Operational Experience with the MICE Spectrometer Solenoid System

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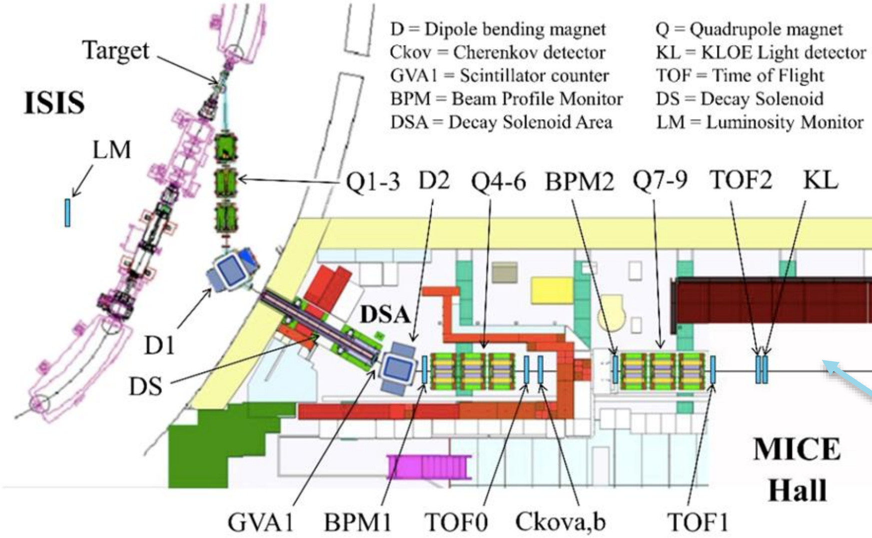
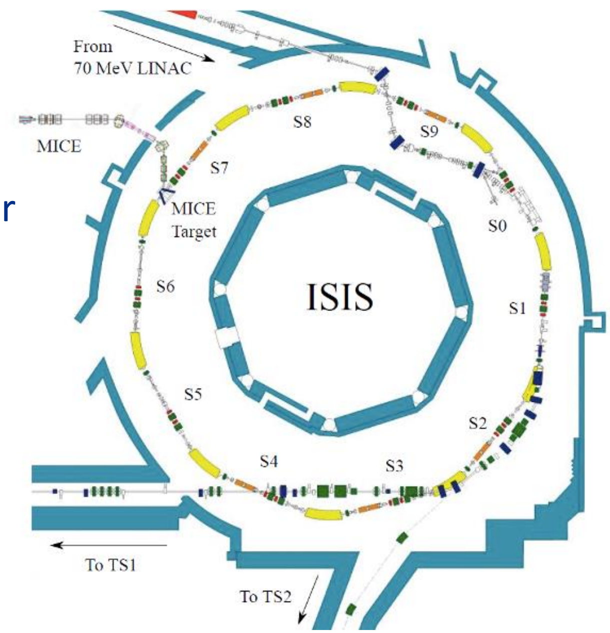
Outline

- MICE Experiment at Rutherford Appleton Laboratory
- Superconducting Spectrometer Solenoids
- Commissioning Effort 2015
  - Quench training
  - Failure Analysis
- Quench Protection System Upgrade

