APPLICATION OF SINGLE CRYSTAL DIAMONDS (scCVD) AS BEAM CONDITIONS MONITORS AT LHC

E. Castro, DESY, Zeuthen, Germany on behalf of the DESY and BRM CMS group.

Abstract

The properties of single-crystal diamonds (scCVD): radiation hardness, low leakage current with negligible temperature dependence and fast signal response, make them attractive to be used as robust particle counters in areas of high radiation dose. The Beam Conditions and Radiation Monitoring system (BRM) of the CMS experiment includes the monitor BCM1F (Fast Beam Conditions Monitor) consisting of 8 scCVD sensors. BCM1F monitors the flux of particles from beam induced backgrounds and from collisions. It protects the inner CMS detectors from high background and delivers feedback on the beam conditions to the LHC.

Since the LHC start up in September 2008, BCM1F has revealed to be a valuable tool in the daily operation of the CMS experiment and the LHC. It was successfully used to keep the background level low, to identify vacuum leaks via the enhanced rate of halo particles from interactions of beam particles with residual gas atoms in the beam-pipe, and to perform an on-line luminosity measurement. In order to cope in future with higher bunch density and luminosity an upgrade of the BCM1F front-end-electronics and data acquisition is foreseen.

Due to the positive experience with the CMS BCM1F, the LHC was equipped with currently 6 BCM1F modules at several positions along the ring where beam losses will be analysed. The modules deliver information about hit rate and arrival time distributions projected on the time of an orbit, allowing to count halo particles originating from each bunch. A characterisation of both BCM1F systems using data collected during the LHC operation is presented.

INTRODUCTION

The CMS experiment contains several systems within BRM to measure independently the dose at several positions inside and near the detector, and the flux of ionising particles [1]. Three systems use diamond sensors. Two systems, using polycrystalline sensors [2], integrate the sensor current over microsecond time intervalls and may induce beam aborts when the current reaches preset limits.

The 8 BCM1F modules are particle counters to monitor the flux of particles with a time resolution of nanoseconds [3]. They consist of scCVD sensors, fast and radiation hard front-end ASICs and and a laser driven analog signal transmission. The back-end electronics containing fast ADCs, discriminators, scaler and TDCs and the data acquisition are operated independently from the CMS data acquisition.

To monitor the particle flux along the LHC 6 more modules, forming the BCM1F4LHC system, are installed at several IPs, as shown in Figure 1. The back-end electronics of BCM1F4LHC is similar to the one of BCM1F and located near the LHC control room.

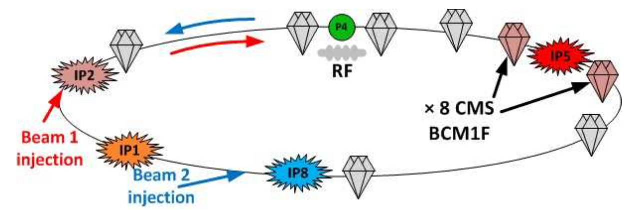

Figure 1: Location of BCM1F modules along the LHC ring.

SINGLE CRYSTAL CVD DIAMOND SENSORS

The charge collections efficiency of scCVD sensors is nearly 100% and signals of sensors with a thickness of about 500μm are sufficiently large to count MIPs. They are operated as solid state ionisation chambers by applying high voltage to thin metal plates on both sides of the sensor to generate an electric field in the bulk. Signals are created due the drift of both electrons and holes with high mobility.

The scCVD sensors used in BCM1F have an area of $5{\times}5$mm^2 and a thickness of 500μm. They have been manufactured by Element Six Ltd. as a result of the collaboration with the CERN RD42 project. A first application of an scCVD diamond sensor in a collider experiment was described in Ref. [4].

THE CMS BCM1F

The BCM1F consists of 2 planes of 4 modules each located at 1.8m on either side of the IP at a distance of 4.5cm from the beam pipe. Each module contains a scCVD sensor, radiation hard front-end electronics and optical transmission of the signal, as shown in Figure 2. The peaking time of the front-end ASIC is about 25 ns and the time resolution about 2 ns. 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 ~6 ns for relativistic particles.

