Commissioning of the calorimetry in the ATLAS tau trigger system

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Abstract. Calorimeters are fundamental in the three levels of the ATLAS tau trigger system. The first level trigger uses the electromagnetic and hadronic calorimeters to make its decision. In the High Level Triggers, these systems are also crucial: both the second level trigger and the third level trigger (Event Filter) heavily exploit the calorimeter based information to identify tau leptons decaying hadronically. While the granularity of the first level is coarse, the second and third level triggers have the full detector read-out. This contribution focuses on the commissioning of the calorimetry in the three levels of the tau trigger with real data. Efficiency measurements with respect to tau candidates reconstructed by the offline algorithms, and distributions of calorimeter based tau information reconstructed at trigger level, are compared to the prediction of the Monte Carlo simulation and the trigger performance with first data is assessed.

1. Introduction
ATLAS is one of the two multipurpose detectors in the center of which the LHC collides proton bunches. It is built with a typical collider detector multi-layer design [1]. In its innermost part, it consists of layers of tracking devices. These devices are made of silicon pixel and strip detectors in the inner volume and transition radiation tubes in the outer part. They operate within a 2T solenoidal magnetic field. The tracker is surrounded by the calorimeters, used to identify and measure the energy of electrons, photons and jets. They consist of electromagnetic (EM) and hadronic (HAD) components. The EM calorimeter uses liquid Argon (LAr) as sampling material, while the HAD calorimeter uses scintillating tiles in the barrel region and LAr in the end-caps. The size and overall shape of the ATLAS detector is defined by the muon chambers in the outermost part, which operate within a toroidal magnetic field of up to 4T.

At the LHC design operation rate of 40 MHz, only one out of $O(10^5)$ collisions in ATLAS will be recorded for analysis. The rest of the events will be rejected by the trigger system. The ATLAS trigger system [2] consists of a hardware-based component, the Level-1 (L1), and the software parts, the Level-2 (L2) and the Event Filter (EF). The L2 and the EF are referred together as High Level Trigger (HLT). Figure 1 provides a graphical description of the ATLAS trigger system.

2. The tau trigger
2.1. Motivation
Tau leptons are the heaviest of the known leptons, with a mass of approximately 1.8 GeV/c². They are key signatures in searches beyond the Standard Model (SM). Due to their high mass,
they are favored in final states produced by processes such as SUSY production of tau-sleptons, charged Higgs, etc. Identifying taus not only increases the sensitivity to searches of physics beyond the SM, but it also increases the sensitivity to SM measurements where leptonic final states are involved, e.g. di-boson production.

Table 1. Tau decay modes and Branching Ratios (BR). The hadronic tau decays are distinguished in 1-prong or 3-prong decays, based on the number of charged pions (which leave tracks in the detector) involved in the decay.

| Tau decay mode     | BR (%) |
|--------------------|--------|
| Leptonic           |        |
| $\tau^\pm \rightarrow e^\pm + \nu + \nu$ | 17.8   |
| $\tau^\pm \rightarrow \mu^\pm + \nu + \nu$ | 17.4   |
| Hadronic 1-prong   |        |
| $\tau^\pm \rightarrow \pi^\pm + \nu$ | 11     |
| $\tau^\pm \rightarrow \pi^\pm + \nu + n\pi^0$ | 35     |
| Hadronic 3-prong   |        |
| $\tau^\pm \rightarrow 3\pi^\mp + \nu$ | 9      |
| $\tau^\pm \rightarrow 3\pi^\pm + \nu + n\pi^0$ | 5      |
| Other              |        |

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The multiple decay modes of the tau leptons are shown in Table 1. The branching ratio into electrons or muons plus neutrinos is approximately 35%. These leptonically decaying taus are selected through the electron or muon triggers. Taus also decay in hadrons (pions, π\(^\pm\) and π\(^0\)) with a branching ratio of approximately 60%. For selecting the hadronically decaying taus, a dedicated tau trigger has been developed [2].

