Commissioning of the ATLAS Level-1 Central Trigger

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Abstract

The ATLAS Level-1 Central Trigger (L1CT) consists of the Central Trigger Processor (CTP) and the Muon to Central Trigger Processor Interface (MUCTPI). The CTP forms the final Level-1 Accept (L1A) decision based on the information received from the Level-1 Calorimeter Trigger system and from the muon trigger system through the MUCTPI. Additional inputs are provided for the forward detectors, the filled-bunch trigger, and the minimum-bias trigger scintillators. The CTP also receives timing signals from the Large Hadron Collider (LHC) machine. It fans out the L1A together with timing and control signals to the Local Trigger Processor (LTP) of the subdetectors. Via the same connections it receives the Busy signal to throttle the Level-1 generation. Upon generation of L1A the L1CT sends trigger summary information to the DAQ and Region-of-Interest to the Level-2 Trigger system.

In this contribution we present an overview of the final L1CT trigger system as it is now installed in the ATLAS experiment and we describe the current commissioning and integration activity at the experimental site. The system is now continuously used during cosmic-ray runs to exercise the full trigger chain and read-out of sub-detectors. These test are bridging the experiment towards the commissioning phase with protons in the LHC started this summer. We discuss in particular the results achieved in operating the system with cosmic-rays and, the commissioning results with the first proton events in the LHC.

I. INTRODUCTION

ATLAS [1] is a general-purpose detector at the CERN Large Hadron Collider (LHC). At the design luminosity of 10^{34} cm⁻²s⁻¹ the detector will be exposed every 25 ns to, on average, 25 proton-proton interactions. These conditions make the environment for the trigger system extremely demanding. It has to reduce the input event rate of 1 GHz to the limit of the storage rate of 200 Hz or less.

The ATLAS trigger system is divided into the Level-1 Trigger (LVL1), which is implemented in dedicated hardware, and in software-based High-Level Trigger. The LVL1 is a synchronous system working at the LHC bunch crossing (BC) rate of 40.08 MHz. It uses information from the calorimeter detector and muon spectrometer to reduce the event input rate to less than 75 KHz within 2.5 μs . Figure 1 shows an overview of the Level-1 ATLAS trigger system.

The Level-1 Central Trigger (L1CT) [2] consists of the

Muon-to-Central-Trigger-Processor Interface (MUCTPI), the Central-Trigger-Processor (CTP), and the Timing, Trigger and Control partition (TTC). The MUCTPI receives information from the muon trigger detectors and combines it before sending it to CTP. The CTP forms the the Level-1 decision every BC and sends it together with the timing and control signals to the TTC partition of each sub-detector. The TTC distributes the timing, trigger and control signals to the sub-detector front-end electronics.



Figure 1: Overview of the ATLAS Level-1 trigger system.

II. THE MUCTPI

The functionality of the MUCTPI is to combine the muon candidates from each muon trigger sector and to produce the total muon multiplicity for each of the six p_T thresholds. It resolves possible candidate double counting due to muon tracks that traverse more than one muon sector. This information is made available to the CTP, and for events selected at Level-1 the MUCTPI sends data to the Level-2 and to the DAQ system.

The MUCTPI is implemented in custom-designed 9U-VME64 modules and comprises 3 different kinds of modules plus a dedicated active backplane. There are 16 Octant Modules (MIOCT) which receive muon candidates from all 208 trigger sector logic. Each MIOCT time-aligns the muon candidates from 13 trigger sectors, resolves candidate overlaps and forms the local multiplicity.



Figure 2: The final MUCTPI as it is installed in the ATLAS experiment.

The results are made available on the backplane (MIBAK). Each module has also memory used either in snapshot or programmable mode to monitor the trigger input or store the calculated candidate multiplicity. The MIBAK forms the total multiplicity and transfers the readout data from the MIOCT to the readout driver (MIROD). The MIBAK also distributes the timing and trigger signals to the system. The candidate multiplicity is sent to the CTP via the CTP interface module (MICTP) which also receives from the CTP the trigger and timing signal. The MIROD, for each Level-1 accepted event, sends summary data to the Level-2 and the DAQ system. Figure 2 shows the system, in its final configuration, as it is installed in the experiment.

