2010

Performance of the ATLAS Jet Trigger in the Early $\sqrt{s} = 7$ TeV Data

Kerstin M. Perez
Haverford College, kperez1@haverford.edu

Follow this and additional works at: http://scholarship.haverford.edu/physics_facpubs

Repository Citation

This Journal Article is brought to you for free and open access by the Physics at Haverford Scholarship. It has been accepted for inclusion in Faculty Publications by an authorized administrator of Haverford Scholarship. For more information, please contact nmedeiro@haverford.edu.
Performance of the ATLAS Jet Trigger in the Early $\sqrt{s} = 7$ TeV Data

The ATLAS Collaboration

Abstract

We present a study on the performance of the ATLAS jet trigger using $pp$ collision data recorded in April & May 2010 at a center-of-mass energy of 7 TeV. Results are shown for inclusive, dijet, and multijet efficiencies for the Level 1 and High-Level triggers. The Level 1 trigger was used to actively select events for the data analyzed in this note. To test its performance, the High-Level trigger was run on the events selected by Level 1, but not used to actively reject events.
1 Introduction

The jet trigger system of the ATLAS experiment is fundamental for jet physics analyses, since jet triggers are the primary means for selecting events containing jets with high transverse momentum ($p_T$). This note summarizes the performance of the jet trigger, including efficiency and some characteristics of jets reconstructed by the trigger algorithms with respect to those reconstructed offline.

The analysis presented here is based on a dataset recorded from beginning of April to beginning of June 2010. This is the same data set, with an integrated luminosity of 17 nb$^{-1}$, used in the first measurement of the inclusive jet cross section[1]. Only the Level 1 trigger (L1) was used to select events during this period. It is based on a sliding-window algorithm that selects high-energy depositions in a square of size $0.4 \times 0.4$, $0.6 \times 0.6$, or $0.8 \times 0.8$ in $\Delta \eta \times \Delta \phi$. In the forward calorimeter ($\eta > 3.2$), no $\eta$ granularity is available at L1 trigger level. More details of the ATLAS trigger system can be found in Ref. [2]. While the Level 2 (L2) and Event Filter (EF) trigger algorithms (collectively known as High-Level Trigger, HLT) were executed and their output was recorded, they were not considered in the actual trigger decision. The L2 trigger is based on a simplified version of a cone clustering algorithm, limited to a maximum of three iterations, on calorimeter clusters with full granularity. The EF uses the same reconstruction algorithms as the offline reconstruction, the only difference being the calorimeter calibration, and the fact that the clusters used to make the jets are only those inside a region of interest surrounding the direction of the L1 jet. Further details on the L2 and EF jet triggers can be found in Ref. [3].

The names of the jet triggers as well as their L1, L2, and EF thresholds are listed in Table 1.

<table>
<thead>
<tr>
<th>Inclusive jets</th>
<th>Threshold (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF__j10</td>
<td>L1_J5 5 7 10</td>
</tr>
<tr>
<td>EF__j20</td>
<td>L1_J10 10 15 20</td>
</tr>
<tr>
<td>EF__j40</td>
<td>L1_J15 15 30 40</td>
</tr>
<tr>
<td>EF__j80</td>
<td>L1_J30 30 60 80</td>
</tr>
<tr>
<td>Forward jets</td>
<td>L1 Name L1 L2 EF</td>
</tr>
<tr>
<td>EF__fj10</td>
<td>L1_FJ5 5 7 10</td>
</tr>
<tr>
<td>EF__fj20</td>
<td>L1_FJ10 10 15 20</td>
</tr>
<tr>
<td>EF__fj40</td>
<td>L1_FJ15 15 30 40</td>
</tr>
<tr>
<td>EF__fj80</td>
<td>L1_FJ30 30 60 80</td>
</tr>
<tr>
<td>Multijets</td>
<td>L1 Name L1 L2 EF</td>
</tr>
<tr>
<td>EF__2j10</td>
<td>L1_2J5 5 7 10</td>
</tr>
<tr>
<td>EF__2j20</td>
<td>L1_2J10 10 15 20</td>
</tr>
<tr>
<td>EF__3j20</td>
<td>L1_3J10 10 15 20</td>
</tr>
<tr>
<td>EF__4j10</td>
<td>L1_4J5 5 7 10</td>
</tr>
<tr>
<td>EF__4j20</td>
<td>L1_4J10 10 15 20</td>
</tr>
<tr>
<td>Summed Jet Energy</td>
<td>L1 Name L1 L2 EF</td>
</tr>
<tr>
<td>EF__je60</td>
<td>L1_JE60 60 N/A N/A</td>
</tr>
<tr>
<td>EF__je100</td>
<td>L1_JE100 100 N/A N/A</td>
</tr>
<tr>
<td>EF__je120</td>
<td>L1_JE120 120 N/A N/A</td>
</tr>
</tbody>
</table>

