A BEAM CONDITION MONITOR FOR THE EXPERIMENTAL AREAS OF THE LHC

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Abstract

The CERN Large Hadron Collider (LHC) will store 2808 bunches per colliding beam, with each bunch consisting of 10^{11} protons at an energy of 7TeV. If there is a failure in an element of the accelerator, the resulting beam losses could cause damage not only to the machine but also to the experiments. A Beam Condition Monitor (BCM) is foreseen to monitor fast increments of particle fluxes near the interaction point and, if necessary, to generate an abort signal to the LHC accelerator control, to dump the beams. The system is being developed initially for the CMS experiment, but is sufficiently general to find potential applications elsewhere. Due to its high radiation hardness, CVD diamond was chosen for investigation as the BCM sensor. Various samples of CVD diamond have been characterised extensively with both a ^{90}Sr source and in a high intensity testbeam in order to assess the capabilities of such sensors and to study whether this detector technology is suitable for a BCM system. A selection of results from these investigations is presented.

INTRODUCTION

The LHC will collide 7TeV proton beams with a nominal peak luminosity of 10^{34}cm^{-2}s^{-1}. Beam losses can be potentially damaging to both the accelerator and the experiments. Whilst a Beam Loss Monitor system [1] is being developed for the LHC accelerator, a complementary system in the experimental areas is required. For this reason a Beam Condition Monitor (BCM) is being developed. It will be based on fast and radiation hard beam sensors.

Chemical vapor deposited (CVD) diamond was chosen as material for the BCM sensor for its properties. Various samples have been characterized extensively with beta particles from a ^{90}Sr source and with protons from a high intensity beam to assess the suitability of such sensors for application to the BCM system. Results from these investigations are presented.

THE BEAM CONDITION MONITOR

The purpose of the BCM is to provide real-time radiation monitoring within CMS [2] and ATLAS [3], to detect and initiate protection procedures for detector subsystems at the onset of beam instabilities and accidents. The goal is to provide monitoring information in the time scale of the LHC beam structure of 25ns.

BCM sensors will be located close to the beam pipe (see figure 1). Fast electronics placed outside the main volume of CMS will process the signal from the sensors.

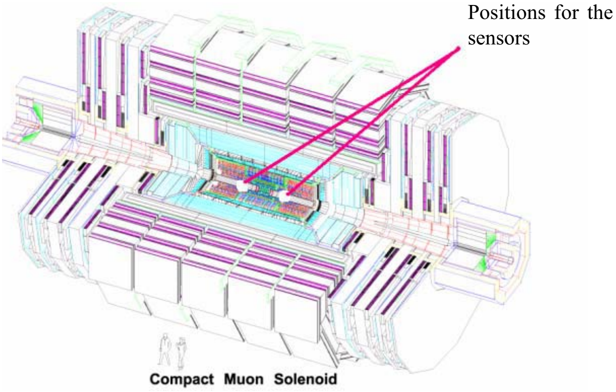

Figure 1: View of the CMS experiment with possible locations for the BCM sensors.

Fluence during normal conditions

The radiation environment close to the Interaction Points (IP), with the LHC generating around $8 \cdot 10^8$ *pp* inelastic events per second is going to be extremely hostile for all the subdetectors and electronics placed nearby. The major radiation sources are:

- The particle production from proton interaction.
- Local beam losses.
- Beam-gas interaction.

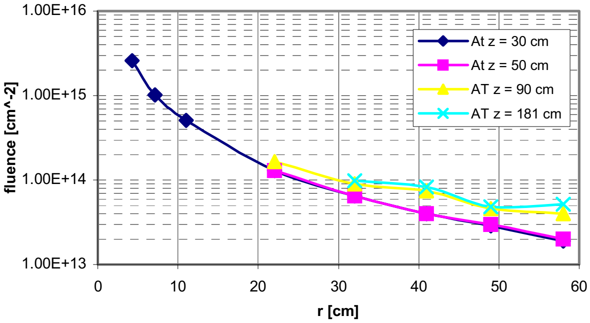

Figure 2: Particle fluence (in 10 years) as a function of the radial distance from the beam axis in the IP5 area. The different curves represent different positions from the interaction point along the beam axis (z-coordinate) [4].

