Triggering on hadronic tau decays in ATLAS: semiconductor tracking detectors in action

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Abstract

Identifying the decay of the hadronic tau leptons plays a crucial role in the search for physics beyond the Standard Model as well as in Standard Model measurements. However, these 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 difficult challenge.

This contribution will summarize the status and performance of the ATLAS tau trigger system during the 2011 data taking period, emphasizing the key role of semiconductor tracking detectors for tracking and vertexing. Different methods that have been explored to obtain the trigger efficiency curves from data will be shown. Finally, in light of the vast statistics collected in 2011, future prospects for triggering on hadronic tau decays in this exciting new period of increased instantaneous luminosity will be presented.

Key words: LHC, ATLAS, Trigger, Taus, Tracking

1. Introduction

Efficiently identifying tau leptons is instrumental in the searches for new physics in the LHC, including the quest for the Higgs boson and several Beyond the Standard Model signatures, due to the large branching fractions of the tau channels. In particular, a low mass Standard Model (SM) Higgs boson as well as the Minimal Supersymmetric (MSSM) Higgs bosons are expected to have branching fractions to taus in the order of 10%.

In ATLAS, third generation charged leptons decay before reaching the active material of the detector. These decays have a rich spectrum of channels, dominated by hadronic modes that resemble QCD jets. Given the large cross section of QCD processes, discriminating against quark and gluon originated jets while maintaining the efficiency for hadronic tau selection poses a hard challenge to the trigger system. For this purpose, the features of hadronic tau decays are exploited: a very low track multiplicity in a thin cone matching a collimated calorimeter cluster.

2. The ATLAS Tau Trigger

The ATLAS trigger system [1] is aimed at reducing the initial bunch-crossing rate of the LHC, 40 MHz, to the data rate for permanent storage, around 200-400 Hz. This is achieved by a three-level system: a hardware-based 'Level 1', L1, and a software-based High Level Trigger, HLT, staged into a 'Level

2', L2, and an 'Event Filter', EF. Each level has a bandwidth cap due to system capabilities, being the maximum output rate of the L1 system 75 kHz.

2.1. Level 1

The first trigger selection is performed by the so-called 'Level 1' system. It is a hardware based system with access to course granularity information from the calorimeters and muon spectrometers. L1 tau triggers fully rely on calorimeter clusters built with the signals provided by the electromagnetic (EM) and hadronic calorimeter systems. Projective trigger towers of size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ are used to seed and form fixed size cluster.

A L1 tau trigger object is defined as a cluster of $n_\eta \times n_\phi = 4 \times 4$ trigger towers. The central $n_\eta \times n_\phi = 2 \times 2$ trigger towers define the 'core region' while the surrounding towers define the 'isolation region'. The transverse energy, E_T , is reconstructed with a subset of the core region, by the sum of energy deposits in the highest E_T 2×1 pair of EM towers and the sum of energy deposits in all 4 hadronic towers. The isolation energy, E_T^{iso} , is reconstructed by summing the energy deposits in all isolation towers. Both the core and isolation energy at L1 have been studied and validated in detail and found to match our simulation as seen in Fig. 1 and Fig. 2.

Then, L1 identifies tau candidates by requiring a minimum E_T and a maximum E_T^{iso} . For instance, the L1 item *L1_TAU15I* requires the candidate E_T to be strictly above 15 GeV and the isolation E_T to be less than or equal to 4 GeV. The values of the different thresholds are set to maximize the efficiency towards the different physics processes as well as to provide sufficient monitoring capabilities, within the bandwidth limits that the L1 trigger system can hold.

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When a L1 tau candidate is accepted, the information about its location is passed on to the trigger system. A Region of Interest (RoI) is defined around that location. All the detector channels laying in that RoI will be read out and tested at the HLT, see Section 2.2.

Figure 1: Resolution of the L1 cluster energy with respect to the p_T of offline tau candidates. The L1 object is required to be associated to the $EF_tau20_medium1$ chain and match to an offline probe tau within $\Delta R < 0.2$. The offline candidates are selected using a tag and probe analysis with $Z \rightarrow \tau\tau \rightarrow \mu h$ events collected by ATLAS during Summer 2011. The analysis follows closely the Tau ID efficiency measurement [3].

Figure 2: Isolation energy of L1 objects associated to the $EF_tau20_medium1$ chain and matched to offline probe taus within $\Delta R < 0.2$. The offline candidates are selected using a tag and probe analysis with $Z \rightarrow \tau\tau \rightarrow \mu h$ events collected by ATLAS during Summer 2011. The analysis follows closely the Tau ID efficiency measurement [3].