THE BCM1F4LHC BLM SYSTEM

Six scCVD diamonds were installed in the LHC tunnel near the beam-pipe to monitor the beam halo and analyse beam losses. They are positioned next to collimators to be sensitive to losses originating from protons hitting the walls of the collimators, and next to ionisation profile monitors

ISBN 978-3-95450-119-9

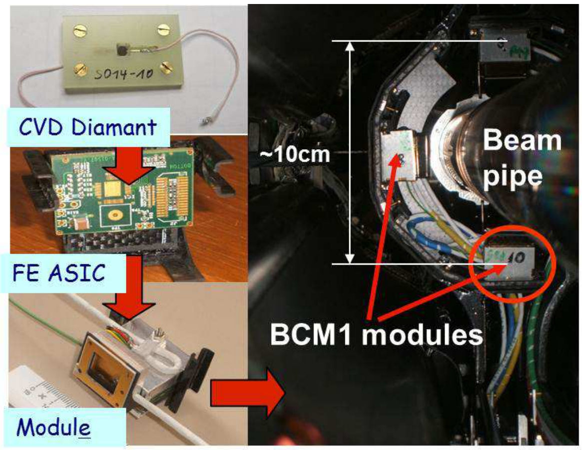

Figure 2: Photograph of one of the CMS BCM1 planes where the BCM1F modules are mounted around the beam pipe.

in the RF zone. Figure 3 shows an example of an installed sensor module.

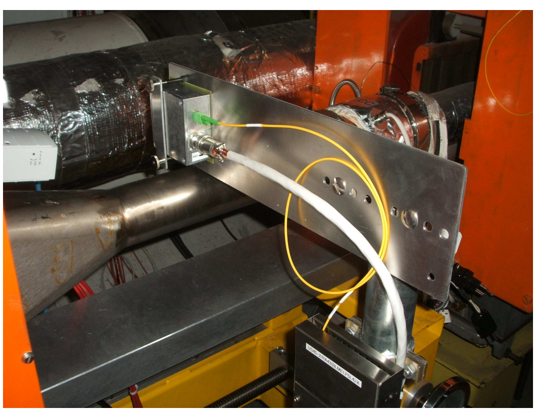

Figure 3: Photo of the installation of the sensor in P4. The yellow and white cables carry the sensor signals and the HV/LV respectively.

The amplified signals are transferred as analog optical signals through fibres to the CERN Prevessin site, where the data acquisition set-up is installed.

DATA ACQUISITION SET-UP

In the service room the analog optical signals are converted back to electrical signals. The analogue signals are duplicated, fanned out, and monitored by either an analogue-to-digital converter (ADC) with 500MS/s, or discriminated and fed into scalers and time-to-digital converters (TDCs). Relevant results are displayed in the control rooms and raw data files are stored permanently on disk for off-line analysis.

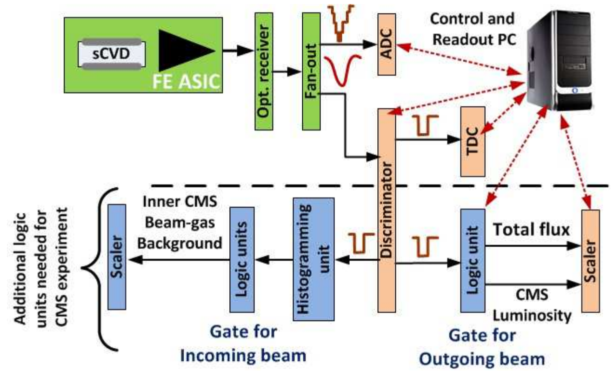

Figure 4: Data acquisition se-tup for BCM1F at CMS and LHC.

PERFORMANCE OF THE CMS BCM1F

Beam Background Measurements

The CMS BCM1F delivers to the LHC control room two numbers from scalers: the total flux of particles in the inner region of the pixel detector (BKGD 1) and the flux or particles due to beam halo (BKGD 2). For the calculation of BKGD 2 only the rates of non-colliding bunches are taken. These rates are also corrected for delayed hits originating from the activation of the material surrounding the sensors. The beam halo rates are a measure of proton scattering on residual gas atoms in the vacuum. This is nicely seen in Figure 5 where the rate of halo particles is measured as a function of the vacuum pressure measured by the gauge VGPB 183 1R5 during the ramp up after bad vacuum conditions on the right side of IP 5. The sensitivity is up to $\sim 0.5 \times 10^9$mbar.

Luminosity Measurement

BCM1F will be used for the on-line luminosity measurement. Since it is independent of the central CMS DAQ it measures the luminosity when the other monitors are not available. Currently the whole system, including special logics and histogramming modules, is under commissioning. However the results are very promising to e.g. luminosity values for each bunch crossing.

Upgrade Plans for the CMS BCM1F

After 2014 LHC will be operated at higher energy and luminosity, with bunches crossing every 25 ns. Because of the peaking time of the currently used FE ASIC of 25 ns, the performance of the whole system will be reduced and particularly the luminosity measurement difficult due to a large dead-time. A new FE ASIC with a peaking time and signal width below 10 ns and a fast baseline recovery is currently being developed. With a gain of 50 mV/fC and a signal-to-noise ratio of $\sim$10 it will discriminate MIPs from noise with better performance.

