Enhanced QPS – performance, commissioning at 3.5TeV, outlook towards 5 TeV

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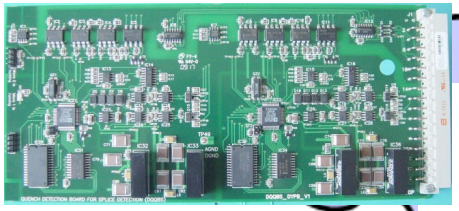
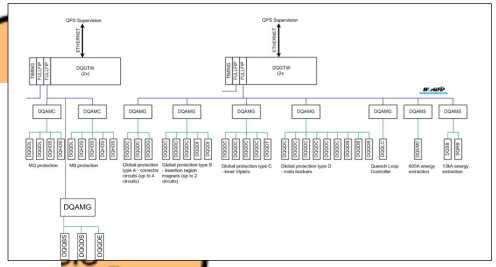
on behalf of the (extended) QPS team

Special thanks to Z. Charifoulline, K. Dahlerup-Petersen, R. Flora, F. Formenti and J. Steckert

What is enhanced QPS (nQPS)?





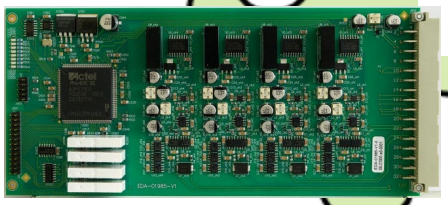
Supervision & data analysis

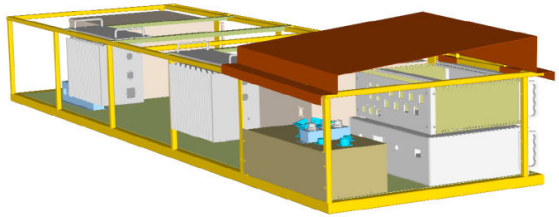
Splice protection & monitoring

436 crates, 3924 detection boards, 872 power packs
~30000 signals
240 km of cables, 7800 connectors

powering

Symmetric qu
detection





What is the functionality of nQPS?

➔ Splice protection system type DQQBS

- Permanently monitors and interlocks the voltage across the interconnections between LHC main magnets
  - Determination of detection threshold based on simulation and tests (→ A. Verweij)
  - Required threshold @ I = 12 kA: U_{TH} = 300 μV, 10 s
  - For 3.5 TeV operation U_{TH} = 500 μV, 10 s is sufficient
- Provides data for enhanced diagnostics via the QPS supervision
  - "Mexican pyramids" → measurement of splice resistance with a resolution of $\Delta R < 1n\Omega$
  - Evaluation of data recorded during coasting to trace development of splice resistances in time

What is the functionality of nQPS?

- **Symmetric quench detection system type DQQDS**
  - Enhances the functionality of the existing protection system in order to detect timely aperture symmetric quenches
    - Design threshold U_{TH} = 200 mV, 20 ms
  - System is detecting as well “normal” quenches and serves as a back-up of the existing system
    - Used for the implementation of the fully redundant UPS AC powering scheme
  - System is essential for magnet training up to nominal current
    - Significant amount of aperture symmetric quenches due to propagation expected

nQPS commissioning I < 2 kA – splice protection

- nQPS can be commissioned and qualified up to I = 2 kA in passive mode e.g. not connected to interlocks and quench heaters
  - Protection ensured by standard QPS, respectively self protecting
- Verification of signal integrity
  - Completeness, wiring errors, noise levels
- Adjustment of device parameters
  - Threshold and filter settings if applicable
  - Splice protection needs to compensate apparent inductive voltage across bus-bar splice during ramp
    - Compensation coefficients to be deduced from data acquired during current ramps
    - Main contribution from instrumentation wires → different sets for the two redundant protection systems
- Splice mapping up to 2 kA
  - Identification of potential problems at moderate currents

nQPS commissioning I < 2 kA – symmetric quench detection

- Symmetric quench detection system is based on a multichannel evaluation logic supervising 3 magnets
  - System is active in all phases of a powering cycle
  - Approach ensures a very reliable detection of quenches
  - The not so easy task consists in the suppression of false triggers in case of activation of the energy extraction systems
    - Risk of multiple quenches
    - Steep learning curve during commissioning in 2009
    - Use of adaptive filters, which are only active during the transition from ramping/coasting to discharge
    - Snubber capacitors for the energy extraction systems needed for operation at higher energies (→ see talk by W. Venturini)
  - The check of the immunity of the symmetric quench detection with respect to fast discharges is a mandatory test to be repeated each time the energy is increased

