Horizontal Test Results of LQXFA/B02 and Plans for testing LQXFA/B03

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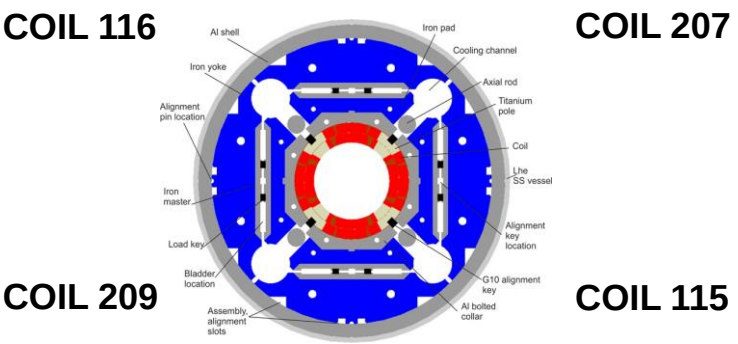
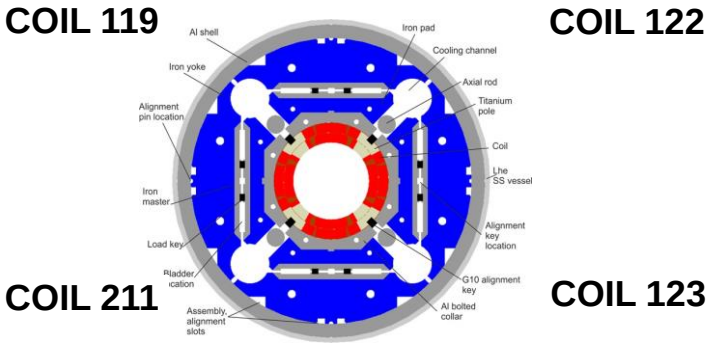
LQXFA/B02

- MQXFA05 and MQXFA06 magnets of LQXFA/B02 have been trained at BNL

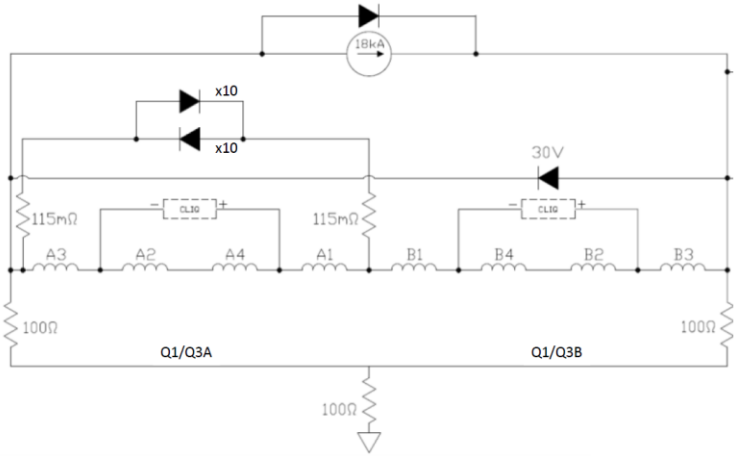


MQXFA05 (MQXFA.A)

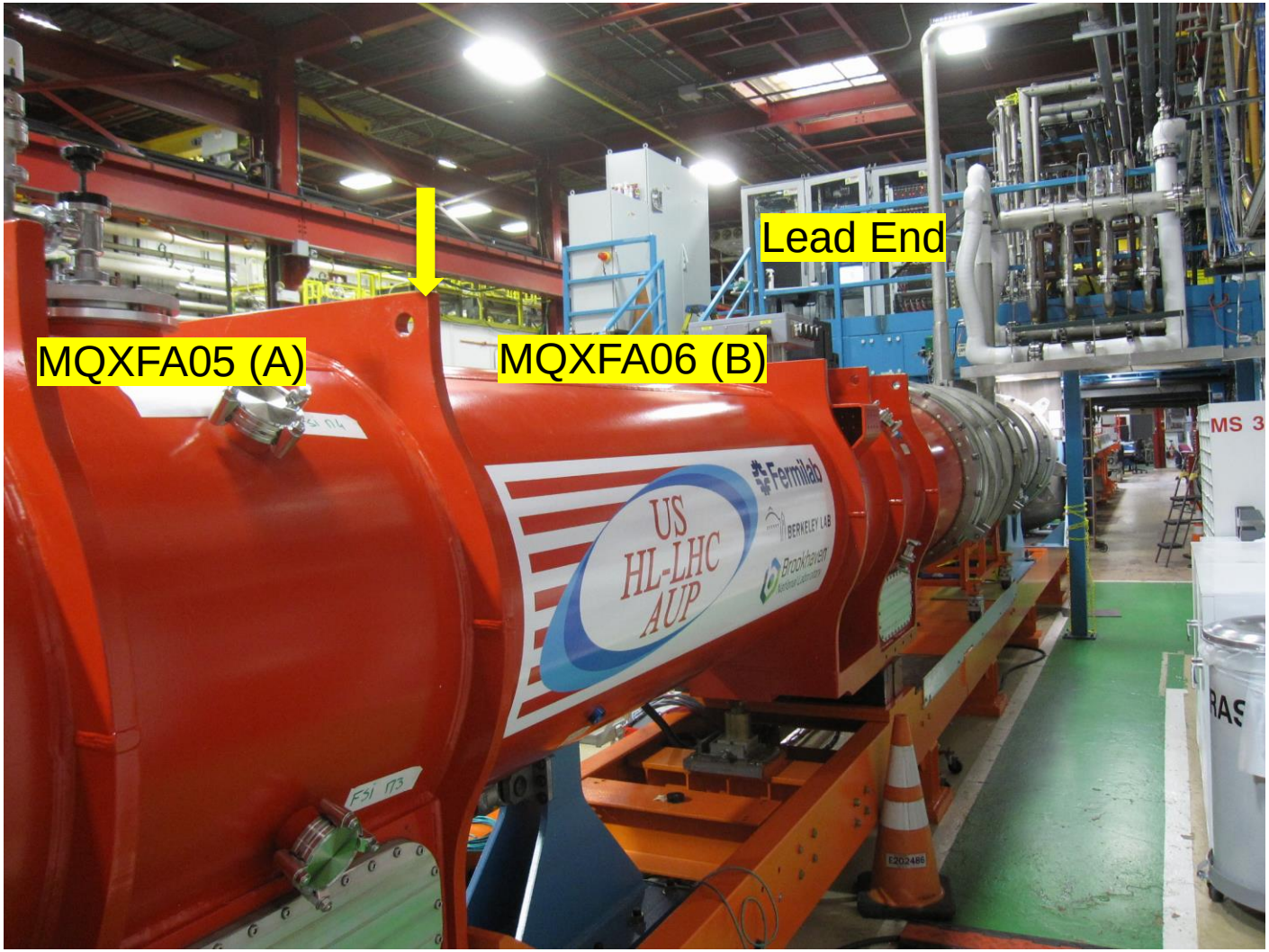


MQXFA06 (MQXFA.B)

