The Compact Muon Solenoid Experiment

Conference Report

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18 June 2018 (v4, 05 July 2018)

Background rate study for the CMS improved-RPC at HL-LHC using GEANT4

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Abstract

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Presented at *ELBA2018 14th Pisa meeting on advanced detectors*

Background rate study for the CMS improved-RPC at HL-LHC using GEANT4

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Abstract

In view of the High-Luminosity LHC (HL-LHC) phase, the Resistive Plate Chambers (RPC) system of the Compact Muon Solenoid (CMS) experiment will be extended up to pseudorapidity $|\eta| = 2.4$ by installing a new generation of RPC (improved-RPC) in the RE3/1 and RE4/1 endcap stations. In the present study, a GEANT4 Monte Carlo simulation study has been done to estimate the background rate on the iRPCs expected in the future runs of HL-LHC.

Keywords: Resistive Plate Chambers, improved-RPC, Monte Carlo Simulation, Detector sensitivity, Background radiation.

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1. Introduction

During the High-Luminosity LHC (HL-LHC) phase the instantaneous luminosity will increase up to $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (a factor five higher than the nominal LHC luminosity). In order to maintain the high performance and to ensure redundancy, the muon system coverage of the Compact Muon Solenoid (CMS) experiment will be extended up to the high-eta region [1]. Two Endcap stations, RE3/1 and RE4/1, will be equipped with a new generation of improved Resistive Plate Chambers (iRPC) [2]. The iRPCs have achieved higher rate capability and better detector longevity and electrical safety by reducing the gas gaps and electrodes thickness from 2 mm to 1.4 mm.

The purpose of the present study is to estimate the iRPC background rate during the future HL-LHC runs. The realistic detector responses of the iRPCs to the different background particles has been estimated using a GEANT4 Monte Carlo simulation [3].

2. Detector sensitivity

The detectors response to background particles, known as the "sensitivity", is defined as the probability for a particle N_{bkg} at a given energy reaching the detector surface, to produce a signal N_{HIT} :

$$S(E) = \frac{N_{HIT}}{N_{bkg}}(E) \quad (1)$$

The sensitivity is a function of the energy of the incoming particles, because at different energies, different processes are responsible for the production of secondary particles. For this reason the iRPC sensitivity has been estimated with respect to the different particles that compose the CMS background at the expected HL-LHC spectra.

3. iRPC geometry in the GEANT4 Monte Carlo simulation

The detector geometry described in the GEANT4 simulation code is the first large size iRPC prototype [2] that has been tested at CERN's Gamma Irradiation Facility (GIF++) [4]. The double gap geometry, having 1.4 mm thickness of gas volume and High Pressure Laminate (HPL) electrodes, was employed with the strip plane sandwiched between the two gas gaps. In order to properly include the secondary radiations produced by high energy particles, all the outer layers of materials composing the trapezoidally shaped detector body (height = 1613 mm, long side = 866.3 mm, short side = 584.1 mm) are also implemented in the simulation code.

For this study the GEANT 4.9.6 version has been used. The "FTFP-BERT-HP" package has been used to describe the physics processes, since it includes all the standard electromagnetic processes and it is the most accurate neutron model, especially at low energies. For the GEANT simulation some assumptions [5] have been applied:

- The particle source is isotropic and particles randomly strike the detector.
- An energy threshold of 100 keV has been applied to the primary and secondary charged particles that produce a signals in the gas gaps. The realistic threshold value of 100 keV was empirically obtained from the iRPC geometry validation study comparing the measured gamma rate at GIF++ and the simulated rate. Figure 1 shows the measured detector sensitivity to the ^{137}Cs gammas at GIF++ as functions of the irradiation conditions (ABS), compared with the simulated sensitivity calculated without any energy threshold and with energy thresholds of 100 keV and 200 keV.
- If more than one charged particles reach the gas gap, only the first one is assumed to generate a signal.

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In order to obtain a statistical uncertainty less than 1%, large numbers of events (3×10^6 for each energy value) have been simulated. The estimation of the sensitivity variance is given by a binomial distribution.

Figure 1: Detector sensitivities to ^{137}Cs gammas measured at GIF++ (red squares) at different background conditions (ABS) compared with the simulated sensitivity: without energy threshold (black circles) and with energy thresholds of 100 keV (green inverse triangles) and at 200 keV (blue stars).

4. iRPC sensitivity and background hit rate

The expected background hit rate in the RE3-4/1 stations during HL-LHC has been estimated scaling the incident particles flux with the iRPC sensitivity. The incident fluxes for the different background particles are estimated implementing the upgraded CMS geometry and the accelerator conditions for proton-proton collisions in the FLUKA simulation code (CMS Fluka study version v.3.7.7.0). In the present background simulations, we assume a centre of mass energy of 14 TeV with a nominal instantaneous luminosity of $5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$. The iRPC sensitivity has been estimated with respect to the different background particles (neutrons, gammas, electrons and positrons), at the expected HL-LHC spectra. The results are shown in Fig. 2, where the sensitivity is reported as a function of the energy of the incoming particles.

Figure 2: iRPC sensitivity with respect to the different background particles (neutrons, photons, electrons and positrons) as a function of the incident particle energy.

The neutron sensitivity values rise in the low energy region ($E_n < 10^{-5} \text{ MeV}$), which is mostly due to gammas coming from the (n, γ) capture reaction whose cross section increases with decreasing in neutron energy as $\sigma \propto 1/\sqrt{E_n}$.

Figure 3 top shows the expected background hit rate as a function of the incident particles energy, estimated from the convolution of the sensitivities and the incident particles fluxes.

The average background hit rate has been estimated using the average sensitivity values, $[n (0.4\%), \gamma (2.4\%), e^{-/+} (6.8\%)]$. Figure 3 bottom shows the contribution of the different particles to the total background hit rate in the RE3/1 station as a function of the distance from the centre of the CMS beam pipe. The average background rate of $\approx 600 \text{ Hz/cm}^2$ indicates the requirement of a minimum rate capability of $\approx 2 \text{ kHz/cm}^2$ for the iRPCs when considering a safety factor of three.

Figure 3: Top: Background hit rate expected in the RE3/1 station during HL-LHC as a function of the energy of the incoming particles. Bottom: Expected background hit rate in the RE3/1 station during HL-LHC as a function of R.

5. Conclusions

A GEANT4 Monte Carlo simulation was used to evaluate the iRPC sensitivity, and to estimate the background hit rate expected during HL-LHC in the RE3/1 and RE4/1 CMS-RPC stations, which was found to be approximately 2 kHz/cm^2 (including a safety factor three).

References

- [1] CMS Collaboration, *The Phase-2 Upgrade of the CMS Muon Detectors*, CERN-LHCC-2017-012, CERN, Geneva Switzerland, LHC Experiments Committee (2017) [CMS-TDR-016]
- [2] K.S. Lee *et al.*, *Thin Double-gap RPCs for the Phase-2 Upgrade of the CMS Muon System*, CERN-CMS-NOTE-2017-005, CERN, Geneva Switzerland (2017) [CMS-NOTE-2017-005]
- [3] S. Agostinelli *et al.* [GEANT4 Collaboration], *GEANT4: A Simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.
- [4] R. Guida [EN and EP and AIDA GIF++ Collaborations], *GIF++: A new CERN Irradiation Facility to test large-area detectors for the HL-LHC program*, PoS ICHEP **2016** (2016) 260.
- [5] J. T. Rhee *et al.*, *Study of the neutron sensitivity for the double gap RPC of the CMS/LHC by using GEANT4*, J. Korean Phys. Soc. **48** (2006) 33.