The performance and development for the Inner Detector Trigger algorithms at ATLAS

Ondrej Penc on behalf of the ATLAS Collaboration

Academy of Sciences of the Czech Republic, Institute of Physics, Prague, CZ

E-mail: `ondrej.penc@cern.ch`

Abstract. A redesign of the tracking algorithms for the ATLAS trigger for LHC's Run 2 starting in 2015 is in progress. The ATLAS HLT software has been restructured to run as a more flexible single stage HLT, instead of two separate stages (Level 2 and Event Filter) as in Run 1. The new tracking strategy employed for Run 2 will use a Fast Track Finder (FTF) algorithm to seed subsequent Precision Tracking, and will result in improved track parameter resolution and faster execution times than achieved during Run 1. The performance of the new algorithms has been evaluated to identify those aspects where code optimisation would be most beneficial. The performance and timing of the algorithms for electron and muon reconstruction in the trigger are presented. The profiling infrastructure, constructed to provide prompt feedback from the optimisation, is described, including the methods used to monitor the relative performance improvements as the code evolves.

ATL-DAQ-PROC-2014-026
22 September 2014

1. Introduction

The ATLAS detector [1] is one of the two general purpose detectors thanks to which the Higgs boson was discovered [2].

To build on this success from Run 1 of the LHC operation which ended in spring 2013, the hardware and software for the ATLAS detector is being upgraded in readiness for LHC Run 2, due to commence in spring 2015.

Towards the end of Run 1, the LHC was routinely delivering instantaneous luminosities of $7.7 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with proton-proton collisions at 8 TeV centre-of-mass energy. Following the upgrade, the centre-of-mass energy will be increased to 13 TeV at a luminosity to $2\times10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The expected parameters of LHC after the upgrade are summarized in Table 1. The upgraded LHC will allow the measurement of the properties and branching ratios of the Higgs boson, and also improvements in the measurements of many Standard Model physics processes and searches for physics beyond the Standard Model.

The time between bunch crossings will be reduced from 50 ns to the 25 ns from the original design, which has the potential, with the increased instantaneous luminosity, to more than double the input rate of physics triggers. This increased collision rate and increased average number of separate proton-proton pileup interactions per bunch crossing will place a significant burden on the hardware and software subsystems of the ATLAS Trigger.

For the upgrade, the ATLAS High Level Trigger (HLT) architecture has been simplified such that both the Run 1 software stages of the HLT – the Level 2 (L2) and Event Filter (EF) – have been merged in to a single HLT stage to run on single CPU nodes. This simplifies the data-flow,

Table 1. Comparison of the LHC parameters at the end of Run 1 and updated parameters for Run 2.

Machine parameter	Run1	Run2	Unit
Centre-of-mass energy	8	13	TeV
Luminosity	7×10^{33}	2×10^{34}	$cm^{-2}s^{-1}$
Bunch crossing spacing	50	25	ns
L1 input frequency	20	40	MHz
Average pileup	21	~ 55	events per bunch crossing

removing the need for network communication between the levels and the need for detector data for L2-accepted events to be also requested from the DAQ system for the EF processing. In addition it can avoid repetition of reconstruction steps in both levels, reducing the processing time [3].

Together with the unification of L2 and EF on the CPU nodes, and the related network changes, the L1 hardware is also being upgraded by the addition of a new Topological Processor (TP) and enhanced Trigger Central Processor using FPGAs instead of custom electronics [4]. The TP uses the topological information on jet or muon directions to achieve additional background rate reduction. In addition, a new hardware stage, the Fast Tracker (FTK) [5], is being added that will reconstruct tracks in the silicon tracker following a Level 1 accept, but before the HLT processing, using massively parallel processing.

