Test results of MQXF series magnets at CERN

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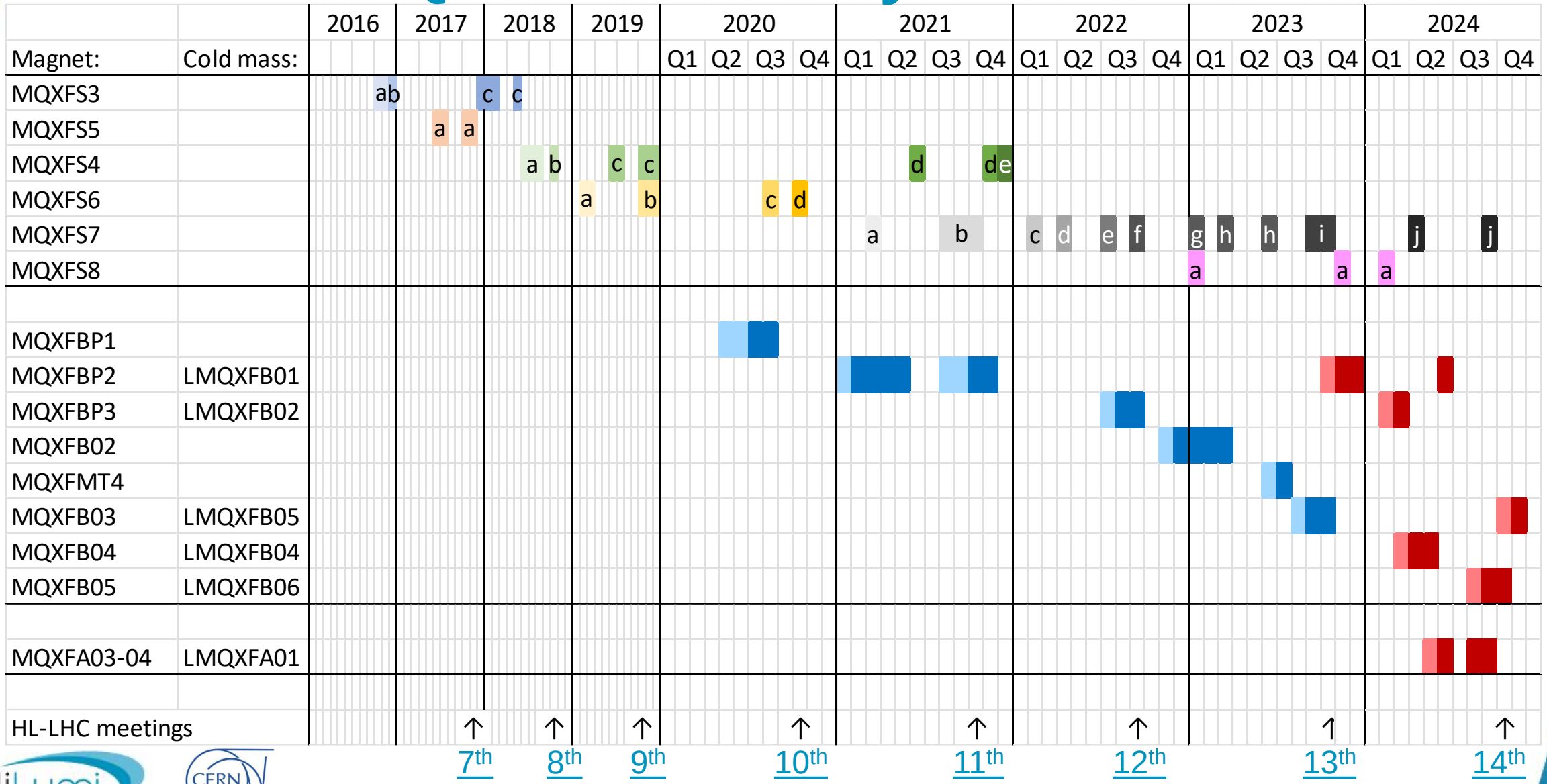
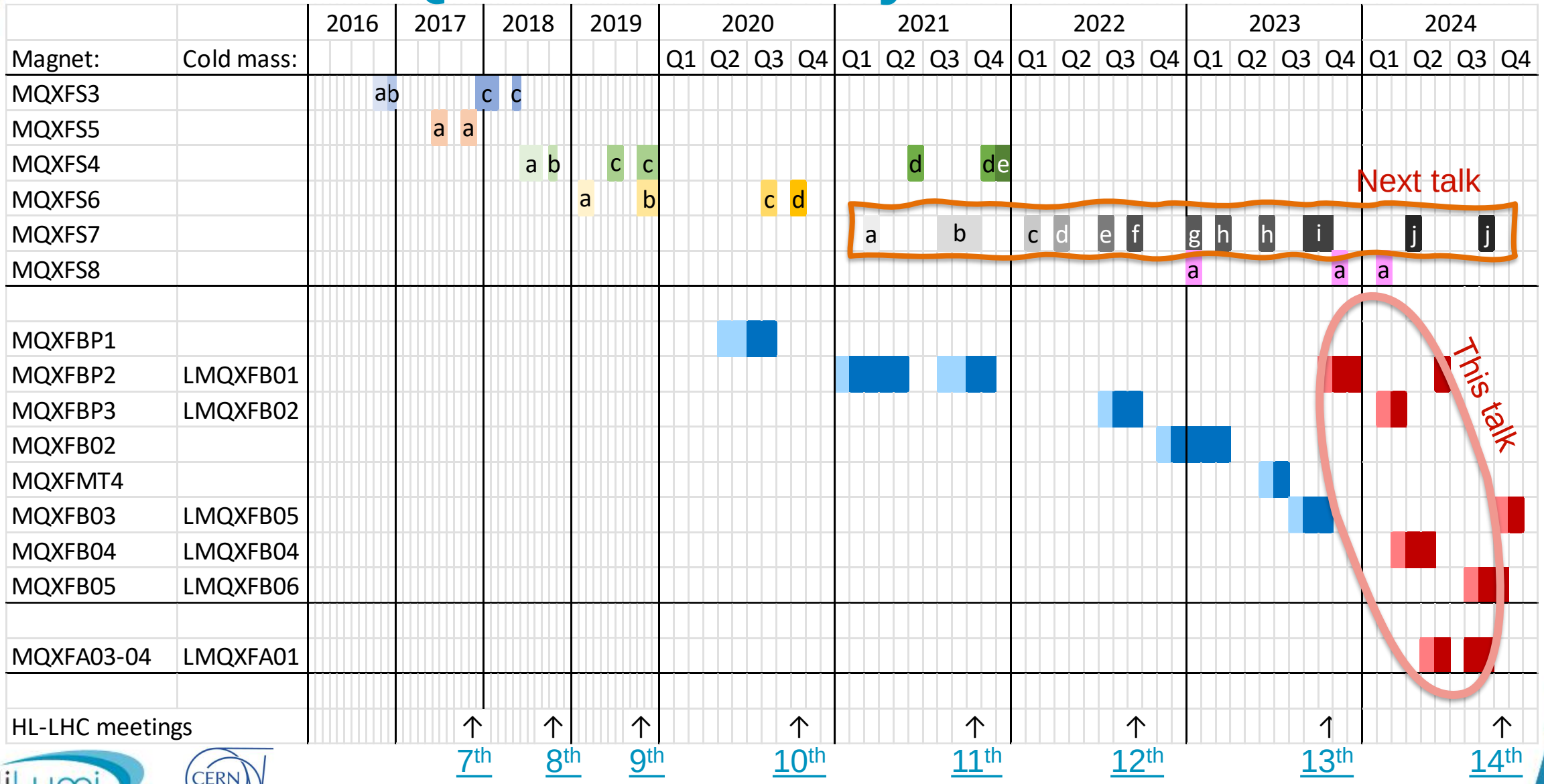
2024.10.08

MQXF test history at CERN



MQXF test history at CERN



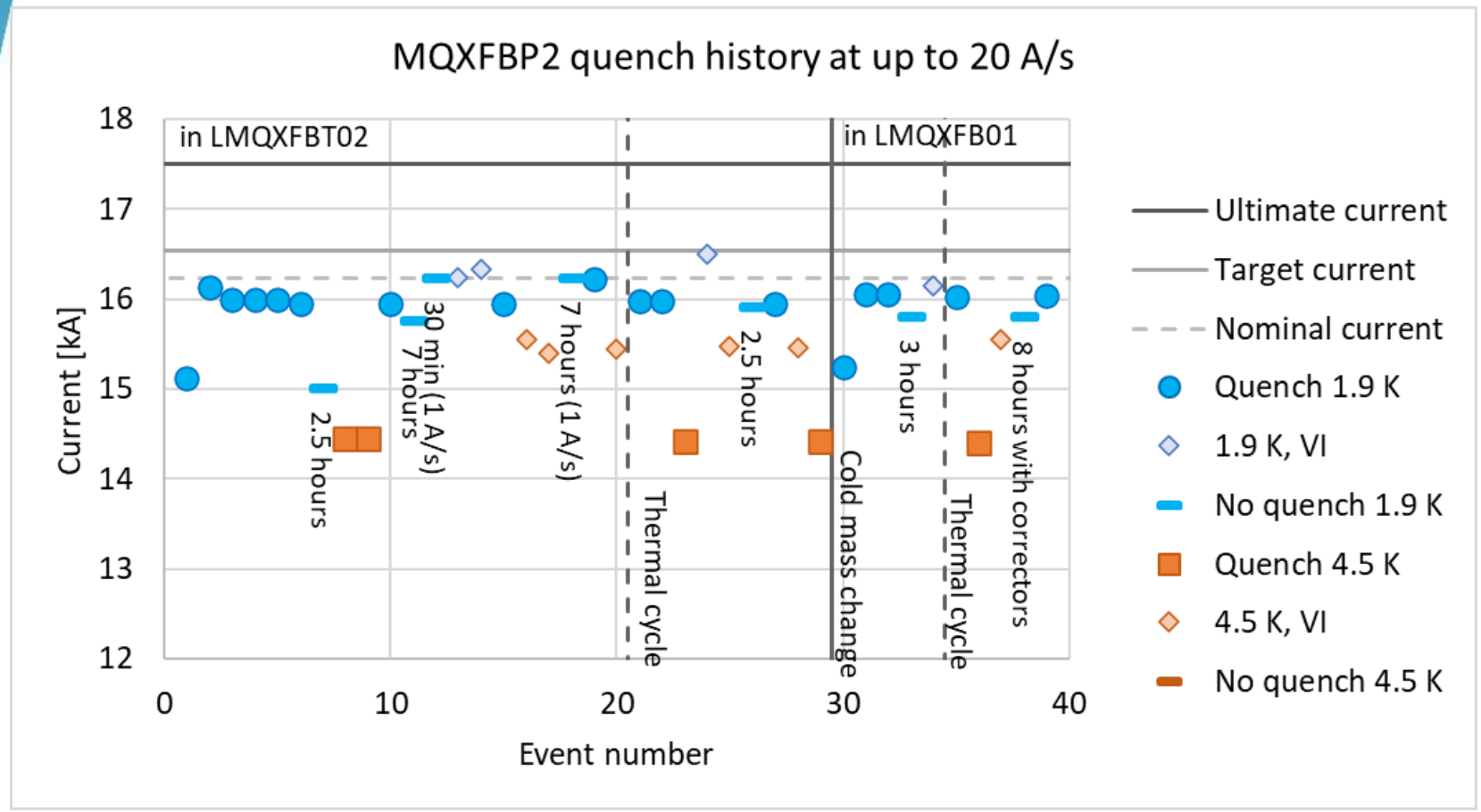
Overview of these five cryomagnets

- Q2b LMQXFB01 (with MQXFBP2)
  - Quench performance: as during standalone test
  - NC: short to ground in busbar (repaired)
- Q2a LMQXFB02 (with MQXFBP3)
  - Quench performance: as during standalone test
  - NC: short QH to coil during 100 K HV test
- Q2b LMQXFB04 and Q2a B06 (with MQXFB04 and B05 respectively)
  - Virgin magnets, good quench performance
  - No NC
- Q3 LMQXFA01 (with MQXFA03 and MQXFA04)
  - Quench performance: quenches during long flat-top
  - NC: leak from cold mass circuit (incl. test station) towards vacuum

