Production testing summary of the MQXFA magnets

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13th HL-LHC Collaboration Meeting
Sept. 27th, 2023

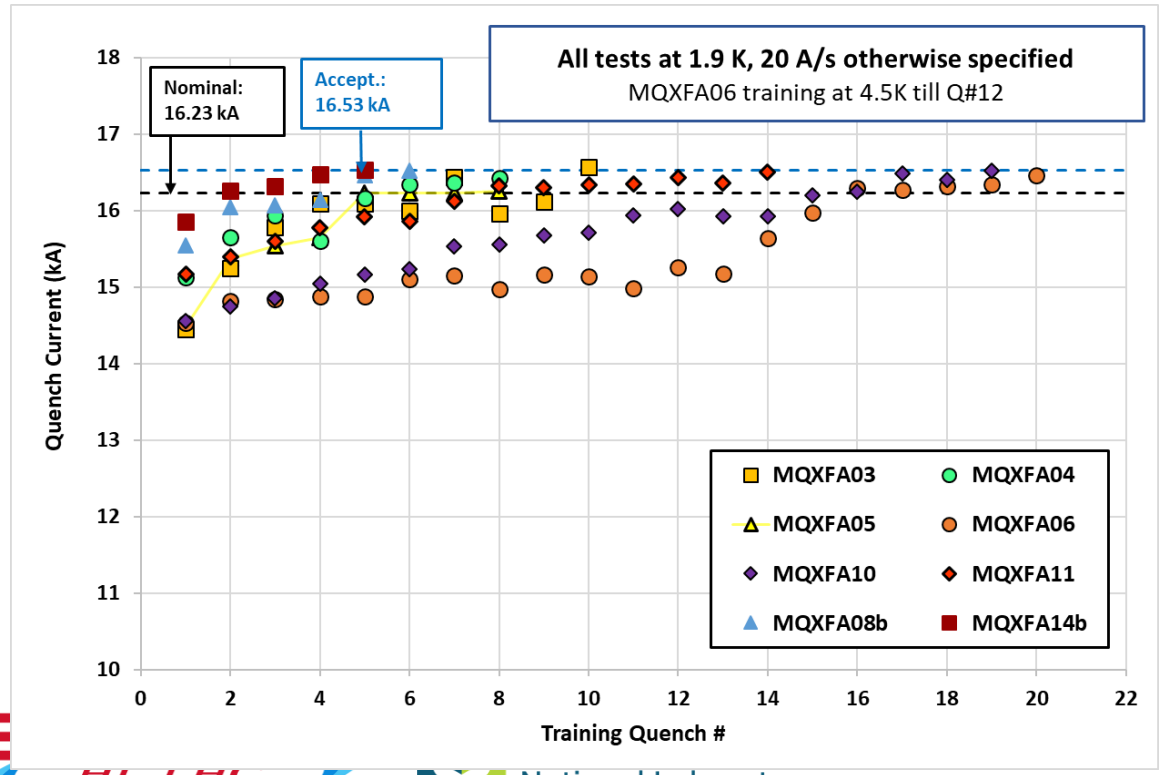
MQXFA test history at BNL

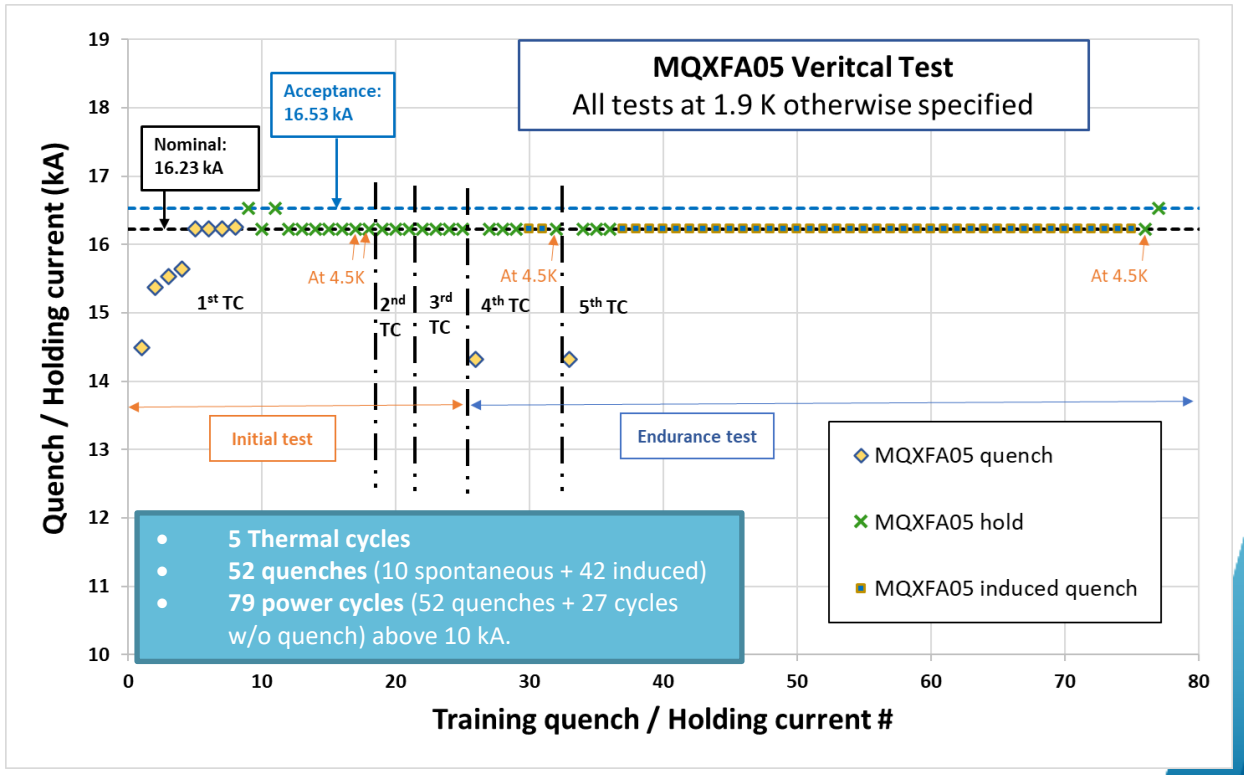
- 11 magnets (not counting prototypes) - 12 tests:

		HL-LHC collaboration meeting
MQXFA03	11-Nov to 19-Dec 2019	
MQXFA04	24-Aug to 7-Oct 2020	
MQXFA05	5-Mar to 19-May 2021	
MQXFA06	14-June to 2-July 2021	
MQXFA07	11-Aug to 25-Aug 2021	11th
MQXFA08	22-Oct 2021 to 11-Feb 2022	
MQXFA05 - Endurance Test	21-Mar to 31-May 2022	
MQXFA10	15-June to 9-Aug 2022	12th
MQXFA11	8-Sep to 25-Oct 2022	
MQXFA08b	6-Jan to 13-Mar 2023	
MQXFA13	14-Apr to 2-Jun 2023	
MQXFA14b	7-July to 24-Aug 2023	13th

Vertical Test Overview

- 8 magnets met acceptance requirements:
  - MQXFA03-06, 10-11, 08b and 14b
- Successful endurance test on MQXFA05.



