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The ATLAS Tau Trigger Performance during LHC Run 1 and Prospects for Run 2

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Abstract

The ATLAS tau trigger is designed to select the hadronic decays of tau leptons. Tau leptons play an important role in Standard Model (SM) physics, such as in Higgs boson decays. Tau leptons are also important in searches for beyond the SM (BSM) scenarios, such as supersymmetry, where they are often produced preferentially. During the 2010-2012 LHC run (Run 1), tau triggers were implemented and used successfully in ATLAS, contributing to several important results such as the evidence for $H \to \tau\tau$. For the 2015 LHC run (Run 2), the LHC will be upgraded. Due to the energy increase, the cross sections for SM processes are expected to get much larger. Additionally, the number of overlapping interactions per bunch crossing (pile-up) is expected to increase significantly. It will therefore be challenging to control trigger rates while keeping interesting physics events. This document summarizes the tau trigger performance in Run 1 and its prospects for Run 2.

Keywords: ATLAS, tau trigger, performance, LHC Run 2

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1. Introduction

Tau leptons are the heaviest known leptons, with a mass of 1.78 GeV/c^2. Due to their large mass, the tau leptons are not only important in SM precision measurements, but also in searches for BSM scenarios.

Tau leptons have a short life time (2.9×10^{-13}s), and thus a short decay length ($c\tau = 87\mu$m). Therefore, tau leptons decay within the beampipe and can only be identified via their decay products. Tau lepton decays can be classified in two categories: leptonic decays and hadronic decays, in 35% and 65% of all cases, respectively. In leptonic decays, taus decay into two neutrinos and either an electron or a muon. Events with leptonically decaying taus ($\tau_{e/\mu}$) can be collected using a muon or electron trigger. Hadronically-decaying taus ($\tau_{\rm had}$) decay into one neutrino, accompanied predominantly by pions, and rarely by kaons.

Information from the tracking and calorimeter subsystems are used in combination in the identification of $\tau_{\rm had}$. In hadronic tau decays, mainly one or three charged pions with zero or one associated neutral pion are present. Their calorimeter showers are collimated along the direction of the tau. The main source of background to the identification of $\tau_{\rm had}$ consists of QCD jets. To distinguish $\tau_{\rm had}$ from QCD jets, requirements are placed on discriminating variables based on the narrow detector signature and the distinct number of tracks.

2. Tau Trigger System in Run 1

The ATLAS [1] trigger system consists of a hardware based Level 1 (L1) and a software-based Level 2 (L2) and event filter (EF). L2 and EF are together referred to as the high level trigger (HLT). The three-level trigger system reduces the initial bunch crossing rate to a feasible rate for disk storage while keeping interesting physics events [2].

At L1, the tau reconstruction is performed based on the energy deposits in the electromagnetic (EM) and hadronic (HAD) calorimeters. These energy deposits are read out in calorimetric towers with a granularity of

$\Delta\eta \times \Delta\phi = 0.1 \times 0.1$. Taus are identified if the uncalibrated sum of the energy deposits in $2{\times}1$ EM towers and $2{\times}2$ HAD towers behind the EM towers exceed a given threshold. An additional isolation requirement can be applied by setting an upper threshold for the energy deposited in a $4{\times}4$ ring surrounding the $2{\times}2$ towers in the EM calorimeter. Isolation requirements can effectively reject QCD jets while maintaining a high-efficiency for selecting $\tau_{\rm had}$. The position of the L1 energy deposit is defined as a region of interest (RoI).

At L2, in addition to calorimeter information, tracks are reconstructed in the RoI with the full detector granularity. Due to the lack of noise suppression, the energy reconstruction at L2 is coarser than the ones at EF and offline. Identification variables such as track multiplicity and the shape of energy deposits are used to distinguish $\tau_{\rm had}$ from QCD jets.

At EF, calorimeter- and track-based observables are calculated with the full detector information. A multivariate method called a Boosted Decision Tree (BDT) combines the information from all the calculated variables in order to optimize signal efficiency and background rejection. Several pile-up robust variables are used as input to the BDT. The EF algorithm is designed to be very similar to its offline counterpart, in order to achieve optimal selection performance [3].

