



Data Acquisition and Analysis @ CERN

Hugo Bajas

1st International WORKSHOP of the Superconducting Magnets Test Stands



Motivations

- Large number of tests per year performed at SM18 from:
 - 10 horizontal benches: A1, A2, B1, B2, C1, C2, E1, E2, F1, F2
 - 3 vertical benches: Longue, Siegtal, Diode/Lead
 - Soon: Cluster D, High Field Magnet, FAIR
- On a broad type of magnets:
 - LHC spare magnets (NbTi: dipole, quadrupole, correctors)
 - HL-LHC magnets (Nb₃Sn: Racetrack, 11T, QXF)
 - FCC models (16 T project , HTS insert: Feathers)

Motivations

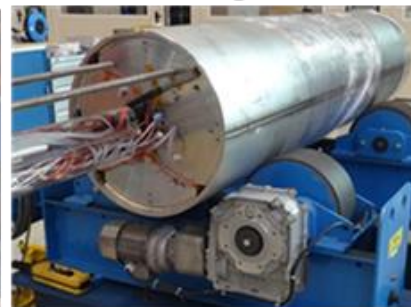
Short Model Coil



Racetrack Model Coil



11T dipole



FRESCA2



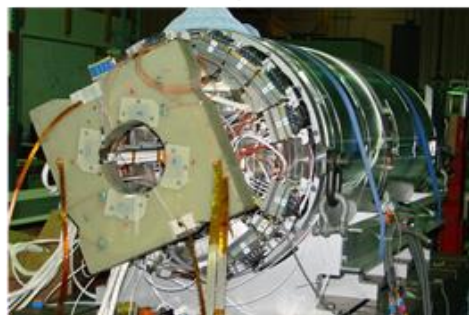
Horizontal benches



HQ



MQXF3



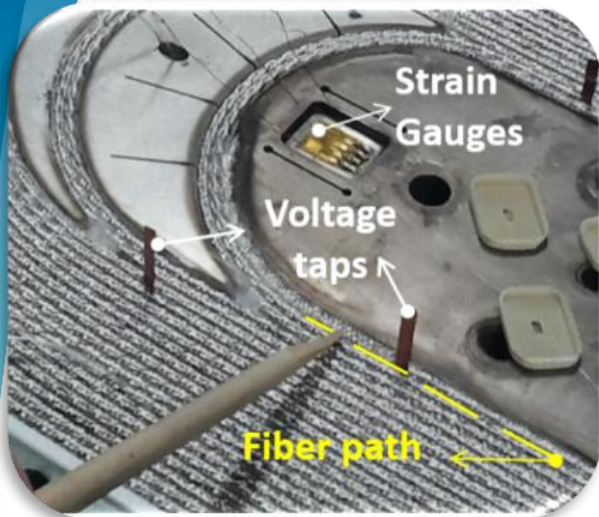
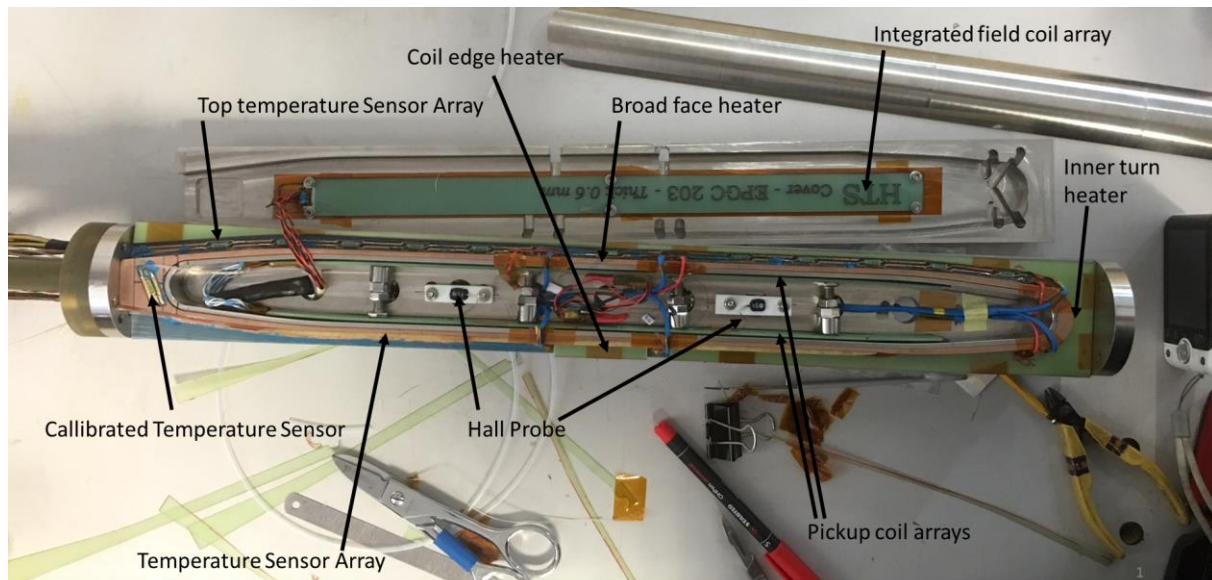
Motivations

- Highly instrumented R&D magnets with various kinds of sensors
...voltages tap, strain gauge, magnetic probe, thermometer, optical fiber

Motivations

- Highly instrumented R&D magnets:
...voltages tap, strain gauge, magnetic probe,
thermometer, optical fiber sensors

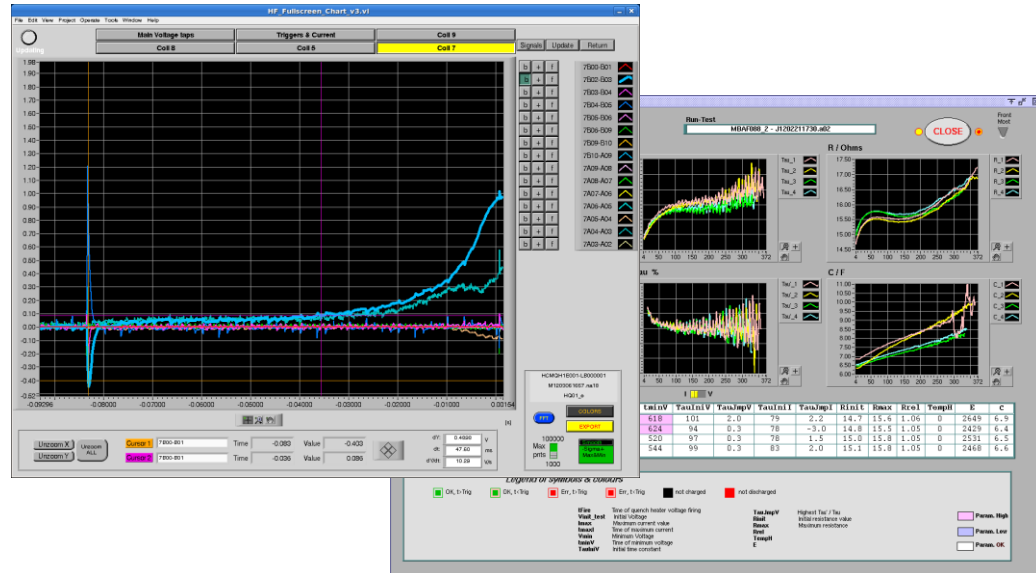
Feather-M0 instrumentation



SMC instrumentation

Motivations

- Need to replace the aging “SM18 Automatic Quench Analysis” LabVIEW software

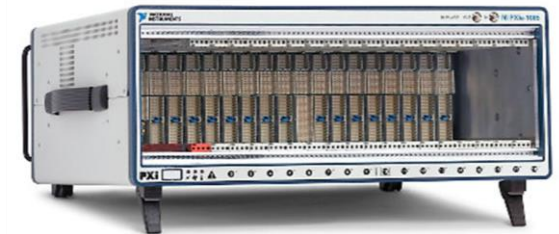


Data Acquisition System

- New Data and Acquisition systems will equip the new test stands
- DAQ based on PXI platform allows:
 - High resolution / High Accuracy measurement (Digital Multi Meter)
 - Long acquisition: Low Frequency (Hz)
 - Ten of micro-volt precision

Long, Diode/Lead/ Siegtal, HFM, Sc link: 146 HF, 72 LF cards
Cluster D: 200 HF, 144 LH cards

- transient acquisition: High Frequency (5 to 200 kHz)
- milli-volt precision
- NI PXI-6225card (Low Frequency)
- INCAA-TR14 cards (High Frequency)



Cluster D: HF Card: NIPXIe-6358

NI PXIe-6358

Simultaneous X Series Data Acquisition



[Zoom/Alternate Images](#)

Starting at ~~\$ 6,086~~ **\$ 5,355.68** (view pricing options)

 [View Data Sheet](#)

- 16 simultaneous analog inputs at 1.25 MS/s/ch with 16-bit resolution; 20 MS/s total AI throughput
- Four analog outputs, 3.33 MS/s, 16-bit resolution, ± 10 V
- 48 digital I/O lines (32 hardware-timed up to 10 MHz)
- Four 32-bit counter/timers for PWM, encoder, frequency, event counting, and more
- Analog and digital triggering and advanced timing with NI-STC3 technology
- Support for Windows 7/Vista/XP/2000

Cluster D: LF Card: NIPXIe-6365

16-bit, 1 MS/s (scanning), 144 analog Inputs

- 144 analog inputs, 2 MS/s 1-channel, 1 MS/s multichannel; 16-bit resolution, ± 10 V
- 2 analog outputs, 2.86 MS/s, 16-bit resolution, ± 10 V
- 24 digital I/O lines (8 hardware-timed up to 10 MHz)
- Four 32-bit counter/timers for PWM, encoder, frequency, event counting, and more
- Analog and digital triggering and advanced timing with NI-STC3 technology

144 Single-Ended channels / 72 Differential channels



Problematic

- To handle a huge amount of data
 - ... from very versatile devices (naming convention, signals ordering)
 - ... from heavy file (200 kHz, 200 channels, 2 sec)
- To convert binary data to readable format into manageable files
- To standardize the data sets for automatic data post-processing and storage

→ Develop a new data analysis framework able to:

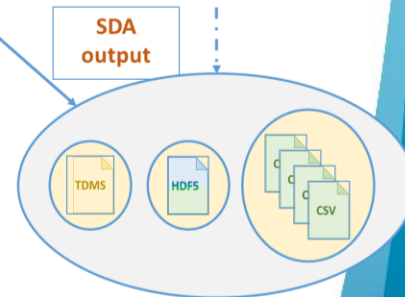
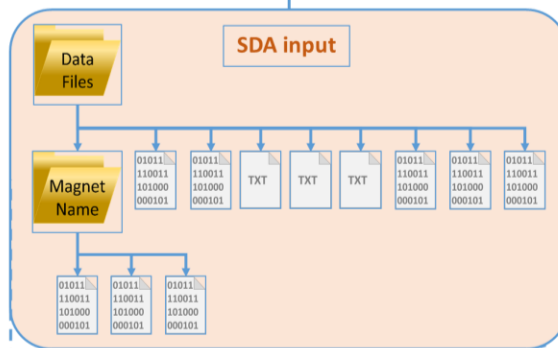
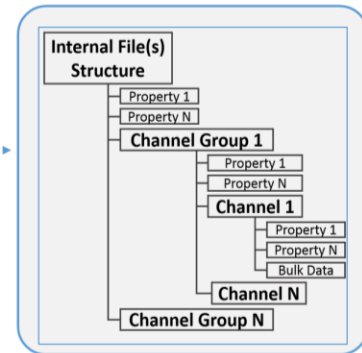
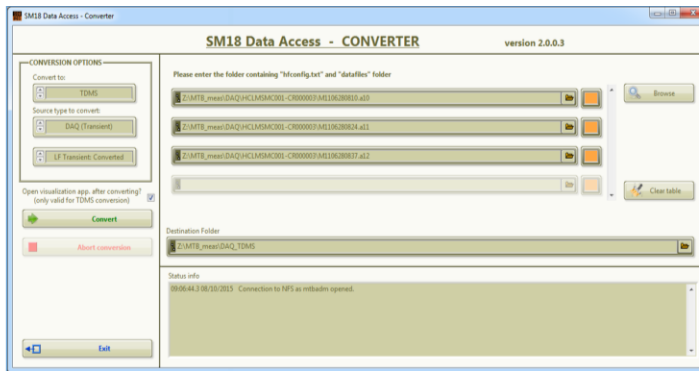
- process with all SM18 data
- extract relevant information during a test to ease operator work
- analyse and report on the test results after a test
- Built-up a database

Strategy

- Full use of the new binary data convertor named “SM18 Data Access (SDA)”
- Profit from National Instrument DIAdem software environment modern tools
- Development of a dedicated program named “DIAdem-AQA” to perform automatic quench analysis and replace old AQA.
- Production of validated data sets for data and formatted test result reports for sharing and archiving

SDA convertor: from binary to .tdms file

- Technical Data Management Streaming (tdms)
- LabView program
- Multiple files conversion
- Data ordering into group, channels, properties.
- HF, MF, LF data conversion
- Plan to convert the whole data stored in SM18 servers.



