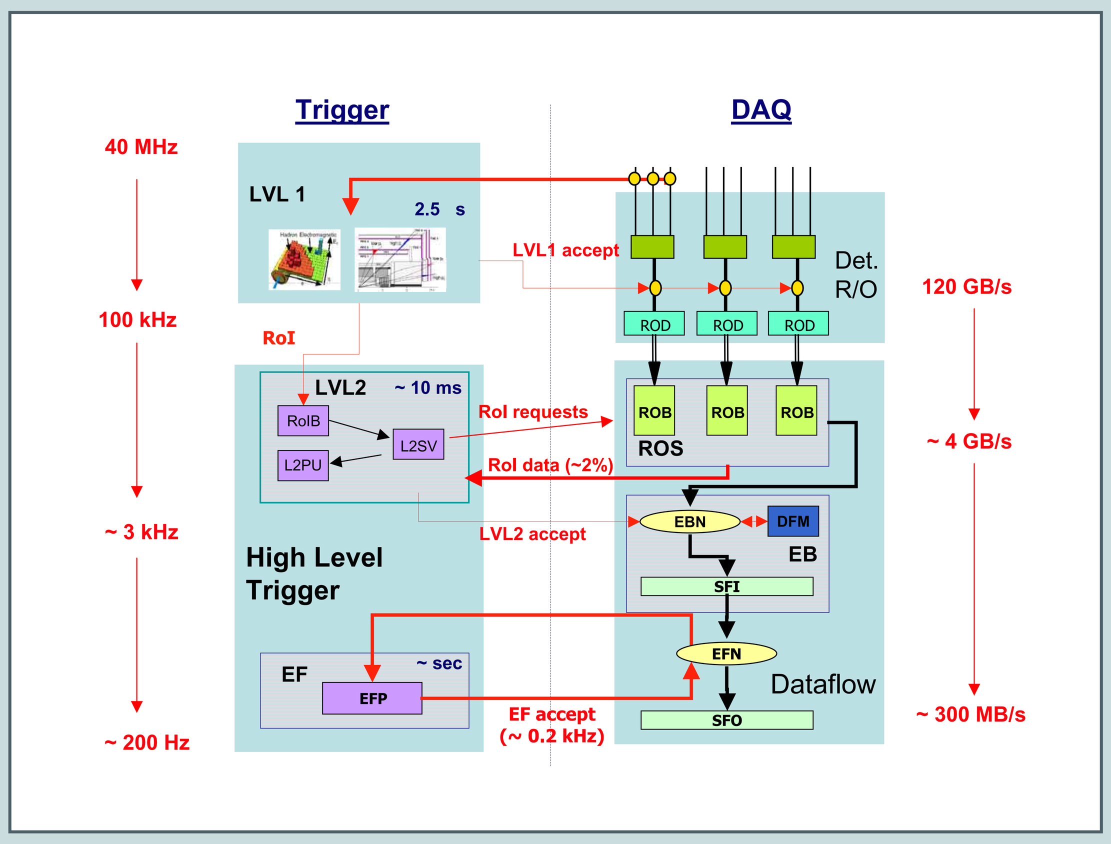
THE ATLAS LEVEL-1 TRIGGER:
STATUS OF THE SYSTEM AND FIRST RESULTS FROM COSMIC-RAY DATA

