Triggering on hadronic Tau Decays in ATLAS: Algorithms and Performance

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Abstract. Hadronic tau decays play a crucial role in Standard Model measurements as well as in the search for physics beyond the Standard Model by the ATLAS experiment at the Large Hadron Collider (LHC). However, hadronic tau decays are difficult to identify and trigger on due to their resemblance to QCD jets. Given the large production cross section of QCD processes, designing and operating a trigger system with the capability to efficiently select hadronic tau decays, while maintaining the rate within the bandwidth limits, is a challenge. This contribution summarizes the algorithms and performance of the ATLAS tau trigger system during the 2011 data taking period. The use of resources and implementation of trigger algorithms in the ATLAS trigger architecture is shown in detail. Moreover, comparisons of data and simulation results, studies of the correlation of the variable definitions at different trigger stages as well as efficiency versus rate analyses are the key elements to describe the performance of the tau trigger. Finally, in light of the vast statistics collected in 2011, future prospects for triggering on hadronic tau decays in the 2012 data taking of increased instantaneous luminosity are presented.

1. Introduction

Tau leptons, τ's, play a crucial role in many physics processes investigated by the ATLAS experiment [1] at the Large Hadron Collider (LHC), within the Standard Model (SM) and beyond. τ leptons have a branching ratio into hadronic decay modes of approximately 65% and 35% into leptonic (electron or muon accompanied by two neutrinos) modes. As the leptonically decaying τ's cannot be distinguished from prompt leptons, only hadronically decaying τ's\(^1\) are considered from now on. The main hadronic decay channels contain one or three charged hadrons, most of the times pions and a small amount of kaons, with additional neutral pions or kaons, as well as a neutrino. Thus, the hadronically decaying τ is characterized by one or three charged tracks and narrow energy deposits in the electromagnetic (EM) and hadronic (HAD) calorimeter. These characteristic decay patterns are utilized in the trigger as well as in the offline τ identification (ID), as for example application of isolation criteria, which efficiently discriminate τ\(^h\) decays from background jets, most of the times stemming from QCD multi-jet processes. Examples of analyses using the hadronic τ trigger are listed in Table 1.

2. The ATLAS Tau Trigger

The ATLAS trigger system [2] has the important task to reduce the collision rate of 40 MHz, as delivered by the LHC, to 400 Hz, which is the rate that can be sustained by offline reconstruction

\(^1\) hadronically decaying τ's here are denoted by τ\(^h\), unless stated otherwise this implies τ\(^h\) and τ\(^-\)
Table 1. Analyses in ATLAS using the hadronic $\tau$ trigger combined with electron, $e$, muon, $\mu$, and missing transverse energy, $E_{T}^{\text{miss}}$, trigger.

| Trigger                  | Channel                  | Analysis & Documentation         |
|--------------------------|--------------------------|----------------------------------|
| $\tau_{h}$ and $\tau_{h}+e/\mu$ | $H \rightarrow \tau_{e/\mu/h}\tau_{h}$ | Higgs search [3]                |
| $\tau_{h}+E_{T}^{\text{miss}}$   | $H^{\pm} \rightarrow \tau_{h}\nu$ | charged Higgs search [4]         |
| $\tau_{h}+E_{T}^{\text{miss}}$   | $W^{\pm} \rightarrow \tau_{h}\nu$ | $\tau$ polarization measurement [5] |
|                           | $\tau_{h}+e/\mu$         | cross section measurement [6]    |
| $\tau_{h}+e/\mu$         | $Z \rightarrow \tau_{e/\mu}\tau_{h}$ | cross section measurement [7]    |

of the data (additionally the same order of rate is written out directly to mass storage for later reconstruction), while maintaining a high signal selection efficiency. In ATLAS a three level trigger architecture is used to achieve this goal. The level-1 trigger (L1) is a hardware-based system which utilizes custom build fast electronics, while the high level trigger (HLT), consisting of level-2 (L2) and Event Filter (EF) trigger, is software-based and carries out its calculations on dedicated processing farms [8].

2.1. Level-1 Trigger
The L1 calorimeter trigger uses information from the EM and HAD calorimeter systems. These so-called trigger towers, with sizes of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$, illustrated in Figure 1, are combinations of several calorimeter cells. Depending on the position within the detector the number of cells merged into a trigger tower is varied. The $\tau_{h}$ candidate’s energy is reconstructed by summing the deposits in the highest energy adjacent pair of $2 \times 1$ EM towers with the energy deposited in the $2 \times 2$ HAD towers behind the EM layer. In addition the isolation energy, defined by the summed energy deposited in an EM ring of $4 \times 4$ around the core region of $2 \times 2$ towers, is calculated.

![Figure 1.](image)

On this level the $\tau_{h}$ lepton candidate is identified by its transverse energy, $E_{T}$, which is in accordance with the trigger items name, e.g. for $L1\_TAU20$ an $E_{T}$ threshold strictly above 20 GeV has to be fulfilled. Further an isolation requirement denoted by an "i" in the trigger item’s name can be applied, by demanding an isolation $E_{T}$ lower than a certain threshold to
further reduce the L1 output rate. During the L1 processing the so-called region-of-interest (RoI) is defined, this is a spacial $(\Delta \eta \times \Delta \phi)$ region which center is defined by the L1 object, and passed to the Higher Level Trigger (HLT), in case the event gets accepted.

2.2. Higher Level Trigger

2.2.1. Level-2 Trigger

Subsequently the L2 system accesses the full calorimeter granularity and performs a track reconstruction within the RoI(s). Discriminating variables used for $\tau_h$ ID are calculated based on track and calorimeter information. Requirements on these variables determine whether the event will pass this level of the $\tau_h$ trigger. Figure 2 displays a comparison of data to Monte Carlo simulation (MC) of number of reconstructed tracks at L2, as well as the difference of L2 $p_T$ to the offline reconstruction with data taken in 2011. The requirements can be adjusted to optimize signal efficiency against background rejection, while considering the output rate limits of the L2 $\tau_h$ trigger.

![Figure 2](image)

**Figure 2.** Here the events are selected by applying a tag and probe selection in $Z \rightarrow \tau \tau \rightarrow \mu \tau_h$ final state. It closely follows the $\tau_h$ ID efficiency measurement described in [9]. The left figure presents the number of tracks of L2 $\tau_h$’s, while the right figure shows the resolution of the L2 $\tau_h$ $p_T$ with respect to the $p_T$ of offline $\tau_h$ candidates [10]. The combination of systematic uncertainties is shown by the bands.

2.2.2. Event Filter Trigger

The last trigger step is performed by the EF, which has access to the complete event data. Since 2012 the Event Filter trigger utilizes the multivariate $\tau_h$ ID algorithms, which are Boosted Decision Tree (BDT)- and Log Likelihood (LLH)-based, as applied in the offline $\tau_h$ ID [9].

3. ATLAS Tau Trigger for 2012

3.1. Performance and Efficiency of multivariate-based Tau Triggers

Figure 3 shows the signal efficiency, defined with respect to the offline $\tau_h$ candidates and background rejection with respect to jets from simulated QCD Events, of the two ID algorithms for 1-prong and multi-prong $\tau_h$’s. Physics analyses using a certain trigger must know the trigger efficiency for data and MC. The definition of the trigger efficiency is the probability of an offline reconstructed $\tau_h$ also passing the $\tau_h$ trigger in question. A data-driven tag and probe analysis based on the selection [7] is used to get a handle on $\tau_h$ probes from data. The isolated muon, $\mu$, in the $Z \rightarrow \tau \tau \rightarrow \mu \tau_h$ decay channel is used as a tag for the process. A reduction of the $W + jets$ and QCD backgrounds is achieved by imposing further restrictions on the event, as for
Figure 3. Performance of the multivariate-based $\tau_h$ triggers at EF. The signal efficiency is defined with respect to the offline identified $\tau_h$ candidates matched to the $\tau_h$’s produced on generator level and the background rejection with respect to a QCD jet sample. Multi-prong $\tau_h$ trigger candidates for BDT- and LLH-based triggers are displayed. The trigger decision is optimized to be 85% and 80% with respect to the offline candidates for 1-prong (left) and multi-prong (right), respectively [10]. The tested Event Filter items had to pass L1_TAU8 and no requirement at L2 (L2_noCut) was required.