DIAdem environment

The image displays the DIAdem software environment with four main windows highlighted by colored boxes and labels:

- NAVIGATOR (Red box):** Shows a file browser interface titled "NAVIGATOR: My DataFinder". It includes a search bar and a tree view of external data. A red label "Hard-drive" is overlaid on the top right of this window.
- SCRIPT (Purple box):** Shows a VBS script editor titled "SCRIPT: Temporary Workspace". The script contains the following code:

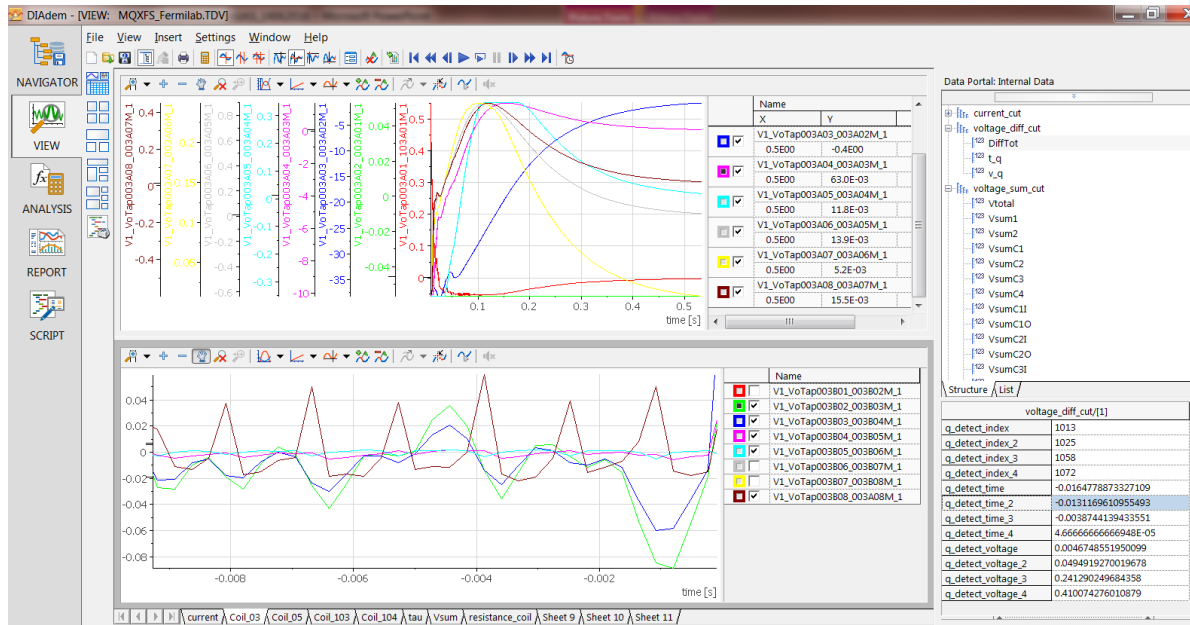
```
21 Call ChnAlloc(oMyname, ChLen,1) ' cable temperature
22 Set Chn_resistance = Grp_Resistance.Channels(oMyname)
23
24 '--- Compute> R = ( U / I ) [V]/[A]=[Ohm]
25 Channels = Array(Chn_resistance,Chn_voltage,Chn_current)
26 Symbols = Array("R","U","I")
27 Formula = "R = IIF( I < .1 , NoValue, U/(I*1000) )"
28 Call Calculate(Formula, Symbols, Channels, "")
29
30 End function
```

A purple label "Script" is overlaid on the top right of this window.
- REPORT (Blue box):** Shows a report viewer titled "REPORT: Report_template_reference_4.TDR". It displays a graph of "Difference Voltage [V]" versus "time [s]". A blue label "Report" is overlaid on the top right of this window.
- VIEW (Green box):** Shows a graph viewer titled "VIEW: View_reference.TDV". It displays a graph of "Difference Voltage [V]" versus "Time". A green label "View" is overlaid on the top right of this window.

On the left side of the interface, there is a vertical toolbar with icons for NAVIGATOR, VIEW, ANALYSIS, REPORT, and SCRIPT, each corresponding to the highlighted window.

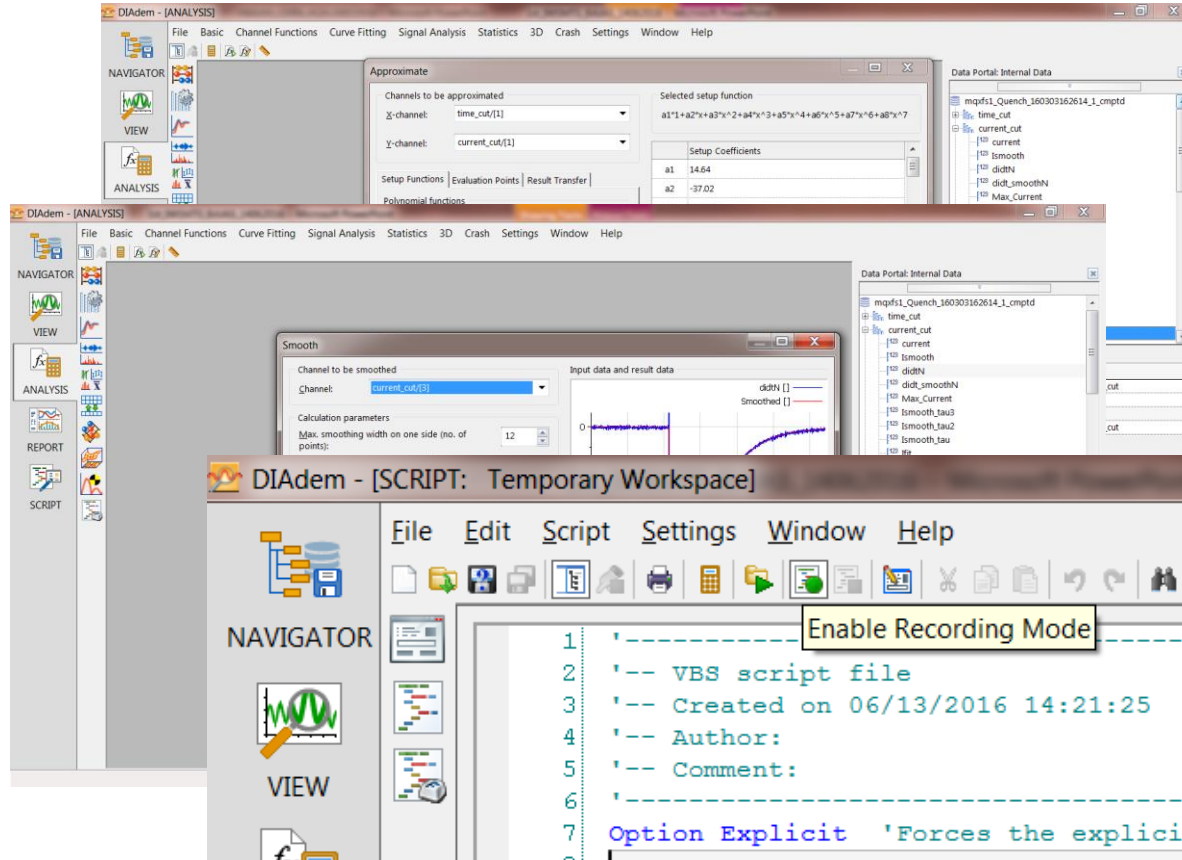
DIAdem environment

- A powerful Viewer
- Handy
- Easy, fast data access
- Zoom and all!



DIAdem environment

- Advanced mathematical functions
- Very useful!
- Dialog with Script mode
- Possibility to record actions
- Simply code your tasks!

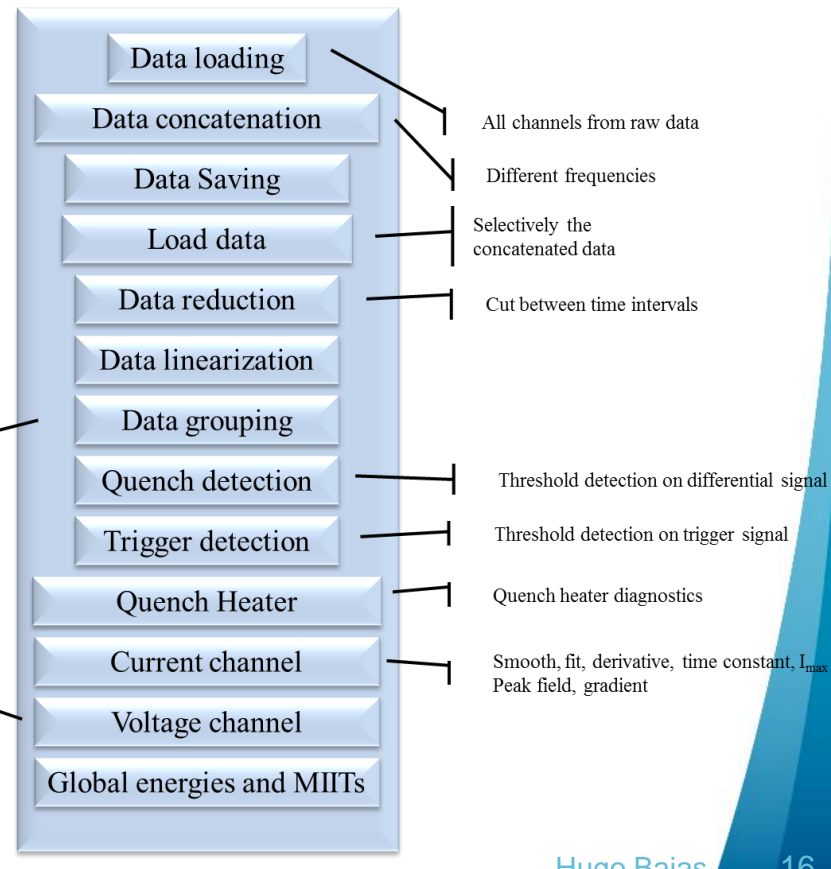


Structure of DIAdem-AQA program

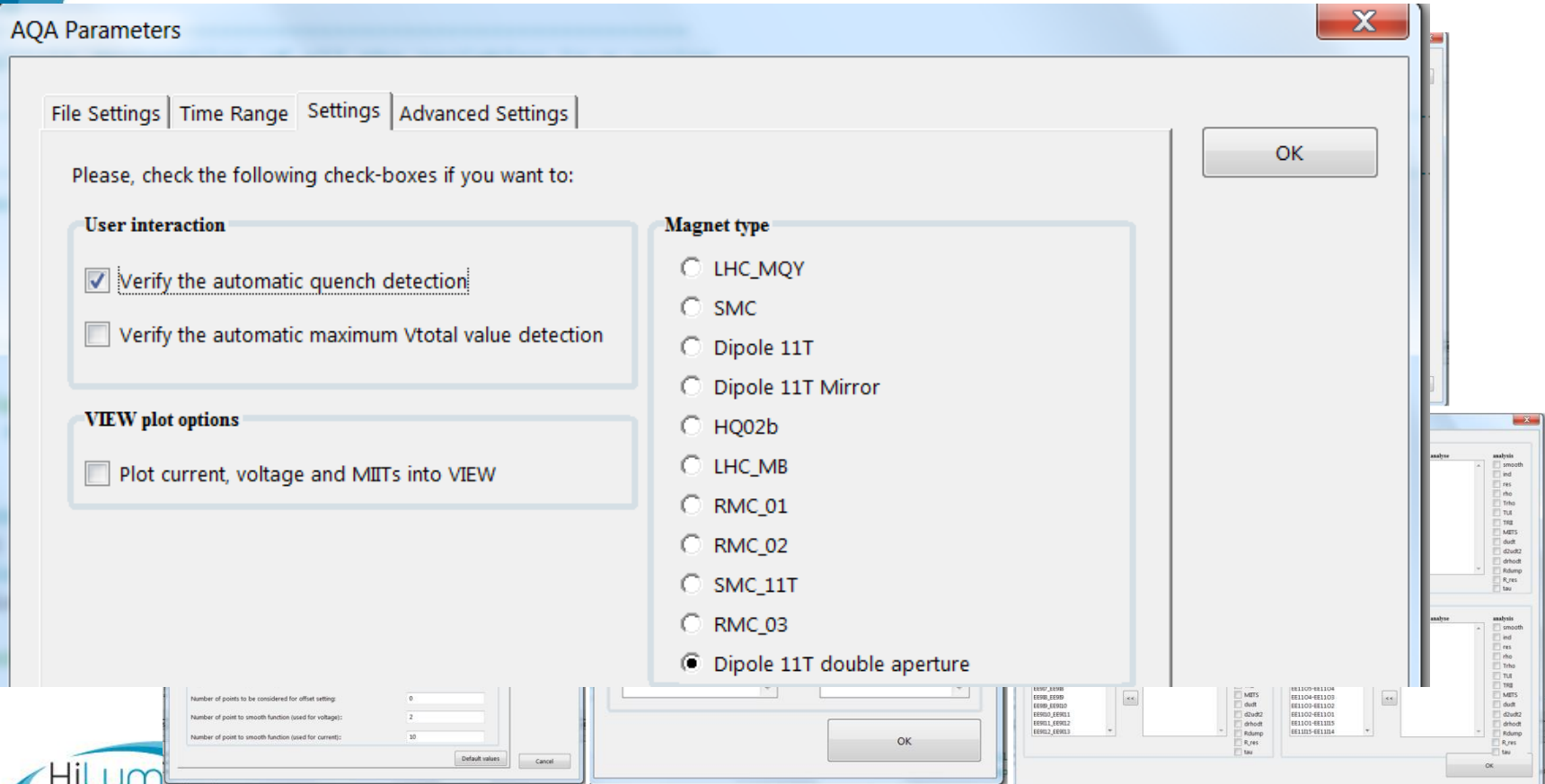
- Program developed within the Script module
- VBA language
- Code structured into routine, subroutine and functions
- Performs automatic tasks for signal analysis

- According to signal (time, current, voltage, temperature, pressure)
- According to signal family (trigger, differential, direct, protection, monitoring)

Create new analysis groups
 Remove outliers
 Smooth
 offset
 threshold detection
 inductive voltage
 resistive voltage
 resistance
 resistivity
 hot spot temperature (3 methods)
 time constant
 Voltage derivative (1st and 2nd)



GUI for DIAdem-AQA

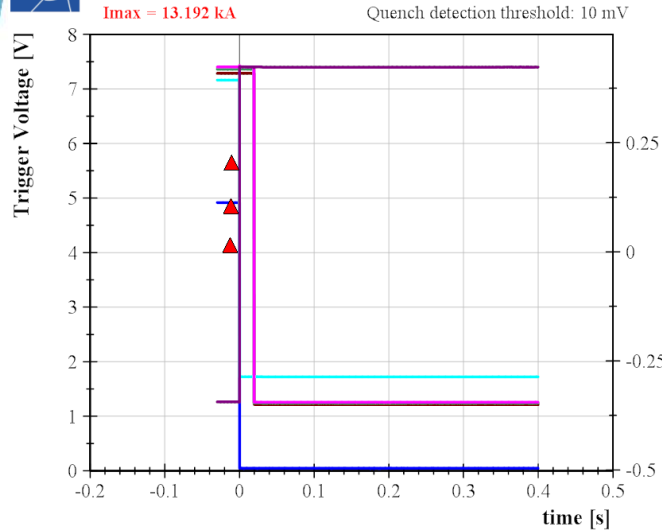


Report Sheets

Trigger signals



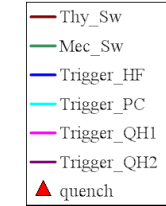
File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana



02/04/2016 TE-MSC-TF

AQA_DIAdem

Differential Voltage [V]



Quench heater delays:

Dt1 = -31.8 ms

Dt2 = -12.3 ms

Switch delays:

Dt_mec = -31.7 ms

Dt_thy = -32.0 ms

Auto detection:

Diff_tot

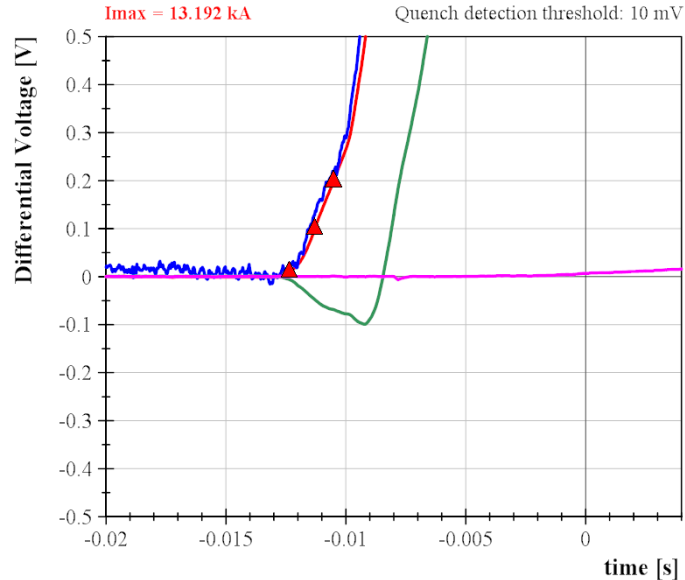
q_t = -12.35 ms

v_t: 9.45 mV

Quench detection signals

AQA_DIAdem

File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana



06/13/2016 TE-MSC-TF H Bajas

Signal: Diff_tot

Threshold 1

q_t = -12.35 ms

v_t = 9.45 mV

Threshold 2

q_t = -11.3 ms

v_t = 98.53 mV

Threshold 3

q_t = -10.52 ms

v_t = 198.5 mV

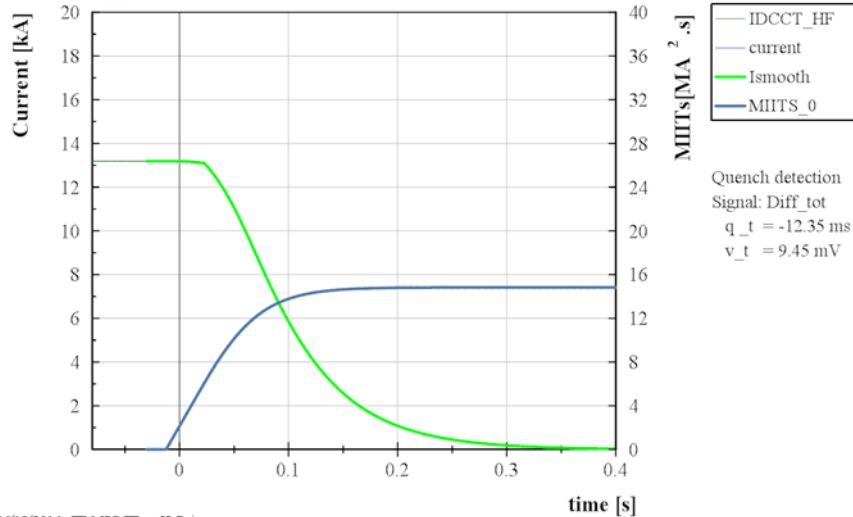
Report Sheets

Current & MIITs

AQA_DIAdem

File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana

$I_{max} = 13.192 \text{ kA}$ $MIITs = 14.83 \text{ MA}^2 \cdot \text{s}$



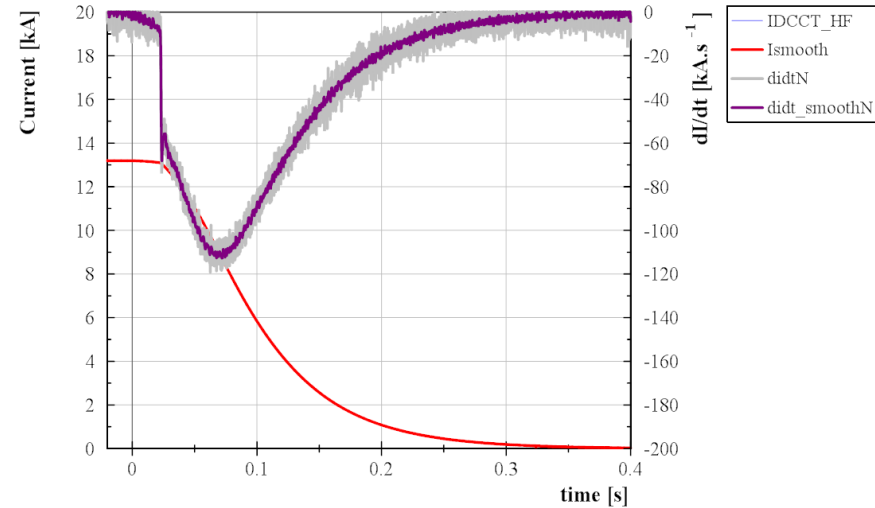
06/13/2016 TE-MSC-TF H. Bajas

Current & dIdt

AQA_DIAdem

File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana

$I_{max} = 13.192 \text{ kA}$ $dIdt \text{ max} = -112.8 \text{ kA} \cdot \text{s}^{-1}$