2.2. High Level Trigger

The high level trigger, HLT, has access to information from all the subdetectors with full granularity, but only in the RoI around the candidate that fired L1.

2.2.1. Level 2

The Level 2 (L2) system performs track reconstruction the RoI as well as calorimeter clusterization with full granular-

ity. The L2 algorithms calculate several identification variables combining the information from the calorimeters and the tracking system, but their performance is limited due to timing constraints. The shower shape and the track multiplicity provide most of the rejection power. Variables such as the weighted electromagnetic radius, Fig. 3, and the number of tracks have demonstrated to offer maximum discrimination. Thus, cuts on these variables have been optimized for each E_T threshold compromising efficiency and rejection.

Figure 3: Distribution of the electromagnetic radius, R_{EM} , at L2. The hatched histogram represents the combined contributions from $Z \rightarrow \tau\tau$, $W \rightarrow \tau\nu$ and $Z' \rightarrow \tau\tau$ signal Monte Carlo samples while the black points represent the data. A dijet selection has been applied to select the events in data.

2.2.2. Event Filter

The RoIs that passed the L2 requirements are reprocessed at the Event Filter level, EF. Instead of using custom algorithms to provide rough identification variables as in L2, the EF runs very similar reconstruction software to the one used in offline analysis [3], thus increasing the correlation and efficiency. Variables such as the track multiplicity, Fig. 4, EM radius or weighted track radius are used to discriminate tau candidates. However, EF reconstruction is still RoI based, thus corrections that require full event information, such as pile-up dependent energy corrections, cannot be applied. Therefore, the correlation between EF and offline reconstruction is not absolute.

The events that pass the EF selection are sent for permanent storage, with a maximum rate in the range between 200 Hz and 400 Hz. Some trigger selections that are meant for monitoring and performance studies are scaled down, in order to not exceed the allowed bandwidth.

3. Tracking in the High Level Trigger

HLT tracking is a significant component of the signature identification and discrimination power. Very fast tracking algorithms provide track reconstruction within the time envelope of 40 ms. Two custom algorithms are currently used at L2, using different strategies: a histogramming and a combinatorial

Figure 4: Number of tracks of EF taus associated to the *EF_tau20_medium1* chain and matched to offline probe taus within $\Delta R < 0.2$. The offline candidates are selected using a tag and probe analysis with $Z \rightarrow \tau\tau \rightarrow \mu h$ events collected by ATLAS during Summer 2011. The analysis follows closely the Tau ID efficiency measurement [3].

Figure 5: Residuals of the inverse of the track p_T between Inner Detector trigger track and a matching offline Inner Detector track. The resolution is quoted as RMS95, the RMS deviation for the central 95% of the distribution. The trigger tracks come from the monitoring triggers in muon region of interest with a threshold of 20 GeV. Small differences between trigger and offline track parameters are expected as a consequence of a simplified material model and different pattern recognition (L2) and partial access to calibration (L2,EF).

approach for pattern recognition. A fast Kalman fitter [4] is then used on the track candidates.

The time constraints at EF are more relaxed than at L2: the average event processing time has to stay below 4 s. Thus, the same algorithms than run for offline reconstruction can be used at trigger level after some small adjustments to the trigger environment. The EF stage benefits greatly from sharing the majority of the tracking reconstruction code with the offline processing.

The baseline pattern recognition for HLT tracking is based on the hits provided by the Silicon detectors (Pixel and SCT). Tracks found with the silicon detectors are subsequently extended to the Transition Radiation Tracker, TRT, (inside-out strategy). For robustness and complementarity, track reconstruction algorithms based on (or starting from) the TRT information are also implemented for both at L2 and EF. Fig. 5 shows the residuals at L2 and EF of the tracking algorithms as a function of pseudorapidity, η . The RMS of $1/p_T$ residuals between matching trigger and offline tracks is presented as a function of track η for tracks with transverse momentum spectrum above 6 GeV, in muon RoIs passing the 20 GeV threshold. The absolute difference in the $1/p_T$ values is small. The agreement in track parameter values is expected to be slightly worse at L2 than at EF due to a simplified material model and also due to the difference in pattern recognition techniques used. Another source of differences between online and offline tracks comes a partial access to the detector calibrations.

