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Triggering on Electrons, Photons, Taus, Jets and Energy Sums at HL-LHC with the Upgraded CMS Level-1 Trigger

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The High-Luminosity LHC (HL-LHC) will open an unprecedented window on the weak-scale nature of the universe, providing high-precision measurements of the standard model as well as searches for new physics beyond the standard model. The CMS experiment is planning to replace entirely its trigger and data acquisition system to achieve this ambitious physics program. Efficiently collecting those data sets will be a challenging task, given the harsh environment of 200 proton-proton interactions per LHC bunch crossing. The new Level-1 trigger architecture for HL-LHC will improve performance with respect to Phase-1 through the addition of tracking information and subdetector upgrades leading to higher granularity and precision timing information. In this work, we present a multitude of trigger algorithms for the upgraded Phase-2 trigger system, which benefit from the finer information to reconstruct optimally the physics objects. Dedicated pile-up mitigation techniques are implemented for lepton isolation, particle jets and missing transverse energy to keep the rate under control. The expected performance of the new trigger algorithms will be presented, based on simulated collision data of the HL-LHC. The selection techniques used to trigger efficiently on benchmark analyses will be presented, along with the strategies employed to guarantee efficient triggering for new resonances and other new physics signals.

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1. New trigger capabilities at the HL-LHC

The High Luminosity LHC (HL-LHC) [1] presents extraordinary physics opportunities by delivering an expected 4000 fb^{-1} of collision data to the experiments. At peak luminosity, 200 proton-proton (pp) interactions per bunch crossing (pile-up, PU) are foreseen. The CMS Level-1 Trigger (L1T), based on generic hardware processing engines, serves to select a broad spectrum of physics signatures in real time. However, the current L1T system cannot be used in the running conditions of the HL-LHC, as this would result in unsustainable rates. Therefore, the L1T has been redesigned to maintain and extend the physics acceptance of the existing L1T, even in the harsher conditions expected at the HL-LHC [2].

A schematic of the design architecture is shown in Figure 1. One of the most anticipated upgrades to the L1T is the Track Trigger (depicted in green), which will, for the first time, use charged particle tracks, reconstructed at the pp collision rate of 40 MHz. Tracker information in the L1T allows for improved momentum measurements and accurate reconstruction of the position of collision vertices, and will therefore be an important handle for PU mitigation. Another new addition is the Correlator Trigger (depicted in yellow), playing a central role in the design of the new L1T. It will receive inputs from multiple subdetector systems on the same electronics board. This allows for matching of "standalone" calorimeter and muon objects to tracker objects, which greatly reduces the trigger rate. Additionally it will host global event reconstruction techniques, such as Particle Flow (PF) [3] and PileUp-Per-Particle-Identification (PUPPI) [4].

The new L1T design makes extensive use of state-of-the art FPGAs and processors, connected via high speed optical links. Combined with an increased latency (from 3.8 to 12.5 μs) to make the final trigger decision, it is possible to evaluate more advanced trigger algorithms, that come with higher computational load. These upgrades therefore form the basis for the wide array of machine learning based trigger algorithms that are anticipated for the HL-LHC era.

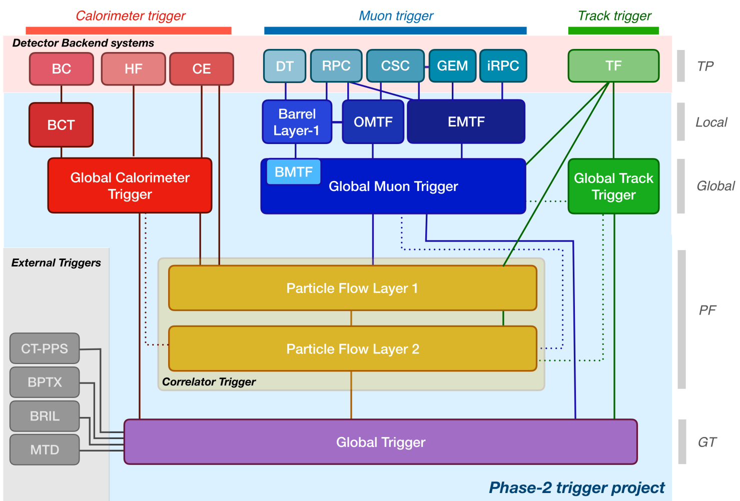

Figure 1: Schematic diagram of the CMS L1T architecture for Phase-2. The highly modular design provides optimum flexibility and robustness, and can be divided into four data processing paths: The Calorimeter Trigger (red), the Muon Trigger (blue), the Track Trigger (green) and the Correlator Trigger (yellow) [2].

2. Triggering on electrons and photons

In the barrel region ($|\eta| < 1.52$), e/γ objects are constructed from 3x5 crystal energy deposits, exploiting the increase in energy measurement granularity by a factor of 25 due to the improved readout of the Electromagnetic Calorimeter. In the end-cap region ($|\eta| > 1.52$) a new High-Granularity Calorimeter will be installed, which provides a rich and detailed description of particle showers. The identification of these clusters is based on multivariate machine learning algorithms. In particular, boosted decision trees will be used to distinguish signal clusters from PU. In the Correlator Trigger the calorimeter-only e/γ objects will then be matched to tracks, in order to greatly reduce the trigger rates, while preserving the current trigger thresholds, even at 200 PU. The efficiencies and rates of the calorimeter-only and track-matched e/γ objects in the end-cap region are shown in Figure 2.

