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# LHCB CALORIMETER FROM TRIGGER TO PHYSICS.

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ON BEHALF OF THE LHCB COLLABORATION

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LHCb is a second generation experiment for CP violation study in B decays. It consists in a 20 meters long single-arm spectrometer to be installed on the future Large Hadron Collider at CERN. For its precision measurement purpose, it combines precise vertex location and particle identification, in addition with a performant trigger system able to cope with high flux. This document addresses the use of the calorimeter data for the LHCb trigger and the physics analyses.

## 1. Introduction

The calorimeter subsystem for LHCb consists in four consecutive semi-projective detectors. Downstream, the Scintillator Pad (SPD) and the Preshower (PS) detectors aim at validating the charged origin and the electromagnetic nature of incoming particle, respectively. Upstream, the electromagnetic (ECAL) and hadronic (HCAL) calorimeters address the energy and position measurement of showering particles. The shashlik electromagnetic calorimeter for LHCb is made of 6000 scintillator pads with a transversal segmentation varying from one to three Moliere radius. The preshower and SPD geometry has been designed for a one-to-one correspondence with the ECAL towers.

The purpose of the LHCb calorimeter system is twofold. First, it participates to the fast trigger system thanks to the fast identification of high transverse energy electron, photon,  $\pi^0$  and hadron candidates. It also deserves the offline identification of electrons and the reconstruction with a good accuracy of prompt photons and  $\pi^0$ 's for physics analyses.

The use of the calorimeter data for the trigger and the offline analysis is addressed in the following two sections, respectively.

## 2. LHCb calorimeter for trigger

The first level trigger for LHCb<sup>1</sup> (Level-0) consists in a fully synchronous hardware device clocked at 40 MHz according to LHC bunch-crossing frequency. It aims at reducing the data flow to 1 Mhz thanks to fast identification of high transverse energy particles that could sign a B decay. For that purpose, the calorimeter system plays a major role. The four calorimetric sub-detectors provide the highest transverse energy electron, photon, neutral pion and hadron to the Level-0 Decision Unit (L0DU) that produces the final Level-0 decision. The strategy for the Level-0 calorimetric trigger consists in performing a global search of ECAL and HCAL clusters made of  $2 \times 2$  pads, at the Front-End level. Charged hadron candidates are produced from the HCAL clusters while the ECAL clusters are identified as electrons or photons thanks to the SPD and PS used in coincidence. Neutral pion candidates are detected as a large activity in Front-End board area ( $4 \times 8$  pads) or as an energetic pair of neighbouring clusters. The calorimeter system also provides the total SPD hit multiplicity and the total HCAL energy to the L0DU. These two latter information are used to reject busy events and halo-muon background, respectively. A schematic view of the architecture of the Level-0 calorimeter trigger is shown in Figure 1.

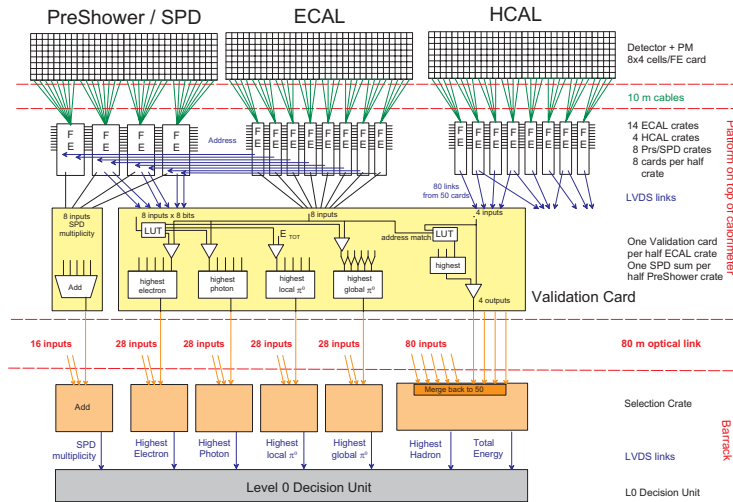


Figure 1. Architecture of the Level-0 calorimeter trigger.

Eventually the L0DU receives the highest transverse momentum candi-

dates from the Muon detector as well as information from the the Pile-Up detector.

The LODU algorithm has been tuned to maximize the offline selected event yield of some typical B decay modes involving various particle flavours ( $\pi\pi$ ,  $J/\Psi(\mu\mu)K_s$ ,  $J/\Psi(ee)K_s$ ,  $K^*\gamma$ , ...). The hadronic trigger dominates the total 1 MHz Level-0 frequency, with an allocated bandwidth of the order of 700 kHz. The inclusive bandwidth allocated to the electromagnetic trigger (electron, photon and neutral pions) and the muonic trigger is about 300 kHz and 150 kHz, respectively. The typical overlap with the offline selection of B decays is 50%, 70% and 90% for hadronic, radiative and di-muon channels, respectively.

The subsequent trigger level for LHCb (Level-1) uses the Vertex Locator and Trigger Tracker sub-detectors to detect high transverse momentum tracks with a large impact parameter. The calorimetric information from the Level-0 are also used to improve the Level-1 performance. For instance, the impact parameter requirements are loosed when an energetic photon or electron is clearly identified at the Level-0.

The last trigger step for LHCb (High Level Trigger, HLT) is a software device currently under development. It will accurately confirm the Level-1 decision using the full tracking device and perform inclusive and/or exclusive reconstructions of the B decay modes of interest. For that purpose, a fast reconstruction of calorimeter data is under study.

### 3. LHCb calorimeter for physics

This section addresses the LHCb strategy for the offline reconstruction of ECAL data<sup>2</sup>. The energy deposits within ECAL are clusterised around the local maxima. Several hypothesis are then made about the cluster origin : photon, electron, photon from Bremsstrahlung process, photons pair from the decay of a high energy  $\pi^0$  and electrons pair from a photon conversion. The energy and the position of the impact is reconstructed according to each of these hypotheses. The matching of the cluster position with an eventual impact extrapolated from the reconstructed tracks is used to decide whether the cluster has a neutral or a charged origin. Neutral and charged clusters are used to reconstruct photons and to identify electrons, respectively.

#### 3.1. *Electron identification*

The calorimeter system provides four estimators for the identification of a reconstructed track as an electron. The main one is the energy/position

matching  $\chi^2$  of the track with an ECAL cluster. The PS and the HCAL energy deposits along the extrapolated track also provide discriminating information. Eventually, the recovery of a hard Bremsstrahlung photon within the ECAL is also used to identify the electron origin of the track. These four calorimetric estimators are combined with the identification provided with the RICH detector to build a global log-likelihood for the electron hypothesis. The distribution of this global estimator is shown on the left part of Figure 2 for electron and pion tracks, respectively.

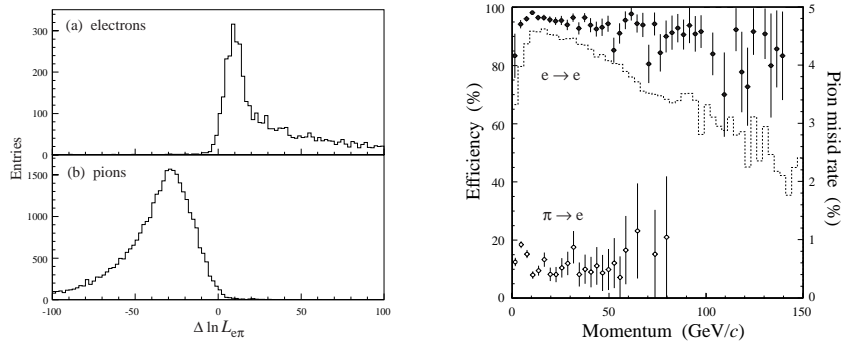


Figure 2. Left : distribution of the delta Log-likelihood ( $\Delta \ln L_{e\pi}$ ) of the electron versus the pion hypothesis, for electron (a) and pion tracks (b). Right: electron identification efficiency and pion misidentification rate as a function of the track momentum. The cut  $\Delta \ln L_{e\pi} > 0$  has been applied as the electron identification criteria.

The electron identification efficiency and pion misidentification rate are shown as a function of the track momentum, on the right part. When produced in the ECAL acceptance, the electron is correctly identified with an average efficiency of 95% while a 0.7% pion misidentification rate is obtained.

### 3.2. Photon reconstruction

The average amount of material a particle crosses before it reaches the calorimeter system represents 70% of radiation length. Accordingly, 44% of the photons produced at the interaction point convert before reaching the ECAL. Late conversions that occur after the magnet may be detected as a single ECAL cluster. This configuration is identified thanks to the SPD hit in front of the ECAL cluster and reconstructed accordingly. The earlier conversion, occurring before the magnet, may be reconstructed using the

tracking system. From detailed simulation, the overall energy resolution for reconstructed photons is expected to be :  $\frac{\sigma_E}{E} = \frac{11.0\%}{\sqrt{E}} \oplus 1.5\% \oplus \frac{170 \text{ MeV}}{E}$  in agreement with the test-beam measurements of ECAL modules.

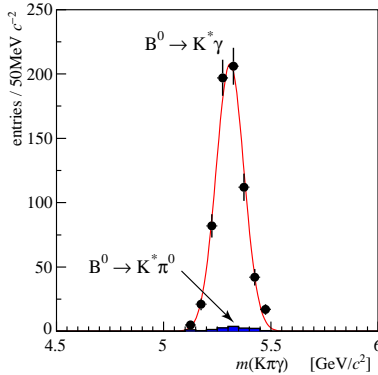


Figure 3. Invariant mass of the  $K\pi\gamma$  system in  $B_d \rightarrow K^*\gamma$  decay mode. The small background contribution from the  $B_d \rightarrow K^*\pi^0$  decay is indicated.

As an illustration of the LHCb physics potential with prompt photons, Figure 3 displays the reconstructed mass for the  $B_d \rightarrow K^*\gamma$  decay mode. The expected resolution is  $\sigma(M_{K^*\gamma}) = 65 \text{ MeV}/c^2$ . The expected annual yield for this channel is  $35 \cdot 10^3$  fully reconstructed events with a background-over-signal ratio less than 0.7 at 90% of confidence level.

### 3.3. Neutral pions

The mean transverse momentum of the  $\pi^0$  coming from a  $B$ -meson decay is about  $3 \text{ GeV}/c$ . Below this value the  $\pi^0$ 's are mostly reconstructed as a resolved pair of well separated photons with a mass resolution of about  $10 \text{ MeV}/c^2$ . For higher momenta, the distance between the impact point of the two photons in the calorimeter becomes of the order of one pad size and the  $\pi^0$ 's cannot be resolved as a pair of clusters within the ECAL granularity. A large fraction of energetic  $\pi^0$ 's thus leads to a single cluster, referred to as a merged  $\pi^0$ . A procedure has been designed to disentangle the potential pair of photons forming the merged  $\pi^0$  clusters. It consists in sharing the pad energy between two virtual sub-clusters according to an iterative procedure based on the expected transversal shape of the photon shower. Each of the two sub-clusters is then reconstructed as coming from a photon, as for isolated photons. A core mass resolution of about  $15 \text{ MeV}/c^2$

is obtained for merged  $\pi^0$ 's. The mass distributions for the resolved and the merged  $\pi^0$  configurations are shown on the left and right parts of Figure 4, respectively.

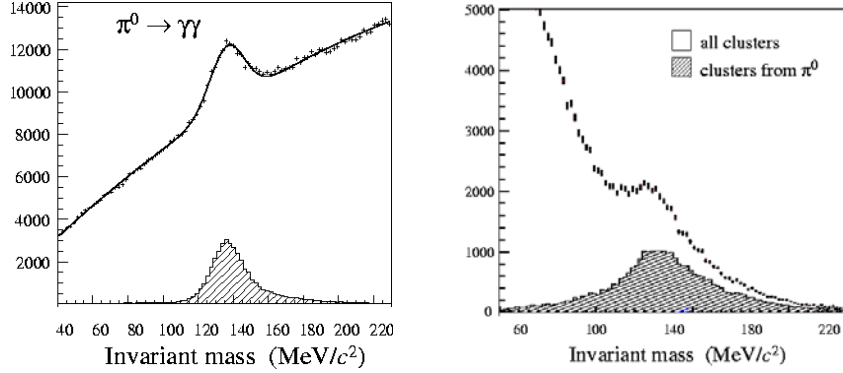


Figure 4. Mass spectrum of resolved (left) and merged (right)  $\pi^0$ 's.

The reconstruction of merged  $\pi^0$  is of major importance for the selection of  $B$ -meson decay on account of their intrinsic large transverse energy. As an illustration,  $12 \cdot 10^3$  reconstructed  $B_d \rightarrow \pi^+ \pi^- \pi^0$  events are expected to be selected each year. About 60% of these selected events involve a merged  $\pi^0$ . The resolution of the reconstructed  $B \rightarrow \pi^+ \pi^- \pi^0$  mass is expected around  $80 \text{ MeV}/c^2$  for this decay channel.

#### 4. Conclusions

The calorimetric devices of LHCb, SPD, PS, ECAL and HCAL, form a complementary system. Used in coincidence, it provides a fast identification of electron, photon and hadron and play an important role for the first level trigger for LHCb.

In addition, the precise reconstruction of prompt photons and neutral pions gives access to the study of important B-meson decay modes to the complete physics program of LHCb.

#### References

1. R. Antunes Nobrega *et al.*, "LHCb trigger system", Technical Design Report **CERN-LHCC-2003-031** (2003).
2. R. Antunes Nobrega *et al.*, "Reoptimized LHCb Detector Design and Performance", Technical Design Report **CERN-LHCC-2003-031** (2003).