A very high efficiency of track reconstruction is fundamental for the performance of the tau trigger. This efficiency has been studied using specific monitoring triggers, which are set up for each major trigger signature and threshold, being identical with the exception that they accept events regardless of the outcome of the Inner Detector trigger reconstruction. Therefore, these triggers provide an unbiased sample for tracking efficiency measurements. The tracking efficiencies of finding a track matching an offline muon in triggers with a transverse mo-

mentum threshold of 20 GeV is shown in Fig. 6. In both cases the efficiencies are very high, 100% in EF and 99% and 98% in L2 in the plateau region for muon and electron efficiency respectively.

Figure 6: L2 and EF Si-tracking efficiency for offline muon tracks of $|\eta| < 2.5$ and that are located inside L2 muon regions-of-interest, shown as a function of the transverse momentum of the offline muon. Offline tracks are selected by cuts that would reduce secondaries and choose tracks which have at least a minimum number of Si hits: $|\eta| < 2.5$, $N_{\text{pixelhits}} > 0$, $N_{\text{SCTclusters}} > 5$, $|Z_{\text{offlineVertex}}| < 200$ mm, with respect to the offline vertex: $|a_0| < 1.5$ mm, $|\Delta z \sin \theta| < 1.5$ mm.

4. Tau Trigger Efficiency

The tau trigger efficiency has been studied with different methods. Physics analysis using data collected with a tau trig-

ger need to understand the trigger efficiency in order to correct properly the estimations from the simulation samples.

A comparison of Z boson decays in data and simulation has been performed with a tag and probe method [3], using data of the 2011 run at a center of mass energy of $\sqrt{s} = 7$ TeV. With this method, an event is tagged by either a good identified electron or muon, in data collected by an unbiased electron or muon trigger, respectively. On the probe side, hadronic tau decays which are reconstructed and identified by the offline algorithms are used to measure the tau trigger efficiency. The amount of data analyzed in this measurement corresponds to roughly 1 fb^{-1} . The results for the EF *tau20_medium* and *tau29_medium* items are shown in Fig. 7. For this item, medium tau trigger identification is applied as well as a cut on E_T of 20 GeV.

Figure 7: Efficiency of the *EF_tau20_medium1* trigger measured using a tag and probe analysis with $Z \rightarrow \tau\tau \rightarrow \mu h$ events collected by ATLAS during Summer 2011. 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. The analysis follows closely the Tau ID efficiency measurement [3].

To gain knowledge of the tau trigger efficiencies at very high energies, where a SM sample of real tau leptons is limited with the current dataset, QCD di-jet events can be used to achieve a reasonable precision. Such a measurement is based on the idea that a jet faking a reconstructed and identified offline hadronically decaying tau lepton should fire the tau trigger at high p_T at the same rate as real hadronically decaying tau leptons. Hence, a di-jet sample is selected in collision data and the trigger efficiency is measured with a tag-and-probe method.

5. Future prospects for 2012 data

After the winter break, the LHC will resume operations. It is expected to restart providing proton-proton collisions sometime between late March and early April, reaching and surpassing soon the maximum instantaneous luminosity of 2011.

The increase in instantaneous luminosity translates into a larger pile-up (the number of secondary interactions per bunch-crossing), which contributes to increase the rate and to degrade the efficiency. The evolution of the event rate as a function of

the instantaneous luminosity is shown in Fig. 8 and 9 for different L1 and EF items, respectively. In general, as pile-up increases trigger rates also increase. However, the degradation of the efficiency of some of the trigger variables not only affects physics signals, but backgrounds as well. In particular, the rate of *EF_tau29T_medium1_tau20T_medium1* shows how pile-up makes this rate saturate, particularly due to the widening of the shower shape.

Figure 8: Level 1 rates before prescale versus the instantaneous luminosity measured by ATLAS for L1 tau items that seed tau chains at HLT. The last digits in the L1 item name correspond to the E_T requirement, e.g. a L1 $E_T > 11$ GeV for L1 TAU11. The data have been collected at a center-of-mass energy of 7 TeV in 2011.

Figure 9: Event Filter output rates versus the instantaneous luminosity measured by ATLAS for selected HLT tau chains collected from September to October 2011. The numbers in the item names correspond to E_T requirements at EF for a given trigger type, e.g. an electron candidate with $E_T > 15$ GeV in e15vh, where vh implies that the η dependent E_T selections were applied at L1 and the energy in core of the hadronic calorimeter is required to be smaller than 1 GeV. The data have been collected at a center-of-mass energy of 7 TeV in 2011.

In order to keep the efficiency for true hadronic tau decays within the limits of the assigned bandwidth, some upgrades are being implemented. These upgrades will include the use of

187 multivariate techniques at EF, trained to maximize the rejection
188 power as well as a redefined set of variables at L2 to provide
189 the necessary robustness against pile-up.

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