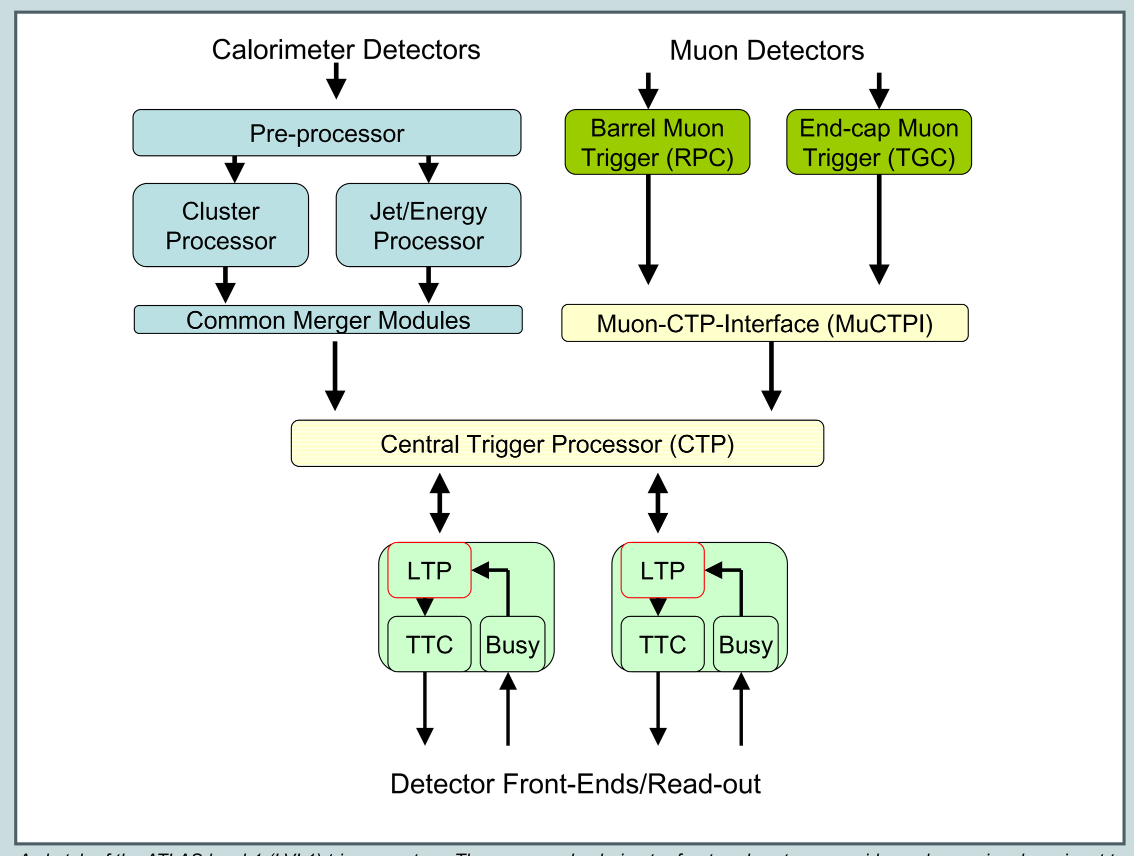
The ATLAS Trigger and DAQ



The three levels of online event selection of the ATLAS trigger and DAQ system are illustrated. At a rate of 100 kHz, the LVL1 trigger system passes regions-of-interest (RoIs) to the LVL2 trigger. For accepted events, the event data is transferred at the same time to the readout system (ROS). At LVL2, the RoIs from different systems are assembled by the RoI builder (RoIB) and passed via the LVL2 supervisor (L2SV) to LVL2 processing units (L2PUs), where the LVL2 algorithms are run. Based on the RoI information, the L2PUs request data for specific detector regions from the readout buffers (ROBs). Events accepted by the LVL2 trigger are passed on to the event builder (EB). These are in turn processed by the event filter (EF) which generates the final online accept signal at a rate of 100-200 Hz.

The ATLAS detector at CERN's Large Hadron Collider (LHC) will be exposed to proton-proton collisions from beams crossing at 40 MHz. At the design luminosity of 10^{34} cm^{-2} s^{-1} there are on average 23 collisions per bunch crossing, with an event size of 1-2 MB of zero-suppressed detector data. A suitable selection procedure must be applied to reduce the incoming rate to 100-200 Hz, digestible by the offline processing and archival storage facilities. A three-level trigger system was designed for that purpose for ATLAS. It selects potentially interesting events to reduce the read-out rate. The first trigger level (LVL1) is implemented in custom-built electronics and makes an event selection based on coarse granularity and resolution detector data. It has to reduce the rate by a factor of 10^4 to less than 100 kHz. The other two consecutive levels, the level-2 trigger (LVL2) and the event filter, are implemented in software and run on commercial PC farms.