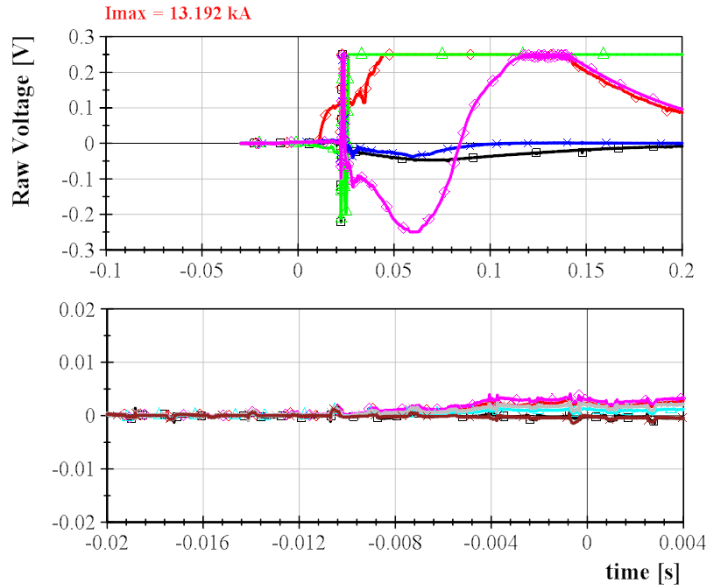
06/13/2016 TE-MSC-TF H. Bajas

Report Sheets

Splice signals

AQA_DIAdem

File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana

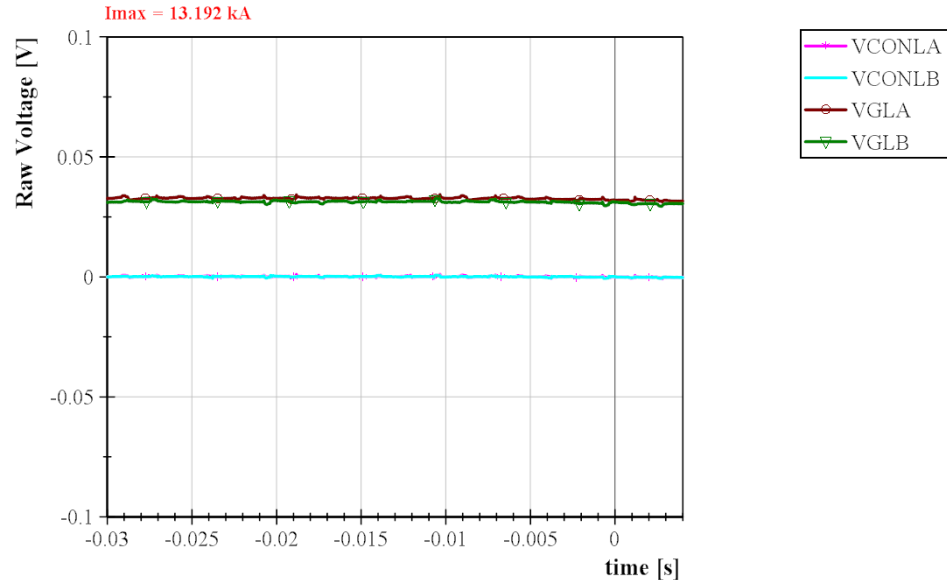


06/13/2016 TE-MSC-TF H. Bajas

Connection signals

AQA_DIAdem

File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana



06/13/2016 TE-MSC-TF H. Bajas

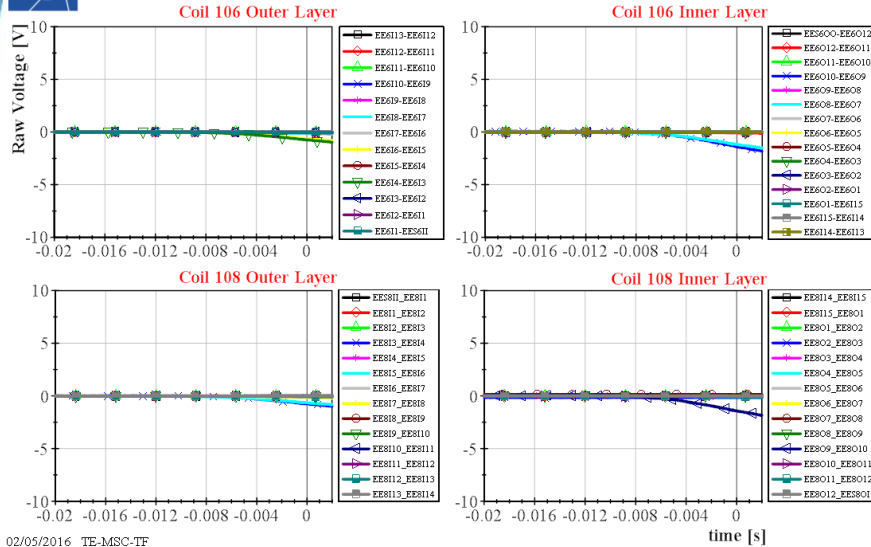
Report Sheets

Quench pattern



File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana

AQA_DIADEM

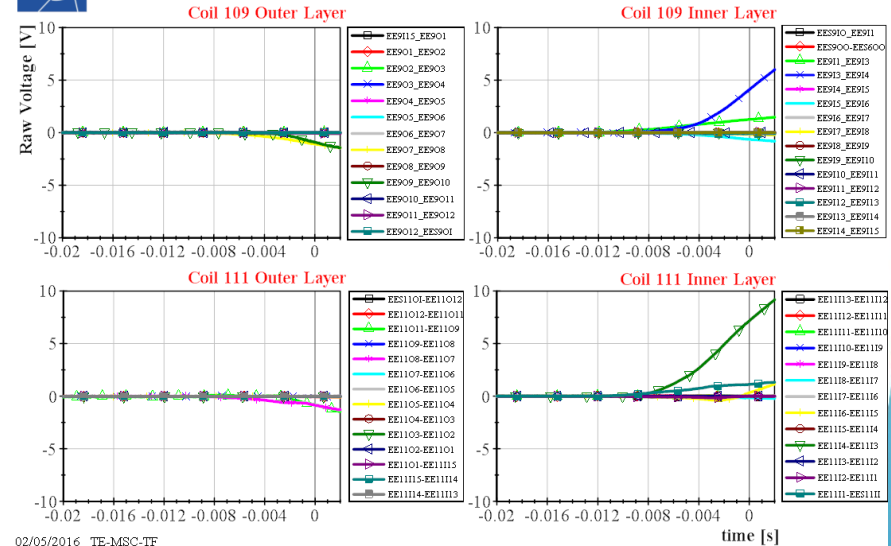


02/05/2016 TE-MSC-TF



File: HCMBHDP0001_0000101_M1602031743_a044(0)_computed_susana

AQA_DIADEM



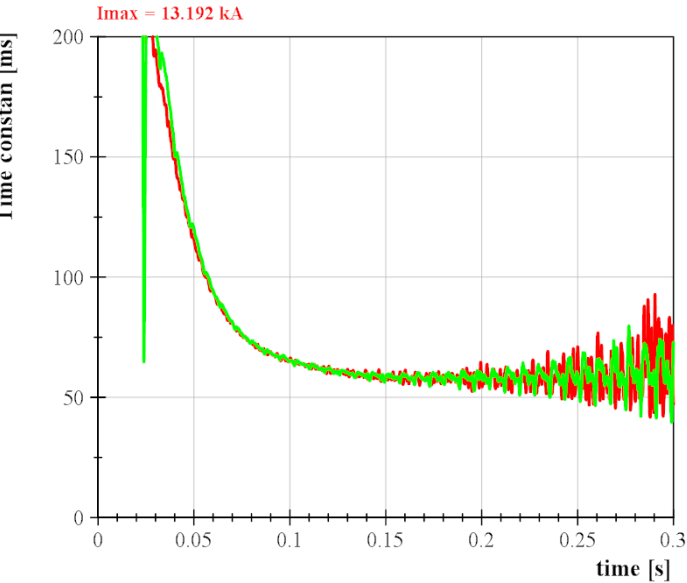
02/05/2016 TE-MSC-TF

Report Sheets

Decay time constant

AQA_DIAdem

File: HCBMHP0001_0000101_M1602031743_a044(0)_computed_susana

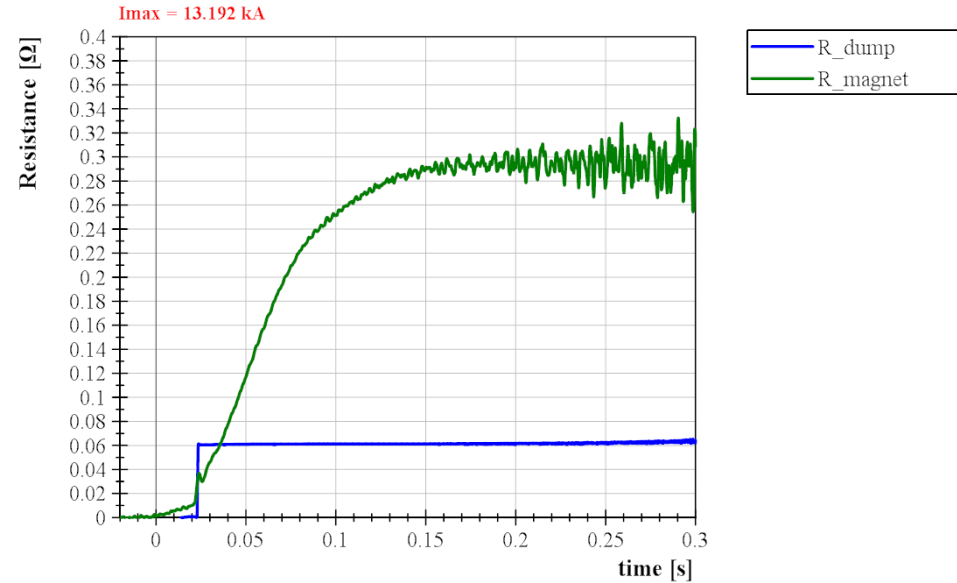


06/13/2016 TE-MSC-TF H Bajas

Coil resistance

AQA_DIAdem

File: HCBMHP0001_0000101_M1602031743_a044(0)_computed_susana



06/13/2016 TE-MSC-TF H Bajas

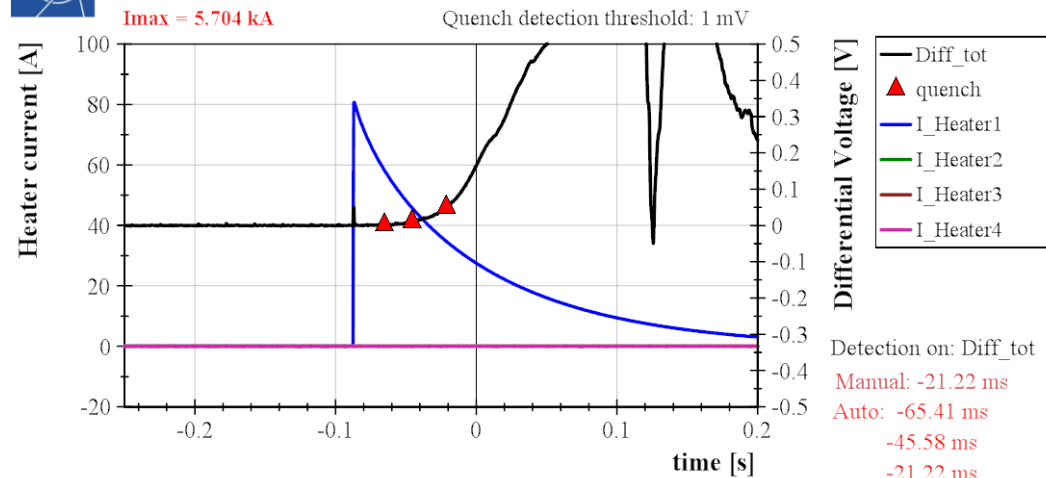
Quench Heater diagnostic

- Quench heater integrity check
- Automatic delay computation
- Example for an LHC-MB
- Example for RMC

AQA_DIAdem



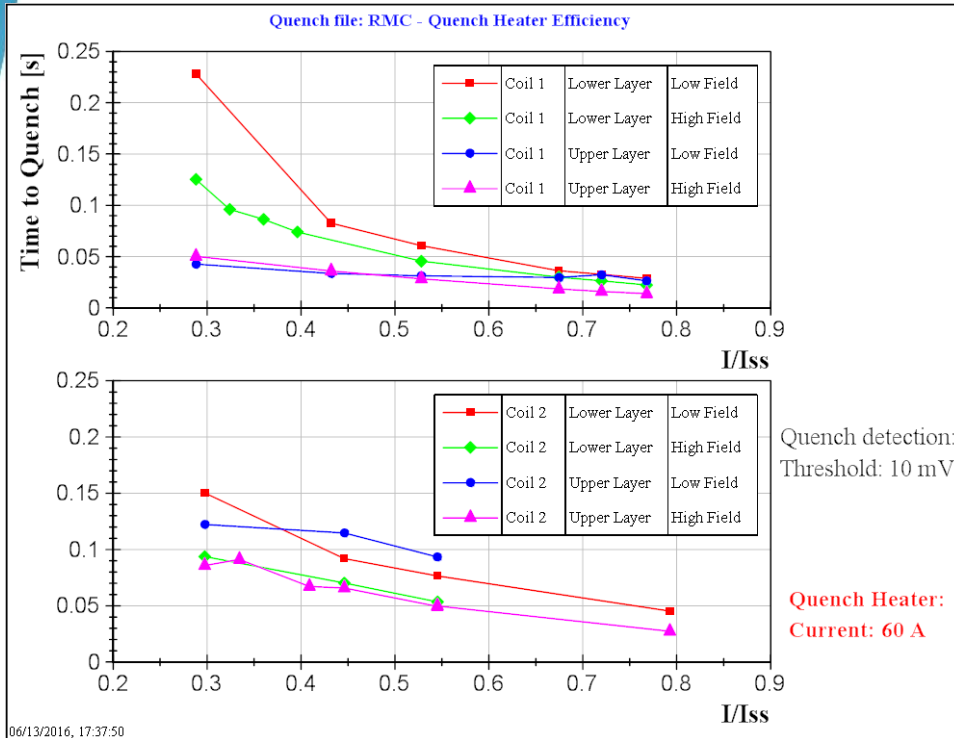
File: HCLMRMC003_CR101201_M1606021449_hh049(0)_cmptd



Delays U_Heater1:	Delays U_Heater2:	Delays U_Heater3:	Delays U_Heater4:
DT (1 mV)= 21.3 ms	DT (1 mV)= 0.0 ms	DT (1 mV)= 0.0 ms	DT (1 mV)= 0.0 ms
DT (10 mV)= 41.1 ms	DT (10 mV)= 0.0 ms	DT (10 mV)= 0.0 ms	DT (10 mV)= 0.0 ms
DT (50 mV)= 65.4 ms	DT (50 mV)= 0.0 ms	DT (50 mV)= 0.0 ms	DT (50 mV)= 0.0 ms

06/02/2016 TE-MSC-TF H. Bajas

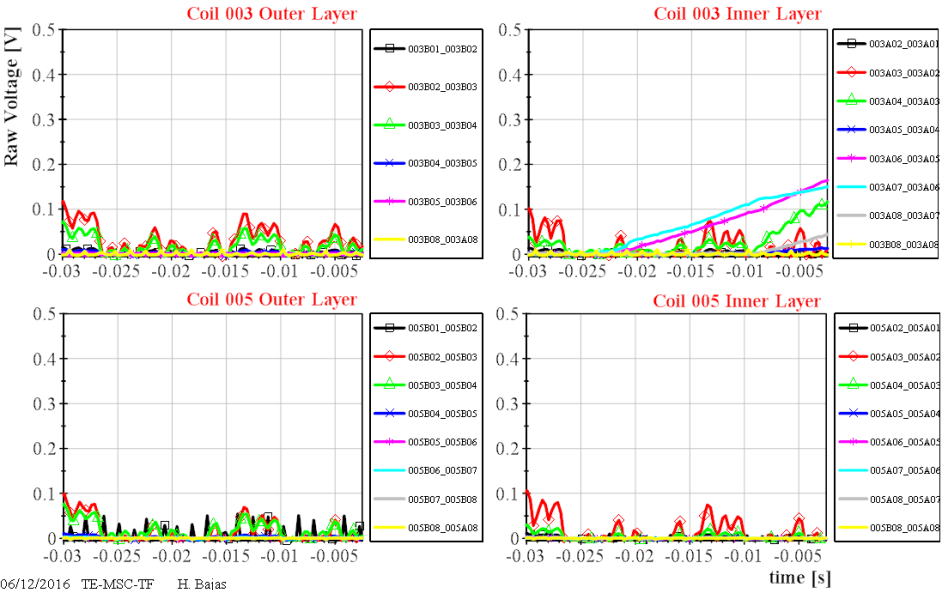
Quench Heater test in RMC



Works for “MQXFS1” FermiLab!

AQA_DIAdem

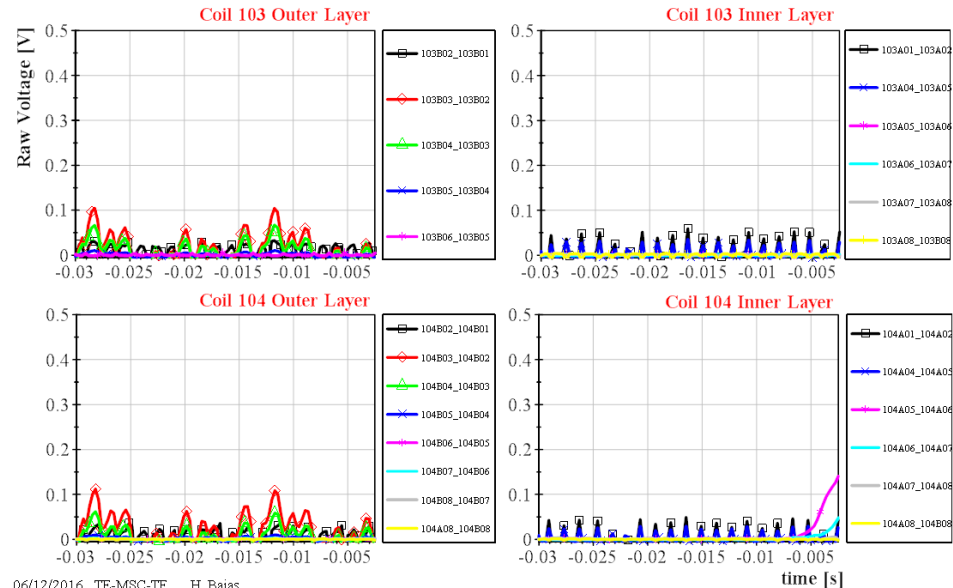
File: mqxf1_Quench_160303123932_1_cmptd I = 15.24 kA



06/12/2016 TE-MSC-TF H. Bajas

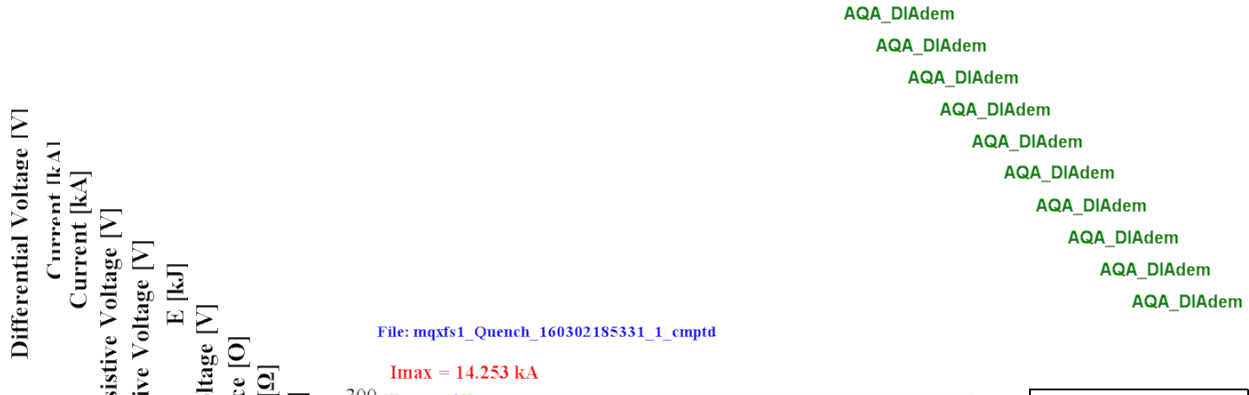
AQA_DIAdem

File: mqxf1_Quench_160307161949_1_cmptd I = 16.94 kA

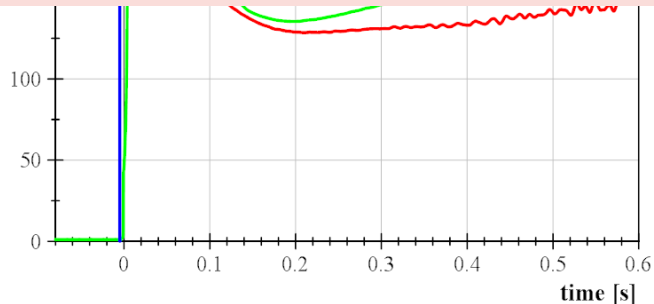


06/12/2016 TE-MSC-TF H. Bajas

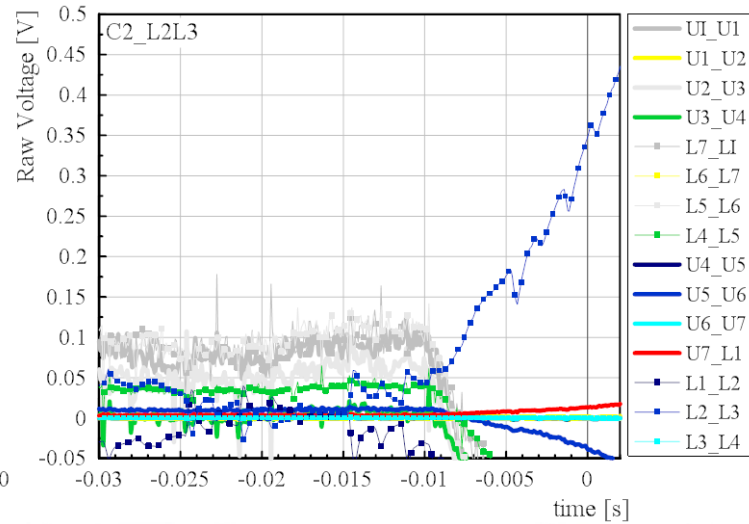
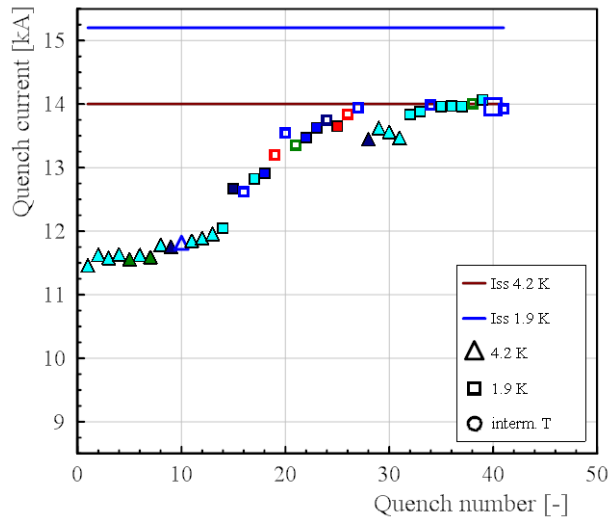
Works for “MQXFS1” FermiLab!



Old SunOs... still accessible though!
Routine for Fermi data extraction... send file by email.
(Stoyan!)



