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Radiation background estimation for the GE11 Triple-GEM detectors in the CMS endcap

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Abstract. The Compact Muon Solenoid (CMS) is a general-purpose particle detector at the Large Hadron Collider (LHC) designed to study a wide range of particles produced in high energy collisions. The interaction of the beams with the pipe, shielding and detector supporting materials can produce neutrons, photons, electrons and positrons, forming a common background radiation field for CMS detector. A Monte-Carlo simulation is used to predict the background rate for a newly installed detector. In the forward region, the upgrade includes Gas Electron Multiplier (GEM) detectors called GE1/1. In this study, an estimate of the GE1/1 detector response to the background radiation is presented. The flux of background radiation is predicted using the FLUKA framework and the response of the detector is predicted using the GEANT4 framework. A comparison with actual GEM slice data is used as validation.

1. Introduction

The sensitivity to new physics of the Large Hadron Collider (LHC) is expected to increase with a series of upgrades to the so-called High Luminosity-LHC (HL-LHC) [1]. The Compact Muon Solenoid (CMS) experiment [2] must follow the LHC evolution and perform detector upgrades to fully seize the increased energy and luminosity. The goal of the CMS upgrade is to improve physics performance of detector subsystems and optimize the particle reconstruction for LHC luminosity up to 5 - 7 $\times$ 10^{34} cm^{-2} s^{-1}. The rise in collision rate with higher luminosity will increase the background rate in the forward region of the CMS muon endcaps. This background radiation field is mainly composed of neutrons, photons (γ), electrons/positrons ($e^{\pm}$) and charged hadrons, namely kaons ($K^{\pm}$) , pions ($\pi^{\pm}$), protons (p) [3]. These background particles can cause damage to detector elements and front-end electronics [4], additionally they can induce spurious signals that degrade detector performance. The GE1/1 background rate is predicted using FLUKA [5] and GEANT4 [6] simulations.

With the aim of gaining operational experience and demonstrating the integration of the GE1/1 system into the trigger, five superchambers (a combination of two single trapezoidal shape triple-GEM detector) were installed as an exercise known as GE1/1 Slice Test [7]. The background data for one of the superchambers (chamber 28 layer-2) was analyzed and hit rate as a function of perpendicular distance R from beam-line was obtained using the zero-bias data [8]. The motivation is to predict the expected hit rate from data within some uncertainty, so that we can estimate the background rates in Run-3 and for future upgrades.

2. Method

For the calculation of the background rate in the GE1/1, the following method is used:

$$\text{Hit-Rate} = \sum_{particle\text{-}type} \text{Flux}\ (particle\text{-}type,\ E,\ \theta,\ \text{R}) \otimes \text{Sensitivity}\ (particle\text{-}type,\ E,\ \theta)$$

where "*particle-type*" is the type of particle (neutron, γ, $e^{\pm}$ and charged hadrons), E is the energy of the incident particle and θ is the angle with respect to the axis perpendicular to the detector surface. The GE1/1 response to background particles is termed as "Sensitivity". Sensitivity is defined as the probability for a charged particle to deposit energy in the sensitive volume (e.g., Ar/CO$_2$ gas), producing primary ionized electrons [9] which go through a multiplication process, so that the charge is large enough to be detected by a readout system with charge thresholds. Flux is multiplied by the average sensitivity obtained by integrating the convolution of sensitivity at a given energy and incident angle with the normalized fraction of particles at that energy and incident angle.

