

The ATLAS Trigger System: Ready for Run 2

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The ATLAS trigger system has been used successfully for data collection in the 2009 – 2013 Run 1 operation of the CERN Large Hadron Collider at centre-of-mass energies of up to 8 TeV. With the restart of the Large Hadron Collider for the new Run 2 data-taking period at 13 TeV, the trigger rates are expected to rise by approximately a factor of 5. Here we present a brief overview of the upgrades to the ATLAS trigger system that have been implemented during the shutdown period in order to deal with the increased trigger rates while efficiently selecting the physics processes of interest. These upgrades include changes to the Level-1 calorimeter trigger, the introduction of a new Level-1 topological trigger module, improvements in the Level-1 muon system, and the merging of the previously two-level High Level Trigger system into a single processing farm.

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1. Introduction

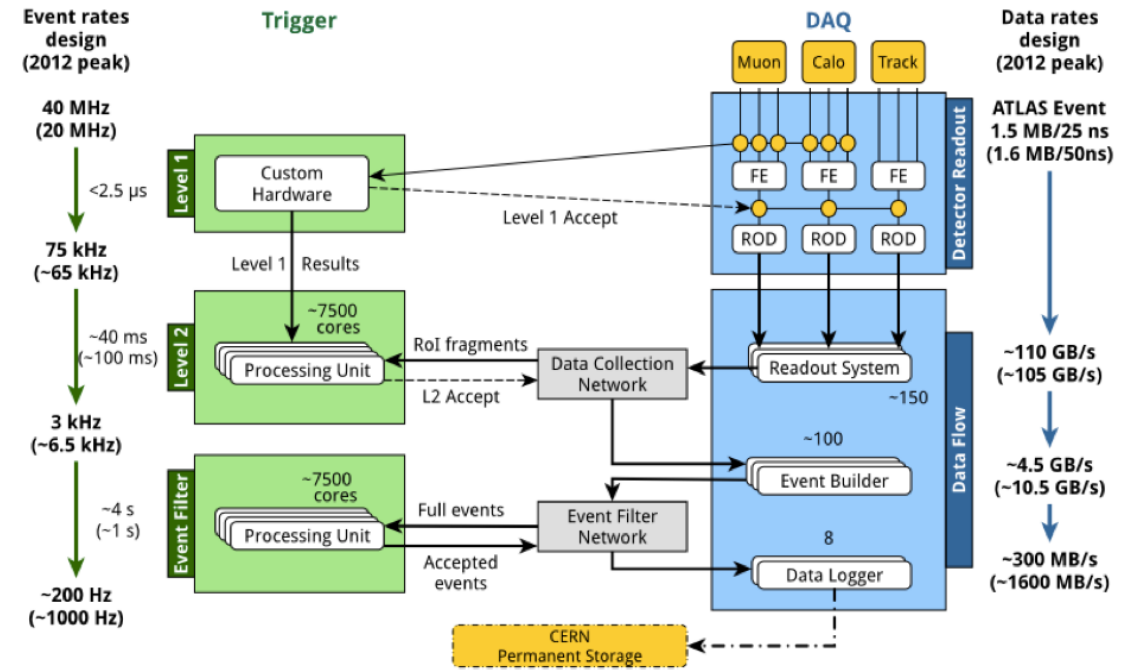
During the CERN Large Hadron Collider (LHC) Run 1, a period between 2009 and early 2013, the ATLAS experiment [1] trigger system [2] operated successfully. It selected events with high efficiency at centre-of-mass energies (\sqrt{s}) up to 8 TeV, for a wide range of physics processes including minimum-bias physics and TeV-scale particle searches. The LHC running conditions during Run 2, are challenging for the trigger system: trigger rates for a Run 1-like system would increase by a factor of roughly 5 – 6. A comparison of Run 1 for 2012 and a prospect of Run 2, planned between 2015 and 2018, parameters is given in Table 1. A factor of two, on average, stems from the increase from $\sqrt{s} = 8$ TeV to 13 TeV, although this rate-increment will be higher for high- p_T jet triggers. An additional factor of 2.5 – 3 stems from the peak instantaneous luminosity increasing from $8 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ to $1 - 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. Furthermore, the peak number of interactions per bunch crossing (μ_{peak}), which was 40 during Run 1, is expected to reach 50 in Run 2. Here we present a selection of upgrades of the ATLAS trigger system for Run 2 in order to improve – or at least preserve – trigger selection efficiencies while keeping the trigger rates at technically feasible levels in the new LHC conditions.

