The ATLAS trigger menu for early data-taking

T. Kono
for the ATLAS Collaboration
CERN, Geneva 23, CH-1211, Switzerland

The ATLAS trigger system is based on three levels of event selection that select the physics of interest from an initial bunch-crossing rate of 40 MHz. During nominal LHC operations at a luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$, decisions must be taken every 25 ns with each bunch crossing containing about 23 interactions. The selections in the three trigger levels must provide sufficient rejection to reduce the rate down to 200 Hz, compatible with the offline computing power and storage capacity. The LHC is expected to begin operations in summer 2008 with a peak luminosity of $10^{31} \text{ cm}^{-2}\text{s}^{-1}$ with far fewer bunches than nominal running, but quickly ramp up to higher luminosities. Hence, we need to deploy trigger selections that can adapt to the changing beam conditions preserving the interesting physics and detector requirements that may vary with these conditions.

We present the status of the preparation of the trigger menu for the early data-taking showing how we plan to deploy the trigger system from the first collision to the nominal luminosity. We also show expected rates and physics performance obtained from simulated data.

1. Introduction

The ATLAS trigger is based on three levels of event selection: Level-1 (L1), which is based on hardware and Level-2 (L2) and Event Filter (EF) (collectively referred as the High Level Trigger or HLT) which are based on software algorithms analyzing the data on large computing farms. The three levels of the ATLAS trigger system must reduce the output event storage rate to $\sim 200 \text{ Hz}$ from an initial LHC bunch-crossing rate of 40 MHz. Large reduction against QCD processes is needed while maintaining high efficiency for low-cross-section physics processes including searches for new physics.

Installation and commissioning of the LHC and ATLAS are currently going on and the LHC beam operation is expected to start in summer 2008. The commissioning of the ATLAS detector will begin with single-beam operation and then with colliding beams at low luminosity with only a few bunches, but quickly ramp up towards the LHC design luminosity. During the commissioning phase and in early physics runs, therefore, it is necessary to prepare appropriate triggers at each stage, in order to collect useful data for understanding of the ATLAS detector, the performance of the reconstruction software and the trigger selections.

At each trigger level, several selection logics can be implemented, where the final decision is taken as the OR of all logics. The entire configuration of the selection criteria used at the three levels is called the trigger menu. The trigger menu must be defined taking into account the availability of detector sub-systems at each phase of the commissioning, the efficiency of selecting signal events and the output rate at each level. Currently, several trigger menus for the startup and early physics runs have been developed and the performance was studied with Monte Carlo (MC) simulation.

2. The ATLAS trigger system

The ATLAS trigger consists of three levels (L1, L2 and EF) and selects events of physics interest. The event rate must be reduced from the initial bunch-crossing rate of 40 MHz to 75 kHz, 1 kHz and 200 Hz after L1, L2 and EF, respectively.

The level-1 trigger is a hardware trigger using data from the calorimeters and muon trigger chambers. The L1 calorimeter trigger is capable of triggering on different types of objects: electromagnetic clusters (EM), hadronic
clusters (TAU), jets (JET), forward jets (FJ), missing transverse energy (XE), total transverse energy sum (TE) and total jet transverse energy sum (JE). The L1 central trigger processor (CTP) receives the multiplicities of localized objects above programmable thresholds (e.g., EM clusters with $E_T$ greater than 20 GeV) found by the calorimeter and muon sub-systems, as well as threshold information for the global quantities (XE, TE and JE). The CTP makes a decision based on multiplicities of various thresholds.

While the threshold values and the logic used in the CTP are configurable, the number of different thresholds for each type of object and the number of independent trigger logics (trigger item) are fixed by the hardware design. In particular, the maximum number of trigger items is 256.

The level-2 trigger is a software-based trigger running on ~500 computing nodes with quad-core dual CPU on each node. The L2 system receives the results of the L1 trigger items and information on Regions of Interest (RoI) where L1 observed interesting objects. Execution of L2 algorithms is controlled by the HLT Steering software which runs the algorithm for each RoI. Algorithms then request data from the detector readout system belonging to the RoI and process data in this RoI. This reduces the time spent on the data transfer and the data processing, allowing the execution time per event to be below 40 ms. The EF execution is also controlled by the HLT Steering. At EF, algorithms similar to the ones in the offline reconstruction are run. Since EF algorithms run after the event building, full event data are available.

