Horizontal Test Results of LQXFA/B01 and Plans for testing LQXFA/B02

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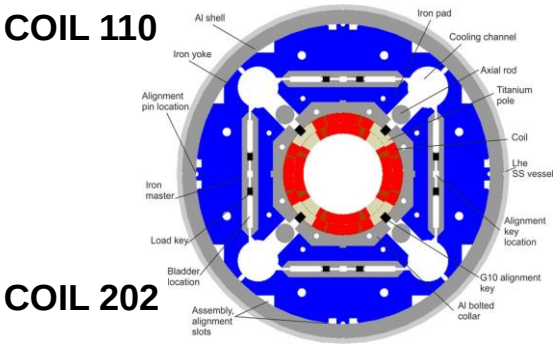
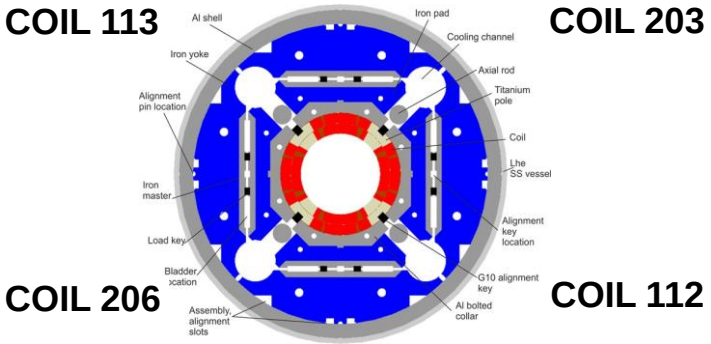
LQXFA/B01

- LQXFA/B01 - the first pre-series cryo-assembly fabricated by HL-LHC AUP with MQXFA03 and MQXFA04 magnets

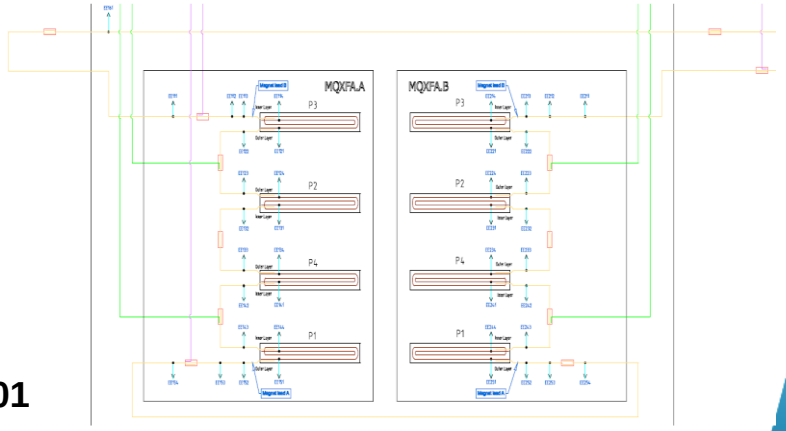


MQXFA03



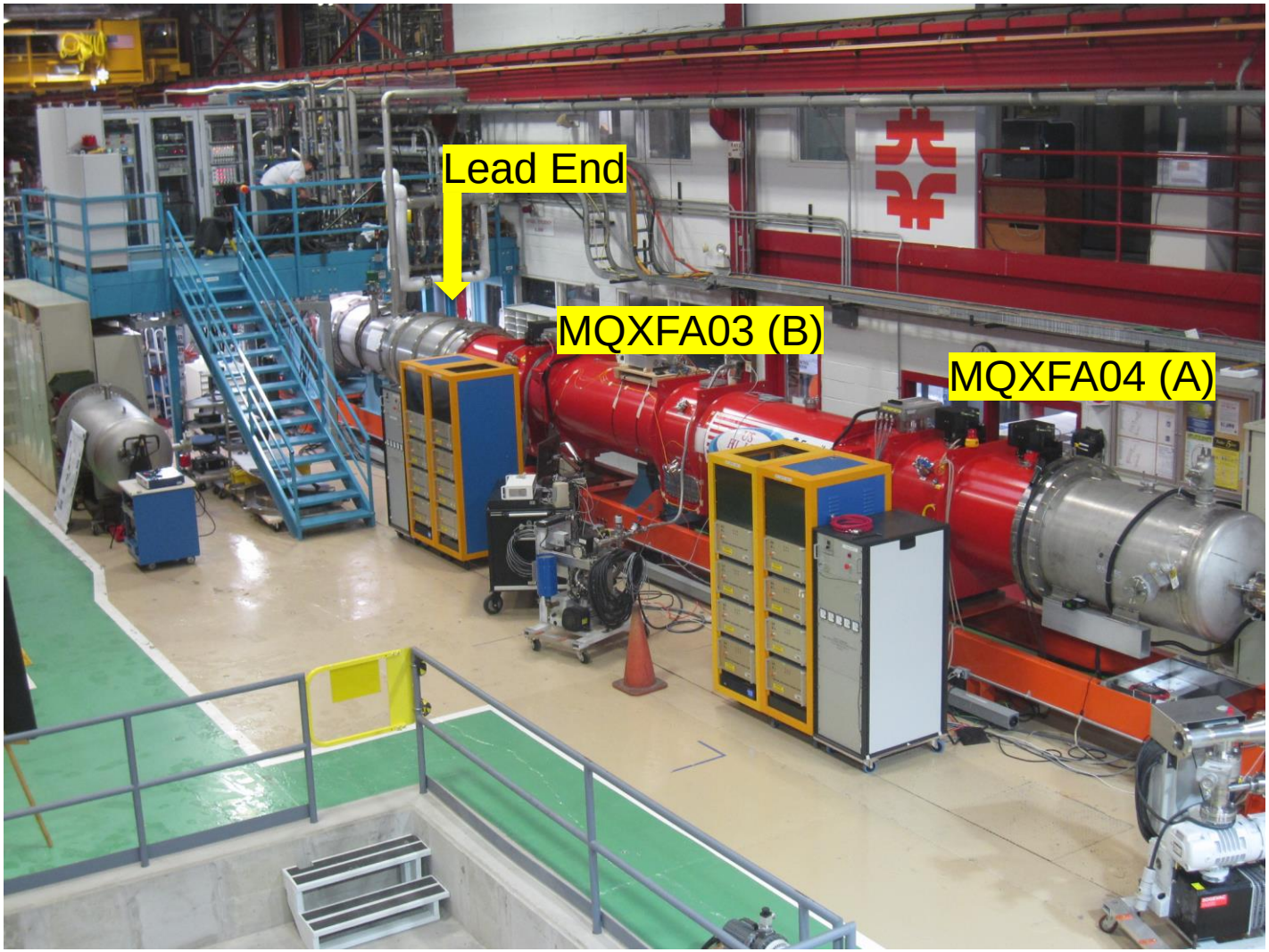
MQXFA04

- Voltage taps used only for quench detection
- Strip heaters on the outer coil layer
- Dump delayed for 1000 ms



