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HPS@L1 algorithm for the upgraded CMS level-1 hadronic tau trigger for the HL-LHC

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The High-Luminosity 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 Compact Muon Solenoid (CMS) experiment is planning to replace entirely its trigger and data acquisition system to achieve this ambitious physics program. Efficiently collecting those datasets 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 the HL-LHC will improve performance with respect to Phase I through the addition of tracking information and updates of the trigger electronics, which will allow to run a simplified particle-flow (PF) event reconstruction on the first trigger level (L1).

In this proceedings, we present the development of an algorithm, which is one of many developed algorithms, to select events containing hadronic tau decays on L1 during LHC Phase II. The algorithm is inspired by the "hadrons-plus-strips" (HPS) algorithm, which has been used for the reconstruction of hadronic taus in offline analyses performed by CMS during LHC Runs 1 and 2. It takes advantage of the capability of the upgraded trigger to perform tracking and PF event reconstruction on L1 and is referred to as the HPS@L1 algorithm. The performance of the algorithm is studied in terms of efficiency and rate expected for a single hadronic tau and for a tau pair (di-tau) trigger, using simulated events. For a tau isolation selection that yields a plateau efficiency of 85% per tau, the algorithm achieves a tau p_T threshold of about 20 GeV for the di-tau trigger, which is lower than the p_T threshold (32 GeV) achieved by the di-tau trigger (using calorimeter-only information) used by CMS during LHC Phase I (with luminosity $2 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$).

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1. Introduction

The Large Hadron Collider (LHC) is preparing for a major upgrade to increase the instantaneous luminosity to $7.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ at a center-of-mass energy $\sqrt{s}$ = 14TeV TeV [1]. This High-Luminosity LHC (HL-LHC) machine is expected to start operations in 2027 and will deliver a total integrated luminosity of up to 4000 fb^{-1} after ten years of operations. This huge amount of data will open the door to a rich and ambitious physics program including both high-precision measurements and searches for physics beyond the standard model (SM).

In order to fully benefit from the resulting increase in data-taking rate, a major upgrade of the CMS detector is necessary as well. The trigger and data-acquisition system will be enhanced significantly by allowing for tracking and particle-flow (PF) event reconstruction at the first trigger level (L1) [2]. The maximum permissible acceptance rate of the L1 trigger will increase from 100 kHz to 750 kHz and its latency from 4μs to 12.5μs. At an instantaneous luminosity of $7.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$, 200 inelastic proton-proton (pp) collisions are expected to occur per bunch crossing. In order to distinguish events of interest from inelastic pp collisions (pileup) occurring in the same bunch crossing, the granularity of the tracking detectors and calorimeters will be enhanced significantly. Modern processors will be used to implement sophisticated algorithms including machine learning-based approaches to target the selection of specific final states.

We expect the ability of the upgraded trigger system to perform tracking and PF event reconstruction at L1 to be very beneficial for physics analyses with τ leptons. In offline analyses of data recorded during LHC Run 1, the resolution in the energy of hadronic τ decays, denoted by the symbol τ_h, that are reconstructed with the PF algorithm has been demonstrated to be significantly better compared to that of those reconstructed using only calorimeter information [3]. A further, related, benefit is that the consistent usage of the PF event reconstruction at the L1 trigger and High Level Trigger (HLT) level as well as in offline analyses increases the correlation between the p_T of τ_h reconstructed on trigger level and of those reconstructed offline, providing trigger efficiency turn-on curves that rise more sharply as function of p_T compared to the mix of calorimeter-based and PF-based reconstruction that was used during LHC Runs 1 and 2. Finally, the availability of tracking information at L1 will allow significant reduction in the L1 acceptance rate of τ_h triggers via imposing isolation criteria with respect to charged particles.

2. HPS@L1 algorithm for L1 tau trigger [2]

The "hadrons-plus-strips" (HPS) algorithm, which is used for τ_h reconstruction in offline analyses of CMS data recorded during LHC Runs 1 and 2 [4, 5], has recently been ported to the HLT, in order to cope with the increase in instantaneous luminosity during LHC Run 2 [6]. The HPS algorithm takes into account that about two-thirds of hadronic τ decays involve the production of at least one neutral pion (π^0) and that the photons produced in the decays of these π^0 have a sizeable probability to convert to electron-positron pairs when traversing the tracking detector, which then get deflected away from the initial π^0 direction by the 3.8 T magnetic field. Accounting for these deflections, the HPS algorithm clusters the photons and electrons obtained from the PF event reconstruction into rectangular strips, which are narrow in η-, but wide in ϕ-direction, and uses these strips, rather than individual photons and electrons as input to the τ_h reconstruction.