III. THE CTP

The CTP receives, synchronizes, and aligns all trigger inputs, and forms the Level-1 Accept (L1A) decision. The L1A is throttled by preventive dead-time and ROD Busy signals from DAQ in order to avoid front-end buffers to overflow. The CTP receives timing signals from the machine if available, or generates them. It sends these signals with the L1A to the TTC partition of each sub-detector. For each L1A it sends summary information to the Level-2 trigger and to the DAQ system. The CTP features also extensive monitoring capabilities. It can count incoming trigger rate and monitor the rate of programmable trigger combinations.

The Level-1 trigger decision is based on several trigger inputs. Candidate multiplicity from the calorimeter and muon detectors comprise electron/photons, taus/hadrons, jets and muons. The calorimeter detectors also provide the following energy flags: the scalar sum of the total transverse energy,



Figure 3: The final CTP as it is installed in the ATLAS experiment.

the total missing transverse energy and the total scalar sum of the jet energy. There are 5 specialized triggers, namely: the Beam Pick-ups (BPTX), the Minimum Bias Trigger Scintillator (MBTS), the Beam Condition Monitors, the Luminosity Counters and the Zero Degree Calorimeter. Each sub-detector can also request triggers for calibration purposes. At any given run period a maximum of 160 trigger inputs can be used. In addition the CTP generates 2 random triggers, 2 pre-scaled clocks and 8 bunch groups. According to a programmable Level-1 trigger menu 256 trigger items are created by combining one or more conditions on trigger inputs. Each trigger item has a mask, a priority and a pre-scale factor. The priority is used in the algorithm to generate dead-time such that high priority items see as little dead-time as possible. The L1A is the logical OR of all enabled 256 trigger items.

The CTP is implemented in 6 different types of customdesigned 9U-VME64 modules and 3 dedicated backplanes as shown in Figure 3. The machine interface (CTPMI) receives the BC and Orbit signals from the LHC, and make them available to all other modules through the common bus (COM). The input module (CTPIN) receives trigger input signals, aligns and synchronizes them. The CTPIN has also scalers to monitor combinations of trigger inputs. There are three CTPIN in a CTP crate in order to receive up to 372 trigger inputs. Up to 160 trigger inputs are sent to the core module (CTPCORE) via the Pattern-In-Time bus (PIT). The CTPCORE combines the trigger signals into up to 256 trigger items, forms the L1A, and sends summary information to the Level-2 and the DAQ system. The CTPCORE applies to each trigger item the pre-scale factor and the preventive dead-time, and at each of these consecutive steps it features counters to register the trigger items

activity. The monitoring module (CTPMON) performs bunchper-bunch monitoring of trigger items. The output module (CT-POUT) sends timing and trigger signals to the TTC partition and receives the busy signal and the calibration request. There are four CTPOUT modules in a CTP crate. The calibration requests are sent to the calibration module (CTPCAL) through the calibration bus (CAL). The CTPCAL time-multiplexes the calibration requests and receives additional front panel input. The NIM to LVDS module receive additional front panel input.



Figure 4: Four LTPi modules connecting the Liquid Argon Calorimeter TTC partition to allow concurrent calorimeter runs independent of the ATLAS running condition.

IV. THE TTC PARTITION

The Timing, Trigger and Control partition distributes timing signals (BC, Orbit), trigger signals (L1A, test triggers), the trigger type word (8-bit), and commands (bunch counter reset (BCR), event counter reset (ECR)) to the front-end readout of each sub-detector. The TTC partition contains a Local Trigger Processor (LTP) which receives TTC signals for the CTP or generates them when running stand-alone. It propagates back to the CTP the busy signal coming from the sub-detector frontend. The TTC partition also contains a TTC system to generate the BCR, to multiplex TTC signals and to send them optically to the sub-detector front-end. There is also a ROD-Busy module which collects the busy signals from the readout drivers of the sub-detector front-end, forms an overall BUSY signal and sends it to the LTP. Optionally, a TTC partition contains an LTP interface module (LTPi).

