Quench Detection System

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on behalf of the QPS team

Outline

- Upgrade of the LHC quench detection system (QDS) during LS1
  - Yellow racks & R2E
- QDS system dependability during LHC operation in 2015
  - Overall system performance
  - Upgrades performed in 2015
  - Experience during the ion run
- Preparation for 2016 operation
  - Firmware upgrade for nQPS DAQ systems
  - Deployment of radiation tolerant QDS for 600 A circuits
    - Includes RU.L4 and RU.R4
- Expected system performance in 2016

QDS upgrade during LS1

- QPS system dependability
  - Overhaul of MB protection systems (“Yellow racks”)
  - Revision of safety critical firmware
  - Automatic system configuration and verification
  - R2E framework:
    - Relocation of equipment (Inner Triplet protection)
    - Deployment of radiation tolerant electronics (IPQ, IPD)
- Enhancement of supervision & diagnostic capabilities
  - Enhanced quench heater circuit supervision
  - Earth voltage feelers
  - QPS fieldbus upgrade
  - CSCM for all sectors (objective added in 2014)

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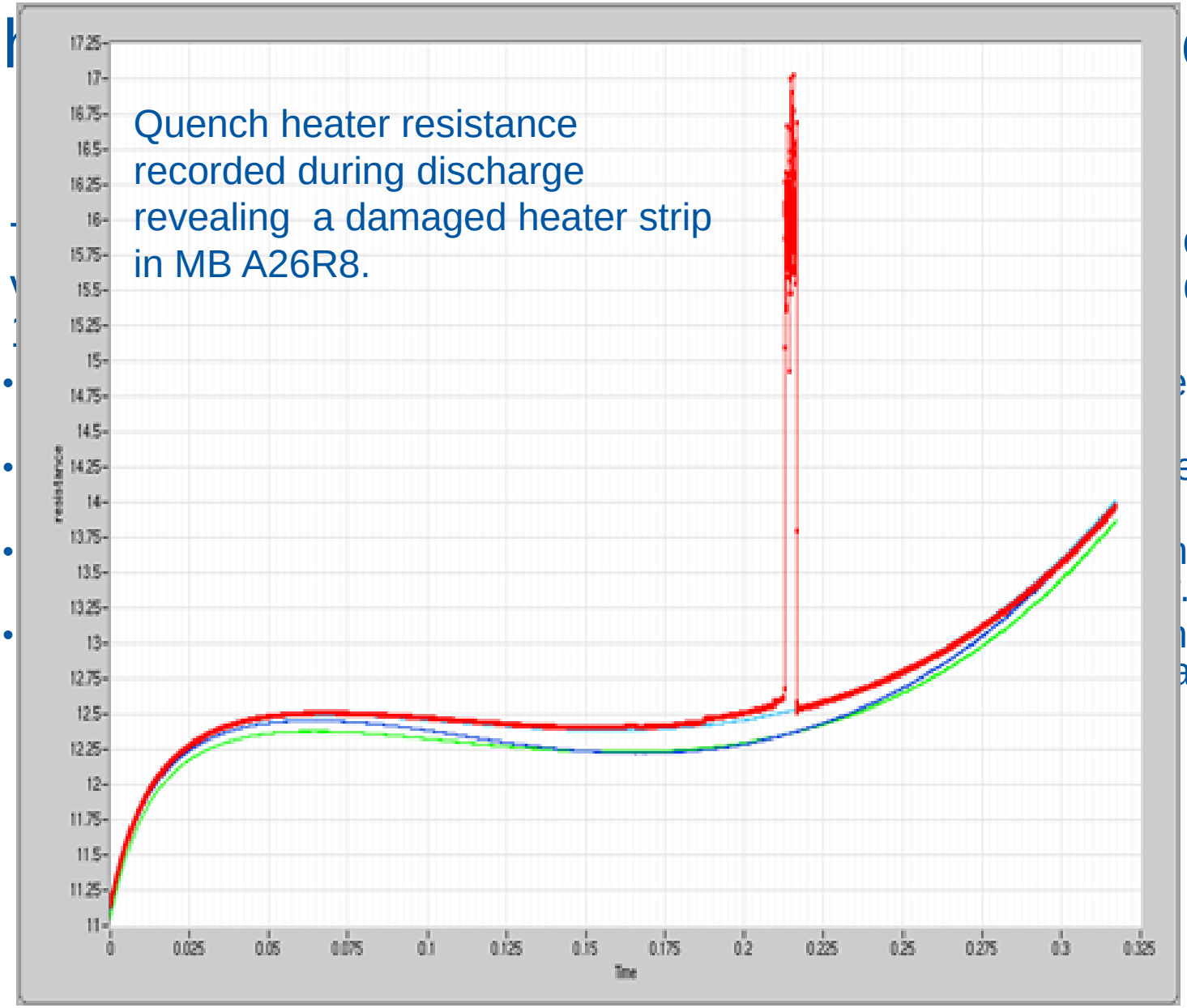
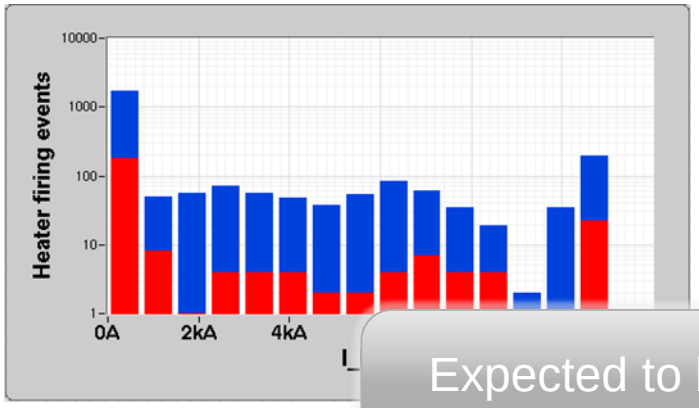


