The Impact of the RPC System on the Trigger Primitives in CMS Barrel Region for Phase-2 Upgrade

Raphael Gomes de Souza[1*], Mauricio Thiel[1], Ece Asilar[2], on behalf of CMS Collaboration

[1]UERJ - Brazil, [2]Middle East Technical University/İstinye University - Turkey. *email: raphael.souza@cern.ch

Introduction

The increasing instantaneous luminosity of the LHC, which will reach approximately $2 \times 10^{34}\,\mathrm{cm}^{-2}s^{-1}$ during the High-Luminosity LHC (HL-LHC) era, presents several challenges for the Compact Muon Solenoid (CMS) experiment. The CMS Level-1 (L1) trigger system must rapidly process trigger primitives (TPs), summary information that converts raw detector hits into preliminary muon candidates. In this work, we present simulation studies on the use of the Resistive Plate Chambers (RPCs) in forming TPs in the muon system barrel region, covering $|\eta| < 1.2$.

CMS Muon System

The CMS experiment at CERN is composed of several types of particle detectors, including the muon system (Figure 1). The muon system in the CMS experiment at CERN is composed of four types of gas-ionization detectors: Drift Tubes (DTs), Cathode Strip Chambers (CSCs), GEMs (Gas Electron Multiplier), and RPCs. DT chambers are used in the central (or barrel) system and they are complemented by a system of RPCs. The barrel chambers are arranged in four stations (MB1, MB2, MB3, MB4). The DT and RPC chambers are mounted in five cylindrical sections called wheels (W-2, W-1, W0, W+1 and, W+2), concentric with the beam axis. All these subsystems are part of the CMS L1 trigger.

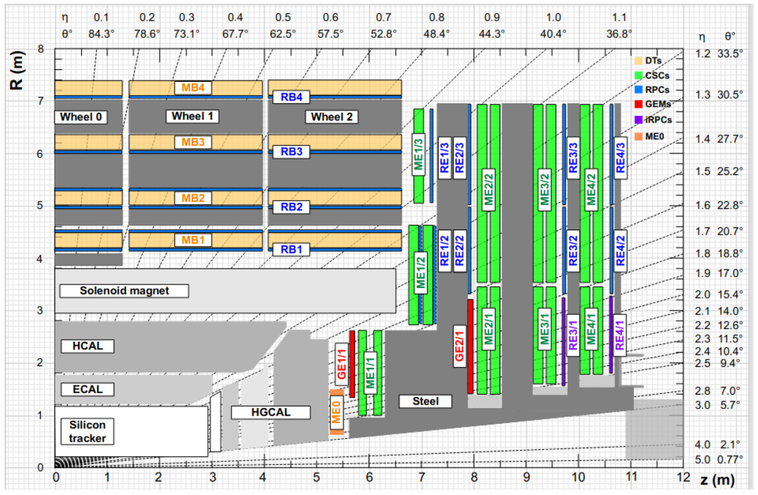


Figure 1: Schematic longitudinal view of one quarter of the CMS detector with the different subsystems which compose the Muon Detector for the Phase-II upgrade of LHC [1].

CMS Level-1 trigger

The L1 trigger is a crucial component of the CMS experiment. It provides the first stage for selecting particle collision events of interest in real time from the immense amount of data that will be produced by the HL-LHC. The configuration of the L1 trigger is shown in Figure 2.

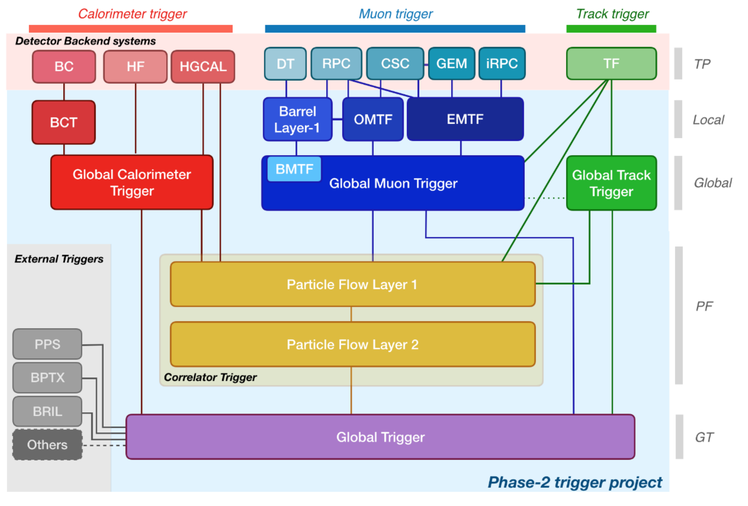


Figure 2: Functional diagram of the CMS L1 Phase-2 Upgrade trigger [2].