A. The LTPi

The LTPi is a switch module from the LTP signals introduced to allow concurrent runs of groups of sub-detectors without the CTP. The LTPi has three inputs (from the CTP, from another LTPi, and from a local NIM input), and three outputs (to the LTP, to another LTPi, and to a local NIM output). The module features active equalizers for the LVDS inputs to reshape the signals after being transmitted through long cables (up to 60 meters), and delay chips (delay25) to compensate cable skew and adjust the phase of signals before the LTP. The LTPi can also generate a trigger type word according to the active signals on the three test-trigger inputs. Presently, almost all sub-detectors are using LTPi modules. The actual connection of TTC partition is organized in three independent loops by using the LTPi. These three loops allow concurrent stand-alone running of the muon detector, the calorimeter detector and the inner detector. Figure 4 shows four LTPi connecting the Liquid Argon Calorimeter TTC partition at the ATLAS experimental site.

V. COMMISSIONING

The L1CT system is being used in cosmic-ray runs since more than 2 years to provide trigger signals to an increasing number of sub-detectors as they are being integrated in the AT-LAS experiment. Since few months the L1CT has been running in its final configuration receiving all foreseen trigger inputs and providing trigger signals to all sub-detectors. Cosmic-ray runs are particularly useful to exercise the system, to spot problems, and to improve monitoring capabilities. These runs are also important to synchronize the distribution of the timing signals to sub-detectors and to timing-in trigger inputs. At the beginning of September we started preparing for the first beam events in the ATLAS experiment. To have a reference signal induced by the beam we used two systems: the BPTX and the MBTS.

A. BPTX

The Beam Pick-ups are electrode pads placed onto the beam pipe at 175 m upstream the ATLAS interaction point. Both beam pipes are equipped with a set of electrode pads to monitor the passage of each beam. When a bunch traverses these pads it induces a very fast (rising time O(ns)) bipolar signal, proportional to the number of protons in the bunch. This signal is discriminated and send to the CTP. The BPTX signal is the time reference for the ATLAS experiment determining the presence of a filled bunch in the detector. It will be also used to monitor the beam intensity and the presence of satellite bunches around filled bunches. At bunch intensity $> 5 \times 10^9$ protons it has a trigger efficiency of 100% up to nominal LHC intensity.

B. MBTS

The Minimum Bias Trigger Scintillator are plastic scintillators placed in the forward region of the ATLAS detector. They are arranged in two discs located 3.5 meters from the interaction point and covering the transverse region within 14–88 cm from the beam axis. Each disc is divided into 8 identically ϕ sectors and each section is divided into an inner and outer part, for a total of 16 scintillators per side. Each scintillator is readout by a single photomultiplier. The signal of the photomultiplier is shaped by using the hadronic calorimeter electronics, it is discriminated and fed into the CTP. The CTP receives a trigger input for each of the 32 MBTS signals. This system is particularly useful in the initial period of the LHC start-up. It is relatively simple to commission, and it has a good trigger efficiency for single beam events like beam-losses, beam-gas, and beam-halo events.



Figure 5: Event display showing one of the events where the beam was dumped onto the collimator upstream the ATLAS detector. The event was triggered by the MBTS and the calorimeter trigger at Level-1.



Figure 6: Event display of one of the first circulating beam event in which all MBTS counters (figure right-hand side) produced a signal.

C. Commissioning with beam

The very first events to trigger on were exceptional events, where a proton bunch was sent onto the beam collimators. About 2×10^9 protons interacted with the collimator upstream the ATLAS detector and resulted in a extraordinary number of secondary particles traversing the detector. The trigger setup for these initial events was such to ensure a good probability to trigger some of these events. The trigger items enabled were the lowest E_T threshold in the electromagnetic and hadronic calorimeter (1EM3, 1TAU5, 1J5) and the MBTS. We chose

