The Compact Muon Solenoid Experiment

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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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A data-driven performance evaluation method for CMS RPC trigger through the CMS muon trigger

Archie Sharma for the CMS Collaboration

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A data-driven performance evaluation method for the CMS RPC trigger through the CMS muon trigger

S. Beri ^a, A. Sharma ^a, S. A. Tupputi ^b for CMS RPC Collaboration

^a*Panjab University, Chandigarh, India*

^b*Università degli Studi di Bari, Italy*

Abstract

The muon system of the CMS (Compact Muon Solenoid) experiment at the LHC (Large Hadron Collider, Geneva, Switzerland) consists of three gaseous detectors with complementary features: the Drift Tube Chambers (DT) in the barrel and the Cathode Strips Chambers (CSC) in the forward region provide good spatial resolution, while the Resistive Plate Chambers (RPC), in both barrel and forward regions, have an excellent time resolution. The measurements of these detectors are used for triggering on muons in the hardware-based Level-1 trigger stage. The Global Muon Trigger (GMT) processor is in charge of collecting and merging the information provided by the three detectors. It transmits final L1 muon trigger candidates (GMT candidates) to the L1 Global Trigger Logic which takes the final trigger decision. The GMT algorithm allows to trace back the detectors whose measurements have been used for each GMT candidate. This feature has been exploited to develop a method for the performance evaluation of the trigger provided by the RPC system.

Key words:

LHC, CMS, Level-1 Trigger, Muons, Resistive Plate Chambers

1. Introduction

At the luminosity expected at the LHC ($10^{34} \text{cm}^{-2} \text{s}^{-1}$), the CMS Level-1 (L1) trigger logic has to decide every 25 ns whether to reject event or not on the basis of the information provided by the calorimeters and muon system detectors [1]. The CMS muon system is instrumented with three different gaseous detectors [2]: Cathode Strips Chambers (CSC) in the forward region and Drift Tube (DT) chambers in the barrel region accomplish the task of providing high spatial resolution ($\sim 100 \mu\text{m}$) for muons tracks identification and transverse momentum evaluation, while Resistive Plate Chambers (RPCs) are mainly trigger-dedicated devices in charge of identifying the correct muon bunch crossing, thanks to their good time resolution ($\sim \text{ns}$). Since the behavior

of these two classes of detectors is complementary in the presence of the same physical processes, such a design makes the CMS muon system a robust detector with respect to triggering, since information yielded both by the tracking and the trigger chambers is used to determine creating muon trigger candidates. The information provided by the three detectors is processed by the Global Muon Trigger (GMT), an hardware-implemented algorithm which performs the task of combining and merging muon detectors informations and finally forwarding, for each event, to the L1 trigger logic (Global Trigger, GT) up to four muon candidates.

2. The GMT algorithm

[3] The Global Muon Trigger is optimized to achieve the best possible signal selection efficiency along with the highest background rejection, exploiting the muon system redundancy for keeping the acceptance frequency under control. Such a task is accomplished by means of a sophisticated algorithm, which combines the parameters of the single sub-detectors in order to best exploit their features and produces a muon candidate by drawing out the most-suited information. The "regional" trigger algorithms of each sub-detector transmit to the GMT up to four regional muon candidates, for the DTs and the CSCs, and up to 4+4 (barrel+endcap) for the RPCs. The GMT merges these regional candidates according to closeness in (η, ϕ) space and processes their parameters in order to achieve the best accuracy. If a regional muon candidate is not confirmed by the complementary sub-detector, the GMT applies quality criteria (number of crossed muon detector layers or, for some regions, pseudorapidity) to determine whether to accept or reject the candidate. Moreover, the GMT makes use of calorimeter information for isolation and MIP bits assignment.

The muon candidates are ranked according to the transverse momentum, measurement quality and, for some regions, pseudorapidity. Finally, the best four candidates in the whole CMS detector are transmitted to the GT, which eventually applies the requirements of the physical L1 trigger paths to the candidates.

