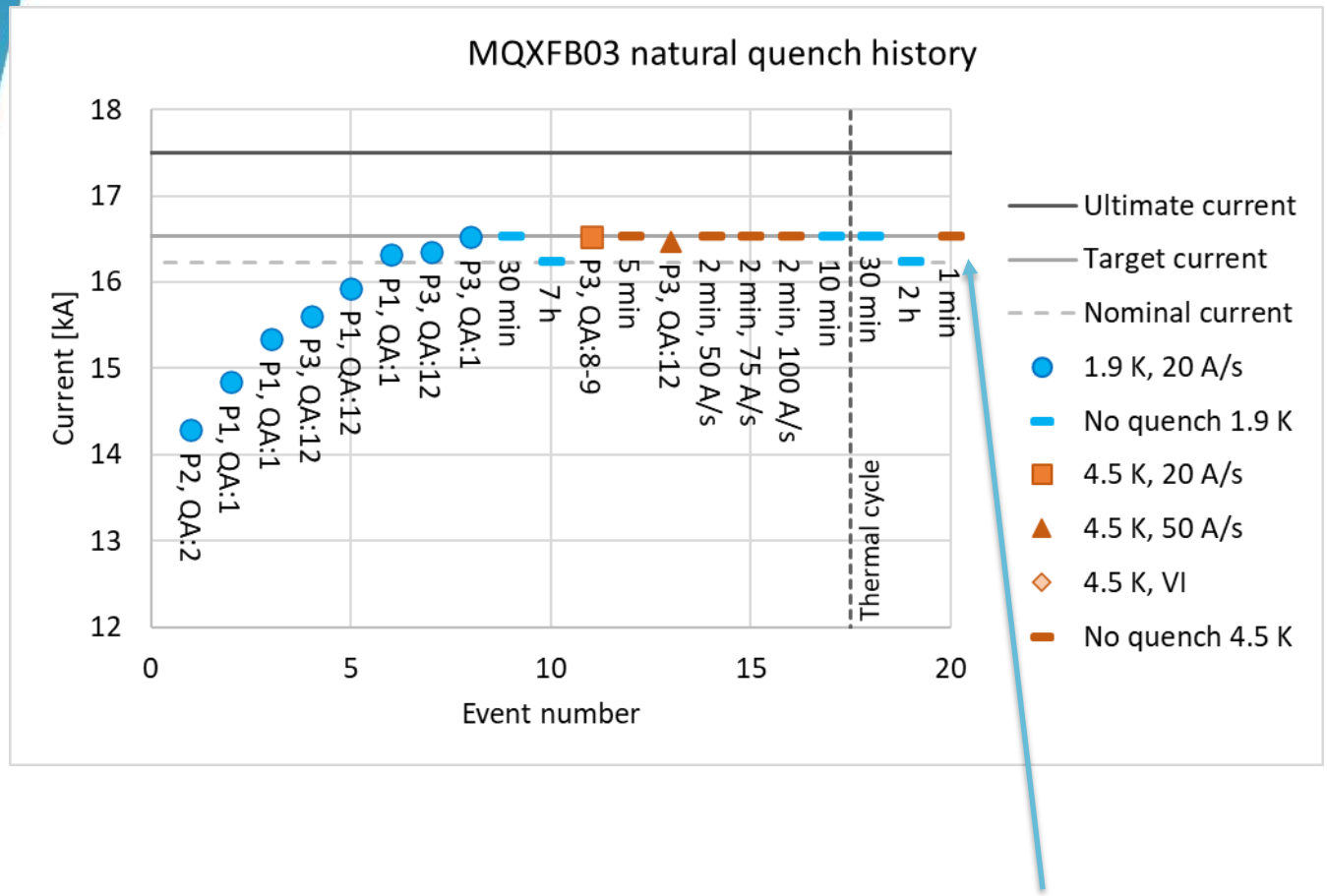






More details on Wednesday in the parallel session by Susana Izquierdo Bermudez

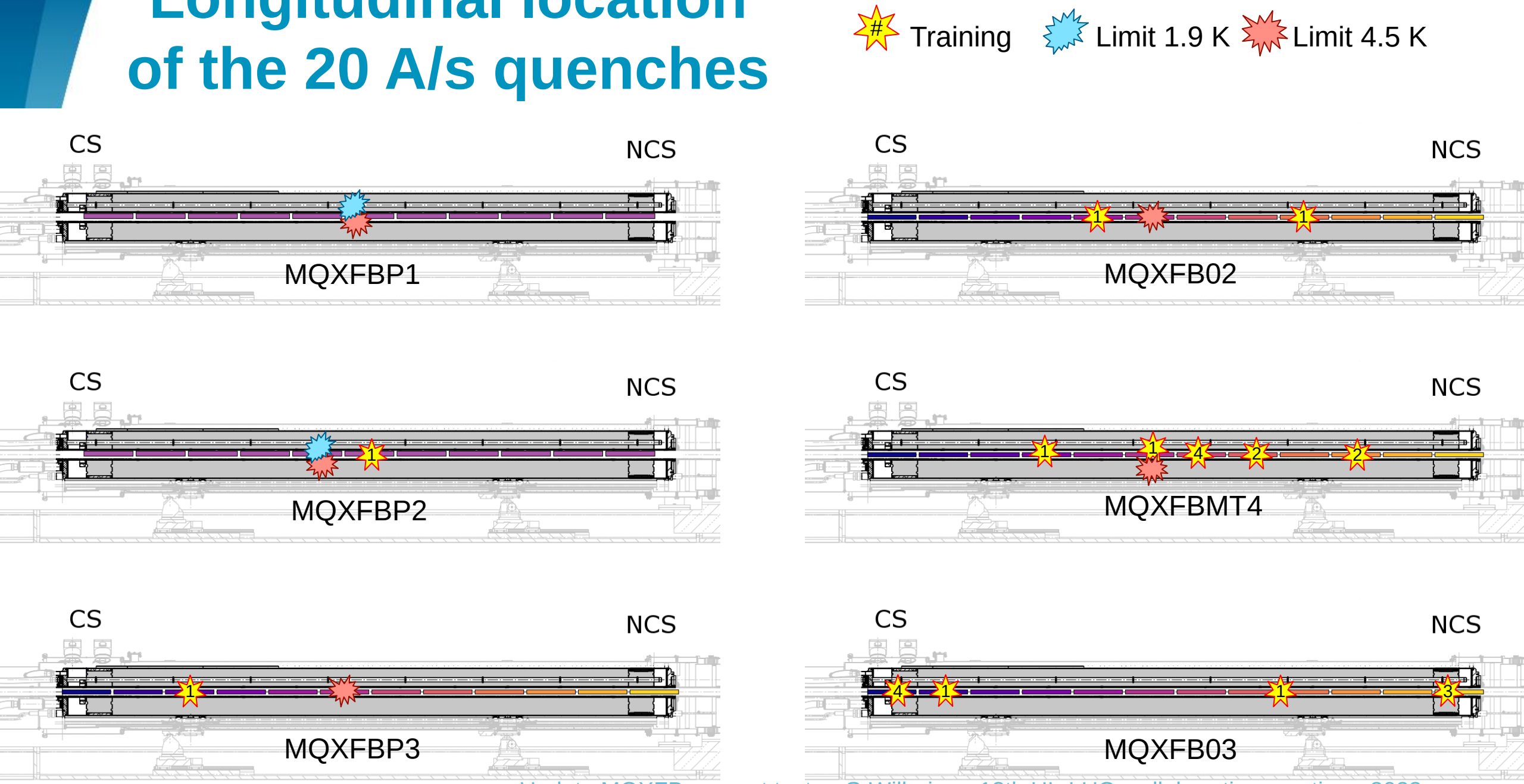
MQXFB03 quench plot



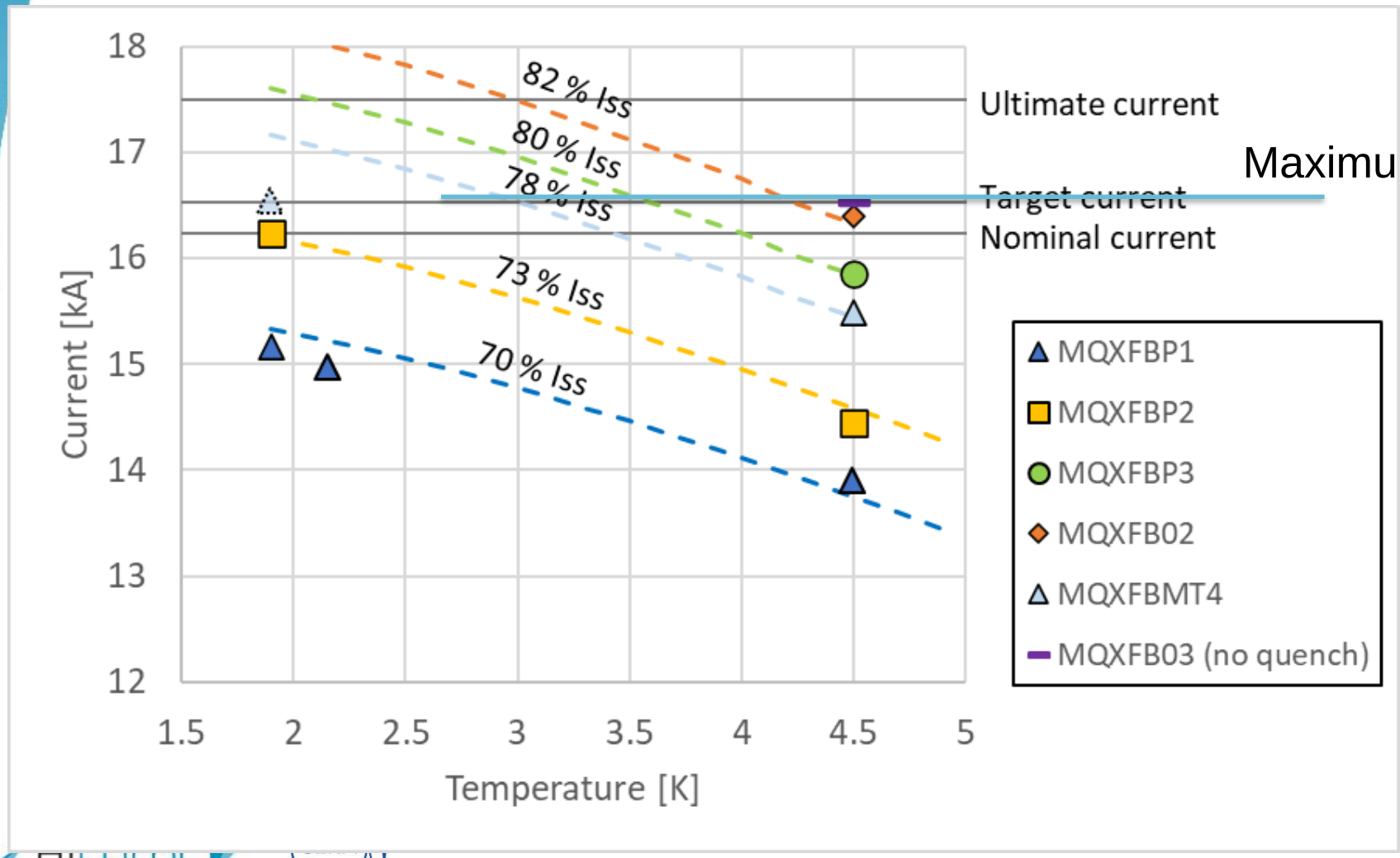
Fresh data point from last night at 02h25 (Pacific Time zone 😋)

- Quenches mainly in the head segments (QA 1 and 12)
- Slower training than the previous 4 magnets, but no quench after thermal cycles.
- The coils P2 and P4 that have a positive CLIQ current pulse experience no training. All training quenches (after the first CLIQ firing) are in P1 and P3. This is further confirmation of the statistical analysis done by S. Stoynev (FNAL).
- Second cool down had no quenches, including the ramp at 4.5 K, performed today.
- V-I measurements could not be performed since we did not manage stable cryogenic conditions at 4.5 K.