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In order to use the HPS algorithm at L1, two main modifications need to be made to the algorithm, in order to reduce its computational complexity.

The first modification concerns the reconstruction of individual decay modes of the τ lepton, namely $\tau^- \to h^-\nu_\tau$, $\tau^- \to h^-\pi^0\nu_\tau$, $\tau^- \to h^-\pi^0\pi^0\nu_\tau$, $\tau^- \to h^-h^+h^-\nu_\tau$, and $\tau^- \to h^-h^+h^-\pi^0\nu_\tau$, where $h^\pm$ denotes either a charged pion or kaon. We assume that the decay modes of τ^+ are identical to those of τ^- through charge conjugation invariance. In the offline implementation of the HPS algorithm, a combinatorial approach is used, which builds multiple τ_h hypotheses, corresponding to different τ decay modes, in parallel and then selects the "best" τ_h hypothesis, taken to be the one of highest p_T (which is typically also the one that is the most isolated) [4].

The main disadvantage of this approach is its high computational complexity. Up to $O(100)$ τ_h hypotheses need to be built in parallel for each hadronic τ decay that gets reconstructed. Our implementation of the HPS algorithm for L1 (viz. HPS@L1 algorithm) avoids this extra computational complexity.

The second modification concerns the reconstruction of the strips. In the offline implementation of the HPS algorithm, the strips are reconstructed using an iterative method. The position of the strip is recomputed at each iteration and its size is adjusted as function of p_T of the strip and of the photon or electron that gets added to the strip, accounting for the fact that electrons and positrons of lower p_T get deflected by a larger angle and those of higher p_T by a smaller angle when traversing the magnetic field. In the HPS@L1 algorithm, we use a modified procedure to reconstruct the strips, which eliminates these iterations.

The HPS@L1 algorithm is seeded by the combination of charged particles of $p_T > 5$ GeV and jets of $p_T > 30$ GeV. The jets are reconstructed using the anti-kT algorithm [7] with a distance parameter of 0.4. All particles reconstructed by the PF algorithm are used as input to the jet clustering. The charged particle seeding the τ_h reconstruction or the charged particle of highest p_T within the jet that seeds the τ_h reconstruction defines the "leading track" of the τ_h. The algorithm proceeds by computing the scalar sum in p_T, denoted by p_T^Σ, of the charged hadrons, photons, and electrons that are within a cone of size $\Delta R = 0.4$, which is centered on the direction of the leading track. The value of p_T^Σ thus obtained is taken as initial estimate of the p_T of the τ_h and is used to compute the expected collimation of the particles produced in the τ decay. Charged particles that are within a "signal" cone of size $2.8/p_T^\Sigma$ as well as photons and electrons that are within a strip of size 0.05×0.20 in $\eta \times \phi$ are taken as τ_h decay products and are used to compute the final τ_h momentum. The signal cone and strip are both centered on the direction of the leading track. In case the size of the signal cone falls short of 0.05 or exceeds 0.10, the size of the signal cone is set to 0.05 and 0.10, respectively. Charged particles that are within an "isolation" cone of size 0.4, centered on the direction of the leading track, and which have not been used to compute the τ_h momentum, are used for the purpose of computing the isolation of the τ_h. We denote the scalar sum in p_T of these charged particles by the symbol I_{ch}. For the purpose of computing the τ_h momentum as well as for the purpose of computing the isolation of the τ_h, only those charged particles that are compatible with originating from the same vertex as the leading track are considered. The condition for charged particles to be considered as originating from the same vertex as the leading track is that their track crosses the beam axis within a distance of less than $\Delta z = 0.4$ cm with respect to the point where the leading track crosses the beam axis. For the case of two τ_h, the leading tracks of both τ_h must cross the beam axis within a distance of less than 0.4 cm from each other.

3. Performance: trigger rate and efficiency

The trigger rate and efficiencies are computed for different isolation selections applied to the τ_h. We study the following isolation selections: $I_{\text{ch}} < 0.20 \times p_T$, $I_{\text{ch}} < 0.10 \times p_T$, and $I_{\text{ch}} < 0.05 \times p_T$, where the symbol p_T in these isolation selections refers to the transverse momentum of the τ_h candidate reconstructed at L1. We refer to these selections as the loose, medium, and tight isolation criteria.

