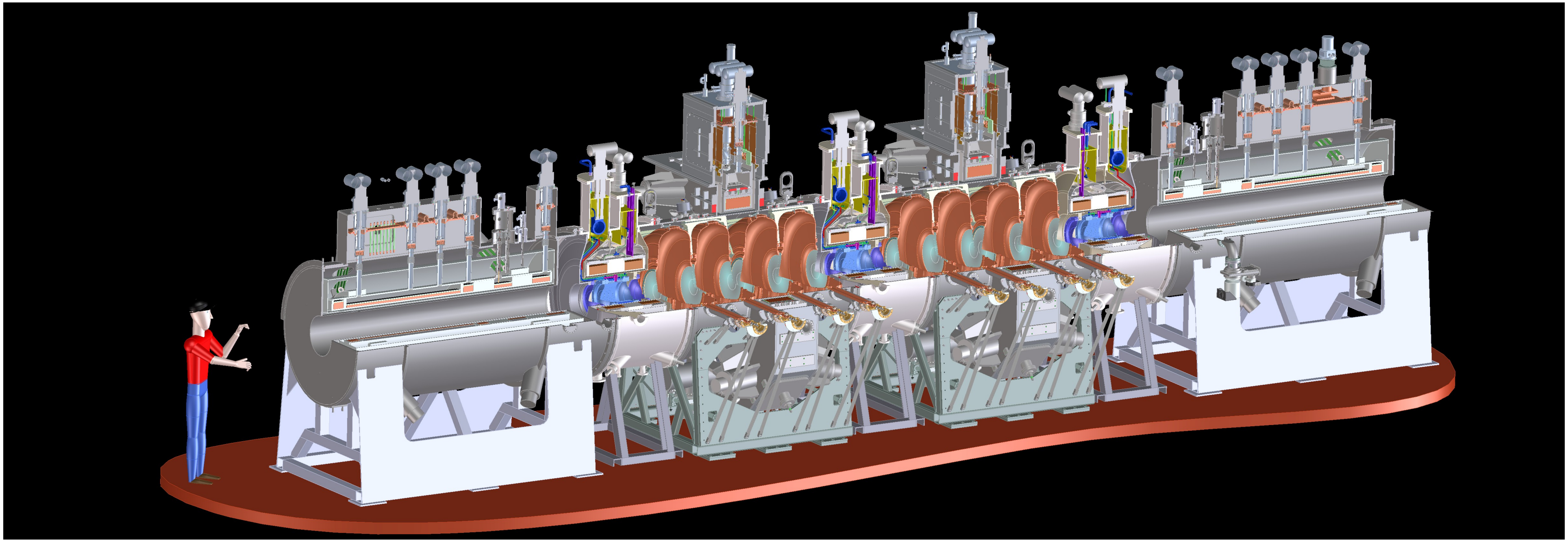
Step IV (V and VI) Magnet Integration

Pierrick Hanlet

17 June 2013



Outline

- **Motivation**
- **Integration Considerations**
- **Lessons learned from SS2 and FC1**
- **Integrated Quench Protection System**
- **Other Considerations**
- **Conclusions**

