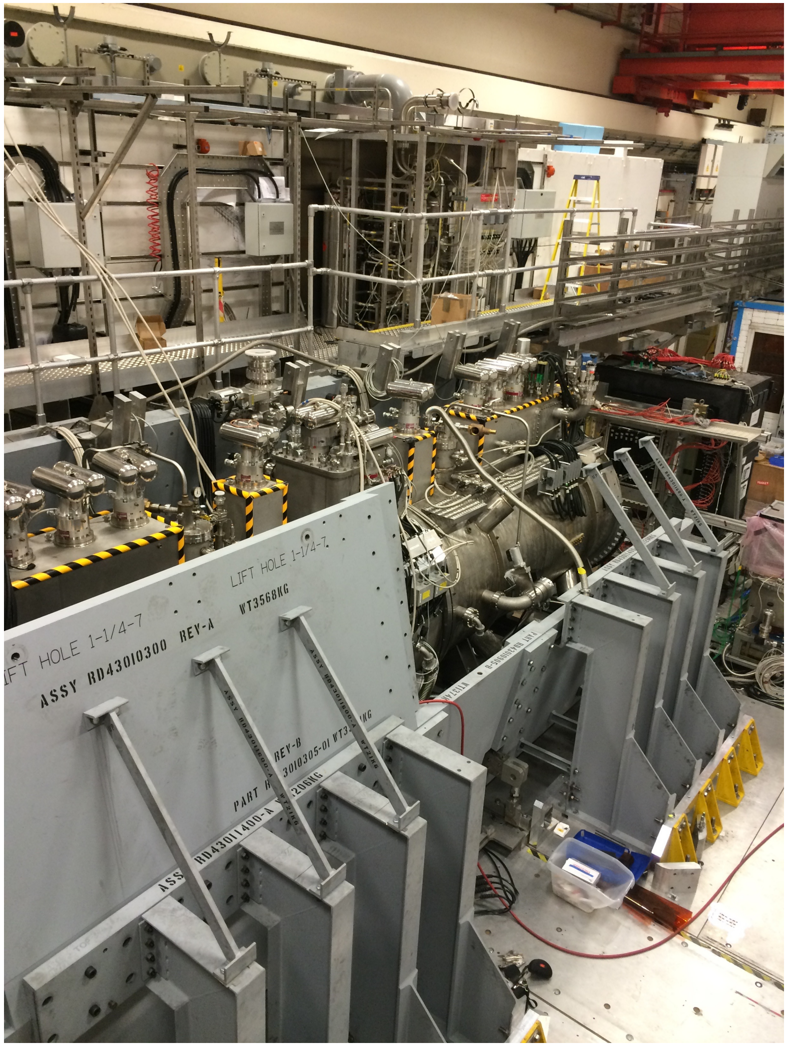
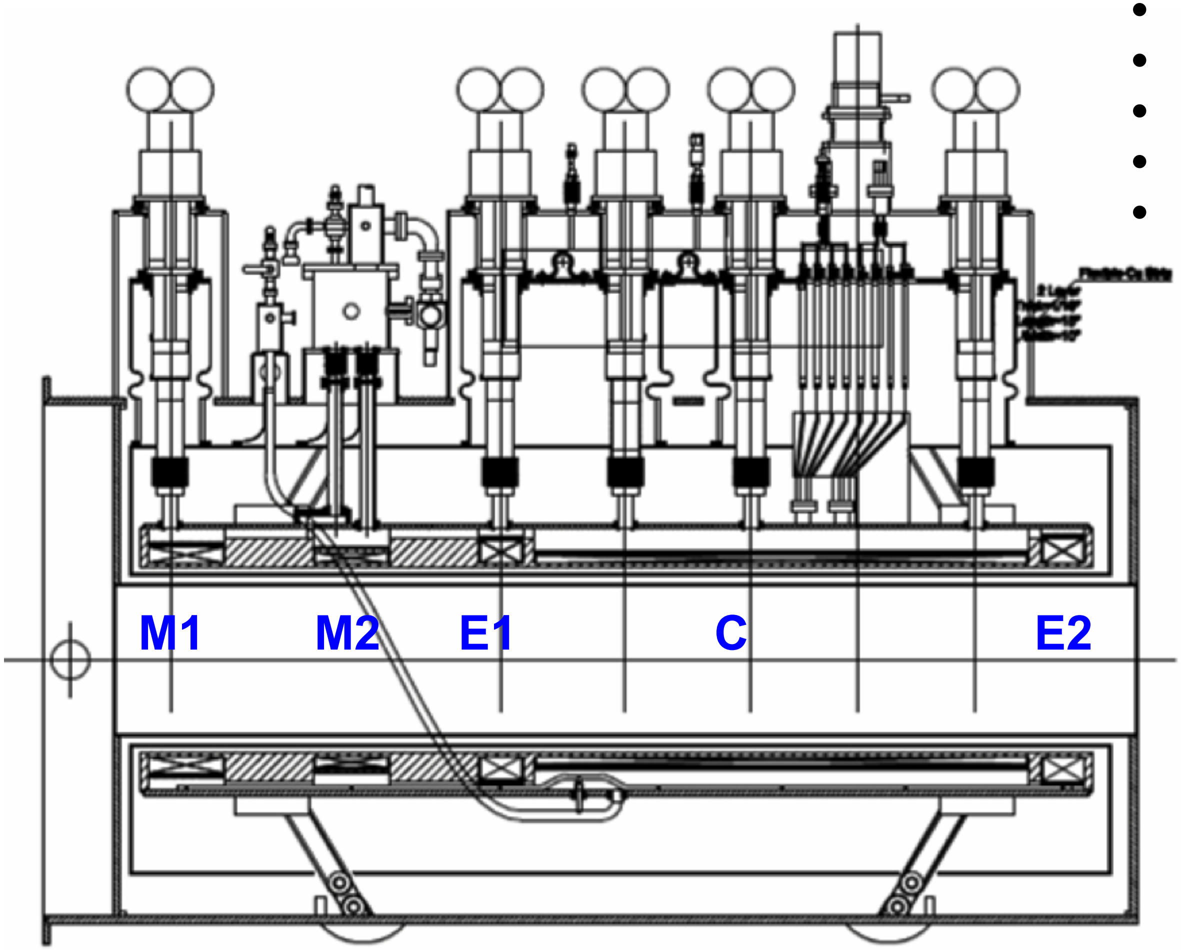
MICE Spectrometer Solenoid Repair



