SIMULATION OF THE LHC BRAN LUMINOSITY MONITOR FOR HIGH LUMINOSITY INTERACTION REGIONS∗

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Abstract

The BRAN (Beam RAte of Neutrals) detector monitors the collision rates in the high luminosity interaction regions of LHC (ATLAS and CMS). This Argon gas ionization detector measures the forward neutral particles from collisions at the interaction point. To predict and improve the understanding of the detector’s performance, we produced a detailed model of the detector and its surroundings in Fluka. In this paper, we present the model and results of our simulations including the detectors estimated response to interactions for beam energies of 3.5, 5, and 7 TeV.

INTRODUCTION

The Large Hadron Collider (LHC) at CERN can accelerate proton beams to 7 TeV and produce proton-proton (pp) collisions with a 14 TeV center of mass energy. Luminosity measures performance of the LHC and is particularly important for experiments in high luminosity (≤10^{34}) interaction regions (IRs), ATLAS (IR1) and CMS (IR5). Detectors of radiation hard Argon gas ionization chambers have been build and installed in both sides of these IRs to monitor and optimize the collision rates [1, 2, 3, 4].

Figure 1 is a schematic layout of one side of a high luminosity IR. A neutral particle absorber (TAN) protects the D2 dipole from forward neutral particles produced in the pp collisions [5]. These neutral particles produce (hadronic/electromagnetic) showers inside the TAN with a rate proportional to the pp collision rate. Our luminosity detector inside the TAN detects these showers and monitors relative changes in the pp collision rate.

Our detectors can make bunch-by-bunch measurements of 1) the rate that the shower is produced in the TAN (normal event) 2) the rate that the showers are produced simultaneously in both sides of the TANs (coincidence event), and 3) the average magnitude of the showers. For the nominal 7 TeV beams of the LHC, pp collisions per bunch crossing (multiplicity) go up to 30, assuming the inelastic pp cross section is 100 mb. In such a condition, both the normal and coincidence rates saturate to the bunch crossing rate and become insensitive to the pp collision rate, and we must use the average signal. Hence, numerical studies of the detector in the past focused on estimating the average signal from the 7 TeV beams [6, 7]. For the 3.5 TeV beams in 2010 and 2011 [8], however, the multiplicity does not exceed two and measurements of the either rates are proportional to the luminosity. Therefore, we did simulations to study performances of our detector in the modes of counting those rates for conditions of the different beam energies. In the following sections, we describe our simulation model and discuss results of the simulations.

MODEL DESCRIPTION

Our simulation model consists of three steps:

1. DPMJET3 [9] simulates particle productions due to the pp collisions. We do not consider the crossing angle and spatial and energy distributions of the beams.
2. The produced particles are transported to the TAN surface by EPICS [10]. Our model includes interactions between the particles and the beam pipe and the D1 dipole field but not the triplet fields.
3. Fluka [11] simulates the shower inside the TAN produced by the particles of Step 2. It then calculates the energy deposition in our detector due to the shower.

Data of Steps 1 and 2 were provided by the LHCf collaboration [12], whose detectors are also inside the TANs at IR1. Figure 2 is a result of Step 2 and shows the energy flux of the particles incident on the TAN surface, normalized to per pp collision. The flux is dominated by neutrons and gammas produced in the pp collisions. Contributions of the particles originated from the beam pipe is small. We may see that the energy flux from 3.5 TeV beams is about one third of that from the 7 TeV beams. This indicates that, even though the detector is designed for the 7 TeV beams, it should see some signal from the 3.5 TeV beams as well.

Figure 3 shows a Fluka simulation of the average energy deposition in the TAN due to the shower. Fluka can also...
In this section, we discuss results of our simulations for IR5\(^1\). The following simulations are based on a model with a simpler geometry than that in Fig. 3, which includes the TAN’s structure only in front of our detector. Our detector has the rectangular cross section with 8 cm sides and so we applied a 15 cm rectangular cut to the particles on the TAN surface. For 50,000 simulated \(pp\) collisions, we simulated the pulse heights of our detectors. Figure 4 shows the efficiency of our detector for the normal events, normalized to per \(pp\) collision, as a function of a given trigger threshold. The noise level of our detector is about 5 mV [3] and so the trigger level is considered between 20 and 40 mV. The simulation indicates that the efficiency of our detector is between 5% to 10% for the 3.5 TeV beams and between 25% to 30% for the 7 TeV beams. Although the efficiency for the 3.5 TeV beams is smaller than that for 7 TeV beams by a factor of 3-5, it should be large enough to be used successfully as a luminosity detector.

