The CMS Level-1 tau lepton and vector boson fusion triggers for the LHC Run II

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Abstract

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The CMS Level-1 $\tau$ lepton and Vector Boson Fusion triggers for the LHC Run II

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Abstract

The CMS experiment implements a sophisticated two-level triggering system composed of Level-1, instrumented by custom-design hardware boards, and a software High Level Trigger. A new Level-1 trigger architecture with improved performance is now being used to maintain high physics efficiency for the more challenging luminosity conditions experienced during Run II. In this paper, the upgrades to the calorimeter trigger are shown along with performance measured on 2017 collision data. The algorithms for the selection of final states with hadronically decaying $\tau$ leptons, both for precision measurements and for searches of new physics beyond the Standard Model, are described. The implementation of the first dedicated Vector Boson Fusion trigger algorithm is presented as well, along with its performance on Higgs physics signals.

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1. Introduction

The CMS (Compact Muon Solenoid) experiment operating at the LHC (Large Hadron Collider, CERN, Switzerland) is a multi-purpose detector consisting of various sub-detectors installed concentrically with respect to the interaction point and designed specifically to characterize different kinds of particles. In 2017, it collected 41 fb$^{-1}$ of data from $\sqrt{s} = 13$ TeV proton-proton collisions in the LHC.

For a high-luminosity experiment such as CMS, the trigger system is essential, since the LHC rate of bunch crossing ($\sim$40 MHz) is far beyond the sustainable event output rate ($\sim$1 kHz). Thus the CMS detector implements a sophisticated two-level trigger architecture composed a hardware Level-1 (L1) and a software High-Level-Trigger (HLT), achieving overall 10$^5$ rate reduction. The upgrade of the Level-1 trigger architecture in 2016 [1] allowed to implement complex algorithms, such as the selection of final states with hadronically decaying $\tau$ leptons, presented here together with the performance in 2017. It also enabled the computation of sophisticated variables involving many types of trigger objects, which was exploited to design specific analysis-targeted algorithms such as the Vector Boson Fusion (VBF) trigger, also addressed herein.

2. The Level-1 $\tau_h$ trigger

The L1 $\tau_h$ trigger algorithm targets at hadronically decaying $\tau$’s. The $H \rightarrow \tau_h\tau_h$ analysis in CMS currently relies on the so-called DoubleIsoTau32er L1 trigger, which selects events with a pair of isolated $\tau_h$ leptons with $p_T > 32$ GeV and $|\eta| < 2.1$ targeting the Higgs decay products.

The challenge of triggering on hadronically decaying $\tau$’s is the presence of multiple clusters arising from the multiple prong decay. Therefore, the identification of the $\tau_h$ energy deposits is done through dynamic clustering specifically designed to target the reconstruction of these secondary clusters. After that, the energy of the $\tau_h$ candidate is calibrated to improve its scale and resolution. Moreover, isolation criterion is applied in order to reject quark and gluon background. During this step, pileup effects throughout the detector are estimated and subtracted at hardware level.

The L1 $\tau_h$ trigger performance has been assessed for data taken in 2017 [2]. The efficiency is evaluated for $\tau$’s used to seed the double-$\tau_h$ HLT and is computed per single-leg

Figure 1: L1 trigger efficiency of isolated $\tau_h$ seeds (i.e. requiring the L1 $\tau_h$ candidate to pass a cut on its isolation transverse energy) as a function of the offline reconstructed transverse momentum $p_T^{\text{off-line}}$, for different L1 thresholds.

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through the tag-and-probe method, as a function of the offline-reconstructed $\tau_h$ transverse momentum. The L1 trigger efficiency for isolated $\tau_h$ seeds for different L1 thresholds can be found in Fig.1. A 90% efficiency is reached at 50 GeV, which is the threshold used in the $H \to \tau_h \tau_h$ analysis. The integrated L1 selection efficiency for isolated $\tau_h$ seeds as a function of the pileup (i.e. number of vertices) is presented in Fig.2. The algorithm shows stable pileup resilience, with 90% efficiency maintained up to 60 interactions per bunch crossing, thanks to the pileup estimator already present at L1.

3. The L1 Vector Boson Fusion trigger

The VBF process contributes as ~10% to the Higgs boson production and has a very characteristic signature, consisting of two jets with high invariant mass and large angular separation, while the Higgs boson decays in the central region of the detector. This distinct topology with excellent signal to background ratio makes it one of the most sensitive categories for Higgs boson analysis.

Contrary to the classic trigger strategies that target the decay mode, the VBF trigger is specific for the production mode. For an event to pass the VBF L1 trigger selection, it is required to have at least one jet with transverse energy $E_T^{L1} > X$ and at least two jets with $E_T^{L1} > Y$ with an invariant mass of $m_{jj}^{L1} > Z$. Two figures of merit are used to choose the $X$, $Y$ and $Z$ thresholds: their combination should provide simultaneously a high rate reduction and a high efficiency.

The performance of the L1 VBF trigger has been evaluated in 2017 data [3]. Fig.3 shows the correlation between the threshold on the leading L1 jet $E_T^{L1}(X)$ and the rate and acceptance gain of the L1 VBF trigger. While keeping $Y = 40$ GeV and $Z = 620$ GeV fixed, the figure shows the dependence of $X$ and the net increase in signal events (acceptance gain), defined as the number of events passing only the VBF trigger over the number of events passing the $\text{DoubleIsoTau32er}$ trigger, as well as the rate per bunch crossing. By raising the leading jet $E_T^{L1}$ threshold, a better rate reduction is achieved, but the acceptance gain coming from including the VBF trigger is reduced. The red star on the plot shows the VBF trigger configuration that was used in 2017: $X = 115$ GeV, $Y = 40$ GeV, $Z = 620$ GeV. This working point provided 43% additional VBF $H \to \tau_h \tau_h$ events with respect to the $\text{DoubleIsolTau32er}$ trigger alone.

4. Conclusions

Throughout Run II, CMS has benefited from a new L1-trigger architecture that has enabled the design of high performance $\tau_h$ seeds as well as L1 algorithms directly targeting the VBF Higgs boson production mode. The combination of the dedicated VBF trigger with the Double-$\tau$ trigger has allowed to reduce significantly the rate and improve the signal efficiency while keeping low $p_T$ thresholds on the Higgs boson decay products. Moreover, the L1 $\tau_h$ trigger allowed the observation of the Higgs boson in the $\tau\tau$ final state in 2017 [4]. Both the VBF and $\tau_h$ triggers have shown outstanding performance and pileup resilience in 2017 and have already been upgraded to maintain the performance in harsher experimental running conditions of the LHC in 2018.

References