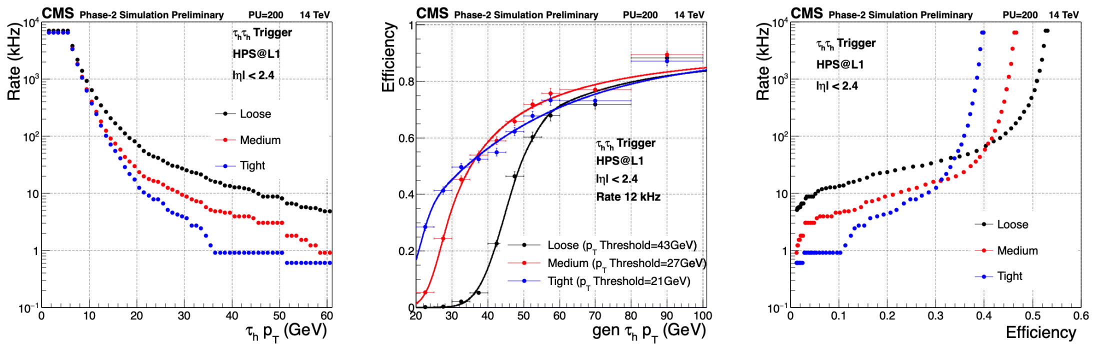

Figure 1: Rate (left), efficiency (middle) and rate vs efficiency (right) of the L1 $\tau_h\tau_h$ trigger [2].

The rates expected for the $\tau_h\tau_h$ trigger are shown in the left plot of Fig. 1, for different selections on the isolation of the τ_h. The rate of the $\tau_h\tau_h$ triggers is given by the product of $28MHz$ [1] times the percentage of simulated empty hard-scatter events passing these triggers. The p_T threshold that is given on the X-axis is applied to both τ_h. The algorithm achieves a target trigger rate of 12 kHz for the L1 τ_h threshold of 43, 27 and 21 GeV for Loose, Medium, and Tight τ_h isolation selections.

The efficiencies of the $\tau_h\tau_h$ trigger for SM $H \to \tau\tau$ events produced via the ggH process are shown in the middle plot of Fig. 1. The efficiency is computed for events containing two generator-level τ_h of $p_T > 20$ GeV and $|\eta| < 2.4$. The efficiencies are shown per τ_h and as function of generator-level τ_h p_T. Each efficiency curve is computed for a p_T threshold corresponding to a $\tau_h\tau_h$ trigger rate of 12 kHz. The algorithm achieves a plateau efficiency of 85%.

The rates of the $\tau_h\tau_h$ trigger as a function of efficiency of the trigger to select SM H$\to$ $\tau\tau$ signal are shown in the right plot of Fig. 1. Points along each curve are obtained by varying the L1 τ_h p_T threshold, which is applied to both τ_h. For a trigger rate of 12 kHz, the Tight τ_h isolation selection achieves a trigger efficiency of 30% for the SM H$\to$ $\tau\tau$ signal.

4. Summary

The ability of the upgraded trigger system to perform tracking and PF event reconstruction at L1 is very beneficial for physics analyses with τ leptons at the HL-LHC. The studies presented here indicate that it will be possible to achieve p_T thresholds close to 20 GeV for the $\tau_h\tau_h$ trigger with a corresponding efficiency of 30% at L1 during HL-LHC run. Such thresholds provide very promising prospects for triggering the SM $H \to \tau\tau$ signal events at the HL-LHC.

[1]The frequency of actual bunch collisions is lower by about 30% compared to the nominal 40 MHz bunch crossing frequency, due to the fact that not all bunches of the two colliding proton beams are actually filled with protons.

References

[1] G. Apollinari et al., *"High-Luminosity Large Hadron Collider (HL-LHC)"*, CERN Yellow Rep. Monogr. 4 (2017) 1, doi:10.23731/CYRM-2017-004

[2] CMS Collaboration, *"The Phase-2 Upgrade of the CMS Level-1 Trigger"* CERN-LHCC-2020-004, CMS-TDR-021

[3] CMS Collaboration, *"Particle-flow reconstruction and global event description with the CMS detector"*, JINST 12 (2017), no. 10, P10003, doi:10.1088/1748-0221/12/10/P10003, arXiv:1706.04965.

[4] CMS Collaboration, *"Reconstruction and identification of τ lepton decays to hadrons and ν_τ at CMS"*, JINST 11 (2016), no. 01, P01019, doi:10.1088/1748-0221/11/01/P01019, arXiv:1510.07488.

[5] CMS Collaboration, *"Performance of reconstruction and identification of τ leptons decaying to hadrons and ν_τ in pp collisions at $\sqrt{s}$ = 13 TeV"*, JINST 13 (2018), no. 10, P10005, doi:10.1088/1748-0221/13/10/P10005, arXiv:1809.02816.

[6] CMS Collaboration, *"Tau lepton run 2 trigger performance"*, CMS Performance Note CMS-DP-2019-012, 2019.

[7] M. Cacciari, G. P. Salam, and G. Soyez, *"The anti-kT jet clustering algorithm"*, JHEP 04 (2008) 063, doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189, LPTHE-07-03.