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The ATLAS FTK system: how to improve the physics potential with a tracking trigger

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Abstract

After a very successful data taking run, the ATLAS experiment is being upgraded to cope with the higher luminosity and higher center of mass energy that the Large Hadron Collider (LHC) will provide in the next years. The Fast Tracker (FTK) trigger system, part of the ATLAS trigger upgrade program, is a highly parallel hardware device processor based on a mixture of advanced technologies. FTK provides global track reconstruction in the full inner silicon detector, with resolution comparable to the offline algorithms, in approximately 100 microseconds, allowing a fast and precise detection of the primary and secondary vertex information. The track and vertex information is then used by the high-level trigger algorithms, allowing highly improved trigger performance for the most difficult signatures, such as b-jets. The expected physics performance of FTK in the harsh environment at high pile-up and high luminosities at LHC Run2 are presented.

Keywords: Fast Tracker, FPGA, Associative Memory, LHC Run2, ATLAS trigger upgrade

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1. Introduction

The LHC first run up to 2012 (Run1) was a remarkable success, leading to a discovery of Higgs boson. Data taking will be resumed in 2015 with a higher center of mass energy and higher luminosity (Run2) to extend its discovery potential. Furthermore, a significant luminosity upgrade is planned around 2019 (Phase-I upgrade). The goals of these future LHC runs will be to measure all possible branching ratios of the Higgs boson precisely and to continue the searches for new physics, maintaining efficiency for experimentally challenging signatures such as moderate momentum heavy particles. In order to achieve these goals, the trigger must be kept as flexible as possible, as well as maintaining and improving its performance for instance for triggering τ and b-jets.

After the Phase-I upgrade, we expect that the energy will reach 14 TeV and the instantaneous luminosity will reach to $3 \times 10^{34} cm^{-2} s^{-1}$. This will pose challenges for the trigger system. The existing trigger system of the ATLAS Experiment [1], consisting of a hardware-based Level-1 and a CPU-based High Level Trigger (HLT), was designed to work well at the LHC design luminosity of $10^{34} cm^{-2} s^{-1}$. In addition to cope with higher luminosity than the design, the detector environment will become harsh by the increase in detector activity arising from 55 to 80 simultaneous interactions per bunch crossing (pileup). Thus, an upgrade in the ATLAS trigger system is planned [2].

Tracking information is critical for distinguishing which events triggered by the Level-1 should be kept for further processing. We propose to build a system of electronics, the Fast TracKer (FTK) [3], which will do global track reconstruction after each Level-1 trigger to enable the HLT to have early access to tracking information. FTK will use data from the pixel and semiconductor tracker (SCT) detectors [1] as well as the new Insertable B-Layer (IBL) pixel detector [4]. FTK will move track reconstruction into a hardware system with massively parallel processing that produces global track reconstruction shortly after the start of HLT processing.

FTK tracks will be an important tool box for the ATLAS HLT, allowing it to circumvent some of these limitations and have improved event selection.

2. Performance

2.1. *τ identification*

The τ plays an important role in Standard Model (SM) processes such as Higgs boson decays. It is also important for physics beyond the SM. The τ lepton can decay leptonically (τ_{lep}, 35%), or hadronically (τ_{had}, 65%). The τ_{had} decay signature is similar to that of jets of hadrons, and the extremely large production cross section of multi-jet events makes it difficult to separate τ_{had} from these jets. A distinguishable feature of τ_{had} decay is that it has 1 or 3 charged particles in a very narrow cone with little activity in a surrounding isolation cone, whereas jets typically have activity distributed throughout the isolation cone.

To check the performance of FTK tracks to separate τ_{had} from jets of hadrons, a sample of $H \to \tau_{had}\tau_{had}$ is used for the signal and multijet QCD event for background. Figure 1 shows the FTK track multiplicities in a cone of $\Delta R < 0.1$ around τ candidates, where $\Delta R = \sqrt{(d\eta)^2 + (d\phi)^2}$ is defined as the distance from leading track of each τ candidate [5]. τ candidates have more 1 track and less 2 tracks reconstructed than jets.