3. Tau Trigger Performance in Run 1

In Run 1, a various set of tau triggers was implemented and operated to maximize the sensitivity to a large range of physics processes. For example, triggers combining requirements on a single $\tau_{\rm had}$ and missing transverse energy, $E_{\rm T}^{\rm miss}$, were used to select $H^{\pm} \to \tau_{\rm had}\nu$ events, while triggers with requirements on two $\tau_{\rm had}$ were used to select $H \to \tau_{\rm had}\tau_{\rm had}$ events.

The efficiency of the tau trigger was measured on real data using a $Z \to \tau_\mu\tau_{\rm had}$ tag-and-probe method. The presence of an isolated muon coming from a τ_μ decay is required to tag the $Z \to \tau_\mu\tau_{\rm had}$ event while the $\tau_{\rm had}$ is used as an unbiased probe of tau trigger performance. To reject the dominant backgrounds to this process, W+jets and QCD multijet final states, events are selected by requiring that the transverse mass, $m_{\rm T}$[1], is less than 50 GeV and the invariant mass for the muon and $\tau_{\rm had}$ is in the range of 40 GeV to 80 GeV. A similar method is used to measure the efficiency of the offline tau identification algorithms [3].

The tau trigger efficiency is defined as the fraction of tau trigger candidates that pass the trigger decision with respect to the total number of offline tau candidates. Figure 1 shows the measured tau trigger efficiency as a function of the number of primary vertices [4]. The $p_{\rm T}$ thresholds at L1 and EF are 11 and 20 GeV/c, respectively, and a requirement on the isolation was made at L1. The track multiplicity of the candidate was required to be equal or less than three. No significant loss of efficiency was observed in events where a large number of vertices were reconstructed, highlighting the fact that the tau trigger performed with a high efficiency in Run 1, even under high pile-up conditions.

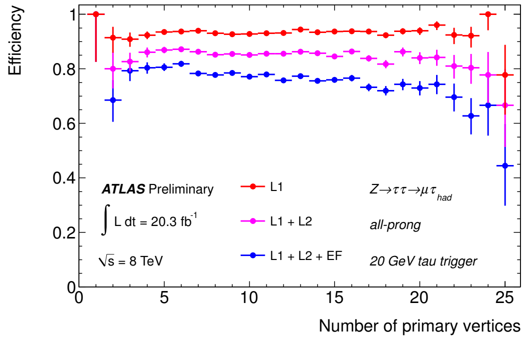

Figure 1: Tau trigger efficiency as a function of the number of primary vertices. L1 and EF p_T thresholds are 11 GeV/c and 20 GeV/c, respectively, and a requirement on the isolation was made at L1 [4].

The efficiency of the tau trigger was also studied in simulated data samples. Figure 2 shows the tau trigger efficiency as a function of offline τ $p_{\rm T}$ in both data and simulation. Good agreement between the data and simulation is observed. A ratio of the efficiency in simulation and data is used to correct the simulated trigger efficiency in physics analyses.

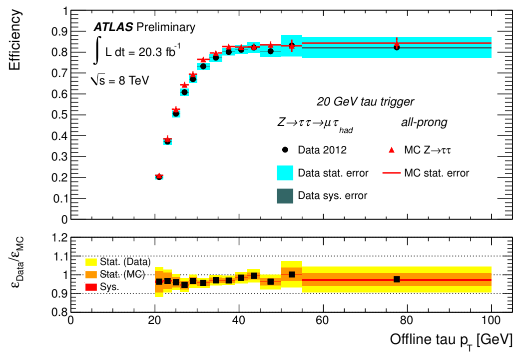

Figure 2: The tau trigger efficiency in both data and simulation as a function of offline τ $p_{\rm T}$ with their ratio [4].

4. Tau Trigger Challenges for Run 2

In Run 2, the LHC will be upgraded to its nominal design energy and luminosity. The cross sections for SM processes are expected to get much larger, while the pile-up is expected to increase significantly. It will

[1] $m_{\rm T} = \sqrt{2p_{\rm T}^{l} \cdot E_{\rm T}^{\rm miss}(1 - \cos\Delta\phi(l, E_{\rm T}^{\rm miss}))}$

be challenging to control the trigger rates while keeping lower p_T thresholds in high pile-up conditions. To handle the trigger rates under Run 2 conditions, several techniques are developed.