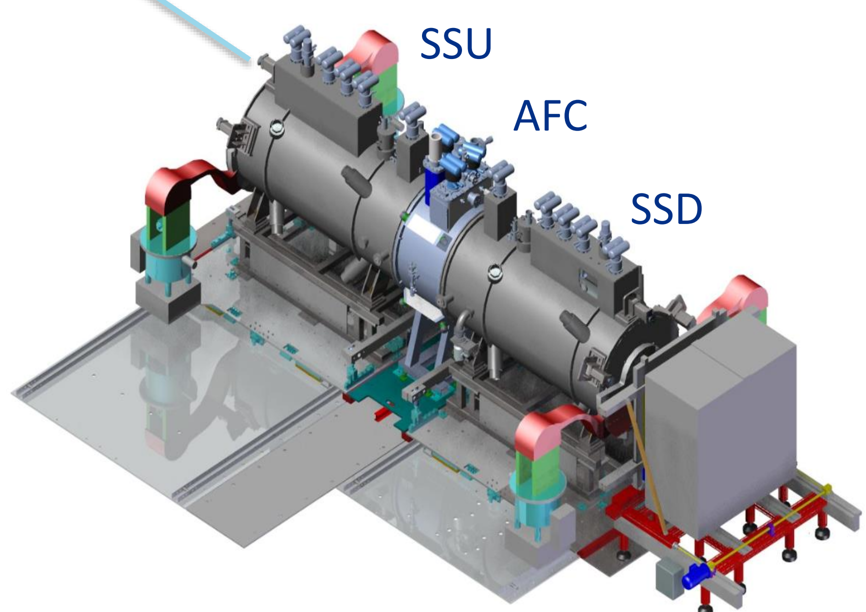
MICE Experiment at RAL



800 MeV Proton accelerator



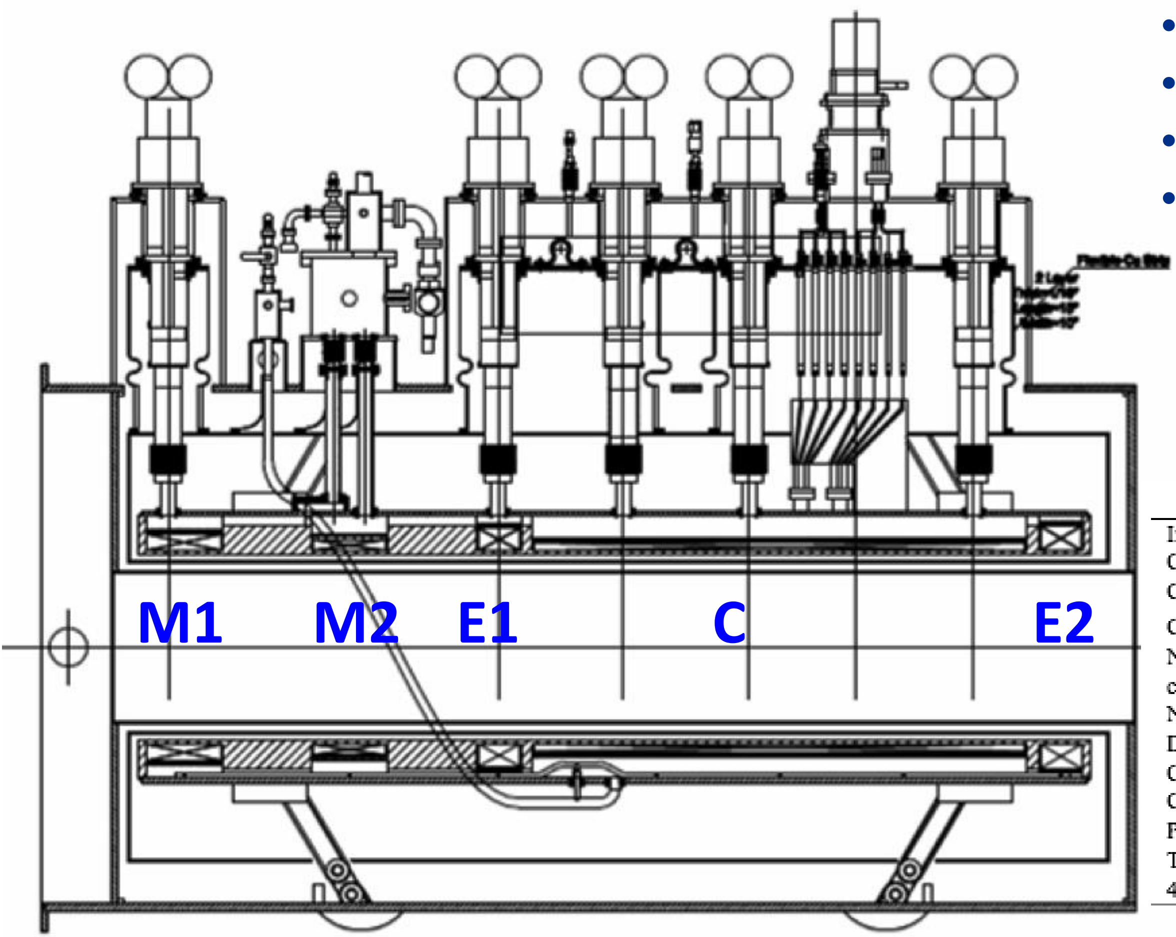
- Stage 4 MICE Cooling Channel
- Upstream and downstream Spectrometer Solenoids SSU and SSD
  - Scintillator Fiber based tracker
- Absorber Focus Coil
  - Hydrogen Absorber is planned for the next run



