A vertex trigger for the LHCb experiment[★]

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Abstract

The LHCb experiment is designed to study CP violation in B -decays at the LHC machine at a luminosity of $2 \cdot 10^{32} \text{ cm}^{-1}\text{s}^{-1}$ and a rate of 40 MHz. It is crucial to efficiently select the interactions containing B -mesons. The silicon detectors are of major importance to identify tracks from B -decays. The design of the LHCb detector and its trigger scheme is presented, with the emphasis on the algorithms and their use of the silicon detectors.

Key words: LHCb, trigger, vertex detector

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1 Introduction

The Large Hadron Collider (LHC) will provide proton-proton collisions at a rate of 40 MHz with a centre-of-mass energy of $\sqrt{s} = 14 \text{ TeV}$. The LHCb experiment is designed to study the decay of B -mesons produced at the LHC. At a centre-of-mass energy of $\sqrt{s} = 14 \text{ TeV}$ the $b\bar{b}$ cross section amounts to 0.5 mb, resulting in 10^{12} $b\bar{b}$ -pairs produced per year at a nominal luminosity of $2 \cdot 10^{32} \text{ cm}^{-1}\text{s}^{-1}$. Both the b and the $\bar{b}$ are predominantly produced in the same forward cone, due to the parton distribution functions of the proton. The LHCb detector is therefore designed as a single arm spectrometer with a coverage of $1.9 < \eta < 4.9$ to provide a good acceptance for both the b and $\bar{b}$ products (1). A short overview of the LHCb detector and its trigger is given, after which the use of silicon detectors in the trigger is discussed. Special emphasis is put on the algorithms used at the second trigger level (L1).

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2 The LHCb detector

The LHCb apparatus consists of a vertex detector (VELO), a tracking system with a dipole magnet, two Ring Imaging Cherenkov counters (RICH), electro-magnetic and hadronic calorimeters and a muon system, see Fig. 1. The tracking system is made of three tracking stations behind the magnet with silicon sensors in the inner region (Inner Tracker) and straw tubes in the outer region (Outer Tracker). In addition a silicon trigger tracker (TT) is placed before the magnet. Polar angles from 300 (250) mrad down to 15 mrad are covered in the horizontal (vertical) plane.

The total proton-proton cross section at 14 TeV amounts to 100 mb, of which approximately 60 mb is “visible”, resulting in at least two tracks in the forward acceptance of the spectrometer. The $b\bar{b}$ cross section is as high as 0.5 mb and it is the task of the trigger to select the interesting decay channels such as $B_s^0 \rightarrow J/\psi\Phi$, $B_s^0 \rightarrow \mu^+\mu^-$, $B_d^0 \rightarrow K^*\gamma$ or the ones with fully hadronic final states such as $B_d^0 \rightarrow \pi^+\pi^-$ and $B_d^0 \rightarrow D^{*\pm}K^\mp$, with branching ratios ranging from 10^{-3} to 10^{-9} . The LHCb trigger is based on the following steps:

- L0 The relative high B -mass results in decay products with large transverse momentum. At the first trigger level high- P_T photons, electrons, hadrons and muons are reconstructed in the electro-magnetic calorimeter, hadronic calorimeter and the muon system, respectively. With a fixed latency of 4 μ s the rate is reduced to 1.1 MHz. A pile-up trigger identifies multiple interactions and is described in more detail in Section 3.
- L1 The long lifetime of the B -mesons is used in the second trigger level. After track reconstruction and primary vertex finding, large impact parameter tracks are identified. Momentum information is added to these tracks, and a software based algorithm reduces the rate to 40 kHz with a maximum latency of 1.7 ms. More details are given in Section 4.

Fig. 1. The LHCb apparatus and the trigger rates are shown.

HLT The higher level triggers (HLT) use the full event information and reduce the rate to 200 Hz, selecting the decay channels of interest.

3 The pile-up veto trigger at L0

At the first trigger level the pile-up veto trigger identifies multiple interactions per bunch crossing. Multiple interactions have a higher multiplicity than single interactions and are more likely to pass L0. Vetoing these events gives a lower input rate to L0, enabling the L0 trigger to lower the P_T -threshold, hence increasing its efficiency. Favouring low multiplicity events furthermore decreases the time needed at L1 and improves the tracking performance offline.

