The ATLAS hadronic tau trigger

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Abstract. The extensive tau physics programs of the ATLAS experiment relies heavily on trigger to select hadronic decays of tau lepton. Such a trigger is implemented in ATLAS to efficiently collect signal events, while keeping the rate of multi-jet background within the allowed bandwidth. This contribution summarizes the performance of the ATLAS hadronic tau trigger system during 2011 data taking period and improvements implemented for the 2012 data collection.

1. Introduction
Hadronic tau decays play a crucial role in precisions measurements of Standard Model (SM) processes as well as in the searches for physics beyond the SM e.g. through searches for the Higgs boson and supersymmetric and exotic ($W'$ and $Z'$) particles.

Due to its short lifetime ($c\tau = 87.11 \mu m$), the tau lepton decays inside the beam pipe. The identification of taus is, therefore, done through their decay products inside the detector. The tau decays into two neutrinos and an electron or muon 35% of the time, while 65% of its decays involve a neutrino and prompt charged hadrons, mostly pions. A dedicated tau trigger has been designed and implemented at the ATLAS experiment [1] to select events where a tau decays into one or more hadrons. A decay like this results in a hadronic jet which is characterized by the presence of a well collimated calorimeter cluster with only a small number of associated tracks.

It is challenging to keep the rates for these triggers low due to the high production rate of multi-jet events. Nevertheless it is advantageous to implement tau triggers to increase the sensitivity of searches for new physics.

2. The ATLAS trigger system
The ATLAS trigger system [2] is divided into the hardware-based level 1 (L1) and the software-based level 2 (L2) and event filter (EF). L2 and EF are referred to together as the high level trigger (HLT). The L1 trigger identifies regions-of-interest (RoI) using the information from calorimeter and muon systems. The decision time at L1 is $\sim 2 \mu s$. L2 takes these RoIs as input and refines the object identification using the information from all subsystems. The average latency at L2 is $\sim 40$ ms. In the EF, algorithms similar to the offline reconstruction are used to select interesting events with an average latency of $\sim 4$s.

3. The ATLAS tau trigger
The tau trigger is designed to select hadronic decays of the tau lepton, which are characterized by the presence of one or three charged pions accompanied by a neutrino and possibly neutral pions.
At L1, the tau trigger uses the electromagnetic (EM) and hadronic (HAD) calorimeter trigger towers to calculate the energy in a core and an isolation region outside the core. The trigger towers have a granularity of $\Delta \eta \times \Delta \phi = 0.1 \times 0.1$. The core region is defined as the two-by-two trigger tower region of $\Delta \eta \times \Delta \phi = 0.2 \times 0.2$. The isolation region is defined as a four-by-four trigger tower region around the core subtracting the two-by-two region in the center. At HLT, selection criteria are applied using tracking and calorimeter-based information. This takes advantage of the narrow energy deposition and low track multiplicity to discriminate taus from the multi-jet background. The selections at HLT are separately optimized for tau decays with one (1-prong) or several (multi-prong) charged particles. EF uses more refined algorithms, which are similar to the offline tau reconstruction algorithms.

4. Performance of the ATLAS tau trigger in 2011

This section describes the performance of the tau trigger using a tag-and-probe method in $Z \rightarrow \tau_\mu\tau_\nu$ events, where one tau decaying into muon is used as the tag, while the hadronically decaying tau is used as the probe. The trigger efficiency is measured w.r.t to the taus identified by the offline algorithms [3]. Figure 1 shows the efficiency of the tau20_medium1 trigger, with respect to the offline identified tau candidates, measured using a tag and probe analysis with $Z \rightarrow \tau_\mu\tau_\nu$ events.

![Figure 1](image1.jpg)

**Figure 1.** Efficiency of the tau20_medium1 trigger, with respect to the offline identified tau candidates, measured using a tag and probe analysis with $Z \rightarrow \tau_\mu\tau_\nu$ events.

![Figure 2](image2.jpg)

**Figure 2.** Efficiency of tau20_medium with respect to the offline identified tau candidates as a function of number of vertices measured in 2011.