- Quench protection includes CLIQ & Strip heaters on the outer coil
- No external EE (Dump delay 1s)



LQXFA/B02 at Fermilab's horizontal test stand

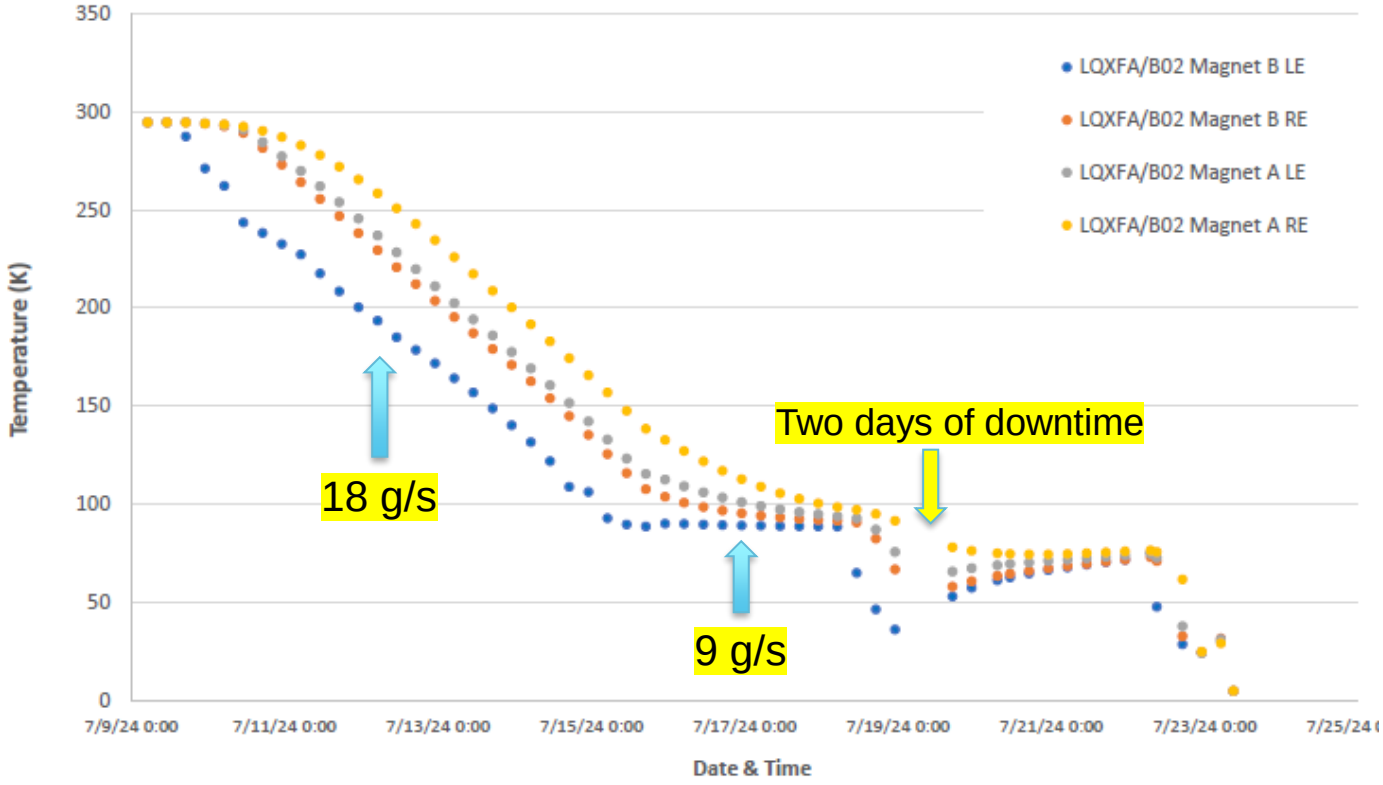


Initial Electrical Checkouts

- All v-taps, temperature sensors and protection heaters functional
- Fast pressure transducers installed at both ends of the cryo-assembly to measure pressure wave after the quench/trip
  - Sensors with wiring will be removed after the test, before cryo-assembly is shipped to CERN
- Successfully passed room temperature insulation (Hipot) tests
  - Lead-to-ground at 2.5 kV, Top plate w/o magnets
  - Coil-to-ground (heaters grounded) at 368 V
  - Quench heater-to-coil (coil grounded) at 460 V
- Cold insulation (Hipot) tests performed at 1.9 K
  - Coil-to-ground (heaters grounded) at 1840 V (1.9 K)
  - Quench heater-to-coil (coil grounded) at 2300 V (1.9 K)