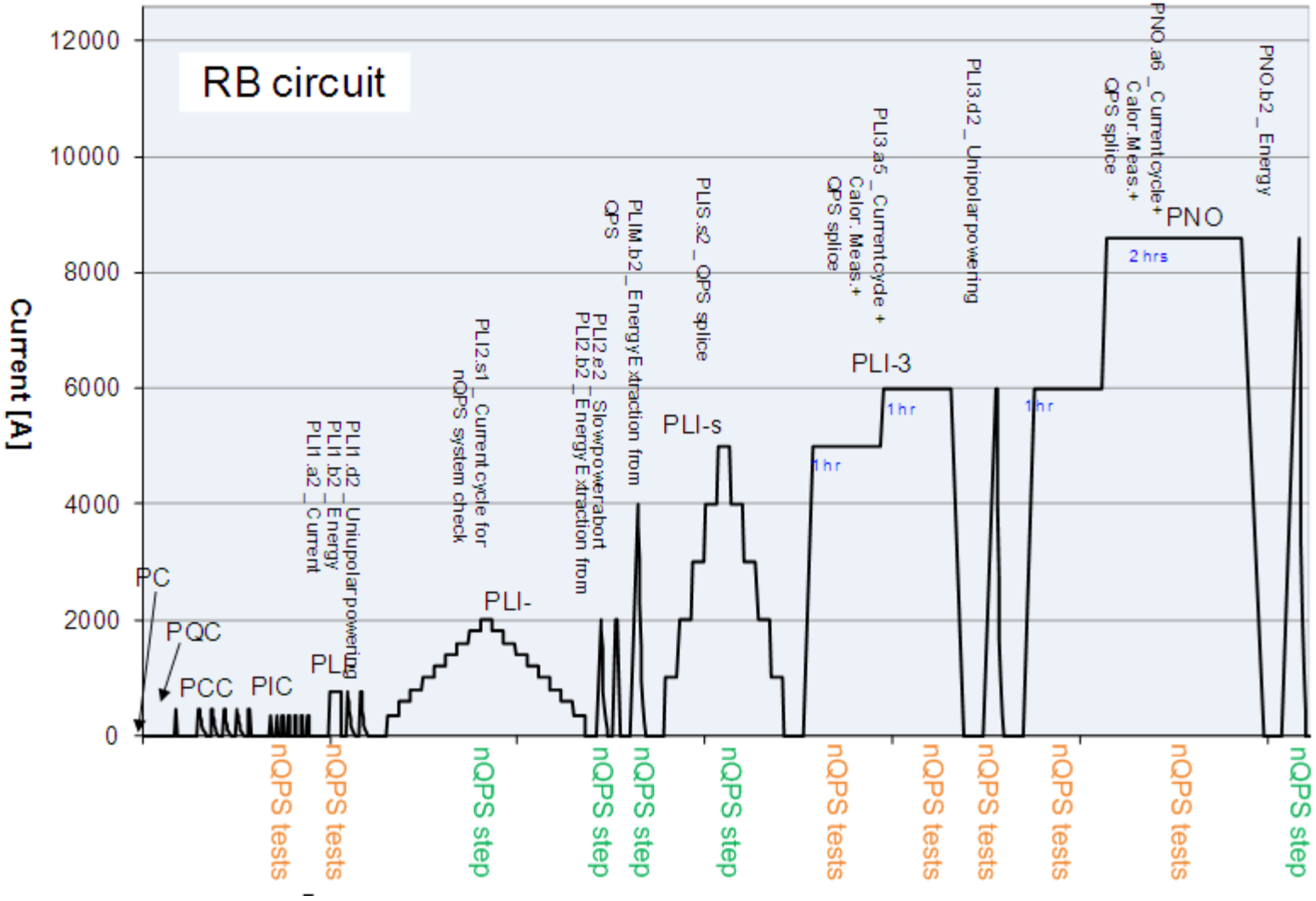
nQPS commissioning I < 2 kA – symmetric quench detection

