The LHCb Detector and Triggers

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LHCb is a dedicated second generation B physics precision experiment at the LHC with the aim of studying CP violation and rare B decays. Its construction and installation is progressing on schedule and it will be ready for the LHC startup in 2007. The LHCb detector provides for a precise vertexing and tracking, excellent particle identification and proper time resolution, and an efficient and selective trigger. An overview and the status of the LHCb detector together with its trigger system is given.

1. Introduction

LHCb is a dedicated second generation B physics precision experiment at the LHC to study CP violation by precise determination of the CKM matrix parameters and to search for rare B decays which could be originated by new physics [1], [2]. LHCb is a single arm forward spectrometer covering a pseudorapidity of $1.9 < \eta < 4.9$. The LHCb detector schematic is shown in Fig. 1. At the LHC collider the proton-proton collisions center of mass energy is $\sqrt{s} = 14$ TeV with a frequency of 40 MHz (bunch crossing of 25 ns). The total inelastic and the $b\bar{b}$ cross sections are $\sigma_{inelastic} \sim 80$ mb and $\sigma_{b\bar{b}} \sim 500$ μb respectively. The $b\bar{b}$ hadrons are produced predominantly in a forward (backward) cone and are correlated. This allows for a single arm spectrometer which requires less space and is less costly to build. LHCb will be a copious source of a large variety of B-hadrons (B$_u$, B$_d$,B$_s$,B$_c$, b-baryons). About $\sim 10^{12}$ $b\bar{b}$ pairs are expected per year. LHCb will run at a luminosity value of $L \sim 2 \cdot 10^{32}$ cm^{-2}s^{-1} lower than the LHC nominal design value of $L = 10^{34}$ cm^{-2}s^{-1}. Lower luminosity is obtained by appropriately defocusing the beams at the LHCb interaction point. The chosen luminosity value is optimized to obtain predominantly single inelastic interactions per bunch crossing which has the advantage of simpler triggering and event reconstruction and limited radiation damage. This moderate luminosity compared to the LHC design is foreseen to be available from the start of LHC. It is expected to collect 2 fb^{-1} per nominal year (10^{7}s). The LHCb detector possesses all the principal requirements for doing B physics: good vertexing and tracking, efficient particle identification (π/K separation), excellent proper time resolution, and an efficient and selective trigger for leptonic and hadronic decays.

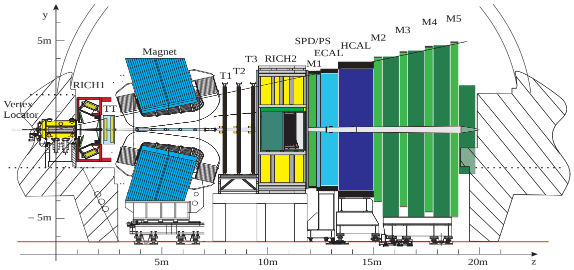

Figure 1. The LHCb detector schematic. The subdetectors are: the VELO (Vertex Locator), the two RICH detectors, the dipole magnet, the four tracking stations (TT, T1 to T3), the Scintillating Pad Detector (SPD) and Preshower, the Electromagnetic (ECAL) and Hadronic (HCAL) calorimeters, and the five muon stations M1 to M5. The coordinate system (x,y,z) is right-handed.

2. The LHCb Detector

2.1. VELO

The vertex locator (VELO) is used to precisely measure the track coordinates close to the interaction region. The mean decay length of B-hadrons is ∼10 mm. It is installed inside a vacuum tank at the interaction point and consists of 21 stations covering a distance in z of $\sim$ 1 m. Each station is made of two pairs of silicon half-discs positioned along the beamline axis, for the r (circular strips) and ϕ measurement (radial strips). The silicon sensors are 300 μm thick with the pitch varying between 35-100 μm. They are operated at -5°C using CO_2 cooling. The pile-up system to reject multiple interaction events consists of two r-disks placed upstream. The sensitive area of the VELO is only $\sim$ 8 mm from the LHC beam, hence it has been built in two retractable halves. The silicon disks are housed in a secondary vacuum (like Roman pots) separated from the beampipe vacuum by an aluminum RF foil 250 μm thick. The silicon disks are retracted by 3 cm during LHC injection. The VELO will be commissioned in testbeams during 2006 and will be installed in early 2007.

