FLUKA SIMULATIONS AND SPS MEASUREMENTS FOR THE LHC BRAN

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Abstract

The LHC collision rate monitors (BRAN) will be used to monitor and optimize the luminosity at the four interaction points (IP). Depending on the expected level of luminosity for a given IP two different designs have been developed for LHC. At IP1 and IP5, the high luminosity experiments, the BRAN consist of fast ionization chambers and at IP2 and IP8, where the collision rate will be smaller, they consist of fast polycristalline–CdTe detectors. A better understanding of the performances of those detectors can be provided by detailed tracking simulations of the collision products coming from the IP within the detector. Here we report about the results of simulations done with FLUKA as well as a comparison with measurements done in the SPS.

INTRODUCTION

The performance of particle colliders is usually quantified by the beam energy and the luminosity which can be defined as the ratio of the collision rate $\dot{N}$ and the cross section σ for a given process:

$$\mathcal{L} = \frac{\dot{N}}{\sigma} \tag{1}$$

The nominal LHC beams consist of 2808 bunches of $1.15\,10^{11}$ protons. ATLAS (IP1) and CMS (IP5) require the highest possible collision rate, $1.0\,10^{34}\,\mathrm{cm^2s^{-1}}$ for nominal conditions, where ALICE (IP2) and LHCb (IP8) require a controlled optimal level of $3.0\,10^{30}\,\mathrm{cm^2s^{-1}}$ for ALICE and $5.0\,10^{32}\,\mathrm{cm^2s^{-1}}$ for LHCb. Collision rate monitors are therefore essential in order to optimize and control the luminosity at the different interaction points. In the LHC it is foreseen to measure the luminosity by monitoring the flux of small angle neutral particles produced by the collisions. Those monitors will be placed on each side of the interaction points in the neutral beam absorber (TAN) at IP1 and IP5 and behind a converter in IP2 and IP8. Given the different levels of luminosity for the different interaction points two different designs have been developed to fulfill the various requirements for each interaction point: a fast ionization chamber for the high luminosity interaction points and a fast polycristalline–CdTe detector for the low luminosity interaction points. The measured signal in the detectors corresponds to the energy deposition of the showers produced by the neutral particles going through this absorber. Tracking simulations of the collision products from the interaction point to the detector can provide estimates on the amplitude of this signal and the efficiency of those detectors.

SIMULATION

Initial conditions

The tracking simulations were performed using the FLUKA [1] code with initial conditions corresponding to the ones at IP5, half crossing angle of 142.5 µrad, and assuming that all the collisions occur exactly at the interaction point. This is of course not realistic for the case of the low luminosity interaction points but should be sufficiently accurate to estimate the performances of the detectors. The TAN absorber is modeled by a copper block with a length set such that the detector is placed at the maximum of the showers, approximately 15 cm as shown in Fig.1. For this study we tracked the product of 100 000 collisions.

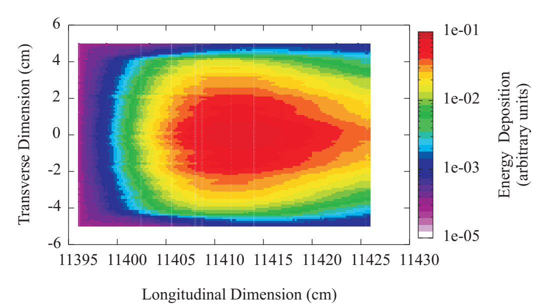

Figure 1: Deposited energy in 30 cm of Copper.

Particle distribution at the TAN

The first step in the simulation was to transport the proton-proton collision products to the TAN situated at 140 m from the interaction point in the case of IP5 [2]. The TAN being situated after D1 (dipole used to separate the beams into two different beam pipes) only neutral particles are left at this point. Looking at the distributions for different energies in Fig. 2 and 3 it is possible, with a simple Gaussian, fit to recalculate the crossing angle as a an intermediate check. The results are summarized in Table 1 and are in good agreement with the expected value of the crossing angle for the high energy neutral particles (142.5 µrad). For the intermediate energies no fit was performed because of the flat shape of the distribution. For the low energy case the peak of the distribution is outside the detector which could come from the interactions with the beam chamber. The average total energy of the incident particles at the TAN per event is of the order of 2.6 TeV.

