Performance of the ATLAS missing $E_T$ trigger with first $\sqrt{s} = 7$ TeV data

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Performance of the ATLAS missing $E_T$ trigger with first $\sqrt{s} = 7$ TeV data

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Abstract. We present an early study of the performance of the ATLAS trigger based on the vector ($E_{\text{miss}}^T$) and scalar ($\sum E_T$) sums of the measured transverse energies, obtained with data collected during the first 2010 LHC runs, with proton-proton collisions at $\sqrt{s} = 7$ TeV. We demonstrate that because of the Level One configuration, calorimeter noise effects don’t significantly affect $E_{\text{miss}}^T$ trigger rates for minbias events. We also show that there are good correlations between Event Filter and reconstructed offline $E_{\text{miss}}^T$ and $\sum E_T$ quantities, and that the trigger efficiencies with respect to these offline quantities follow Monte Carlo expectations. From these studies, we conclude that $E_{\text{miss}}^T$ and $\sum E_T$ HLT rejection can safely be enabled as soon as rates become too high for Level One rejection alone.

1. Introduction

Over the last few months, the ATLAS detector collected a sufficient number of 7 TeV LHC collision events to allow studying the performance of the ATLAS Trigger and Data Acquisition system (TDAQ). Such studies of the TDAQ system are critical for a successful physics program because they allow optimizing the rate and the efficiency at which interesting events are collected for thorough physics analyses. In particular, a large spectrum of physics results relies on the capacity of the ATLAS TDAQ system to efficiently collect events based on the estimate of the missing transverse energy ($E_{\text{miss}}^T$) contained in each event. The $E_{\text{miss}}^T$ trigger is, for example, the primary trigger to be used in new physics searches for processes involving new weakly interacting particles, which could account for the astronomically observed dark matter. In addition to discovery perspectives, the $E_{\text{miss}}^T$ trigger can also be used in combination with other triggers to control the rate of signatures involving low energy objects. For example, the $E_{\text{miss}}^T$ trigger is necessary in order to measure non-boosted Ws in the tau channel. Finally, the negligible statistical correlation with lepton triggers make it ideal to estimate the performance of those lepton triggers (and vice versa). It is currently being used to provide the first data-driven estimate of the electron trigger and identification efficiencies to be used in W and Z cross section measurements. The following performance studies of the $E_{\text{miss}}^T$ trigger will demonstrate that at the early stage of the detector commissioning the $E_{\text{miss}}^T$ trigger is already performing well enough to realise its physics potential.

Special triggers also exist, which set a minimum threshold to the scalar sum of transverse energies ($\sum E_T$). Such triggers provide a good estimate of the overall calorimeter activity, and constitute a good complement to the $E_{\text{miss}}^T$ triggers for performance studies, as much as for physics purposes. The performance of such triggers will also be presented in the following.
1.1. Overview of the $E_T^{\text{miss}}$ trigger system

The MET trigger requires that the magnitude of the vector sum of all transverse energies exceeds some thresholds. At Level One (L1) [1], only calorimeter information is used from the so-called “trigger towers” which correspond to the analog sums of all calorimeter cells in an ($\eta, \phi$) range of $0.1 \times 0.1$ aligned along a given direction, formed by dedicated hardware. Next, the L1 pre-processor digitizes and applies noise subtraction to the formed trigger towers, and then produces jet elements, by summing the digital words of 4 adjacent trigger towers. Using all the jet elements in the event, the jet/energy processor then computes the calorimeter energy sums along the x-axis ($E_x$) and y-axis ($E_y$). Instead of computing MET from the quadratic sum of $E_x$ and $E_y$, a look-up-table is used to accept/reject the events based on the $(x, y)$ components of the measured energies. The scalar sum of the energy deposited in the calorimeter ($\sum E_T$) is obtained similarly, without, however, the need for a look-up table to determine which thresholds the energy measurement satisfies.

The High Level Trigger (HLT) consists of a set of software-based algorithms which perform the $E_T^{\text{miss}}$ and $\sum E_T$ reconstruction from detector input (Feature Extraction or FEX algorithms) or specify the selections which defined the various $E_T^{\text{miss}}$ or $\sum E_T$ trigger chains to be included in the trigger menu (hypothesis algorithms) [2]. Because $E_T^{\text{miss}}$ and $\sum E_T$ are global quantities, they only need to be computed once per event. This makes it possible to design many different hypothesis testing algorithms, for very specific physics needs, without noticeably increasing the execution time which is one of the major constraints at trigger level.

At Level Two (L2), the FEX algorithm simply fetches the L1 result and refines it by applying a correction taking into account the muons reconstructed at L2 (muons do not deposit much energy in the calorimeters and therefore constitute a source of fake $E_T^{\text{miss}}$). At the Event Filter (EF), the third and last of the trigger levels, contributions from both calorimeters and muon spectrometers are recomputed using the full granularity of the detectors. The 3D missing momentum vector is computed, although only its transverse projection is used to select events. In order to reduce the electronic noise contribution and therefore improve the resolution of the $E_T^{\text{miss}}$ measurement, only positive energy calorimeter cells above 3 noise RMS are considered in the $E_T^{\text{miss}}$ and $\sum E_T$ reconstruction. This one-sided noise cut causes a shift in the $\sum E_T$ measurement which can be somewhat accounted for by a similar shift in the $\sum E_T$ thresholds defining the trigger chains. This resolution can be further improved by the application of a simple cell-based calibration, optimised to reproduce the offline calibrated Met and $\sum E_T$ measurements.

1.2. Offline reference and configuration for commissioning period

The offline MET algorithms include corrections that cannot be implemented at trigger level. The reference selected for this study is the one provided by the offline MET, Topo, which is the best offline one still comparable to the EF algorithm described above. This algorithm accounts for the energy deposited in topological clusters [3] defined from seed calorimeter cells with an energy threshold (2-sided cuts) above 4 times the RMS of the signal expected from electronic noise, plus all cells above 2 RMS surrounding them and all adjacent cells. The $E_T^{\text{miss}}$ offline reconstruction obtained from MET,Topo is based only on uncalibrated calorimeter energy measurements. It provides the best offline performance for uncalibrated $E_T^{\text{miss}}$ measurements and therefore constitutes the targeted $E_T^{\text{miss}}$ reconstruction for trigger algorithms. The same topological clustering algorithm is also used for $\sum E_T$ calculation, and is referred as MET,Topo $\sum E_T$.

The ATLAS calorimeters are non-compensating, i.e. the correct hadronic energy scale is only recovered after applying an object-based calibration to the measured energy depositions. Such calibration is presently being validated for the full offline $E_T^{\text{miss}}$ reconstruction [4], and no reference is currently available to calibrate $E_T^{\text{miss}}$ trigger quantities (a simplified hadronic calibration has indeed been implemented, but is not yet used in trigger chains or monitoring.
histograms). For this reason we focus, for both trigger and full-reconstruction quantities during commissioning period, on the $E_{\text{miss}}^T$ performance with uncalibrated energies only (energies at the “electromagnetic” (EM) scale).

Finally, because the muon trigger is also separately in the process of being validated, muon corrections are ignored both at L2 and EF for the present performance studies. This means that the L2 results are identical to those at L1; hence only L1 and EF distributions will be shown. The effects of muon corrections on minimum-bias events are anyway negligible.

1.3. Data and preselection

The studies to be shown here have been obtained by taking the events in runs 152845 and 152878, all with stable LHC beam conditions, corresponding to an integrated luminosity of about 52 µb$^{-1}$. Such runs have been flagged as “good” by looking at the status of each subdetector and at the result of basic data quality checks. During these runs, the HLT was run in pass-through mode, meaning that it did not reject any events. However, the $E_{\text{miss}}^T$ trigger has been configured to process all events passing L1, which makes it possible to perform accurate debugging and better performance and efficiency studies.

A set of event preselections are applied in order to estimate the performance of the $E_{\text{miss}}^T$ and $\sum E_T$ triggers on events of physics collision origin (as opposed to noise or cosmic events). Collision candidates are selected by requiring that the timing of the minimum-bias trigger scintillators is consistent with a collision (i.e. the time difference between scintillators installed at positive and negative pseudorapidities is consistent with zero). In addition a similar requirement has also been put on the timing of liquid-argon calorimeter cells. Furthermore, when explicitly mentioned, “good events” are selected by excluding those with badly measured jets. Bad jets are defined as those for which any of the following are true [5]:

- when less than 20% of the jet energy is deposited in the EM calorimeter, 90% of this jet energy is distributed over less than 6 calorimeter cells;
- when more than 95% of the jet energy is deposited in the EM calorimeter, more than 80% of the total jet energy comes from cells with an abnormal signal shape;
- the energy of the primary cells of the jet has been deposited more than 50 ns before or after the nominal proton-proton collision time.

We refer to these criteria as the jet clean-up cuts.

2. Results of performance studies

Figure 1 shows the correlation between L1 and offline $E_{\text{miss}}^T$, before and after removing events by applying the jet cleanup cuts described above. By comparing the upper and lower plots, we can see that the lowest L1 threshold on $E_{\text{miss}}^T$, which is L1XE10, cuts away most of the events with badly measured or unphysical jets. This shows how the conservative L1 calorimeter-based trigger settings help to control $E_{\text{miss}}^T$ trigger rates. However, the L1 to offline correlation is not linear. This is because L1 is still using conservative commissioning-phase values, and future modifications of these settings are expected to improve L1 $E_{\text{miss}}^T$. For this reason, all current trigger chains based on $E_{\text{miss}}^T$ or $\sum E_T$ start with a rather low L1 threshold compared to the EF threshold. The signal efficiency therefore currently depends mainly on the EF performance which is significantly better.