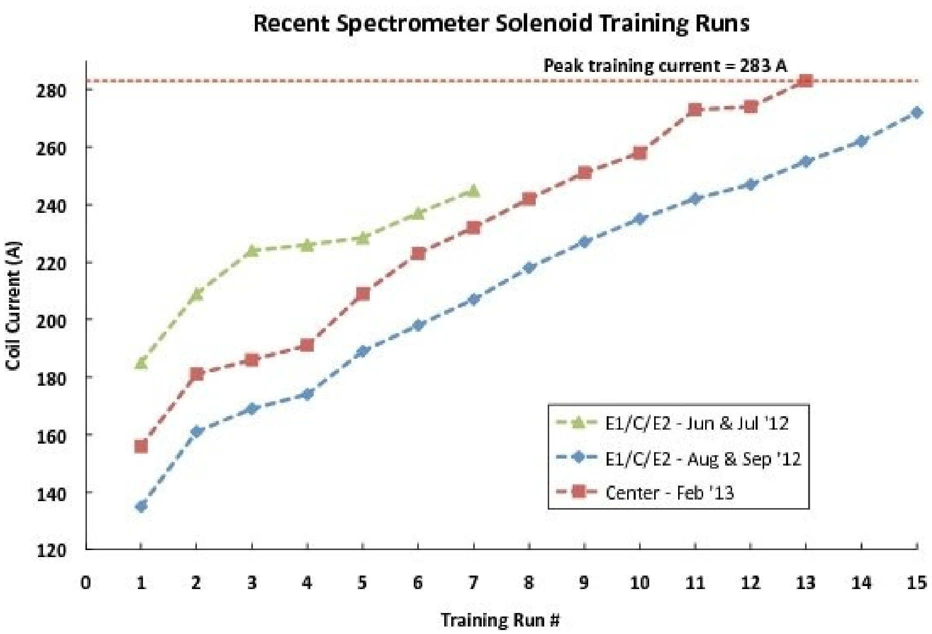
Motivation

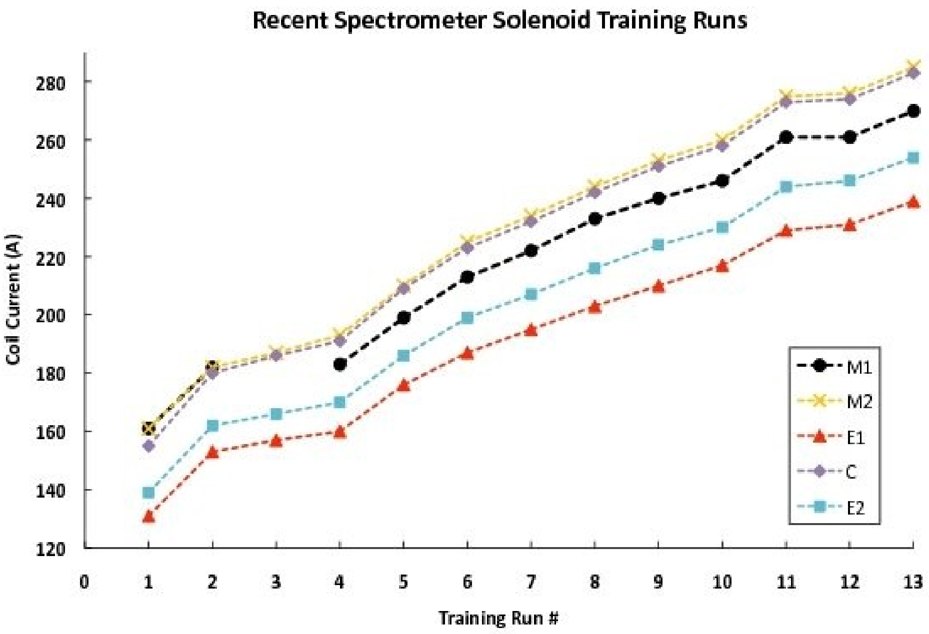
- To date, magnet systems modular
- OK for Step I
- Will not work for string of coupled superconducting magnets
- Must think globally
- Issues being addressed with:
  - Run Control
  - State Machines
  - Integrated Quench Protection System

Integration Considerations

- ***Installation***
- ***Services – sharing resources***
- ***Integrated Controls & Monitoring***
- ***Cooling Channel Operations***
  - ***Cooling magnets – not simple procedure***
  - ***Training magnets – many quenches***
  - ***Powering/normal operation***
  - ***Quench recovery***
- ***Integrated Quench Protection System***