MICE Spectrometer Solenoids

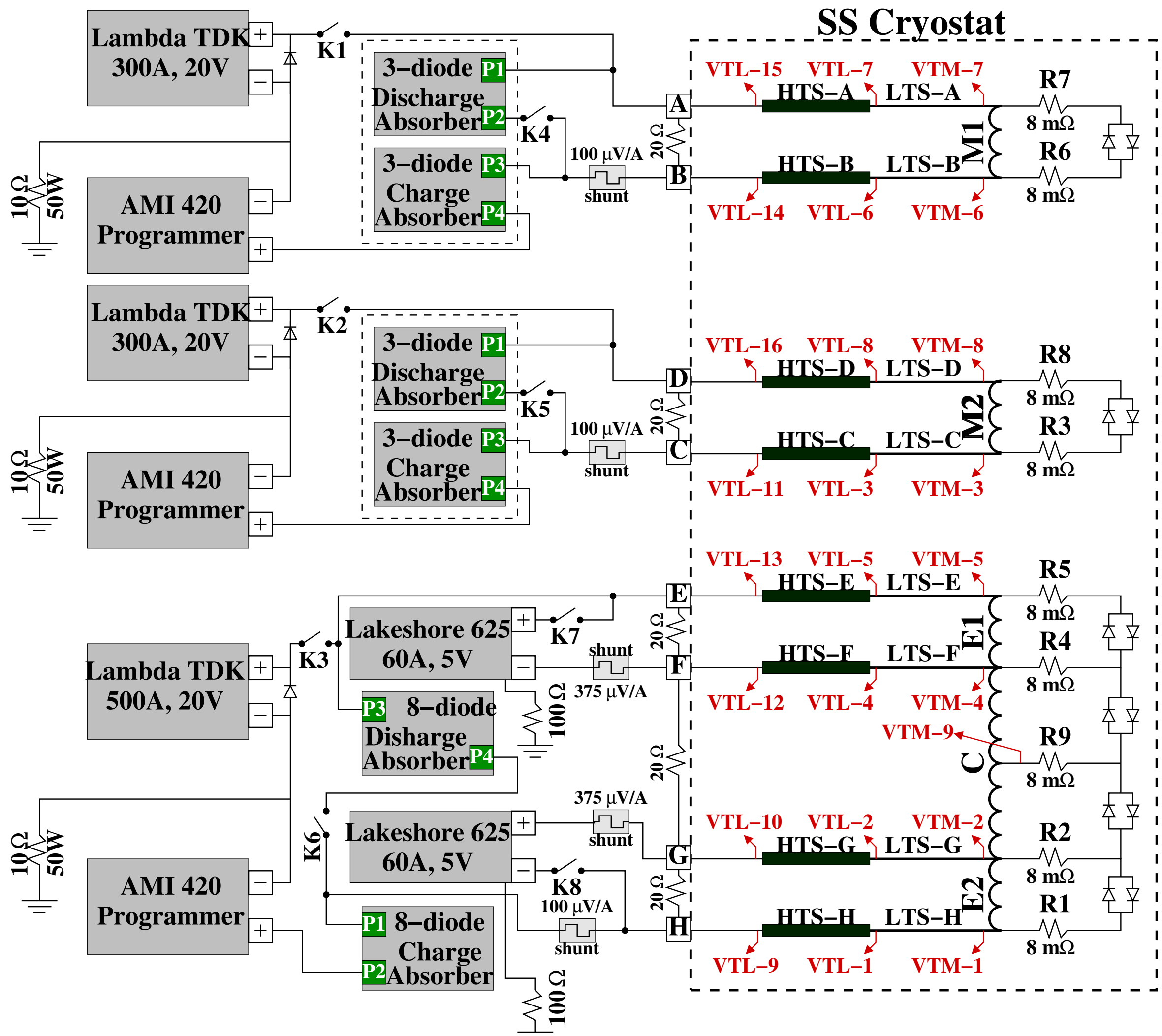
- These magnets have had a long history and I will make NO attempt to review it in any detail here.
  - Steve and Soren will fill in some of the details
- Both magnets met the full specification at the vendor and were fully mapped.
  - Cryogenic operation was very good. Both magnets had significant cooling headroom (SS2 more than SS1)
- SS2 (in upstream position of the beam line – SSU) has reached full operating current at RAL, but full training (soak, solenoid mode) has not been completed.
- SS1 (in downstream position – SSD) had a lead failure during training.
- What is the optimal path forward?

Reminder: Basic design



- 5 2-stage CCs
- 1 single-stage CC
- 5 Coils
- Max current ~300A
- High inductance 10-40H

Power system



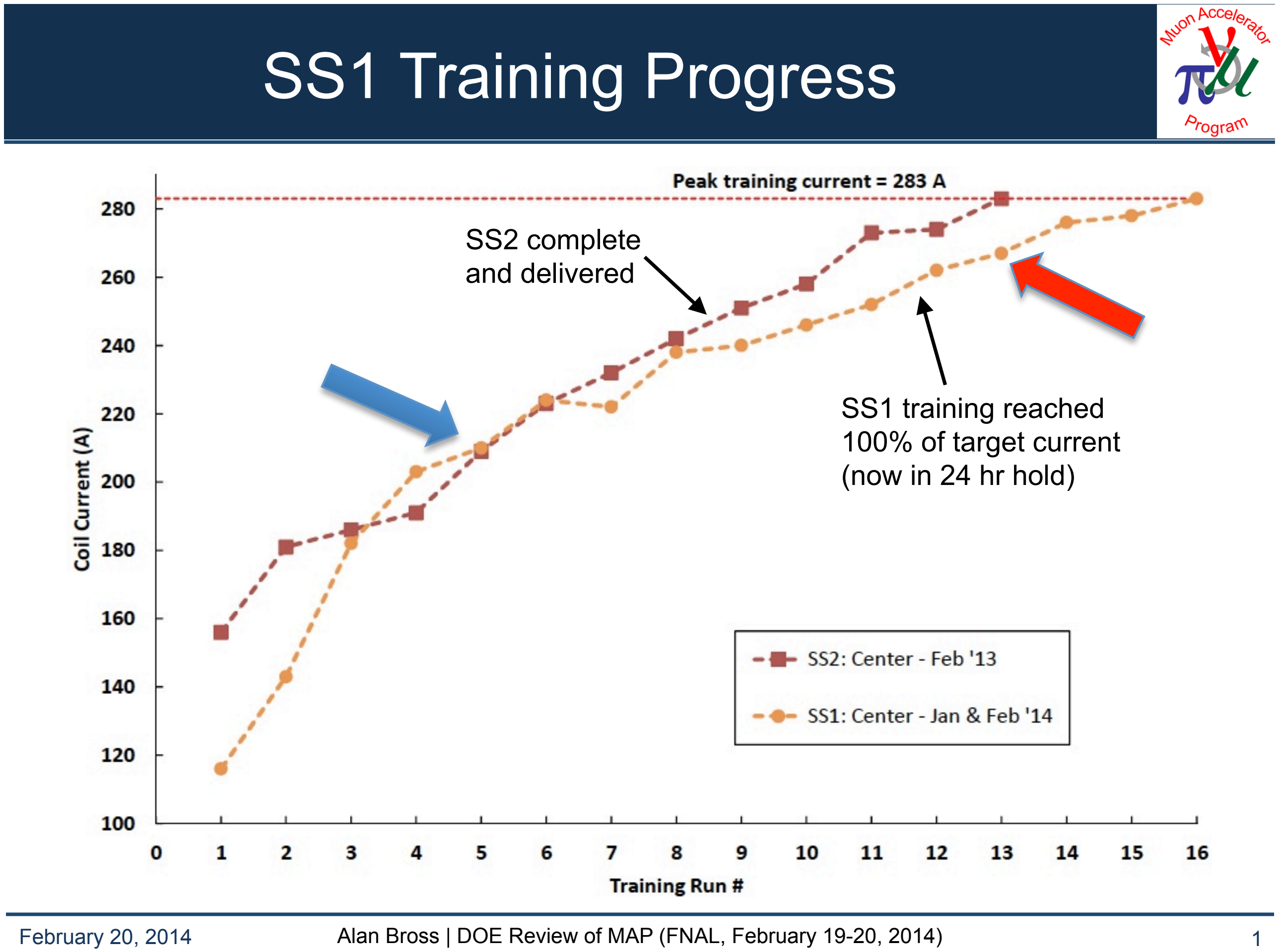
Power delivery system

- 2 Vacuum feedthroughs bring power into vacuum space
  – One for ECE, one for M1 and M2
- Copper leads to HTS
  – $IL/A = 3.6 \times 10^6$ A/m
- HTS:
  – HTS-110 500A (M1, M2, C) and 250A E1 and E2
- LTS:
  – Vacuum feedthrough: Proprietary Wang design based on SSC superconductor
  – Inside He space: Cu stabilized conductor

Training SSD

- SSD has been a bit problematic at RAL
  - Some vacuum issues
  - Lost voltage tap on LTS lead of M2 coil
- In the training run of September 13th, 2015 all was going very well.
  - Implementation of additional QP for the M2 lead had not yet been done, so a decision was made to ramp only M1 and ECE
  - A quench occurred at ~ 260A in ECE (much higher than expected, next slide).
- QP system performed as expected, nothing outwardly unusual except for the large current.

