The First Result of Global Commissioning of the ATLAS Endcap Muon Trigger System in ATLAS Cavern

T. Sugimoto[a], Y. Okumura[a],Y. Takahashi[a],M. Tomoto[a], C. Fukunaga[b], M. Ikeno[c], H. Iwasaki[c], K. Nagano[c], M. Nozaki[c], O. Sasaki[c], S. Tanaka[c], Y. Yasu[c], Y. Hasegawa[d], H. Oshita[d],T. Takeshita[d], M. Nomachi[e],Y. Sugaya[e], T. Kubota[f], M. Ishino[f], N. Kanaya[f], T. Kawamoto[f], T. Kobayashi[f], T. Kuwabara[f], H. Nomoto[f], H. Sakamoto[f], T. Yamaguchi[f], T. Kadosaka[g], K. Kawagoe[g], H. Kiyamura[g], H. Kurashige[g] , T. Niwa[g], A.Ochi[g], C. Omachi[g], H. Takeda[g] , R. Lifshitz[h], N. Lupu[h], S. Bressler[h], S. Tarem[h], E. Kajomovitz[h], S. Ben Ami[h], O. Bahat Treidel[h], Y. Benhammou[i], E. Etzion[i], D. Lellouch[j], L. Levinson[j], G. Mikenberg[j], A. Roich[j]

[a]Nagoya University, Nagoya, Japan
[b]Tokyo Metropolitan University, Hachioji, Japan
[c]KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[d]Shinshu University, Matsumoto, Japan
[e]Osaka University, Osaka, Japan
[f] ICEPP, University of Tokyo, Tokyo, Japan
[g]Kobe University, Kobe, Japan [h]Technion Israel Institute of Technology, Haifa, Israel
[i]Tel Aviv University, Tel Aviv, Israel
[j]Weizmann Institute of Science, Rehovot, Israel

takuya.sugimoto@cern.ch

Abstract

We report on the ATLAS commissioning run from the view point of the Thin Gap Chamber (TGC), which is the ATLAS end cap muon trigger detector. All the TGC sectors with on-detector electronics are going to be installed to the ATLAS cavern by the end of September 2007. To integrate all sub-detectors before the physics run starting from early 2008, the global commissioning run together with other sub-detectors has been performed from June 2007. We have evaluated the performance of the complete trigger chain of the TGC electronics and provide the trigger signal using cosmic-ray to the sub-systems in the global run environment.

I. Introduction

In the ATLAS detector system, Thin Gap Chamber (TGC) is used to generate the level-1 muon endcap trigger signal. Since many years, we have optimized and designed the electronics as well as the software system for this purpose [1]. Based on the idea described in this reference, we have then constructed our own custom ICs (ASICs), boards and modules. The validity tests of these components have been done in various ways.

The first slice system with electronics set of the minimum number of input channels (128) necessary to produce a local trigger signal has been set up in 2001 and we have extended gradually the system either by using final ones instead of prototype components or adding some more components for both the trigger and readout data processing streams. In this slice test system, we have used input signals generated by pulse pattern generators. Inputting many different patterns, we have confirmed the validity of the trigger logic implemented in the system, and predicated the latency based on the measurement from this setup. We have published the results in [2].

We have brought the system into the beam test runs using the real chambers in 2003 [3] and 2004 [4]. In this setup the chambers are arranged to configure a part of actual TGC setup in the ATLAS detector. We have tried to validate the system with the chamber signals which were produced by high energy muon hit with CERN SPS H8 beam line. In these beam tests our system has been integrated into the whole ATLAS level-1 trigger system as well as the data acquisition system. TGC trigger candidate signals has been inputted to the central level-1 trigger processor and were distributed to the sub-detector components.

From 2004, the mass production of the electronics components has been started. In early 2005 we have also started the assembly of a TGC 1/12 sector unit. The sector is a unit for construction of an endcap station (as we have discussed later we have three stations in each endcap side) as well as the trigger and readout logical unit, and it consists of 18-22 chambers in which the number depends on the endcap station where the sector is mounted. The on-detector electronics system ramified into the sector were mounted on the sector surface. We have tested carefully the cabling and the electronics mounted on a sector with the embedded test pulse system and cosmic rays. The sectors were regarded as ready for mounting in a station if this test was passed successfully. The mass production of the 1/12 sectors has been completed recently in the end of August 2007. The construction and the electronics test have been discussed in detail in [5] and [6].