Advanced training plot for SMC runs



SMC3a_M1107061456_a49

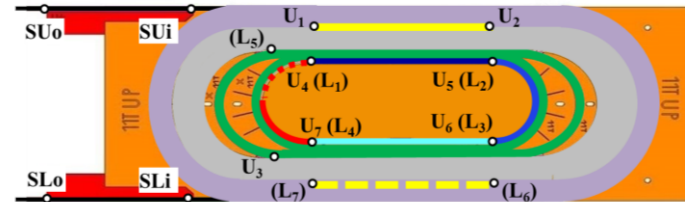
quench # 40

$I_{max} = 13.95 \text{ kA}$

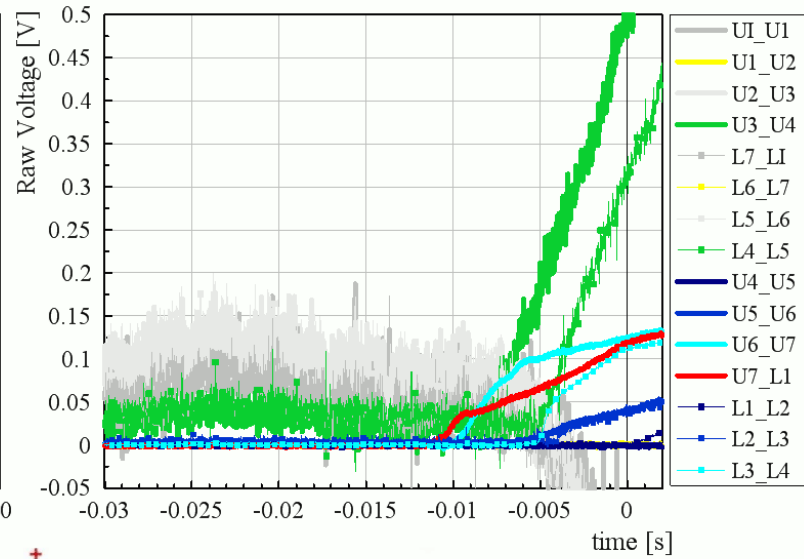
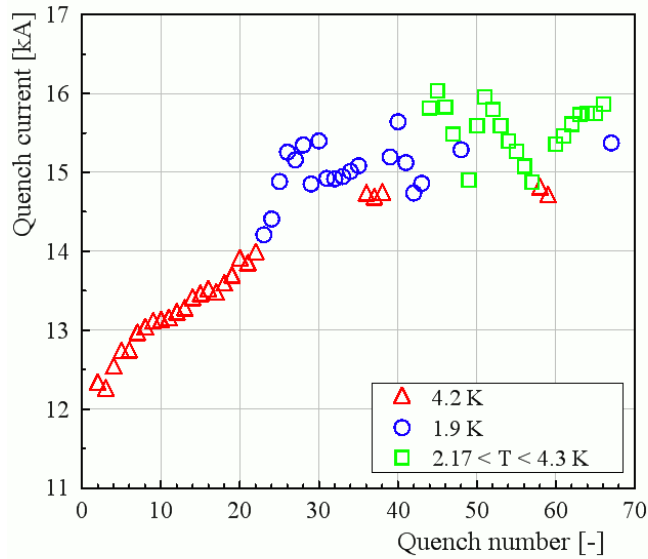
$t_{quench} = -10.2 \text{ ms}$

$B_{peak} = 12.5 \text{ T}$

MIITs = $5.85 \text{ MA}^2 \cdot \text{s}$



Movie for training... SMC11T_1 Run1



Source file: O1506091125_na01(1)_cmptd.TDMS

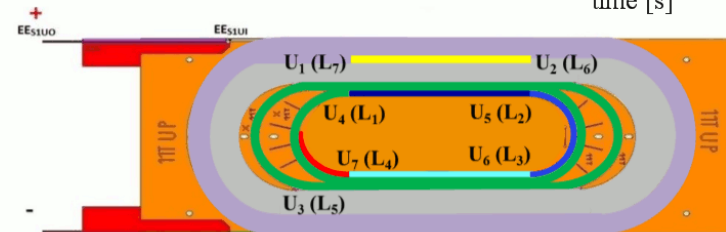
quench # 1

$I_{\max} = 10.55 \text{ kA}$

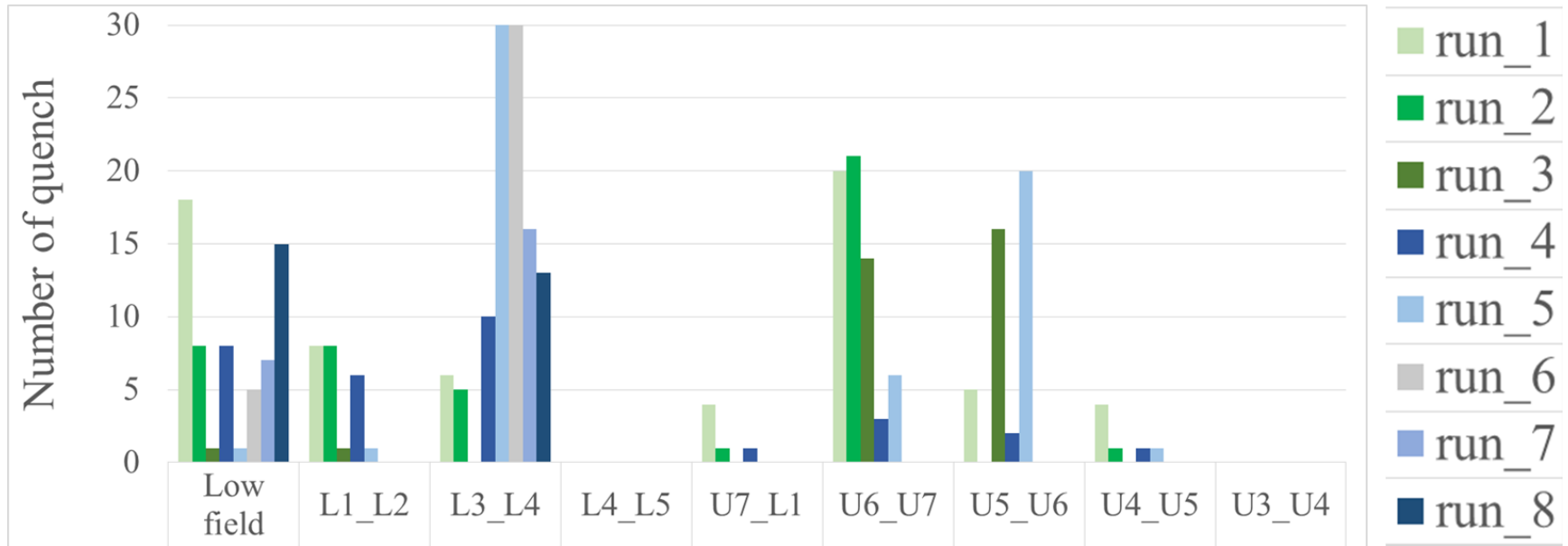
$t_{\text{quench}} = -11.05 \text{ ms}$

$B_{\text{peak}} = 9.9 \text{ T}$

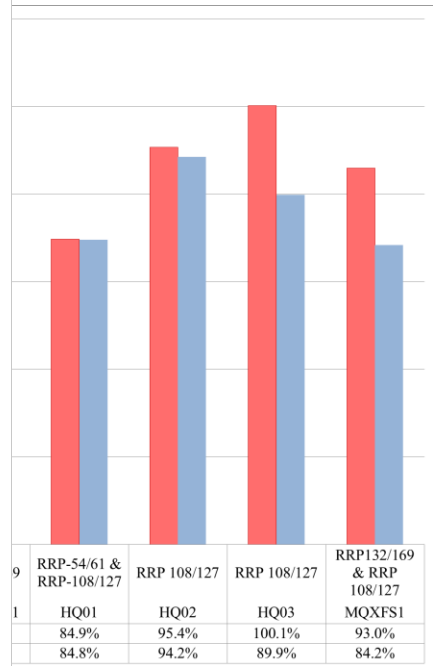
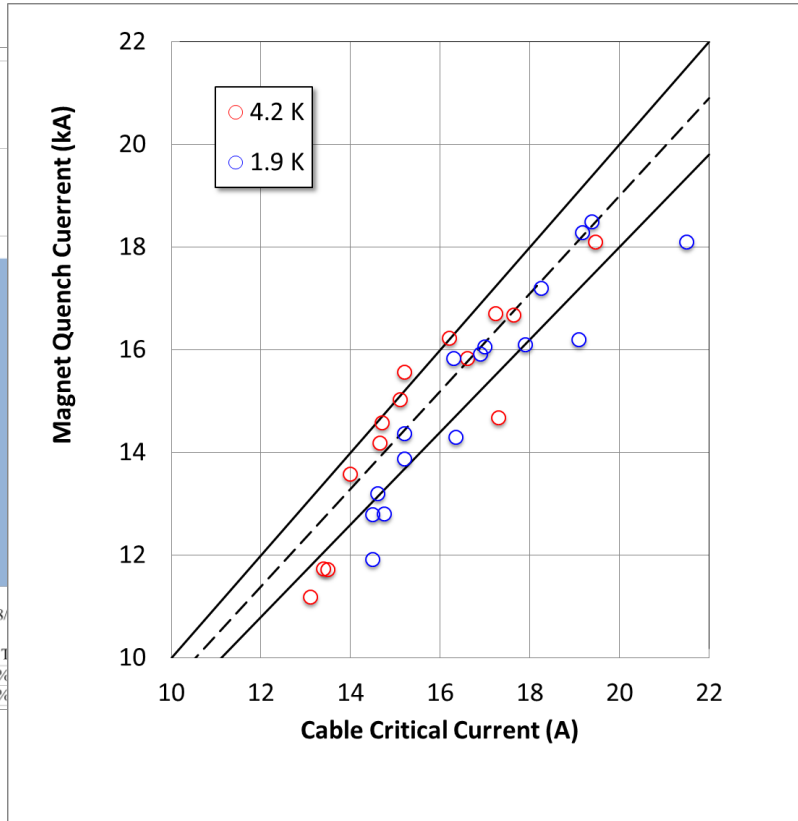
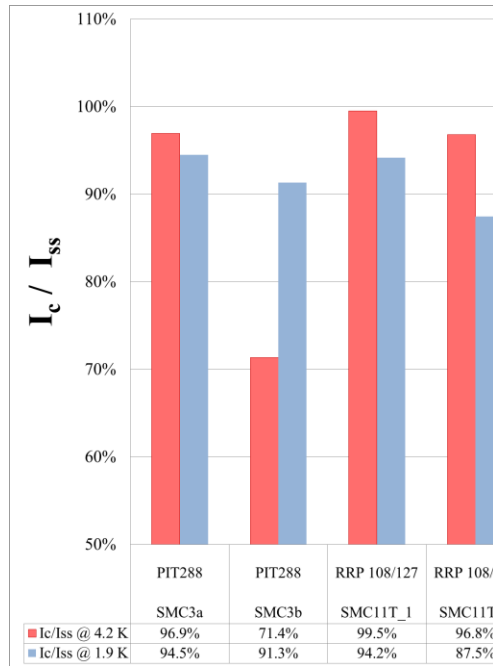
MIITs = $2.76 \text{ MA}^2 \cdot \text{s}$



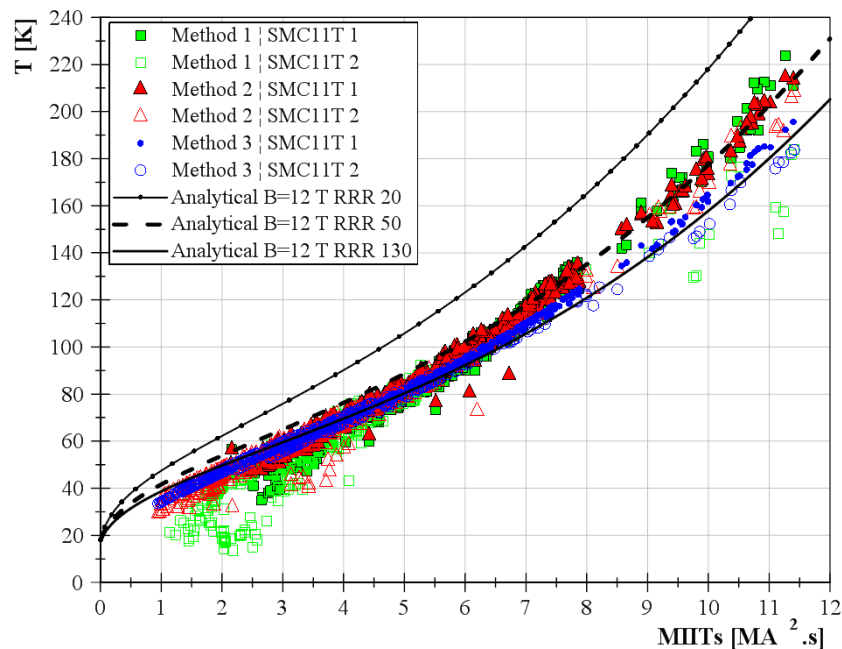
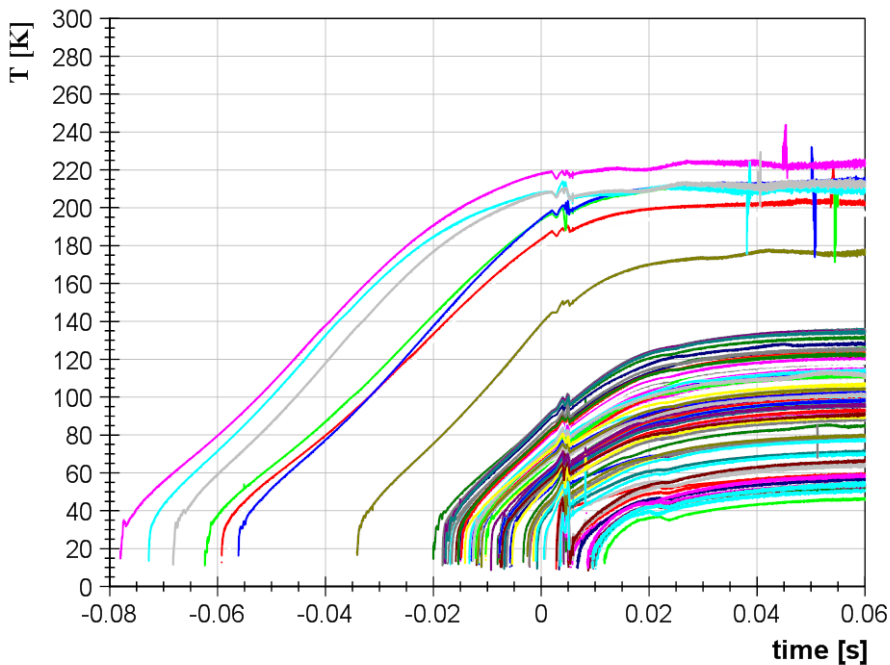
Statistic on Quench location