Figure 5 shows the efficiency of our detector for the coincidence events, normalized to per \(pp\) collision, as a function of a given trigger threshold. The simulation indicates that the efficiency is no more than 1% for the 3.5 TeV beams whereas the efficiency for the 7 TeV beams is on the order of 10%. The difference between 3.5 TeV and 7 TeV beams is about an order of magnitude unlike the case of the normal events.

Our detector cannot resolve the events generated from multiple \(pp\) collisions in a single bunch crossing. Therefore, when the multiplicity is more than one, we must consider the efficiencies per bunch crossing instead of per \(pp\) collisions. Suppose \(p_n\) is the efficiency of the normal event for one \(pp\) collision and \(M\) is the multiplicity. If we choose a trigger level of 20 mV, \(p_n \approx 10%\) for the 3.5 TeV beams and \(p_n \approx 30%\) for the 7 TeV beams from Fig. 4. The efficiency for the normal event modified to per bunch crossing.

\(^1\)Detectors of the LHCf experiment are inside the TANs of IR1 at present but they will be removed in summer 2010 and replaced by a copper bar. This changes the showers in the TANs of IR1 and hence we have postponed detail studies of IR1.
$P_n$, is given by

$$P_n = 1 - (1 - p_n)^M. \quad (2)$$

When the multiplicity is more than one, the notion of a coincidence is modified since we may have normal events of individual $pp$ collisions on both sides. We suppose $p_c$ is the efficiency for the coincidence event for one $pp$ collision. From Fig. 5, $p_c \approx 1\%$ for the 3.5 TeV beams and $p_c \approx 10\%$ for the 7 TeV beams with the 20 mV trigger level. The efficiency for the coincidence event modified to per bunch crossing, $P_c$, is given by

$$P_c = 1 - \left[2(1 - p_n)^M - (1 - 2p_n + p_c)^M\right]. \quad (3)$$

We note that $P_c$ depends not only on $p_c$ but also $p_n$. Figure 6 shows the efficiencies of our detectors for the normal and coincident events per bunch crossing as a function of the multiplicity, calculated from Eqs. 2 and 3 for the trigger level of 20 mV. The efficiencies for one $pp$ collisions, $p_n$ and $p_c$, are from the simulations of Figs. 4 and 5. For the 3.5 TeV beams, the multiplicity is lower than two and the both efficiencies are nowhere near the saturation. Hence, the rate measurements are effective to monitor changes in the $pp$ collision rate. Whereas, for the 7 TeV beams, the both efficiencies saturate to 100% when the multiplicity approaches ten. As discussed previously, in such a case, the observed event rate saturates to the bunch crossing rate and becomes insensitive to changes in the collision rate. Beyond this point, we must use the average signal.

**CONCLUSIONS**

Argon gas ionization chambers, which detect showers inside the neutral absorbers, are used to measure and optimize the collision rate of the two high luminosity IRs in LHC. Simulations predict that efficiencies of the detectors for the 3.5 TeV beams are about 10% and 1% for one $pp$ collision through detecting the normal and coincidence events and those for the 7 TeV beams are about 30% and 10%. Counting measurements are effective for the 3.5 TeV beams where multiplicity does not exceed two. On the contrary, for the 7 TeV beams, the counting measurements become ineffective when the multiplicity approaches ten and we must use the average signal beyond this point.

**ACKNOWLEDGMENT**

Authors would like to thank to H. Menjo for providing the simulated data of the particle fluxes on the TAN surface and E. Bravin, A. Drees, M. Placidi, and V. Talanov for their support and useful discussions.

**REFERENCES**