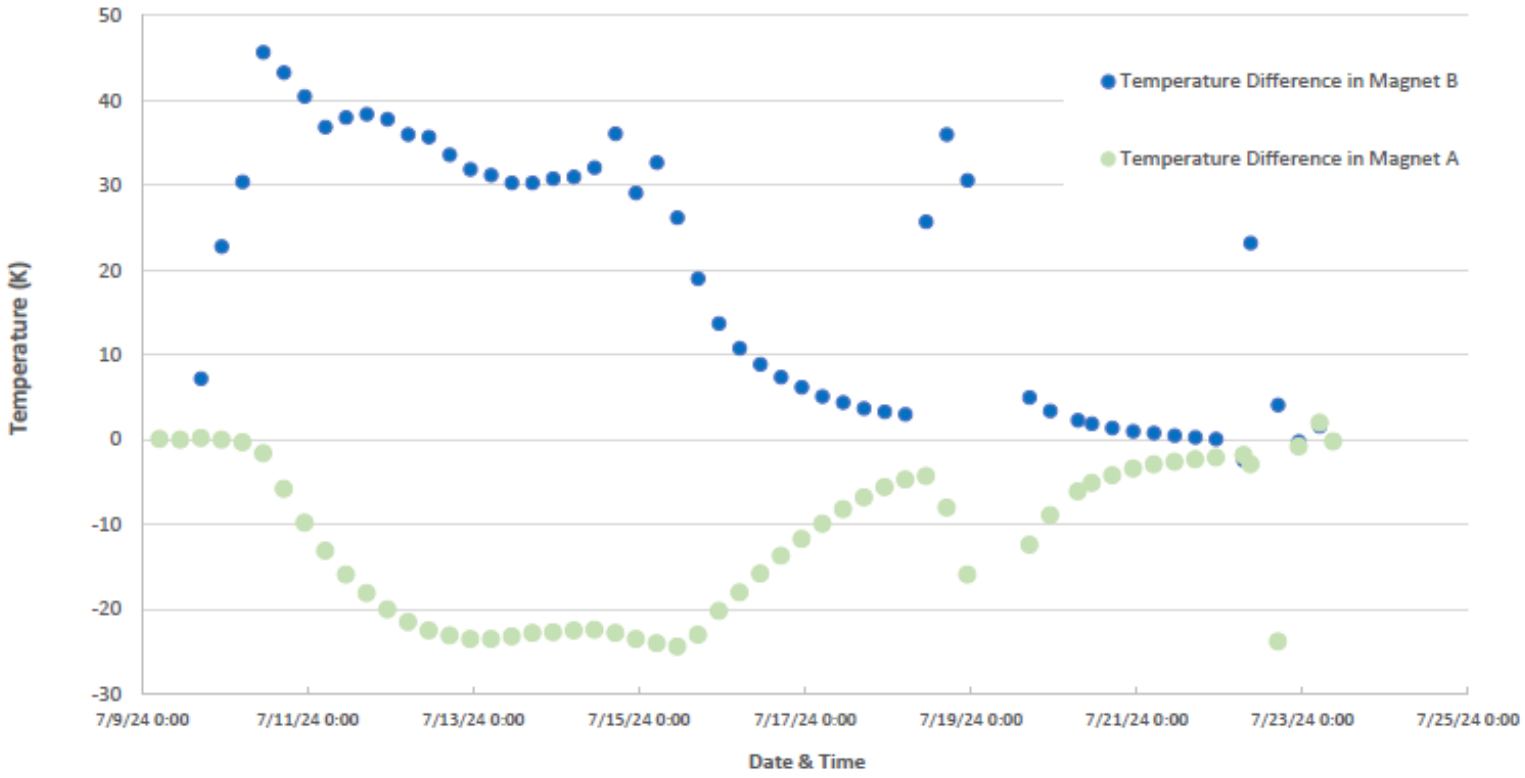
LQXFA/B02 controlled cooldown

- 14 days of cooldown from Jul 9 to Jul 23 (compare to 19 days in LQXFA/B01)
  - Two days of downtime due to cybersecurity issues
  - GHe mass flow rate varied from 9 g/s to 18 g/s



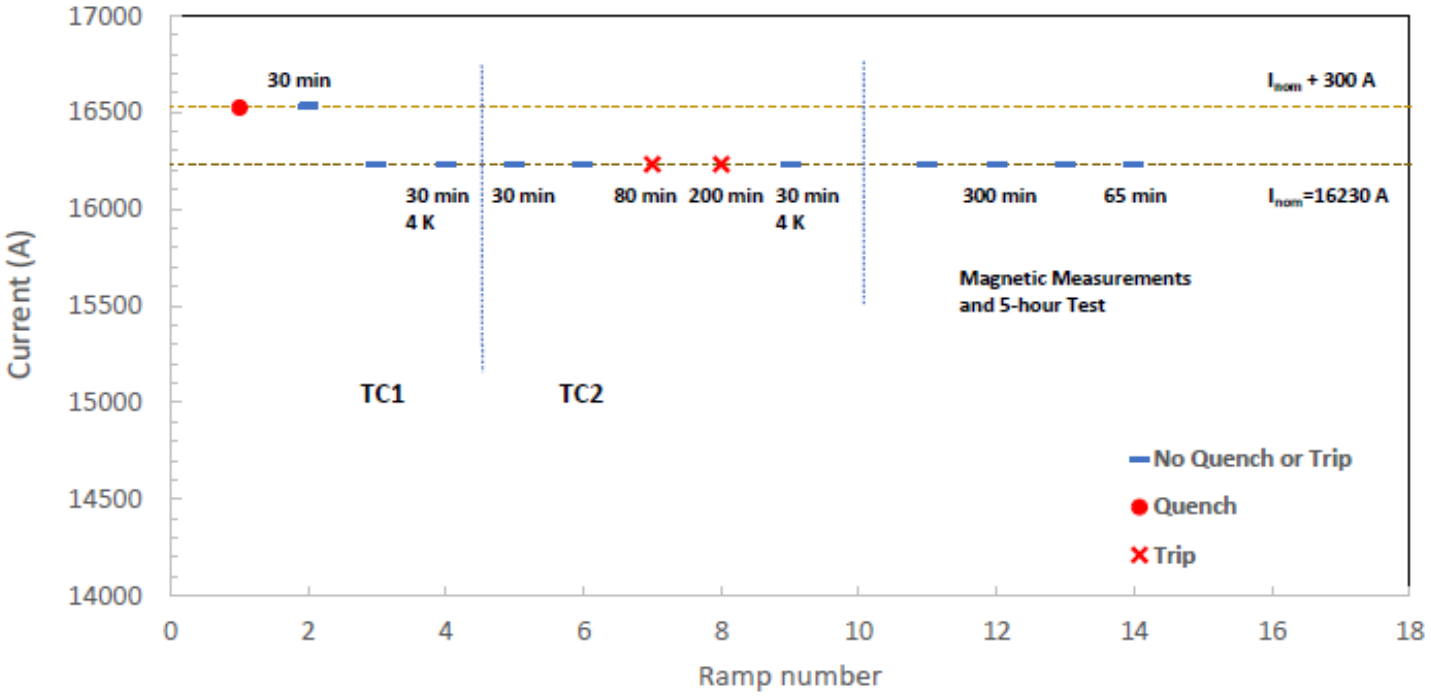
LQXFA/B02 Controlled cooldown (2)

- Better temperature control with temperature sensors installed on both ends of each magnet in LQXFA/B02



