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ATLAS Transverse Missing Energy Trigger Performance

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Missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) is a useful way to signal particles not interacting with the detector such as those predicted by Beyond Standard Model theories. The ATLAS experiment at the LHC employs a missing transverse momentum trigger that uses calorimeter-based global energy sums, together with specifically developed pile-up mitigation techniques, to keep the selection efficiency high for events with non-interacting particles while minimizing the overall trigger rate. The high number of pile-up interactions was one of the major challenges faced during the Run 2 of the LHC and a continuous effort was needed to improve the pile-up rejection and to keep the trigger rate reasonable. This contribution presents the techniques used to improve the Run 2 missing transverse momentum trigger performance, describes the Run 2 performance and discusses an outlook for further improvements for Run 3 of the LHC.

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1. Introduction

The missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) arising from particles not interacting with the detector is useful for detecting new physics that predicts invisible particles. Several Beyond Standard Model (BSM) theories predict not-yet observed particles carrying no electromagnetic or strong charge that would appear in the ATLAS detector [1] at the LHC as $E_{\mathrm{T}}^{\mathrm{miss}}$.

The $E_{\mathrm{T}}^{\mathrm{miss}}$ is defined as the vectorial sum over transverse momenta of several input components. Algorithms calculating the $E_{\mathrm{T}}^{\mathrm{miss}}$ at the trigger level differ in how they use calorimeter information to find $E_{\mathrm{T}}^{\mathrm{miss}}$ while minimising the impact of mismeasurement, which is especially important in scenarios with high pile-up (PU).

2. ATLAS Run 2 Trigger and Data Acquisition

In the ATLAS experiment, the trigger system is designed to select events of interest while minimizing the data read-out rate, reducing the number of bunch crossings for which the detector data needs to be read out. In response to the 40 MHz LHC collision rate the ATLAS detector produces data at a rate of over 50 TB/s, an unsustainable amount of data to be handled. Moreover, most of those data are not of interest for the ATLAS physics program.

The ATLAS trigger (Figure 1) [2] is separated into two systems: the firmware based Level 1 (L1) trigger and the software based High Level Trigger (HLT). The L1 trigger receives the full 40 MHz input rate and reduces it to an output rate of 100 KHz limited primarily by the read-out of the individual detector components. The HLT trigger is run on the output of the L1 trigger and further reduces the output rate to a final rate of approximately 1 KHz.

One of the main upgrades to the ATLAS trigger system foreseen for the Run 3 of the LHC is the installation of the Fast TracKer (FTK), a track finding system implemented in custom hardware that is designed to provide charged particle track reconstruction within 100 μs of every event accepted by the L1 trigger (at a maximum operating rate of 100 KHz). The FTK system is in the process of being commissioned at the time of writing.

3. The ATLAS $E_{\mathrm{T}}^{\mathrm{miss}}$-Trigger

The $E_{\mathrm{T}}^{\mathrm{miss}}$ is calculated both at L1 and HLT trigger level. At L1, the inputs to the sum are the L1 calorimeter trigger towers over the full η range, with a granularity of about $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ counted in the detector region with $|\eta| < 2.5$ and larger for the detector region with $|\eta| > 2.5$.

The $E_{\mathrm{T}}^{\mathrm{miss}}$ calculation at HLT is performed accessing the full calorimeter cell-level energy measurement. Several algorithms have been run concurrently at the HLT level. While in Run 1 only algorithms using calorimeter cells and clusters were used, during Run 2 other algorithms were developed, amongst which MHT and PUFIT [2] were found to be an improvement over the previous ones. The algorithms used during Run 2 were:

- **Cell**: The inputs to the sum are the $\sim$188k individual calorimeter cells. A two-sided noise suppression is applied as signal cleaning, passing only cells whose energy fullfills $|E_{\mathrm{i}}| > 2\sigma$, $E_{\mathrm{i}} > -5\sigma$.

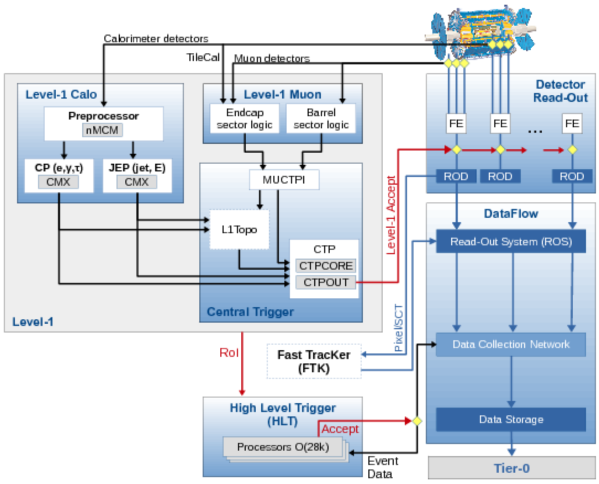

Figure 1: The ATLAS data acquisition and trigger system [2].

- **MHT Jet-Based**: The inputs to the sum are the trigger level jets built by the anti-kt algorithm with radius parameter $R = 0.4$ which uses the calorimeter topo-clusters reconstructed from the full set of calorimeter cell information as inputs. The clusters are calibrated with the local calibration weights (LCW). The jets have an area-based pile-up subtraction applied.
- **Pile-up fit (PUFIT)**: The inputs to the sum are the calorimeter topoclusters where an event-per-event fit is performed estimating the E_{T} contribution from pile-up in each of the towers.

For high thresholds, trigger rate is dominated by events in resolution tails, whose population may vary with the algorithm. Combinations of algorithms accounts for different mismeasurement sources so that efficiency on true-$E_{\mathrm{T}}^{\mathrm{miss}}$ events can be improved for the same rate.

4. The PUFIT algorithm

The PUFIT algorithm was the primary $E_{\mathrm{T}}^{\mathrm{miss}}$ algorithm for the 2017-18 data taking. It follows the approach of correcting the $E_{\mathrm{T}}^{\mathrm{miss}}$ calculation for the PU contribution. First, the algorithm groups the calorimeter transverse energies into *towers* in η and ϕ (different from the L1 ones). The energy sum in each tower is calculated using topoclusters with the local calibration weighting ($\mathrm{tc}_{\mathrm{lcw}}$) applied. The algorithm selects only events where at least one calorimeter tower has an energy deposit with E_{T} above a certain threshold, in order to suppress minimum bias events. Then, a least squares fit is performed to determine the $E_{\mathrm{T}}^{\mathrm{miss}}$ contribution inside hard scattering towers from pile-up, taking into account resolutions. The fit strategy is based on the consideration that the $\mathrm{E_T}$ deposits from PU, individually and in total, should be uniformly distributed in ϕ and should not produce any real-$E_{\mathrm{T}}^{\mathrm{miss}}$. The PU contributions are therefore subtracted from the $\mathrm{E_T}$ for towers above threshold.

In Figure 2, the combined L1 and HLT efficiency of the missing transverse energy triggers HLT_xe110_pufit_L1XE50 (PUFIT) and HLT_xe110_mht_L1XE50 (MHT) as well as the efficiency of the corresponding L1 trigger (L1_XE50) are shown as a function of the reconstructed

$E_{\mathrm{T}}^{\mathrm{miss}}$. The comparison is performed using a subset of the 2017 ATLAS data of 1.3 fb^{-1} with a W $\rightarrow \mu\nu$ selection to provide a sample enriched in real-$E_{\mathrm{T}}^{\mathrm{miss}}$. The PUFIT algorithm shows a better efficiency for values of the $E_{\mathrm{T}}^{\mathrm{miss}} > 130$ GeV.

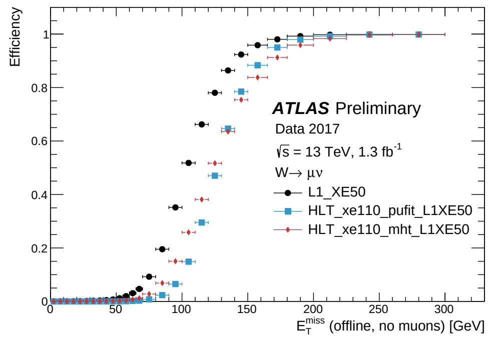

Figure 2: The combined L1 and HLT efficiency of the $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers HLT_xe110_pufit_L1XE50 and HLT_xe110_mht_L1XE50 and corresponding L1 trigger (L1_XE50) [3].