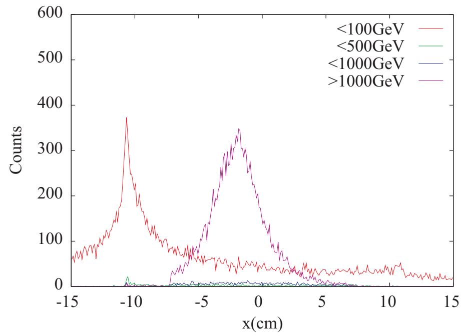

Figure 2: Initial neutrons distributions for different energies.

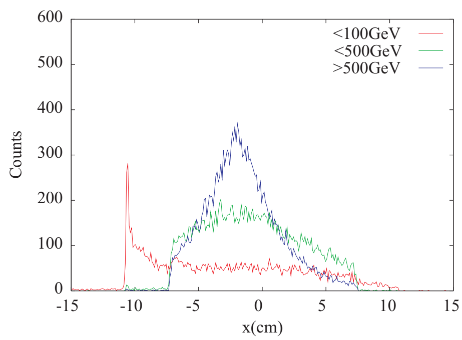

Figure 3: Initial photons distributions for different energies.

Simulation Model

In all IPs the detector is placed behind a copper block with a length of 15 cm and a transverse size of 10 cm in both directions in order to completely shadow the detector. The geometry of the detectors was simplified for the simulation but respects the dimensions of the technical drawings. All the materials were modeled using the FLUKA database and the option COMPOUND for the CdTe. In the case of the ionization chamber the gas is assumed to be Argon with a pressure of 10 bar. All the collision products are tagged with an initial event number which is recorded during the transport, this allows linking the energy deposition in the detector with its source and studying each event separately. The energy deposition was recorded using EVENTDAT.

Table 1: Gaussian fit results of the particle distribution at the TAN.

	Photons	
Enegy(GeV)	>500 GeV	>100 GeV
Pos. of the peak(cm)	-1.99 $\pm$ 0.03	-1.92 $\pm$ 0.09
Sigma (cm)	2.31 $\pm$ 0.12	5.46 $\pm$ 0.41
Crossing angle(μrad)	142 $\pm$ 2	137 $\pm$ 6
	Neutrons	
Enegy(GeV)	>1000 GeV	>500 GeV
Pos. of the peak(cm)	-2.01 $\pm$ 0.02	-1.86 $\pm$ 0.12
Sigma (cm)	2.39 $\pm$ 0.04	6.81 $\pm$ 0.67
Crossing angle(μrad)	144 $\pm$ 2	133 $\pm$ 9

SIMULATION RESULTS FOR THE CDTE DETECTOR (IR2 AND IR8)

The BRANs installed at IP2 and IP8 [3] consist of ten CdTe disks for a total width of approximately 10 cm. Each disk is giving an independent signal in counting mode. In order to be as close as possible to the realistic case the ten channels where simulated and studied separately.

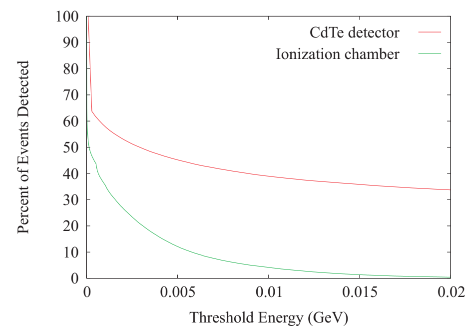

Figure 4: Percent of event detected versus the threshold energy.

Figure 4 shows the number of events detected for a given threshold energy and represents the efficiency of the detector depending on its sensitivity. The electronic noise from the detector is expected to be equivalent to 30 mV which corresponds to a deposited energy of 4.14 MeV as calculated with Equation 2. Applying a cut–off to compensate for this noise we would still detect $\approx 47\%$ of the events. The total energy deposited in the detector is $\approx 2.10^4$ GeV which gives an average deposited energy per proton-proton collision of 0.2 GeV.

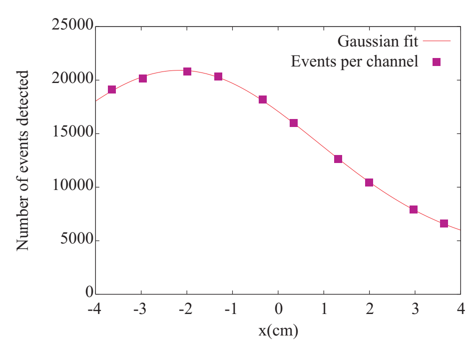

Figure 5: Number of events detected in each channel.