Since several endcap stations in a side has been nearly constructed in the cavern in May 2007, we have recently done an integrated data acquisition test using parts of the barrel and the endcap muon chambers (RPC; Resistive Plate Chamber and TGC for the trigger and Monitored Drift Tube, which we denote MDT in short, for high precision muon tracking) with cosmic rays. Participated ATLAS sub-systems were RPC and TGC with their level-1 muon trigger systems, MDT, the level-1 trigger central system, and the data acquisition system. RPC and TGC detected cosmic ray muons and then their electronics systems generated the trigger signals. The signals are relayed to the level-1 central trigger system, and it distributed the signal to the readout system of sub-detectors (TGC, MDT, Level-1 trigger etc.) We have succeeded to take data and got some sensible results. In this report we would like to discuss mainly the cosmic ray trigger system of TGC in the ATLAS cavern and the data analysis done with data (MDT and TGC) taken by this combined runs after we discuss short review of the ATLAS and TGC level-1 trigger systems.

II. ATLAS LEVEL-1 TRIGGER SYSTEM

In this section we briefly review the ATLAS level-1 trigger, whereas the discussion in this section will be limited to some relevant parts of the system for this report.

The level-1 trigger system comes to the first stage of the ATLAS event selection system which is composed of three stages. The level-1 trigger system uses only raw electric signals of sub-detectors to make trigger decision, and intends the event selection rate from 40MHz of bunch crossing down to 100KHz. The trigger decision should be done within maximum latency of 2.5μs. The system must also identify the bunch crossing to which an event of the trigger belongs. As shown in Fig. 1, basic ingredients of the level-1 trigger system are the calorimeter, RPC and TGC as the signal sources, MUCTPI (MUon CTP I/F), CTP (Central Trigger Processor) and TTC as signal processing and distributor systems.

From about 7000 trigger towers data, the calorimeter trigger system tries to identify isolated high-p_T electron/γ, hadron/τ with $|\eta| < 2.5$ with its cluster processor, and jets, large missing E_T, ΣE_T with $|\eta| < 3.2$ and also jets and ΣE_T with $|\eta| < 4.9$ with its Jet/Energy-sum processor. The information of the position and the energy of clusters/jets are fed forward to the CTP; Central Trigger Processor.

For muon trigger, RPC covers barrel region ($|\eta| < 1.05$) and TGC covers the endcap and forward regions ($1.05 < |\eta| < 2.4$). Both RPC and TGC identified muons with six pT thresholds based on hit information of total about 800 000 strip and wire channels. The information of the position and pT for muon candidates are sent then to MUCTPI where signals at the overlaps over two segments in RPC and ones between the barrel and the endcaps are processed. MUCTPI tries to identify single muon to avoid the double count if signals from a track are observed in two different segments.

The main task of CTP is to accept several inputs from the calorimeter and muon triggers, and makes the overall trigger decision. The output trigger signal generated by CTP is called L1A (Level 1 Accept).

The TTC system is responsible for distributing fast timing signals to the front-end electronics of the sub-detectors, which are LHC clock, L1A trigger signals, BCR (Bunch Crossing Reset), ECR (Event Count Reset) and test pulses. Thus L1A issued by CTP is distributed to all the ATLAS readout systems by the TTC complex system (it consist of fibers, distributers and front-end receiver chips etc.).