Longitudinal location of the 20 A/s quenches



Temperature dependency

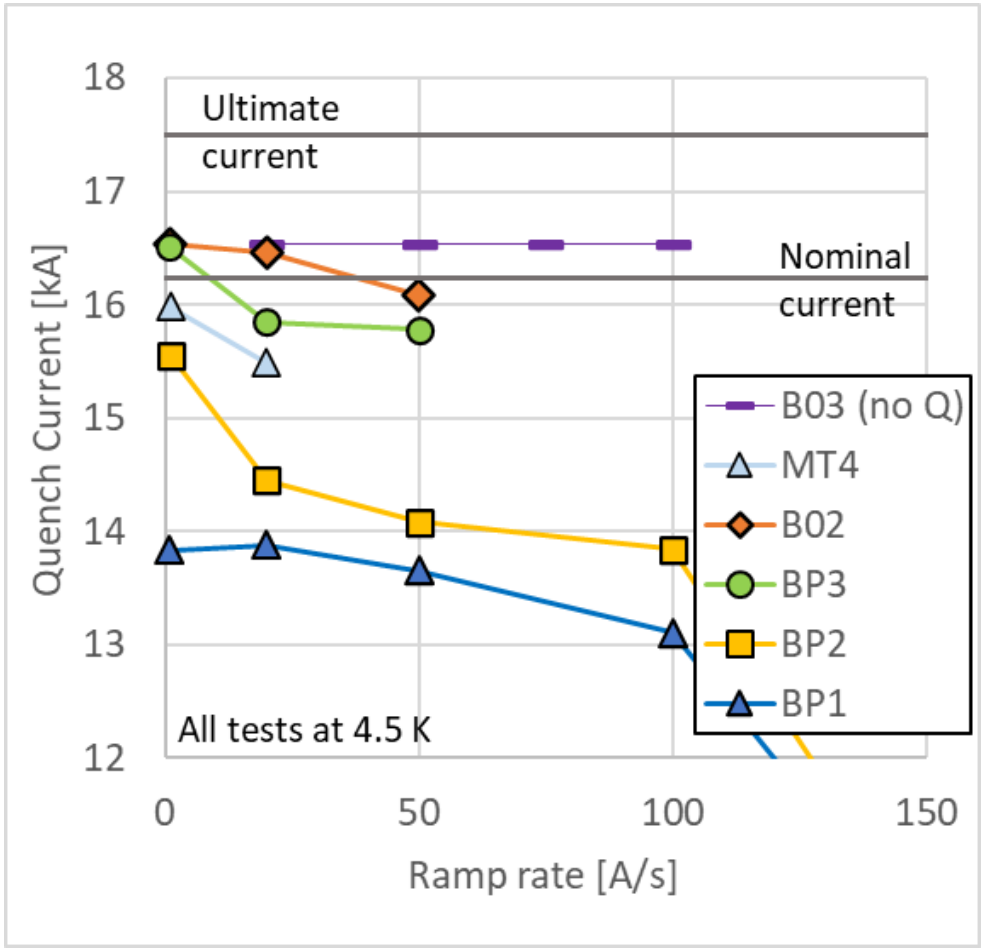


Maximum target current 16.53 kA (~82 %)

We can only test at 4.5 K up to ~82 % of short sample current.

The MQXFB03 shows **no signs of limitation** up to this level of 82 % and is the first magnet to reach target current of 16.53 kA at 4.5 K.

Ramp rate dependency, compared to previous magnets



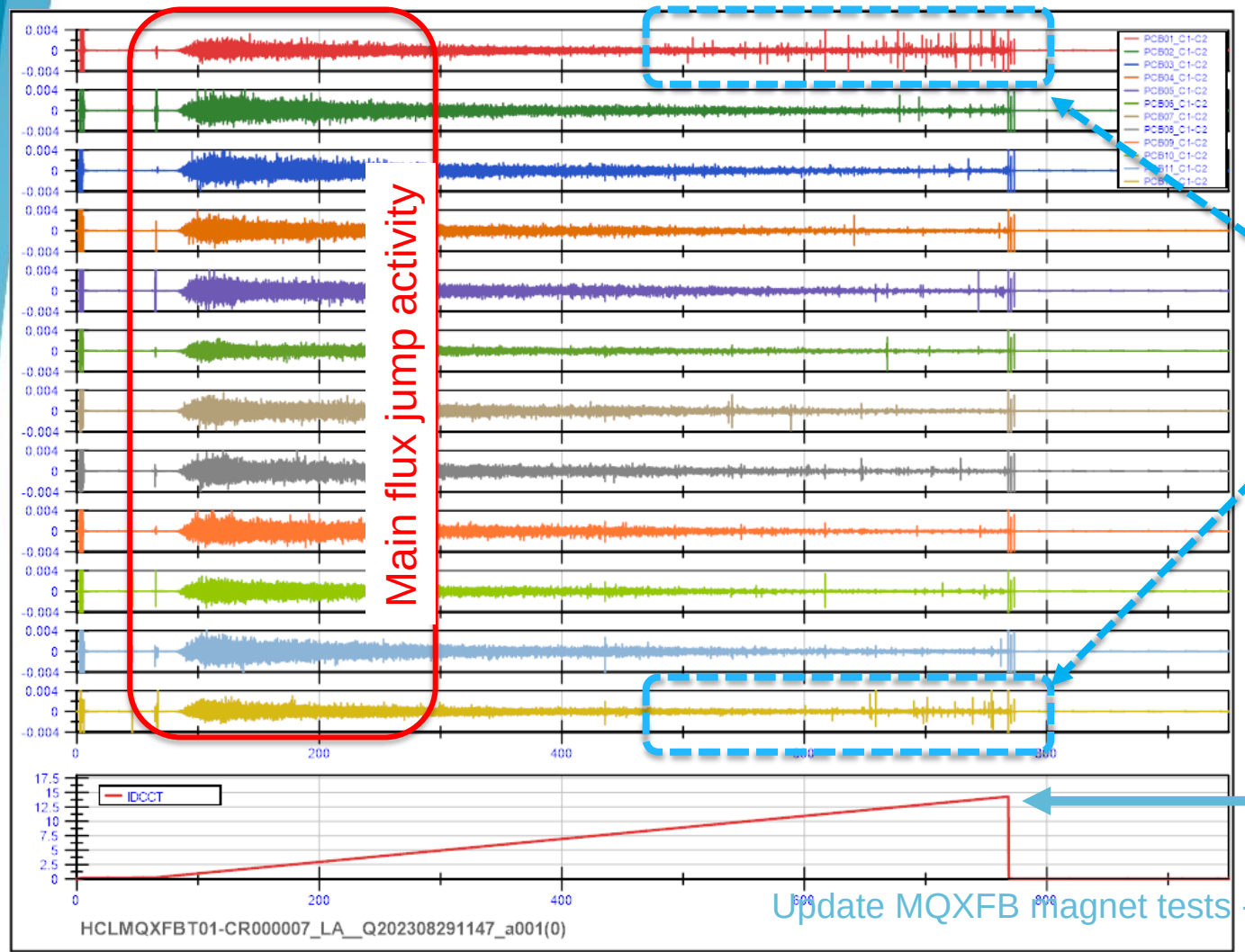
Even when increasing the ramp rate up to 100 A/s (therefore increasing the temperature in the coil to above 4.5 K due to losses) the MQXFB03 does not quench.