The pile-up veto detector consists of two VELO stations (2) located upstream of the interaction point, covering the pseudo-rapidity range $-4.2 < \eta < -1.9$. The silicon sensors only measure the radial coordinate of the tracks and are readout with the Beetle chip (3). For each combination of two hits on station A and station B, the primary vertex is calculated with $Z_{prim.vtx} = \frac{R_A Z_B - R_B Z_A}{R_A - R_B}$, and is stored in a histogram. The highest peak is identified as the primary vertex, with a resolution of 2.8 mm. The precision is good enough to resolve multiple interactions, given the size of the beamspot of approximately 53 mm. Subsequently the hits contributing to the primary vertex are removed, and the procedure is repeated. If a second peak is found with two or more entries (i.e. “tracks”) the event is vetoed. The histogramming and peak-finding is performed using large FPGAs. Studies are ongoing whether these interactions with overlapping events can contribute to the physics performance.

4 L1: the second level trigger

The L1-trigger uses the long lifetime of the B -mesons by identifying large impact parameter tracks, using the VELO (2). As a signature to select B -decay tracks, and to distinguish genuine high impact parameter tracks from tracks suffering from multiple Coulomb scattering, momentum information is used, obtained both from the L0 decision unit and from the TT station.

The VELO consists of 170k channels in 21 stations positioned at $-15 < Z < 75$ cm. One station is made of two 220 μm thick R -sensors and two ϕ -sensors with a pitch varying from approximately 40 to 100 μm and dimensions of $0.8 < R < 4.2$ cm. The R -sensor is segmented in four 45° sectors in the inner region, and two 90° sectors in the outer region. The radial strips in the ϕ -sensor are tilted with a stereo angle between 10° and 20° . On average 1000

clusters per event are found with a clustering algorithm running in FPGAs on the front-end electronics board. The data is shipped at a rate of ~ 4 Gbyte/s via a switch to a farm of 300-400 CPUs, which are arranged in a 2d torus topology, connected through SCI.

Given the limited time available at L1, initially only the R -sensors in the VELO are used to reconstruct the RZ -projection of the tracks. Approximately 8 forward 2d-tracks are found per 45° sector with an efficiency of $\sim 98\%$. Subsequently the primary vertex is reconstructed with a resolution of 60(20) μm in the longitudinal (transverse) direction and the RZ -projection of the impact parameters is determined. Recently the strip layout of the R -sensor is re-optimised to speed up the algorithm, resulting in four 45° sectors also in the outer region, with additional beneficiary effect on the strip capacitance. The 2d-tracks are matched to a limited number of muon, electron and hadron candidates from the L0 decision unit. A selection of 2d-tracks are then reconstructed in 3d using the azimuthal information from the ϕ -sensors and are subsequently matched to hits in TT.

The TT consists of four silicon planes located before the magnet at $Z = 215$ cm and $Z = 245$ cm, ensuring a magnetic field between the TT and the VELO of $\int Bdl \approx 0.1$ Tm. The wide pitch (200 μm) sensors are tilted with a stereo angle of 0° , -5° , $+5^\circ$ and 0° . On average 400 clusters are found per event in about 150k channels.

The 3d-tracks from the VELO are matched to the hits in TT to measure the momentum with a resolution of $\sim 30\%$. The 3d-tracks that correctly match with muon, electron and hadron candidates achieve a momentum resolution of 5%, 10% and 15% respectively. The final L1 decision is obtained by consid-

Fig. 2. (a) The J/ψ -mass provides a clear signature for $B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\Phi$ events (bottom) with negligible contribution from background (top). (b) The L1 performance is shown for various B -decay channels.

ering the impact parameter significance of the two 3d-tracks with the highest transverse momentum (4). In addition, events containing two muons consistent with the J/ψ -mass are always accepted at the cost of little bandwidth, see Fig. 2a. A large fraction of useful signal events can be selected with negligible contribution from background. Studies are ongoing to include tracks that match to electron and hadron candidates.

The performance of the L1 decision algorithm is shown in Fig. 2b. A selection efficiency for offline selected events of 50% to 70% is achieved with a minimum bias retention of 4%, corresponding to an output rate of 40 kHz. First results indicate that the time needed for track and vertex reconstruction is below 20 ms, which is the right order of magnitude assuming $10\times$ faster CPUs at LHC startup. At present the latency foreseen at L1 is 1.7 ms, but a more flexible system is under study, where CPUs can easily be used for both the trigger farm and DAQ farm. A larger maximum latency and buffer depth, together with a lower output rate of about 5 kHz, will allow for a more flexible trigger scheme.

5 Conclusions

The present status of the first and second level trigger for the LHCb experiment have been discussed. The use of silicon detectors and the performance of the algorithms have been shown. Multiple interactions are distinguished from single interactions at L0 with an input rate of 40 MHz. At L1 the vertex detector is used to find high impact parameter tracks, whereas the TT detector and L0 objects provide momentum information. Depending on the B -decay channel, a selection efficiency between 50% and 70% is reached for a L1 output rate of 40 kHz.

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