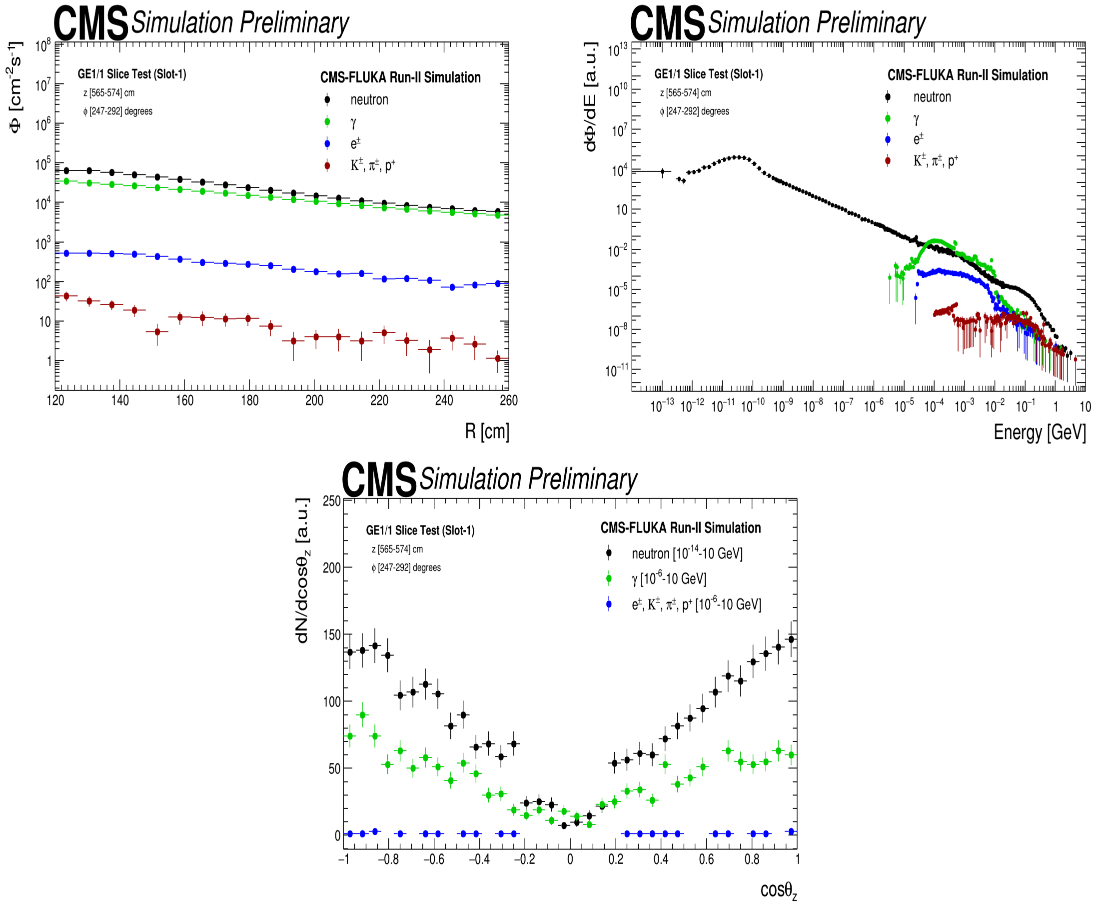

Figure 1. Particle flux arriving to GE1/1 volume, normalized to luminosity (top-left). Energy spectra of incoming particles (top-right), direction cosine of different particles with respect to axis perpendicular to detector surface (bottom)

3. Simulation

The flux and sensitivity are estimated using FLUKA and GEANT4 respectively.

3.1. FLUKA Simulation

The particle flux, differential energy spectrum and direction cosines at the CMS in the region 120 cm $<$ R $<$ 260 cm, 565 cm $< |Z| <$ 574 cm for all particles is estimated using FLUKA v2011-3.0 shown in figure 1.

The primary *pp* collisions with an energy of 6.5 TeV per beam including the effect of magnetic field are simulated for Run-2 geometry. An inelastic cross section of 80 mb is used for normalization of flux to luminosity 1.5×10^{34} cm^{-2} s^{-1}.

3.2. GEANT4 Simulation

The response of a GE1/1 detector is estimated using he GEANT4 v10.6. The primary particle are uniformly generated at a distance of 3 mm from a surface of same size and shape as of the drift board of the GE1/1 detector. Energy range used for different particles are 10^{-3}-10^{4} MeV for neutrons, 10^{-3}-10^{4} MeV for γ's, 10^{-2}-10^{4} MeV for $e^{\pm}$ and 10^{-1}-10^{4} MeV for charged hadrons $(K^{\pm}, \pi^{\pm}, p)$. The dimensions of CMS specific trapezoidal shape GE1/1 detectors are used for the GEANT4 simulation [9].

3.2.1. A single Triple-GEM Detector. A simplified single triple-GEM detector geometry (without service volume i.e. cooling system, cover and GEB) is simulated to study the effect of energy and angle of the incident particle on sensitivity. The sensitivity of GE1/1 detector is studied as a function of the energy and the angular distribution of each particle shown in figure 2 using threshold of 28.1 eV and 674.4 eV per incident particle for drift and transfer-1 gap respectively.