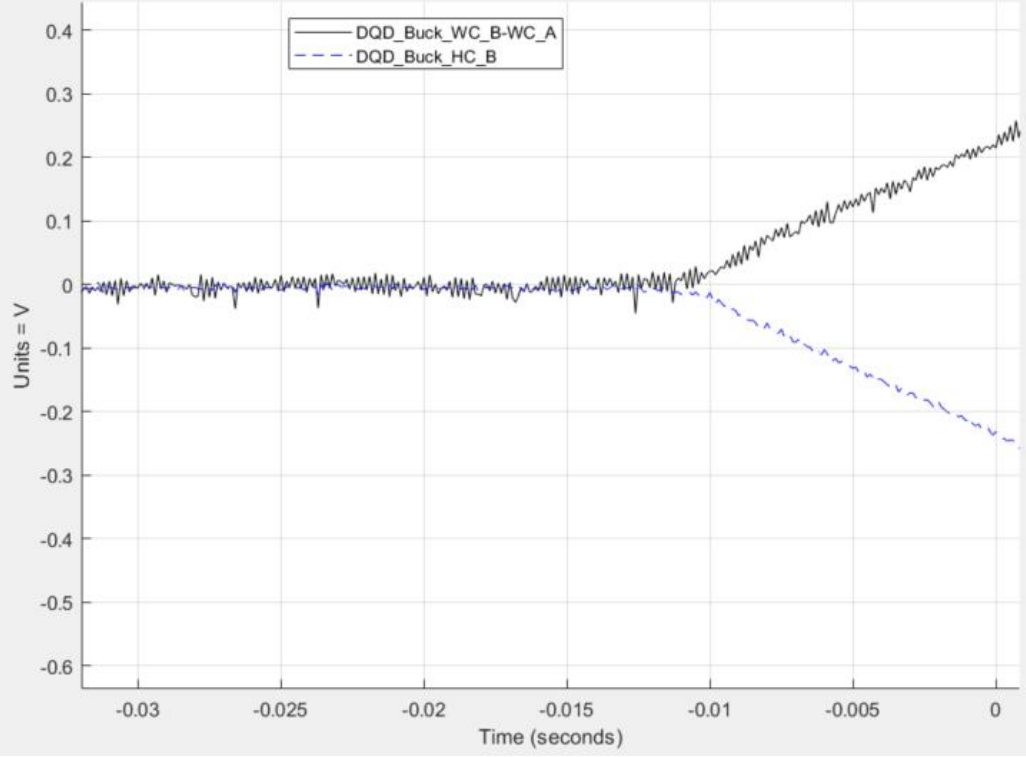
LQXFA/B02 Quench Performance

- Only one quench in two test cycles
  - Quench at 16524 A, see details on the next slide
- Two power supply related trips during the holding current test at the nominal current of 16230 A



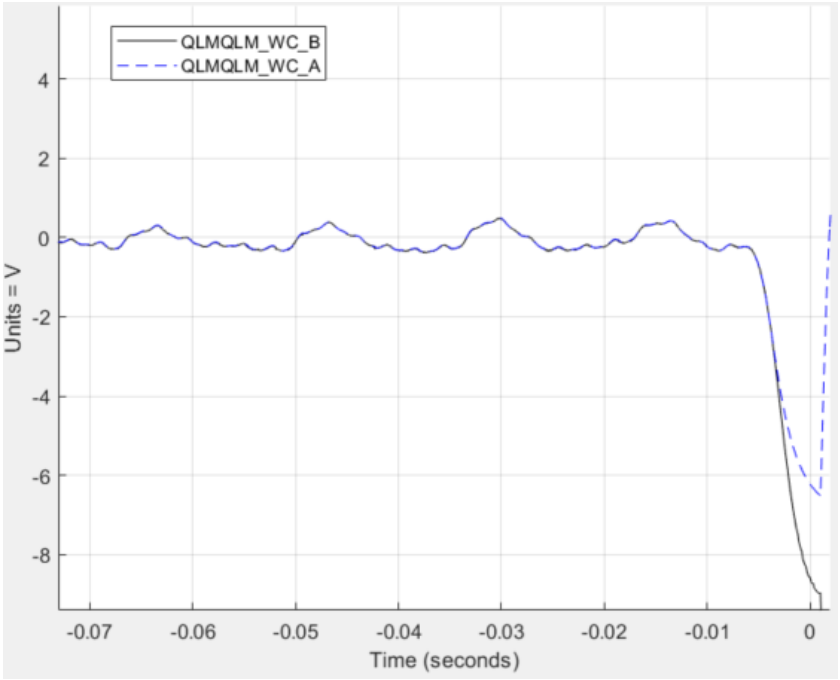
Quench in TC1

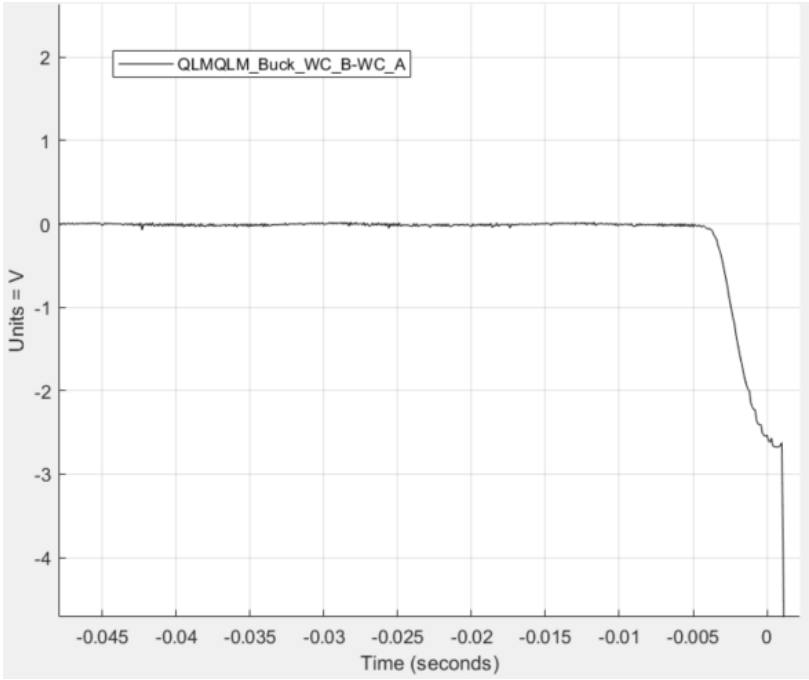
- Only one spontaneous quench in MQXFA06 (B), coil 122 (pole 1)
  - Quench current 16524 A
  - Quench Integral 27.2 MIITs



