DIAMOND MONITOR BASED BEAM LOSS MEASUREMENTS IN THE LHC

C. Xu*, B. Dehning, F. S. Domingues Sousa, CERN, Geneva, Switzerland
E. Griesmayer, CIVIDEC Instrumentation, Vienna, Austria

Abstract

Two pCVD Diamond based Beam Loss Monitors (dBLM) are installed near the primary collimators of the LHC, with a dedicated, commercial readout-system used to acquire their signals. The system is simultaneously able to produce a high sampling rate waveform and provide a real-time beam loss histogram for all bunches in the machine. This paper presents the data measured by the dBLM system during LHC beam operation in 2016.

INTRODUCTION

Diamond detectors with nanosecond time resolution and high dynamic range have been successfully tested and used in the LHC [1, 2]. Two diamond detectors are installed next to the primary collimators in the insertion region 7 (IR7) of the LHC for both beam1 (B1) and beam2 (B2).

The initial acquisition system used oscilloscopes to digitize the output of these diamond detectors, however, due to the lack of dedicated software, the beam loss measurements performed with this set-up was neither systematically logged nor analysed since the start of LHC Run2.

A dedicated commercial readout-system was therefore installed in order to better utilize the high time resolution provided by the diamond detectors. The data acquisition software was developed so that automatic data logging would be possible, and the system could provide valuable multi-purpose data for accelerator studies.

SYSTEM DESCRIPTION

Diamond Beam Loss Monitor

The diamond based detector system is comprised of poly-crystalline diamond detectors (CIVIDEC Instrumentation GmbH) with a size of $10 \, mm \times 10 \, mm \times 0.5 \, mm$ [3]. Each detector is connected to an AC-DC splitter, where the AC-part of the signal is amplified by a current amplifier with 40 dB gain and bandwidth of 2 GHz (both the AC-DC splitter and the preamplifier are provided by CIVIDEC Instrumentation GmbH). The detector system is mounted on a metal panel on top of the beam pipe, 6 meters downstream of the primary collimators (TCP) in IR7 (shown in Fig. 1). The coaxial cable which connects the detector system to the readout system is about 250 m long. The diamond detectors are operated with a bias voltage of 500 V.

Readout System

The detector signals are read out by the ROSY® data acquisition system also provided by CIVIDEC Instrumentation

Figure 1: dBLM installation in the LHC IR7.

GmbH. The ROSY® system comes with all the acquisition and triggering functionalities of a digital oscilloscope. In addition, an integrated FPGA provides dead-time-free online signal processing. The ROSY® system has an embedded Linux operating system and provides a programmable interface to control the system and transfer the acquired data. This system is installed in the LHC service tunnel and is connected to the CERN technical network via an Ethernet cable.

The ROSY® system is simultaneously able to produce a high sampling rate waveform and provide a real-time beam loss time histogram. In the histogram mode, the system synchronizes to the LHC turn clock and increases the corresponding bin when the loss signal exceeds a user defined threshold. The bin width is 1.6 ns. Figure 2 explains the operational principle of the histogram mode.
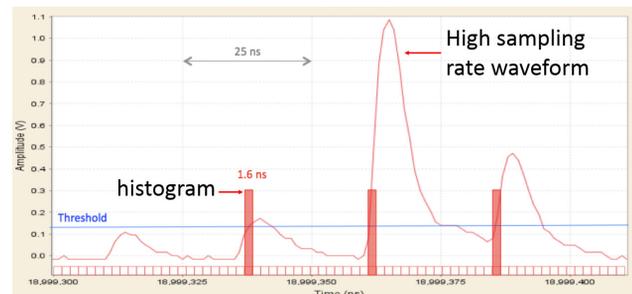
Figure 2: Beam loss signals exceeding a threshold causes the corresponding bin to increase in value [4]. The data is captured using the post-mortem application from CIVIDEC Instrumentation GmbH.

