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ATLAS Detector Upgrade from LHC to the HL-LHC

Xiawei Liu

Cape Cod Academy, Osterville, Massachussets, 02655, United States.

Abstract

Currently, people have already achieved a great success in the discovery of universe and on specifying fundamental particles in the Standard model. However, these currrent achievements is largely insufficient for scientists to discover more particles that perform roles in the Standard Model of Universe, sunch as Higgs Bosoms and dark matter. Therefore scientists have decided to temperarily shut down the current ATLAS detector and upgrade it to a High Luminosity Large Hadron Collider. This paper started by introducing the organization CERN and mainly discusses the LHC Phase-II upgrade of the trigger and data follow system that includes the Phase-II Trigger's basic architecture, upgrade of Calorimeter Trigger, Muon trigger, Level-1 Track trigger, and Central Trigger System. The paper also introduces some problems that may be encountered during the upgrade process and posed some possible solutions to these problems. By applying the upgrade from LHC to HL-LHC, it is possible to enhance people's perception towards the Standard Model and therefore leads to key technological breakthroughs.

Keywords

ATLAS Detector; LHC Phase-II; HL-LHC.

1. Introduction

1.1. CERN and LHC

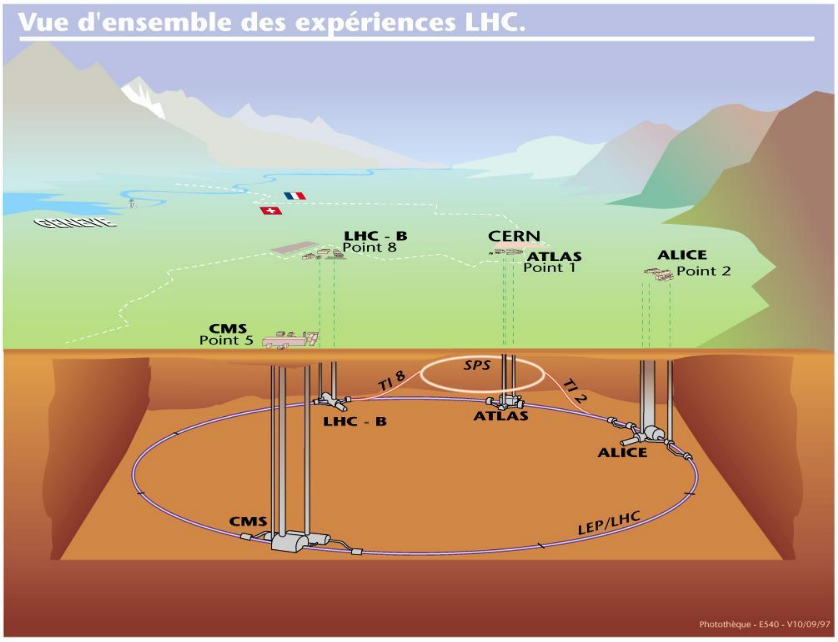

Figure 1. The location and structure of the Large Hadron Collider [1]

The European Organization for Nuclear Research (also known as CERN) is a research organization located in the Franco-Swiss border near Geneva, Switzerland, which operates the world's most powerful particle accelerator——Large Hadron Collider (LHC). This organization,

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established in 1954, gathers the most innovative and most elite physicists in the world together to perpetually push the study of particle physics beyond its limit. This research centre's primary function is to build the most advanced particle accelerator globally, such as the LHC for particle physicists. The LHC, built by CERN on 10 September 2008, consists of a 27-kilometre ring of superconducting magnets with several accelerating structures to boost the particles' energy along the way. [2] In the accelerator, proton beams are accelerated in the opposite direction at speed near the light. Then, different beams will collide with each other at fixed locations known as the detectors in the accelerator.

1.2. ATLAS Detector

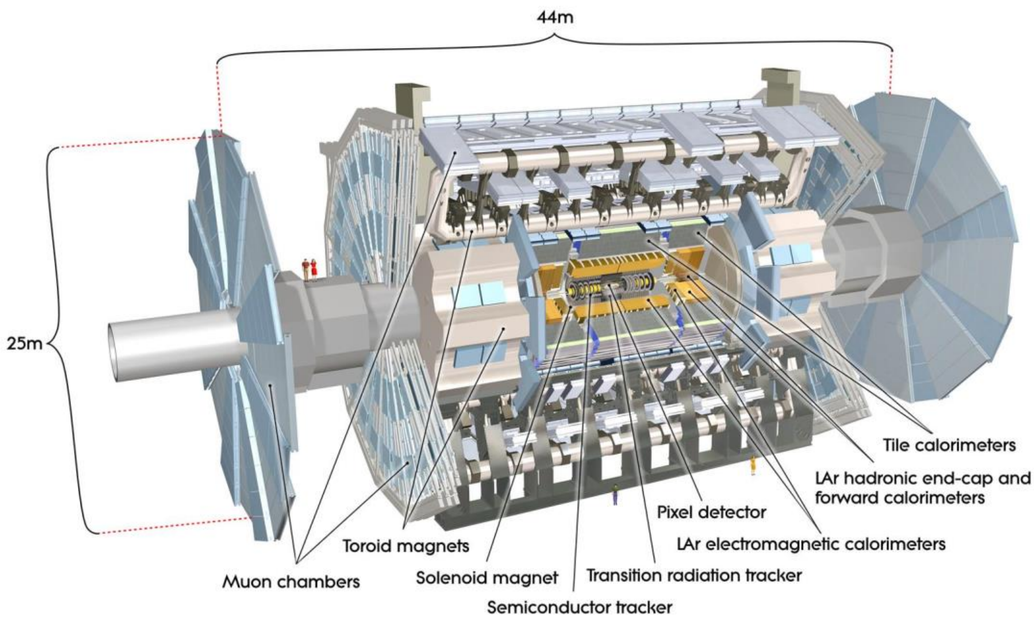

Figure 2. The structure of the ATLAS Detector[3]

ATLAS stands for A Toroidal LHC Apparatus, which is the largest and general-purpose detector build by CERN for detecting proton-proton collisions happening in the LHC. As shown in the figure, the detector is 44 meters long and 25 meters high, weighing about 7,000 tons. The sensor contains three essential structures: the magnet system, a toroid magnet and solenoid magnet; the inner detector contains a transition radiation tracker, a semiconductor tracker, a pixel detector; and Calorimeters which has liquid argon calorimeters and tile calorimeters. The magnet system's function is to bend the charged particles to separate them into their unique piles, therefore making their momenta easier to be measured. The inner detector is used to measure the pathway, momentum, and charge of the particles. Calorimeter, the one that will be mainly focused on in this report, is used to measure particles' energy by absorbing them using high-density metal.

2. Upgrade of the Trigger and Data Flow System

Since people invented the term experiment, the goal of doing it has always been finding the unique and most exciting phenomena in hundreds of worthless data. In the LHC, the trigger system is like the water filter that can decide which event happened in the particle detector can be kept when only a tiny fraction of its total can be recorded. Due to the limitations of the data storage capacity and computing power, the trigger system is expected to be upgraded once the High Luminosity-LHC (HL-LHC) is adopted because High Luminosity means even more data and a lower acceptance rate.

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2.1. The Phase-II Trigger Architecture

Several possible Phase-II trigger architectures have been considered. One possibilitywould be a single-stage trigger, along the lines of the current system, formed from the existing calorimeter and muon triggers with a Level-1 trigger accept (L1A) at a rate of less than 200 kHz. [4] However, this structure has a problem because it is not compatible with the estimated rate since the High Luminosity is adopted. Therefore, to meet the high flow, the phase-II trigger will need additional trigger system facilities.

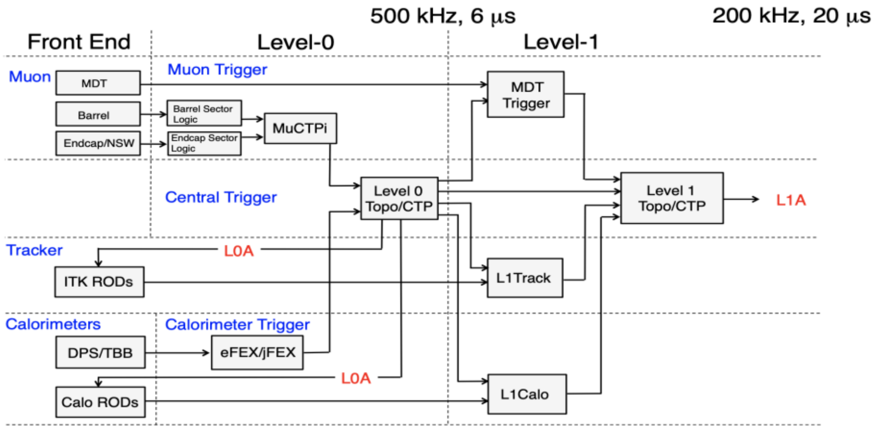

Figure 3. A block diagram of the architecture of the Split Level-0/Level-1 hardware trigger proposed for the Phase-II upgrade. (The MDT trigger is shown as part of Level-1 but may be used at Level-0).[4]

As shown in figure 3, now the baseline option will be using a 2 stage trigger where the latency at Level-0 is 6 μs, and the acceptance rate is 500 kHz. After being processed by the Level-0 trigger, the information is brought into the level-1 trigger, where the data can be processed under a longer latency, 20 μs, with an acceptance rate of 200 kHz. Therefore, the trigger on the HL-LHC will be more selective than that on the LHC. By comparing the Phase II upgrade tracking system by the Phase I tracking system, it is easy to tell that the construction of the Level-0 tracker for both phases is essentially the same. However, the Level-1 trigger now includes four new structures.

a) Level-1CalorimeterTrigger

b) Level-1MuonTrigger

c) Level-1 Track Trigger

d) Level-1 Central Trigger

2.1.1. Calorimeter Trigger

In the HL-LHC Phase-II upgrade, the front-end and back-end electronics will both be replaced. In the upgrade, the new front-end electronics will digitize all channels every bunch crossing and transmit the data of the detector on high-speed links to new calorimeter back-end electronics in USA15.[4]

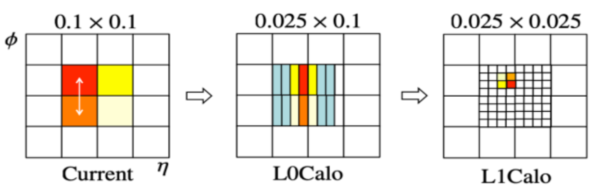

Figure 4. The EM granularity available in the current Phase-II Level-0 and Phase-II Level-1 EM triggers.[4]

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As shown in figure 4, after the upgrade of the Level-0 Calorimeter Feature Extractor, it is easy to tell that the upgrade provides further background rejection, which gives 3-4 times the trigger rate. This upgrade makes the calorimeter tracker more selective and precise.

In the L1 Calorimeter trigger upgrade, asynchronous is a crucial point since it will process the L0 accepts at a rate up to 500 kHz and with a peak rate up to 20 MHz. Also, the Level-1 Calorimeter system can access complete granularity calorimeter data, which will significantly improve the measurement of the trigger object's position and energy. Using more accurate trackers will cause a sharper turn-on curve and more accurate clusters matching to tracks found by the L1 tracker trigger. Besides, the update to higher granularity will enhance the background rejection for electromagnetic electron and photon triggers. Lastly, the L1Cal system can determine a more accurate estimation of every object's ET; besides, it could also make the jet-finding algorithms more sophisticated.

2.1.2. Muon Trigger

Under this upgraded 2 level structure, in order to achieve the goal of the pT threshold, 20 GeV is the upper bound of the Level-1 Muon trigger. Furthermore, upgrades of the current Level-1 muon trigger systems includes barrel and endcap regions. In addition, hit information from Monitored-Drift-Tubes (MDTs) is used in the 2 Level trigger decision for the first time in order to improve the muon trigger region of interests (ROIs) momentum resolution and to improve the poorly measured low-momentum muons' rejection. In addition, another way to decrease the Level-1 muon trigger rate by sharpening up the high-pT resolution of muon trigger ROIs would be to substantially increase the present RPC system tracking capability.[4]

2.1.3. Level-1 Track Trigger

Even though there are already Calorimeter trigger and Muon trigger, it is still difficult for them alone to significantly reduce the trigger rate under the modest increase of the pT thresholds. After using simulations and studies of the L1 trigger rates from data, it turns out that including a tracking trigger in the Phase-II L1 Trigger can provide a significant reduction on the trigger rates for a single lepton trigger with a factor of 5. There are two types of track triggers.

1. RoI-driven Level-1 Track: This track trigger provides all tracks in several relatively small inner tracking detector regions. These small regions are defined by the electromagnetic and muon ROIs from the L0 Trigger. In addition, it can only be where the considered areas are determined by the EM and muon ROIs from the Level-0 trigger and can only be applied in a 2 level trigger architecture.

2. Self-seeded Level-1 Track: The self-seeded L1Track design performs a fast track reconstruction of *all* high momentum tracks (pT > 10 GeV) in the full coverage of the tracker without requiring external seeds.[4]

2.1.4. Central Trigger System

The Level-0 Central Trigger System's upgrade combines the functionality of the Level-0 Central Trigger Processor (CTP) and the Topological processor. However, in order to ensure that the Phase-I system does not impose constraints on the Phase-II system, a new system will be required. While fitting into the latency of Level-0, which is 6 μs, the Level-0 Central Trigger System also has to provide trigger accept signals at rates of at least 500 kHz. Therefore, in order to fit all these requirements, ATCA, using high-speed optical links for both incoming trigger signals and outgoing trigger and timing signals, is the current candidate for the implementation of the Level-0 Central Trigger.

After upgrading Level-0 CT, it is also necessary to upgrade the Level-1 CT in order to meet the acquisition of latency at 20 μs and data rate at 200 kHz. The upgrading of Level-1 CT is alike that of the Level-0 CT, since Level-1 CT receives its data from the Level-0 CT and additional detectors such as muon trigger and calorimeter trigger.

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In the Phase-II upgrade, two new elements will be introduced: the communication between the detector front-ends and back-ends, and the off detector trigger, timing, and control system. A new bidirectional standard is foreseen for the communication between the detector front-ends and back-ends, which will carry trigger and timing signals, control signals, as well as readout data. Bidirectionality and increased bandwidth concerning the current system are essential for upgrading the off-detector trigger, timing, and control system.

2.2. Data Acquisition

After the upgrading from LHC towards the HL-LHC and the benefit of High Luminosity, its challenging appears. The magnitude and rate of data flow are skyrocketing. Therefore, upgrading data acquisition is also needed. After investigating the Level-1 accept rate and the expected event size, it shows that the bandwidth required to assure the transfer of data at least increased by a factor of 4 compared to the current data acquisition system.

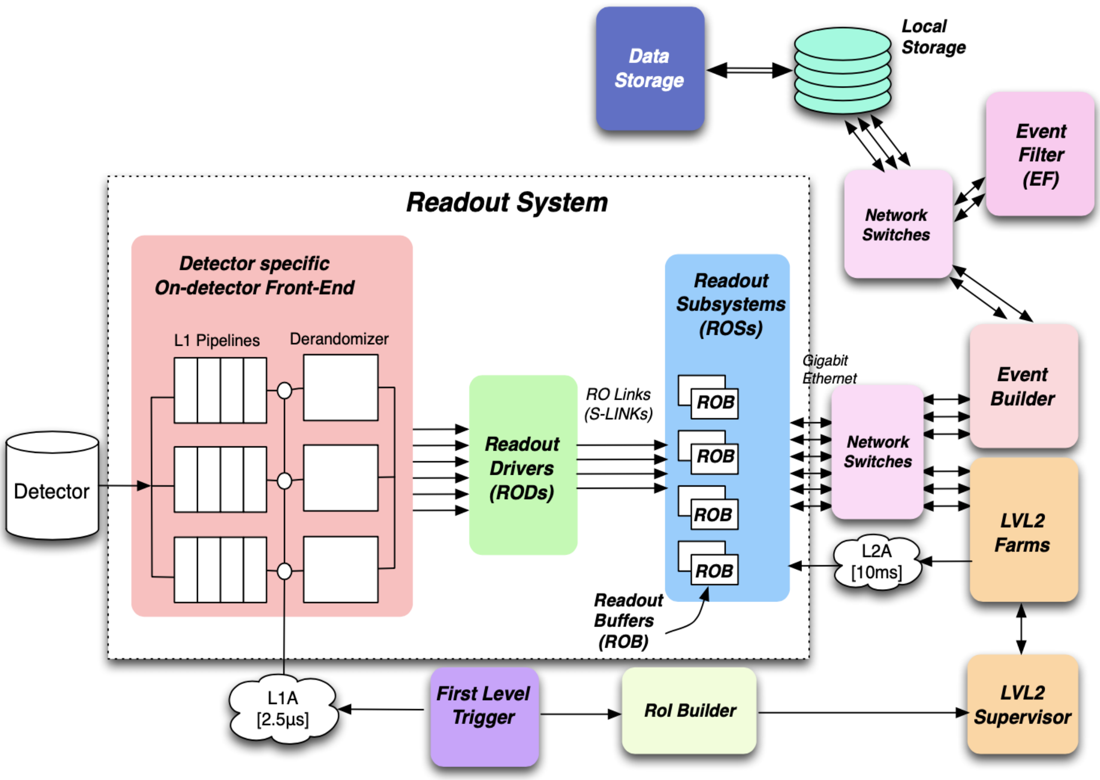

Figure 5. System overview of the ATLAS dataflow and readout system[4]

As shown in figure 5, the readout system is the "core" of the dataflow, and it interfaces the detector-specific front-end to the DAQ/HLT units, which build and filter the events before the data are transferred to mass storage.[4] There are many function blocks in the figure, and they can be categorized into five categories.

a) Detector front-end (FE) electronics: inputs the signal from the detector towards the readout system.

b) Readout Drivers (RODs): multiplexing of several FE data streams, optional processing, formatting of the FE streams into output ROD fragments.[4]

c) Readout Links (ROLs): ROD fragments are transmitted at the Level-1accept event rate.

d) Readout Buffers (ROBs): store the ROD fragments temporarily.

e) Readout Systems (ROSs): housing and control of the hardware modules that implement the ROBs.[4]

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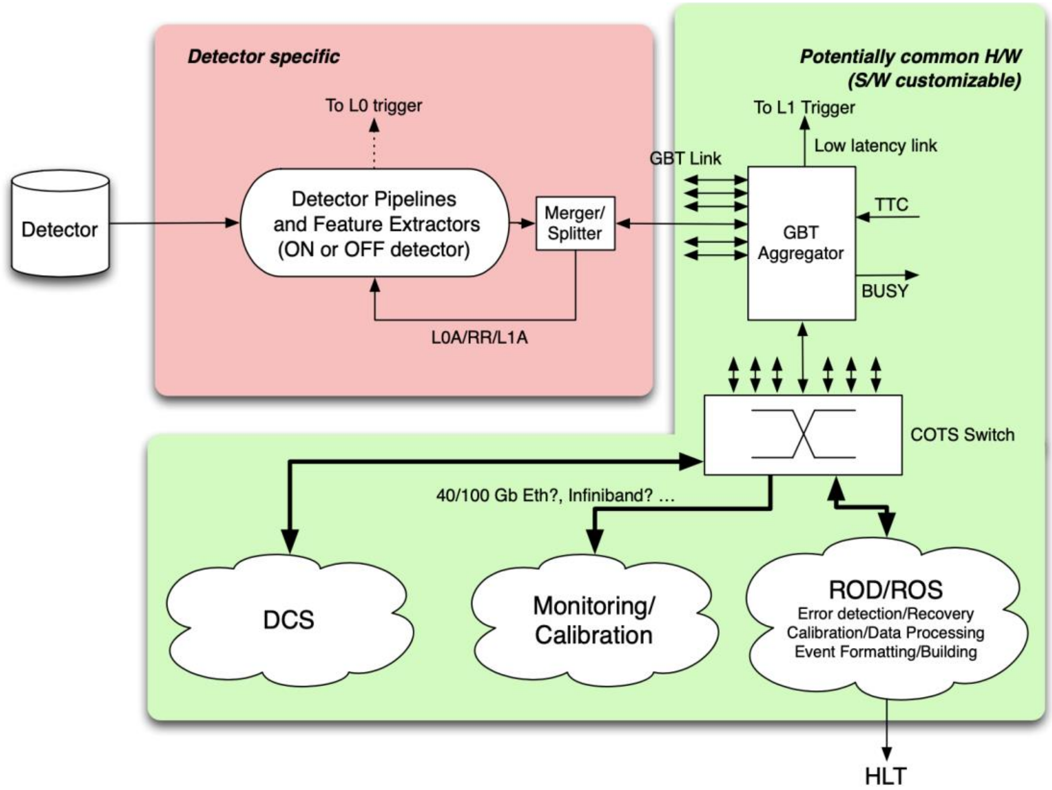

Figure 6. Readout architecture overview for the Phase-II upgrades

As shown in figure 6, in the Phase-II upgrade of the Readout architecture, the system will be more based on commercial available high-speed switching networks and links. By adopting the retail network, there are several advantages: the capability of reorganizing the readout connectivity without physical re-cabling, scalability and staging capabilities, large scale production of a single ROD design, thus lower production and maintenance costs, easier long-term maintainability by avoiding multiple implementations of standard functionality, faster and more effective integration and commissioning, and more effective usage of manpower and resources.[4]

3. Conclusion

In conclusion, the ATLAS detector upgrade from the LHC towards the HL-LHC is a very significant improvement. High luminosity means more possibility, and possibility implies the future. After analyzing and reading through all the materials about the upgrading of the trigger system and data acquisition, general ideas and possibilities of future development on the HL-LHC are discussed and reported in the paper above.

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