About quench heater circuit usage ...
Statistics for LHC main dipoles, 2014-2015

- Data provided by Zinur Charifoulline

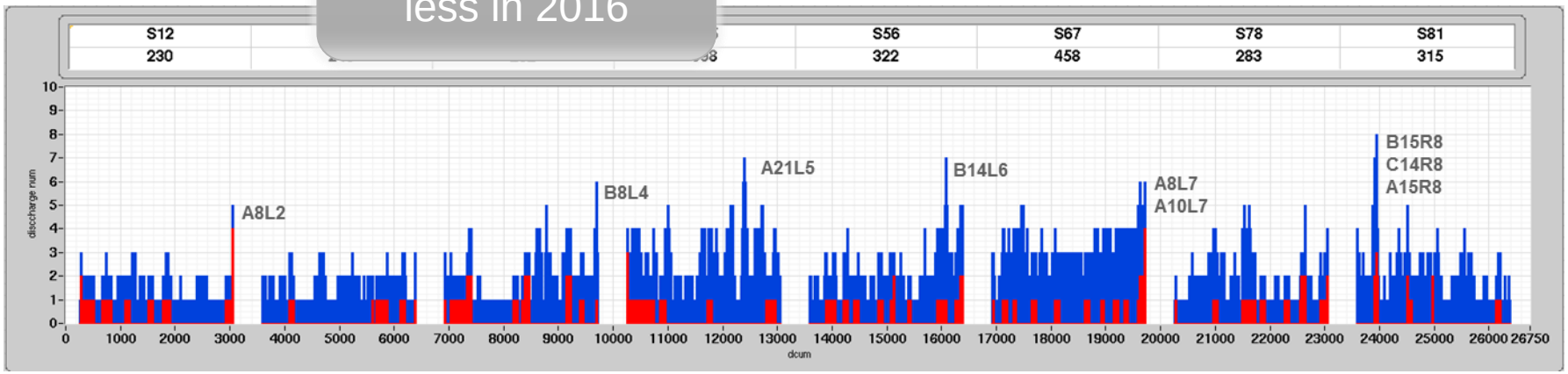


No firing campaign scheduled for 2016

Since October 20
- ✓ 2533 full charge
- ✓ about 1660 firings at zero current

Since April 2015 (1st beam in the machine):
- ✓ 247 full charge firings in total
- ✓ about 175 firings at zero current

Expected to be less in 2016



Improved availability & maintainability

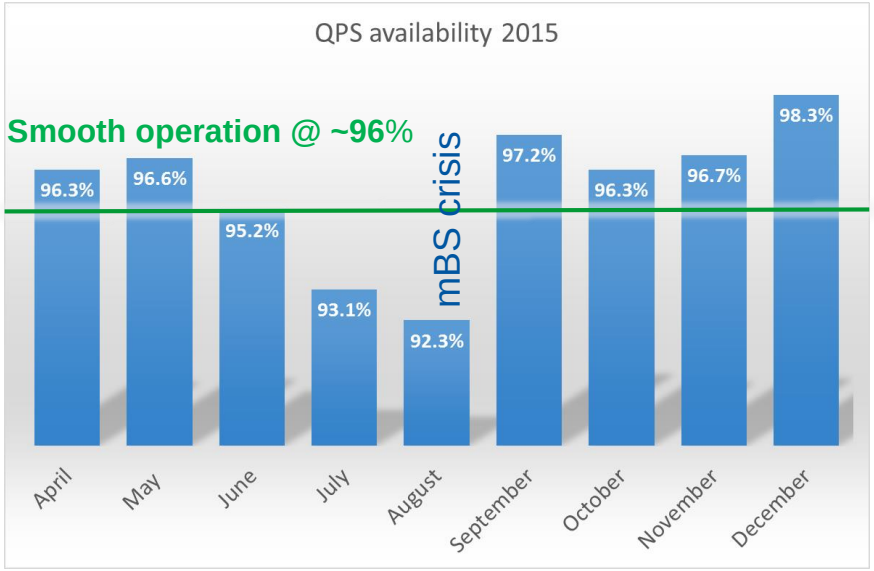
- Remote control options
  - Remote power cycle of detection crates
- MPE stand-by service statistics for QDS+DAQ interventions
  - In 2015 14% of all interventions were requiring access to the LHC compared to 41% in 2012!
  - 11 interventions requiring access in 2012, fully transparent in 2015
- Update of QPS supervision
  - FESA2 → FESA3
  - Configuration management
  - QPS field-bus upgrade →higher data transmission rates
  - Revision of LOGGING data retrieval
    - Analog data recorded without dead-bands
  - Installation of earth voltage feelers for the main circuits

