The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

31 October 2011 (v3, 21 November 2011)

The Performance of the Beam Conditions and Radiation Monitoring System of CMS

Anne Dabrowski for the CMS Collaboration

Abstract

The Beam Conditions and Radiation Monitoring System (BRM), is installed in CMS to protect the CMS detector from high beam losses and to provide feedback to the LHC and CMS on the beam conditions. The primary detector sub-systems are based on either single crystal diamond sensors (BCM1F) for particle counting with nanosecond resolution or on polycrystalline diamonds (BCM2; BCM1L) for integrated signal current measurements. Beam scintillation counters (BSC) are also used during low luminosity running. The detectors have radiation hard front-end electronics and are read out independently of the CMS central data acquisition and are online whenever there is beam in the LHC machine. The various sub-systems exploit different time resolutions and position locations to be able to monitor the beam induced backgrounds and the flux of particles produced during collisions. This paper describes the CMS BRM system and the complementary aspects of the installed BRM sub-detectors to measure both single particle count rates and signal currents originating from beam backgrounds and collision products in CMS.

Presented at *IEEE-nss-mic-rtsd2011: IEEE2011: Nuclear Science Symposium and Medical Imaging Conference*

The Performance of the Beam Conditions and Radiation Monitoring System of CMS

A. E. Dabrowski, N. Bacchetta, A. J. Bell, E. Castro, M. Guthoff,
R. Hall-Wilton, M. Hempel, H. Henschel, W. Lange, W. Lohmann,
S. Müller, O. Novgorodova, D. Pfeiffer, V. Ryjov, D. Stickland, R. Walsh,
On behalf of the CMS Collaboration

Abstract—The Beam Conditions and Radiation Monitoring System (BRM), is installed in CMS to protect the CMS detector from high beam losses and to provide feedback to the LHC and CMS on the beam conditions. The primary detector sub-systems are based on either single crystal diamond sensors (BCM1F) for particle counting with nanosecond resolution or on polycrystalline diamonds (BCM2; BCM1L) for integrated signal current measurements. Beam scintillation counters (BSC) are also used during low luminosity running. The detectors have radiation hard front-end electronics and are read out independently of the

CMS central data acquisition and are online whenever there is beam in the LHC machine. The various sub-systems exploit different time resolutions and position locations to be able to monitor the beam induced backgrounds and the flux of particles produced during collisions. This paper describes the CMS BRM system and the complementary aspects of the installed BRM sub-detectors to measure both single particle count rates and signal currents originating from beam backgrounds and collision products in CMS.

A. E. Dabrowski is with CERN, CH-1211 Genève 23, Switzerland (telephone: +41 76 487 5629, e-mail: corresponding author anne.dabrowski@cern.ch).

N. Bacchetta is with Università e INFN Italy, (e-mail: nicola.bacchetta@cern.ch).

A. J. Bell is with Université de Genève. Section de Physique. 24, quai Ernest-Ansermet CH-1211 Genève 4 Switzerland and CERN, CH-1211 Genève 23, Switzerland, (e-mail: alan.bell@cern.ch).

E. Castro is with DESY, 15738 Zeuthen & 22607 Hamburg, Germany, (e-mail: maria-elena.castro-carballo@desy.de).

M. Guthoff is with Karlsruher Institut für Technologie, 76049 Karlsruhe, Germany and CERN, CH-1211 Genève 23, Switzerland (e-mail: moritz.guthoff@cern.ch).

R. Hall-Wilton is with European Spallation Source ESS AB - Box 176, 22100 Lund, Sweden, (e-mail: richard.hall-wilton@ess.se).

M. Hempel is with DESY, 15738 Zeuthen & 22607 Hamburg, Germany and Brandenburgische Technische Universität, 03046 Cottbus, Germany, (e-mail: maria.hempel@desy.de).

H. Henschel is with DESY, 15738 Zeuthen & 22607 Hamburg, Germany, (e-mail: hans.henschel@desy.de).

W. Lange is with DESY, 15738 Zeuthen & 22607 Hamburg, Germany, (e-mail: wolfgang.lange@desy.de).

W. Lohmann is with DESY, 15738 Zeuthen & 22607 Hamburg, Germany and Brandenburgische Technische Universität, 03046 Cottbus, Germany, (e-mail: wlo@ifh.de).

