Simulation studies of the impact of the CMS radiation environment on RPC detectors

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on behalf of CMS Muon group

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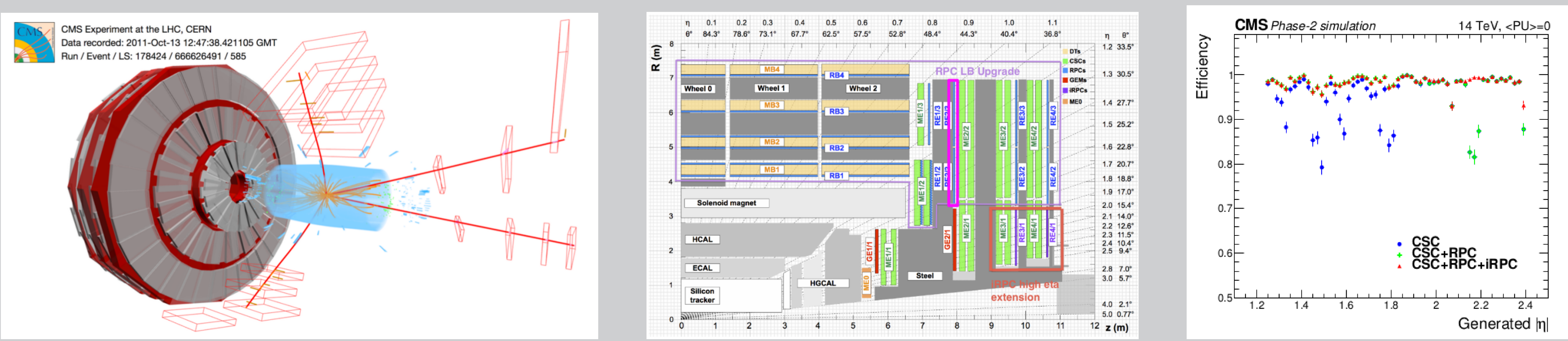
Introduction

The High-Luminosity Large Hadron Collider (HL-LHC) upgrade aims to increase its luminosity by a factor of 5 beyond the LHC's design value, increasing the potential for discoveries after 2025. The increased collision rate of particles will be a challenge for the CMS systems as higher levels of radiation could degrade them and affect their performance. It is therefore important to understand the expected radiation environment and its impact on the different sub-detectors. In this study we use the FLUKA simulation package to reproduce the radiation environment during CMS Run-2 and the GEANT4 simulation package to estimate its impact on the RPC detectors. Results are compared with measurements collected by the RPC system during 2018 and reasonable agreement is observed. This study serves as a benchmark for future simulations with a Phase-2 (HL-LHC) configuration.

The RPCs at the CMS Muon System

In the Compact Muon Solenoid (CMS) experiment, muons can be identified and measured individually and accurately. Figure 1: (a) The Resistive Plate Chambers (RPCs) are mainly used as trigger devices, but also contribute to the reconstruction of particles in both barrel and endcap regions up to $|\eta| = 1.9$, (b) The background radiation studies play a decisive role in understanding the performance of the detectors, and could help to improve the design for the upgrade of the muon system for the High Luminosity phase [1-2]. The implementation of new RPCs with improved technology (iRPC) at the endcap region will increase the eta coverage up to $|\eta| = 2.4$ [3], (c) The increase of luminosity during the HL-LHC will increase the potential of discovery but it will increase as well the radiation background to which the detectors are exposed, thus the simulation studies help to better understand the parameters to take into account to keep the detectors safe and performing at high efficiency.



(a) (b) (c)

Figure 1: (a) CMS event display with four muons, probably stemming from a Higgs boson decay. Red boxes show the activated RPCs. (b) A quadrant of the CMS experiment. The red square indicates where additional RPCs will be placed to extend the muon system coverage. The pink rectangle shows the RPC simulation area. (c) A clear improvement of the additional stations at the level of 15% can be seen in $|\eta| = 2.1$ and 2.2.

Background Radiation

Incoming particles at different energies are responsible for different processes in the production of the secondary particle in the detector. The expected incident particles' flux has been estimated with a FLUKA simulation taking into account the CMS geometry for Run 2, assuming pp collisions at 13 TeV at the nominal instantaneous luminosity of $1.5 \times 10^{34} cm^{-2} s^{-1}$ (Figure 2).

