
CERN

Case studies, surprises and problems

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On behalf of MP3-team for **GSI-CERN workshop on the protection of superconducting magnet circuits**, 15-16 March 2017

Content

GSI-CERN workshop on the protection of superconducting magnet circuits
15-16 March 2017 **R.Schmidt 28/02/2017**

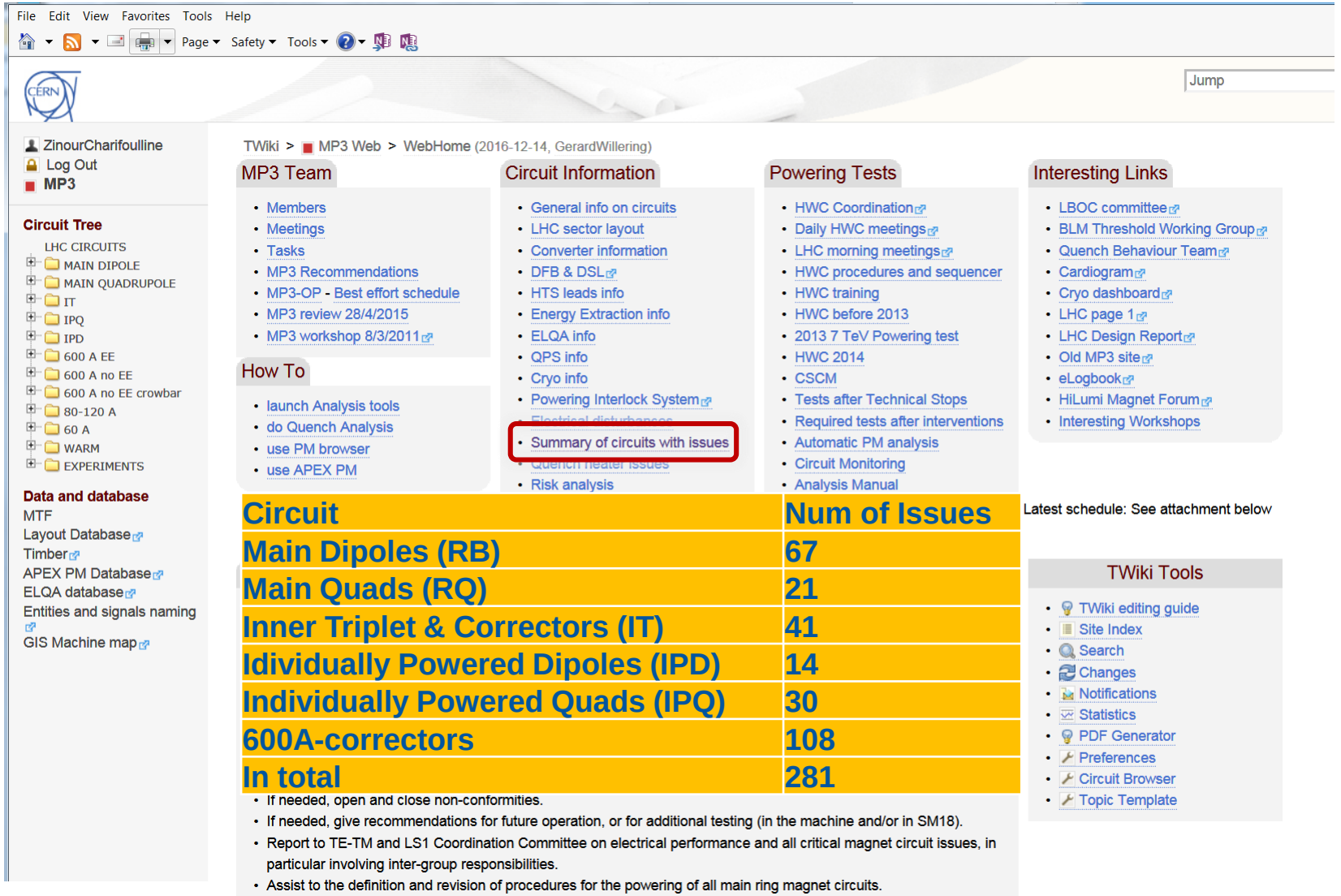
Draft Programme

Abstracts
…

7. Case studies, surprises and problems
- Massive quenches due to em-waves
- Symmetric quenches
- Quench propagation
- Shorts to ground

…

LHC Magnet Circuits, Powering and Performance Panel - MP3



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Page Safety Tools

Jump

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MP3

Circuit Tree

LHC CIRCUITS
- MAIN DIPOLE
- MAIN QUADRUPOLE
- IT
- IPQ
- IPD
- 600 A EE
- 600 A no EE
- 600 A no EE crowbar
- 80-120 A
- 60 A
- WARM
- EXPERIMENTS

Data and database

MTF
Layout Database
Timber
APEX PM Database
ELQA database
Entities and signals naming
GIS Machine map

TWiki > MP3 Web > WebHome (2016-12-14, GerardWillering)

MP3 Team
- Members
- Meetings
- Tasks
- MP3 Recommendations
- MP3-OP - Best effort schedule
- MP3 review 28/4/2015
- MP3 workshop 8/3/2011

How To
- launch Analysis tools
- do Quench Analysis
- use PM browser
- use APEX PM

Circuit Information
- General info on circuits
- LHC sector layout
- Converter information
- DFB & DSL
- HTS leads info
- Energy Extraction info
- ELQA info
- QPS info
- Cryo info
- Powering Interlock System
- Summary of circuits with issues
- Risk analysis

Powering Tests
- HWC Coordination
- Daily HWC meetings
- LHC morning meetings
- HWC procedures and sequencer
- HWC training
- HWC before 2013
- 2013 7 TeV Powering test
- HWC 2014
- CSCM
- Tests after Technical Stops
- Required tests after interventions
- Automatic PM analysis
- Circuit Monitoring
- Analysis Manual

Interesting Links
- LBOC committee
- BLM Threshold Working Group
- Quench Behaviour Team
- Cardiogram
- Cryo dashboard
- LHC page 1
- LHC Design Report
- Old MP3 site
- eLogbook
- HiLumi Magnet Forum
- Interesting Workshops

Circuit	Num of Issues
Main Dipoles (RB)	67
Main Quads (RQ)	21
Inner Triplet & Correctors (IT)	41
Idividually Powered Dipoles (IPD)	14
Individually Powered Quads (IPQ)	30
600A-correctors	108
In total	281

- If needed, open and close non-conformities.
- If needed, give recommendations for future operation, or for additional testing (in the machine and/or in SM18).
- Report to TE-TM and LS1 Coordination Committee on electrical performance and all critical magnet circuit issues, in particular involving inter-group responsibilities.
- Assist to the definition and revision of procedures for the powering of all main ring magnet circuits.
- Set-up and run the CCC support team during the “hardware commissioning” campaign.

