The design and performance of the ATLAS jet trigger

Shima Shimizu
on behalf of the ATLAS collaboration
Kobe University, Rokkodai-cho 1-1, Nada-ku, Kobe 657-8501, Japan
E-mail: shima.shimizu@cern.ch

Abstract. The ATLAS jet trigger is an important element of the event selection process, providing data samples for studies of Standard Model physics and searches for new physics at the LHC. The ATLAS jet trigger system has undergone substantial modifications over the past few years of LHC operations, as experience developed with triggering in a high luminosity and high event pileup environment. In particular, the region-of-interest based strategy has been replaced by a full scan of the calorimeter data at the third trigger level, and by a full scan of the level-1 trigger input at level-2 for some specific trigger chains. Hadronic calibration and cleaning techniques are applied in order to provide improved performance and increased stability in high luminosity data taking conditions. In this note we discuss the implementation and operational aspects of the ATLAS jet trigger during 2011 and 2012 data taking periods at the LHC.

1. Introduction
A jet is a collimated spray of hadrons. It is produced by a scattered quark or gluon with high transverse energy \( E_T \) and is an important signature in the collider physics. The LHC provided proton-proton collisions at the centre-of-mass energies of 7 TeV with luminosity up to \( 3.65 \times 10^{33} \text{cm}^{-2}\text{s}^{-1} \) in 2011 and of 8 TeV with luminosity up to \( 7.73 \times 10^{32} \text{cm}^{-2}\text{s}^{-1} \) in 2012, with a frequency of 20 MHz. In the operation of the ATLAS detector [1], the ATLAS trigger performs the first selection of interesting collision events at the LHC. The ATLAS jet trigger [2] is designed to tag jets with high flexibility, to adapt to the LHC beam conditions and to allow a variety of physics analyses using the ATLAS data.

2. Overview of the ATLAS jet trigger system
The ATLAS trigger system consists of three levels, Level 1 (L1), Level 2 (L2) and Event Filter (EF), where L1 is hardware-based and L2 and EF are software-based. The system can deal with a maximum bunch-crossing rate of 40 MHz. L1 is designed to give a trigger rate rate of 75 kHz (70 kHz was the actual peak value in 2012) with a fixed latency less than 2.5 \( \mu \text{s} \), L2 to give 3.5 kHz within 40 ms (5 kHz in 75 ms in 2012) and EF to have an output rate of 200 Hz within 4 s (700 Hz in about 1 s in 2012). The ATLAS jet trigger is allocated about 20 % of the total bandwidth of the ATLAS trigger.

The schematic illustration of the ATLAS jet trigger, which includes upgrades in 2011, is shown in Figure 1. At L1, jet finding is performed with a sliding window algorithm applied on L1 calorimeter towers, which have a granularity of \( 0.2 \times 0.2 \) in pseudo-rapidity \( \eta \) and azimuthal angle \( \phi \). The algorithm looks for local energy maxima in the ATLAS calorimeter. The detector region where a maximum is located is called Region of Interest (ROI) and...
the information of the ROI is passed to L2. In the original implementation of the L2 jet trigger algorithm, jets were reconstructed with the cone algorithm in ROIs using calorimeter cells. Starting from 2011, a new Full Scan algorithm was added to the L2 system. The new algorithm, L2 Full Scan, can perform reconstruction of anti-$k_t$ [3] jets (as implemented in the FastJet package [4]) using L1 calorimeter towers with a granularity of $0.1 \times 0.1$ in $\eta \times \phi$, across the entire ATLAS detector. In this algorithm, electromagnetic energies of jets can be corrected to compensate for calorimeter response to hadrons and for energy loss in dead materials. The reconstructed jets at this layer are called L2FS jets or L1.5 jets. These L2FS jets and ROI from L1 can be used as inputs at L2 for further jet reconstruction with anti-$k_t$ or cone algorithms using calorimeter cells. At EF, topological clusters [5] are created from calorimeter cells and reconstruction of anti-$k_t$ jets is done using topological clusters across the entire detector. All the offline jet algorithms and calibration can be applied at EF.

The ATLAS jet trigger has a variety of possible configurations and this variety is increased especially by the newly implemented L2 Full Scan. Not only single jet triggers and multijet triggers but combined triggers with other physics signature, such as missing transverse energy, are also possible, with several choices in jet reconstruction such as constituents, jet algorithm and jet calibration.