This shows that the margin is higher than shown in the previous plot.

Within the test limits (4.5 K, 100 A/s, 16.53 kA) the magnet shows no signs of instability and no performance limit.

MQXFB03 Precursors during ramp – first ramp in CD 1

Quench antenna containing 12 segments of 60 cm long each.

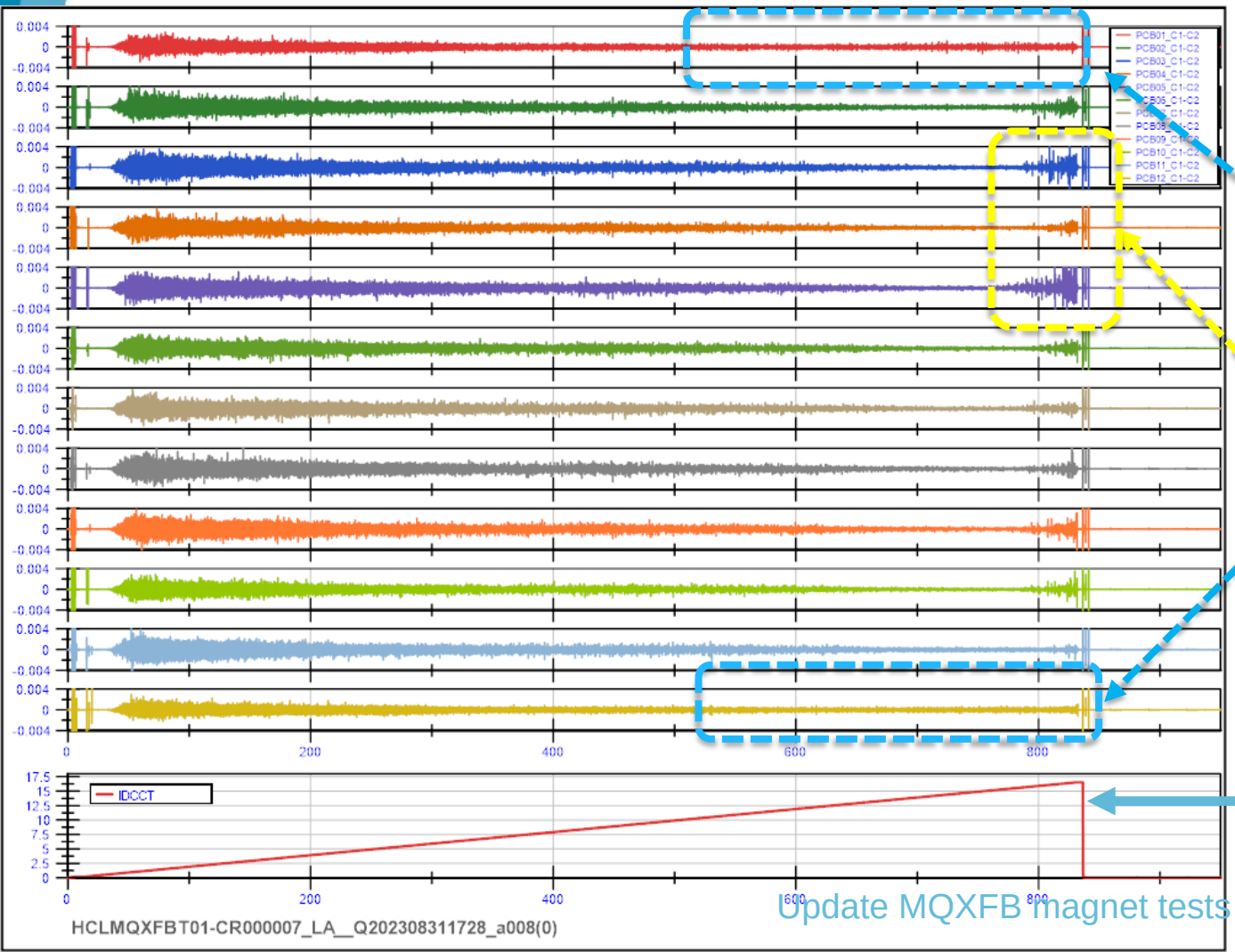


During first ramp to quench, the most precursor (motion) activity occurs in the magnet ends (segment 1 and 12).

