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RPC Radiation Background Simulations for the High Luminosity Phase in the CMS Experiment

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Abstract

The high luminosity expected from the HL-LHC will be a challenge for the CMS detector. The increased rate of particles coming from the collisions and the radioactivity induced in the detector material could cause significant damage and result in a progressive degradation of its performance. Simulation studies are very useful in these scenarios as they allow one to study the radiation environment and the impact on detector performance. Results are presented for CMS RPC stations considering the operating conditions expected at the HL-LHC.

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ABSTRACT: The high luminosity expected from the HL-LHC will be a challenge for the CMS detector. The increased rate of particles coming from the collisions and the radioactivity induced in the detector material could cause significant damage and result in a progressive degradation of its performance. Simulation studies are very useful in these scenarios as they allow one to study the radiation environment and the impact on detector performance. Results are presented for CMS RPC stations considering the operating conditions expected at the HL-LHC.

KEYWORDS: Resistive Plate Chambers; Simulations; Radiation background; CMS Experiment

Contents

1 Introduction

The High Luminosity Large Hadron Collider (HL-LHC) upgrade represents a new challenge in detector technologies. The increase in luminosity will produce an order of magnitude higher background radiation than the one produced with the current operating conditions at the LHC. The background field consists mostly of neutrons and γ particles. To understand the effects of this background on the functionality of the Resistive Plate Chambers (RPCs), which form part of the muon system of the CMS experiment, we study the impact of different kinds of radiation particles (γs, neutrons, electrons and positrons) using the Geant4 and FLUKA simulation packages for an estimate of the radiation environment and detector response respectively.

2 CMS Muon Detector Upgrade

Background radiation studies play a decisive role in understanding the performance of the detectors and could help to improve the design of the muon system upgrade for the high luminosity phase [1]. CMS uses double-gap RPCs with a 2mm gap formed by two parallel bakelite electrodes with a bulk resistivity of about 10^{10} Ω·cm. A copper readout plane of strips is placed between the two gaps. They operate in avalanche mode with a gas mixture composed of 95.2% $C_2H_2F_4$, 4.5% C_4H_{10} and 0.3% SF_6. The HL-LHC improved RPCs (iRPCs) will have a higher rate capability, better detector longevity, and electrical safety achieved by a reduced gas gap (from 2 to 1.4mm). iRPCs will increase the eta coverage up to $|\eta| = 2.4$, where η is the pseudorapidity, and will provide timing information at the level of 1.5 ns, adding redundancy and robustness in this region as shown in Fig. 1.

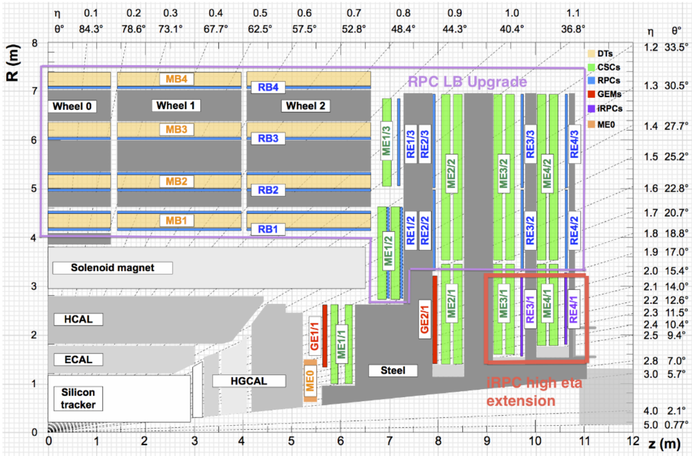

Figure 1. A quadrant of the CMS experiment, where the RPCs are located in the barrel and endcaps. The Drift Tube (DT) chambers are labeled MB (Muon Barrel) and the Cathode Strip Chambers (CSC) are labeled ME (Muon Endcap). The chambers of the upgrade system are highlighted in red, including the Gas Electron Multiplier (labeled ME0 and GE). The square indicates where the iRPCs will be placed to extend the muon system coverage. The upgrade regions are labeled RE3/1 and RE4/1 for the third and forth endcap stations.

3 Radiation Simulation

For the simulation of particle transport and the interaction with matter FLUKA [2] and Geant4 [3] Monte Carlo simulation packages were used. FLUKA provides an accurate description of particle flux including particles with a substantial lifetime, as in the case of neutrons, where the standard CMS simulation framework (CMSSW) is constrained due to simulation time. The CMS-FLUKA geometry used corresponds to a scenario compatible with the HL-LHC, with a description of the High Granularity Calorimeter (HGC), a new design of the beampipe and the upgrade muon stations. Incoming particle information is propagated to a Geant4 simulation where the detector response is obtained. The Geant4 simulation uses a description of the RPC detector geometry which is performed by utilizing a variety of geometrical layer elements and following the description presented in Section 2. The modeling of particle interactions and physics processes was performed using the Geant4 FTFP_BERT_HP physics list which includes the standard electromagnetic processes and an accurate description of low energy (thermal) neutrons.

4 Results

4.1 Detector Sensitivity and Background Hit Rate

Due to the interaction of radiation particles with RPC chambers a signal could be induced with a probability known as detector sensitivity, which depends mostly on the type of incident particle and its kinetic energy. Usually the particle triggering the signal is not the primary particle but rather the secondary charged particles. The sensitivity of a double gap RPC chamber for neutrons, photons, electrons and positrons as a function of their energy is shown in Table 4.1. The sensitivity results for iRPCs can be found in [4].

Type of particle	**Neutrons**	**Photons**	$e^{\pm}$
Sensitivity (%)	0.27	1.6	29

Table 1. Double gap RPC sensitivity. Sensitivity is defined here as the ratio of events whose signal was found in the detector divided by the original number of generated events, with a constraint of at least one charged particle entering at least one of the gas gaps.

The background hit rate is a quantity that can be directly compared to experimental measurements. It is defined as the convolution of the detector sensitivity and the particle flux. The background hit rate as a function of the radius (distance to beam pipe) for the RE3/1 station [5, 6] is shown in Fig. 2 where the total contribution is represented with empty full circles.

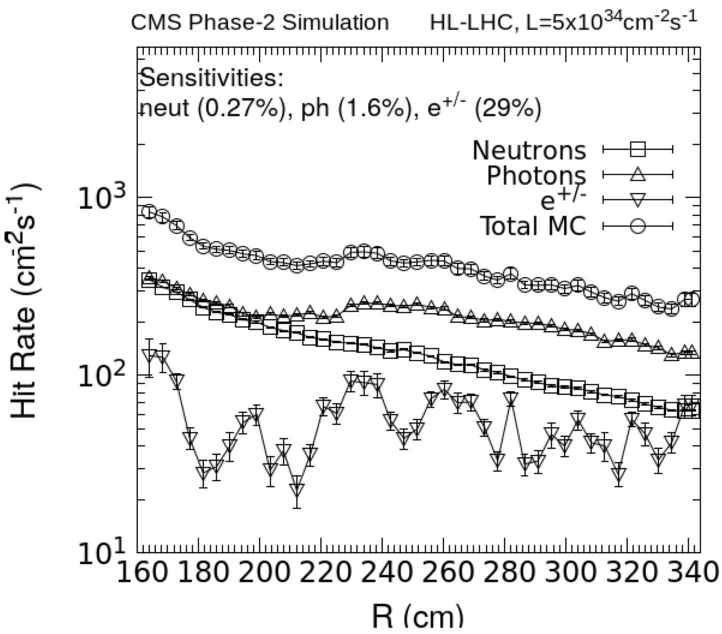

Figure 2. Estimated background hit rate for the RE3/1 station.

4.2 Studies on the Influence of Neutron Shielding for RPC Stations

The RPC stations to be installed in the HL-LHC will be protected with neutron shielding (based on b-polyethylene) located strategically at the edge of the chamber that is closer to the beam-line (where the particle flux is more intense). This aims to protect the detector and electronic components from the harsh radiation environment. In the simulation we can study the effect of this shielding by comparing the rate of background particles coming from different regions around the detector. These different regions are shown in Fig. 3 and the effect of neutrons and photons (using sensitivity values from Table 4.1) is presented in Figs. 4 and 5 respectively, where the effect of the shielding is more pronounced around R=220 cm. The final design of the shielding is still under study for the HL-LHC.

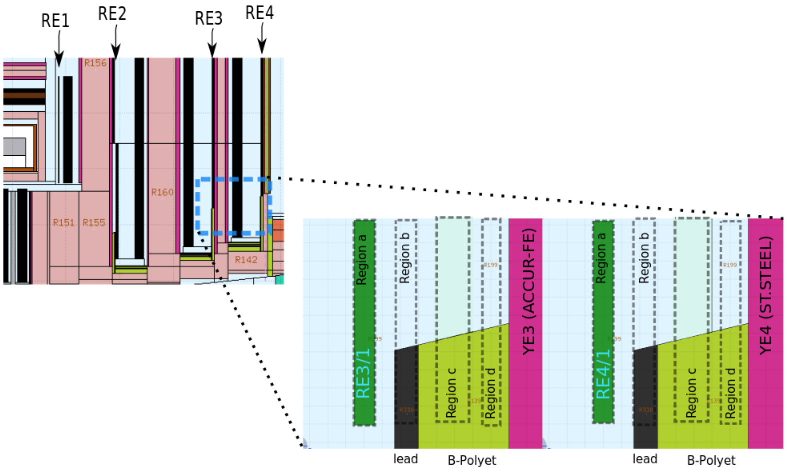

Figure 3. Regions near the upgrade RE3/1 and RE4/1 stations.

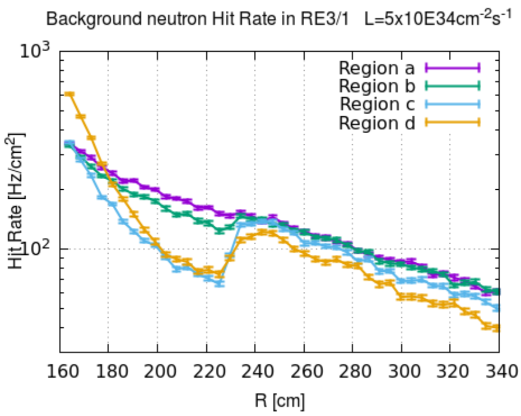

Figure 4. Estimated background hit rate near the upgrade RE3/1 station for neutrons.

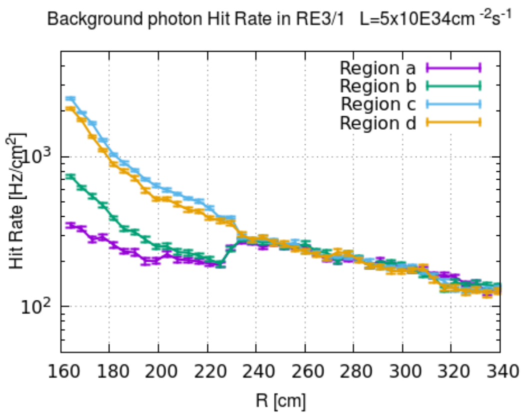

Figure 5. Estimated background hit rate near the upgrade RE3/1 station for photons.

5 Conclusion

The radiation environment for the HL-LHC was studied using simulations. The luminosity considered was 5×10^{34} cm^{-2}s^{-1}. The impact of background particles on the RPC chambers was studied by obtaining an estimate of the detector sensitivity. These studies are relevant in optimizing the detector design and the shielding materials to prevent possible damage to the detector and its electronic components. In the future, similar studies will be updated with a more detailed description of HL-LHC CMS geometry and a refined estimate of the detector sensitivity.

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