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RPC background studies at CMS experiment

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Abstract

During Run2 the high instantaneous luminosity, up to $2.2 \cdot 10^{34}\ cm^{-2}\ s^{-1}$, lead to a substantial hit rate in the Compact Muon Solenoid experiment's muon chambers due to multiple background sources to physics processes sought for at LHC. In this article we will describe the analysis method devised to measure and identify the contributions to such background in the Resistive Plate Chambers.Thorough understanding of the background rates provides the base for the upgrade of the muon detectors for the High-Luminosity LHC.

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1. The Compact Muon Solenoid Experiment

The Compact Muon Solenoid (CMS) is a general purpose experiment to explore the physics of the TeV scale in proton-proton collisions provided by the CERN Large Hadron Collider (LHC). The centre-of-mass energy $\sqrt{s}$ is equal to 13 TeV during the Run2 data taking, i.e. 2016-2018, and to 13.6 TeV during the Run3, started in 2022. It is made up of different sub-detectors in order to detect particles and to reconstruct objects, featuring a superconducting solenoid that generates an approximately uniform magnetic field of 3.8 T, and an field of approximately 1.8 T in the CMS detection volume outside the solenoid. Muons constitute an important signature of new physics and their detection, triggering, reconstruction and identification at CMS experiment is guaranteed by various sub-detectors. Fig. 1 shows a schematic view of the muon system: Drift Tubes and Resistive Plate Chambers (RPC) in the central region (barrel) and Cathode Strip Chambers, Gas Electron Multiplier (GEM), and RPC in the forward region (endcap). GEM detectors have been installed after Run2.

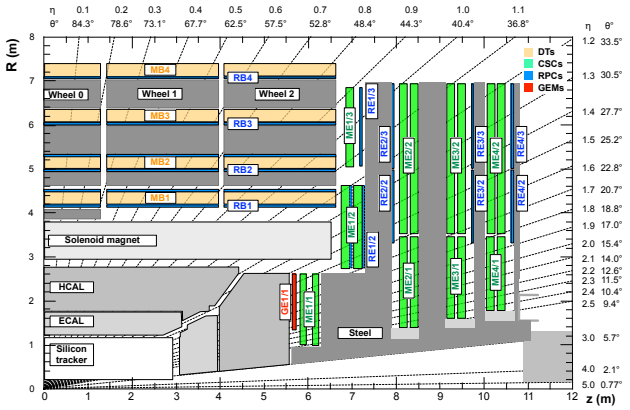

Figure 1: CMS Muon System schematic view. (1) (2)

1.1. Resistive Plate Chambers at CMS

RPCs are double-gap chambers with Bakelite plates operating in avalanche mode with an intrinsic time resolution of ≈ 2 ns. The latter is much less than the front-end electronic time window of 25 ns, allowing to assign the correct time slot of the detected particles and they are mostly used as trigger detectors both at the barrel and endcap (3). Chambers in the barrel are labelled as *RB* followed by number of station from 1, innermost station, i.e. closer to the beam, up to 4, outermost station. Chamber in the endcap are labelled as *RE* followed by the number of the disk and the number of the ring. RPCs are installed up to $|\eta| < 1.9$, where η is the pseudorapidity. Particles are detected as "cluster" of adjacent hit strips, referred as reconstructed hit in the detector.

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2. Background Studies

The quality triggering, identification, and reconstruction of muons could be degraded by background particles in the muon system. Understanding and analysing the background is a key point for maintaining robust operation and future upgrade choices. The background is made up of long-lived background (neutron background in the CMS cavern) and of the promptly induced background in the collisions. The background rate is expected to increase with the instantaneous luminosity, since the number of simultaneous collisions increases. The analysis of data taken on 2018 (Run2) shows in Fig. 2 a linear trend of the background hit rate as a function of the instantaneous luminosity for two different regions as example.