2.2. Implementation
The tau trigger is designed to select hadronically decaying taus, as jets with special characteristics (low track multiplicity, isolation and narrowness, as described in Fig. 2). At L1, the tau trigger uses EM and HAD calorimeter trigger towers in clusters of size \(\Delta\phi \times \Delta\eta = 0.2 \times 0.2\), to calculate the energy in a core region and the surrounding trigger towers between \(0.2 \times 0.2\) and \(0.4 \times 0.4\), to calculate the energy in an isolation region. At L2, the tau reconstruction starts from the L1 RoI, building a cluster with its initial center at the L1 RoI position. The energy weighted \(\eta - \phi\) position is identified, the L2 energy is calculated in a region of \(\Delta\phi \times \Delta\eta = 0.1 \times 0.1\), and the shape variables are obtained in a window of \(0.3 \times 0.3\). Tracking algorithms are executed to identify associated tracks. Selection criteria are applied to distinguish taus from multi-jet backgrounds. The EF uses refined algorithms, similar to the offline reconstruction ones, to build tracks and clusters, and selects taus with different criteria for the 1-prong and the multi-prong decays.

![Figure 2. A jet from a hadronic 3-prong tau decay, versus a jet from a QCD process. The taus are associated with low track multiplicity, narrow and isolated jets and this is how they are distinguished from the QCD jets.](image)

The performance of the tau trigger is evaluated using Monte Carlo simulated events. Selection requirements are applied in a set of calorimeter and tracking variables, to optimize the trigger efficiency, and to acquire a steep turn-on. Because of various effects, the main being the hadronic L1 resolution, the L1 turn-on is slow and not compensated at the L2 and EF selections (Fig. 3). To select taus with a high efficiency above a certain tau \(p_T\) threshold, looser selections have to be applied at L1, L2 and EF.

3. Tau trigger menu and efficiency measurements in early data
The trigger menu is made up of a list of triggers (L1 item \(\rightarrow\) L2 chain \(\rightarrow\) EF chain), including prescales at each level. It contains the physics triggers of interest, triggers for calibrations and other physics studies (e.g. efficiency measurements and background estimations) and pass-through (PT) triggers for performance studies.

For the tau trigger system, various tau and tau-combined signatures are included in the menu. An indicative menu is summarized in Table 2.

In order to use a trigger in a physics analysis, its efficiency needs to be evaluated. In early data, the following three methods are being considered for efficiency measurements:
Table 2. An indicative menu for the tau trigger system. In reality the trigger menu contains many more triggers (especially for commissioning, at the initial data taking phase). Calibration triggers that use tau signatures are also listed.

| Type           | Motivation          | Trigger            |
|----------------|---------------------|--------------------|
| Single Tau     | Higgs→τ⁺τ⁻         | tau50_loose        |
| Multi Tau      | Higgs→τ⁺τ⁻          | 2tau29_loose       |
| Combined       | top, Z→τ⁺τ⁻         | tau12_loose_e10_loose |
|                | top                 | tau16_loose_3j40   |
|                | W→τν                | tau12_loose_xe20   |
| Commissioning  | Trigger efficiency  | tau12_loose_PT     |
| Calibration    | Hadronic            | trk9_loose         |
|                | ID alignment        | trk6_IDCalib       |

- **Tag and Probe method**: using a single-object inclusive trigger, di-object events can be studied. One object is selected by the trigger and reconstructed offline to tag the event. The second object, which was not used in the online selection, can then be used to study the trigger response. Measuring the tau trigger efficiency in Z→τ⁺τ⁻ events is an example of this style of analysis.

- **QCD fake taus**: this method uses the copiously produced QCD tau-like events present in the early data, when enough statistics of real taus from W and Z bosons are not yet available. The tau trigger efficiency can be extracted using fake taus, provided the turn-on, as given by Monte Carlo simulations, is the same and the denominator well defined.

- **Bootstrap method**: the efficiency, \( \epsilon_B \), of a trigger chain B, with threshold higher than a chain A, can be indirectly measured as \( \epsilon_B|A \) in a sample triggered by A, provided that \( \epsilon_A \) is measurable: \( \epsilon_B = \epsilon_B|A \times \epsilon_A \).

