

Level-1 Muon Triggers for the CMS Experiment at the HL-LHC

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The High Luminosity LHC (HL-LHC) is expected to commence operation in 2029 with an expected luminosity of $7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. While this luminosity will bring a higher data rate beneficial to the search for interesting physics, it comes with the consequence of a pileup of ~ 200 . These harsher operating conditions will require the upgrade of the trigger system. The track reconstructing algorithms of the Level-1 Trigger for the three Muon Track Finder (MTF) regions (Barrel, Overlap, Endcap) will be developed in order to maintain and possibly improve the current event selection precision. Stand-alone candidates from the outer tracking system will also be taken into account in the decision of the Global Muon Trigger (GMT). The MTF and GMT will be implemented in a custom X2O board.

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Phase-2 Level-1 (L1) Muon Trigger System The High Luminosity Large Hadron Collider (HL-LHC) is expected to commence operation in 2029. In the baseline scenario, HL-LHC will operate with a luminosity five times higher than the current value, at $7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. While this increase in luminosity will provide a higher data rate beneficial to the search for potentially interesting physics, it would also jeopardise the current trigger system, with an expected pileup of ~ 200 . In order to upkeep and even improve the event selection efficiency and purity in these harsher conditions, the trigger system of the CMS [1] requires an upgrade [2]. Its proposed scheme is shown in figure 1.

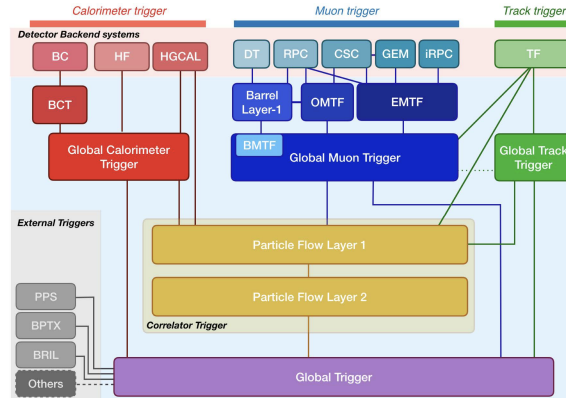


Figure 1: The Phase-2 L1 Trigger. The Global Muon Trigger (GMT) will receive information from three muon track finders (MTFs): BMTF, OMTF and EMTF. These receive information from several types of muon chambers. The GMT will also receive information from the Track Trigger (TT). The information from the GMT, the Calorimeter Trigger and the TT will be further processed by a two-layer Particle-Flow (Correlator) Trigger. The final L1 decision is taken by The Global Trigger on the basis of aforementioned modules.

In the muon system, the Cathode Strip Chambers (CSCs), Drift Tube (DT) chambers, and Resistive Plate Chambers (RPCs) already installed inside the detector for Run-1 and Run-2 will remain, but will be joined by improved RPCs (iRPCs) and Gas Electron Multipliers (GEMs, already installed for Run-3). The latter two detector types will lead to a higher redundancy and better precision at the highest $|\eta|$ values. The data obtained from these muon detectors will be prepared for processing in the trigger algorithms of the barrel layer-1 segment finder [3] together with RPC, iRPC and eventually CSC concentrators and splitters.

Stand-alone Muon Track Finders (MTFs)

Barrel MTF (BMTF) BMTF track finding will be performed using a Kalman Filter algorithm, which was developed for the ongoing Run-3 and underwent some validation on 2018 (Run-2) data. This algorithm, called the Kalman Barrel Muon Track Finder (KBMTF), works with Trigger Primitives (TPs) reconstructed by the barrel layer-1 segment finder, which encode the position and azimuthal bending angle of a muon candidate in each barrel station. Each TP (or 'stub') will be composed of hits from both RPCs and DT superlayers, a combination which will yield a sufficiently high efficiency and improve time resolution.

The algorithm begins a track from a TP from the outermost available muon layer, and propagates the track inwards by incorporating TPs in inner muon layers. After up to four such TPs have been

taken into account, the Kalman gain of the track is updated, and thus the state vector and covariance (or uncertainty) matrix can be corrected.

Overlap MTF (OMTF) The Naive Bayes Classifier approach used during Run-2 and Run-3 will be used as a baseline for track finding in the OMTF region during Phase-2. This approach considers hits in CSC, DT and RPC chambers. A comparison is made between hit patterns built from run data in from particular event and hit patterns simulated for different p_T values. The latter so-called 'Golden Patterns' encode the probability density function (PDF) for the bending angle with respect to a reference hit position, typically found in the innermost muon layer. Neural Networks and the improvement of quality (attributed on the basis of chambers involved in candidate reconstruction) assignment will assist this track finding approach, aiming to improve momentum resolution with respect to the pure Naive Bayes Classifier approach. The OMTF is susceptible to the effects of DT aging due to the increase in luminosity, however the simulation results suggest high resistivity of developed algorithms against it.

Endcap MTF (EMTF) The EMTF will employ a twofold muon identification process similar to that of the OMTF. It will involve hit selection based on pattern recognition and the assignment of kinematics parameters based on the assigned pattern. The Phase-2 algorithm (EMTF++) will include hits from CSCs and RPCs as in previous runs, as well as the new iRPCs and GEMs. Applying the Phase-1 algorithm (EMTF) to the high luminosity conditions results in a non-linear relationship between the rate and the pileup. EMTF++ exhibits linear rate behaviour with respect to pileup as a result of improved pattern recognition and more precise p_T assignment to be performed by Neural Networks; these take into consideration such parameters as time, quality and the bending angle of contributing TPs, as well as their (2D) positions.