The LVL2 trigger of ATLAS is based on the concept of "regions of interests". Algorithms request full-resolution data only from a fraction of the detector, from regions that were identified by the LVL1 trigger as regions of interest. For that purpose, event information like the coordinates of a particle candidate or energy and momentum values are generated by the LVL1 trigger systems and sent to the LVL2 trigger processors in forms of so called regions-of-interest (RoIs). Thereby the amount of full-resolution data that is accessed by the LVL2 is reduced to a few percent of the total event size significantly reducing the processing time. At LVL2 the rate is reduced by a factor of about 50 to a few kHz. The event filter in turn has access to the full resolution data of the whole detector. It runs essentially offline-like algorithms and selection and has to provide another factor of 10 in rate reduction.



A sketch of the ATLAS level-1 (LVL1) trigger system. The muon and calorimeter front-end systems provide analogue signals as input to the off-detector trigger electronics. The LVL1 calorimeter trigger digitises and processes the data and sends information about electron/photon and hadron/tau candidates along with jet multiplicities and missing and global transverse energy to the CTP. The LVL1 muon trigger provides information about candidate muon tracks for six transverse-momentum thresholds separately for 208 trigger sectors to the MuCTPI. The MuCTPI resolves overlaps of trigger sectors and determines candidate multiplicities for each of the six threshold, and passes the multiplicities on to the CTP. If the event is accepted, a LVL1 accept signal is fanned out to all the sub-detectors to initiate the readout. This holds also for the LVL1 trigger system itself, which generates readout data and RoIs for the LVL2 trigger.

The ATLAS Level-1 Trigger

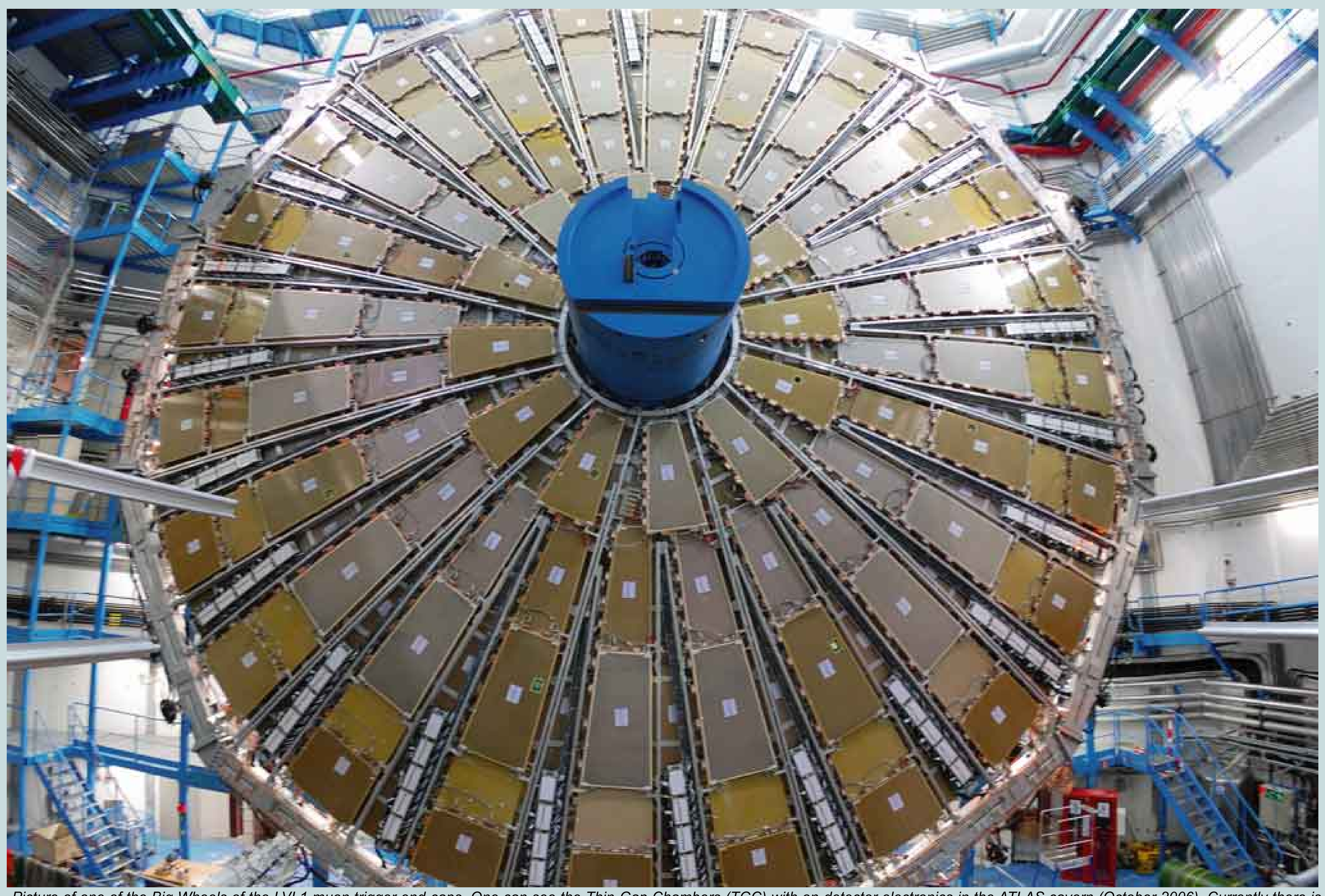
The first-level trigger of ATLAS is a hardware-based system that has the demanding task of reducing the event rate from 40 MHz to below 100 kHz within a fixed latency of less then 2.5 microseconds. The LVL1 trigger consists of three parts: the calorimeter trigger, the muon trigger, and the central trigger.