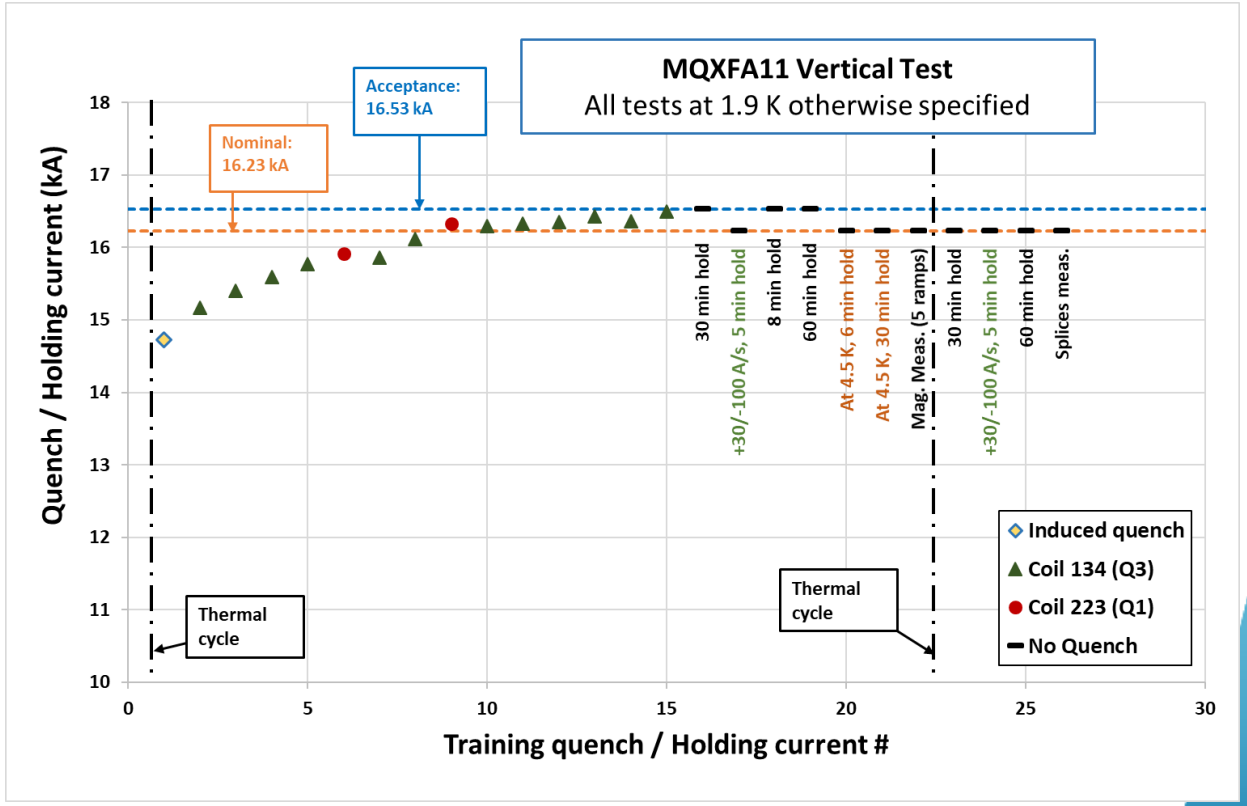


Outline

- Quench test results
  - MQXFA11
  - MQXFA08b
  - MQXFA13
  - MQXFA14b
- Magnetic measurement results
- Summary

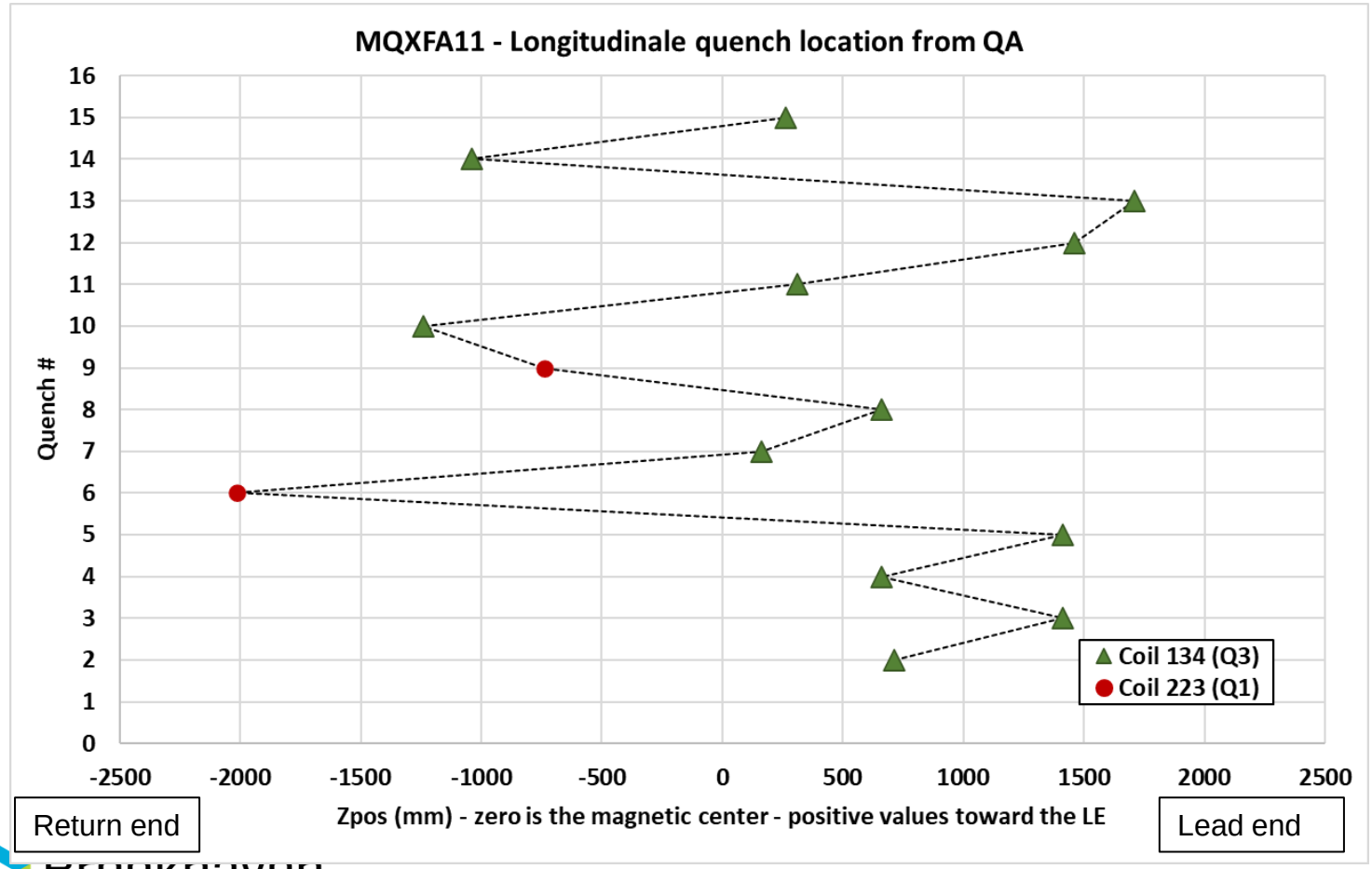
MQXFA11

- Reached nominal + 300A after 15 quenches.
- 12 quenches were in coil 134 in quadrant 3 (first quench was a false trip on a spike).
- 11 ramps without quench (3 to nominal + 300 A).
- After the thermal cycle, 4 ramps to nominal without quench.