LMQXFB01

Q2b with MQXFBP2 and MCBXFBP1e

MQXFBP2 quench plot

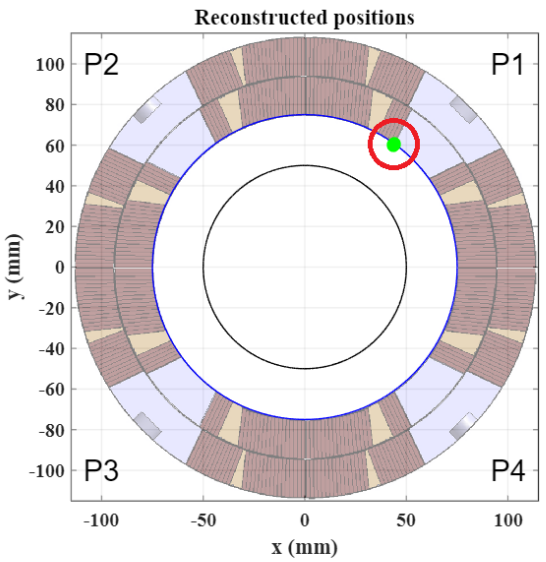


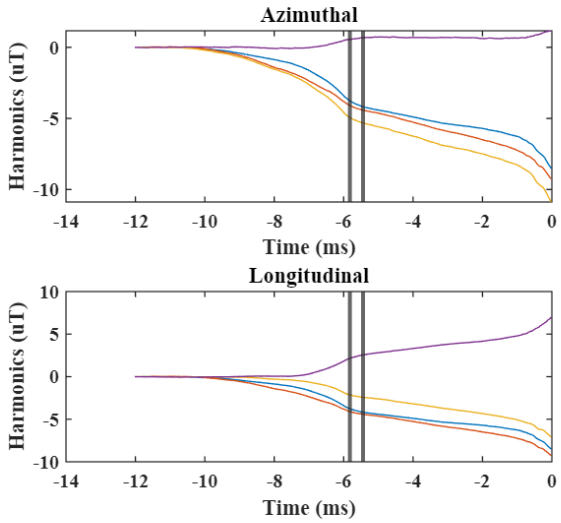
The magnet behavior is the same as it was during the standalone test

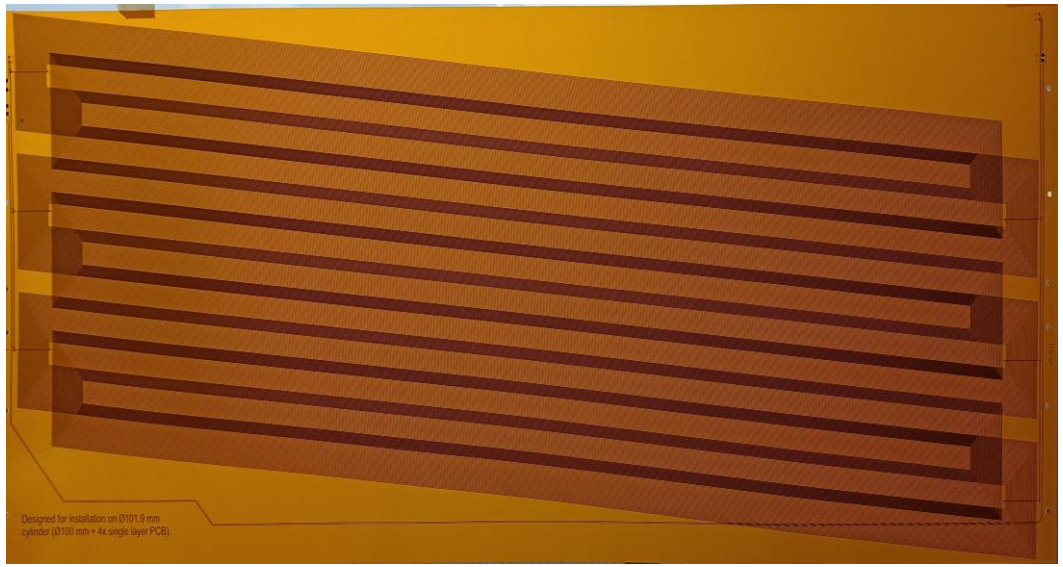
Quench level at 1.9 K, 20 A/s: 16.0 kA

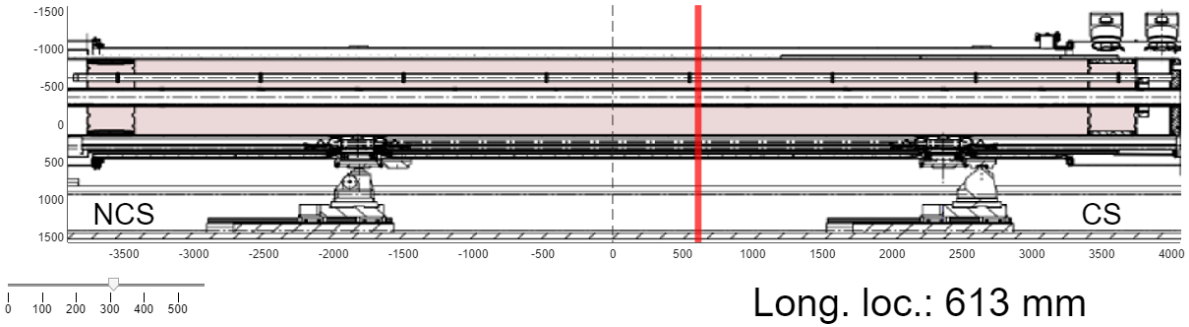
Quench level at 4.5 K, 20 A/s: 14.4 kA

MQXFBP2 quench localization with helical quench antenna

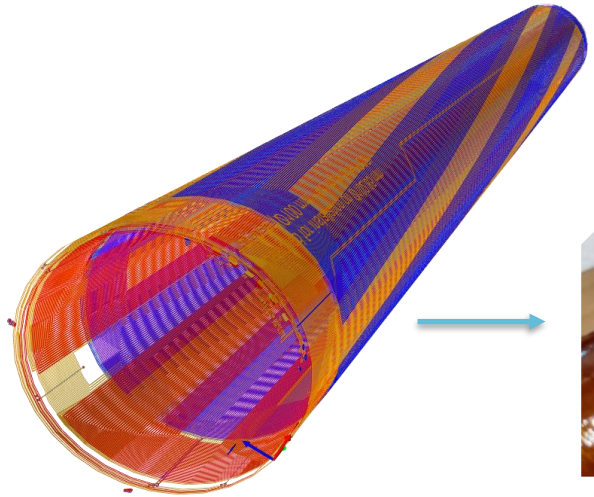


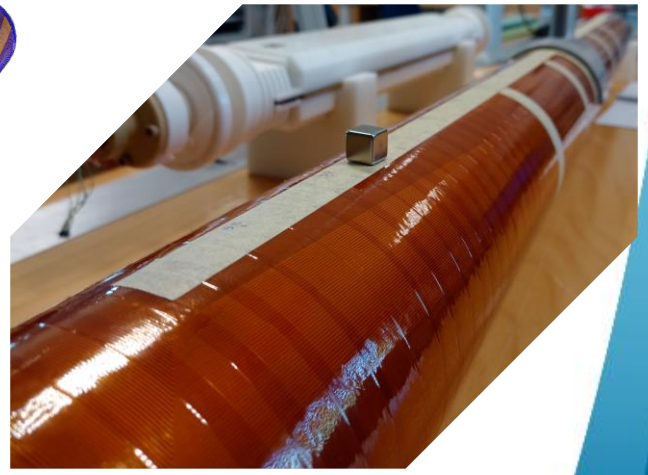






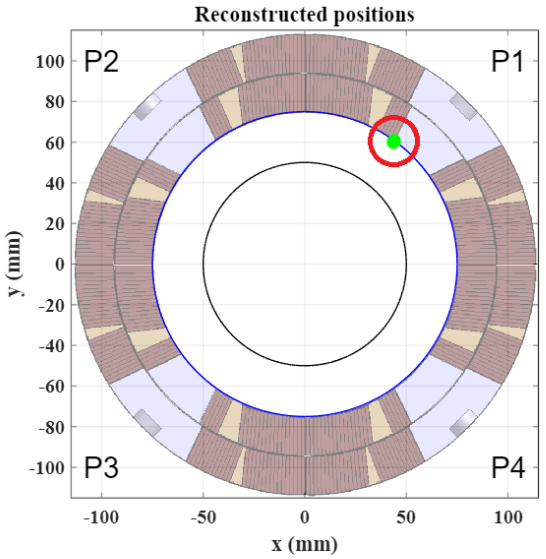
Long. loc.: 613 mm

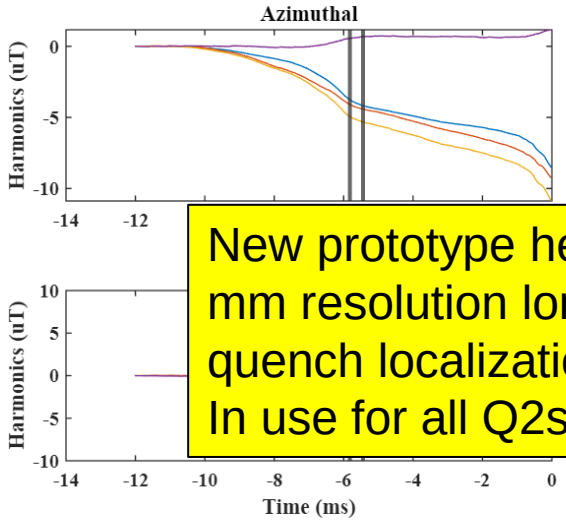


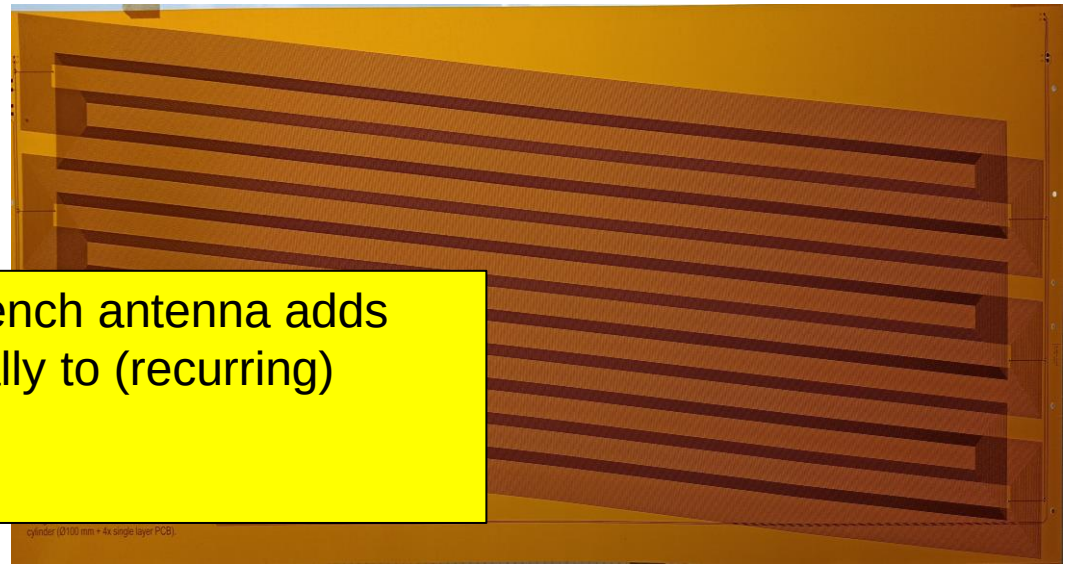


See: https://indico.cern.ch/event/1445929/

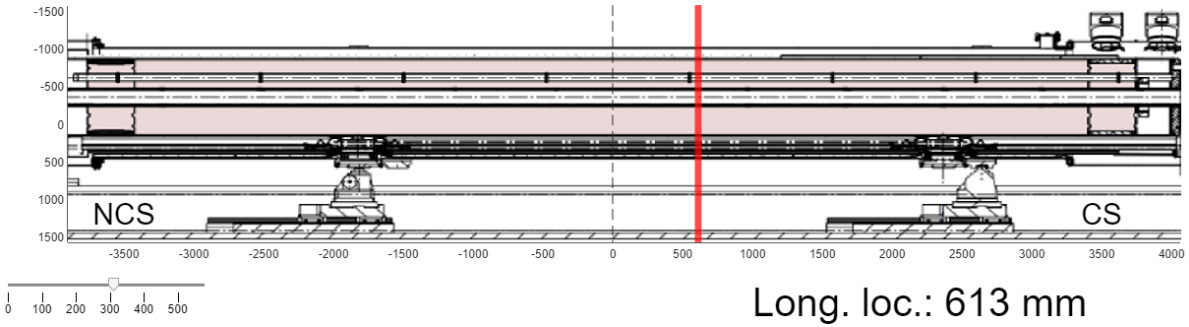
MQXFBP2 quench localization with helical quench antenna