The LVL1 calorimeter trigger system receives trigger signals from the barrel calorimeter detectors, the electromagnetic liquid-argon calorimeter and the hadronic scintillator-tile calorimeter. On-detector electronics combine the analogue signals to 7200 trigger towers, which are passed on to the calorimeter-trigger system which resides in the counting rooms next to the ATLAS cavern. The trigger system consists of three subsystems. The PreProcessor receives the trigger-tower input signals with a typical granularity of 0.1 x 0.1 in eta and phi. It digitises the analogue signals, assigns a proton-proton bunch crossing to the rather broad trigger pulses, and does a final lookup-table based calibration in transverse energy before sending digital data streams to the next two calorimeter subsystems: the algorithmic trigger processors. The first one is the Cluster Processor which identifies and counts isolated electrons/photons and hadrons/tau leptons. The transverse energy of the electron/photon (hadron/tau) candidates is discriminated against up to 16 (8) programmable thresholds. The Jet/Energy-sum Processor identifies jet candidates and discriminates them against 8 programmable thresholds. It also calculates missing and total transverse energy of the whole event.

For each of the trigger objects, multiplicity and threshold information are sent to the central-trigger system synchronously with the 40 MHz machine clock via Common Merger Modules which carry out merging before sending. Upon reception of a LVL1-accept signal (L1A) data is sent to the readout system and the LVL2 trigger.

The various electronic modules that make up the LVL1 calorimeter trigger are either in full production or are about to be. They are installed at the ATLAS experimental site as soon as they become available. The analogue cables connecting the calorimeter front-end electronics with the off-detector calorimeter trigger are laid, tested and connected for the barrel and one end-cap, for the other end-cap the cables are being laid (February 2007). First connection tests with the LVL1 central trigger were successful.

A full crate of pre-production PreProcessor modules of the LVL1 calorimeter trigger. Most of the functionality of these modules is on replaceable Multi-Chip Modules (MCMs). These MCMs each contain a processing ASIC and four ADCs. All the MCMs (3000) are available and final production of the 124 PreProcessor modules is in full swing (February 2007).



Picture of one of the Big Wheels of the LVL1 muon trigger end-caps. One can see the Thin-Gap Chambers (TGC) with on-detector electronics in the ATLAS cavern (October 2006). Currently there is one out of six wheels installed.