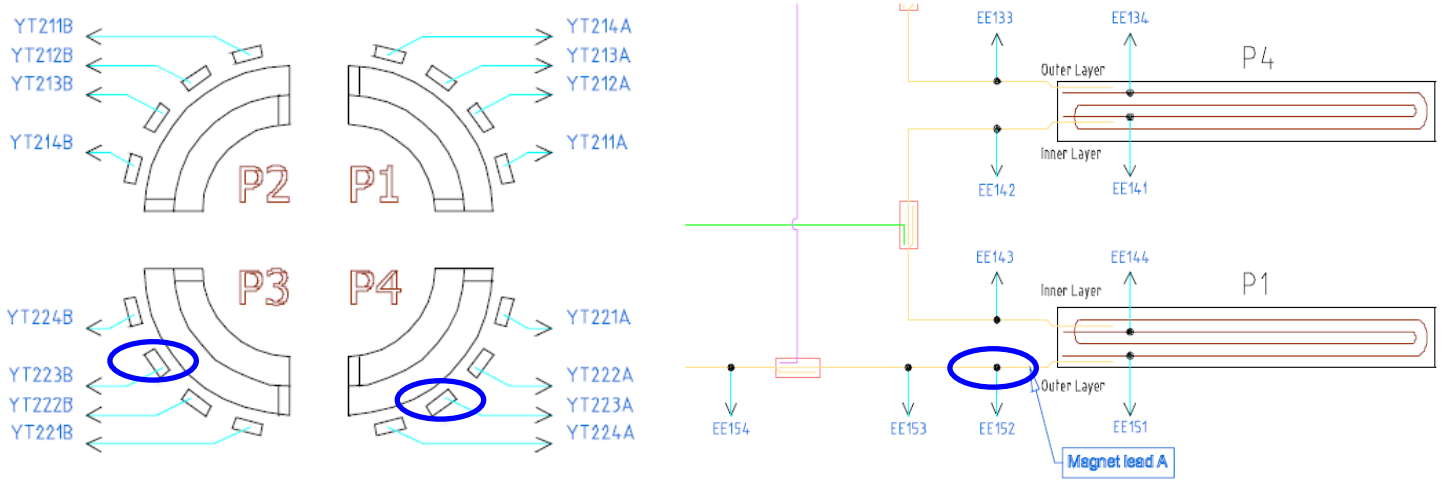
LHCLMQXF_E0001

LQXFA/B01 at Fermilab's horizontal test stand



Initial Electrical Checkouts

- Cryo-assembly was received at the test facility with one open heater (YT223 in MQXFA03) and one open voltage tap EE152

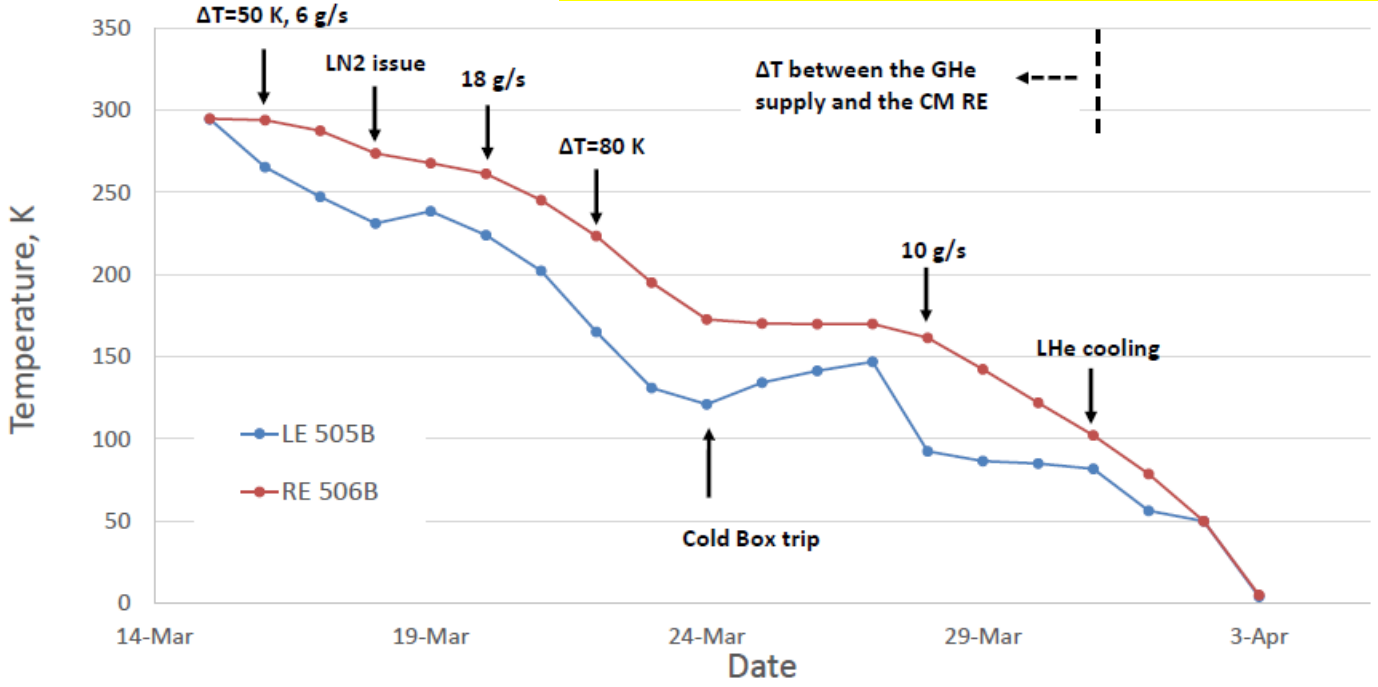


- Room temperature insulation (Hipot) tests: no failures
  - Coil-to-structure at 2.5 kV for Top plate leads w/o magnets
  - Coil-to-ground at 368 V
  - Quench heater-to-coil at 460 V