	bunch spacing	\sqrt{s}	peak-instantaneous luminosity	collisions per bunch crossing
Run 1 (2012)	50 ns	8 TeV	$8 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$	25 – 40
Run 2	25 ns	13 TeV	$1 - 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	25 – 50

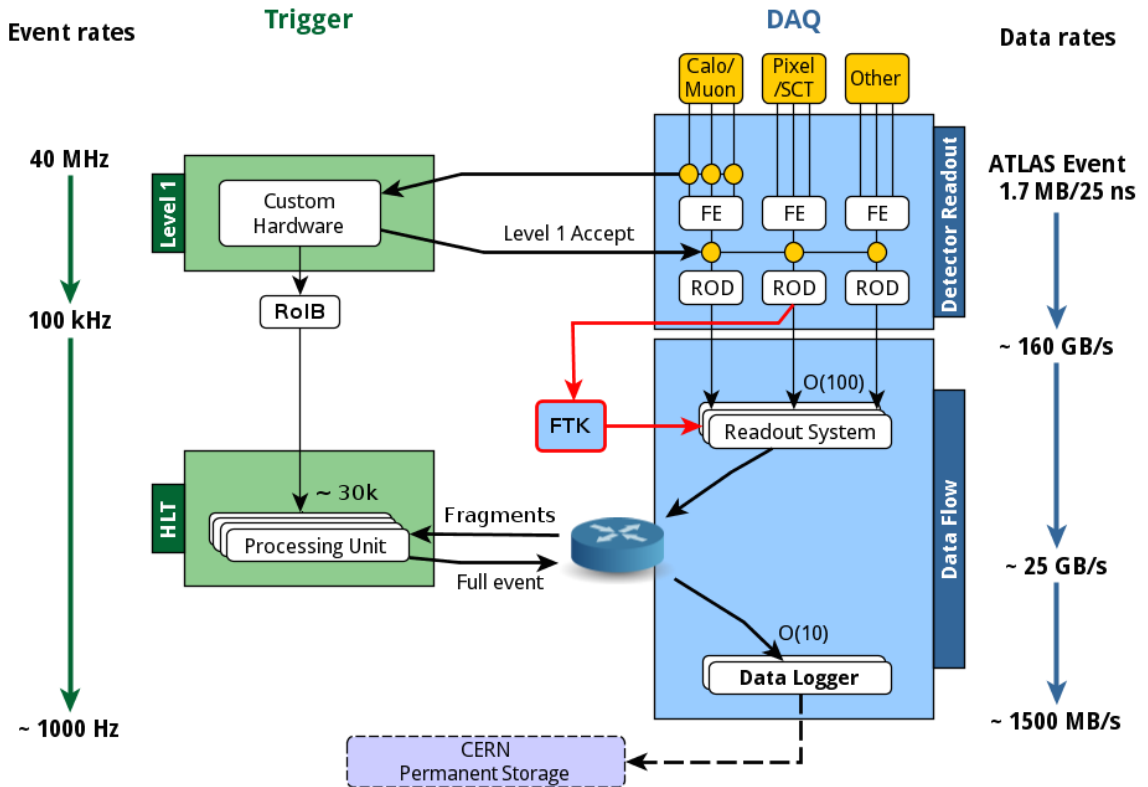
Table 1: Typical LHC running conditions during Run 1 and expected parameters for Run 2.