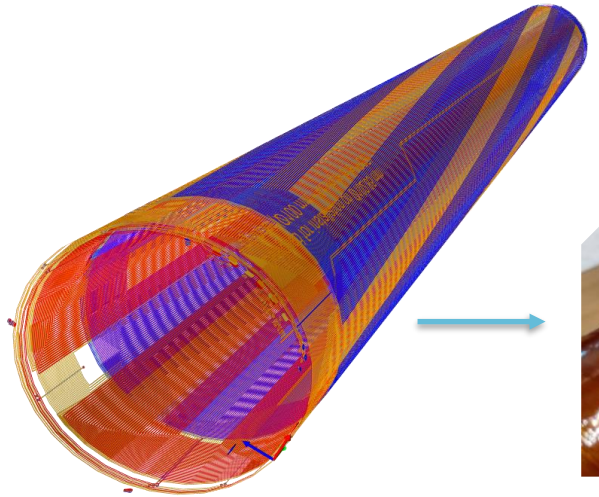


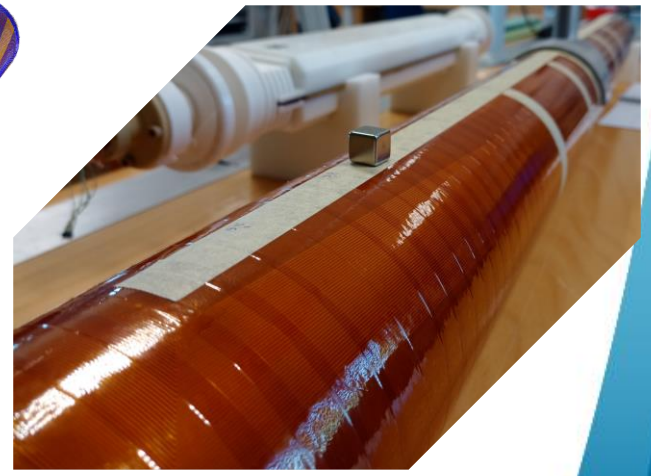


New prototype helical quench antenna adds mm resolution longitudinally to (recurring) quench localization.
In use for all Q2s and Q3.



Long. loc.: 613 mm

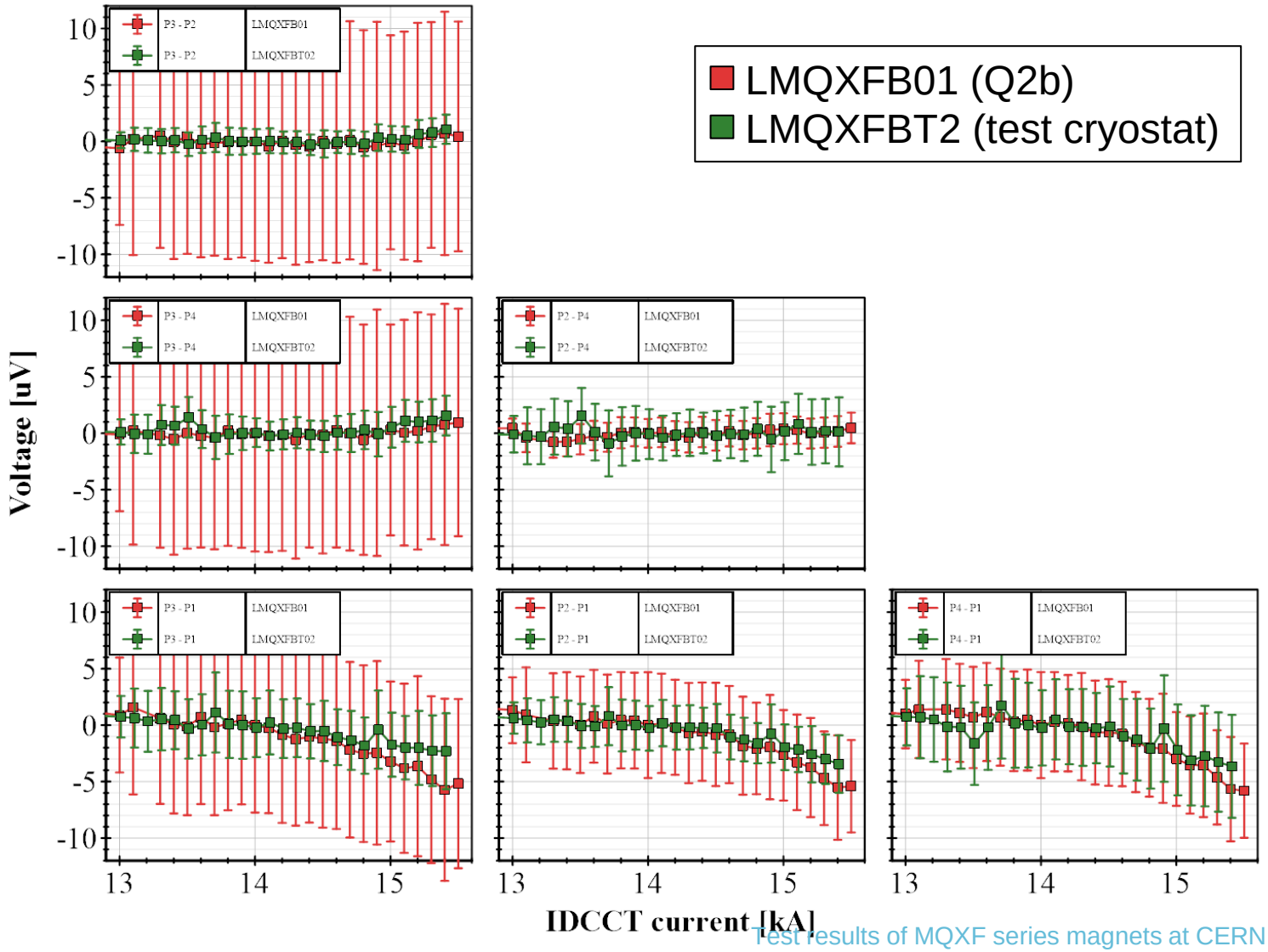




See: https://indico.cern.ch/event/1445929/

MQXFBP2 VI measurements at 4.5 K

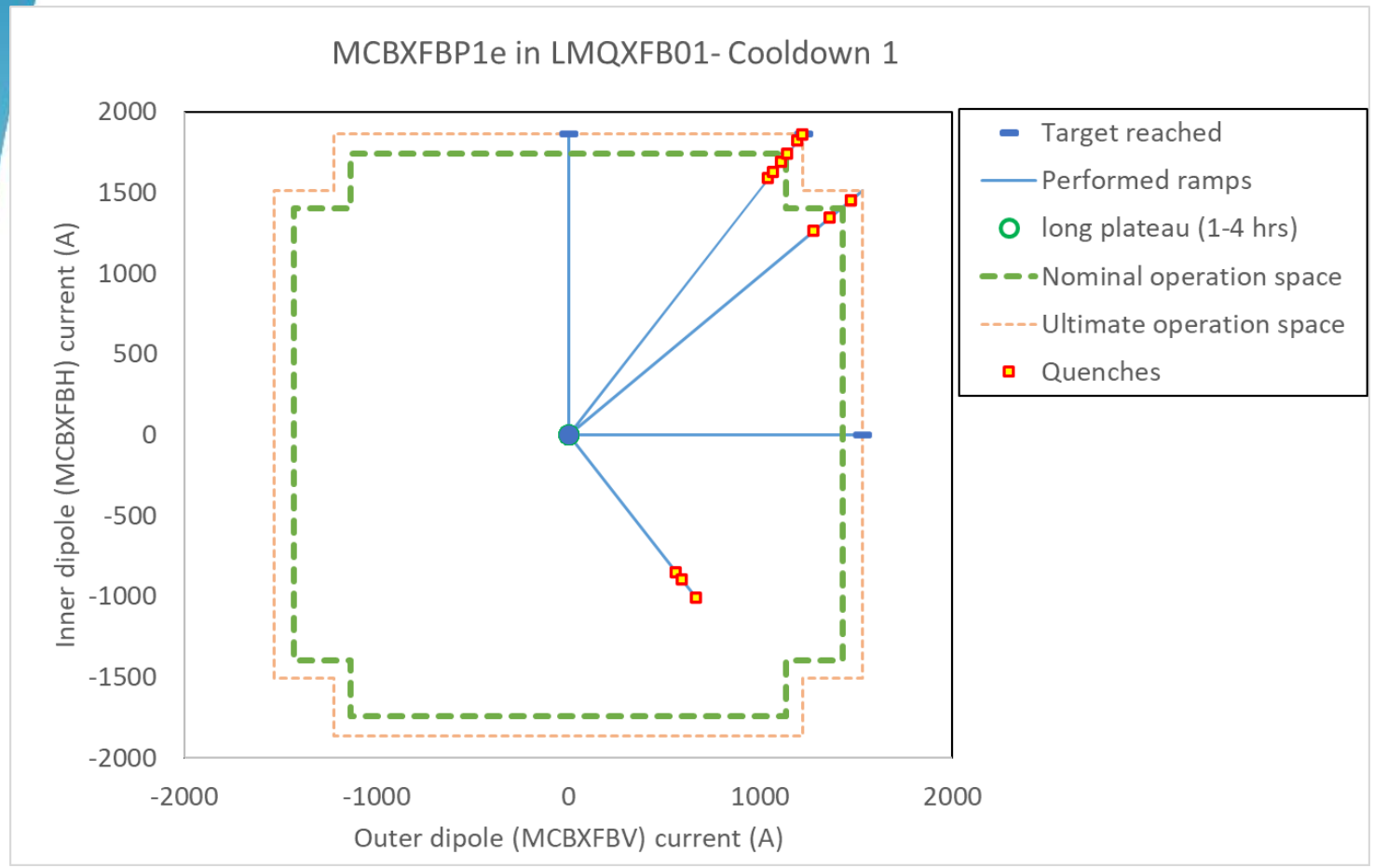
Files: HCLMQXFB001-CR000001_2__20240620124655__4.5K
MQXFBP02_3__20211026082240__4.5K



Measurements rather noisy but the transition is visible in the bottom row
(P3-P1, P2-P1, P4-P1)

This matches what we've seen in standalone configuration

MCBXFBP1e quench plot – nominal ramp rate



- MCBXFBP1e performs very similar to MCBXFBP1d during its vertical test
- Two nominal current combinations reached in the first quadrant. Three quenches in the fourth quadrant.