Trips at the nominal current

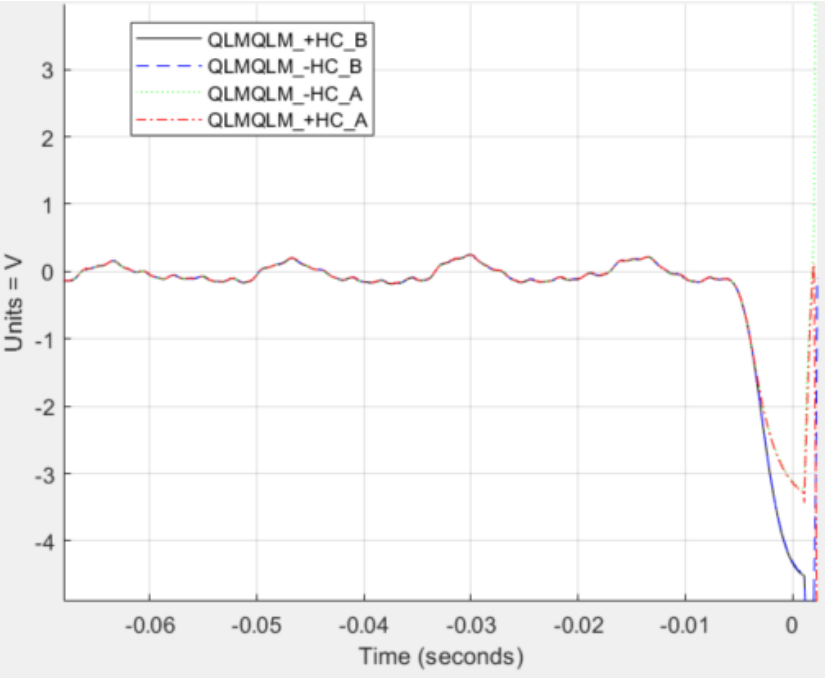
- Two trips at I_{nom} with very similar pattern
  - No resistive signals in coils or leads, only inductive signals in all coils
  - Quench detection has been triggered due to difference between the inductive signals in magnets B and A

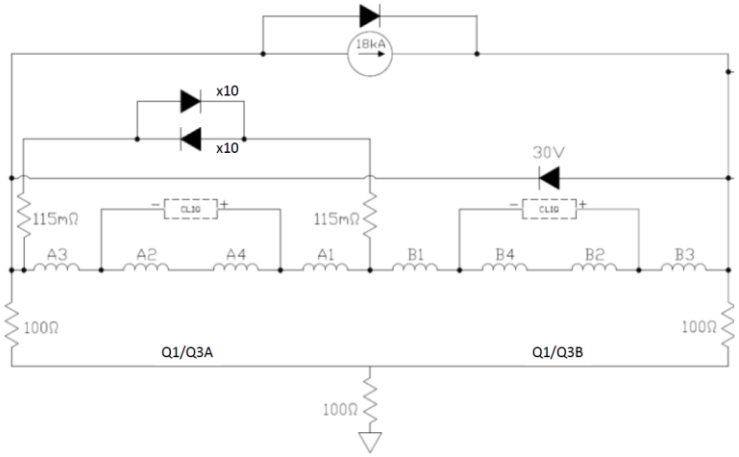




Trips at the nominal current (2)

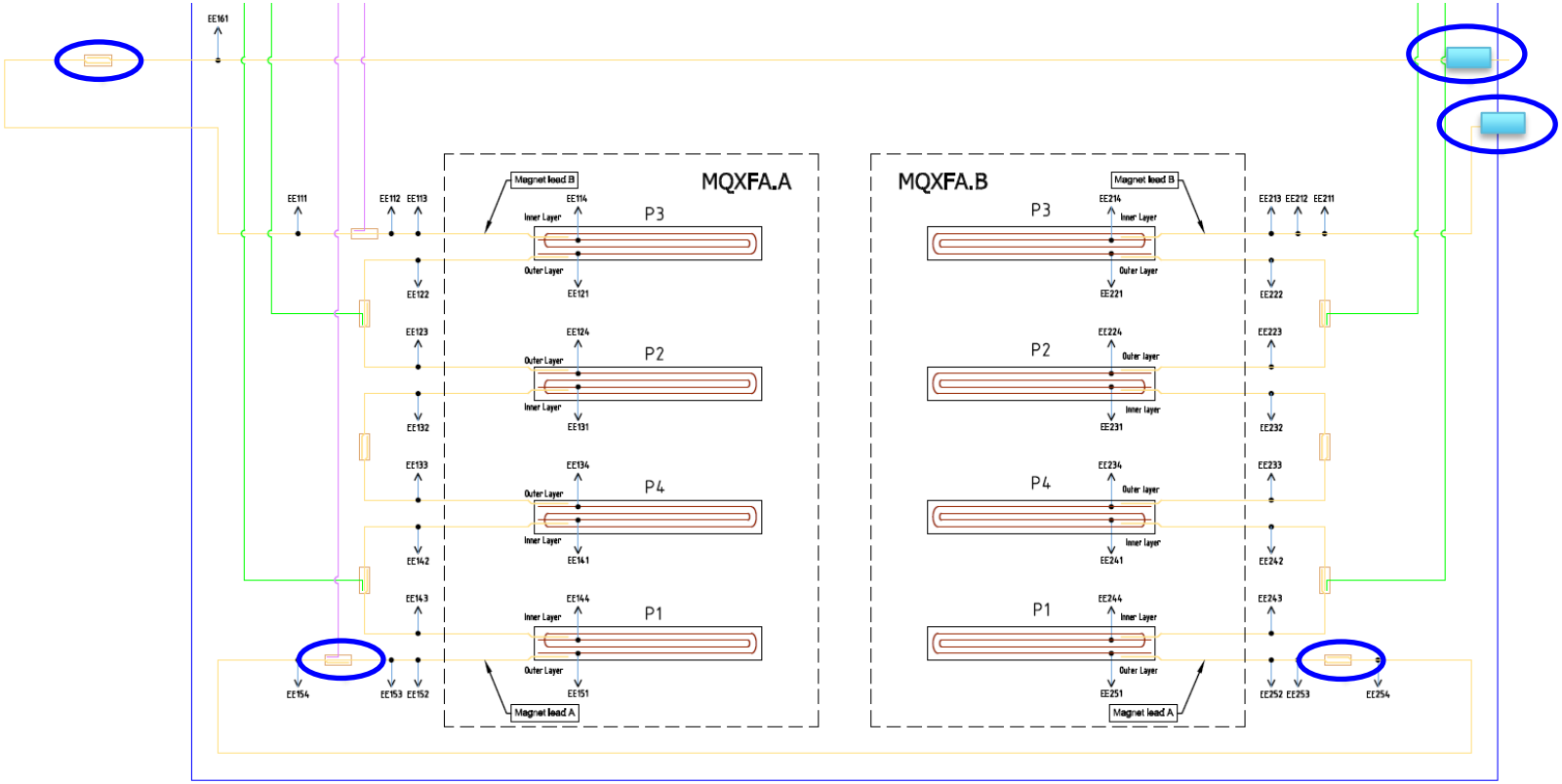
- Difference in the inductive signals could be related with the protection diode system connected to the magnet A
- We are not familiar with this type of the power supply failure
  - Investigation of these events still in progress, no apparent cause of the problem was found yet