- Signal (magnets → detector) and trigger (detector → quench heaters) mapping to be checked very carefully
  - Combined with heater firing test of existing QPS
    - Firing of quench heaters of a previously power cycled magnet (typically up to injection current) creates a voltage spike recorded by the symmetric quench detection system
  - Heater firing triggered by the symmetric quench detection
    - Verification that the system is protecting the right magnet
  - Mapping has to be checked only after installation and each major intervention requiring disconnection of nQPS cables
  - Heaters and interlocks to be tested once per year

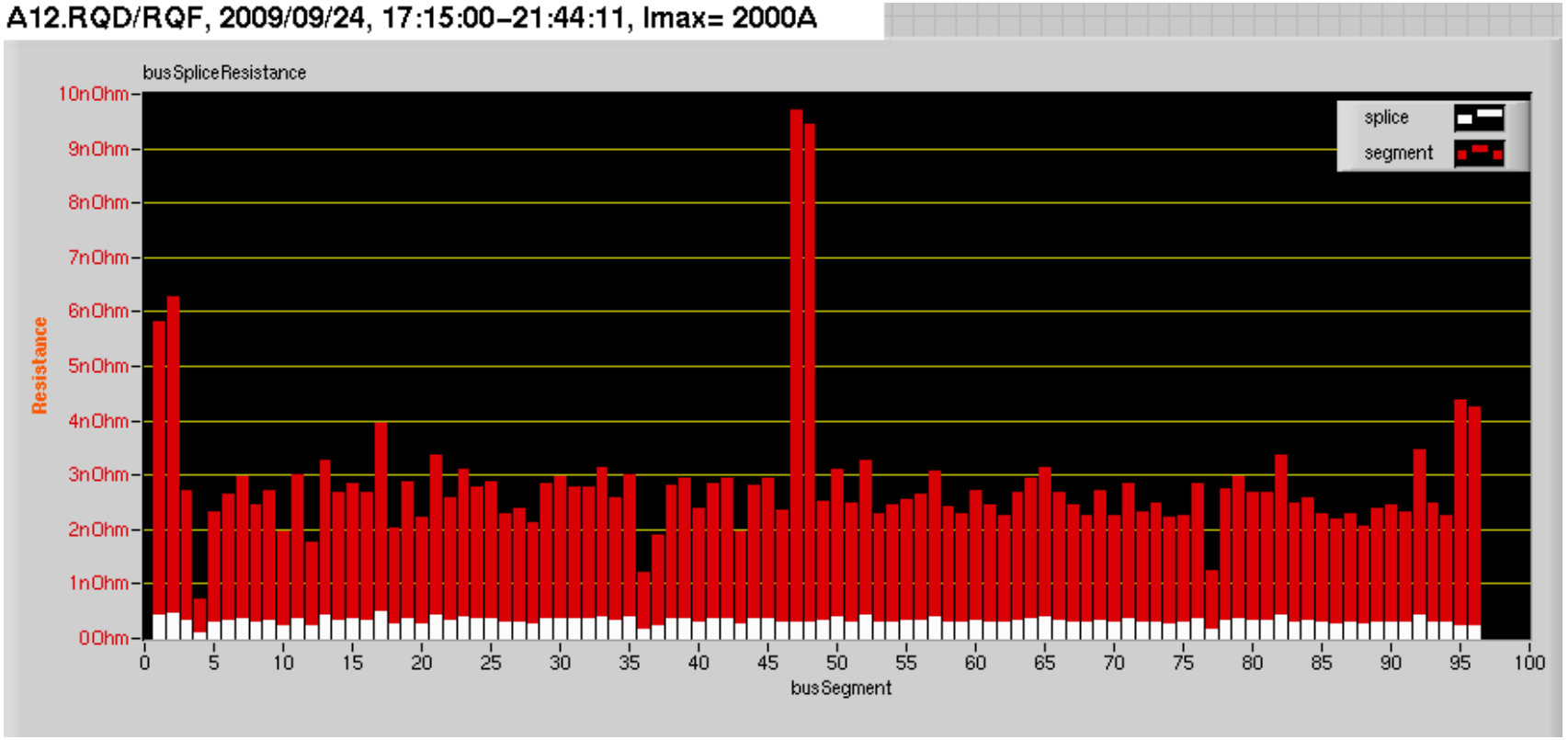
nQPS commissioning I > 2kA

- ➔ nQPS fully operational once successfully commissioned to 2 kA
  - Signal to noise ratio for splice measurements will improve with increasing current → better resolution
  - False trigger immunity of symmetric quench detection systems during activation of the energy extraction carefully to be checked (applies as well to existing QPS)
  - Installation of snubber capacitors for energy extraction systems required for I > 6000 A
    - Delivery to be completed in March 2010
    - Installation will require about 2 days per sector
  - First tests performed end 2009 in sector 1-2
    - Activation of energy extraction systems at 4 kA confirmed immunity of nQPS during fast power abort sequences