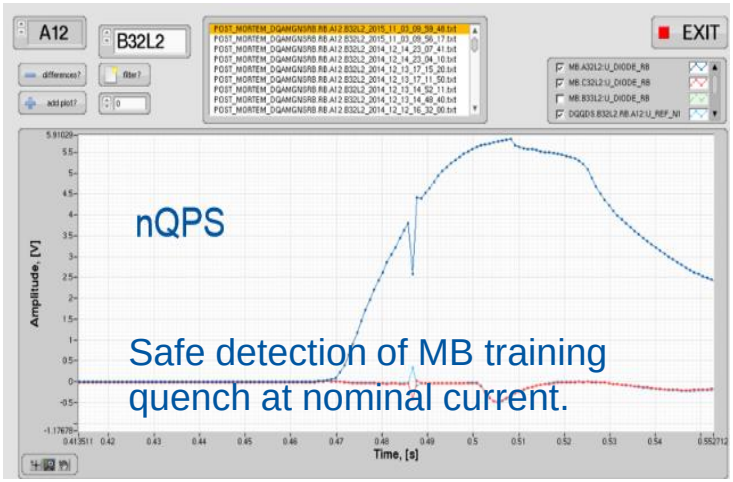
System immunity to ionizing radiation (R2E)

- ☑ Relocation of QPS equipment previously installed in UJ14, UJ16, UJ56
  - Inner triplet protection
- ☑ Deployment of radiation tolerant electronics for quench detection systems for IPQ and IPD protection
- ☑ Ghosts from the past ...
- Deployment of radiation tolerant electronics for quench detection systems for 600 A protection
  - Upgrade started - to be completed during YETS

QDS system dependability in 2015

- Challenging year after major system upgrades during LS1
  - Significant (not foreseen) effort to overcome post LS1 teething problems affecting overall system availability (96.79%)





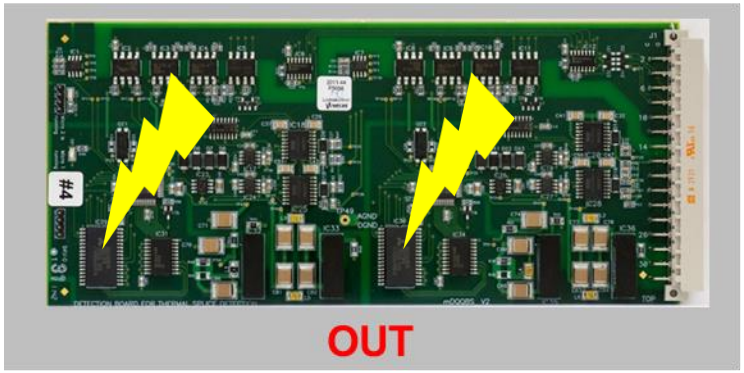
- Very (=100%) reliable operation and effective protection of superconducting circuits
  - Detection of 40 main dipole quenches during proton run 2015

Note: $A_{QPS} = (T_{OPERATION} - T_{FAULT(AFT)})/T_{OPERATION}$

DQQBS back-grade during TS#2

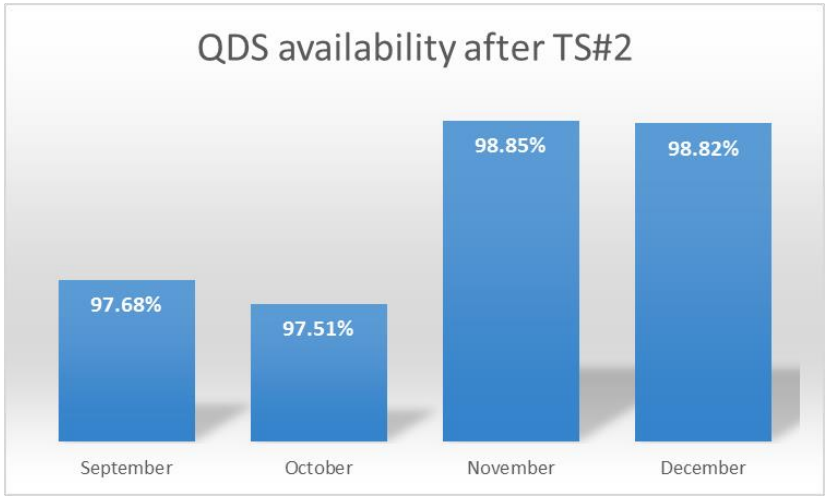
- Necessary due to problems with the radiation tolerance of the hybrid circuit boards installed for the CSCM test in 2014
  - Exchange of 1248 QPS circuits boards (6.1 % of total installed quantity)
  - Test of 2496 hardwired interlocks (18.5 % of all QPS interlocks)
  - Verification of 4992 analog signals
  - Successfully completed within one week
  - Very challenging, demanding and hopefully exceptional exercise

Many thanks for all the essential support provided by internal and external teams!



QDS system dependability after TS#2

- Significant improvement of system availability



No faults in main magnet protection units!

	QTY	SEP	OCT	NOV	DEC	TOTAL
QDS600	114	1	3	0	0	4
QDSIPQDT	76	0	1	1	0	2
nQPS	436	11	4	4	2	21
QDSRB	**1232**	**0**	**0**	**0**	**0**	**0**
QDSRQ	**392**	**0**	**0**	**0**	**0**	**0**
QDSRBQ	16	0	0	0	1	1
Σ	**2250**	12	8	5	3	**28**
DUMPS		1	3	1	1	**5 (3 x SEU)**

QDS main failure modes

- R2E related problems

Example for a hardware fault:

1. Broken multilayer ceramic chip capacitor causes faulty input signal on a symmetric quench detection board type DQQDS.
2. Detection algorithm triggers correctly causing heater firing and beam dump.
3. Faulty board is replaced by standby service.
4. Allocated fault time is 7.2 h + penalties for pre-cycle ...
5. There are 58 capacitors of the incriminated type (same value and rating) on each of the 1632 DQQDS boards currently installed in LHC.
6. 1 out of 94656 caps failing in 2015 → $\lambda_{2015} = 1.2 \times 10^{-9}\ h^{-1}$

- Data acquisition & transmission
  - Stalled bus recovery etc. → further mitigation & consolidation currently ongoing (YETS 15/16)

QDS preparation for 2016 operation

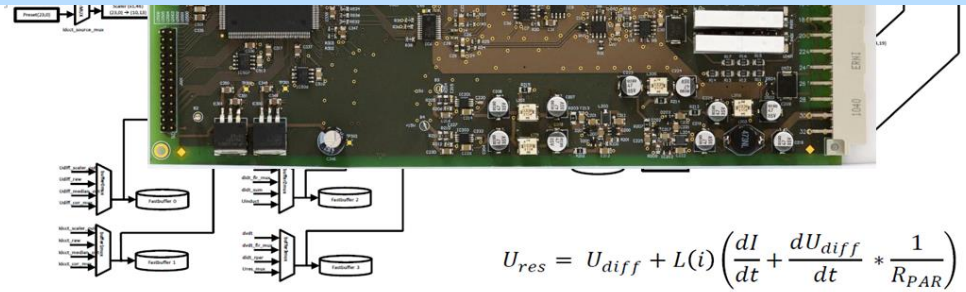
- Firmware upgrade for nQPS DAQ systems
  - Sampling [illegible] creased to 10 Hz
  - Better de[illegible] mmunication faults; transparent error handling

Completed last week!

- Deployment of radiation tolerant QDS for 600 A circuits
  - Mandatory for radiation exposed areas in point 1, 5 and 7

nDQQDG Signal pipeline v7 (r140)

New detection systems are no longer requiring re-calibration cycles (resets) → we will try hard to upgrade as well RU.L4 and RU.R4 ...



$$U_{res} = U_{diff} + L(i)\left(\frac{dI}{dt} + \frac{dU_{diff}}{dt} * \frac{1}{R_{PAR}}\right)$$

J. Steckert

QDS performance in 2016 – an estimate

- Considering a successfully implementation of the ongoing upgrades:
  - The same level of availability as in 2015 after TS#2 (~98%) should be feasible despite the increasing radiation load
    - The required overall (QDS + HDS + EE) availability for smooth LHC operation is: $A_{QPS} \geq 96\%$
  - The system maintainability is expected to improve, mainly to the better handling of certain error types
- The complexity of the system remains a challenge
  - Almost 14000 possibilities to stop LHC at any time ...