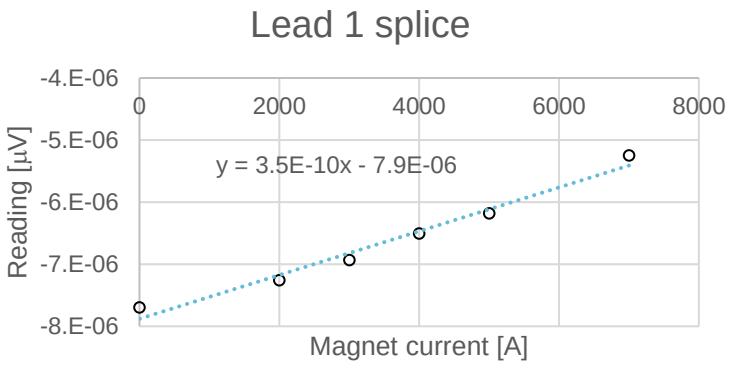
Splice measurements

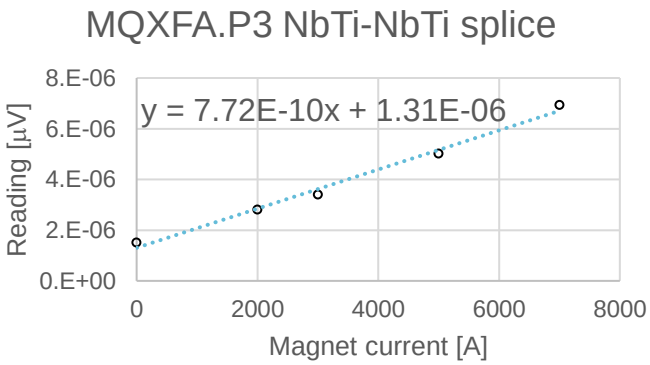
- All splices, made at Fermilab, have been measured
  - Includes two splices required for connected magnets to the test facility

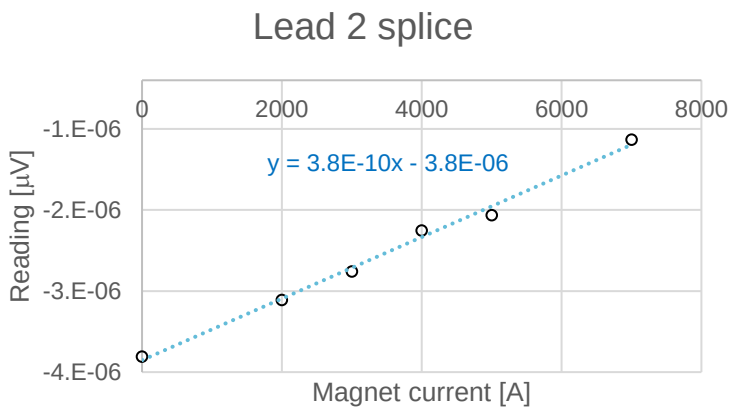


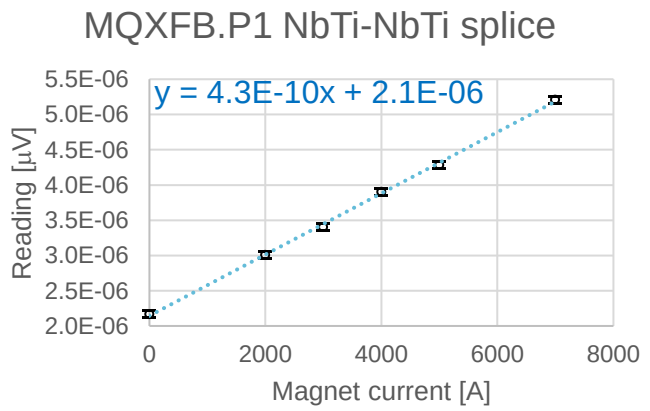
Splice measurements (2)

- Measurements were performed at 1.9 K for currents up to 7 kA
- All splice resistances are less than 1 nOhm









