PROCEEDINGS OF SCIENCE

The ATLAS Jet Trigger at 13 TeV

Giulio Cornelio Grossi* **on behalf of the ATLAS Collaboration**
Lousiana Tech University
E-mail: giulio.cornelio.grossi@cern.ch

The new Large Hadron Collider centre of mass energy and expected high luminosity conditions impose more demanding constraints on the ATLAS online trigger than ever before. The immense rate of proton-proton collisions must be reduced from the bunch-crossing rate of 40 MHz to approximately 1 kHz before the data can be written to disk for offline analysis. The ATLAS Trigger System performs real-time reconstruction and selection of these events in order to achieve this reduction. The selection of events containing jets is extremely challenging at a hadron collider where nearly every event contains significant hadronic activity. It is, however, of crucial importance for several physics analyses, including early searches for new physics in the new kinematic regime. Following the very successful first Large Hadron Collider run in 2010-12, the ATLAS Trigger has been upgraded, to include a new hardware topological module and a restructured High Level Trigger system, merging the two previous software-based processing levels. After summarising the overall performance of the jet trigger during the first Large Hadron Collider run, the software design choices and use of the topological module will be reviewed. The expected performance of jet trigger for the second LHC run is described and compared with the first trigger results from the Run 2 collisions data.

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*Speaker.

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1. Introduction

During Large Hadron Collider (LHC) Run 1 2010-2012, the ATLAS detector [1] used a three-level trigger system [3, 2], where the final two processing levels (Level 2 and the Event Filter) were based on software applications running on separated CPU nodes in the Trigger Data Aquisition computing cluster. Event building, during which the data fragments assigned to each bunch crossing are combined into a single event, happened between Level 2 (L2) and the Event Filter (EF). The EF reconstruction and selection algorithms had access to the full event information. The L2 algorithms analyzed only regions of interest (RoI) in the detector, identified by the Level 1 (L1) trigger, to reduce the network bandwidth required by the detector data when reading out the detector at the L2 rate. Figure 1 shows a scheme of the ATLAS trigger system during Run 1.

For the LHC Run 2, which started in 2015, these two processing levels were merged into a single High Level Trigger (HLT), with event building happening on request at any time during the processing of each event. The new scheme has the advantage of reducing the overhead from reading the same data multiple times from the readout buffers. Figure 2 shows a scheme of the ATLAS trigger system during Run 2.

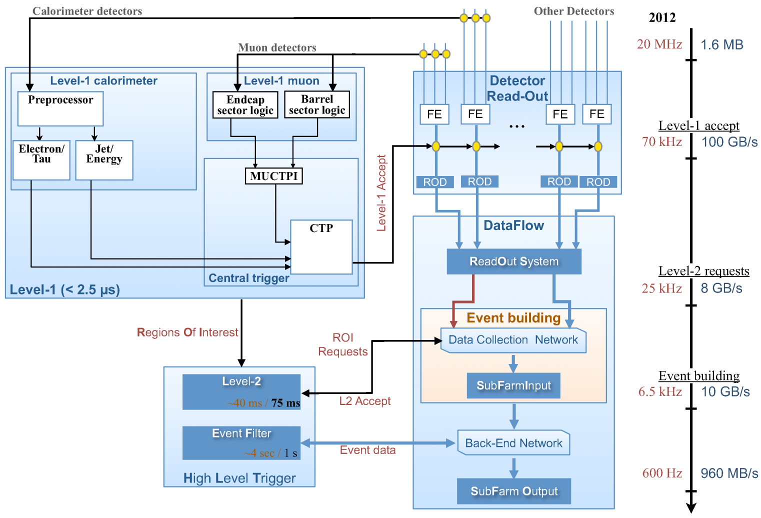

Figure 1: Scheme of the ATLAS trigger during Run 1. Taken from Ref. [8].

2. L1 and HLT Jet Triggers

The L1 Trigger uses the calorimeter energy deposition to identify jets produced by the colliding hadrons. Jets identified by L1 are then used as *seeds* for the HLT, which performs full event reconstruction to refine the jets identification.

