

# Preparation of Test Data from the Simulated and Test Beam Data for Testing the ATLAS New Small Wheel FPGA-Based Trigger Processor

Jayasree S<sup>1</sup>, Reshmy V R<sup>2</sup>, Dr. Lorne Levinson<sup>3</sup>

<sup>1,3</sup>Weizmann Institute of Science, Rehovot, Israel and CUSAT, Sarabhai Institute of Science and Technology, Vellanad, Trivandrum, (DIST)-Kerala 695543, India

<sup>2</sup>CUSAT, Sarabhai Institute of Science and Technology, Vellanad, Trivandrum, (DIST)-Kerala 695543, India

**Abstract:** This paper deals with the development of a test program for testing the FPGA based trigger processor for the ATLAS detector in LHC experiment in CERN. This detector will be upgraded in order to benefit more from the high luminosity. As the luminosity increases there will be large number of fake data will be produced. To filter this fake trigger a three level trigger system is used. The trigger processor is a hardware (FPGA) processor that receives data from the ATLAS detector. In order to develop and test the trigger algorithm we need to inject simulated data into the processor's input path. The ATLAS detector simulation programs generate hits in detectors. We also have real detector data recorded in test beams. Both must be processed to provide the input expected by the trigger processor.

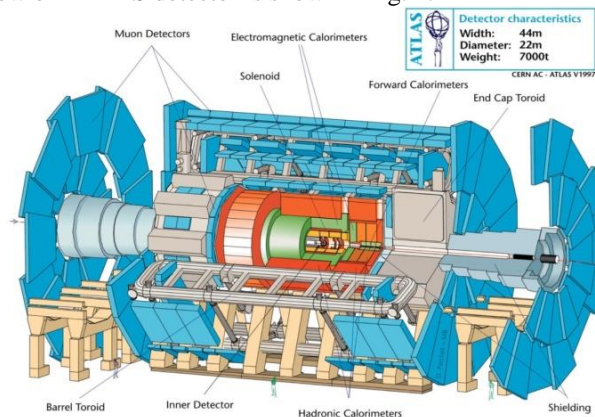
**Keywords:** CERN, ATLAS, LHC, Higgs Bosons, Muons

## 1. Introduction

The CERN is a European research organization for particle physics. It operates the world's largest and complex particle physics equipment, Large Hadron Collision (LHC) [1]. LHC is an underground large accelerator ring of 27 kilometers in circumference at the CERN Laboratory in Geneva, Switzerland. LHC in CERN has seven detectors to detect particles and to study about them. ATLAS (A Toroidal LHC Apparatus) [Error! Bookmark not defined.] is one of those detectors. It was involved in the discovery of the particle consistent with Higgs Boson [2]. Higgs Bosons are elementary particles whose existence can explain why some fundamental particles have mass and some others don't.

An event in the ATLAS detector is the occasion of two elementary particles colliding [3]. Billions of collision will occur in the ATLAS detector per second. Whenever a particle hit the ATLAS detector it will produce signals. These particles are released by the collision of two bunches of protons. Protons released from the proton source outside the detector, are accelerated in opposite directions in the LHC and will collide at the center of ATLAS detector. Interesting collision will release six different types of particles including photons, electrons and leptons like muons. The signal generated in the ATLAS detector by the particle hits will be stored for further analysis. There are six different layers of detectors in ATLAS for detecting these particles. For the further high sensitive experiments in future, the ATLAS detector need to be upgraded as those experiments need to be performed in higher luminosity. This upgradation procedure is planned for different stages. This ATLAS detector will undergo a long shutdown in 2018. After that second long shutdown in 2018 the accelerator luminosity will be increased to  $2-3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . This is in the Phase I upgradation.

In order to benefit from the expected high luminosity performance that will be provided by the Phase-I upgraded LHC, the first station of muon [4] end-cap system (Small Wheel, SW) will be replaced. The muon end cap, shown in fig. 1, system is used to detect muon particles. Muons are one among the different elementary particles released at the time of proton collision in the ATLAS detector. A cross sectional view of ATLAS detector is shown in fig. 1.