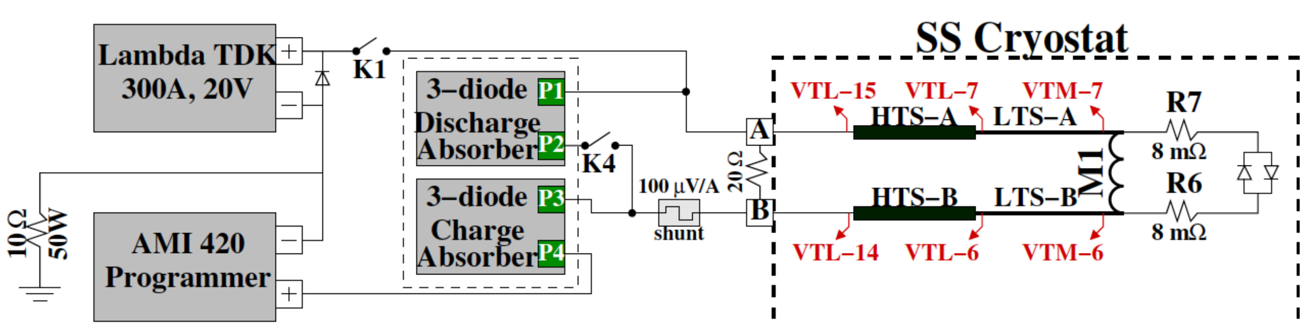
Training history



Lead failure

- However, upon entering the hall the odor of burnt FR4/G10 was extremely strong. Strongest at He relief valve
- After a great deal of analysis, it has now been determined that (see diagram on next slide):
  - One leg of M1 dead short to ground. This is LTSA lead.
  - LTSB lead not connected to coil (open), but connected to LTSA with ~ 2.4KOhm resistance.
  - M2 coil OK.
  - No damage seen anywhere else.
    - However, M2 coil has 1.3 KOhm resistance to M1 (& ground)
  - AC measurements show that QP on M1 not active indicating a break in the internal QP circuit. Most likely point is indicated in the figure on the next slide (x next to diodes) because there is another short to ground on this leg of the circuit.
  - All other coils OK (including their QP circuit).

M1 circuit after fault



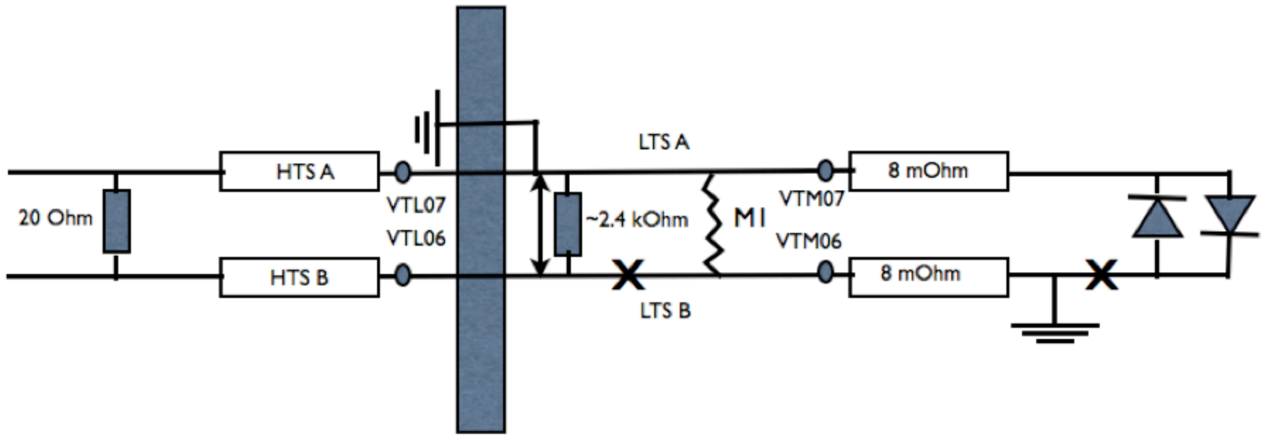
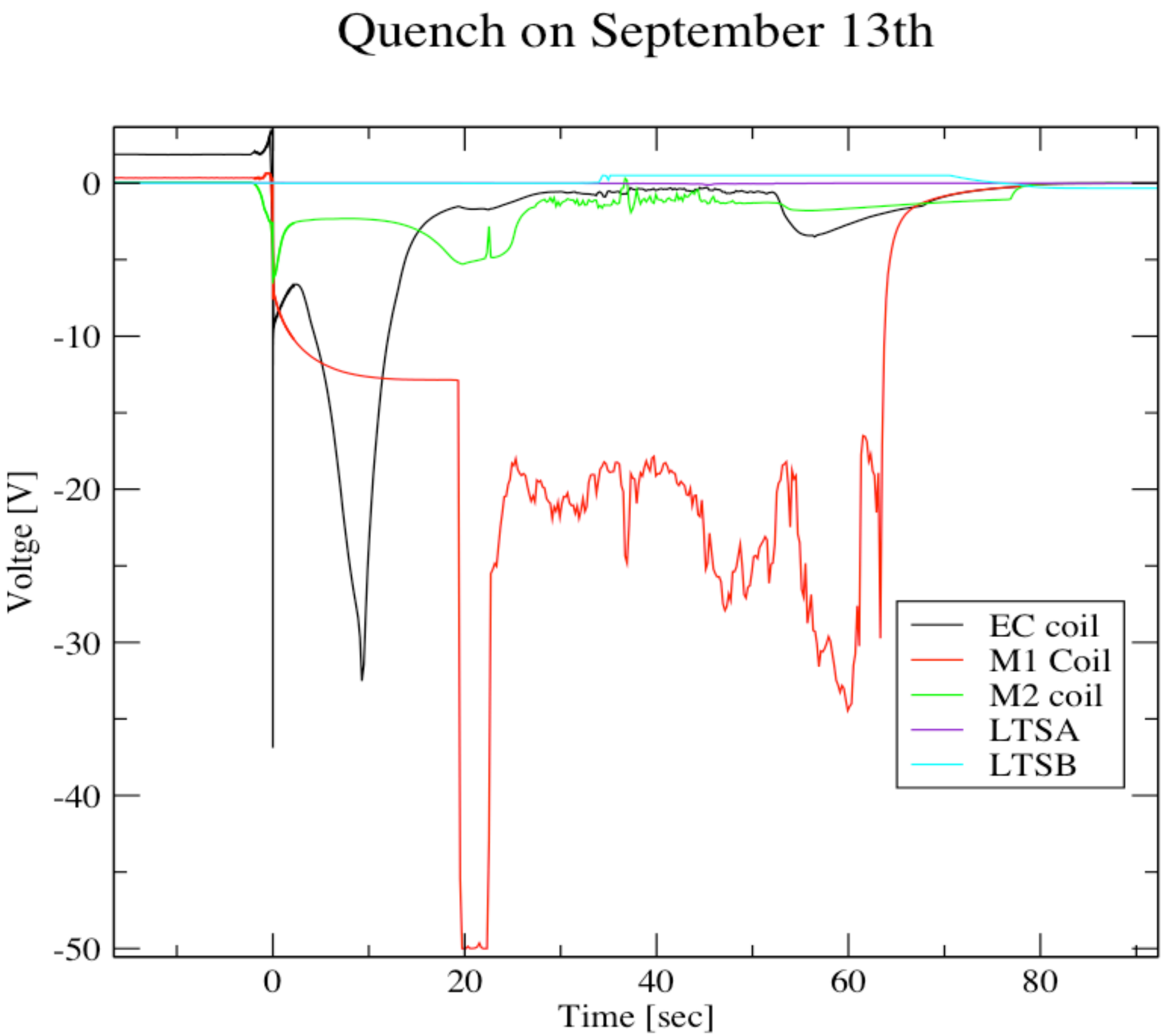


Diagram of the M1 circuit. Resistance (four wire and two wire) measurements revealed:

i) Lead A has hard short to ground,

ii) LTSB is shorted to LTSA through 2.4 kOhms and LTSB is not connected to the M1 coil on the Lead B side.