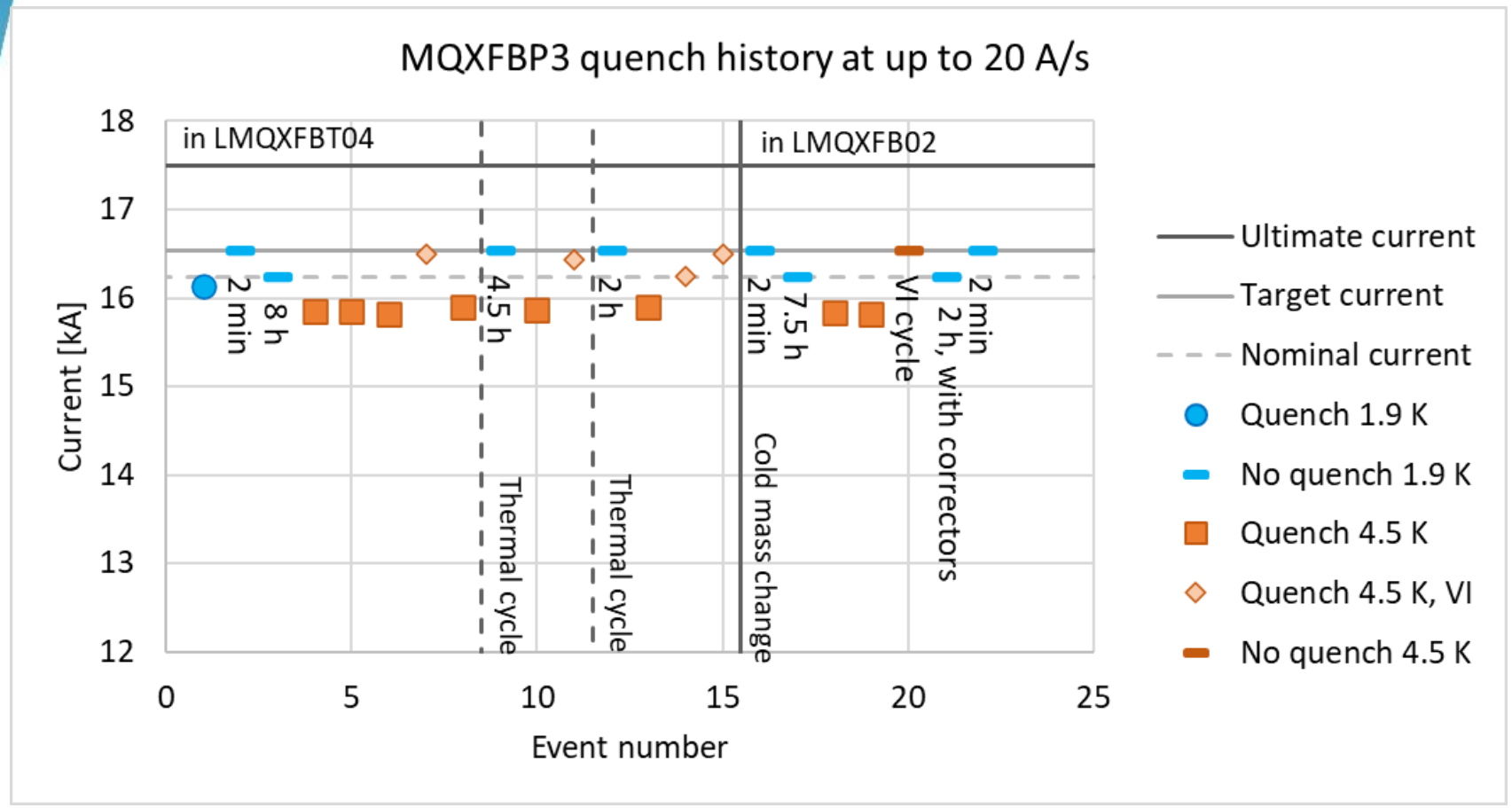
NC: Ground fault in the MQXFB circuit

- A ground fault in the MQXFB circuit was found after a few days of testing and quenches.
- The magnet was warmed up, endoscopy revealed a weak point in the busbars in front of the magnet
- The cold bore was removed, the busbar insulation was improved
- During the second cool down no further defect was found
- NCR: https://edms.cern.ch/document/3012323

LMQXFB02

Q2a with MQXFBP3 and MCBXFBP2d

MQXFBP3 quench plot



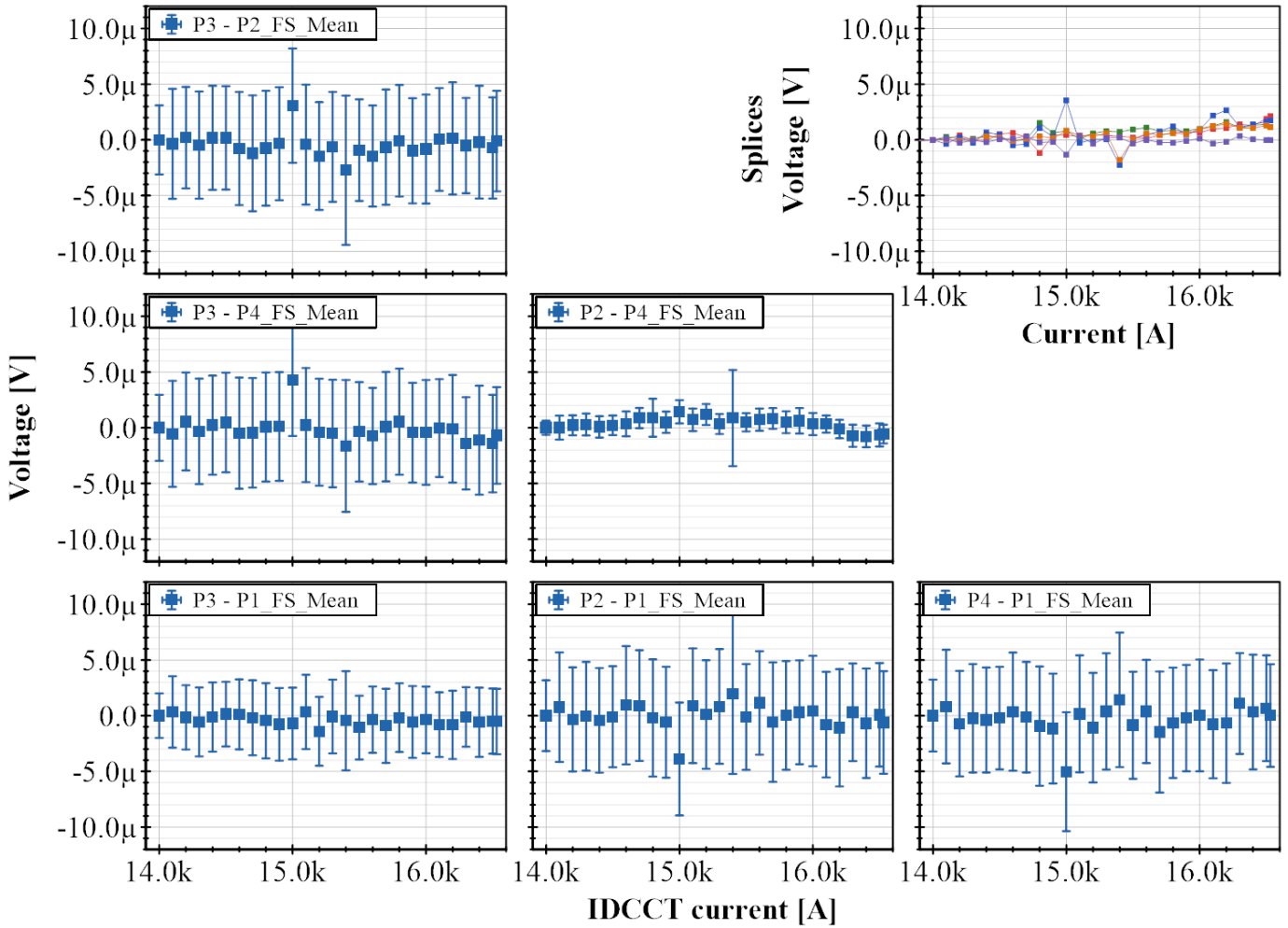
The magnet behavior is the same as it was during the standalone test

At 1.9 K, 20 A/s: reached target current

Quench level at 4.5 K, 20 A/s: 15.8 kA

MQXFBP3 VI measurements at 4.5 K

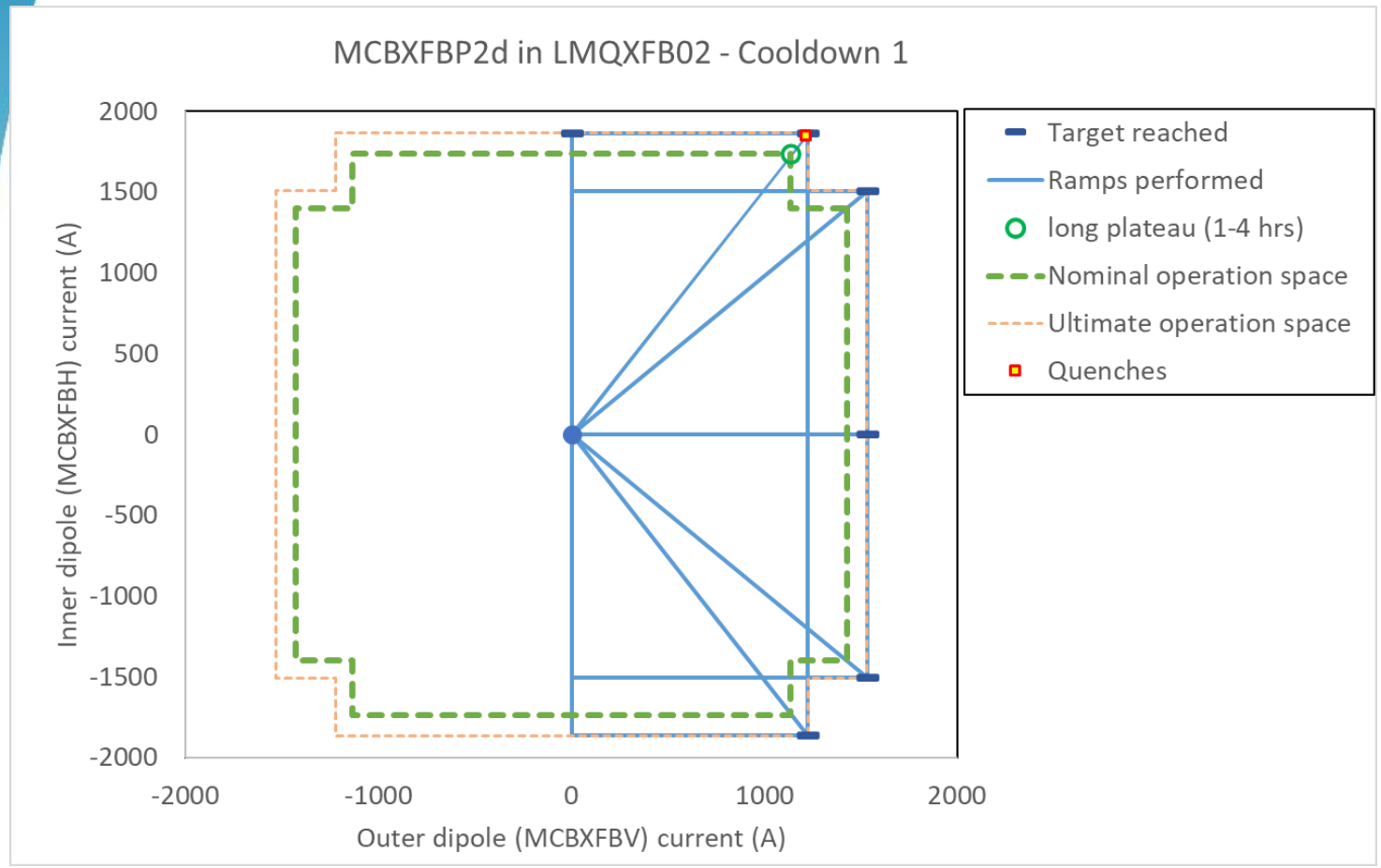
File: HCLMQXFB001-CR000002__J20240304090628__Splice-VI