nQPS commissioning & hardware commissioning

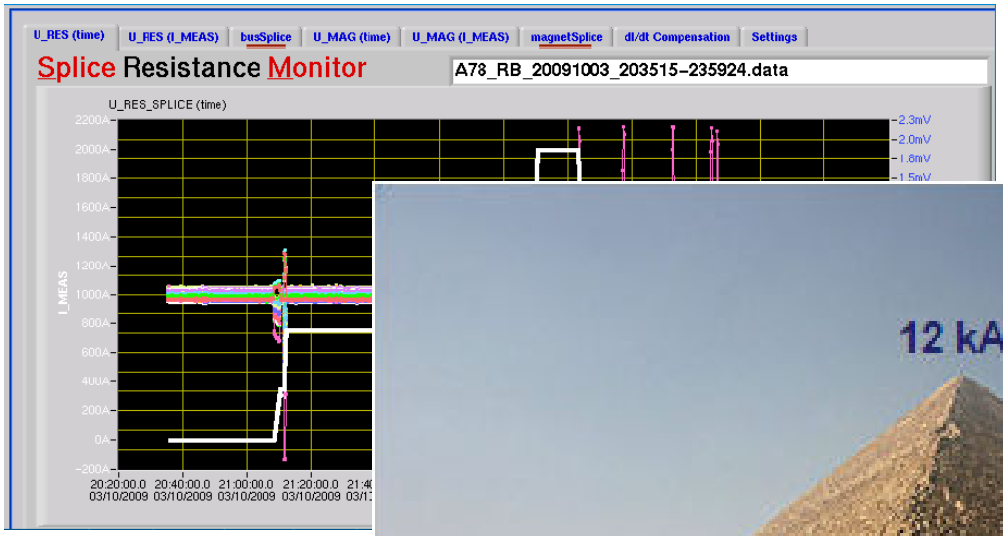


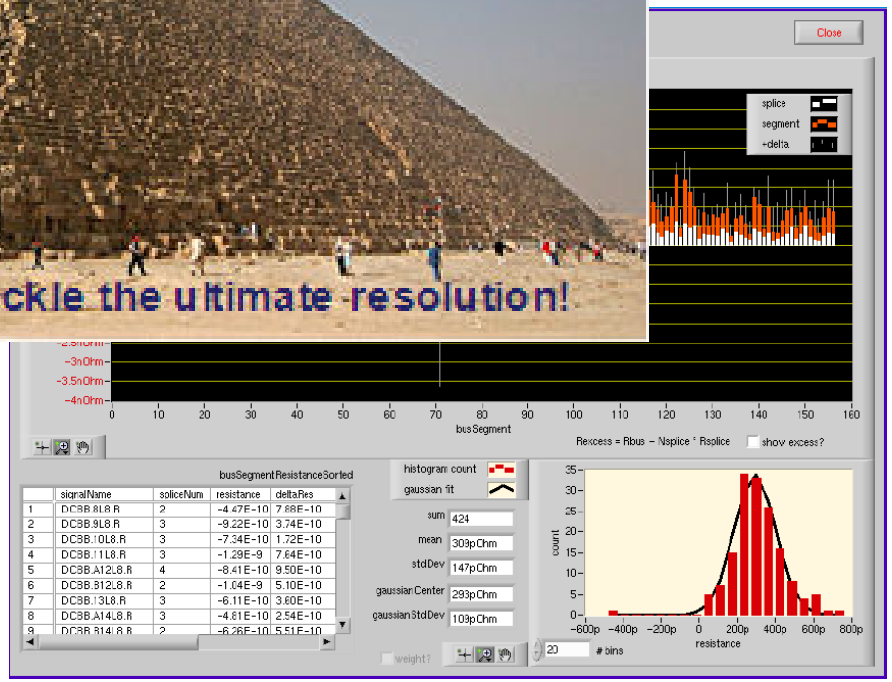
nQPS performance – splice mapping



- First splice mapping in LHC
  - First real test of splice protection system hardware, nQPS supervision, data transmission, storage and analysis
  - Sufficient resolution already at I = 2 kA to qualify splices (~ 400 pΩ)
  - High resolution as well due to remarkable precision of power converter

