First Experience with the LHC Beam Loss Monitoring System

Bernd Dehning, Till Böhlen, Ewald Effinger, Jonathan Emery, Fabio Follin,
Eva Barbara Holzer, Stephen Jackson, Daniel Kramer, Grzegorz Kruk, Pascal Le Roux,
Julien Mariethoz, Marek Misiowiec, Laurette Ponce, Chris Roderick,
Mariusz Sapinski, Christos Zamantzas (CERN, Geneva),
Markus Stockner (EBG MedAustron, Wr. Neustadt; CERN, Geneva),
Dariusz Bocian (Fermilab, Batavia; CERN, Geneva),
Viatcheslav Grishin (IHEP Protvino, Protvino, Moscow Region; CERN, Geneva),
Hitomi Ikeda (KEK, Ibaraki; CERN, Geneva),
Agnieszka Priebe (Poznan University of Technology, Poznan)

Abstract

The LHC beam loss monitoring system (BLM) consists of about 4000 monitors observing losses at all quadrupole magnets and many other likely loss locations. At the first LHC operation in August and September 2008 all monitors were active and used to observe the losses during the initial beam steerings, at collimators, at the LHC dump and during aperture scans. The different acquisition modes and their presentation are shown. Aperture scan loss patterns and a detailed loss pattern leading to a magnet quench are discussed. The observed signals of the BLM system are analyzed in terms of response time, sensitivity and noise performance.

INTRODUCTION

The main function of the LHC beam loss system [1] is the protection of superconducting magnets against quenches or damages. In addition to beam permit inhibit actions, loss measurements during the filling process and its optimisation as well as other lifetime tunings are other foreseen tasks of the system. The system will change thresholds automatically, corresponding to the beam energy and allows to follow the loss duration dependent quench levels of the superconducting magnets (signal integration times between 40 μs and 80 s). The system consist of about 4000 monitors distributed along the ring and the extraction lines. The detectors are ionisation chambers and secondary emission monitors (SEM). The later, less sensitive than the ionisation chambers, are only located in areas with high radiation fields like the collimation areas. The whole system was used, except the SEMs, because of the low beam intensities during the three injection tests and tests with circulating beams in August and September 2008.

MONITORS AND THRESHOLDS

BLM measurements of the 10th of September 2008 are shown in Fig. 1 for the whole ring (green bars). The white and light blue areas separate odd and even octants of the ring from each other. The values on the logarithmic vertical axis are given in units of Gy/s and the dynamic ranges from $2\ 10^{-7}$ to about 20 Gy/s. The minimum value of $2\ 10^{-7}$ is only adjusted at few channels, the up to 20 times higher bias current levels are foreseen to be used in test modes after the commissioning of the system. The red dots show the threshold values for a beam energy of 450 GeV. Their variations are due to different quench or damage thresholds and also to varying monitor locations. The beam is injected left of the centre of octant 2 and is stopped by a collimator left of the ATLAS experiment near the centre of octant 1 after almost a full turn.

NORMALIZED MEASUREMENTS

The sensitivity of the system is demonstrated by subtracting the bias current of every channel from the measurements (see Fig. 2). In this display mode the signal to sensitivity ratio can be estimated by comparing loss measured near the centre of octant 5, left of the CMS experiment, which is more than 100 times larger than for all monitors shown (about 2000). Here as well the beam is injected left of the centre of octant 2 with an intensity of $2\ 10^9$ protons. This intensity is the lowest to be injected in the LHC and it will be possible with a pilot bunch intensity to predict the losses which will occur if the beam intensity is increased during the injection process by two orders of magnitude.

ABSOLUTE MEASUREMENTS

The upper limit of the dynamic range for the acquisition system is chosen to allow the measurement of fast losses (using the signal integration window of 40 μs) at 450 GeV beam energy. This feature was tested during the first quench of LHC bending magnets (see Fig. 3). The one bunch pilot beam ($2\ 10^9$ protons) has been steered into a bending magnet under an angle of 750 μrad. It can be seen that the loss is increasing by two orders of magnitude at the beginning of the bending magnet and decreases again towards its end (red curve recorded by red monitors). At the beginning of the following quadrupole magnet an increase of losses is observed due to an increase and decrease of the aperture in between the two magnets. The blue curves show the loss measured with monitors foreseen for the counter rotating beam. Their signal levels are

