The ATLAS Trigger System: Ready for Run-2

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The ATLAS Trigger System: Ready for Run-2

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Abstract. The ATLAS trigger system has been used very successfully for the online event selection during the LHC's first run (Run-1) between 2009 and 2013 at centre-of-mass energies ($\sqrt{s}$) between 900 GeV and 8 TeV. The trigger system consists of a hardware Level-1 (L1) and a software-based high-level trigger (HLT) that reduces the event rate from the design bunch-crossing rate of 40 MHz to an average recording rate of a few hundred Hz. During the next data-taking period (Run-2) starting in early 2015, the LHC will operate at $\sqrt{s} = 13$ TeV, resulting in roughly five times higher trigger rates.

We will review the upgrades to the ATLAS trigger system that have been implemented during the long shutdown and that will allow us to cope with these increased trigger rates while maintaining or even improving our efficiencies to select relevant physics processes. These include changes to the L1 calorimeter trigger, the introduction of new L1 topological trigger modules, improvements in the L1 muon system and the merging of the previous two-level HLT system into a single event-filter farm. Finally, we will summarize the commissioning status of the trigger system in view of the imminent restart of data-taking.

1. Introduction

During the Run-1 period between 2009 and early 2013, the ATLAS trigger system [1] operated very successfully. It selected events with high efficiency at centre-of-mass energies ($\sqrt{s}$) up to 8 TeV, for a wide range of physics processes including minimum-bias physics and TeV-scale particle searches.

During the foreseen Run-2 period between 2015 and 2018, the LHC running conditions, as summarised in Table 1, are expected to be challenging to the trigger system: trigger rates for a Run-1-like system are expected to increase by a factor of roughly five in total. A factor of two increase is expected from the increase of $\sqrt{s}$ up to 13 TeV, and will be even higher for high p_{T} jets. The additional factor of 2.5 originates from the peak-luminosity increase from 8×10^{33} cm^{-2}s^{-1} to 1-2 $\times 10^{34}$ cm^{-2}s^{-1}. In addition, the peak number of interactions per bunch crossing (μ_{peak}), which was 40 during the 2012 run, is expected to go up to 50. The bunch spacing reduction from 50 ns to 25 ns, while helping to control the increase in in-time pile-up (interactions occurring in the same bunch-crossing as the collision of interest), will nevertheless increase both the out-of-time pile-up (interactions occurring in bunch-crossings just before and after the collision of interest) and beam-induced fake trigger rates, particularly in the muon system.

In these proceedings, a series of upgrades to the ATLAS trigger system for Run-2 [2] are reviewed. These improvements help to reduce the trigger rates down to acceptable levels, while maintaining or even improving efficiencies in the challenging LHC conditions.

Table 1. The LHC running conditions during Run-1 and Run-2.

Period: year	Bunch spacing	$\sqrt{s}$	Peak luminosity	Peak number of collisions per bunch
Run-1: 2012	50 ns	8 TeV	$8 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$	40 (at $8 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$)
Run-2: 2015-2018	25 ns	13 TeV	1-2 $\times 10^{34}\text{cm}^{-2}\text{s}^{-1}$	25-50 (at $1 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$)

2. New Trigger Features in Run-2

Figure 1 shows a schematic overview of the ATLAS Trigger and DAQ system planned for Run-2. The trigger system consists of a hardware Level-1 (L1) and a single software-based high-level trigger (HLT). This new two-stage system will reduce the event rate from the bunch-crossing rate of 40 MHz to 100 kHz at L1 and to an average recording rate of 1 kHz at the HLT. During Run-1, this was a three-stage system with two stages in the HLT. At L1, fast custom-made electronics find regions of interest (RoI) using the calorimeter and muon data with coarse information within a latency of 2.5 μs. The L1 system in Run-2 consists of the L1 calorimeter trigger system (L1Calo), the L1 muon trigger system (L1Muon), new L1 topological trigger modules (L1Topo) [3] and the Central Trigger Processors (CTP) [4]. At the HLT, fast algorithms accessing data from an RoI, or offline-like algorithms using the full-event information run on a unique PC farm within a processing time of 0.2 s on average. At the end of 2016, a hardware track finder (FTK) is planned to be fully integrated and will provide tracks to the HLT at the L1 rates. For Run-2, many new features were implemented in all the sub-systems. These proceedings describe the major upgrades that have been implemented in L1Calo, L1Muon, L1Topo and the HLT.

