THE LHCb TRIGGER*

J.A. Hernando

CERN, Geneva, Switzerland

(Received November 15, 2006)

The LHCb experiment relies on an efficient trigger to select a rate up to 2 kHz of events useful for physics analysis from an initial rate of 10 MHz of visible collisions. In this contribution, we describe the different LHCb trigger algorithms and present their expected performance.

PACS numbers: 07.05.Fb, 12.15.Hh, 13.75.Cs

1. Introduction

LHCb is a dedicated experiment to study CP violation and rare decays of B mesons at LHC. The status of the construction of the experiment was presented in this conference by T. Nakada. The physics reach of LHCb was addressed in the conference in the following presentations: search for rare and radiative B meson decays by I. Belyaev, the determination of the B_s oscillations phase by L. Fernandez, and the measurement of the α and γ angles of the CKM unitary triangle by O. Deschamps and J. Radermacker. For a more detailed description of the detector see [1, 2]. Here, we describe the trigger of the experiment and present its expected performance.

At LHC energy and with a nominal luminosity of $2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 100 kHz $b\bar{b}$ pairs would be produced at the interaction region of LHCb. These $b\bar{b}$ pairs are mostly produced in the forward–backward direction, for this reason the LHCb detector is a forward spectrometer which covers a range in pseudo-rapidity 1.9–4.9. Despite the large number of produced $b\bar{b}$ pairs, the B meson decays relevant for physics analysis have very small branching ratios (10^{-3}–10^{-9}), therefore the rate of events useful for physics analysis is only few tenths of Hz.

The LHCb trigger is divided in two levels. The first level trigger (L0) is a pure hardware trigger that reduces the initial rate of 10 MHz of visible collisions to 1 MHz. L0 uses the fact that B mesons, due to their large mass,

* Presented at the "Physics at LHC" Conference, Kraków, Poland, July 3–8, 2006.

decay into particles with relative large transverse momentum, to trigger in events with large transverse energy deposit in the calorimeters or with relative large transverse momentum muons or dimuons. If a L0 decision is issued, the full detector data is read out at 1 MHz and send via a Gigabit Ethernet switch to an Event Filter Farm (EFF) composed by approximately 1800 CPU nodes. In each CPU a C++ application processes the data and reduces the rate to approximately 2 kHz. This constitutes the second trigger level, named High Level Trigger (HLT). Each HLT application has access to all data in one event, thus, in principle, it could be executing the off-line selection algorithms, but given the large input rate and the limited CPU power available, the HLT aims to reject the bulk of the events by using only part of the information available. HLT selects first events with typical b signatures, particles with relative transverse momentum that are detached from the primary vertex, and in a second step, reconstructs and selects inclusive and specific B meson decays.

2. The L0 trigger

The L0 trigger combines the information from the muon chambers, the electromagnetic and hadron calorimeters, the SPD detector and the Pile-Up system. The muon chambers provide the two highest transverse momentum muons in each quadrant. The calorimeters provide the largest transverse energy for different cluster types: electron, π^0 and hadron, and the total transverse energy deposit in the event. In addition, the SPD detector provides the charged track multiplicity. This information is sent out to the L0 Decision Unit (L0DU) that also receives as input the estimated number of interactions of the crossing from the Pile-Up system. The L0DU performs a simple arithmetic calculation with the received inputs and issues a decision for different trigger types: muon, dimuon, hadron, electron and π^0. The total latency of the L0 trigger is 4 μs, while the latency of the reconstruction algorithms in the calorimeter and muon detectors is 1 μs.

A L0 muon (or dimuon) trigger is issued if the momentum of one (or two) muons in the event is above a certain threshold (~ 1.1 GeV). A L0 hadron trigger is issued in events with few interactions and not too large charged track multiplicity, if the transverse energy of a cluster of hadron type is above 3.5 GeV. This leads to an output rate of ~ 200 kHz for the muon and dimuon triggers and ~ 700 kHz for the hadron trigger. The efficiency on off-line selected B meson decays into muons, for example $B_s \to J/\Psi(\mu^-\mu^+)\phi$, is $\sim 85\%$, while the efficiency on decays of B mesons into hadrons is typically 50% (*i.e.* $B_d \to \pi^+\pi^- \sim 45\%$). For more details about L0, please see [3].

3. The HLT trigger

The schematic of the different trigger sequences of the HLT is shown in figure 1. The HLT is subdivided in so-called alleys, where each alley addresses one type of the L0 triggers: muon (and dimuon), hadron and calorimeter (electron and π^0). Most of the L0 triggers are of one type, and only 15% of the events have more than one L0 trigger type, and therefore are processed by more than one alley. Each alley enriches the b content of the events, by refining the momentum of the L0 candidates and incorporating impact parameter information. Each alley is itself subdivided in two sub-triggers (named pre-trigger and trigger). The pre-trigger aims to obtain a large reduction of the rate in a small computing time by using only part of the information available. Each alley provides a summary with the reason why an event triggered; this summary is used offline to estimate the effect of the trigger in the physics analysis. If an event is selected by at least one alley, then it is processed by the inclusive triggers, where specific resonances are reconstructed and selected, and the exclusive trigger, which aims to fully reconstruct B final states. The HLT decision is a logical or of the inclusive and exclusive triggers. In the following subsections, only the muon and the hadron alleys are described with some detail.

