The ATLAS Level-1 Central Trigger

Mark Stockton for the ATLAS collaboration
CERN, CH-1211 Geneva 23, Switzerland
E-mail: Mark.Stockton@cern.ch

Abstract.

The ATLAS Level-1 trigger system is responsible for reducing the anticipated LHC collision rate from 40 MHz to less than 100 kHz. This Level-1 selection counts jet, tau/hadron, electron/photon and muon candidates, with additional triggers for missing and total energy. The results are used by the Level-1 Central Trigger to form a Level-1 Accept decision. This decision, along with timing signals, is sent to the sub-detectors from the Level-1 Central trigger, while summary information is passed into the higher levels of the trigger system. The performance of the Central Trigger during the first collisions will be shown. This includes details of how the trigger information, along with dead-time rates, are monitored and logged by the online system for physics analysis, data quality assurance and operational debugging. Also presented are the software tools used to efficiently display the relevant information in the control room in a way useful for shifters and experts.

1. Introduction

The ATLAS trigger uses a three-level architecture. The Level-1 (L1) trigger, is entirely implemented in custom built electronics and is designed to reduce the rate from the anticipated 40 MHz to less than 100 kHz. The subsequent higher-level trigger (HLT) selection is done by software run on PC farms. The L1 trigger decision (L1 accept or L1A) is made by the Central Trigger Processor (CTP) using information from coarse grained calorimeter information, dedicated muon-trigger detectors, and a variety of additional trigger inputs from detectors in the forward regions. A full description of the ATLAS detector can be found here [1].

The L1 calorimeter trigger uses low granularity trigger towers, from the Liquid Argon and Tile Calorimeters, to identify electron/photon, tau/single hadron and jet signatures and calculates missing and total transverse energy sums. The L1 muon trigger receives low granularity input from dedicated trigger detectors. Two detector types are used: Resistive Plate Chambers (RPC) in the barrel region (|η| < 1.05) and Thin Gap Chambers (TGC) in the end-caps (1.05 < |η| < 2.4). The resulting triggers can provide up to two candidates muons per sector for six programmable thresholds.

Located 175 m upstream of the interaction point are the Beam Pick-ups (BPTX) [2]. These electrostatic button pick-up detectors are used to monitor the phase between bunches and the LHC clock, which drives the ATLAS electronics. Originally used directly as beam triggers, they now provide the LHC bunch crossing pattern used by ATLAS to create bunch groups as described in section 2.4. Other forward detectors, not described here and that input to the L1 trigger, are the: Minimum Bias Trigger Scintillators, Zero Degree Calorimeter, Beam Conditions Monitors and LUCID (a Luminosity measurement Using Cerenkov Integrating Detector).
2. L1 Central Trigger

The central trigger system forms the L1A, following the logic defined by the trigger menu, consisting of single items, each with energy and multiplicity conditions, and combinations of these items. It consists of the CTP, Muon to CTP Interface (MUCTPI) and the Trigger Timing and Control system (TTC). Here a brief overview is given of the main parts of the system (see [1] for more details).

2.1. Hardware Overview

Figure 1 shows diagrams of the main boards of the central trigger. The MUCTPI takes data directly from the muon processors and forms multiplicities. It can be used to resolve overlaps and then passes the data to the CTP. If an event passes the trigger conditions region of interest information is sent to the Level-2 trigger and data acquisition system (DAQ). In the CTP, the three CTP input (CTPIN) boards each accept 4×31 inputs, via LVDS signals, all of which are monitored with scalers. Of the 372 input signals 160 signals are selected by a switch matrix and made available via the Pattern In Time (PIT) bus, to then be used by the CTPCORE, see below, and for monitoring in the CTPMON, see section 3.

The CTPCORE module forms the L1A using the signal delivered via the PIT bus as well as internally generated random triggers. It forms up to 256 trigger items by combining the trigger conditions. Some of these can be bunch groups, see section 2.4, which specify the LHC bunch-crossing identification (BCID) per LHC revolution where each particular item is allowed to fire. Individual prescales are optionally applied to each item, followed by a gate, which is controlled by a veto signal, then finally a logical OR of the items. The veto signal introduces dead-time, see section 3.1, using protective dead-time rules and by requests from ATLAS subsystems. The L1A, and other timing signals, are then transmitted to the sub-detector systems via the TTC. The CTP data stored upon each L1A contains the status of the PIT bits and all items: before and after prescale and after veto for the firing bunch, and optionally in a window of early and late signals.