3.2.2. Superchamber. To compare the prediction with experimental data, a superchamber geometry (including service volume for both detectors) has been simulated to obtain the average sensitivity for superchamber 28 layer-2. This geometry includes all the components i.e. pull-outs, readout electronics and cooling system as explained in [9] along-with single Triple-GEM detector. The Triple-GEM detector [10] of a superchamber facing towards the interaction point of *pp* collisions is called “Layer-1” while the one facing outwards is called “Layer-2”. A threshold of 56.2 eV and 1.21 keV per incident particle are used for drift and transfer-1 gap respectively, assuming gain of approximately $\approx 10^{4}$.

Particle	Average Sensitivity of Layer-1 (%)	Average Sensitivity of Layer-2 (%)
Neutron	0.63 ± 0.01 (stat.)	0.75 ± 0.01 (stat.)
γ	0.29 ± 0.01 (stat.)	0.20 ± 0.01 (stat.)
$e^{\pm}$	1.18 ± 0.03 (stat.)	0.31 ± 0.01 (stat.)
Charged Hadrons ($K^{\pm}$, $\pi^{\pm}$, p)	27.0 ± 1.3 (stat.)	25.1 ± 1.2 (stat.)

Table 1. Average Sensitivity for each type of particle for the layer-1 and layer-2 of the superchamber configuration.

4. Systematics

The accuracy on the sensitivity estimations depends on a correct description of the physics processes and on a realistic detector modeling. To quantify the collective impact on hit-rate,