S. Müller is with Karlsruher Institut für Technologie, 76049 Karlsruhe, Germany and CERN, CH-1211 Genève 23, Switzerland (e-mail: stefen.mueller@cern.ch).

O. Novgorodova is with DESY, 15738 Zeuthen & 22607 Hamburg, Germany and Brandenburgische Technische Universität, 03046 Cottbus, Germany (e-mail: olga.novgorodova@desy.de).

D. Pfeiffer is with CERN, CH-1211 Genève 23, Switzerland and University of Canterbury, Private Bag 4800, Christchurch, New Zealand, (e-mail: dorothea.pfeiffer@cern.ch).

V. Ryjov is with CERN, CH-1211 Genève 23, Switzerland, (telephone: +41 22 767 9461 e-mail: vladimir.ryjov@cern.ch).

D. Stickland is with Princeton University, Princeton, NJ 08544-0708 (USA), (e-mail: david.peter.stickland@cern.ch).

R. Walsh is with DESY, 15738 Zeuthen & 22607 Hamburg, Germany, (e-mail: roberval.walsh@cern.ch).

Manuscript received November 14, 2011.

Thanks to the support and collaboration received from Karlsruhe Institut für Technologie, DESY, and the CARAT FP7 program.

Thank the support and collaboration received from the LHC Beam Instrumentation group.

Diamond detector R&D has been done in collaboration with the RD42 collaboration.

I. INTRODUCTION

THE Beam Conditions and Radiation Monitoring System (BRM) [1], is installed in CMS to protect the CMS detector from possible damage induced by a high beam loss and to provide feedback to the LHC and CMS on the beam conditions.

The primary detector sub-systems, used for beam monitoring during nominal LHC running, are based on either single crystal diamond sensors (BCM1F) [2] for particle counting with nanosecond resolution or on polycrystalline diamond sensors (BCM2; BCM1L) for integrated signal current measurements. All diamonds are grown using chemical vapor deposition (CVD) techniques. The diamond sensors were chosen because of their radiation hardness due to their large displacement energy and their low, under small temperature changes, constant leakage currents. This removed the need for active cooling, and makes these detectors attractive for installation in radiation hard environments, as is the CMS forward region, or in the CMS inner region where the access to services like cooling is at a premium. The detectors have radiation hard front-end electronics, are read out independently of the CMS central data acquisition and are online whenever there is beam in the LHC machine. Beam scintillation counters (BSC) are used in addition during low luminosity running, to provide minimum bias triggers and beam induced background monitoring.

The various sub-systems exploit different time resolutions and position locations to be able to monitor the beam induced backgrounds and measure the flux of particles produced during collisions. In the near future, CMS will commission the first diamond-based pixelated-tracking detector for online luminosity and beam-spot measurements [3]. This paper describes the CMS BRM system and the complementary aspects of the installed BRM sub-detectors, as shown in Fig. 1, to measure both measure both single particle count rates and signal

Fig. 1. A schematic of a quadrant of the CMS detector, showing the longitudinal position of the installed BRM detectors. The IP and center of the CMS detector is in the bottom right hand corner.

Fig. 2. Photographs of the installed BCM polycrystalline diamond sensors, with different mechanical mountings, to suit the installation location.

currents originating from beam backgrounds and collision products in CMS.

II. BCM2 AND BCM1L POLYCRYSTALLINE DIAMOND DETECTORS FOR PROTECTION OF CMS AND BEAM MONITORING

Installed in CMS are 32 polycrystalline CVD diamonds sensors with an active area of $1 \times 1 \text{ cm}^2$ and a thickness of $400 \mu\text{m}$. They are metalized with $0.1 \mu\text{m}$ of tungsten-titanium and operated with a bias voltage of 200 V. This produces a signal that is comparable with a 1 m long ionization tube and proportional to the incoming particle flux through the sensor. Each diamond sensor is readout using the same electronics as is used in the LHC Beam Loss Monitoring (BLM) system [4], as designed by the LHC Beam Instrumentation group. These electronics integrates the detector current, in 12 different time intervals, ranging from the shortest integration window (“running sum”) of $40 \mu\text{s}$ (1/2 an LHC beam orbit) to the longest time scale of 83 s (2^{20} orbits) [5]. From the evolution of the integrated detector current as a function of time, the loss duration of the beam loss event can be calculated. Prior to installation, the sensors were cross-calibrated with a LHC BLM ionization detector [6].