The ATLAS muon spectrometer consists of muon chambers for precision measurements and dedicated fast muon detectors for providing information about muon candidates to the LVL1 central trigger. Resistive-plate chambers (RPCs) are used in the barrel region (|eta| < 1.05) and thin-gap chambers (TGCs) in the end-caps (1.05 < |eta| < 2.4). The muon trigger receives as input the pattern of hits in the muon trigger chambers from more than 8 x 10^5 input channels. Coincidences in different trigger stations are identified independently in eta and phi, based on geometrical roads whose width is related to a certain transverse-momentum threshold making use of deflection of muons in the magnetic field. The coincidence allows six transverse momentum thresholds to be used at the same time. Moreover, muon tracks are identified with a proton-proton bunch crossing. In both the barrel and end-cap systems track candidates are subsequently combined within trigger sectors. There are in total 64 sectors for the barrel and 144 sectors for the end-caps. For each clock cycle, the muon trigger system sends the muon candidate multiplicities per sector for each of the six transverse-momentum thresholds to the central trigger.

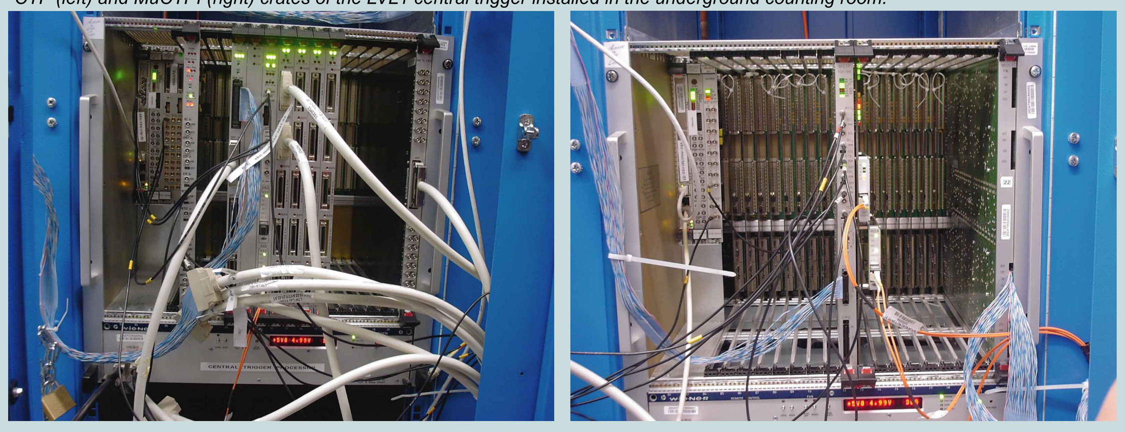
The installation of the LVL1 muon trigger chambers is in full swing. The first out of 16 sectors of the muon barrel detector is equipped with temporary gas systems and is being used in integration tests since August 2006. Pre-production versions of the off-detector parts of the LVL1 muon barrel trigger are available and being used in integration tests. Production of the final boards is expected to commence in spring 2007.

Analogue trigger cables installed in the ATLAS counting rooms. Almost all 776 cables are installed and tested, the analogue receivers and patch panels are also in place.

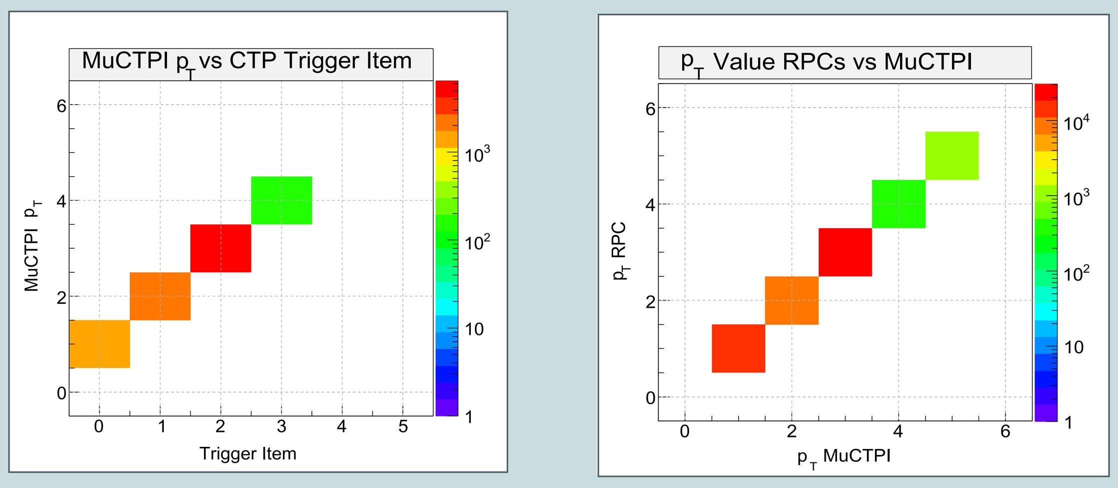
The LVL1 central trigger is composed of the Central Trigger Processor (CTP) and the Muon-to-CTP-Interface (MuCTPI). The MuCTPI receives muon candidate information from the barrel and end-cap muon trigger chambers and resolves cases where a candidate traverses a region with overlapping trigger sectors to avoid double counting. It forms muon multiplicities for the six configurable transverse-momentum thresholds and sends these data to the CTP as trigger input. The CTP then derives the LVL1 trigger decision based on the information received from the calorimeter and muon trigger systems according to a programmable trigger menu which aims at selecting high-transverse-momentum leptons, photons and jets, as well as large missing and total transverse energy. The CTP applies also dead time and prescale factors and distributes the LVL1 accept (L1A) signal to the various sub-detectors to initiate data readout.

Busy signals from sub-detectors are propagated to the CTP allowing to throttle the generation of L1As. For accepted events the CTP and MuCTPI send data to the readout system as well as to the LVL2 trigger.
A demonstrator of the MuCTPI and a crate of final CTP modules are already installed in the underground counting room next to the ATLAS cavern. The current MuCTPI provides almost the full functionality of the final system, missing only some flexibility in the handling of overlaps between muon trigger sectors. One sector input board out of 16 is currently available, corresponding to one octant of one half of the detector. It provides inputs for 14 out of 208 trigger sectors. The final boards are expected to become available for integration in the experiment mid 2007. The CTP crate is equipped with the final boards, with one out of three input boards currently installed.

CTP (left) and MuCTPI (right) crates of the LVL1 central trigger installed in the underground counting room.