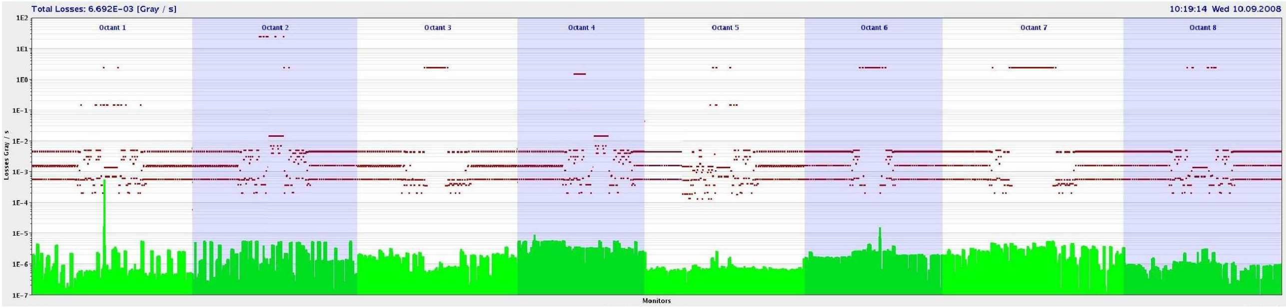

Figure 1: Control room beam loss display with loss at a collimator in octant 1. The losses (green bars) and beam permit threshold values are drawn in a logarithmic scale as function of the monitor number.

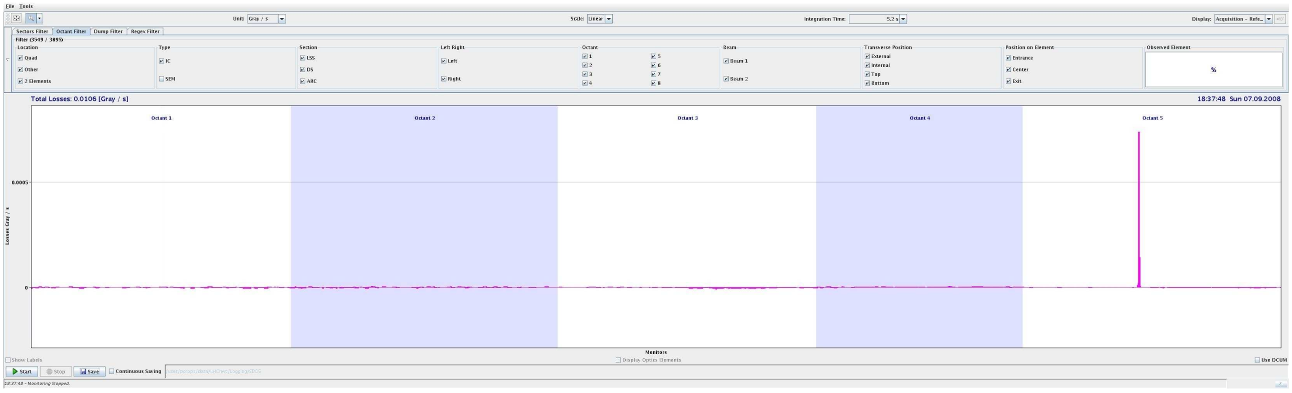

Figure 2: Control room beam loss display with a loss at a collimator at octant 5. Loss values are drawn in a linear scale with electronics bias current subtracted as function of the monitor number.

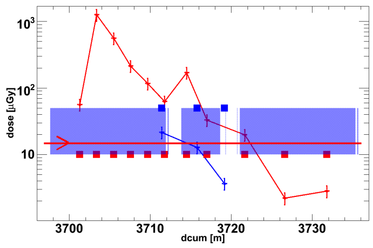

Figure 3: Beam loss measurements showing the loss which initiated the second quench of an LHC magnet. The red and blue curves show the measurements initiated by the same impacting protons on either side of the magnet.

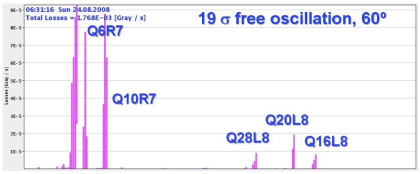

Figure 4: Control room display with losses created by aperture scans in the LHC ARC.

about 5 times lower, as a result of a stronger attenuation of the secondary particle shower from the increased thickness of matter in between the proton impact location and the ionisation monitors. The placement of the blue monitors corresponds to the nominal placement of monitors in the LHC ARC: three monitors per beam, six per magnet. The first and second are foreseen to observe the losses due to beam size increases and orbit excursions as well as misalignments between magnets. The third is foreseen to observe misalignment losses at the exit of the quadrupole magnet. The expected nominal loss pattern have been seen during the first aperture scans at the LHC (see Fig. 4). An unclosed orbit bump has been used to test the aperture limitations in octant 8. It is seen that in the ARC (cells 12R7 to 12L8) systematically a maximum of three monitors show losses.

TIME RESOLVED MEASUREMENTS

The system allows to display and store data with a frequency of 1 Hz. In addition, for predefined integration windows of either 40 μs or 2.5 ms, 2048 samples of data can be acquired (giving a total of 82 ms or 5 s) and displayed every 30 seconds. The synchronous acquisition of all channels is started by a dedicated timing event and the results are shown on one display. As an example, loss measurements from one circulating bunch with 40 μs integration time of one monitor are shown of the 10th of September 2008 (see Fig. 5).