These pCVD diamond sensors, see Fig. 2, are grouped together into two different detector families, BCM1L and BCM2, depending on their longitudinal location with respect to the CMS interaction point (IP). The BCM1L detector is mounted in two rings of 4 diamond sensors each, with an inner

radius of 4.5 cm, located at $Z = \pm 1.8 \text{ m}$ from the IP. The BCM2 detector is mounted at longitudinal position of $Z = \pm 14.4 \text{ m}$, and can further be characterized into two sub-detector systems; namely BCM2-inner which consists of an inner ring with 4 diamonds sensors mounted at a radius of 5 cm and BCM2-outer, consisting of 8 diamond sensors mounted at an inner radius of 28 cm.

The BCM1L and BCM2-inner detectors are used primarily for the protection of CMS and can be thought of as extension of the LHC BLM system. The CMS tracker community is concerned both with short time scale high beam losses that can cause damage to their detector electronics and longer time scale high machine induced backgrounds, that result in large particle flux to traverse the pixel detector, increasing the detector occupancy, causing problematic conditions for the track reconstruction, a strain on the detector readout and an increased radiation dose to the detector. In these conditions, the inner detector will also receive an increased radiation dose. The radiation concern defines the abort thresholds for both the $40 \mu\text{s}$ integration time scale and the 83 s integration time scale, which is implemented into the BCM abort threshold levels. The thresholds are defined based on studies of possible permanent damage scenarios to the tracker and pixel detector. At the time of this publication, no beam abort had been asserted by CMS due to currents that exceed the imposed detector thresholds.

A. Signal current measurements during a LHC fill

Fig. 3. An example of the BCM1L and BCM2 mip flux, measured during a particular LHC fill and the instantaneous luminosity as measured by the CMS HF calorimeter.

During a typical LHC physics fill, the BCM1L and BCM2 detectors measure a signal current that is dominated by collision products. Figure 3 shows the BCM1L and BCM2 measured MIP flux together with the instantaneous luminosity as measured by the HF detector [10]. Owing to their different locations, the BCM2 measures approximately, 6 times higher a signal for collisions products than BCM1L, because of the higher particle flux produced in the forward region.

The signal current measured by BCM1L and BCM2, is linear as a function of the instantaneous luminosity as measured by the HF detector, see Fig. 4 (a) and Fig. 4 (b). Hence, any deviations from linearity is an indication of an enhancement of the measured particle flux due to machine

(a) BCM1L

(b) BCM2

Fig. 4. The BCM1L (a) and BCM2 (b) current is linear with instantaneous luminosity. This linear relationship is valid during any LHC fill where the vacuum pressure is typically $< 10^{-9}$ mbar.

induced background. Slow changes (averaged from fill to fill) in the slope of the correlation, can give an indication of possible losses in detector efficiency due to an exposure to radiation. The longterm monitoring of this efficiency as a function of integrated luminosity is an ongoing study at CMS. Any small losses in detector efficiency are compensated for by a corresponding lowering of the detector thresholds, in order to maintain the equivalent protection to CMS.

The CMS detector is $-Z/+Z$ and ϕ symmetric, except for the installation of the forward, tungsten and quartz sampling calorimeter (CASTOR) [11]. It is approximately 1.6 m in total length and installed only on the $-Z$ side, directly behind the BCM2. This detector is a potential source of a large flux of low energy neutrons [6], which could have a damaging effect on the diamond sensors [6]. The 32 installed polycrystalline CVD (pCVD) diamonds, located in different locations of the CMS cavern provide a unique opportunity to study the effects of exposure to radiation in pCVD diamond detectors. This work is ongoing, including comparisons to Fluka Monte Carlo [7] simulations [6].

