

# QPS - ANALYSIS OF MAIN PROBLEMS, AREAS TO TARGET, POSSIBLE IMPROVEMENTS

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## Abstract

The fault statistics of the LHC Quench Protection System QPS for the LHC run 2011 will be presented and the various fault types explained. Starting with teething and EMC related problems, the tune feedback compatibility, hardware faults of the quench heater power supplies and spurious openings of electrical circuit breakers will be described in more details. Hereby as well the necessary and potential consolidation measures will be discussed. The role of the MPE standby service for the system availability will be addressed. Finally radiation induced faults and the respective mitigation and consolidation measures will be treated as separate subject.

## PROTECTION OF SUPERCONDUCTING ELEMENTS IN THE LHC

The protection of the superconducting circuits of the LHC, i.e. magnets, bus-bars and current leads is ensured by electronic quench detection systems in combination with other active protection elements such as quench heater discharge power supplies and energy extraction systems [1][2]. In addition there are passive protection elements as cold by-pass diodes and cold parallel extraction resistors being not subject of this contribution. The active protection systems cover 544 superconducting circuits of the LHC with nominal current ratings from 550 A to 11870 A. The systems incorporate a large number of individual protection and data acquisition devices requiring very high levels of reliability and availability.

Table 1: Circuits covered by the protection system

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

Regarding only the interlocking channels, a mean time between failure (MTBF) of 24 hours for the complete system, which is hardly acceptable for accelerator operation, calls already for an individual device MTBF of  $0.33 \cdot 10^6$  hours and an event free time of one week for  $2.3 \cdot 10^6$  hours. It is noteworthy that the manufacturers of electronic components typically guarantee a component MTBF between  $0.2$  and  $1.0 \cdot 10^6$  hours.

Table 2: Protection equipment installed in LHC

System type	Quantity
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
<b>System interlocks (hardwired)</b>	<b>13722</b>

## BASIC FAULT STATISTICS

Figure 1 and 2 summarize the basic fault statistics focussing on hardware failures and radiation induced faults; the latter ones basically determining the fault rate in the 2<sup>nd</sup> half of year 2011.

The hardware failures were mostly related to a malfunction of the quench heater discharge power supplies.

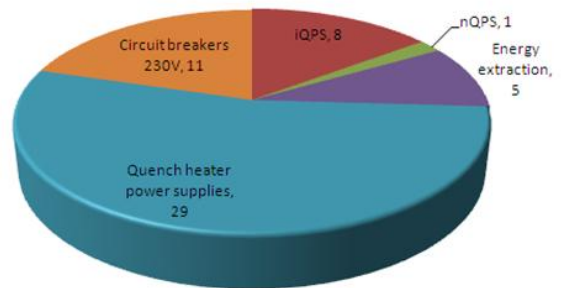


Figure 1: Hardware failures of QPS and energy extraction systems reported during LHC operation in 2011.

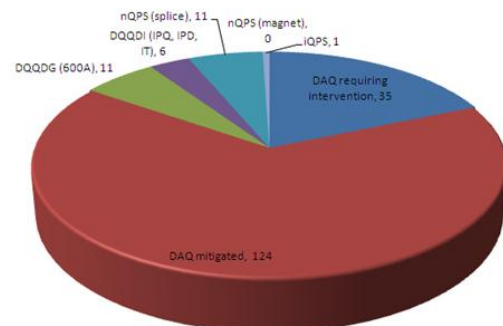


Figure 2: Radiation induced faults during the 2011 LHC proton run.

### Teething problems & EMC related faults

At the start-up of LHC operation in 2009 and as well in 2010 many problems related to communication links, local bus instabilities, electrical connections and faulty (noisy) electronic circuit boards have been reported. In a tedious process almost all of these shortcomings have been sorted out. One can however expect that some of the problems will reappear after the long shutdown 1 (LS1).

During the LHC run 2010 and 2011 frequent trips of the protection systems for the insertion region magnets during thunderstorms and general perturbations of the electrical network have been observed. These spurious triggers concern basically the systems allocated to magnets Q9 and Q10. The cause of the problem is related to the warm instrumentation cable length and the cable routing in the LHC tunnel, which is supposed to be modified within the upgrade of these protection systems during LS1.

As a temporary resolution it is proposed to raise the voltage detection threshold for these circuits. Recent calculations [3] have demonstrated that up to currents to 4 kA (compatible with 4 TeV operation) a detection threshold of  $U_{TH} = \pm 400$  mV with  $t = 10$  ms evaluation time is safe. The respective ECR has been issued for an implementation during the Xmas break.