Latest schedule: See attachment below

TWiki Tools
- TWiki editing guide
- Site Index
- Search
- Changes
- Notifications
- Statistics
- PDF Generator
- Preferences
- Circuit Browser
- Topic Template

Content (selected issues)

- ✓ 2008 HWC - RB Unbalanced apertures
- ✓ 2008 HWC – Quench heater issues (open, …)
- ✓ 2008 HWC – RB incident, 1 V threshold?
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 20
- ✓ 2014 HWC – IPD LE of RB.A31 -> heater firing in RB2.L1
- ✓ 2014 RUN – IPQ RQ5.L6 not protected against symmetric quenches?
- ✓ 2014 RUN – IPQs frequent trips due to thunderstorms (10 -> 20 ms)
- ✓ 2014 RUN – IPQs Q8&Q9 trips when MB in A8-B10 quenches
- ✓ 2016 RUN – RB A31L2 possible inter-turn shot

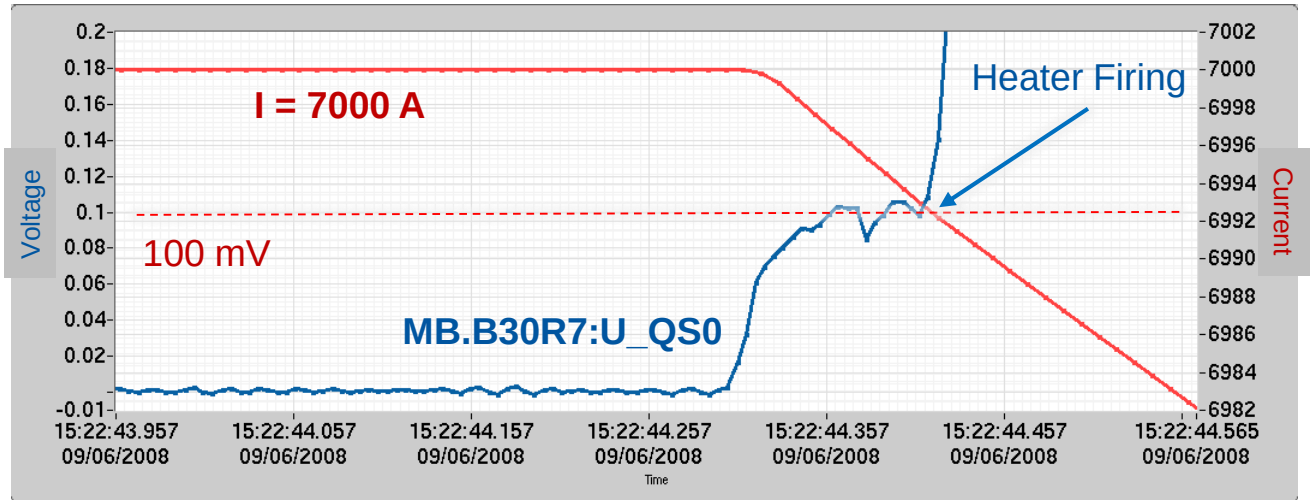
Final content:

- ❑ RB-circuits: Unbalanced Apertures
- ❑ RB-circuits: High Resistive Magnets
- ❑ RB-circuits: Symmetric & Massive Quenches
- ❑ RB-circuits: Voltage Feelers & Ground Fault
- ❑ RB-circuits: Secondary Quenches ?

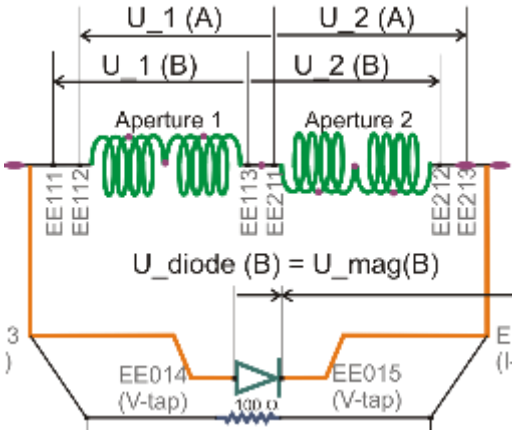
RB: Unbalanced Apertures (1)

HWC 2008, RB-circuit Powering Test, Fast Power Abort at 7000 A :

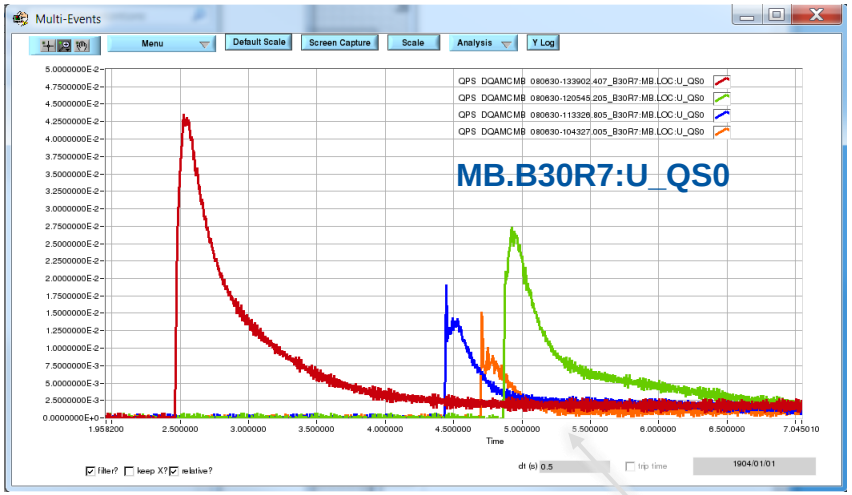
- Quench detected in MB.B30R7 during fast discharge at 7000A (dI/dt ≈ -70 A/s);
- But it was not a real quench. There was an inductive voltage difference between two apertures, which grows with dI/dt and exceeds 100 mV threshold;
- Thanks to iQPS => special technique, so called QPS Snapshot, has been developed and first time used to trigger the PM Data collection which allowed to prove the assumption and to find the solution (see next slide);

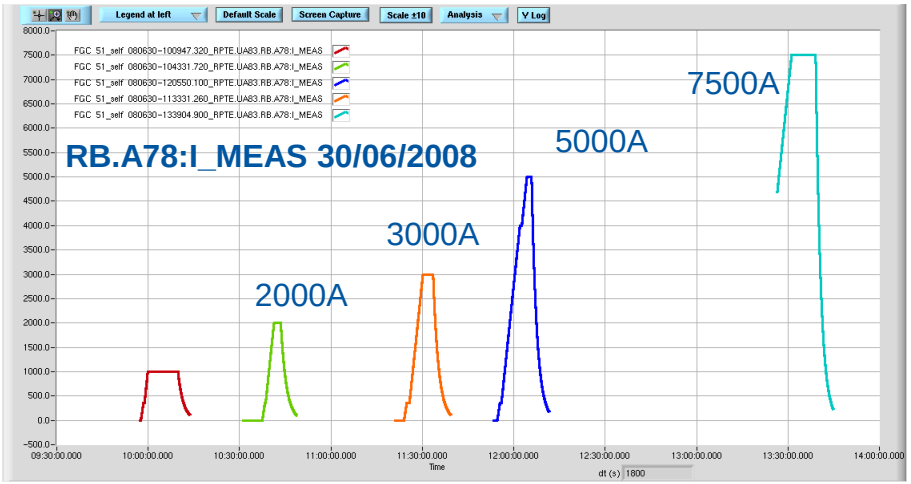


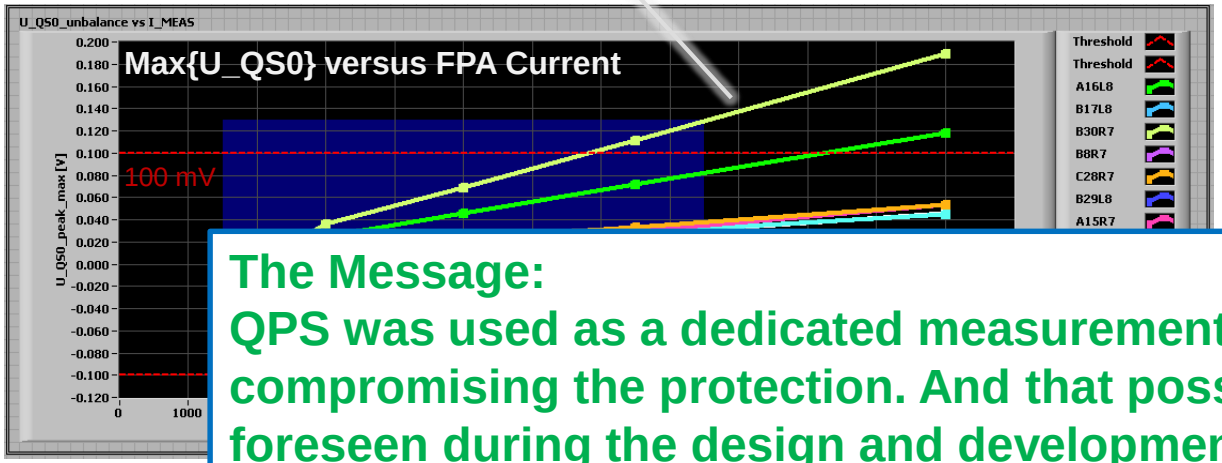
U_QS0 = U_1 + U_2



RB: Unbalanced Apertures (2)