LQXFA/B01 controlled cooldown

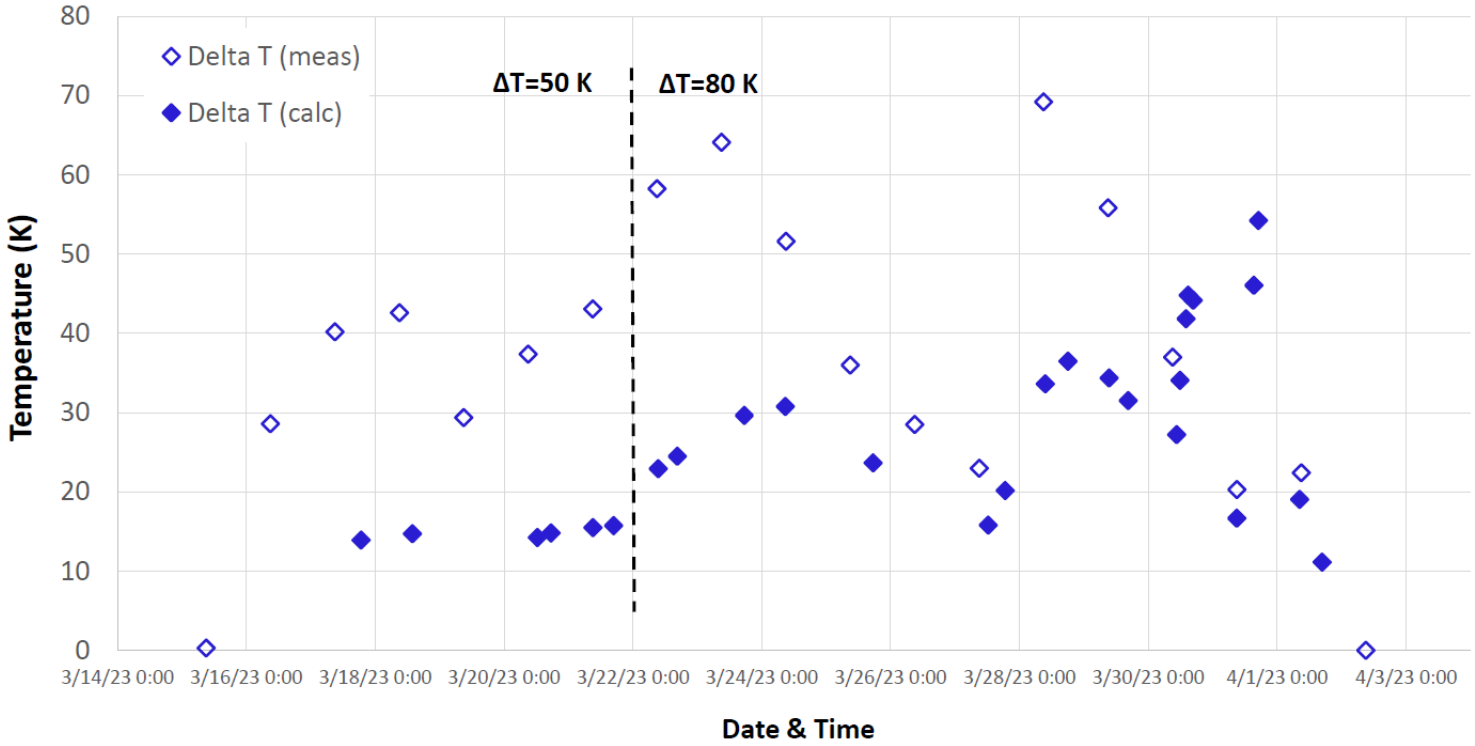
- 19 days of cooldown: Mar 15 - Apr 3
  - About 5 days of downtime due to various issues
  - First week running with the 50 K temperature difference across the cold-mass
  - GHe mass flow rate varied from 5 g/s to 18 g/s

Platinum RTDs 505/506 are installed on the CM end plates



LQXFA/B01 Controlled cooldown (2)

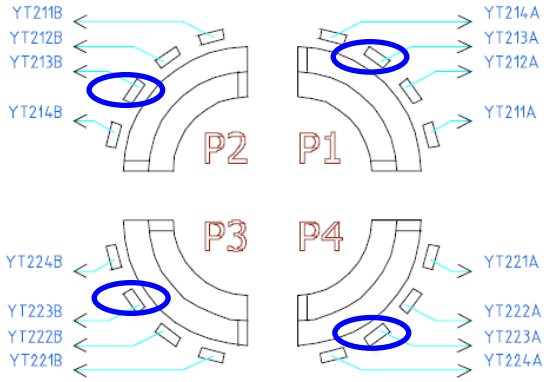
- ΔT requirement between the GHe supply and the CM RE changed from 50 K to 80 K
  - Delta T (meas) - difference between the temperature readings of the RTD sensors 505/506 located on the magnet ends
  - Delta T (calc) is based on the magnet resistance measurements



Cold Electrical Checkouts

- Coil-to-ground at 1840 V
- Quench heater-to-coil Hipot at 2300 V

Test Item	Resistance to GND/Coil	Target HV (V)	Current Threshold(μA)	Ramp Time (s)	Arc Sense Setting	Voltage Lead Location	Return Location	Max Ramp Current (μA)	Leakage Current(μA)	Success?	Type of Failure Arc or BreakDown	Breakdown V + Current
YT111 & YT112	>60Mohms	2300	10	230	1	P221 A-B	CLIQ Lead (Coil Grounded)	2.7	0.0	YES		
YT113 & YT114	>60Mohms	2300	10	230	1	P222 A-B	CLIQ Lead (Coil Grounded)	5.3	0.0	YES		
YT121 & YT122	>60Mohms	2300	10	230	1	P223 A-B	CLIQ Lead (Coil Grounded)	3.7	0.0	YES		
YT123 & YT124	>60Mohms	2300	10	230	1	P224 A-B	CLIQ Lead (Coil Grounded)	4.7	0.0	YES		
YT211 & YT212	>60Mohms	2300	10	230	1	P225 A-B	CLIQ Lead (Coil Grounded)	4.0	0.0	YES		
YT213	>60Mohms	2300	10	230	1	P226 A	CLIQ Lead (Coil Grounded)			NO	Breakdown	2190V (>10mA)
YT214	>60Mohms	2300	10	230	1	P226 B	CLIQ Lead (Coil Grounded)	2.9	0.0	YES		
YT221 & YT222	>60Mohms	2300	10	230	1	P227 A-B	CLIQ Lead (Coil Grounded)	3.2	0.0	YES		
YT224	>60Mohms	2300	10	230	1	P228 B	CLIQ Lead (Coil Grounded)	2.3	0.0	YES		



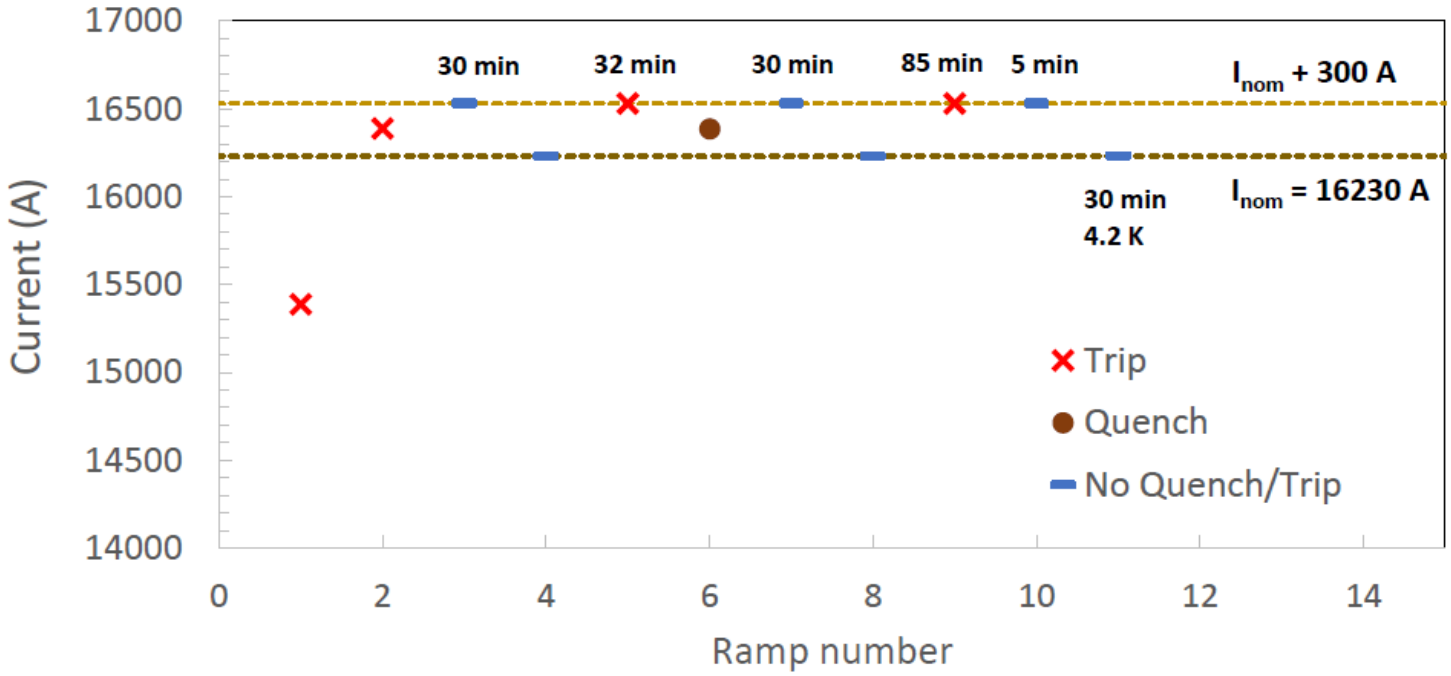
MQXFA03: YT213A/B heater failed the Hipot test around 2190 V