2. The HLT tracking

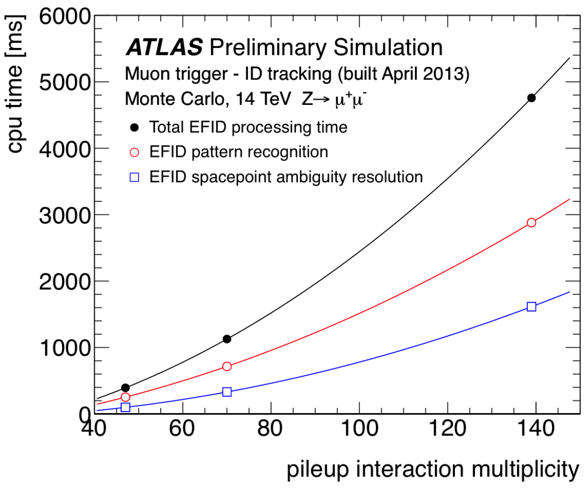
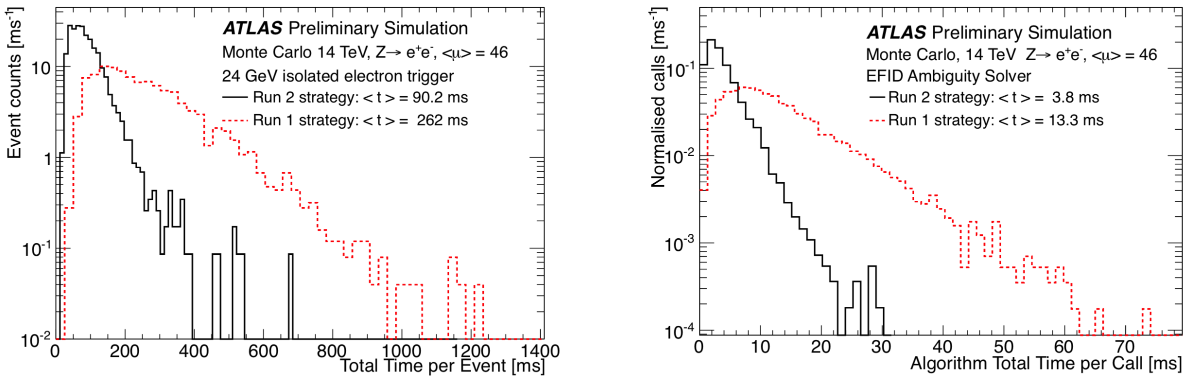


Figure 1. The Event Filter Inner Detector (EFID) trigger track reconstruction time for the ATLAS muon trigger as a function of the pileup interaction multiplicity. Shown are the times for the main pattern recognition algorithm (red) and Ambiguity Solver (blue) together with the total EFID tracking time (black) [6].

In both Run 1 and Run 2 the HLT tracking system runs as two stages. During Run 1, these were a fast tracking stage at L2, and an independent, precision tracking stage which runs a modified version of the offline tracking for the EF. In both of these stages, the independent pattern recognition was performed. During Run 1, this EF tracking was one of the most time consuming stages of the HLT processing.

The high pileup multiplicity and high rate expected for Run 2 highlight the need for a new tracking strategy and software optimisation. The CPU time consumption in simulated Run 2 events as a function of the pileup interaction multiplicity is illustrated in Figure 1. Shown are



(a) (b)

Figure 2. The distribution of total processing time for the complete processing for the 24 GeV isolated electron trigger (a) and processing time for the Ambiguity Solver (b). Both plots compares the tracking algorithms that were executed during Run 1 (dashed red line) and algorithms that are supposed to be executed during Run 2 (solid black line) [6].

the times for the two most time consuming stages of the EF Inner Detector (ID) trigger strategy as used during Run 1. The time consumption can clearly seen to grow non-linearly with the pileup multiplicity, clearly indicating that this would quickly become too costly to run in the HLT at high multiplicities.

These long processing times have lead to an optimisation of the tracking code for the Precision Tracking, and a redesign of the trigger tracking strategy to be used for Run 2. The new strategy also had to include the data from the new Insertable B-layer (IBL) [7] – the new layer of high precision pixel detectors in the centre of the ATLAS Inner Detector.