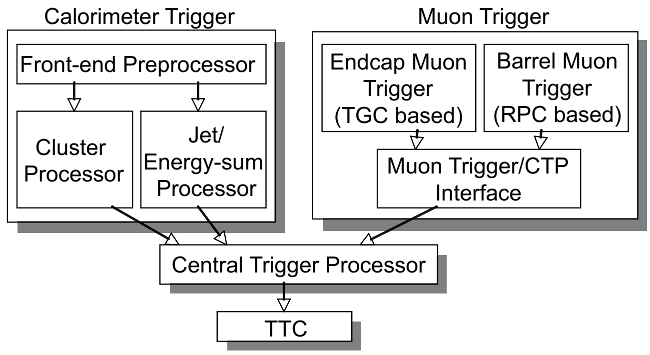

Figure 1: Block Diagrams of the ATLAS level-1 Trigger Processing

III. MUON ENDCAP TRIGGER SYSTEM

As described in Section I., TGC is used as muon trigger detector in the ATLAS endcap region. TGC detects muons with two coordinates (with wires for η and strips for ϕ), and it is subdivided in η and ϕ space into trigger sectors. The trigger sector is a logical unit that is treated independently in the trigger signal processing. TGC endcap in one side is further divided into two regions, End-cap ($|\eta| < 1.9$) and Forward ($|\eta| > 1.9$). There are two different trigger sector shapes for these two regions. The size of an End-cap trigger sector is $\Delta\eta \times \Delta\phi = 0.9 \times 0.13$, and the total number of the sectors is 48/side while the size of the Forward sector is 0.5×0.26, and the number of the sectors is 24/side.

The on-detector trigger electronics receives as input the pattern of hits from about 320 000 channels in TGC. For both sides, three TGC stations are used to identify isolated muons whose $p_T > $ 6GeV/c, and these stations are called M1, M2 and M3. M3 is the furthest from the interaction point. As the M1 is triplet (TGC three layers) and the another stations are doublet (two layers each), with total seven observations the coordinates (η and ϕ) and the p_T are evaluated for a muon. The M1 (M2) station is positioned in 13m (15m) from the interaction point in Z direction (along the beam) while the distance between M2 and M3 are about 50cm. The radii of the stations are 10m and 12m for M1 and M2 as well as M3 respectively.

Coincidences in different stations are identified in η and ϕ independently, based on geometrical path whose width is related to a programmable p_T threshold making use of the deflection of muons in the magnetic field. The coincidence operation is done in two steps for each coordinate. The principle of the trigger logic for this two step coincidence is similar for both coordinates except number of measurement points and granularity. Firstly consistency check of the hit positions is done, on the hand, if the signals come from a single track with using two doublet stations. If there are three measurements out of the four layers of two doublets are regarded as the same origin, i.e., a single muon track, the coordinate η (ϕ) at M3 and its difference $\Delta\eta$ ($\Delta\phi$) from M2 to M3 are recorded and passed to the next coincidence circuit with a local trigger signal. On the other hand the triplet data are checked if it has sensible hit data for single muon track. If there are two hits out of three layers for wire or one out of two for strip channels, then the coordinate value at M1 is recorded in this case and the data are sent also to the next stage. But no local trigger flag is set even if the triplet trigger condition is satisfied. In this second coincidence test, if the local trigger flag is set, the hit position of the above data (the coordinate at M3 and one observed at M1) are checked if both the coordinate data are consistent with the same muon track. If this test is passed, the updated information about the coordinate difference and the coordinate at M3 are sent to the sector logic. Unless the track matching is done, simply the data recorded in the first coincidence operation (with two doublets) are fed to the sector logic. Besides the trigger logic operation, the front-end part of the on-detector electronics identifies the proton-proton bunch crossing of candidate tracks.

In the off-detector electronics, which is installed in a counting room next to the ATLAS cavern (called USA15), combines the trigger data of two coordinates into muon candidates per trigger sector. The Sector Logic sends two muon candidates at maximum per trigger sector with p_T threshold values and position at the M3.

Currently (August 2007) assembly and installation of full TGC stations including the on-detector electronics components of one side has been completed (Fig. 2), and one station in the other side are being constructed in the cavern.

