LHCb trigger system design and commissioning with $\sqrt{s}$ =7 TeV proton-proton collissions at LHC

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The LHCb experiment needs fast mechanisms to reject uninteresting events while at the same time being very efficient in keeping those useful for precise measurements of CP symmetry violation and rare decays parameters in the B meson system. Proposed strategies and their performance evaluation on real data coming from the first pp collisions at LHC are described.

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1. B PHYSICS AT THE LHC

At a nominal energy of 14 TeV and a luminosity of $2{\times}10^{32}\text{cm}^{-2}\text{s}^{-1}$, proton-proton collisions delivered by the Large Hadron Collider (LHC) constitute an ideal environment for the study of the properties and decays of b flavored hadrons. B_d, B_u, B_s and Λ_b particles are copiously produced, with a distribution peaked at low polar angles, a fact which dictates the form of the LHCb detector [1] as a single arm forward spectrometer, covering an acceptance region of 10-300 mrad.

At design luminosity and assuming a cross section of 500 μb, the $b\bar{b}$ quark pair production rate is 100 kHz. 15% of those b hadrons and their decay products will be found inside the detector acceptance. Interesting decay processes are rare, typically with a relative probability of 10^{-4} or below, and thus are expected to occur at a maximum rate of 1 Hz. In contrast, the total rate of events with reconstructible tracks in the detector acceptance will be of 10 MHz, which indicates that signal events will be diluted by background in a proportion of one to ten million at best.

The purpose of the LHCb trigger system is to reject uninteresting events by looking for b hadron decay product signatures, coming from its heavy mass and long lifetime, namely tracks with higher transverse momentum (p_T) than those originated at the primary vertex (PV), and significant impact parameter (IP) to this PV.

2. LHCb TRIGGER DESIGN

Data taking is constrained by two conditions: firstly, full readout of the detector is designed to work at a maximum rate of 1MHz. Secondly, available offline storage and analysis resources are estimated to be sufficient for the equivalent to 2 kHz of events to be stored for a nominal year (10^7s) of operation.

Consequently, the LHCb trigger [1] [2] is divided into two stages. The first one (Level zero or L0) is implemented in custom electronics, managing detector readout. Figure 1 shows that some subdetectors can also be read through a trigger path, synchronous to LHC clock at 40 MHz. This information is then used to trigger full readout. Events flow then into a second stage (High Level Trigger or HLT) which consists of software algorithms running on a cluster of 16000 processors (approximately 1/3 currently installed) named the Event Filter Farm (EFF), which produces the final decision to discard or retain the event.

2.1. Level 0

L0 relies on the presence of high transverse momentum (p_T) or energy (E_T) candidates in the

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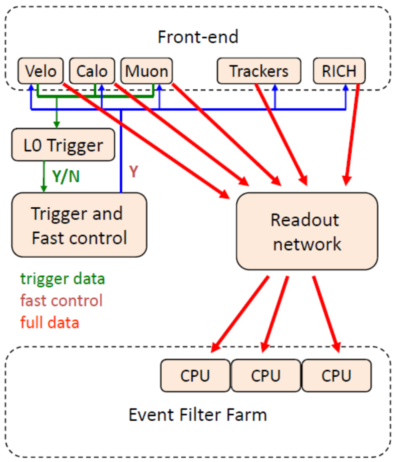

Figure 1. LHCb trigger and DAQ systems.

calorimeter and muon systems, which are used as seeds for the next stage.

- Calorimeter clusters are formed by combining energy deposited in regions of 2x2 cells. According to energy deposition in different calorimeter layers, clusters can be classified as electrons, photons, charged hadrons and neutral pions, and the highest E_T candidate of each type is considered.

- Muon candidates are track segments reconstructed by searching for straight line combination of hits in muon stations. Assuming they are produced at the nominal origin, for a known magnetic field, segment slopes given by M1 and M2 hits can be used to compute p_T with a resolution of 20%. The two highest p_T candidates found per detector quadrant are selected and used to produce a decision, based on a single candidate or a pair.

The final L0 decision is obtained by applying different thresholds on measured p_T or E_T to each type of L0 object, which reduces both the event rate and the number of candidates per event to be further processed.

2.2. High Level Trigger

The HLT has access to full event information, however a complete reconstruction is not possible at 1MHz, so a two step process is needed:

- HLT1 relies on the partial reconstruction of the events, which are first classified according to their L0 origin, entering then different sequences of algorithms that try to confirm the L0 seeds with high p_T tracks. PVs are reconstructed at this stage, so cuts on track IP can be applied as well. Finally, companion tracks can also be used in order to access new discriminating variables for improved performance.

- HLT2 is executed at 40 kHz starting with the full reconstruction of the event. Inclusive selections searching for generic signatures (displaced vertices, dilepton pairs, etc) as well as exclusive fully reconstructed b decays are tried. If any selection succeeds, the event is finally sent to storage.