2. New features for Run 2

During Run 1 the trigger was a three-stage system including a hardware-based Level-1 (L1), and two stages in the High Level Trigger (HLT): Level-2 and the Event Filter. In the new Run 2 trigger system the Level-2 and Event Filter are merged into a single software-based HLT. The Run 2 trigger reduces 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 after passing the HLT. The L1 is based on fast custom-made electronics; it collects coarse information from the calorimeter and the muon spectrometer and processes it with a latency of less than $2.5 \mu\text{s}$. In Run 2, the L1 trigger consists of the L1 calorimeter trigger system (L1Calo), the L1 muon trigger system (L1Muon), the Central Trigger Processors (CTP), as well as the new L1 topological trigger modules (L1Topo). At the HLT, fast offline-like algorithms have access to higher resolution information than the L1 and run on a PC computing cluster with a processing time of 0.2 s per event on average, on the regions of interest as defined by the L1. A hardware fast track finder (FTK) is expected to be fully integrated in the trigger by the end of 2016; it will provide tracks to the HLT at rates of up to 100 kHz [3]. For Run 2 major upgrades have been implemented for L1Calo, L1Muon, L1Topo and the HLT. Figure 1 shows a schematic overview of the ATLAS Trigger and DAQ system for Run 1 and Run 2.



(a)



(b)

Figure 1: The setup of the ATLAS trigger and data acquisition system for Run 1 (a) is compared to Run 2 (b). Event and data rates are also given.

2.1 The L1 Topological Trigger Module

The new L1Topo is currently being commissioned [4]. It is capable to reconstruct derived physical quantities with a rate of 40 MHz, with the field-programmable gate arrays (FPGAs) returning topological calculation results within 100 ns. Examples of such derived quantities and properties (see figure 2(a)) are angular separations between reconstructed objects such as missing energy, leptons, jets; invariant and transverse masses, as well as the scalar sum of the p_T of objects. An example physics analysis use case is the $ZH \rightarrow \bar{\nu}\nu\bar{b}b$ analysis, in which the selection could be shifted from the HLT to L1, thus drastically increasing the trigger rate for this item, is shown in figure 2(b).

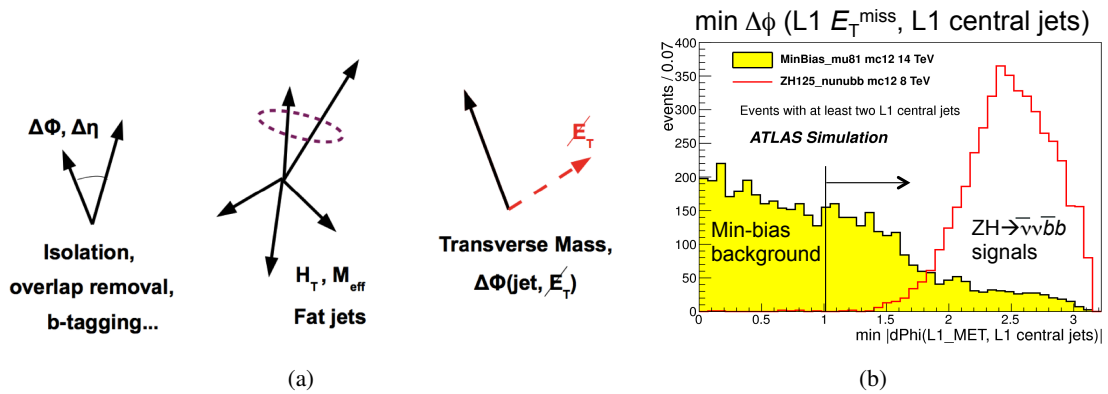


Figure 2: (a) Examples of derived physical quantities and properties that the L1Topo module is able to calculate. (b) The azimuthal angle between the missing transverse energy direction and the nearest central jet: a possible application to the $ZH \rightarrow \bar{\nu}\nu\bar{b}b$ analysis. Taken from ref. [4].

2.2 The L1Calo Trigger

The L1Calo system processes signals from the electromagnetic and hadronic calorimeter and provides trigger signals to the CTP. Just one example of the many updated components for L1Calo are the new Multi-Chip Modules (nMCM); a L1Calo Run 2 upgrade overview diagram is shown in figure 3(a) [4]. The nMCMs enhance the flexibility of signal processing and, for example, allow for dynamic pedestal subtraction; the rate-reducing effect of this technique on the missing E_T trigger is shown in figure 3(b). Furthermore, L1Calo has increased the number of definable thresholds from 28 in Run 1 up to 57 in Run 2.