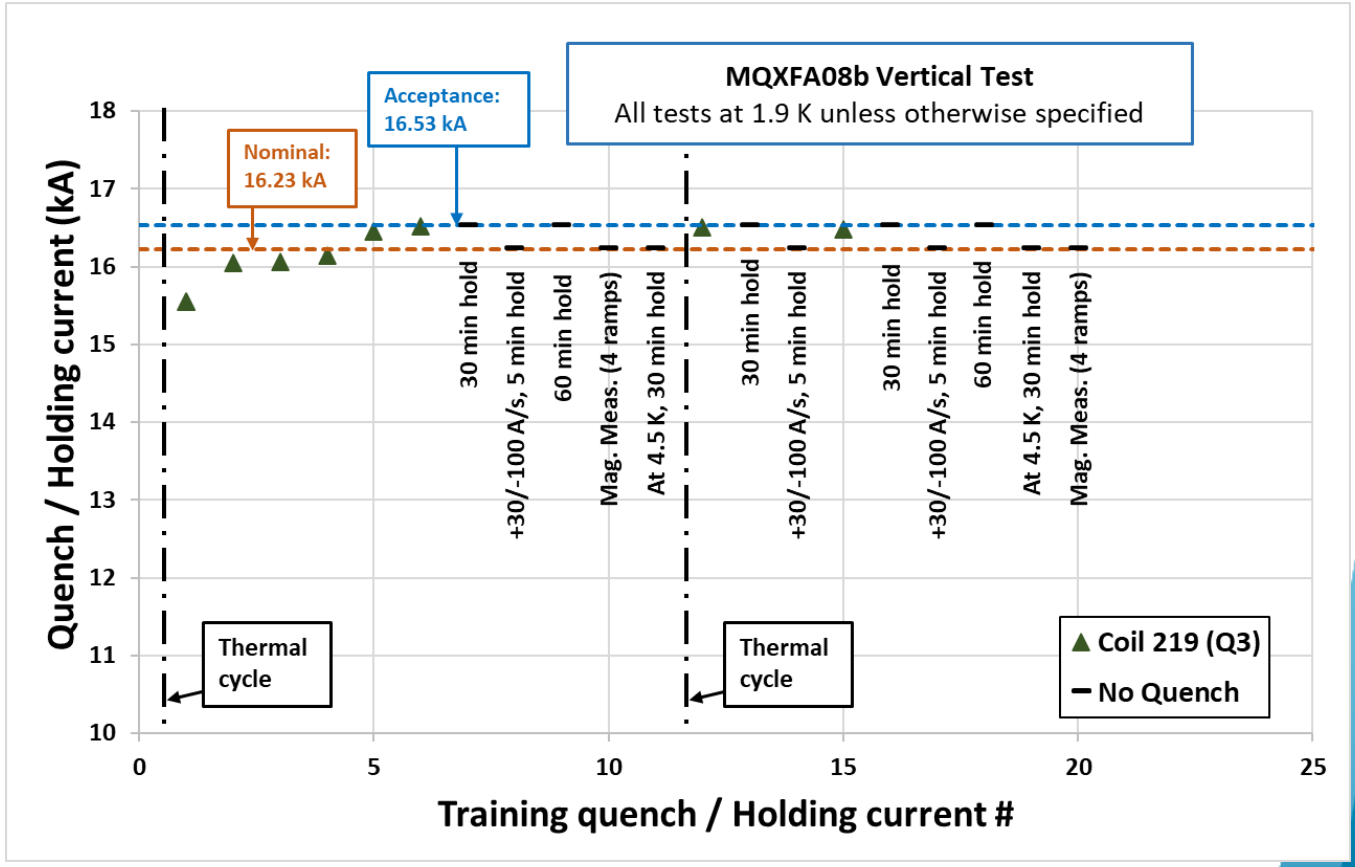
MQXFA11 – Quench localization from the Quench Antenna Array

- 13 out 14 quenches in the straight section.
- No recurring quench location.



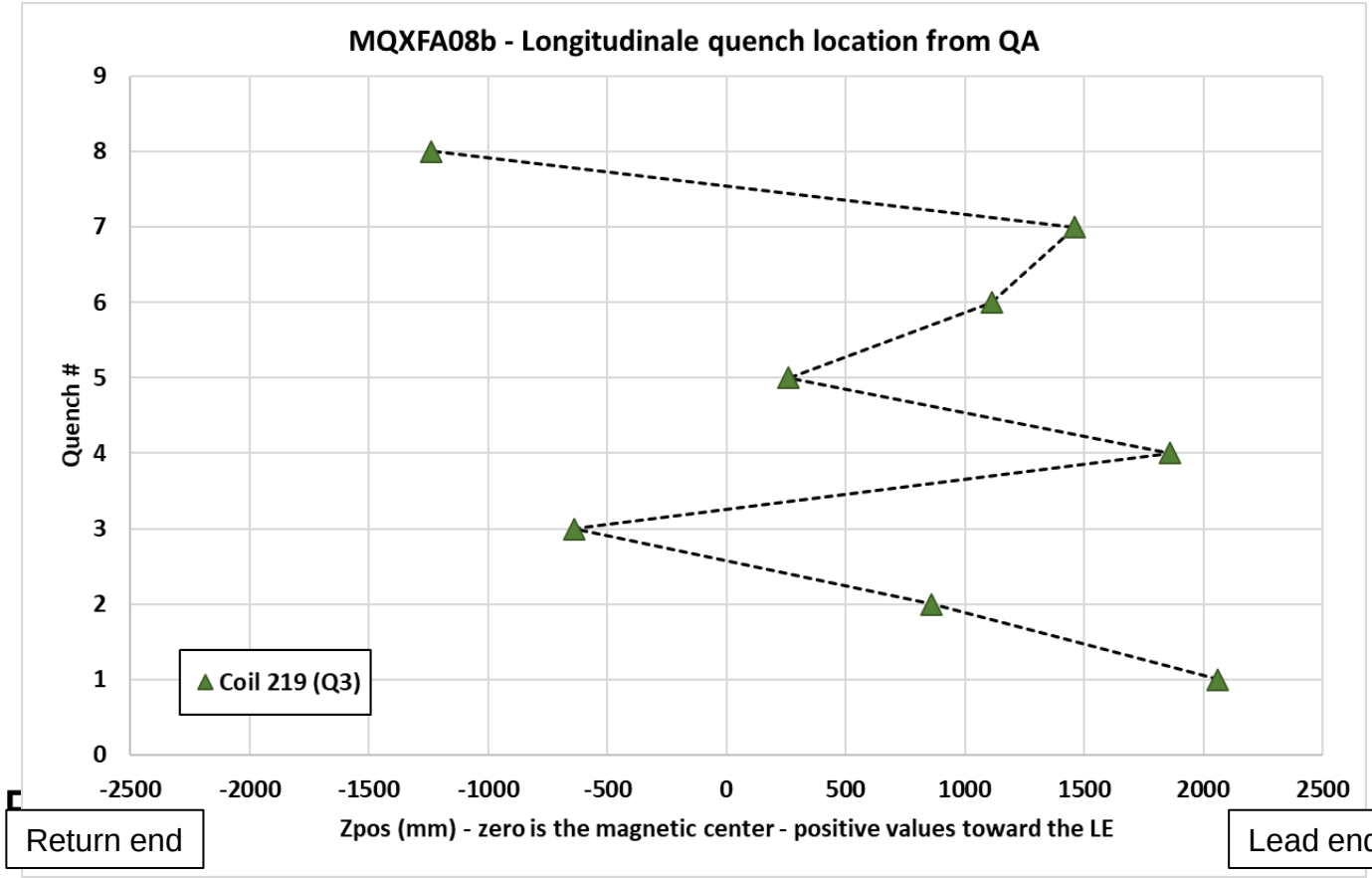
MQXFA08b

- First re-assembly: built by replacing the limiting coil (213) in MQXFA08 by a new coil (219) in quadrant 3.
- All quenches occurred in coil 219.
- After the thermal cycle 2 additional quenches above nominal current (at 16.51 kA and 16.48 kA)



