PROCEEDINGS OF SCIENCE

Development of the ATLAS muon trigger system on multi-threaded software framework

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The ATLAS muon trigger system consists of a hardware-based and a software-based trigger, and it can efficiently select events containing muons in the final state for physics analyses. The ATLAS experiment plans to restart the Run3 data-taking in 2021 in higher luminosities. In the higher luminosities, there is new challenge that wall time of reconstructing events increases on the software system. In order to cope with the challenge, multi-threaded software framework has been developed to reduce memory requirement because CPUs have increased core counts and decreased available memory per core. As a part of the major upgrade in the ATLAS software, we have been developing multi-threaded software framework of the muon trigger system, and validated the execution on single thread. The development and validation result will be outlined.

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1. Introduction

The trigger system of the ATLAS experiment [1] is an essential component of it to collect events of high interest for physics analyses. Events containing muon in the final state are of crucial importance in many physics analyses, ranging from precise Standard Model measurements to searches for new particles. An efficient and well-understood muon trigger is essential to provide these events for the analyses.

The ATLAS muon trigger system is designed as a two-stage system that consists of a hardware-based trigger (Level-1 muon tigger) and a software-based trigger (High-Level muon trigger). Events accepted at the Level-1 muon trigger are passed to the High-Level muon trigger, and taken the final acceptance decision.

The ATLAS experiment plans to restart the Run3 data-taking in 2021 with a center of mass energy of $\sqrt{s} = 14$ TeV in higher luminosities, but the muon trigger system has new challenges that the wall time of reconstructing events on the software system increases and maximum available memory per core decreases due to increasing number of tracks and core counts in CPUs. To cope with the challenges, we have started developing the High-Level muon trigger as a part of the major upgrade in the ATLAS software. An overview and development of it will be outlined.

2. The ATLAS muon trigger

2.1 Muon system

The ATLAS muon trigger selects events including muon with transverse momentum p_{T} greater than a predefined threshold on the basis of the information provided by the Muon Spectrometer (MS) [2] and the Inner Detector (ID) [3] of the ATLAS detector. The MS consists of three large air-core superconducting toroids and four types of subdetectors with different purposes as shown in Figure 1. The integration of the magnetic field of the toroids ranges between 2.0 and 6.0 Tm across most of the detector. Three layers of Resistive Plate Chambers (RPCs) and three layers of Thin Gap Chambers (TGCs) are installed to provide fast responses for the Level-1 muon trigger. Three or two layers of Monitored Drift Tube chambers (MDTs) and one layer of Cathode Strip Chambers (CSCs) are installed to provide precise track information for the High-Level muon trigger as well as offline muon reconstruction for physics analyses. The ID consists of the pixel, semiconductor tracker (SCT) and transition radiation tracker (TRT), arranged in successive layers. These subdetectors provide track measurements for the High-Level muon trigger and offline muon reconstruction.

2.2 High-Level muon trigger

The muon reconstruction at the High-Level muon trigger is split into a fast and a precise reconstruction step. In the fast reconstruction step, muon candidate's p_{T} is measured from the angle deviation or the curvature radius in the magnetic field. Selection criteria defined for each muon trigger chain are applied to these muon candidates to allow early rejection of fake muon, such as protons originating from beam background. If the fast reconstruction step is passed successfully, the muon candidate enters the precise reconstruction step. In the precise reconstruction step, muon

