OVERVIEW OF LHCb

HERVÉ TERRIER (on behalf of the LHCb collaboration)

Laboratoire d'Annecy-le-Vieux de Physique des Particules, 9 Chemin de Bellevue, BP 110 F, 74941 Annecy-le-Vieux CEDEX

An overview of LHCb experiment is given, focusing on detector, trigger and expected physics performances. LHCb is a second generation b physics experiment design to do precise measurements of CP violation in B meson system and to study b hadron rare decays.

1 Introduction

The LHCb experiment [1,2] has been designed to study CP violation and rare phenomena in B meson decays with very high precision. The physics goal being to provide an understanding of quark flavor physics, and possibly to reveal physics beyond the Standard Model. The experiment will be based at CERN and will study the decay of b quarks from $b\bar{b}$ pairs produced in proton-proton collision. It will operate at an average luminosity of $2\times10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, much lower than the maximum design luminosity of the LHC, in order to have a number of interactions per crossing dominated by single interaction. This facilitates the triggering and reconstruction by assuring low channel occupancy. In addition, the radiation damages are more manageable. To achieve its physics goals, the experiment will have to perform, a high track reconstruction efficiency, a good $\pi - K$ separation for momenta from few to $\sim$100 GeV/c, a very good propertime resolution ($\sim$40 fs), and, a high trigger efficiency (both for final states including leptons and for those with hadrons only). These needs have led to the detector design that is represented on Fig. 1 and that is described in the next section.

2 LHCb detector description

LHCb detector is a single-arm spectrometer with a forward angular coverage from 10 mrad to 300 (250) mrad in the bending (non-bending) plane. The choice of the geometry has been motivated by the fact that at high energies both the b and $\bar{b}$ hadrons are produced at small angles with respect to the beam pipe [1]. This is illustrated by Fig. 2 obtained from PYTHIA
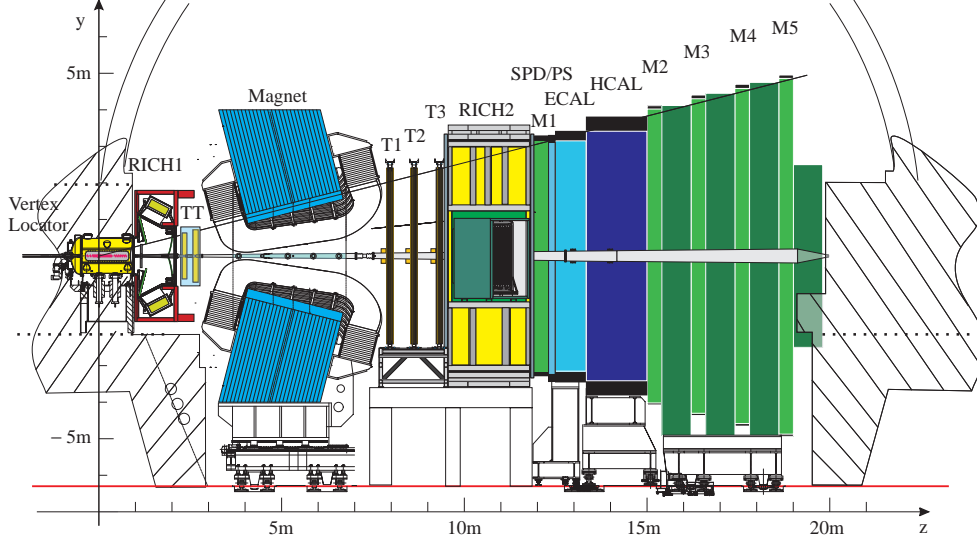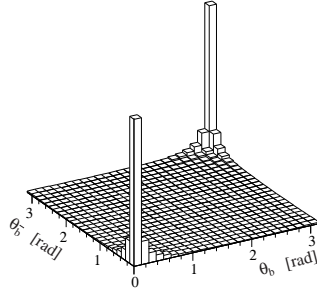
Figure 1: Side view of LHCb detector.