US HL-LHC AUP

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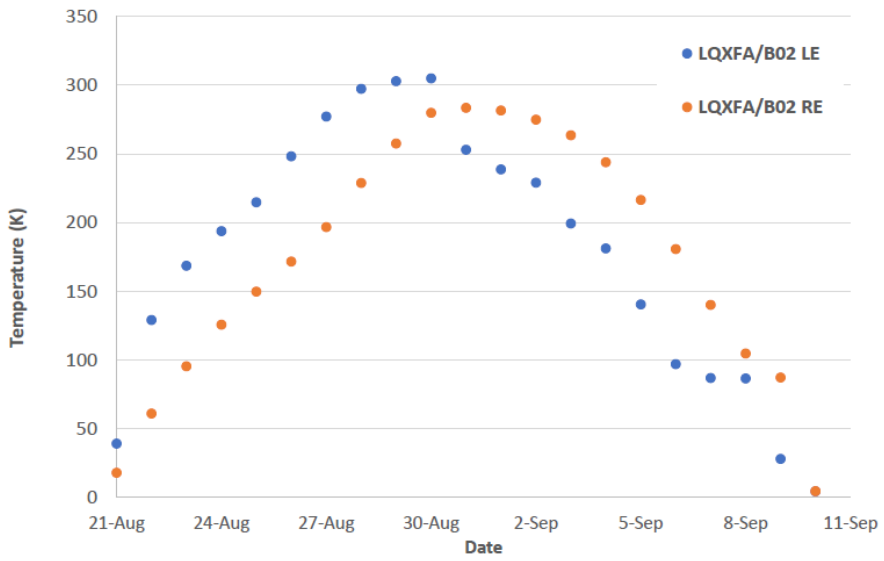
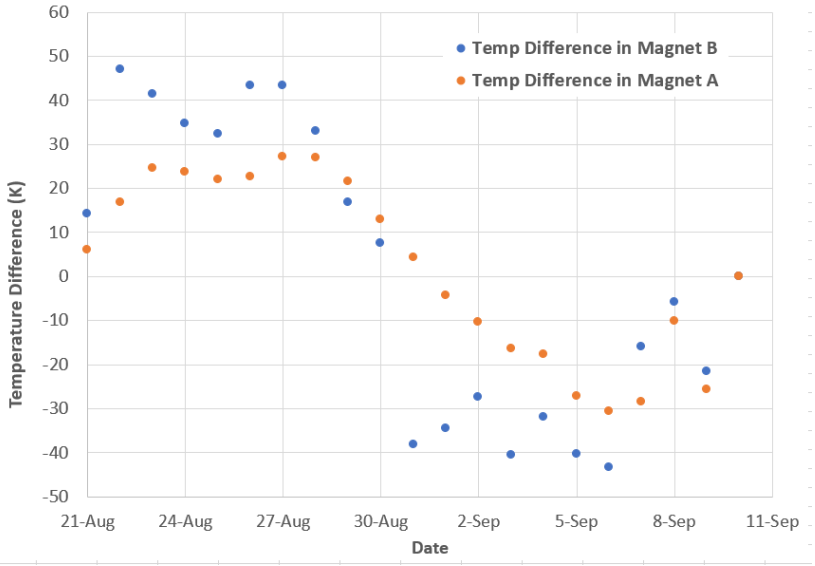
Thermal Cycle

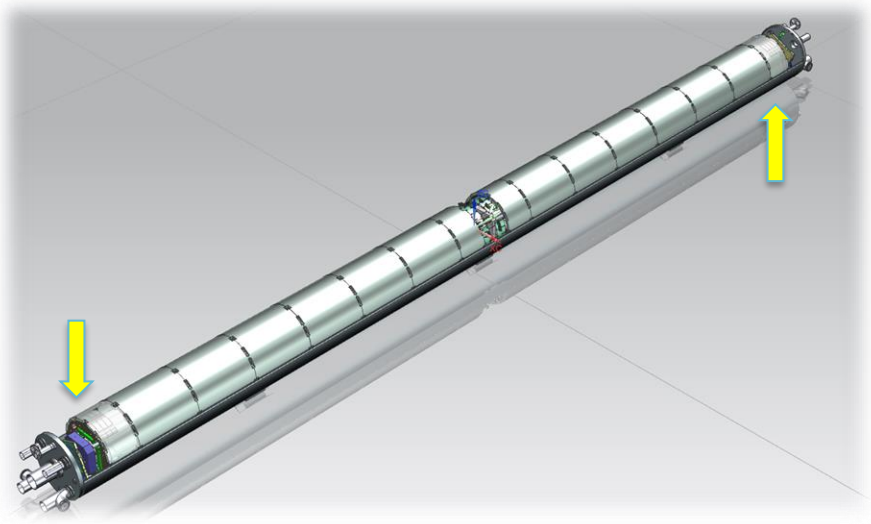
- Controlled warmup and cooldown from Aug. 21 to Sep. 10
  - Total of 20 days. Further improvement will require modification or upgrade of the heat-exchanger in the helium return line

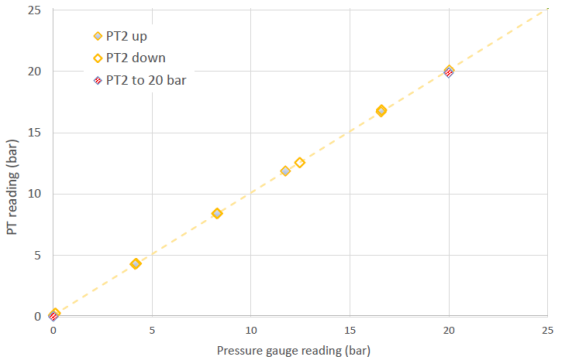


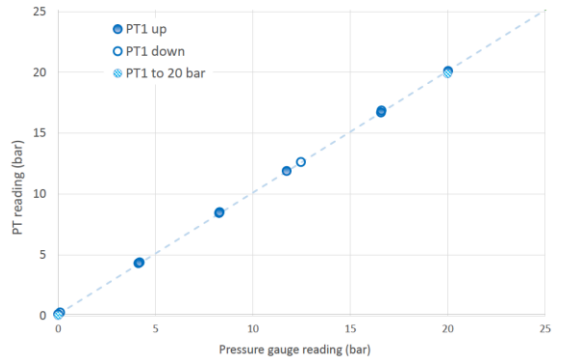


Pressure wave measurements

- Fast “cold” pressure transducers by *WIKA Sensor Technology* were installed at both ends of the LQXFA/B02 cryo-assembly, close to the cold-mass end plates
  - Rated for pressures up to 25 bar, frequency response above1000 Hz
  - Sensors calibrated during the cold mass pressure test up to 20 bar