The hadronic and the electromagnetic calorimeters [5, 4] are segmented into regions of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ named *Trigger Towers* (TTs). *Jet Elements* (JE), with a granularity of 0.2×0.2, are then constructed from 2×2 groups of TTs. A L1 algorithm is then applied, consisting of a sliding window of size 2×2, 3×3 or 4×4 *Jet Elements*. A jet is reconstructed and used to define an RoI if the sum in E_{T} is greater than the required threshold. New components have been installed in the L1 Calorimeter trigger system for the Run 2, namely:

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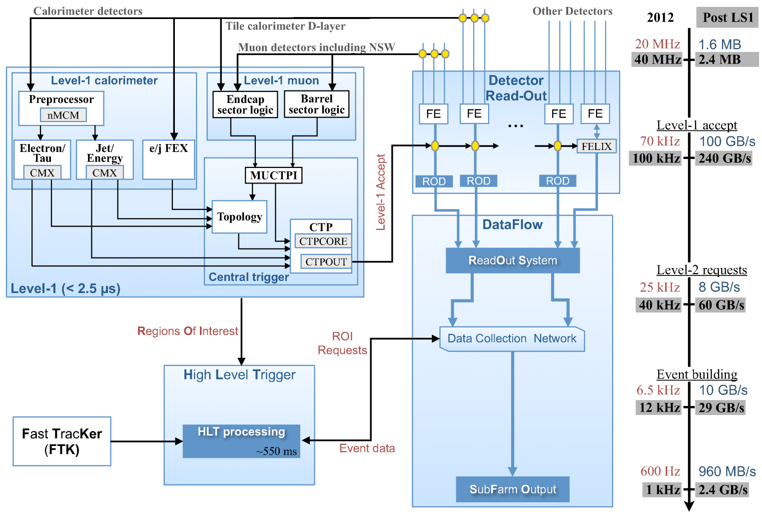

Figure 2: Scheme of the ATLAS trigger during Run 2. Taken from Ref. [8].

- L1 Topological Processor (L1 Topo): it uses algorithms on FPGA processing events at the L1 input rate and performs real-time event selection based on the geometrical relationship between trigger objects and variables, i.e E_{T}, $\sum E_{\mathrm{T}}$, M_{eff}, $\sum E_{\mathrm{T}}^{\mathrm{jet}}$, MET.
- new Multi Chip Module (nMCM): digitizes analogue calorimeter signals. Applies a dynamic pedestal subtraction and a specific jet energy calibration.
- Common Merger eXtender module (CMX): merges candidate counts and energy sums. Transfers data to L1 Topo and provides faster communications.

The merging of L2 and the EF has provided the opportunity to improve the trigger processing and reduce the processing time. A combined HLT allows the pooling of CPU resources, with a consequent increase in the time available to run more sophisticated algorithms based on those used for offline (after data taking, during subsequent processing) reconstruction. These reconstruction algorithms can be applied to perform either a *Full Scan* (FS), using the full calorimeter data, or a *Partial Scan* (PS) using only the data from RoIs. Jets reconstructed with *Full Scan* are the most similar to those reconstructed by the offline based algorithms.

3. Jet Reconstruction and Calibration

Jet reconstruction in ATLAS is carried out by clustering *topological clusters*, which are group of cells which are topologically connected [6]. The cells are selected using the energy significance of a cell $|E|/\sigma$, where σ is the cell noise. If $|E_{cell}| > 4\sigma$ the cell is identified as *seed*. If $|E_{cell}| > 2\sigma$ the cell is identified as *neighbour*. The *topological clusters* are then calibrated, starting from the electromagnetic scale and identifying the hadronic clusters. Weights for the hadronic response are then applied, defining a *Local hadronic Cluster Weighting* (LCW). Calibrated *topological clusters* are used as input for jet building by the jet clustering algorithm. Jets are formed from the topological clusters using the anti-k_t algorithm [7], predominantly with radius parameter $R = 0.4$.

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The transverse energy, E_{T}, of the jets reconstructed in the trigger may be further refined by applying a jet energy scale calibration factor dependent on jet η and p_T and extracted from Monte Carlo simulation. Additionally, the fraction of the jet transverse momentum, p_T, arising from energy deposits in independent collisions (pileup), can be subtracted on an event-by-event basis, using the calculated area of each jet and the modal value of the energy density measured in the region $|\eta|<2$ in each particular event as it's done for the offline jet reconstruction.

4. Jet Trigger Monitoring

The monitoring infrastructure is essential to assess the quality of data taken during physics runs. Monitoring histograms are used to monitor jet trigger jet multiplicity, η vs. ϕ maps and E_{T} distributions. Different infrastructure is used for the online (during data taking) and offline monitoring.

4.1 Online monitoring

The aim of the online monitoring is to provide prompt information about the jet trigger functioning during a run. This information is used by the trigger or DataQuality online shift in the ATLAS Control Room to quickly identify problems and to report them to the trigger experts. There are two systems for monitoring the trigger performance: the *Online Histogram Presenter* (OHP), which is an easy manageable system for the control room for fast feedback, and the *Data Quality Monitoring Framework* (DQMF), which is a more sophisticated system doing more complex automatized checks based on histogram properties. Both of them are based on the same histograms made on the HLT farm during the HLT processing.

4.2 Offline monitoring

Monitoring histograms are also produced offline (after data taking). At this stage a full reconstruction of the events is performed, and more detailed histograms can be produced. These histograms are used to monitor the jet trigger jet multiplicity, η vs. ϕ maps, E_{T} distributions, but also trigger efficiency, correlation histograms between HLT and offline reconstruction and resolution between HLT and offline reconstruction. The results from the comparison with offline are used by the monitoring shift to determine whether there were any significant problems with the trigger or detector operation, that would prevent the run being marked as usable for physics analysis.

5. Jet Trigger performance in 2015 with $\sqrt{s}$ = 13 TeV

Figures 3 and 4 show the results with early 2015 data obtained by the ATLAS jet trigger at $\sqrt{s}$ = 13 TeV. Figure 3 shows the comparison of the efficiency as a function of E_{T} from Monte Carlo simulation with the data for three jet-trigger signatures with different E_{T} thresholds. Figure 4 shows the efficiency across the η-ϕ plane for offline jets with p_T > 30 GeV from the 25 GeV threshold trigger. The triggers all reach full efficiency within 30 GeV of their respective trigger threshold. The efficiency seen in the simulation increases slightly more sharply than in the data, due to small differences in the resolution of the trigger jets with respect to offline. For this reason, physics analyses typically only used jets from any particular trigger in the plateau region where the trigger is fully efficient.

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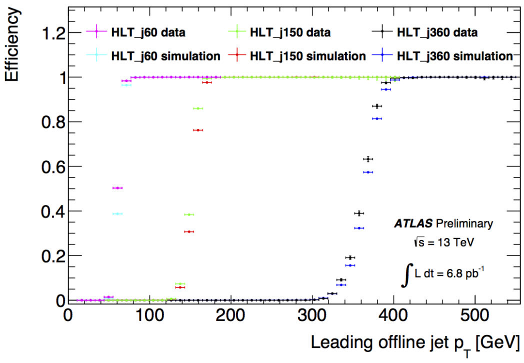

Figure 3: Jet trigger efficiency in bins of p_T of the leading jet for different HLT chains. Data and Monte Carlo predictions are shown. Taken from Ref. [9].

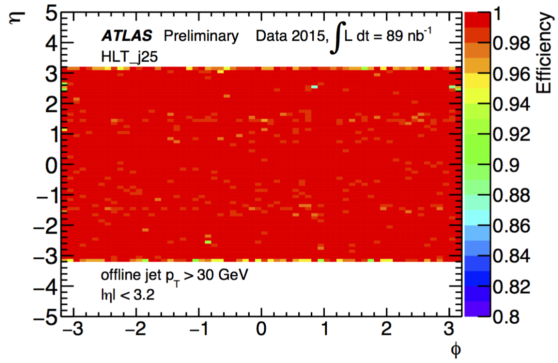

Figure 4: Jet trigger efficiency in bins of η and ϕ of the leading jet for HLT_j25 chain in the central region ($|\eta|$ <3.2). Taken from Ref. [9].

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