QPS - analysis of main problems, areas to target, possible improvements

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Outline

- Introduction
- Basic fault statistics
- Teething problems & EMC related problems
- Tune feedback compatibility
- Quench heater power supplies
- Circuit breakers
- Radiation induced faults
- Interventions
- Summary

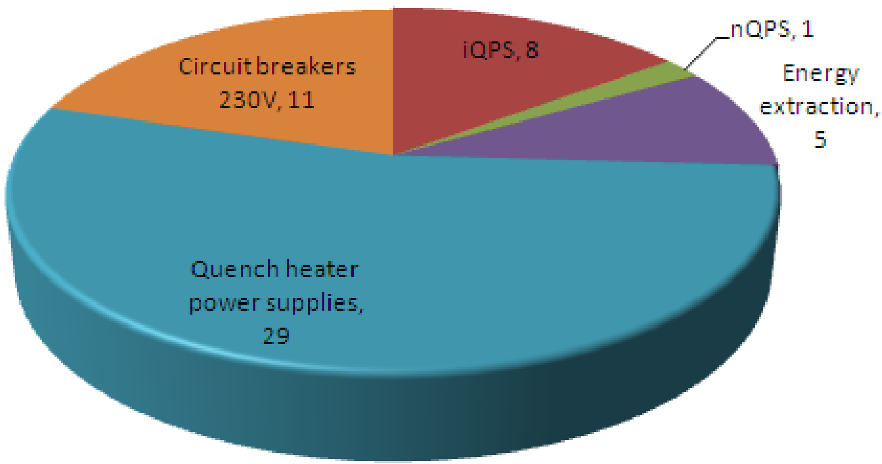
Circuit type	Quantity
Main bends and quads	24
Inner triplets	8
Insertion region magnets	94
Corrector circuits 600 A	418
Total	544

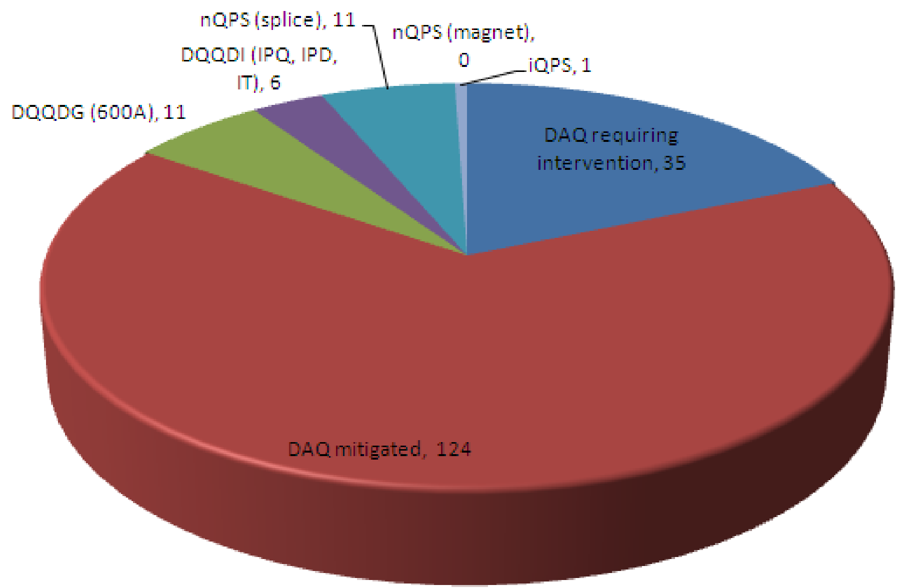
The size of the system is the principal problem as it asks for very low failure rates not always easily to achieve. Due to the same reason mitigation and consolidation measures are normally not straightforward to implement.

Quench detection systems	7568
Quench heater discharge power supplies	6076
Energy extraction systems 13 kA	32
Energy extraction systems 600 A	202
Data acquisition systems	2532
System interlocks (hardwired)	**13722**

QPS – basic fault statistics

QPS and QPS related hardware faults causing interventions (54 outside TS).





QPS radiation induced faults (190).

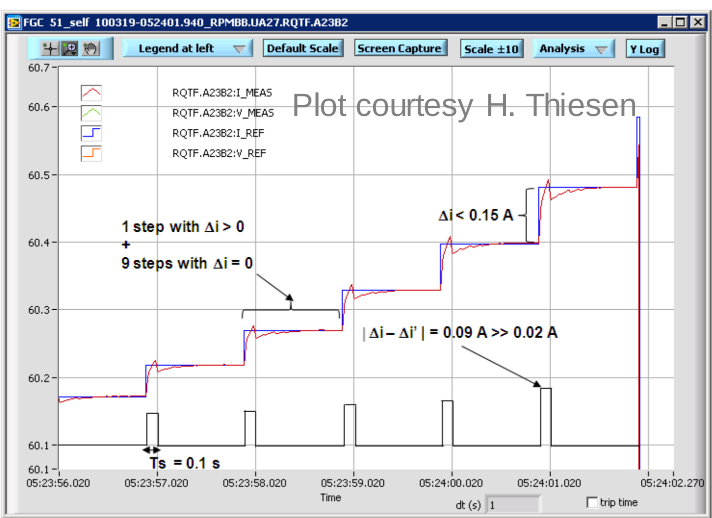
Teething problems & EMC related faults

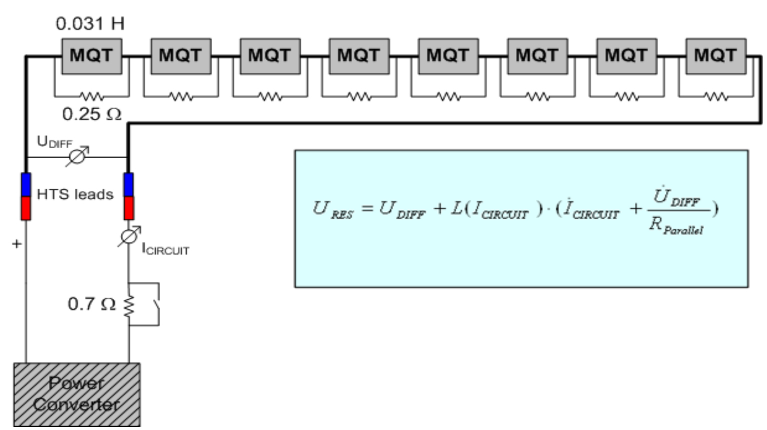
- → Communication problems, local bus instabilities, bad connections, noisy boards, corrupted data … → almost completely resolved
  - Tedious process basically in 2009 and 2010
  - Exercise partially to be repeated after LS1
- → Frequent trips of protection systems for insertion region magnets during thunderstorms and general perturbations of the electrical network
  - Concerns basically Q9 and Q10 and usually does not dump the beam (anyhow gone) but fires quench heaters
  - Problem is related to the warm instrumentation cable length and routing
    - To be modified and protection systems upgraded within LS1
  - As a temporary resolution it is proposed to raise the voltage detection threshold for these circuits
    - $U_{TH} = \pm 400$ mV safe up to 4 kA → ECR issued for implementation during Xmas break

Tune feedback compatibility

- ➔ The tune feedback applies only small changes in current but creates a voltage signal, which QPS cannot distinguish from a real quench
- ➔ As first mitigation measure the discrimination time of the detection systems has been increased to t_{EVAL} = 190 ms
- ➔ In 2011 there were still a significant number of trips e.g. during squeeze
  - – re-evaluation of detection settings has been launched (➔ A. Verweij)
- ➔ D
  - – ±2V, t_{EVAL} = 190 ms, |I| < 100 A
  - – ±100 mV, t_{EVAL} = 190 ms, 100 A ≤ |I| ≤ 200 A, $|I_{MAX}|$ ≤ 200 A

If the tune feedback is applied with |I| > 100 A (e.g. after LS1) further mitigation and consolidation measures will become necessary.





Quench heater discharge power supplies

- The principal cause of failure of the quench heater discharge power supplies is related to a malfunction of the mains switch.
- The fault is caused by the mechanical breakdown of one of the plastic materials used for the construction of the switch, most likely due to an excess of hardener in its composition
- Repa ... replace all 60 ... ing 2012.
  - In ... B quench h ... loss of o ... AQ sy
- Still 2
  - 2 ... ormal w

Period	Qty.	Total
Xmas break 2010/2011	916	916
2011 TS #1	268	1184
2011 TS #2	316	1500
2011 TS #3	396	1896
2011 TS #4	392	2288
2011 TS #5	412	2700
Xmas break 2011/2012 (planned)	3376	6076

- Many thanks to BE-OP for their continuous support during the repair campaign!!!

