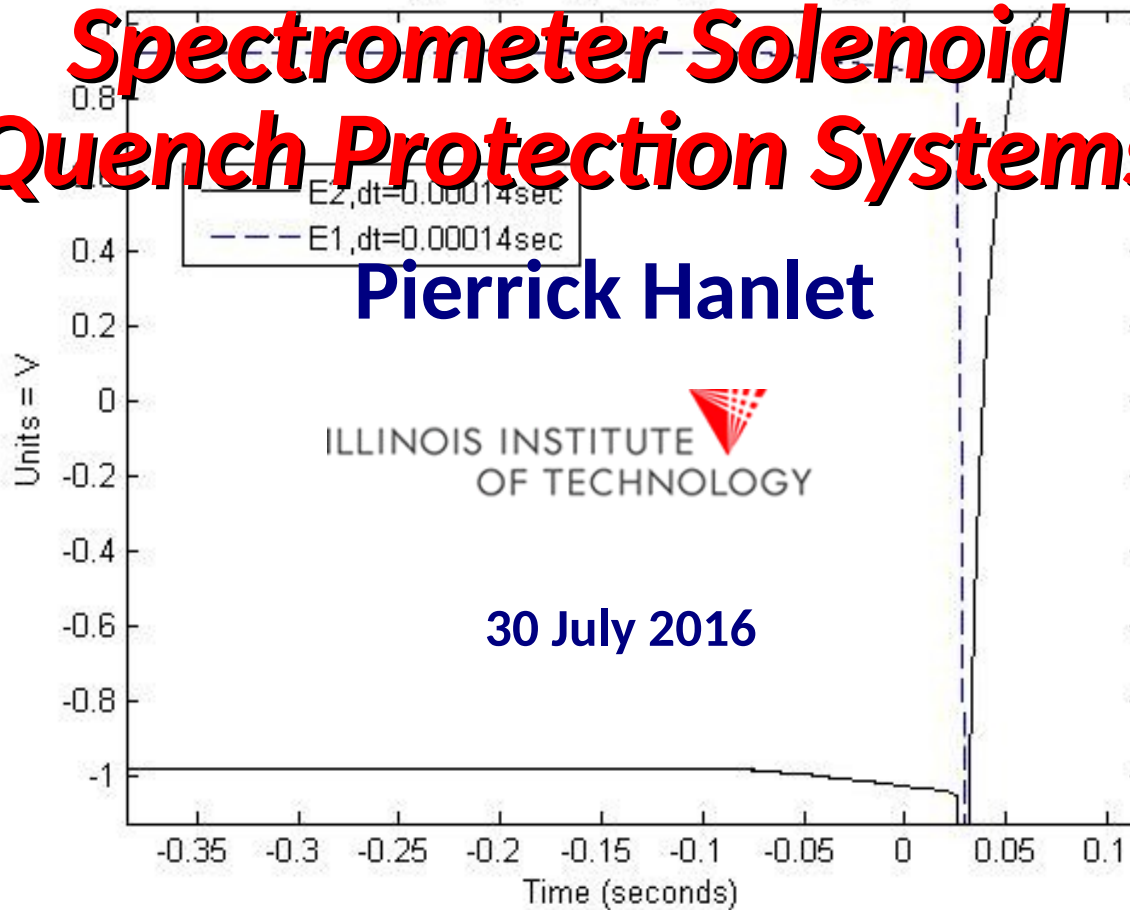




Magnitude vs. Time
MICE_SSU_2016_Jul_05_17-36-10 (1).qda

Spectrometer Solenoid Quench Protection Systems

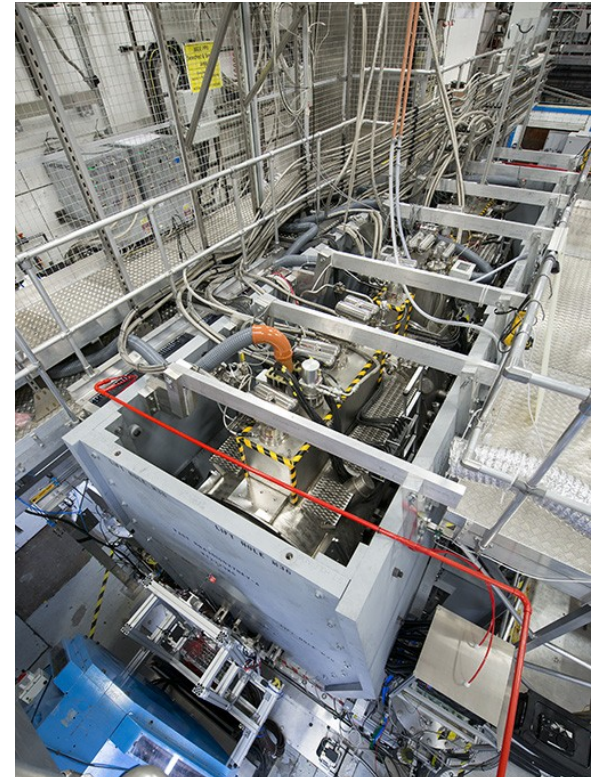


Pierrick Hanlet

ILLINOIS INSTITUTE
OF TECHNOLOGY

30 July 2016

- Description of system
- Principle of SS QPS (Quench Protection System)
- Upgrades since last CM
- Plots
- What is next?