First ramp to quench at 14.2 kA in CD 1

MQXFB03 Precursors during ramp – Fully trained magnet in CD 1

Quench antenna containing 12 segments of 60 cm long each.

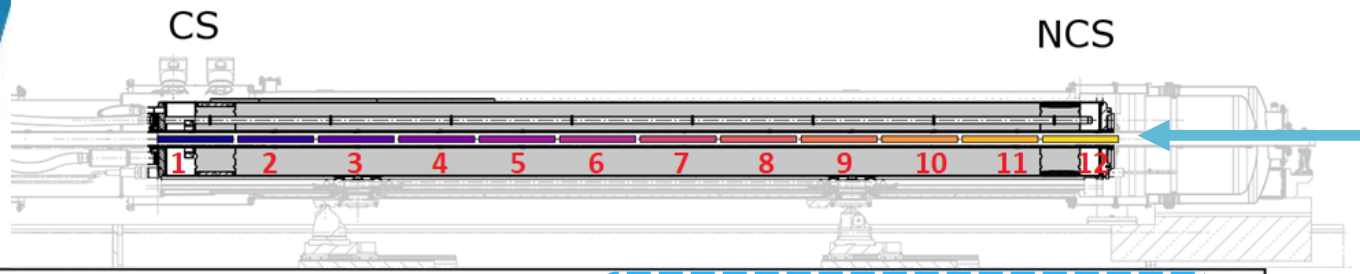


When fully trained (in the 8th ramp to quench) the magnet heads don't show activity anymore. This is an additional confirmation that the magnet is fully trained.

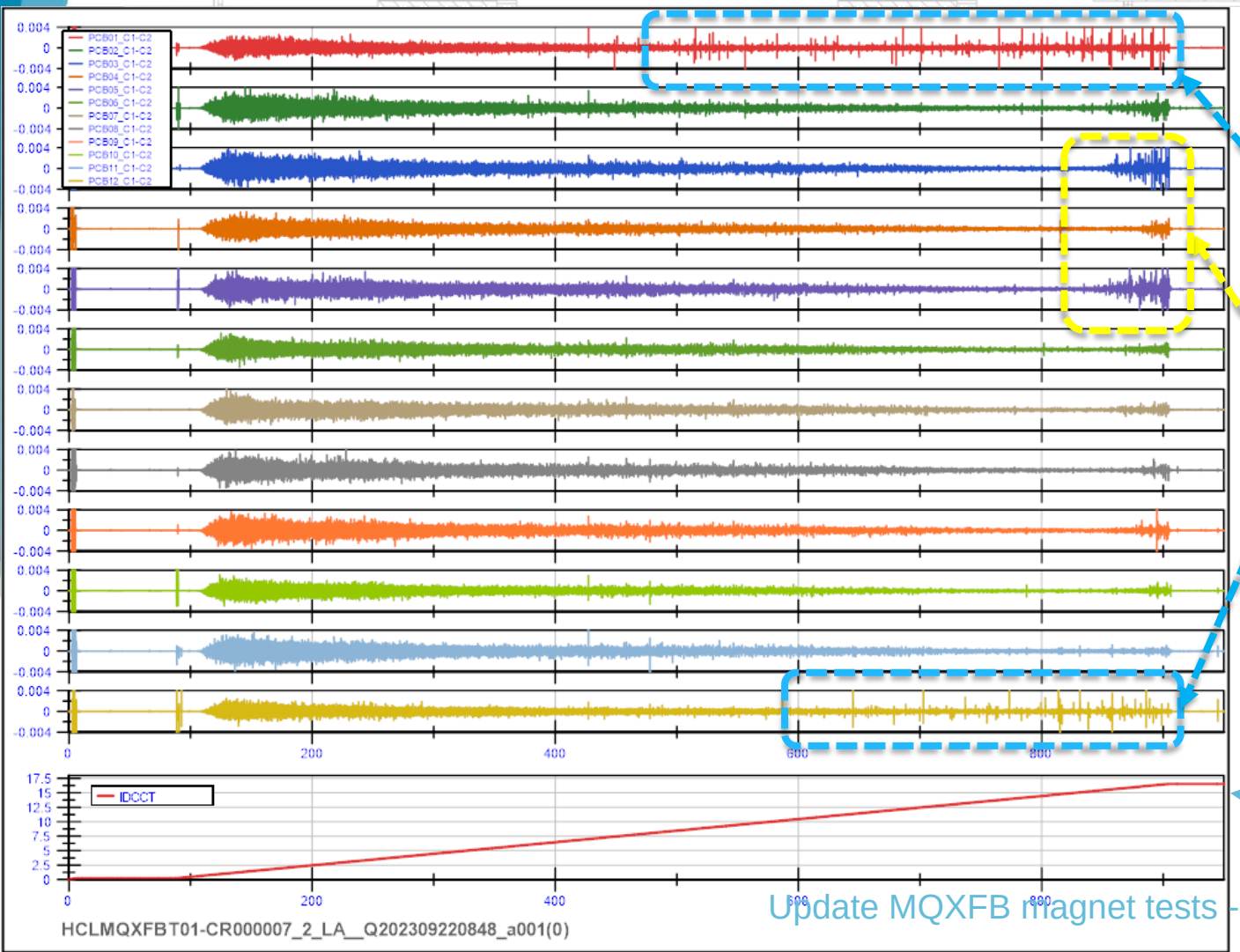
At high currents (>15 kA) we identify activity in the straight part of the magnet, with highest activities in segment 3 and 5. Very new data, not particularly worrying, but as foreseen monitoring will continue.