B. Measurement of beam loss during increased vacuum activity

An increase in pressure in the long straight section of the LHC [8], results in a corresponding increase in the number of interactions of the primary beam protons, with rest gas in the beam pipe (beam gas interactions). The products of

(a) Vacuum activity during the fill

(b) Extracted collision and beam background components

Fig. 5. (a) The BCM2 and BCM1L data for an LHC fill (#1440) where an increase in the vacuum pressure, corresponded to an excess in detector current compared to that expected from only collision products. (b) By exploiting the differences in the sensitivity of the BCM2 and the BCM1L detectors to collisions and beam gas background, the beam gas background can be extracted [9]. The time structure of the beam background component is in good agreement with the fluctuations in the vacuum pressure.

these beam gas interactions are secondary particles, preferably produced at small angles, and can be measured by the CMS BCM detectors. Figure 5 (a) shows an unusually sharp rise in the vacuum pressure during the middle of a fill for physics and the corresponding beam loss as measured with the two BCM detectors. Due to their different locations, the two BCM detectors have a different sensitivity to measuring collision and beam gas products. This difference in sensitivity can be exploited, as described in detail in [9], to extract separately the beam gas and collision components of the measured current, see Fig. 5 (b). The variation of the vacuum pressure as a function of time corresponds well to the variation of the extracted beam gas background signal, as shown in Fig. 5 (b).

C. Measurement of beam loss event duration

Although the LHC BLM data is logged only every second, the time scale of a short duration beam loss event can be calculated by analyzing the maximum current, in each of the integration time windows of the electronics, during the readout second surrounding the short loss. An example of a relatively short beam loss, is one that is believed to be produced by the circulating beam interacting with dust particles falling in the

(b) BCM2 and BLM data for different integration times during the UFO event.

Fig. 6. (a) The raw BCM2 data for the time around the UFO event (Time $\approx$ 22:09), as plotted using the 81.92 ms integration duration from the electronics, in all BCM2 channels. (b) The BCM2 and BLM detector data from different integration times from the electronics, between $40 \mu\text{s}$ and 1.2 s, from the 1 second readout time when the UFO occurred.

inner beam pipe volume. These so called UFO events have a duration of about 1 ms and happen rather frequently around the LHC ring [12]. An example of one of these UFO events was measured close to CMS and produced a large signal in the BCM detectors [9]. From this data, the time structure of the event could be investigated.

Figure 6(a) shows the raw data of that event measured in all BCM2 channels in one readout second. During the LHC machine mode “squeeze”, when the two beams are focused at the experimental interaction points, (Time $\approx$ 22:09), a beam loss spike that reached about 25% of the abort level was also measured by the detector. Collisions started thereafter (Time $\approx$ 22:38), but the beam was dumped after one minute for reasons unrelated to the UFO. Figure 6(b) shows the data of that spike from the different integration times normalized 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. When the integration time is longer than the event the measured values go down. In this way an estimate of the timescale of the event can be determined, in this case 0.3 ms.

Fig. 7. The position of the BCM1F detector with respect the the IP, allows for a good separation of collision products from incoming machine induced background, by exploiting the time arrival difference of particles.

Fig. 8. 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.

III. BCM1F - SINGLE CRYSTAL DIAMOND DETECTORS FOR PARTICLE FLUX MEASUREMENTS WITH NANOSECONDS RESOLUTION

In addition to the 32 polycrystalline diamonds installed in CMS as described in section II, the BCM1F detector [2], [13] contains 8 single crystal CVD diamond sensors, installed in two planes located at 1.8 m on either side of the IP. The distance between the sensors and the IP is optimal for the separation of incoming and outgoing particles and corresponds to a time-of-flight of $\approx 6 \text{ ns}$ for relativistic particles, see Fig. 7.

The BCM1F sensors have an active area of $5.0 \times 5.0 \text{ mm}^2$, a thickness of $500 \mu\text{m}$ and are metallized on both sides to operate as solid state ionization chambers, see Fig. 8. The sensors are coupled to a charge-sensitive, radiation-hard amplifier ASICs of the type JK16 [14], which collects the induced charge and shapes proportional signals. Using an optical driver, the signals are transmitted as analogue optical signals to a service room where they are converted back to electrical signals in the optical receiver. As shown in Fig. 8, the analog signal is duplicated and fanned out, and monitored by either an analog-to-digital converter (ADC) or discriminated for single particle measurements [15] as described in the following section.