Easy Access: All Nb₃Sn magnet I_c



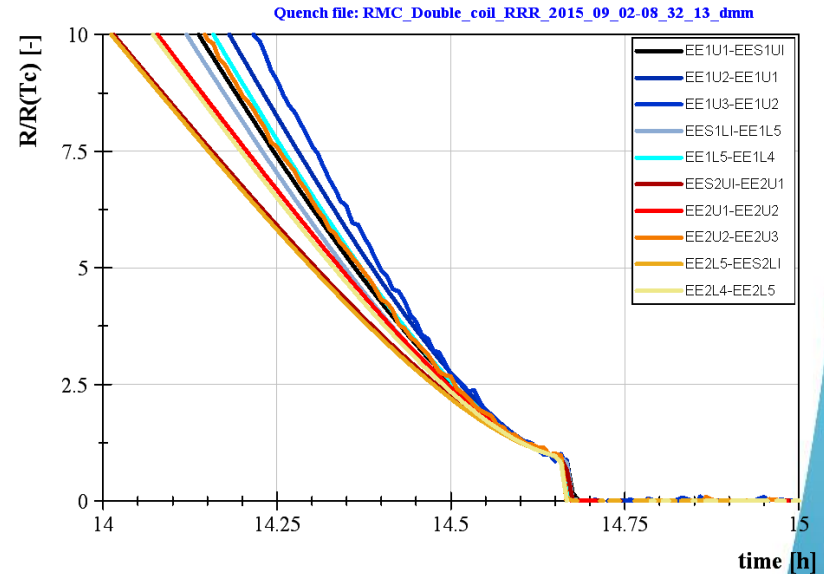
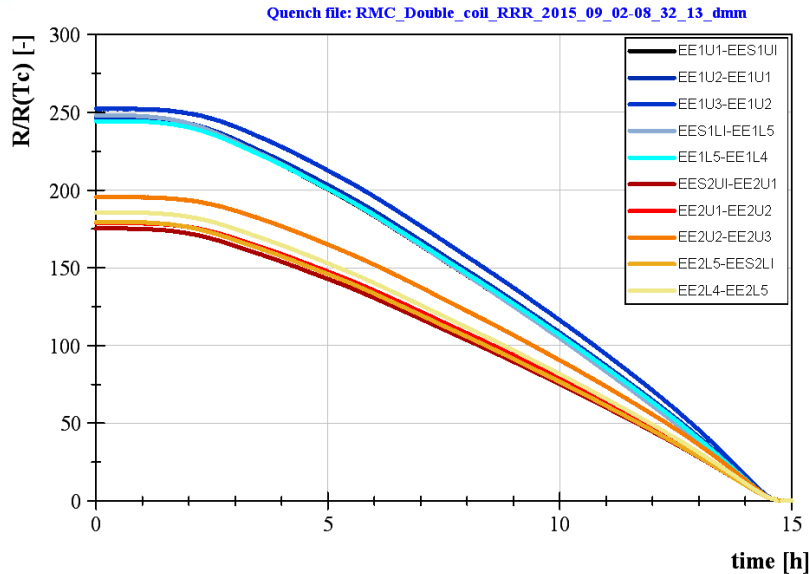
Easy Access: SMCs Hot Spot Temperature



Long Acquisition...

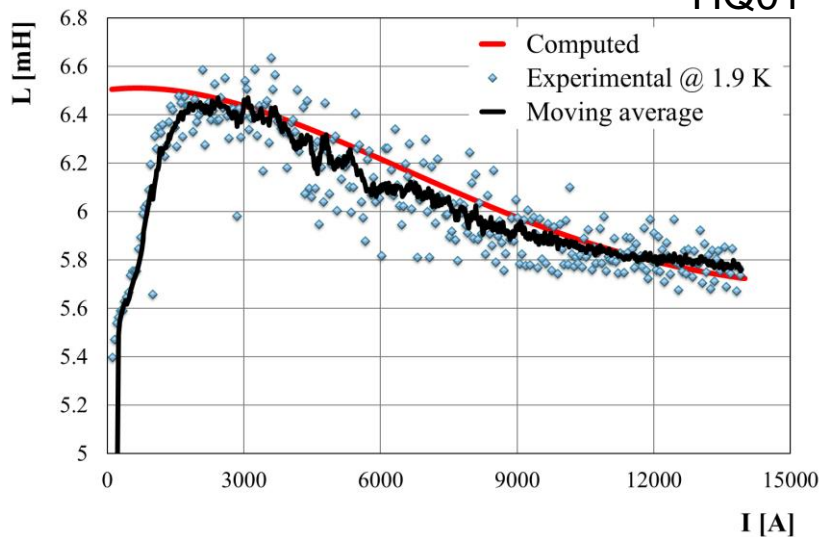


Residual Resistivity Ratio calculation

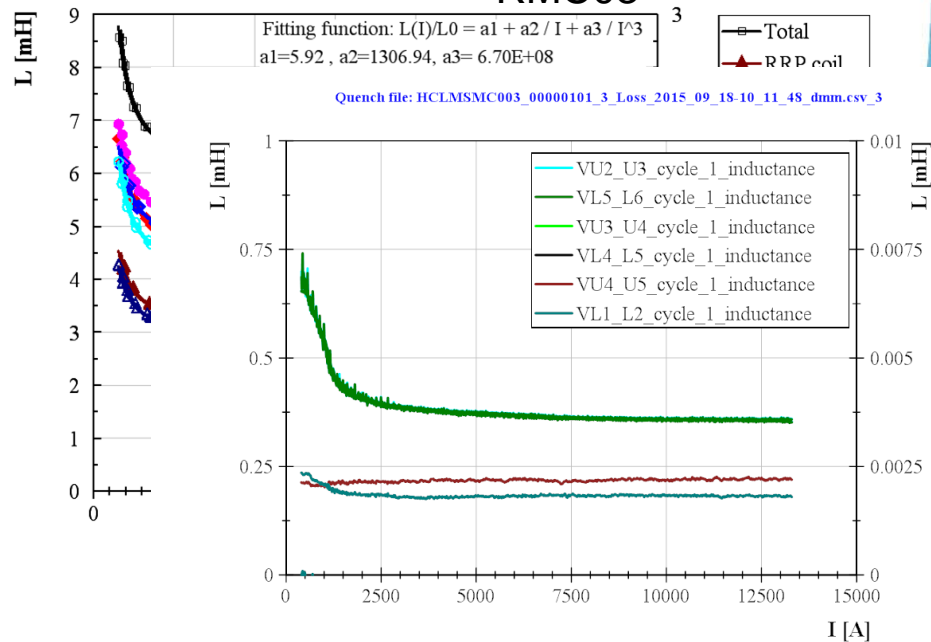


Magnet inductance computation

HQ01

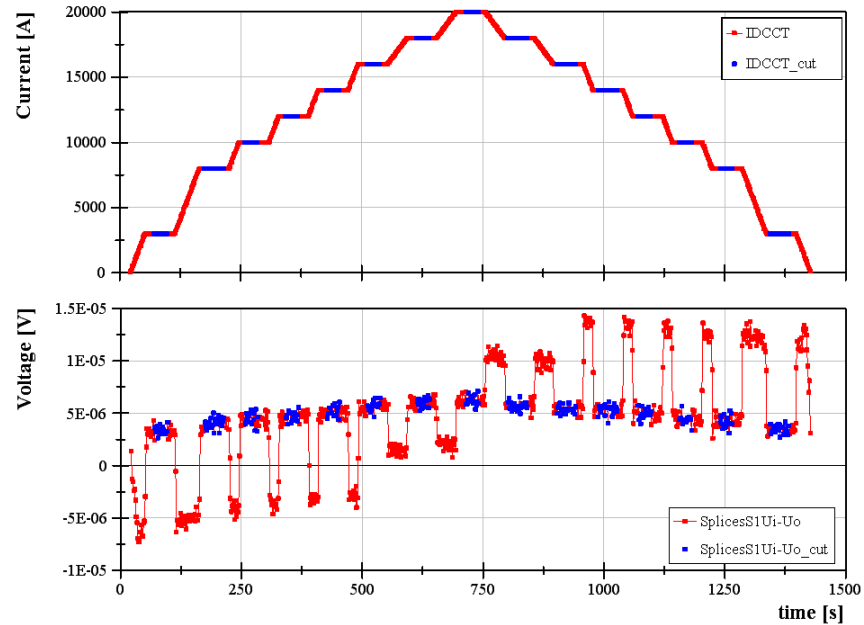


RMC03

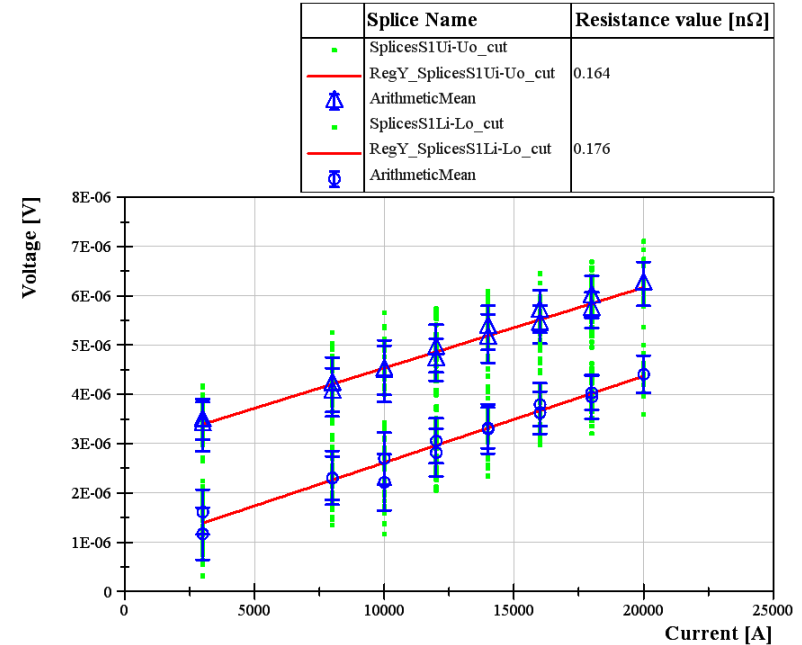


Splice resistance analysis

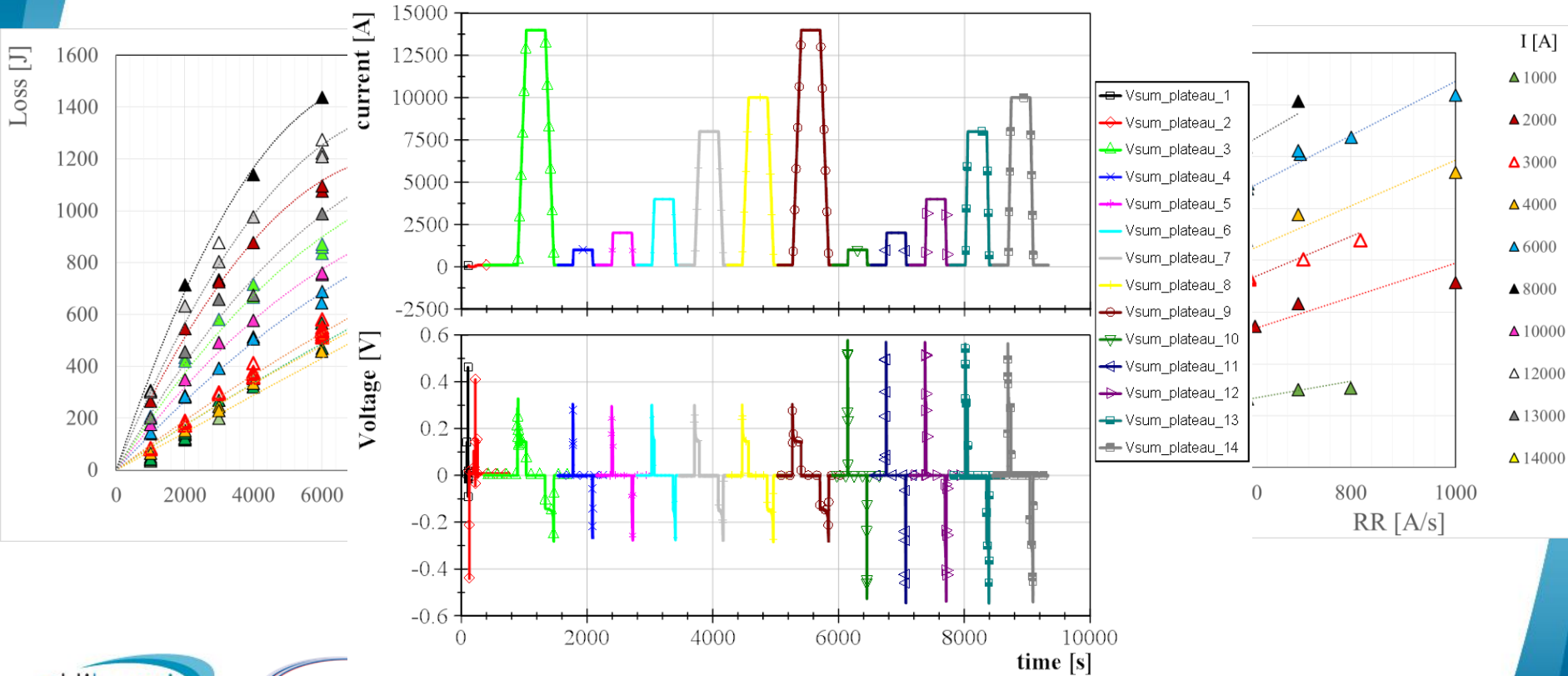
HCLMRMC-CR000101_Splices_2015_07_08-09_15_36_dmm.csv



HCLMRMC-CR000101_Splices_2015_07_08-09_15_36_dmm.csv



AC loss data analysis



Concluding remarks

- Time constant of the discharge: still missing ingredient... dynamic inductance, resistance built-up?
- AC loss: room for improvement in term of statistics (other coils)
- Dump resistance at FermiLab: interesting...
- Hot Spot Temperature!



Thank you for your attention

Special acknowledgment to Fatima Gomez delaCruz, Jose Vicente Gomez,, Antonella Chiuchuiolo, Gerard Willering, Jerome Feuvrier, Vincent Desbiolles, Juan Carlos Perez, Chrisitan Giloux, Maryline Charrondiere, Marta Bajko....