Events are written out into one or several Streams depending on the EF chains that were passed. The data streaming allows one to reprocess events separately for each stream. This would be useful, for example, if new calibration constants for the muon spectrometer become available, one can reprocess events in the muon stream first without processing events triggered only by the jet trigger. The ATLAS experiment has adopted the inclusive streaming model, i.e., an event passing several EF chains may be directed to several streams. This makes the system simpler at the analysis stage since all events passing the same trigger are contained in the same stream. However, this results in duplicating event data, so the overlap between streams must be kept as low as possible.

It is planned to have five to ten physics streams. In addition to physics streams, there are two special types of streams. One is the express stream which will be used for prompt reconstruction with a short delay after the data-taking. The primary purpose of the express stream is monitoring and debugging before the bulk reconstruction, therefore events in the express stream consist of a sample of high-purity signal events from the physics streams. The other type of stream is the calibration stream which contains events triggered by calibration triggers used to collect a large data sample for detector calibrations. Events which caused errors during online running, e.g., time-outs, crashes etc. are sent to the debug stream to be investigated further.

3. Trigger menu for early running

3.1. Strategy of the trigger menu commissioning

At the beginning of LHC beam commissioning, the luminosity is expected to be very low ($L < 10^{31}$ cm$^{-2}$s$^{-1}$) with only a few bunches in the LHC ring. During the low-luminosity running, rates of physics process are rather low and emphasis will be put on commissioning the trigger system and understanding the trigger performance for higher luminosities.

We plan to start with a simple menu to first trigger on filled bunches using the beam pick-up system (BPTX) and Minimum Bias Trigger Scintillators (MBTS). Data collected by such triggers can be used to adjust the timing of various detector system with respect to the LHC bunch-crossing. Once the timing-in of the sub-systems has been done, the standard L1 trigger can be turned on at low thresholds, but initially running the HLT in pass-through mode which means that HLT algorithms are run, but not used to make the trigger decision. These data can be used to commission the HLT selection.
Table I: Lowest L1 $E_T$ thresholds used in the menu at the luminosity of $10^{31}$ cm$^{-2}$s$^{-1}$.

| Signature                  | Lowest L1 threshold (GeV) | Lowest unprescaled L1 threshold (GeV) |
|----------------------------|---------------------------|---------------------------------------|
| Muon                      | 4                         | 4                                    |
| EM cluster                | 3                         | 7                                    |
| TAU (hadronic cluster)    | 6                         | 40                                   |
| Jet                       | 10                        | 120                                  |
| $E_T$                     | 15                        | 70                                   |
| $\Sigma E_T$              | 150                       | 650                                  |
| $\Sigma E_T^{jet}$        | 120                       | 340                                  |

3.2. Trigger menu for $L=10^{31}$ cm$^{-2}$s$^{-1}$

For early physics runs, several trigger menus for various luminosities are being prepared. In the startup phase, the luminosity is expected to be much lower than the LHC design luminosity ($10^{34}$ cm$^{-2}$s$^{-1}$). We have prepared a comprehensive menu to be used at a luminosity of $10^{31}$ cm$^{-2}$s$^{-1}$, which includes about 130 L1 items and ~180 L2 and EF chains. At this luminosity, the physics emphasis is to trigger on Standard Model processes such as QCD jets, $B$-physics and $W/Z$ events and for use in understanding the detector and reconstruction performance. For the trigger itself, data collected at low luminosity should allow studies of the trigger selection algorithms and the optimization of the trigger for higher luminosities.

At $10^{31}$ cm$^{-2}$s$^{-1}$, rates are comparatively modest, so low thresholds and loose selections can be used at L1, and the HLT can be run in pass-through mode for most physics processes.

Table I shows the lowest thresholds used for each L1 object type with and without prescales. At L1, all muon thresholds can be run unprescaled. They are used for single and multi-muon triggers, and also for $B$-physics triggers at the HLT. The lowest thresholds for unprescaled L1 items for EM and TAU cluster triggers are 7 and 40 GeV, respectively, which run without any isolation criteria. The EM object triggers are used for electron and photon triggers at the HLT. The TAU trigger is used to trigger on the hadronic $\tau$ decay from $Z$, $W$ and top. Eight L1 jet thresholds and corresponding prescales are chosen to give an approximately flat trigger rate across the jet $E_T$ spectrum up to $E_T > 100$ GeV, beyond which no prescaling is applied. The jet triggers are run in pass-through mode at the HLT at this luminosity. The samples selected by jet triggers are used for QCD background studies for many
channels. Figure 1 shows the flat jet $E_T$ spectrum as selected by the trigger. The total transverse energy and $E_T$ triggers are not expected to be crucial for the early running, but are included in the menu to test the performance.