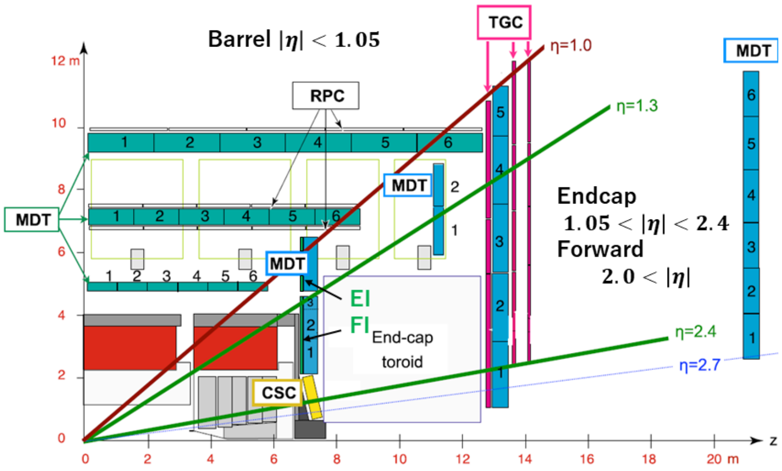

Figure 1: Schematic drawing of one quarter cross-section of the muon system of the ATLAS detector [4]. The pseudorapidity η is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.

candidate's p_{T} is measured by using algorithms close to offline muon reconstruction. These reconstruction steps are processed at only Regions of Interest (RoIs), provided by the Level-1 muon trigger, to satisfy time requirement of reconstructing events in online system, with a few exception of muon trigger chains using the information of the full detector, such as multi-muon triggers [4].

3. Development of the muon trigger on multi-threaded software framework

3.1 Multi-threaded software framework

The ATLAS experiment has started developing the future software framework, AthenaMT (Athena Multi-Threaded) [5], for Run3. The ATLAS software framework, Athena [6], was designed on the basis of a serial processing model, and played a key role in the discovery of the Higgs Boson [7] and the other ATLAS observations during Run1, from 2009 to 2012. During Run2, from 2015 to 2018, a multi-process version of Athena, AthenaMP [8], was deployed and allowed the sharing of the memory pages for large static structure, such as detector geometry, to save memory requirement. However, due to the limitation of the sharing memory, the memory and CPU requirements of reconstructing events will be a huge challenge in future higher luminosities. Therefore, AthenaMT has been developed to overcome the challenge. This is designed on the basis of the Intel Threaded Building Block [9]. A model of how AthenaMT components process within a single event is shown in Figure 2. In AthenaMT, threading can be coordinated across the execution of a program, including High-Level trigger, and it is possible to maximize memory saving [5].

3.2 Development of the High-Level muon trigger

In order to run programs of High-Level trigger in AthenaMT, it it necessary to implement the scheduler, which can coordinate threading and execute algorithms by using Data Flow (DF) and Control Flow (CF). DF is input/output data dependencies of the algorithms. CF is an additional set of dependencies that logical rules determine the order of execution of the algorithms based on

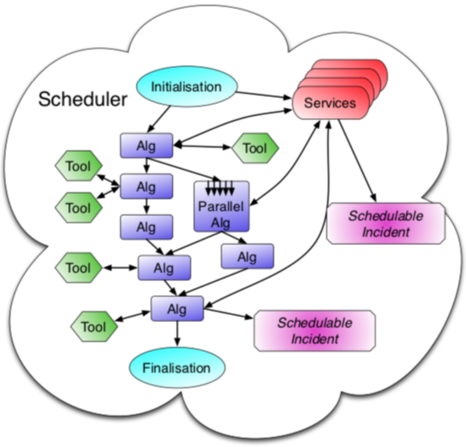

Figure 2: A model of framework elements processing within a single event in AthenaMT [5].

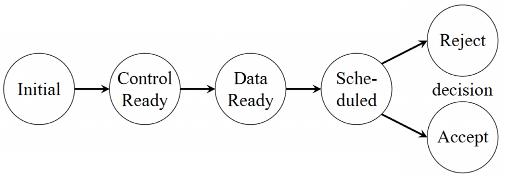

Figure 3: The state machine of the scheduler.

decisions taken in the other algorithms. The state machine of the scheduler is shown in Figure 3. All algorithms are in the Initial state at the beginning of event processing. At the next stage, algorithms are enabled by CF (Control Ready), and then the algorithm is executed once its input data are available (Data Ready) and as soon as there are free compute resources (Scheduled). After execution, an algorithm returns a boolean status flag, either negative decision (Event Rejected) or positive decision (Event Accepted), which can be used as input to the CF.