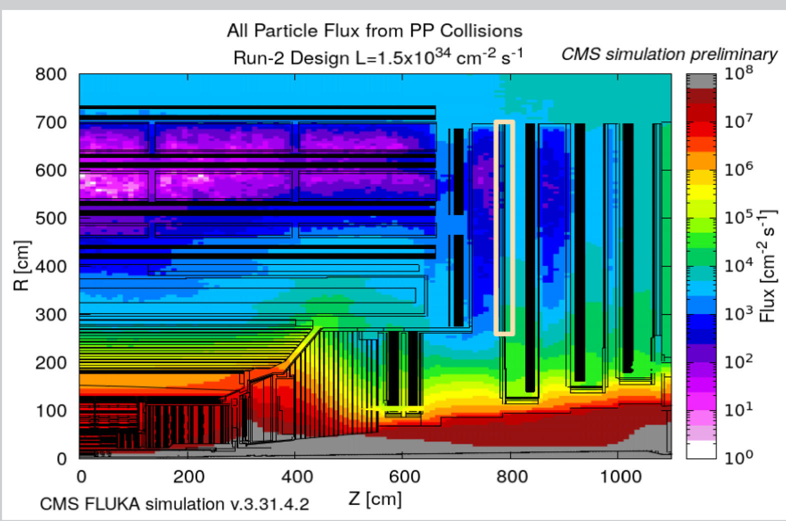


Figure 2: MC simulation of the particle flux in a quadrant of the CMS detector using FLUKA. The particle flux in RE22/23 (shown in the beige rectangle) has contributions in low and high R from leaking between barrel and endcap calorimeter and cavern. In the intermediate part the flux is attenuated due to an effective shielding from other detector elements.

Monte Carlo (MC) estimation of the flux (Figure 3) and of the differential distribution of the flux in energy (Figure 4) for n, γ, e^+, e^- crossing the volume defined by RE22/23 stations using FLUKA. Simulation cut-offs are: Hadrons 1 keV, Muons 1 keV, n 0.01 MeV, γ 3 keV, e^- 30 keV. γ and e^- have significantly higher cut-offs in some other regions (heavy parts).

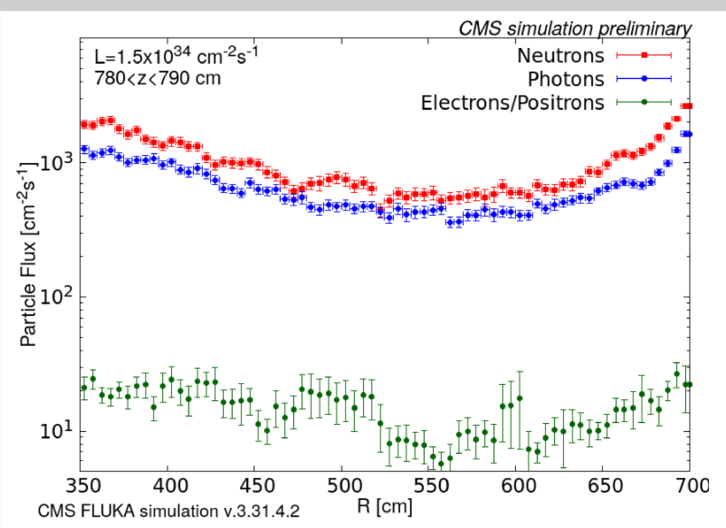


Figure 3: MC estimation of the flux. Inelastic collision cross section used for normalization is 80 mb. The distributions are normalized according to an instantaneous luminosity of $1.5 \times 10^{34} cm^{-2} s^{-1}$.

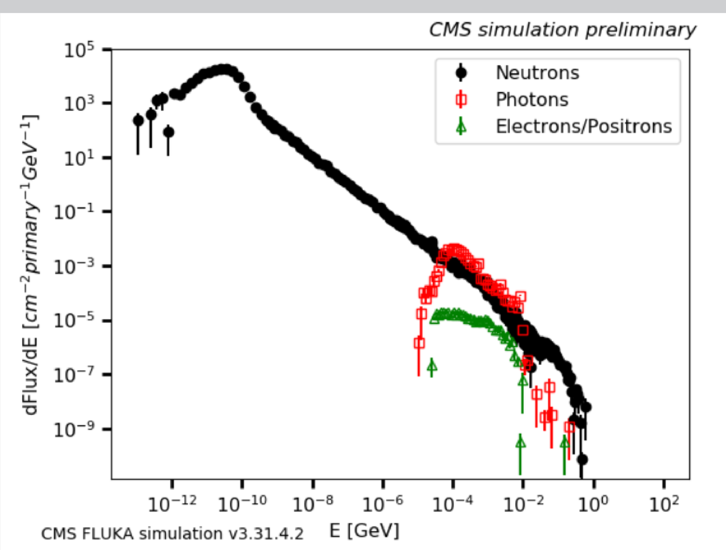


Figure 4: MC differential distribution of flux in energy. The scored energy lower thresholds are $10^{-6} GeV$ for EM particles and $10^{-14} GeV$ for neutrons

Sensitivity vs Energy for RE22

Sensitivity is defined as the probability for a background particle to create a signal in at least one of the RPC gas gaps.