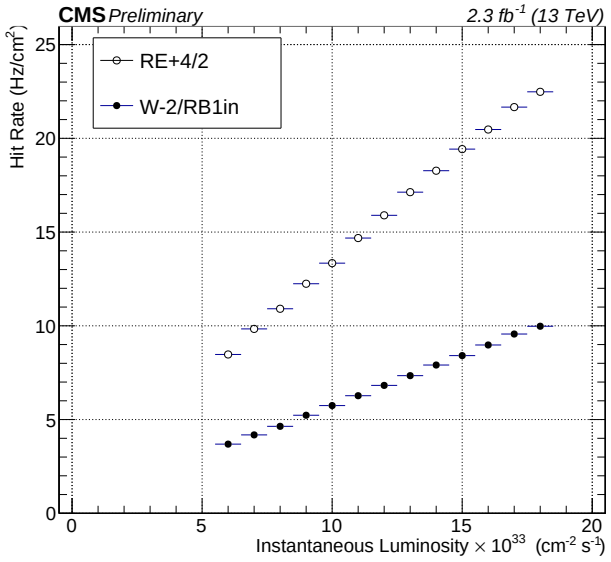

Figure 2: Background hit rate as a function of instantaneous luminosity for two different regions, the first layer of the innermost station of wheel -2 (W-2/RB1in) with full markers, and the second ring of the fourth positive endcap disk (RE+4/2). The rates show linear trends.

The data analyzed are enriched in background, which is dominated by the one measured during collisions, since the number of triggered events is much larger than the one with no collisions, and as such is influenced by the LHC filling scheme. One LHC orbit consists of 3564 units, said buckets, spaced 25 ns, and assigned an identification number each, called BX Id. The way those buckets are filled with a proton bunch or left vacant defines the filling scheme. The one adopted here has 48 consecutive colliding bunches, spaced by small or large gaps where there are not collisions (7 or 31-35 consecutive non-colliding bunches). Fig. 3 shows the rate as function of BX Id for the W-2/RB1in region at fixed valued of $1.0 \cdot 10^{34}\ cm^{-2}\ s^{-1}$ of instantaneous luminosity, the shaded area indicates positions along the LHC orbit without collisions and it shows lower rates as expected than the rates measured during collisions. The ensemble of all colliding BXs are referred to as *Colliding* region, to the *Non Colliding* region the whole of all gaps between two

trains. The region before the first colliding bunch is labelled as *Pre-Beam* region, and the one after the last colliding bunch as *AbortGap* region.

The rate trend as function of instantaneous luminosity is stud-

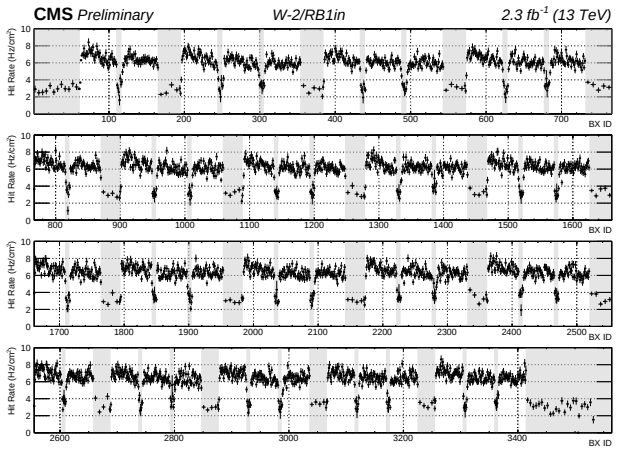

Figure 3: Background hit rate as function of BX Id for the W-2/RB1in region at fixed value of $1.0 \cdot 10^{34}\ cm^{-2}\ s^{-1}$ of instantaneous luminosity, the shaded area indicates positions along the LHC orbit without collisions.

ied separately for the four region of the filling scheme, i.e. *Colliding (C)*, *Non Colliding (NC)*, *Pre-Beam (PB)*, and *AbortGap (AG)* region. Fig. 4 (left) shows the rate trend for the *Colliding (green)*, *Non Colliding (red)*, *Pre-Beam (cyan)*, and *AbortGap (blue)* region.