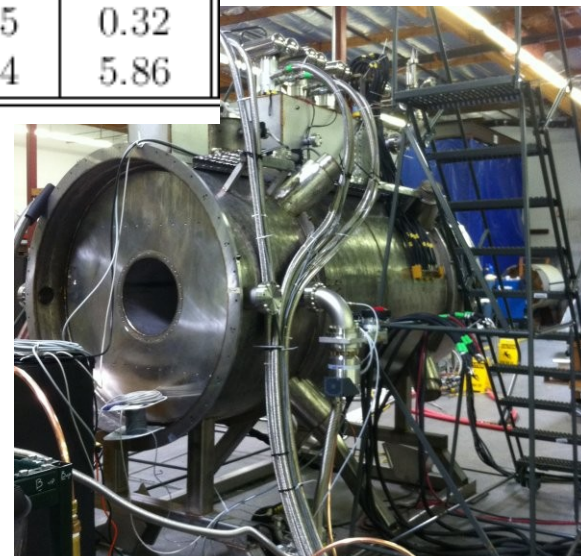


SS2 (SSU) As Built

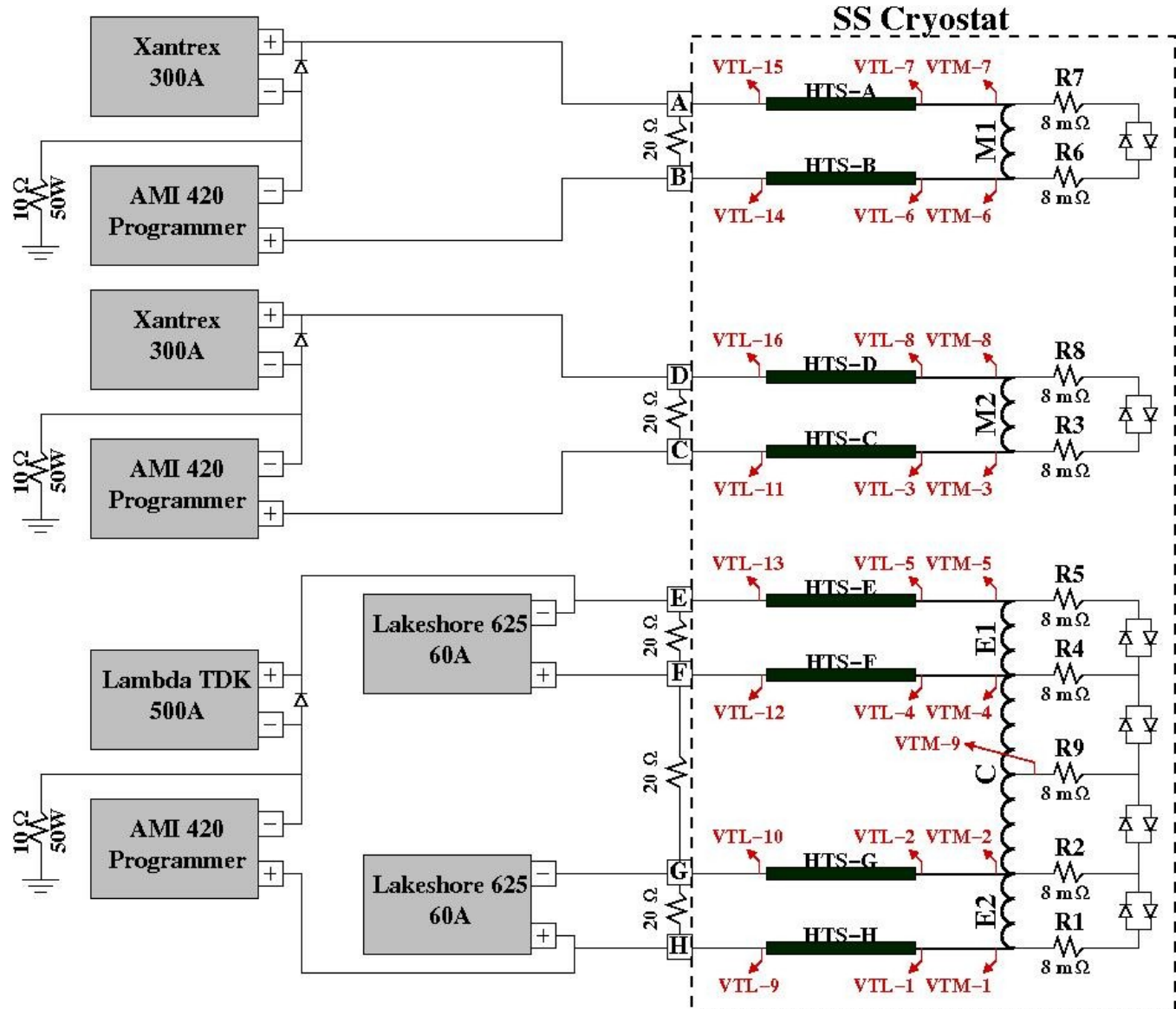
Table 1: Summary of MICE Spectrometer Solenoid Magnet (SS2) Parameters.