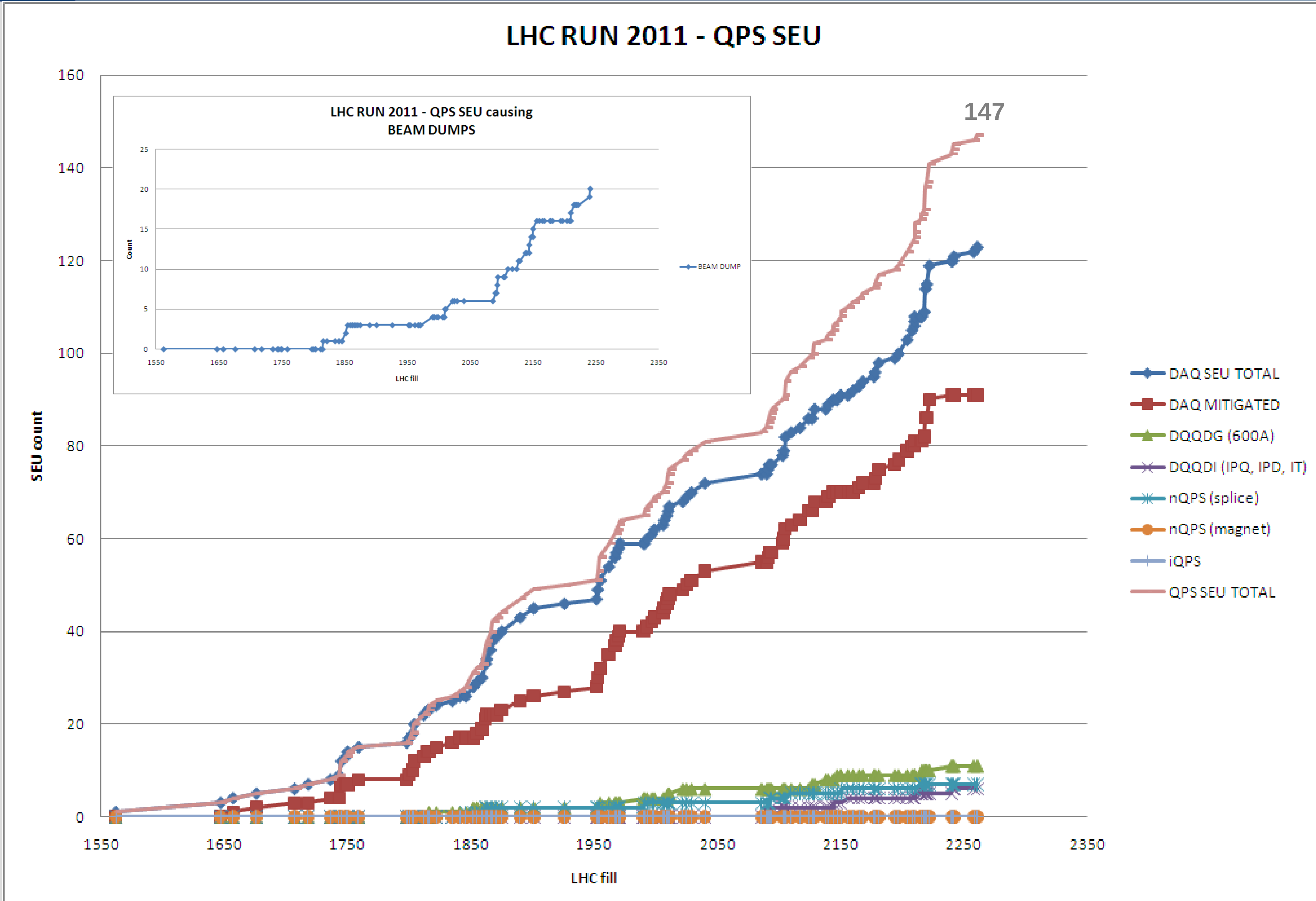
Circuit breakers

- ➔ Spurious opening of F3 circuit breakers without obvious reason
  - F3 and F4 circuit breakers are used to protect the distribution lines powering the QPS racks installed in the LHC tunnel
  - Any spurious trip causes a fast power abort of the concerned sector and requires an access for re-arming
    - F4 circuit breakers do not show this kind of problem but are a different make and have a higher rating
  - **12** trips in 2011 causing **4** dumps out of stable beam conditions
- ➔ Fault is frequent enough to cause trouble and ask for remedy but too rare to be traced down easily or to be reproduced in the lab
  - Measurements and fault analysis done in close collaboration with EN-EL
- ➔ In order to come to a conclusion prior to LS1 a proposal has been made to swap the F3/F4 circuit breakers on concerned QPS racks
  - One sector swapped during TS#5, more to come during Xmas break 2011/2012
  - In the best case the problem will disappear; in case the F3 breakers continue to trip these devices must be replaced during LS1