Figure 2 compares EF and offline $E_{\text{miss}}^T$ or $\sum E_T$ for good events only. A clear linear relationship can be seen between trigger level and reconstructed offline quantities. This indicates that the selections operated by the EF $E_{\text{miss}}^T$ and $\sum E_T$ algorithms don’t significantly bias offline $E_{\text{miss}}^T$ and $\sum E_T$ measurements and that such triggers will be highly efficient. The ~15 GeV offset observed in the $\sum E_T$ EF to offline scatter plot is an artefact of the 1-side noise suppression cut as explained in section 1.1.
This good correlation between EF and fully reconstructed quantities, however, also applies to events with unphysical jets, in contrast to what is observed at L1. As can be seen in figure 3, there is a difference between EF $E_{T}^{\text{miss}}$ distributions before and after applying jet clean-up cuts, showing that the EF $E_{T}^{\text{miss}}$ trigger alone will not eliminate events with bad jets affecting the EF $E_{T}^{\text{miss}}$ measurement. However, to pass the full trigger chain, both L1 and EF trigger decisions will be required, meaning that much of the bad jet contributions will be rejected by the L1 trigger and not survive to the final data sample. Figure 3 shows the effects of removing all events which do not pass L1_XE10 (the softest L1 $E_{T}^{\text{miss}}$ signature) or the ATLAS standard jet clean-up cuts. As one can see, only a few events at high $E_{T}^{\text{miss}}$ rejected by jet clean-up cuts survive the L1_XE10 trigger. Work is in progress to understand whether these bad jet events
Figure 3. EF $E_T^{\text{miss}}$ distribution for all collision candidates (full circles •), after applying jet clean-up cuts (open circles ○), or passing a L1 Missing ET threshold of 10 GeV (full squares ■). The errors bars reflect statistical uncertainty only.

Figure 4. Event Filter (EF) trigger level $E_T^{\text{miss}}$ distribution for real collision candidate data and Monte Carlo (MC) events, after applying the jet clean-up cuts. The MC distribution has been normalized to the data distribution (same integrated luminosity). The errors bars reflect statistical uncertainty only.

can be reduced at EF with additional checks.

Figure 4 shows the good agreement which is obtained by comparing the measured $E_T^{\text{miss}}$ distribution at EF with the corresponding simulated distribution from minimum bias events, after applying the jet clean-up cuts. Figure 5 shows the trigger efficiency curves, the fraction of events which pass the EF trigger as a function of offline $E_T^{\text{miss}}$ or $\sum E_T$, with no L1 trigger requirement. Good agreement is again seen between data and simulation. Figures 4 and 5 demonstrate that the ATLAS missing transverse energy HLT algorithms are well understood, and perform as expected on physics events. The $E_T^{\text{miss}}$ and $\sum E_T$ trigger algorithms are therefore validated and ready for rejecting events (as soon as the L1 rate becomes too high). Moreover, the turn-on curves presented in figure 5 are steep: they reach an efficiency plateau only few GeV above the trigger threshold. This shows that the distortion of the offline $E_T^{\text{miss}}$ or $\sum E_T$ distributions by trigger preselection is small. This demonstrates the high performance of the $E_T^{\text{miss}}$ high-level trigger algorithms with respect to the offline $E_T^{\text{miss}}$ quantities featuring the best performances (MET$\_\text{Topo}$).

3. Summary and conclusion
The performance of the ATLAS triggers based on the scalar and vector sums of the transverse energies has been shown, for the first 2010 runs at $\sqrt{s} = 7$ TeV LHC proton-proton collisions. Because the hadronic calibration is still being validated for the full offline reconstruction, all plots here show the distributions obtained using the uncalibrated energy measurements.
Figure 5. EF turn-on curves for $E_T^{\text{miss}}$ with threshold at 5 GeV (top left) and 20 GeV (bottom left), and for $\sum E_T$ thresholds of 30 GeV (top right) and 100 GeV (bottom right). The simulation correctly reproduces the results obtained with real collision candidate data, after applying the jet clean-up cuts. The errors bars reflect statistical uncertainty only.

The results show:

(i) a good correlation between offline and EF trigger-level quantities ($E_T^{\text{miss}}$ and $\sum E_T$),

(ii) bad jet contribution to trigger rates are controlled by L1 $E_T^{\text{miss}}$ preselection,

(iii) steep efficiency turn-on curves for EF $E_T^{\text{miss}}$ and $\sum E_T$, and

(iv) good Monte Carlo to data agreement.

From these studies, we conclude that the HLT algorithms can be safely used to reject events, as soon as the L1 rate becomes too high. To optimise the signal efficiency, the current trigger chains based on $E_T^{\text{miss}}$ and $\sum E_T$ all start with a rather low L1 threshold compared to the EF one, so that the final turn-on curve is very similar to what is obtained using EF alone. The $E_T^{\text{miss}}$ trigger is therefore in good shape to deliver its full physics potential.

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