A. Single-particle counting during a fill

A copy of the discriminated signals are made, and digitized by a multi-hit CAEN v767 time-to-digital converter (TDC) board with 0.8 ns resolution for arrival time measurements

Fig. 9. Single particle counts from BCM1F measured with the TDC, during a portion of the LHC orbit.

Fig. 10. A schematic, illustrating which of the non-colliding bunches are chosen from the fill pattern for each of beam 1 and beam 2 and used in the normalized beam-gas flux measurement. The “albedo” pedestal measurement is done in the 40 ns window prior to the train of selected non-colliding bunches, in order to estimate the contribution from activation products, to the beam gas measurement.

mapped on a beam orbit. Using the LHC orbit as a trigger and the internal 40 MHz clock that is very close to the 40.07 MHz LHC clock, the TDCs provide the time of each hit within an LHC orbit. Fig. 9 shows the arrival time distribution of the particles during a portion of the LHC orbit. The peaks with higher count rate are dominated by the products of colliding bunches, while the lower amplitude count rate corresponds to products from non-colliding bunches, preceding the bunch train. Counts from these preceding non-colliding bunches, and can provide a clean measurement of beam induced background. The bunch fill pattern in this region of the orbit can be identified by the TDC data as 30 colliding bunches spaced by 50 ns, preceded by 6 non-colliding bunches, see Fig. 9. The hits recorded after the last colliding bunch, correspond to a convolution of two sources; firstly the beam induced background from 6 following non-colliding bunches and secondly a dominant background that follows an exponential distribution, corresponding to the decay of activation products following the collisions [6].

B. CMS normalized beam-gas flux measurement

1) *Measurement considerations:* As shown in the TDC measurement of Fig. 9, the number of hits in the BCM1F

Fig. 11. A schematic of the logic implemented in the electronics in order to measure the normalized incoming and out-going beam 1 and beam 2 beam-gas flux using BCM1F.

detector is dominated by collision products. In addition, after collisions, a flux of particles is measured that exceeds the level of what could have been the rate of beam-induced background, as indicated by the hit rates from the non-colliding bunches prior to collisions. Hence, in order to have the highest sensitivity to machine induced backgrounds, only non-colliding bunches that precede the colliding bunches should be used for the measurement.

From previous studies of the albedo flux [16], the short lived activation products produced in the BCM1F region have a half life of the order of $2 \mu\text{s}$. Hence, in order to reduce the contamination from this albedo flux, a further restriction on the non-colliding bunch sample was made, namely that the non-colliding bunches had to be well separated from a previous colliding bunch. A separation distance of 900 ns was chosen in order have the best compromise between the number of non-colliding bunches for the beam-gas measurement and the amount of contamination from the albedo flux. In order to measure the remaining albedo contamination in the beam gas background sample, a gate of 40 ns was opened before the first non-colliding bunch in the selected train, and correctly scaled for a pedestal measurement and this is shown schematically in Fig. 10.

2) *Online measurement implementation:* The normalized beam gas flux measurement is implemented online independent of the CMS central data acquisition, by using the following steps

- In real-time measure the bunch pattern of beam 1 and beam 2 with the BPTX [17].
- Select non-colliding bunches by generating an 8 ns wide gate from the BPTX signal, co-incident with the time arrival of incoming non-colliding bunches in BCM1F.
- Open a VETO gate, 900 ns long after a colliding bunch, thus permitting only non-colliding bunch intervals, well separated from collisions (reduce albedo products) to be selected.
- Use 12 ns time of flight between the -Z and +Z BCM1F detector planes to gate separately incoming and outgoing

- beam 1 and beam 2 gas rates, as measured by the BCM1F.
- Measure a pedestal rate in 40 ns window before non-colliding bunch train, to estimate the non-beam gas component of the measured rate due to activation from collision products.
- Measure the bunch charge for each selected non-colliding bunch, online using the Fast Beam Current Transformer (FBCT) [18], so as to obtain a correctly normalized beam-gas flux measurement, per 10^{11} particles.

The NIM logic implemented for the beam gas measurement is shown schematically in Fig 11. The count rates in the relevant gates are integrated with a scaler module and the rates are published every second. The normalized beam-gas flux is then calculated, and published to CMS and the LHC every second.

