PROCEEDINGS OF SCIENCE

The ATLAS trigger system

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The ATLAS experiment in the LHC Run 3 is recording up to 3 kHz of fully-built physics collision events out of an LHC bunch crossing rate of up to 40 MHz, with additional rate dedicated to partial readout. A two-level trigger system selects events of interest to cover a wide variety of physics while rejecting a high rate of background events. The selection of events targets both generic physics signatures, such as high p_T leptons, jets, missing energy, as well as more specific signatures targeting specific physics, such as long-lived particles, or di-Higgs events. We will present an overview of the ATLAS trigger system in Run 3, including improvements to the first-level trigger hardware and high-level trigger software compared to Run 2, and of the trigger performance in 2022.

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1. Introduction

The Large Hadron Collider (LHC) Run 3 (2022–2025) will bring an increase in the collision center of mass energy (13 to 13.6TeV) and peak instantaneous luminosity (up to $2.1 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$). The latter will lead to an increase in the average number of simultaneous collisions (pile-up) from 40 to 65, and increase the stress on the experiments' trigger systems. To cope with these conditions, the ATLAS trigger system underwent a major upgrade during the LHC Long Shutdown 2 (2019–2021). This document gives an overview of the ATLAS trigger system and its upgrades for Run 3.

2. First level trigger and upgrades for Run 3

The first level (L1) trigger system selects events based on coarse detector information, identifying high-energy regions of interest (RoI). It is divided into a calorimeter trigger (L1Calo) and a muon trigger (L1Muon). Information from the calorimeter and muon triggers is combined in a topological trigger processor (L1Topo) to calculate quantities such as the angular separation between physics objects. The information from these three systems is combined in the Central Trigger Processor (CTP), which combines the information of the different systems and decides if the event is selected or rejected based on a pre-defined set of selections (menu). The total L1 output rate is limited to 100 kHz due to detector readout constraints. The L1 trigger system was updated to keep Run 2 thresholds/rates in the higher pile-up, as well as making use of improvements on the detectors (or new detectors in general) [1].

L1 calorimeter trigger

The upgrades of the L1 calorimeter system aim at making use of the improved granularity in the Run 3 liquid-argon calorimeter trigger readout. Three FPGA-based Feature EXtractors were introduced: an electromagnetic feature extractor (eFEX), for the reconstruction of electrons, photons and tau leptons, benefitting from the increased granularity to improve the rejection of misidentified jets; a jet feature extractor (jFEX) that reconstructs jets and hadronic taus; and a global feature extractor (gFEX), which reconstructs global event quantities, such as missing transverse energy. The Run 2 system was used for data-taking in 2022, with the new systems running in parallel for validation and commissioning, which is successfully ongoing. Figure 1 shows a comparison of the efficiency of Run 2 and Run 3 L1 systems to identify single electrons, measured with early commissioning data. A comparable performance between both systems can be observed.

L1 muon trigger

The upgrades of the L1 muon system aim at extending its functionality and taking advantage of the new endcap detectors — New Small Wheel [3] and BIS78 [4] — which aim at reducing the rate of fake muons in the region of pseudorapidity $2.7 > |\eta| > 1.2$ by up to 6 kHz [5]. It was upgraded with additional muon information and thresholds as well as the use of full detector granularity for RoI reconstruction. The current focus is on the readiness of the New Small Wheel pad trigger for the 2023 physics run.

3. High Level Trigger and upgrades for Run 3

The High-Level Trigger (HLT) is a software-based system, which analyses the events selected by the L1 trigger, using as inputs the RoIs where the L1 trigger identified high p_{T} objects. It uses

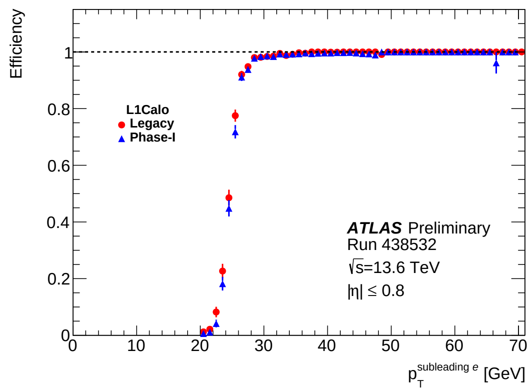


Figure 1: L1Calo single electron trigger efficiencies in the inner calorimeter barrel $|\eta| < 0.8$, measured using $Z \to ee$ events with the tag-and-probe method, as a function of subleading electron p_{T}, for the Run 2 system (red) and for the Run 3 (eFEX-based) system (blue). Source: [2]

higher granularity and more sophisticated selection algorithms.