- No dead short to coil or ground, small current leakage at 200 V
- Dummy load is used instead of YT213

No degradation of the heater to coil and heater to ground insulation observed after the thermal cycle

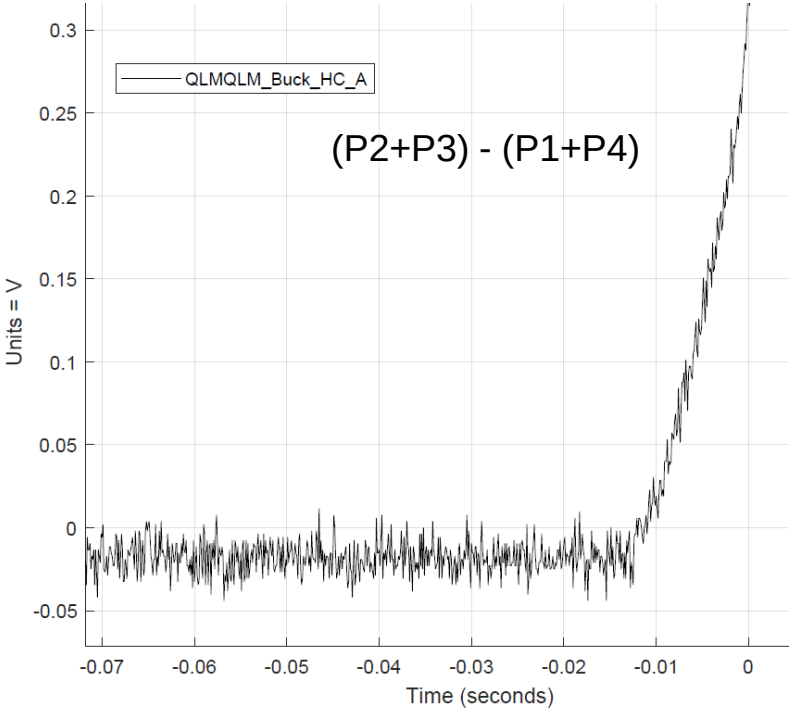
LQXFA/B01 Quench Performance in TC1

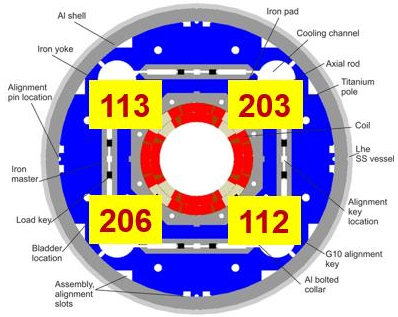
- Magnets reached the acceptance current Inom+300 A w/o a quench, but with two trips in leads
  - One of the Cu-SC lead joints in the top plate assembly exhibited higher resistance and the LHe level adjustments were required
- Two attempts of the holding current test
  - First trip at Inom+300 A=16530 A caused a minor detraining

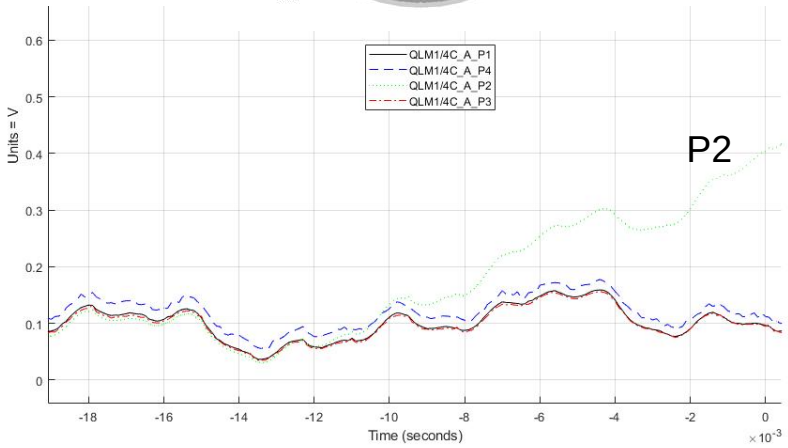


Quench in TC1

- Only one spontaneous quench in magnets
  - Quench at 16386 A, in MQXFA04 (Magnet A), coil 113 (P2)
  - Quench Integral 27.8 MIITs (w/o external energy extraction)