2.2. RICH

The particle identification system consists of two RICH detectors. At large polar angles the momentum spectrum is softer than at small polar angles, therefore two RICH detectors are required. The upstream detector RICH 1, covers the low momentum charged particle range ∼1-65 GeV/c using aerogel and C4F10 radiators, while the downstream detector RICH 2 covers the high momentum range up to and beyond 100 GeV/c using a CF4 radiator. RICH 1 covers the full LHCb acceptance from 25 mrad to 300 mrad (horizontal) and 250 mrad (vertical) and is located upstream of the magnet to detect the low momentum particles. RICH 2 is located downstream of the magnet and has a limited acceptance of 15 mrad to 120 mrad (horizontal) and 100 mrad (vertical) where there are mainly high momentum particles. In both RICH detectors the focusing of the Cherenkov light is accomplished using a combination of spherical and flat mirrors to bring the image out of the acceptance. RICH 1 has a vertical optical layout symmetry, instead for RICH 2 it is horizontal. Hybrid Photo Detectors (HPD) are used to detect the Cherenkov photons in the wavelength range 200-600 nm. The HPDs have a granularity of 2.5×2.5 mm^2 at the photocathode and the anode is a silicon array of 1024 pixels. The HPDs are surrounded by an iron shield and are placed in Mumetal cylinders to permit operation in magnetic fields up to 50 mT. Both RICH detectors have been installed in the LHCb pit and will be completed in spring 2007.

2.3. Tracking

The tracking system is used to find charged particle tracks and measure their momenta. It consists of the VELO and four tracking stations; one tracking station (TT) is before the magnet and the other three are placed behind the magnet (T1,T2,T3). Each tracking station consists of four layers; two outer layers with vertical readout strips and two inner layers with the readout strips rotated by a stereo angle of +5° and -5° respectively. The Trigger Tracker (TT) is the first station and consists of four silicon microstrip planes. The silicon is 500 μm thick with a pitch of 183 μm, the strips are up to 37 mm long and it is operated at 5°C. The track occupancy close to the beampipe is high, hence the three remaining tracking stations (T1 to T3) consist of an Inner Tracker (IT) and an Outer Tracker (OT) covering $\sim$ 2% and $\sim$ 98% of the tracker area respectively. About 20% of the tracks pass through the IT and $\sim$ 80% through the OT. The IT uses silicon microstrip sensors with thickness of 320 μm and 410 μm depending on the location, a pitch of 198 μm and lengths up to 22 cm. The OT consists of Kapton-aluminum straw tubes 5 mm in diameter and 4.7 m long filled with Ar-$C0_2$ drift gas. The OT production is completed, while the IT and TT chambers are in production.

The magnetic field is produced by a warm dipole magnet. It weighs 1600 tons and its power consumption is 4.2 MW. The field integral is 4 Tm which is required by the tracking system for the measurement of momenta with a precision of ∼0.4% up to 200 GeV/c. The magnetic field extends up to the VELO (region of RICH 1 and TT) for trigger improvement. The magnet has been installed, commissioned and the field map measured. The magnetic field polarity will be regularly reversed to reduce the experimental systematic errors.

