PROCEEDINGS OF SCIENCE

Level-1 muon triggers algorithms for the CMS upgrade at the HL-LHC

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In view of the HL-LHC, the Phase-2 CMS upgrade will replace the entire trigger and data acquisition system. The detector readout electronics will be upgraded to allow a maximum L1 output rate of 750 kHz, and a latency of 12.5 µs. The upgraded system will be entirely running on commercial FPGA processors and should greatly extend the capabilities of the current system, being able to maintain trigger thresholds despite the harsh environment as well as trigger on more exotic signatures such as long-lived particles to extend the physics coverage. The function of the muon trigger is to identify muon tracks in the experiment and measure their momenta and other parameters for use in the global trigger menu. In addition to the muon detector upgrades that include improved electronics and new sub-detectors, the presence of a L1 track finder in CMS will bring some of the offline muon reconstruction capability to the L1 trigger, delivering unprecedented reconstruction and identification performance. We review the current status of the algorithm developments for a highly efficient L1 muon trigger reconstruction from prompt and displaced muons and the measured performance on emulators and firmware demonstrators.

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1. Introduction

The High luminosity LHC (HL-LHC) is expected to reach an instantaneous luminosity of $7.5 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$, never achieved before. This luminosity allows to collect an amout of data that will lead to a rich scientific program but also implies challenging conditions for the CMS detector [2] and, in particular, the trigger system, which will face an increase in pile-up (PU) of a factor of 5. As a result, several things must be taken into consideration: The detectors will operate in a high radiation environment, hence, the electronics must be checked to be resistant to aging. Besides, Higher luminosity implies higher occupancy in the detector, resulting in a more complex reconstruction process. Also, the Level-1 (L1) muon trigger rate will also increase. As a result a precise measurement of the p_T is crucial to keep the rate under control without increasing the p_T threshold.

In order to face these challenges, the L1T needs to be upgraded. In the upgrade the maximum L1 output rate will be increased to 750 kHz while the latency will raise to 12.5 µs, allowing higher-level object reconstruction and identification. The system will run on commercial Field Programmable Gate Array (FPGA) processors. It will include new reconstruction algorithms that will improve the efficiency with respect to Run 2 keeping the rate under control and triggering on exotic signatures such as long lived particles. Besides, an increase in η coverage is expected by adding iRPC and GEM subdetectors.

The upgrade of the three muon track finder algorithms (MTF) and the global muon trigger is presented here. The definition of three algorithms to reconstruct standalone muons is motivated by the detector geometry as shown in fig. 1

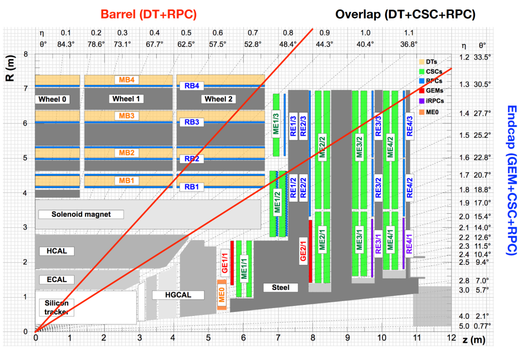

Figure 1: View of the Phase-2 CMS muon detector system. A quadrant section in the r-η plane, with $\eta > 0$ and $\phi = 90$.

2. Barrel Muon Track Finder

In the barrel region, the Barrel Muon Track Finder (BMTF) combines information from two muon sub-detectors, the Drift Tubes (DTs) and the Resistive Plate Chambers (RPCs), in order to reconstruct both prompt and displaced standalone muons using a Kalman Filter algorithm, this is called kBMTF. First, a muon stub from the outermost muon detector is taken as seed and the curvature (k), position (ϕ), and bending (ϕ_B) are estimated. Then, using compatibility criteria hits are selected in the next station (going inwards) and the computation of k, ϕ and ϕ_B is performed again. This process is repeated until the innermost (last) station. For displaced-muon reconstruction, the track is stored without further constraints while for prompt muon reconstruction, the track is propagated to the CMS center. This algorithm is capable of achieving an efficiency as high as the one obtained during Phase-I but at lower rate. The efficiency as a function of p_T is shown in fig. 2 (right) for different p_T thresholds, while the rate for the new algorithm and the Phase-I one are shown in the center plot. Left plot in fig. 2 also shows that the displaced-muon algorithm is sensitivity to long-lived signatures for vertex displacements greater than 60 cm.

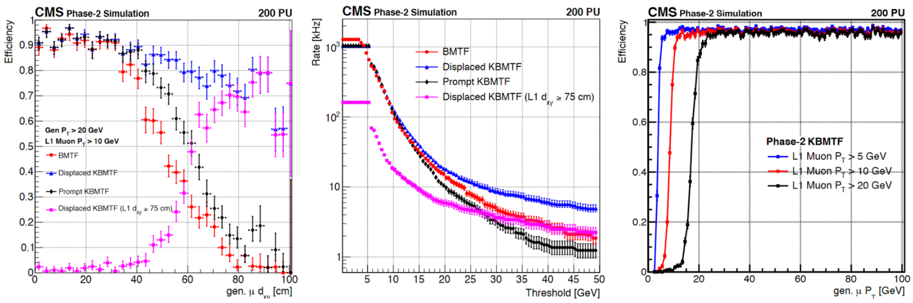

Figure 2: Performance of the kBMTF algorithm. Efficiency as a function of vertex displacements (left), rate (center) and efficiency as a function of p_T (right). Figure taken from [1].

