A PROTOTYPE READOUT SYSTEM FOR THE DIAMOND BEAM LOSS MONITORS AT LHC

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Abstract

Diamond Beam Loss Monitors are used at the LHC for the measurement of fast beam losses. In this note, specimen LHC loss measurements with the prototype readout system “ROSY” from CIVIDEC are presented. The readout system is FPGA-based for on-line, real-time, and dead-time-free data processing, including a Linux-based server for the interconnection to a GUI. The loss analysis makes full use of the fast signal response of the diamond detectors with 1 ns time resolution and 6.7 ns double pulse resolution. Two examples are presented: applications of the Time Loss Histogram with 1.6 ns binning and 1.2 ns time jitter for loss measurements that are synchronized with the LHC revolution period and a beam-loss-based tune measurement for all circulating bunches in parallel.

LHC BEAM LOSSES

The beam losses in the LHC are concentrated at two locations where collimators scatter off orbit and off momentum protons. At these locations losses occur during all operational phases of a proton fill. From injection losses lasting only few turns up to steady state losses during the operation with colliding beams. The time structure of the losses is given by the time structure of the circulating protons. Under nominal conditions the protons are concentrated in bunches spaced by 25 ns. These conditions could be violated by false manipulations, but also by physical effects. To control the proton bunch spacing a loss detector and acquisition system with a time resolution of about 1 ns is needed.

Figure 1: Diamond Beam Loss Monitor.

Losses from different bunches could have very different loss amplitudes. The time structure of the bunch distribution along the ring is not symmetric and single or groups of bunches may experience different excitations. To allow high sensitivity loss measurements single particle detection capability of the detector is of advantage. These loss measurements could be analysed digitizing the amplitude signal e.g. for bunch-by-bunch loss variation over several turns. The dynamic range of the system is limited by the electronic acquisition chain.

For repetitive losses lasting over seconds or minutes an accumulation of counts of signals exceeding a threshold will results in measurements, which could span over several order of magnitudes. Especially rich information could be gained by synchronising counters with the revolution period of the accelerator and creating a loss arrival time histogram.

DIAMOND BEAM LOSS MONITOR

The diamond beam loss monitors (Figure 1) consist of pCVD diamond detectors, 10 mm x 10 mm x 0.5 mm in size with gold electrodes of 8 mm x 8 mm on both sides. The diamond detectors are operated with a bias voltage of 500 V, which corresponds to an electric field strength of 1 V/um. Currently ten pCVD diamond beam loss monitors are installed at the LHC and the SPS.

The diamond detectors are connected to an AC-DC splitter, where the DC-part of the loss signal has an upper cut-off-frequency of 1.6 Hz (considering a 1 MΩ input impedance of an electrometer amplifier).

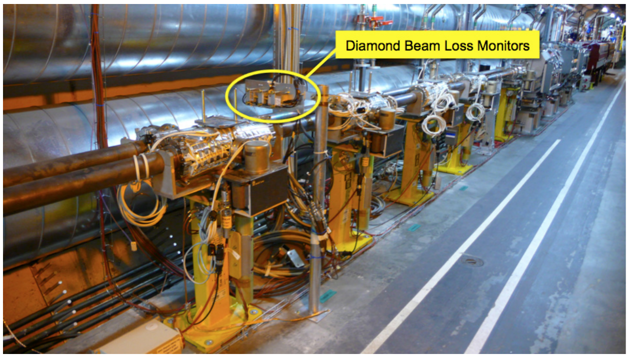


Figure 2: Location of the Diamond Beam Loss Monitor.

The AC path is connected to a 2 GHz broadband current amplifier with 40 dB gain. This has a lower cut-off frequency of 25.6 kHz and an effective upper -3 dB cut-off frequency of 850 MHz. On this channel, the losses can be recorded on a bunch-by-bunch basis, whereas the DC channel measures the dark current of the detector and the DC losses. The Diamond Beam Loss Monitor used for the measurements is mounted in the LHC collimation area in IP7 on the lefthand side (TCLA.D6L7.B2). See Figure 2.

A low-pass filter is foreseen for the DC measurement. The effective cut-off frequency of this filter depends on the input impedance of the used electrometer amplifier.

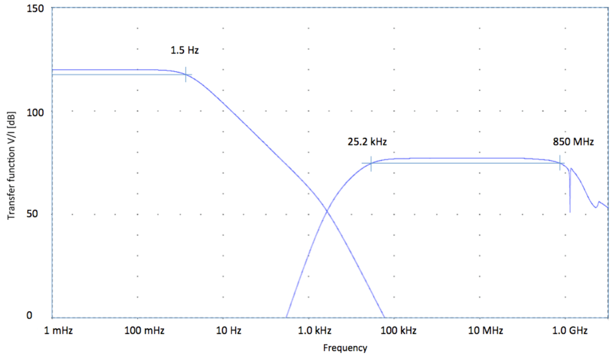


Figure 3: Transfer function of the diamond beam loss monitor (PSpice simulation).

In the case of a 1 MΩ input impedance of the electrometer amplifier, the cut-off frequency is 1.6 Hz. The corresponding transfer functions are shown in Figure 3. CK50 RF cables with a length of 250 m run from the diamond detectors to the readout system [1].

PROTOTYPE READOUT SYSTEM

General

A prototype readout-system ROSY (Figure 4), designed and built for the data acquisition from the LHC Diamond Beam Loss Monitors. It provides on-line, dead-time-free acquisition and processing of the detector signals.

ROSY contains the full acquisition and trigger functionalities of a digital oscilloscope. Data is processed in real time in the integrated FPGA.

Figure 4: ROSY with four analogue input channels.

The following applications are implemented:

1. A digital oscilloscope with 4 channels and 5 GS/s.
2. A Time Loss Histogram with 1.6 ns binning.
3. A Post Mortem Recorder with up to 1 GB memory.

Results are transferred from the FPGA memory via an internal USB 2.0 interface to the embedded Linux-based device server and from there via Ethernet to the control system, or to the client software, where the graphical user interface provides access to the data for on-line monitoring.

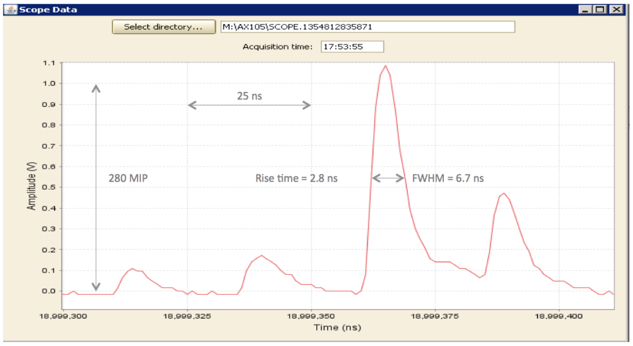
Scope Mode

The scope mode acts like a standard digital oscilloscope with four channels and a sampling rate of 5 GS/s. In Table 1 the general parameters are summarized.

Table 1: ROSY - General Parameters

Analog inputs:	4
Sampling rate :	5 GS/s (1.25 GS/s per channel)
Analog bandwidth	350 MHz
ADC resolution	8 bit
Input impedance	50 Ω

The plot in Figure 5 shows the beam losses of four subsequent bunches with a bunch spacing of 25 ns. The timing and amplitude parameters of the loss signals are given in Table 2.



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Acquisition time: 17:53:55

Figure 5: Pulse shape of the losses in scope mode as recorded with one of the diamond beam loss monitors.

Table 2: Loss Signals - Timing Parameters [2,3]

Rise time:	2.8 ns
FWHM:	6.7 ns
Fall time:	6.2 ns
Amplitude response:	3.6 mV/MIP
Resolution:	1 MIP
Dynamic range:	1:1000

Time Loss Histogram

The principle of the Time Loss Histogram application shown in Figure 6 provides the histogram of the losses

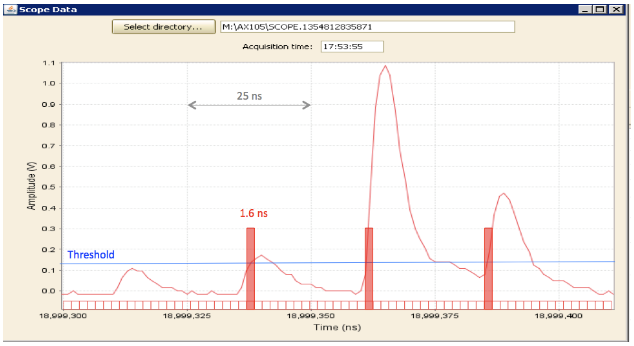

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Figure 6: Losses and Time Loss Histogram.

referenced to the LHC turn clock and accumulated in a corresponding time interval. The signal is discriminated with a threshold. The corresponding bin counter is incremented when the signal exceeds the threshold.

The maximum revolution period is 100 us, which corresponds to the implementation of 62'500 counters with 32 bits. The bin width is 1.6 ns. For the 88.924 us revolution period of the LHC, 55'750 counters are used.

Time Resolution

A 40 MHz reference signal was used for the determination of the time resolution. Figure 7 shows the Time Loss Histogram with a separation of 25 ns and 1.6 ns binning. Each signal produces a time distribution which is 2-3 bins wide. The rms value of this time distribution corresponds to the time resolution. The time resolution of the Time Loss Histogram is 1.2 ns. Figure 8 shows a Time Loss Histogram taken during the operation of the LHC at a bunch spacing of 25 ns.

TIME LOSS MEASUREMENT

The following measurements are done with the diamond BLM BLMED.06L7.B1E10_ TCHSS.6L7.B1, which is located directly downstream of the primary betatron collimators for beam 1 in IR7. The measurements were taken during the 25ns run in December 2012.

Steady-State Losses

Figure 7 shows a measurement of the steady-state losses after the energy ramp to 4 TeV with 25ns bunch-spacing. The time structure of the LHC beam is clearly resolved: the 89.2 us turn period, the 3 us beam abort gap, the first 12 bunches followed by the main bunch trains of 2 or 4 times 72 bunches, intercepted by the 1 µs LHC injection gaps, and the 0.2 µs SPS injection gaps.

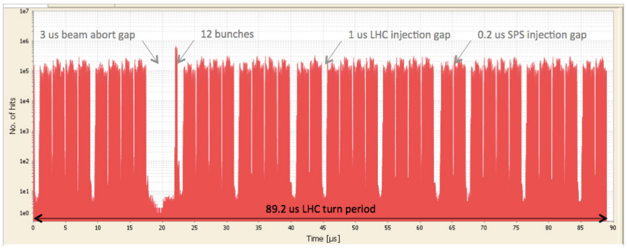

Figure 7: Steady-state losses at top energy.

Injection Cleaning

Figure 8 shows measurements taken directly before the injection of a new bunch train. The injection cleaning by the transverse damper excites the (unbunched) beam in a dedicated region with white-noise. This leads to corresponding beam losses to depopulate this region prior to the next injection. Figure 11 illustrates the (bunched) losses from the circulating beam and the (unbunched) losses due to the injection cleaning. The injection cleaning starts 1us after the last circulating bunch.

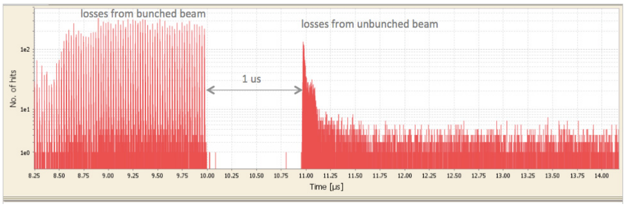

Figure 8: Injection cleaning.

Cross Talk

The measurement in Figure 9 shows losses around the first six nominal bunches during the energy ramp. The smaller bunched loss-spikes are thought to be due to satellite bunches and cross-talk losses created from the other beam. The satellite bunches have a time difference of n×25 ns from the nominal bunches, which indicates that these losses are coming from the same beam. The cross talk loss can be seen as small spikes which do not match the 25 ns pattern of the main losses. The cross talk loss is separated by three orders of magnitude from the normal losses for this case.

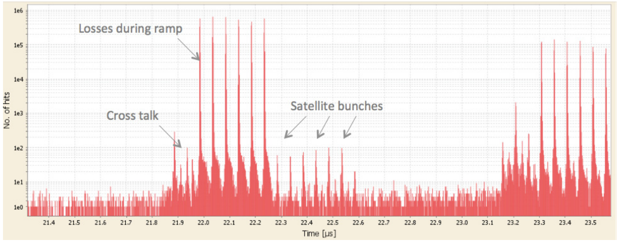

Figure 9: Losses during ramp.

Beam Abort Gap Cleaning

The Figure 10 shows unbunched losses due to the beam abort gap cleaning followed by bunched losses from a single nominal bunch, 12 nominal bunches and one batch of 72 bunches. The bunched beam losses increase along the 72-bunch batch due to electron-cloud build-up, which is mainly affecting the later bunches in the batch.

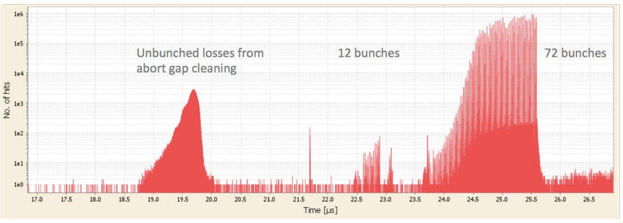

Figure 10: Unbunched beam losses due to beam abort gap cleaning.