Parameter	M1	M2	E1	C	E2
Coil inner radius (<i>mm</i>)	258	258	258	258	258
Coil thickness (<i>mm</i>)	46.2	30.9	60.9	22.1	67.8
Coil length (<i>mm</i>)	201.3	199.5	110.6	1314.3	110.6
Current Center Axial Position (<i>mm</i>)	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 (<i>A/mm²</i>)	137.7	147.8	124.3	147.7	127.1
Coil current (max) (<i>A</i>)	264.8	285.6	233.7	275.5	240.2
Coil self inductance (<i>H</i>)	12.0	5.0	9.0	40.0	11.3
Coil Stored Energy (<i>MJ</i>)	0.42	0.20	0.26	1.55	0.32
Peak Field in Coil (<i>T</i>)	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





Principle

- Superconductors have no resistance, $\Delta V = IR = 0$
 - voltage taps (VTs) across each segment
 - HTS (High Temperature SC) from warm external leads
 - LTS (Low Temperature SC) between HTS and coil
 - coils
- When ramping magnets, $\Delta V = -L \, dI/dt$ on coils (not leads)
- Additional $\Delta V = -M \, dI/dt$ from adjacent coils
- Center coil has a center VT
- **Each coil has LTS sections without VTs – no protection!**
- To protect magnets:
 - monitor voltages across leads, trip on ΔV above threshold
- When thresholds are exceeded, open contactors



Principle

To protect the magnets:

- **LEADS:** monitor lead VTs, trip on ΔV above threshold
 - LTS leads have 10mV thresholds
 - HTS leads have 1mV thresholds
 - QPS sums leads
 - separate contactors for leads (more later)
- **MATCH COILS:** monitor VTs across M1 & M2:
 - threshold set on $\Delta V - L \, dI/dt$, where L is a “balancing” parameter
 - threshold set on $\Delta V - M \, dI/dt$, where M is a “balancing” parameter to account for other coils
 - request dI/dt for FC



Principle

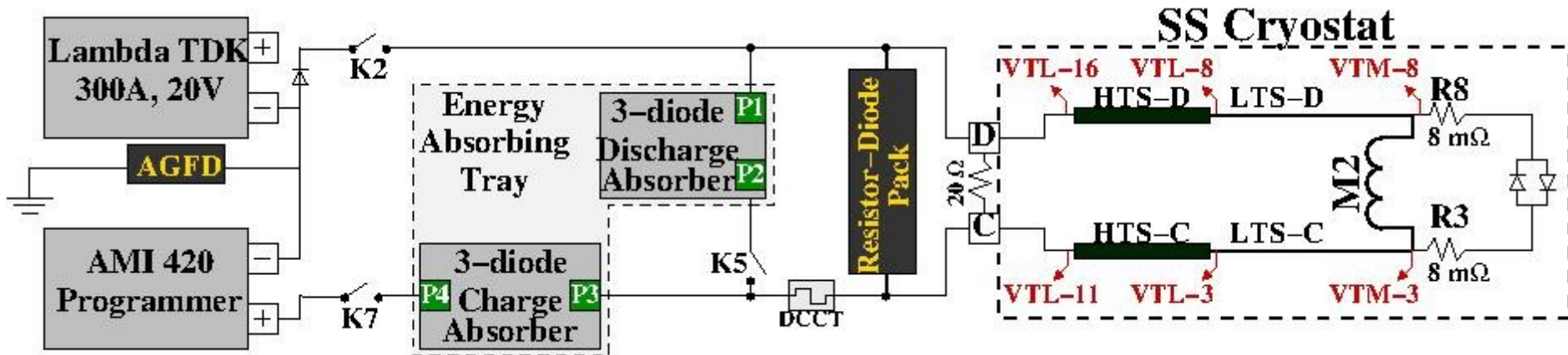
To protect the magnets – continued:

- **CENTER:** monitor VTs across $E1+C/2$ and $E2+C/2$, trip on ΔV above threshold
 - $E1 - C - E2$ are wired in series and have single 300A PSU
 - trim power supplies sink current on $E1$ and $E2$
 - since C coil has center VT, can buck the 2 half coil signals
 - threshold is set on $(E1+C/2) - L (E2+C/2)$ where L is a “balancing” parameter