MICE cooling channel

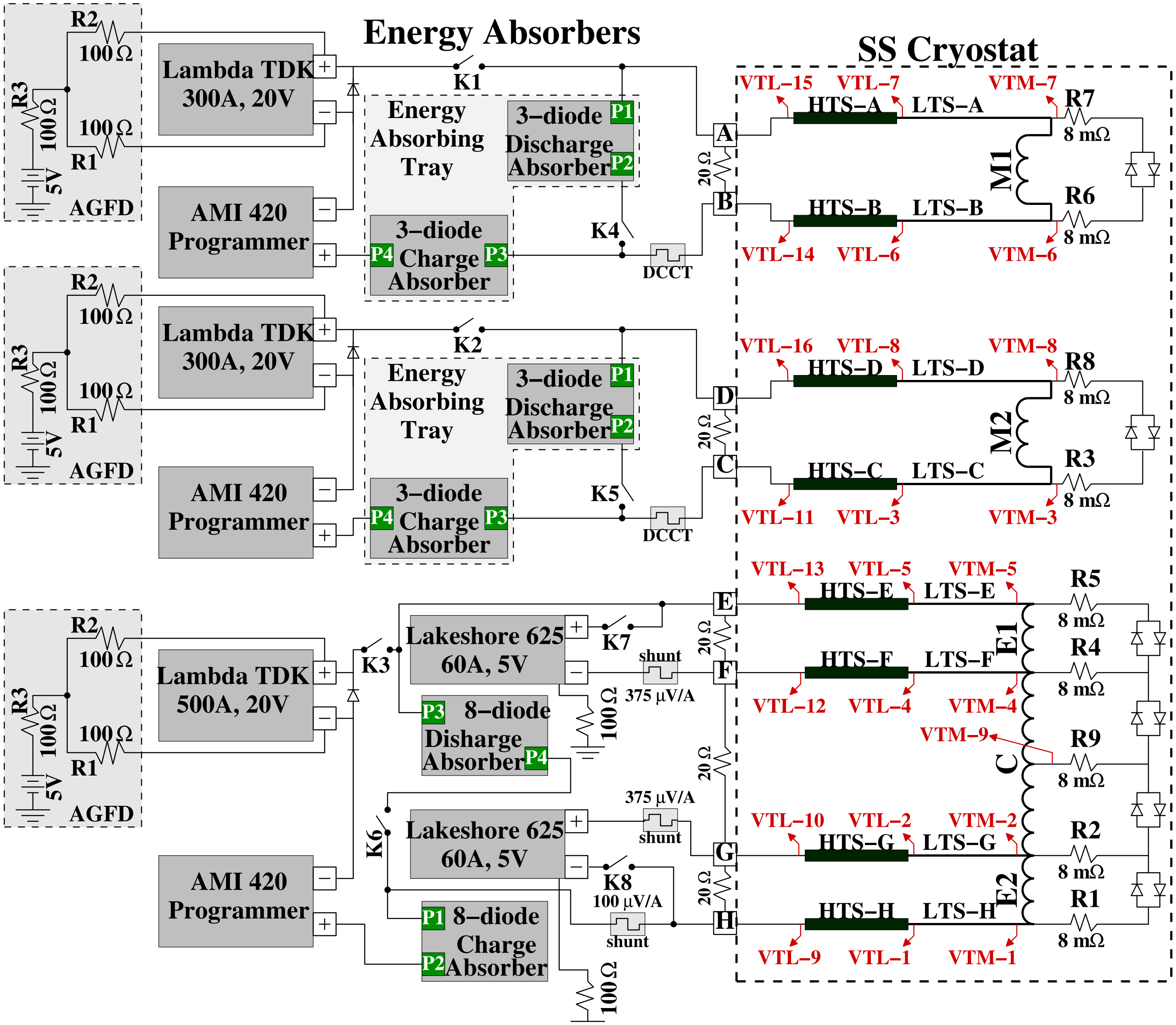
Spectrometer Solenoids

- 5 2-stage CCs
- 1 single-stage CC
- 5 Coils -NbTi (4:1 Cu/Sc)
- Max current ~300A
- High inductance 10-40H



	M1	M2	E1	C	E2
Inner Coil Radius (mm)	258	258	258	258	258
Coil Thickness (mm)	46	31	61	22	68
Coil Length (mm)	201	199	110	1314	111
Coil Average J (A/mm^2)	137	148	124	147	127
Number of Layers per coil	42	28	56	20	62
Number of turns per coil	115	114	64	768	64
Design Current (A)	265	285	234	275	240
Coil Self Inductance (H)	12	5	9	40	11
Coil Stored Energy (MJ)	0.42	0.20	0.26	1.55	0.32
Peak Field in Coil (T)	5.30	4.30	5.68	4.24	5.86
Temperature Margin at 4.2 K (K)	-1.6	-1.8	-1.5	-2.0	-1.5