3. Endcap Muon Track Finder

In the Endcap region, the Endcap Muon Track Finder (EMTF) uses information from RPCs, Cathode Strip Chambers (CSCs) and the new Gas Electron Multipliers (GEMs). It was shown that the rate scaled linearly with PU when using the algorithm implemented during Phase-I. Hence a new algorithm based on a Deep Neural Network (DNN) has been developed (EMTF++). This DNN uses pattern recognition techniques in order to identify trigger primitives compatible with muon trajectories and estimate the most likely p_T of the muon. The inputs to the DNN are the angular position (θ and ϕ), the bending, time and quality.

As shown in fig. 3 (left) an efficiency over 95% is achieved for $p_T > 20$ GeV, which improves the Phase-I performance. Besides, the rate increases slower as a function of PU (right plot).

A displaced-muon pattern is also provided using an alternative NN. This achieves an efficiency greater than 50% for vertex displacements between 30 and 100 cm.

4. Overlap Muon Track Finder

In the Overlap region, the Overlap Muon Track Finder (OMTF) uses information from the DTs, RPCs and CSCs. The reconstruction algorithm is based on a Bayes Classifier. As a starting point, the position ϕ is measured for each hit. Then, a hit is selected as reference and the $\Delta\phi$ with respect to that reference hit is obtained for each hit. Afterwards, the pattern reconstructed with the actual hits is compared with precomputed ones for muons with several different values of p_T. Applying a naive Bayes Classifier the most probable p_T for the given hit pattern is obtained.

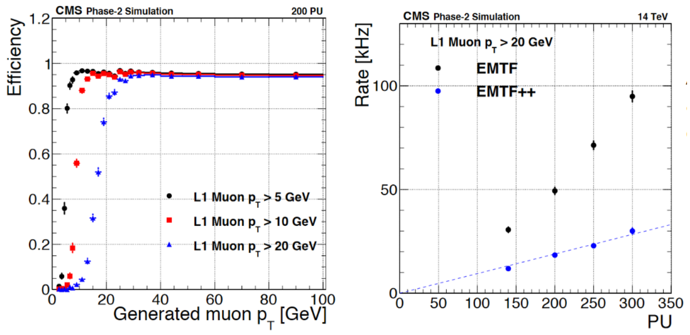

Figure 3: EMTF++ performance. Left plot shows the efficiency as a function of the p_T for the new algorithm. Right plot shows the rate as a function of the PU for the old and new algorithm. Figure taken from [1].

This algorithm is very dependent on the MB1 (innermost DT chamber) measurement, which is expected to be the DT chamber most affected by aging. Nevertheless, the efficiency is expected to be over 90% for a $p_T > 20$ GeV in all aging scenarios with a 5% decrease between the non-aging scenario and the worst-case scenario, as shown in fig. 4. The rate is also kept under control as shown in the right plot of fig. 4.

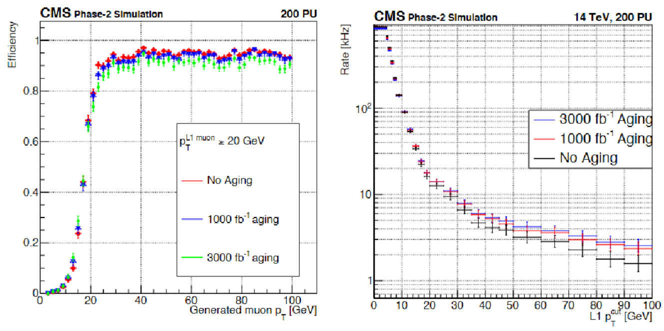

Figure 4: OMTF performance. Left plot shows the efficiency as a function of p_T in three aging scenarios. Right plot shows the rate in the same aging scenarios. Figure taken from [1].

5. Global Muon Trigger

In the HLT and in the offline software the muon reconstruction combines information from the tracker and the muon system. With the Phase-2 L1 muon trigger not only the standalone muons can be reconstructed but also new types of muon objects by taking advantage of the availability of tracks from the track finder. There are several options for combining L1 tracks with information from the muon stations. One is to geometrically match tracker tracks to standalone muons from the regional track finder. Another one is to match a tracker track with a standalone muon stub (single muon segment) allowing that track to be reconstructed as a muon.

Combining information results in a better estimation of the muon p_T. It also reduces the rate and allows for L1 seeding at lower p_T. The track+stub reconstruction reduces the impact of the gaps between the DT wheels.

References

[1] K. Klein *et al.* [CMS], "The Phase-2 Upgrade of the CMS Tracker," CERN-LHCC-2017-009.

[2] CMS Collaboration, "The CMS Experiment at the CERN LHC", JINST 3 S08004 (2008), doi:10.1088/1748-0221/3/08/S08004

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