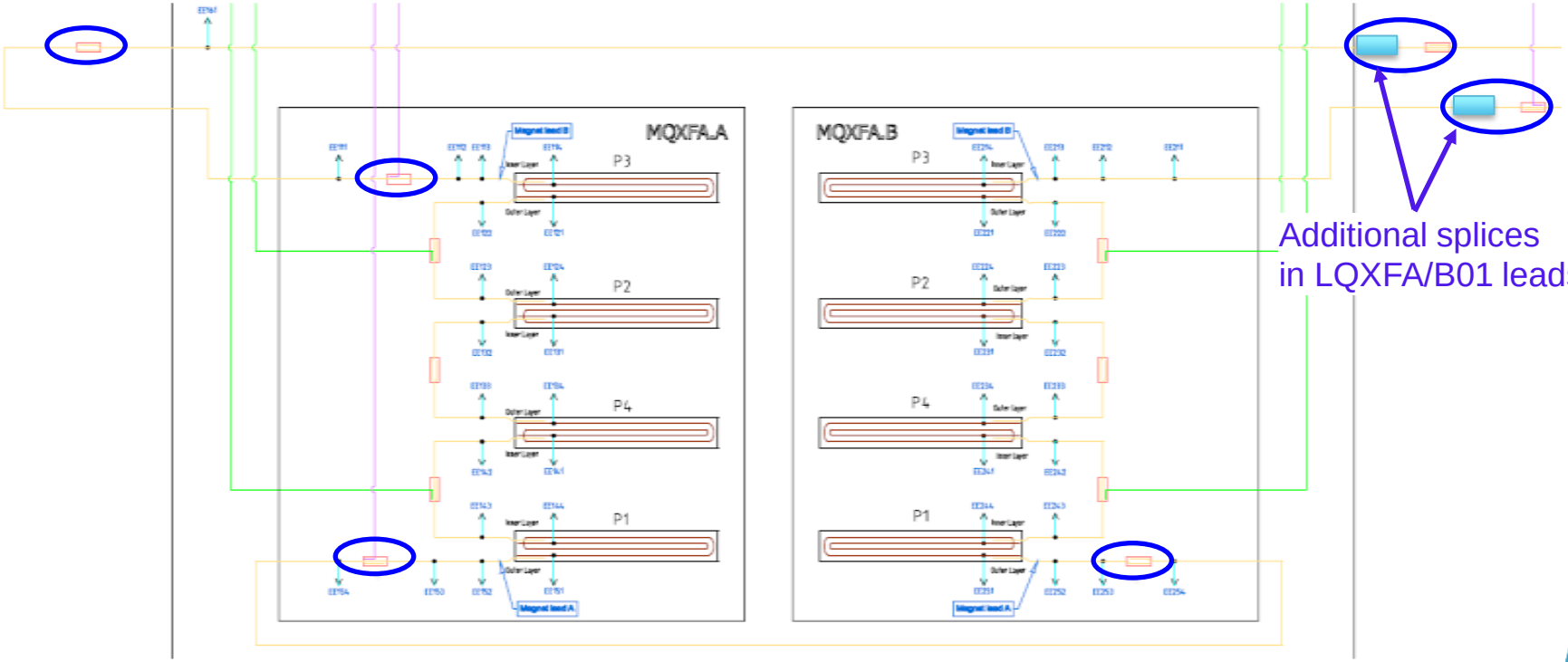






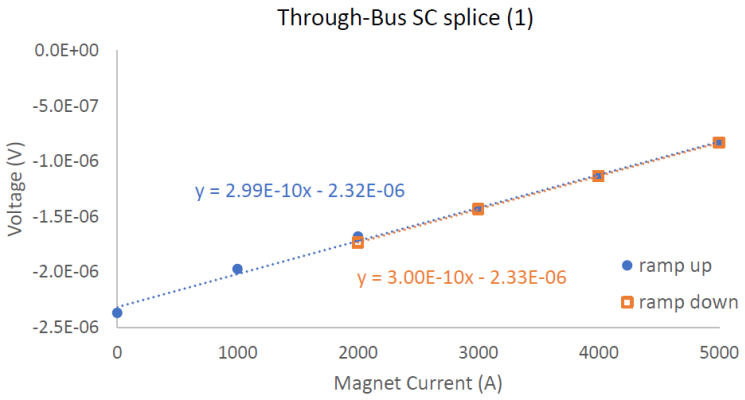
Splice measurements

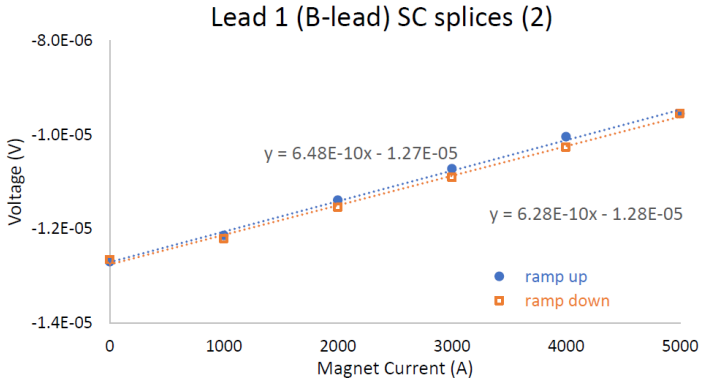
- Two additional splices were made in LQXFA/B01 power leads to add extra length for testing at Fermilab (and CERN)
  - Lead length w/o the additional splice is sufficient for the tunnel installation at CERN

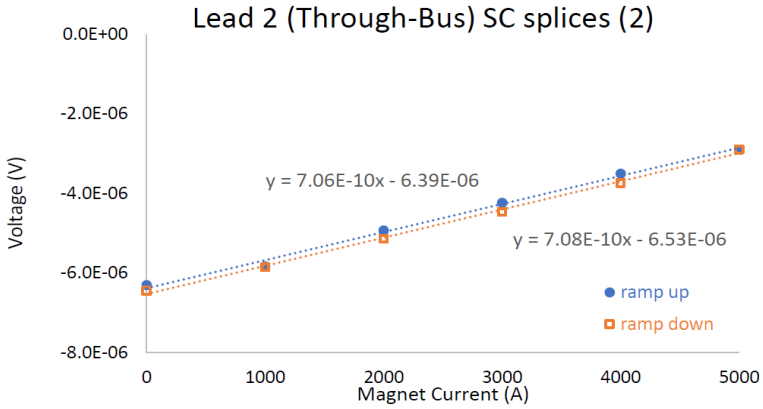


Splice measurements (2)

- Splice measurements were made at 1.9 K for currents up to 5 kA
  - 8-channel MUX system based on Keithley 2182A Nanovolt Meter
- Two-splice segments are measured ~0.7±0.1 nΩ, and single splice segments - less than 0.3±0.1 nΩ