Powering of SSU and SSD



M1, M2 individually powered, E1, C, E2 (EC) powered in series

Energy absorbers used to control up and down current ramp

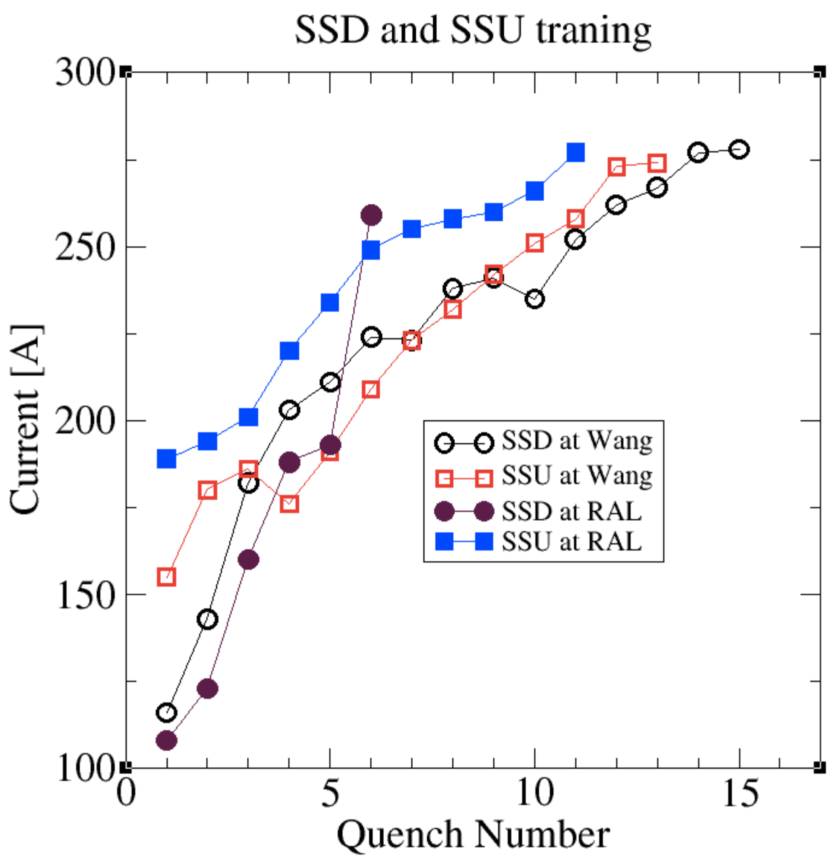
Internal Diode based Energy Dump system

Voltage segment based quench detection system

Active Ground Fault Detection system

Commissioning SSU and SSD

Initial commissioning was done in Summer and fall of 2015



SSU and SSD cold HiPot: Limited to ~ 250 V

- 1600 V internal peak voltage during quench

SSU initial bus-work incorrect – 1 month of delay

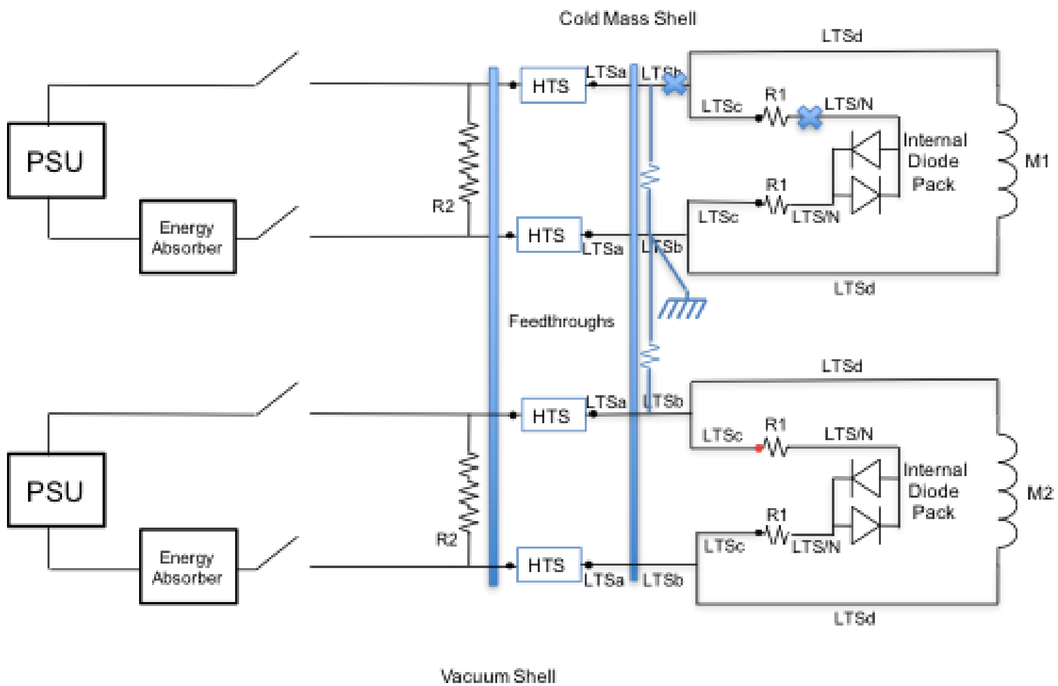
Both magnet does not remember its training
SSU training at RAL similar than at Wang NMR

