

# The LHC Beam Loss Monitoring System's Data Contribution to other Systems.

Christos Zamantzas, Bernd Dehning, Ewald Effinger, Jonathan Emery, Gianfranco Ferioli, Stephen Jackson  
AB/BI, CERN, Geneva, Switzerland

**Abstract**—The strategy for machine protection and quench prevention of the Large Hadron Collider (LHC) at the European Organisation for Nuclear Research (CERN) is presently based on the Beam Loss Monitoring (BLM) system. At each turn the BLM system is able to acquire and process in real-time data from approximately 4000 detectors in order to decide if the beams should be permitted to continue circulating or their safe extraction is necessary.

At the same time in the system, by making full use of its VME based processing cards, data is continuously recorded from both the acquisition, the processing results as well as the status of the electronics which later will be provided to various systems in the LHC.

Part of the recorded data will be used to drive an on-line event display and write an extensive logging database at a refresh rate of 1Hz. Other parts of the same processing units, initiated by external triggers, will provide fast updates of the loss pattern seen in the last 20ms by 640us integrals, necessary for the automated collimator adjustments, 100ms worth of data for every beam injection and scheduled dump to verify the correctness of those procedures, and the last 1.7s by 40us integrals to be used for post-mortem analysis in the event of an unforeseen dump as well as FFT analysis studies.

The paper discusses the realization of each of those recording functions and their verification with beam measurements.

## I. INTRODUCTION

THE Large Hadron Collider (LHC) is the next circular accelerator being constructed at the European Organisation for Nuclear Research (CERN). It will provide head-on collisions of protons at a centre of mass energy of 14 TeV for high energy particle physics research. The LHC is currently being installed in the 27 km long LEP tunnel. In order to reach the required magnetic field strengths, superconducting magnets cooled with superfluid helium will be used. The energy stored in the LHC can potentially damage many elements of the accelerator or could make its operation very inefficient.

The strategy for machine protection and quench prevention of the LHC is mainly based on the Beam Loss Monitoring (BLM) system. At each turn, there will be several thousands of data to record and process in order to decide if the beams should be permitted to continue circulating or their safe extraction is necessary to be triggered. The decision involves a

proper analysis of the loss pattern in time and a comparison with predefined threshold levels that need to be chosen dynamically depending on the energy of the circulating beam. This complexity needs to be minimized by all means to maximize the reliability of the BLM system and allow a feasible implementation. The processing of the acquired data is needed to be performed in real-time and thus requires dedicated hardware to meet the demanding time and space requirements.

To overcome such limitations, a great effort has been committed to provide a highly efficient, reliable and feasible implementation of the BLM system by employing various state of the art analogue and digital techniques, which included redundancies and optimizations across all of its levels of abstraction. Consecutively, the system is making use of modern field programmable gate arrays (FPGAs), which include the resources needed to design complex processing and can be reprogrammed making them ideal for future upgrades or system specification changes.

In consequence, the BLM system by performing its requested tasks it is able to have a constant and very detailed view about the state of the whole machine. It becomes obvious that by recording and relaying such information it can assist other systems to operate more efficiently, identify weaknesses or failing components and provide a history to understand the events that forced an unforeseen beam dump. Thus, a subsequent effort has been done to tap into its resources, extract and provide the most relevant parts.

## II. BLM SYSTEM OVERVIEW

The BLM system can be easily sub-divided geographically to the tunnel and the surface building installations. Around 3700 *Ionization Chambers* and 280 *Secondary Emission Monitors* are the detectors of the system and have been placed at various strategic locations around the ring. The tunnel cards, called *BLECFs* [1], acquire and digitize the data from the detectors and transmit those at the surface using redundant *Gigabit Optical Links (GOL)* [2]. There, the data processing cards, named *BLETCs* [3], receive those data and by performing continuous elaborate and multistage processing [4] it is able to decide whether or not the beam should be permitted to be injected or continue circulating.