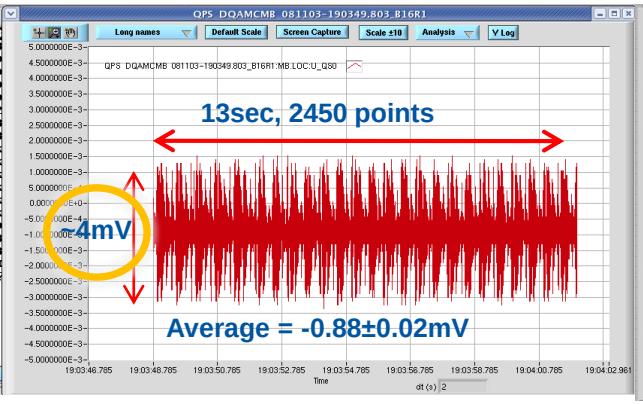
Solution: iQPS-threshold has been increased from 100 mV up to 265 mV:
A16L8 – 3504
B17L8 – 2006
B30R7 – 1007 *
B8R7 – 1031

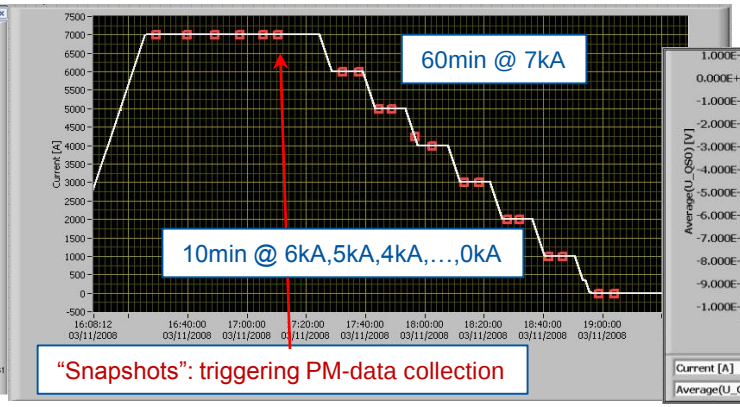
The Message:
QPS was used as a dedicated measurement system without compromising the protection. And that possibility was already foreseen during the design and development of QPS. Great!

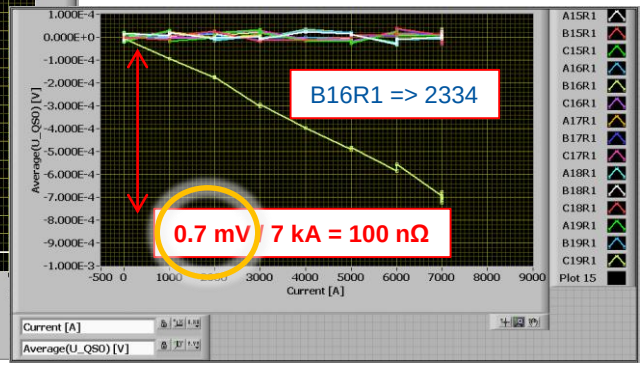
RB: High Resistive Magnets (1)

HWC 2009, RB-circuit Powering Test, Special Pyramids:

- The same technique – triggering the PM Data collection (snapshots) on plateaus;
- The analysis of iQPS:U_QS0-signals allowed to detect two high resistive, 100 and 50 nΩ, magnets, while expected resistance is about 2.5 nΩ (8 x 300 pΩ). Magnets were replaced, opened and repaired later on.







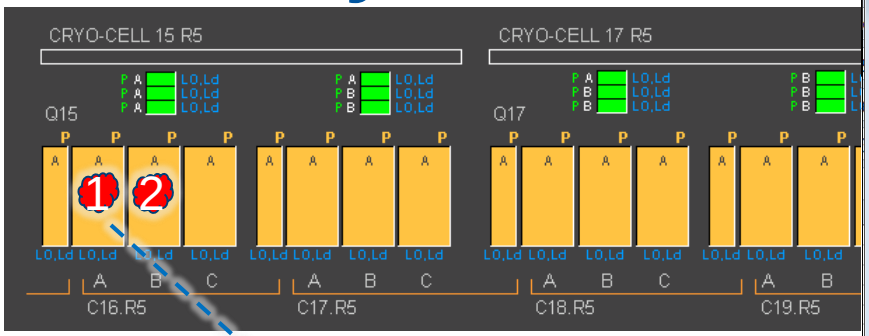
The Message:
QPS was used as a dedicated measurement system without compromising the protection. But plus dedicated analysis …

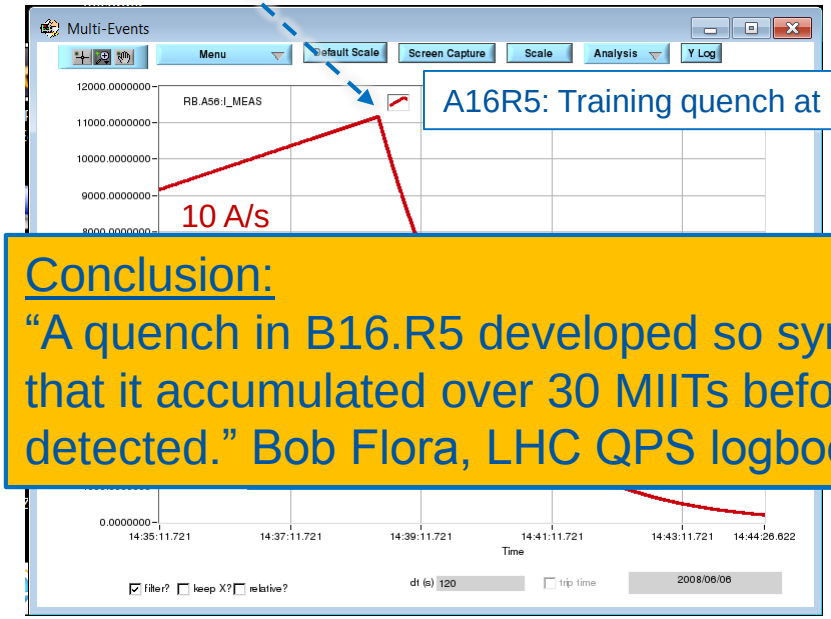
RB: Symmetric Quench in 2008 (1)

2008

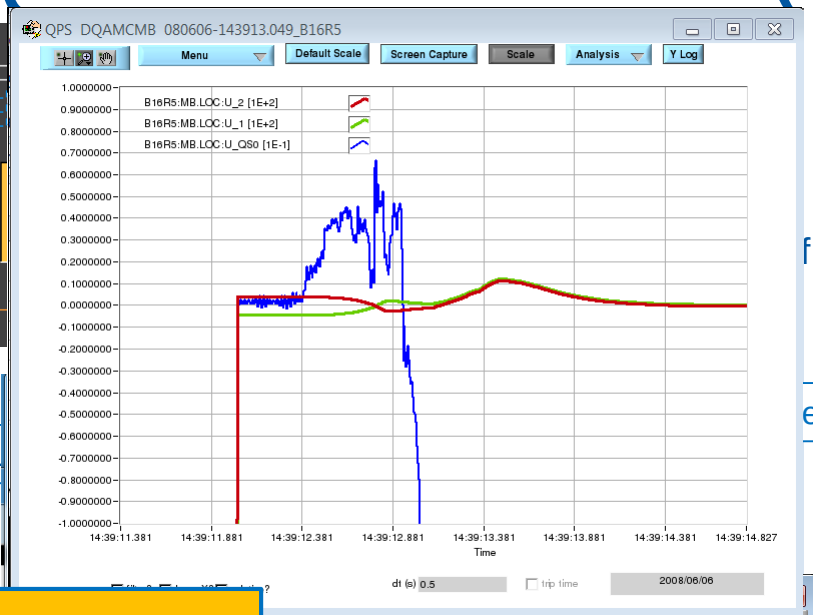
- Very first LHC HWC: QPS IST, Powering Tests, Surprises, …;
- All sectors was commissioned to injection level;
- In May-June RB.A56 (main dipoles) – 1st training to 7 TeV;
- First beams in LHC in September;
- Incident in RB.A34 during HWC-powering test;
- Repairing of the machine and QPS upgrade:
  I. nQPS - Splice protection (*cause of incident*);
  II. nQPS - Symmetric quench protection (*next slide*);
  III. nQPS - Voltage feelers;