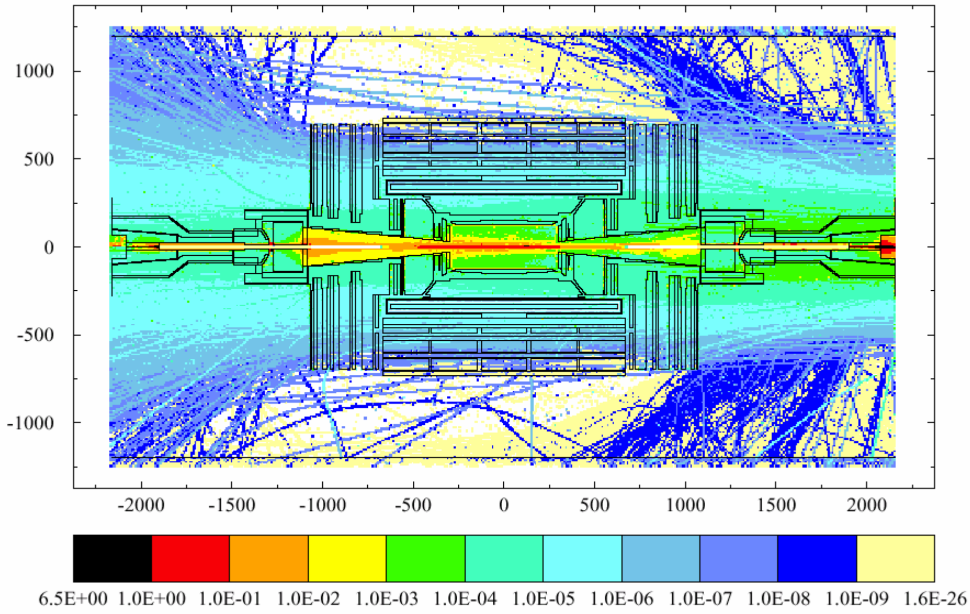

Figure 3: Simulation showing a mapping of the dose in Gy due to an unsynchronised beam abort accident. The dose is integrated during 260ns, which is the duration of the accident [9].

Figure 2 shows the particle fluence over a period of 10 years of LHC operation inside CMS depending on the radial position, with respect to the beam line, at different z coordinates (beam axis positions). The plot shows the great radial dependence of the particle fluence in comparison with the almost no dependence at all along the beam axis. BCM sensors will be placed very near to the beam pipe, which external perimeter is at 4.3cm from the beam axis. They must resist all the fluence they will receive during 10, or more, years of machine operation and must still be operational.

The flux during normal operation near the interaction point is 50 to 60 minimum ionizing particles (MIPs) per cm^2 each micro second [4], or around 1-2 MIPs per bunch crossing. Therefore, the BCM sensor and readout system must be capable of detecting single MIPs to be able to monitor the flux level per bunch crossing (each 25ns).

Accident scenarios

There are several beam accident scenarios which could be potentially dangerous for the experiments [5], [6] leading towards a maximal flux increase up to 10^9 times the flux during normal running conditions.

The time-scale of a beam accident is dependent on the failure and can vary between 250ns to several milliseconds.

The accidents where the beam is lost in a single turn are called ultra-fast losses [7]. They can be provoked by an injection failure or by a failure during a beam dump (pre-fire of the kicker magnets or unsynchronized beam abort). Figure 3 illustrates an unsynchronized beam abort, that happens when the dump kicker does not hit the abort gap. It is considered to be the “worse case” scenario [8, 9]. Some bunches will be deflected but still running in the accelerator until they found an aperture restriction, in the case of Figure 3, the CMS. The BCM cannot predict this type of accidents, thus do anything for preventing them. Therefore the sensor devices and readout electronics inside the CMS must be able to handle the high flux, 10^9particles/(cm^2·260ns), at which they will be exposed at least once per year.

The accidents which occur in less than 5ms, but more than a single turn (85μs), are called very-fast losses [7]. Table 1 lists the 5 fastest multiturn failures that can happen at LHC. In those failure the BCM must be able to detect the degrading conditions and act consequently.