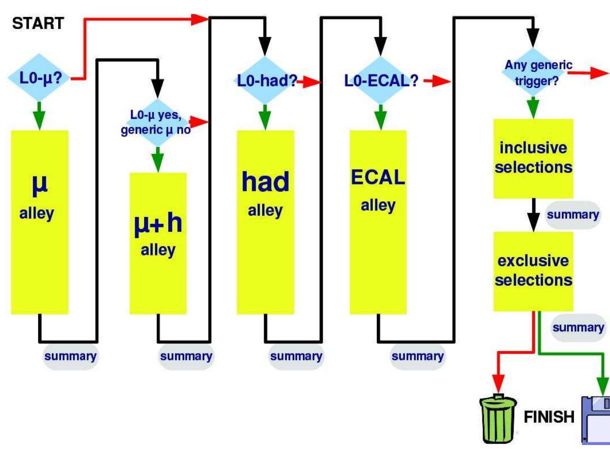

Fig. 1. Flow-diagram of the different trigger sequences in the HLT. Squares represent reconstruction algorithms, while diamonds indicate where the trigger decisions are taken.

3.1. The muon alley

The muon alley processes events which triggered the L0 muon or dimuon trigger. This accounts for approximately 200 kHz. Muon candidates are reconstructed using the information from the muon stations, that extends the muon candidates provided by the L0 where only muons with large transverse momentum were reconstructed. Assuming that the muons come from the interaction region, their momentum can be measured with a precision of $\sigma_p/p \sim$20%, that can be improved to 5% by matching the muon to tracks reconstructed using the Velo hits. In a last step, the momentum can be refined up to 1% adding the information of the Tracking stations (T stations).

The muon alley selects events with a muon with large transverse momentum ($>$ 3 GeV) and significant impact parameter. That leads to $\sim$ 1 kHz output rate, from there 600 Hz corresponds to events with a $b \to \mu$. This is a b-tagged enhanced sample; it could also be used for data mining, that is, to search for B meson decays in the other b. In addition to the single muon sample, the alley selects events with a large invariant dimuon mass ($>$ 2.5 GeV). In order to have a manageable output rate, dimuon events with smaller masses are accepted if they have a significant impact parameter. The sample of dimuons around the J/Ψ mass could be used to measure the error in the B proper time or to calibrate the magnetic field, for example. The efficiency of the muon alley on off-line selected events (*i.e.* $B_s \to J/\Psi(\mu^+\mu^-)\phi$) is $\sim$ 85% (for both pre-trigger and trigger) and the output rate of the muon alley is $\sim$ 2 kHz.

3.2. The hadron alley

The hadron alley addresses the L0 hadron triggers, which correspond to $\sim$ 700 kHz rate of events. The Velo detector and Trigger Tracker (TT) stations were designed to provide a fast estimation of the momentum and impact parameter of the tracks. The Velo detector is composed of planes of silicon strip sensors of semicircular shape the size of half a compact disk. The sensors have two strips layouts; in one layout, the strips run in the radial coordinate away from the beam line, in the second one, they do in the ϕ coordinate. Using the R Velo hits, tracks are reconstructed in the radial-beam line plane and primary vertices computed. Tracks with a given impact parameter are converted into 3D tracks, adding the ϕ Velo hits, and their momentum is measured, using the information from the TT stations and the fringe magnetic field in front of the magnet, with a precision of σ_p/p 20–40%, enough to take a pre-trigger decision. The momentum of the tracks is further refined to $\sim$ 1 % adding the information from the T station. In order to measure the momentum, passing by TT is a necessary step, as using information from the T stations is an expensive time processing task.

The hadron alley selects events with a track, or a combination of tracks, with enough transverse momentum and significant impact parameter. In addition, tracks should form a vertex, and their combined momentum should point to the primary vertex. The pre-trigger step reduces the rate to 30 kHz.

The efficiency in off-line selected B meson decays into hadrons (*i.e.* $B_d \to \pi\pi$, $B_s \to D_s K$) is 80–85%. The trigger decision further reduces the rate to 5 kHz and the efficiency on the off-line selected signal events is $> 90\%$. The hadron alley consumes most of the processing time of the HLT, the pre-trigger algorithms run in ~ 2 ms (in a 2.8 GHz Xenon CPU) while the trigger decision algorithms run in ~ 10 ms.

3.3. The inclusive and exclusive triggers

The combined output rate of events accepted by all the alleys is less than 10 kHz, a rate at which the reconstruction of all the remaining tracks can be performed. From a set of tracks selected with very loose cuts on their momentum and impact parameter, composite particles, like $\phi \to K^+K^-$, $D^0 \to hh$, are constructed. At this level, a D^* inclusive trigger selects events with a $D^* \to D^0(K^+\pi^-)\pi^+$ candidate ($\sim$ 250 Hz). This sample could be used to calibrate the particle identification of the RICH detectors. It also enhances the potential of LHCb to study charm physics.

After the inclusive triggers, the exclusive triggers select specific B decays. As an example $B \to \pi\pi$ events are selected requiring two tracks which make a good vertex and have a invariant mass in a range around the B mass; in addition, the B candidate should have a significant impact parameter. That results in an efficiency to select $B \to \pi^+\pi^-$ of 88%.

The final output rate of the exclusive selections is $\sim$ 200 Hz, that in addition to the single muon, dimuon, D^* and other inclusive samples amounts for a total rate of 2 kHz.

4. Conclusions

We have described the L0 and HLT triggers of the LHCb experiment. The L0 trigger is already well established. The HLT algorithms that will run in an 1800 CPU nodes Event Filter Farm have been also defined. The number of CPU nodes has been estimated basing on the measurement of the processing time of the HLT algorithms. We have shown that HLT will efficiently select B meson decays relevant for physics studies and inclusive samples to be used for calibration purposes and to study systematic effects.

REFERENCES

[1] LHCb Technical Proposal, LHCb, CERN/LHCC 98-4.

[2] LHCb Reoptimized Detector Design and Performance Technical Design Report, LHCb, CERN/LHCC 98-4.

[3] LHCb Trigger System Technical Design Report, LHCb, CERN/LHCC 03-031.