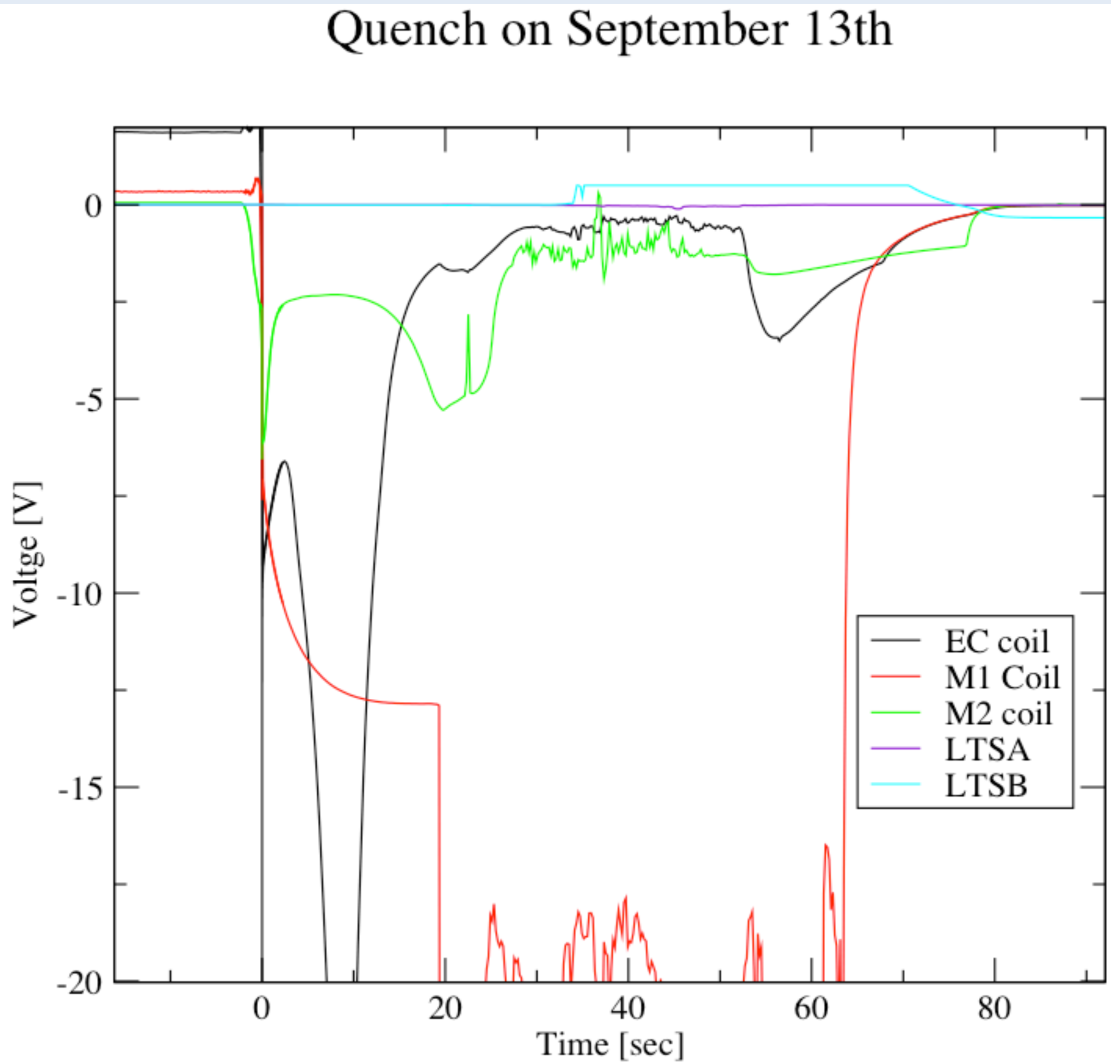
QP data – M1



Quench on September 13th
Voltge [V]
Time [sec]
0
-10
-20
-30
-40
-50
0
20
40
60
80
EC coil
M1 Coil
M2 coil
LTSA
LTSB