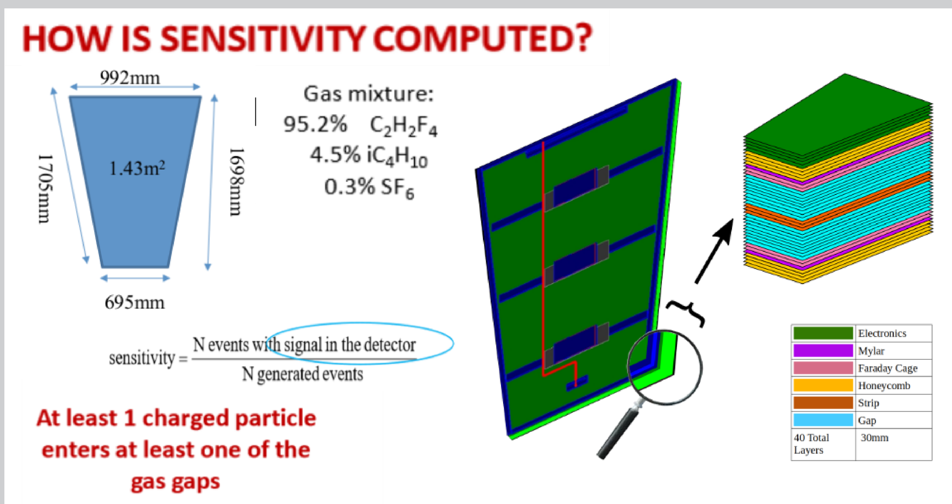


Figure 5: RE22 geometry simulation in Geant4.

Sensitivity of the double gap RPC detector simulation as a function of the energy of the incident particle for different kinds of particles using GEANT4. The simulation generates 100,000 events per particle: n, γ, e^+, e^-.

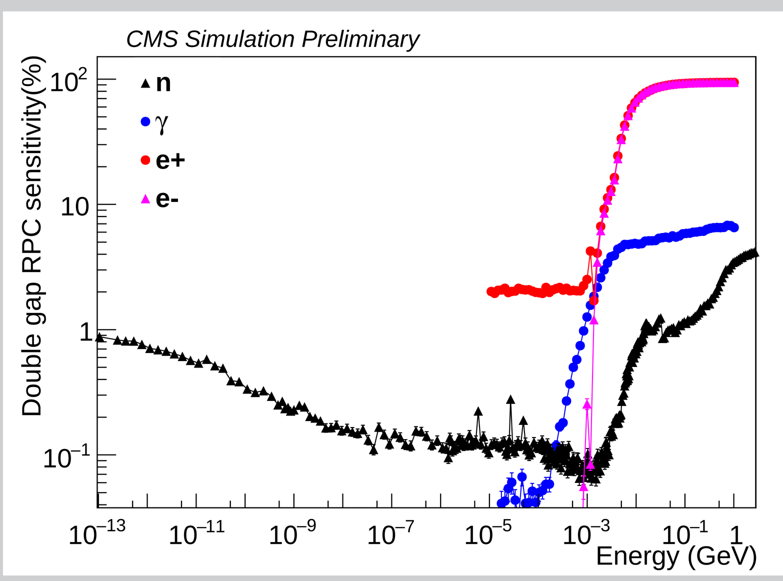


Figure 6: The sensitivity vs energy for a double gap RPC chamber

Hit Rate

To compare with data we need to convert fluxes to hit rates. From the convolution of the sensitivity and the incident particles' flux, obtained by FLUKA, the expected background hit rate is estimated.

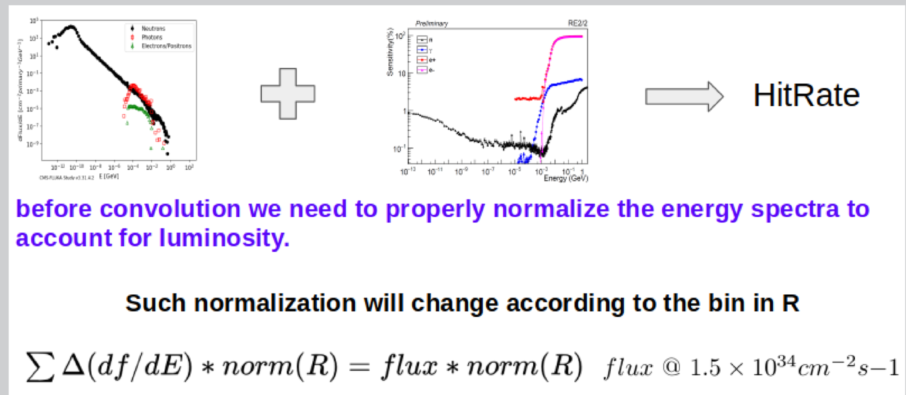


Figure 7: Convolution of Energy Spectra and Sensitivity.