The ROSY® system has 4 analog input channels for the waveform measurement, each channel having a maximum

_____
* chen.xu@cern.ch

sampling rate of 5 GS/s (when using all 4 channels). A maximum buffer size of 1×10^9 samples is available to store the data from all 4 channels. The system's dead-time for transferring the data to the client application varies de-pending on the number of samples acquired. The 8-bit ADC has a vertical range from ±100 mV to ±5 V. Data acquisition is edge-triggered by one of the 4 channels, configurable before the acquisition is started.

DAQ Software

A Python script has been developed to configure the ROSY® system and store the detector data from both types of measurement for offline analysis. The script utilizes the PyJapc library [1] to obtain LHC machine status parameters, starting and stopping the data acquisition automatically de-pending on the machine status. The detector data are compressed and uploaded to the CERN EOS file system [5] for long term storage. An independent graphical user interface (GUI) has been developed to provide online monitoring and a quick review of the detector data without interrupting the data acquisition process. Figure 3 shows a screenshot of the GUI software, in which the time loss histogram is visible in the top plot and beam loss signal waveforms from multiple LHC turns are shown in the bottom plot. In this particular case both data sets were simultaneously acquired during an LHC beam injection in 2016.
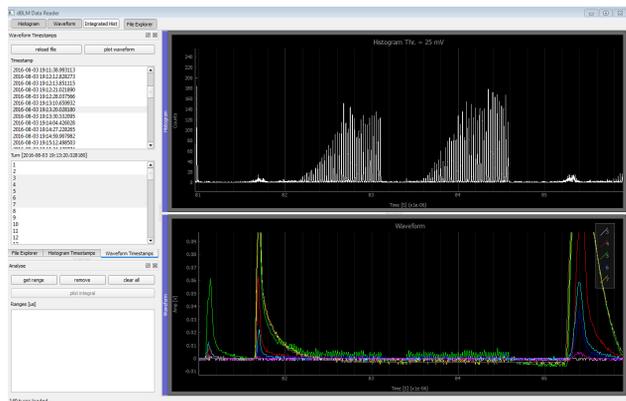
Figure 3: A screenshot of the GUI software for online monitoring of the dBLM data acquired by the ROSY® system.

BEAM LOSS MEASUREMENT

Time Loss Histogram

As described previously, the time loss histogram accumulates the static beam loss over multiple turns for each 1.6 ns of the 88.9 µs LHC turn period.

Figure 4 shows a time loss histogram of beam1 acquired during the stable beam period of one particular fill, when the beams are colliding for physics. The time structure of the LHC beam can clearly be resolved from the histogram. The

---

[1] PyJapc is a python interface to CERN Java API for Parameter Control, developed by the CERN Beam-Instrumentation department.

total width of the histogram corresponds to the 88.9 µs LHC turn period. During this fill, there were in total 2076 bunches in the machine, constructed of one 12-bunch train, one 48-bunch train and 21 96-bunch trains. The gaps between the bunch trains correspond to the LHC injection gaps, required to accommodate the risetime of the injection kickers. The large, 3 µs gap preceding the 12-bunch train is the beam abort gap, required to accommodate the risetime of the LHC beam dump extraction kickers. The losses visible in the beam abort gap mainly come from crosstalk with the other beam, with its 96-bunch time structure clearly visible during this period.
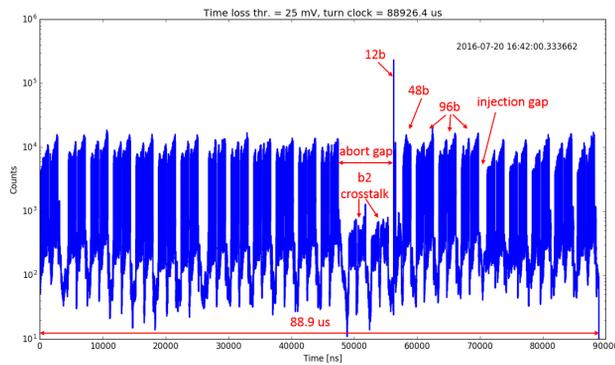
Figure 4: Time loss histogram of beam1 during physics operation in stable beam.