Figure 3. The trigger efficiency as a function of the simulated tau true visible \( p_T \), for the trigger tau16_loose, as evaluated in Z→τ⁺τ⁻ and A→τ⁺τ⁻ events. The left plot shows the efficiency for the three trigger levels and the right plot the overall EF trigger efficiency in the 1-prong and 3-prong selections. The trigger, tau16_loose, is more than 95% efficient for 1-prong taus of \( p_T >\approx 30 \) GeV and 3-prong taus of \( p_T >\approx 50 \) GeV.
4. Rates and performance in 900 GeV proton-proton collisions

A clean sample of real hadronic tau decays is not available in the early data. It is therefore important to extract useful information from fake taus which are produced in multi-jet events, with the goal to collect a large enough data sample to check the performance of the tau trigger.

The first collision data provided by the LHC were 900 GeV $p - p$ collisions. One of the primary aspects of the tau trigger has been to check the trigger rates and whether they follow expectations from simulated events, but also extrapolations from the cosmic ray data taking, which were extensively used for the evaluation of the tau trigger algorithms [3]. In Fig. 4, the cumulative L1 tau object rate is plotted as a function of different $E_T$ thresholds for cosmic ray and collision data. For a given threshold value, only tau objects with $E_T$ larger than the threshold are taken into account. The black points represent all L1 tau trigger objects without imposing any requirement on the Minimum Bias Trigger Scintillators (MBTS). From this distribution two subsets have been selected, one by requiring the MBTS trigger and timing constraints consistent with collision events (blue boxes) and a second one by vetoing on the MBTS trigger decision (red triangles), selecting events dominated by cosmic ray events. A good agreement is observed between the rates from cosmic ray and non-MBTS collision data.

**Figure 4.** Cumulative L1 tau trigger rate as a function of the L1 tau object $E_T$ threshold, normalized to one colliding bunch pair. For a given threshold value, the objects considered have a transverse energy greater than this value.

![Cumulative L1 tau trigger rate](image)

In the 900 GeV collision data, the performance of the tau trigger has been evaluated by studying the events selected by the MBTS counters, requiring good runs for the calorimeter and tracking detectors. The events entering in the tau data sample were required to have at

**Figure 5.** Fraction of the offline tau candidates matched to a L1 trigger object with $E_T > 5$ GeV as a function of the $E_T$ of the offline tau candidate. The dashed (solid) line represents the fit to the data (Minimum Bias Monte Carlo simulated events).

![Fraction of offline tau candidates](image)
least one offline reconstructed tau with at least one associated track. The L1 trigger efficiency is defined as the fraction of events that passed a L1 tau trigger. Figure 5 shows that the observed efficiency in data is measured to be similar to the expected one, estimated in minimum bias simulated events. The 900 GeV data variables used in the tau trigger selection were compared to the expectations from simulations. Some representative calorimeter variables are shown in Fig. 6. A reasonable agreement was found, within the limited available statistics, verifying the good detector and tau-trigger performance.

5. Conclusions
The ATLAS tau trigger system has been developed using simulated events and the evaluation of the algorithm performance had already started before collisions, using cosmic ray data. The first collision data at 900 GeV have provided an estimation of the good performance of the tau trigger. In addition to that, the calorimeters and tracking detectors, that contribute to the tau trigger reconstruction, are seen to perform well. New results with increased statistics are now expected from the 7 TeV LHC collision data. Verifying the good performance of the tau trigger system, is an important component for the commissioning of the ATLAS trigger and detector systems.

References
[1] The ATLAS Collaboration, G. Aad et al., The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3, S08003, 2008
[2] The ATLAS Collaboration, G. Aad et al., Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN report CERN-OPEN-2008- 020, Geneva, 2008.
[3] M. Shamim, on behalf the ATLAS Collaboration, Optimization and Performance of the ATLAS Tau Trigger with Cosmic Data, ICATPP Proceedings, http://villanolmo.mib.infn.it/ICATPP11th_2009/accepted/HEP/Shamim.pdf.