For Run 2 the fast tracking stage is based on the pattern recognition algorithms used in L2 during Run 1 [8], but has been completely rewritten to provide a new Fast Track Finder stage. This identifies hits in the layers of the ID and makes up a pattern that later on becomes a track using hits in Regions of Interest (RoI), identified by the L1 trigger system. The RoIs determine the parts of the detector that are worth further investigation. The clusters within an RoI from the silicon tracking detectors are combined with the geometrical information to provide three-dimensional space-points. The subsequent pattern recognition is then based on space-point triplet finding within the subset of three different ID layers followed by the merging of triplets that are consistent with the same track trajectory [9]. This pattern recognition is followed by a preliminary track fit, rejection of outlying hits, and extension of the tracks into the Transition Radiation Tracker (TRT) - a straw tube tracker, which surrounds the silicon detectors. In the Run 2 strategy the task of the second stage tracking is to perform the final track fit, and the resolution of the ambiguities between close or crossing tracks. This stage is known as the Precision Tracking, and in the Run 2 scenario.

During Run 1, the EF tracking ran the pattern recognition anew, even after the L2 tracking. With the new single node HLT strategy for Run 2, the pattern recognition stage of the Precision Tracking can be omitted, instead using the pattern recognition from the Fast Track Finder. The execution times for the Run 1 and Run 2 strategies on simulated Run 2 data can be seen in Figure 2(a). The *Run 1 strategy* runs those algorithms that were executed during Run 1 data taking, which consisted of the fast tracking stage, followed by the modified version of the full offline tracking, running the pattern recognition and Ambiguity Solver stages. In contrast, the *Run 2 strategy* also runs a fast tracking stage, but then performs the Precision Tracking by directly seeding the Ambiguity Solver stage from the output of this fast tracking stage rather than running the offline pattern recognition. Comparison of the Ambiguity Solver part of the reconstruction running in both strategies is seen in Figure 2(b). The Run 2 HLT code will also be able to seed the Precision Tracking with alternative track seeds such as tracks from the FTK. The IBL data was fully integrated into the complete reconstruction process during the redesign of the trigger tracking code.