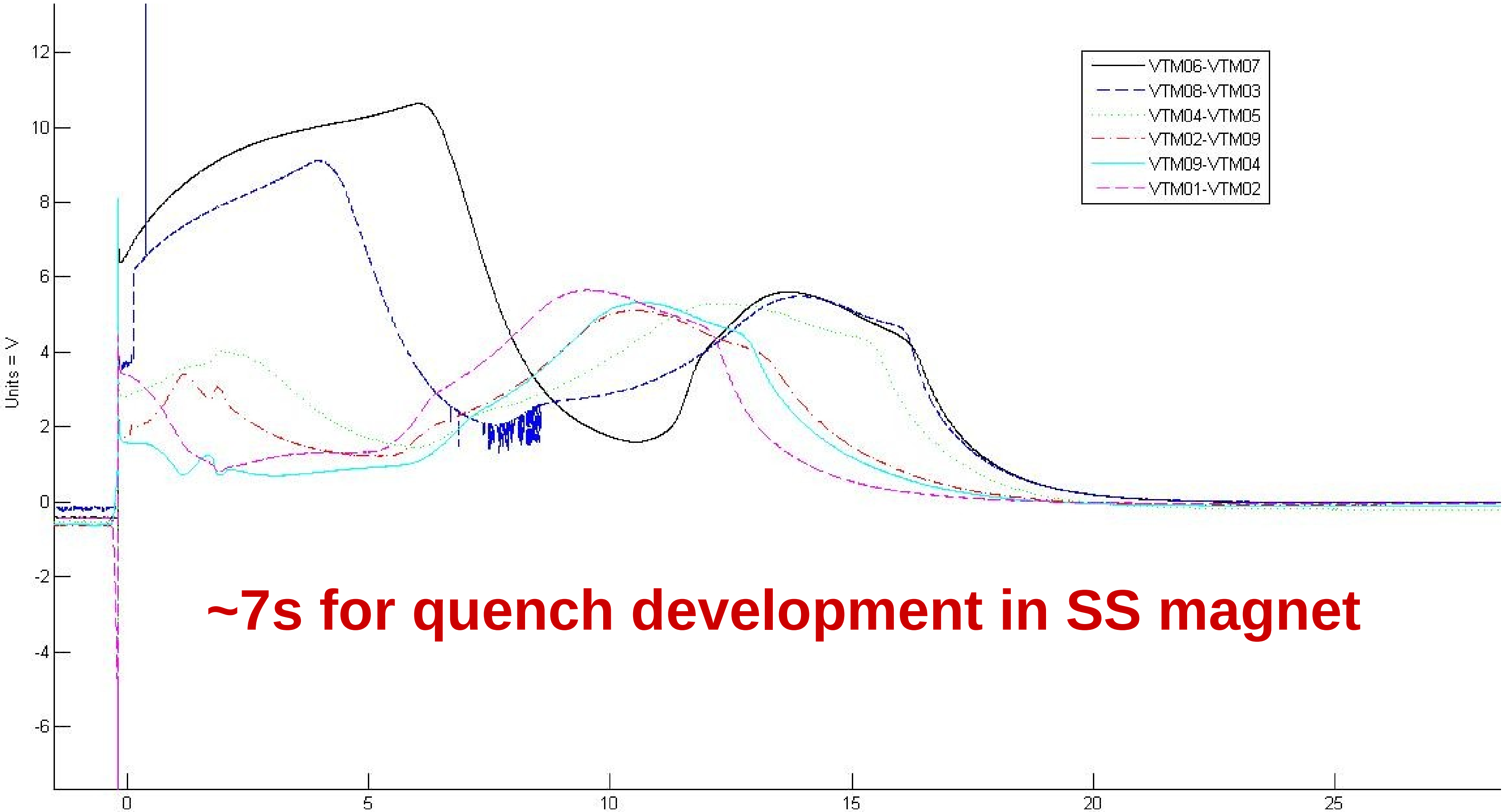
SS2 Training History





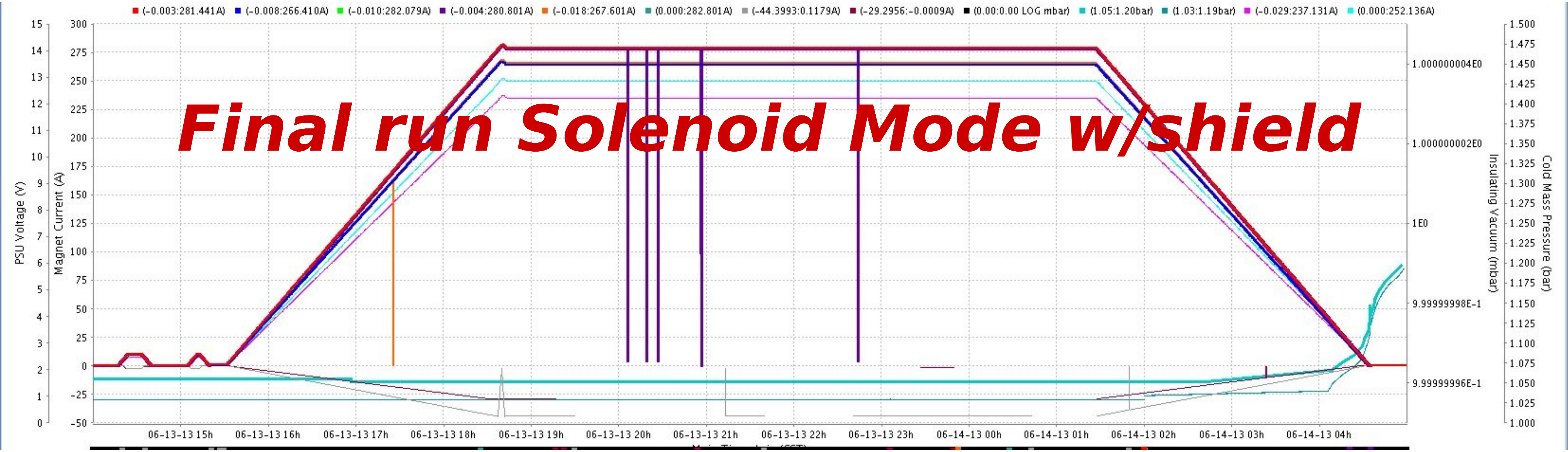
- ***13 training quenches for SS2***
- ***1 to "re-train" directly to solenoid mode***
- ***1 more when shield was added***

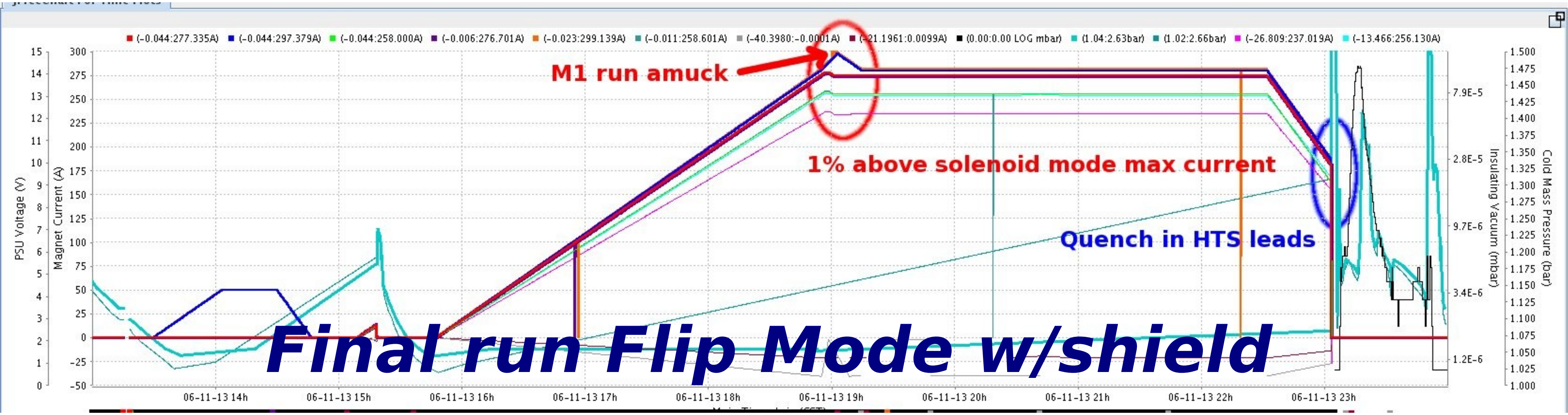
SS2 Final Training



- ***Quench develops in coils via "quench back"***
- ***Progress made when sufficient monitoring***