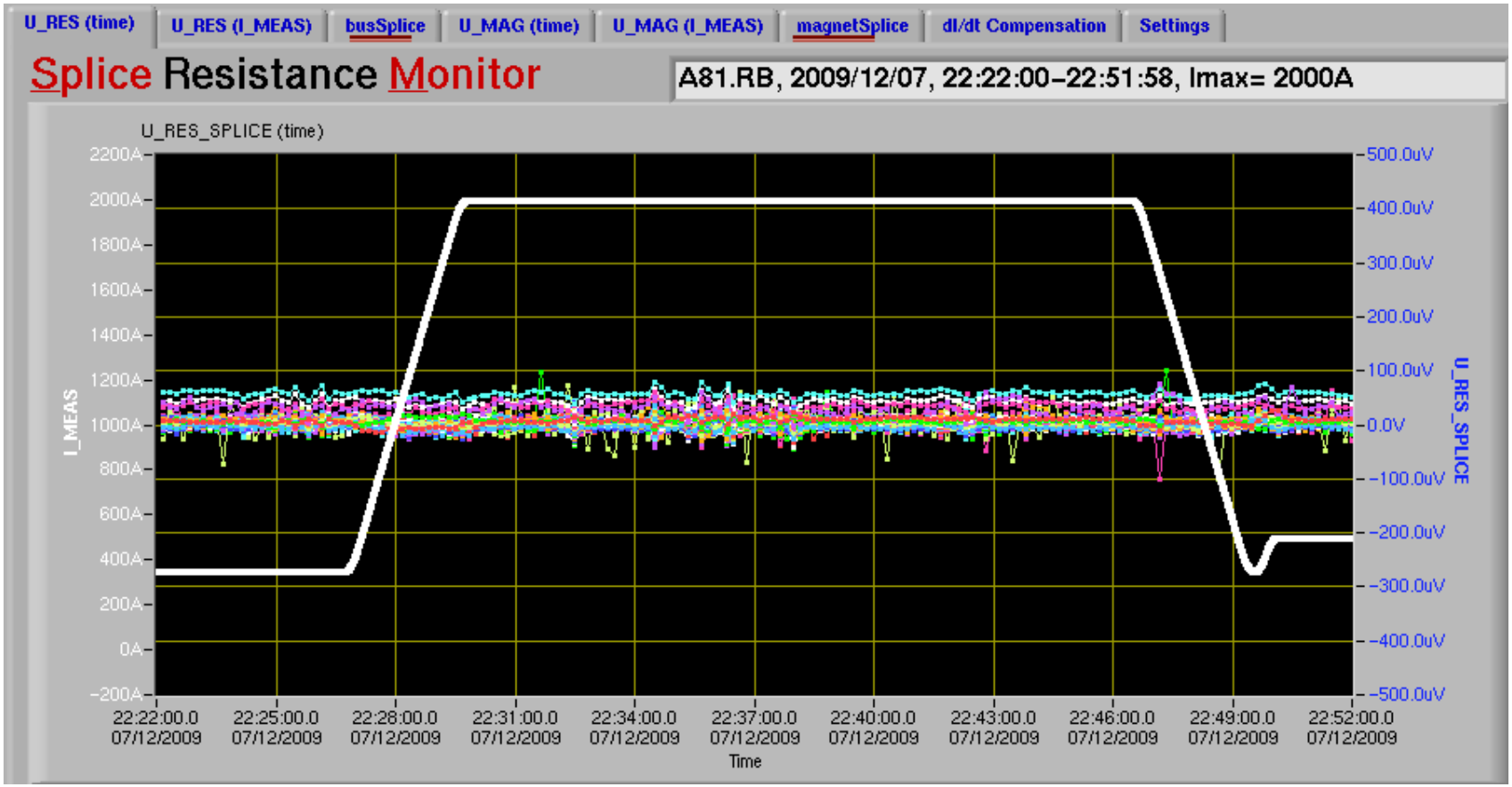
nQPS performance – splice mapping





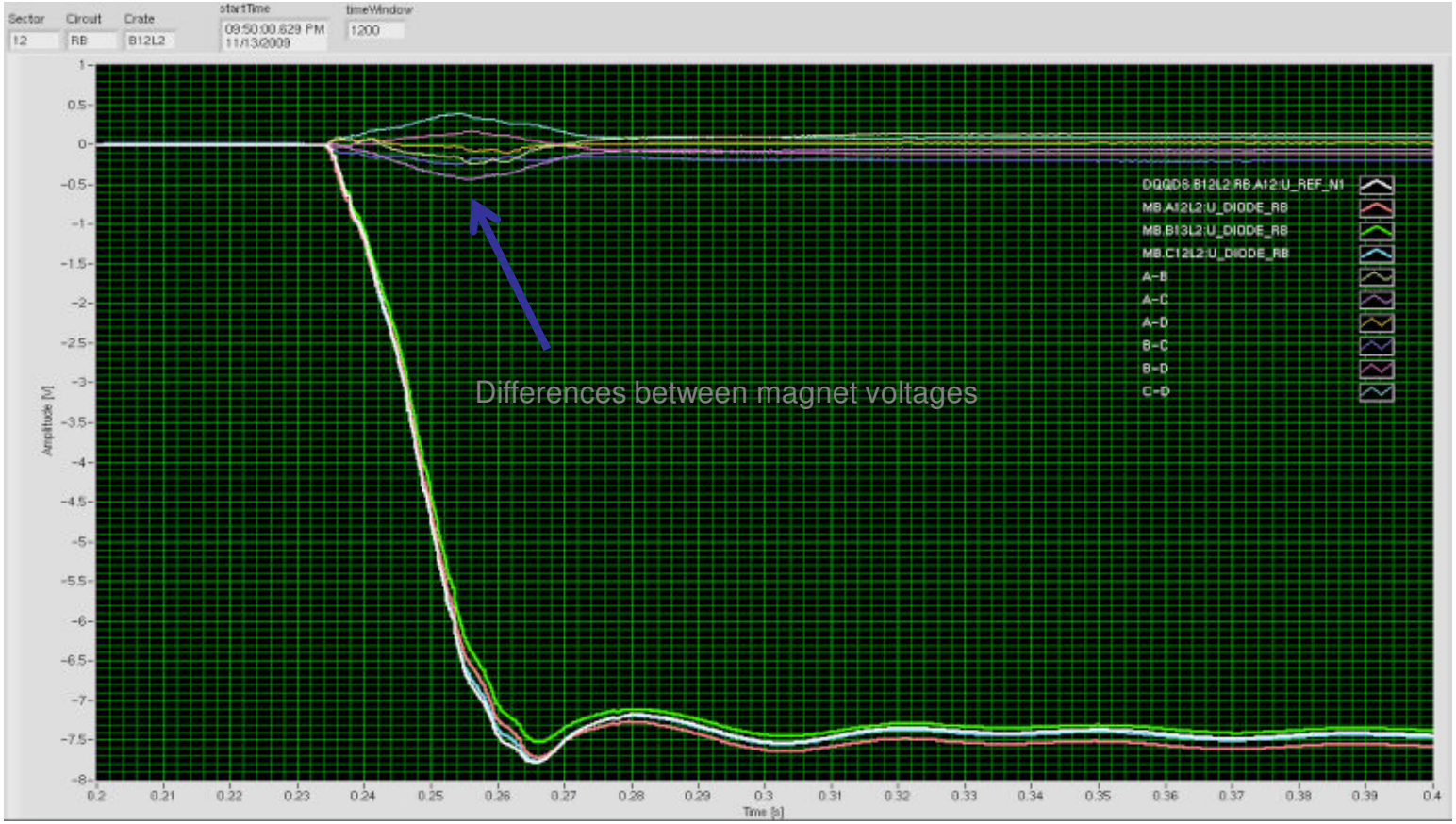
- Splice mappi
  example of a
  - 10 min p
    total (fully
- Measurement combined with internal splice mapping of magnets
  - Snapshot method using “old” QPS