Upgrades to general HLT software

The software frameworks used for object reconstruction at the HLT and in physics analyses have been migrated to a common multi-threaded framework, AthenaMT [6], making more efficient use of available memory while keeping high throughput [7]. This allows the use of analysis-level reconstruction software directly at the HLT, reducing the differences between the trigger and offline objects, thereby improving the trigger efficiency.

Tracking at the HLT

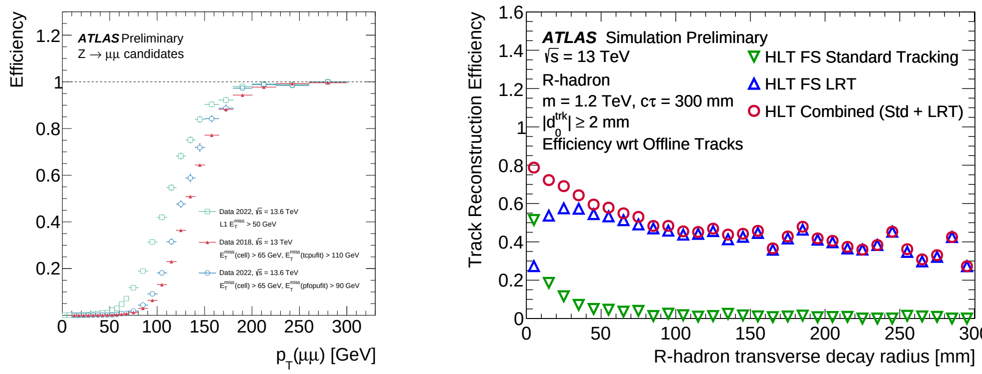
CPU-based, full detector tracking for jet, b-jet and missing transverse energy triggers has been implemented at the HLT. This enables the usage of Particle Flow techniques, which use track information to improve object resolution at low p_{T} and reduce the charged pile-up contribution. Figure 2a shows the improved performance of Particle Flow-based missing transverse energy triggers, in comparison with calorimeter-only reconstruction.

The processing time of full detector tracking algorithms can exceed one second, which is much larger than the average processing time needed to fit within the CPU budget. To overcome this limitation, an early rejection (pre-selection) step based on calorimeter-only information was implemented. For b-jet triggers, a fast b-tagging algorithm — fastDIPS [8] — was developed, which runs on tracks reconstructed within a RoI around the calorimeter-only jets.

A dedicated algorithm for the reconstruction of tracks with large transverse impact parameter — large radius tracking (LRT) — has been implemented, running either in RoI or full detector mode. Figure 2b shows the track reconstruction efficiency for the (charged) decay products of a long-lived supersymmetric R-hadron for two different HLT tracking strategies and their combination, where one can see that for a transverse decay radius above 100 mm, only LRT has non-zero track reconstruction efficiency.

Unconventional trigger strategies

For Run 3, ATLAS has expanded its usage of unconventional trigger strategies with additional resources and trigger chains. One of the explored strategies is the recording of full events in raw



(a) **(b)**

Figure 2: Left: Efficiencies for the missing energy trigger measured with $Z \to \mu\mu$ events where $p_{\mathrm{T}}(\mu\mu)$ is used as a proxy for $E_{\mathrm{T}}^{\mathrm{miss}}$ in 2018 and 2022 data. Ref: [9]; Right: Track reconstruction efficiency for the decay products of a 1.2 TeV supersymmetric R-hadron as a function of the truth transverse decay radius of the R-hadron for two different HLT tracking strategies and their combination. Ref: [10]

format to be processed opportunistically when computing resources are available, the so-called *delayed* trigger stream. $HH \to 4b$ analyses for Run 3 explored dedicated *delayed* triggers, which led to an increase of total trigger efficiency by about 6% [11].

Besides the limited processing time, the HLT is also constrained by the finite bandwidth of the data acquisition system. One strategy to reduce event size and bandwidth requirements is to record only partial event information, i.e. the objects used in the trigger decision, allowing the use of triggers with lower thresholds/higher rates and extending the physics reach to smaller particle masses and coupling strengths [12].

4. Conclusions

This document described the ATLAS trigger system and summarized the status of its upgrades for Run 3 of the LHC. The L1 calorimeter and muon trigger systems were upgraded to both improve their baseline functionality as well as exploit improved trigger readout and new sub-detectors. The HLT has been upgraded to a multi-threaded framework, common with the one used for offline analysis reconstruction. This and other general computing improvements have allowed the implementation of full event scan tracking and an advanced reconstruction algorithm for tracks with large transverse impact parameter. It also allowed exploring unconventional triggering strategies that take advantages of the available resources, increasing physics reach to smaller masses and coupling strengths. Commissioning of the new systems is ongoing successfully.

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