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Conference Report

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Design and Experiences with the Beam Condition Monitor as protection system in the CMS Experiment of the LHC.

Moritz Guthoff on behalf of the CMS Beam Radiation Monitoring group

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DESIGN AND EXPERIENCES WITH THE BEAM CONDITION MONITOR AS PROTECTION SYSTEM IN THE CMS EXPERIMENT OF THE LHC

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Abstract

The Beam Condition Monitor (BCM) is used as a protection system at the Compact Muon Solenoid (CMS) experiment at the LHC. In order to prevent damage to the pixel and tracker detectors it can trigger a beam dump when high beam losses occur. The system consists of two sub systems, BCM1L and BCM2, at different locations. Poly-crystalline Chemical Vapor Deposition (pCVD) diamonds are used as detector material. The readout electronics is identical to the Beam Loss Monitor (BLM) system of the LHC. From cross calibration measurements, a direct comparison between BLM and BCM system is possible. The BCM system is therefore a transparent extension of the BLM system into the CMS cavern. The BCM2 system has been active in the LHC beam abort system since first beam in the LHC. This paper shows the experience with the BCM system and measurements of selected events showing the abilities of the system for monitoring purposes.

INTRODUCTION

When too high beam losses at the LHC [1] occur the generated particle shower can damage electronics or cause a quench in the superconducting magnets. Therefore the LHC is equipped with Beam Loss Monitors that can automatically assert a beam dump if the losses reach a dangerous level [2]. The experimental caverns are not equipped with BLMs. It is the responsibility of the experiments to monitor the beam conditions in this area. For this, CMS is equipped with the Beam Condition Monitoring (BCM) system [3] utilising diamonds as detectors and a readout electronic identical to the BLM system [4].

The detector is composed of pCVD diamonds with a size of 1x1 cm^2 and a thickness of 400 μm. The bias voltage is 200V which gives a sufficient signal that is comparable with a 1m long ionisation tube. They are metallised with 0.1 μm tungsten-titanium. The measured leakage current of the detector is proportional to the particle flux. In testbeam studies the detectors were cross calibrated with a BLM tube and the measured signal is therefore directly comparable [5]. The BCM system consists of the BCM1L with two rings of 4 diamond detectors with an inner radius of 4.5 cm at Z = ±1.8 m and BCM2 with two detector rings at Z = ±14.4 m. A inner ring with 4 diamonds with an inner radius of 5 cm and a outer ring with 8 diamonds with an inner radius of 28 cm. In all calculations the outer ring is not included since it gives too low a signal at the current beam intensities.

Although the main purpose of the system is the protection of CMS it can also be used for monitoring. The electronic measures with several integration times up to 83 s at the same time. The shortest integration time available is used for protection (40 μs). The longer integration times give a good monitoring signal because of a higher sensitivity[5].

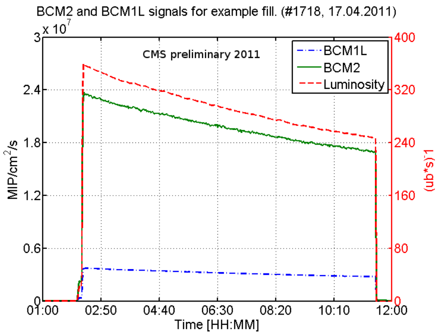

Figure 1: The BCM1L and BCM2 signals during one fill, showing that the BCM data follows well the luminosity.

While the BLM system uses ionisation chambers, this was not an option for CMS since they are too big to be placed inside the CMS detector. Diamond behaves like a solid state ionisation chamber and is radiation hard, compared e.g. to silicon. Monte Carlo simulations predict for the most exposed detectors, the BCM2 inner rings, a half life of 6 years at LHC design conditions (14 TeV, 10^{34} $cm^{-2}s^{-1}$, 10^7 s collision time per year)[5]. Since these intensities are not yet achieved we do not expect significant degradation in the next 10 years.

MEASUREMENTS WITH BEAM

In figure 1 the signals from BCM2 and BCM1L for a typical LHC fill can be seen. For the BCM data an integration time of 5.2 s with an average over 1 minute is used. The signals follow the luminosity well. BCM2 is about 6 times more sensitive to collision products than BCM1L because of its location. This chapter shows events categorised by their duration.