In order to satisfy the requirement of High-Level trigger, it is necessary to execute algorithms only at RoIs. To do this, Event Views are supported in AthenaMT. This is a class that presents a sub set of data in the whole Event Store to scheduled algorithms. Algorithms can be processed on only the information around RoIs by using Event Views, and also the information of the full detector.

To make the algorithms thread-safe in AthenaMT, many algorithmic codes should be changed in each trigger signature. In the muon trigger signature, the algorithms of the fast reconstruction step have been migrated. The further migration of the public tools to the private ones is yet to be done.

4. Validation of High Level muon trigger on single thread

We validated the migrated muon trigger on single-thread, in order to confirm if the migrated algorithms can be processed by the scheduler and Event View in AthenaMT. The results are shown in Figure 4 and 5. Figure 4 shows distributions of muon's p_{T} estimated at the fast reconstruction step in the High-Level muon trigger. There are a few muons under 20 GeV p_{T} threshold due to regions of the low magnetic field of the toroids, but all muons with p_{T} over the threshold are kept and most of muons with p_{T} under the threshold are rejected. Figure 5 shows trigger efficiencies of the fast reconstruction step. At all p_{T} thresholds, all muons with p_{T} over the threshold are kept. It is also confirmed that p_{T} thresholds are looser in higher p_{T} region because the resolution gets worse in higher p_{T}. Since these results are observed as expected, the execution of these migrated algorithms in AthenaMT is confirmed.

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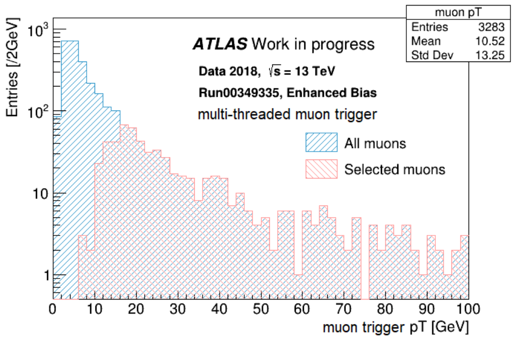

Figure 4: Distributions of muon's p_T estimated at fast reconstruction step in High-Level muon trigger. In blue, the distribution of all muons passed to the fast reconstruction step is shown. In red, the distribution of muons over 20 GeV p_T threshold at the fast reconstruction step is shown.

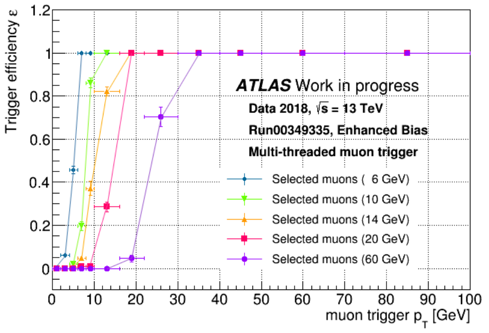

Figure 5: Trigger efficiencies with 6 GeV (in blue), 10 GeV (in light-green), 14 GeV (in orange), 20 GeV (in red) and 60 GeV (in purple) p_T threshold of fast reconstruction step in High-Level muon trigger as a function of muon's p_T estimated at the step.

5. Conclusion

Muon trigger is of crucial importance for fulfilling the physics program of the ATLAS experiment. For data taking during Run3 at a center of mass energy of 14 TeV, development of multi-threaded software framework is ongoing. We have been developing the High-Level muon trigger, and most of the algorithms of the fast reconstruction are updated. Development of the remaining algorithms is ongoing. We validated the execution of the algorithms on single thread. Results are as expected. Next step is to finally validate them on multithread.

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