Specific details on trigger strategies in relation to LHCb main objectives can be found in [3].

3. TRIGGER AND FIRST COLLISIONS AT 7 TeV

On March 30th 2010, the LHC provided the first proton collisions at 7 TeV. The low initial collision rate was easily absorbed by LHCb with a trigger configuration based on a “minimum bias” L0 (some activity to be found in the calorimeter or muon systems) and an HLT which did not run in rejection mode, although certain selections were run in “pass through” so that their performance could be monitored. Having collected $\sim$2nb^{-1}, progress in the accelerator performance increased the instantaneous luminosity and visible rate, as Figure 2 shows. The minimum bias triggers were prescaled and HLT1 introduced in a soft rejecting mode. In this scenario, the efficiencies on hadronic decays of promptly produced D mesons are about 4 times higher than in the case with the trigger thresholds used at nominal luminosity that are optimized for B decays.

Signal efficiencies on reconstructed and selected hadronic and muonic decay modes are in good

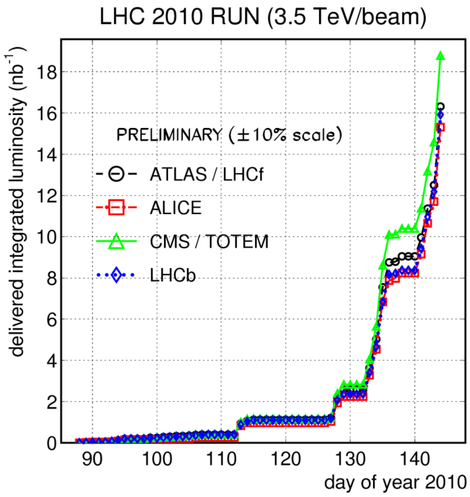

Figure 2. Delivered integrated luminosity.

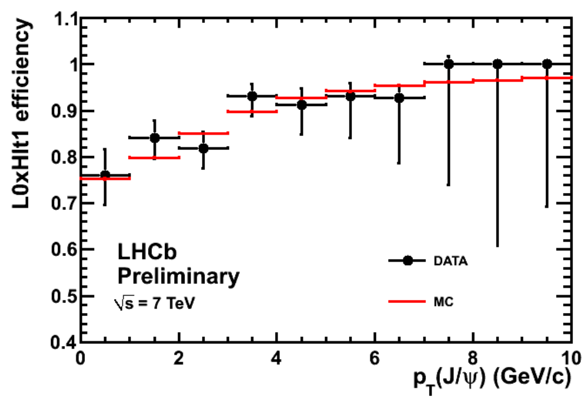

Figure 3. Muon trigger performance: efficiency on $J/\psi \to \mu^+\mu^-$ for data and MC.

agreement with simulation. Figure 3 presents a comparison of the combined L0 and HLT1 efficiency on $J/\psi \to \mu^+\mu^-$ data and Monte Carlo (MC) as a function of J/ψ p_T. The integral value for data is $(84.7 \pm 2.0)\%$ to be compared with $(86.7 \pm 0.1)\%$ for MC.

Figure 4 shows the efficiency on reconstructed and selected $D^* \to D^0(K\pi)\pi$ decays versus minimum bias retention as a function of the IP and p_T cuts applied to the triggering hadronic track, proving the validity of these discriminating variables. The combined L0 and HLT1 efficiency in this inital scenario is typically $\sim 65\%$.

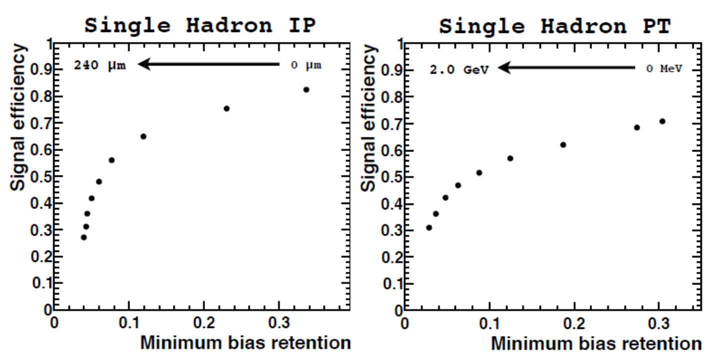

Figure 4. Hadron trigger discriminating variables validation on real data reconstructed and selected $D^* \to D^0(K\pi)\pi$: triggering hadron track IP to PV (left) and p_T (right).

4. CONCLUSIONS

LHCb trigger commissioning is well advanced and the experiment has passed the minimum bias Physics regime. Taking data with a fully operational selective trigger, the efficiencies on real data can be measured in good agreement with MC.

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