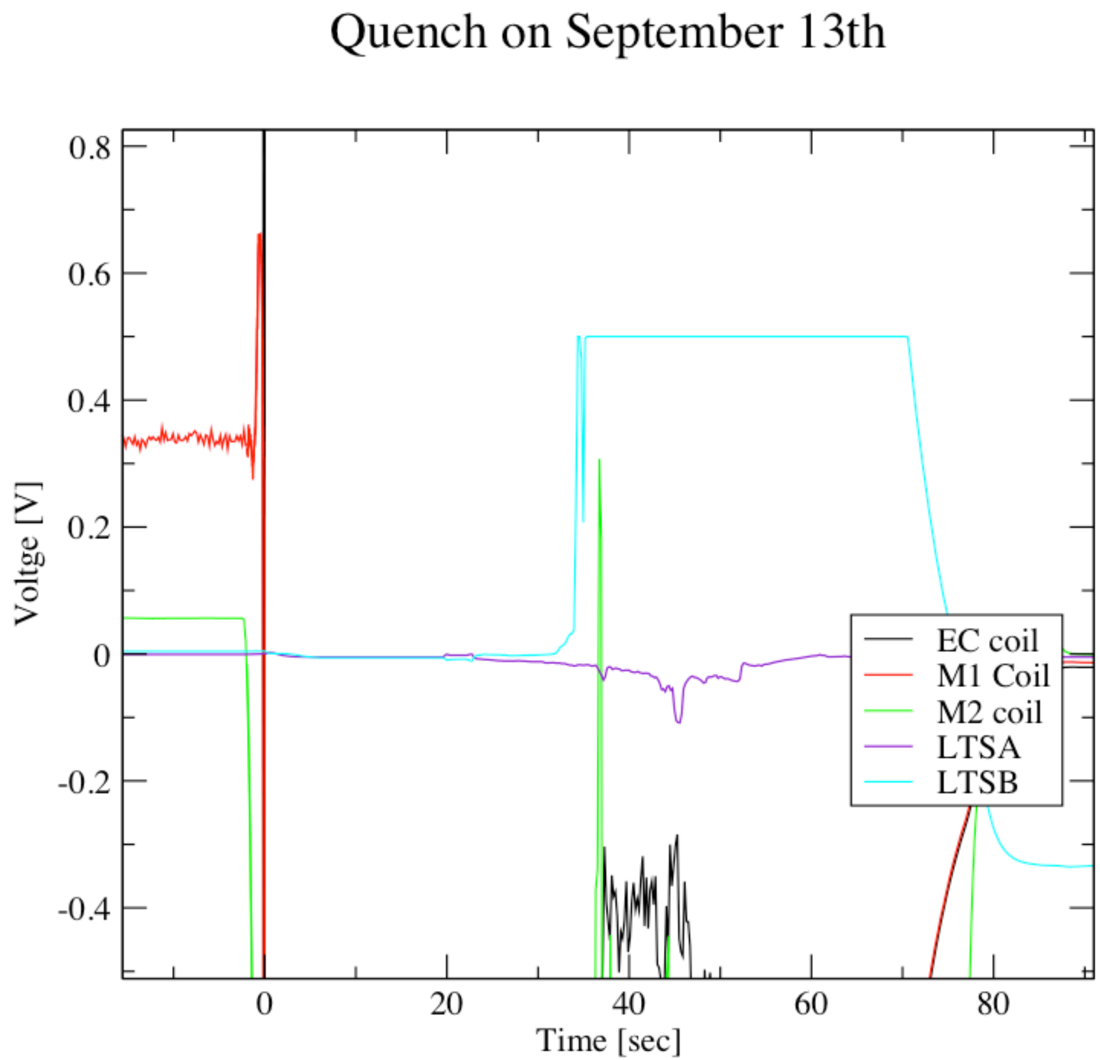
QP data – M1

Expanded V scale



QP data – M1

Expanded V scale II

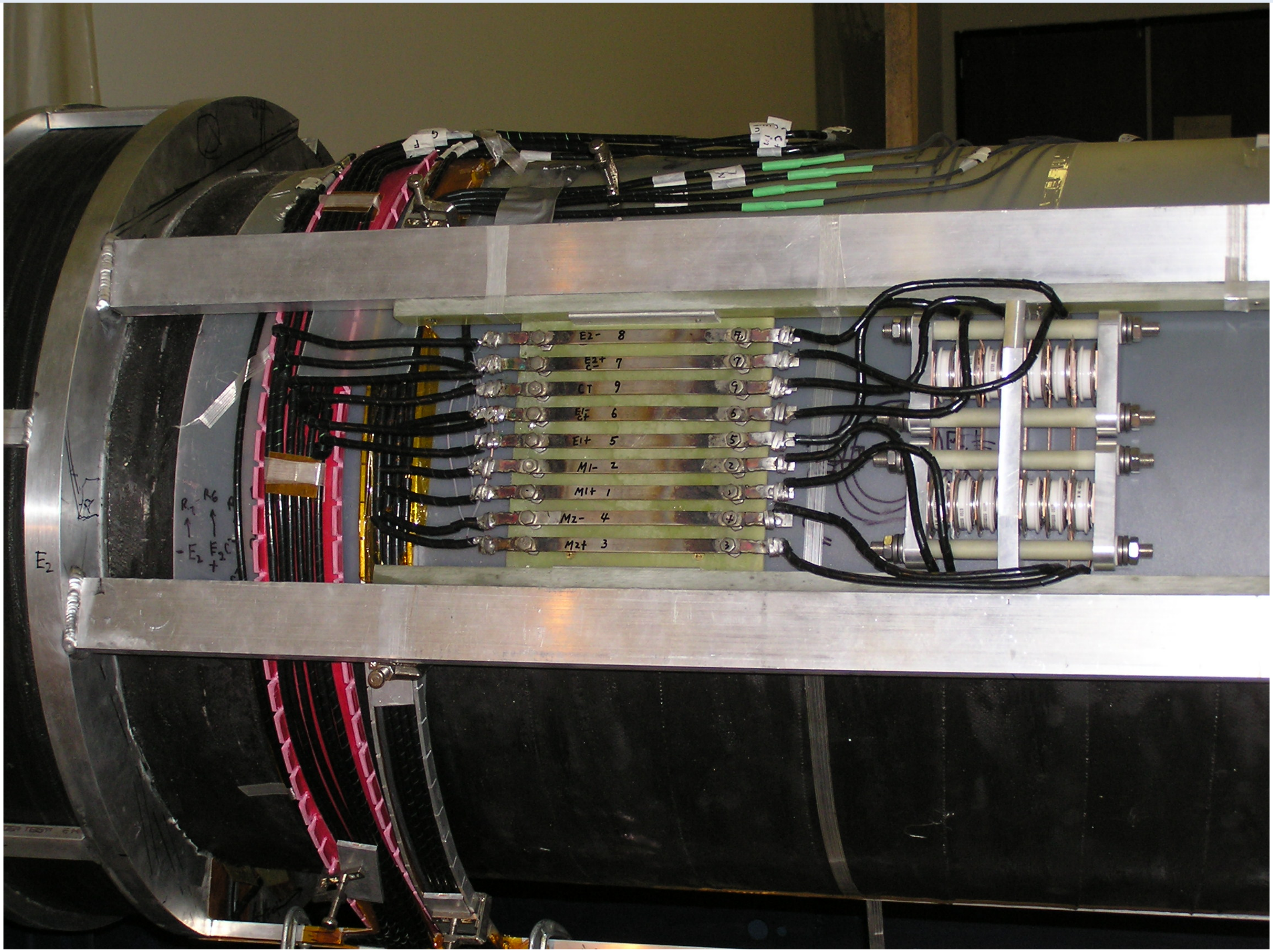


Analysis

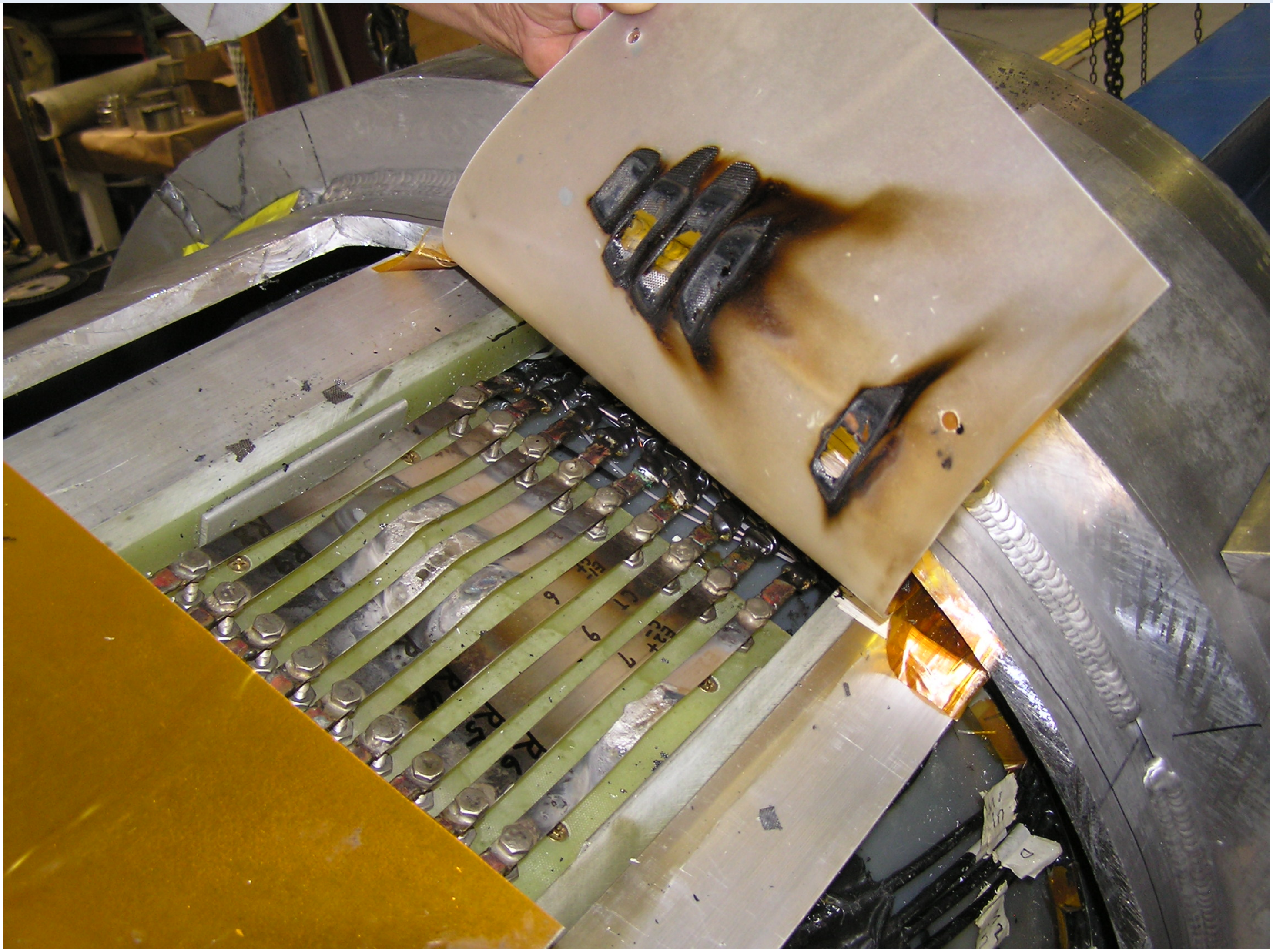
- Quench initiated on ECE and initially proceeded normally
  - There is no evidence that any LTS leads were involved initially
- At ~ 20 sec, the internal QP for coil M1 failed
  - The voltage on the coil increased rapidly and, it appears that an arc at the LTS power feed through (from vacuum to LHe volume) occurred which burned out the lead and effected M2 (the power leads for M1 and M2 utilize the same 4 pin feed through).
- What caused the QP failure?