Although many triggers can be run with low thresholds without prescales, triggers with higher thresholds, which can be used at the design luminosity, are also included in the menu for test purpose.

Table II: Total and unique rates for a selected raw data stream configuration.

| Stream              | Total rate (Hz) | Unique rate (Hz) |
|---------------------|-----------------|------------------|
| egamma              | 55              | 48               |
| muon                | 35              | 29               |
| jetTauEtmiss        | 104             | 89               |
| minbias             | 10              | 10               |
| express             | 18              | 0                |
| calibration         | 15              | 13               |

Figure 2 shows a summary of the EF output rates for different groups of triggers, estimated by running the trigger on 7 million simulated minimum-bias events. Grouping of triggers is done in such a way that the “Electron” group consists of all single-electron and multi-electron triggers. Combined signatures like $e + \mu$ are assigned to the “Other topological” group. The rate of each group accounts for the overlap between individual trigger chains belonging to the group. The cumulative rates account for the overlap between the trigger groups. The total output rate of the EF is about 200 Hz, compatible with the target output rate. The L1 and L2 rates are estimated to be about 12 kHz and 620 Hz, respectively.

A possible streaming configuration at a luminosity of $10^{31}$ cm$^{-2}$s$^{-1}$ is four physics streams: electrons and photons, muons, minimum-bias triggers and jet/\Tau/\Pie/ triggers. The stream names indicate the type of trigger signatures they contain. The streaming configuration is defined to have approximately the same proportion of events in each stream and keep the total overlap to less than 10%. The total and unique rates for this streaming configuration are shown in Table III. The overlap between muon triggers and $B$-physics triggers is about 15%, so these have to be merged.
into one stream. The same applies to the overlap between jet triggers and $\tau/\not{E}_T$ triggers. The final optimization of the streaming configuration must be done by analyzing the overlaps with real data.

### 3.3. Evolution to higher luminosities

As the luminosity increases, it becomes necessary to use higher thresholds and tighter selections, and also to turn on HLT selections. Already at a luminosity of $10^{33}$ cm$^{-2}$s$^{-1}$, rates from interesting physics events such as $W$ and $Z$ production become significant, and the use of isolation criteria and $\not{E}_T$ triggers become important. Many prescaled triggers with loose selections and pass-through triggers are included in the menu to study the performance of tighter selections and to optimize the menu for higher luminosities. The optimization must be done by investigating the trigger performance on real data.

### 4. Conclusion

Several trigger menus for different phase of the commissioning and the early running of the ALTAS experiment are being developed. Initially, the commissioning of the trigger system will be done using the BPTX and MBTS as inputs to the L1 trigger. This allows one to adjust the timing of various sub-systems of the ATLAS detector and to commission other L1 triggers. At low luminosity, e.g. $10^{31}$ cm$^{-2}$s$^{-1}$, it is possible to use low thresholds and to use only the L1 trigger to select events. This allows one to study the performance of higher-threshold triggers and to optimize the HLT selections with real data, which is crucial for optimizing the trigger menu as the luminosity increases. The trigger menu for the luminosity of $10^{31}$ cm$^{-2}$s$^{-1}$ has been developed and studied in detail using simulated minimum-bias events. Thresholds, prescales and streaming configurations have been optimized after a few iterations to meet the restriction of 200 Hz output. For the menu at higher luminosities, triggers with higher thresholds and combined signatures will be used for the main physics selections. The initial running will allow further optimization of the trigger menu and reliable extrapolation to higher luminosities.

### References

[1] ATLAS Collaboration, High-Level Trigger, Data Acquisition and Controls Technical Design Report, CERN/LHCC/03-022 (2003).

[2] ATLAS Collaboration, Detector and Physics Performance Technical Design Report, CERN/LHCC/99-14/15 (1999).

[3] ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 S08003 (2008).