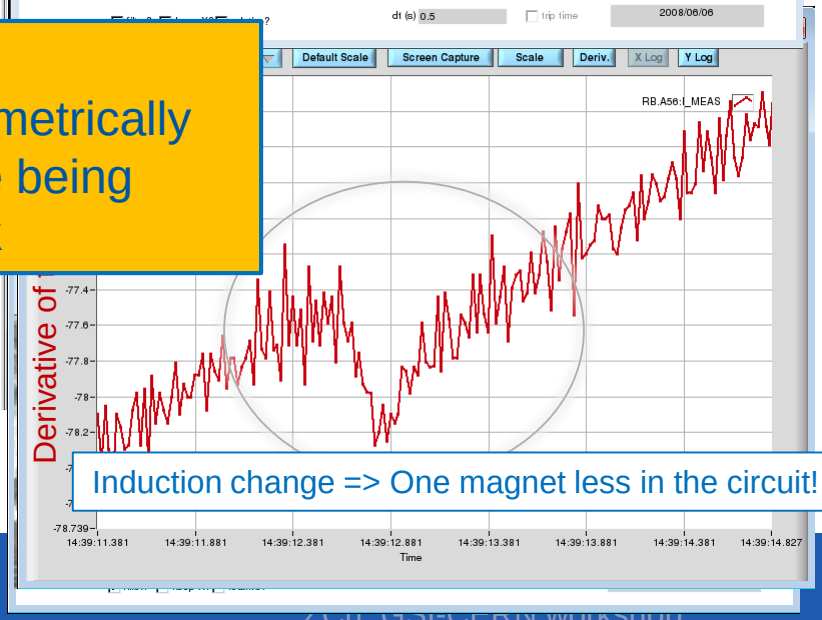
RB: Symmetric Quench in 2008 (2)





A16R5: Training quench at 111





Induction change => One magnet less in the circuit!

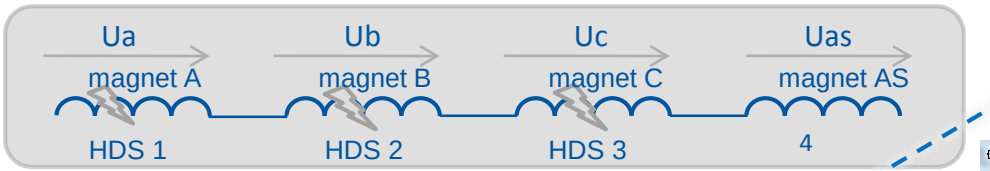
out 154)
f 48)

e opening

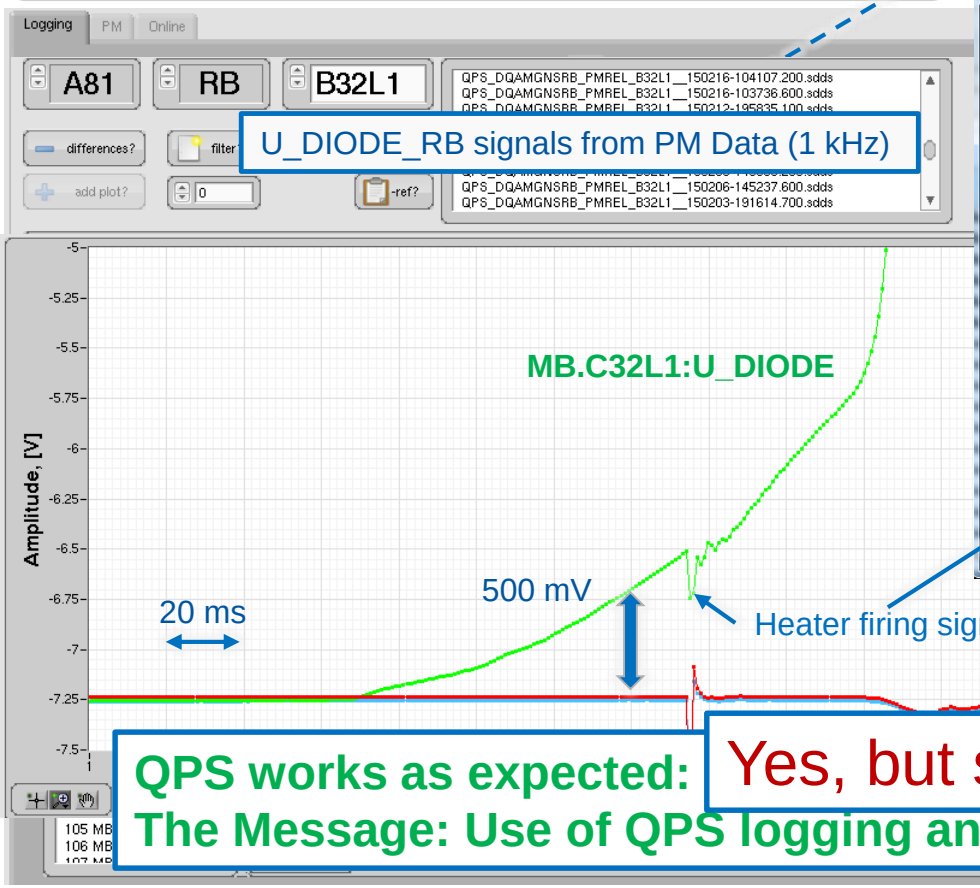
Conclusion:

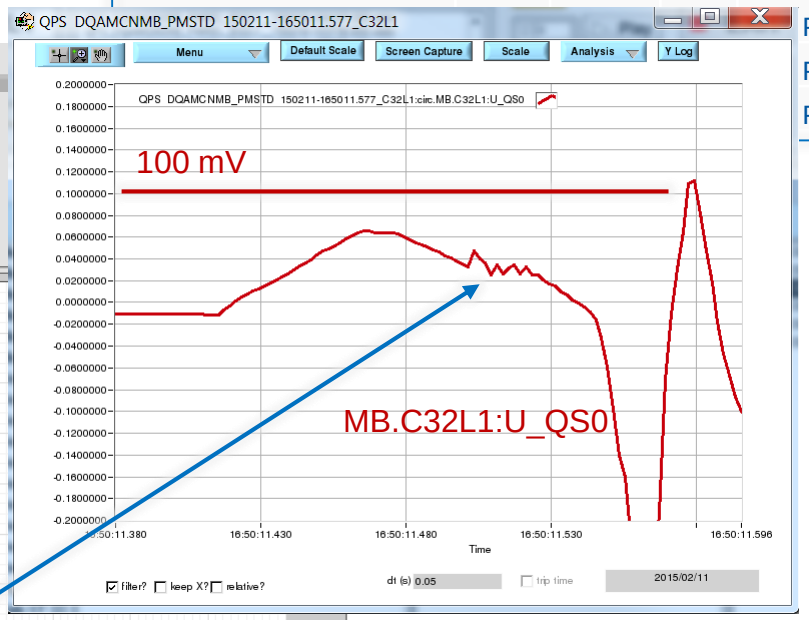
"A quench in B16.R5 developed so symmetrically that it accumulated over 30 MIITs before being detected." Bob Flora, LHC QPS logbook

RB: Symmetric Quench in 2015 (3)



150211-164930.614_A27L1	iQPS	10491	1	T
150211-164930.644_B32L1	iQPS	10491	2	T
150211-164931.148_C33L1	iQPS	10460	3	EM/TW
				P
				P
				P

