DIAMOND DETECTORS FOR LHC

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Abstract

Diamond detectors are installed at the LHC as fast beam loss monitors. Their excellent time resolution [1] make them a useful beam diagnostic tool for bunch-to-bunch beam loss observations [2], which is essential for the understanding of fast beam loss scenarios at the LHC [3, 4].

INTRODUCTION

Diamond is probably the most versatile, efficient and radiation-tolerant material available for use in beam detectors. Correspondingly, it has a wide range of applications in beam instrumentation and in beam diagnostics. Currently ten diamond detectors are in use as fast beam loss monitors at the LHC at CERN. The nanosecond time response in combination with the sensitivity to single particles makes them ideal for use in fast beam loss detection. A beam dump caused by a so called UFO, an "unidentified falling object", is shown. UFOs are believed to be dust particles with a typical size of a few micrometers, which lead to beam losses, which last about ten revolutions of the proton beam.

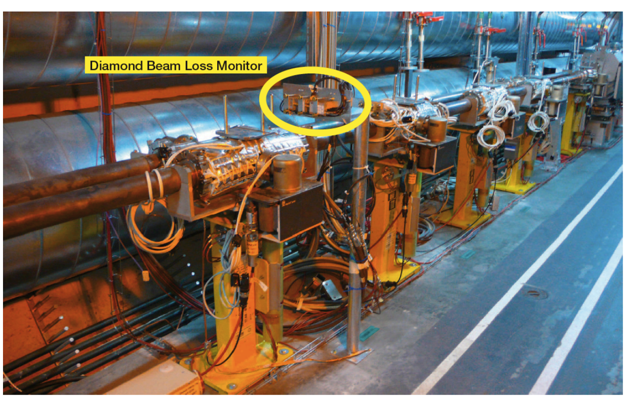

Figure 1: Installation of a Diamond Beam Loss Monitor in the LHC tunnel in IP 7.

THE DIAMOND MONITORS

The diamond monitors were provided by CIVIDEC Instrumentation and installed at TCLA.D6L7.B2. They are composed of a diamond detector (pCVD diamond material, substrate size 10 mm x 10 mm x 0.5 mm, gold electrodes 8 mm x 8 mm, operated at 500 V bias voltage), a 4 GHz AD-DC splitter, and a 2 GHz, 40 dB RF amplifier. A CK50 cable with a length of about 300 m connects the beam loss monitor the readout instrumentation. A LeCroy oscilloscope was used for the digital readout (Waverunner 104MXi, 1 GSPS, 1 GHz, 8 bit ADC). The installation of the diamond beam loss monitor in point 7 is shown in Figure 1.

SPACIAL LOSS PROFILE

A beam abort, which was obviously caused by an UFO event in the injection area in point 4, was recorded on the 27th of August 2012 with a diamond beam loss monitor, which was located in the cleaning area in point 7. Figure 2 shows the spacial loss profile of this event, i.e. the recorded loss amplitude versus the 89 μs turn period of the LHC.

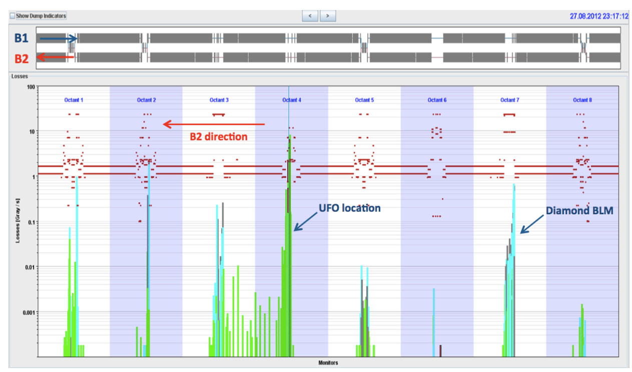

Figure 2: Spatial loss profile versus the LHC turn period of 89 μs. Beam abort event caused by an UFO.

In the following figures, data of the beam abort event, taken with the diamond beam loss monitor, are shown. Starting with a buffer size of 500 μs, a zoom into the memory in four stages is provided. Each zoom reveals insights into the loss structure of the LHC.

The 500 μs Zoom

The Figure 3 shows the loss profile in a time window of 500 μs. The beam losses increase over a period of some microseconds and the dump causes a high pulse at the end of the loss pattern. The tree beam abort gaps define the revolution period of the LHC.

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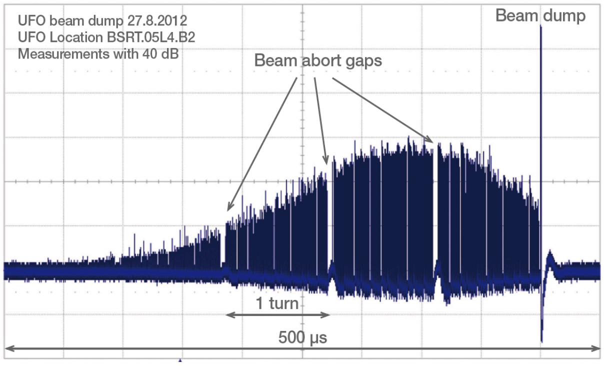

Figure 3: 500 µs zoom; UFO location in Point 4, recorded in the collimation area in Point 7 with a 10x10x0.5 mm3 diamond detector with 40 dB signal amplification. The length of the loss is about 0.5 ms. Beam abort gaps are clearly resolved.

The 100 µs Zoom

In Figure 4 the zoom of 100 µs indicates the time structure of the bunch trains within one turn.

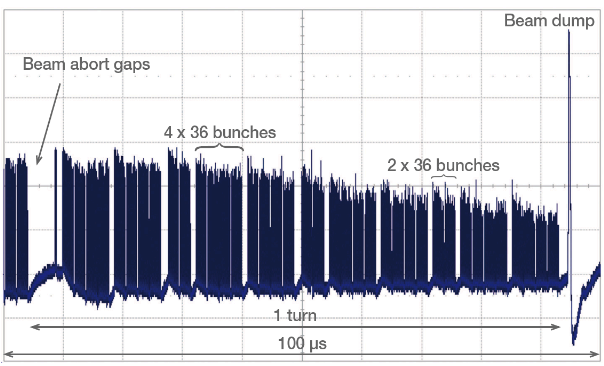

Figure 4: 100 µs zoom; the beam abort gap, and the bunch structure is resolved: a pattern of two 4x36 bunches and one 2x36 bunches are periodically cycling in the LHC. The losses caused by the beam abort are synchronous to the beam abort gap.

The 10 µs Zoom

The individual bunch trains can be resolved in Figure 5, which shows a 10 µs zoom of the data. The LHC injection gap and the SPS injection gaps separate individual bunch trains.

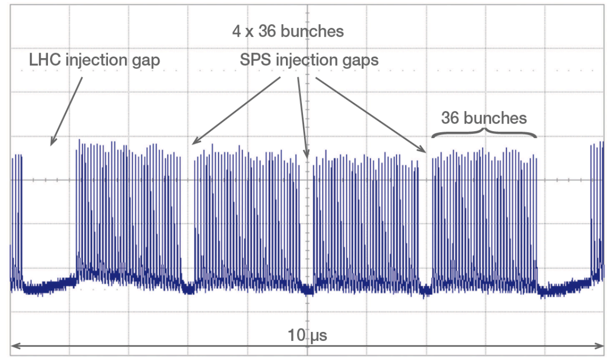

Figure 5: 10 µs zoom; the structure of 4x36 bunches is resolved. The LHC injection gap and the SPS injection gaps separate the bunch trains containing 36 bunches each.

The 2 µs Zoom

The Figure 6 shows a 2 µs zoom and resolves the 32 bunches which are in this bunch train. Also, the 50 ns bunch spacing is visible. All bunches inside a batch contribute to the beam losses, as it is expected for a macro particle interaction.

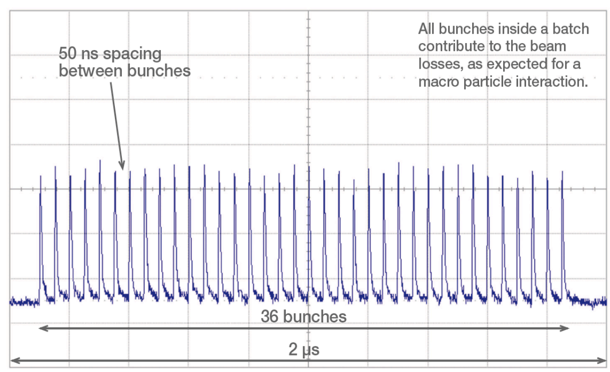

Figure 6: 2 µs zoom; the bunches are separated by 50 ns, 36 bunches form a batch. It is remarkable that all bunches inside a batch contribute to the beam losses, as expected for a macro-particle interaction.

The 200 ns Zoom

In the 100 ns zoom of Figure 7 the single bunches are resolved, the 50 ns bunch separation can clearly be identified and all pulse parameters can be determined. In this example the amplitude of the left bunch is 397 mV, the rms baseline noise is 9.9 mVrms, the rise time is 2.34 ns, the pulse width is 6.06 ns and the fall time is 10.34 ns.

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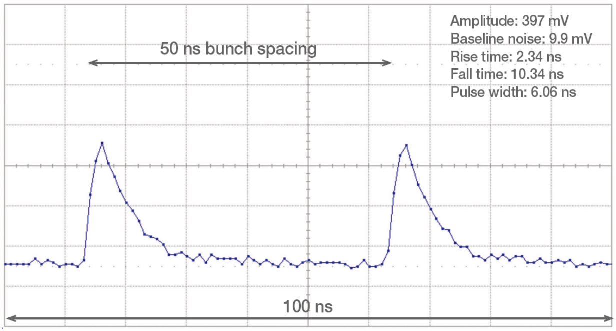

Figure 7: 100 ns zoom; single bunches are resolved with a rise time of 2.34 ns, a rms baseline noise of 9.9 mV and an amplitude of 397 mV. The corresponding intrinsic time resolution is 58 ps.

SIGNAL PROPERTIES

Analogue Bandwidth

The analogue bandwidth BW of the measurement setup can be estimated via the rise time $t_r = 2.34$ ns as:

$$BW = \frac{0.35}{t_r} = \frac{0.35}{2.34\ \text{ns}} = 150\ \text{MHz}$$

which has to be set into correlation with the cable length of about 300 m.

Intrinsic Time Resolution

The intrinsic time resolution (TR) of the monitor is defined as the ratio of the baseline noise and the slope of the signal. In the example in Figure 7 the noise is 9.9 mV and the slope can be estimated with 170 mV/ns, resulting in:

$$TR = \frac{noise}{slope} = \frac{9.9\ \text{mV}}{170\ \text{mV/ns}} = 58\ \text{ps}$$

In this example the intrinsic time resolution is 58 ps.

It should be mentioned that the baseline noise is determined by the readout system rather than by the diamond detector. The intrinsic time resolution is limited by the quantization noise of the 8-bit ADC and by the bandwidth limitation, which is mainly determined by required length of the RF cable.

CONCLUSION

Bunch-to-bunch losses were measured at the LHC accelerator at CERN using diamond detectors. An UFO event, which occurred in point 4, was recorded with a diamond detector in the IR7 cleaning region. A buffer of 10 ms was filled with data at 1 GSPS data rate. The excellent amplitude resolution of single particles using a 40 dB as well as the excellent time resolution of the nano-second range is demonstrated in this report. These measurements also proved that beam losses in the LHC originate almost equally from all bunches. Data was taken with a digital oscilloscope, but it is foreseen for the end of 2012 to make them available on-line in the LHC control room.

REFERENCES

[1] H. Frais-Kölbl, E. Griesmayer, H. Pernegger, H. Kagan, “A fast low-noise charged particle CVD diamond detector”, IEEE Trans. on Nuclear Science, Vol. 51, No. 6, p. 3833 – 3837, December 2004.

[2] B. Dehning, E. Effinger, D. Dobos, H. Pernegger, E. Griesmayer, “Diamond detectors as beam monitors”, CERN-BE-2011-001 BI, March 2011.

[3] E. Griesmayer, B. Dehning, E. Effinger, H. Pernegger, D. Dobos, H. Frais-Kölbl, “Test of a diamond detector using unbunched beam halo particles”, CERN-ATS-2010-027, February 2012.

[4] M. Hempel et al., “Bunch-to-bunch beam loss diagnostics with diamond detectors at the LHC”, Proceedings of HP 2012, September 2012.

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