nQPS performance – inductive compensation



- Resistive voltage during ramp and coasting after fine tuning of the inductive compensation values in sector 8-1
  - Procedure for determination of coefficients and download to device developed and successfully tested

nQPS performance – symmetric quench detection

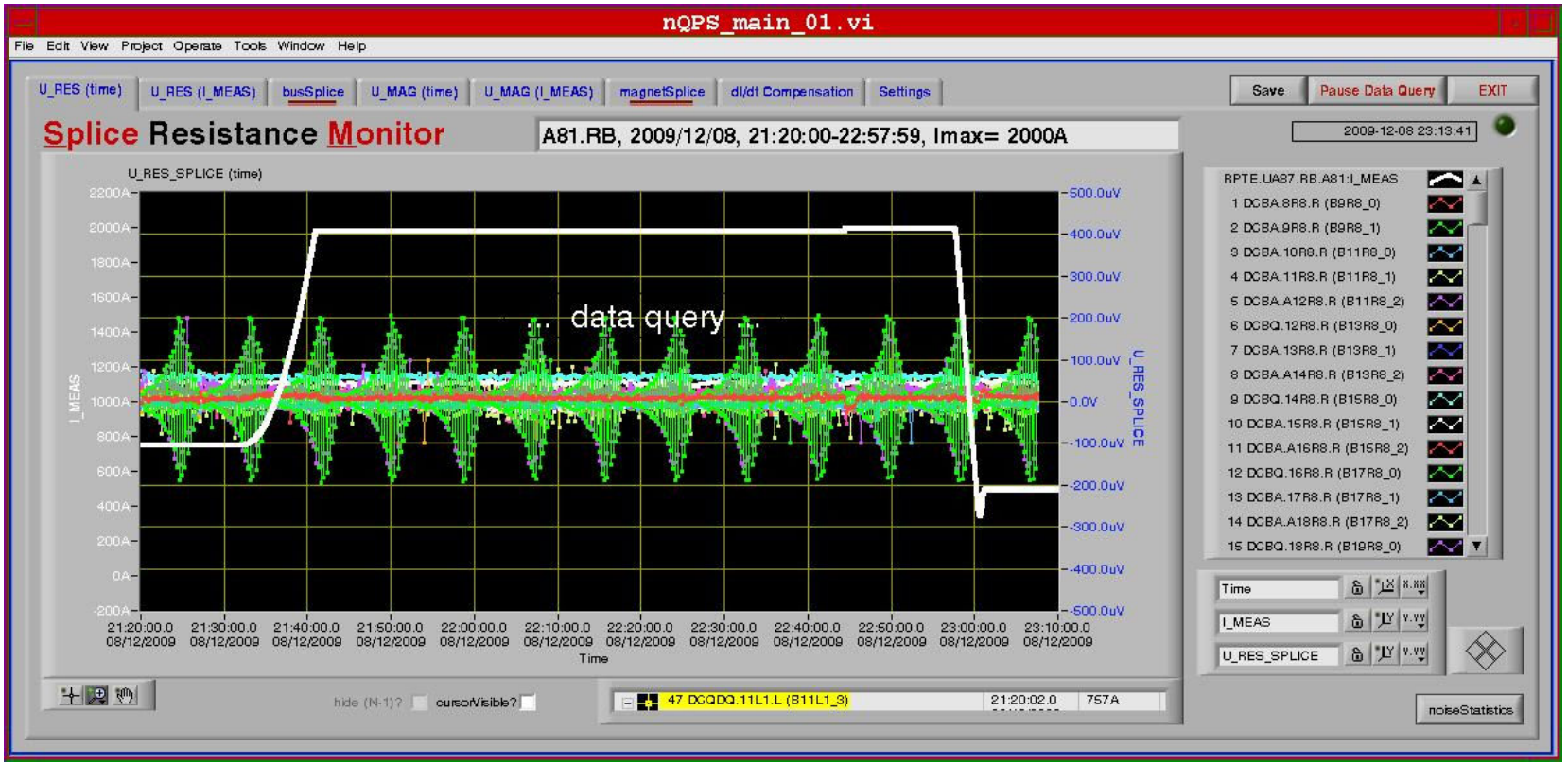


- Activation of energy extraction systems at I = 4 kA and data recorded by a symmetric quench detection board (dump of diagnostic buffer)
  - System would have triggered without adaptive filtering

nQPS performance – sector 1-2 experience

- Sector 1-2 has been the only sector during the 2009 run with nQPS being fully activated and interlocking
  - Good stability during LHC operation with beam
    - Apart from the transfer line magnets (→ next slide) no interference by other LHC equipment (BLM's, kickers …) so far observed
    - nQPS adds about 500 hardwired interlock channels per sector (total number will increase from 7700 to 11500)
  - System fully integrated into QPS supervision – substantial effort by the controls groups to handle the significantly increased data flow
    - Enhanced QPS control options (= more knobs) essential for commissioning
  - Dedicated tools for nQPS analysis successfully validated
    - Splice resistance monitor (Z. Charifoulline)
    - Specialist tools for device diagnostics and maintenance
  - Very valuable input for final commissioning of nQPS

nQPS performance – sector 1-2 experience



➔ nQPS during acceleration cycle

- Crosstalk from transfer lines giving problems to operate with U_{TH} = 300 μV threshold only for a limited number of systems
- Not an issue with U_{TH} = 500 μV, long term solution currently being assessed (source, transfer line settings, nQPS settings)

nQPS roadmap & outlook

- Final commissioning up to 3.5 TeV of nQPS in all LHC sectors to be completed in the very near future
