PROCEEDINGS OF SCIENCE

The ATLAS Run-3 Trigger Menu

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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 physics signatures, such as long-lived particles or di-Higgs events. An overview of the ATLAS trigger menu system will be presented, highlighting the new developments and changes for Run 3.

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1. The ATLAS Run-3 Trigger System

The ATLAS [1] two-level trigger system [2] performs the online selection and recording of interesting events. The Level-1 (L1) trigger is mainly based on two independent systems, which use custom electronics to trigger on coarse granularity information from the calorimeters (L1Calo) and the muon detectors (L1Muon). The kinematic information from the reconstructed objects is used by the L1 topological processor to apply topological selections. The L1 trigger decision is formed by the Central Trigger Processor. Events are accepted at a rate up to the maximum detector read-out rate of 100 kHz at a fixed latency below 2.5 µs. Accepted events are sent to the software-based High-Level-Trigger (HLT), which runs on a computing farm of 60k CPU cores and selects up to 3 kHz of fully-built physics collision events (with additional rate for partial readout) to be sent to permanent storage, with an average processing time of around 600 ms. HLT algorithms reconstruct events at a progressively higher level of detail, either in the full detector volume or in restricted Regions-of-Interest (regions where candidate trigger objects have been identified by the L1 trigger).

Run-3 Upgrades

Before the start of Run 3, the trigger system underwent a major upgrade to optimise the performance under the new LHC running conditions: the centre-of-mass energy of proton-proton (*pp*) collisions increased from 13 TeV to 13.6 TeV, with the mean number of interactions per bunch crossing (*pile-up*) increasing from 33.7 to 52. The upgraded system was designed to handle higher levels of pile-up while keeping the same selection efficiency and lower the L1 trigger rate. The L1Calo trigger was upgraded to perform on-detector digitisation of the energy from the LAr calorimeters, allowing reconstruction of electromagnetic clusters with up to ten times better granularity and jets with four times better granularity, as well as algorithms processing data from the entire calorimeter. The L1Muon system was renewed, with the introduction of the New Small Wheel, covering the forward detector region, and consequently a new endcap trigger processor, improving the rejection of fake muons. The HLT software, already redesigned in Run 2 to support multi-processing (inter-event parallelism), was further adapted to support multi-threaded execution (adding intra-event and intra-algorithm parallelism). This reduces the usage of memory per core, allowing to run at higher pile-up without saturating the memory of the HLT farm.

2. Trigger Menu

Events are selected to be recorded if they satisfy the conditions of one or more *trigger chains*. A trigger chain is a sequence of reconstruction and/or selection algorithms targeting a specific signature. A *trigger menu* is the list of trigger chains used for data-taking with their configuration. To facilitate offline data processing, accepted events are recorded into different data sets, called *streams*, which are designed to have minimal overlap. The streams of interest for physics analyses are: the main physics stream, containing events for general physics analyses, the B-physics and light states (LS) stream, containing events specific to B-physics analyses, and the hadronic physics stream, containing specialised hadronic triggers including selections for Vector Boson Fusion and di-Higgs. In addition, the trigger-level analysis (TLA) stream records a limited number of trigger objects with a small event size, accepting events at higher rates while taking up a minor fraction

of the total HLT output bandwidth. Events in the main stream are reconstructed promptly, while the other physics streams are reconstructed when resources are available (*delayed streams*). Stream rates and output bandwidth are shown in Figure 1.

The Run-3 menu for *pp* data-taking is designed to exploit the new Run-3 features while maintaining consistency with the Run-2 menu (e.g. similar trigger thresholds) to facilitate the combination of the data sets. It is constructed to dedicate most of the bandwidth to generic physics signatures, but also contains analysis-specific triggers (targeting e.g. long-lived particles, di-Higgs), which profit of the additional resources available thanks to the Run-3 trigger improvements.

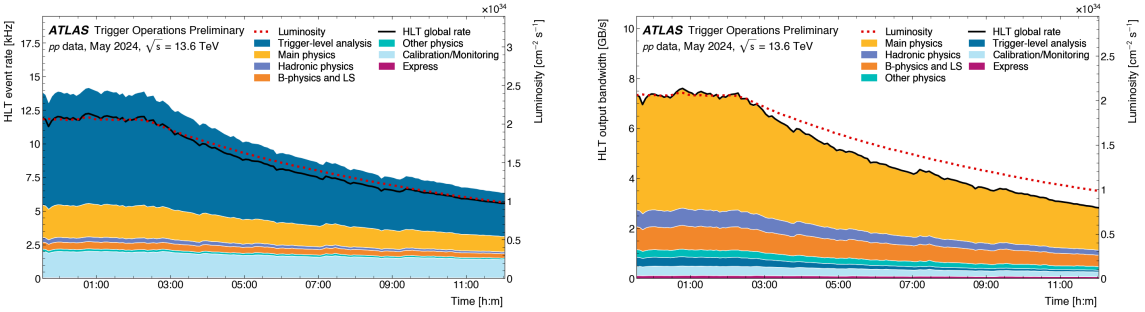

Figure 1: Output rate (left) and bandwidth (right) for the HLT streams as a function of time in a *pp* LHC fill taken in May 2024, with a peak pile-up of 63 [3].

Operation Strategy

The trigger menu has to be able to cope with a variety of LHC beam conditions. The constraints limiting the available rate are the maximum L1 rate of 100 kHz, the HLT bandwidth and CPU resources of the HLT farm, and the offline prompt processing capabilities. During each LHC fill, luminosity declines, increasing resource availability. Trigger rates can be adjusted during the fills to maximise the usage of available resources by applying *prescale factors*, that allow to enable/disable triggers or to execute them on a fraction of events. The prescaling strategy is particularly important for low-p_T B-physics and TLA triggers, enabled or progressively unprescaled when luminosity declines. Figure 1 shows periodic increases in rate/bandwidth, caused by prescale changes.

3. Conclusion

The ATLAS trigger menu is designed to maintain high efficiency in selecting events of interest for all ATLAS physics analyses, while keeping the trigger rates within the strict system limits. The trigger menu was successfully redesigned for Run 3, maximising the use of the improved features of the trigger system, upgraded to cope with the increased centre-mass-energy and pile-up, while maintaining consistency with the Run-2 menu.

References

[1] ATLAS Collaboration, JINST **19**, P05063 (2024).
[2] ATLAS Collaboration, JINST **19**, P06029 (2024).
[3] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerOperationPublicResults.