Development of a L1 tau lepton trigger algorithm using the CMS high-granularity calorimeter information

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HL-LHC AND THE CMS PHASE-2 UPGRADE

The HL-LHC will integrate 10 times the current LHC luminosity, and have an instantaneous luminosity 3 times the Run 2 peak value.

This will result in unprecedented levels of radiation and high pileup (PU) collision rate.

The CMS Collaboration will replace:
- the tracking detectors
- the barrel backend electronics
- the muon detectors
- the endcap calorimeter

The Phase-2 trigger system implements the well-established two-level trigger architecture with Level-1 (L1) and High-Level-Trigger (HLT), targeting a 7.5 kHz output rate.

The L1 trigger will operate at hardware level implementing custom processor boards and FPGAs, using the CMS detector enhanced granularity and fully reconstructed tracks.

The HLT will operate at software level using as input the CMS detector full-granularity information and more sophisticated algorithms.

The high-granularity calorimeter (HGCAL) will be a 5D (x, y, z, E, t) sampling calorimeter; its main features are:
- silicon-based electromagnetic compartment (~25X₀)
- silicon-based + scintillator tiles hadronic compartment (~10X₀)
The algorithm targets hadronically decaying tau leptons ($\tau_h$) detected by HGCAL and it is developed foreseeing its implementation in the calorimeter trigger section of the L1.

The main hardware improvements for the L1 Phase-2 system, w.r.t. the current system, will be:

- the extensive use of state-of-the-art FPGA boards and processors for optimised reconstruction
- the use of high-speed optical links to facilitate the aggregation of data
- the implementation of a highly modular architecture to meet different HL-LHC running conditions

The main new features of the L1 Phase-2 system will be:

- the implementation of the correlator trigger where higher level variables can be computed to introduce PU mitigation and providing an L1 output with performance closer to offline reconstruction.
- the first ever inclusion of tracker information
- the inclusion of the HGCAL trigger information. Its trigger primitive generator takes trigger cells (sums of silicon/scintillator tiles) as input and with a two-staged architecture clusters them in 3D-clusters (HGCAL trigger primitives)

The algorithm takes as an input the 3D-clusters produced by the HGCAL trigger primitive generator and assumes a tau-to-cluster one-to-one correspondence. The minimal requirement $E_T^{\text{clus.}} \geq 4 \text{ GeV}$ is applied to form the L1 candidates.

Next is a clusters three stage calibration:

- $\eta$-dependent PU subtraction
- clusters’ shape dependent correction
- energy dependent correction

The last step is the identification of the hadronic decay mode in three categories using a Random Forest Classifier exploiting the clusters’ shape variables.

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The efficiency of the L1 algorithm is evaluated with simulated collisions with 200 average PU events. The efficiency as a function of the generated visible $\tau_h$ lepton $p_T$ shows a sharp turn-on, both for the aggregated and split decay modes cases, that reaches 100% at plateau. The single-$\tau_h$ rate corresponding to different L1 threshold shows a large reduction for $p_T \geq 30$ GeV.

The many L1 trigger upgrades permit substantial improvement in the implementation of $\tau_h$ trigger algorithms. A better knowledge of the shower features allows the use of sophisticated BDT-based trigger primitive selection and calibration.

The discussed algorithm shows great preliminary performance, namely:

- a 19% energy resolution (~14% better than the Run 2 performance)
- a sharp selection efficiency that reaches 100% at plateau
- the possibility to separate the decay modes at L1 level

The main undergoing and future developments of the discussed $\tau_h$ algorithm are:

- the calculation and exploitation of quality and isolation variables (undergoing)
- the inclusion of QCD-jet rejection (undergoing)
- the exploitation of the L1 track trigger information
- the firmware implementation (planned for this summer/autumn)

REFERENCES: The Phase-2 Upgrade of the CMS endcap calorimeter (CMS-TDR-019); The Phase-2 Upgrade of the CMS Level-1 Trigger (CMS-TDR-021)