SSD: lost V-tap - decided not to run M2 for the current ramp of the 6th quench

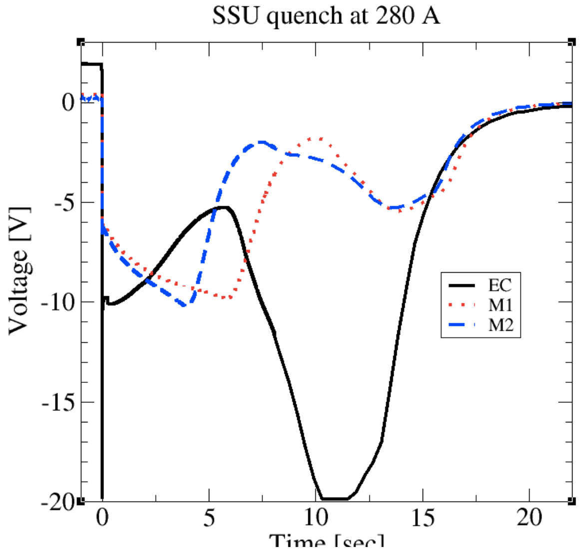
SSD after q6

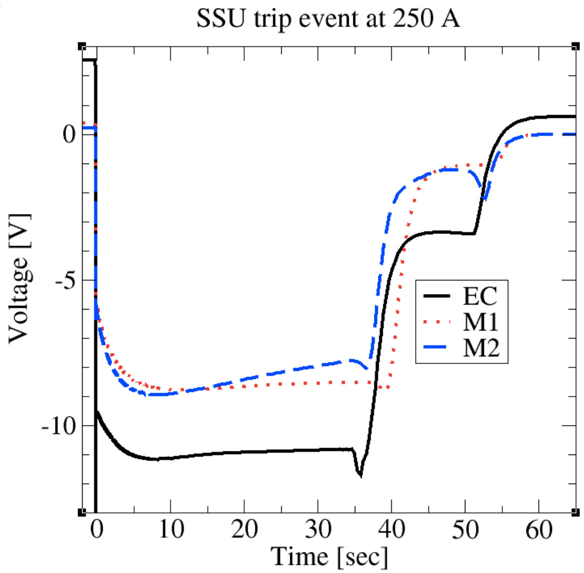
Electrical tests were performed to verify the status of SSD