It is possible to define the inclusive (or total) background as:

$$B_{Tot} = \frac{N_C B_C + N_{NC} B_{NC} + N_{PB} B_{PB} + N_{AG} B_{AG}}{N_C + N_{NC} + N_{PB} + N_{AG}} \quad (1)$$

where B is the background measured and averaged in each region and N is the number of bunches of the region. The delayed (or secondary) background can be estimated as weighted average of the background measured in the three regions with no collisions:

$$B_{Sec} = \frac{N_{NC} B_{NC} + N_{PB} B_{PB} + N_{AG} B_{AG}}{N_{NC} + N_{PB} + N_{AG}}. \quad (2)$$

The prompt (or primary) background can be estimated as the difference of the rate measured during collisions and the delayed background.

Fig. 4 (right) shows the inclusive (black), prompt (yellow), and delayed (magenta) background rates trend as function of instantaneous luminosity.

All rates are fitted as a linear function of the instantaneous luminosity, with the intercept representing the intrinsic RPC noise.

2.1. Background Rate vs η

In order to have a clear overview of the rate in different detector regions, the background rate is evaluated as a function of η at fixed value of $1.0 \cdot 10^{34}\ cm^{-2}\ s^{-1}$ of instantaneous luminosity, extracted from a linear fit, as shown above.

Fig. 5 shows the total, prompt, and delayed in the barrel region. The three rates increase with $|\eta|$. The prompt rate decrease with the increasing of R, i.e. the distance of the chambers to the beam axis, in the outermost region the delayed background dominates, associated to the slow neutron background of the cavern, thus the delayed and total rate distributions are overlayed.

Fig. 6 shows the total, prompt, and delayed background rate in the endcap region, averaged between the positive and negative region. The prompt rate increases with the increasing of $|\eta|$, while the delayed background rate shows an initial decreasing and a consecutive increasing.

2.2. Run3 Results

The background studies have been performed on Run3 data, taken on August 2022, at $\sqrt{s} = 13.6\ TeV$. The first results have been compared to the previous ones on Run2. Fig. 7 shows the background rate as a function of instantaneous luminosity for the Wheel+1 outermost region (W+1/RB4). As for this study the filling scheme is not taken into account and the colliding rate dominates, the two filling scheme are slightly different, 2400 colliding bunches in 2022 w.r.t. 2544 colliding bunches in 2018. Multiple mitigation actions, the most prominent being the installation of a set of shields during the Long Shutdown 2 (2019-2022), show a significant reduction of background in the outermost barrel region, improving the longevity and stability of the chambers.

3. Conclusions

Understanding the background is a key point for maintaining robust operation and for future upgrade choices. This study allowed to quantify the increase of background rate as function of instantaneous luminosity, as well as the effect of the LHC filling scheme, and allowed to separate different components of the background: prompt, delayed, and total. Prompt background rate increases with the decreasing of the distance to the beam in the barrel region and with the absolute value of η, while the delayed background rate dominates in the barrel outermost region. The effectiveness of background mitigation actions was tested, the most prominent being the installation of set of shields during the LS2, showing a significant reduction of background in the outermost barrel region, improving the longevity and stability of the chambers.