SS2 Training History

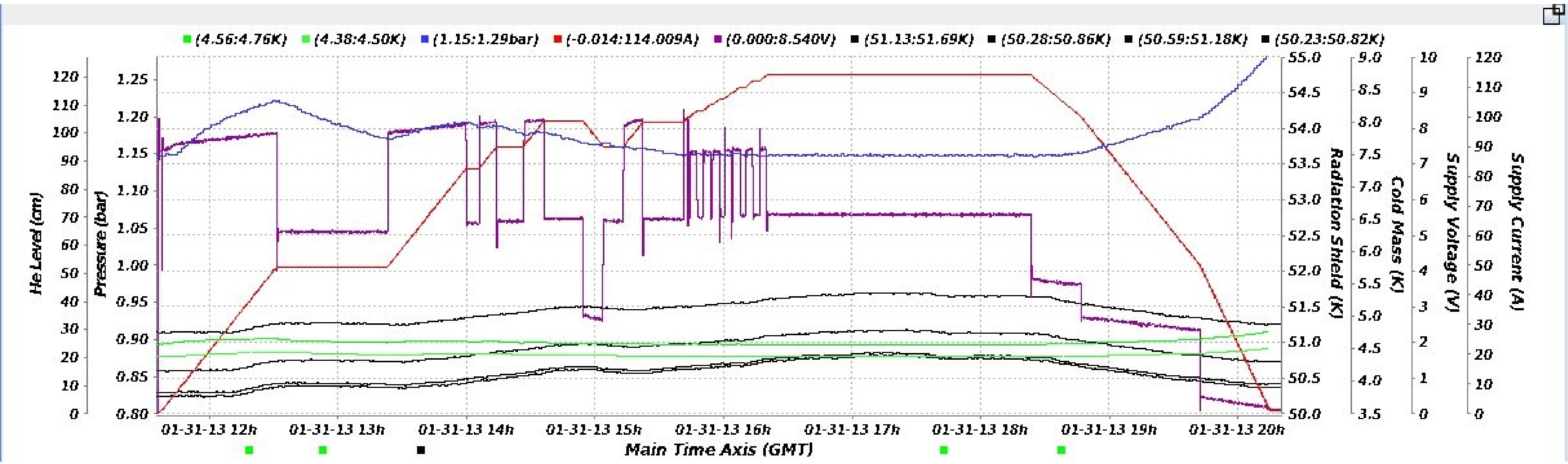




SS2 Leasons Learned

- Will need to retrain after warming
- ~13 quenches
- recool magnet after quench >500l of LHe
- 4-5 hours to recover and settle
- additional quenches w/new forces
- ~6 seconds for 5 coils to quench
- transients ~100μs

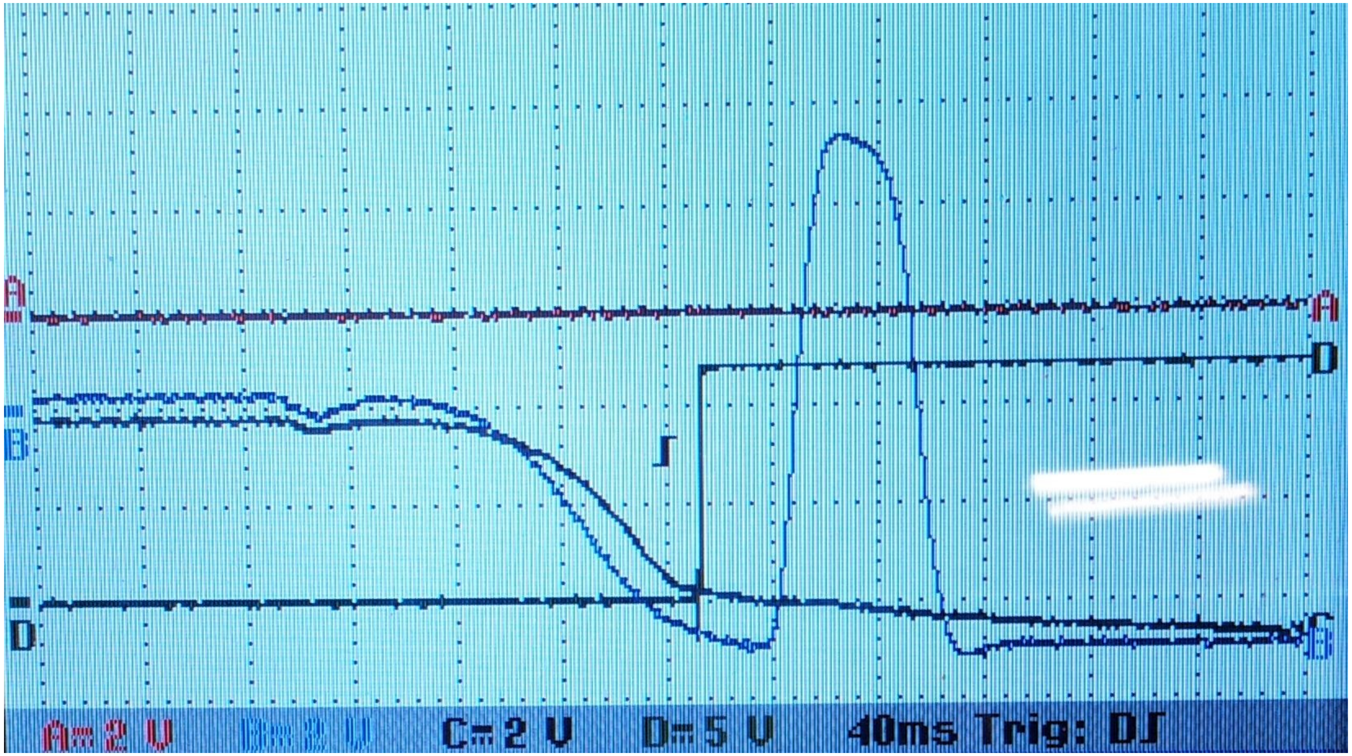
FC1 Training History



- ***successful solenoid mode training – 3 required***
- ***trouble replicating in flip mode – 10 so far***

FC1 Training History

- ***Is there sufficient monitoring?***



- ***Quench develops <1s***

FC1 Leasons Learned

- ***unknown required quenches for training***
- ***using coolers to recool***
- ***~3 days to recover and settle***
- ***additional quenches w/new forces (?)***
- ***<1 second for 2 coils to quench***
- ***DL working on improved data logging***
- ***MUCH still to be learned***

Now Imagine ...

Now imagine ...