Figure 5 shows the number of events detected in each channel, as well as a Gaussian fit on this distribution. The position of the peak allows us to calculate the crossing angle. The results of the Gaussian fit give us the peak situated at -2.08$\pm$0.02 cm, for a sigma of 4.11$\pm$0.04 cm, from which we get a crossing angle of 149$\pm$2 μrad, which is comparable to the expected value of 142.5 µrad. The half crossing angles at IP8 and IP2 are of the order of 200 µrad and 150 µrad respectively and the detector is situated at 113 m from the IP in both cases. Applying a geometrical transformation we can give an estimate of what would be the position of the peaks for those IPs (-2.31 cm at IP8 and -1.75 cm at IP2). Rescaling the efficiency with the estimated peak values would give an efficiency of 45% for IP8 and 49% for IP2.

SIMULATION RESULTS FOR THE IONIZATION CHAMBER (IR1 AND IR5)

The ionization chambers [4] consist of four quadrants made of 1 mm slices of pressurized mixture of Argon and Nitrogen at 10 bar separated with copper electrodes. The detectors are installed just before D2 in the TAN situated at 140 m from the interaction point. In order to simplify the geometry the detector was modeled as layers of Copper and Argon. Applying a 5 mV cut off to the efficiency curve shown in Fig. 4, which corresponds to a deposited energy of 0.24 MeV as calculated in the final section, we expect to detect $\approx 45\%$ of the proton–proton collisions. The total energy deposited in the detector is ≈ 200 GeV which gives a deposited energy per proton–proton event of 2.0 10^{-3} GeV.

SIMULATION AND MEASUREMENTS AT 350 GEV

Measurements with test beam were performed in the SPS at 350 GeV for both detectors, in this section we will describe the results and try extrapolate the results to the 7 TeV in order to give an estimate of the signal at this energy.

CdTe Detectors

The four CdTe detectors have been placed behind a 15 cm thick copper block and irradiated with π^- at 350 GeV. The signal amplitude can be expressed as:

$$s = \frac{E}{I_w}\varepsilon\frac{q_e}{\tau}RG, \qquad (2)$$

where E is the deposited energy, I_w is the energy required to create a pair (4.43 eV), ε is the collection efficiency (20%), q_e is the electron charge, τ the pulse length (5 ns), R and G are the amplifier input impedance and gain (50 Ω and 100). Simulations were made using the same geometry as for the 7 TeV case and similar beam conditions in order to reproduce the measured threshold scan. The signal was calculated from the deposited energy using Equation 2. A Comparison between the simulations and the measurements showed that the predicted and measured signals disagree by a factor four. Applying this correction factor to the signal definition the 30 mV threshold would represent a deposited energy of 17 MeV which would reduce the efficiency of the detector to 35% and give an average pulse amplitude of 0.36 V per proton proton collision at 7 TeV.

Ionization Chamber

The ionization chamber was irradiated with a 350 GeV proton beam. In the case of a 15 cm long absorber and with a gas pressure of 8 bar the measured pulse height was equal to 5 mV [5], scaling it up to 10 bar would give a pulse height of 6.2 mV. The simulations of this experiment gave an average deposited energy per incident proton of 0.3 MeV for a gas pressure of 10 bar. We can give an estimate of the simulated pulse height with the following formula [6]:

$$s = c_\varepsilon\frac{E_{deposited}}{dE/dx_{min}}FG\frac{\varepsilon}{B_d} = 6.31\,\text{mV}, \qquad (3)$$

where c_ε the collection efficiency (0.5), F represents the number of ionization pairs created by a minimum ionizing particle (583 for 6 mm of Argon at 10 bar),G the gain (0.32.10^{-6} V/e$^-$), ε the losses in the cable (0.96) and B_d the ballistic deficit (2.75). This theoretical result is in relatively good agreement with the measurements knowing that this calculation underestimates the real dE/dx. Taking the measured value as a reference and looking at the 7 TeV simulation we obtain an average pulse height per event of 41 mV.

CONCLUSION

FLUKA simulations were performed for both BRAN designs. Comparison with the SPS test beam measurements and the simulations at 350 GeV are in good agreement for the ionization chamber but diverge by a factor four for the CdTe detectors. Using these results at 350 GeV as a reference we were able to estimate the performances of the BRANs at 7 TeV where both designs seem to behave as expected.

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