Figure 5 shows a zoom-in view of the 12-bunch train from the same histogram. It shows that beam loss from a single bunch is contained within 4 bins, corresponding to 6.4 ns. The 25 ns bunch spacing can clearly be resolved from this histogram.
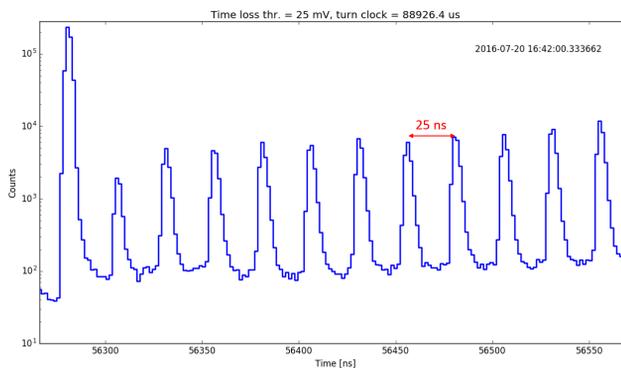
Figure 5: Zoom-in view of the 12-bunch train.

The evolution of the time loss histogram can give information about changing beam loss patterns or rates. In order to be able to calculate beam loss variations through changes to the time loss histogram, the DAQ software records the evolution of the histogram every second.

On July 20th 2016, a time loss histogram was acquired parasitically during an end of fill machine development (MD) experiment intended to measure the transverse beam halo population. During the experiment, a primary collimator

(TCP) in IR7 was moved towards the beam core to scrape away any beam halo. Higher than normal beam loss was therefore created when the beam halo was intercepted by the TCP jaws. Figure 6 shows the beam loss recorded by a standard ionization chamber BLM at the same location as the dBLM during this process.
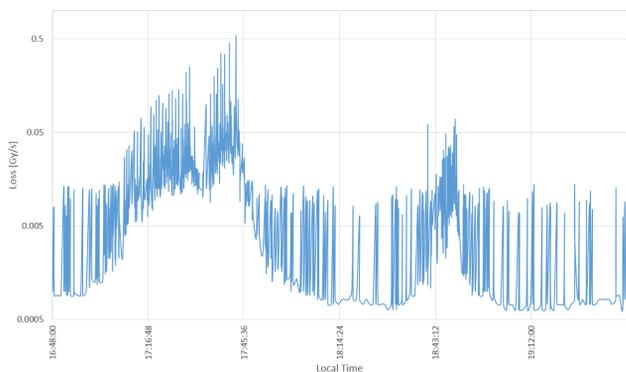
Figure 6: Beam loss recorded by an ionisation chamber BLM at the same location as the dBLM during halo scraping.

The top plot of Fig. 7 shows the time loss histogram recorded by the dBLM system during the same time period. By integrating the bin contents of the 12-bunch and 48-bunch trains separately and plotting the integrated counts as a function of time, the beam loss evolution corresponding to the two separate bunch trains can be obtained (as shown in the bottom plot of Fig. 7). The result indicates that losses from the 12-bunch train are significantly larger than from the 48-bunch train. It is worth noting that the loss evolution calculated from the evolution of the time loss histogram does not directly correspond to the total loss seen by the ionisation chamber. This can be explained by the fact that the histogram does not take into account the size of the loss, increasing as long as the loss signal from the beam exceeds the threshold, regardless of the amplitude.
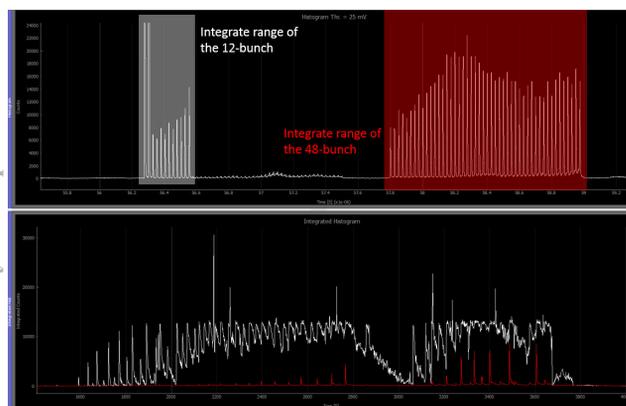
Figure 7: Time loss histogram of beam1 during a halo scraping experiment. Snapshot of the 12-bunch and 48-bunch train histogram (top) and loss evolution of each train (bottom).

Waveform

Two channels of the ROSY® system are used to record the dBLM detector signal and LHC turn clock respectively. The LHC turn clock is used to align the waveform signal from the dBLM to the beam time structure that is resolved by the time loss histogram data. In this way, the beam loss amplitude can be associated to a single bunch on consecutive turns with an uncertainty of ±1 bin.

The bottom plot of Figure 8 shows the waveform data acquired during eight consecutive turns after the injection of 96 bunches (2 closely spaced trains of 48 bunches) into a machine with 48 bunches already circulating. In the same figure, the top plot shows the time loss histogram accumulated during the whole injection process. Using the LHC turn clock, the beam loss signature shown in the waveform can be associated to the location of the loss within the 88.9 μs revolution period. The large beam loss signal before and after the bunch train in the waveform corresponds to the beam out of the main buckets from the SPS injector which is injected into the LHC during the rise or fall time of the LHC injection kicker (referred to as the recaptured beam in [2]). While most of this beam is intercepted by collimators in the injection region, their loss signature near the primary collimator in IR7 can be seen to last up to 100 turns. The first loss signal in the waveform data is due to the tail of the circulating beam being affected by the injection kicker field.
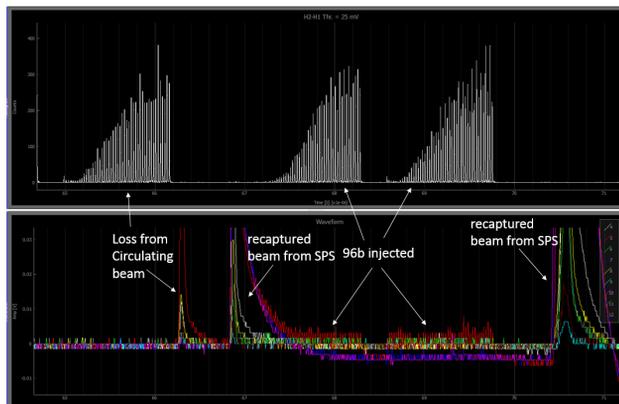
Figure 8: LHC injection loss recorded by the dBLM in IR7.

SUMMARY

The dBLM and its associated DAQ software has shown that it is capable of achieving the goal of providing useful data for further understanding beam dynamics in the LHC and optimizing its operation. The system can automatically configure and start the acquisition for predefined periods of interest, and logs the data for offline analysis. Further development is now underway to fully integrate the system into the LHC control and logging infrastructure.

ACKNOWLEDGEMENT

The author would like to thank G. Valentino and F. Burkart for their helps in understanding the dBLM data, and R. Jones for proofreading the paper and his valuable inputs.

REFERENCES

[1] F. Burkart et al. , "Diamond particle detector properties during high fluence material damage tests and their future applications for machine protection in the LHC," in proceedings of IPAC14, Shanghai, China

[2] F. Burkart et al. , "Investigation of injection losses at the LHC with diamond based particle detectors," in proceedings of IPAC16; Busan, Korea

[3] CIVIDEC Instrumentation GmbH, http://www.cividec.at

[4] H. Frais-Kölbl et al. , "A prototype readout system for the diamond beam loss moni-tors at LHC," in proceedings of IBIC13, Oxford, UK

[5] CERN EOS, https://eos.readthedocs.io