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The CMS Level-1 τ 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 a hardware Level-1 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 τ leptons 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.

Keywords: Trigger. Calorimetry.

PACS: 29.85.Mc, 29.85.Vj

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 to characterize different kinds of particles. In 2017, it collected 41 fb^{-1} of data from $\sqrt{s} = 13 \text{ TeV}$ 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 ($\sim 40 \text{ MHz}$) is far beyond the sustainable event output rate ($\sim 1 \text{ kHz}$). Thus the CMS detector implements a sophisticated two-level trigger architecture composed of 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 τ 's (τ_h). 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.

2. The Level-1 τ_h trigger

The L1 τ_h trigger algorithm targets hadronically decaying τ '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 τ_h leptons with $p_T > 32 \text{ GeV}$ and $|\eta| < 2.1$ targeting the Higgs decay products.

The challenge of triggering on hadronically decaying τ 's is the presence of multiple clusters arising from the multiple prong decay. The identification of the τ_h energy deposits is done through dynamic clustering to target the reconstruction of these secondary clusters. The energy of the τ_h candidate is calibrated to improve its scale and resolution. Isolation criterion is applied in order to reject quark and gluon background, while pileup effects throughout the detector are estimated and subtracted.

The L1 τ_h trigger performance has been assessed for data taken in 2017 [2]. The efficiency is evaluated for τ_h 's used to seed the double- τ_h HLT and is computed per single-leg through the tag-and-probe method, as a function of the offline-reconstructed τ_h transverse momentum. The L1 trigger efficiency for isolated τ_h seeds for different L1 thresholds can be found in Fig.1. A 90% efficiency is reached at around 50 GeV, the threshold used in the $H \rightarrow \tau_h \tau_h$ analysis. The integrated L1 selection efficiency for isolated τ_h seeds as a function of the pileup (i.e. number of vertices) is presented in Fig.2. The

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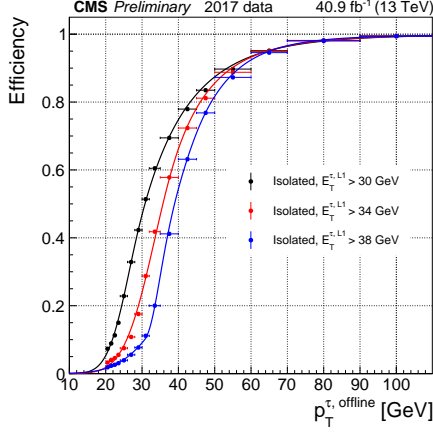


Figure 1: L1 trigger efficiency of isolated τ_h seeds (i.e. requiring the L1 τ_h candidate to pass a cut on its isolation transverse energy) as a function of the offline reconstructed transverse momentum $p_T^{\tau,offline}$ for different L1 thresholds.

algorithm shows stable pileup resilience, with 90% efficiency maintained up to 60 interactions per bunch crossing.

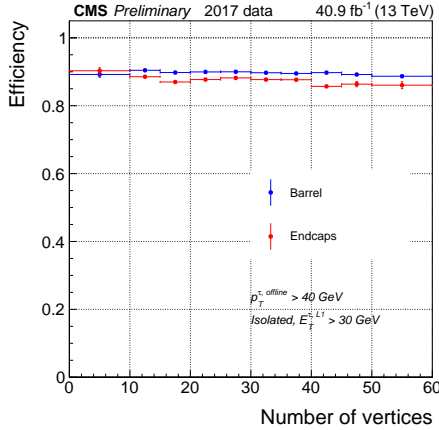


Figure 2: Integrated L1 selection efficiency for isolated τ_h seeds with a L1 threshold of $E_T^{L1} > 30$ GeV matched to an offline-reconstructed τ_h with $p_T^{\tau,offline} > 40$ GeV, as a function of pileup for the barrel ($|\eta| < 1.305$) and endcaps ($|\eta| > 1.479$).

3. The L1 Vector Boson Fusion trigger

The VBF process contributes as $\sim 10\%$ to the Higgs boson production and has a very characteristic signature, with 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 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 $m_{jj}^{L1} >$

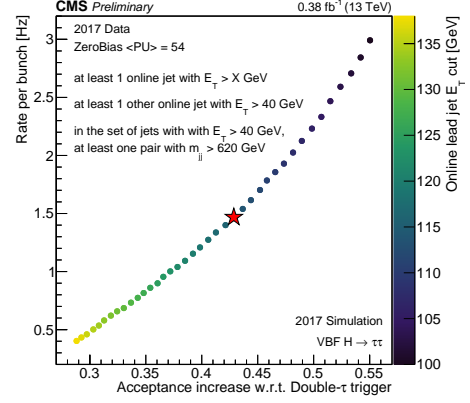


Figure 3: In this figure, the VBF trigger is defined with $Y = 40$ GeV and $Z = 620$ GeV, while X is varied. The net increase of signal events and the rate for the VBF trigger is estimated as function of the X cut. The star corresponds to the configuration in 2017.

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 *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.

4. Conclusions

During Run II, CMS has benefited from a new L1-trigger architecture that enabled the design of high performance τ_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- τ trigger has allowed to reduce significantly the rate and improve the signal efficiency while keeping low p_T thresholds on the Higgs boson decays to τ_h 's.

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