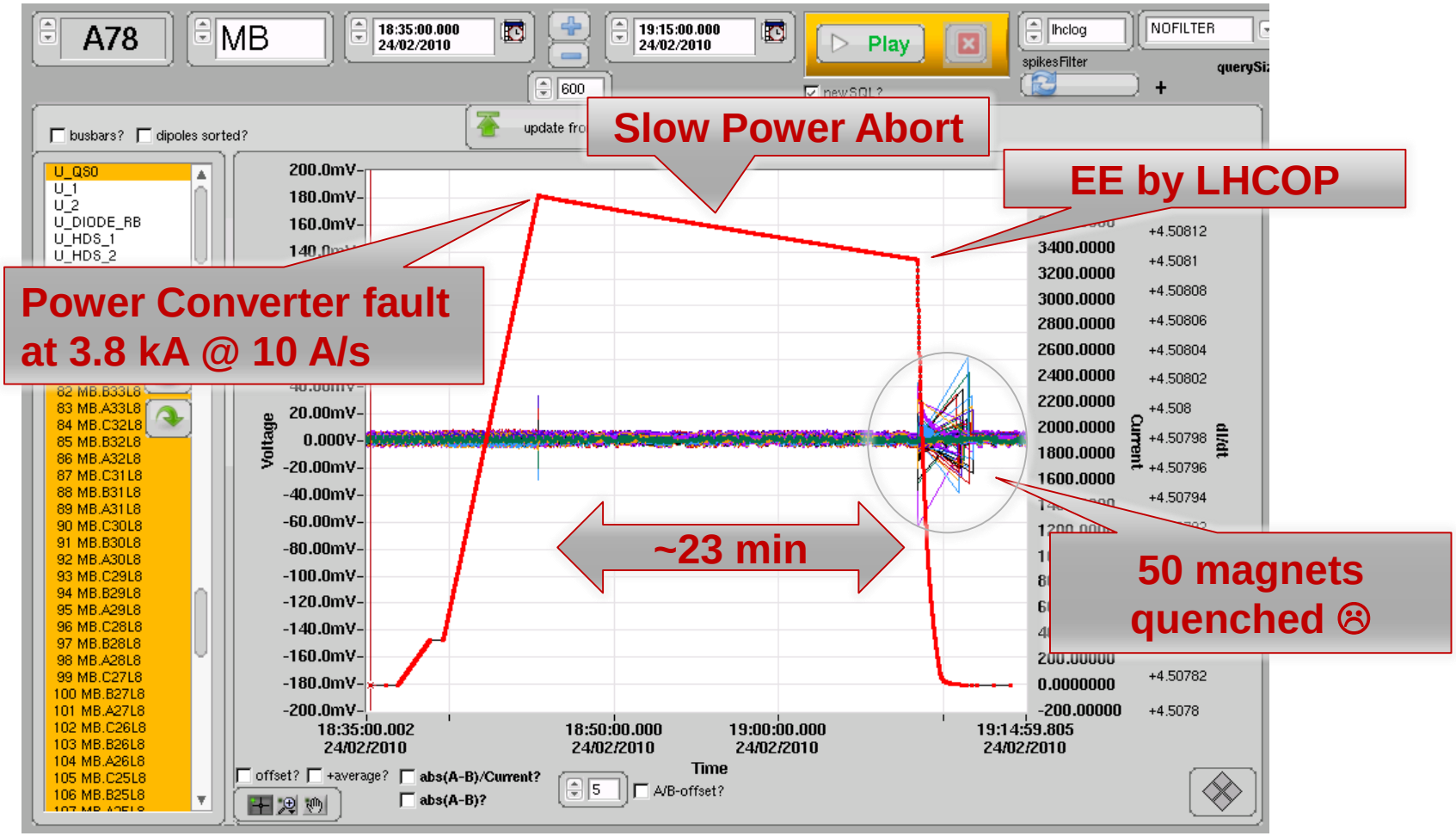




QPS works as expected: Yes, but something in between ☹

The Message: Use of QPS logging and PM data to understand the event.

RB: ~~Symmetric~~ Massive Quench in 2010 (4)

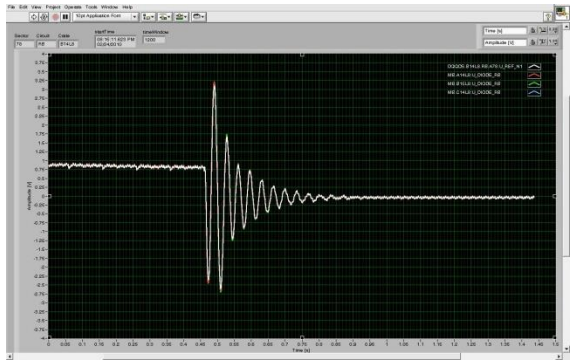


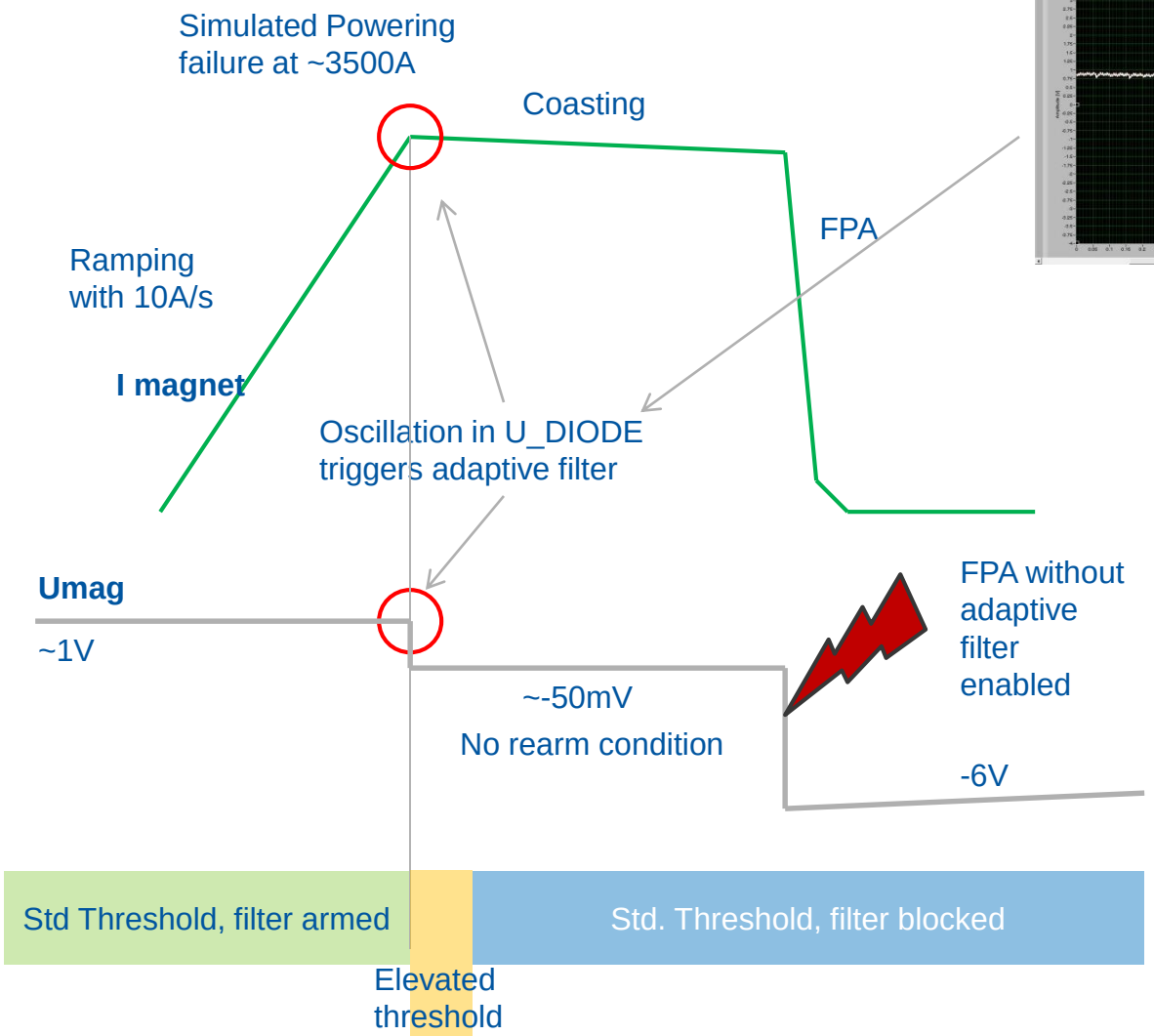
“Side effects” of power converter oscillations