Measurements rather flat, no indication of superconducting to normal transition

Same situation as we observed in the standalone test

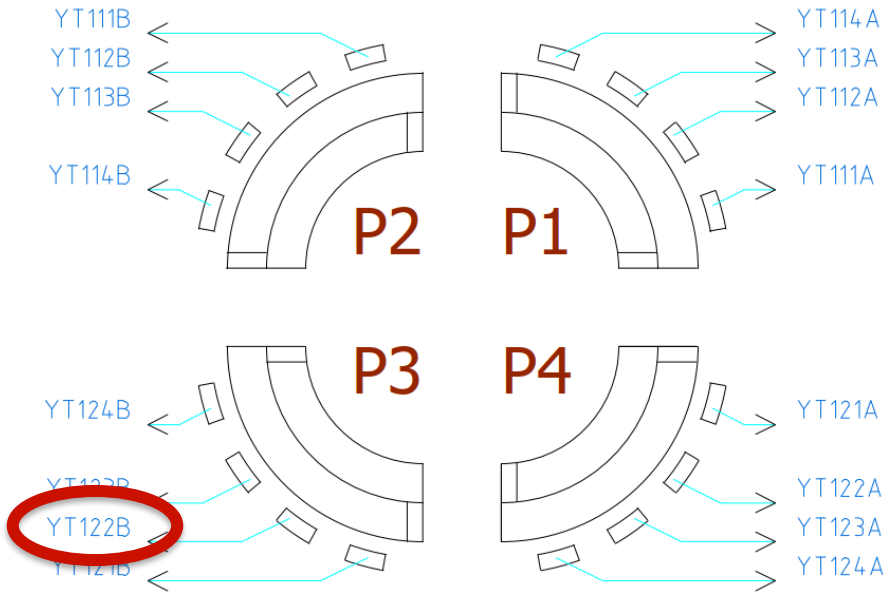
MCBXFBP2d quench plot



- MCBXFBP2d only had one quench, almost at ultimate current
- No quenches when changing polarity
- Overall similar behavior as during the vertical test

NC: QH to coil fault during HV test at 100 K

- HV test at 100 K results at 850 V:
  - MQXFB+QH vs Ground: OK
  - MQXFB vs Ground+QH: OK
  - QH vs MQXFB+Ground: breakdown
- Further investigation localized the fault between QH YT122 B terminal and coil P3, the last breakdown at 450 V.
- QH YT122 was disconnected at the level of the IFS to avoid using it during operation.
- Proposal to *use as is* in the IT String, and test procedure changed to reduce risk of overvoltage
- NCR: https://edms.cern.ch/document/3069797



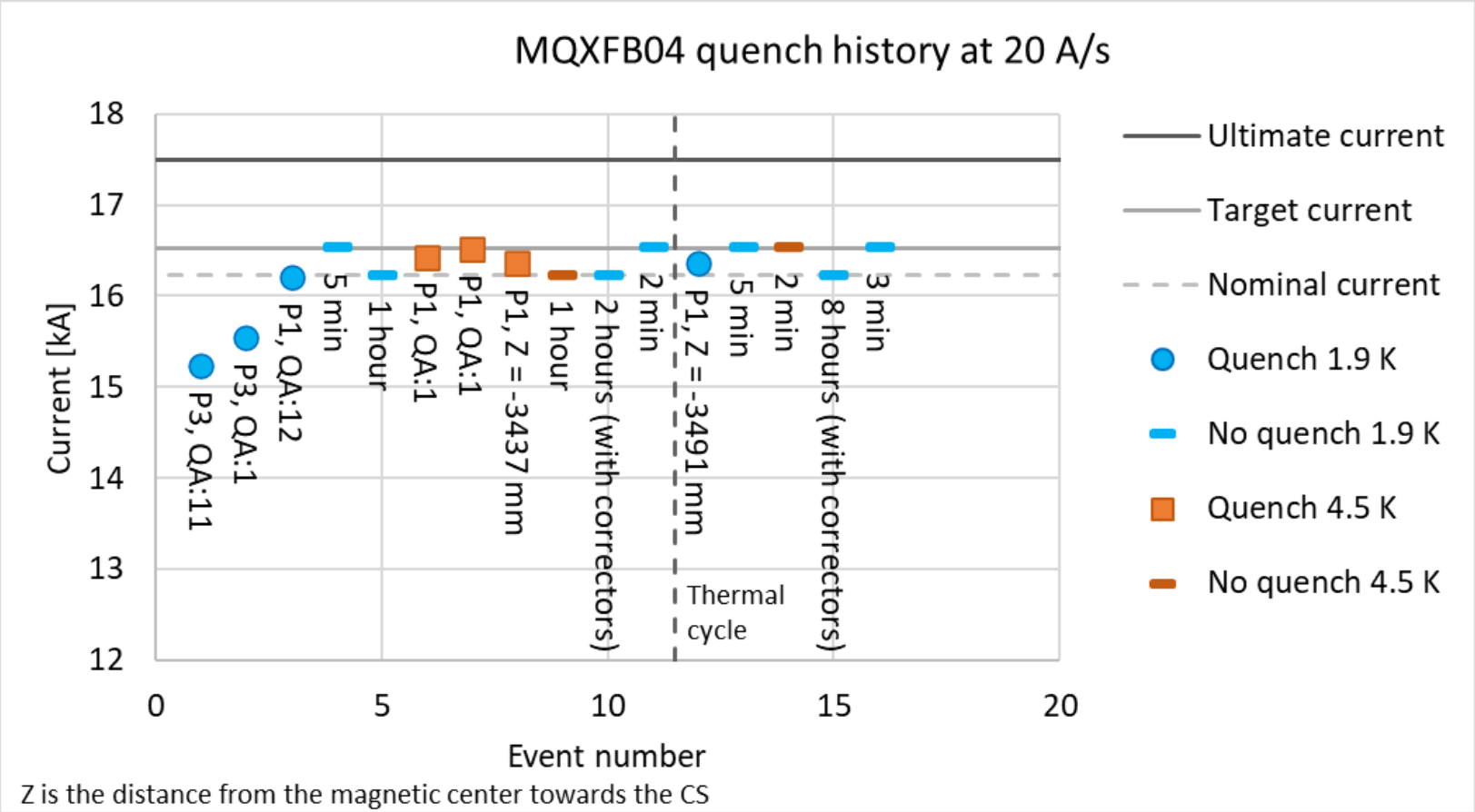
Summary LMQXFB01 (Q2b), LMQXFB02 (Q2a)

- Cold and power tests finished
- Both cryomagnets considered ready for the IT String (from testing point of view), despite some non-conformities
- Q2a installed in the IT String
- Q2b under preparation for the IT String

LMQXFB04

Q2b with MQXFB04 and MCBXFB02b

MQXFB04 quench plot



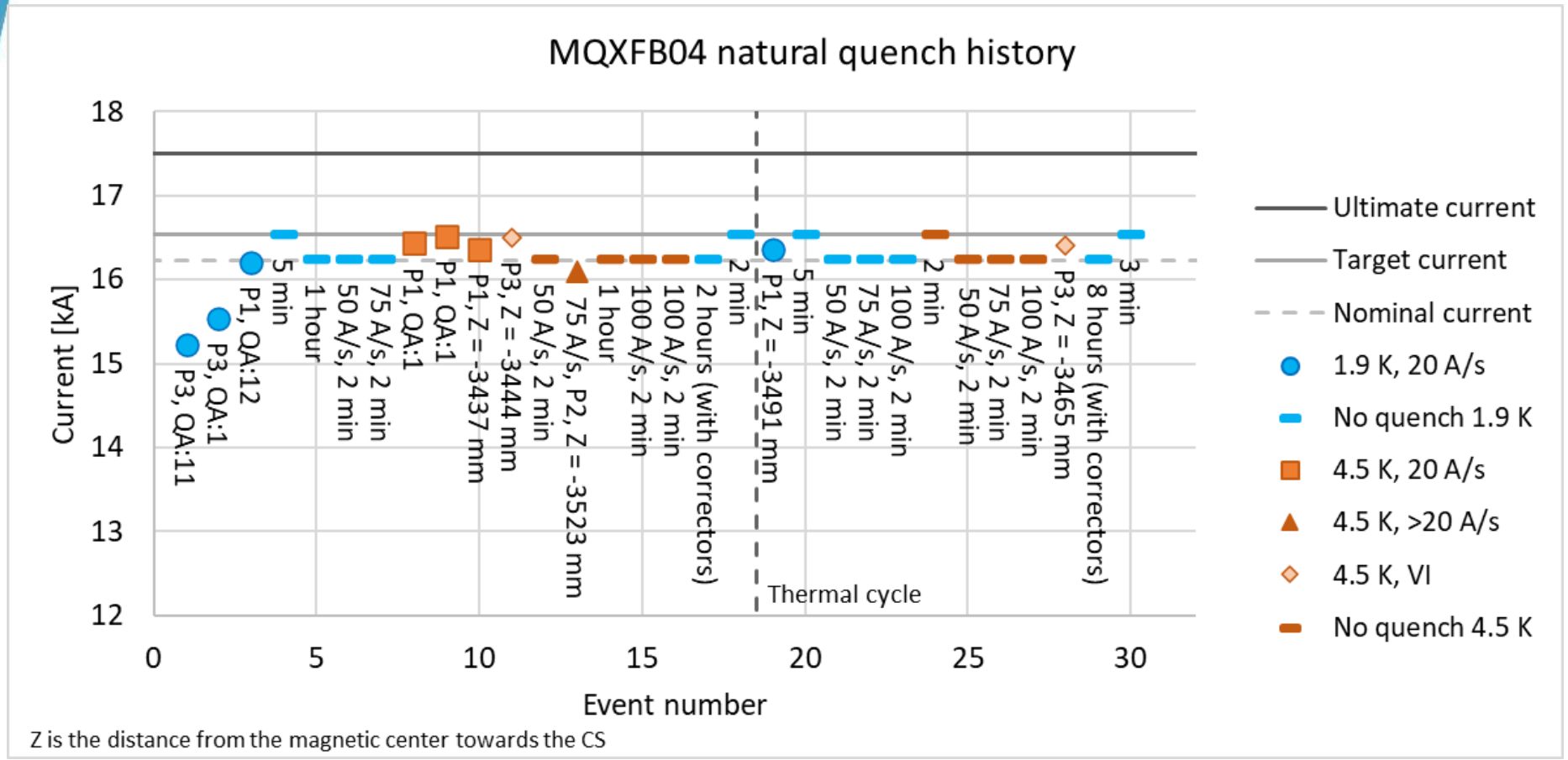
Z is the distance from the magnetic center towards the CS

Fast training to the target current at 1.9 K

Very good training memory: only one quench above nominal current after thermal cycle.