5. MET Trigger Performance Results in Run 2

The performances of the missing transverse momentum trigger during Run 2 have been monitored in both L1 and HLT, using different metrics and selections. The efficiency for a given trigger in a given event selection is defined as the fraction of events passing the event selection that also pass the trigger. The efficiencies for different algorithms are compared by setting thresholds so that they have the same trigger rate. This can be displayed as a function of some parameter, such as the offline reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$.

In Figure 3 (left), the trigger rates for the L1 trigger L1_XE50 are shown as a function of the pile-up. The rates are estimated by applying different noise cuts to data unbiased by a trigger selection and tuning zero suppression for pile-up conditions. In particular, two different noise suppression thresholds ("loose" and "tight") are applied to the $E_{\mathrm{T}}^{\mathrm{miss}}$ from the forward calorimeter (FCAL). The rate is greatly reduced by using the tight threshold with not much loss in trigger efficiency.

The performances of the lowest unprescaled $E_{\mathrm{T}}^{\mathrm{miss}}$-triggers for the years 2015 to 2018 are shown in Figure 3 (right) in terms of trigger efficiencies. Since the trigger calculation does not contain the muon contribution (it uses only information from the calorimeter), a $Z \rightarrow \mu\mu$ selection is applied. The transverse momentum of the Z boson is then used as a proxy for the real-$E_{\mathrm{T}}^{\mathrm{miss}}$ coming from particles that do not interact with the calorimeter. The lower efficiencies in the turn-on region shown for the measurements from later years are due to the threshold having been raised to compensate for increased pile-up. Nevertheless, high efficiency was maintained for events with $E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV.

6. Outlook and Conclusions

Several improvements during Run 2 led to good efficiency of the ATLAS missing transverse

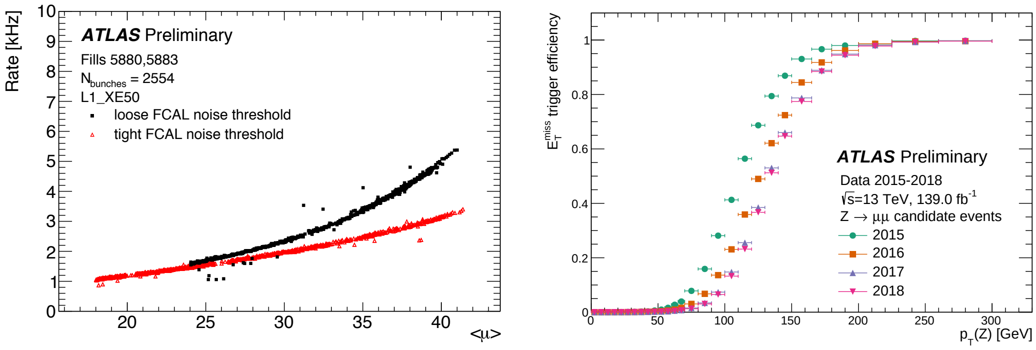

Figure 3: (Left) The trigger rates for the first-level $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger L1_XE50. (Right) L1 and HLT efficiency of the lowest unprescaled $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers for the years 2015 to 2018 [3].

energy trigger while mitigating the effect of the increased pile-up at high luminosity. In particular, the new PUFIT algorithm was succesfully deployed and used as primary $E_{\mathrm{T}}^{\mathrm{miss}}$ calculation. Also, combinations of algorithms were used to fully exploit the different properties and improve the trigger efficiency.

New studies are ongoing to further reduce the effects of the pile-up for the upcoming Run 3 data taking of the LHC. One of the most promising strategies is to exploit the tracks from the new FTK system adding a term to the $E_{\mathrm{T}}^{\mathrm{miss}}$ calculation of existing algorithms like MHT, accounting for the $\mathrm{p_T}$ of tracks coming from the hard scatter interaction but not belonging to any high-$\mathrm{p_T}$ object.

Finally, during the long shutdown following the Run 2 data taking, the ATLAS $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger software is undergoing migration to multi-threaded computing along with the other signatures composing the ATLAS trigger system.

References

[1] ATLAS Collaboration, JINST 3 (2008) S08003

[2] ATLAS Collaboration, Eur. Phys. J. C77 (2017) no.5, 317

[3] ATLAS Collaboration, Missing Energy Trigger Public Results