The electron-cloud effect is initiated by the proton beam synchrotron light photons releasing electrons at their impact on the vacuum chamber wall. These initial electrons are accelerated in the electrical filed of the proton beam releasing also electrons from the wall at impact. An avalanche effect is occurring reaching a density that the circulating protons are significantly

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scattered and measureable losses occur. Losses from the beam abort gap cleaning are becoming higher towards the righthand side (maximum at 19.7 us), which indicates that the losses are due to particles with a negative momentum deviation ($dp/p < 0$).

Single Bunch Instability

Figure 11 shows two single bunches becoming unstable at the end of the squeeze (i.e. while reducing the transverse beam size by strong focusing in the low-beta insertions) at a beam energy of 4 TeV. The losses from the unstable bunches are three orders of magnitude higher than the steady-state losses.

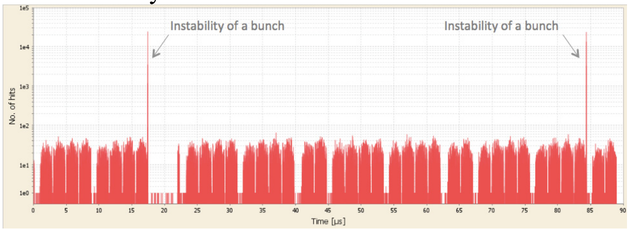

Figure 11: Single-bunch instabilities.

This effect has been observed in several fills in 2012 and was reproducible. The reason is related to a reduction of the beam-beam separation and a corresponding crossing of an instable regime. The modelling of this process is difficult, and all input from additional diagnostics is very valuable.

TUNE MEASUREMENT

Bunch-by-bunch tune estimates have been derived from beam loss measurements. The loss measurements were made on Beam1 with a sampling frequency of 1 GS/s. The data was taken during the EOF test of the beam-beam MD on 13.12.2012, when Beam 2 was dumped first, which led to a coherent oscillation of Beam1 due to the sudden absence of the long-range Beam-Beam deflections.

The acquired data allows the determination of the fractional tune values for all circulating bunches at the same time on a bunch-by-bunch basis.

The frequency resolution is limited by the length of the buffer used. This may be significantly improved with a new acquisition system after LS1, where a buffer size up to 1 GS might be available. The used buffer length of 18 ms corresponds to about 200 LHC turns.

After a base-line correction, the measured turn-by-turn beam losses for each bunch are converted to the frequency spectrum via a FFT. Figure 12 shows a bunch-by-bunch tune estimate for four bunches. The FFT frequency resolution df/f depends on the length of the buffer. The desired df/f = 10^{-4} requires 10^4 turns of the 11 kHz turn period to be recorded.

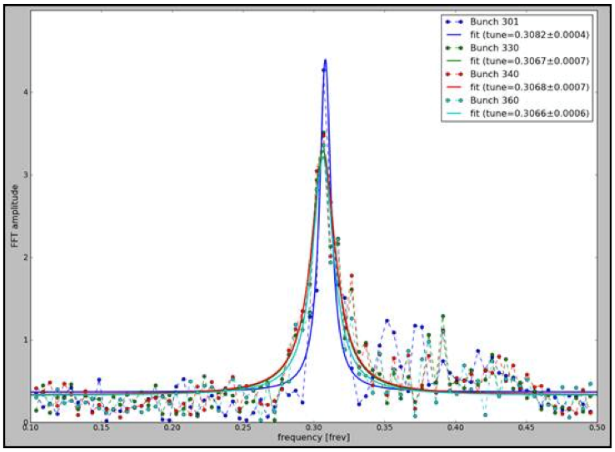

Figure 12: The frequency spectrum of the four bunches.

The frequency spectrum of the four bunches shows a tune of 0.3082, 0.3067, 0.3068 and 0.3066 with a maximum error of $\pm 7\text{x}10^{-4}$. The nominal tune values according to the BBQ are 0.307 for the horizontal tune and 0.320 for the vertical tune.

SUMMARY

The prototype readout systems ROSY AX106 was used for beam loss measurements with the LHC diamond beam loss monitors. The turn loss histogram with its 1.6 ns binning showed a time resolution of 1.2 ns. The measurements included steady-state losses, losses due to injection and beam abort cleaning and inter-beam cross talk. Loss-based bunch-by-bunch tune measurements were shown to be feasible using the post-mortem application. The tune resolution could be improved to ±7x10-4 by fitting a modified Lorentz-function. The underlying FFT resolution is limited by the available buffer length of presently 32 MS and could be significantly improved with a larger buffer of 1 GS.

ACKNOWLEDGMENT

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