3. Pileup and noise suppression

Due to the high instant luminosity provided by the LHC, calorimeter energy deposits in an interesting event can be affected by other additional interactions (called pileup) in the same bunch crossing or in close bunch crossings. In the 2012 operation, the average number of interactions per bunch crossing was 20.7 [6]. A noise suppression tool is implemented at L2 and EF and only calorimeter cells with energy depositions above a certain threshold are considered in the jet reconstruction at L2 and EF since 2011. Figure 2 shows efficiencies of single jet triggers at L1, L2 and EF measured using 2011 data. Pileup suppression improves the jet energy resolution and hence steepens the turn-on curves of the efficiencies.
Figure 2. Efficiencies of single jet triggers at L1, L2 and EF are shown for anti-$k_t$ jets with a jet size of $R = 0.4$ in the central region of $|\eta| < 2.8$ (left) and in the forward region of $3.6 < |\eta| < 4.4$ (right), as a function of offline jet $E_T$. For L2 and EF, efficiencies with and without noise suppression are compared by full markers (with suppression) and open markers (without suppression). [7]

Figure 3. Jet angular resolution in $\eta$ is shown for L1 jets, L2FS jets (denoted as L1.5) with different tower sizes in inputs and L2 jets. The trigger algorithms are run offline and $\eta$ differences with offline jets are plotted. The algorithms use a sliding window of $0.8 \times 0.8$ for L1, anti-$k_t$ with a jet size of $R = 0.4$ for L2FS and a three-iteration cone with a jet size of $R = 0.4$ using inputs from the L1 ROI for L2. [7]

4. Performance of L2 Full Scan trigger
Performance of the new L2 Full Scan trigger was tested by running the algorithm offline on the proton-proton collision data in 2011. Figure 3 shows $\eta$ differences between online jets and corresponding offline jets. It shows that jet angular resolution is quite improved in L2FS jets compared to L1 jets.

The processing time needed for L2FS is also checked. The time taken to read-out and to find jets for L2FS was measured during lead-lead collisions at the LHC, where multiplicity in the ATLAS detector is extremely high. They are shown in Figure 4. The total latency is within the nominal time limit at L2 of about 40 ms.

5. Efficiency of L2 Full Scan in the 2012 operation
L2FS was in use in the 2012 operation and Figure 5 shows the efficiencies of single jet triggers at L2FS. In the plot, efficiency of a trigger requiring a jet with the electromagnetic (EM) transverse energy of 15 GeV and that of a trigger requiring a jet with the calibrated transverse energy of 35 GeV, where hadronic energy calibration is applied to EM energy, are shown. While both
Figure 4. The time taken to read out the L1 calorimeter towers (left) and the time taken for jet finding using the anti-$k_t$ algorithm with a jet size of $R = 0.4$ (right) are shown using towers with granularity of $0.1 \times 0.1$ and $0.2 \times 0.2$ as input, at the L2 Full Scan (denoted as L1.5). They were measured in lead-lead collisions in 2011. [7]

Figure 5. Efficiencies of single jet triggers at L2FS for anti-$k_t$ jets with a jet size of $R = 0.4$ in the central region of $|\eta| < 2.8$, as a function of offline jet $p_T$. Two triggers are compared, one requiring a jet with an electromagnetic energy of 15 GeV (EM J15) and one requiring a jet with a calibrated energy of 35 GeV (EM+JES J35), where hadronic energy calibration is applied. [7]

Figure 6. Efficiency of multi jet triggers requiring six jets at L1 (L1 6j10) and L2FS (L2FS 6j10) measured in events with six offline anti-$k_t$ jets for a jet size of $R = 0.4$, where each jet should have $E_T > 30$ GeV and $|\eta| < 2.8$, as a function of $E_T$ of the sixth jet. The events are preselected using a trigger requiring four jets. While the L1 multijet trigger has an inefficiency of more than 5 % even at $E_T = 100$ GeV of sixth jet due to the different geometry.
between L1 sliding windows and offline jets, the efficiency is recovered in the L2FS multijet trigger. It shows one of the advantages of L2FS, which performs jet reconstruction across the entire detector, not only in ROIs given by L1.

6. Summary
The ATLAS jet trigger was designed to tag jets with high transverse energies in proton-proton collisions provided by the LHC with high instantaneous luminosity and collision rates up to 40 MHz. It consists of three levels, L1, L2 and EF, where the output rate is reduced at each level with longer latencies at higher levels. A new algorithm called L2FS was implemented at L2 in 2011. It enables reconstruction of anti-$k_T$ jets using L1 calorimeter towers across the entire ATLAS detector, in addition to jet reconstruction within ROIs identified at L1. The processing time of L2FS is within the requirement of L2 even in lead-lead collisions. It provides jet finding at L2 with good angular resolution and also provides more flexibility in the jet trigger configurations. As seen in the improved jet trigger efficiencies in the 2012 data-taking, the ATLAS jet trigger has achieved excellent performance in the ATLAS operation.

References
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