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MD#1182: Calibration of diamond particle detectors in IP6

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Diamond BLM, Asynchronous Beam Dump, Machine Protection, Fast Failures

Summary

In case of an asynchronous beam dump with a fully filled LHC machine it is expected that all standard ionisation chamber Beam Loss Monitors (IC BLM) around the LHC dumping region in IP6 will be saturated. Diamond Beam Loss Monitors (dBLM) were therefore installed next to the movable dump protection absorber (TCDQ) downstream of the extraction kickers. These detectors allow resolving losses at a nanosecond timescale and with an dynamic range of several orders of magnitude; thus, allowing to know the number of nominal bunches impacting the TCDQ. After a first series of calibrations using asynchronous beam dump tests, an experiment was conducted during MD#1182 to demonstrate the possibility of resolving a nominal bunch hitting the TCDQ.

The impact parameter of the bunches on the TCDQ was first scanned using probe bunches with lower intensity then tests were done with nominal bunches (1.1e11 p/bunch) at injection energy. High energy calibration of the losses was also attempted unsuccessfully. Due to different behaviour in observed in B1 and B2 an inspection in the LHC tunnel was performed. The analysis results and prospects for future MDs are presented below.

1. Introduction

During an asynchronous beam dump it is expected that several bunches of the circulating beam will impact on the movable dump protection absorber (TCDQ), protecting the aperture of the LHC against dump kicker failures [1]. This collimator is expected to withstand the impact of 36 nominal intensity bunches (36 times 1.1e11 p+ at 6.5 TeV) without damage. Due to saturation of the IC BLMs it is necessary to use dBLMs to directly measure the number of bunches impacting the TCDQ, which eases the assessment of potential damage following such an event.

These dBLMs are installed directly downstream of the TCDQ and need to be calibrated to ensure their full functionality. This MD was devided into two parts: first to measure the response of the dBLMs caused by a nominal bunch impacting the TCDQ, after having determined the bump amplitude leading to the highest signal with probe bunches. The second part involved moving circulating nominal bunches into the TCDQ in order to directly determine the signal per proton ratio for high energy (6.5TeV) protons.

2. Measurement setup

Originally 500 µm thick dBLMs with a bias voltage of 500 V were installed in IP6. They were equipped with AC/DC splitters and an oscilloscope for the readout. Due to the saturation of this setup during asynchronous beam dump tests done in April and May 2016, with only diluted nominal bunches impacting the TCDQ. These detectors were exchanged to 100 µm thick diamonds with 100 V bias voltage with a significantly lower efficiency. 20 dB attenuators were added to lower the signal amplitude down to the 10 V range. Due to an estimated 150 V seen by the scope during the test on May 15th one MΩ terminators were installed to protect the oscilloscope. The new setup was expected not to saturate from the signal caused by a focused nominal bunch impacting the TCDQ at top energy.

During the low energy part of the experiment, the beam was steered to the TCDQ using a three corrector orbit bump to reproduce the impact angle of the beam on the TCDQ caused by the kick of the MKDs [2]. The rendering of the beam 2 (B2) bump in YASP is shown in **Figure 1**. The bunch intensity was measured by the SPS transfer line FBCT and received from the IQC data.

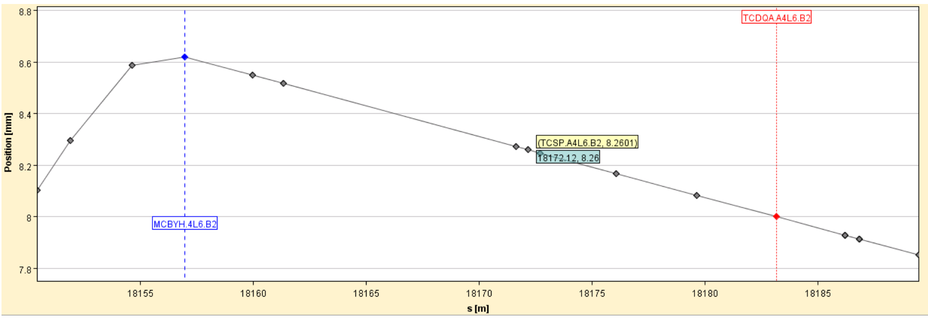

Figure 1 – YASP output for an 8 mm bump at the B2 TCDQ

The collimators (TCDQ, TCSP) were set at the same aperture as in the top energy settings of the LHC in order to mimic the shower conditions of an asynchronous beam dump as close as possible. They were set at a half gap of 8.3 σ (i.e. 5.41 mm, with top energy beam size) during both parts of the MD [3].

In order to shift the beam into the collimator within the shortest time, a special bump was designed for the high energy part of the MD. The goal was to use the lowest current from each involved corrector and reach the maximum kick rapidly [2].

3. Re-arming of the XPOC and unforeseen blocking interlocks

During the injection energy part of the MD, unmaskable BLMs in IP6 caused the XPOC to require an expert review before resuming operations. Following the advice from the TE-ABT expert and in agreement with machine protection it was decided not to re-arm the XPOC after each injection and to close some primary collimators in IP 3 and 7 to intercept any circulating beam.

During the top energy part of the MD, unmaskable BLMs in IP6 caused a beam dump before any signal was recorded on the dBLMs; this exercise was attempted twice without success.

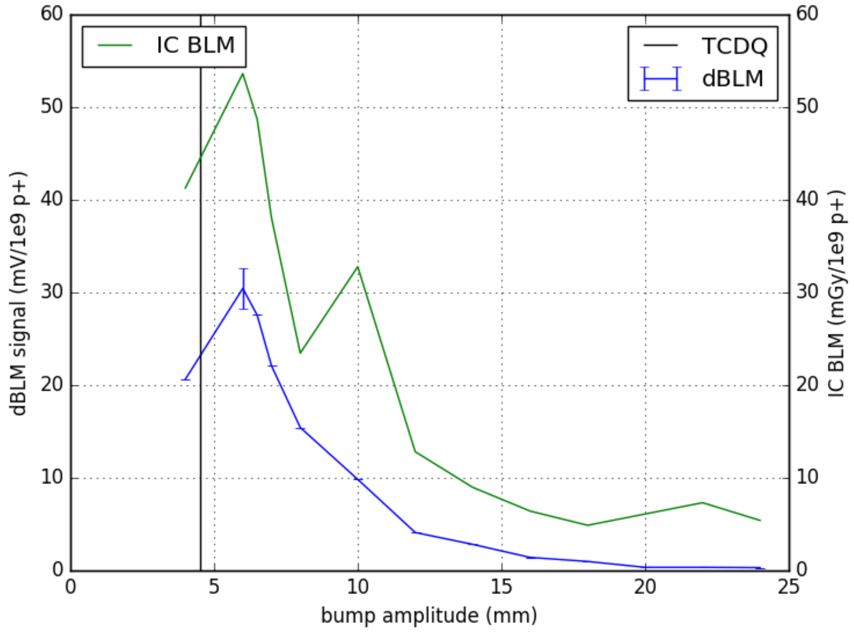

Figure 2 – normalized dBLM and BLM signal versus bump amplitude B1

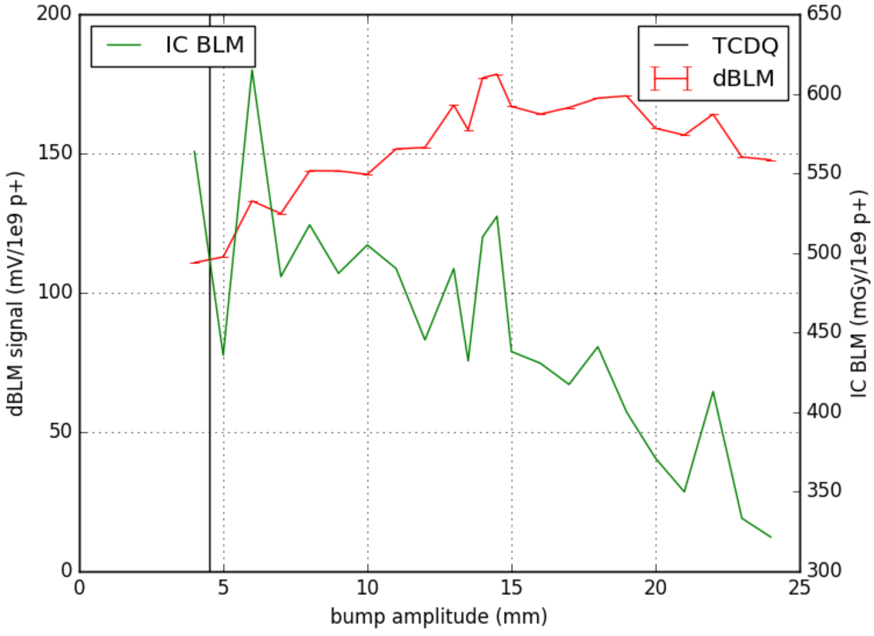

Figure 3 - normalized dBLM and BLM signal versus bump amplitude B1

4. Calibration of the signal strength versus bump amplitude

4.1 Beam 1

Probe bunches (6-9e9 p+ at 450 GeV) from the SPS were shot at the TCDQ with various bump amplitudes. The dBLM signal normalised to bunch intensity as a function of the bump amplitude is shown in **Figure 2**. One can see that the signal amplitude is the highest for a bunch fully impacting the TCDQ with a low impact parameter (small bump in the left part of the plot). The signal of the neighbouring IC BLM shows a good correlation with the dBLM signal. A nominal bunch (1e11 p+ at 450 GeV) was then shot at the determined bump amplitude of 6 mm and a signal of a maximum of 1.5 V was recorded. **Figure 6** show the response of the dBLM for a probe and nominal bunch (blue B1). It can clearly be seen that the signal amplitude is linear to the bunch intensity.

4.2 Beam 2

Probe bunches (6-9E9 p+) from the SPS were shot at the TCDQ with various bump amplitudes. The dBLM signal normalised to the bunch intensity as a function of the bump amplitude is shown in **Figure 2**. One can see a very different behaviour from Beam 1 and from the IC BLM signal. It was also not anticipated that the signal levels would be much higher and that the bump amplitude yielding the highest signal would be so large. A nominal was nonetheless shot at a bump amplitude of 14.5 mm yielding a maximum signal of 2.6 V. The red signals in **Figure 6** represent the response to a probe and a nominal impacting the B2 TCDQ. One can see that the signal maximum is a factor 5 larger than for B1 and the detector saturated when firing the nominal, as evidenced by the shape of the rising edge.

5. High energy calibration of the signal versus the number of protons

As mentioned above the top energy part of the MD was unsuccessful due to unmaskable BLMs dumping the beam before the diamonds could measure anything, both on B1 and B2.

Using the data acquired during asynchronous beam dump tests after TS2, it was possible to make an estimate of the ratio of signal to protons for a high energy dump and compare it to the data from the low energy part of the MD. This method leads to a larger uncertainty as the exact impact parameter of the diluted bunch hitting the TCDQ during such a test is unknown. An analysis of high energy and injection energy asynchronous beam dump tests suggests that the signal from high energy protons is a factor 6 (±1) larger than with injection energy protons.

6. Inspection of the dBLMs during TS3

Due to the discrepancy between B1 and B2 during the MD an inspection was performed in the LHC tunnel to discard the possibility of an unknown difference in layout between B1 and B2. This inspection did not evidence any difference between the setups of the dBLMs in terms of condition, distance and orientation relative to the beam pipe as well as cabling. Photographs taken during this intervention can be seen in **Figures 4 and 5**.

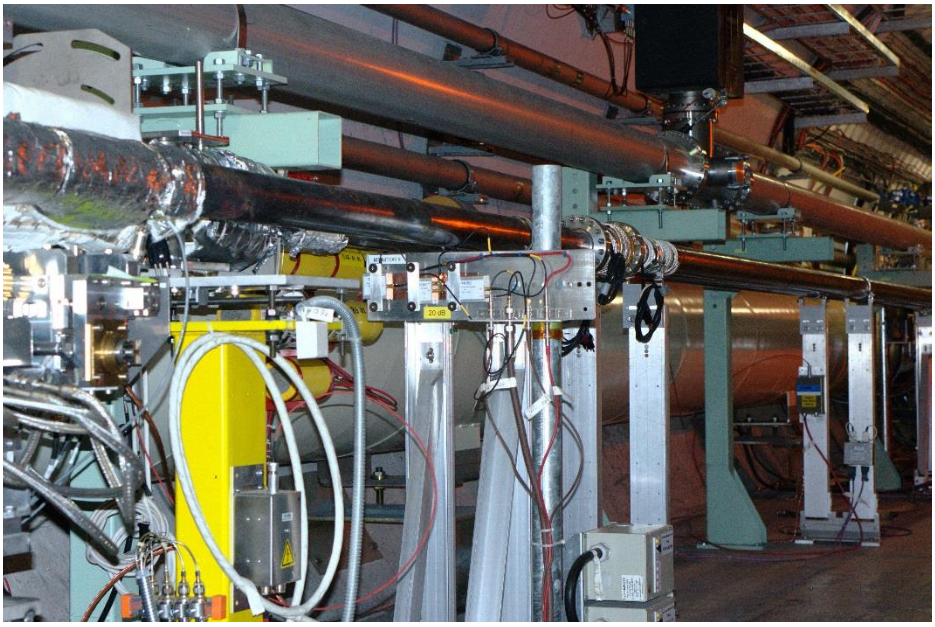

Figure 4 – B1 dBLM plate in IR6

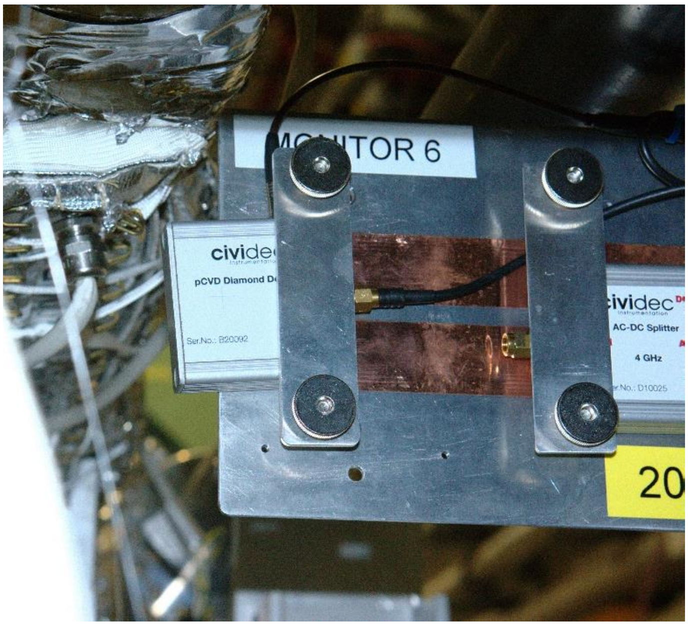

Figure 5 – B2 dBLM plate in IR6

7. Further analysis of the data

The study of the signals from nominal bunches impacting the TCDQs shows that the signal is a factor 5 higher on the B2 dBLM for the kick yielding the highest signal as compared to B1. The signal shape for B2 (see **Figure 6)** suggest the saturation of the dBLM during the test with a nominal bunch.

The calculation of the ratio of the integrated signals shows the expected behaviour between the probe and the nominal on B1, with an integral ratio of 0.13, which reflects the relative population of the probe, bunches to the nominal (0.14±0.01). The same ratio for beam 2 has a value of 0.32, which, again, suggests saturation as the intensity ratio was 0.016 ±0.01.

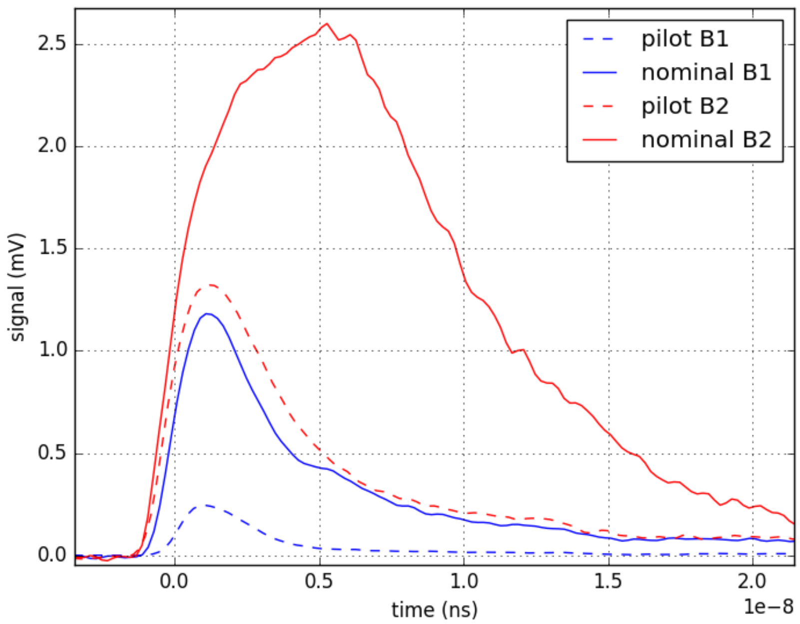

Figure 6 – dBLM signal for B1 and B2 for a nominal and a probe bunch at the highest yield bump amplitude

The response of the diamonds as a function of the impact parameter of the bunches initially showed an inconsistent behaviour. By looking at the signals from different IC BLMs around the dump region (namely the BLMs next to TCSP and TCDQA instead of TCDQM) a much better fit between the dBLM and IC BLM signal was obtained, as evidenced by **Figure 7**. One can deduct from the data that, despite the used bump having been designed to shoot the beam at the TCDQ, the bunches were actually impacting at the TCSP because of an mis-interpretation of the sign convention for the B2 bumps in YASP. A single shot was nevertheless shot at the TCDQ because of a 0 A current in the corrector circuit at that time, the corresponding bump amplitude is -6 mm, this shot is indicated with stars in **Figure 7**. One can see that for this shot the TCDQ BLM signal is actually higher and the TCSP signal much lower. The layout of the various BLMs and collimators involved is further explained in **Figure 8**.

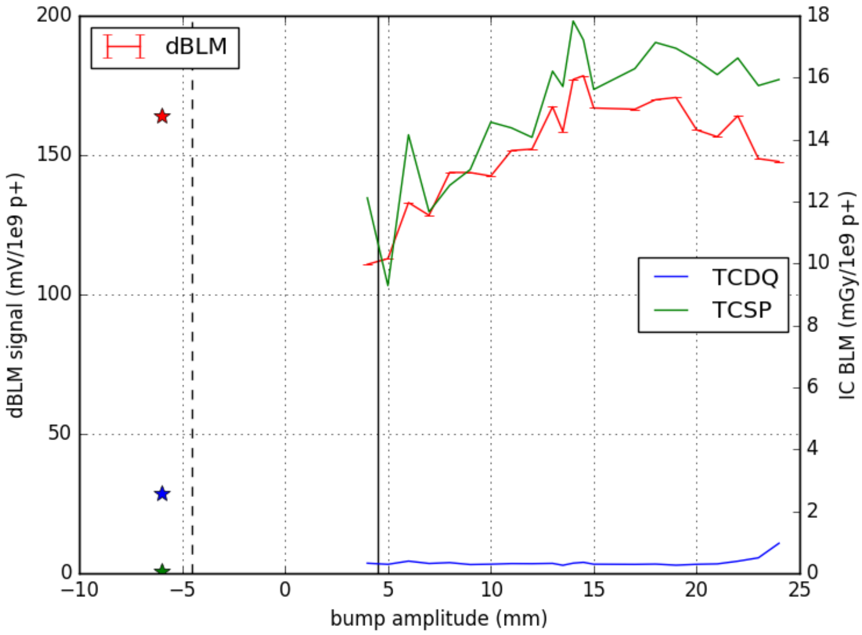

Figure 7 – RS02 TCDQ and TCSP signal versus dBLM signal as a function of bump amplitude for B2, the full black line shows the aperture of the TCSP and the dashed line the TCDQ which was on the other side. The shot fired at the TCDQ is indicated with stars.

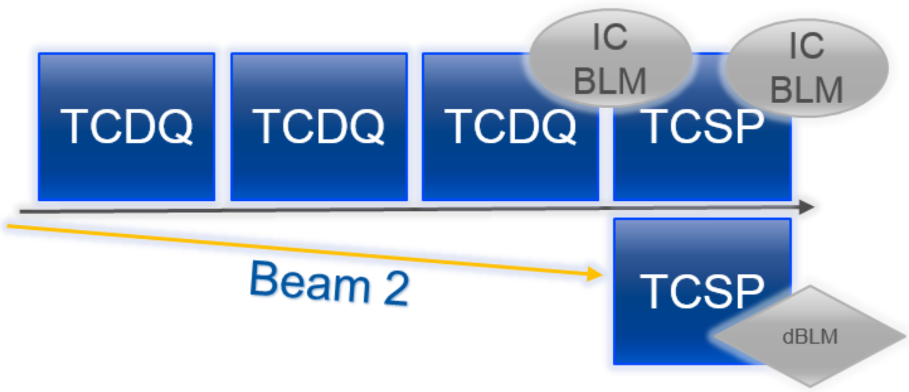

Figure 8 – Schematic of the Collimator and BLM layout in IP6 for Beam 2.

8. Conclusions

After analysis of the results of this MD it is possible to state that the B1 dBLM setup in IP6 should not saturate in case of an asynchronous beam dump. The expected maximum voltage in this case would be of about seven times 1.5 V which would lead to 10.5V, just above the maximum of 10V. The attenuation will be increased by an extra 3 dB for margin. The same cannot be said of the B2 layout as the beam was not shot at the TCDQ.

After having identified the problem experienced in B2 it is proposed to repeat this experiment in B2 during an MD in 2017.

References

[1] Beam based measurements to check integrity of LHC dump protection elements, *IPAC 16*, C. Bracco *et al.*

[2] MD#1182 procedures, M. Valette *et al.*

[3] Collimator settigns for 2016, *CollWG*, R. Bruce