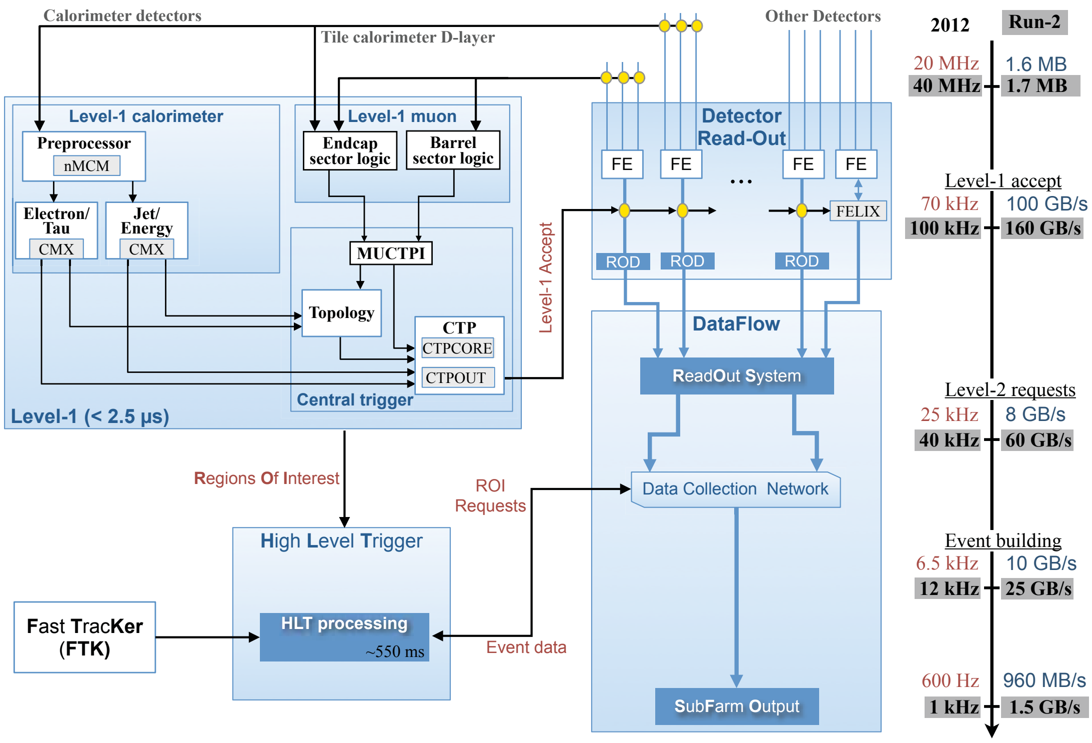

Figure 1. Schematic overview of the Run-2 configuration of the Trigger and DAQ system.

2.1. L1 calorimeter trigger

The L1Calo system processes signals from the electromagnetic (EM) and hadronic calorimeters in a pipeline and provides trigger signals to the CTP. During Run-1, one of the most severe problems of the L1Calo system was the high L1 rates of missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) triggers, which were strongly affected by pile-up near the start of a bunch train, as shown in Figure 2. This behaviour resulted from an unbalanced overlap of bipolar signal shapes in the Liquid Argon calorimeter.

The solution adopted for Run-2 is to use more flexible signal processing in the new Multi-Chip Modules (nMCM) built with FPGAs instead of ASICs, as displayed in Figure 3. This allows the L1Calo system to use an auto-correlation filter and dynamical pedestal subtraction based on global cell occupancy and a bunch position in each LHC bunch train. Significant rate reduction can be achieved with the new system in Run-2 for the $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers, as shown in Figure 4. For instance, in the case of a 70 GeV threshold, the rate is expected to be reduced by a factor of 50.

Furthermore, the number of thresholds to be applied to the different L1 trigger objects are roughly doubled with respect to Run-1: from 12 to 25 for jets and forward jets, and from 8 to 16 for both EM and tau clusters.