### Tune feedback compatibility

The tune feedback applies only small changes in current but creates a voltage signal, which the quench detection systems not always can distinguish from a real quench. As a first mitigation measure the discrimination time of the detection systems has been increased to  $t_{EVAL} = 190$  ms. Despite this there has been still a significant number of trips in 2011 e.g. during the squeeze. Therefore a re-evaluation of the detection settings has been launched and concluded in 2011. The detection settings [3] for the 2012 LHC run will allow an increased detection threshold of  $U_{TH} = \pm 2$  V for currents less than 100 A.

### 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 provoked 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. A repair campaign has been launched in 2010 with the objective to replace all 6076 faulty switches during technical stops of the LHC until spring 2012. At the time of writing this mission has been accomplished [4].

In addition the implementation of the 3 out of 4 condition for the MB quench heater power supply availability (no injection inhibit in case of loss of one power supply) within the R2E firmware upgrade for MB DAQ systems allowed to defer the necessary repair to a convenient time. In 2011 still 29 interventions were necessary but

23 in the shadow of other machine accesses; only 3 were required outside normal working errors.

### Circuit breakers

Another hardware failure concerns the spurious opening of F3 circuit breakers without obvious reason.

The F3 and F4 circuit breakers are used to protect the distribution lines for the redundant UPS powering of 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 the circuit breaker. So far the problem occurred only with F3 circuit breakers and not with F4, which are a different make and have a higher rating. In total 12 trips causing 4 dumps out of stable beam conditions have been registered in 2011. The fault has to be regarded as frequent enough to cause trouble and ask for remedy but too rare to be traced down easily or to be reproduced in the lab.

In order to come to a conclusion prior to LS1 a proposal has been made to swap the F3/F4 circuit breakers of the concerned QPS racks. One sector has been already swapped during technical stop 5 the remaining sectors will be swapped during the Xmas break 2011/2012.

In the best case the problem will disappear in 2012 but at least it will give an indication whether and what hardware modifications will be necessary to be implemented during LS1.

## RADIATION INDUCED FAULTS

Due to functional requirements a significant amount of QPS and EE equipment is exposed to radiation during LHC operation. In 2011 radiation induced faults were responsible for most of the QPS triggers in stable beam conditions asking for consolidation measures to be implemented prior to LS1.

### Radiation induced fault statistics 2011

Figures 3 through 6 present the radiation induced fault statistics for the LHC proton and ion run in 2011.

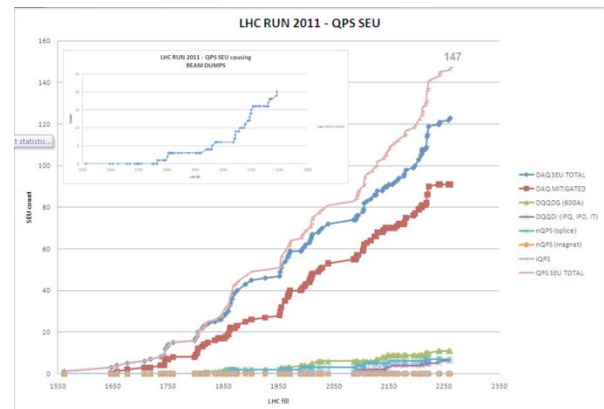


Figure 3: Radiation induced fault statistics for the LHC proton run 2011.

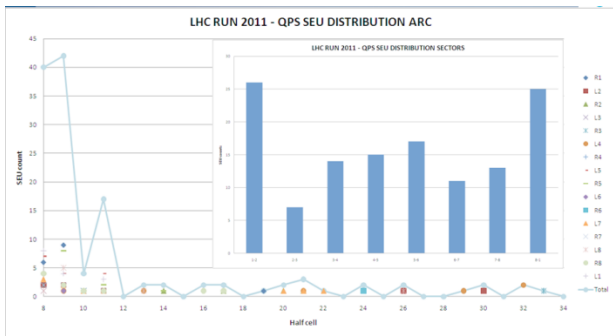


Figure 4: SEU distribution in the regular arc during the LHC proton run 2011.

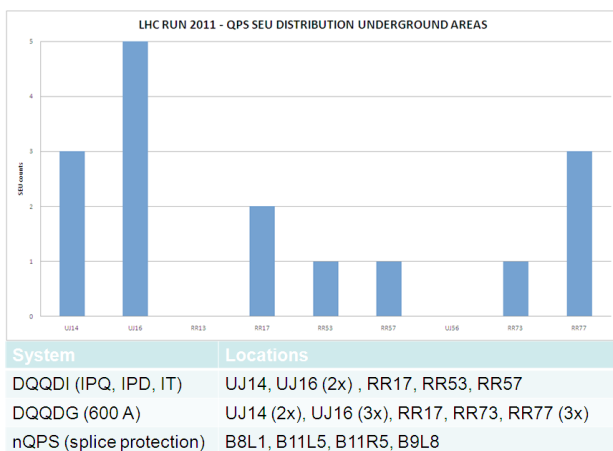


Figure 5: SEU distribution in the LHC underground areas during the LHC proton run 2011.