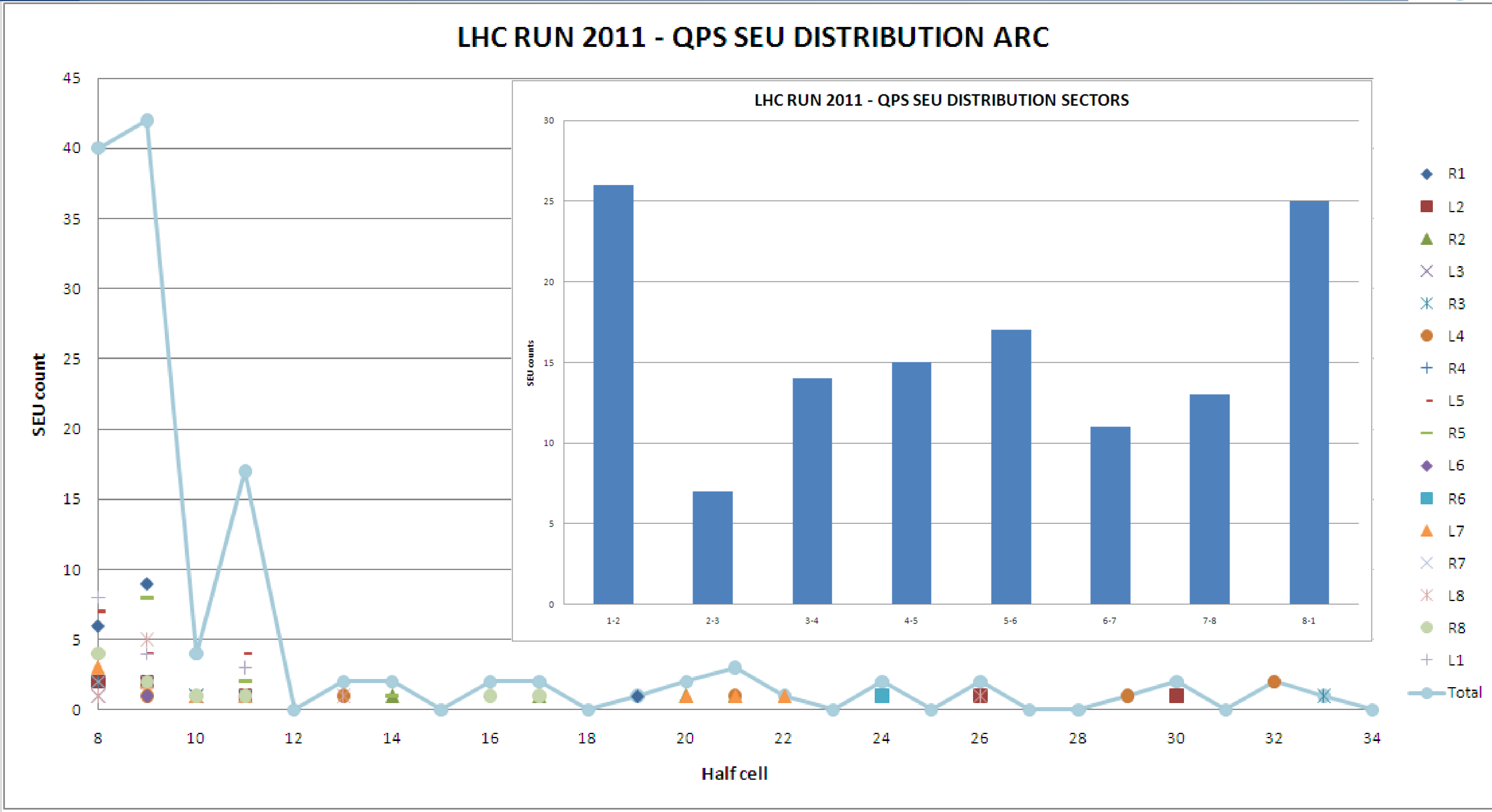
Radiation induced faults

- ➔ Due to functional requirements a significant amount of QPS and EE equipment is exposed to radiation during LHC operation
  - LHC tunnel
    - Main magnet protection, nQPS, some 13kA EE systems (e.g. point 3)
  - Partly shielded areas (RR13, 17, 53, 57, 73, 77, UJ14, 16, 56)
    - IPQ, IPD, IT, 600 A protection, EE 600 A, EE 13 kA
- ➔ Fault analysis has to be done very carefully as not all problems are related to radiation
  - Equipment faults, EMC, bad connections, circuit breakers, real triggers (very rare but not excluded)
- ➔ Radiation induced faults are responsible for most of the QPS triggers in stable beam conditions
  - Consolidation measures prior to LS1 necessary
- ➔ **Confirmed** radiation induced faults are transmitted regularly to the R2E project to be included in their statistics

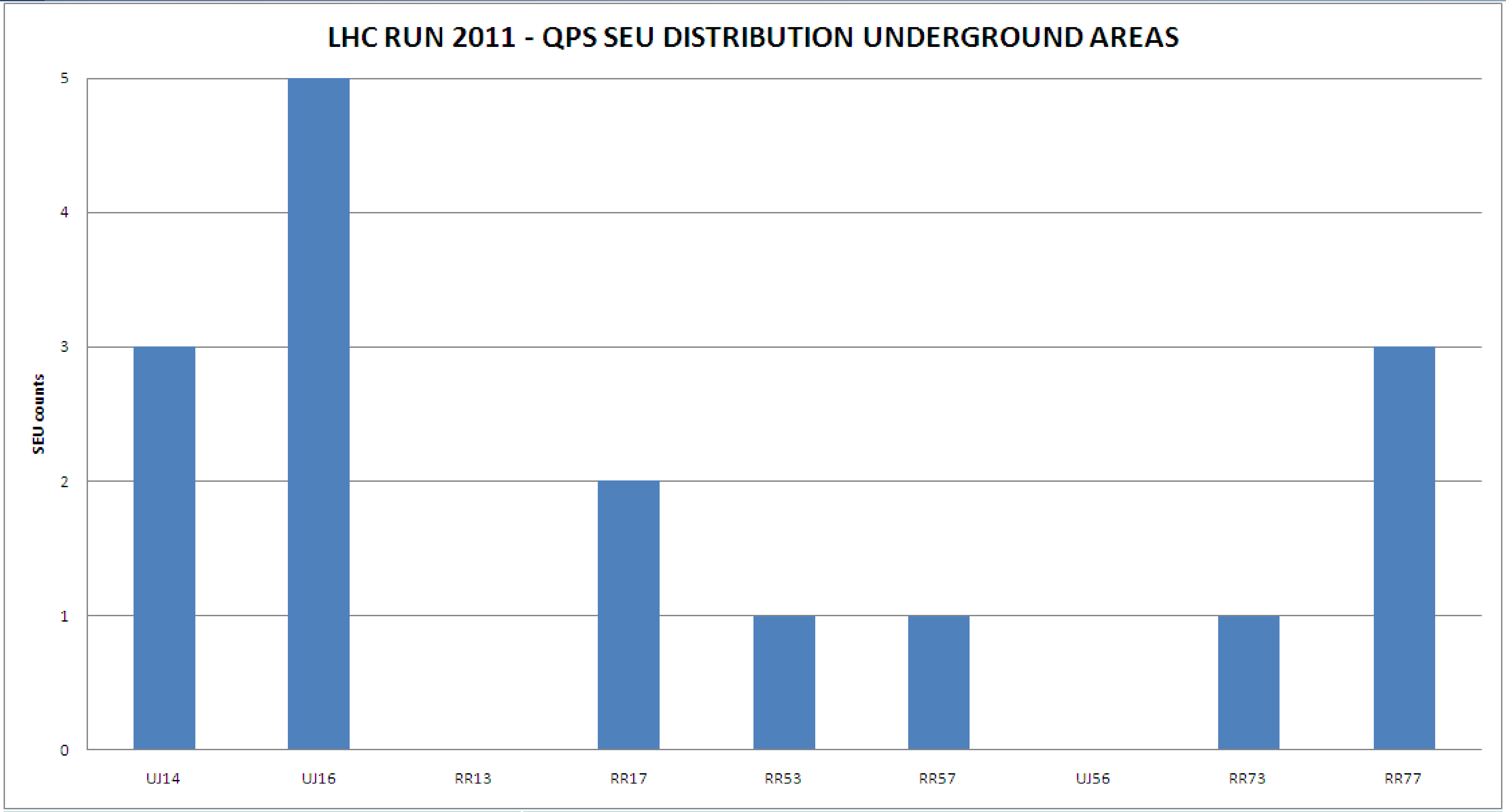
Radiation induced fault statistics 2011 - proton run



Radiation induced fault statistics 2011 - distribution

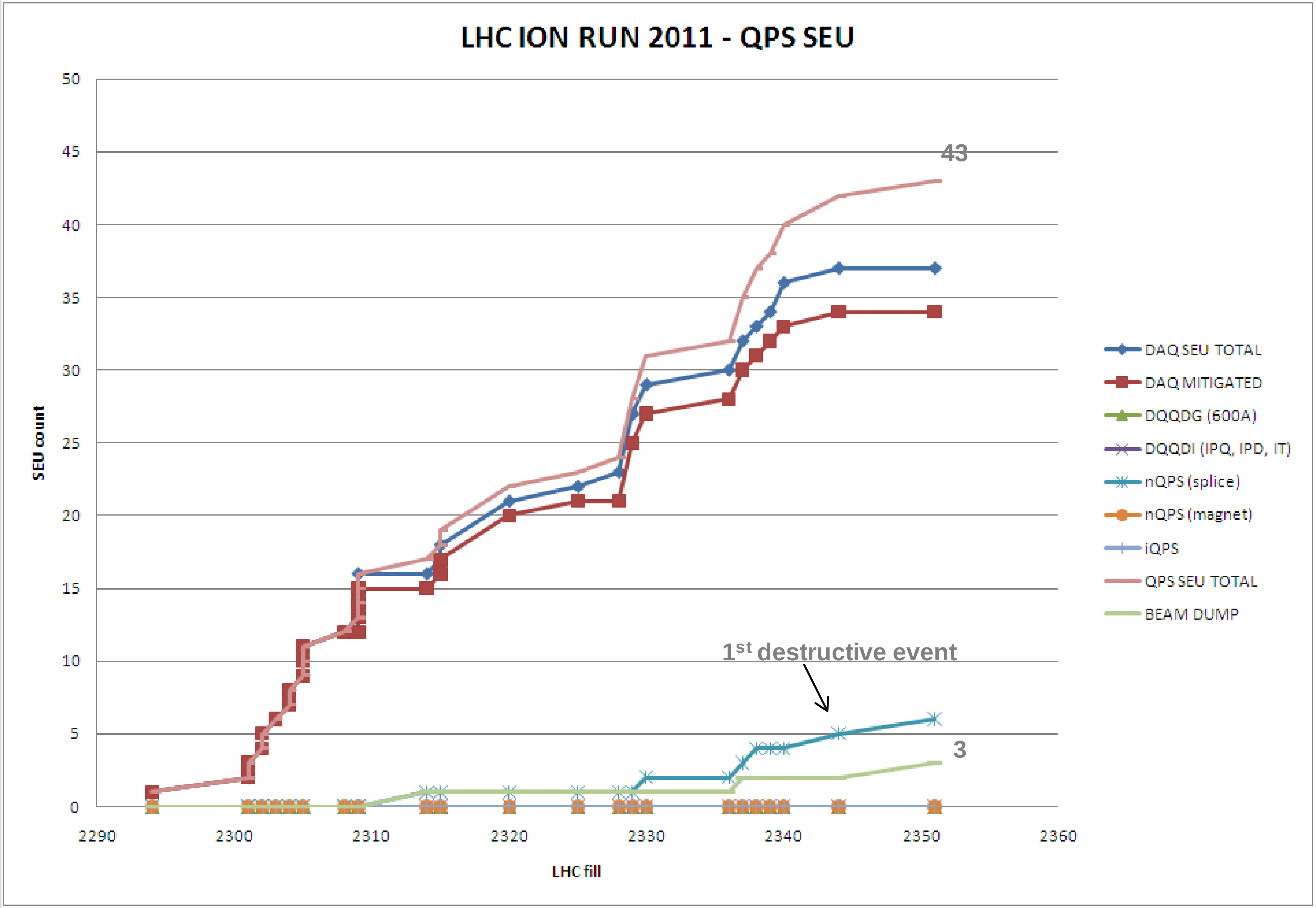


Radiation induced fault statistics 2011 – spurious triggers



System	Locations
DQQDI (IPQ, IPD, IT)	UJ14, UJ16 (2x) , RR17, RR53, RR57
DQQDG (600 A)	UJ14 (2x), UJ16 (3x), RR17, RR73, RR77 (3x)
nQPS (splice protection)	B8L1, B11L5, B11R5, B9L8

Radiation induced fault statistics 2011 – ion run



Radiation induced fault statistics 2011 – spurious triggers

Detection system type	Exposed systems	Radiation induced spurious triggers
DQQDL (MB & MQ protection, analog, radiation tolerant)	4032	0
DQQDS (MB & MQ protection, digital, radiation tolerant)	1632	0 (1 caused by host controller during ion run)
DQQDG (600 A, digital, partly hardened)	250 out of 836	10
DQQDI,T (IPQ, IPD, IT, digital, partly hardened)	138 out of 408	6
DQQBS (nQPS splice protection, partly hardened)	2068	6 (2 during ion run)
DQQDC (HTS lead protection, partly hardened)	508 out of 1198	0

– DQQDG and DQQDI,T are hardware equivalent and differ only in firmware

– DQQBS and DQQDC are hardware equivalent and differ only in firmware

– DQQBS and DQQDC have on board redundancy A/B (two interlock channels)

Mitigation and consolidation measures – DAQ systems

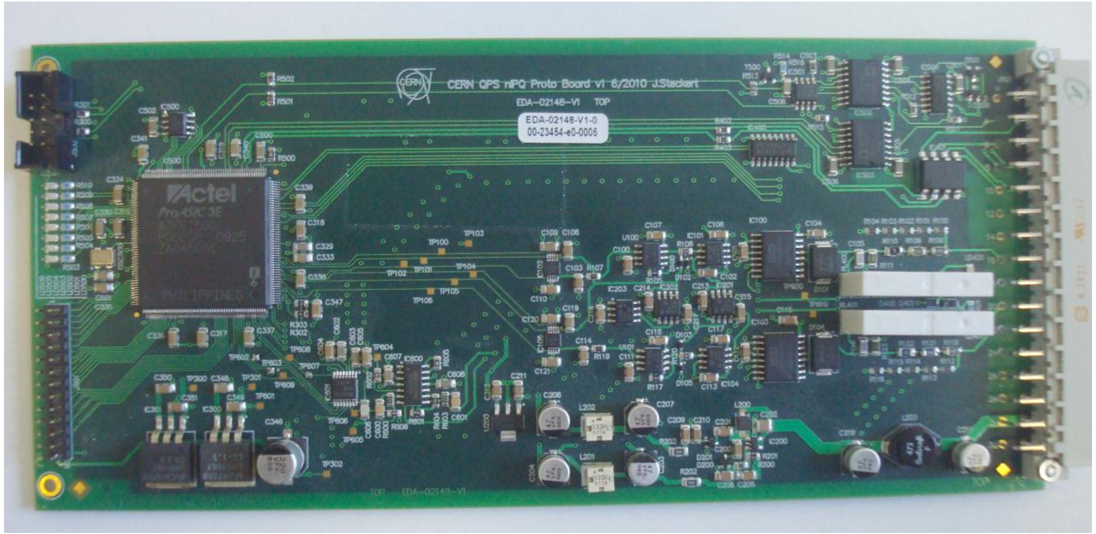
- Firmware upgrade for DQAMCMB and DQAMCMQ as first mitigation measure
  - Deployment completed during TS#5 (1624 units)
  - Upgrade includes 3 out of 4 condition for MB quench heater power supply availability (no injection inhibit in case of loss of 1 power supply)
- Full consolidation requires hardware upgrade (new board)
  - Incriminated chip is located on quench detection board type DQQDL
    - Replacement already successfully exploited with DQQDS board
  - Design completed, prototype testing phase started
  - Production covering DS areas 02/2012, procurement of components started
- Replacement of the fieldbus coupler chip (MicroFip™) by NanoFip^{CERN}
  - Significant development and integration work to be done
  - First fieldbus segments to be upgraded during LS1
  - Auto power-cycle option for MicroFip™ currently being evaluated as intermediate solution