2.4. Calorimeters

The calorimeter system consists of three subdetectors: the SPD/PS (Scintillating Pad Detector and Preshower), the ECAL (Electromagnetic Calorimeter) and the HCAL (Hadronic Calorimeter). The calorimeters are used to identify electrons, photons and hadrons, to measure their positions and energies, and for triggering. The SPD/PS consists of two planes of scintillating pads with a 2 X_0 lead wall in-between for $e-\gamma$ separation. The detector elements are 15 mm thick scintillator pads. WLS fibers placed in a groove in the scintillator collect the light which is then brought by long clear fibers to multi-anode photomultiplier tubes placed above and below the detector. The SPD/PS is made of 16 identical super modules, each consisting of 26 modules mounted in two columns. The modules close to the beam line have a higher granularity. Immediately behind there is the ECAL followed by the HCAL. The ECAL is a Pb/scintillator Shashlik (25 X_0, 1.1 λ_I). The ECAL modules are made of lead absorber plates interspaced with scintillator tiles. WLS fibers penetrate the Pb/scintillator stack through holes and are readout by photomultipliers. There are 3 module types with different segmentation. The ECAL consists of two halves with $\sim$ 3300 modules stacked 6 m high. The HCAL is an iron/scintillator tile type readout by photomultipliers. It is built in two halves each consisting of 26 stacked modules. The ECAL and HCAL are installed, while the SPD/PS installation is in summer 2006. The energy resolution was measured in testbeams: $\frac{\sigma(E)}{E} \sim \frac{10\%}{\sqrt{E}} \oplus 1.5\%$ for the ECAL and $\frac{\sigma(E)}{E} \sim \frac{80\%}{\sqrt{E}} \oplus 10\%$, while the electron identification efficiency is $\varepsilon(e \to e) \sim 95\%$ and the misidentification rate is $\varepsilon(\pi \to e) \sim 1\%$.

2.5. Muon System

The muon system is used for muon identification and high P_T muon triggering. It consists of five stations. M1 is located in front of the calorimeter system and M2 to M5 are located behind it interleaved with three iron muon filter plates. The muon chambers are built using 1380 MWPC except for the inner part of M1 where 24 triple-GEMs are used because of the high rate. The muon identification efficiency is $\sim 94\%$ with a pion misidentification rate of $\sim 1\%$. The muon filters have been installed. The muon chambers will be completed by the end of 2006 and the installation will be completed by spring 2007.

3. Trigger

The purpose of the trigger is to select interesting B-meson decays [3]. The background to signal ratio is large $\frac{\sigma_{ine}}{\sigma_{b\bar{b}}} \sim 160$, the branching ratios are small ($< 10^{-3}$) and there is a limited detector acceptance, hence a selective and efficient trigger is required to extract the small fraction of interesting events. The typical B-meson signatures are: leptons and hadrons with large P_T, secondary vertices, and tracks with large impact parameter.

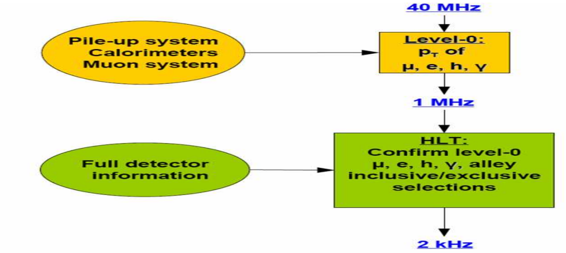

Figure 2. LHCb trigger schematic.

The LHCb trigger has two levels called L0 (Level0) and HLT (High Level Trigger), see Fig. 2. L0 reduces the input rate from 40MHz (bunch crossing rate) to 1 MHz. It is a hardware trigger built with custom electronics and has a fixed latency of 4 μs. The HLT reduces the rate from 1 MHz to about 2 kHz. The full detector information is available to the HLT. It is a software trigger based on a CPU farm of about 1800 nodes and it latency depends on the total number of CPUs used.