At 4.5 K: some quenches between nominal and target current, we attribute them to lack of training margin

MQXFB04 quench plot (all ramp rates)

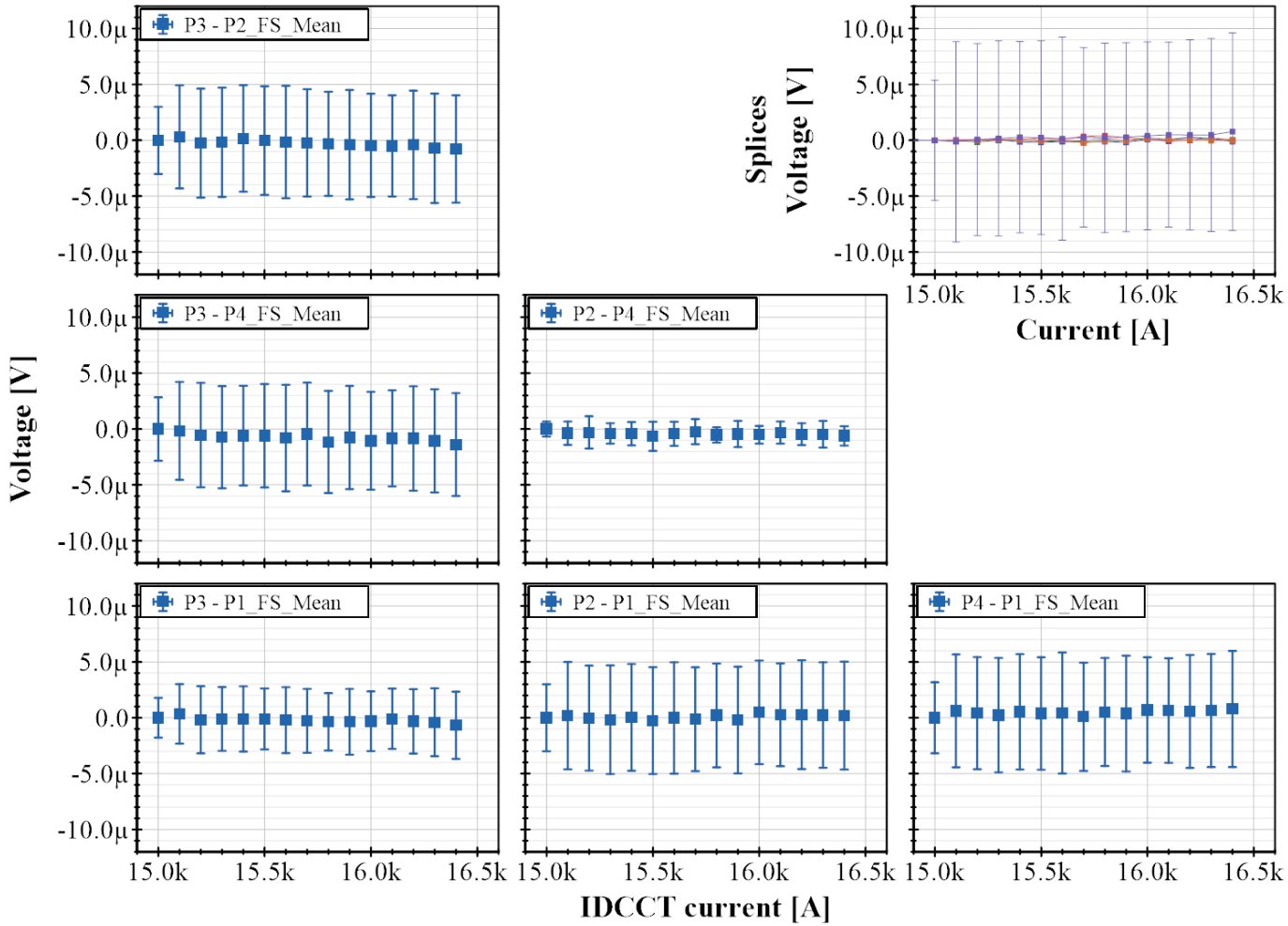


Z is the distance from the magnetic center towards the CS

Very good performance at higher ramp rates as well

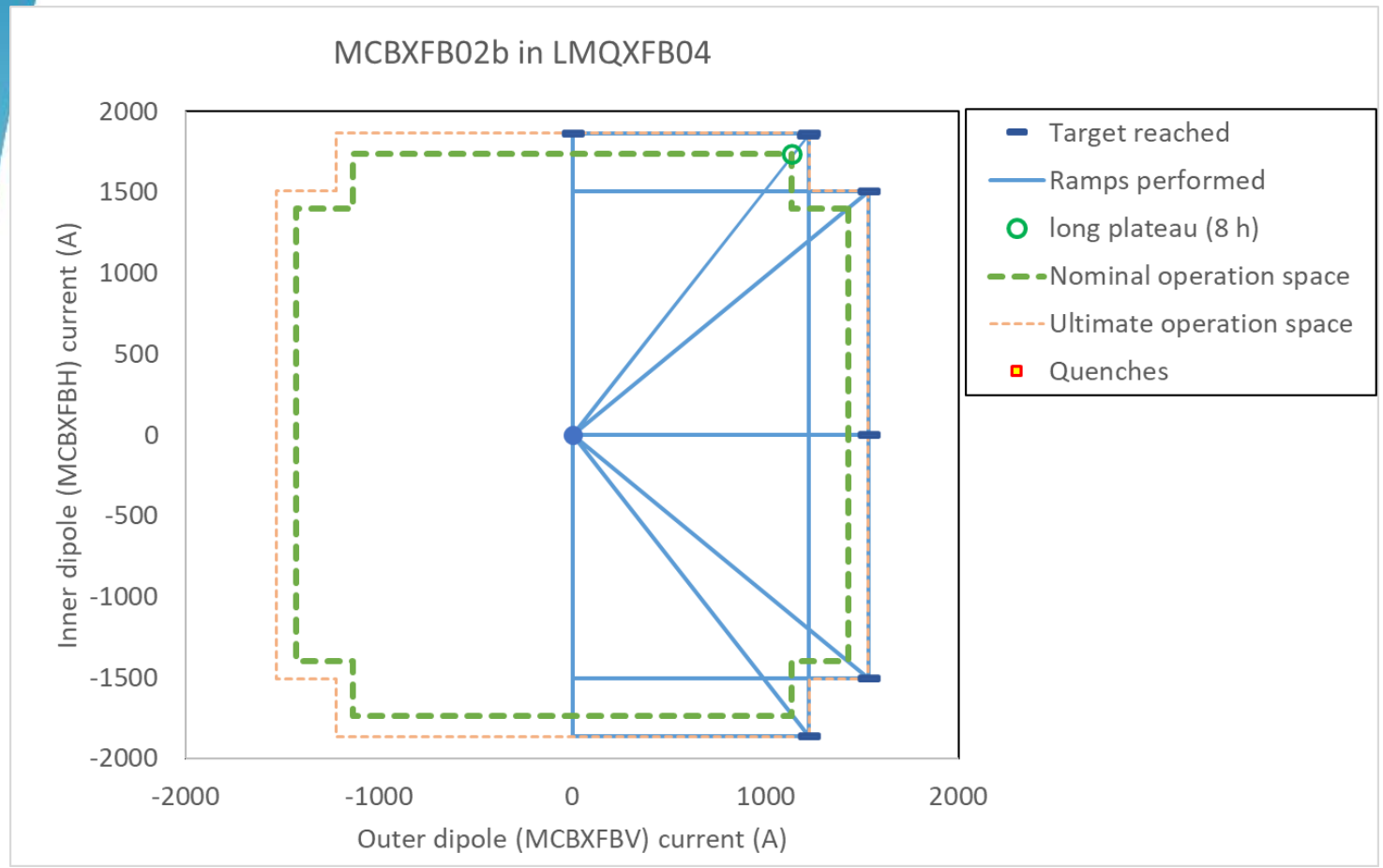
MQXFB04 VI measurements at 4.5 K

File: HCLMQXFB001-CR000004__J20240502132416__Splice-VI



Measurements rather flat, no indication of superconducting to normal transition

MCBXFB02b quench plot



- No quenches in MCBXFB02b
- No quenches when changing polarity
- Same behavior as during the vertical test

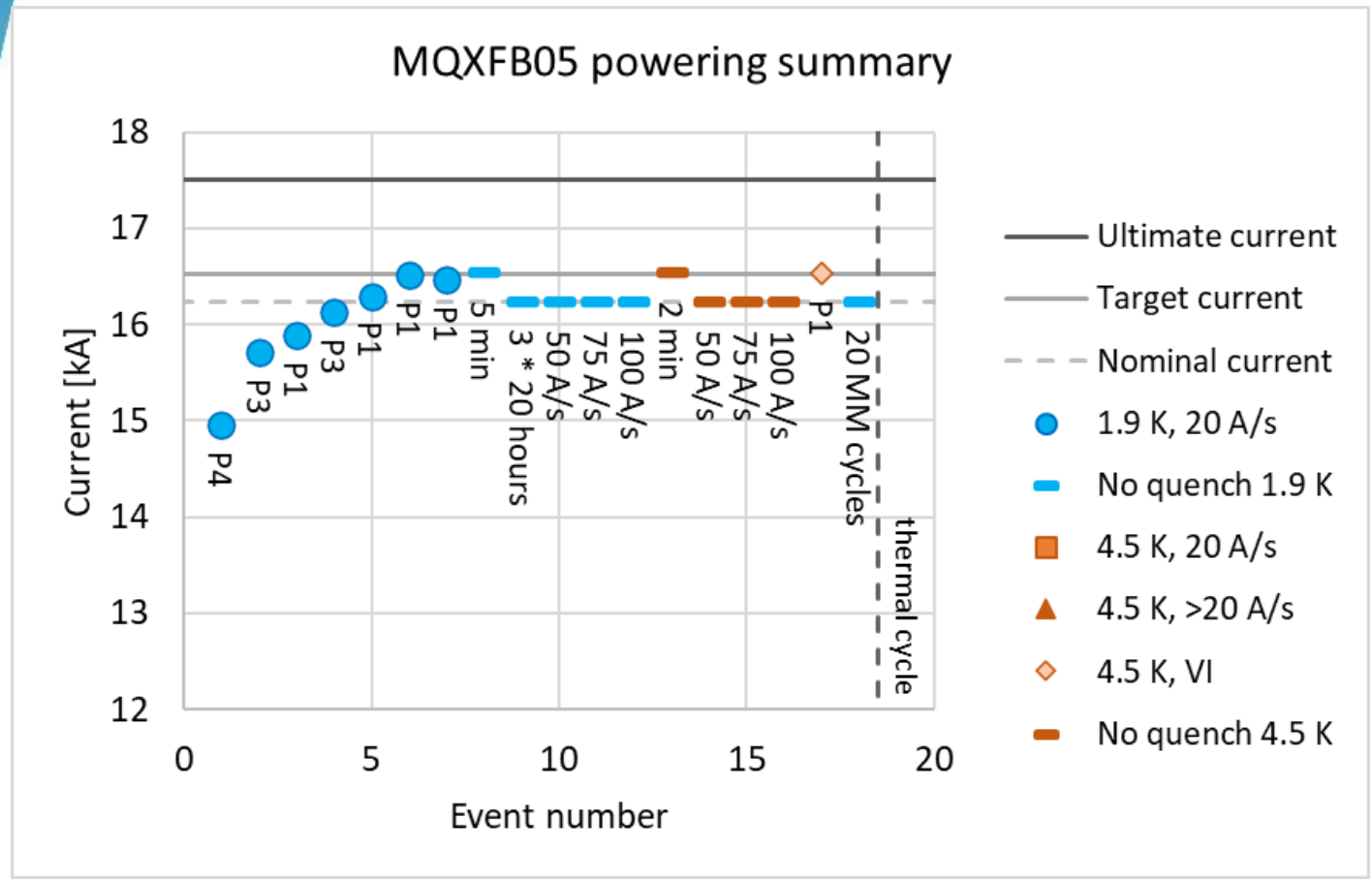
LMQXFB04 other results

- Splice measurements: within specs
- HV test: all passed OK
- No critical non-conformities found

LMQXFB06

Q2a with MQXFB05 and MCBXFB04

MQXFB05 quench plot (all ramp rates)



