A BEAM LOSS SCINTILLATOR SYSTEM FOR BACKGROUND MONITORING AT THE LHCb EXPERIMENT

V. Talanov *, R. Dzhelyadin (IHEP, Protvino), A. Bobrov, A. Bondar (BINP, Novosibirsk), F. Alessio, G. Corti, R. Jacobsson (CERN, Geneva), M. H. Lieng (TU Dortmund)

Abstract

The LHCb experiment at the Large Hadron Collider (CERN) has developed a complete high-speed and high-sensitivity background monitor based on a pair of plastic scintillators and a custom-made LHCb readout board to record fast LHC beam losses with time information. The system is installed close to the LHCb Vertex Locator and it has been operational since the LHC pilot run providing valuable information to the LHC Operations crew during beam commissioning and to the LHCb Control Room about the experimental conditions at the physics runs.

The system is able to record fast beam losses at a rate of 40 MHz, providing information regarding the bunch crossing of the loss and the intensity of the loss calibrated in number of Minimum Ionizing Particles. A full control and monitoring system has been developed as well within the framework of the LHCb Experimental Control System. A complete simulation of the system has been central in converting the response of the system into physical quantities.

In this paper we will describe the system in its components and functionalities, the commissioning phase, the simulation framework and the first results with real beam at the LHC.

INTRODUCTION

The Beam Loss Scintillator (BLS) detector is made of two cubic-like plastic scintillators installed 12 cm away at both sides of the LHC beam pipe on the horizontal plane, at ~ 2 m from the LHCb Interaction Point in the opposite direction to that of the spectrometer. The initial scope of the scintillators was to look at injection problems [1]. However, the opportunities of using such scintillators as a continuous detector have been exploited. It is in fact, the only instrument within LHCb which is able to measure fast losses of the beam in the experimental area. Although the instrument is not able to protect the experiment, it is however able to predict possible incidents by analyzing the behavior of the beam and the evolution of the background. Eventually the system has proved his good performance and reliability as an independent source of luminosity measurement in LHCb.

The installed system comprises two scintillators of the size $4\times4\times3$ cm^3. Each scintillator is directly attached to a PhotoMultiplier, HAMAMATSU multi-mesh R2490-05 for one side and EMI pan-type 9839A for another side. The photocathode of each PMT is 40 mm diameter with a red light LED fast driver aside for calibration. Each scintillator itself is inserted in a steel tube and shielded against stray magnetic field. A TYVEK envelope is wrapped around each of the cubic scintillator in order to collect light. The whole tube is fixed with some rubber rings in the center of the PMT. Fig. 1 shows the position of the scintillators at the shielding wall between the LHCb Interaction Point and the accelerator tunnel.

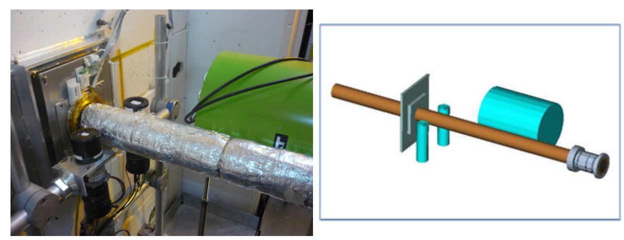

Figure 1: Left: the BLS system as installed in the LHCb cavern. The covered round pipe is the LHC beam pipe. Right: BLS model as implemented in the LHCb simulation.

The pulse generated from the PMT is then processed by an electronics limiter (LeCroy 612AM) which is able to limit the pulse between +0.2 and –5 V regardless of the input signal which can be as high as to –200 V. The limiter has two outputs that allow having the signal observed through an oscilloscope and a hardware readout system at the same time.

In view of the scope of the system as described earlier the readout of the BLS needs a hardware board which must be able to integrate and to read out the signal in short time scale (~ 25 ns clock cycle, 40 MHz). It is necessary to analyze the beam over a few turns (~ 5–10) at 25 ns time space just after each injection and also to monitor beam effects during a “stable” run, looking at the fine 25 ns structure of the beam. At injection, several problems — “marginal-over-injection” or “under-injection” effects, beam-beam effects (e.g. impedance effects) and misplaced bunches — can occur. It is therefore possible to predict wrong machine settings and injection timings or hardware failures. During circulating beam, misplaced bunches can surely lead to undesired effects as well as an undesired population of protons in the abort gap. LHCb is also the only detector really exposed to a possible dirty beam cleaning since the LHC betatron cleaning is located in one of the adjacent sectors.

Simulations of background estimates at injection and circulating beam are essential to know nominal rates from minimum bias p-p events and from beam halo enabling

* Corresponding author: talanov@ihep.ru. Work partly supported by the Russian Foundation for Basic Research grant No. 10-07-00435

to adjust the sensitivity of the instrument according to the available “dynamic range” of the readout and to set an adequate readout threshold.

THE BLS READOUT SYSTEM

In order to readout the signal generated by the scintillators complying with the requirements presented in the Introduction section, the LHCb Beam Phase and Intensity Monitor board (BPIM) has been chosen [2]. The BPIM is a custom-made board originally developed by the LHCb Online group to read out the signal generated from the beam pick-ups (BPTXs) dedicated to LHCb. Its main purpose is to measure bunch-by-bunch continuously at 40 MHz the intensity of the beam and the phase of the beam with respect to the LHC clock, allowing for a continuous monitoring of the beam. The board makes use of very fast current amplifiers and a high-performance TDC.

The board is also equipped with an ADC to digitize the analogue integration of the input pulse and an FPGA to process information and to perform online data analysis. Two FIFOs 16k deep and 16k wide will ensure an online storage of data to be retrieved by the Control System, interfaced by a server running on a Credit Card PC mounted on the board. The global LHCb bunch clock and orbit clock are fed to the board. This allows the board to identify a loss with a particular BXID. The system is aligned to the whole LHCb. The board has two general purpose ECL outputs and one general purpose 8-bit LVDS output that can be connected to the LHCb Readout Supervisor. A TTL input allows having a generic input to trigger the readout externally.

Two types of processing modes have been identified for the readout of the system:

- *Triggering on injection mode*: in this mode the BLS is triggered by an external pulse. This is the preferred mode during injection, where an LHC pre-pulse is transmitted to each board and each board records losses for more than 15 turns at 40MHz. This allows having a fine structure of the losses around the injection line.
- *Continuous readout mode*: each board continuously looks at losses measured by the scintillators. If a loss is above a programmable threshold, a running sum of 12 BXID is performed. In this mode, a full 25ns structure of each loss is recorded and the worse loss every 5 seconds is transmitted to the LHC and LHCb control room as a background estimation number.

BLS AND BACKGROUND ANALYSIS

The BLS system is not able to protect the machine from beam accidents since it is not connected to a hardware beam dump. It is however the only instrument able to observe fast losses from the beam in the LHCb experimental area whose information can be correlated with other instruments and with the detector data taking.

In the framework of a background study at the LHC, background protection and beam analysis, the LHCb experiment is publishing a series of background numbers BCKG 1-2-3 which correspond to different measurements of beam losses around the LHCb Interaction Point. BCKG1 value gives a measurement of normalized losses in the inner region of the detector, BCKG2 gives a measurement of normalized beam halo and BCKG3 gives the fraction of measured losses compared to the experiment abort threshold (so-called Dump threshold). BCKG1 and BCKG3 are constantly provided by the Beam Conditions Monitor (BCM) [3] and are the normalized (to a maximum scale of 100) measurements of beam losses respectively over 80 μs and 1280 μs and averaged over the upstream and downstream BCM stations. BCKG2 is provided by the Beam Loss Scintillator system themselves and the measurement is normalized to the beam energy in MeV and to a scale of 0–100.

RESULTS AND PERFORMANCE WITH THE FIRST LHC BEAMS

The Beam Loss Scintillator system was extensively used during first LHC beams. It was used during the commissioning of the LHC transfer lines (injection lines) for single bunch high intensity injection, multi bunch injection and trains injection, during the commissioning of the first LHC circulating and colliding beams and it is continuously used during the period of circulating beams at the LHC.

LHC Injection lines studies

Feedback to the machine was given in order to improve the settings of the injection line and to minimize beam losses around the experimental area. The background estimation was performed together with the BCM in order to cover a very large range of losses. When the losses are high, the BLS system tends to reach the saturation and the BCM becomes a more precise instruments. The two systems together exploit the full range of losses from small and fast ones (BLS) to large and accumulated ones (BCM). An example of how losses look like at injection around the LHCb experiment is provided in Fig. 2.

Background measurements

The BLS system is used for background estimation at LHCb. In particular the BLS provides the LHC machine with an estimation of the BCKG2 number which gives an indication of fast losses around the LHCb Interaction Point. This number has been decided to be calculated as the averaged loss of the two highest independent losses as detected by the two BLSs every 5 seconds.

Abort gap monitoring

By construction of the LHC machine, before each first bunch in each beam (Bunch ID = 1), there should be a 3 μs gap where no protons should be present. This gap is called

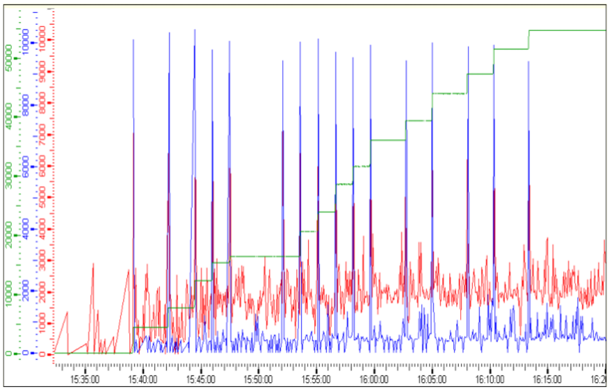

Figure 2: The BLSs show a typical structure of losses during injection of high-intensity multi-bunch in the machine. At each step an increase in beam intensity (green line) corresponds to a loss as measured by the BLS. The X axis shows time, on the Y axis are ADC counts in a.u.

abort-gap. For the LHCb purposes, the BLS provides a continuous monitoring of this gap, looking for possible distribution which could arise during periods of beam.

Independent luminosity measurement

The BLS system is extremely sensitive to colliding beams due to its position within the LHCb detector. By definition, such device can be used as a luminometer in order to obtain an LHCb-independent measurement of luminosity, pileup corrected.

The cross-section of the BLS system, expressed in μb, is calibrated with the LHCb L0CALO trigger rate, whose cross-section is known to a precision of about 10% from Monte-Carlo simulations. The BLS cross-section can be therefore expressed as a function of the HV chosen and the ADC internal threshold in the readout board and it is automatically changed whenever the two parameters are changed. Considering these two parameters, the cross-section can then vary between 50% and 90% of the LHCb cross-section. The BLS as a luminometer is used as the official online luminosity measurement during collisions whenever the L0CALO trigger is not running.

Moreover, thanks to the 40 MHz readout capabilities of the readout board, the BLS is the only system in LHCb which is able to measure online luminosity per bunch. This allows the experiment and the machine to study possible beam-beam effects for colliding bunches at the LHC and therefore exploit possible drop in luminosity or background increase around the LHCb Interaction Point. This information is constantly fed back to the machine coordinators for complementary studies.

THE BLS SIMULATION

Simulations of the BLS response to estimate the signal rates were performed for various conditions of the machine operation, to determine the BLS settings. The BLS geometry and material description, shown in Fig. 1, has been introduced in the common detector description database of the LHCb experiment. Dedicated algorithm and monitoring package have been written within the framework of the LHCb simulation application [4] based on Geant4 [5]. A digitization algorithm to produce the same signal from the BLS as the readout system is in preparation.

A couple of examples of the BLS simulation for the case of the p-p events in the IP at 450 GeV are given in Fig. 3. The figure on the left shows the distribution of the energy deposited per event in one of the two scintillators — a clear one MIP peak around 7 MeV is observed. The figure on the right shows the hit distribution vs. time, demonstrating that that most of the particles cross the BLS 7–8 ns after the collision takes place in the Interaction Point.

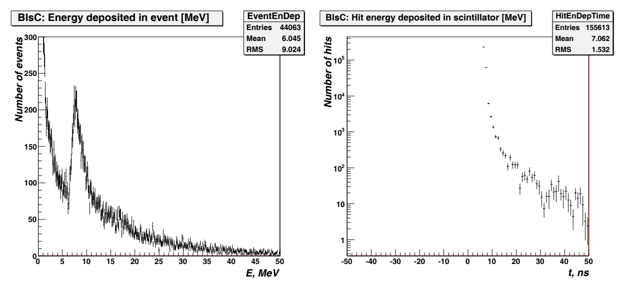

Figure 3: LEFT: Total energy deposited, MeV, in one BLS in the p-p event, RIGHT: Time profile of energy deposition.

CONCLUSION

LHCb has developed a complete system for beam and background monitoring at the LHC. The core of the system is a pair of scintillators with high speed and precision readout electronics. This system was initially intended to only look at fast losses during injection, while other uses of the system were exploited. The performance of system with the first LHC beams providing valuable information for background estimation, injection losses and behavior of the beam was described, and the results of the BLS response simulation were presented.

REFERENCES

[1] R. Dzhelyadin, "The injection beam monitor counter", EDMS document 935193, CERN, Geneva, 2010.

[2] F. Alessio *et al*, "A complete system for controlling and monitoring the timing of the LHCb experiment", CERN-THESIS-2008-007, Torino Univ., 2008.

[3] C. Ilgner *et al*, "The Beam Conditions Monitor of the LHCb Experiment", arXiv:1001.2487.

[4] The LHCb Collaboration, "LHCb Computing: Technical Design Report", LHCC 2005-019, CERN, Geneva, 2005.

[5] The Geant4 Collaboration, "Geant4 Developments and Applications", IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270–278.