- Oscillations exceed onset value of adaptive filter
- Since power supply is off after oscillation U_DIODE is slightly negative
- Rearm condition is not fulfilled
- If switches open some time after the oscillation, abort is not protected by adaptive filter → SymQ will fire heaters
- Oscillations on top of a FPA will cause strong perturbations and trigger the old QPS as well
(11 magnets fired at 6kA)

Jens Steckert

Event of feb-24 mass firing after FPA from 3.8 kA





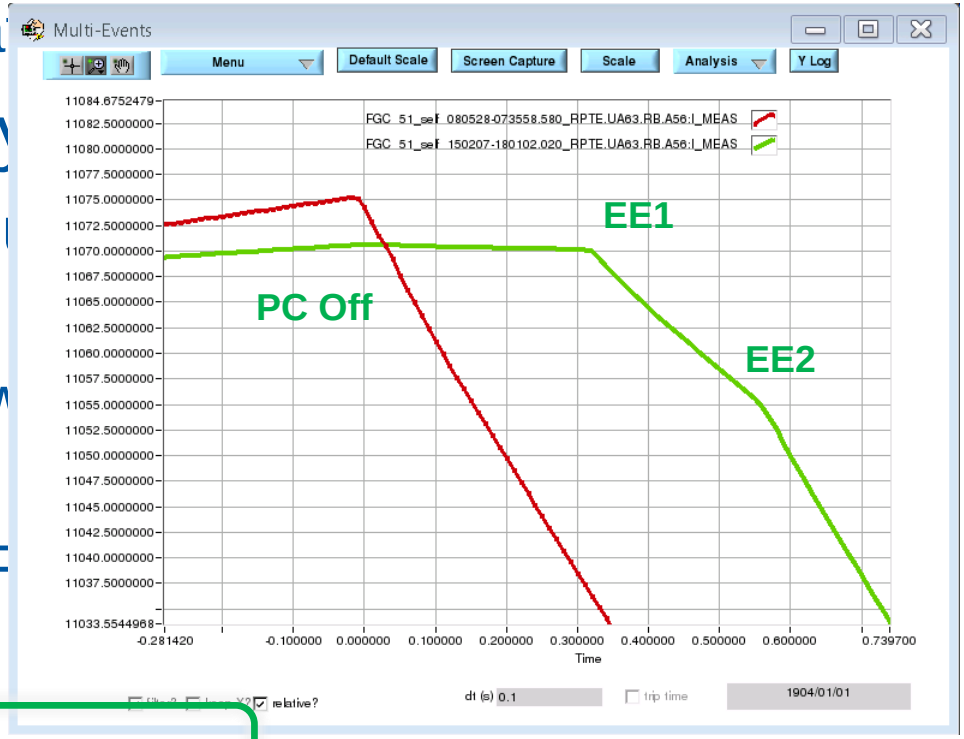
- Power converter switch-off caused oscillation <-2V on U_DIODE
- Adaptive filter is activated
- Filter switches back to std threshold after 1.3s
- During coasting U_DIODE stays negative (no rearm cond.)
- At FPA filter is not available, threshold stays low

→ **SymQ triggers (…in 50 cases)**

Jens Steckert

QPS's way to 6kA

- Delay extraction switch in respect to PC fault
  - This decouples FPA transients from oscillations → 100ms are feasible, old QPS hea
- Increase thresholds of Sy
  - Makes the detector less s by FPA/ringing etc.
  - Calculations for 6 kA show ~800 mV
  - SymQ will be immune to F