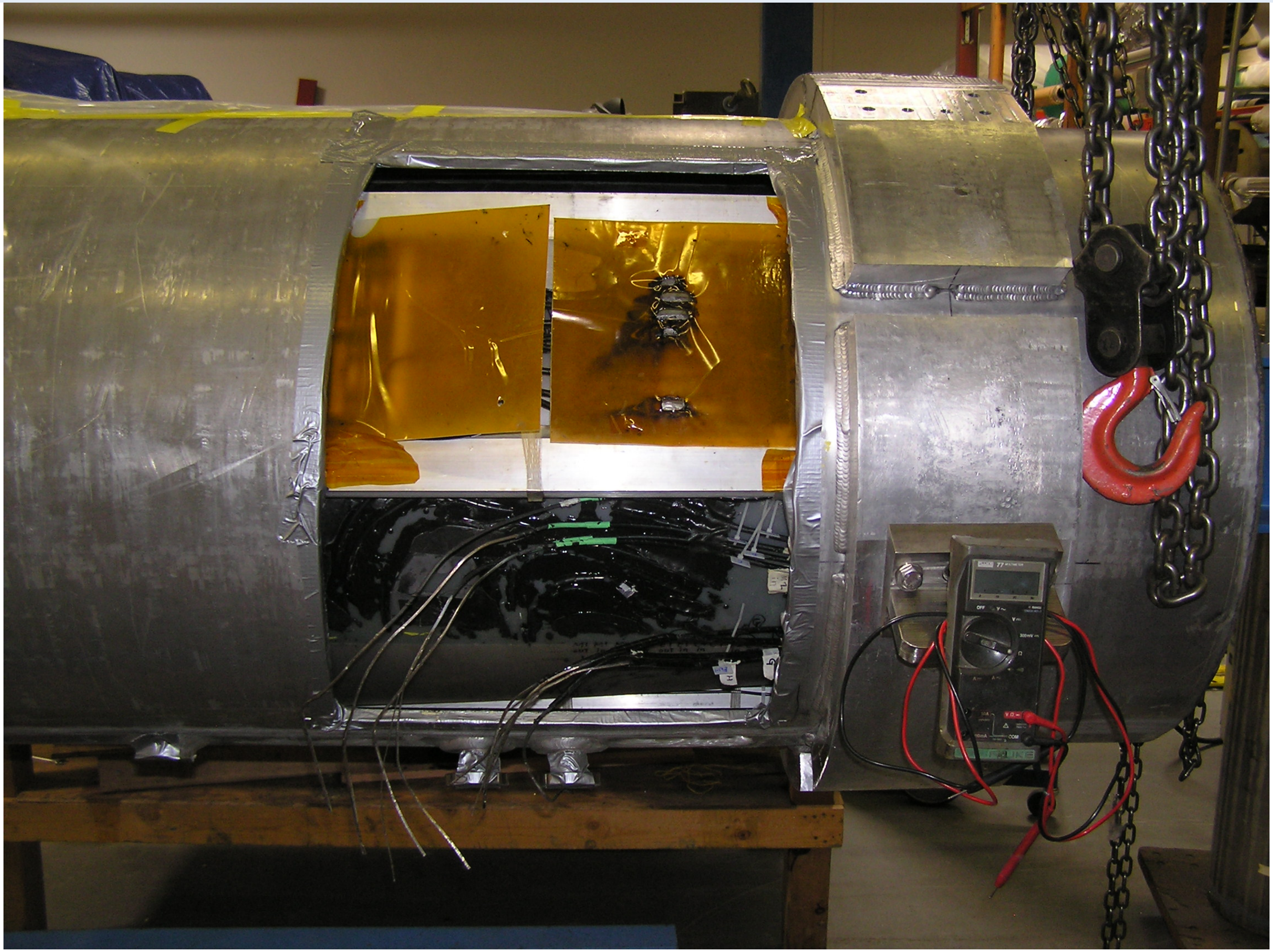
Internal QP

Original Wang configuration



We have add previous issues



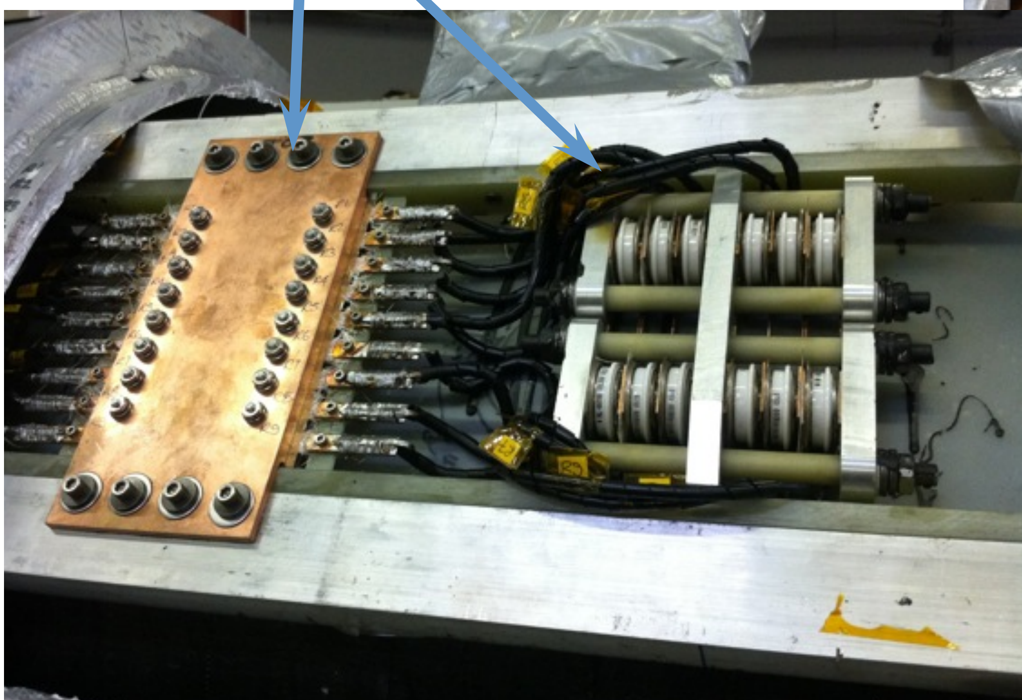


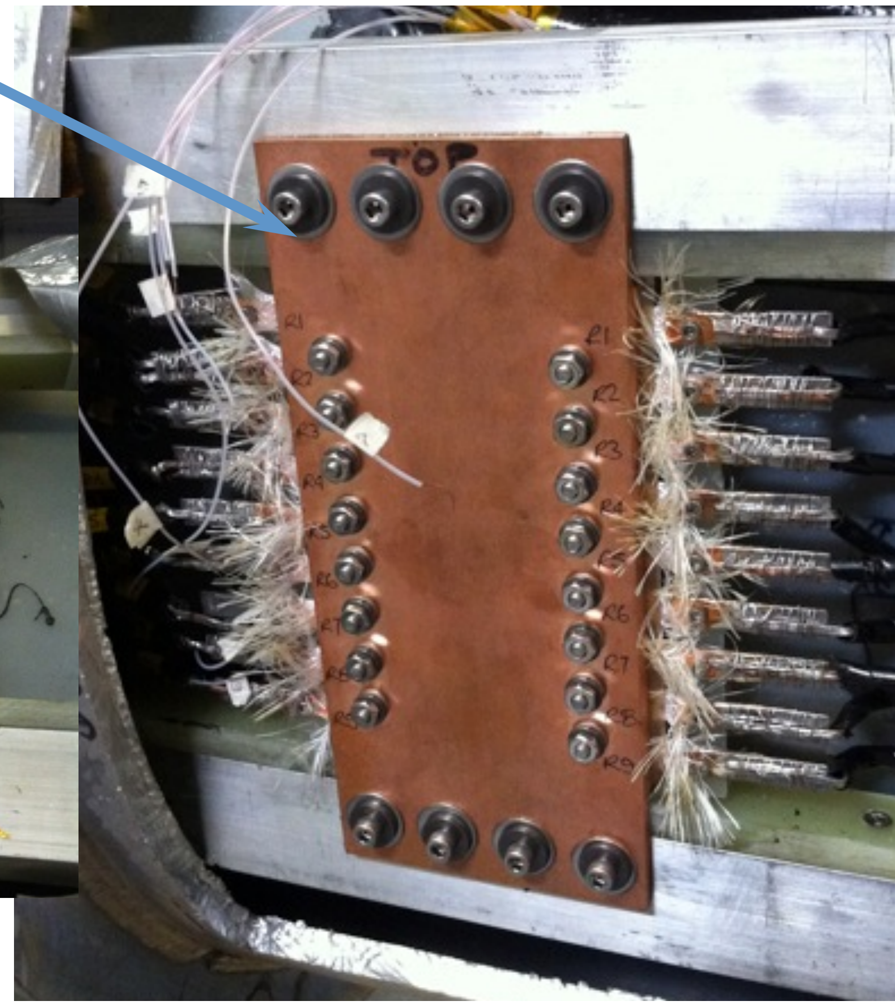
LBNL re-design

Picture of final configuration for SS2/SSU

Conductively cooled resistors