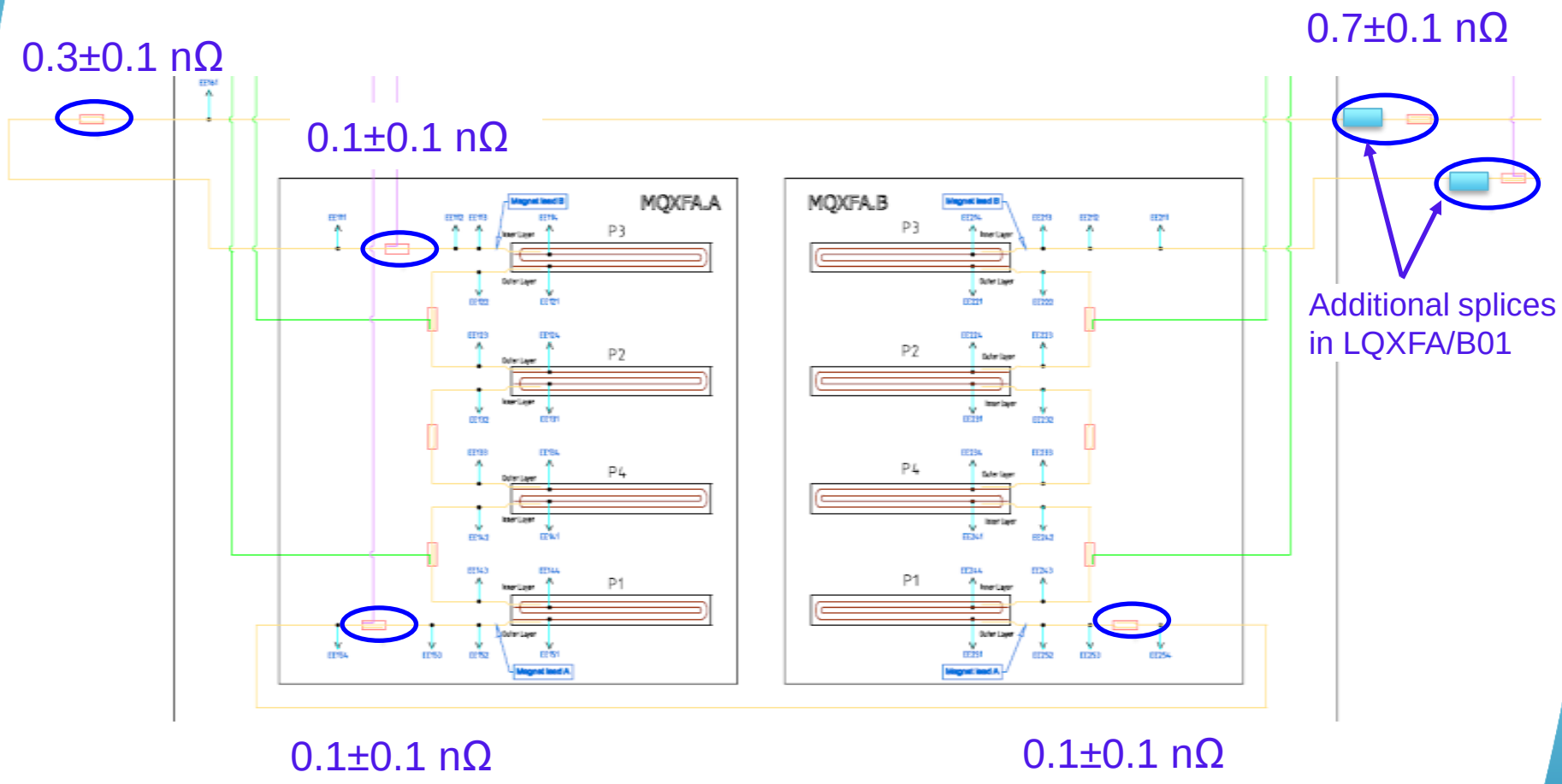






Splice measurements (3)

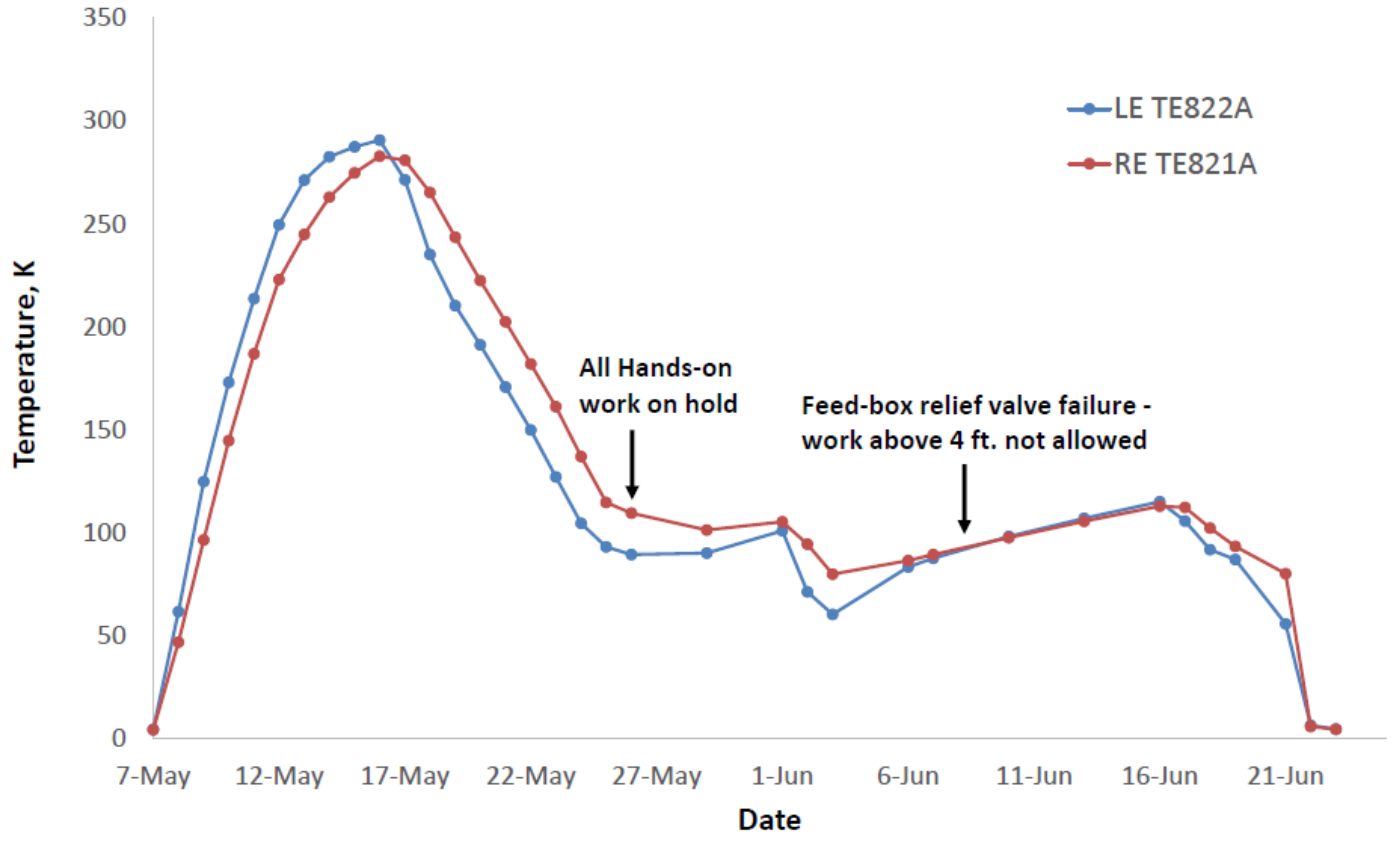
- Splices resistance values well below the required 1 nΩ