Since last CM

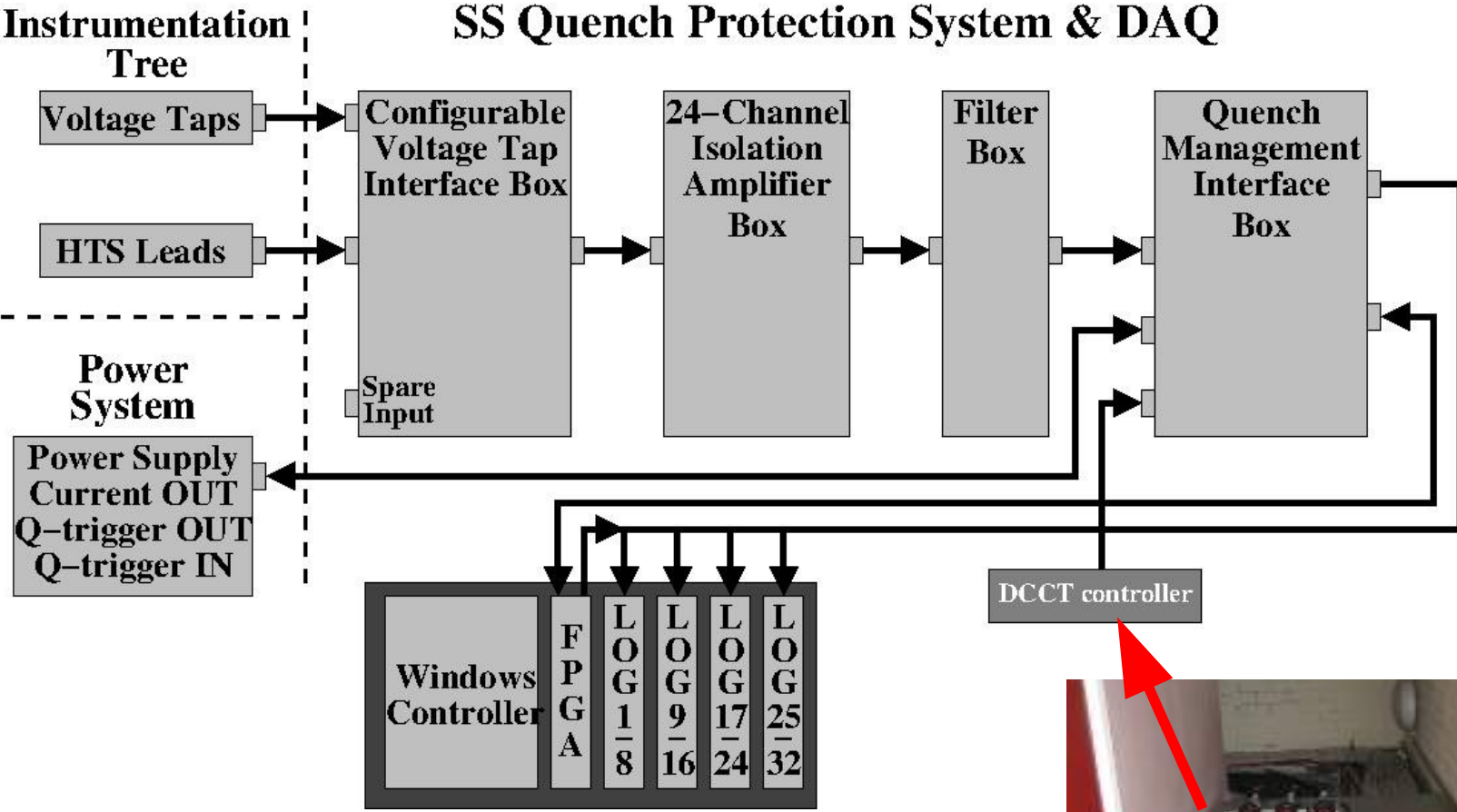
- Alan, Sandor, and I found VTs for both SSD center tap and SSD-M2, this allowed
 - protecting SSD with $(E1+C/2) - L (E2+C/2)$
 - protecting one of SSD M2 LTS leads
- Updated Power train and QPS
 - added external Resistor-Diode pack
 - added DCCT information for I and dI/dt measurements
 - added to EPICs interface





SS QPS Layout

SS Quench Protection System & DAQ





SS QPS Features

- digital (FPGA) and redundant analog QD
- signals monitored and stored:
 - lead voltages
 - coil voltages
 - currents & dI/dt signals
 - triggers
- open contactors and reports to control system
- data loggers store fast ($\sim 7\text{kHz}$) data in ring buffer
- output signals to EPICS – 5Hz – slow logging



QPS Interface

ISOAMP Configuration Program

Ch	Name	ISOAmp Settings Controls	Status Indicators	SPI Devices Registers HEX Code Monitor
Ch 1	SPARE1	Gain 1 Offset 0.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 2	E2_C/2	Gain 0.501961 Offset -6.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 3	E1_C/2	Gain 0.501961 Offset -6.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 4	SPARE2	Gain 1 Offset 0.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 5	M2	Gain 0.1 Offset -4.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 6	M1	Gain 0.1 Offset -2.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 7	SPARE3	Gain 1 Offset 0.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 8	SPARE4	Gain 1 Offset 0.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 9	HTS-E	Gain 30.1176 Offset 103.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 10	HTS-F	Gain 30.1176 Offset 99.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 11	HTS-G	Gain 30.1176 Offset 99.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 12	HTS-H	Gain 30.1176 Offset 99.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 13	HTS-A	Gain 30.1176 Offset 103.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 14	HTS-B	Gain 30.1176 Offset 107.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 15	HTS-C	Gain 30.1176 Offset 120.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 16	HTS-D	Gain 30.1176 Offset 105.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 17	LTS-A	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 18	LTS-B	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 19	LTS-C	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 20	LTS-D	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 21	LTS-E	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 22	LTS-F	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 23	LTS-G	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1
Ch 24	LTS-H	Gain 10.9871 Offset 33.00 Read Write AutoZero	Output Polarity Sat- Sat-	Gain 7F 1 Offset 7F 1

Configuration Settings File: C:\MICE\Config\IsoAmp_Config_SSU_20160526.ini

Buttons: Read Config, Write to IsoAmp, Read IsoAmp, Write Config

AutoZero All Channels: AutoZero Process:

NI-8541 2: USB0-0:0323-0:7166-0172A5D0

NI-8541: USB0-0:0323-0:7166-0172A5D0-RAW

stop STOP

IsoAmp Configuration

Quench Characterization

SSU Quench Characterization

Modules: PXI Slot7

Channel Names	External Gains
L_M1	E
L_M2	E
L_E1	E
L_C	E
L_E2	E
L_E3	E
NOSIGNAL	E
NOSIGNAL	E
NOSIGNAL	E
Module ON	71420 7142

Channel Names	External Gains
VTM02-VTM02	E
VTM02-VTM09	E
VTM02-VTM04	E
VTM04-VTM05	E
SUM_SC	E
VTM05-VTM07	E
VTM05-VTM05	E
SUM_HTC	E
Module ON	71420 7142

