LHCb 2000-050 CALO 7 July 2000

# Performance of the Calorimeter Triggers

**Olivier Callot** 

Laboratoire de l'Accélérateur Linéaire - Orsay

## ABSTRACT

The purpose of this note is to review the performances of the three triggers using the calorimeters, namely the hadron trigger, the electron trigger and the photon triggers. The previously available numbers were obtained at the time of the Technical Proposal [1] using the 3x3 method. In June 1999, the collaboration has decided to implement the calorimeter triggers as proposed by the Bologna and Orsay groups, as described in several LHCb notes [2], [3], [4] and [5].

For various physics channels the various trigger performances are measured versus the P<sub>T</sub> cut, and this cut is adjusted to obtain the wanted rejection on Minimum Bias events so that the L0 rate stays at the required level of no more than 1 MHz. For the hadron trigger, we study  $B_d^0 \rightarrow D_S K$  and  $B_d^0 \rightarrow \pi\pi$ , for the electron trigger we study  $B_d^0 \rightarrow e + X$  and  $B_d^0 \rightarrow J / \Psi K_S^0$ .

## 1. The Level 0 Calorimeter Trigger

The Level 0 Calorimeter trigger is designed to select events with a high  $E_T$  particle, either in the hadronic calorimeter (HCAL) for the hadron trigger or in the electromagnetic calorimeter (ECAL) for the electron and photon triggers. The main requirement of the Level 0 trigger is to reduce the trigger rate from the beam-crossing rate of 40 MHz to 1 MHz. As there is also a muon trigger, the sharing of the bandwidth is not simple, and is based on an optimization of the physics performance as explained in section 12.3.5 of the TP [1]. A proposed working point is 5 % minimum bias retention for the hadron trigger and 1 % for the electron trigger.

### 1.1. Hardware implementation

The implementation of the trigger is described in [5], and more details on the front-end processing and on the Final Selection are described in [6] and [7]. The intermediate step performed in the Validation Cards is not yet completely frozen.

#### 1.1.1. General

The basic scheme is show on Figure 1. The selection is performed in several steps.

- The deposited energy in each cell is converted in transverse energy  $E_T$  using a Look-Up Table.
- A sum on every 2x2 area is performed.
- The highest sum on each front-end board is selected, and further processed. This processing is different for ECAL and HCAL, and is called the 'validation' step.
- Last, the highest transverse energy candidate for each type of particle is selected in the Selection Crates. One can also select the second highest hadron, and compute the total transverse energy in the calorimeter.
- The selected information is sent to the Level 0 Decision Unit (L0DU), where the proper thresholds are applied and the combinations are performed to obtain the global LHCb Level 0 decision.



Figure 1: Overall view of the Level 0 Calorimeter trigger

#### 1.1.2. ECAL validation

The information from the electromagnetic calorimeter ECAL is not enough to select electrons or photons. One uses also the PreShower detector to identify an early shower, which signs an electromagnetic particle. And the SPD detector is used to identify if the incoming particle is charged or neutral. At every beam crossing, the address of the candidate of each front-end card is passed to the PreShower electronics, which sends back the information of the four corresponding PreShower and SPD cells, in fact they are sent to the Validation card. The information is one bit per cell, a simple threshold is being applied in the PreShower and SPD electronics. The ECAL Validation Card takes a decision according to these 8 bits. An electron is defined as having at least one of the four SPD cells and the corresponding PreShower cell fired. A photon is defined as any of the four PreShower cells fired and not identified as electron. In order to reject dirty candidates, one rejects the candidate if three or four PreShower cells are fired. One foresees to perform this validation using a Look-Up Table, so in fact any combination of the 8 bits can validate the candidate as electron or photon. But a given candidate can not be simultaneously electron and photon: This allows to use a single output link for each ECAL front-end card.

#### 1.1.3. HCAL validation

The purpose of the HCAL Validation Card is to add to the transverse energy measured in HCAL the energy deposited in ECAL by the selected candidate. In order to perform this operation, one would need to connect all ECAL cells to the HCAL electronics, which would be too complex and quite expensive. One can argue that adding the ECAL energy is relevant only if it is important, and in this case there is a large chance that this released energy is a local maximum in ECAL. We then send only one information per ECAL front-end card. This becomes technically and economically feasible. The HCAL Validation Card receives the ECAL candidates of all the cards in front of the HCAL front-end card. We are currently studying the possibility to send the HCAL information to the ECAL Validation cards, duplicating the HCAL information when needed, to reduce the number of links (80 instead of 188), and also to have a single type of validation card. This option looks promising, but more work is needed before it can become the baseline. This will not change the functionality of the validation process.

A decision on which ECAL candidate to use is taken by matching the addresses, using Look-Up Tables, and keeping the best match, i.e. the one with the highest transverse energy. We have envisaged three matching algorithms:

- 1. The ECAL 2x2 area is (in projection) entirely contained in the 2x2 HCAL area.
- 2. The ECAL 2x2 area overlaps the HCAL 2x2 area.
- 3. It is contained in the Y direction and overlaps in the X direction. This allows for the bending of charged tracks.

We have selected option 3. Note that the optimal choice may be different for different regions, as the cell size ratio between HCAL and ECAL changes from 1 to 3 depending on the location in the calorimeter. The HCAL transverse energy is then corrected by the matching ECAL one, to obtain the best estimate of the transverse energy of the candidate. Note that there is no minimum requirement on the HCAL energy, except that it has to be the maximum on the card. One obtains from time to time a candidate where almost all the energy has deposited in fact in ECAL.

#### **1.2. Software simulation**

The proposed hardware trigger has been simulated in the general LHCb simulation framework.

#### 1.2.1. SICB code

The trigger simulation uses the calorimeter digitization bank as input, and reproduces the proposed hardware processing, with a conversion do integer  $E_T$ , 2x2 sums, selection of the highest candidate in each front-end card, validation by the SPD and PreShower (ECAL) or addition of the best ECAL candidate (HCAL), selection of the highest  $E_T$  candidate. All curves are shown with this transverse energy as horizontal axis.

#### 1.2.2. Event generation

Events are generated according to the usual LHCb procedure. In particular, inclusive events are generated in a 600-mrad cone, and other physics channels are generated in 400-mrad cone. But in this later case, an acceptance cut is performed using the AXSEL routine, requiring that the tracks of the signal channel be in the spectrometer acceptance, and the photons in the calorimeter acceptance. The efficiency for the signal is normalized to the events in this acceptance. We have generated only a single interaction per beam crossing.

## 2. Performance of the hadron trigger

#### 2.1. Minimum Bias acceptance

The acceptance and the rejection factor of the hadron trigger for minimum bias events are shown on Figure 2. The rejection is equal to the inverse of the acceptance. The required rejection factor is not fully defined, as the sharing of the Level 0 bandwidth is still to be optimized, but the TP value is a 6% acceptance, or a rejection factor of 16. This sets the hadron trigger threshold around 3.4 GeV/c.



Figure 2: Minimum bias acceptance for the hadron trigger. Full circle (left scale): Efficiency. Open circle (right scale) rejection factor.

## 2.2. Signal acceptance

Figure 3 shows the signal efficiency on two channels,  $B_d^0 \to \pi\pi$  and  $B_s^0 \to D_s K$ . The efficiency is measured on events where the decay products are in the spectrometer acceptance.



Figure 3 : Acceptance for  $B_d^0 \to \pi\pi$  (left) and  $B_s^0 \to D_s K$  (right) with the hadron trigger

One can check that the highest  $E_T$  is a good variable by comparing its distribution in the inner and outer part of the calorimeter. As can be seen on Figure 4, the two distributions (for  $B_d^0 \to \pi\pi$  events) are similar even if there is a bit more events at high  $E_T$  in the inner part.



Figure 4  $E_T$  distribution in the Inner and Outer HCAL

## 3. Performance of the electron trigger

#### 3.1. Minimum bias

The acceptance and rejection factors for minimum bias events are shown on Figure 5 for the electron trigger. The allocated bandwidth will set a rejection factor around 100, which means an  $E_T$  threshold around 2.5 GeV/c



Figure 5: Acceptance (left) and rejection factor (right) of the electron trigger on Minimum Bias events

## 3.2. Signal acceptance

The acceptance is given here on two test reactions



Figure 6 Efficiency for  $B_d^0 \rightarrow e + X$  (left) and  $B_d^0 \rightarrow J / \Psi K_s^0$  (right) with the electron trigger. The trigger rejection is shown with open circle, using the right scale.

## 4. Photon trigger

The efficiency and rejection of the photon trigger is shown on Figure 7.



Figure 7 Efficiency and rejection of the photon trigger

The importance of the photon trigger can be studied on the  $B_d^0 \rightarrow K^* \gamma$  channel. Figure 8 shows the signal efficiency and rejection of the photon and hadron triggers on these events. The main trigger is clearly the hadron trigger. One can study the overlap between the two triggers. Typically, less than half the events accepted by the hadron trigger are also accepted by the photon trigger. With a threshold around 3.4 GeV, the efficiency with only the hadron trigger would be about 47 % while it increases to 58 % with the addition of the photon trigger with a threshold around 3.8 GeV.



Figure 8 Efficiency and rejection of the photon (left) and hadron (right) trigger for  $B_d^0 \rightarrow K^* \gamma$  events

The analysis of these  $B_d^0 \rightarrow K^* \gamma$  events will clearly require a selection of high  $E_T$  photon. With a 4 GeV transverse energy cut, the photon trigger efficiency improves dramatically, as shown on Figure 9. The limited maximum efficiency is due to the threshold on the PreShower signal, and the identification as electron in case there is a signal in the SPD. Note that the hadron trigger has the same efficiency on those events with a high  $E_T$  photon. In other words, the Level 0 efficiency on these selected events is about 55 % due to the photon trigger, plus about 20 % due to the hadron trigger when the photon trigger hasn't fired.



Figure 9 Photon trigger efficiency for  $B_d^0 \rightarrow K^* \gamma$  events where the photon has at least 4 GeV E<sub>T</sub>

## 5. Summary and future work

The Level 0 calorimeter triggers are performing reasonably well, according to the simulations. The performances can still be adjusted, in particular in the area of the Validation step.

# 5.1. $\pi^0$ trigger

This possibility has been envisaged, as the physics one can do with such a trigger would be interesting, in particular for the  $B_d^0 \rightarrow \rho \pi$  channels. Only a small fraction of the events are not triggered by the hadron

trigger, and the photon trigger already helps for those events where only the  $\pi^0$  has transverse momentum. A specific trigger is still under investigation [8], which would select  $\pi^0$  with the two photons in two neighboring front-end cards. Even if the efficiency will be small, these events will have very clean  $\pi^0$  and will then be efficiently reconstructed offline.

### REFERENCES

- [1] The LHCb Collaboration, "Technical Proposal", CERN/LHCC 98-4, 20 February 1998
- [2] *The LAL LHCb group*, "An Alternative High PT Electron and Hadron Trigger for LHCb", LHCb 98-058, 4 September 1998
- [3] *C. Beigbeder at al.*, "An Update of the 2x2 Implementation of the Level 0 calorimeter Triggers", LHCb 99-007, 29 April 1999
- [4] *A.Bertin et al*, "Proposal for a Level 0 calorimeter trigger system for LHCb", LHCb 99-013, 29 May 1999
- [5] C. Beigbeder et al., "A Joint Proposal for the Level 0 Calorimetric Triggers", LHCb 99-017, 7 June 1999
- [6] *C.Beigbeder et al,* "The front-end electronics for the calorimeter triggers", LHCb 2000-010, 8 March 2000
- [7] *A. Bertin et al.*," The selection crates for the L0 calorimeters trigger", LHCb 2000-018, 13 April 2000
- [8] Z.Ajaltouni et al, "Proposal for a  $\pi^0$  trigger at level-0", LHCb 2000-024, 19 May 2000