First data with the ATLAS Level-1 Calorimeter Trigger

R. Achenbach[1], P. Adragna[2], M. Aharrouche[3], V. Andrei[1], B. Åsman[4], B.M. Barnett[5], B. Bauss[3], M. Bendel[3], C. Bohm[4], J.R.A Booth[6], J. Bracinik[6], I.P. Brawn[5], D.G. Charlton[6], J.T. Childers[1], N.J. Collins[6], C.J. Curtis[6], A.O. Davis[5], S. Eckweiler[3], E. Eisenhandler[2], P.J.W. Faulkner[6], J.E. Fleckner[3], F. Föhlisch[1], M.P. Gallacher[6], C.N.P. Gee[5], A.R. Gillman[5], C. Göringer[3], M. Groll[3], D.R. Hadley[6], P. Hanke[1], S. Hellman[4], A. Hidvégi[4], S.J. Hillier[6], M. Johansen[4], E.-E. Kluge[1], T. Kuhl[3], M. Landon[2], V. Lendermann[1], J.N. Lilley[6], K. Mahboubi[1], G. Mahout[6], K. Meier[1], R.P. Middleton[5], T. Moa[4], J.D. Morris[2], F. Müller[1], A. Neusiedl[3], C. Ohm[4], B. Oltmann[3], V.J.O. Perera[5], D.P.F. Prieur[5], W. Qian[5], S. Rieke[3], F. Rühr[1], D.P.C. Sankey[5], U. Schäfer[3], K. Schmitt[1], H.-C. Schultz-Coulon[1], S. Silverstein[4], J. Sjölin[4], R.J. Staley[6], R. Stamen[1], M.C. Stockton[6], C.L.A. Tan[6], S. Tapprogge[3], J.P. Thomas[6], P.D. Thompson[6], P.M. Watkins[6], A. Watson[6], P. Weber[1], M. Wessels[1], M. Wildt[3]

[1]Kirchhoff-Institut für Physik, University of Heidelberg, Heidelberg, Germany
[2]Physics Department, Queen Mary, University of London, London, UK
[3]Institut für Physik, University of Mainz, Mainz, Germany
[4]Fysikum, Stockholm University, Stockholm, Sweden
[5]STFC Rutherford Appleton Laboratory, Chilton, Oxon, UK
[6]School of Physics and Astronomy, University of Birmingham, Birmingham, UK

***Abstract*—The ATLAS Level-1 Calorimeter Trigger is one of the main elements of the first stage of event selection for the ATLAS experiment at the LHC. The input stage consists of a mixed analogue/digital component taking trigger sums from the ATLAS calorimeters. The trigger logic is performed in a digital, pipelined system with several stages of processing, largely based on FPGAs, which perform programmable algorithms in parallel with a fixed latency to process about 300 Gbyte/s of input data. The real-time output consists of counts of different types of physics objects and energy sums. The final system consists of over 300 custom built VME modules, of several different types. The installation at ATLAS of these modules, and the necessary infrastructure, was completed at the end of 2007. The system has since undergone intensive testing, both in standalone mode, and in conjunction with the whole of the ATLAS detector in combined running.**

The final steps of commissioning, and experience with running the full scale system will be presented. Results of integration tests performed with the upstream calorimeters, and the downstream trigger and data flow systems will be shown, along with an analysis of the performance of the calorimeter trigger in ATLAS data taking. This will include trigger operation during cosmic muon runs from before LHC start-up, and a first look at LHC proton beam data.

SUMMARY

The ATLAS Level-1 trigger is designed to provide a trigger decision within a fixed time of 2 μs in order to reduce the LHC bunch-crossing rate of 40 MHz down to a rate of less than 75 kHz of events to be retained for the second level of event selection. The calorimeter trigger (L1Calo) processes the calorimeter information, which comprises an input of over 7000 analogue signals. The trigger logic identifies high-p_T jets, electron/photon and tau candidates, and measures total and missing E_T. All of the physics algorithms are implemented in FPGAs to allow flexibility to accommodate changing LHC conditions and trigger requirements. The results, around 100 data bits per LHC bunch-crossing, are transmitted to the Central Trigger Processor (CTP) which makes the final Level-1 decision.

Along with the trigger decision path, L1Calo also provides read-out data and 'region-of-interest' (RoI) data on events accepted for further processing. The read-out data is used to monitor and understand the trigger decision, but the RoI data is used at a more fundamental level to guide the second level trigger. The correct operation of all these streams is necessary in order for ATLAS to be operational from the first day of LHC beam. Much of this functionality can be verified via calorimeter calibration systems and rare high-energy cosmic muon events. However, the final tuning of timing and signal processing requires LHC beam to obtain the correct alignment relative to beam collisions.

The Level-1 Calorimeter trigger system consists of many designs of module, spread over several sub-systems. A simplified schematic of the modules and dataflow is shown in fig. 1. The real-time path consists of three subsystems: the Preprocessor (PPr), Cluster Processor (CP) and Jet/Energy-sum Processor (JEP). The Preprocessor system consists of 124 Preprocessor Modules (PPM), which provide the input data used by both the CP and JEP systems. Physically, they are 9U VME modules which fit occupy eight crates. The module input consists of analogue pulses, mostly

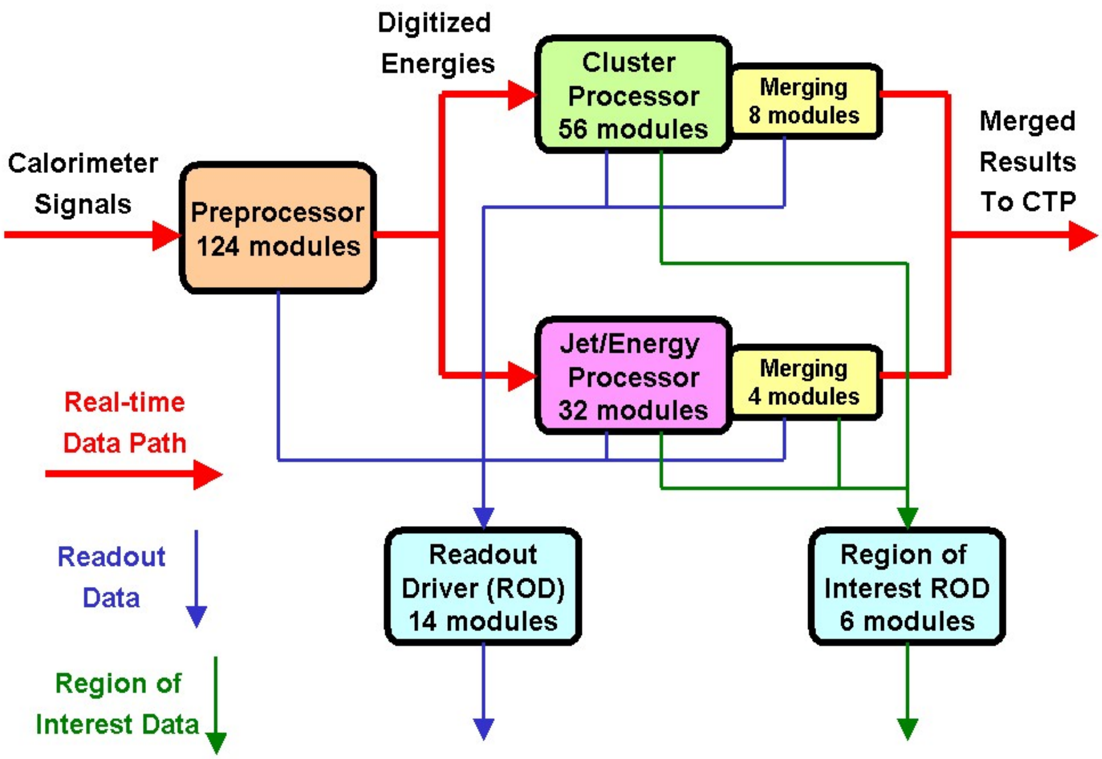

Fig. 1. Module types, numbers and connectivity in the complete Level-1 Calorimeter Trigger System

corresponding to 0.1x0.1 sums in eta/phi space, from the ATLAS calorimeters. These input signals are often referred to as trigger towers. These towers are digitized and energy is assigned to the correct bunch-crossing from which each pulse originated. Finally, lookup tables perform the E_T calibration for these trigger towers and the output forms the basis of the digital trigger decision.

The Cluster Processor (CP) system consists of 56 Cluster Processor Modules (CPM) which identify and count electron/photon and tau candidates. The final sums are performed in 8 Common Merger Modules (CMM), and sent to the CTP. Together, these occupy four 9U VME crates. The Jet/Energy-sum processor (JEP) consists of 32 Jet/Energy Modules (JEM) which count jet candidates and make missing and total transverse energy sums, with the final results again being summed in 4 CMMs. The JEP system fits into two 9U crates, which are identical to those of the CP system. Both systems require the exchange of a large volume of data between neighbouring modules, for which a common custom backplane has been designed.

The read-out and Region-of-Interest data is handled by 20 Read-out Driver modules (ROD). These receive data from all of the other modules, and these data are reformatted into standard ATLAS event fragments, and transmitted into the ATLAS data-flow infrastructure.

The full system has been installed since the end of 2007, and has now been tested both stand-alone and in integrated runs with the rest of ATLAS over a long period. Even before the end of 2007, a partial system was being used to form triggers on high-energy cosmic events in ATLAS. During 2008, these integration and cosmic runs became increasingly sophisticated, allowing the correct performance of many aspects of the system to be thoroughly tested. Events with significant energy could be used to cross-check the trigger decision against the data read-out from the calorimeters themselves. The integration with the ATLAS data-acquisition and high level trigger systems could also be checked using this data.

It is hoped that LHC will start to produce beams during the summer of 2008. This will precipitate a great deal of analysis of beam and signal timing in order to optimize the performance of the calorimeter trigger. This will have to be executed quickly and efficiently to ensure that the trigger is properly timed for first collisions. When proton-proton collisions are achieved, it will then be necessary to measure the efficiency of the trigger and decide on suitable thresholds to maximize the potential for LHC physics.

The architecture and hardware realization of the L1Calo system will be presented, along with results from data taking in 2008, showing how the trigger achieved its goals in all areas – namely, calorimeter integration, algorithm implementation, trigger formation and RoI provision.