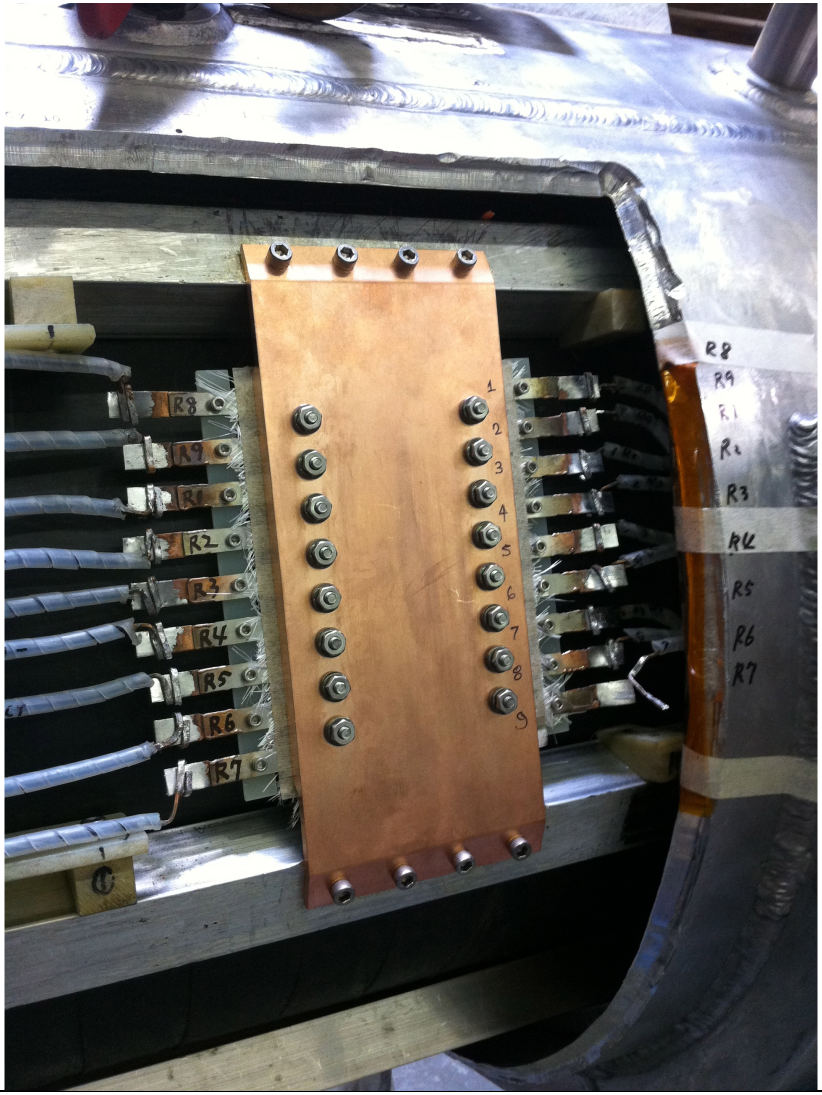
Quench protection circuitry



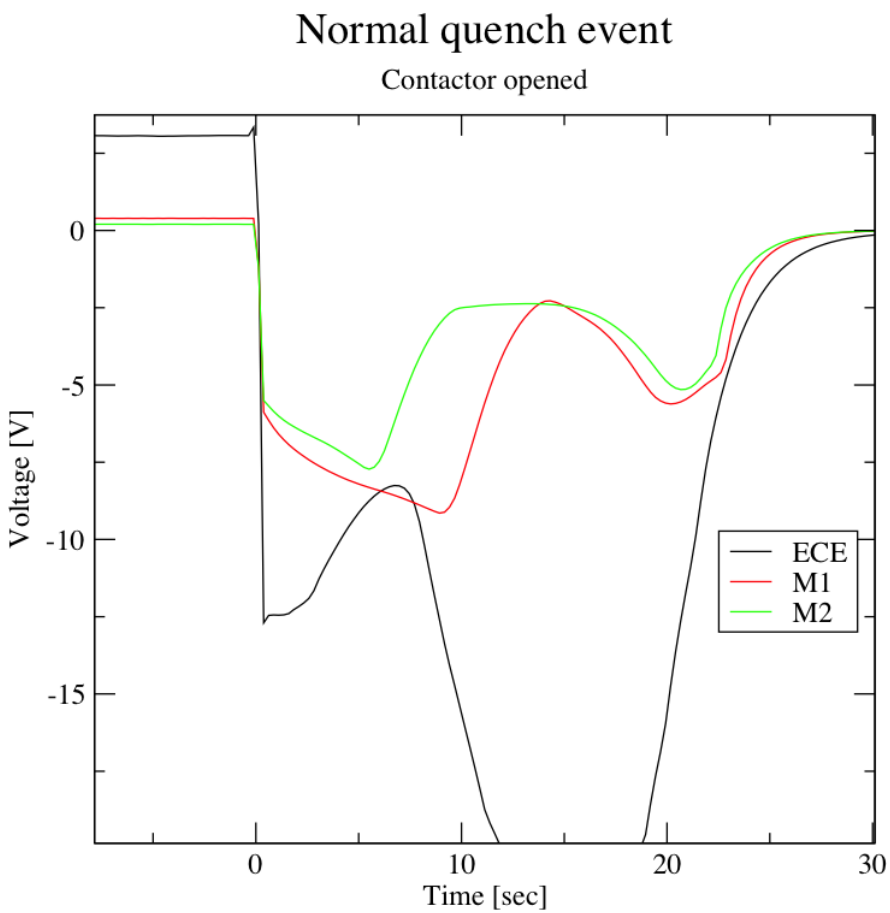


SS1/SSD

This is a photo of the QP pack for SSD/ SS1. What is not known at this time is exactly how the terminations were made. Did Wang follow the procedures used on SSU/SS1?