Note: tests still ongoing

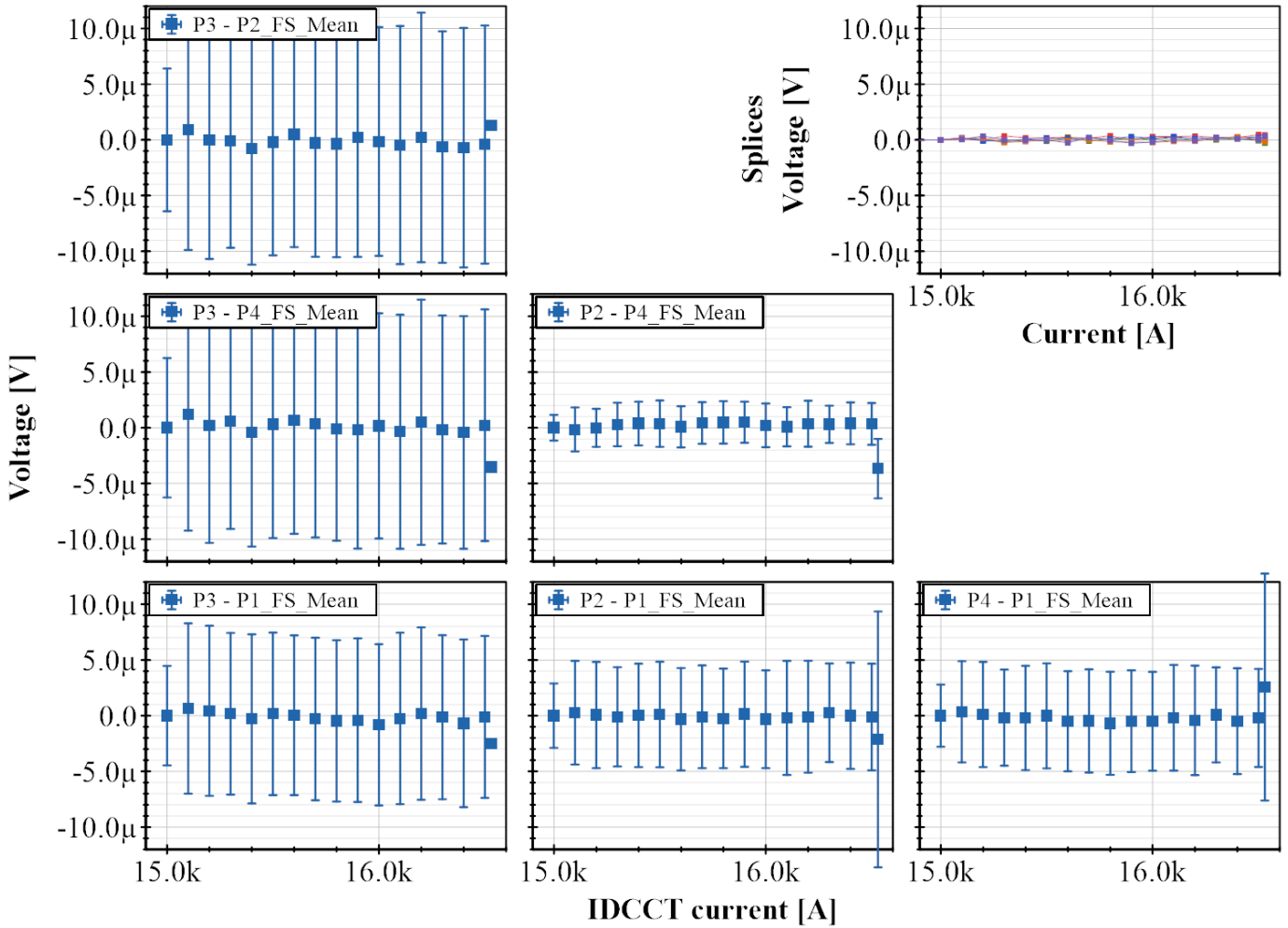
After reaching target current, no further quenches at 1.9 K

The quench at 4.5 K was at target current (lack of training margin)

First time in a Q2 that we power 3 x 20 hours

MQXFB05 VI measurements at 4.5 K

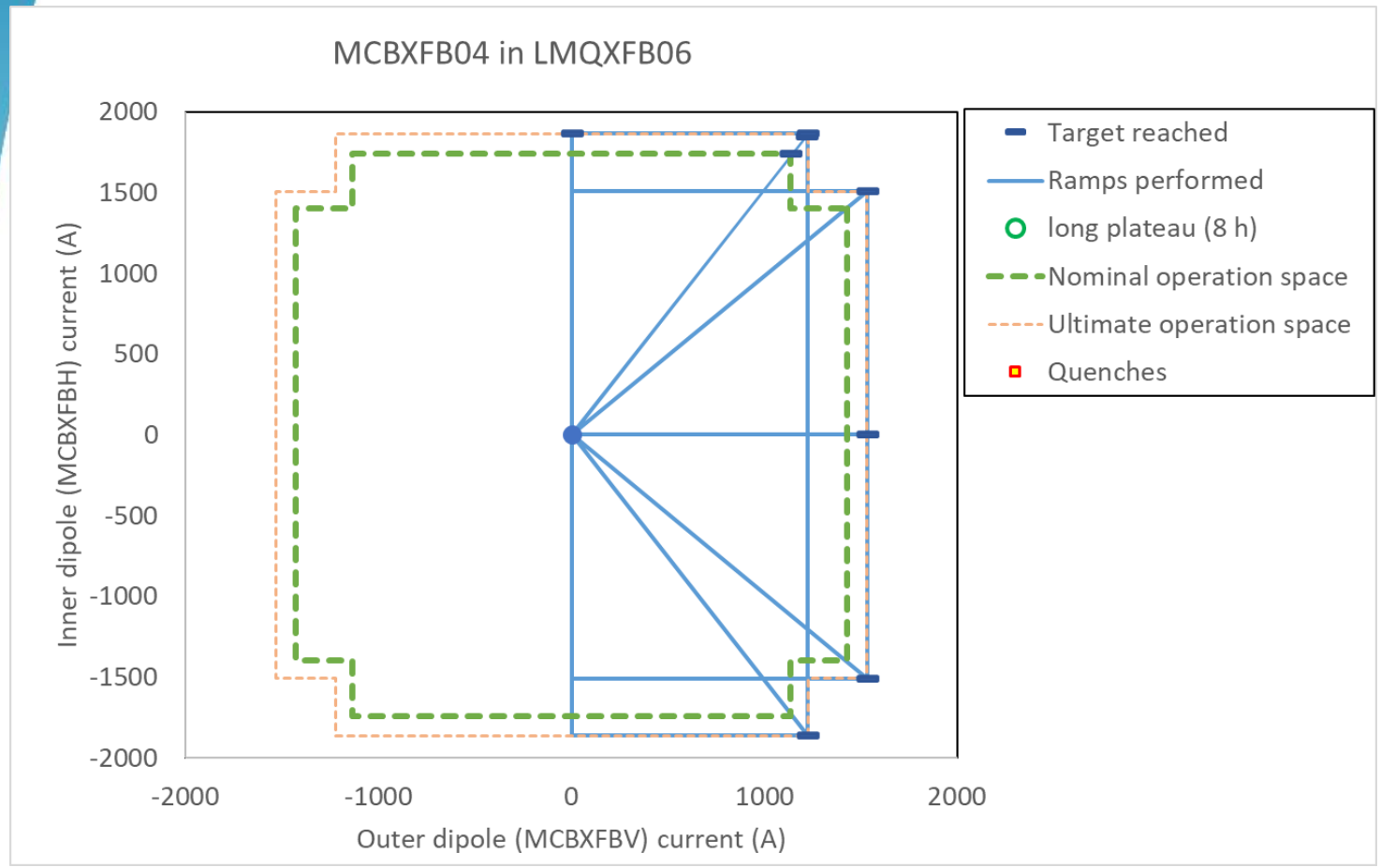
File: HCLMQXFB001-CR000006__J20240924171633__Splice-VI



Measurements rather flat, no indication of superconducting to normal transition

Point at 16.53 kA affected by the quench

MCBXFB04 quench plot



- No quenches in MCBXFB04
- No quenches when changing polarity
- Same behavior as during the vertical test
- Long plateau not done yet – to be done during the second cool down.

LMQXFB06 other results (so far)

- Splice measurements: within specs
- HV test: all passed OK (so far)
- No critical non-conformities found (so far)

Summary LMQXFB04 (Q2b), LMQXFB06 (Q2a)

LMQXFB04:

- Cold and power tests finished
- No non-conformities found
- Ready for the LHC (from testing point of view)

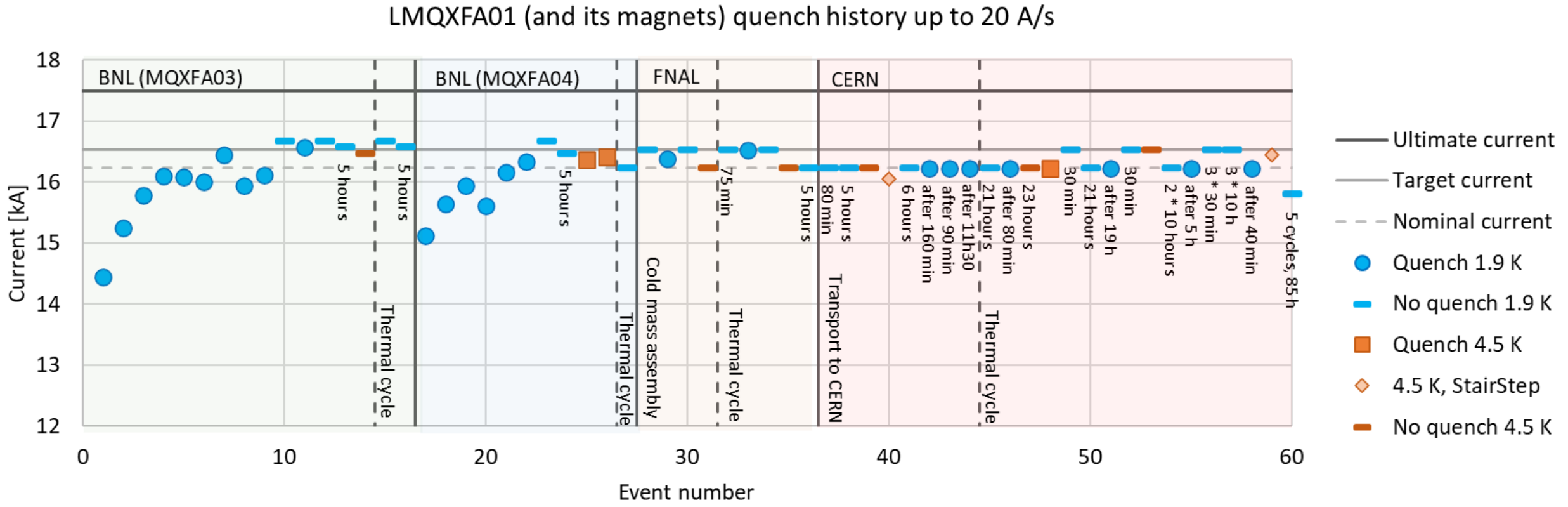
LMQXFB06:

- Tests ongoing
- No showstopper identified so far

LMQXFA01

Q3 with MQXFA03 and MQXFA04

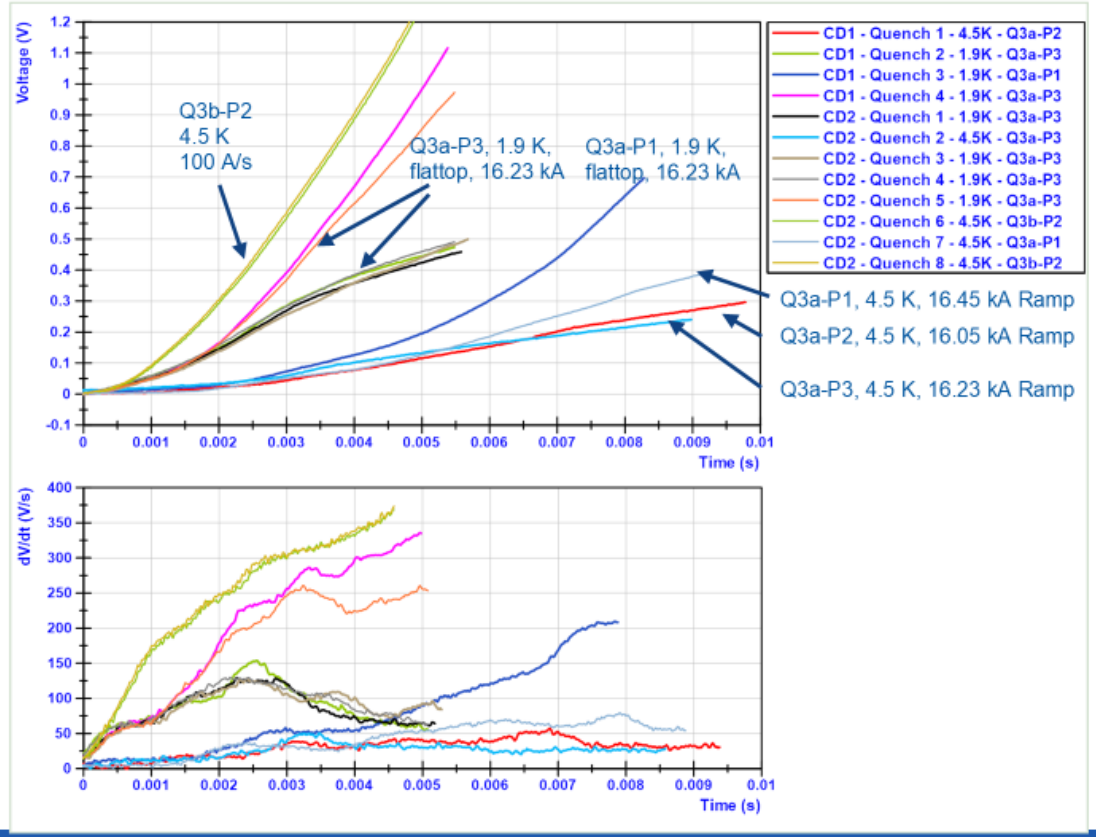
LMQXFA01 quench plot



The two magnets have good training memory after transport to CERN. Unexpected flat-top quenches happened during magnetic measurements (event 42), prompted a second cool down and extended testing.