Table 1: Top 5 of the fastest multiturn losses after equipment failure. The second column specifies the operation mode for which the losses can occur (injection versus collision optics). The third column gives the maximum time interval before beam loss will happen [5].

Magnet system	**Operation mode**	**Δt**
D1 warm	Collision	5 turns
Damper	Injection	6 turns
Warm quadrupole	Any	18 turns
Dump septum	Any	35 turns
Warm orbit corr.	Collision	35 turns

CVD DIAMOND AS BCM SENSOR

Inside the experiment there are space and mass constraints, therefore the BCM sensors must be small (i.e. ionization chambers, secondary emission chambers). Polycrystalline CVD diamond was chosen for investigation as the BCM sensor because of its high radiation hardness [10], fast response time, and minimal services requirements.

The charge collection properties of several samples were characterized with beta particles from a ^{90}Sr source approximating minimum ionizing particles (MIPs). A MIP in diamond will generate on average 36 electron-hole pairs per µm [11]. The generated electron-hole pairs will drift toward the electrodes driven by the applied electric field.

Radiation tolerance

The radiation tolerance was tested with protons up to a fluence of $2.8{\cdot}10^{15}$protons/cm^2 which is equivalent to the fluence expected after 10 years of normal operating conditions in the LHC near the CMS interaction point. We have observed a degradation of the signal by 28% after the irradiation.

For the purpose of testing the response to a flux equivalent to the "worst case" beam accident scenario, samples were placed in a dedicated high intensity 24GeV proton beam from the Proton Synchrotron (PS) facility at CERN. In order to approximate an unsynchronized beam abort the beam spill was composed of one up to a maximum of eight bunches, each containing ~10^{11} protons at an energy of 24GeV (MIPs). The 1σ width of the bunch was 10.5ns, and the inter-bunch spacing was 262ns. The bunch intensity varied by a factor ~53 from the highest intensity area ($1.5{\cdot}10^{10}$protons/cm^2 ±30%) near the centre to the periphery of the beam. The response signal from diamond sample to a shot with 8 bunches is shown in figure 4. The bunch structure is clearly visible in the CVD diamond signal, with the interbunch spacing of 262ns, consistent with the PS machine data.

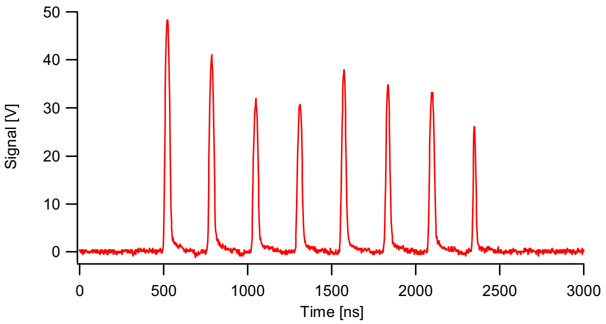

Figure 4: Response signal of a 300 µm diamond sample, biased at 300V, to an 8 bunch shot.

Integrating the pulses of figure 4 we obtain a particle fluence ranging from $7{\cdot}10^7$ to 10^8 protons/cm^2. The difference from the dosimetry value is about a factor three but well within the same order of magnitude. Another aspect that can be observed from figure 4 is the large amplitude of the signals, which represent currents of the order of 1A.

CONCLUSIONS

A development of a BCM for the experimental areas of the LHC will serve not only as redundant system for the Beam Loss Monitors but also to provide a detailed radiation monitoring in a position close to the IP.

CVD diamonds are able to withstand intense beams. They have been exposed to particle fluxes similar to an unsynchronized beam abort within the CMS experiment. Under such conditions the diamond samples are found to respond and recover from consecutive high intensity beam bunches.

The observed high currents generated in the diamond from conditions similar to an unsynchronized beam abort require that a protection system for the BCM readout electronics be implemented.

From characterization station measurements on CVD diamonds, which have been irradiated up to $2.8{\cdot}10^{15}$protons/cm^2, equivalent to 10 years of LHC running at normal conditions, we only observed a decrease of the output signal to a MIP of 28%.

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