Figure 2: Polar angles of the b and $\bar{b}$ hadrons produced in proton-proton collisions with $\sqrt{s} = 14$ TeV calculated by the PYTHIA event generator.

event generator [3]. Figure 1 shows a side view of the detector that consists of the beam pipe, the vertex detector (VELO), the dipole magnet, the tracking system (TT, T1-T3), two Ring Imaging Cherenkov detectors (RICH1 and RICH2), the calorimeter system (SPD/PS, ECAL and HCAL) and the muon system (M1-M5). The VELO has to provide precise measurements of track coordinates close to the interaction region in order to get good proper time resolution. It is made of circular silicon stations placed along and perpendicularly to the beam axis. With the excellent momentum resolution achieved by the tracking system, the proper time of reconstructed B mesons can be measured with a resolution of $\sim$40 fs [2]. The tracking system is composed of the dipole magnet which is a warm magnet and has a field integral of 4 Tm, a Trigger Tracker (TT) located in front of the magnet entrance and three tracking station (T1-T3) placed behind the magnet. TT stations are made of silicon sensors and play two roles. Firstly, it will be used in the Level-1 trigger to assign transverse momentum information to large impact parameter tracks. Secondly, it will be used in the offline analysis to reconstruct tracks, in particular the decay products of long-lived neutral particle that decay outside the VELO. Each T station consists of an Inner Tracker (IT) close to the beam pipe and an Outer Tracker (OT) surrounding the IT. The IT is made of silicon strip detectors and the OT of straw tubes. Charged tracks are reconstructed with a high efficiency of $\sim$95% with a low rate of wrongly reconstructed tracks, which does not introduce significant additionnal combinatorial background in the reconstructed B meson signals. RICH system is composed of two elements located in front of TT and behind T stations. To cover the momentum range from few to $\sim$100 GeV/c, three different radiators

have been chosen : silica aerogel and two fluorocarbon gases, C_4F_{10} and CF_4. In this momentum range, the average efficiency for kaon identification is 88% for an average pion misidentification rate of 3%. The main purpose of the calorimeter system is to identify electrons and hadrons and to provide measurements of their energy and position. These measurements are used by the trigger system and for the off-line analysis. The structure consists of four elements, a scintillator pad detector (SPD), a preshower (PS), an electromagnetic calorimeter (ECAL) and an hadronic calorimeter (HCAL). These elements employ similar technologies, i.e. scintillators coupled to wavelength-shifting fibers read out by fast photodectors. The electron identification efficiency for tracks in ECAL acceptance is ∼94% with a pion misidentification rate of ∼0.7%. The muon detector is used to identify muons for the trigger and off-line analysis. It consists of five stations, M1 in front of the calorimeter system and M2-M5 behind the calorimeter, interleaved with iron shielding plates. Each station is made of four layers of Multi Wire Proportional Chambers (MWPC) except for M1 which is made of two. For tracks in muon detector acceptance, muon identification efficiency is ∼93% with a pion misidentification rate of ∼1%.

3 LHCb trigger

The trigger [4] is one of the biggest challenge for the LHCb experiment, the $b\bar{b}$ pair creation cross section being less than 1% of the total cross section. It is designed to distinguish events containing B mesons from minimum-bias events through the presence of particles with a large transverse momentum (p_T) and the existence of secondary vertices. The trigger is divided in three levels : Level-0 (L0) implemented in custom electronics, Level-1 (L1) and High Level Trigger (HLT) both executed in farm processors. The L0 trigger will reduce the 40 MHz LHC beam crossing rate to 1 MHz. The events are triggered by requiring at least one lepton or hadron with a p_T exceeding 1 to 3 GeV/c. Events can also be rejected based on global event variables such as track multiplicities and number of interactions. The L1 trigger selects events with an output rate of 40 kHz. The L1 algorithm reconstructs tracks in the VELO and matches these tracks to L0 muons or calorimeter clusters to identify them and measure their momenta. The fringe field of the magnet between the VELO and TT is used to determine the momenta of particles with a resolution of 20-40% and events are selected based on tracks with a large p_T and significant impact parameter to the primary vertex. Finally the HLT will select the stored events with a frequency of 200 Hz. The HLT algorithm has access to all data and starts by reconstructing the VELO tracks and the primary vertex. A fast pattern recognition program links the VELO tracks to the tracking stations T1-T3. The final selection of interesting events is a combination of the confirmation of the L1 decision with better resolution, and selection cuts dedicated to specific final states. In addition to the events stored by HLT, 1.8 KHz will be stored to get systematics from the data (e.g. a trigger on high di-muon mass will be used to calibrate tracking, inclusive $b \to \mu$ events will be selected to calibrate trigger, and D^* events to calibrate the particle identification).