- **cooling channel:**
  - 2 SS and 1 FC in Step IV
  - 2 SS, 2 FC, 1 CC in Step V
  - 2 SS, 3 FC, and 2 CC in Step VI

- **training the cooling channel chain**
  - new forces
  - number of training runs
  - requisite LHe
  - time to recool channel
  - duration of quench propagation – logging

Integrated QPS

- QPS is Quench Protection System
- existing systems:
  - Fermilab TD – SS and CC
  - Daresbury – FC (and DS)
- must keep existing QD functionality
  - identify similarities and differences
  - keep all? reuse parts? completely new?
- determine requirements: SS, FC, CC
- outline integrated system

Integrated QPS

For each system:

- number of voltage taps
- signals for quench detection
- coupling of these signals
- dynamic range of the signals
- requisite time resolution for transients
- duration of quench

Existing Systems

Voltage Tap Input
- 3 Voltage taps
- 3 Resistive measurement

→

Amplifier
- Central tap amplified
- Outer taps to provide reference

→

Isolator
- Signal isolated from magnet

↓

Comparator
- Window comparator to compare signals

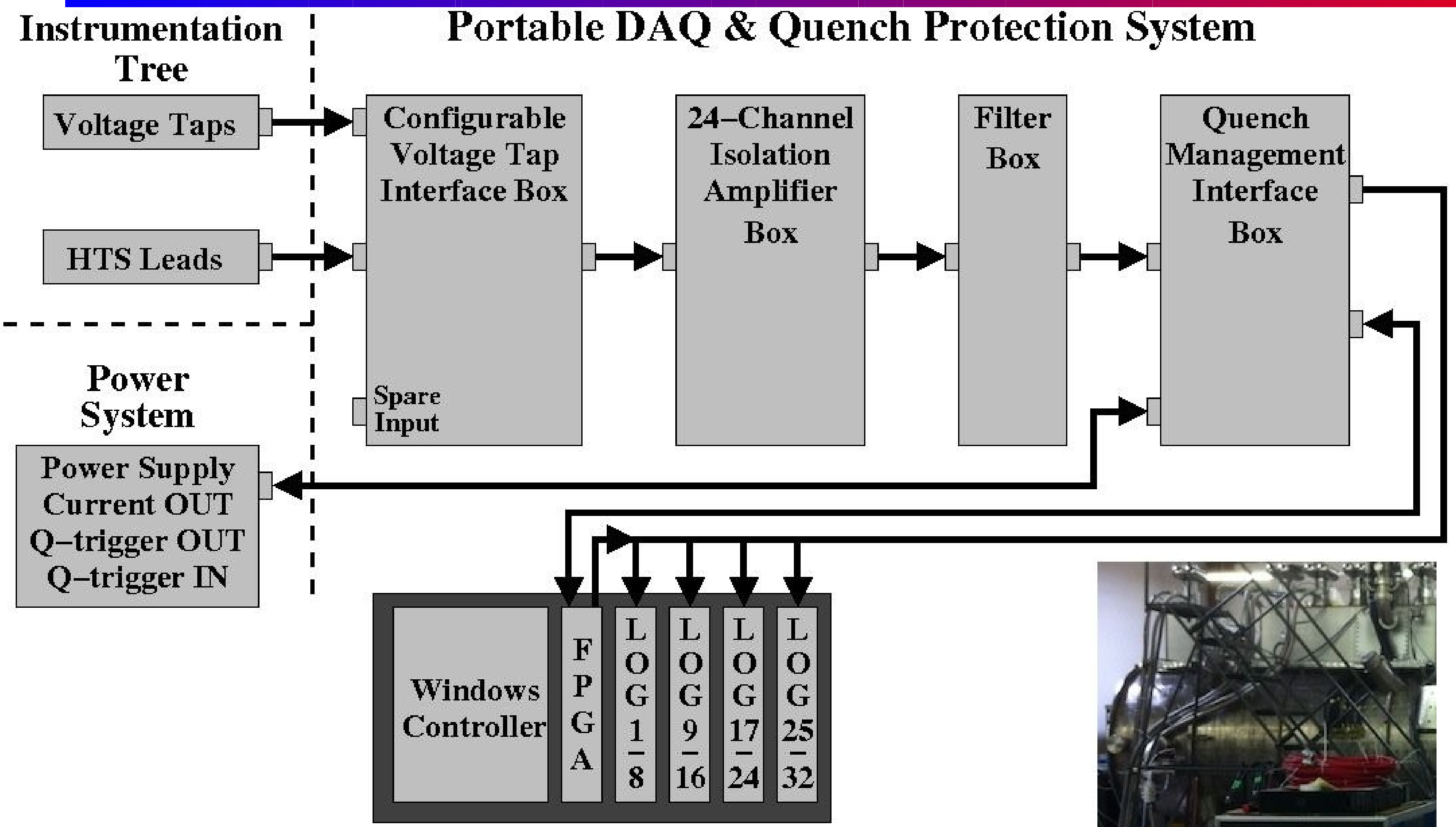
←

De–Energizer
- Signal out of range
- System latched in quench state

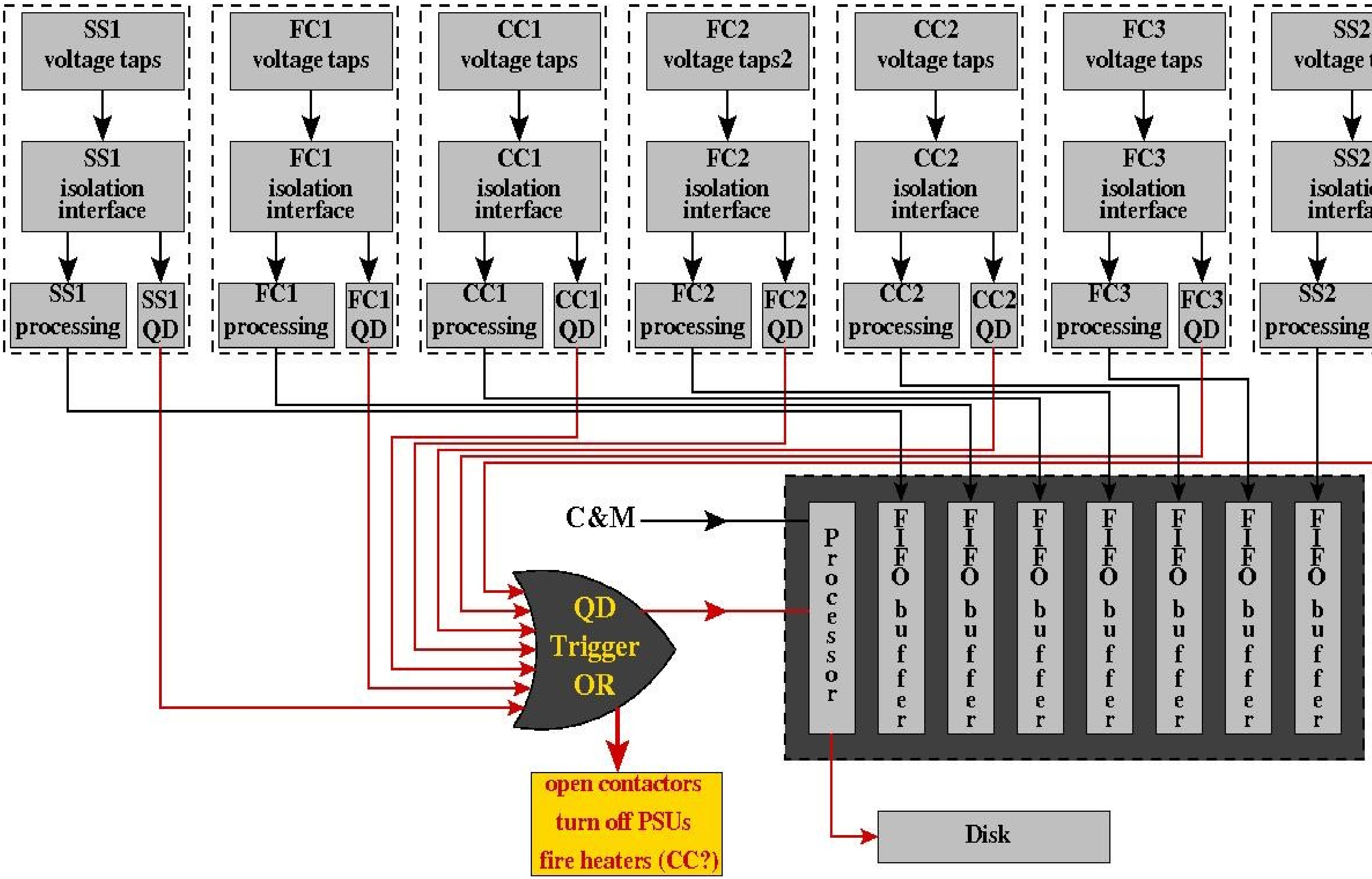
←

Quench Trigger
- Relay chain commenced
- Magnet contactors opened

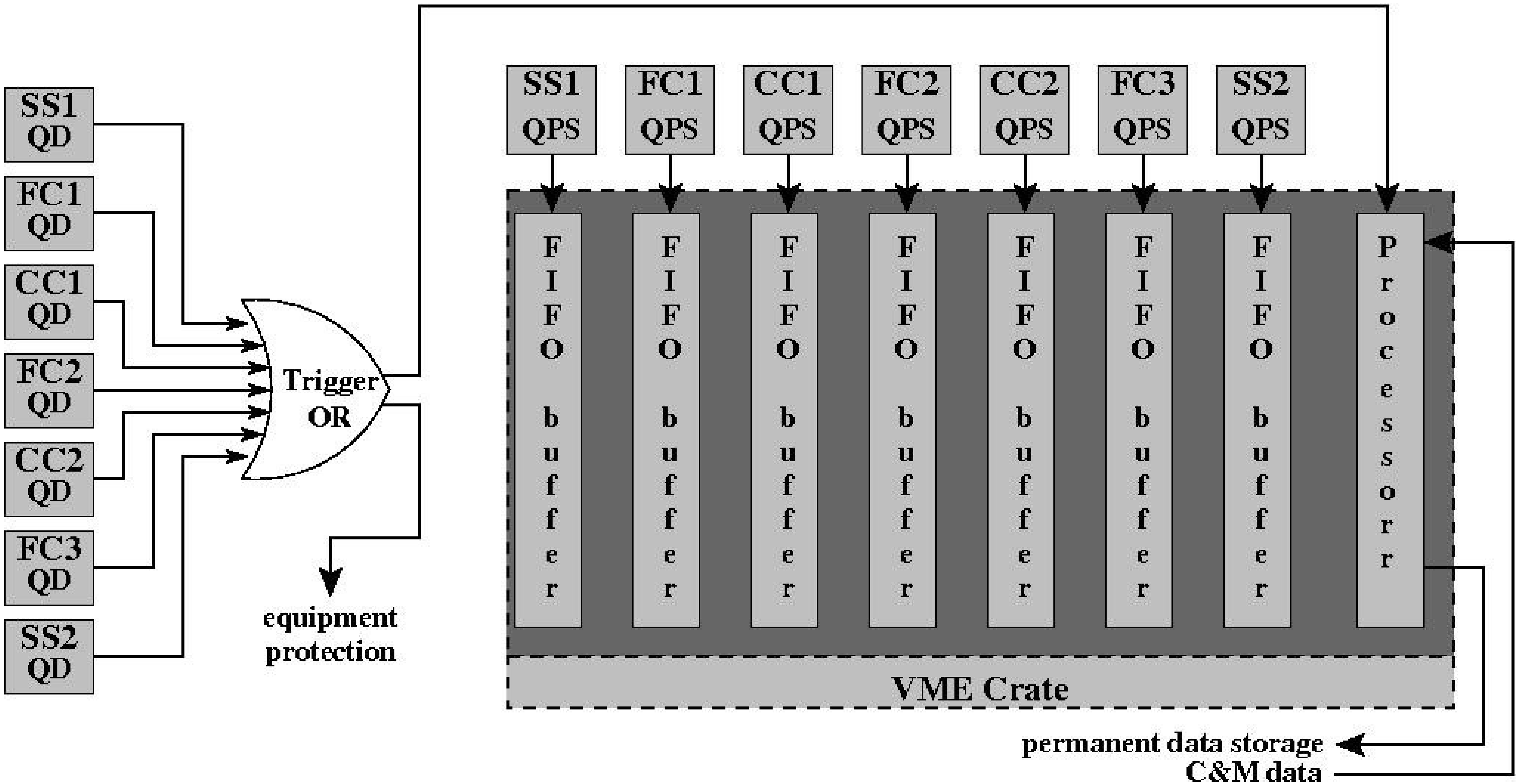
Existing Systems



Possible Plan



Possible Plan

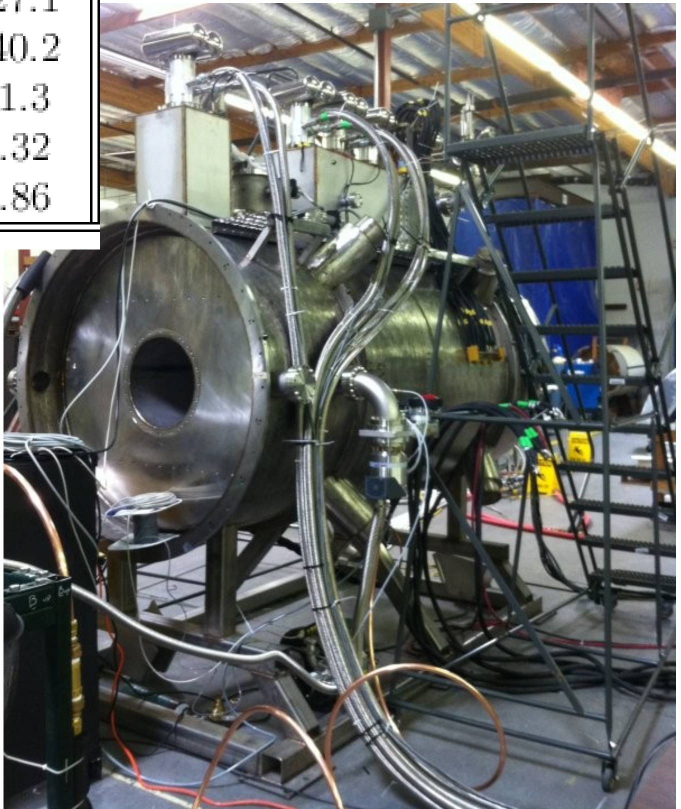


SS2 As Built

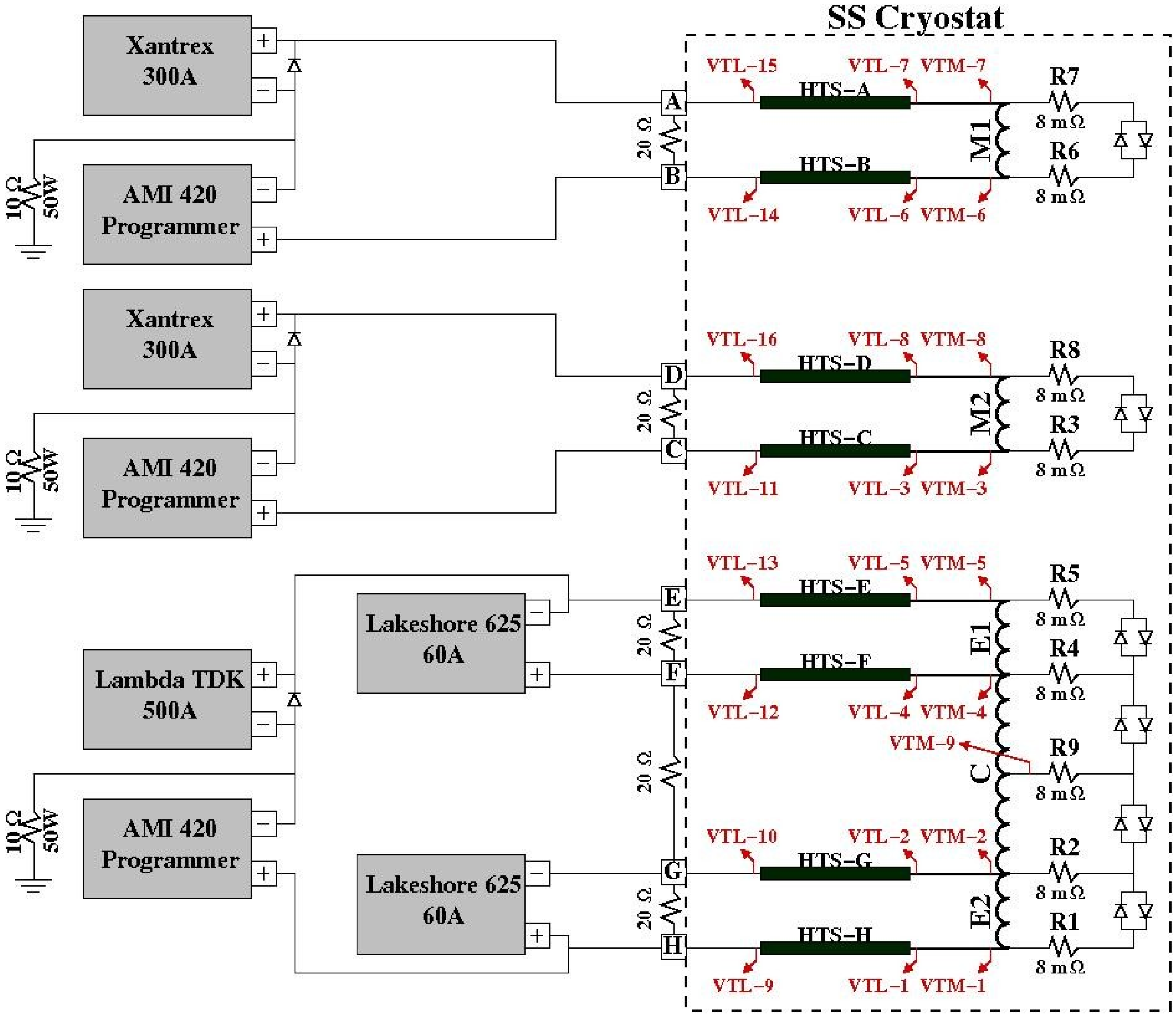
Table 1: Summary of MICE Spectrometer Solenoid Magnet (SS2) Parameters.