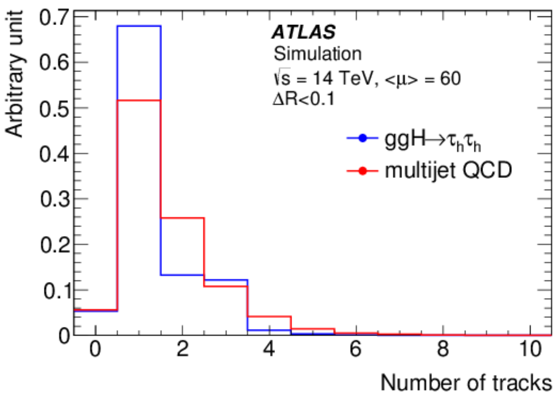

Figure 1: Number of FTK tracks inside a cone of $\Delta R < 0.1$ around τ candidates [5]. A signal sample of $H \to \tau_{had}\tau_{had}$ events is shown in blue, and a multijet QCD background sample is shown in red.

With the use of tracking information, the performance of τ identification can be improved at the HLT. Figure 2 shows the the multijet QCD background efficiency versus event-level $H \to \tau_{had}\tau_{had}$ signal efficiency for several HLT selections [5]. The Level-1 selection used requires two Level-1 tau candidates with 12 and 20 GeV and a calorimetric isolation as well as a Level-1 jet candidate with $p_T > 25$ GeV. Comparing the selections between with FTK (red circle in the figure) and with calorimeter selection as well as higher L1 thresholds (black star in the figure), an improvement of signal efficiency is obtained with a same background efficiency.

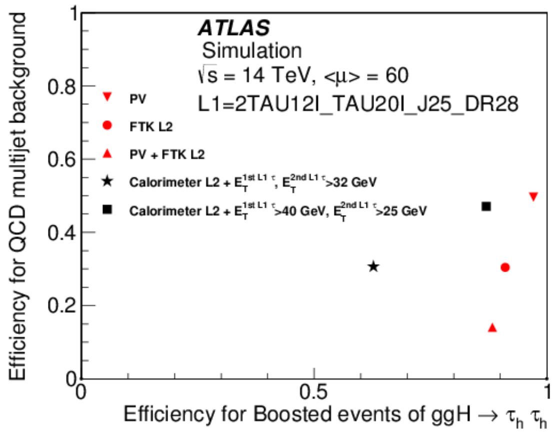

Figure 2: Efficiency of di-tau triggers for QCD multi-jet background and signal ($H \to \tau_{had}\tau_{had}$) under the number of pile-ups corresponds to 60 and center-of-mass energy 14 TeV [5]. The red downwards pointing triangle shows the per event efficiency of the HLT selection which requires that the jet and at least one of the two τs to be consistent with the primary vertex (PV). The red circle shows the per event efficiency for applying the FTK selection at HLT. The red upwards pointing triangle show the per event efficiency for applying the FTK selection at HLT and the primary vertex consistency requirement. The black star shows the efficiency of applying the calorimeter cluster selection and adding the requirement that both the Level-1 tau candidates have $E_T > 32$ GeV. The black triangle shows the efficiency for the same selection described above but with Level-1 τ candidates satisfying $E_T > 40$ GeV for the first and $E_T > 25$ GeV for the second.

2.2. *b-jet tagging*

New physics that couples to heavy fermions may be rich in b-quarks. It is important that the ATLAS trigger efficiently selects jets from b-quarks while providing a large rejection factor against other jets. This is a challenging task for the current HLT because purely jet-based triggers either have very high thresholds for single jets, or have many jets in multi-jet triggers. The Region of Interest (ROI) is set around a potentially interesting region defined by Level-1 trigger. The single jet thresholds are typically too high for b-tagging to be useful, and the multi-jet triggers produce too many ROIs and CPU constraints at HLT. The availability of FTK tracks following Level-1 trigger removes the constraints on the number of ROIs to be considered for b-tagging and allows the use of sophisticated algorithms at HLT.