The first technique consists in applying topological selections at L1 using the new topological trigger processor. This processor calculates variables combining information from different L1 objects as well as event quantities, such as E_T^{miss}. It will be available from the beginning of Run 2 [5]. In many cases, the event kinematics of signal and backgrounds events are expected to be significantly different. As an example, in the $H \to \tau\tau$ final state, the dominant QCD multijet background produces fake τ_{had} candidates that are more angularly separated than the τ_{had} produced in signal events. These background events can thus be effectively suppressed by applying a topological requirement on the pseudorapidity, $\Delta\eta$, and the azimuthal angle, $\Delta\phi$, between the two L1 tau candidates (Figure 3). It is therefore possible to reduce the rate significantly with little loss in signal efficiency.

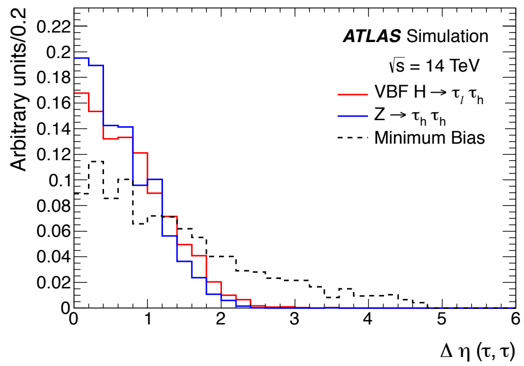

Figure 3: $\Delta\eta$ between the two L1 tau candidates. $\Delta\eta$ in signal event (red and blue) tends to be smaller than QCD jets (dashed line) [5].

The second technique consists in using the topological clustering algorithm at the beginning of the HLT. In Run 1, the energy of L2 tau candidates was calculated using the raw sum of the energy in calorimeter cells. Due to the lack of noise suppression, the energy resolution at L2 was poor, and consequently lead to some efficiency loss in the trigger turn-on region. For Run 2, the energy resolution is expected to improve greatly due to the use of the topological clustering algorithm. This will allow to recover the corresponding efficiency loss observed in Run 1.

The third technique consists in using the Fast Tracker (FTK) [6], which will be available in the barrel region ($|\eta| < 1.1$) in 2015, and will offer full inner detector coverage in 2016. The FTK can reconstruct all tracks with $p_T > 1$ GeV/c at the beginning of the HLT ($\sim 100\mu s$). Track-based variables are very efficient at discriminating τ_{had} from backgrounds. The extra background rejection obtained by requiring that the FTK track multiplicity in the isolation region is less than or equal to 2 allows to lower the p_T requirements on the candidates, in comparison to the case when only calorimeter information is used to obtain rejection (Figure 4 [7]). Furthermore, the FTK can provide primary vertex information. By applying corrections based on the number of primary vertices, the tau identification is expected to be more robust against pile-up.

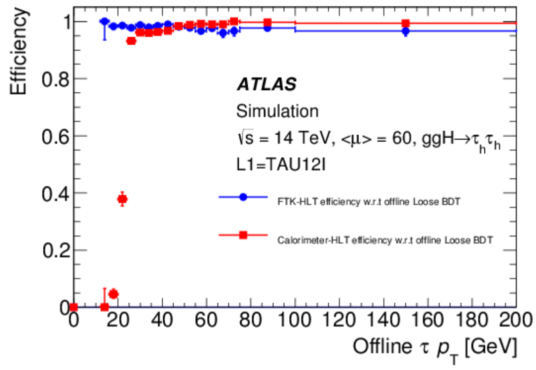

Figure 4: Tau trigger efficiency as a function of offline τ p_T when applying the FTK selection (blue) and calorimeter clusters selection (red) at the beginning of HLT [7].

5. Conclusion

In this document the ATLAS tau trigger performance in Run 1 and prospects for Run 2 are summarized. In Run 1, τ_{had} candidates were effectively identified at trigger level even under the highest pile-up conditions. The efficient data taking led to several important results such as the evidence for $H \to \tau\tau$ [8]. Since the LHC will be upgraded to higher energy and higher luminosity, it will be more challenging to control trigger rates while keeping the tau trigger efficiency high. Several techniques are developed and they are showing promising results for future data taking.

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