2.2. Operation

The central trigger system is installed underground at ATLAS and is fully operational. In 2010, it ran with L1 output rates of typically around $10^4$ Hz, although it is capable of handling much higher rates. Current ATLAS runs use a trigger menu of 230 out of the 256 items available and the prescale sets are updated on average seven times per run, to adjust the trigger rates to fill the fixed output bandwidth as luminosity decreases. The CTP is maintained by a group of roughly ten people, with an on-call support at all times. The high degree of reliability of the system is evidenced by the fact that this support is called, typically, less than once per week.

With the arrival of collisions came ideas for new software developments to automate some of the tasks done by shifters. For example, the CTPCORE is now used to automatically prescale trigger rates from certain monitoring (i.e. not physics) trigger items. If the software finds that the rate exceeds the value of a configurable threshold then the prescale is updated, after approval from the shifter. Should the rate lower again then the prescale automatically reverts,
again after approval from the shifter. A second example is in the CTPIN, where the software can automatically mask inputs from detectors that are disabled, which, for example, can be the case during ATLAS runs with parallel sub-detector tests or calibration runs.

### 2.3. MUCTPI Timing

One of the tests performed on the MUCTPI was to check for transmission errors by performing a clock fine delay scan between the MUCTPI and the logic modules of the RPC and TGC. The test indirectly measures the relative phase between the incoming muon trigger sector data and the MUCTPI clock. It is performed by altering the phase of the MUCTPI clock, that strobes the incoming muon sector data, by 0.5 ns steps over the full 25 ns range. During this the sector logic modules send a known repetitive test pattern and then for each delay step the data transmission is checked using diagnostics memories. Figure 2 shows that with the current operating point at 3 ns (for the MUCTPI clock fine delay), the signals are strobed correctly with no errors and with timing margins of more than ±5 ns for all 208 trigger sectors.

![Figure 2. Results from a clock fine delay scan, showing the number of sectors with at least one error per delay setting, for RPC (left) and TGC (right).](image)

### 2.4. Bunch groups

The CTP bunch group conditions are used in combinational logic “AND” with other trigger conditions before the L1A is generated. There are eight distinct groups, each with its own particular purpose, defined for each LHC bunch. An illustrative example is given in figure 3. The collision bunch group contains the BCIDs for which the two beams meet in ATLAS, and is thus used by physics data trigger items. The three single beam bunch groups, used for beam background estimates, select bunches corresponding to beams passing through ATLAS, but not colliding. Another bunch group selects a few bunches after collisions, again for monitoring backgrounds and also for slow particle searches. Two bunch groups have a more technical purpose; the calibration requests group defines the times at which sub-detectors may request calibration triggers, typically in the long gap where there are no collisions. The bunch counter reset veto group leaves a short time slice for distribution of the LHC bunch counter reset signal to the on detector electronics. As the LHC fill scheme can vary from fill to fill, ATLAS has developed and commissioned a procedure for monitoring and redefining the bunch groups using the BPTX, see section 1. An online application measures the fill scheme seen by the BPTX and calculates the corresponding bunch groups. The ATLAS trigger shifter compares the suggested bunch groups to the current configuration of the CTP and may generate a new configuration at the press of a button.

### 3. Monitoring

The CTPMON is equipped with scalers counting the number of signals for all 3564 bunch slots (each representing a 25 ns portion of the beam orbit), for each of the 160 PIT lines. The counters are read out and published as online monitoring histograms every ten seconds. The numbers are also written to a conditions database for permanent storage at a configurable rate, typically once
per five minutes. The CTPIN is equipped with 768 counters to monitor all inputs, but unlike the CTPMON they are not bunch-aware. The CTPIN data-rate is thus much lower than that of the CTPMON and can be published and permanently stored with a higher frequency. In addition, all inputs can be monitored, not only those available at the PIT bus. There are also additional scalers in the CTPCORE, important for dead-time corrections, to monitor the rates of the 256 trigger items before and after prescale, and after veto. An example of the CTP monitoring is shown in figure 4 for the 35 GeV missing energy trigger. The timing plot shows the timing of this trigger item, where each curve represents the timing for all BCIDs with colliding bunches, showing that this item is well timed in. The second plot then shows the rate as a function of BCID, which illustrates that the rate is similar rate for all BCIDs with colliding bunches, where the variations are due to luminosity variations. A further example of the per-bunch monitoring is shown in figure 5 as described in the next section.