→ With this measures safe operation at 6kA should be ensured

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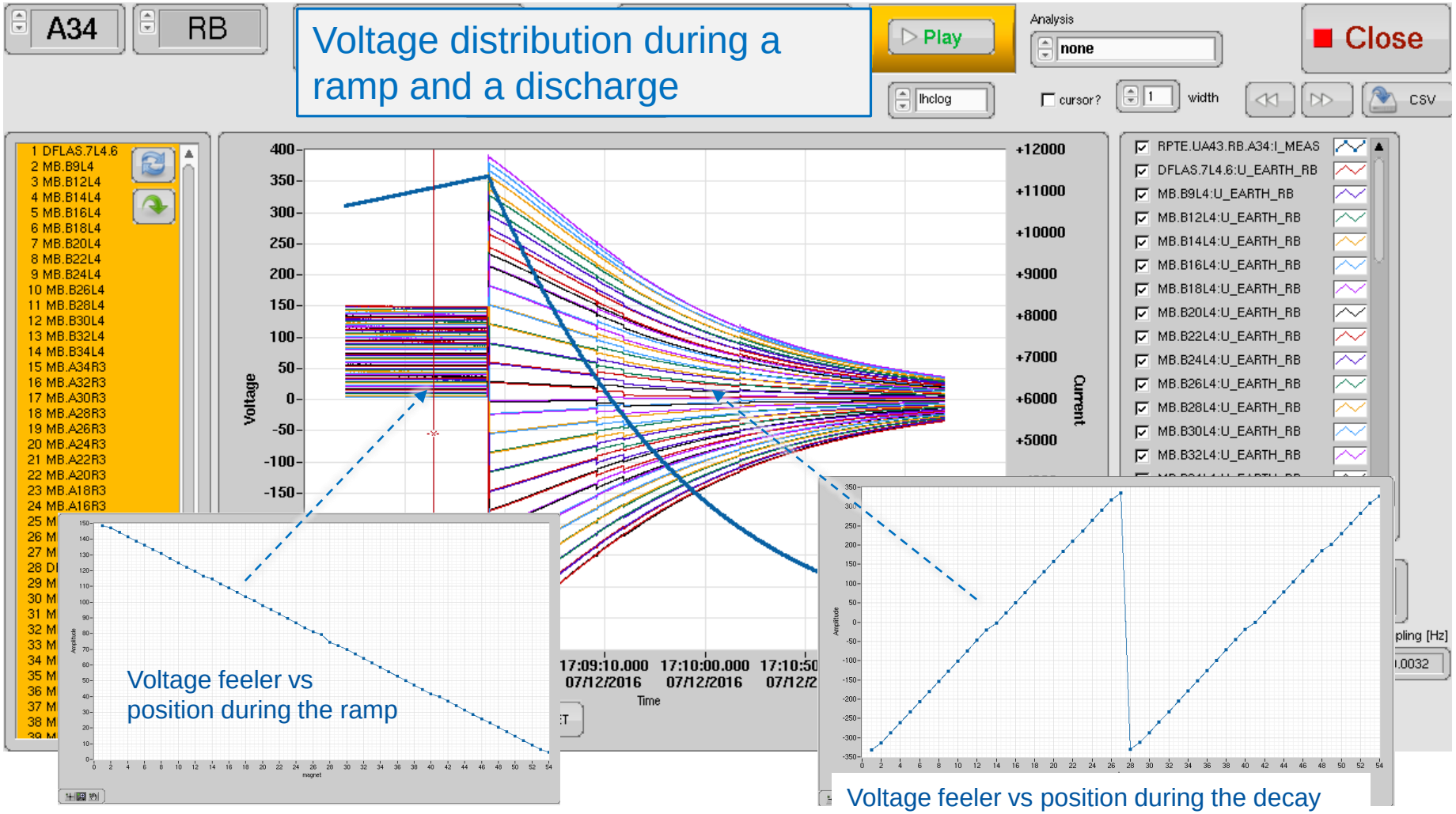
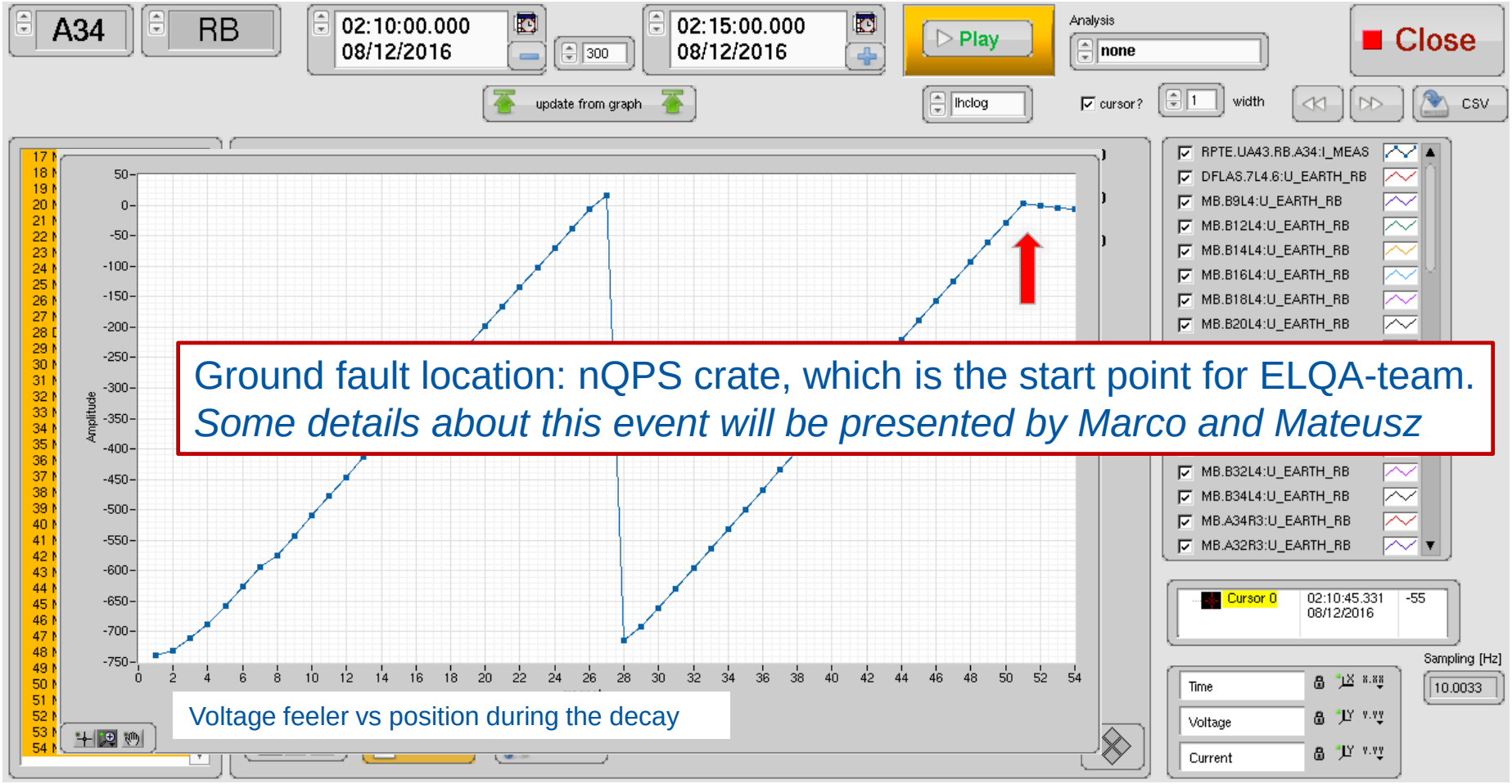
RB: Voltage Feelers (1)



RB: Voltage Feelers (2)

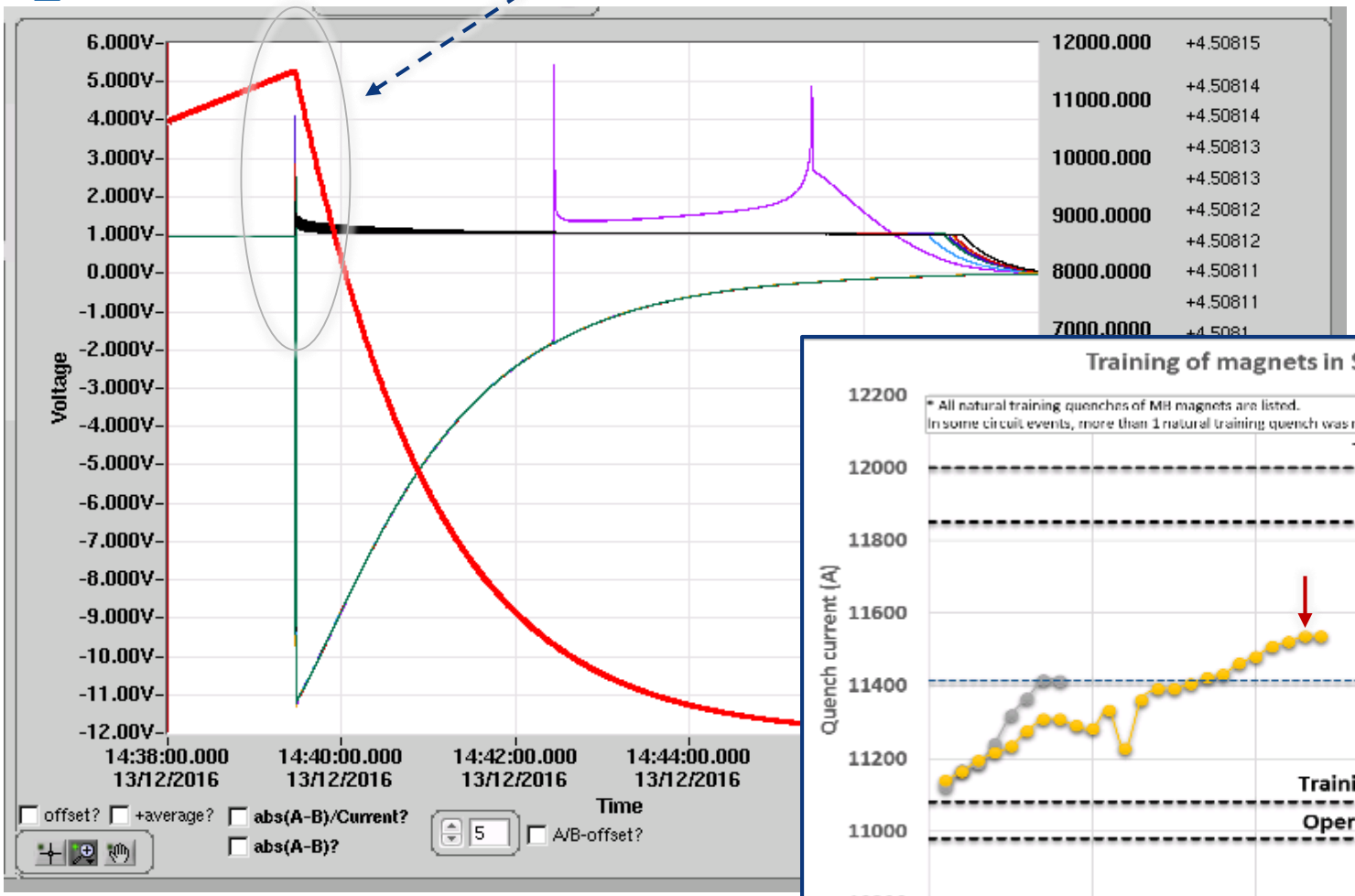
Short to ground event during the training quench



RB: Secondary Quenches (1)