L0 receives input from the pile-up system of the VELO, the calorimeters and muon systems. The pile-up system is used to reject events with multiple bunch crossing, the calorimeters find and select clusters (hadrons, e, γ) with high E_T, while the muon system selects high P_T muons. These trigger conditions are fed into the L0 decision unit (L0DU) where they are logically ORed and a L0 trigger decision is formed. Events are selected based on global event variables e.g. charged particle multiplicity, pile-up and total E_T in the HCAL. The L0 efficiency is $\sim$ 50% for hadronic channels, $\sim$ 90% for μ channels and $\sim$ 70% for radiative channels. The L0 trigger hardware is under construction and the commisioning is in early 2007.

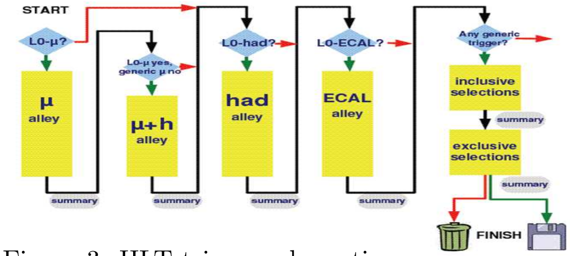

Figure 3. HLT trigger schematic.

All the detector information is available to the HLT. The starting point is the L0 decision, see Fig. 3. There are four independent alleys. The alley chosen depends on the L0 decision. The alleys produce a summary for monitoring purposes containing information on the decision taken, type of trigger, the quantities used and the reconstructed quantities. Each alley consists of three main steps: first the L0 trigger confirmation, then a fast rejection using reconstructed quantities and finally the alley dependant trigger algorithm. After the generic-HLT yes the processing continues to the inclusive (for systematic studies and inclusive B and D*) and exclusive selections (reconstructed B-decays) of the HLT. The expected HLT output rate is 2 kHz subdivided in: exclusive B $\sim$ 200 Hz for core physics, D* $\sim$ 300 Hz for particle identification efficiency studies and D-decays, dimuon $\sim$ 600 Hz for tracking and lifetime measurements, inclusive b$\rightarrow \mu \sim$ 900 Hz for trigger efficiency and data mining. The HLT trigger is in its final stage of development.

4. Expected Offline Performance

The LHCb detector performance [2] was obtained by running a full Monte Carlo simulation of the detector using the programs Pythia (pp interactions generator), EvtGen (B-decays) and GEANT4 (tracking) in conjunction.

The primary vertex resolution (VELO) is $\sim$ 8 μm in x (horizontal-axis) and y (vertical-axis) and $\sim$ 44 μm along z (beamline axis), while the proper time resolution is $\sim$ 40 fs (for $\mathrm{B}_S \rightarrow \mathrm{D}_S\pi$ decays). The tracking efficiency and ghost rate for tracks that originate in the VELO and go through all four tracking stations is $\sim$ 94% for tracks with $p > 10$ Gev/c and $\sim$ 3% for tracks with a $p_T > 0.5$ GeV/c respectively. The momentum and impact parameter resolutions are $\sim$ 0.4% and $\sim$ 40 μm respectively. The RICH K, π identification efficiency is $\sim$ 90% with a misidentification rate less than $\sim$ 10% for tracks between 20 and 80 GeV/c. The RICH particle identification reduces noticeably the background from competing channels. The e and μ identification efficiency is $\sim$ 95% with π misidentification rate of $\sim$ 1%. The π^0 reconstruction efficiency ($\mathrm{B}^0 \rightarrow \pi^+\pi^-\pi^0$) is $\sim$ 50%.

5. Summary

LHCb is a dedicated B-physics experiment with precise vertexing and tracking, an excellent particle identification and proper time resolution, and an efficient and selective trigger. The construction and installation of the subdetectors is progressing on schedule. The first level trigger (L0) hardware is being constructed and will be commissioned in early 2007, while the second level trigger (HLT) is in its final stage of completion. LHCb will be ready for the LHC pilot run foreseen for the second half of 2007. The LHCb collaboration aims to get physics results early from the LHC.

REFERENCES

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