3. Triggering on jets, taus and energy sums

The standard approach to reconstruct jets in the current L1T uses calorimeter-only information. However, with the upgraded L1T, jets can also be reconstructed using PUPPI candidates, which are formed in the Correlator Trigger using information from all subdetectors. The PUPPI candidates are binned in pseudo-trigger towers and clustered in a 9x9 window around a local energy maximum. It has been shown that this approach gives similar performance to the AK4 jet reconstruction algorithm that is employed offline. PUPPI jets can also be used to trigger on H_T, the scalar sum of jet p_T. Figure 3 (left) shows that for a fixed trigger rate, the PUPPI jets approach significantly lowers the trigger threshold with respect to the standard calorimeter-only approach.

Hadronically decaying taus (τ_h) can be reconstructed with calorimeter-only information, using the same 7x7 tower geometry as used to reconstruct calorimeter-only jets. The central 3x5 towers are used to define the p_T of the τ_h, while the remaining towers are used to compute the τ_h isolation. Both the isolation and the cluster shape are then used to distinguish τ_h objects from jets. To drastically lower the trigger thresholds for τ_h objects, PUPPI candidates will be used. A neural network was

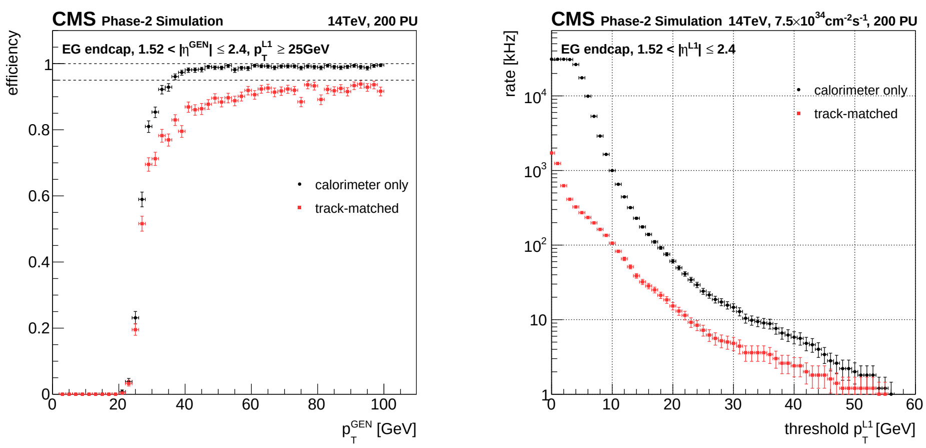

Figure 2: Reconstruction efficiencies (left) and trigger rates (right) for calorimeter-only and track-matched electron objects in the CMS end-caps [2].

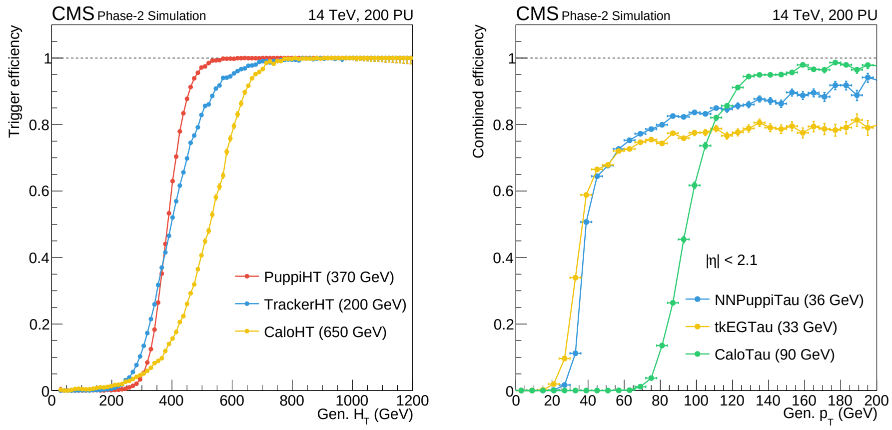

Figure 3: Left: Trigger efficiency at a fixed rate of 10.5 kHz with H_T computed using PUPPI candidates (red), tracker-only information (blue) or calorimeter-only information (yellow). Right: Efficiency at fixed rate for hadronically decaying taus, reconstructed using PUPPI candidates (blue), track-matched calorimeter objects (yellow), or calorimeter-only information (green) [2].

developed to reconstruct τ_h objects, using properties of the 10 highest p_T PUPPI candidates within ΔR<0.4 of the charged particle seeding the reconstruction. The improved performance of the PUPPI based algorithm with respect to the calorimeter-only algorithm is shown in Figure 3 (right).

The missing transverse energy, E_T^{miss}, is computed as the negative vector sum of particle momenta. When using PUPPI candidates for this computation, E_T^{miss} based triggers can be constructed with similar thresholds as those implemented in the current L1T system. For a flexible and robust trigger system, an alternative approach is developed to compute E_T^{miss} using only tracker information, relying strongly on track purity requirements to mitigate contributions from PU.

4. Conclusion

The Phase-2 CMS Level-1 Trigger upgrade will offer new capabilities, such as track-matching and global event reconstruction, as well as more sophisticated machine learning based algorithms. Novel trigger strategies are continuously being developed to maintain and extend the physics acceptance of today, even in the HL-LHC era.

References

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