ISBN 978-3-95450-119-9

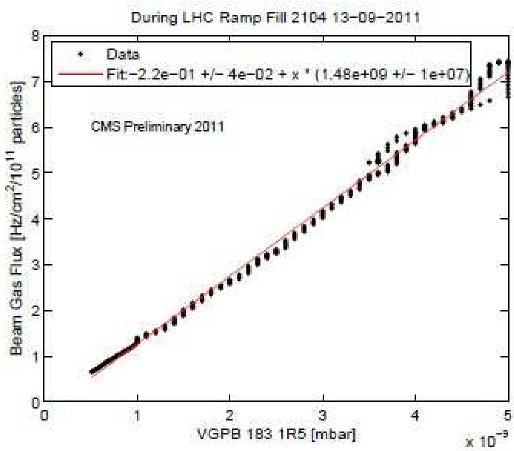

Figure 5: The rate of beam halo particles as a function of the vacuum pressure on the right side of IP 5.

PERFORMANCE OF THE LHC BCM1F

Total Flux

The discriminated sensor signals are fed to a scaler that counts the hit rate. Depending on the location of the sensors, the rates account for beam halo, beam losses, proton interaction with residual gas atoms due to vacuum degradation or collision products coming from nearby interaction points. Figure 6 shows an example of the rates for several proton-proton fills with collisions in the experiments Alice and LHCb (IP2, IP8 respectively).

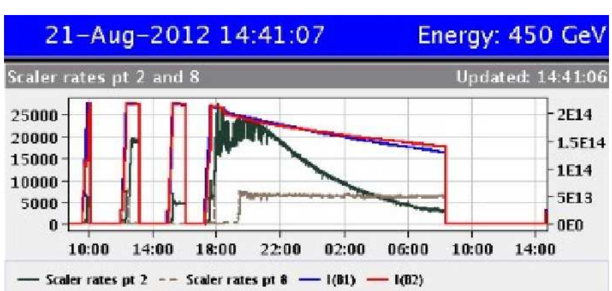

Figure 6: OP Vistars display: Beam 1 and 2 currents (in blue and red respectively) are overlapped with the scalers rates. Upper plot: P2 (black) and P8 (grey) rates.

Time Distribution of the Signals

The TDC measures the time of a hit within an orbit. The information is relevant ta assign hits to bunches. Interesting are also hits not synchronous with bunches or even hits in the so called abort-gap, which should not contain beam particles. Figure 7 is an example of a TDC plot for sensor in IP8, revealing a clear bunch structure of the halo from the incoming bunch train and collision products.

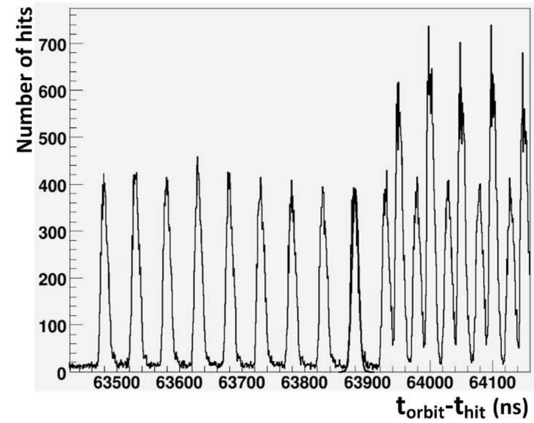

Figure 7: Sensor in IP8: zoom in one orbit of the distribution of hits with respect to the orbit trigger: lower peaks are hits due Beam 1 travelling towards IP8, higher peaks are the collision products overlapping with Beam 2 coming from the IP8.

CONCLUSIONS

The CMS BCM1F is a fully operational monitor that provides information to grant safe data of LHC and CMS. Its sensitivity and reliability in the daily operation shows that new monitoring capabilities can still be exploited. An upgrade of the FEE will grant its performance after the first long LHC shutdown. The BCM1F4LHC delivers valuable information on the halo at several positions along the ring and will allow diagnostics in case of beam losses with nanosecond time resolution. It demonstrates the potential of the scCVD sensors to be used as BLMs.

ACKNOWLEDGEMENTS

Special thanks to Bernd Dehning and other members of the CERN BE department for support.

REFERENCES

[1] A.J. Bell, "Beam and Radiation Monitoring for CMS", 2008 IEEE Nuclear Science Symposium Conference Record, p. 2322.

[2] M. Guthoff, "Design and experiences with the beam condition monitor as a protection system in the CMS Experiment of the LHC", Proceedings of DIPAC 2011, Hamburg, Germany.

[3] A.J. Bell, " Fast Beam Conditions Monitor BCM1F for the CMS Experiment", Nucl. Instrum. Meth. A614 (2010) 433–438.

[4] W. Lange, et al., "Investigation of a single crystal diamond sensor and its application in background measurements for HERA", talk given at the NoRHDia Workshop 2006, GSI Darmstadt, `http://www-norhdia.gsi.de/index.php?mgid=6`

ISBN 978-3-95450-119-9