PROCEEDINGS OF SCIENCE

Triggering on electrons, photons, tau leptons, 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 provide Standard Model measurements of unprecedented precision, as well as searches for new physics with significantly enhanced discovery potentials. The Compact Muon Solenoid (CMS) experiment is planning to replace entirely its trigger and data acquisition systems to pursue this ambitious physics program. Recording, reconstructing, and analyzing interesting events will be a rather challenging task, in an environment of 200 proton-proton interactions per LHC bunch crossing. The new Level-1 Trigger architecture for the HL-LHC will achieve a significantly improved performance by utilizing tracking information, taking advantage of the higher granularity of the upgraded detectors, and utilizing precise timing information. In this report, we present several trigger algorithms for the upgraded Phase-2 trigger system, along with their expected performance.

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1. Introduction

Experiments at the CERN LHC have already made numerous discoveries, the most prominent being that of the Higgs boson, and have significantly advanced our understanding of elementary particles and their interactions. However, a more powerful machine, the High-Luminosity LHC (HL-LHC), with a significantly upgraded CMS detector [1] and extended triggering capabilities, could be best positioned to probe unexplored regions of new physics parameter space. The HL-LHC is expected to start in 2029, with an instantaneous luminosity reaching $L = 7.5 \times 10^{34}$ cm^{-2}s^{-1} at a center-of-mass energy of $\sqrt{s} = 14$ TeV.

The Phase-2 CMS Level-1 (L1) Trigger [2] exploits enhanced subdetectors, upgraded electronics, and advanced algorithms compared to the current system. More specifically, the maximum total L1 rate will increase from 110 kHz to 750 kHz, and the latency will extend from 3.8 μs to 12.5 μs. The system will also benefit from more granular detector inputs, including data from the newly installed High Granularity Calorimeter (HGCAL) and, for the first time, the Tracker. Moreover, the new Very Front-End electronics will allow for finer sampling at 160 MHz (40 MHz in Phase-1), and advanced machine learning (ML) techniques will be embedded in state-of-the-art FPGA firmware.

2. Electrons and photons algorithms

In the Barrel region ($|\eta| < 1.5$), the granularity of the trigger improves to the crystal level (from the previous 5×5 crystal region), and e/γ objects are reconstructed in the ECAL within an $\eta \times \phi$ region covering 3×5 crystals. In the endcaps ($1.5 < |\eta| < 3$), the 3D shower shapes of the HGCAL are used for the reconstruction [4]. A matching with tracks (L1 Tracks) can take place to decrease the L1 rate of the e/γ objects, where the matching is performed using either the Elliptic ID [2] or the Composite ID [3]. The former uses geometrical criteria, while the latter uses Boosted Decision Trees (BDT). Figure 1 shows the expected performance of the L1 e/γ Trigger.

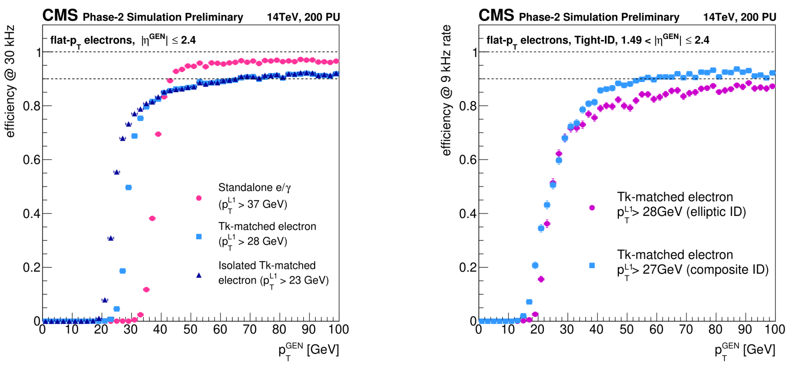

Figure 1: Phase-2 L1 e/γ performance: (left) Turn-on efficiency comparison between the standalone algorithm and the L1 Track-matched with the Elliptic ID with and without Isolation [2], (right) Comparison of Elliptic ID vs Composite ID [3].

3. Jets, energy sums, and hadronic taus algorithms

Also, for jets, the granularity of the ECAL is improved, and the reconstruction at L1 is performed in a region covering 9×9 crystals (Calo jet) [4]. These jets can also be matched with L1 Tracks (Track jet) [2]. The Tracker input at L1, along with the powerful electronics, allows the use of the ParticleFlow and PileUp-Per-Particle-Identification (PUPPI) algorithms (PUPPI jet) [2]. For hadronically decaying taus (τ_h), a region of $\eta \times \phi = 3 \times 3$ crystals is used (Calo Tau). However, more sophisticated algorithms have been developed, utilizing Tracker information and real-time ML techniques (NNPuppi, TauMinator) [5, 6]. Figure 2 shows the expected performance of the L1 jets and τ_h.

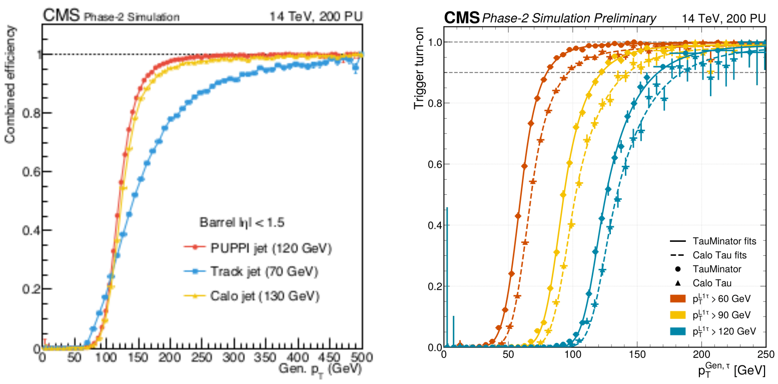

Figure 2: Phase-2 L1 jets and τ_h performance: (left) Turn-on efficiency in the Barrel region ($|\eta| < 1.5$) for the L1 jets [2], (right) Turn-on efficiency comparison of the CaloTaus and the Calo+Neural Networks taus (TauMinator) [5].

4. Conclusions and outlook

The CMS HL-LHC L1 Trigger upgrade program proposes novel, yet solid and flexible approaches that can successfully overcome challenges for all physics objects. The upgraded triggers will use tracking information, more powerful detectors, and precise timing information, and utilizing ML approaches will provide physics analysis with the best possible datasets. Novel trigger strategies are continuously being developed to maintain and extend the physics acceptance of today.

References

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