Hit rate MC as a function of the radial distance from the interaction point.

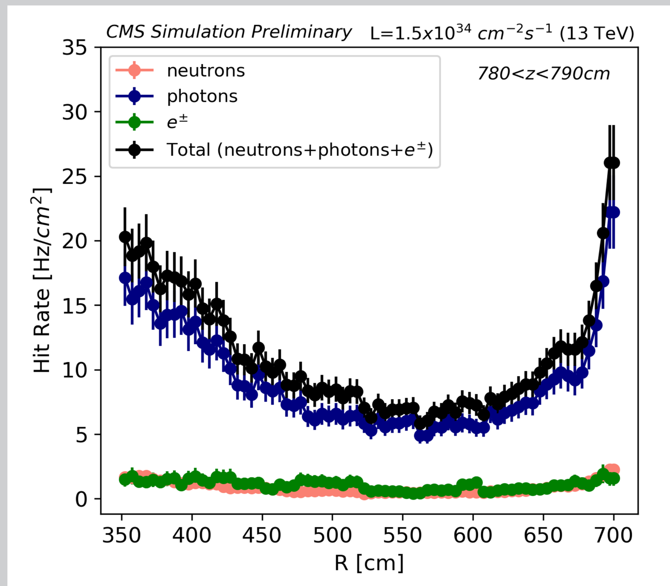


Figure 8: The hit rate is defined as the number of particles reaching the RPC station (particle flux) which is convoluted with a detector response (sensitivity) expressed in Hz/cm^2.

Comparison Data vs MC

Comparison of hit rate as a function of the pseudorapidity between simulation and RPC data collected during 2018. The data and MC show good agreement, the largest deviation is within a factor of two.

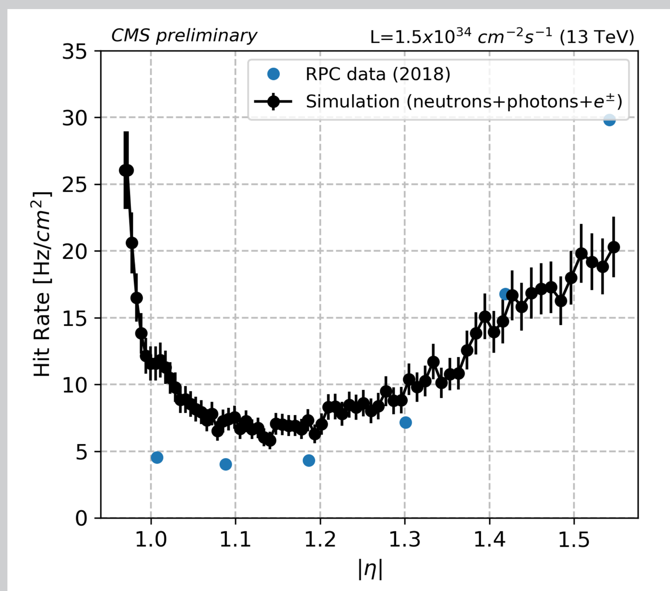


Figure 9: The RPC hit rate is measured at the strip level during LHC pp collision runs. The strip rate is calculated by using the incremental counts of the RPC trigger link boards. The incremental counts are taken during typical time intervals of the order of 100 s. The resulting rates are then averaged over the total runtime and normalized to the strip area. No trigger selection is applied at this stage, resulting in an inclusive measurement of the radiation background rates [4].

Conclusions

Experimental results corresponding to an instantaneous luminosity of $1.5 \times 10^{34} cm^{-2} s^{-1}$ were compared to a simulation prediction in which FLUKA and GEANT4 are combined to build a background model. FLUKA is used to get the particle flux and differential distribution fluence in energy related to the RE22/23 region. A dedicated Geant4 simulation is used to get the response of the RPC to different particles.
Results of the hit rate for RE22/23 seem to be consistent with previous estimates. Reasonable agreement (within a factor of 2) is obtained between data and MC, except for low η in which several factors could contribute to an increase in particle rate in simulation, such as edge effects, contributions from low energy particles not seen in the detector due to thresholds.

References

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