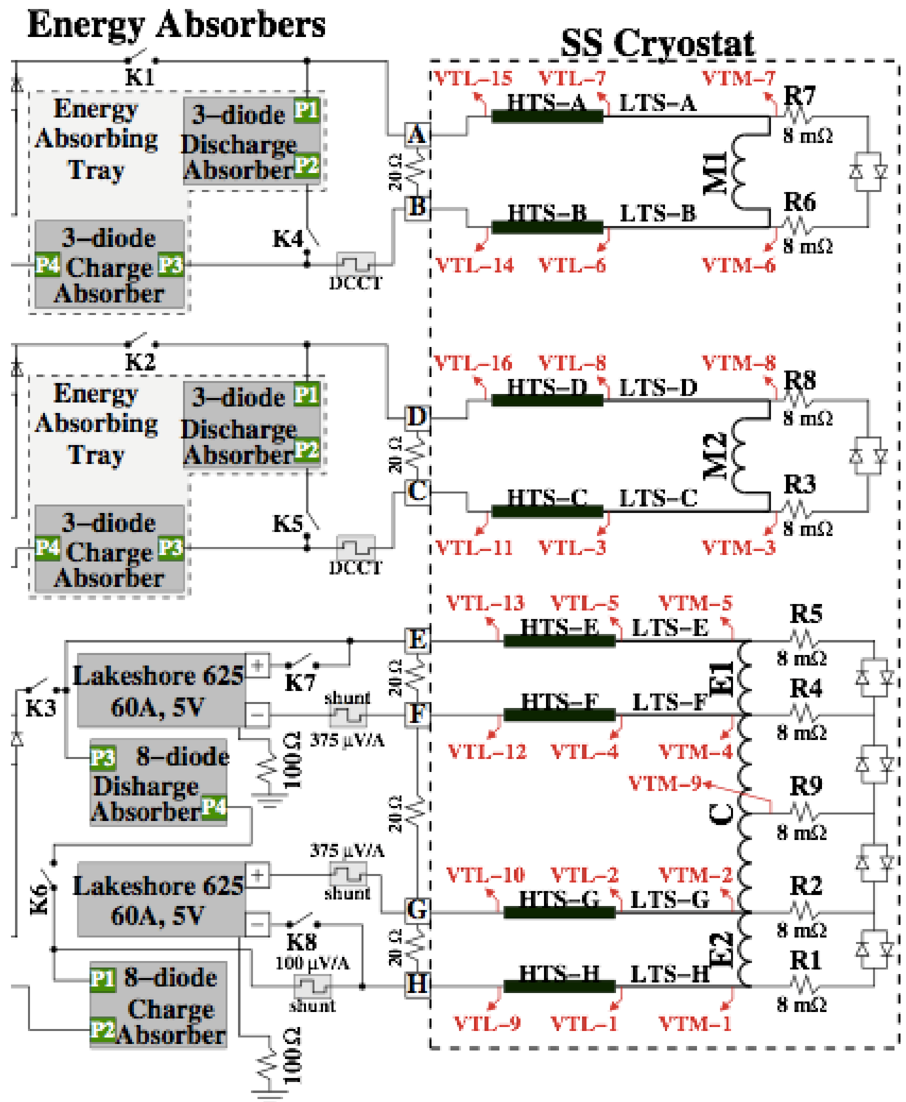
- M1 circuit was opened
- one of the M1 lead was shorted to ground
- between the two M1 leads the resistance was 5.7 kΩ
- between the M2 and M1 lead the lowest resistance was 2.6 kΩ.



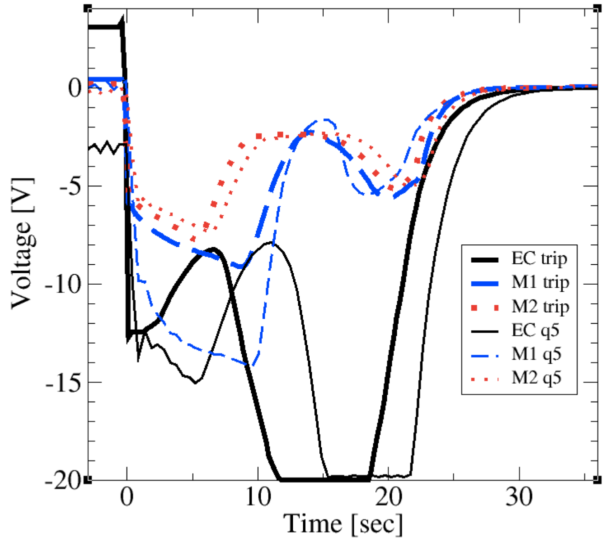
SSU Quench and Trip Event

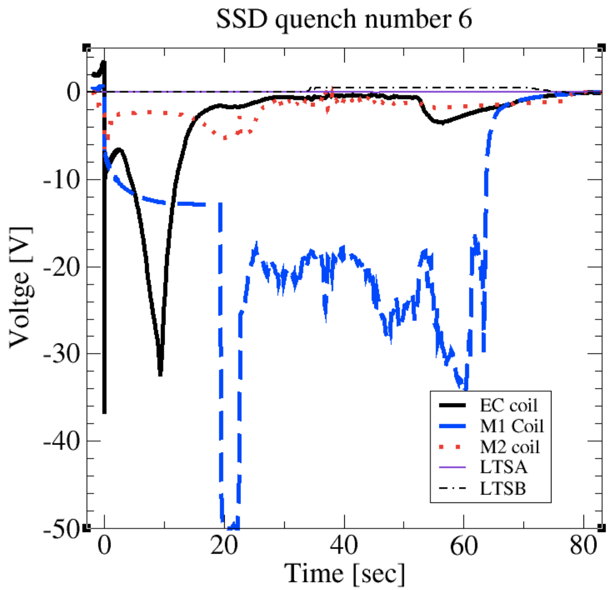






SSD Trip quench 5 and 6





Sequence: first q5 then a trip event

5th quench EC quenched first (M1 current at 198 A) was a normal quench with normal Voltage traces

