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 ($\leq 10^{34}$) 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.

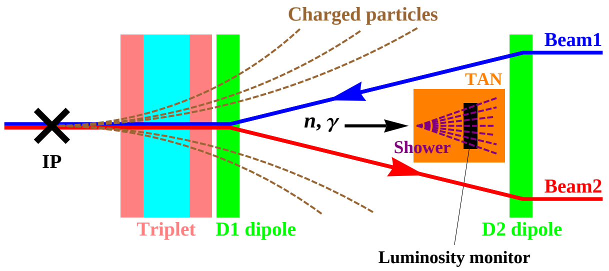

Figure 1: Schematic layout of one side of a high luminosity IR. The detector inside the TAN monitors showers produced by forward neutral particles from the *pp* collisions.

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

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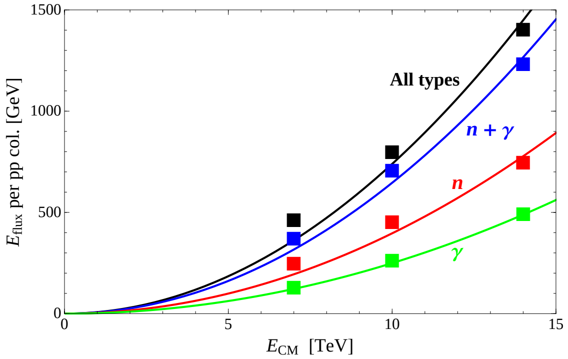

Figure 2: An average energy flux of the particles incident on the TAN surface inside the detector's geometrical aperture. The flux is dominated by neutrons and photons originated from the *pp* collisions. The curves are quadratic fits.

calculate the energy deposition from an individual shower generated by one *pp* collision. The deposited energy in our detector from the shower is used for ionization of Argon gas. A high voltage system collects the image charges of the electrons and then the signal is amplified and shaped. The following equation gives the conversion from the energy deposition in the detector, $E_{\rm dep}$, to the pulse height of the signal, h, in unit of V [13, 14]:

$$h=\frac{1}{2}\frac{E_{\rm dep}}{W_{\rm Ar}}\frac{GA}{B}\,, \tag{1}$$

where the factor $1/2$ is from that our detector collects the image charges of the electrons, $W_{\rm Ar}=26$ eV/pairs is referred to as W-function and is the required energy to produce an electron/iron pair in Argon gas, hence $E_{\rm dep}/W_{\rm Ar}$ is the number of produced electron/ion pairs, $G=0.32\ \mu$V/electron is the amplifier gain, $A=73\%$ is the cable attenuation, and $B\simeq 2.75$ describes a deficit due to the shaper's finite integration time (*ballistic deficit*) [14]. After substituting these numbers, the factor to convert $E_{\rm dep}$ to h is 1.63 mV/MeV. In this way, we can simulate the signal of our detector for each simulated *pp* collision.

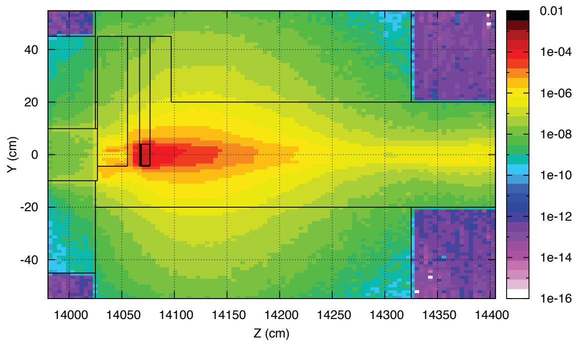

Figure 3: Average energy deposition in a TAN per *pp* collisions simulated by Fluka. The particles produced by the collisions are incident from the left side. The center of detector is located at $(x,y,z)=(0,0,14070)$ cm.

SIMULATION RESULTS

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, $p_n\simeq 10\%$ for the 3.5 TeV beams and $p_n\simeq 30\%$ for the 7 TeV beams from Fig. 4. The efficiency for the normal event modified to per bunch crossing,

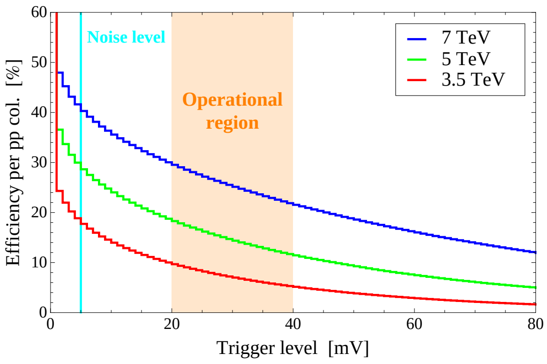

Figure 4: Detector efficiencies for the normal events normalized to a *pp* collision.

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[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.

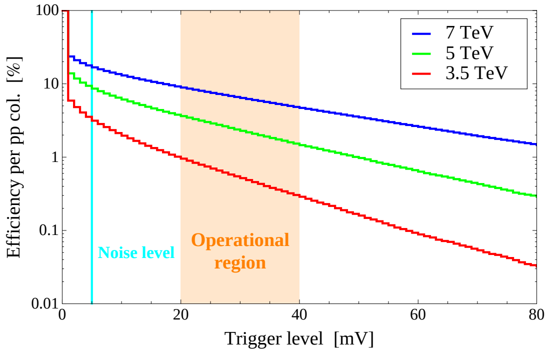

Figure 5: Detector efficiencies for the coincident events normalized to a *pp* collision.

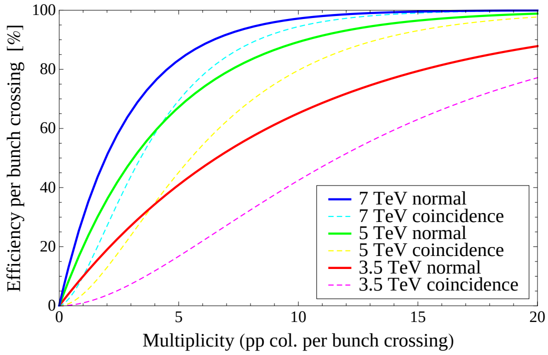

Figure 6: Efficiencies for the normal and coincidence events per bunch crossing vs. multiplicity.

P_n, is given by

$$P_n = 1 - (1 - p_n)^M \,. \tag{2}$$

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, $p_c \simeq 1\%$ for the 3.5 TeV beams and $p_c \simeq 10\%$ 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

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

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 to 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.

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