**Figure 1:** Cross sectional view of ATLAS

While using SW in high luminosity there were a lot fake triggers. As the background rate increases the performance of muon tracking chamber also decreases. In order to solve this problem, it is decided to replace SW with new Small Wheel (NSW). ATLAS detector also has three level trigger system. The first level (L1) [5] [6] is implemented in custom-built electronics. The L1 consists of calorimeter, to identify electron, photon and muon. These three level will help to reduce the fake trigger.

## 2. Literature Review

The ATLAS detector will help to study the fundamental forces that shaped the nature. In the Phase II upgrade of LHC

[7] the Small Wheel, a muon detector, will be replaced by new Small Wheel. This NSW will improve the sensitivity and the resolution of the data. While reconstructing muon tracks with high precision as well as furnishing information for the Level-1 trigger the NSW will be put to operate in a high background radiation region of about  $15\text{kHz}/\text{cm}^2$ . The ATLAS Trigger System reduces the event rate from the bunch-crossing rate of  $40\text{MHz}$  to an average recording rate of  $200\text{Hz}$ .

The NSW have two chamber technologies. One is primarily for the Level-1 trigger function, small-strip Thin Gap Chambers (sTGC) [Error! Bookmark not defined., 8] and the other is for precision tracking (Micromegas detectors, MM). The sTGC are mainly used for triggering provided their single bunch crossing identification capability. The sTGC has two quadruplets each has four layers. A layer of sTGC will contain pads, wires and strips readouts.

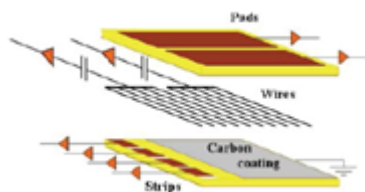


Figure 2: Schematic view of a sTGC

The sTGC is used as Level 1 Triggering device. In Level 1 triggering trigger [9] 25 percent of the total trigger, which are fake, will be removed. Fake triggers are those that come from the non-pointing tracks.

All the data acquisition part and simulations will be handled by a tool called ROOT [10]. ROOT is a powerful software framework addressing all the scientific requirements. It is developed by a group of scientists in CERN. ROOT is an object-oriented framework to solve the data analysis challenges of high-energy physics. ROOT provides both a programming interface to use in own applications and a graphical user interface. ROOT is a free, open-source product. It is a powerful tool to cope with the demanding tasks typical of state of the art scientific data analysis.

ROOT uses a C++ interpreter (CINT) and C++ compiler. This means that ROOT allows saving and accessing terabytes of data in a highly optimized way. ROOT has designed the TTree and TNtuple classes specifically for that purpose. The TTree class is help to reduce disk space and enhance access speed. A TNtuple is a TTree that can hold only floating-point numbers; a TTree on the other hand can hold all kind of data.

### 3. Analysis of Problem

In NSW, sTGC will be implemented, which has two Quadruplets. For each quadruplet four pad layers are there. When the particles pass through the pad layers it will create signals in the pad which are read by checking the strips at that region and will be converted into digital by an application specific integrated circuit (ASIC). Implementation of these should be tested at each and every point. The coordinates of the particle and the trajectory should be known to test the output of the detector. Since the

data acquired in the LHC run is very large this will not be quiet efficient to collect data from the lab to do the test. These performance criteria are demanding. To conduct the test in the lab in presence of detector is not always feasible. So, in order to conduct the test on these NSW some program to prepare simulated and test beam data is needed.

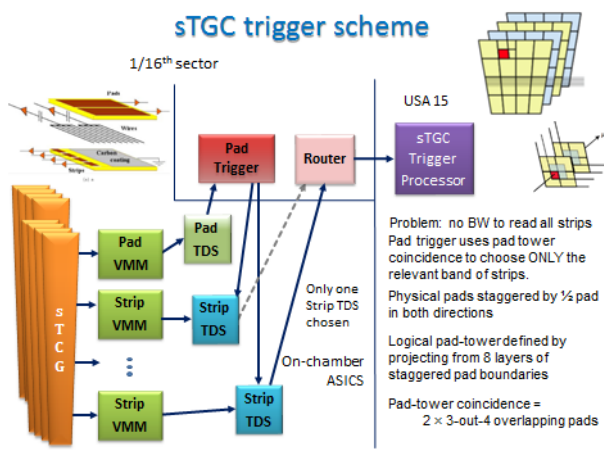
### 4. Proposed Work

This work focuses on the improvement of detection efficiency of muons by doing computer simulations of the data from the Muon Spectrometer detector (details in the objectives section).