TPs for muons in the barrel region are first formed using data from the DT system, which provides spatial and temporal measurements processed using an algorithm called the Analytical Method (AM). Information from the RPC system, which provides time resolution superior to that of the DT system, is combined with the DT TPs to form so-called DT+RPC super-primitives [3]. A simulated distribution of RPC flag types is shown in Figure 3. The TPs have flags (called RPC flags) that indicate how they were constructed:

- **Flag 0:** AM DT TP without RPC time information
- **Flag 1:** Timing information from RPCs is incorporated to form DT+RPC super-primitives
- **Flag 2:** TPs are built with RPC Only segments, i.e., TP is a combination of two RPC Hits (two layers)

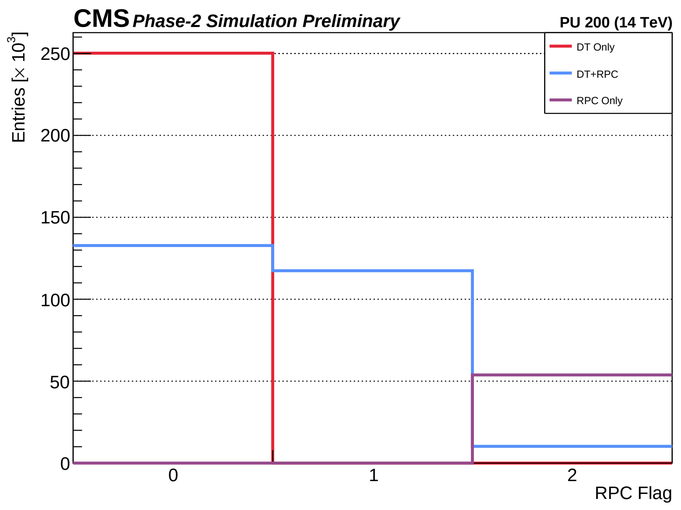


Figure 3: Simulated distribution of TP RPC flags. The y axis shows all TP entries from all events.

Improved time estimate for Flag 1 TPs

The orientation of the two RPC layers in relation to a DT chamber is illustrated in Figure 4. In the current implementation of the AM algorithm for the first and second muon stations (MB1/RB1 and MB2/RB2), when RPC hits are available in both layers, the time t_{DT} associated with the DT TP is taken from the RPC hit closest in azimuth (ϕ) to that of the DT TP. As an alternative, we evaluated using the average time of the two RPC hits to find t_{DT}.

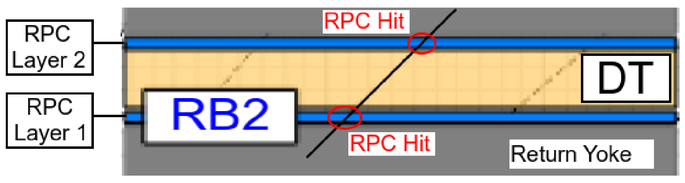


Figure 4: Schematic view of a muon producing hits in the RPC layers of the second station Station (RB2) of the CMS barrel muon system.

The current implementation is:

$$t_{\mathrm{DT}} = t_{\mathrm{RPC}}^{\mathrm{Layer\ 1}} \quad \text{or} \quad t_{\mathrm{DT}} = t_{\mathrm{RPC}}^{\mathrm{Layer\ 2}} \tag{1}$$

The alternative we proposed is:

$$t_{\mathrm{DT}} = \frac{t_{\mathrm{RPC}}^{\mathrm{Layer\ 1}} + t_{\mathrm{RPC}}^{\mathrm{Layer\ 2}}}{2} \tag{2}$$

The impact of this modification can be seen in Figure 5, showing an improvement in the TPs time resolution.

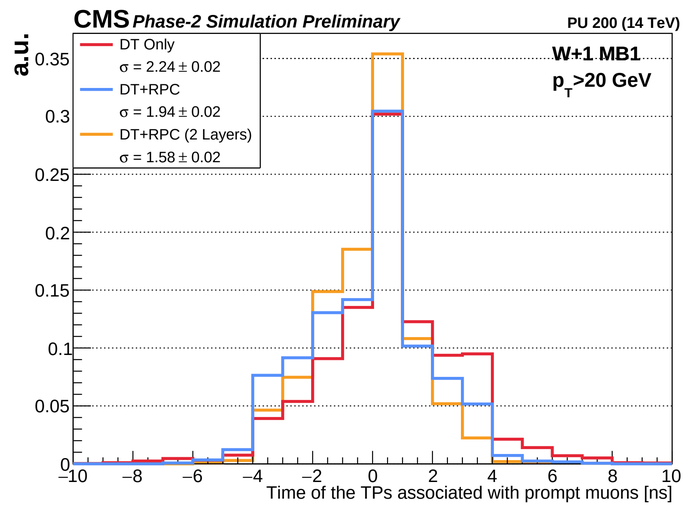


Figure 5: Simulated timing distribution of the trigger primitives associated with a generated muon with DT AM (Analytical Method) (Red line), DT AM + RPC (Blue line) and DT AM + RPC with the correction (Golden line) for the station 1 and wheel +1 (MB1 W+1).