example a requirement on transverse mass$^2$, cuts on the angles between the selected objects and the missing $E_T$, $E_T^{\text{miss}}$, opposite charge of the selected $\mu$ and $\tau_h$, as well as the constraint on the selected candidate pair’s invariant mass to lie within an optimized selection range. The trigger efficiency is measured as a function of the offline $\tau_h$’s transverse momentum, $p_T$, as presented in Figure 4, which shows the efficiencies of the new multivariate-based EF_tau20_medium$^3$ trigger.

3.2. Tau Trigger Pileup Stability
Studies of the $\tau_h$ trigger algorithms and selections used in 2011 with respect to pileup robustness showed a degradation of the efficiency with increasing pileup conditions. This effect is demonstrated in the left plot of Figure 5, illustrating the BDT based EF_tau20_medium trigger efficiency, with respect to the offline medium BDT ID, as a function of numbers of vertices, measured using the tag and probe analysis with events collected in 2011. To recover this pileup induced loss of efficiency several innovations were realized in the $\tau_h$ trigger algorithms. In 2012 a smaller calorimeter cone size of 0.2 compared to 0.4 in 2011 and the implementation of a selection of tracks originating from the same interaction point as the highest $p_T$ track (all tracks were considered before) provide robustness against pileup. The effect of introducing this modified selection in the $\tau_h$ trigger is presented in right plot of Figure 5, which thereby provides a prospect for 2012 $\tau_h$ trigger efficiency, using the 2011 data.

3.3. Tau Trigger Rate Control for 2012
A trigger has to balance between maintaining the rate within the bandwidth limits and high signal selection efficiencies for analyses. Keeping the output rates under control is a crucial part of efficient and stable data acquisition. Figure 6 presents the trigger rates as a function of the instantaneous luminosity for combined $\tau_h$ triggers. Here as representative cases a di-$\tau_h$,

\[ m_T \equiv \sqrt{2p_T \cdot E_T^{\text{miss}} + (1 - \cos \Delta \phi(l, E_T^{\text{miss}}))} \]

$^2$ The term EF_tau20_medium implies a 20 GeV requirement on the $E_T$ at EF and medium selections on the shower shape variables.
Figure 4. Expected efficiency in 2012 with respect to the offline identified $\tau_h$ candidates as a function of the offline $\tau_h p_T$. The multivariate-based EF$_{\text{tau20_medium}}$ trigger is rerun on the full 2011 dataset from unbiased $Z \rightarrow \tau\tau \rightarrow \mu\tau_h$ events, collected by the tag and probe method. Selections applied at EF are based on multivariate techniques, the left figure is based on the BDT method, while the right uses the LLH method. In 2012, the BDT-based $\tau_h$ triggers will be used as the baseline, this is the reason why the label in the left figure states EF$_{\text{tau20_medium}}$ [10].

Figure 5. Left: Efficiency of the BDT based EF$_{\text{tau20_medium}}$ trigger with respect to the offline BDT identified $\tau_h$ candidates as a function of number of vertices measured in 2011. Right: Expected efficiency in 2012 with respect to the offline BDT identified $\tau_h$ candidates as a function of number of vertices. In 2012 a smaller calorimeter cone size than in 2011 and the implementation of a selection of tracks originating from the same interaction point as the highest $p_T$ track (all tracks were considered before) provide robustness against pileup. The thus improved BDT EF$_{\text{tau20_medium}}$ trigger for 2012 was rerun on the full 2011 dataset [9, 10].

and combinations with electron ($_e$), with muon ($_\mu$) and $E_T^{\text{miss}}$ ($_{xe}$) triggers were chosen. The numerical figures in the name of each trigger chain correspond to the $E_T$ or $p_T$ threshold required at EF.

4. Prospects for this Year
With the recently implemented improvements we expect to see improved performance of hadronic tau trigger in 2012.
Figure 6. The trigger rates as a function of instantaneous luminosity for combined $\tau_h$ triggers are shown [10].

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