PERFORMANCE OF THE FAST BEAM CONDITIONS MONITOR BCM1F IN THE CMS EXPERIMENT AT LHC

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Abstract

The Beam Conditions and Radiation Monitoring System, BRM, is installed in CMS to protect the detector and to provide feedback to LHC on beam conditions. It is composed of several sub-systems that measure the radiation level close to or inside all sub-detectors, monitor the beam halo conditions with different time resolution, support beam tuning and protect CMS in case of adverse beam conditions by firing a beam abort signal. This paper presents the Fast Beam Conditions Monitor, BCM1F, which is designed for fast flux monitoring, measuring with nanosecond time resolution, both the beam halo and collision products. It uses single-crystal CVD diamond sensors and radiation hard front-end electronics, along with an optical transmission of the signal. Since November 2009 BCM1F has been recording data from beam halo, beam losses, proton-proton and lead-lead collisions and it became an invaluable tool in the everyday CMS operation. A characterization of the system on the basis of data collected during LHC operation is presented.

INTRODUCTION

The Large Hadron Collider (LHC) [1] at CERN has been successfully providing proton-proton and lead-lead collisions since autumn 2009. The high-energy beams with very large intensities pose issues concerning the beam losses and the safety and operation of the detectors.

The Compact Muon Solenoid (CMS) [2] is a multipurpose detector designed around a 3.8T solenoid magnet at interaction point (IP) 5 of the LHC. The detector systems in CMS have been designed with very high radiation tolerance, however, beam losses may still cause harm to detector components so their advent must be detected. The CMS is equipped with a Beam Conditions and Radiation Monitoring (BRM) [3] system that allows diagnosis of adverse beam conditions and can initiate beam aborts or shut down vulnerable detectors , if necessary.

The BRM is composed by eight subsystems, working on different time scales, that monitor the beam conditions and the radiation levels throughout CMS. In order to be useful as beam monitoring devices, the detectors must be radiation hard.The BRM sub-detectors are decoupled from the LHC power supply and the central CMS data acquisition and must be active whenever there is beam in the LHC.

The CMS Fast Beam Conditions Monitor (BCM1F) [4] is one of the BRM sub-systems. It was designed to monitor the flux of particles with a time resolution of nanoseconds, being able to diagnose adverse beam conditions such as beam losses. It is installed inside the pixel volume close to the beam-pipe and it consists of two planes of 4 modules each located on both sides of the IP. It also provides information on the background conditions in the region of CMS pixel detector.

BCM1F SYSTEM OVERVIEW

BCM1F delivers bunch-by-bunch information on both the beam halo and collision products near the beam pipe and close to the IP in CMS. It uses radiation hard single-crystal Chemical Vapor Deposition (sCVD) diamond sensors for particle detection with low leakage current (range of pico-Amperes).

Four modules, consisting of a sensor, a pre-amplifier and an optical driver, are arranged around the beam pipe at a distance of 4.5 cm from the beam axis, and on two planes located at 1.8 m on both sides of the IP. This distance is optimal for the separation of incoming and outgoing particles and corresponds to a time-of-flight of ~6 ns for relativistic particles. The whole design fulfils the requirements of size to fit in the space-constrained region near the tracker. The time resolution is 1.3 ns, less than the time between bunch crossings [4]. The radiation hardness is sufficient to operate them several years inside CMS. BCM1F measures the flux of beam halo particles as well as of collision products, thereby providing *CMS Background 1* to the LHC control.

Readout Chain and Data Acquisition

The sensors have a size of $5 \times 5 \times 0.5$ mm^3. They are metallized on both sides and operate as solid state ionization chambers, as illustrated in Figure 1. Charge-sensitive, radiation-hard amplifier ASICs of the type JK16 [5] collect the induced charge and shape proportional signals. Using an optical driver, they are transmitted as analogue optical signals to a service room where they are converted back to electrical signals in the optical receiver. The analogue signals are then fanned-out into a discriminator and into an analog-to-digital converter (ADC). The ADC samples the waveform of the signals to obtain a precise digital image whilst the discriminator supplies logical signals to a scaler and to a time-to-digital converter (TDC). The data acquired by these three readout devices are processed immediately. Relevant results are displayed in the control room and passed on to the central CMS data acquisition. Raw data are stored permanently on disk for off-line analysis.

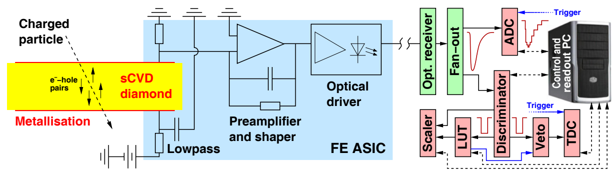

Figure 1: Schematic of the BCM1F readout chain. (Left) Front-end module, including sensor, pre-amplifier and optical driver. (Right) Back-end elements in the counting room.