these trigger items because they had a large probability to fire a signal, they were timed-in with the detector readout and because they had an acceptable cosmic trigger rate of about 20 Hz. A small cosmic trigger rate helped in minimizing the dead-time of the system, and thus enhancing the probability of being ready to trigger on the "collimator event". Figure 5 shows one of these events as reconstructed in the ATLAS detector. After these spectacular events, we had a phase where the beam had been circulating for several turns. At the beginning of this phase the beam was not very collimated producing large signals in the detector (fig. 6) and had a lifetime of 10 to few hundreds LHC turns. In these conditions we had signals in the BPTX, in the MBTS and in the other triggers contributing to the L1A. These events enabled us to measure the relative delay of the BPTX with respect to the MBTS. We measure the BPTX delay by looking at the scope traces (fig. 7) of the BPTX and the MBTS, and by using the CTP readout data. The BPTX input to the CTP was then pipelined by the appropriate delay. The BPTX trigger bit was taken as the time reference of the passage of a bunch in the AT-LAS detector. For this first period the BPTX signal was the only trigger item contributing to the L1A decision. The oscilloscope screen shot in Figure 7 shows the BPTX discriminated pulse and signals from three MBTS counters. The time separation between two consecutive signals in each channel corresponds to the LHC turn of $89\mu s$. It is interesting to notice that the BPTX and the MBTS are sensitive to different beam conditions. At the beginning of injection (first pulses) there were BPTX triggers and little signals in the MBTS, this is probably due to the fact that the bunch had its maximum intensity and it was relatively clean. After few turns the BPTS didn't fire a trigger probably because the bunch lost intensity, while the MBTS were still producing large signals being sensitive to beam-halo.

The monitoring capabilities of the CTP were particularly useful at this time. We constantly monitor online the rate of each trigger input to the CTP versus time. This is the first sanity check to determine if trigger signals sent to the CTP are actually received, and to monitor the behavior of trigger inputs which are not enebled in the trigger menu. For all Level-1 trigger items included in the trigger menu, the rate at each step towards the Level-1 trigger decision is monitored, made available on the online information service, and permanently stored in a database. The rate is sampled for each luminosity block: a programmable time interval that represents the time unit of data taking of the experiment. The rate is calculated for signals on the PIT bus, for trigger items before pre-scale, after pre-scale, and after dead-time is applied. This information is essential to determine the dead-time of the experiment. This information is based on counters that record signals every bunch crossing, independent of whether or not the corresponding event will be accepted by the trigger decision. For events accepted by the full trigger chain the L1CT readout data are available offline. The CTP can be programmed such that it sends to the DAQ system together with the information relative to the Level-1 decision the activity of each trigger item in a programmable time window around the bunch-crossing corresponding to the L1A. This information is relevant to determine the time alignment of trigger items with respect to the L1A. Figure 8 shows such information in the form of a two-dimentional plot. On the x-axis there are the different trigger items before pre-scale (this plot only shows item 8 to 86

of the 256 items), and on the y-axis there is time in unit of BC with respect to the L1A. For this data sample the L1A was always fired by the BPTX. By using this information, after having integrated more events, we started to determine the time offset of stable trigger items with respect to the L1A. After the very first period of circulating beam in the LHC, the beam became much more clean, circulating in the LHC for several minutes. During this phase, the majority of the events had activity only in a small part of the detector, being compatible with beam-halo and beam-gas events. At this stage we triggered also on forward muons using the muon forward trigger input (TGC). Figure 9 shows a display of an event triggered by the TGC and also seen in the muon precision chambers. This event is compatible with a beam-gas event upstream the ATLAS detector.



Figure 7: Oscilloscope screen shot. From top to bottom the four channels correspond to the BPTX discriminated pulse and signals from three MBTS counters. The time separation between consecutive signals in each channel corresponds to the LHC turn of $89\mu s$.



Figure 8: Two-dimentional plot that shows the number of triggers for each trigger item around the BC associated to the L1A. The plot shows only items 8 to 86 of the 256 items. The time window on the y-axis in unit of BC is centered on the BC of the L1A (BC=0) and goes from -15 to 15 BCs. The colors (gray intensities) are proportional to the number of triggers in the cell.



Figure 9: Event display of an event triggered by the forward trigger muon detector (red), seen also in the muon precision chambers (blue).

VI. CONCLUSION

The ATLAS first-level trigger is a 40MHz synchronous system based on information from the calorimeter and the muon detector and on dedicated trigger detectors. It reduces the event rate from 1GHz to about 75KHz within a latency of less than 2.5 μs . Since a few months the system is complete and it has been routinely used during cosmic-ray data taking. This September, we have successfully used the system with the LHC in inject and dump mode and with single beam radio-frequency capture and circulating for several minutes. These first days of data taking with beam represented an important milestone in the commissioning and operation of the trigger system. We succeeded in collecting beam events then reconstructed in the ATLAS detector, and we started the final phase of the commissioning of the L1CT with circulating beam in the LHC.

REFERENCES

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