Warmup and cooldown for TC2

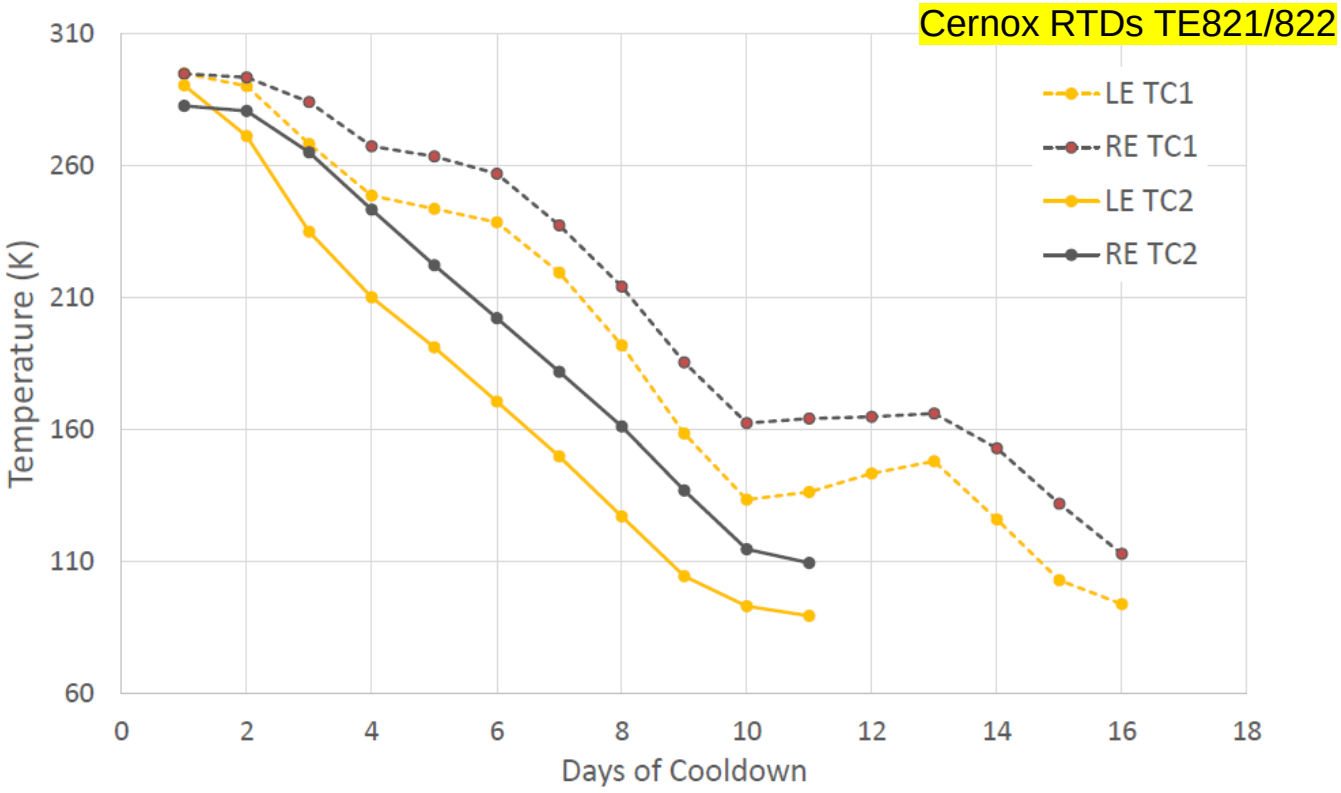
- Controlled warmup just over 1 week. Cooldown was interrupted few times

Cernox RTDs TE821/822 installed in the CM shell openings



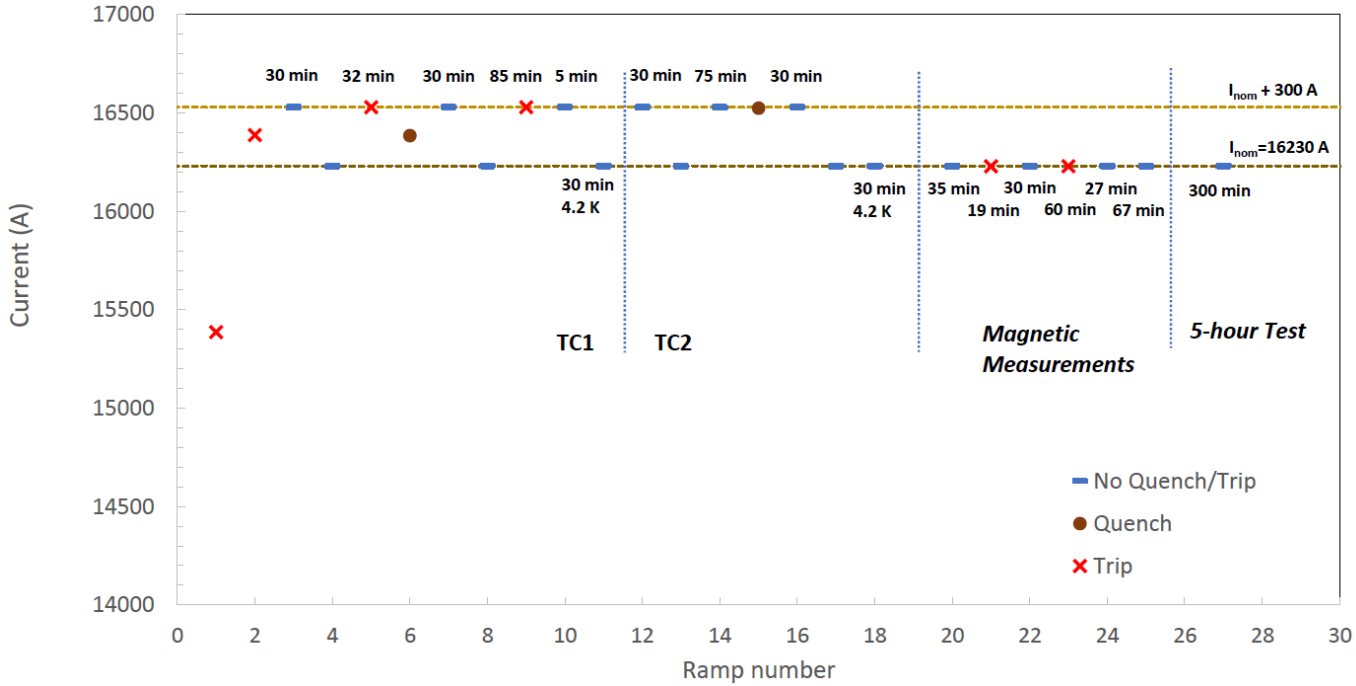
Cooldown in TC1 and TC2

- First cooldown used for optimizing the controlled cooldown parameters
  - Two weeks are expected for 1.9 K cooldown. Further improvement requires upgrade of the heat exchanger in the Helium return line



LQXFA/B01 Quench Performance in TC2

- The acceptance current reached w/o a quench.
  - Only one spontaneous quench in TC2 at 16525 A in MQXFA03, coil 111 (P4), QI 27.6 MIITs
- The holding current test failed after 75 min due to the same LHe stability issue (no trip thanks to PLC interlock modification)
  - High ramp rate test (with 150 A/s ramp down) successfully done



Plans for Testing LQXFA/B02

- Improvements of the cryogenic system components are planned before LQXFA/B02 test
  - Inspect and fix Feed box helium supply valves
  - Replace failed flowmeter and plastic rotameters
  - Upgrade valve actuators
  - Improvements will be prioritized and executed as test schedule allows
- Root cause of the liquid helium instability is understood
  - No additional investigation is required
- The Cu-SC lead joint repair will increase robustness to the LHe level fluctuations in future
- Second liquefier maintenance to be completed by the end of October
- LQXFA/B02 test prep work to be completed in November