Ramp to full current, quench at full current. Magnet fully trained in CD1

MQXF03 Precursors during ramp – first ramp in CD 2



Quench antenna containing 12 segments of 60 cm long each.

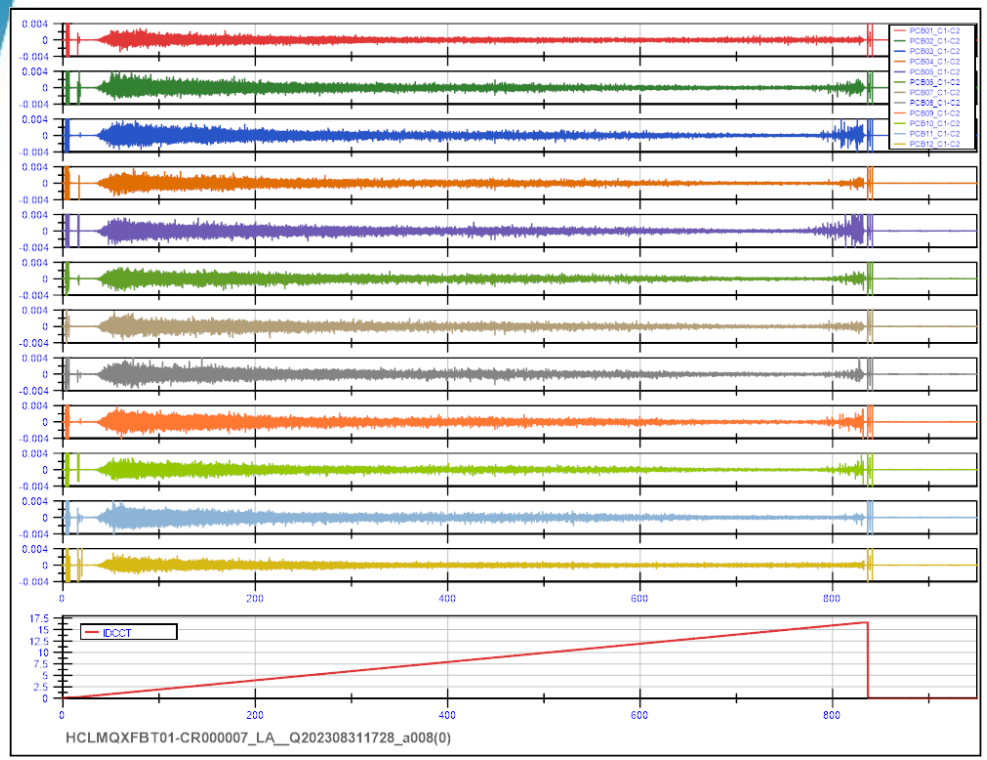


After thermal cycle, the first ramp shows again quite some activity in the magnet ends, already from around half the target current. However, none of the precursors lead to quench.

At high currents (>15 kA) activity in the straight part of the magnet still persists, also in the second cool down.

First ramp in CD 2, reaching target current at 16.53 kA.

MQXFB03 Precursors during ramp



Note:
Precursors during ramp are studied since long time in magnets.

Precursor activities shown here are for a perfectly stable magnet.