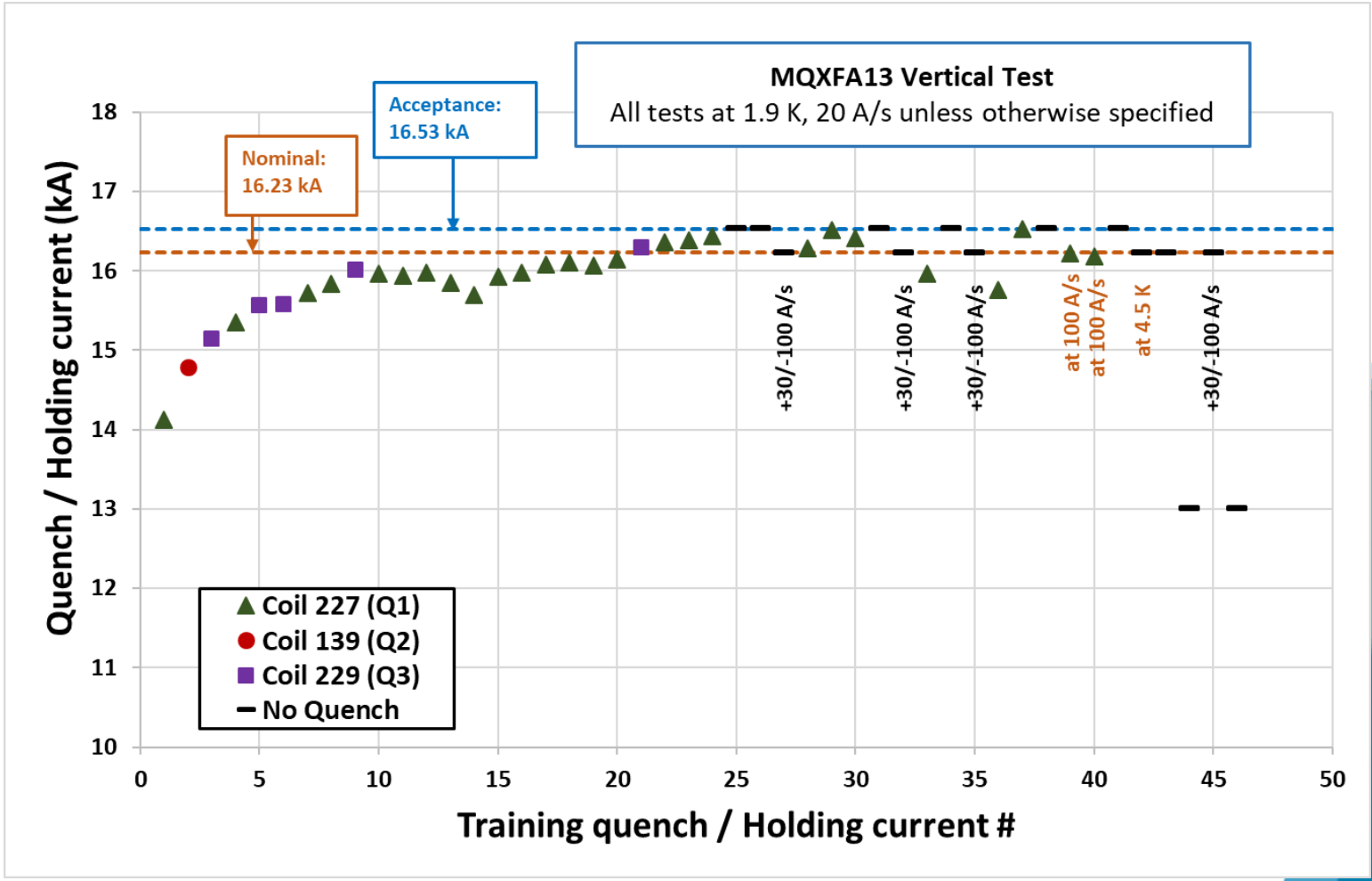
MQXFA08b – Quench localization from the Quench Antenna Array

- First quench in the lead end of the coil.
- Following quenches in the straight section (no recurring location).