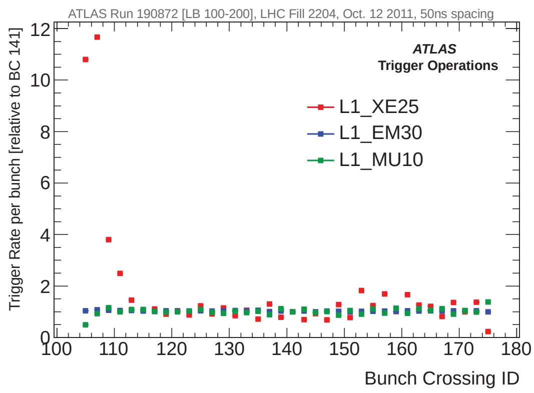

Figure 2. L1 trigger rates as a function of bunch crossing identifier (ID), measured across one of the bunch trains of a typical LHC fill with 50 ns spacing during a Run-1 operation. L1_XE25 is a $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger with a 25 GeV threshold. L1_EM30 is a single electron/photon trigger with a 30 GeV threshold. L1_MU10 is a single muon trigger with a p_{T} threshold of 10 GeV. The L1_XE25 trigger has a significantly higher rate near the start of bunch trains.

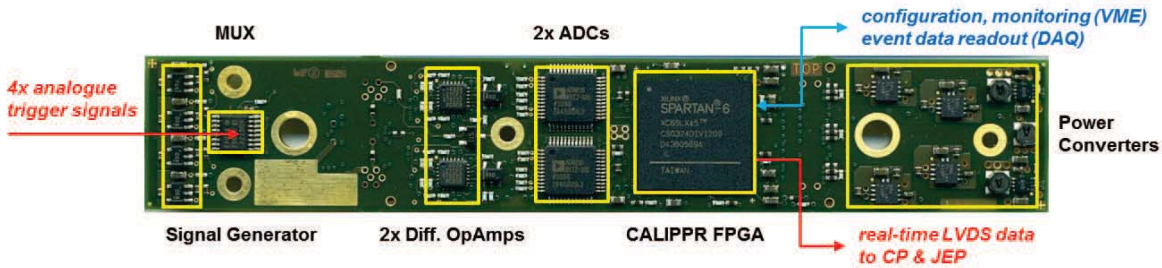

Figure 3. The new pre-processor Multi-Chip Module (nMCM).

2.2. New L1 Topological trigger module

The new L1 Topological trigger modules (L1Topo), which are introduced for Run-2 and include 2 FPGAs per module, calculate event topological quantities between L1 objects within the L1 latency of $\sim 2\ \mu$s and allow the CTP to perform L1 selections based on these quantities. A wide variety of algorithms (around 15) are implemented. The typical examples, as shown in Figure 5, include angular separations between the L1 objects (for better signal-to-background

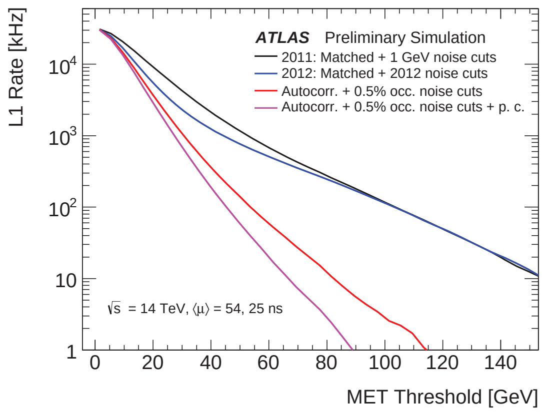

Figure 4. The projected L1 trigger rate as a function of the $E_{\mathrm{T}}^{\mathrm{miss}}$ threshold from a 14 TeV Monte-Carlo simulated minimum bias sample at an average μ of 54 and a 25 ns bunch spacing. The two lines on top correspond to the operation scenarios with 2011 and 2012 noise cuts using matched filters, while the bottom two lines correspond to two Run-2 scenarios with noise cuts using an auto-correlation filter with and without a pedestal subtraction, both possible thanks to the upgraded L1Calo system.

