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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.

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, the impact of different kinds of radiation particles (γs, neutrons, electrons and positrons) is studied using the FLUKA and Geant4 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 [2] with a 2mm gap formed by two parallel bakelite electrodes with a bulk resistivity of about $10^{10}\ \Omega$·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) [3] will have a higher rate capability, better detector longevity, and electrical safety achieved by means of 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 figure 1.
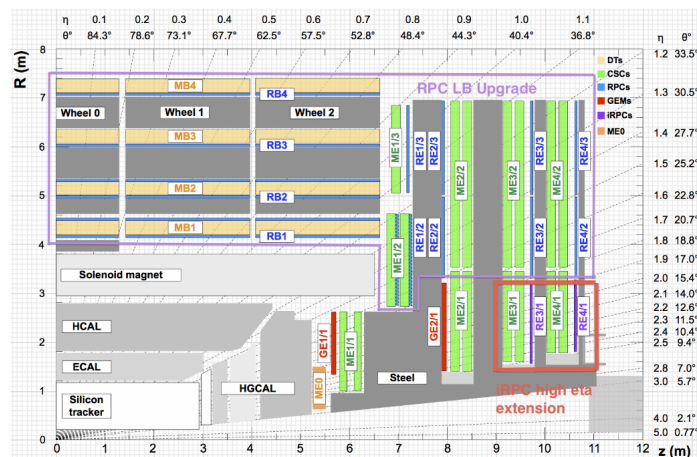
Figure 1. A quadrant of the CMS experiment, where the RPCs are located in the barrel and endcaps. The Drift Tube (DT) chambers are labeled MB (Muon Barrel) and the Cathode Strip Chambers (CSC) are labeled ME (Muon Endcap). The chambers of the upgrade system are highlighted in red, including the Gas Electron 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 [4] and Geant4 [5] 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) focuses on prompt particles and does not properly consider their contribution due to constraints on the simulation time window. The CMS-FLUKA geometry used corresponds to a scenario compatible with the HL-LHC, with a description of the High Granularity Calorimeter (HGC) [6], a new design of the beampipe and upgraded muon stations [7]. 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, 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 energy averaged sensitivity of a double gap RPC chamber for neutrons, photons, electrons and positrons is shown in table 1. The sensitivity results for iRPCs can be found in [8].

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 with a signal in the detector divided by the original number of generated events. If more than one charged particle reaches the gas gap, only the first one is assumed to generate the signal.

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 [7, 9] is shown in figure 2 where the total contribution is represented with empty full circles.
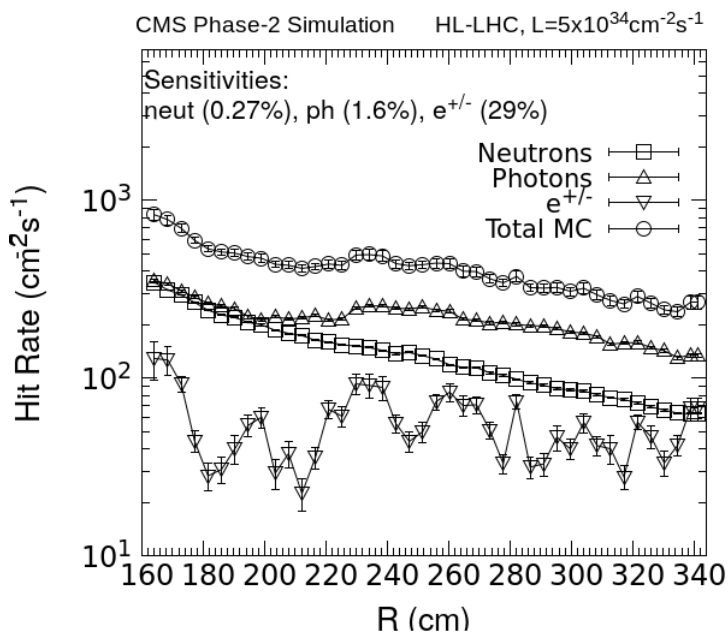

Figure 2. Estimated background hit rate for the RE3/1 station.

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 Borated Polyethylene) located strategically at the edge of the chamber that is closest to the beamline, where the particle flux is more intense. This aims to protect the detector and electronic components from the harsh radiation environment. In the simulation the effect of this shielding can be studied by comparing the rate of background particles produced by different sources (such as collision points, decay in flight, conversions, etc.) arriving at the regions described in figure 3. The rates for neutrons and photons (using sensitivity values from table 1) are presented in figures 4 and 5

respectively, where there is an increase in the flux starting at R=220 cm. This increase, also visible in figure 2, can be attributed to the lack of shielding material in that region. The final design of the shielding is still under study for the HL-LHC.
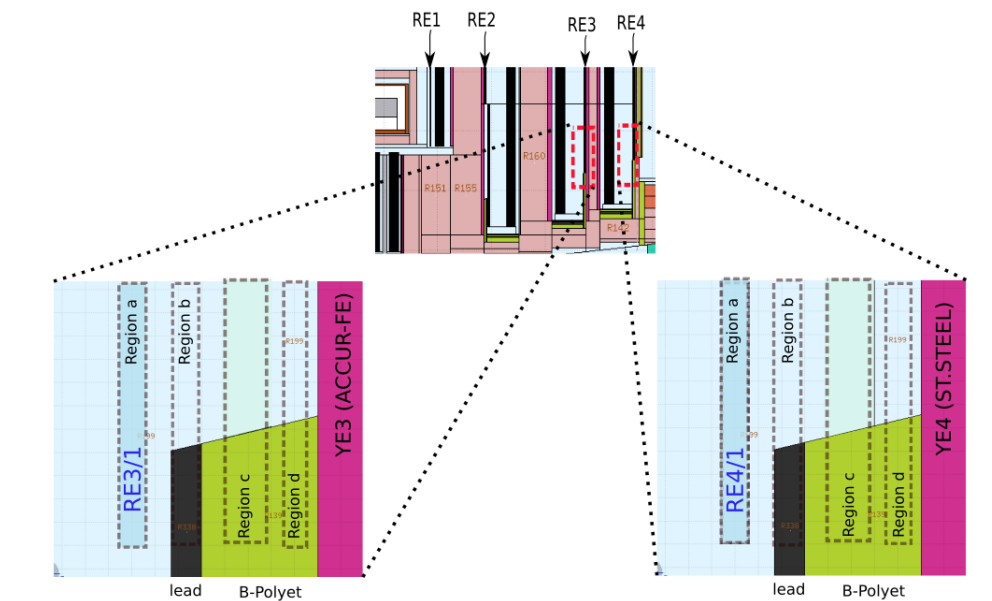
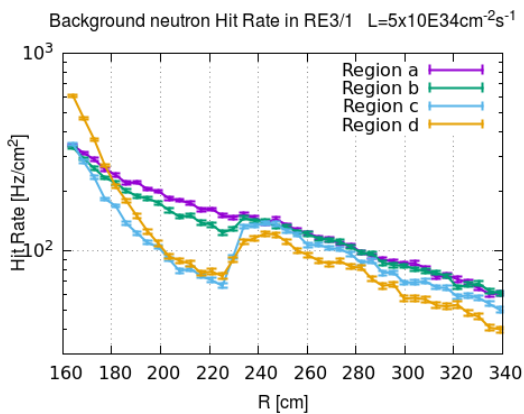**Figure 3**. Regions near the upgrade RE3/1 and RE4/1 stations.

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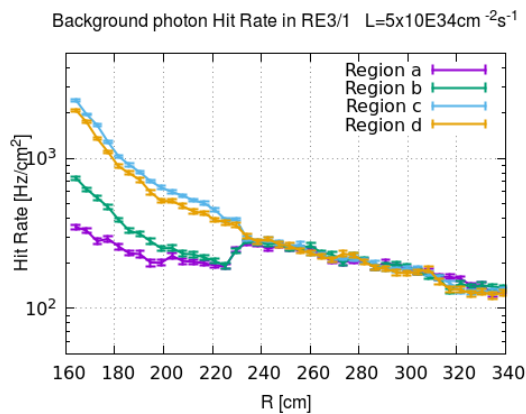

Figure 5. Estimated background hit rate near the upgrade RE3/1 station for photons.

5 Conclusion

The radiation environment for the HL-LHC was studied using simulations. The luminosity considered was $5 \times 10^{34} \, \mathrm{cm}^{-2} \, \mathrm{s}^{-1}$. 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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