MB.A16R4 - Training Quench at 11552 A

U_DIODEs vs time

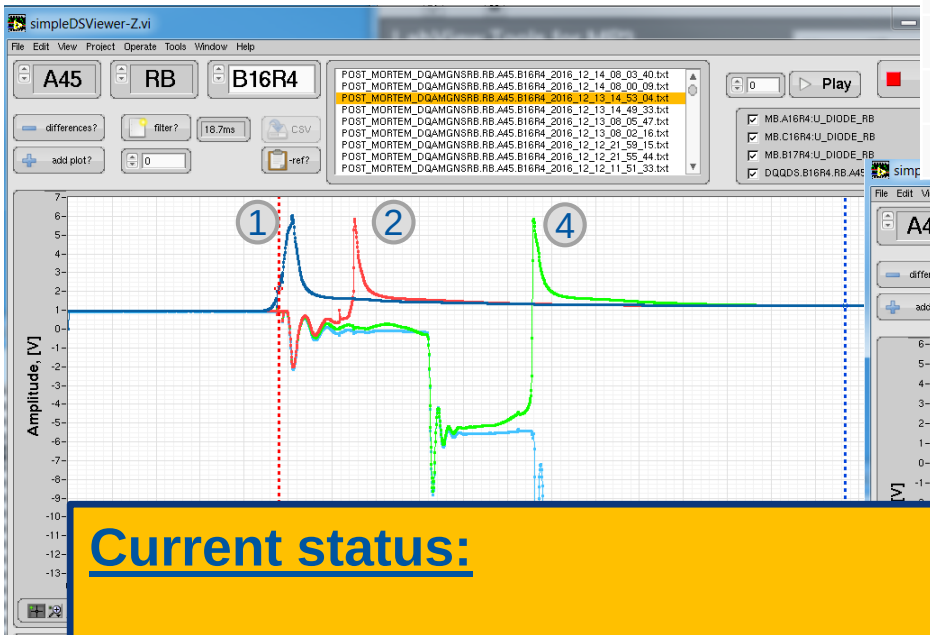


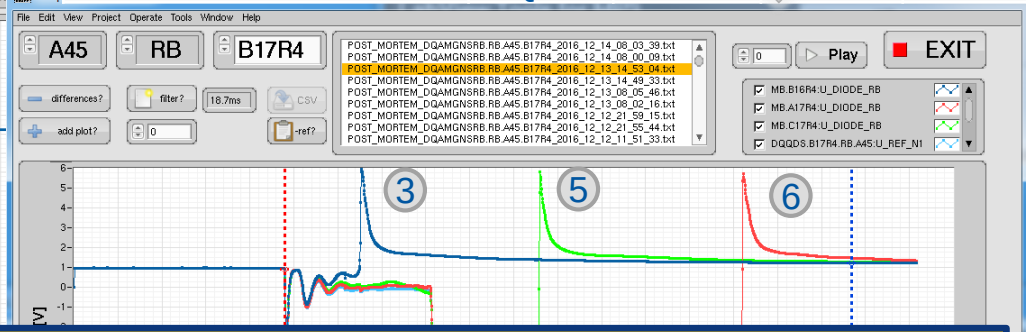
RB: Secondary Quenches (2)

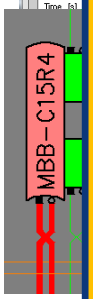
~ 1 sec

RB.A45, 13-12-2016, 14:39:27

161213-143927.518_A16R4	iQPS	11522	1	T
161213-143927.708_C16R4	nQPS	11521	2	EMC
161213-143927.712_B16R4	nQPS	11521	3	EMC
161213-143928.106_B17R4	nQPS	11521	4	EMC
161213-143928.111_C17R4	nQPS	11521	5	EMC
161213-143928.534_A17R4	iQPS	11473	6	EMC



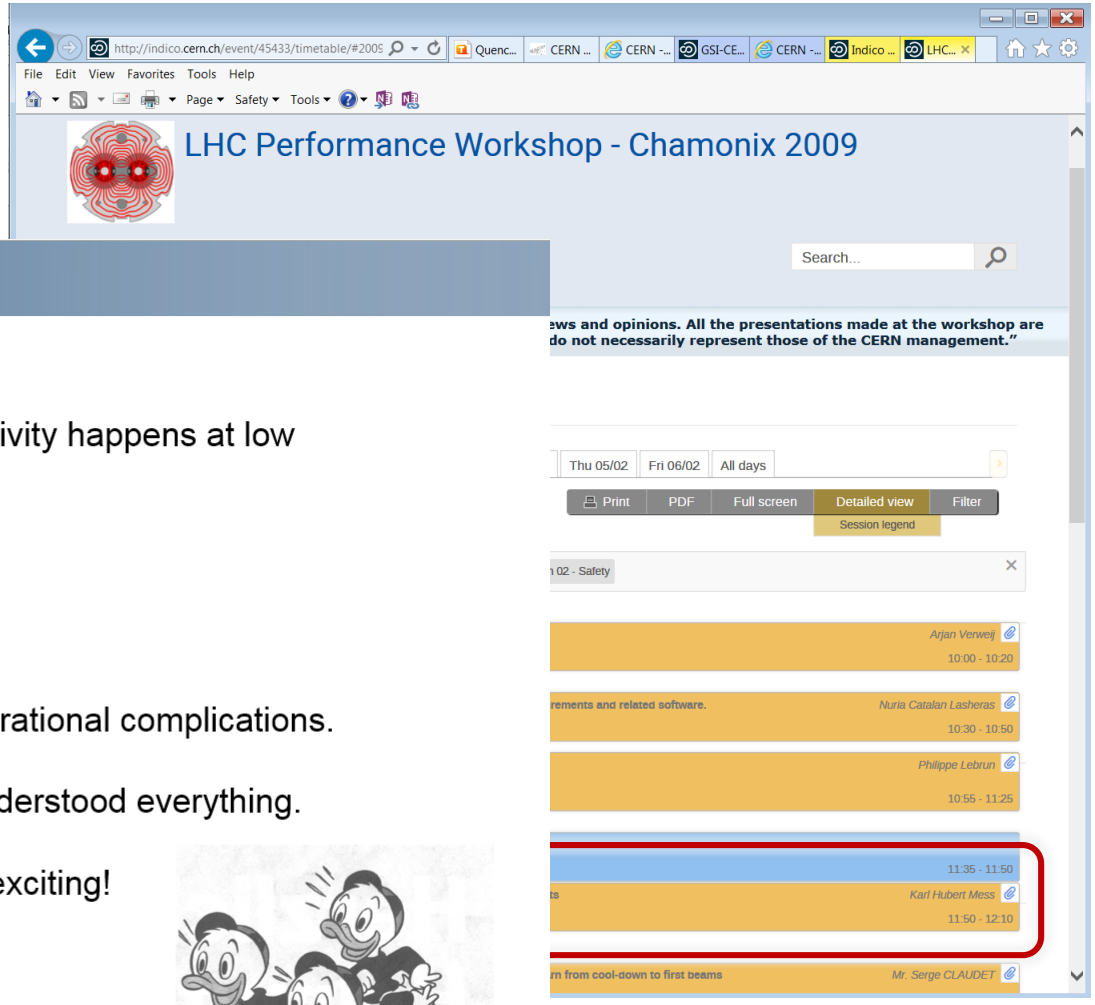




Current status:

- ✓ Phenomena not yet fully understood;
- ✓ Seems, higher the current higher the effect;
- ✓ Chain or massive quenches – to be worried about?
- ✓ Needs to be solved or mitigated if we continue the training to 7 TeV

Conclusions



Summary

- We rediscovered Ohms law.
- We rediscovered that superconductivity happens at low temperatures.
- We rediscovered Faradays law.
- We rediscovered Kirchhoffs law.
- We discovered shortcomings & operational complications.
- We discovered that we have not understood everything.
- The re-commissioning will be very exciting!
- A challenge again! Good luck!

Chamonix 2009, K. H. Meß, DG-PRJ-LHU Superconducting Electrical Circuits

Karl Hubert Mess, “Superconducting Electrical Circuits”


Thanks!

www.cern.ch