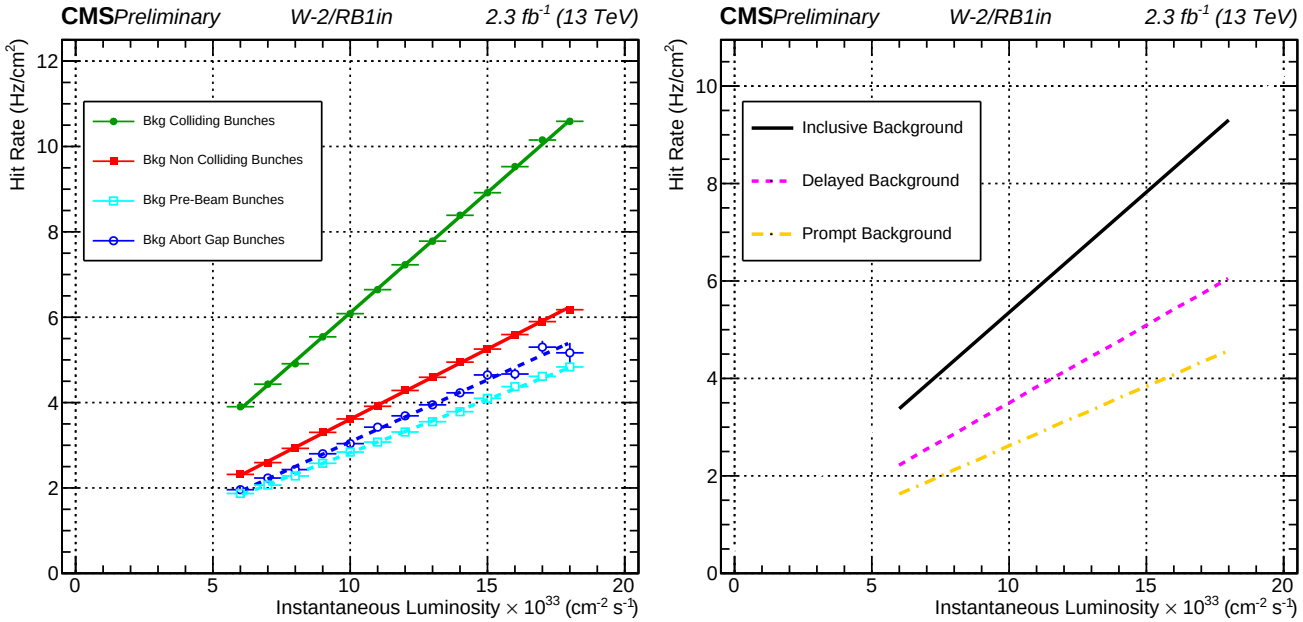

Figure 4: Background hit rate as function of instantaneous luminosity for the W-2/RB1in region in the *Colliding* (green), *Non Colliding* (red), *Pre-Beam* (cyan), and *AbortGap* (cyan) regions (left). Inclusive (black), delayed (magenta), and prompt (yellow) background hit rate (right).