The simulated efficiency curves for the stand-alone muon triggers under Phase-2 conditions are shown in figure 2.

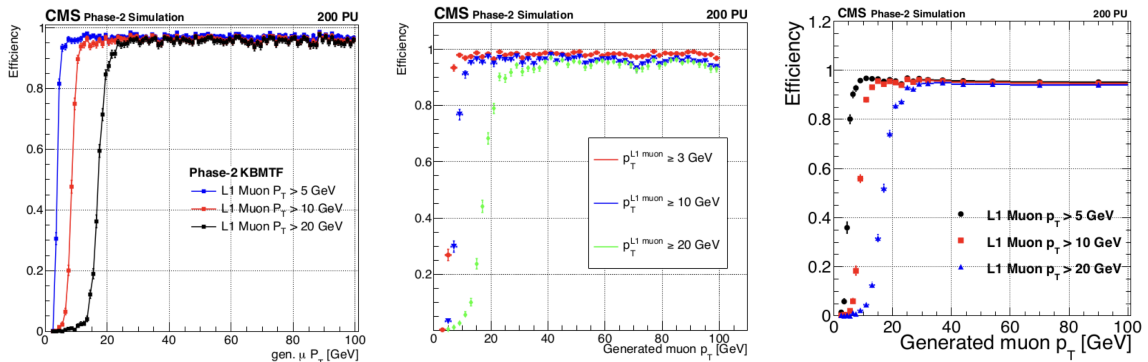


Figure 2: Efficiency curves with respect to generated p_T values for different L1 p_T thresholds. From the left: KBMTF, OMTF and EMTF++. All MTF efficiency curves plateau at $\sim 95\%$.

Global Muon Trigger (GMT) The main purpose of the Phase-2 GMT is to further improve the muon track candidates reconstructed by the MTFs. It may be achieved by the merging of the muon system information with track candidates provided by the Tracking Trigger on the basis of

reconstruction in the outer silicon tracking system. The difficulty of combining information between the two systems arises from the ambiguous matching of tracker tracks to deposits in the muon system or candidates reconstructed therein. However, the overwhelming benefit of such a combination is that the p_T resolution of the candidates will be significantly improved. The underlying reason of this is that rate from stand-alone MTFs is dominated by low p_T muons mismeasured as high p_T ones in the muon system, while the tracking system provides a cleaner discrimination between these track types. Identification channels to be made available include comparing the propagated track from the tracker to the standalone MTF muon candidate, or comparing the propagated track directly with the TPs (optionally comparing only to those TPs contributing to MTFs candidates). Various reconstruction methods have been simulated in different CMS regions. A sample of performance plots resulting from these simulations are presented in figure 3.

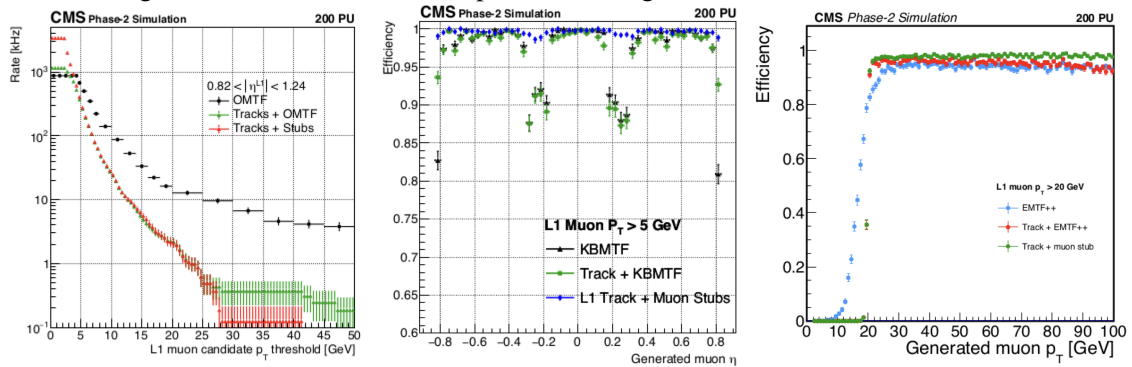


Figure 3: From left to right: rate in the Overlap region - comparison of GMT rate using stand-alone OMTF, tracks and OMTF, and tracks and stubs; efficiency in Barrel region as a function of η - comparison of GMT efficiency for stand-alone KBMTF, tracks and KBMTF, and L1 tracks and stubs; efficiency in Endcap region as a function of generated p_T - comparison of GMT efficiency curves from stand-alone EMTF++ only, tracks and EMTF++, and tracks and stubs.

X2O Board The X2O board is a processing board with a modular design currently in the post-prototyping stage of development, which will implement the MTFs and GMT into the Phase-2 L1 trigger system. The board is to be equipped with a Xilinx UltraScale+ VU13P FPGA processing unit and optical module with up to 25 Gb/s optics. A total of 36 boards will be installed in the muon trigger system, with 6 for the OMTF, 12 for the EMTF and 18 for the GMT (the BMTF will be implemented in the GMT, see figure 1).

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References

- [1] CMS Collab., *The CMS Experiment at the CERN LHC* JINST 3 (2008) S08004
- [2] CMS Collab., *The Phase-2 Upgrade of the CMS Level-1 Trigger* CERN-LHCC-2020-004
- [3] CMS Collab., *The Phase-2 Upgrade of the CMS Muon Detectors* CERN-LHCC-2017-012