Beam Test of the ATLAS Level-1 Calorimeter Trigger System

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Abstract

The ATLAS experiment at the LHC requires a highly efficient and flexible event selection system. An essential part is the Level-1 Calorimeter Trigger, which produces its results within 2 μs. It consists of a Preprocessor, a Cluster Processor (CP), and a Jet/Energy-sum Processor (JEP). The CP and JEP receive digitised trigger-tower data from the Preprocessor and produce trigger multiplicity and region-of-interest information. Intermediate results are supplied to the data acquisition system for monitoring and diagnostic purposes by using Readout Driver modules. The Preprocessor Modules digitise calorimeter pulses and prepare data for the CP and JEP. The CP Modules (CPMs) are designed to identify isolated electron/photon and hadron/tau clusters. The Jet/Energy Modules (JEMs) localise and classify jet candidates, and sum total and missing transverse energy. The Common Merger Modules combine information from CPMs and JEMs and send it to the Central Trigger Processor which makes the Level-1 event acceptance decision.

Several of these modules will be integrated with the calorimeters and data acquisition system in the ATLAS test-beam at CERN to form a realistic trigger slice. The 25 ns bunch structure of the test-beam and the calorimeter calibration facilities will enable this system to process data from calorimeter cells to produce Level-1 triggers at rates up to 100 kHz. Measurements of trigger performance will be presented, including signal cross-talk and latency, and demonstration of event recovery and synchronisation.

Summary

The ATLAS Level-1 Calorimeter Trigger provides information for the Level-1 trigger decision by identifying and counting hit clusters in the calorimeters, as well as estimating total and missing energy. It consists of three subsystems: the Preprocessor (PPr), electron/photon and tau/hadron Cluster Processor (CP) and Jet/Energy-sum Processor (JEP). The two processors send results as multiplicities for every bunch crossing to the Central Trigger Processor (CTP), which, together with the Muon Level-1 Trigger information, makes a Level-1 Accept decision. The latency of the Level-1 trigger is limited to 2 μs. On receipt of a Level-1 Accept, the processors send more detailed information on the types and locations (Region-of-Interest or RoI) of events to the Level-2 Trigger system. Intermediate results are also sent to the data acquisition (DAQ) system for monitoring and diagnostic purposes.

The Preprocessor Modules (PPMs) provide the input data used by both the CP and JEP systems. They take analogue pulses from the ATLAS calorimeters, digitise and synchronise them, and identify the bunch-crossing from which each pulse originated (Bunch-Crossing Identification or BCID). Finally, lookup tables perform the final E_T calibration for the trigger towers that form the basis of the trigger. Data are sent downstream to the CP and JEP systems using LVDS 400 Mbit/s serial link chipsets in order to reduce the I/O requirements.

A total of 7200 analogue signals have to be processed, from which 6400 Trigger Towers are sent to the CP system. Operating at the LHC 40 MHz bunch-crossing rate, the real-time tasks of the Cluster Processor Modules (CPMs) are:

- To identify isolated electron candidates, photons and hadronic τ decays, using information from the ATLAS electromagnetic and hadronic calorimeters
- To calculate the multiplicity of e/γ and τ candidates passing different threshold conditions on E_T
- To transmit these multiplicities to the Level-1 Central Trigger Processor (CTP) via the Common Merger Modules (CMMs), which sum the e/γ and τ multiplicities from individual CPMs

The cluster-finding algorithm requires the exchange of a large volume of data between neighbouring CPMs, for which a custom backplane has been designed. This also provides the connectivity from CPMs to CMMs in the same crate. On receipt of a positive trigger decision, or Level-1 Accept, each CPM sends the coordinates of potential e/γ and τ candidates to the Level-2 Trigger system as Regions-of-Interest (RoIs) to guide Level-2 processing. Preparation and processing of data on the modules are performed with FPGAs, in order to add flexibility to the system. Five CPMs have been built and fully tested.

The Jet/Energy-sum processor (JEP) utilises the complete ATLAS calorimetry. The Jet/Energy Module (JEM) identifies, localises and classifies jets on a granularity of 2x2 Trigger Towers. Each JEM provides hit multiplicities from a calorimeter sub-region to a CMM, together with a scalar energy sum Sum-E_T and the vector energy sums E_X and E_Y needed for E_T-miss calculation. The CMMs gather information from all JEMs and send it to the CTP. On receipt of a Level-1 Accept, the JEP system also outputs data for monitoring purposes and to help in building the Level-2 trigger decision. The JEP uses the same custom backplane as the CP. Both systems have been designed to handle Level-1 trigger rates up to 100 kHz, with instantaneous burst rates of up to 8 MHz.

Prototypes of Readout Driver (ROD) modules were built to handle RoI or DAQ data received via G-links from up to four CP or JEP trigger modules. The use of FPGAs on those boards enables the use of the same PCB layout, with different versions of firmware to handle the different data formats.

Tests have already been done to integrate successfully three CPMs, two JEMs, two CMMs and up to four RODs, using the playback memories on individual modules to feed data into the chain. The ATLAS online software has been used to perform long soak tests and explore the domain of validity of real-time data. A similar architecture will be installed in the ATLAS test-beam at CERN, and integrated with PPMs, electromagnetic and hadronic calorimeters and the data acquisition system. Tests will include:

- Checking that the energy deposit in the calorimeter is correctly located in the trigger tower
- Measuring cross-talk and performing soak tests
- Verifying the Level-1 trigger rate up to 100 kHz
- Measuring the trigger latency
- Checking that events are correctly flagged and recovered when using the 25 ns test-beam bunch structure.

The results of these studies will be presented.