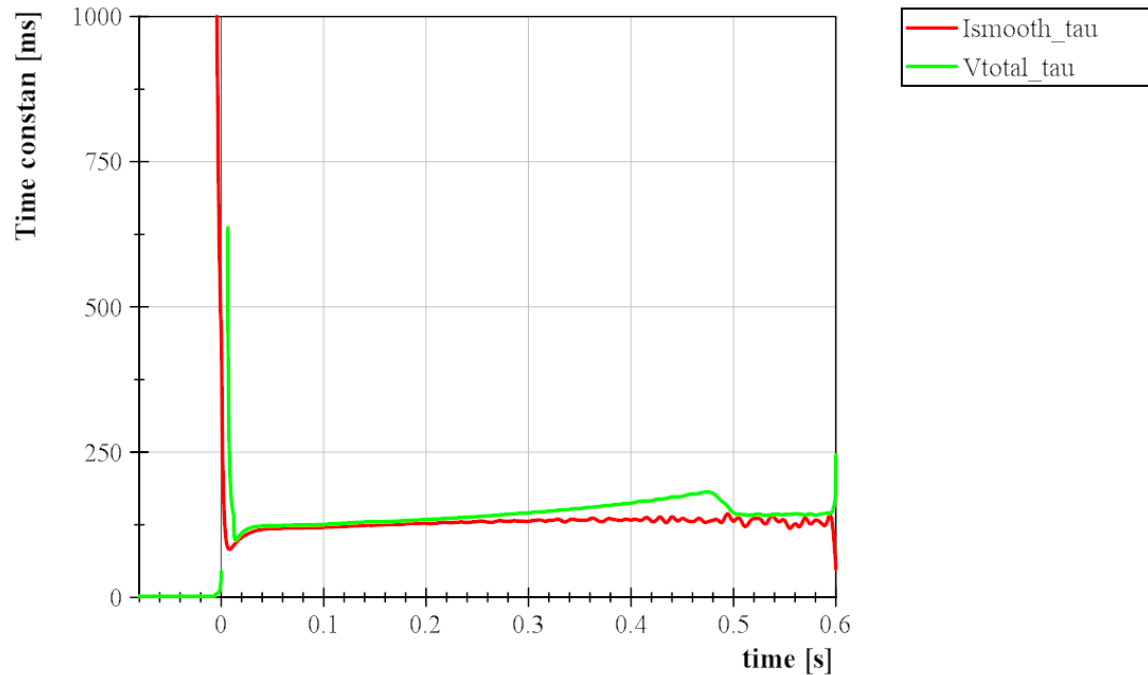
Time constant issue



File: mqxf1_Quench_160419154948_1_cmptd

$I_{max} = 8.261 \text{ kA}$

AQA_DIAdem



06/13/2016 TE-MSC-TF H. Bajas

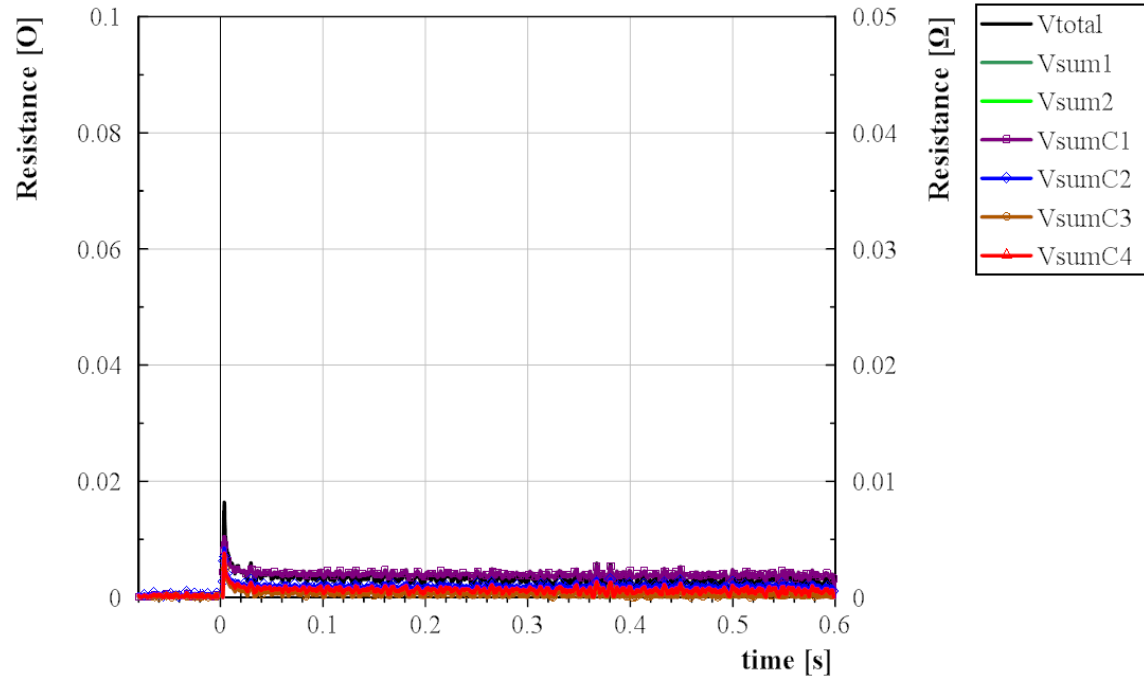
Coil resistance or Dynamic Inductance



File: mqxf1_Quench_160420111348_1_cmptd

$I_{max} = 3.334 \text{ kA}$

AQA_DIAdem



06/13/2016 TE-MSC-TF H. Bajas

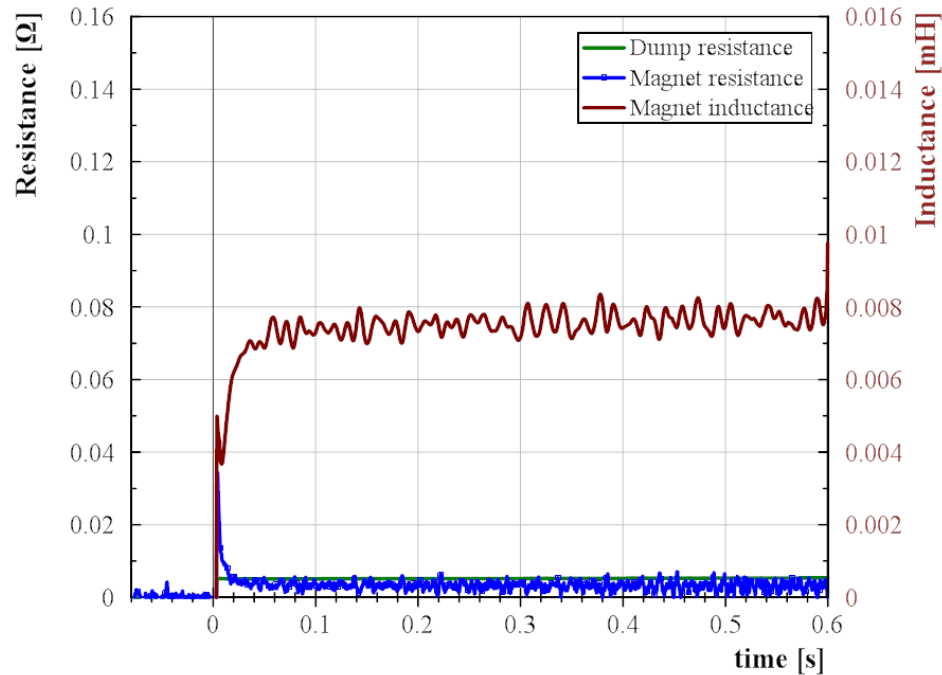
Coil resistance or Dynamic Inductance



File: mqxf1_Quench_160420110246_1_cmptd

AQA_DIAdem

$I_{max} = 1.712 \text{ kA}$



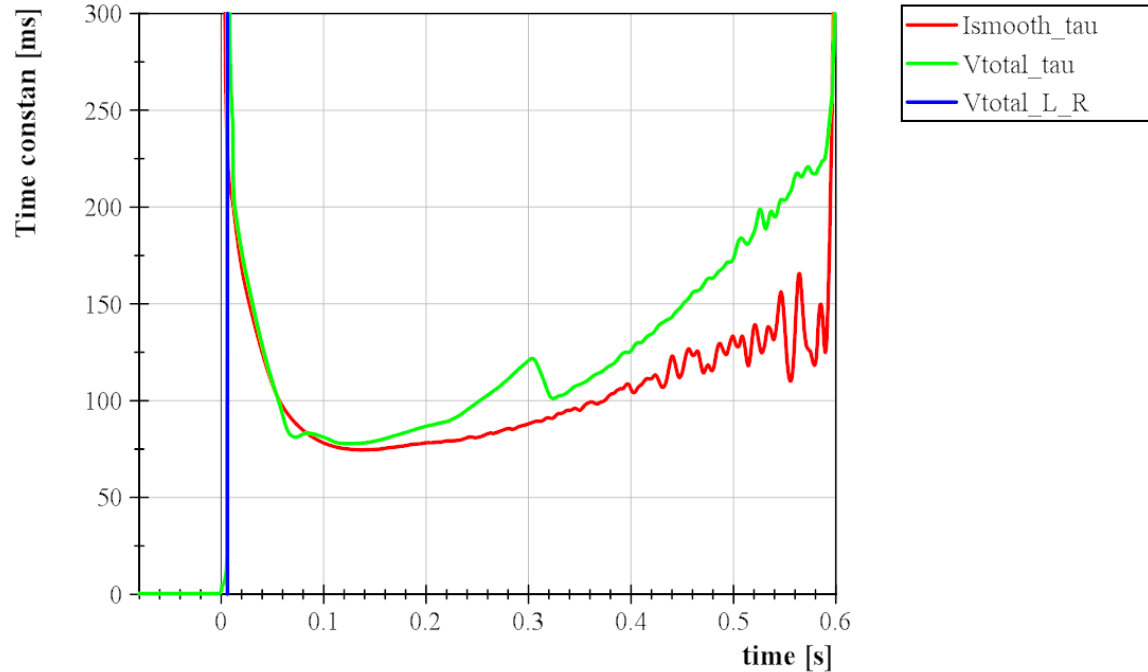
06/13/2016 TE-MSC-TF H. Bajas

MQXFS time constant

AQA_DIAdem

File: mqxfst1_Quench_160318155340_1_cmptd

$I_{max} = 18.093 \text{ kA}$

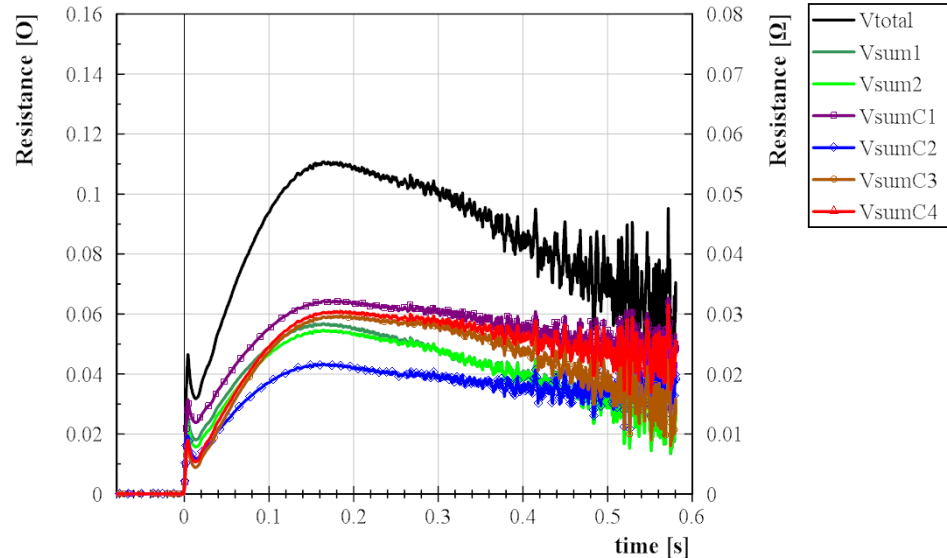


MQXFS resistance growth

AQA_DIADEM

File: mqxfsl_Quench_160304120151_1_cmptd

$I_{max} = 16.402 \text{ kA}$

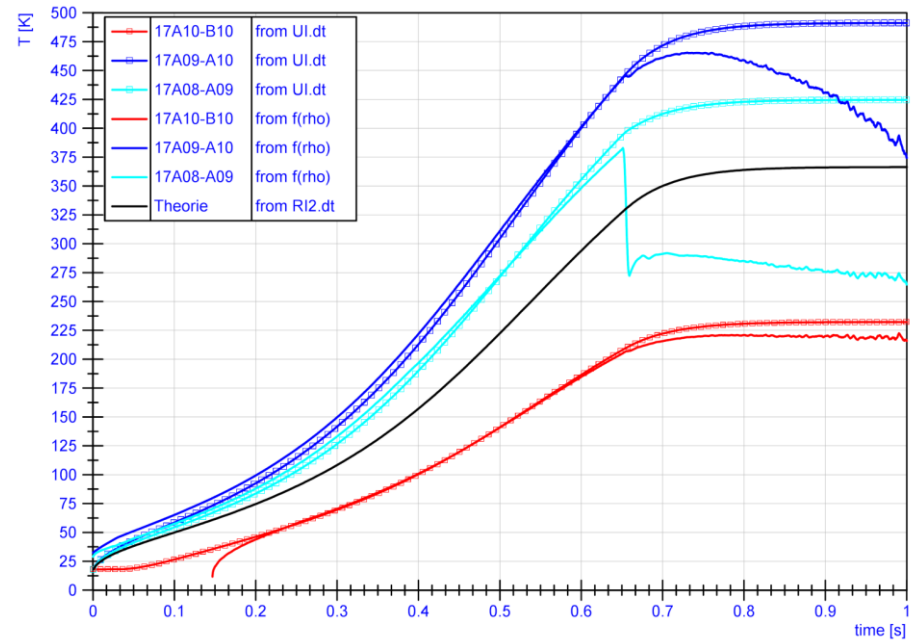
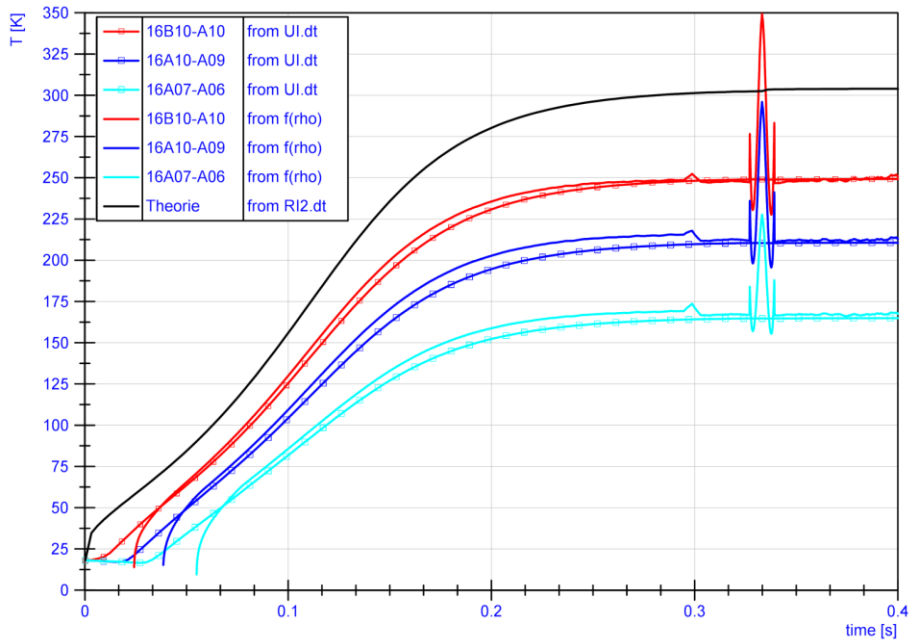


06/12/2016 TE-MSC-TF H. Bajas

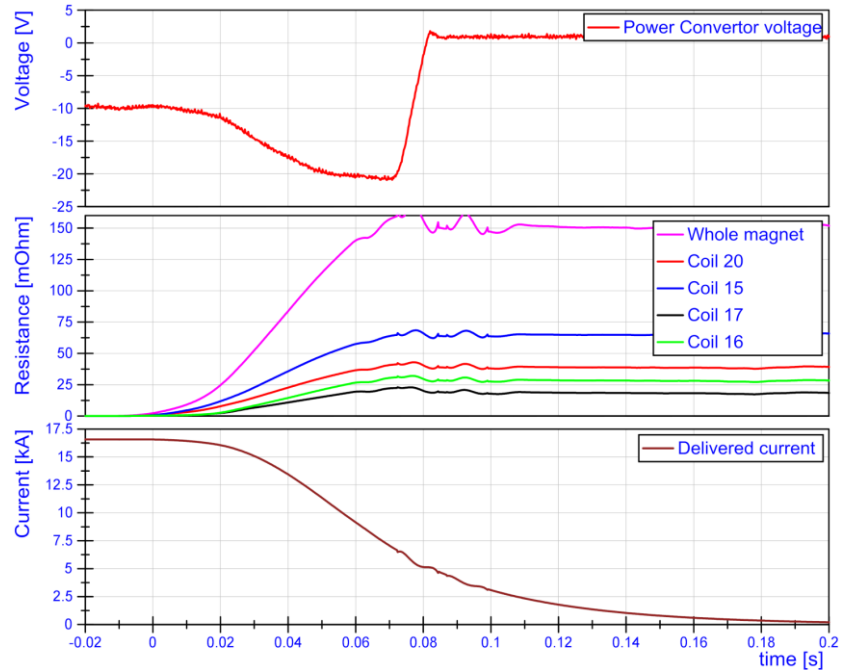
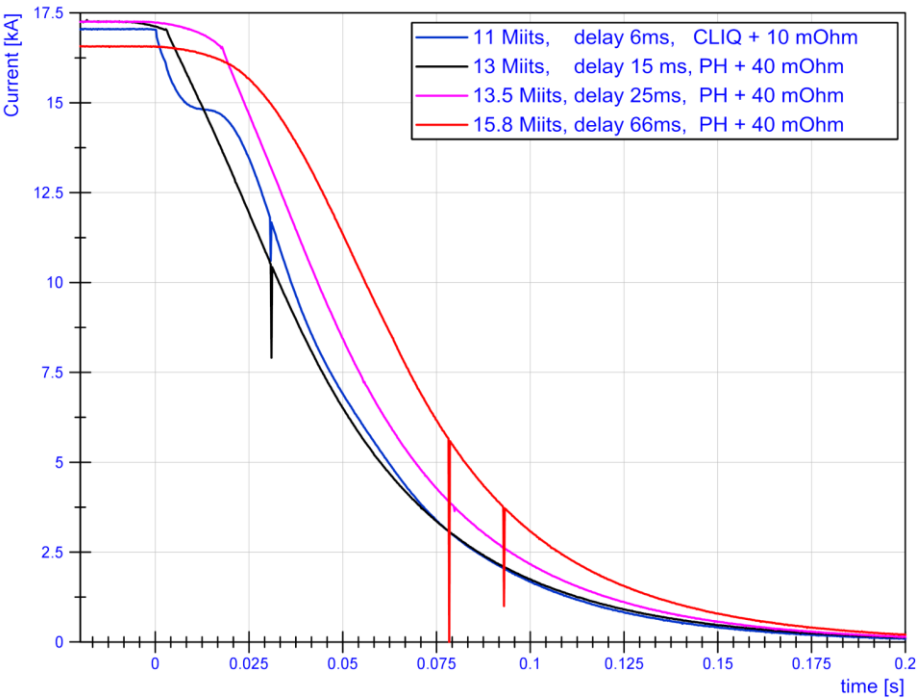
What is more?



Hot Spot Temperature (HQ02)



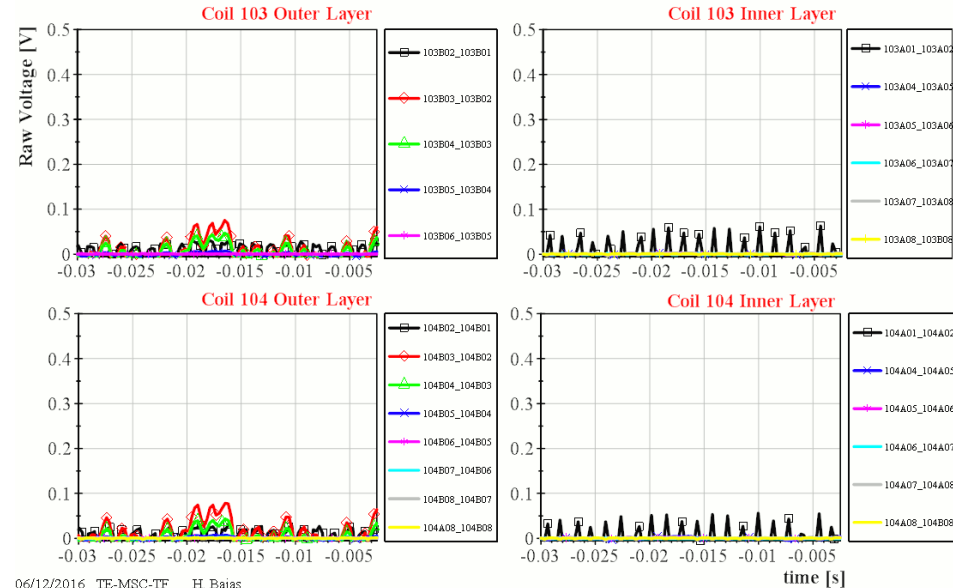
Hot Spot Temperature (HQ02)



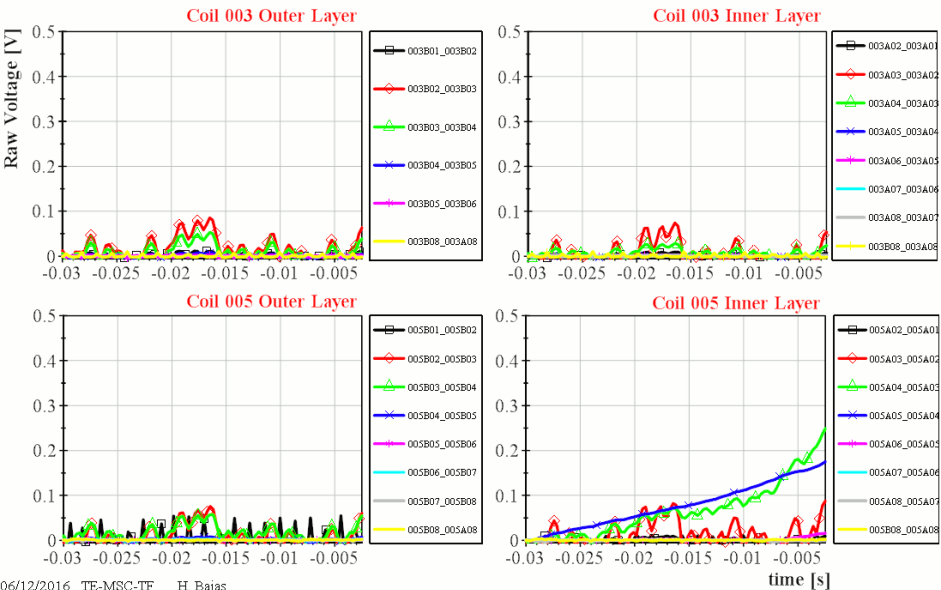
Example with “MQXFS1” FermiLab set data

AQA_DIAdem

File: mqxf1_Quench_160302185331_1_cmptd I = 14.25 kA

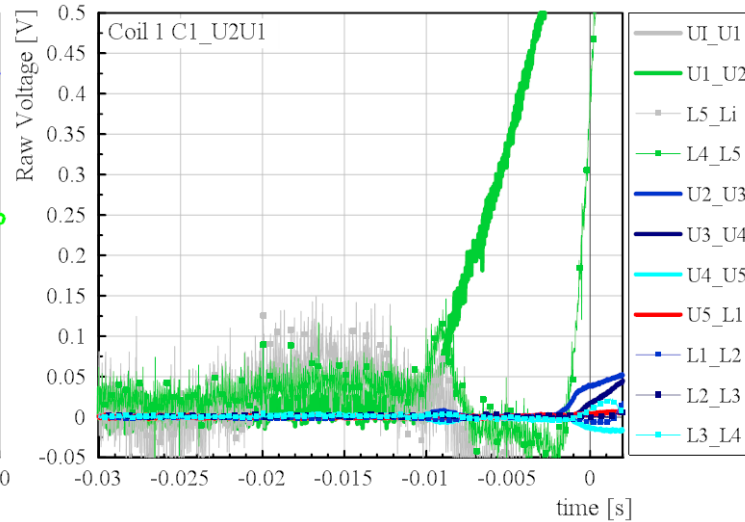
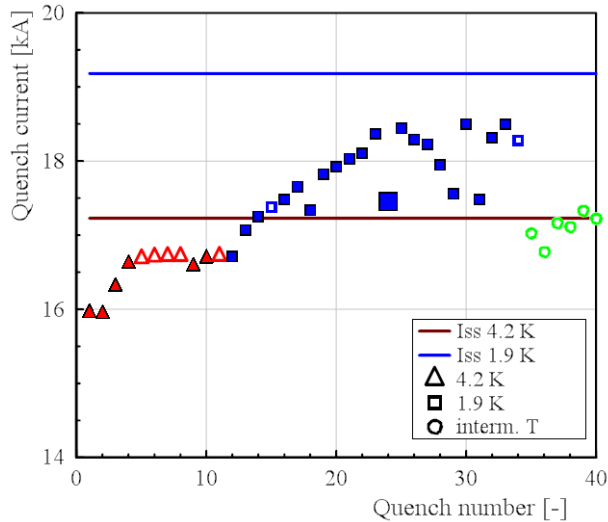


File: mqxfst1_Quench_160302185331_1_cmptd I = 14.25 kA



06/12/2016 TE-MSC-TF H. Bajas

Training of RMC-03 1st run



HCLMRMC003_CR101201_M1509081728_a017

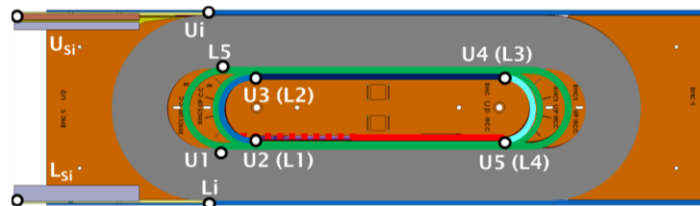
quench # 24

$I_{\max} = 17.45 \text{ kA}$

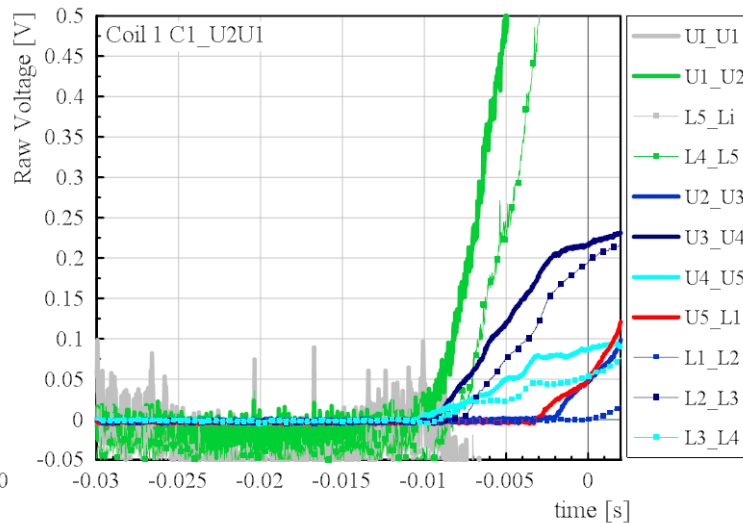
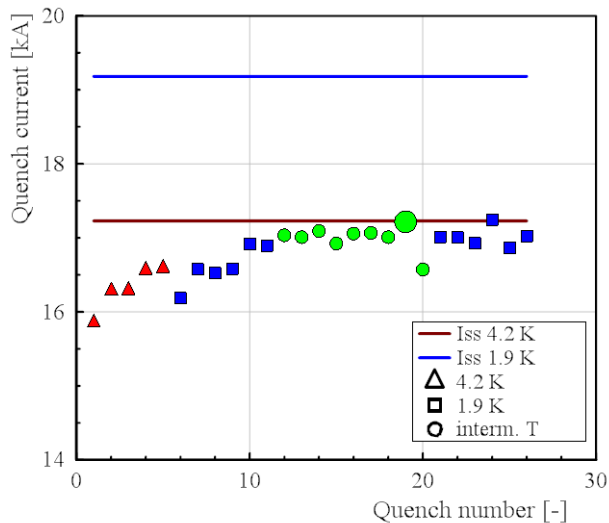
$t_{\text{quench}} = -10.83 \text{ ms}$

$B_{\text{peak}} = 15.3 \text{ T}$

MIITs = $19.21 \text{ MA}^2 \cdot \text{s}$



Training of RMC-03 2st run



HCLMRMC003_CR101201_M1605271413_b017

quench # 19

$I_{\max} = 17.22 \text{ kA}$

$t_{\text{quench}} = -9.23 \text{ ms}$

$B_{\text{peak}} = 15.1 \text{ T}$

MIITs = $18.07 \text{ MA}^2 \cdot \text{s}$

