The ATLAS Hadronic Tau Trigger

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Abstract. During the 2012 run, the Large Hadron Collider (LHC) reached instantaneous luminosities of nearly $10^{34} \text{cm}^{-2}\text{s}^{-1}$, with bunch crossings occurring every 50 ns. In this difficult environment of several overlapping interactions per bunch crossing (pile-up), the trigger system of the ATLAS detector has the task of reducing the event rate from 20 MHz to a few hundred Hz while keeping the most interesting physics events. Being the heaviest of all leptons, the tau lepton plays an important role in many physics processes. The ability to trigger on events containing hadronically decaying taus is therefore of special interest. This paper summarizes the concept of the ATLAS tau trigger and the improvements made in 2012. Furthermore the performance of the triggers including efficiency and rate measurements are presented and an outlook towards future developments of the tau trigger algorithms is given.

1. Introduction

As a third generation particle with a mass of 1.777 GeV/c$^2$, the tau lepton is not only interesting for precise measurements of the Standard Model of particle physics (SM) but also for searches of physics beyond the Standard Model (BSM). Specifically, the measurements of the Higgs couplings to fermions rely on the $H \rightarrow \tau \tau$ decay [1] to answer the question if the Higgs properties agree with the predictions of the SM. The availability of a trigger for hadronic tau decays enhances the sensitivity to $H \rightarrow \tau \tau$ decays as well as to other processes with tau leptons in the final state. Since the branching ratio of the $H \rightarrow \tau \tau$ decay is relatively small the tau trigger has to have a large background rejection power while keeping a good acceptance for real taus.

Tauplets have a short lifetime of $2.9 \cdot 10^{-13}$ s and a decay length of 87 $\mu$m. Therefore they decay already within the beam pipe and have to be identified via their decay products. In 35% of the cases a tau decays leptonically into an electron or a muon and neutrinos. In the ATLAS experiment [2] at the LHC, these decays are covered by the electron and muon triggers while the hadronic tau trigger aims to trigger the remaining 65% of the taus which are decaying hadronically ($\tau_{\text{had}}$).

The main background of these hadronically decaying taus are quark or gluon jets (QCD) since they both produce particle showers in the electromagnetic and hadronic calorimeter. To differentiate between these particle showers the inner structure of the signatures has to be studied. While QCD jets contain a larger number of tracks coming from charged hadrons (see figure 1), the $\tau_{\text{had}}$ decays mainly into one or three charged pions, some neutral pions and a neutrino. Therefore a typical $\tau_{\text{had}}$ signature consists of one or three tracks (called one-prong and multi-prong) in the inner detector which form a narrow collimated jet inside the calorimeter (see figure 2). Compared to QCD jets almost no energy is deposited in the calorimeter cells.
around this inner cone. Thus an isolation requirement can be added to distinguish the real $\tau_{\text{had}}$ signal from the QCD background.

![Figure 1. Typical signature of a QCD jet.](image1)

![Figure 2. Typical signature of a hadronic tau decay.](image2)

2. ATLAS tau trigger

To record events with feasible rate while keeping the most interesting events for physics, three levels of trigger system are employed [3].

The level 1 trigger (L1) is hardware based and uses the information about the energy deposits in the electromagnetic (EM) and hadronic (HAD) calorimeter to identify L1 taus. These energy deposits are read-out in calorimeter towers with a granularity of $\Delta \eta \times \Delta \phi = 0.1 \times 0.1$. A L1 $\tau_{\text{had}}$ is identified if the energy deposit in $2 \times 1$ pairs of EM towers and in the $2 \times 2$ HAD towers lying behind the EM towers is above the threshold given by the trigger item. An additional isolation requirement can be applied by setting an upper threshold for the energy deposited in a $4 \times 4$ EM ring around the $2 \times 2$ core region. The cone centered at the position of a $\tau_{\text{had}}$ candidate which satisfies the L1 requirements is called region of interest (RoI) and given to the next trigger level.

The level 2 trigger (L2) is software based and uses the full detector granularity within the RoI's given by the L1 trigger. In addition to the energy information coming from the calorimeter, the inner detector is used to get reconstructed tracks in the RoI's. To distinguish between QCD jets and $\tau_{\text{had}}$, discriminating variables such as the track multiplicity, the narrowness of the decay products and the shape of the particle showers are used [4].

The Event Filter (EF) is the final software based trigger level and uses the full detector information. The algorithms are very similar to the offline reconstruction algorithms [5] to achieve optimal background rejection.

![Figure 3. The ratio of the scalar sum of the $p_T$ of all the tracks in the isolation region to the scalar sum of the $p_T$ of all the tracks in the core region is one of the discriminating L2 variables. It is shown as a function of the average number of interactions per bunch crossing. Pile-up dependence is avoided when only tracks with $-2 \text{ mm} < \Delta z < 2 \text{ mm}$ are considered.](image3)

During the 2012 run, due to the increase of the center-of-mass energy to 8 TeV and the doubled instantaneous luminosity, a much higher number of pileup events (multiple interactions per bunch crossing) was expected compared to the 7 TeV LHC operation. Such new conditions...
are very challenging for the trigger system, therefore several changes of the trigger algorithms have been implemented in 2012 to make the trigger performance independent on the number of pile-up events.

For the L2 tau trigger, the size of the cone in which the decay products lie was reduced from $\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2} < 0.4$ to 0.2. Furthermore an additional threshold of $|\Delta z_0| < 2$ mm is introduced, which is the distance along the z-axis$^1$ between the candidate track under consideration and the track with the highest transverse momentum ($p_T$) (see figure 3).

Since 2012 multivariate algorithms (MV) such as Log-Likelihood (LLH) and Boosted Decision Trees (BDT) are used instead of threshold based selections [4] at EF level. They take several pile-up robust variables as input and were optimized for a working point of 80% (for one-prong taus) and 85% (for multi-prong taus) of signal efficiency. Due to a $\sim$60% higher background rejection for multi-prong taus, the BDT algorithm was chosen over the LLH algorithm for online running.

3. Tau trigger performance 2012

During the 2012 data taking period, the tau trigger was operated with different $p_T$ thresholds and its performance studied. The trigger efficiency, defined as the probability of a reconstructed and identified offline $\tau_{\text{had}}$ candidate to pass the trigger, was measured on real data using the tag-and-probe method applied to the decay $Z \rightarrow \tau\tau \rightarrow \mu\nu\tau_{\text{had}}$. In this decay the isolated muon is used to tag the process while the hadronically decaying tau can be used to probe the tau trigger performance. Requirements on the transverse mass $m_T^2$, the angle between the objects and the visible mass are further used to reject the main background of W+jets and QCD.

![Figure 4](image1.png) **Figure 4.** The efficiency of the tau trigger with a 20 GeV $p_T$ threshold, an isolation requirement and three or less tracks is plotted against the $p_T$ of the offline $\tau_{\text{had}}$ [7].

![Figure 5](image2.png) **Figure 5.** The efficiency of the tau trigger with a 20 GeV $p_T$ threshold, an isolation requirement and three or less tracks is plotted against the number of primary vertices (pile-up) [7].

Figures 4 and 5 show the efficiency of the tau trigger using a $p_T$ threshold of 20 GeV, a requirement on the calorimeter isolation and three or less tracks. The cumulative efficiency of L1, L2 and EF is plotted against the $p_T$ of the offline $\tau_{\text{had}}$ (figure 4) and the number of primary vertices (pile-up) (figure 5). No significant loss of efficiency in high pile-up events is observed compared to the 2011 trigger where the L2 and EF efficiencies dropped as low as 40% for events with 15 primary vertices. These plots show that the 2012 improvements of the tau trigger algorithms are working very well in reducing the pile-up dependency.

1 In the ATLAS experiment the z-axis is defined as the direction of the beam pipe.

2 $m_T = \sqrt{2p_T^{\tau_{\text{had}}} \cdot E_T^{\text{miss}} (1 - \cos \Delta \phi(\tau_{\text{had}}, E_T^{\text{miss}}))}$, where $E_T^{\text{miss}}$ is the missing transverse energy.
The biggest challenge of an increasing instantaneous luminosity for the trigger system are the high rates. In order to keep the rates constant the easiest solution is increasing the $p_T$ thresholds of the triggers. That leads to a loss of interesting events with low energy taus. In order to prevent the loss of efficiency at low energies while keeping the rates manageable, combinations with different trigger objects (di-$\tau_{\text{had}}$, a $\tau_{\text{had}}$ with a muon, a $\tau_{\text{had}}$ with an electron and a $\tau_{\text{had}}$ with missing transverse energy) were used to identify interesting events in 2012. In table 1 the tau triggers running during the whole 2012 period are shown. For some periods additional triggers with lower thresholds were used.

Table 1. Single and combined tau triggers which run for the whole 2012 data period.

| trigger       | thresholds                                                        |
|--------------|-------------------------------------------------------------------|
| single $\tau_{\text{had}}$ | $\tau_{\text{had}} p_T > 125$ GeV                                |
| di-$\tau_{\text{had}}$     | isolated $\tau_{\text{had}} p_T > 29$ GeV + isolated $\tau_{\text{had}} p_T > 20$ GeV |
| $\tau_{\text{had}} + \mu$   | $\tau_{\text{had}} p_T > 38$ GeV + muon $p_T > 15$ GeV           |
| $\tau_{\text{had}} + e$      | isolated $\tau_{\text{had}} p_T > 20$ GeV + electron $p_T > 18$ GeV |
| $\tau_{\text{had}} + E_T^{\text{miss}}$ | isolated $\tau_{\text{had}} p_T > 29$ GeV + $E_T^{\text{miss}} > 55$ GeV |

In figure 6 the trigger rates for single and combined tau triggers at EF level are shown as a function of the instantaneous luminosity.

Figure 6. The trigger rates for some single and combined tau triggers at EF level which were running in mid 2012 are shown as a function of the instantaneous luminosity [7].

4. Conclusion & Outlook

In this paper the concept of the ATLAS tau trigger and the improvements made in 2012 are summarized. The performance in 2012 shows that the goal to make the tau triggers robust against events with high pile-up has been accomplished successfully. As a consequence of this success, the tau triggers were used by several analyses, including the $H \rightarrow \tau\tau$ analysis [1] (see figure 7).

After the first long shutdown of the LHC the bunch crossing rate is expected to increase by a factor two. Having such a high rate combined with a high instantaneous luminosity, it will be challenging to keep the tau trigger rates low without increasing the thresholds significantly. Improvements could be achieved by using topology information for multi-object triggers at L1.
and using topological energy clustering at an early stage to improve energy resolution. A new fast hardware tracker (FTK) [6] will provide track reconstruction before the L2 trigger, improving level 2 latency and providing prompt information to be used by trigger algorithms.

![Figure 7. This ATLAS event display shows an event candidate for a $H \rightarrow \tau\tau$ decay. It contains two hadronically decaying taus, $E_T^{\text{miss}}$ and an additional jet [1].](image)

References

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