2.3 The L1Muon Trigger

A new coincidence logic was set up including signals from the new inner muon chambers (the so-called new small wheel, TGC EIL4, or Forward Inner station (FI)) as well as with the extended barrel of the tile calorimeter; as sketched in figure 2.3. The goal of this logic is to reduce the rate of L1 muon candidates stemming from low- p_T proton pollution in the forward regions, $1.0 \leq |\eta| \leq 1.9$, by a factor of 2 compared to the rates observed in Run 1 (see figure 2.3). In addition, L1Muon also makes use of the newly installed trigger chambers at the “feet” of the ATLAS detector to extend its coverage.

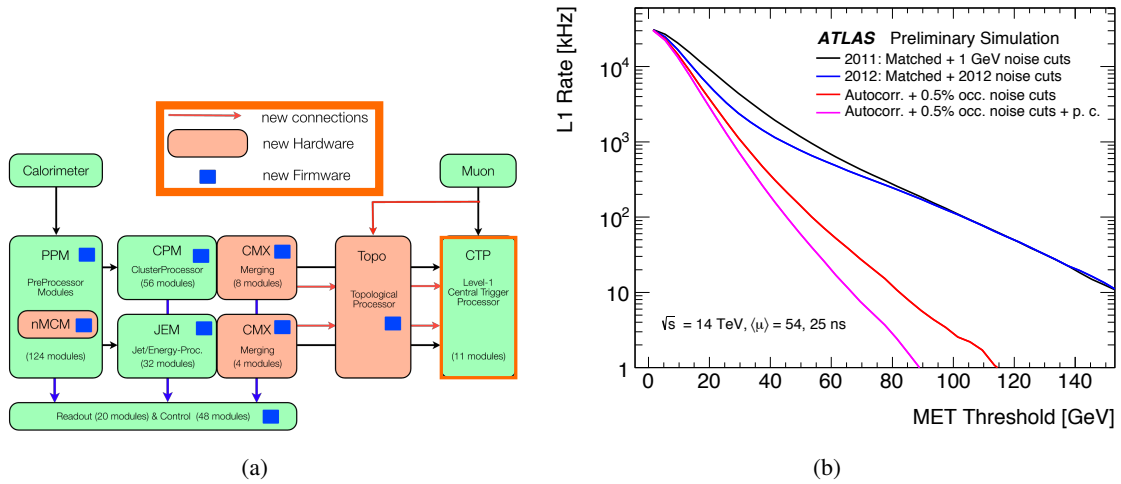


Figure 3: (a) New (red) and updated (blue squares) components of the L1Calo system for Run 2. (b) Simulated Level-1 trigger rate as a function of the missing E_T threshold from 14 TeV minimum-bias Monte Carlo for $\langle\mu\rangle = 54$ and a 25 ns bunch spacing. Shown are the operation scenarios with 2011 (black) and 2012 (blue) noise cuts using matched Finite-Impulse Response (FIR, a type of digital filter, used in bunch-crossing identification) filters and two options for Run 2 with noise cuts optimised for a trigger tower occupancy of 0.5% using autocorrelation FIR filters with (pink) and without (red) a pedestal correction (p. c.) which are possible with the upgraded L1Calo trigger system. Taken from ref. [5].

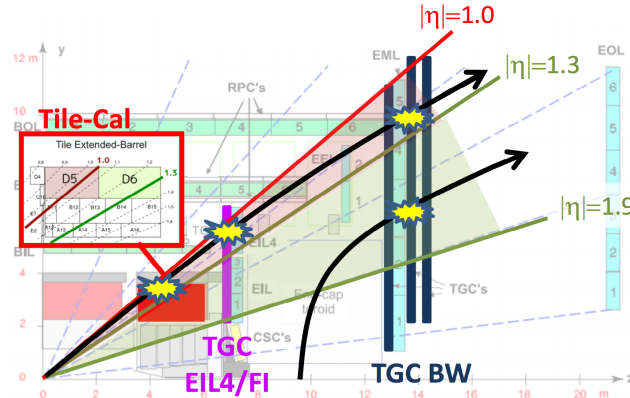


Figure 4: New (pink) and updated components of the L1Muon system, with an overlaid sketch demonstrating the coincidence logic to reduce the low- p_T proton pollution. Taken from ref. [4].