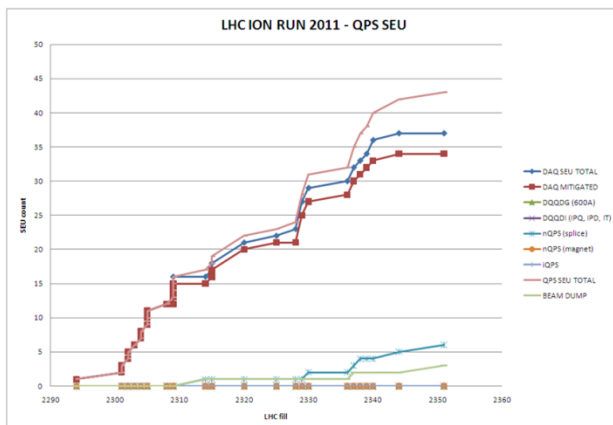


Figure 6: Radiation induced fault statistics for the LHC ion run 2011.

### Mitigation and consolidation measures-DAQ systems

The major problems with the DAQ systems in 2010 and 2011 has been a malfunction due to a radiation induced fault causing a permanent trigger state of the device. In order to overcome the problem a firmware upgrade has

been successfully applied as a first mitigation measure. The full consolidation will require a hardware upgrade to be deployed in critical areas during 2012 and LS1.

In addition it will be necessary to replace in the future the discontinued and not fully radiation tolerant fieldbus coupler chip (MicroFip™) used in the DAQ systems by the by the NanoFip FPGA currently under development at CERN [5]. This change however will require a significant development and integration work to be done for the QPS DAQ systems. It is foreseen upgrading the first fieldbus segments during LS1. An auto power-cycle option for MicroFip™ is currently being evaluated as an intermediate solution for the LHC run 2012.

### Mitigation and consolidation measures – nQPS splice protection

During the LHC run 2011 the splice protection systems caused a few spurious triggers mainly due to data corruption of digital filters. For the LHC run 2012 a firmware upgrade implementing a triplication of digital filters and other modifications will be applied for the devices installed in the most critical areas. This measure it is expected to cure a significant amount but not all radiation induced faults

Potential hardware upgrades are currently being evaluated and will be deployed in hot zones during LS1.

### Mitigation and consolidation measures – IPQ, IPD and IT protection

The radiation exposed quench detection systems for the insertion region magnets will be upgraded to a radiation tolerant design using flash based FPGA ProAsicA3PE1500™ (see figure 7). The new systems are similar to the symmetric quench detection board type already successfully being exploited in the LHC. The production of 200 boards will be launched in February 2012 and the installation in the LHC underground areas UJ14, 16, 56 and RR13, 17, 53, 57 is foreseen to be completed by June 2012 (technical stop 2).



Figure 7: Radiation tolerant FPGA based quench detection board for the protection of insertion region magnets.

### Mitigation and consolidation measures – 600 A protection

The existing digital quench detection systems type DQQDG will be upgraded to new FPGA based systems

similar to the radiation tolerant circuit boards developed for the protection of the insertion region magnets. The core will be a flash based FPGA of type ProAsicA3PE3000™. The high dynamic range of the current reading requires a high resolution ADC. A potential candidate is the fast high resolution 24 bit  $\Sigma\Delta$  ADC TI™ ADS1271 where the modulator part has already been successfully radiation tested by the TE-EPC group [6]. The development and type testing of these circuit boards including the complex firmware is expected to be completed by end of March 2012[7] permitting a deployment in LHC from mid 2012 onwards.

### INTERVENTIONS – MPE STAND-BY SERVICE

During the LHC exploitation a round-the-clock support to operation in case of system faults is ensured by a standby service team formed by equipment specialists. In the event of a hardware fault the performance of the stand-by service is crucial in order to minimize the machine downtime.

Intensive training and growing experience of the team members allowed reducing the average time for an intervention in the LHC from 2.3 hours in 2010 to 1.3 hours in 2011[8].

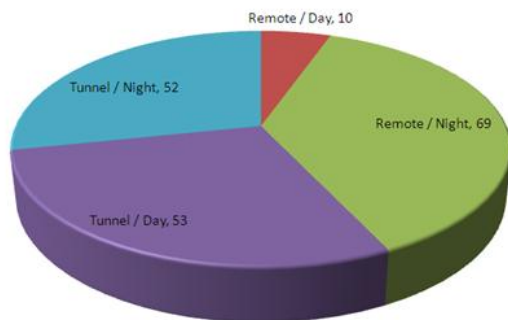


Figure 8: Interventions of the TE-MPE standby service during the LHC run 2011.

### SUMMARY

During the LHC exploitation in 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. In consequence 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 limiting 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.

So far none of the observed faults caused a total loss of magnet and/or circuit protection.

### REFERENCES

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