3) *Measurement performance:* The LHC fill 2104, see Fig. 12(a), has been used to show the performance of the online beam-gas measurement, since during this fill, there was a higher than normal vacuum activity on both sides of the IP5, and hence a measurable machine induced background from beam 1 and beam 2 in the inner CMS detector region, using the BCM1F detector. As shown in Fig. 12(b), during the period of the fill when the beams are being accelerated, an increase in the vacuum pressure on the left side of CMS is measured by vacuum gauge VGPB 147 1L5 (located at 14.7 m from the CMS IP on the +Z side), see Fig. 12(b) (blue). At the same beam gas flux measurement for beam 1 (averaged incoming and outgoing beam 1) similarly increases, and is well correlated to the pressure profile as measured by this vacuum gauge. Followed by this event, the pressure on the right hand side of CMS starts to increase, see Fig. 12(b) (black) and continues to increase until the end of the ramp cycle, and the two beams are at their flattop energy of 3.5 TeV. The beam gas measurement for beam 2 (averaged incoming and outgoing beam2) is well correlated to the pressure profile as measured by the vacuum gauge VGPB 183 1R5 (located at 18.3 m from the CMS IP on the -Z side) during this period. During flattop energy, but before collisions, the vacuum pressure starts to decrease and this is also well correlated to a reduction in the beam 2, normalized beam-gas flux. Fig. 12(c) shows the evolution of the vacuum during the full fill. The beam 2, normalized beam-gas flux is still well correlated to the to the pressure profile as measured by the vacuum gauge VGPB 183 1R5, indicating that the despite the abundance of collision products during high luminosity production, the beam-gas algorithm is still sensitive to residual beam-gas interaction products, and the pedestal contribution from collision products is well subtracted. Finally Fig. 12(d) shows a linear relationship between the pressure as measured by the vacuum gauge VGPB 183 1R5 and the beam 2, normalized beam gas measurement. This shows that the beam-gas measurement is sensitive down to a pressure of about 0.5×10^{-9} mbar and the linear relation confirms that the particle flux measurement is dominated by beam-gas interactions.

IV. OUTLOOK

The BCM2 and BCM1L signal current is integrated using the LHC BLM electronics. The system is reliable, linear

with luminosity (during fills of low machine induced beam background) and no beam abort has been asserted so far, due to high beam losses. The duration of the various integration time windows of the electronics can be used to measure the duration of short time scaled beam loss events.

The BCM1F detector has successfully used single particle counting techniques to monitor machine induced beam backgrounds and collision products for the CMS detector since 2009. CMS plans to fully commission the BCM1F detector as an alternate on-line luminosity measurement in the future. A new schema for measuring the normalized beam-gas flux has been commissioned in 2011 based on the normalized flux from well separated non-colliding bunches. The measurement is well correlated to changes in the vacuum pressure and is sensitive to pressure increases above 0.5×10^{-9} mbar. The measurement is implemented in real-time and provides a normalized beam-gas flux for each of beam 1 and beam 2.

The successful performance of the BCM1F detector for CMS has lead to collaboration between the beam instrumentation group of the LHC, CMS and DESY to build BCM1F detectors for particle counting with nanosecond resolution for beam loss measurements in the LHC. The first BCM1F detector for the LHC is installed about 70 m from the IP of the LHCb experiment and is presently being commissioned with beam.

After an exposure to 5 fb^{-1} , work is presently ongoing to bench mark any possible degradation in the diamond sensor detector efficiency with Fluka based Monte Carlo simulations. The 40 diamond sensors installed in CMS in different locations, provide a valuable sample for long-term radiation damage studies to diamond.

REFERENCES

- [1] A.Bell, *Beam & Radiation Monitoring for CMS*, IEEE Nucl. Sci. Symp. Conf. Rec. (2008) 2322.
- [2] A. Bell et al., *Fast Beam Conditions Monitor BCM1F for the CMS Experiment*, Published in Nucl.Instrum.Meth. A614 (2010) 433-438 DESY-09-178. Nov 2009. 16 pp. e-Print: arXiv:0911.2480 [physics.ins-det]
- [3] R. Hall-Wilton et al., *Results from a beam test of a prototype PLT diamond pixel telescope*, Nucl. Instr. and Meth. A(2010), doi:10.1016/j.nima.2010.04.097 (in press).
- [4] B.Dehning et al, *LHC Beam Loss Monitor System Design*, BEAM INSTRUMENTATION WORKSHOP 2002: Tenth Workshop, Vol.648/1p.229-236
- [5] E.Effinger, et al, *The LHC beam loss monitoring system's data acquisition card*. 12th Workshop on Electronics For LHC and Future Experiments 2006, pp.108-112
- [6] Steffen Müller, PhD thesis, *The Beam Condition Monitor 2 and the Radiation Environment of the CMS Detector at the LHC*
- [7] A. Fasso, A. Ferrari, J. Ranft, and P.R. Sala, *FLUKA: a multi-particle transport code*, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773
- [8] LHC Design Report, CERN-004-003
- [9] M. Guthoff, *Design and experiences with the beam condition monitor as a protection system in the CMS Experiment of the LHC*, proceedings of European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators, DIPAC'11, Hamburg, Germany, (2011)
- [10] CMS Collaboration, *Measurement of CMS luminosity*, CMS Physics Analysis Summary CMS-PAS-EWK-10-004.
- [11] P. Goettlicher for the CMS-CASTOR collaboration, *Design and test beam studies for the CASTOR calorimeter of the CMS experiment*, Nucl. Instrum. Meth. A 623 (2010) 225.
- [12] T. Baer et al., *UFOs in the LHC*, Proceedings of IPAC2011 conference, San Sebastian, Spain, (2011) pp 1347-1349
- [13] R. Hall-Wilton et al., *Fast beam conditions monitor (BCM1F) for CMS*, 2008 IEEE Nuclear Science Symposium Conference Record, pp. 3298-3301.

(a) An overview of the sequence of the beginning of LHC fill 2104, showing firstly an injection of bunch trains of beams 1 and 2, followed by the energy ramp and finally the collisions as measured by the sudden increase in luminosity.

(b) During the LHC ramp, an increased vacuum pressure is measured on the left hand side of CMS by vacuum gauge VGPB 147 1L5 and then on the right hand side by vacuum gauge VGPB 183 1R5. The normalized beam 1 beam-gas flux is well correlated to the vacuum VGPB 147 1L5 while the normalized beam 2 beam-gas flux is well correlated to the pressure measured by the vacuum gauge VGPB 183 1R5.

(c) An evolution of the improvement of the vacuum conditions, especially on the right side of CMS during the fill, and the correspondingly reduced normalized beam 2 beam-gas flux.

(d) A strong correlation of the normalized beam-gas measurement for beam 2 with the vacuum pressure as measured by the vacuum gauge VGPB 183 1R5 during the ramp, confirming that the particle flux measurement is dominated by beam-gas interactions.

Fig. 12. The normalized beam-gas flux measurement for beam 1 (averaged over the incoming and outgoing beam 1 measurements), is well correlated to the pressure profile as measured on the left side of CMS by vacuum gauge VGPB 147 1L5. The normalized beam-gas measurement for beam 2 (averaged over the incoming and outgoing beam 2 measurements) is well correlated to the pressure profile as measured by the vacuum gauge VGPB 183 1R5. The linear relationship between the beam gas and the vacuum shows that the BCM1F detector is measuring the products of beam gas interactions during this time.

- [14] J. Kaplon and W. Dabrowski, *Fast CMOS binary front end for silicon strip detectors at LHC experiments*, 2005 IEEE Transactions on Nuclear Science 52(6), pp.2713-2720.
- [15] E. Castro et al, *The CMS Beam Conditions and Radiation Monitoring System*, proceedings of the TIPP 2011 conference in Chicago, 2011, submitted.
- [16] R. Walsh, *Performance of the The CMS Fast Beam Conditions Monitoring*, proceedings of the 2010 IEEE Nuclear Science Symposium Conference.
- [17] T. Aumeyr, *Beam Phase and Intensity Monitoring for the Compact Muon Solenoid Experiment*. Master thesis, Vienna University of Technology, 2008.
- [18] D. Belohrad et al, *The LHC Fast BCT system: A comparison of Design Parameters with Initial Performance*, proceedings of the Beam Instrumentation Workshop (BIW10), Santa Fe, New Mexico, USA, 2 - 6 May 2010 CERN-BE-2010-010