The ratio of the efficiency in data and Monte Carlo (MC) simulation is also shown, demonstrating that the performance of the trigger in data and MC agree. The term tau20_medium1 implies a 20 GeV requirement on the transverse energy, medium selections on the shower shape variables and strict requirement on the number of tracks for an EF tau candidate. Figure 2 shows the performance of a trigger, with 20 GeV threshold at EF but less stringent requirement on the number of tracks, as a function of number of vertices measured in data. The number of primary vertices is a measure of the overlapping interactions in the same bunch crossing (BC) which is also known as pile-up. At L1, the trigger efficiency shows no dependence on pile-up while at L2 and EF efficiencies decrease with increasing number of pile-up interactions. This is mainly due to two reasons. Firstly, the shower shape variables used at the trigger level in 2011 were highly pile-up dependent with no procedure implemented to correct for pile-up dependence. Secondly, the optimization of selection requirements at the HLT for the shower shape variables was performed using only the MC samples with fewer number of pile-up interactions than observed in data.
5. Improvements in tau trigger algorithms for 2012

In 2011, the average number of collisions per BC was 10-12 corresponding to a peak instantaneous luminosity of $3.65 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$ at $\sqrt{s} = 7 \text{ TeV}$ and 50 ns bunch spacing. While in 2012, the peak instantaneous luminosity of $7 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$ at $\sqrt{s} = 8 \text{ TeV}$ and 50 ns bunch spacing would be expected. This would result in an average of $\sim 28$ pile-up events while the peak value could be up to 35. A large number of improvements were added to the tau trigger algorithms and selection criteria before the start of data taking in 2012. This is to avoid degradation in the performance as a function of pile-up.

- At HLT, the energies of the cells in a cone of radius $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$ around the cluster direction are summed up to calculate the total energy of the cluster, after applying noise suppression. The value of $\Delta R$ will be changed from 0.4 to 0.2.
- Shower shape variables, such as the energy weighted radius in the EM calorimeter will be removed from the set of selection variables.
- New variables including the ratio of the energy in a cone of radius 0.1 to that in 0.2, the $p_T$ weighted distance of tracks from the cluster direction, and the ratio of tau cluster energy to the $p_T$ of the leading track will be added to the list of selection variables.

![Figure 3](image-url)  
**Figure 3.** Average value of SumPtRatio at L2 as a function of the average number of interactions per BC in $Z \rightarrow \tau \tau$ simulated events.

![Figure 4](image-url)  
**Figure 4.** $\Delta Z_0$ distribution as observed in 2012 (8 TeV) data, with an average value of eighteen interactions per BC. A Lorentzian function is fitted to the distribution and the quoted value of $\sigma$ integrates 68% of the area of the central peak.

- To select tracks associated with the tau candidate a requirement will be applied on the $|\Delta Z_0|$ of each track. The $|\Delta Z_0|$ of a track associated with trigger object is defined as the longitudinal coordinate difference with respect to the leading track. Large values of $|\Delta Z_0|$ correspond to tracks coming from additional vertices created in overlapping interactions. Figure 3 shows the average SumPtRatio at L2 as a function of the average number of interactions per BC in simulated $Z \rightarrow \tau \tau$ events. The SumPtRatio is the ratio of the scalar sum of the $p_T$ of all tracks in the isolation region, defined as annulus between $0.1 < \Delta R < 0.3$ with respect to the leading track in the RoI, to the scalar sum of the $p_T$ of all tracks in the core region, defined as the $\Delta R < 0.1$ cone around the leading track. A requirement of 2mm on the $|\Delta Z_0|$ provides robustness against pile-up.

- Figure 4 shows the $\Delta Z_0$ distribution, as observed in 2012 data at $\sqrt{s} = 8 \text{ TeV}$ with an
average value of eighteen interactions per BC. This distribution justifies the requirement of 2 mm with no additional loss of signal events in data due to resolution effects.

- At EF, the simple cut based selections will be replaced by the Multivariate (MV) algorithms known as Boosted Decision Tree (BDT) and Log Likelihood (LLH). A decision tree is a structure which defines a recursive sequence of cuts on multiple variables which separate signal from background. The averaging technique known as “boosting” is used to deal with statistical fluctuations. The likelihood function, for signal and background is defined as the product of the one-dimensional probability density functions, of each identification variable. A set of pile-up robust variables is used as input to the MV algorithms.

Figures 5 and 6 demonstrate the expected performance of the MV based tau triggers (BDT and LLH) at EF in simulated events for one-prong and multi-prong taus, respectively. Signal MC samples for \(Z \rightarrow \tau \tau\), \(W \rightarrow \tau \nu\) and \(Z' \rightarrow \tau \tau\) were combined to evaluate the performance of MV algorithms. The signal efficiency is defined with respect to the offline identified tau candidates and the background rejection is evaluated using simulated multi-jet events. The operational point, along the curves, for a set of medium selections is chosen to have 85% and 80% signal efficiency for one-prong and multi-prong taus, respectively.

![Figure 5. Performance of the multivariate based tau triggers for one prong taus at EF.](image)

![Figure 6. Performance of the multivariate based tau triggers for multi-prong taus at EF.](image)

6. Performance of the ATLAS tau trigger in 2012 Data

ATLAS has been collecting data with the latest and improved version of the tau trigger since May 2012. The performance of the tau trigger has been verified in data. Figure 7 shows the efficiency of tau20,medium1 trigger, with respect to the offline tau candidates identified by the BDT algorithm, as a function of number of vertices measured in 2012 data while Figure 8 shows the same as a function of the \(p_T\) of the offline tau candidate. The trigger efficiency is measured using a tag and probe analysis with \(Z \rightarrow \tau \mu \tau\) events following the offline tau identification efficiency measurement [3]. Comparing Fig. 2 and Fig. 7 one can see that with the new selections, the loss of efficiency as a function of pile-up has been recovered to a large extent.

7. The tau trigger thresholds in 2012

In order to make maximum use of the data collected by the tau trigger, it is important to apply loose selections and keep the \(p_T\) thresholds at L2 and EF lower than those used in the offline analyses. Although the LHC is expected to deliver peak luminosity which is a factor of two...
higher than the one delivered in 2011, yet due to the improvements added to the tau trigger algorithms for 2012, it is possible to keep the $p_T$ thresholds at HLT similar to those used in the 2011 run. Furthermore, combining the tau trigger with other triggers such as electrons, muons and missing transverse energy (MET) helps with controlling the rates while keeping the threshold low. Table 1 shows a list of single and combined tau triggers along with the thresholds at EF. The combinations and thresholds are optimized for a specific analysis as shown in the first column of the table.

### Table 1. Single and combined tau triggers being used in 2012.

| Process | Trigger | $p_T(\tau)$ at EF [GeV] | MET > [GeV] |
|---------|---------|-------------------------|-------------|
| $H^+ \rightarrow \tau_h \nu$ | $\tau + \text{MET}$ | 29 | > 40 |
| $H^0(Z^0) \rightarrow \tau_h \tau_{e,\mu}$ | $\tau + e$ | 20 | $p_T(e) > 18$ |
| | $\tau + \mu$ | 20 | $p_T(\mu) > 15$ |
| $H^0_{\text{MSSM}} \rightarrow \tau_h \tau_h$ | $\tau + \tau$ | 38, 38 |
| $H^0_{\text{SM}} \rightarrow \tau_h \tau_h$ | $\tau + \tau$ | 29, 20 |
| $Z' \rightarrow \tau_h \tau_h$ | $\tau + \tau$ | 100, 70 |
| $W' \rightarrow \tau_h \nu$ | $\tau$ | 115 |

### 8. Conclusions

The ATLAS tau trigger has performed remarkably well over the 2011 LHC run, collecting data for physics analysis [4, 5, 6, 7], monitoring and calibration purposes. The efficiency of the trigger has been analyzed with tag-and-probe methods showing good agreement between data and MC simulations. Pile-up robust selections have been implemented for the 2012 run in order to recover...
the efficiency loss observed in 2011 data. The performance of newly implemented algorithms has been verified in data collected in 2012 at $\sqrt{s} = 8$ TeV.

References

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