3.1. Dead-Time

Preventive dead-time is introduced by the CTP to stop the front-end buffers from overflowing, and is calculated in two ways: simple (or fixed) and complex. The simple dead-time is a programmable number of bunch crossings (BC) after each L1A, used for example to avoid overlapping readout windows. The complex dead-time uses a leaky bucket model to emulate a front-end buffer. In this model when the bucket is full there is dead-time. It is defined by $X$ (in units of L1A) being the size of the bucket (i.e. the front-end buffer) and $R$ (in BC) being
the time it takes to leak 1 L1A. With these numbers the trigger rate, on average, is limited to \(X\) triggers in a time period of \(X \times R\) bunch crossings. The current settings within ATLAS are: 5 BC (simple) and \(X = 7, R = 415\) BC (complex). As already described in section 3, the dead-time is monitored per bunch in the CTPCORE as can be seen in figure 5. This shows the bunch train pattern, of around 400 bunches spaced by 150 ns, that produce collisions in ATLAS. This then produces a rate of L1A, which is matched by the simple dead-time veto. The complex dead-time has a more complicated curve, showing how the front-end buffers fill and empty. There is also the DAQ busy, not shown, coming from the sub-detector back-ends that is in logical “OR” with the preventive dead-time.

3.2. Online Software

Online software has been designed to make the data easier to understand in the control room. Two examples of this are the MUCTPI and BUSY Monitoring presenters. Figure 6 shows the first page of the MUCTPI Monitoring presenter. It displays the trigger rate of each of the RPC (centre lines) and TGC (left and right disks) sectors. Here the rate is the sum of both candidates for all thresholds, but it can be configured to show the sum of any of these candidates. This image, created by the software, was taken during a run of stable beam collisions. There is a large enough rate to see the eight-fold structure of the muon detector in the RPC, this is harder to see in the TGC due to statistics. The numbers on the blue/purple coloured background show the MIOCT slot numbers, showing how these are linked between TGC and RPC. The same presenter can also tabulate the results, show histograms, and provides functions to perform the timing analysis as done in figure 4.

The second presenter, for BUSY Monitoring, is shown in figure 7. This relates to dead-time as described above, where during the periods with stable beam collisions the busy fraction must remain low for the majority of the run, so as not to affect data taking by inducing dead-time. The software shows the busy fraction for each detector along with the current dead-time settings. This is a typical busy fraction observed during running and would update automatically showing red bars, with a size proportional to the busy fraction, were the busy fractions to increase. Those in pink or grey are the busy fraction for disabled detectors, as shown in this case for ALFA as it has not yet been installed, and so can be ignored.

3.3. Offline Monitoring

As already mentioned in section 3 all the monitoring data is written out for permanent storage. Each of these log entries has a time stamp allowing plots to be made showing performance as a function of time. Following on from the previous section, figure 8 shows the busy fraction as
a function of time. Here markers have been added to show the period of stable beam collisions so one sees that the majority of the high busy rates did not affect data taking (again ignore ALFA as it is not installed). All trigger item rates are continuously monitored online and figure 9 shows an example for several muon trigger items. The number in the item name gives the transverse momentum cut (in GeV) and MU0_COMM applies no geometrical constraint (road) so only requires a time constraint. This plot clearly shows that as expected the rate reduces as the luminosity lowers during the run. Also shown is the gap in rate during the two periods of stable beams, where primarily the cosmosics rate remains.

4. Conclusion
The ATLAS L1 trigger has been fully commissioned. The software developed for monitoring the CTP has been invaluable for debugging the system and checking data quality, both in the control room and offline. The CTP has performed flawlessly and reliably, to allow ATLAS to collect a 7 TeV physics data-set of 45 pb$^{-1}$ (on 04/11/2010).

References
[1] The ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003.
[2] C. Ohm, T. Pauly, The ATLAS beam pick-up based timing system, Nucl. Instr. and Meth. A(2010), doi:10.1016/j.nima.2010.03.069, arXiv:0905.3648v1