Short Time Scale Events

Short time scale events, shorter than the readout time of 1 s, can be analysed using the different integration times. An example of this are beam losses believed to be produced by dust particles falling into the beam. These so

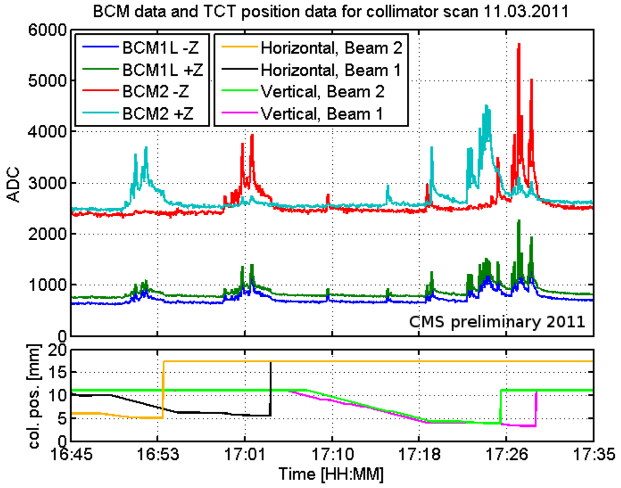

Figure 2: During this collimator scan the TCTs were moved in until they scraped the beam. The lower plot shows the position of the TCTs. The upper plot shows the BCM1L and BCM2 data averaged over one side. When the TCT scrapes the beam the BCM detectors measure beam losses. BCM1L +Z and -Z measures the same for beam 1 and beam 2. BCM2 measures a high signal downstream.

called UFO events have a duration of about 1ms and happen quite often around the LHC. Only one UFO was close to CMS and big enough to give a clear signal in the BCM detectors. Figure 3(a) shows the raw data of that event. During squeeze a spike that reached about 25% of the abort level showed up in the data. Collisions started later but the beam was dumped after one minute for reasons unrelated to the UFO. Figure 3(b) shows the data of that spike from the different integration times normalised to Gy/s. A BLM detector close to CMS is also plotted and gives exactly the same timing structure. The duration of this event was about 0.3 ms. An estimate of the duration of the event can be obtained by looking at the charge integrated with different integration times.

Long Time Scale Events

During the machine commissioning in 2011 a collimator scan with the last collimator before CMS (TCT) was performed. Beam losses produced there pose the biggest threat for CMS. In figure 2 the signals from BCM1L and BCM2, averaged over one side, as well as the positions of the collimators can be seen. When the collimator scrape the beam, signals are clearly seen in BCM2 and BCM1L. BCM1L detects about the same signal on the upstream and the downstream side of the event. This is as expected, since there is no significant material between the +Z and -Z positions that could absorb particles or produce showers. BCM2 detects signals almost only downstream. On the upstream side the particle shower is not developed yet. It is produced inside CMS and then detected downstream. There was no correlation in signals from horizontal or vertical detectors with respect to horizontal or vertical collimator movement. The detected particle shower develops in both directions.

A typical beam loss over a longer time scale is due to a bad vacuum. The beam interacts with the gas and high losses are produced. On 25th OCT 2010 the vacuum degraded during collisions and thereby producing high beam losses as measured by BCM1L and BCM2, see figure 4. Since the collision and background signals can be clearly identified this event can be used to study background.

Background Discrimination

The signal in the BCM detectors during collisions is the sum of the signal coming from collision products and the signal due to machine induced background. The sensitivities of BCM1L and BCM2 towards those components are different. BCM2 measures about 6 times higher value from collisions than BCM1L, while the background signal is roughly the same. By comparing both signals a background value can be calculated. The same way a background suppressed collision signal can be calculated.
The different sensitivities are parameterized as:

$$\text{Measurement}_{BCM1L} = \text{background} + \text{collisions}$$
$$\text{Measurement}_{BCM2} = \text{background} \cdot \text{c}_b + \text{collisions} \cdot \text{c}_p$$

Figure 5 shows the calculated background and collision signal for the vacuum bump event.

CONCLUSIONS

The BCM system works very well within its design parameters and has been active in the LHC beam abort since the first running of LHC. It delivers invaluable information about the beam condition for the running of CMS and the LHC. It can be used for the monitoring of long and short time scale events. The system works very stably with no major problems, no LHC downtime due to system failure and no false beam aborts.