Each *BLETC* card receives data from two tunnel cards, which means that it can treat up to 16 channels simultaneously and 16 of those cards are accommodated in a VME crate. A PowerPC running LynxOS is the VME master which collects

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All authors are with CERN, CH-1211 Geneva 23, Switzerland (e-mails: firstname.lastname@cern.ch).

C. Zamantzas is the corresponding author (telephone: +41 22 767 3409, e-mail: christos.zamantzas@cern.ch).



Fig. 1: Losses (Gy/s) recorded in the Logging database during the 2007 ‘Machine Development’ test in the SPS accelerator. They have been plotted using the TIMBER tools provided for the extraction of data from the database. [top] Plot of the 40  $\mu$ s integrals from different Ionisation Chamber channels showing occurring losses at the beam injection. [bottom] Plot of ten integrals (spanning from 40  $\mu$ s to 84 s) from the same Ionisation Chamber channel showing losses at the collimator.

and prepares the recorded data for the external systems. These tasks are accomplished by a real-time control software build for the front-end computers using the Front-End Software Architecture framework, known as FESA [5].

### III. DATA CONTRIBUTION

In the LHC, storage and off-line analysis of the loss measurements are needed to allow tracing back the loss signal developments as well as the origin of the beam losses in conjunction with other particle beam observation systems. Such data will be sent over the VME-bus some of them in a continuous and other in an externally triggered mode.

#### A. Logging System

The main purposes of the *LHC Logging Project* are to manage the information required to improve the performance of the machine and individual systems, to meet specific

requirements of records of the beam history and make available long term operational statistics. [6]

The BLM system will publish continuously data for the *Logging* system at 1 Hz. Those include:

- The maximum loss values observed in the last second in the 12 running sums for each channel.
- Their corresponding threshold values.
- Detailed error and status information for almost every component of the system as well as,
- Detailed description of the channel, which include both of the ‘*machine*’ and ‘*expert*’ names for each channel as well as its geographical position.

By providing a long term storage of such information and analyzing over long periods of operation, it can provide information about abnormal high loss locations and foresee failing components. Thus, it is expected to assist in the correct

operation, the scheduling of the interventions and hopefully increase the availability of the machine.

The BLM logging data are initially collected by the Concentrator system which forwards them to the Measurement database as well as any other client that will need to access those data as they get published at 1Hz.

The *Concentrator* system apart from collecting the data from the distributed front-ends it has the additional tasks of tracking the front-ends' health and issuing alarms in the case one of them becomes unresponsive as well as, converting the data to a more user friendly unit, that is Gy/s.

The *Measurement* database serves as a first stage in the transport of the data and gives quick access for the users but it is only a temporary storage, in the range of the last week, of the converted data. Subsequently, in regular intervals of the order of 15 minutes, a process collects all new entries in the *Measurement* database and copies them to the *Logging* database for permanent storage. In addition, this process sweeps from the values noise and other not-interesting data using predefined filtering criteria.

Examples of records in the Logging database collected during the 2007 'Machine development' tests in the SPS accelerator at CERN can be seen in Fig. 1.

### B. Post Mortem System

In order to reconstruct the event sequence around a beam and power abort, transient data need to be recorded for all beam and equipment parameters over a sufficiently long time interval. This data set is referred to as the Post Mortem Event. The collection and the concentration of the data in the form of the post-mortem event and the subsequent analysis of this data are the task of the Post Mortem System. Its main objective is the reconstruction of the event sequence that leads to a beam or power abort.