Refresh Rate (ms): 50

Start Logging time: 21:37:47.661 28/07/2016

ARM DATA LOGGERS

SHOW SLOW DATA

STOP MEASUREMENT

ARMED

Quench Detected

Epics Channels: 30

Loggers Channels: 30

Slow Data SR [Hz]: 2

Slow Data

EPICS Transfer: ON

STOP PROGRAM

QC Configuration File: C:\MICE\Config\QC_Config_SSU_20160525.ini

Buttons: LOAD, SAVE

Message: Data Saved and plotted. Waiting for user command

Fast Data Parameters: Sample Rate [Hz]: 7142, Pre-trig window [sec]: 5, Post-trig window [sec]: 25



QPS Interface

SSU Coils Quench Detection

Controls | Plots

Current Date: 29/07/2016
Current Time: 14:59:49
Magnet Name: SSU
Stand: RAL, UK

Configuration File:
C:\MICE\Config\QDCoils_Config-SSU_20160728.ini

Load Save

EPICS TRANSFER ON

Channels	Gains	Raw Data [V]	Data with Gains[V]
M1_Idot	1	-0.008	-0.008
E2_C/2	0.5	0.001	0.002
E1_C/2	0.5	0	0
M2_Idot	1	-0.001	-0.001
C_Idot	1	0	0
M2	0.1	-0.001	-0.009
M1	0.1	0	0.003
E1_Idot	1	-0.192	-0.192

M1-SUM(Idot)

Threshold [mV]: 250

Channel Offsets [mV]: M1: -1, M1_Idot: 0, M2_Idot: 0, C_Idot: 0, E1_Idot: 0

Balance: 0.069

First Fault: ●

M2-SUM(Idot)

Threshold [mV]: 200

Channel Offsets [mV]: M2: 0, M1_Idot: 0, M2_Idot: 0, C_Idot: 0, E1_Idot: 0

Balance: 0.0055

First Fault: ●

E2_C/2-E1_C/2

Threshold [mV]: 200

Channel: E1_C/2

Balance: -1.1

Offsets [mV]: -1

First Fault: ●

Trip Date: 29/07/2016
Trip Time: 00:16:07
Threshold: 0
Timer [us]: 10

DQD_Trip ■ AQD_Trip ■
Leads Trip ■ AGFD_Trip ■

RESET ENABLE
RESET
STOP

Balance Mode: OFF

MANUAL Manual Trip First Fault ●

Enable Ext. Trip Status Ext. Trip First Fault

Auto Enable 30 sec

Range Limit HB HB Status QML_15V ISOAMP AQD_PS AGFD_PS

EPICS TRANSFER ON

Current Date: 29/07/2016
Current Time: 14:59:49
Magnet Name: SSU
Stand: RAL, UK

Configuration File:
C:\MICE\Config\QDLeads_Config-SSU_20160728.ini

Load Save

Channels	Gains	Raw Data [V]	Data with Gains[V]
LTS_SU	10	0.004	0
HTS_SU	20	0.005	0
LTS_M1	10	0	0
HTS_M1	20	0.001	0
LTS_M2	10	0	0
HTS_M2	20	0	0
LTS_ECE	10	0.002	0
HTS_EC	20	0.003	0

LTS_SUM	[-20, 20]	Offset [mV]: -1	Threshold [mV]: 20	First Fault: ●
HTS_SUM	[-2, 2]	Offset [mV]: -4	Threshold [mV]: 2	First Fault: ●
LTS_M1	[-10, 10]	Offset [mV]: 0	Threshold [mV]: 10	First Fault: ●
HTS_M1	[-1, 1]	Offset [mV]: 0	Threshold [mV]: 1	First Fault: ●
LTS_M2	[-10, 10]	Offset [mV]: -2	Threshold [mV]: 10	First Fault: ●
HTS_M2	[-1, 1]	Offset [mV]: -1	Threshold [mV]: 1	First Fault: ●
LTS_ECE	[-10, 10]	Offset [mV]: 0	Threshold [mV]: 10	First Fault: ●
HTS_ECE	[-1, 1]	Offset [mV]: -4	Threshold [mV]: 1	First Fault: ●

Trip Date: Trip Time:

Threshold: 0 Timer [us]: 10

Leads SUM Trip ■ Coils_Trip ■

M1_EDP Timer [ms]: 0.000
M2_EDP Timer [ms]: 0.000
ECE_EDP Timer [ms]: 0.000

RESET ENABLE
RESET
STOP

Balance Mode: OFF

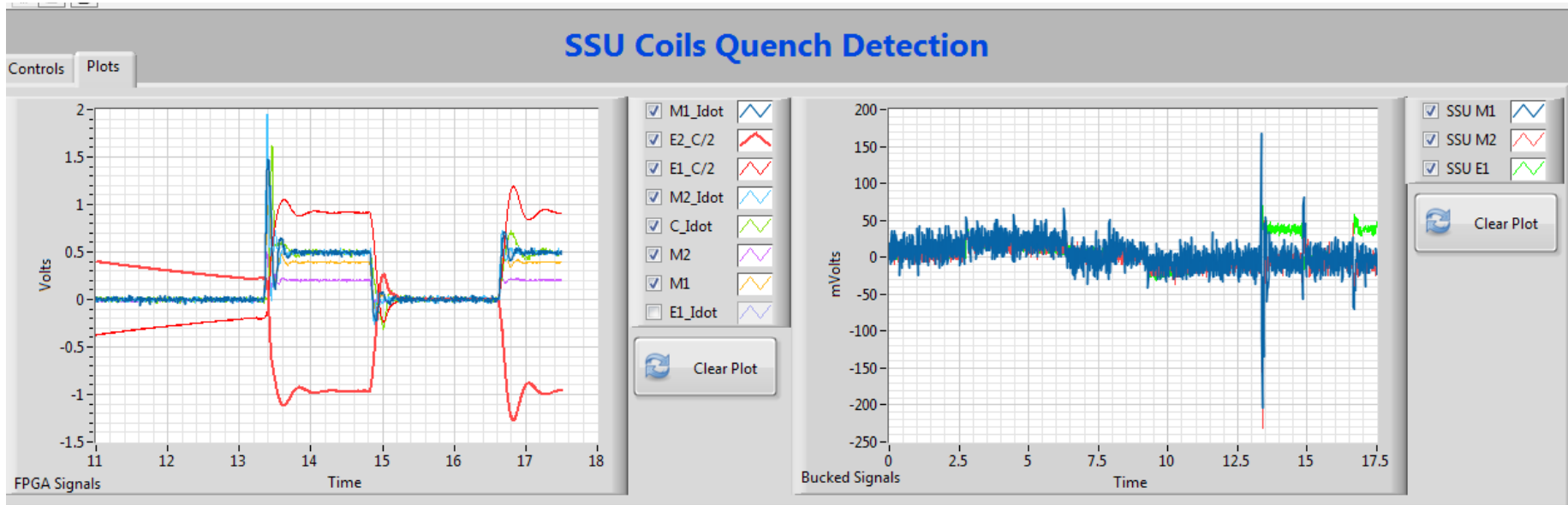
MANUAL Manual Trip First Fault ●

HB Range Limit

Coils and Leads QD Configuration



QPS Interface

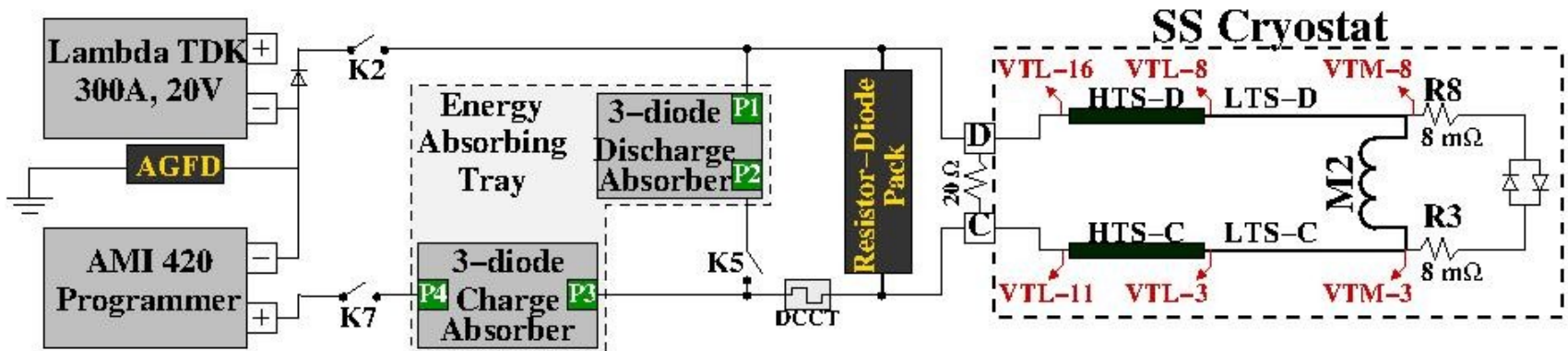


Coils QD Configuration - monitoring



Quench Scenario

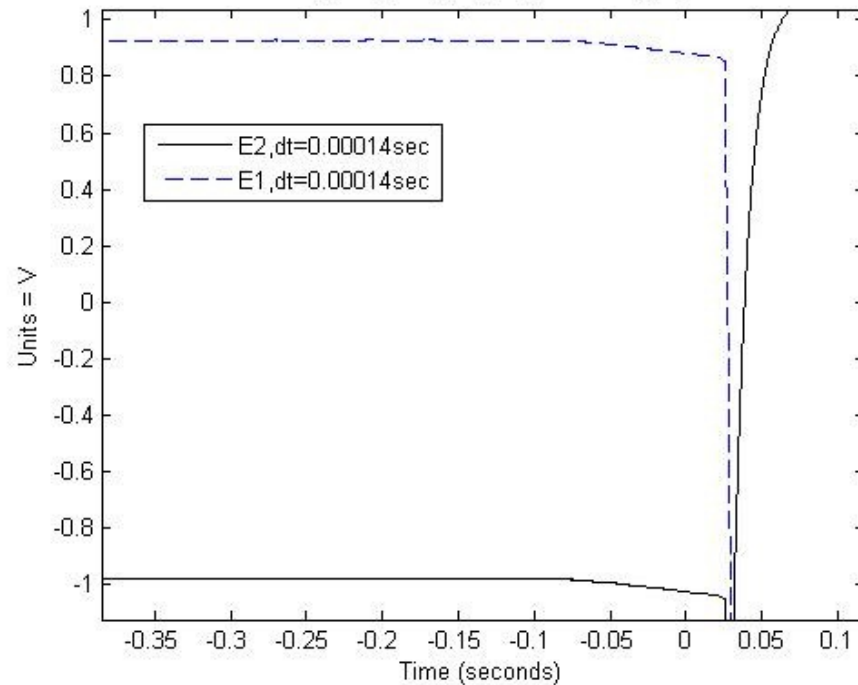
- Any quench will first open PSU contactors (K2 & K7)
- To protect internal dump circuit (the LTS section without VTs), energy is extracted through Discharge Absorber
- If HTS or LTS leads show voltage growth, QPS opens K5 to prevent damage to leads => energy is dissipated in internal absorber
- If then, the internal circuit opens, the Resistor-Diode pack will become the energy dump
- Output fast data and Quench signals