Efficiency for RPC Only Case

To evaluate the robustness of the level-1 muon trigger, we used simulation to study the case when the DT system is unavailable so that barrel TPs can be formed only using the RPC system and hence only Flag 2 TPs occur. To estimate the Flag 2 efficiency, we employed a matching process between reconstructed RPC hits (denominator) and TPs (numerator). The matching was based on azimuthal curvature ($\Delta\phi$) and bunch crossing time. The efficiencies for the three types of TPs for the two innermost barrel layers in all five wheels are shown in Figure 6. The TP time resolutions are shown in Figure 7.

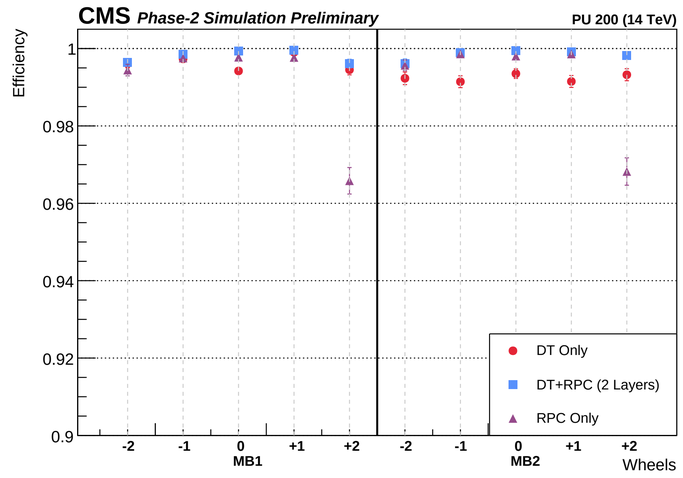


Figure 6: Simulated Trigger Primitive efficiencies for the MB1 and MB2 stations in the five wheels of the CMS barrel muon system.

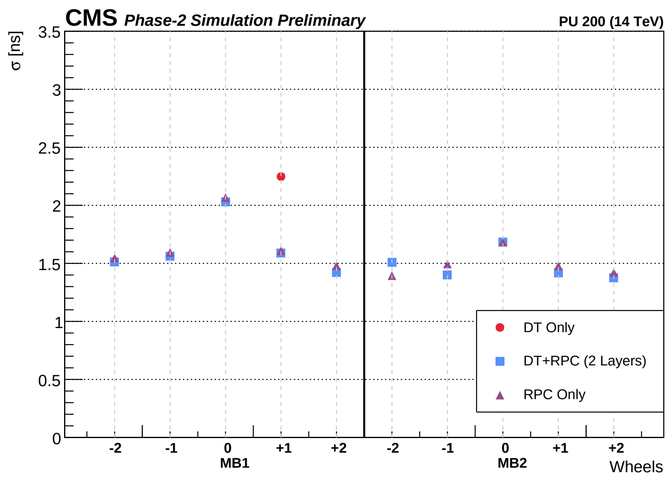


Figure 7: Simulated Trigger Primitive time resolution for the MB1 and MB2 stations in the five wheels of the CMS barrel muon system.

Conclusion

We studied the behavior of muon Trigger Primitives in the CMS barrel system for the Phase-2 Upgrade using simulated collision data under high-pileup conditions, averaging 200 interactions per bunch crossing. We found that the TP time resolution could be improved by using the average time of the two RPC layers. The time resolution achieved when RPC information is included ranges from 1.4 to 2 ns, depending on the wheel and station. TP efficiency is close to 100% in the DT-only and DT+RPC scenarios, and efficiency remains greater than 96% for the RPC-only case.

References

[1] CMS Collaboration. CMS RPC background studies and measurements. 2020.

[2] CMS Collaboration. “Technical Design Report”,CERN report number CMS-TDR-021. 2020.

[3] CMS Muon Group. The Analytical Method algorithm for trigger primitives generation at the LHC Drift Tubes detector. 2023.