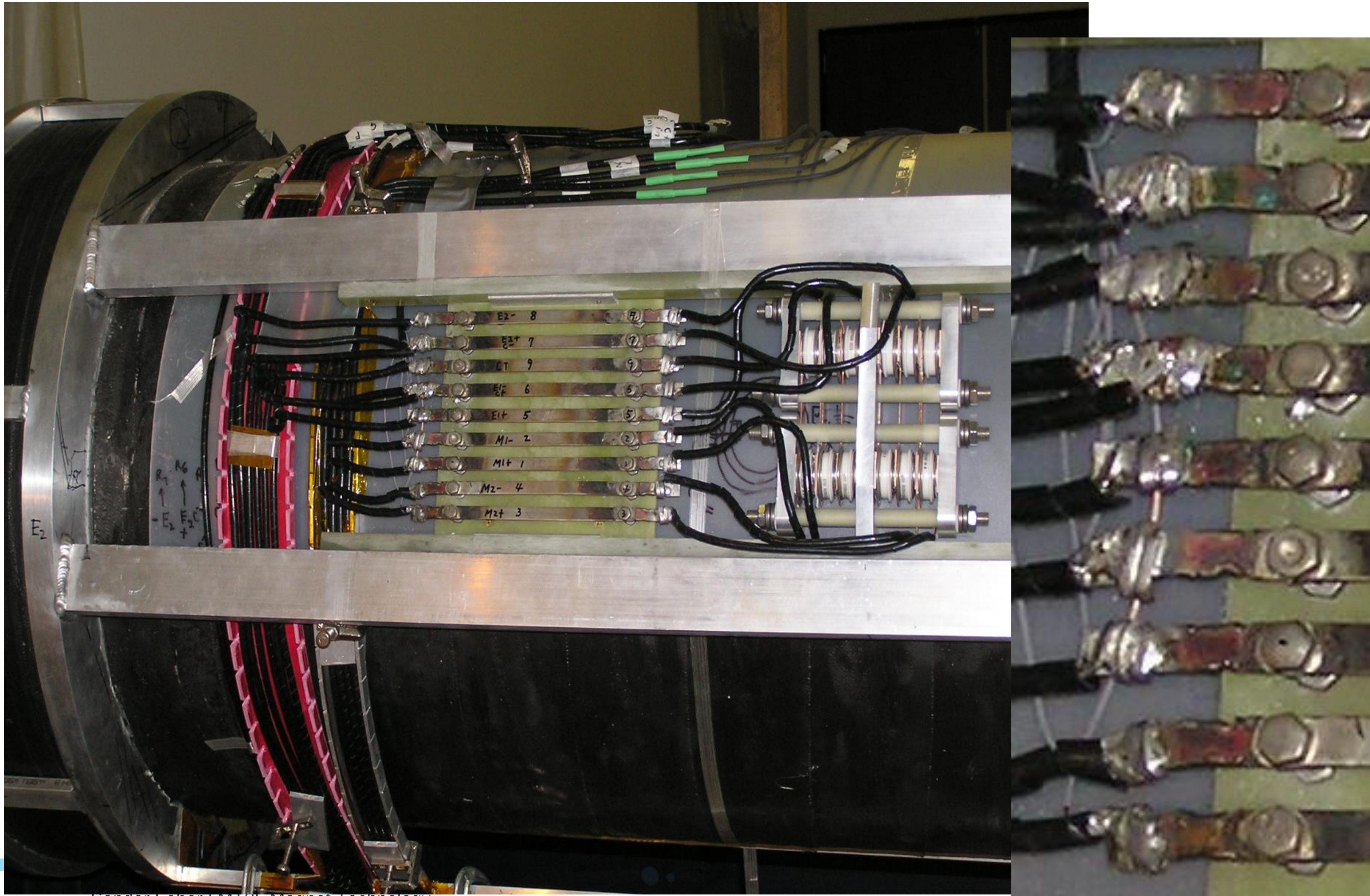
The trip during ramp down (M1 current at 195 A)

- No EC quench
- M1 absolute voltage is a lot larger that expected
- M2 quenches about the same time as it quenched during q5