The transverse impact parameter distribution is the basic input to b-tagging. This distribution is sensitive to the long lifetime of particles within the *b*-jet and provides a means of separating *b*-jets from light-flavor jets. The transverse impact parameter of tracks associated to light-flavor and heavy-flavor jets is shown in Figure 3 for both the re-fitted FTK and the offline tracks, with the fully simulated samples of $t\bar{t}$ events [5]. A longer positive tail is present for the tracks associated to heavy-flavor jets for both the offline and FTK tracks, as is expected for *b*-jets. The light flavor jets have a symmetric distribution with much smaller tail, allowing good separation between the two classes of jets.

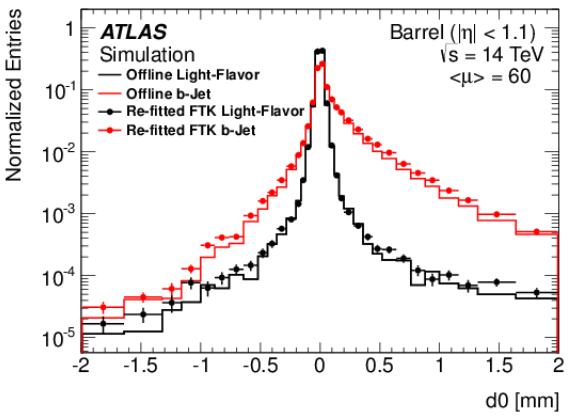

Figure 3: The transverse impact parameter distribution is shown for tracks associated to light-flavor (black) and heavy-flavor (red) jets. The solid lines show the distribution for the offline tracks, whereas the points show the FTK tracks re-fitted at HLT [5].

In Run1, *b*-jet tagging in the HLT began with a calorimeter-based jet pre-selection that tightened the jet p_T thresholds. With the use of FTK, track finding can be run with looser the HLT jet thresholds without putting additional load on the HLT processors, allowing HLT to require tighter *b*-jet tagging. Figure 4 shows two such working points of b-tagging from a draft Run2 menu along with some examples of re-optimized working points in which the b-tagging is run with lower jet thresholds [5]. The output rates of the various trigger items are shown as a function of the event-level tth ($h \to b\bar{b}$) efficiency. With the quasi-offline quality tracking information, HLT can use tight b-tagging requirement which rejects the light-flavor jet and keeps more heavy-flavor jet. Comparing "2b55_4j55_Medium" and "2b35_4j35_Tight", the jet p_T threshold is lowered while keeping signal efficiency and reducing the HLT trigger rate.

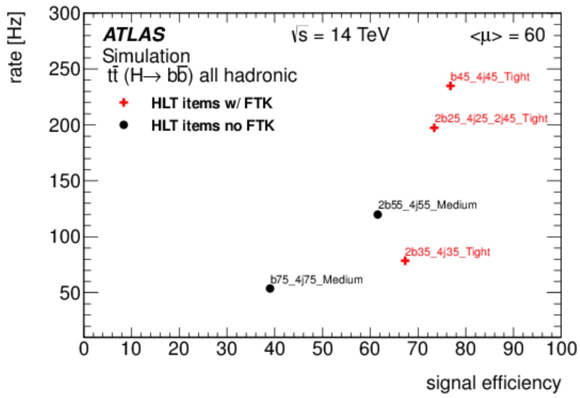

Figure 4: HLT trigger rate v.s. signal efficiency at the number of pile-up corresponds to 60 and center of mass energy 14 TeV [5]. The black points show *b*-jet items that will fit into the HLT constraints without FTK, red points show options with significantly larger input rates possible with FTK. All operating points assume the re-fitted FTK performance. The efficiencies are quoted with respect to the inclusive signal and include the L1 efficiency. The trigger names specify the jet multiplicities, p_T thresholds and b-tagging operating points. For example, the "2b55_4j55_Medium" trigger requires at least two medium b-tagged jets above 55 GeV and four or more jets above 55 GeV.

3. Conclusion

The Fast Tracker (FTK) trigger system, part of the ATLAS trigger upgrade program, is a highly parallel hardware system that provides all track information for any event accepted by Level-1 trigger. FTK has a potential to improve various trigger performance in terms of τ identification and *b*-jet tagging, then eventually physics performance for Run2 LHC and after.

A part of FTK will be installed for the barrel region ($|\eta| < 1.0$) at late 2015, full coverage ($|\eta| < 2.5$) will be established in 2016.

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