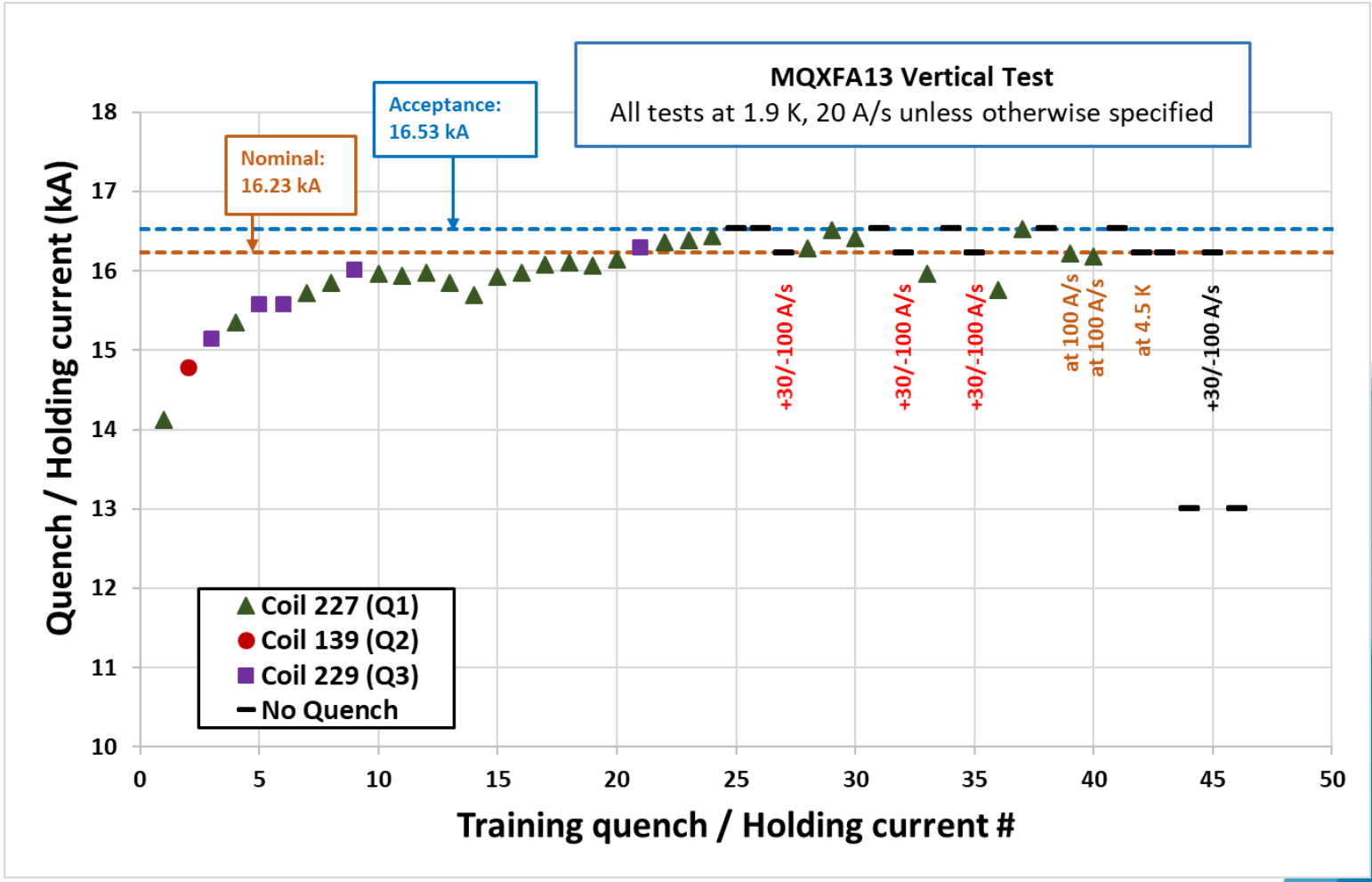
MQXFA13

- Training “typical” up to quench #9.
- Drop in quench current (315 A) between quench 10 and 14.
- Training continued from quench 15.
- Reached 16.53 kA on the 25th ramp.



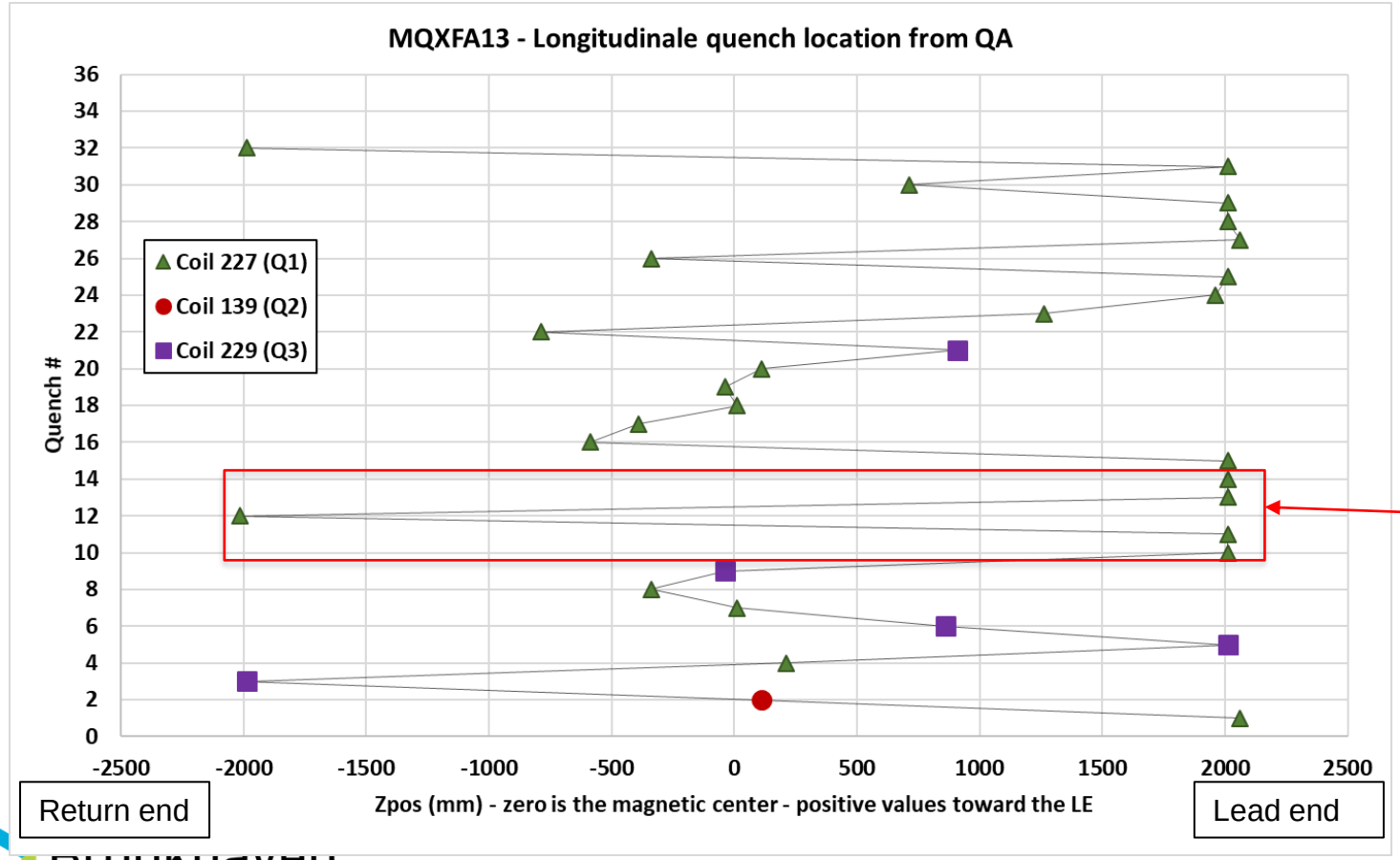
MQXFA13

- Following the ramp at +30/-100 A/s, there was a drop in quench current in the subsequent ramp at 20 A/s.
- Magnet trains back again to 16.53 kA.
- Behavior was repeatable 3 times.
- Ramps at 100 A/s showed lower quench current (16.22 and 16.21 kA).
- All these quenches occurred in coil 227 (Q1.).



MQXFA13 – Quench localization from the Quench Antenna Array

- Recurring quenches in the coil ends.