ACKNOWLEDGEMENTS

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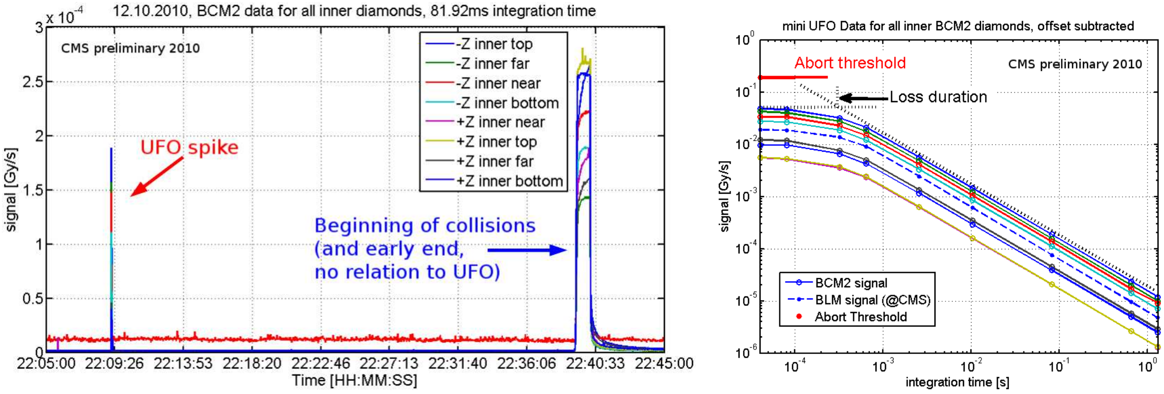
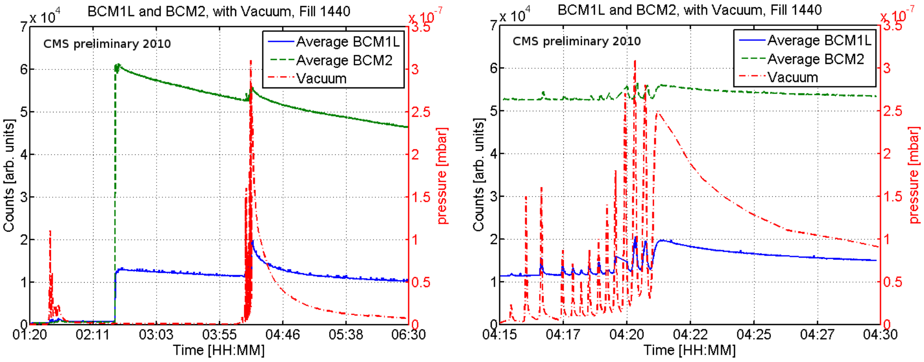


(a) Raw BCM data around UFO event.

(b) Data from different integration times during UFO event.

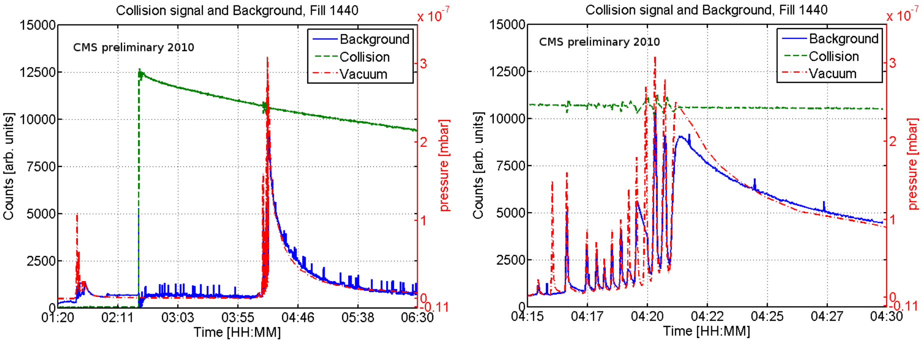
Figure 3: 3(a) The raw BCM2 data for the time around the UFO event. The UFO event shows up in all channels in one readout second. 3(b) The BCM2 data of different integration times between 40 μs and 1.2 s for the second the UFO occurred. The values are normalised to integration time (in Gy/s). A BLM detector close to CMS that is also plotted. When the integration time gets longer than the event the measured values go down. This way a rough timescale of the event can be determined, in this case 0.3 ms.



(a) BCM Data from fill with vacuum bump

(b) Zoom in around vacuum bump

Figure 4: The BCM2 and BCM1L data for a fill (#1440) where a clear long time scale background event occurred. The beam loss happened when the vacuum quality decreased suddenly and a higher signal in the BCM detectors is seen. The right plot shows a zoom in on the time during the vacuum bump.



(a) Background during collimator scan.

(b) Background during vacuum bump.

Figure 5: The calculated background and collision signal for the vacuum bump event. Vacuum pressure overlaid to show that the measured background follows the vacuum.