3 Calorimeter trigger requirements and environment

The Level-1 Calorimeter Trigger must have high selectivity for several different types of high-E_T objects — electrons and photons, jets, and hadrons from tau decays, as well as missing and total transverse energy. The trigger uses reduced-granularity data from the calorimeters amounting to ~7200 trigger towers, and processing is performed using pipelined digital custom electronics. The range of algorithms is therefore limited, but all algorithms and selection criteria are programmable at the level of parameters. Formal requirements for the trigger are described in the *Level-1 Calorimeter Trigger User Requirements Document* [3-1].

In addition to sending its results to the Central Trigger Processor, the calorimeter trigger must send region-of-interest (RoI) information for all potential trigger objects to the level-2 trigger, in order to limit the amount of data it must transfer to verify these features in more detail. Information from the calorimeter trigger is read out and recorded by the data acquisition system in order to be able to tell what caused the trigger, and to allow monitoring of the performance of the trigger system. A diagram showing all the calorimeter trigger's external interfaces is shown in Figure 3-1.

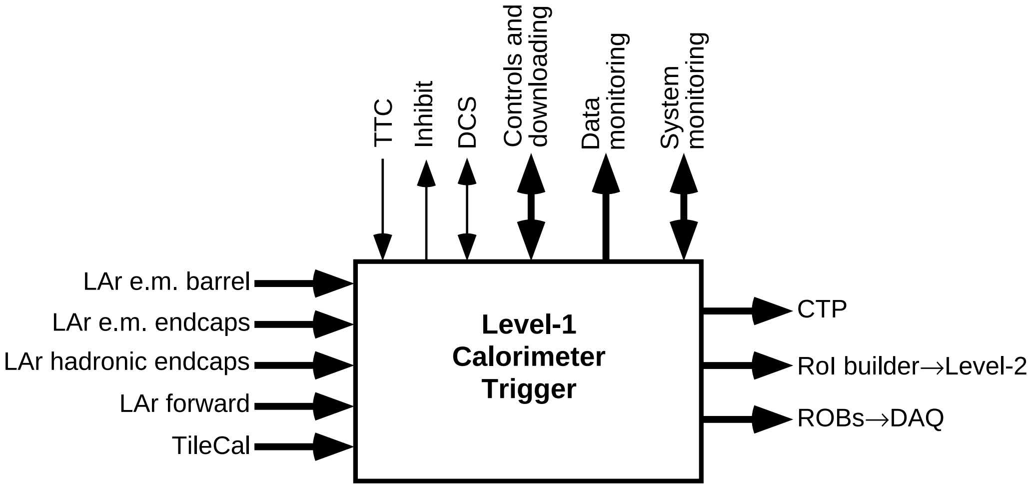

Figure 3-1 Inputs and outputs of the Level-1 Calorimeter Trigger system.

The calorimeter trigger receives one analogue signal per trigger tower from the ATLAS calorimeters. A trigger tower covers, in general, an area of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$. For $|\eta| > 2.5$ the tower size changes to larger values, and for $|\eta| > 3.2$ the tower definition becomes more complicated.

The 'building' of tower signals is done by the calorimeter electronics, separately for electromagnetic and hadronic. They are summed over the full depth of each calorimeter. Due care must be taken to ensure similar pulse shapes, relative timing, and calibration of the calorimeter cells that form the trigger tower signals so that the sum represents a sufficiently good, linear energy value in its peak amplitude. It should be noted that the calorimeter trigger will work with values of transverse energy (E_T) only, with a dynamic range of at least 250 GeV. Performance at the low-energy end is limited by noise of typically ~ 0.5 GeV per trigger tower.

Pulses from all ATLAS calorimeters are several bunch-crossings wide. For every LHC bunch-crossing, the calorimeter trigger has to decide whether potentially interesting interactions occurred, and to do this the transverse energy deposited in each trigger tower for that bunch-crossing must be extracted. To achieve this the trigger carries out a digital process of bunch-crossing identification (BCID) on all trigger towers. It must be stressed that, despite this nomenclature, BCID involves accurate energy measurement as well as assigning every pulse to a unique bunch-crossing.

Trigger tower signals from very large energy deposits saturate before reaching the calorimeter trigger's digitizers. Such signals must also be assigned to the correct bunch-crossing and must *always* produce a trigger and an RoI, since they represent signals above all trigger thresholds and could be due to new and exciting physics. To do this, the shape characteristics of saturated pulses must be accurately known and controlled in order for the BCID logic to function correctly.