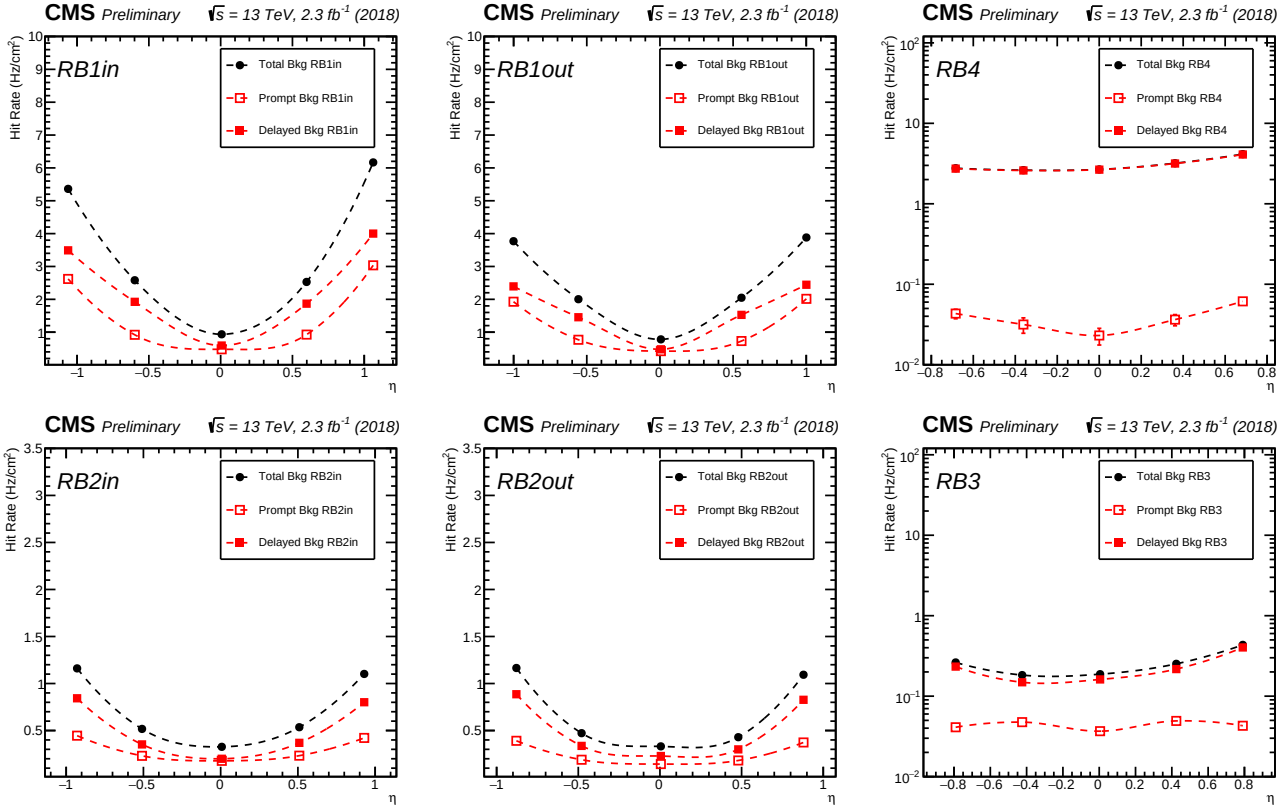

Figure 5: Total, prompt, and delayed background hit rate as function η at fixed value of $1.0 \cdot 10^{34}\ cm^{-2}\ s^{-1}$ instantaneous luminosity for the barrel. In the RB4 region the total background rate is dominated by the delayed component and the two distributions are overlayed.

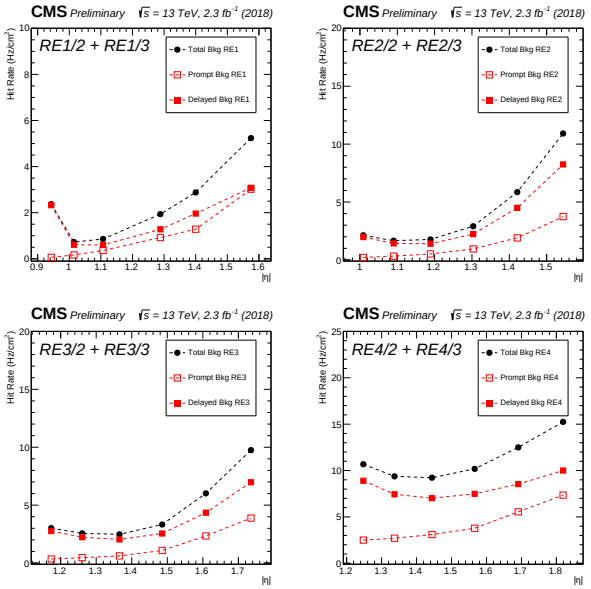

Figure 6: Total, prompt, and delayed background hit rate as function of $|\eta|$ at fixed value of $1.0 \cdot 10^{34}$ cm^{-2} s^{-1} instantaneous luminosity averaged for the positive and negative endcap regions.

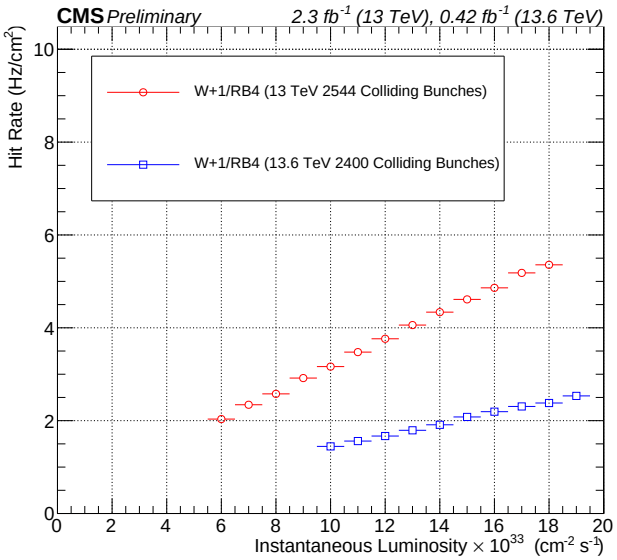

Figure 7: Background hit rate as a function of instantaneous luminosity for W+1/RB4 region. Run2 measured rate (red) is higher than Run3 measured one (blue).

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