Parameter	M1	M2	E1	C	E2
Coil inner radius (mm)	258	258	258	258	258
Coil thickness (mm)	46.2	30.9	60.9	22.1	67.8
Coil length (mm)	201.3	199.5	110.6	1314.3	110.6
Current Center Axial Position (mm)	124.0	564.0	964.0	1714.0	2464.0
Number of layers	42	28	56	20	62
Number of turns/layer	115	114	64	768	64
Number of turns	4830	3192	3584	15360	3968
Coil current density (A/mm^2)	137.7	147.8	124.3	147.7	127.1
Coil current (max) (A)	264.8	285.6	233.7	275.5	240.2
Coil self inductance (H)	12.0	5.0	9.0	40.0	11.3
Coil Stored Energy (MJ)	0.42	0.20	0.26	1.55	0.32
Peak Field in Coil (T)	5.30	4.32	5.68	4.24	5.86

- ***25 voltage taps***
  - ***8 pairs on HTS leads***
  - ***8 pairs on LTS leads***
  - ***6 across coils***
- ***resistively coupled/isolated***



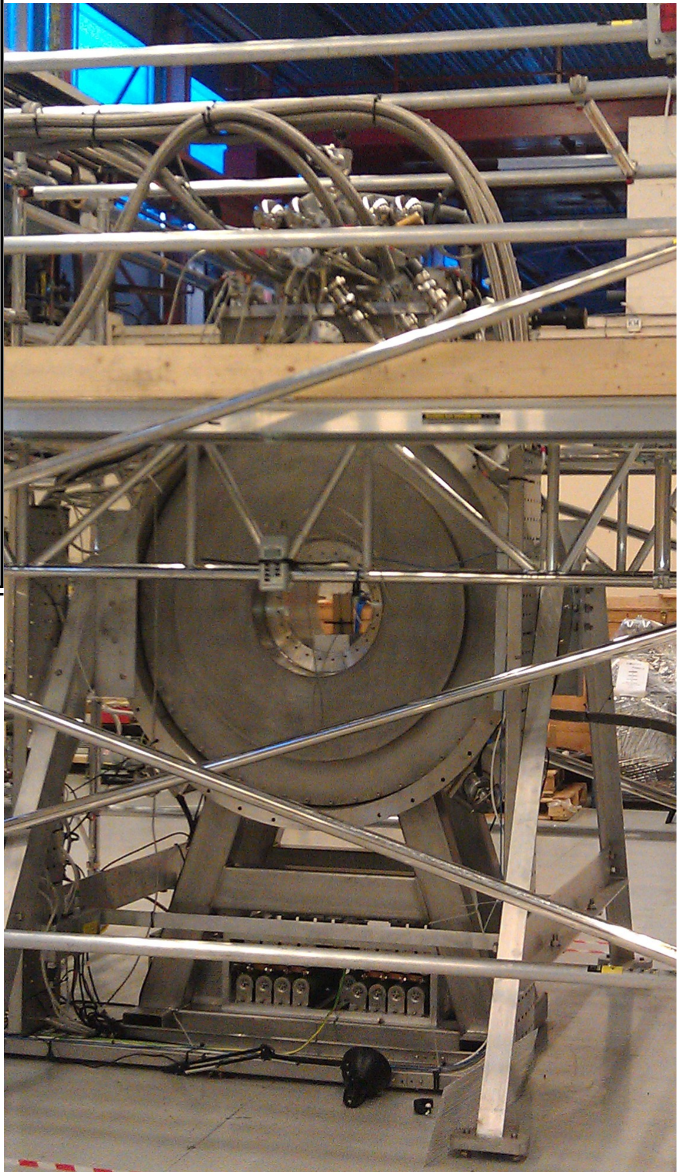
SS Simplified Layout



FC1 As Built (?)

Table 1: Summary of MICE Focus Coil Solenoid Magnet (FC) Parameters.

Parameter	C1	C2
Coil inner radius (mm)	267.6	267.6
Coil thickness (mm)	94.3	94.3
Coil length (mm)	213.3	213.3
Current Center Axial Position (mm)	239.3	405.4
Number of layers	84	84
Number of turns/layer (average)	134	134
Number of turns	11256	11256
Coil current density (A/mm^2)	125.8	125.8
Coil current (max) (A)	224.8	224.8
Coil self inductance (H)	80.3	80.3
Coil Stored Energy (MJ)	2.03	2.03
Peak Field in Coil (T)	7.52	7.52



- ***12 voltage taps***
  - ***4 pairs on HTS leads***
  - ***4 pairs on LTS leads***
  - ***2 across coils***
- ***resistively coupled/isolated***

CC1 Design

Table 1: Summary of MICE Coupling Coil Solenoid Magnet (CC) Parameters.

Parameter	Value	Unit
Coil inner radius	750.0	mm
Coil outer radius	852.5	mm
Coil length	285.0	mm
Number of layers	96	
Number of turns/layer	166±3	
Conductor Width (no insulation)	1.60	mm
Conductor Height (no insulation)	0.95	mm
Average Conductor Width (with insulation)	1.73	mm
Average Conductor Height (with insulation)	1.06	mm
Cu:Superconductor ratio	3.9	
Coil current (max)	210.1	A
Coil Stored Energy	12.9	MJ
Coil self inductance	584.0	H
Peak Field in Coil	7.37	T

Other Considerations

- Considerations
  - common mode
  - ground loops
  - cable inductance
- Testing plan must be properly detailed
- Run Control and State Machine key components of operation
- Using Fermilab Engineering Manual
- MICE note in preparation

Conclusions

- To date, magnets treated as isolated
- Will not work for integrated magnets
- Initiating plan for integration

- Operation under Run Control and State Machines
- Integrated QPS required
- Specification & Design is beginning