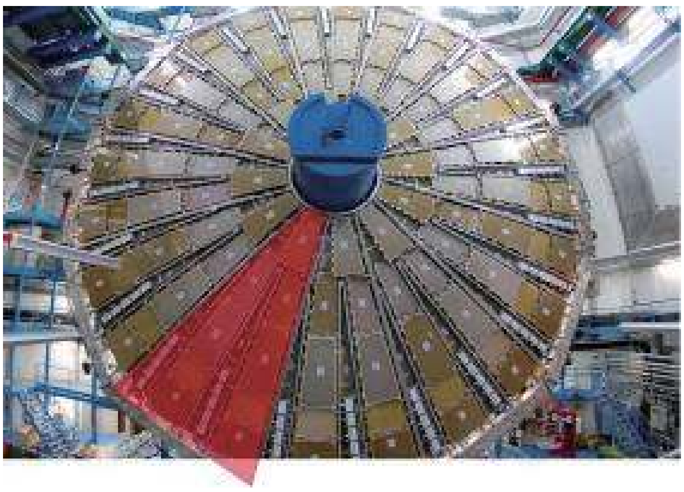

Figure 2: Completed TGC station M1 (the most outer one), the shaded (red) part in the figure means the sector used in the current global commissioning. Original in color

IV. Integration of Muon Endcap Trigger System

A. TGC Cosmic Ray Triggers

For the first global commissioning run done in the middle of June 2007, we have used only one 1/12 sector (C09) of the M1 station (triplet). The sector is shown as the shaded area in Fig. 2. This sector contains four End-cap trigger sectors and two Forward trigger sectors. In order to participate the global commissioning run with one 1/12 sector of the M1 station and to signal the cosmic ray muons with this sector, we have to devise special trigger logic rather than the normal muon trigger for the beam-beam collision mode. We have already a trigger logic to detect muons using the M1 triplet information solely in the normal trigger mode as discussed in Section III. However, as a trigger window in the M1 station is constructed to form a projective tower along a line from the interaction point, the efficiency to detect cosmic ray muons which are normally injected vertically to the flight line of muon from the interaction point will be low. Note also that TGC gas system is still temporary. We used CO_2 for this commissioning test, and estimated the chamber efficiency of about 20%. Considering this situation, we have grouped two End-cap trigger sectors and one Forward sector into one segment (this corresponds to 1/24 sector consequently), and then made logical sum for the triplet coincidence signals of all the trigger towers in this segment. Even if the number of triplet towers which have muon signals in a segment is only one, the signal will be identified as a cosmic ray muon. For the signal generation, we used only the trigger information of wires, and neglected one of strips. Since we intended to increase the trigger rate, we took this OR logic scheme and neglect of the strip trigger. After adjusting the threshold voltage appropriately, we observed the rate of the cosmic ray muon as 3 – 5Hz.

The trigger information from two segments is relayed independently with two 90m optical fiber cables to the sector logic installed in USA15, then the data have been further sent to MUCTPI. Although we used the sector logic, it had not special trigger logic implemented but made pass-through of data to MUCTPI.

B. Results of Commissioning and Integration with TGC Cosmic Ray Trigger

Although only the triplet wire trigger has been activated for the determination of cosmic ray muon candidates, important achievements with this global commissioning could be listed as follows;

1. the trigger path from the TGC sector logic as the normal output of the TGC trigger system to the ATLAS central trigger system has been established,
2. TGC segment installed into the ATLAS DAQ system could configure its own system, and readout data through the standard ATLAS DAQ system of ROD-ROS chain, and
3. TGC Detector Control System (DCS) was successfully implemented into the ATLAS central DCS-DAQ system, and

could control and monitor various detector items necessary for the TGC operation from this framework.

Among these achievements, we would like to discuss how we could confirm the TGC trigger worked fine. The central trigger in turn was configured to trigger on the muon signals provided by TGC and RPC, and distributed L1A that initiated the readout system of the sub-detectors involving TGC. Fig. 3 shows readout TDC distributions of the endcap MDT with TGC and RPC triggered [7]. The distribution with TGC triggered show a clear distribution of minimum ionization particle between 1000 and 2000 counts with a sharp peak at around 1200 without background while the same distribution triggered by RPC is smeared out on top of offset values due to background over all the counting range. This indicates more appropriate muon trigger signals were sent to the endcap MDT readout system from TGC than RPC from the trigger timing point of view, and hence the TGC was succeeded to send correct cosmic ray muon signals over sub-detectors in the vicinity.