During the 6th quench (M1 current at 258 A) M1 was arcing

- EC quenched first
- M2 was not powered – quench back delayed significantly
- M1 circuit opened at ~ 20 sec
- M1 shorted to ground at ~ 30 sec

Internal Quench Protection Circuit

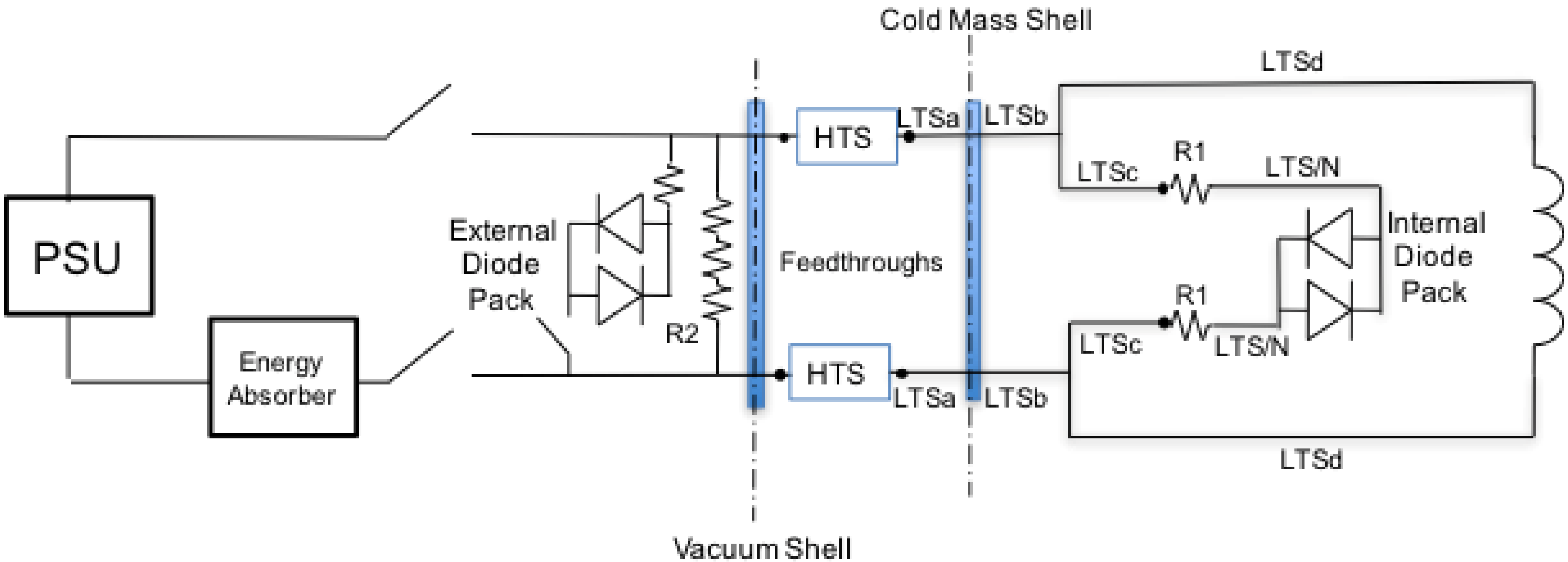


Quench Protection Upgrade

Additional practical reasons:

- Safe cold HV withstand to ground values measured for SSU and SSD were ~ 150 V (breaks down ~ 250 V)
  - Localized at the feedthrough (air-to-vacuum) region
- HTS lead voltage less than 3 mV
  - QPS HTS lead quench detection threshold value is set at 1 mV
- Keep the LTS lead voltages during quench as low as possible
  - Apply low detection threshold values to keep the hot spot temperature as low as possible
    - No clear understanding (as built) what are the lead dimensions and/or cooling conditions, consequently quench integral value limits are not known.

Quench Protection Upgrade



- Carefully selected External diode pack (M1 and M2 ~ 5 V, for ECE ~ 10 V), and R2 (0.5 Ω)
- Contactor for the External diode pack is open; not to interfere with PS operation
- Direct protection of LTSa and LTSb segments with V-taps
- LTSd is only protected with the magnet; low threshold settings are required to lower the hot spot temperature; dI/dt based protection

Conclusions

- Operational experience of the SS magnets at RAL was described
- Failure of the SSD M1 coil was analyzed and shown that the most likely scenario for the failure was due to poor manufacturing quality control.
- To avoid a similar failure, the QPS has been upgraded.