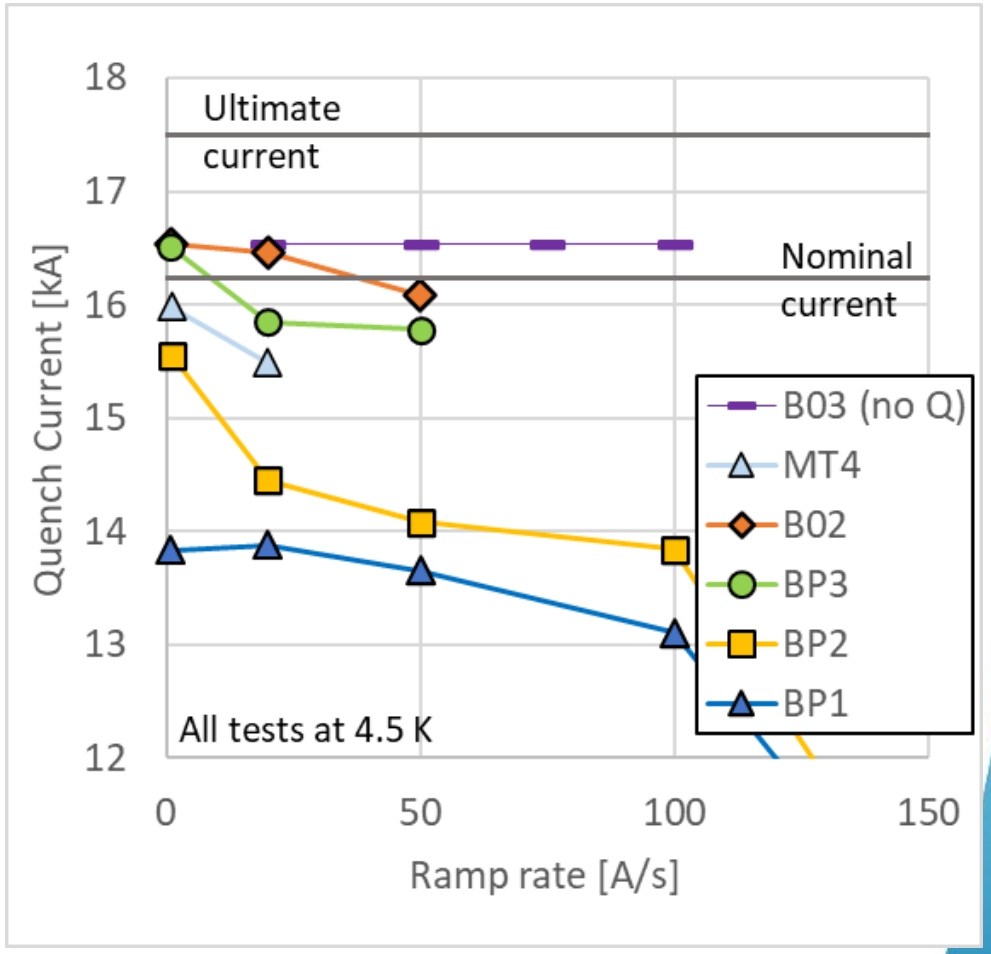
We will monitor them for future magnets too, for comparison.

Conclusions MQXFB03

We can only test at 4.5 K up to ~82 % of short sample current.

The MQXFB03 shows no signs of limitation up to this level of 82 % and is the first magnet to reach target current of 16.53 kA at 4.5 K, even at 100 A/s

With training only in the magnet ends and no sign of performance limits, it shows a very *different performance signature* as all previous MQXFB and even MQXFS magnets that were tested before.



Thank you

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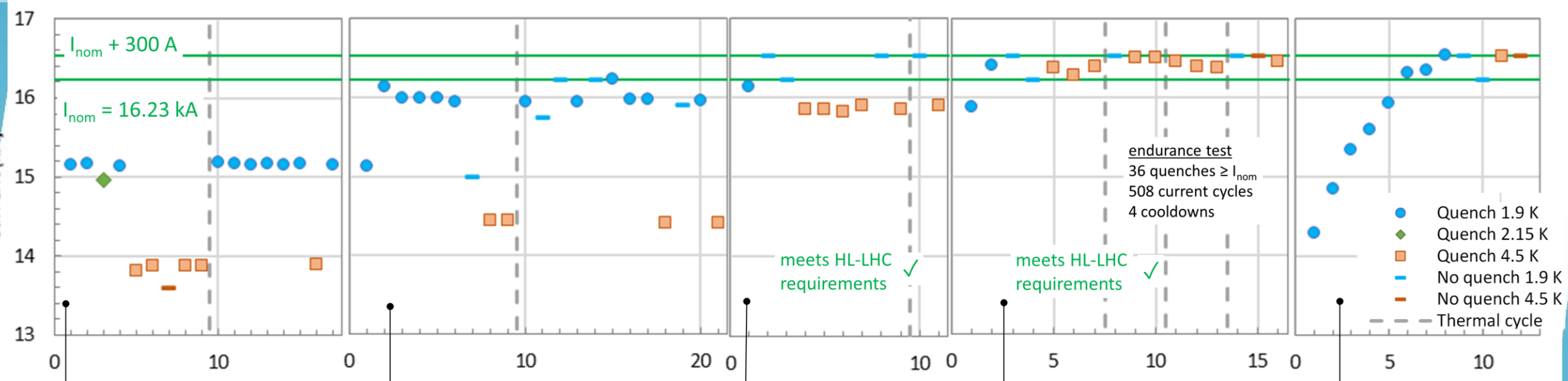

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reached target at 1.9 K
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