2.4 The new HLT

For Run 2, the Run 1 Level 2 and Event Filter trigger stages were merged into a single trigger stage, the High Level Trigger. A reduction of complexity is achieved, while improving the flexibility at the same time. Furthermore, higher efficiency of resource utilisation and minimisation of duplicate data-fetching are only a few of the improvements of the single-stage merged HLT. A notable software improvement is the adoption of offline techniques and code (where feasible). This harmonisation benefits the data analyses. Due to the improved similarity between online and

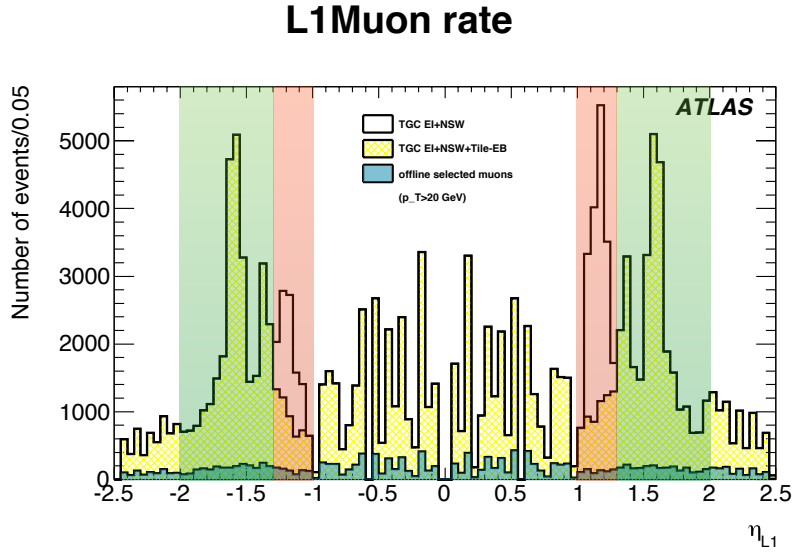


Figure 5: The low- p_T proton pollution rate distribution, as measured in Run 1, as a function of the pseudorapidity, η , where the red (coverage of the Tile Extended-Barrel) and green (coverage of the new small wheel) overlaid η -regions correspond to the regions shown in (a). Many L1Muon candidates stemming from low- p_T protons (yellow fill) will be rejected by the new coincidence logic in the $1.0 \leq |\eta| \leq 1.9$ regions and thus reduce the rate. Taken from ref. [4].

offline reconstructed physics objects the acceptance, after requiring the typical analysis selection criteria, is increased. Moreover, advanced multiprocessing techniques were implemented in order to fully utilise the available hardware.

3. Conclusion

The ATLAS trigger system was upgraded to meet the challenges of Run 2, aiming to improve physics analysis acceptance, rate reduction, efficiency, area coverage and stability with respect to Run 1. The ATLAS trigger is ready for Run 2. Only a small selection of the trigger and data acquisition upgrades deployed between Run 1 and Run 2, such as the new L1Topo, the L1Calo, the L1Muon and the new merged HLT, was briefly discussed here.

References

- [1] ATLAS Collaboration, *JINST* **3** (2008) S08003.
- [2] ATLAS Collaboration, *Eur. Phys. J. C* **72** (2012) 1849, [[arXiv:1110.1530 \[hep-ex\]](https://arxiv.org/abs/1110.1530)].
- [3] ATLAS Collaboration, [CERN-LHCC-2013-007](https://cds.cern.ch/record/1354471), [ATLAS-TDR-021](https://cds.cern.ch/record/1354471).
- [4] ATLAS Collaboration, [CERN-LHCC-2013-018](https://cds.cern.ch/record/1354471), [ATLAS-TDR-023](https://cds.cern.ch/record/1354471).
- [5] ATLAS Collaboration, <http://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults>