

# MACHINE PROTECTION SYSTEM RESPONSE IN 2011

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## Abstract

The performance of the machine protection system during the 2011 run is summarized in this paper. Following an analysis of the beam dump causes in comparison to the previous 2010 run, special emphasis will be given to analyse events which risked to exposed parts of the machine to damage. Further improvements and mitigations of potential holes in the protection systems as well as in the change management will be evaluated along with their impact on the 2012 run. The role of the restricted Machine Protection Panel (rMPP) during the various operational phases such as commissioning, the intensity ramp up and Machine Developments is being discussed.

## REVIEW OF PROTECTION DUMPS

At the end of the 2011 run, the LHC machine protection systems had cleanly executed around 1200 beam dump requests, corresponding to a slight decrease of 10% with respect to the previous operational year 2010. As already in 2010, no beam inducted quench at 3.5 TeV was observed, although the machine was routinely operated with more than 100MJ of stored beam energy per beam. Even during the various machine development phases devoted to the understanding of the quench margin of the LHC magnets no magnet was quenched with circulating beam. This indicates the presence of operational margins which will become important when understanding the performance reach of the machine with respect to effects of electron clouds and UFOs [1]. Consequently no equipment damage was recorded during the run, apart from damage occurred in the SDD calibration unit of ALICE following kicker erratic's during beam injection [2].

As during previous years all beam dump events from 3.5 TeV, be it a programmed dump or a premature beam dump request, have been meticulously analysed and validated by the operation crews and Machine Protection System (MPS) experts and have been used to build a knowledge database to assess possible long-term improvements of the LHC machine protection and equipment systems [3].

With respect to the previous operational year, 40% more of the fills were successfully ramped to 3.5 TeV, being proof of a much improved mastering of the machine and the operational cycle. At the same time, a small relative increase of false triggers from the Machine Protection Systems itself could be observed, mostly due to the much accentuated effects of intensity and luminosity related issues in the LHC equipment systems, resulting in numerous premature beam dumps as will be

discussed later in this paper. The most remarkable change with respect to the 2010 run was however that fact that beam dumps from beam monitoring equipment such as beam loss monitors and interlocked beam position monitors have decreased by a factor of 3 (as shown in Figure 1).

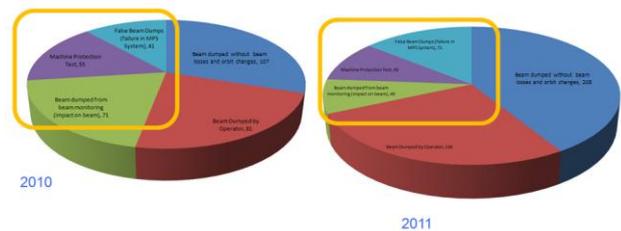


Figure 1: Causes of beam dumps for the past two operational years 2010 (left) and 2011 (right)

This confirmed that the numerous mitigations and additional protection systems being put in place during the 2010 and 2011 runs have brought a considerable improvement to the redundancy of the active machine protection systems. The dependability of the backbone systems of LHC machine protection remained hereby mostly constant, apart from a strong increase in Single Event Upsets (SEU) and environment related triggers (such as failures of the electrical distribution ...). Such failures were predominant in systems like the Quench Protection System (QPS) or the PLC based Powering Interlock System (PIC) as shown in Figure 2. For both systems corresponding mitigation actions have been already prepared and put in place, like for example the deployment of a new failure tolerant firmware version for QPS controllers in exposed locations or the full relocation of all interlock PLCs during the TS#3 of the 2011 run.

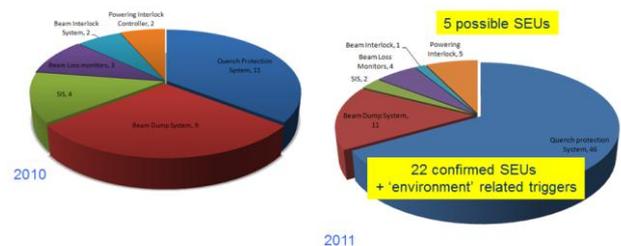


Figure 2: Fraction of false dump triggers from machine protection systems in 2010 (left) and 2011 (right)

The fact that 95% of false positives occurred above injection energy confirms the correlation with intensity and/or luminosity related effects on electronics, as it can also be seen from Figure 3.

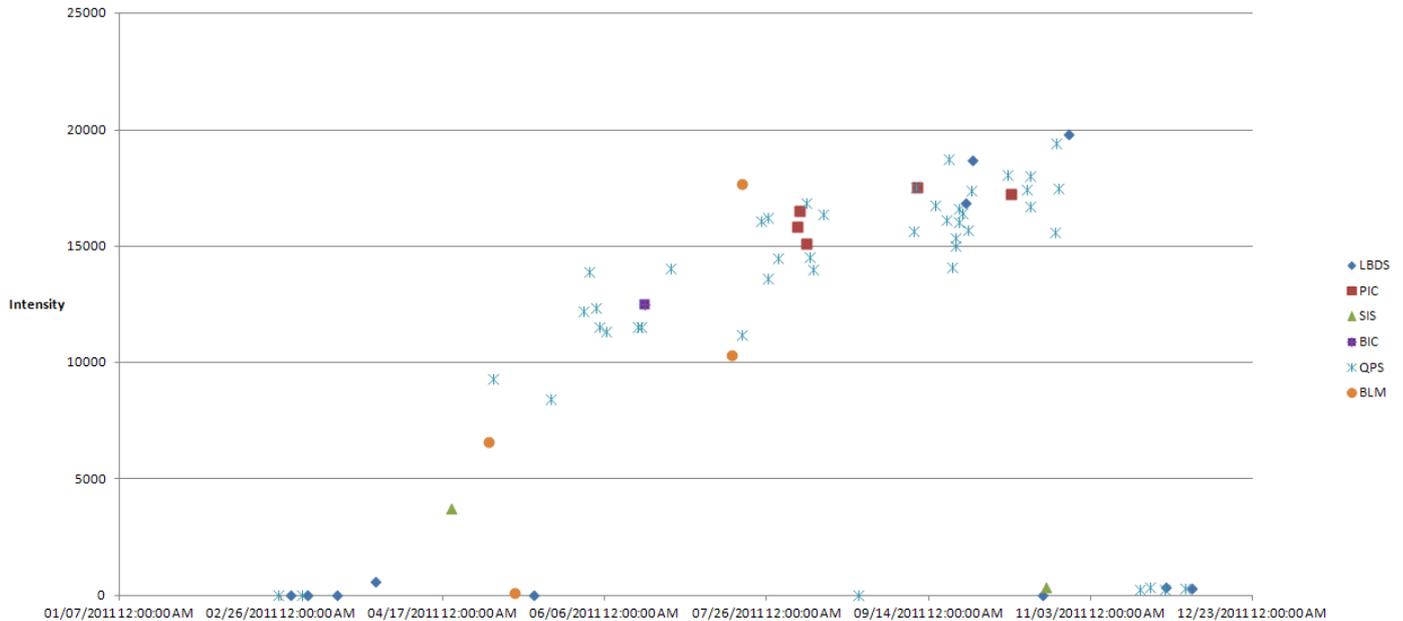


Figure 3: False beam dumps from machine protection systems as a function of time (x-axis) and intensity in the machine (y-axis)

While false positives from the LBDS, SIS, BI and BLM system are more or less equally distributed over time and in first order (due to low statistics) independent from the circulating beam intensity, it is clearly visible from the Figure 3 that there is an accumulation of QPS faults with higher beam intensities towards the second part of the operational year 2011. Also all failures caused by spurious stops of the powering interlock PLCs exclusively occurred during operation with high beam intensities, and in addition occurred on all five occasions in locations of higher radiation levels such as UJ14, UJ16 and UJ56.

#### *Beam dumps from beam monitoring*

The number of beam dumps triggered through the beam monitoring systems (beam loss monitors and interlock beam position monitors) is a good measure to assess the effectiveness of the active protection systems. Some 40 fills have been prematurely dumped from such systems during the 2011 run, indicating possible further improvements of the redundant active detection. The beam dumps were mostly a consequence of slow losses, caused by vacuum activities, feedback issues or other transverse beam instabilities. Despite the fact that the machine always has been very well protected in these cases (namely by the very performing beam loss monitoring system), a future evolution of the machine parameters towards higher energies and smaller  $\beta^*$  values will require tighter collimator settings and lower BLM thresholds. Therefore to maintain the current good level of orbit stability is absolutely mandatory. To maintain the current level of dependability also when exploring a new operational envelope, additional interlocks for e.g. the orbit corrector current and a beam current change monitor should be developed and put in place for future runs.

## **FUTURE IMPROVEMENTS OF THE MACHINE PROTECTION SYSTEMS**

One of the most promising systems to introduce additional redundancy into the MPS is the so called beam current change monitor, which was a vital part in many other MPS systems in e.g. HERA. It was proposed for a use in the LHC as early as 2005 [4]. With a HERA like system it would be possible to detect changes of less than 0.1% of the total beam current within some 10 turns. The BI group in collaboration with a DESY consultant has started a development of such a system for the LHC in mid of 2010. A first prototype of the system is installed and recording first data (see Figure 4). As shown in Figure 5 (illustrating a comparison between the measurement from the DCBCT and the beam current change monitor) the system however still shows some unexplained dependency of bunch length or beam position during the first part of the flat top and the squeeze of the particle beams, which needs to be fully understood and mitigated before an active interlock can be implemented based on this measurement.