3. ATLAS code optimisation

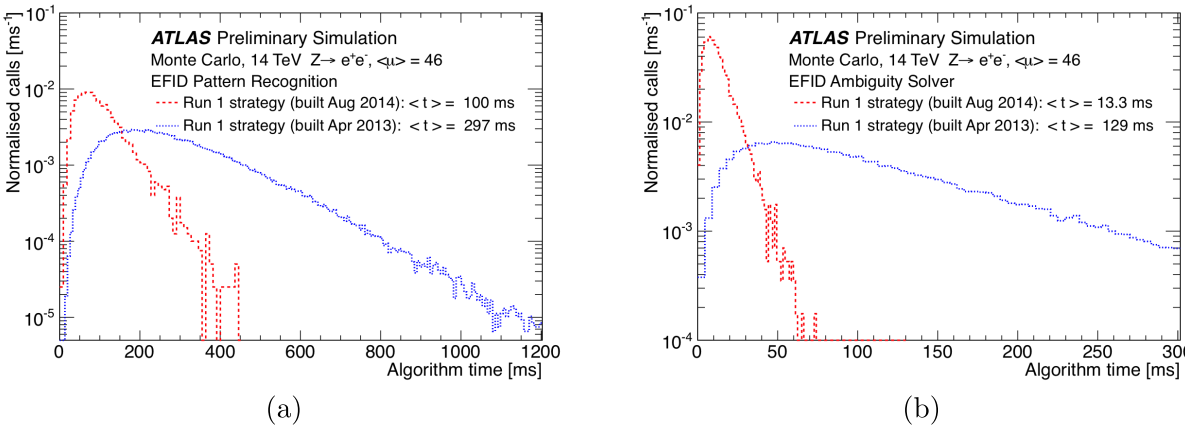


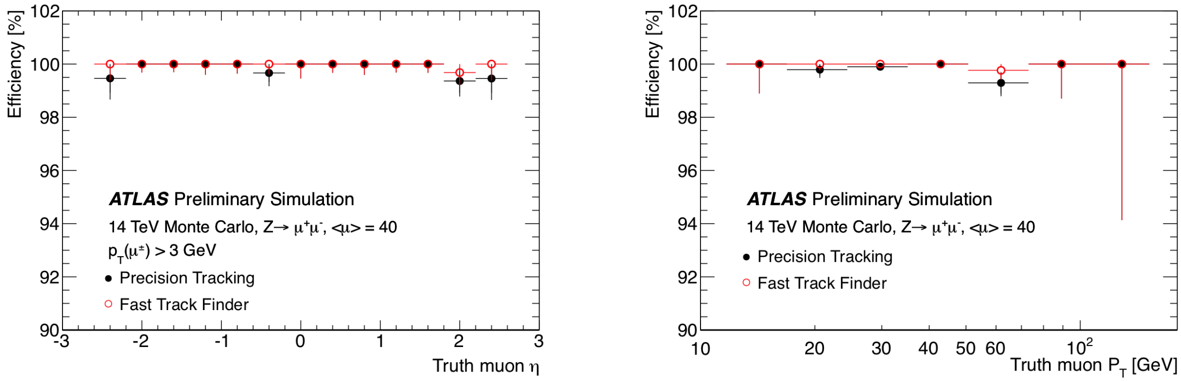
Figure 3. The distribution of processing times per call for the pattern recognition stage (a) and for the Ambiguity Solver stage (b) of the Event Filter Inner Detector trigger tracking. Shown are the times for the tracking strategy used during the ATLAS Run 1 data taking in 2012 but implemented in different versions of the ATLAS code; one built in April 2013 (blue dashed line) and a more recent build from August 2014 (red dashed line) [6].

The performance of the upgraded LHC machine will place significant demands on the ATLAS trigger system and will need to deal with very busy events containing many individual pileup interaction in each bunch crossing. Profiling and optimisation of the new tracking code has been performed as part of the overall redesign to identify the code where further optimisation will be most beneficial. For the Run 2 Fast Track Finder, the profiling tool Callgrind [10] is being used to determine the most often called, or computationally expensive parts of the code. Even small and simple changes in the code can lead to significant reduction of the execution time of an algorithm. For instance, the precalculation of a constant variable before a for-cycle or the prevention of precalculation of a variable, if there is a possibility the variable will not be used. Other optimizations, such as avoiding branch misprediction or cache misses are discussed have also been studied previously [8].

An example of successful optimisation is depicted in Figure 3. This shows the processing times for the versions of the pattern recognition and Ambiguity Solver stages of the Run 1 strategy from two different releases of the ATLAS software, one from 2013 and the other from August 2014. The code from 2014 is significantly faster than that from 2013 as the offline tracking algorithms used in the Event Filter tracking underwent significant optimisation prior to the later build. The second example, Figure 3(b), shows that optimised code executes an order of magnitude faster. This is significant, since the Ambiguity Solver is still executed in the Run 2 trigger tracking, whereas the pattern recognition is not.

4. Muon efficiency in the Run 2

The outstanding performance of the ATLAS trigger during Run 1 is also required for Run 2. Figure 4 shows the efficiencies of the Fast Track Finder, and the Precision Tracking in the Run 2



(a) (b)

Figure 4. The muon finding efficiency for the ATLAS Inner Detector trigger tracking with respect to the true muon pseudorapidity (a) and transverse momentum (b). The efficiency is shown for the Run 2 strategy, for both the Fast Track Finder (hollow red points), and the Precision Tracking (solid black points) [6].

strategy with respect to true muons estimated using simulated Run 2 Monte Carlo $Z \rightarrow \mu^+\mu^-$ events with a mean number of 40 additional pileup interactions per bunch crossing. The efficiency is above 99 %, illustrating that the ATLAS trigger performance has been preserved. The Fast Track Finder serves to seed the Precision Tracking which performs additional rejection of fake tracks using the Ambiguity Solver algorithm, and refits the track. The apparent small loss of the efficiency for the Precision Tracking at high pseudorapidity is due to the rejection of poorly reconstructed, mismeasured, or split tracks which result from the looser requirements of the fast tracking which is optimised for efficiency rather than purity. The simulated data also contain hits from the IBL.