separation, isolation and overlap removal), reconstruction of invariant masses of pairs of objects (for B-physics di-muon events with low p_{T} down to 4-6 GeV), global quantities like H_{T} (sum of jets' E_{T} for fat jets identification), as well as transverse energy and $\Delta\phi$ between L1 $E_{\mathrm{T}}^{\mathrm{miss}}$ and other objects. These topological selections are very useful for selection of final states with $E_{\mathrm{T}}^{\mathrm{miss}}$, jets and taus, like Standard-Model Higgs decays such as $ZH \to \bar{\nu}\nu\bar{b}b$ and $H \to \tau\tau$. As shown in Figure 6, the smallest azimuthal-angular distance ($\Delta\phi$) between the L1 $E_{\mathrm{T}}^{\mathrm{miss}}$ and central jets gives a good separation between the ZH signal and minimum bias background events. By requiring $\Delta\phi > 1$, the L1 $E_{\mathrm{T}}^{\mathrm{miss}}$ threshold can be lowered from 70 GeV to 50 GeV with negligible loss of efficiency.

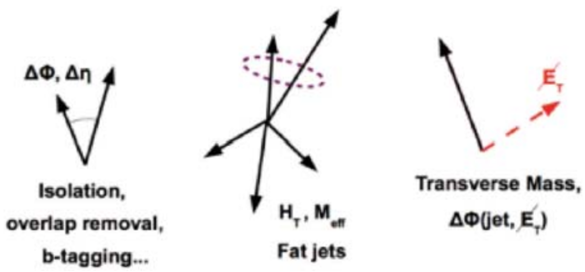

Figure 5. Typical quantities that can be calculated by the new L1Topo modules.

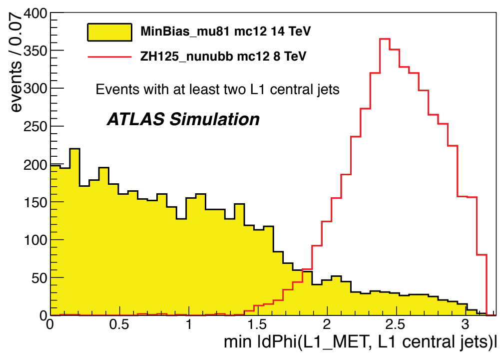

Figure 6. The smallest azimuthal-angular distance $\Delta\phi$ between L1 $E_{\mathrm{T}}^{\mathrm{miss}}$ and L1 central jets with $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 2.5$ for minimum bias (filled histogram) and $ZH \to \bar{\nu}\nu\bar{b}b$ (open red histogram) events with at least two L1 central jets.

2.3. Improvements in the L1 muon system

Improvements are implemented also in the L1 muon system. During Run-1, L1 muon rates in the forward region were mostly fake due to low-p_{T} charged particles (i.e. protons) produced away from the interaction point. At 25 ns, the fake rate from this source is expected to increase.

The solution adopted for Run-2 is to introduce a requirement for coincidences with the inner detector in order to clean up these charged particles. Figure 7 shows the muon spectrometer together with the new segment coincidences. The first new coincidence at $1.3 < |\eta| < 1.9$ is with the inner muon chambers placed just before the endcap toroid. The additional coincidence at $1.0 < |\eta| < 1.3$ is with the extended barrel region of the Tile calorimeter. At 25 ns bunch-spacing and with these new coincidences requirements, roughly 50 % rate reduction is expected for background L1 muons with p_T above 20 GeV in the region $1.0 < |\eta| < 1.9$.

Furthermore, additional muon chambers have been installed in the feet of the barrel region, which will give 4 % larger acceptance for L1 muons.

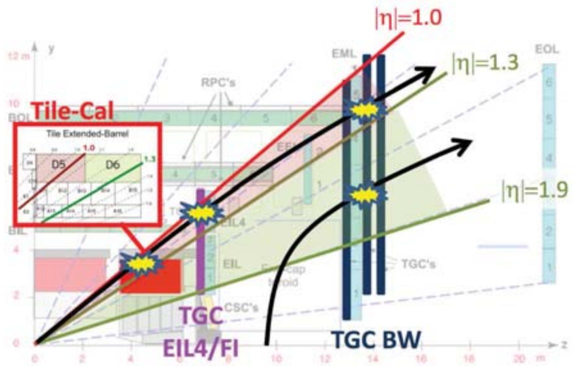

Figure 7. The ATLAS muon spectrometer including a view of the coincidences with the inner muon chambers before the toroid and with the Tile calorimeter.