Fig. 1. The yield of muons from W decay ($\sqrt{s} = 7$ TeV) is higher in the [20-50] GeV/c transverse momentum kinematical region.

3. A data-driven method for trigger performance evaluation: description and analysis features

The GMT algorithm keeps trace of the sub-systems that provided the measurement for its candidates. This feature has been the starting point for implementing a data-driven method for muon trigger sub-system performance evaluation. In order to evaluate the single muon RPC trigger efficiency, in the barrel for instance, all the events are selected in which the information for GMT has been supplied from DTs, and amongst these the number of events in which information from RPCs has been used as well is counted up. The efficiency values drawn in such a way are then compared with Monte Carlo predictions, which evaluates efficiency as the ratio of GMT candidates supplied in any way by RPCs to the total number of generated events. In general, there may be more GMT candidate even with just one muon in the event. In order to deal with this issue, the muon tracks reconstructed in the muon system during the software-based trigger stage (High Level Trigger, HLT) have been used. Indeed, such tracks (called L2 tracks) are iteratively reconstructed through the muon system layers starting from a seed which represents a starting vector applied at the first station reporting a hit. The seed contains information about the L1-accepted GMT candidate (if any) associated with it. Therefore the GMT candidates to look at have been harvested from the L2 tracks seeds, and the L2 track parameters have been used for a more precise binning resolution with respect to what the L1 muon trigger resolution allows.

The results henceforth shown have been obtained with three single muon Monte Carlo samples:

- (i) $W \rightarrow \mu\nu$ from 7 TeV pp collisions events;
- (ii) high transverse momentum (70-200 GeV/c) single muon events;
- (iii) low transverse momentum (0-10 GeV/c) single muon events.

Within the official CMS software framework (CMSSW, [5]), each sample has been generated with PYTHIA [6] and the particle interaction and propagation as well as the simulation of the CMS detector have been carried out with the GEANT4 framework [7]. The RPC simulated efficiency has been set to 95%. The three single muon samples have been used for the need to probe as wide as

(a) Section view of CMS barrel muon system. Geometrical discontinuities between sectors are shown.

(b) Residuals distributions of azimuthal angle evaluated by muon trigger with respect to positively (continuous line) and negatively (dashed line) charged generated muons.

Fig. 2.

possible a muon transverse momentum range with respect to what the $W \rightarrow \mu\nu$ sample provide (Fig. 1). Moreover, the magnetic field bends muon trajectories in opposite directions depending on the charge. It follows that muons emitted in the same azimuthal cone undergo different paths through the muon system chambers and hence experience in different ways the geometrical discontinuities of the muon system (Figs. 2(a) and 2(b)).

For the data-driven method events with just one L2 muon are selected and their seed-associated

(a) Comparison of the two methods along η

(b) Comparison of the two methods along ϕ . In order to de-convolute the pseudorapidity effect they are shown with respect to wheel 0 only ($|\eta| < 0.2$).

Fig. 3. Comparison of the two methods for the $W \rightarrow \mu\nu$ sample. The geometrical cracks of the muon system are responsible for the dips in efficiencies. Analogous patterns have been observed with the other samples.

GMT candidate is requested to be L1-accepted and to contain information from DT, as explained. For the Monte Carlo truth, the events are selected requesting the presence of one generated muon (coming from W decay for the W sample). Therefore, in both methods, the number of events in which the L1-accepted GMT candidate has used RPC information is accumulated. The issue of performance evaluation is not addressed by now, since the current start-up RPCs instrumentation in the forward

region has at its disposal only three RPC layers, which is the minimal number of layers to provide a trigger, according to the RPC trigger logic: even if it is fairly possible to have an agreement between the data-driven and the Monte Carlo methods, the efficiencies are nevertheless not so high due to the current instrumentation.

The goal of the study is to obtain the best possible agreement between data-driven and MC efficiencies for method validation and the least possible curve dependency on transverse momentum, in order to make the method useful for further physics analysis.

4. Results

In figures 3(a) and 3(b) the efficiency curves obtained with the two methods are shown for $W \rightarrow \mu\nu$. Here the effects of muon system geometrical dis-

(a) Comparison of efficiency curves with the two methods for positively charged muons.

(b) Comparison of efficiency curves with the two methods for negatively charged muons.

Fig. 4. Efficiencies vs. p_T after having applied cuts. The dashed vertical lines separate the transverse momentum regions in which the three different samples have been used: low- p_T muons (0-10 GeV/c), $W \rightarrow \mu\nu$ (20-70 GeV/c) and high- p_T muons (70-200 GeV/c).

	MC μ^+	Data-driven μ^+
0-10 GeV/c	$88.9 \pm 0.2 \%$	$93.5 \pm 0.3 \%$
11-70 GeV/c	$94.6 \pm 0.8 \%$	$95.4 \pm 0.8 \%$
71-200 GeV/c	$99.6 \pm 0.13 \%$	$98.3 \pm 0.5 \%$
	MC μ^-	Data-driven μ^-
0-10 GeV/c	$88.9 \pm 0.2 \%$	$91.6 \pm 0.2 \%$
11-70 GeV/c	$94.0 \pm 1.1 \%$	$94.9 \pm 1.02 \%$
71-200 GeV/c	$99.5 \pm 0.1 \%$	$98.3 \pm 0.5 \%$

Table 1

Global efficiencies for each sample obtained with the two methods.

continuities are clearly noticeable both in pseudorapidity and azimuthal angle. This heavily affects the behavior of the efficiency curves over the transverse momentum range. As stated above, the geometrical design of muon system is such that individual sub-system triggers cannot have a high efficiency near geometrical cracks. The GMT is designed to increase efficiencies in such regions for the L1 muon trigger as a whole, but still, for a single sub-system, this drawback can not be circumvented. For these reasons appropriate cuts have been introduced in (η, ϕ) space in order to rule out the geometrical regions in which the RPC system intrinsically cannot trigger in a highly efficient fashion. The cuts take into account the 4 cracks in η occurring between the 5 wheels composing the muon system and the cracks in ϕ between the 12 sector slices of each wheel. This strategy has been used for the high- p_T single muon sample as well, with a different set of ϕ cuts with respect to the $W \rightarrow \mu\nu$ case. Only η cuts have been applied instead for the low- p_T single muon sample, since the bending of the magnetic field on the trajectories of such muons is greater than in the high- p_T case, and most of such muons leave hits in chambers of different sectors. After applying such cuts, the agreement between the two curves improves considerably and the intrinsic efficiency values increase to $\sim 95\%$ on average for the $W \rightarrow \mu\nu$ sample, while for the high- p_T one they approach 100%. On the other hand, the low- p_T sample allows to scan the low momentum region with higher statistics than with muons from W. The final average efficiency is slightly greater than 90% (Figs. 4(a), 4(b)). Average efficiency values are given in table 1.

5. Conclusions

The data-driven performance evaluation method shows good agreement with the MC-truth method after having ruled out the intrinsically inefficient geometrical regions in (η, ϕ) space. The strategy has provided a flat trend of efficiencies with respect to transverse momentum with exception for the momentum ranges in which the results are affected by statistical fluctuations (like at the edges of the momentum range for the muons from W decay) or where the transverse momentum is too low. Indeed, for low momentum muons the fluctuations of the numerator (and, for the data-driven case, of the denominator as well) of the efficiency ratios have a larger dependence on the effective trajectories of the muons across the chambers, and even with pseudo-rapidity cuts, the results could still be totally different bin by bin. Besides, such effects are also enhanced by the smaller probability of low momentum muons to hit enough chambers to create a trigger. The method has therefore shown its feasibility. Further studies are foreseen to use it for other muon detectors as well and to eventually incorporate it in the software in for physics-oriented performance evaluations.

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