LMQXFA01 flat-top quenches investigation

Characteristics quenches – voltage build up



4 quenches with normal voltage buildup for quenches, with a slope of 20-40 V/s.

All Q3a-P3 flattop quenches at 1.9 K have a very fast voltage buildup already in the first ms of > 60 V/s.

The Q3b-P2 quenches at 4.5 K at 100 A/s show an even faster voltage buildup.

In none of the quenches any precursor is visible, also not in the Quench Antenna data.

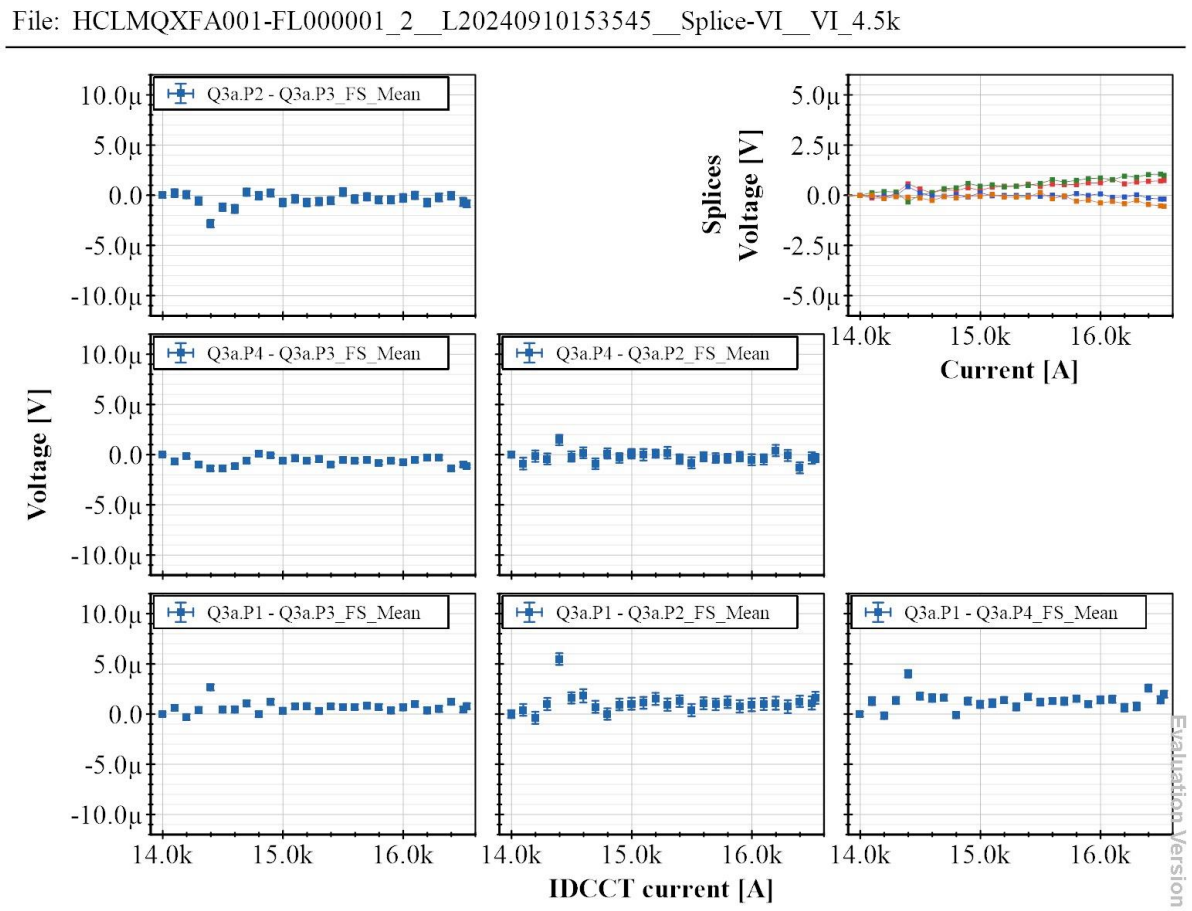
The slope will depend on two parts:
- Longitudinal propagation velocity & turn to turn propagation, see next slides.

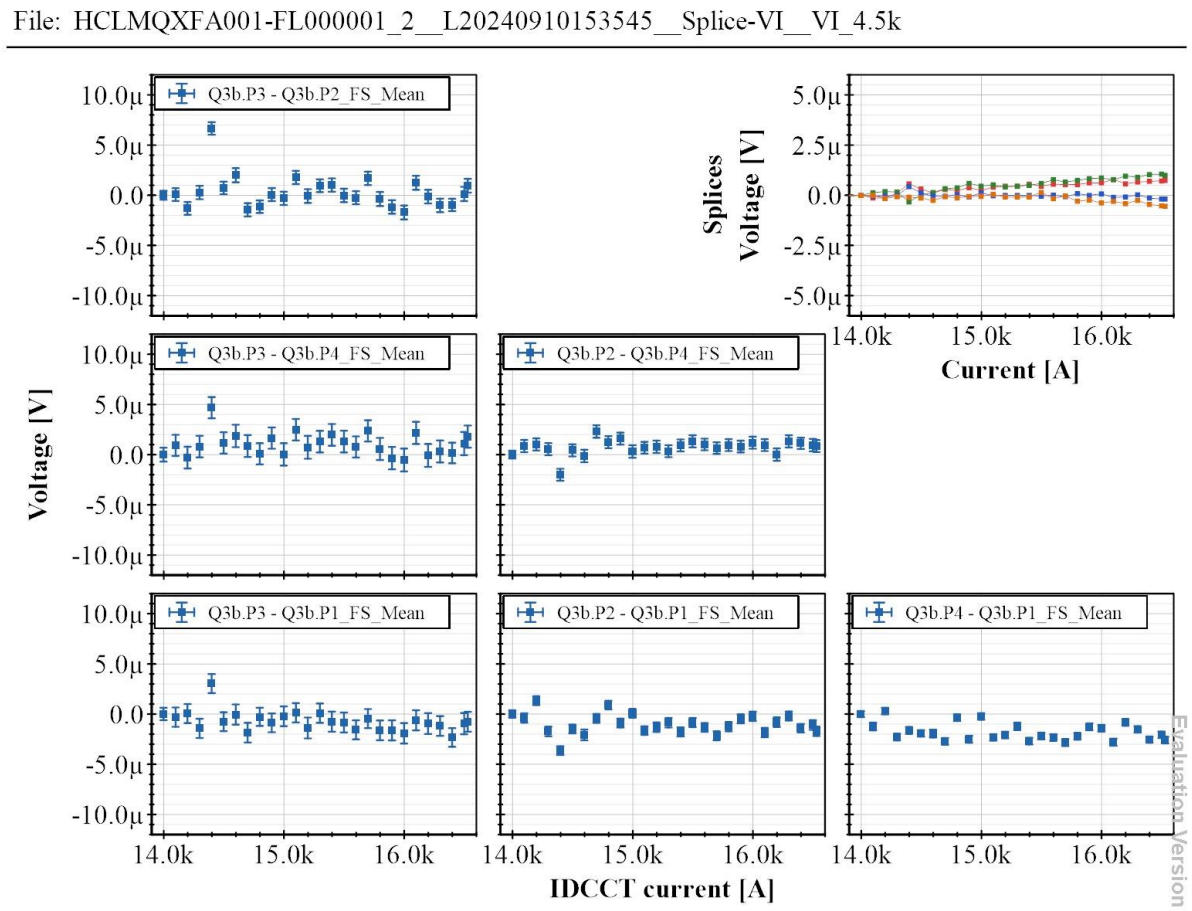
Most flat-top quenches characterized by very fast dV/dt at the start of the quench

These quenches were in MQXFA04, coil P3, near NCS

A detailed investigation is reported in: https://indico.cern.ch/event/1447894/

LMQXFA01 VI measurements at 4.5 K





Measurements rather flat, no indication of superconducting to normal transition

NC: high leak rate to vacuum

- Leak rate between cold mass circuit (cold mass + test station) and vacuum at room temperature is 2.5 10^{-5} mbar L/s (normal values: 10^{-7} – 10^{-6} mbar L/s)
- Before the first cool down, investigation with a He sniffer at the cryomagnet connections could not identify the leak.
- After the second cool down the leak was roughly localized close to the cryomagnet – test station connection area (and not the MRB side)
- Leak tests will be repeated with the CP cold mass, to help identify if the leak is at the cryomagnet or test station side.
- NCR: https://edms.cern.ch/document/3124113

Summary LMQXFA01 (Q3)

- Cold and power tests finished
- Acceptance tests passed OK
- Two important nonconformities found:
  - Quenches during long flat-top operation
  - Higher than expected leak rate
- Ready for the IT String (from testing point of view)

Some words about documentation

- We have one test plan in EDMS per cryomagnet type, detailing tests from:
  - TE-MSC-TM: mechanical preparation, electric and magnetic measurements
  - TE-CRG: leak tests and cool down/warm up preparation
  - BE-GM: geometric measurements
  - TE-MPE: reference ELQA tests
- The test report includes a summary of all these tests either explicitly or by reference
  - As example see the LMQXFB02 report (EDMS 3076641)
- In addition, we agreed on an MTF structure to report the activities and key information (to be implemented in October)

Conclusions

- Series testing ramping up: five (!) Q2/Q3 cryomagnets tested this year, probably one more
- No NC found (so far) in the first two cryomagnets for HL-LHC
- New tools (e.g. helical QA) and procedures (e.g. powering overnight) implemented for improved test analysis and efficiency

References

- Test plan:
  - Q2: https://edms.cern.ch/document/2873724
  - Q3: https://edms.cern.ch/document/2959525
  - Q3 addendum: https://edms.cern.ch/document/3153284
- Test reports:
  - LMQXFB01: https://edms.cern.ch/document/3023791 (in work)
  - LMQXFB02: https://edms.cern.ch/document/3076641
  - LMQXFB04: https://edms.cern.ch/document/3076642 (in work)
  - LMQXFB06: https://edms.cern.ch/document/3170453 (placeholder)
  - LMQXFA01 for acceptance: https://edms.cern.ch/document/3094617
  - LMQXFA01 full tests: https://edms.cern.ch/document/3094622 (in work)
- Photos:
  - https://cds.cern.ch/record/2879572?ln=en
  - https://cds.cern.ch/record/2895375?ln=en
  - https://cds.cern.ch/record/2899920?ln=en
  - https://cds.cern.ch/record/2911476?ln=en