Figure 4: Prototype installation of beam current change monitor

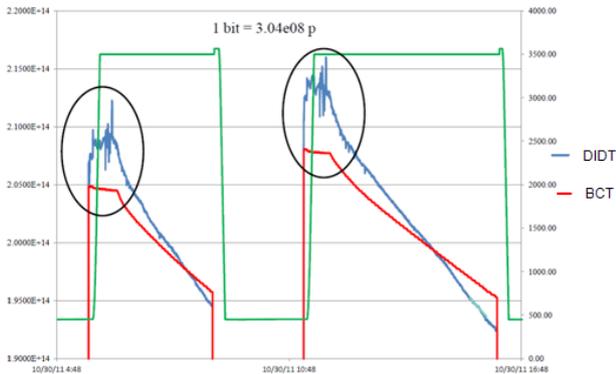


Figure 5: Comparison of beam current measurements with the DCBCT (red curve) and the beam current change monitor (blue curve)

A second system, to become operational already during the 2012 run, is a new software interlock system monitoring the power converter currents of corrector circuits to protect against operations- and feedback-failures. While this system will be redundant to the already existing SIS interlock for the arcs it will add a level of protection in LSS 1/2/5 and 8 due to its capability of tracking bump shape amplitudes and variations as illustrated in Figure 6. It therefore has a key interest for all other (non-COD) power converters where currently no current tracking is being performed.

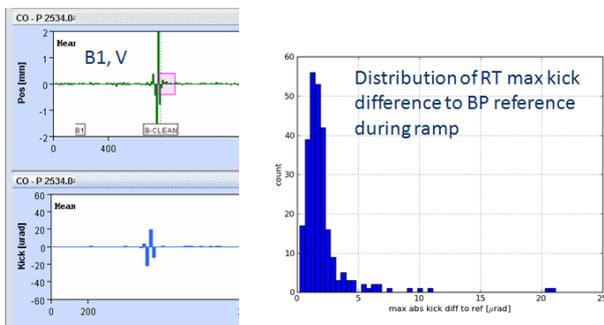


Figure 6: Orbit bump >2mm developing during the ramp of fill 1717. The system clearly identifies the unusually high kick applied by calculating the difference between the applied kick and the BP reference.

Other relevant changes of the Machine Protection System for the 2012 are as follows:

- BLM HV checks implemented at HW level
- New (shorter) BLMs in injection lines, providing > dynamic range
- New LBDS TSU firmware (including recommendations of external audit) and increased re-trigger delay to avoid asynchronous dumps following internal TSU failures
- SMP-GMT hardware cross-checker
- First draft of operational procedure in case of non-working dump ready

- Operational procedure for abort gap cleaning
- Improvements of Roman Pot Controls
- ...and many others....[5]

### Commissioning and validation procedures, Machine Developments and Change Management

The re-commissioning of the MPS system for the 2012 run will be done as for 2011 according to the well established procedures documented in the Machine protection share point site [5]. For future re-commissioning campaigns it is expected to introduce an even more formal approach through the use of the recently developed accelerator testing tool for HWC, which will allow for the possibility of more rigorous sequencing, dependencies and documentation as well for the beam commissioning phase.

Additional developments to improve the tracking of relevant changes to the MPS systems should be defined and put in place, as 2011 has seen not less than 90 considerable changes to hardware and software components of the machine protection systems. Changes in machine protection systems require more than any others a n appropriate culture and level of responsibility of the equipment expert to assure the dependability of the deliverables. Additional controls tools for intelligent rollbacks, centralized information on deployments/server reboots and RBAC like protections against changes on operational machines would further facilitate this effort.

This also applied to some extent to machine development periods, which by definition explore new machine and machine protection territory, often requiring numerous changes to the machine and machine protection systems to allow for the MDs to be performed. It has to be said that the MD requestors have demonstrated a high level of responsibility by proactively providing the required MP documents. More than 20 documents have been approved in EDMS for the MD periods in 2011 [6], and the preparation phase has proven very useful for the MD and MPS teams and often helped to increase the efficiency of the MDs. Certain flexibility with respect to the agreed procedure has shown to be useful on a few occasions, but must not become the standard procedure.

### CONCLUSIONS AND OUTLOOK

The LHC Machine Protection and Equipment Systems have been working extremely well during the 2011 run thanks to a lot of commitment and rigor of operation crews and machine protection experts. Ever more failures are captured before effects on the particle beams are seen (i.e. no beam losses or orbit changes are observed). Therefore not a single quench with circulating beam has been observed, although the machine has been routinely operated with more than 100 MJ stored in each particle beam, which is 10 orders of magnitude more than the 10 mJ needed to quench a magnet. No evidence of a major

loophole or uncovered risk in the protection architecture has been identified. At the same time additional active protection measures should be investigated and deployed for future runs. Maintaining the current level of good orbit stability will be of primary importance in view of future evolutions of the beam parameters towards higher energies and operation with lower  $\beta^*$ . Despite the high dependability of the machine protection systems during the past two operational years we have to remain vigilant also in the following years when more emphasis will be given to increase the overall machine availability.

## REFERENCES

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