FPGA collect all the data send from the strip Trigger Data Serializer and decide what to send to corroborate with sector logic in Big Wheel. The sTGC NSW trigger logic uses pad tower triggers to drastically reduce the amount of sTGC data to be processed on each bunch crossing for the Level-1 trigger. Three-out-of-four coincidences are made in pad towers, separately in the pivot and confirmation quadruplets. These are then combined to choose a band of strips in each of the eight sTGC layers to be read out into the trigger processors in USA15 (Fig 3). On detecting a peak in the signal from a strip, an application specific integrated circuit named VMM digitizes the peak amplitude to a 6-bit value which is immediately sent serially over one line per channel, to the strip Trigger Data Serializer, TDS. There, all active strips are saved and are tagged with an id called the Bunch Crossing ID (BCID), awaiting possible selection by the pad tower trigger for transmission off-detector. The pad 'hit' bits from all channels are serialized and sent within one BC to the pad trigger. The pad coincidence logic, running in parallel with the strip data collection will help for the trigger process. Then the band of strips in each layer that passes through the tower generating the pad coincidence is selected. These candidates are then sent via fast serial links to the Sector Logic to be combined with Big Wheel candidates.

This FPGA trigger processor which is going to use in the Phase II upgrade of ATLAS trigger processor need to test thoroughly. To test the this processor offline all the ASICs are replaced by a program and data are collected and filtered by program itself. In order to develop and test the trigger algorithm one need to inject simulated data into the processor's input data path. The ATLAS detector simulation programs generate hits in detectors. The real detector data is also recorded in test beams. Both must be processed to provide the input expected by the trigger processor. This paper focus on both simulation and real test beam data.

In the case of simulation the output of the simulation will be a digitalized files. Digitalized files are those which explains the response of the detector and shows it as histograms. digitalized files are read and processed with ROOT. The digitalized file are presented as Raw Data Output (RDO) files which are ntuple information about the strips and pads. An ordered list of large number of elements is called an n-tuple. From this digitalized file ntuple such as strip data, pad section, angel of hit and BCID etc. are read which is also an input.



**Figure 3:** Schematic view of Level 1 trigger system

At the same time, real detector data recorded that can be computationally regenerated are also read as input. These inputs will be read and processed to find other relevant information like angle of hit, centroid of hit etc. These will be then processed to find the output that the FPGA processor expects.

The FPGA takes the input as binary at each clock tick. VMM is measuring Time Over Threshold (TOT). Each clock signal is 5ns and for each clock if the value is high i.e. above a threshold the signal will count high and in all other case low. So the output will be having only 0s and 1s for low and high respectively. In each clock a bit of all the pad and strips set will be outputted.

### 5. Methodology

To test the FPGA trigger processor the input that processor accept should be fed into the processor input track. The processor input is a Gaussian like pattern generated from the signals that the strip and the pad get when the particle hit on them. While creating pattern it is done for both real time data and simulation.

For the real time data the charge response of the detector will be stored in files. In the case of real time data only the relevant data is stored. Since there are 4 pad layers, 2 even layer and 2 odd layer, in a quadruplet there are four pad files. The overlapping area of even and odd layer is called a tower. There will be 64 strips running out of a pad layer. The strips will be running horizontally to these pads. The signals greater than a threshold value is accepted and for those signals pattern is created by putting 1 for the bits corresponding to signal position.

In the case of simulation file the data created by simulation is a digitalized file. From the digitalized RDO data, this is a root file and gives the response of the detector as charge on the detector. The event reading in this uses the TFile concept in ROOT to read and store the data. To store large quantities of same-class objects, some methods that can access and handle large quantity data at same time should be used. The TTree in ROOT is optimized to reduce disk space and enhance access speed. It can handle large amount of data at same time and in a single line. Ttuple is a specialized kind of TTree especially for float data type.

These tuples are the response of all the points in the detector. The most challenging portion is to filter the data, since it shows the signal from the non relevant portion also. This is done by mapping the charge to the corresponding pad and the strip coordinate system. Only the portion where the pad and strip signal overlaps are read and stored for further process. Once the data are read from the digitalized file and relevant data are stored then the pattern creation for the FPGA trigger processor can be preceded like the real test beam data. In which only the value above the threshold are only taken and other are discarded. For those selected value the corresponding bit position are filled with ones and others are filled with zero.

### 6. Experimental Result

The input for the FPGA trigger processor is prepared in two tracks. The first track in which the real test beam data is read and stored in files. Since there are 4 pad layers four file are there. These files are read and those charge value above threshold are found. For those above threshold values the pattern is creates as per the format of the FPGA.

For the simulation the digitalized files are read and stored to TFile as tuple. The tuple help to handle data as row. Data that are read by the tuple are stored in a file and processed as in the case of real test beam data.

### 7. Conclusion

The Phase II up gradation of ATLAS detector which is main detector in LHC experiment in CERN to find the Higgs Particle is going to conduct. As part of this the Level 1 trigger system need to be reconstructed to remove 75 percent of the fake trigger. For that the sTGC is implemented and it consists of pads and strips. To create a new trigger algorithm FPGA processors are used. In order to develop and test these trigger algorithm test data should be fed into its input track. This data can be taken from both simulation and from data read by some program.

This paper proceeds in two track on for reading the events from test beam and other for the simulation. In the case of events from test beam, 8 files (4 for pads and 4 for strips) are read and from the 8 files input for the FPGA trigger processor is created. So there will be 4 resulting files with pattern for pads and 16 for strips, since strips has 4 band in each pad layer. Form the simulation charge for all the points in the detector are read and only the relevant points are stored and processed like the test beam data.

### 8. Acknowledgment

First I would like to thank God Almighty for all the blessings. I would like to place on record my deep sense of gratitude to **Dr. C.G Sukumaran Nair, Head of Department, Ms. Sudha S.K., Associate Professor, Computer Science and Engineering, SIST.** I would like to thank **Mrs. Reshmy. V. R., Associate Professor, Department of Computer Science and Engineering, SIST** for her support and guidance. A special thanks go to **Ms. Julia**

Narevicius (Engineer) for helping me and especially, the discussion with her was very much helpful for this project.

## References

- [1] ATLAS Collaboration: "The ATLAS Experiment at the CERN Large Hadron Collider", JINST 3, 2008, S08003
- [2] ATLAS Collaboration: "*Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC*", Phys. Lett. B, 2013, 726, 1-3, 88-119.
- [3] Rossi, L. and Brüning, O., "High Luminosity Large Hadron Collider A description for the European Strategy Preparatory Group", Tech. Rep. CERN-ATS-2012-236, CERN, Geneva, Aug, 2012.
- [4] M.Marx: "*The Online Muon Identification with the ATLAS Experiment at the LHC*", Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013,1-6.
- [5] Y.Munwes: "*Upgrade of the First Level Muon Trigger in the End-Cap New Small Wheel Region of the ATLAS Detector*", IEEE, Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013 3rd International Conference, 2013, 1-8.
- [6] G. L. Miotto et.al.:" Configuration and Control of the ATLAS Trigger and Data Acquisition" Proceedings in NIMA,2009,1-4.
- [7] ATLAS Collaboration: et al "Technical Design Report New Small Wheel" 2013, Issue 1, CERN-LHCC-2013-006
- [8] E. Etzion, Y. Benhammou, J. Ginzburg, M. Ishino, L. Levinson, G. Mikenberg, N. Panikashvili, D. Primor, and V. Smakhtin, "The Certification of ATLAS thin gap chambers produced in Israel and China", arXiv:physics/0411136 [physics].
- [9] A. Negri, "ATLAS TDAQ System Integration and Commissioning"., Nucl. Inst. And Meth. in Phys. Res. A, 2010, 519-521.
- [10] R. Brun, F. Rademakers: "ROOT- An object oriented data analysis framework", Nucl. Inst. And Meth. in Phys. Res. A, 389, 1997, 81-86.