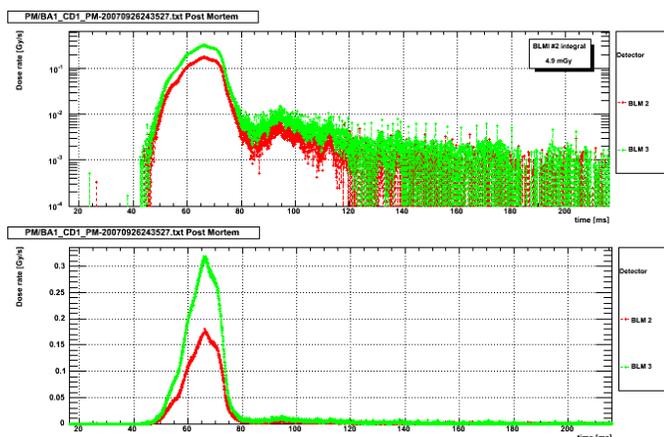


Fig. 2: Plots of the Post Mortem data recorded in the test setup of the SPS accelerator (zoomed). The losses have been induced by scrapping of the proton beam. [top] logarithmic scale [bottom] linear scale.

For this purpose in the BLM system, data are stored onboard of the *BLETC* and on the front-end with the aim to

provide detailed information about the losses that caused this unforeseen event.

This is realized with a circular buffer that is able to keep constantly the last 1.7 seconds, i.e. 43,690 samples of the 40 us integrals for each channel.

Its contents are frozen by an event arriving together with the timing information. The timing system is constructed in a way that allows to globally freeze those buffers as well as to add a delay in the arrival of this trigger with the purpose of including in the data information about the events followed the beam dump request initiated by the Beam Interlock System

In addition, to facilitate the off-line processing of those data each front-end adds also the last 512 samples of the 1.3 s integral (that is equal to the last 11 minutes), the threshold values used for each channel and the detailed error and status information collected for the system.

### C. Collimation System

The LHC Collimation system consists of 42 ring collimators and absorbers per beam and 14 transfer line collimators. [7] The BLM system will provide data to assist the correct alignment and setup of each collimator and it is foreseen for the future the collimation control system to use those data for an automatic beam-based alignment of its complete system.

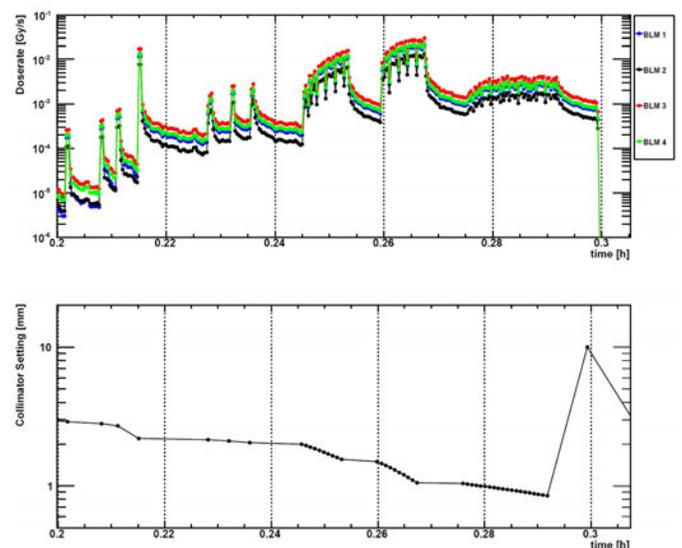


Fig. 3: Beam Losses induced by the collimator movement. [top] Maximum value of the 1.3 s Running Sum measured in the last second. [bottom] Relative position of the collimator w.r.t. the centre of the beam over time.

For those purposes, the BLM system provides continuously at 1Hz its 1.3 second integrals through the use of the *Concentrator* and, when triggered by the collimator movement, the last 82 ms worth of data organized in the form of 32 samples of the 2.54 ms integrals from dedicated for this purpose FIFO buffers using direct transmission of packets to the collimation gateways.

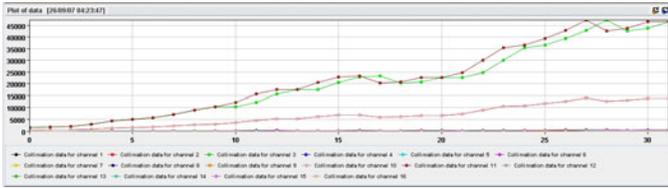


Fig. 4: Plot of a collimation triggered 82 ms data acquisition recorded at the SPS accelerator. The units are BLM bits vs. samples.

Examples of both types of data provided to the Collimation system can be seen in Fig. 3 and Fig. 4 which have been recorded during the 2006 ‘Machine development’ tests in the SPS accelerator at CERN.

#### D. Beam Dump System

The extremely high destructive power of an LHC beam imposes an external dump, where the beam must be extracted completely from the machine, diluted to reduce the peak energy density and then absorbed in a dedicated system.

Similarly to the post-mortem data, for the beam dump system one more circular buffer will record continuously the acquired data in order to provide detailed information about the correct extraction operations.

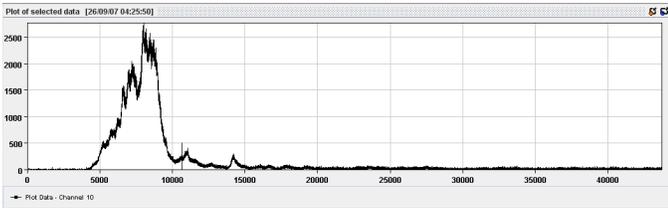


Fig. 5: Plot of a Beam Dump data acquisition for one channel recorded at the SPS accelerator. The units are BLM bits vs. samples.

The buffer will be frozen by a dedicated for this purpose event arriving with the timing information. The data to be transmitted will provide information equal to a total of two hundred LHC turns with a  $40 \mu\text{s}$  granularity. The timing system will have the ability to choose the number of samples recorded after the Beam Dump by applying the necessary delay on the transmitted event.

An example of a beam dump recording taken in the SPS accelerator’s dump can be seen in the plot of Fig. 5.

#### E. Fixed Displays in the Control Room

The on-line displays in the control room will be a valuable tool for the operator that will allow them with in a glimpse of the eye to visualise the beam loss map of the accelerator and provide them the ability to check with more detail channels of interest.

Data from all used BLM channels, which are more than 4000, will become available to the displays through the use of the Concentrator system at 1 Hz. To ease the supervision of the machine, it will provide several possibilities for the displaying of the data.

The beam losses will be initially normalised and secondly reduced on those having ‘interesting’ information so that

abnormal or high local rates can thereby be spotted easily. More specifically, the 12 values calculated by the running sums for each detector will be normalised by their corresponding threshold values and from those 12, the highest value will finally be displayed as a representative of that detector.

Moreover, it will provide the choice of displaying the data in either Gy/s or Amps in order to have understandable and comparable units with the other observation systems. It will issue warnings and alarms on channels that approach the magnet quench levels.

Finally, it will provide the ability to the operator to interact with the display. That is, to select only specific channels of interest and include status information concerning this channels.

## IV. RESULTS

Over the last two years the continuously transmitted logging data from various test setups, including test setups in operational accelerators the HERA (DESY, Germany) and SPS and PS Booster (CERN, Switzerland), have been used to test and verify the linear response of the system.

Both of the databases, i.e. the *Measurement* and the *Logging* databases, indented to store data from the logging acquisition as well as the *Concentrator* system have been in production since September 2007. At the time of the writing only a small part of the *BLM* system has been linked, i.e. three of its twenty-five front-ends, in order to minimize the stress on the test host servers but enough to evaluate the functionality and its correct operation. The complete system is expected to be connected and the full load to be forwarded in the databases after the server upgrade in the begging of 2008.

