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. 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. The Time Loss Histogram has 1.2 ns time jitter for loss measurements that are synchronized with the LHC revolution period. Beam-loss-based tune measurements are feasible.

The **Diamond Beam Loss Monitors** 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.

Figure: Diamond Beam Loss Monitor.

Time Loss Histogram

The **Time Loss Histogram** provides the time information of the losses 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 time interval 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.

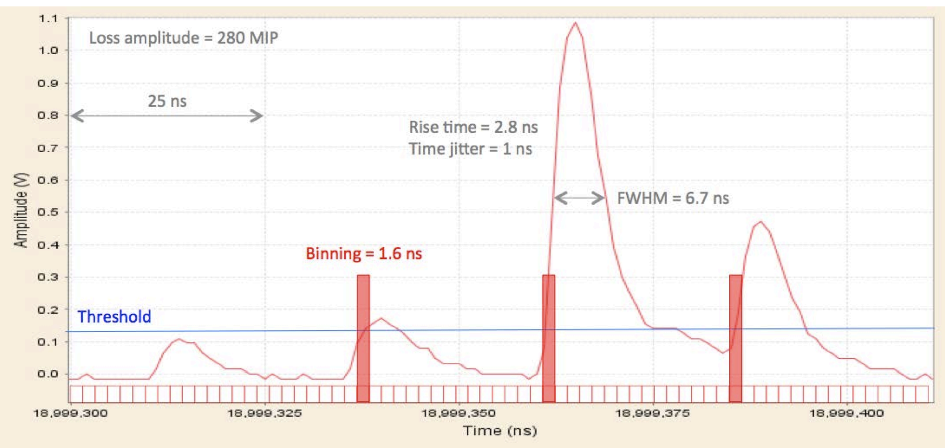

Figure: Pulse shape of the losses of a diamond beam loss monitor.

Time Resolution

A 40 MHz reference signal was used for the determination of the time resolution. The figure 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.

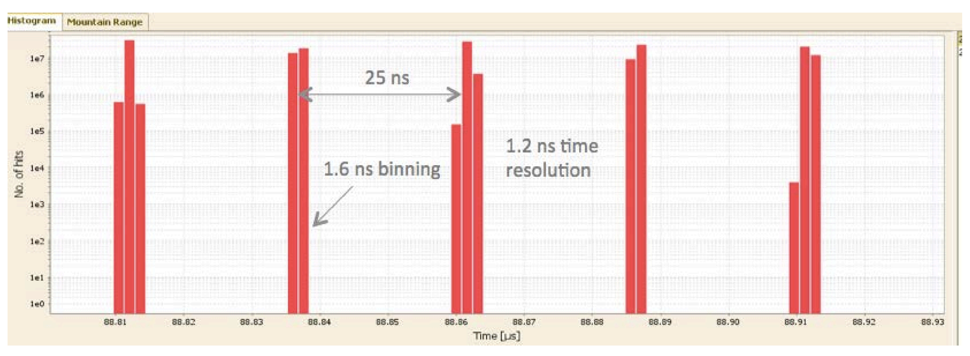

Figure: Time resolution of the Time Loss Histogram.

Steady-State Losses

The figure shows a measurement of the steady-state losses after the energy ramp to 4 TeV with 25 ns 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 us LHC injection gaps, and the 0.2 us SPS injection gaps.

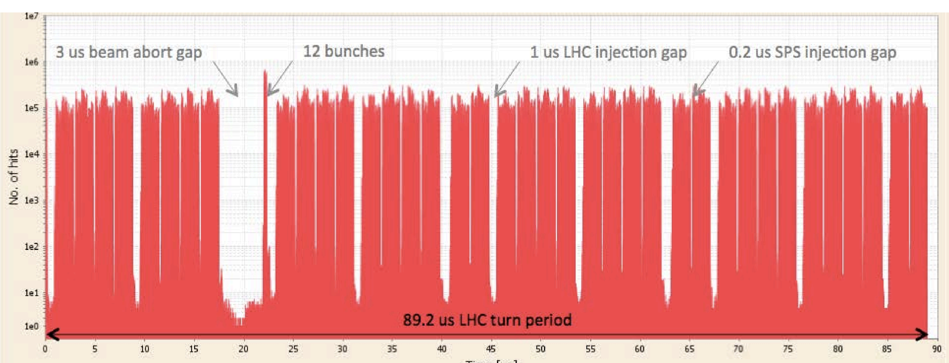

Figure: Steady-state losses at 4 TeV.

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). Currently ten Diamond Beam Loss Monitors of this type are installed at the LHC. In the collimation areas two in Point 3, two in Point 6 and two in Point 7, in the LHC injection area one in Point 2 and one in Point 8, and two at the SPS extraction.