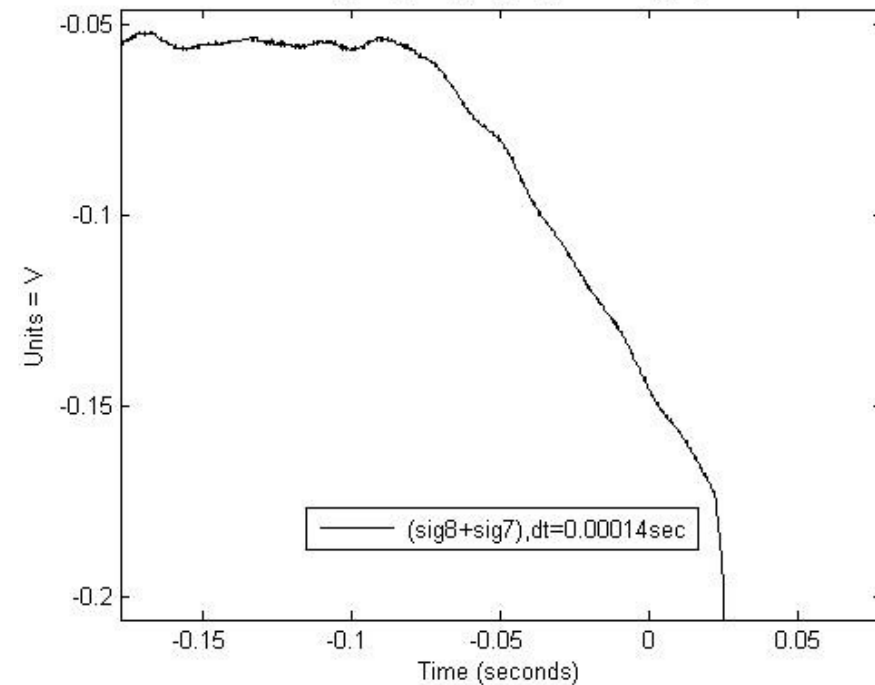


Quench Fast Data Plots

Magnitude vs. Time
MICE_SSU_2016_Jul_05_17-36-10 (1).qda

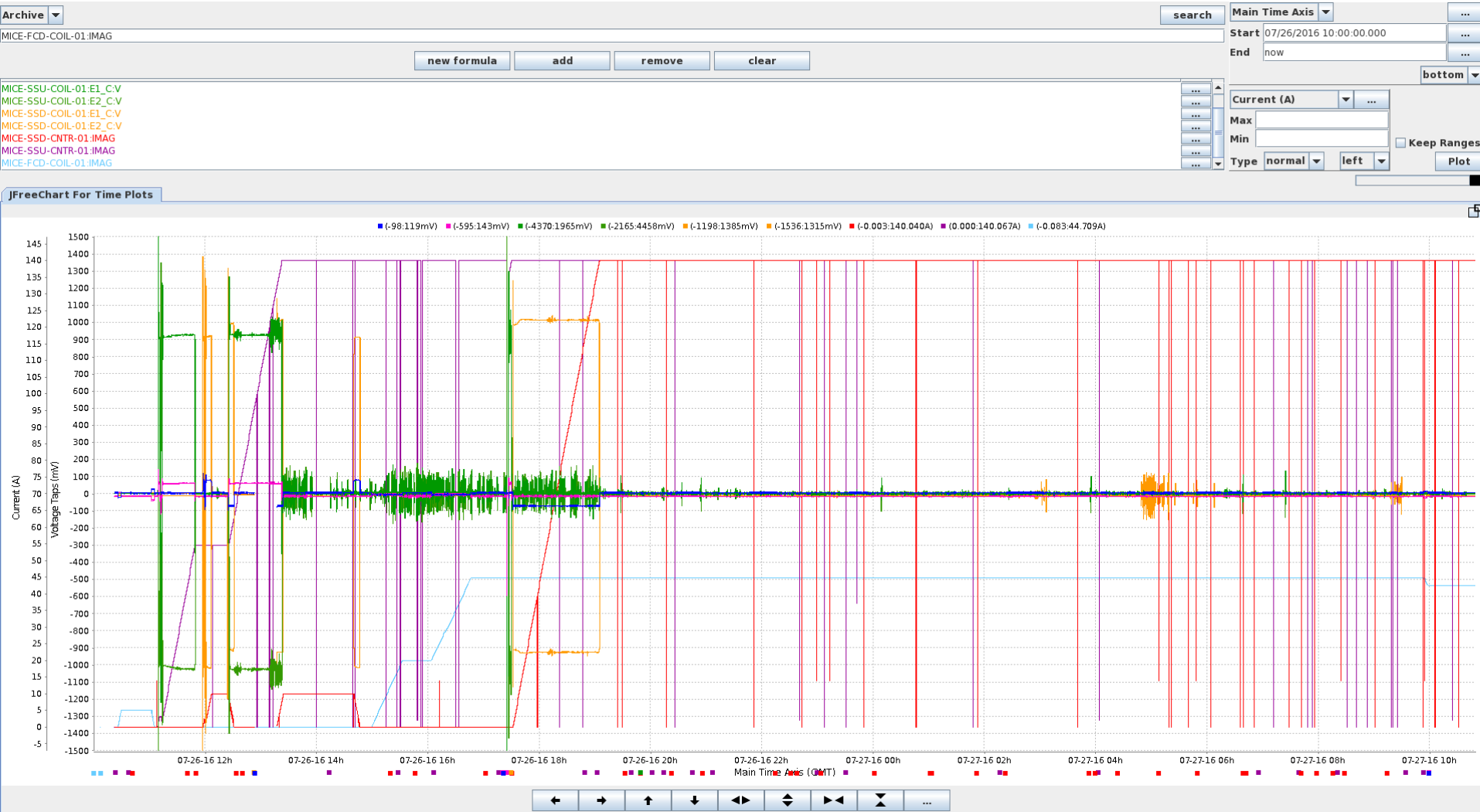


Magnitude vs. Time
MICE_SSU_2016_Jul_05_17-36-10 (1).qda





Quench Slow Data Plots



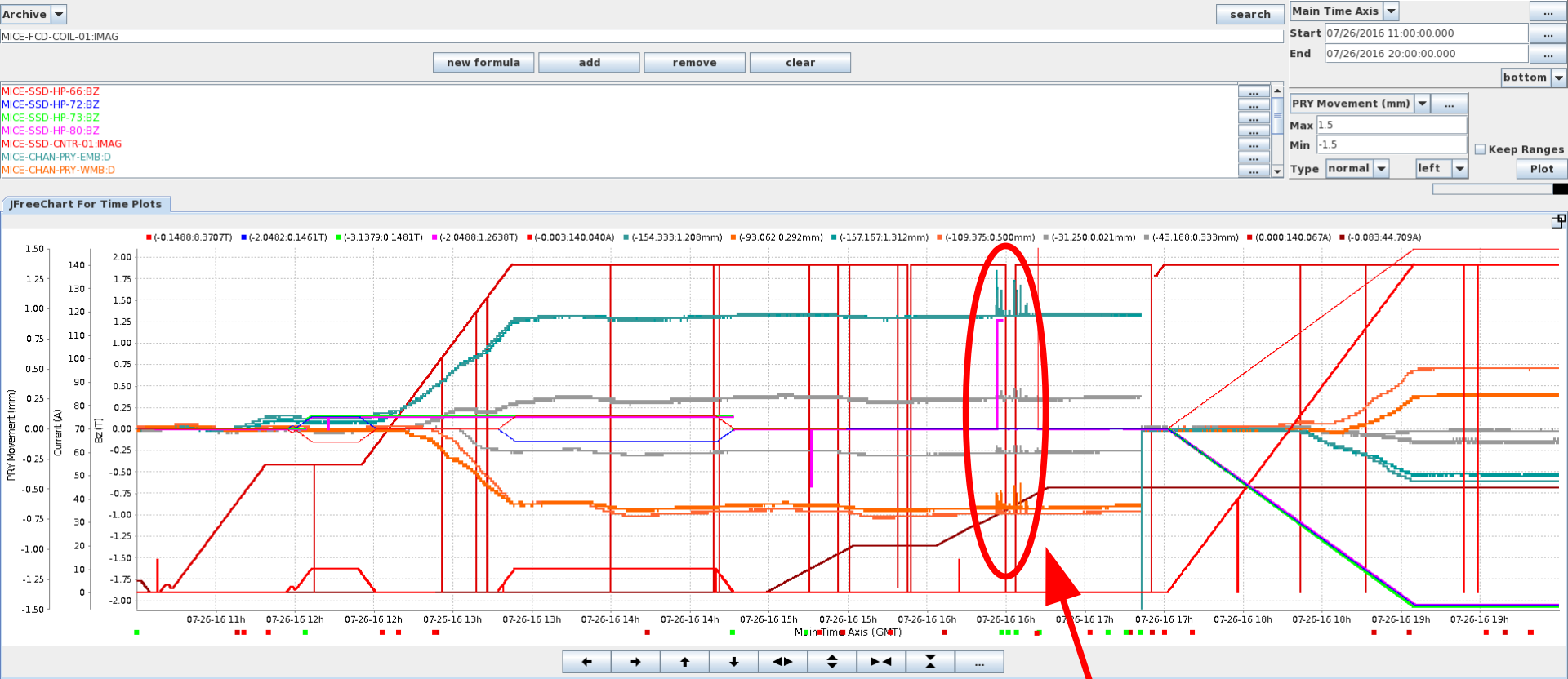


Quench Slow Data Plots





Quench Slow Data Plots



PRY Movement



What's Next

Biggest remaining issue is the noise – note that the coil thresholds are now set to 50X lower than when the magnets were first trained at Wang, NMR

- try to find source, then decide to fix or live with it
- add FC DCCT
 - use to remove mutual inductance contribution
 - will serve as independent current measurement – fixes AMI430 communication problem when system trips
- software modifications
 - QD signals to EPICS
 - inhibit threshold adjustments from live screen
 - additional information from AGFD