5. Summary

The ATLAS trigger performed exceptionally well during Run 1. To deal with the significantly larger rates and occupancies expected during Run 2, the ATLAS tracking trigger code has been redesigned and significantly improved. The high efficiencies of the ID trigger tracking for the muons in $Z \rightarrow \mu^+\mu^-$ Monte Carlo show that the trigger performance has been preserved. This will allow ATLAS to continue the previous successes from Run 1 also in to Run 2.

The significant reduction of the time required by the tracking, as illustrated by the reduction by a factor of three in the processing time for the complete trigger for the 24 GeV isolated electron trigger for Run 2, when compared with Run 1, promises that the more challenging requirements for the trigger during Run 2 will be met. The successful installation of the IBL and the inclusion of the data from it in the tracking trigger code, together with provisions to include the FTK in the HLT provide a very bright outlook for the ATLAS tracking trigger and will allow ATLAS to rise to the challenge of data taking for the coming years.

6. References

[1] ATLAS Collaboration 2008 The atlas experiment at the cern large hadron collider *Journal of Instrumentation* **3** S08003 URL `http://stacks.iop.org/1748-0221/3/i=08/a=S08003`

[2] ATLAS Collaboration 2012 Observation of a new particle in the search for the standard model higgs boson with the atlas detector at the lhc *Physics Letters B* **716** 1 – 29 ISSN 0370-2693 URL `http://www.sciencedirect.com/science/article/pii/S037026931200857X`

[3] Bartoldus R S *et al.* 2013 Technical Design Report for the Phase-I Upgrade of the ATLAS TDAQ System

Tech. Rep. CERN-LHCC-2013-018. ATLAS-TDR-023 CERN Geneva final version presented to December 2013 LHCC.

[4] Simioni E *et al.* 2012 Topological and Central Trigger Processor for 2014 LHC luminosities Tech. Rep. ATL-DAQ-PROC-2012-041 CERN Geneva

[5] Shochet M, Tompkins L, Cavaliere V, Giannetti P, Annovi A and Volpi G 2013 Fast TracKer (FTK) Technical Design Report Tech. Rep. CERN-LHCC-2013-007. ATLAS-TDR-021 CERN Geneva aTLAS Fast Tracker Technical Design Report

[6] ATLAS Collaboration 2014 ID Trigger timing and efficiency results Tech. Rep. ATL-COM-DAQ-2014-088 CERN Geneva

[7] Capeans M, Darbo G, Einsweiller K, Elsing M, Flick T, Garcia-Sciveres M, Gemme C, Pernegger H, Rohne O and Vuillermet R 2010 ATLAS Insertable B-Layer Technical Design Report Tech. Rep. CERN-LHCC-2010-013. ATLAS-TDR-19 CERN Geneva

[8] ATLAS Collaboration 2013 Studies for the development of the Inner Detector trigger algorithms at ATLAS Tech. Rep. ATL-DAQ-PUB-2013-002 CERN Geneva

[9] ATLAS Collaboration 2012 Performance of the atlas trigger system in 2010 *The European Physical Journal C* **72** 1849 ISSN 1434-6044 URL `http://dx.doi.org/10.1140/epjc/s10052-011-1849-1`

[10] Nethercote N and Seward J 2007 *Proceedings of the 2007 ACM SIGPLAN Conference on Programming Language Design and Implementation* PLDI '07 (New York, NY, USA: ACM) pp 89–100 ISBN 978-1-59593-633-2 URL `http://doi.acm.org/10.1145/1250734.1250746`