Table 1: Jet triggers and thresholds used in this analysis.
Chain names (first column) refer to the EF thresholds, but since Level 1 was only used for rejection, also the full L1 name (second column) is given. Triggers defined with the letter “J” refer to central jets, those with “FJ” to forward jets, and those with “JE” to total jet energy in the central part of the calorimeter. The number before these letters represents the minimal multiplicity required, while that after the letters the jet threshold. L1 thresholds should not be interpreted strictly as GeV, but merely as hardware thresholds, which in the case of jets, are very different from the calibrated jet energy scale. Nevertheless, for ease we will refer to the units as GeV for the rest of the note.

Calibration constants that correct for the lower hadron response of the non-compensating calorimeters in ATLAS (hadronic energy scale) were not available at the time of data-taking. Instead calibration factors (so-called EM+JES [4]) were applied at analysis level to the sum of the jet energy deposits in the electromagnetic and hadron calorimeters (the so-called electromagnetic scale\(^1\)), without applying a compensation factor between them.

The trigger efficiency is defined as the probability to satisfy the trigger as a function of an observable such as jet \(p_T\), pseudorapidity (\(\eta\)), or rapidity (\(y\)), and is calculated as the ratio of the jet distribution in events that passed the trigger with respect to a reference distribution. We studied the efficiency per event, defined as the probability that the jets in a given event would satisfy the trigger, and the efficiency per jet, defined as the probability that a specific jet would satisfy the trigger condition. The difference between per event and per jet approaches is that while in the first case all jets in an event that passed the trigger are positively contributing to the efficiency, in the second case we consider only the offline jets matched in \(\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}\) to a trigger jet. To have an unbiased sample, we consider the events selected by the minimum bias trigger MBTS\(_{1}\), requiring a single hit in one of the Minimum Bias Trigger Scintillators (MBTS) covering the endcap calorimeter region at both sides of the detector. Jets are then selected offline, and matched to the trigger ones.

The assumption that the minimum bias trigger is unbiased and orthogonal with respect to jets has been tested comparing the efficiency obtained with respect to this trigger with that obtained with respect to events selected by the Zero-Degree Calorimeter (ZDC), a detector placed in the very forward region just after the LHC beampipe splits in two. The limited statistics of the ZDC sample does not allow to test this assumption with good precision, so we assign a 5% systematic uncertainty to the efficiency points smaller than 80%, and a 1% uncertainty for the points above this value, based on the maximal differences observed between the efficiencies calculated with respect to either MBTS or ZDC. These systematic uncertainties are shown summed in quadrature with the statistical uncertainties on the efficiency curves presented here.

The event selection used in this study is the same as the one used in the other jet analyses in ATLAS [1]. Jets were reconstructed offline from calorimeter clusters at the electromagnetic scale, using the anti-\(k_T\) jet algorithm [5] with \(R = 0.4\) or \(R = 0.6\), in the region \(|\eta| < 2.8\). Jets were calibrated using parameters taken from the simulation after comparison with the data [4]. Cleaning cuts were applied to suppress jets reconstructed from noise, cosmic rays, etc. They were based on rejecting jets with almost all energy coming from a very small number of cells, or with abnormal electromagnetic components, as explained in detail in Ref. [6].