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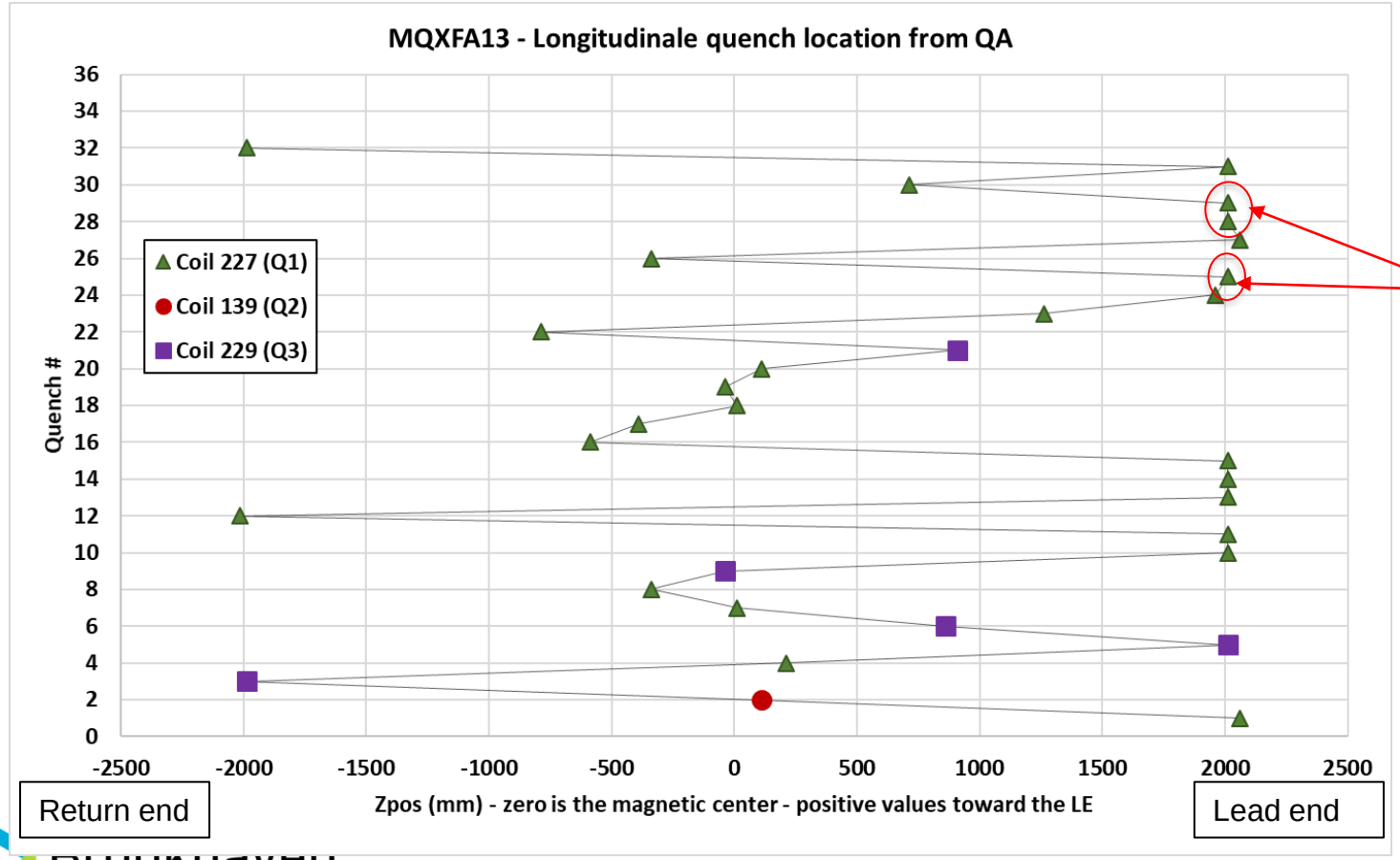

Quenches following the +30/-100 A/s ramp.

MQXFA13 – Quench localization from the Quench Antenna Array

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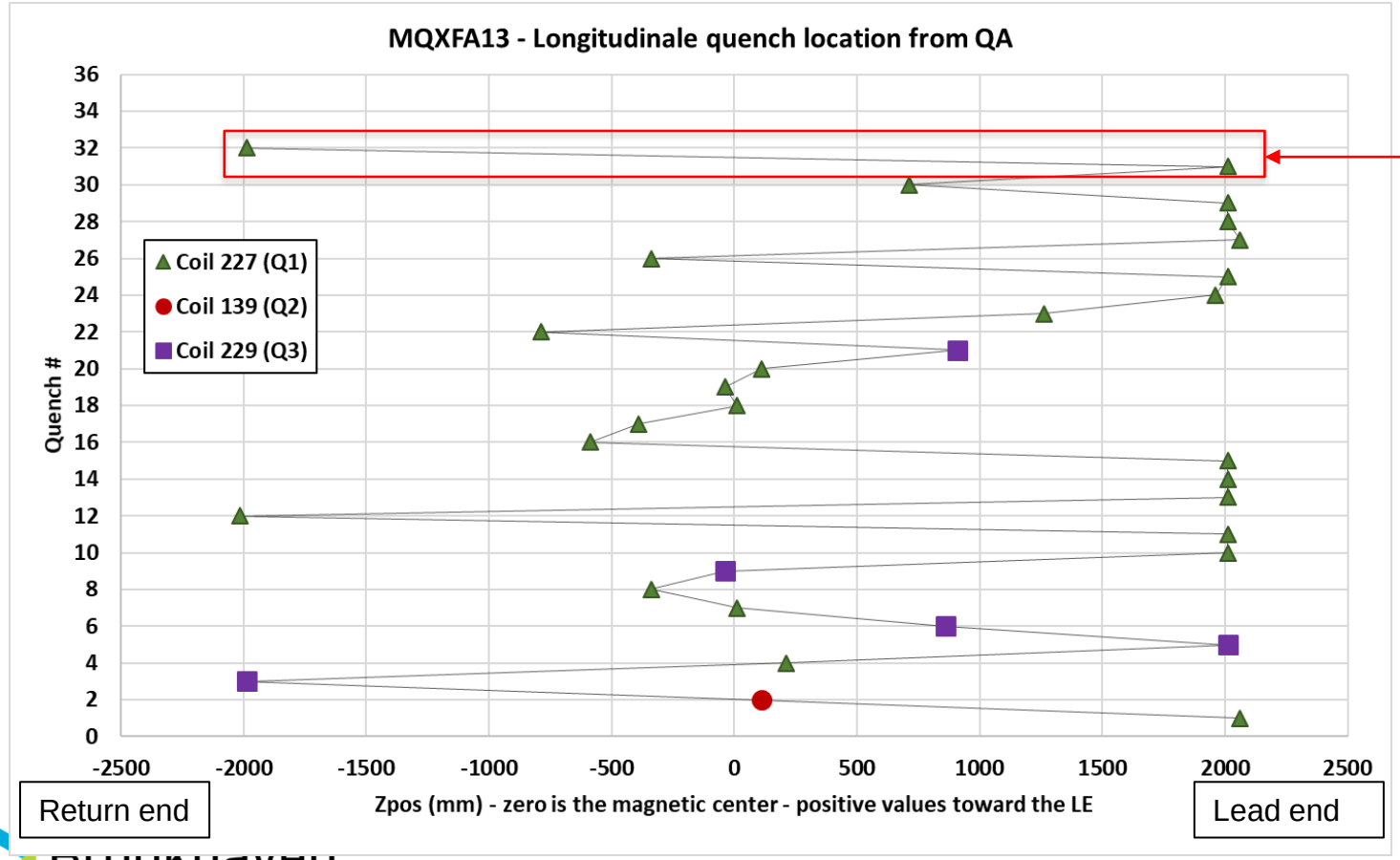