  - Successfully started in sector 8-1, 1-2 and 2-3 in calendar week 4; other sectors in preparation
  - Firmware of symmetric quench detection systems updated taking into account the results from 2009
- Commissioning to 5 TeV
  - Installation of snubber capacitors for energy extraction systems
  - No major commissioning campaign required from 3.5 TeV and 5 TeV

nQPS roadmap & outlook

- Extension of nQPS to IPQ, IPD and IT to be prepared
  - Upgrades only for diagnostic purposes; circuits are fully protected by the present system (→ see talk by J. P. Tock)
  - Necessary additional signal cables already installed
- Radiation tolerance
  - Several test campaigns in 2009 (PSI and CNGS) confirming design approach
  - Potential problem related to radiation weakness of latest version of field-bus chip (MicroFip™ → see talk by J. Serrano)
    - Affects only supervision not protection
    - Temporary workaround for QPS boards available
    - Long term solution required for all QPS systems

Summary

- Commissioning of the enhanced QPS in 2009:
  - Complete mapping of the interconnection splices in the LHC main circuits for the first time – no bad surprises
  - Successful validation of nQPS design
  - Re-cabling campaign completed
    - Electrical tests by ELQA team completed for 3 sectors
- Enhanced QPS exploitation during the LHC run in 2009:
  - No showstoppers revealed so far
  - The main constraint with respect to the overall dependability (= reliability + availability + safety) of the QPS system is the large equipment number
- Full commissioning of the enhanced QPS up to 3.5 TeV after the re-cabling campaign to be completed soon
  - System will be ready to be commissioned to 5 TeV once snubber capacitors have been installed
  - No major commissioning campaign required from 3.5 TeV → 5 TeV

Thanks!