Data was compared with Pythia 6.4.21 simulation, that implements leading-order matrix elements from perturbative QCD for \(2 \rightarrow 2\) processes, followed by parton showers, calculated in leading-logarithm approximation, and uses the Lund string model for hadronisation [7].

---

\(^1\)The electromagnetic scale is the basic calorimeter signal scale for the ATLAS calorimeters. It gives the correct scale for the energy deposited in electromagnetic showers, while it does not correct for the lower hadron shower response nor for energy losses in dead material.
Figure 1: The efficiency for an anti-$k_T$ jet with $R = 0.4$ to satisfy L1 as a function of the jet $p_T$, integrating over $|y| < 2.8$. Left to right, and top to bottom are efficiencies for the four lowest L1 thresholds: 5, 10, 15, and 30 GeV.

2 Level 1 Trigger Performance

Per jet efficiencies for anti-$k_T$ jets with $D = 0.4$ to satisfy L1 jet thresholds of 5, 10, 15, and 30 GeV are shown in Fig. 1 as a function of the calibrated offline jet $p_T$. There is general agreement between results from simulation and data though the details differ. The slight inefficiencies at high $p_T$ are due to offline jets being split into two by the L1 jet algorithm. Since the size of the jets at Level 1 is smaller than the typical offline jet, high $p_T$ offline jets can be seen by the trigger as separate jets, which therefore leads to inefficiencies well above the plateau region. In Fig. 2 the efficiency for the lowest L1 trigger threshold is shown as a function of jet $\eta$ for three different regions of the offline reconstructed jet transverse momentum (20 < $p_T$ < 40 GeV at the top; 20 < $p_T$ < 40 GeV and $p_T$ > 60 GeV at the bottom), and for two values of $R$ (0.6, top left plot; 0.4, the others), as used in the offline jet reconstruction. The low transverse momentum region exhibits a strong dependence on $\eta$ particularly in the regions around $|\eta| \sim 1.5$, between the barrel
Figure 2: The efficiency for an anti-\(k_T\) jets to satisfy L1 as a function of the jet \(\eta\) for the 5 GeV L1 jet threshold. The efficiency is integrated in three bins in \(p_T\): \(20 < p_T < 40\), \(40 < p_T < 60\), and \(p_T > 60\) GeV which correspond to the three regions of the efficiency as a function of jet \(p_T\). The upper-right and both lower plots are for jets reconstructed offline with \(R = 0.4\); the upper-left plot requires \(R = 0.6\).

and endcap calorimeters. Better agreement between data and simulation is observed for jets that are reconstructed with a radius \(R = 0.6\), reflecting the impact of jet size on the efficiency. The inefficiencies and discrepancies between simulation and data get very small as the jet \(p_T\) increases. Residual problems only remain near \(|\eta| = 1.5\), the transition region between the barrel and endcap calorimeters; the efficiency in data is lower as only part of the calorimeter in that region was included in the L1 trigger for this data sample. The lower-right plot in Fig. 2 shows the same efficiency as a function of jet \(\eta\), but this time for calibrated offline jet \(p_T > 60\) GeV. The efficiency is flat in \(\eta\) and close to one; this fact has lead to the choice of the minimum jet \(p_T\) of 60 GeV used in the jet cross section analyses [1].

Final states with multiple jets are important for the study of high-order QCD, for mea-
measurements of $t\bar{t}$ production in the fully hadronic decay channel, and for many searches for new physical phenomena. For this reason, two-jet, three-jet, and four-jet triggers were defined at L1, with $p_T$ thresholds of 5 and 10 GeV. This efficiency was calculated per event (not per jet), for the two three-jet triggers as a function of the third jet $p_T$ (Fig. 3), and as a function of the fourth jet $p_T$ for the four-jet triggers (Fig. 4). As for the single-jet efficiency, data are slightly above the Monte Carlo.

The sum jet $E_T$ triggers (JE) also select events with high jet multiplicity. Figure 5 shows the distribution of $H_T$, defined as the total offline jet $E_T$, for all events that survive the event selection, and for those that pass three different JE trigger thresholds. The figure also includes the L1 JE trigger efficiency as a function of the offline $H_T$ distribution, defined as the sum of
Figure 5: Upper-Left: Distribution in $H_T$ (transverse momentum sum for all jets reconstructed with the anti-$k_T$ algorithm with $p_T > 7$ GeV), for unbiased events and for events that satisfy the various JE triggers. The other three plots present the efficiency for an event to satisfy the various JE thresholds of 60, 100, and 120 GeV, meaning that the sum of transverse momenta of the Level-1 jets in the event will exceed the threshold value.

all anti-$k_T$ jets in the event above 7 GeV transverse momentum. The efficiencies determined in the simulation provide a reasonable description of the data.

3 High-Level Triggers

The behavior of jets found at L2 was extensively studied in this dataset since L2 will be the first part of HLT enabled for active rejection in the future. It is important to note that a completely independent analysis of the L2 jet trigger is not possible. The L2 jets were reconstructed from L1 jets and triggered by L1 $\rightarrow$ 5. The bias of this trigger cannot be removed. We will, however, mention L2 jets as if we were solely analysing the L2 jet trigger.
Figure 6: Difference between the $\Phi$ (left) and $\eta$ (right) values between jets reconstructed at Level-2 and offline with the anti-$k_T$ algorithm using parameter $R = 0.4$. Trigger and offline jets are matched according to the smallest $\Delta R$ separation.

Figure 7: Ratios of transverse momenta of jets reconstructed at L2 and offline with the anti-$k_T$ algorithm with parameter $R = 0.4$, as a function of the $E_T$ (left) and $\eta$ (right) of the offline jet. Both jet collections are calibrated to electromagnetic scale.

The angular resolution of L2 trigger jets with respect to jets reconstructed offline, is shown in Fig. 6. The average energies of L2 jets agree quite well with those of the matching offline jets in both data and simulation. This is shown in Fig. 7 as a function of the offline jet $E_T$ and $\eta$. The deviation from unity at low $E_T$ in the ratio of the L2 jet $E_T$ to the offline jet $E_T$ is caused by resolution smearing across the L2 jet threshold: if both distributions have Gaussian fluctuations, the cases when the numerator has an upward fluctuation and the denominator a downward one lead to a larger effect on the ratio than the opposite case, so on average there will be a positive bias. The shape and magnitude of this bias are well-matched between data...
Figure 8: Efficiency for an anti-\(k_T\) jet with \(R = 0.4\) to satisfy the L2 requirement for four choices of L2 threshold. Left to right, and top to bottom, thresholds are at 7, 15, 30 and 60 GeV. Note: events are selected using the minimum bias trigger; no L1 jet trigger was specifically required in these distributions.

and simulation. Note that the offline jets in Fig. 7 were calibrated to the electromagnetic scale since this is the calibration used at L2. A small discrepancy between data and Monte Carlo is also visible in the high-\(\eta\) region, and is due to some high-voltage tests occurring in the forward part of the calorimeter during the period examined here. Figure 8 shows the trigger efficiency for the lowest L2 thresholds of 7, 15, 30, and 60 GeV. These turn-on curves are considerably sharper than the corresponding Level 1 ones, and a good agreement between data and Monte Carlo is found, apart perhaps for the highest threshold where statistics is quite poor.

The jet trigger was limited to inclusive and multi-jet topologies for the initial data-taking period, with no cuts on the relative directions of the jets. These signatures will be prescaled with increasing luminosity, but the efficiency for certain final state configurations can be maintained by requiring specific topologies in the HLT trigger. As an example, triggers that require dijets with large rapidity differences, or small differences in azimuthal angle have been implemented
4 Conclusions

Properties of the ATLAS jet trigger have been shown for the initial data-taking period with $\sqrt{s} = 7$ TeV. Simulation generally reproduces results of the Level 1 and High-Level Triggers in data in resolution and efficiency. Turn-on curves reach plateau values for expected jet transverse energies, and this fact has allowed the use of these triggers for precision jet cross section measurements. The use of HLT for rejection will further sharpen these curves, allowing to lower rate and keep very similar plateau values. Further understanding of these distributions, particularly the small deviations thereof, will improve with increasing integrated luminosity.

References