2.4. Improvements in the HLT system

In Run-2, Level-2, Event Builder and Event Filter farms are merged into a unique HLT farm for simplification and dynamic resource sharing. The technical details can be found in Ref. [5]. Algorithms can still reconstruct trigger objects in RoIs, but now, also unseeded reconstruction algorithms can be run for specific detectors such as the calorimeters and the muon spectrometer. HLT algorithms have been redesigned to take full advantage of the new single HLT system. For instance, processing time can be saved by seeding an offline-like tracking algorithm by a previous fast tracking one, as shown on the schema of Figure 8. Also, trigger performance can be very similar to offline performance by running cluster finding in the full calorimeters right after the L1. Significant improvements in the algorithm performances are described in Ref. [6].

Another important improvement is the significant increase of the bandwidth; the L1 total rate can be increased from 70 kHz to 100 kHz, and the HLT total output rate can be increased from 600 Hz to 1-1.5 kHz at peak luminosity.

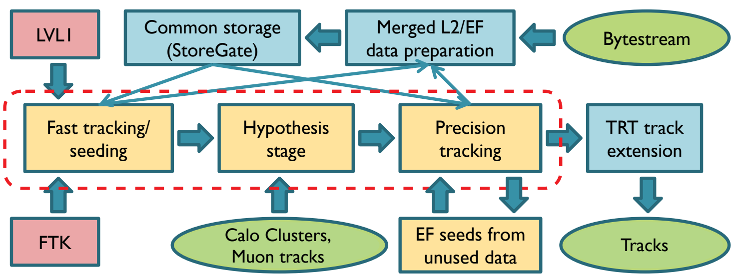

Figure 8. Schematic of the HLT tracking software that is redesigned for Run-2.

2.5. New Trigger Strategy in Run-2

Using the new Run-2 features, a new trigger strategy for bandwidth allocation has been developed in order to maximise the physics coverage. (1) Due to the additional L1 trigger items, the strategy is more flexible than during Run-1. (2) As in Run-1, most of the bandwidth is allocated to generic triggers such as inclusive single electron or muon triggers with E_{T} thresholds of 25-30 GeV. (3) In order to cover all considered event topologies, more dedicated or multi-object triggers are added. In total, a large set of trigger selections is implemented: $\sim$ 300 L1 selections and $\sim$ 1000 HLT selections. These are all being validated both online and using Monte-Carlo simulated samples. With these selections, no significant efficiency loss is expected in the planned physics programme of ATLAS Run-2, despite the challenging LHC conditions.

3. Recommissioning of the ATLAS Trigger System

Since almost one year, the new trigger system has been tested and debugged step by step with the improved DAQ system and ATLAS detector. A series of milestones have been achieved so far: (1) installation of new L1 sub-systems such as L1Calo, L1Muon, L1Topo and CTP (2) intense integration tests of the merged HLT system, (3) data collection with L1 and HLT selections, and (4) deployment of the operation and monitoring tools [7]. The trigger system is currently being operated by the shift crews with expert-on-call support. The ATLAS trigger system is considered to be ready for Run-2. Final commissioning is progressing well using cosmic muon events and initial LHC beams.

4. Conclusion

The ATLAS trigger system was upgraded in order to maintain the trigger rates at acceptable levels under the challenging LHC conditions in Run-2, while keeping good physics coverage. Many improvements were introduced to L1Calo, L1Muon and L1Topo for keeping L1 thresholds low, to a merged HLT farm for running offline-like HLT selections for keeping lower rates, and to the flexible trigger strategy making use of the increased bandwidth. No significant efficiency loss is expected on the planned physics programme of ATLAS Run-2. Commissioning is progressing well towards the restart of the physics data-taking. The ATLAS trigger system is considered to be ready for Run-2. Following the LHC future roadmap and physics programmes for higher luminosities, preparation for the Run-3 trigger upgrade [2] has already started, in particular on the L1 systems.

5. References

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