PERFORMANCE OF BCM1F

Signal Sampling

The signals from the sensors are fed into a CAEN v1721 flash ADC where they are digitized. The amplitude spectra from proton-proton collisions is shown in Figure 2. The pedestal peak around zero constitutes the baseline. In the signal region the first maximum is associated to minimum ionising particles (MIP). The peak on the right is caused by saturation of the front-end electronics.

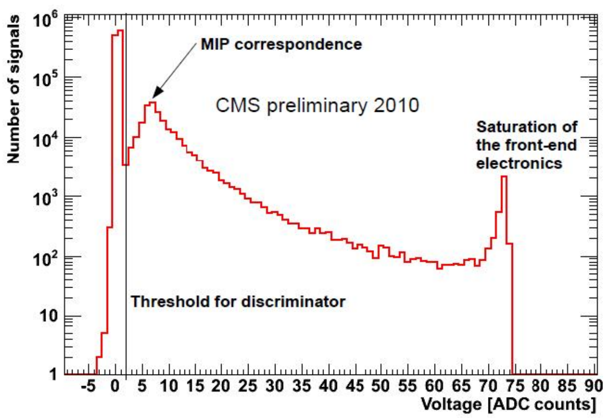

Figure 2: Pulse height spectrum of signals from proton-proton collisions. The peak around zero corresponds to the pedestal peak, a MIP signal is seen at ∼8 ADC counts and the last peak at ∼10 MIPs is due to the saturation of the front-end.

The amplitude spectra is used to monitor the pulse height and to estimate the SNR. Another task of the ADC is to monitor the baseline stability and to do performance studies.

Particle Rates

The discriminated signals of each channel are input into a CAEN v560B scaler that provides the hit rate. In Figure 3, the rates show the different steps of a fill: before beam injection the rates come from noise, cosmics and possibly from de-activation of the material in the vicinity of BCM1F. As beams are injected and accelerated the rates increase due to a higher beam-gas interaction caused by the increase of the vacuum pressure. The vacuum pressure stabilises during the flat-top and the rate of BCM1F is constant. When the collisions start the rate jumps orders of magnitude and is due to hits arising from the collisions, expected to be proportional to the luminosity. After dumping the beams, BCM1F records hits with a rate that drops exponentially with a lifetime of ∼34 minutes. This decay can still be observed for longer time scales. Further investigation of this effect might be important to estimate the radiation dose in the CMS pixel detector area.

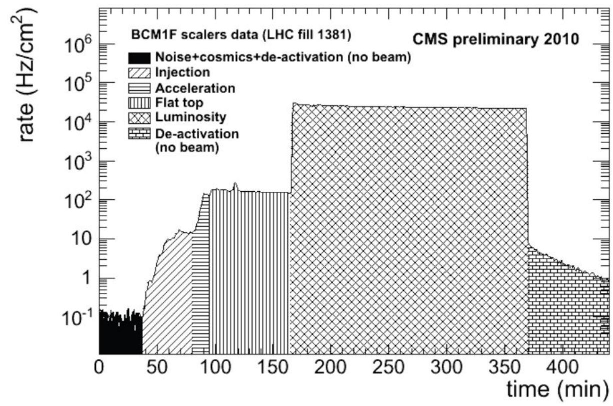

Figure 3: Hit rate with the scalers during an LHC fill. Different steps of the fill are well charazterized.

Timing Information

The discriminated analogue signals are also digitised by a multi-hit CAEN v767 TDC board with 0.8 ns resolution. Using the LHC orbit as a trigger and the LHC bunch clock as sampling clock, the TDCs provide the time of the hits within an LHC orbit. The time can be converted into the bunch number in an orbit what allows the identification of each single bunch. Figure 4 shows the arrival time distribution of the particles within an orbit in an LHC fill. Clearly seen are the peaks from colliding and non-colliding bunch trains consisting of eight proton buches spaced by 150ns. Figure 5 is an zoom into a train of colling and non-colliding proton bunches in CMS spaced by 50ns.

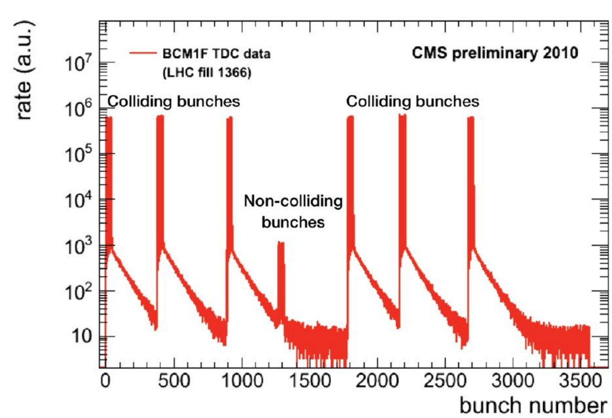

Figure 4: Hit rate as a function of time. Time is given in units of bunch numbers corresponding to 24.95 ns.

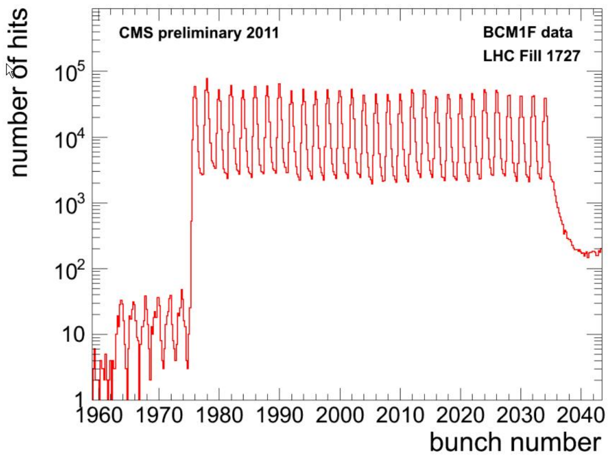

Figure 5: Zoomed train of 50ns spaced colliding and non-colliding bunches.

THE ALBEDO EFFECT

After the occurrence of collisions, long tails with exponential shapes are observed in the rates of the TDCs. This can be clearly seen in Figure 4. Fitting the exponential and the constant contributions, a lifetime of (2.12 ± 0.02) μs is obtained. Simulations using the FLUKA Monte Carlo [6] describe well the shape of the hit rate distribution and give information about the particle contents of the albedo. The tails are mostly caused by neutrons, photons, electrons and positrons. Further investigations are needed to understand the origin of these particles and evaluate the impact on CMS operations.

SENSITIVITY OF THE SYSTEM TO BEAM CONDITIONS

BCM1F showed to be very sensitive to beam conditions inside CMS such as vacuum quality, collimator and van der Meer scans. Also, BCM1F delivers a fast luminosity estimate.

Figure 6 illustrates the effect of an increase of the beam-gas interaction rates for Beam 2 entering the CMS experiment as the consequence of an increase of the vacuum pressure.

In addition, the BCM1F is being used as a luminosity estimation due to the good agreement of the rates with the instant luminosity provided by the CMS Forward Hadron Calorimeter [reference] as it is shown in Figure 7. In the figure the rates of the eight BCM1F sensors were normalized to the HF instant luminosity.

CONCLUSIONS

The BCM1F, has been used as a beam conditions monitoring tool since the LHC restart in autumn 2009. Thanks to the data acquisition architecture, it provides: rates, bunch identification and luminosity estimation to the CMS operators and background rates to LHC. BCM1F became a key

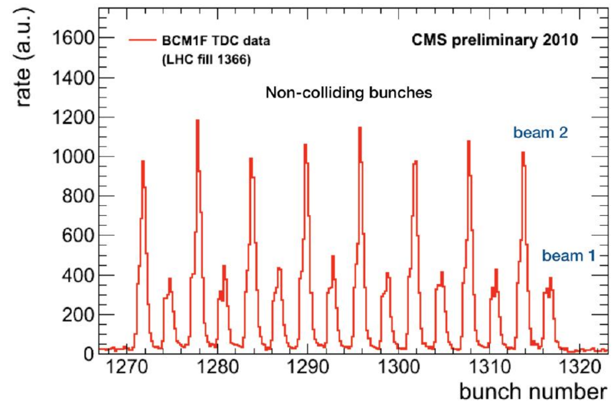

Figure 6: Hit rate in a bunch train of non-colliding bunches reflecting degradation in vacuum conditions by increasing rates of Beam 2.

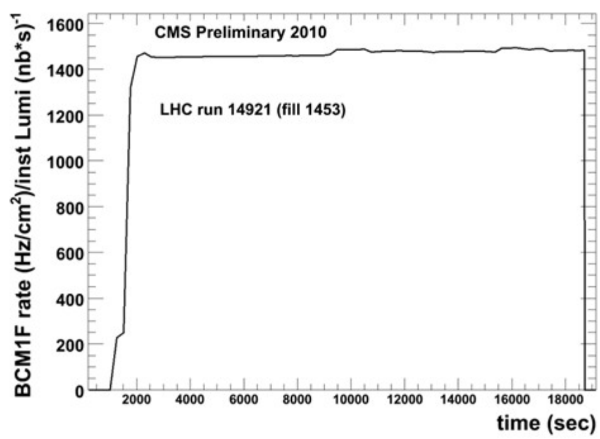

Figure 7: BCM1F hit rates normalized to HF instant luminosity during a proton fill.

tool in the BRM system by giving valuable beam information and it shows, in the day-by-day operation, that new monitoring capabilities are still to be exploited.

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