In order to give an indication of the performance required of the calorimeter trigger, Table 3-1 lists maximum allowed rates for triggers on specific types of trigger objects with the transverse-energy thresholds shown, and minimal efficiencies, at two values of the luminosity. The maximum rates allowed must include ample safety margins for such things as uncertainties in cross-sections, machine backgrounds, etc.

Table 3-1 Calorimeter trigger rate and efficiency requirements. Energies shown are transverse.

Trigger signal	Level-1 maximum rate (kHz)	Level-1 minimum efficiency
Luminosity = 10^{34} cm^{-2}s^{-1}:		
≥1 isolated e/γ > 30 GeV	22	95%
≥2 isolated e/γ > 20 GeV	5	90%
≥1 jet > 290 GeV	0.2	95%
Large missing-E_T	1	90%
Luminosity = 10^{33} cm^{-2}s^{-1}:		
≥1 isolated e/γ > 20 GeV	8	95%
≥2 isolated e/γ > 15 GeV	2	90%
≥1 jet > 180 GeV	0.2	95%
Large missing-E_T	0.1	90%

The rapidity coverage of the electron/photon and hadron/tau triggers must match that of the ATLAS precision tracking, namely $|\eta| < 2.5$. For the jet trigger the coverage must extend to $|\eta| < 3.2$. Trigger information beyond this is needed only for the missing-E_T trigger.

So as to reduce the amount of data that the level-2 trigger must examine, the level-1 trigger system sends it so-called region-of-interest (RoI) information for each bunch-crossing that produces a trigger at level-1. This tells the level-2 trigger where in the detector to look for features of interest. RoI information must be produced by both the level-1 calorimeter and muon triggers. In the case of the calorimeter trigger, this must be done for all types of trigger object listed above. The Central Trigger Processor also sends information, so that the level-2 trigger knows which kinds of RoI can be objects that caused the level-1 trigger.

The RoIs that are sent to the level-2 trigger for local calorimeter triggers (i.e. electron/photon, jet, hadron/tau) consist of information on the coordinates of the feature, and on which threshold conditions it has passed. The coordinate information is at the granularity of the basic elements of that type of trigger, and corresponds to the local maximum in transverse energy. The missing-E_T trigger sends its E_x and E_y components, and the total-E_T trigger sends its energy sum.

Data are read out to the data acquisition system from the calorimeter trigger in order to allow a full understanding of the trigger path for all events found to be interesting in the offline data analysis. To achieve this, the E_T values after BCID as well as the results sent to the Central Trigger Processor must be recorded for all triggered events. Combined with a knowledge of trigger parameters, this allows the full trigger logic to be reconstructed offline. For a subsample of events, additional data will be read out in order to monitor and check the correct operation of the trigger. The raw calorimeter data, extending over several bunch-crossings, combined with the BCID results allows verification of the synchronization and the BCID. The correct functioning of the trigger processor itself can be verified by comparing trigger results with the input data and simulating the operation of the trigger processor in software. In case of problems, intermediate trigger data will be read out to allow more detailed verification of its operation

Calibration of the calorimeter input signals must be done using a combination of real data and the calorimeter pulser system. Online checks for tower-to-tower variations can be done using data from the trigger system alone, but full calibration will involve detailed comparison of the readout data from the calorimeters with that for the trigger. The quality of the input data to the trigger must be monitored during normal operation by making online plots of such things as trigger-tower pulse height and timing.

The latency allowed for the calorimeter trigger obviously depends on the cable delays for receiving signals and for sending level-1 trigger results back to subdetector front-end buffers, as well as the latency of other logic, such as the Central Trigger Processor, in the trigger chain. The total level-1 trigger latency, which must be less than 2.0 μs, is in fact dominated by these external factors and so the calorimeter trigger latency must be very short. An estimate is given in Section 8.3 and the latency of the entire level-1 system is summarized in Chapter 18.

In the following five chapters we describe the current situation concerning the level-1 calorimeter trigger. First, in Chapter 4, we describe the simulation work that has led to our choice of trigger algorithms as well as our current understanding of their performance. Then we describe the organization of the signals from the calorimeters, and also the vital problem of bunch-crossing identification and how we intend to solve it, in Chapter 5. Chapter 6 gives a detailed description of the current design for the calorimeter trigger system. In order to give an idea of our experience and the lessons we have learned from the technologies involved, we then have a description of our test-beam and laboratory work over the past six years in Chapter 7. Finally, in Chapter 8 we discuss a number of important issues for the implementation of our proposed design for the trigger.

3.1 References

3-1 *Level-1 Calorimeter Trigger User Requirements Document*, version 1.1.0, ATLAS working document, ATL–DA–ES–0001, April 1998.