Commissioning and Integration



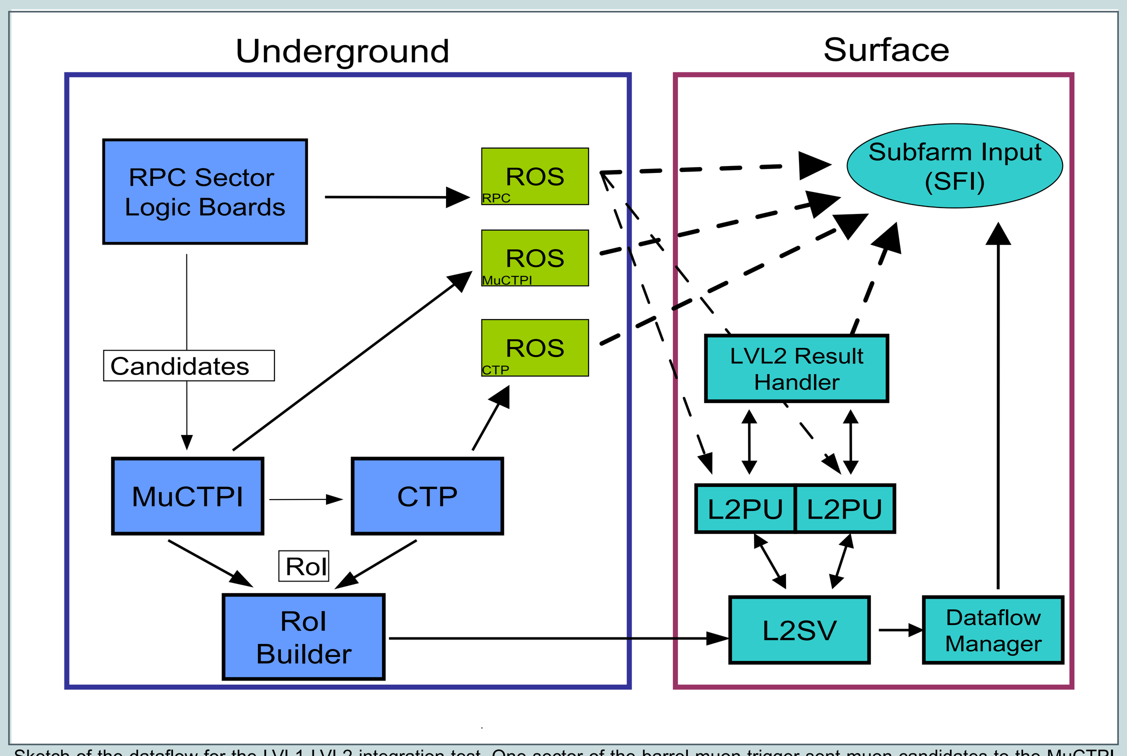
Plots from the combined cosmic-ray runs of the muon-barrel detector and the central-trigger system. To verify the correct functioning of the system and the data integrity, crosschecks between data from different parts of the system are performed. Shown on the left-hand side is the correlation between the muon-candidate transverse-momentum extracted from the MuCTPI data and the trigger item fired at the CTP. Since the trigger menu contained one item per momentum threshold, the linear correlation is exactly expected. The right-hand side shows the correlation between the muon-candidate momentum threshold extracted from the RPC data with the threshold from the MuCTPI. The data transfer between the two sub-systems and the formatting in the MuCTPI work as expected, the linear correlation illustrates that no errors were encountered.

Various combined cosmic-ray runs including different sub-detectors of ATLAS were performed since August 2006. The runs were taken in the following setups:

> In an initial integration activity, one sector of both the barrel muon trigger chambers and the precision chambers was equipped with a temporary gas system. Cosmic-muon data were recorded with the muon chambers providing muon candidates for MuCTPI and CTP. Included in the readout was in addition the central hadronic calorimeter.

> An ATLAS-wide effort to establish regular cosmic-ray data taking activities to integrate step by step the whole of ATLAS towards first collisions in 2007 was started in December 2006. Cosmic rays were recorded with parts of the barrel hadronic and electromagnetic calorimeters. The CTP provided a common clock and distributed the LVL1-accept signals to initiate the detector readout. As a next step it is planned to integrate one sector of the barrel muon detectors into this setup (end of February 2007).

> Integration tests of the LVL1 and LVL2 trigger systems are also ongoing. Mid of February 2007 a LVL2 trigger algorithm was run for the first time in real online mode during a cosmic-ray run. One sector of the muon barrel trigger was operated together with MuCTPI and CTP, which provided region-of-interest (RoI) data to the LVL2 farm. A trigger algorithm was run that selected muon candidates. The algorithm was seeded by the LVL1 RoI data and requested in turn sub-detector data from the readout system to reconstruct a muon candidate track.



Sketch of the dataflow for the LVL1-LVL2 integration test. One sector of the barrel muon trigger sent muon candidates to the MuCTPI. Upon generation of a LVL1 accept signal, all sub-detectors sent their data to the readout system (ROS). MuCTPI and CTP sent in addition regions-of-interest (RoIs) to the RoI builder, which passed the data on to the LVL2 processing units (L2PUs) via the LVL2 supervisor (L2SV). On the L2PUs, LVL2 algorithms were run which requested data from the readout system (ROS) to reconstruct muon candidates. In case of a LVL2 accept, a message was sent to the dataflow manager, which initiated the readout and assembling of the whole event at the subfarm input (SFI).

D.Berge for the ATLAS first-level trigger community

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