- Firmware upgrade
  - Triplication of digital filters and other modifications
  - Expected to cure a significant amount but not all faults
  - Development completed - type tests to be completed
  - Partial deployment during Xmas break (half cells 8 to 11 around IP1, 2, 5, and 8)
- Hardware upgrade
  - Technology evaluated – two possible options
    - FPGA based version using high resolution ADC
      - Additional radiation test campaign for ADC wishful
    - Standard technology with optimised firmware and modified evaluation logic
      - Using three instead of two redundant processors and majority voting
      - This option could be implemented on a relatively short timescale but requires a more detailed study
  - Design in 2012 → installation in hot zones during LS1

Mitigation and consolidation measures – IPQ, IPD and IT protection

➔ New digital quench detection systems type nDQQDI

- Similar to symmetric quench detection board developed for nQPS
  - Core is flash based FPGA ProAsic™ A3PE1500
- Board design and firmware development by J. Steckert
- New board is (of course) not fully compatible with previous version
  - Some specialist work required to integrate it into QPS supervision
- 200 boards including spares required for consolidation (starting 2012)
  - UJ14,16,56, RR13,17,53,57



Prototypes are currently under test and the series production will be launched early 2012.

Mitigation and consolidation measures – 600 A protection

- ➔ New digital quench detection systems type nDQQDG
  - Similar to nDQQDI board developed for nQPS
    - Core is flash based FPGA ProAsic™ A3PE3000
  - High dynamic range of the current reading requires a high resolution ADC or a complex digital to analog feedback circuit
    - Fast high resolution 24 bit ∑Δ ADC TI ADS1271
    - Modulator part successfully radiation tested by TE-EPC
  - Firmware is by far more complex than for nDQQDI
    - Complex digital filter system including non-linear filters
    - Numerical derivative of current, look-up tables for circuit inductance
    - Algorithms well known but transfer to FPGA not trivial
  - 300 boards including spares required for consolidation (starting mid 2012)
    - UJ14,16,56, RR13,17,53,57,73,77
    - 1st prototype to be delivered before the end of the year

Interventions – MPE stand-by service

- During the LHC exploitation a round-the-clock support to operation in case of ... ment sp ... -by se...
- Int ... to rec ... 20...

Energy extraction, 5

te / Night, 69

Summary

- During the LHC exploitation in 2010 and 2011 the protection system for superconducting circuits of the LHC demonstrated its reliability and capability to ensure the integrity of the protected superconducting elements.
- While most of the radiation induced faults are transparent to LHC operation, the number of beam dumps caused by spurious triggers is close to reach the maximum admissible limit.
  - Some consolidation measures to be applied already during Xmas break 2011/2012
  - The proposed measures will not lead to zero radiation induced trips but allow to limit the number of faults despite increasing luminosity
- The maintenance of the system will require a continuous effort and further developments will be necessary to adapt the system to the evolution of the LHC.
- None of the observed faults caused a total loss of magnet and/or circuit protection.
  - Redundancy of the protection systems is essential