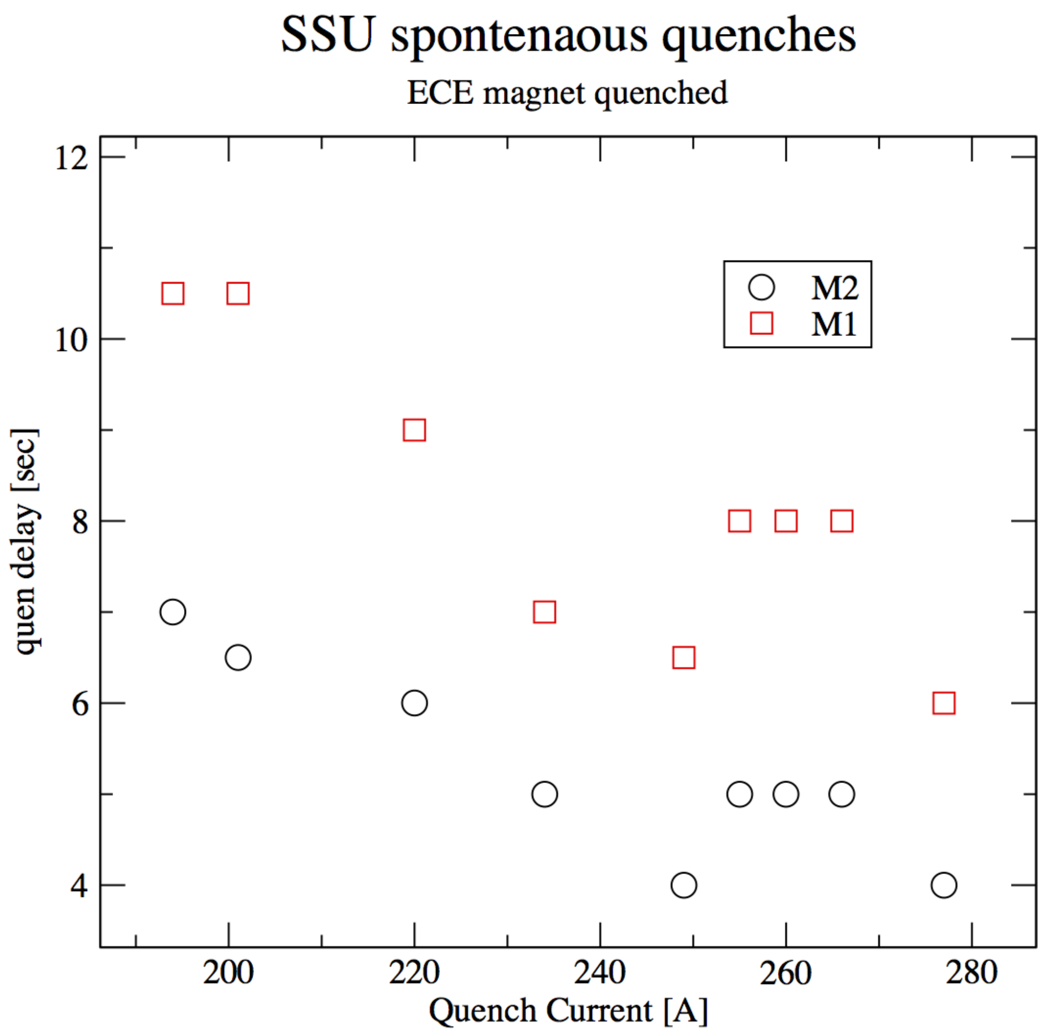
Normal Quench



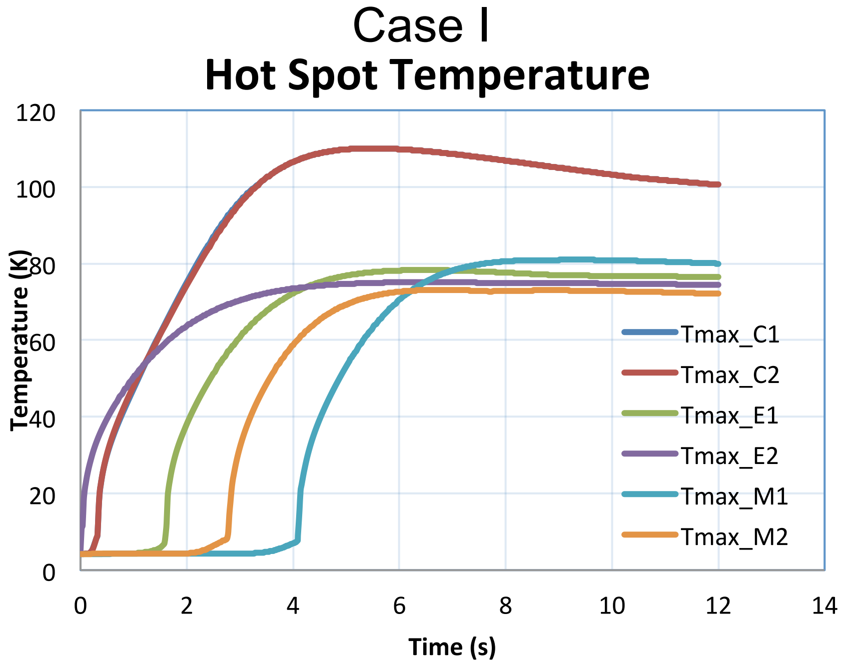
- These are data from a normal quench
  - All coils ramping together to their design current
  - NOTE: In this case, the quench occurred as the currents were ramping down
- ECE initiated the quench (QP system detected and sent trigger to open contactors)
- M2 followed, then M1
  - As predicted.

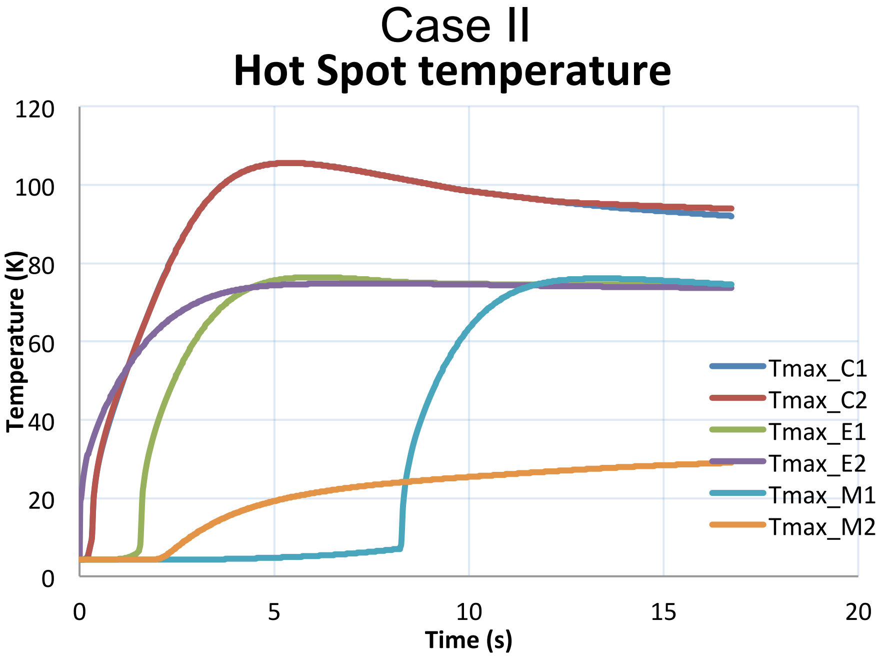
Quench delay

M1 & M2



Quench propagation analysis without M2 powered





- Compared the results with (case I)and without (case II) M2 powered.
- Quenches were initiated in E2 in both cases.
- The quench current in case I is 265A in all coils.
- In case II, the quench currents in ECE and M1 are 260A and 250A, respectively.

Quench delay

- Time to Q for M1 increased by ~ 2X
- However, overall scale in simulation does not agree with data
  - There is a qualitative understanding
    - LHe & gas not modeled exactly
    - The thermal properties of the mandrel + insulation between coils and the bobbin are not precisely known
    - The starting location of the quench will affect the heat propagation from the hot spot to the mandrel, this will cause time difference. The model is always set so that the innermost layer initiates the quench.
- Given the above, there is qualitative agreement:
  - The quench delay of M1 increased by ~2X, from 10 seconds to 20+ seconds.

Moving Forward

- Can obtain lattice to allow MICE Step IV running without SSD M1 coil. However, limits momentum scan
- Harder when RF is added
  - Impossible?
- However, risk that a M2 lead will fail must be considered high at this point
  - M2 has been powered at low current (5A) and all looked good.
- Need guidance on how to proceed