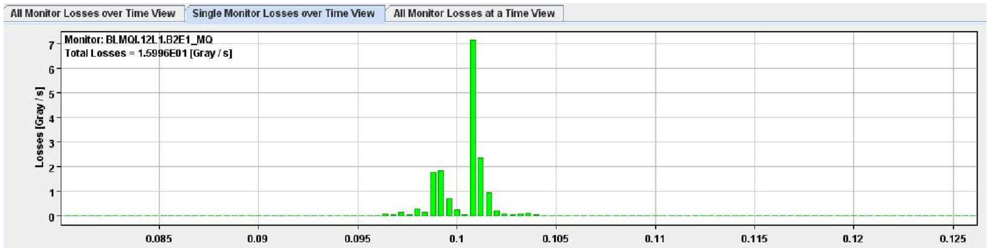

Figure 5: Capture data loss display with a time resolution of 40 μs of one LHC monitor.

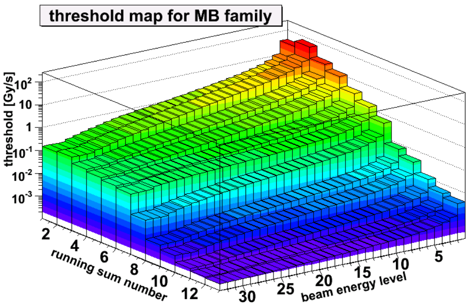

Figure 6: Beam permit threshold settings of a bending magnet channel as function of the beam energy level (lowest beam energy level corresponds to 250 GeV) and running sum window (lowest corresponds to 40 μs and largest to 80 s).

THRESHOLD SETTINGS

To allow the operation of the LHC superconducting magnets with maximal possible beam losses near to their quench levels the threshold settings for each channel are energy and loss duration dependent (see Fig. 6). Automatically, during the ramp of the magnets from injection field settings to top settings beam permit thresholds are changed in 32 steps (right side axis). The loss duration dependent quench levels are approximated with 12 integration windows (left side axis). For the protection against quenches and damages it was required that each channel of the BLM system has the right to issue a beam permit inhibit signal. Therefore, it was not possible to gain operational reliability against false signal inhibits by requiring that more than one channel needs to exceed a threshold. To check the false inhibit probability the distribution of the 80 μs integration window signals during times without beam of four example channels are shown in Fig. 7. The upper limit is set to its threshold value at 5 TeV (most sensitive) and the overflows would show the number of false beam permit inhibits. About 100’000 values are recorded corresponding to about 30 hours of operation and no overflows are observed. Data of all LHC channels were only available from an off beam period between the 12th to the 16th of September (see Fig. 8). Out of the 3548 channels (only ring monitors and no SEMs) 19 channels located on 4 electronics cards caused overflows. The observed large fluctuations are caused by faulty acquisition cards.

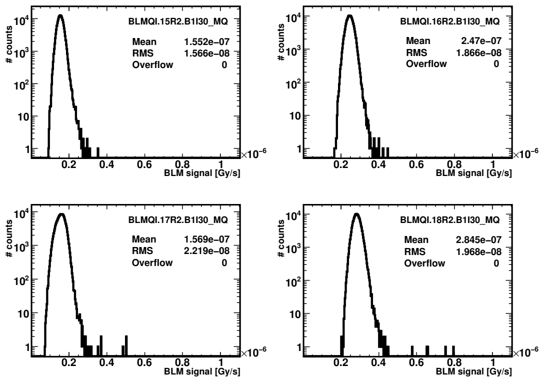

Figure 7: Bias current and noise level distribution of beam loss channels.

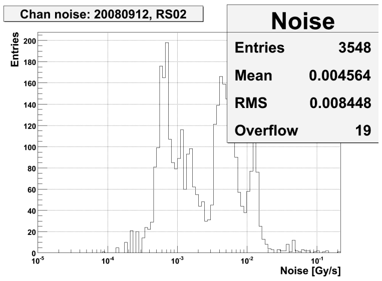

Figure 8: Bias current and noise level distribution of all ionisation chamber beam loss channels in the ring. The upper limit corresponds to the beam permit threshold setting.

SUMMARY

The LHC BLM system was available for the first beams in the LHC. It has been crucial for the observation of losses during the first injection studies and aperture scans. Its sensitivity to measure losses lower than 1 % of the pilot bunch intensity of 2 10^9 protons has been demonstrated. The observed loss patterns are as expected. The observed bias current and noise patterns indicate that no major faulty signals are introduced in the BLM acquisition chains and in consequence it is expected that the number of false beam permit signal inhibits will be low.

REFERENCES

[1] Future literature can be found: http://cern.ch/blm and at http://cern.ch/blm/talks_and_papers