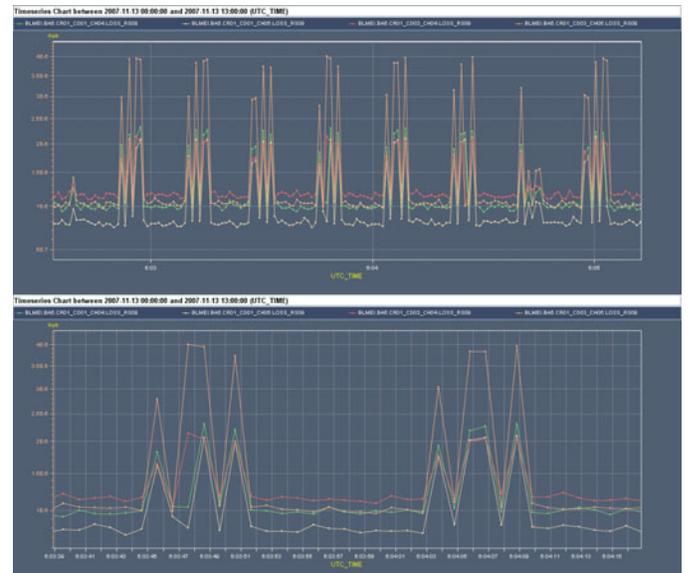


Fig. 6: Losses (Gy/s) recorded in the Logging database using the SPS test-setup and plotted using the TIMBER tools. [top] The 1.3 s integrals from 4 channels showing losses at the collimator (over several minutes). [bottom] The 1.3 s integrals from 4 channels showing losses at the collimator (over several seconds).

The *Post Mortem* data acquisition is one more part of the system that has been extensively tested with different triggering conditions. As a result it has become the main tool in the identification of problems in the BLM system operation when under beam conditions. By using this buffer and the detailed information it included, it became possible, among others, to verify the calibration factors for both the *ICs* and the *SEMs*, to identify well hidden cross-talk initiated problems with the tunnel installation cabling, and to test the response of different filter configurations in the *BLECF* inputs (see Fig. 7).

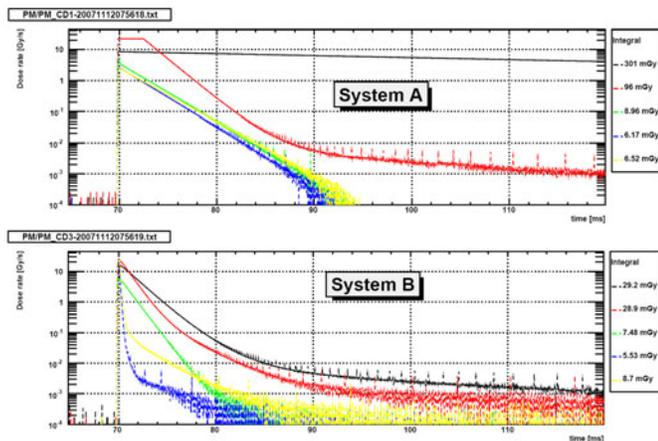


Fig. 7: Plot of Post Mortem data recorded synchronously from two parallel systems in the collimation area of the SPS with the purpose of identifying the response of different input filters used by the acquisition electronics [8].

The two separate transmission channels for the Collimation data has been available from October 2006 and have been tested in different conditions. The recent addition of the *Concentrator* system has even allowed further and more valid tests in the transmission chain. Those have shown that a filtering component will need to be introduced in the Collimator control system that will discard information from not interesting channel and ease the processing needs of the control software.

The *Beam Dump* system's data needs has not been clear up to very recently. For this reason, it was decided to take the worst case requirements; that is, equal to the *Post Mortem* system's needs. This choice has allowed the early evaluation of the impact on the available resources and the system load of such an inclusion request in the system. The positive results and the understanding of the *Beam Dump* systems needs will

allow the safe addition of this service in the next iteration of the system, scheduled for January 2008.

In conclusion, the BLM system will be able in the LHC start-up to provide not only the baseline requirements but also all of the advanced features, most of them requested outside of its specifications, and is expected to be not only part of the machine protection mechanism, but also a great tool for understanding and operating this new machine.

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