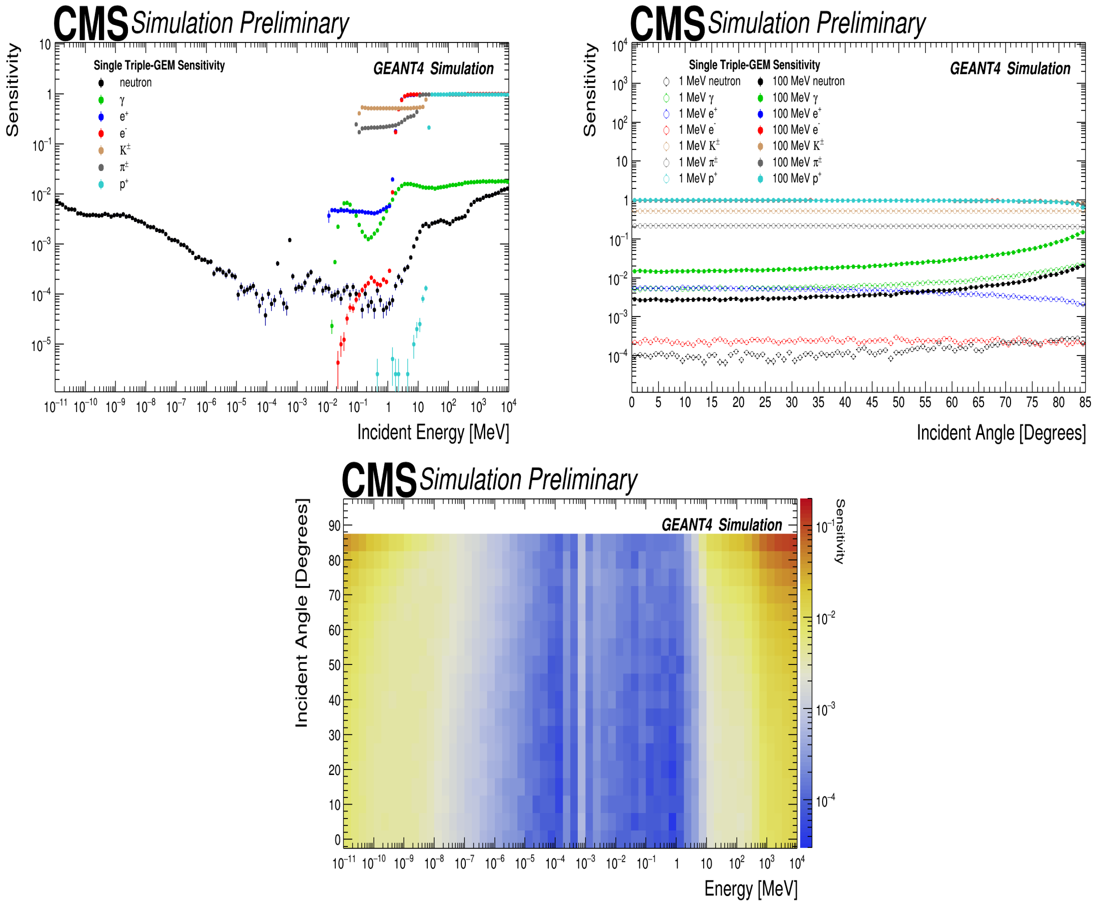

Figure 2. Sensitivity as a function of kinetic energy, for different particles, at incident angle of zero degrees with respect to normal to the detector surface (top-left). Sensitivity as a function of incident angle for different types of particles for 1 MeV and 100 MeV (top-right). Sensitivity 2D map for neutrons (bottom)

systematics on flux and sensitivity are considered for different parameters. Below are the paramters considered for GEANT4 systematics:

- Drift Gap Width (DGW) - variations of ±10% of nominal value (3 mm)
- Gas Mixture Proportion (GMP) - a variation of ±10% in Ar and CO_2 proportion of nominal (70:30)
- Source Generation Point (SGP) - a variation of ±2 mm from nominal (3 mm)
- Source Plane Area (SAR) - variations of ±10% of nominal (area of drift board)

Maximum systematics for DGW, GMP, SGP and SAR are found to be 1.4 %, 1.0 %, 9.9 % and 6.7 % respectively for each type of particle. FLUKA systematics is evaluated comparing the particle flux between the two CMS-FLUKA geometry, both consistent with Run-2 data taking scenario. The average uncertainty evaluated is 15.0%. The total combined uncertainty from FLUKA simulation and GEANT4 detector simulation is estimated to be about ≈ 14.5 % on hit rate, after adding them in quadrature for the whole range of R considered in this study.

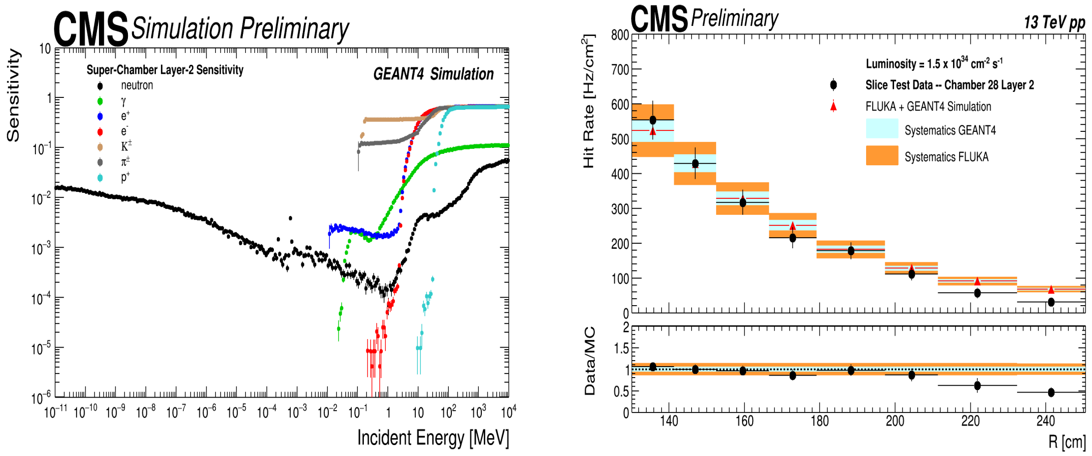

Figure 3. Sensitivity of "layer-2" as a function of incident energy for different particles (left). Comparison of slice test data with FLUKA+GEANT4 Simulation of Chamber 28 Layer-2 (right).

5. Comparison of Background Modeling and Experimental Data

A comparison between simulation and experimental measurements can be used to validate the model presented in this study. Figure 3 (right) compares the simulation with measured hit rate from data of layer-2 of superchamber 28 from the CMS experiment. The simulation results are obtained by taking the multiplication of average sensitivity shown in table 1 and values shown in Figure 1 (top-left). The FLUKA+GEANT4 simulation model discussed here describes the data hit rate well within the total uncertainties (including both statistical and systematics uncertainty added in quadrature) for the different data points correspond. The simulation prediction for first two η sectors show a larger discrepancy from data most likely due to relatively higher threshold set for these two sectors as compared to other sectors during data taking operations. Such effects can be studied in detail using GARFIELD software and a simulation of the electronics.

6. References

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