MQXFA13

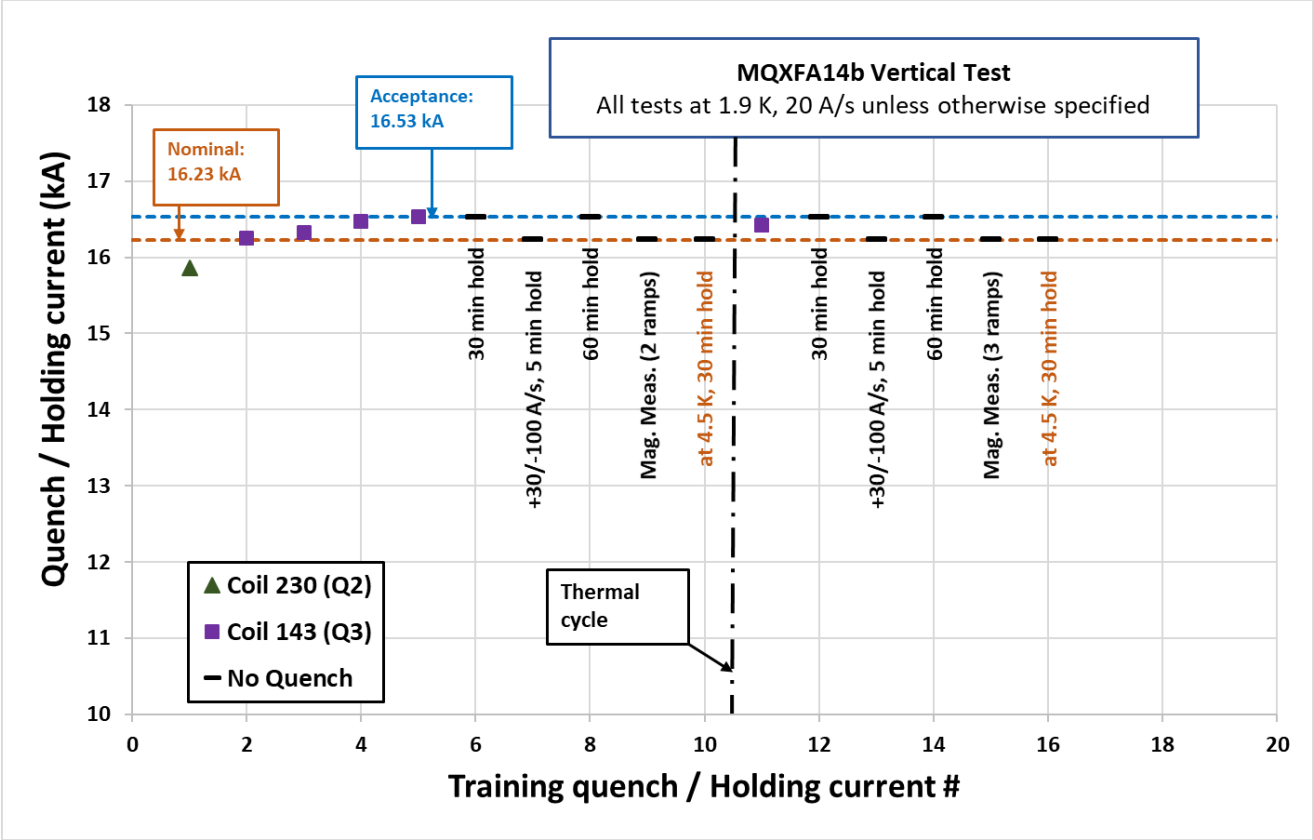
- Analysis of CMM data showed that all MQXFA13 coils had small arc-length in the ends, with coil 227 the smallest ever.
- FEM analysis of MQXFA13 as built showed risk of high strain with moderate prestress, and this issue may be prevented with higher local prestress.
- MQXFA13 test was stopped in order to replace coil 227 and avoid damage to the other coils.
- More details in:

  “MQXFA, magnet assembly and preload” by Dan Cheng.

MQXFA14b

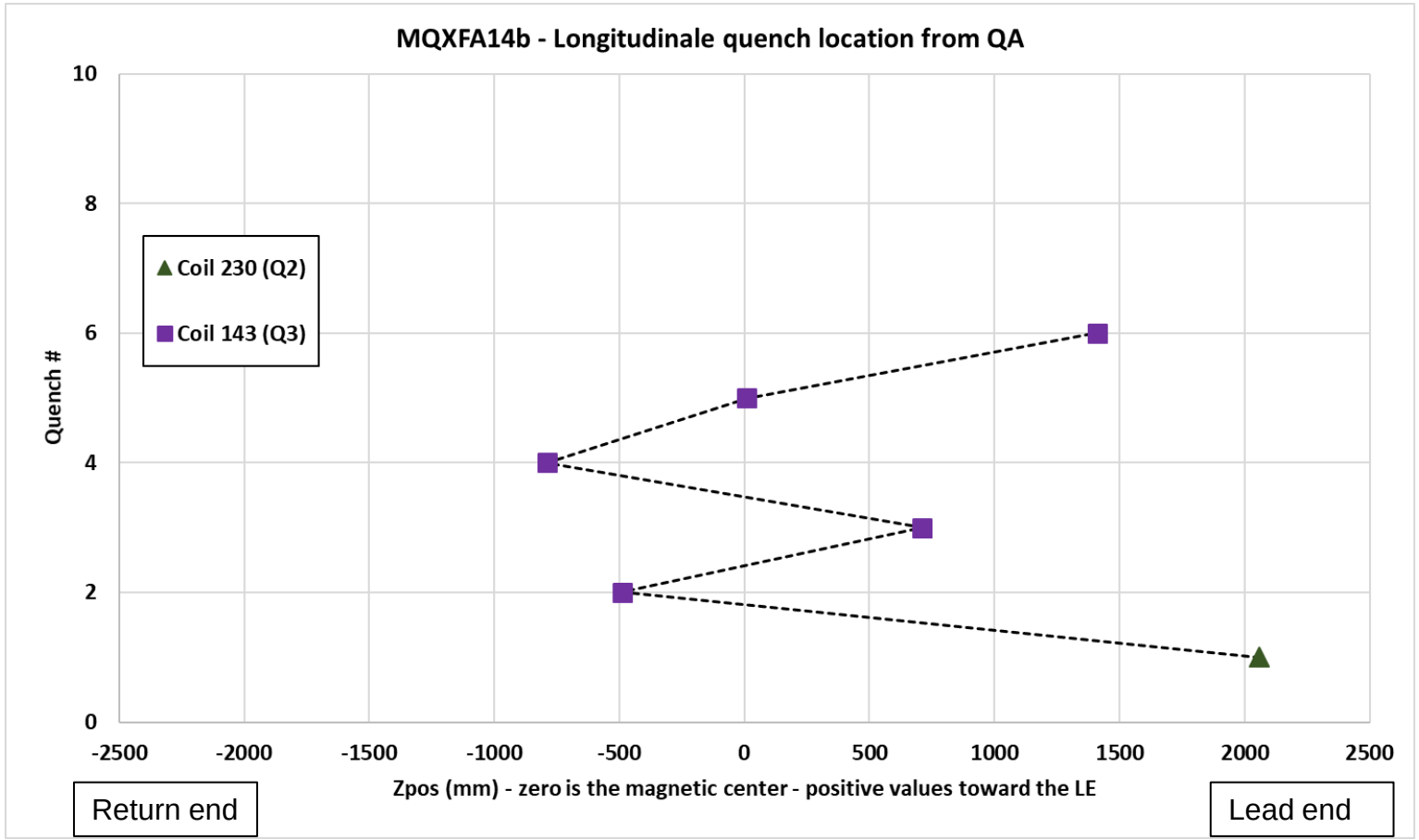
- Assembled using revised MQXFA specifications and targets.

- Achieved nominal + 300A after 5 quenches.
- All quenches except the first were in quadrant 3 (coil 143).
- After the thermal cycle
  - One quench at 16.42 kA.
  - 7 ramps without quench (2 to nominal + 300 A).