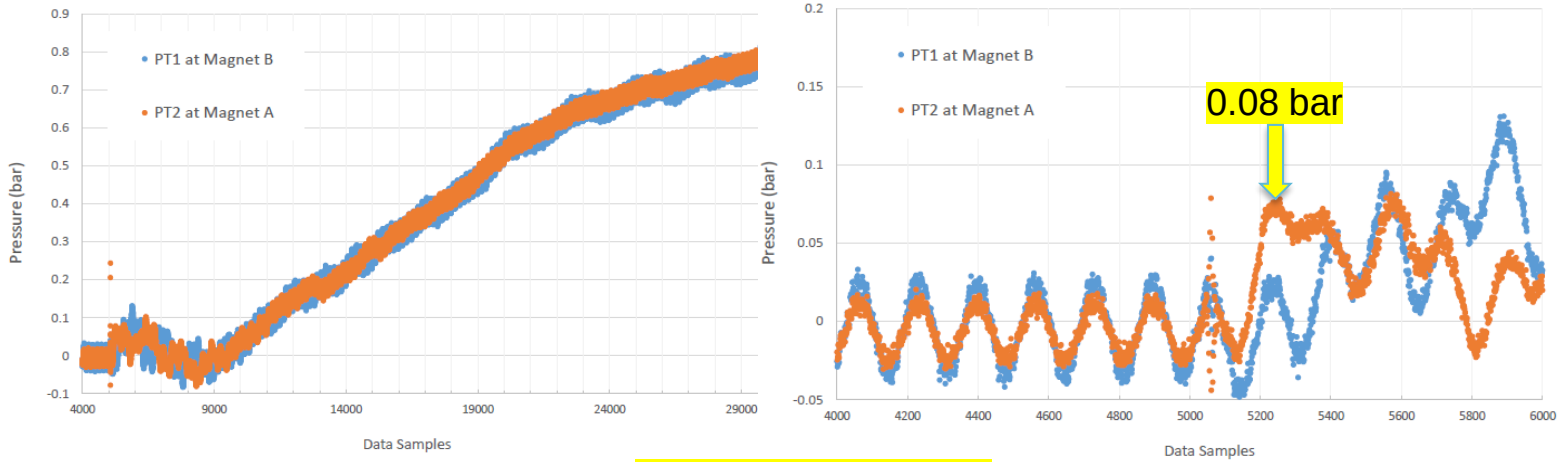






Pressure wave measurements (2)

- Manual trip in Magnet A at 6 kA (single magnet configuration)
  - Data analysis still in progress
  - PT1 (B) signal delay with respect to PT2 (A) is about 20 ms
  - Pressure PT2 reached about 0.08 bar in 5 ms
  - At the nominal current, if pressure continues linear increase all 20 ms, it may reach 0.08 x 4 = 0.32 bar
  - We plan high current tests with one of the future cryo-assemblies



Sampling rate 10 kHz

Cryogenic System improvements

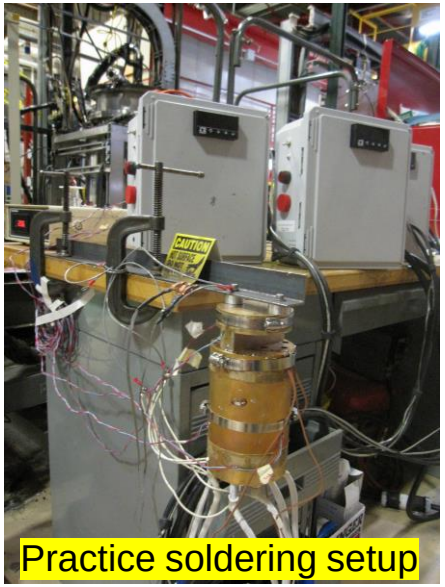
- First cryo-assembly test demonstrated that cryogenic system improvements were necessary to meet the Horizontal CA test requirements

- Following upgrades have been completed in preparation for LQXFA/B02 test
  - Various monitoring instrumentation have been added for improvement of the controlled cooldown and warmup of the cryo-assembly
  - Quench recovery automation was improved
  - Fully automated 4.5 K overnight operation has been implemented
  - Helium line heaters are installed to expedite the cooldown and warmup processes
  - Most of the failed instrumentation was replaced or repaired (pressure transmitters, flowmeters and rotameters, leaking valves)
  - Current lead joint improvement has been implemented

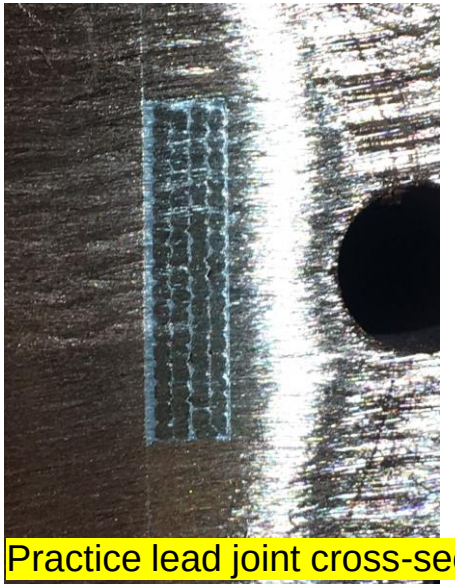
Current lead joint improvement

- One of the current lead joints at Stand 4 exhibited increased resistance
  - To avoid overheating of the superconducting bus, the helium liquid level was elevated accordingly
- New copper fixture was designed, fabricated and tested to improve the cooling conditions of the lead joint


New copper fixture

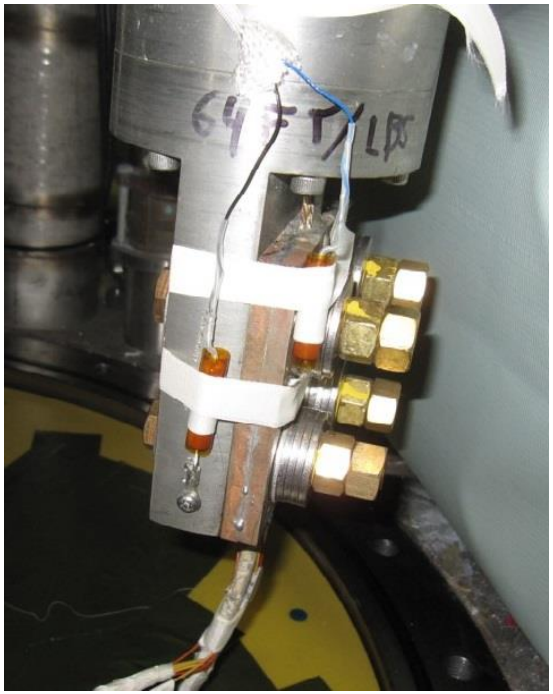


Practice soldering setup


Practice lead joint cross-section

Current lead joint improvement (2)

- The lead joint with increased resistance was modified with the newly developed fixture
  - Heat load from this specific lead joint was reduced by factor of 10
  - Other two lead joints will be modified later



Lead joint with increased resistance

Modified lead joint at Stand 4

LQXFA/B02 Test Summary & Plans for LQXFA/B03 Test

- LQXFA/B02 cryo-assembly successfully tested at Fermilab's horizontal test stand

- LQXFA/B02 test goals are achieved
  - Only one spontaneous quench in two test cycles
  - Nominal and acceptance currents are reached at 1.9 K
  - Nominal current was reached at 4 K
  - Ramping down at 150 A/s was validated
  - Nominal current was successfully held for 5 hours

- Horizontal Test Stand is ready for LQXFA/B03 test
  - Cryogenic plant maintenance is scheduled for November
  - Cold test of LQXFA/B03 is expected to start in December