LQXFA/B01 leaving the Magnet Test Facility

Conclusions

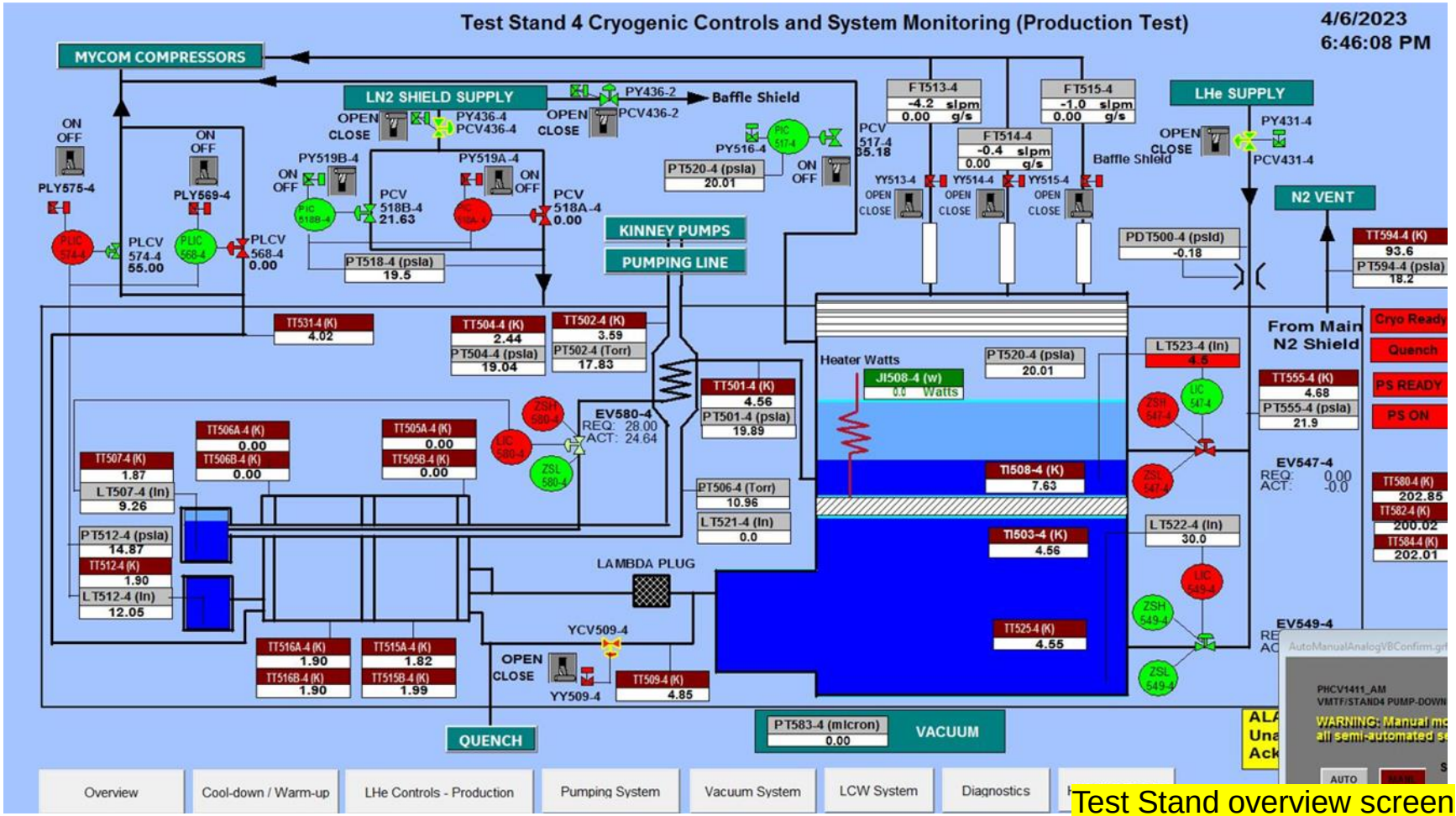
- The first pre-series cryo-assembly LQXFA/B01 successfully tested at Fermilab's horizontal test stand
  - The test facility upgrades successfully commissioned with a cryo-assembly for the first time
  - Liquid level instabilities and power supply issues, as well as Lab-wide safety pause made the commissioning and test longer than expected
  - The cryogenic issues were identified and fixed, allowing the completion of the horizontal test

- LQXFA/B01 test goals are achieved
  - Only two spontaneous quenches in magnets - one per magnet
  - Nominal and acceptance currents are reached at 1.9 K
  - Nominal current was reached at 4.2 K
  - Ramp down at 150 A/s was validated
  - Nominal current was successfully held for 5 hours

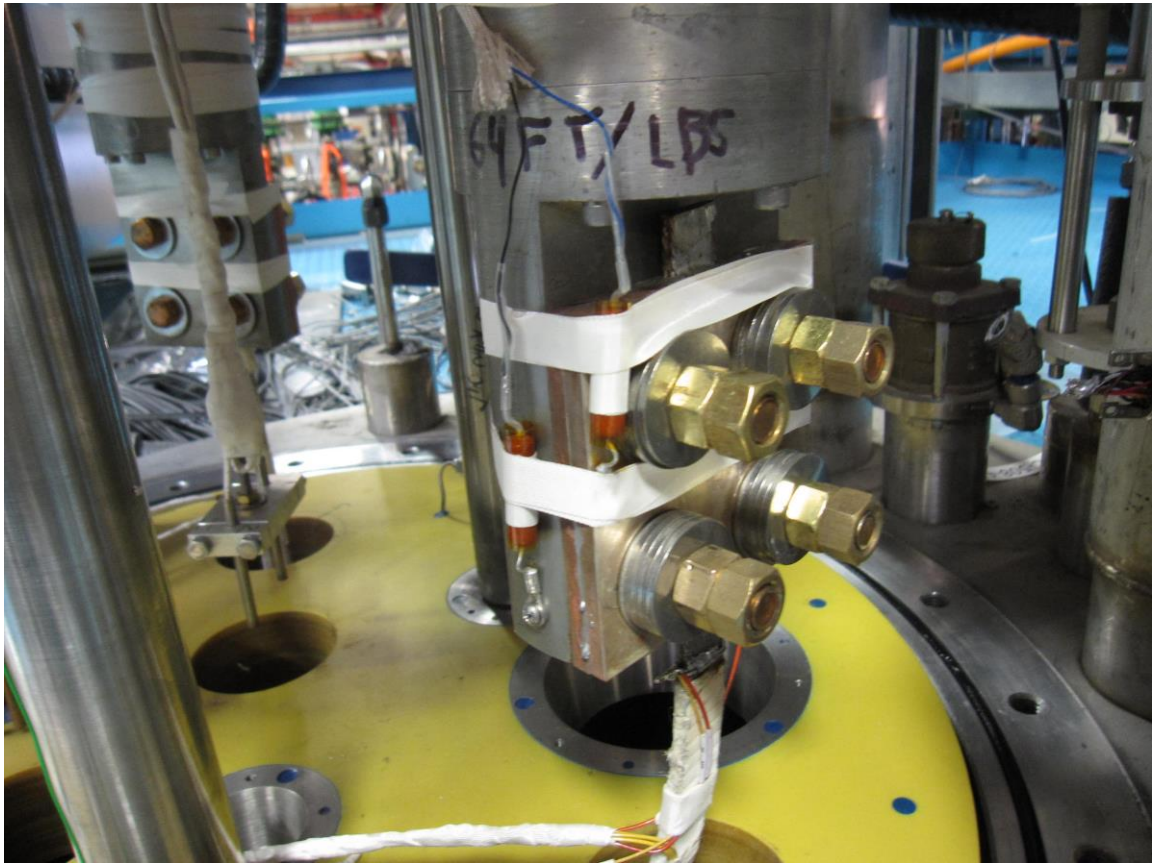
Backup Slides

LQXFA/B01 Test Status (2)

- On Apr. 6, LQXFA/B01 was cooled down to 1.9 K



Test Stand overview screen


64 FT/LBS