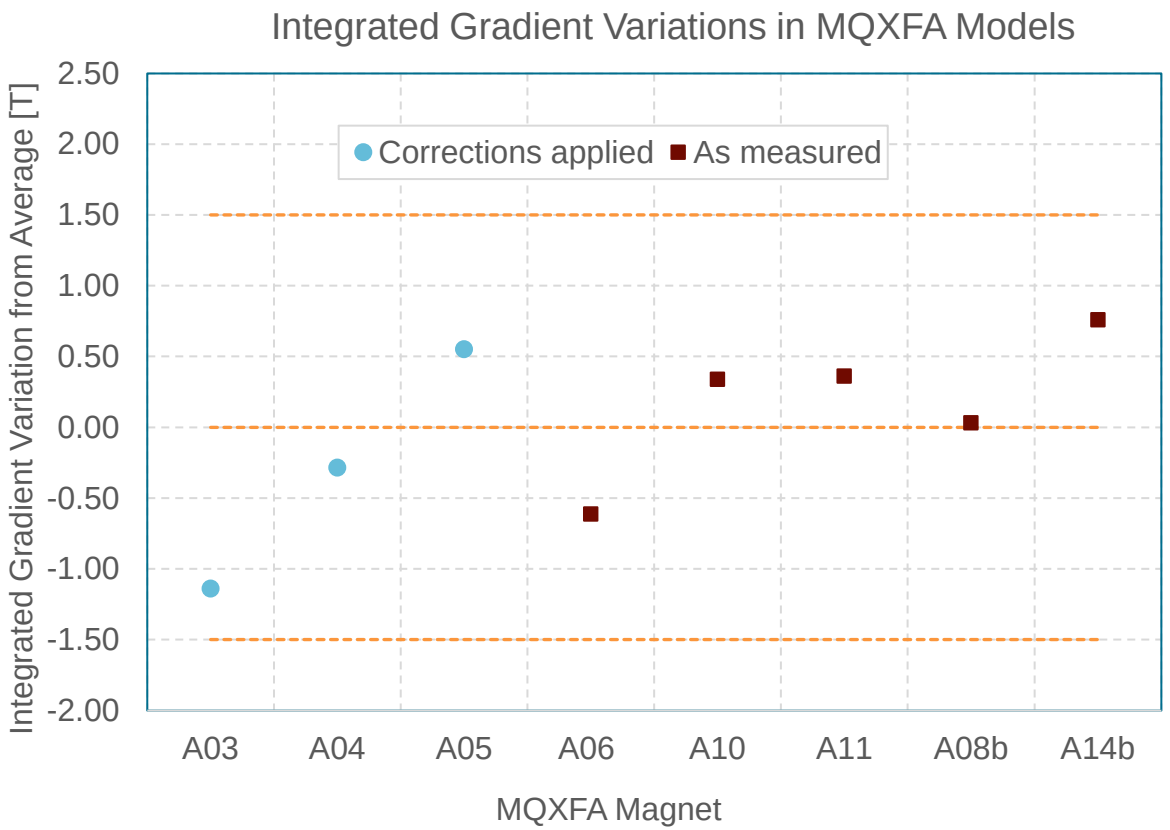


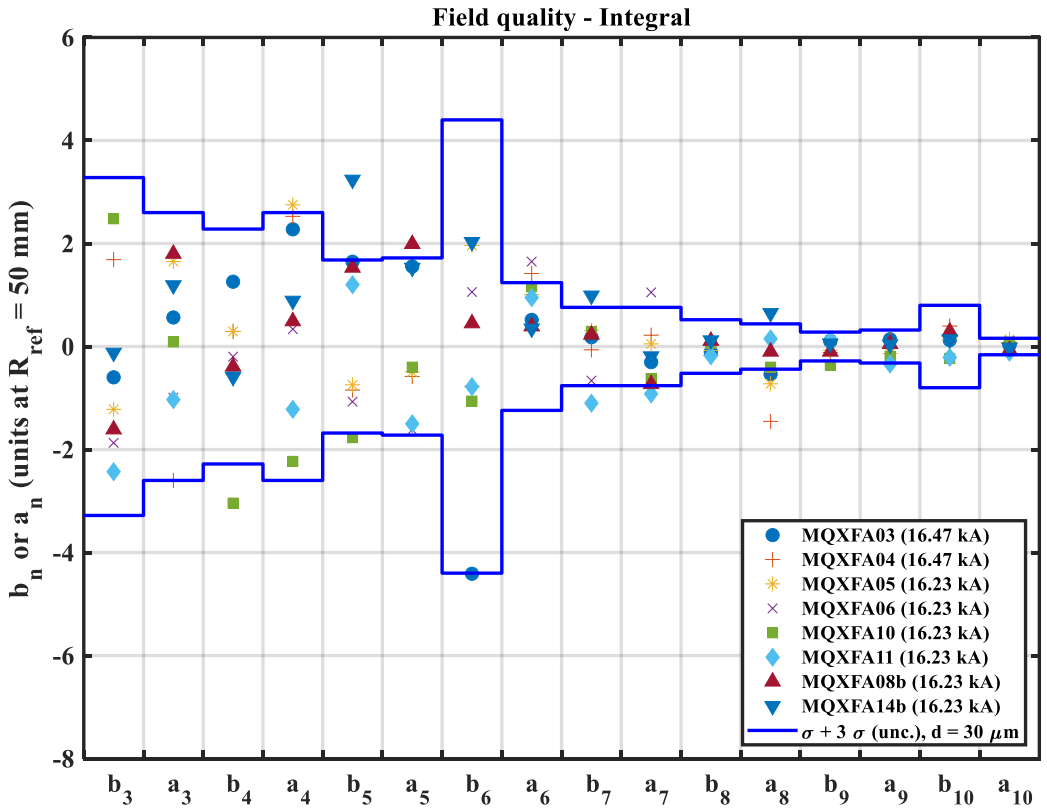
MQXFA14b – Quench localization from the Quench Antenna Array

- No recurring quench location.



Integrated Gradient and Field Quality





Average integrated gradient at 16.23 kA: 562.38 T

Correction factors applied to account for measurements taken at different currents as well as changes in the measurement setup and coil design.

More in:

“Field quality and integrated gradient in MQXFA magnets and LQXFA/B01” by Joe Di Marco.

US HL-LHC AUP

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Magnetic Shims

- Used in 5 magnets.
- Implement based on warm measurements during magnet assembly at LBNL
- Obtained correction is in agreements with expectations.

	Calculated	Measured*
MQXFA05	$\Delta b_3 = 4.5$; $\Delta a_3 = -4.4$	$\Delta b_3 = 4.5$; $\Delta a_3 = -4.5$
MQXFA06	$\Delta a_3 = 3.9$; $\Delta a_5 = -0.8$	$\Delta a_3 = 4.4$; $\Delta a_5 = -0.7$
MQXFA10	$\Delta a_3 = 4.1$; $\Delta b_4 = -1.4$	$\Delta a_3 = 2.7$; $\Delta b_4 = -1.4$
MQXFA11	$\Delta a_3 = 4.9$; $\Delta a_5 = -0.6$	$\Delta a_3 = 3.7$; $\Delta a_5 = -0.9$
MQXFA14b	$\Delta b_3 = 1.6$; $\Delta a_3 = 2.5$	$\Delta b_3 = 1.8$; $\Delta a_3 = 2.8$

(*) Based on the straight section averages

Summary

- 8 MQXFA magnets met requirements during vertical test.
- MQXFA11:
  - Successfully met vertical test requirements.
- MQXFA08b:
  - First successful test of an MQXFA magnet after replacing a coil.
  - All quenches occurred in the new coil.
- MQXFA13:
  - Test stopped for replacing the coil showing ramp-rate dependence.
- MQXFA14b:
  - Assembled with revised specs and pre-load targets.
  - 5 quenches to reach acceptance current.
- Magnetic field measurements:
  - Within the expected bound (with the exception of few outliers).
  - Correction from the magnetic shims in agreements with expectations.
- All cold and warm high voltage withstand tests were successful.

THANK YOU