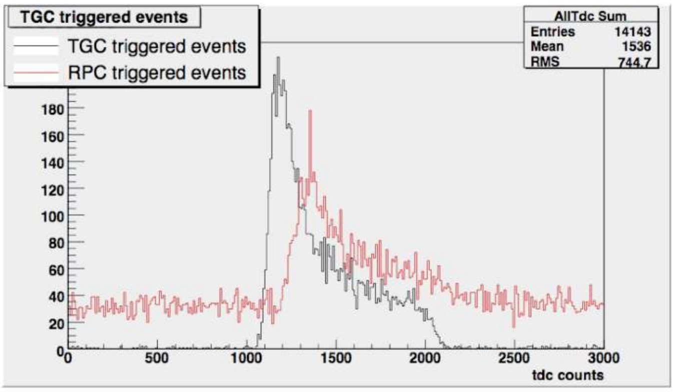

Figure 3: TDC distribution of the endcap MDT in the M2 station; original color. The histogram shown in black is the TDC distribution with TGC cosmic ray muon trigger while the one in red is the distribution with barrel RPC cosmic muon trigger. TGC trigger gives the appropriate timing for muons to be observed in the endcap MDT. Original in color

In the meantime we have measured the latency of the cosmic ray muon trigger that can be measured in the following way;

1. the test pulse at the timing of a trigger signal generated by the TGC system is injected into the TGC readout system,
2. the depth (length) of the readout pipeline is adjusted so that the corresponding test pulse is just at the output-end of the pipeline (L1) buffer when L1A issued by this TGC trigger is inputted to the TGC readout system (this time duration is actually the latency), and
3. we can find that the latency is just this adjusted depth ($\times$ 25ns).

With this procedure, we have found the latency observed are 76 clocks (1.90μs) in this setup. We can also estimate this latency value simply from several measurements done in the previous slice or beam tests [2, 3] with adjusting actual cable length. Then we found the latency estimated for this setup was 75 clocks. We can find that the core part of the level-1 trigger system is working stable from the point of view of timing.

V. Conclusion

The transfer of trigger data from TGC muon trigger system to the central trigger system via MUCTPI has been succeeded. Both the systems could be frequently co-operated in test runs with cosmic ray muon triggers in combination with other ATLAS sub-detectors like muon precision chambers (MDT). In this circumstance, as shown in Fig. 3, the TGC cosmic ray muon trigger system was found to provide sensible muon triggers to the endcap MDT, although we have been forced to set up some temporal modification to the trigger generation logics. Since we found that the cosmic ray muon triggers has been very useful for validity test and integrity check of the sub-detector system (including also TGC), TGC should participate with gradually larger scale than this in forthcoming global commissioning runs in order to provide reliable cosmic ray muon triggers which will be useful for detector tuning and elimination of bugs if any.

VI. Acknowledgments

We are grateful to the ATLAS MDT group, especially, Prof. Frank Taylor and Dr. Joao Guimaraes da Costa for their kind permission for us to use the TDC distribution data taken by MDT in the global commissioning.

References

[1] ATLAS First Level Trigger Technical Design Report CERN/LHCC/98-14 (1998), http://atlasinfo.cern.ch/Atlas/GROUPS/DAQTRG/TDR/tdr.html

[2] K. Hasuko *et al.*,"The First Integration Test of the ATLAS End-cap Muon Level 1 Trigger System", *IEEE Trans. Nucl. Sci.* **50** (2003) 864-868.

[3] K. Nagano *et al.*, "Beam Test of the ATLAS End-cap Muon Level1 Trigger System", Proceedings of the 9th Workshop on electronics for LHC and future experiments, Amsterdam, 2003, pp.265 - 269 CERN 2003-06 (2003)

[4] Submitted to Nuclear Instruments and Methods A

[5] H. Nomoto *et al.*, Installation and Test of the ATLAS Muon Endcap Trigger Chamber Electronics", Proceedings of the 11th Workshop on electronics for LHC and future experiments, CERN 2007-01 (2007)

[6] T. Kubota *et al.*, "Final Test at the Surface of the ATLAS Endcap Muon Trigger Chamber Electronics", presented in this workshop.

[7] ATLAS MDT group, private communication, June 2007.