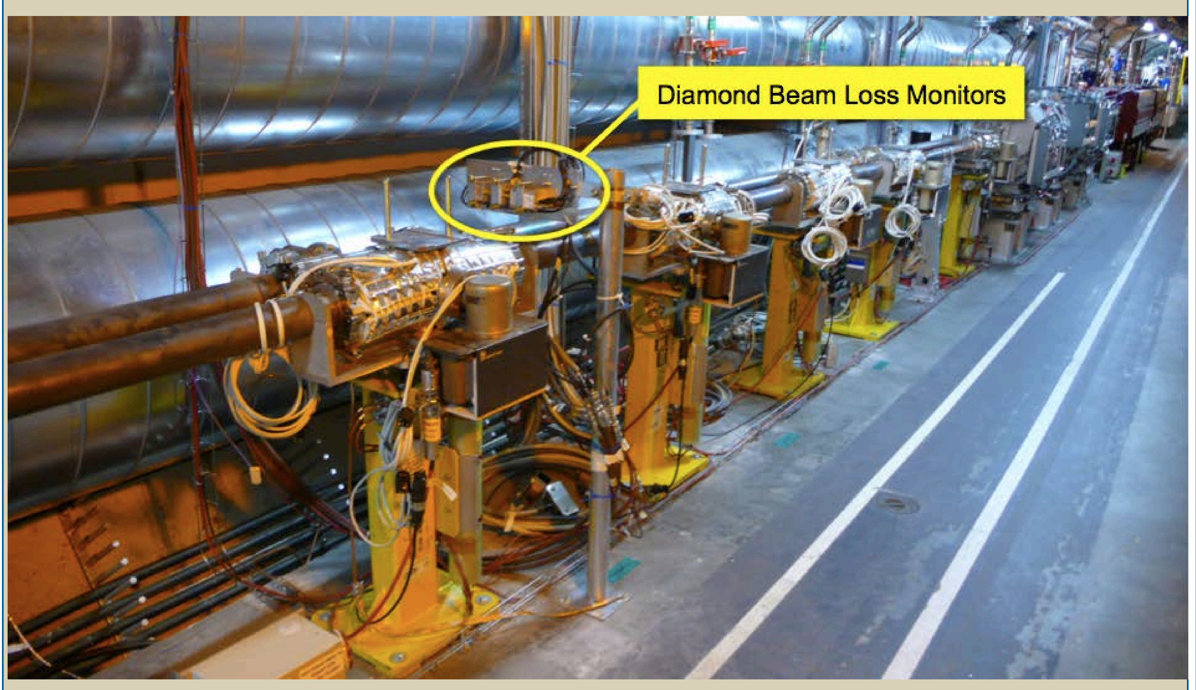

Figure: Location of the Diamond Beam Loss Monitor in the LHC IP7.

Tune Measurement

Bunch-by-bunch tune estimates have been derived from beam loss measurements. The loss amplitude over the number of turns for four different bunches is shown in the bottom figure. Loss measurements were made on Beam1 with a sampling frequency of 1 GS/s. 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.

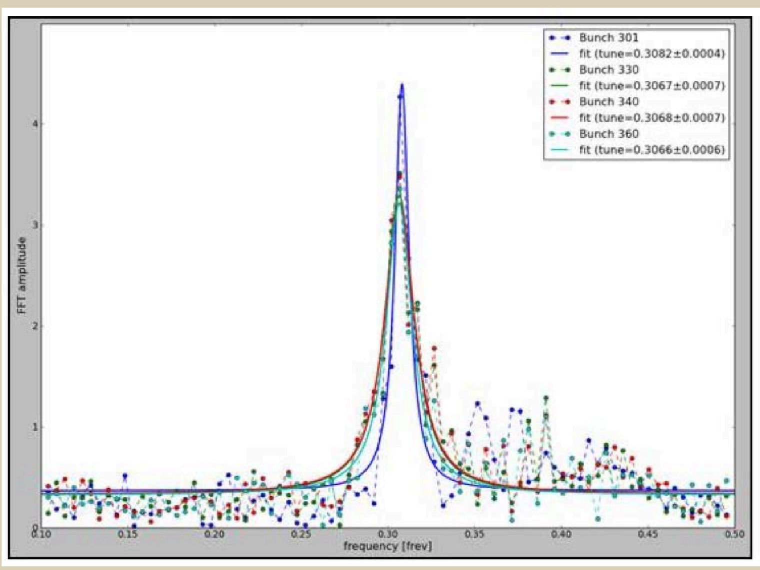

Figure: The tune measurement is represented by the frequency spectrum of four bunches which shows a tune of 0.3082, 0.3067, 0.3068 and 0.3066 with a maximum error of ±7x10^{-4}.

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 an upgraded acquisition system after LS1, where a buffer size up to 1 GS will be available. The used buffer length of 18 ms corresponds to about 200 LHC turns.

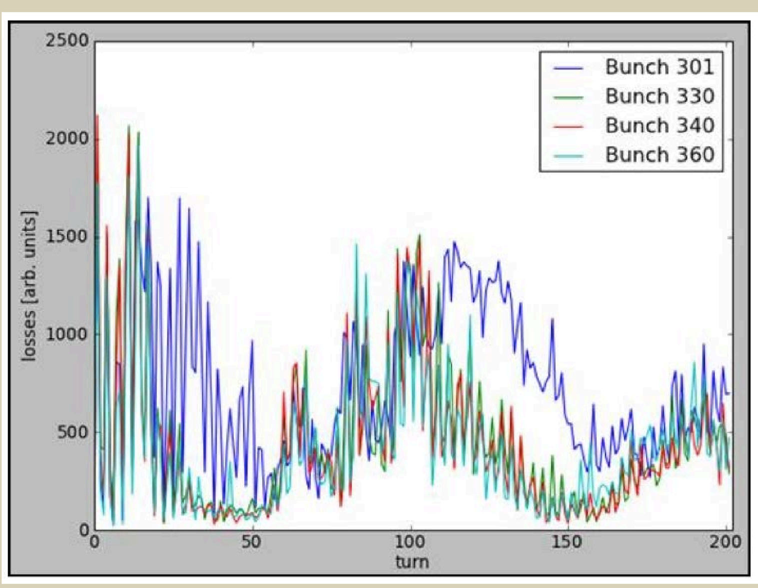

Figure: Turn-by-turn beam losses of four individual bunches over 200 turns.

After a base-line correction, the measured turn-by-turn beam losses for each bunch are converted to the frequency spectrum via a FFT. The top figure shows a bunch-by-bunch tune estimate for four bunches. The nominal tune values according to the BBQ are 0.307 for the horizontal tune and 0.320 for the vertical tune.

ROSY - a prototype readout-system was designed 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. 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.

Figure: ROSY – The Diamond Readout System.

The following applications are implemented:

1. A digital oscilloscope with 4 channels, 5 GS/s, 350 MHz.
2. A Time Loss Histogram with 1.6 ns binning and 1.2 ns time resolution.
3. A Post Mortem Recorder with 4 channels and up to 1 GB memory.

Single Bunch Instability

The figure 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: Single-bunch instabilities.

Cross Talk

The measurement 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.

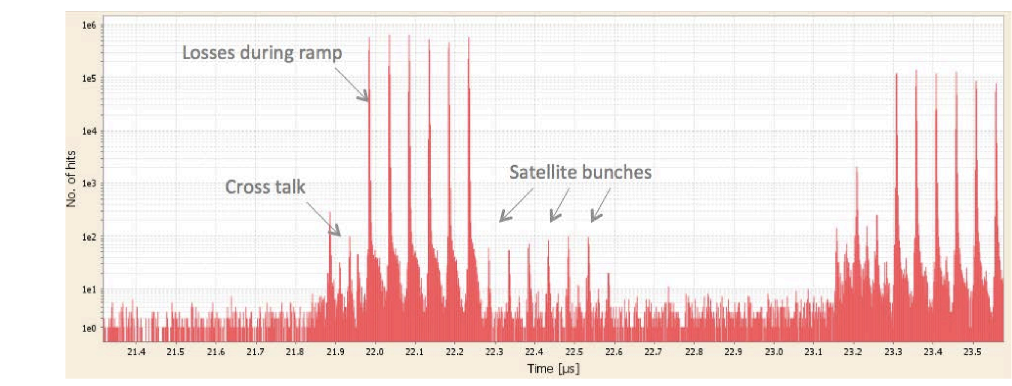

Figure: Losses during ramp.

Injection Cleaning

Measurements were 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. The figure illustrates the (bunched) losses from the circulating beam and the (unbunched) losses due to the injection cleaning. The injection cleaning starts 1 us after the last circulating bunch.

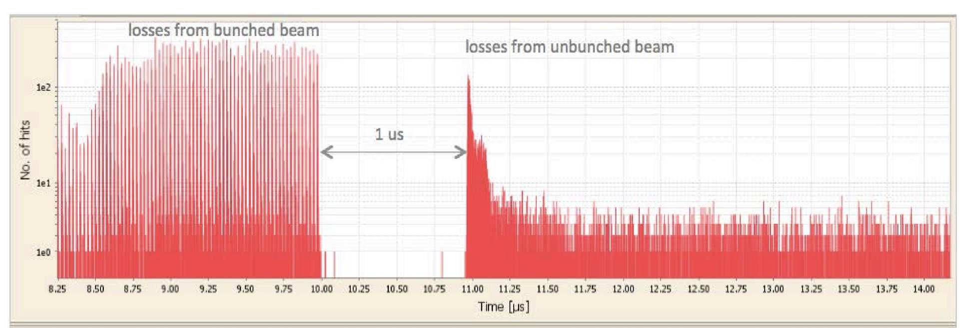

Figure: Injection cleaning, losses from bunched and unbunched beams.