4 LHCb expected physics performances

"Toy Monte Carlo" programs have been used to estimate the LHCb sentivities to some CP observables. These programs include signal resolution, efficiency, purity, etc. taken from studies with fully-simulated events. Nevertheless, assumption need to be made concerning the properties of background events due to the lack of statistics. In the real analyses, these properties and the systematics effects will be extracted from the data. Here only statistical errors are given.

The LHCb physics program includes many topics. For some of them, expected sensitivities corresponding to one year of data taking (integrated luminosity of 2 fb^{-1}) and a $b\bar{b}$ pair production cross-section assumed to be 0.5 mb will be given hereafter. B_d^0 mixing phase will be

measured with $B^0 \to J/\psi\, K_S^0$ decay with a sensitivity ~ 0.02. B_s^0 mixing phase ϕ_s and decay-width $\Delta\Gamma_s/\Gamma_s$ will be assessed with $B_s^0 \to J/\psi\, \phi$ decay. This channel presents several challenges. Indeed, an angular analysis is needed as J/ψ and ϕ are vector mesons. In addition, the oscillation frequency Δm_s is expected to be large, requiring excellent proper-time resolution. The expected sensitivities to ϕ_s and $\Delta\Gamma_s/\Gamma_s$ are respectively 0.064 and 0.018. Δm_s will be measured with $B_s^0 \to D_s^- \pi^+$ decay that is flavor-specific and give access to Δm_s through flavour asymmetry analyses (see Fig. 3). The sensitivity on Δm_s is 0.009 (0.016) for $\Delta m_s = 15$ ps^{-1} (30 ps^{-1}). Moreover, oscillations can be observed (5σ) for Δm_s values up to 68 ps^{-1}.
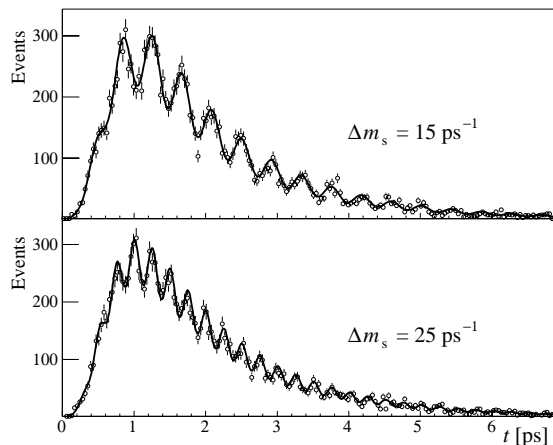
Figure 3: $B_s^0 \to D_s^- \pi^+$ decay rate for two different values of Δm_s. Only B_s^0 decays which have been tagged as not having oscillated are included. The curve shows the result of the likelihood maximization.

The measurement of the angle γ of the unitarity triangle will be done in three different ways. Time-dependant decay asymmetries in $B_s^0 \to D_s^\mp K^\pm$ decays combined with ϕ_s measurement from $B_s^0 \to J/\psi\, \phi$ decay, will give $\sigma(\gamma) = 14° - 15°$ without theoretical uncertainty. Time-dependant CP asymmetries in $B_d^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ decays, in combination with measurement with $B^0 \to J/\psi\, K_S^0$ and $B_s^0 \to J/\psi\, \phi$ respectively, will give $\sigma(\gamma) = 4° - 6°$ assuming U-spin symmetry [5]. Time-integrated rates of $B^0 \to D^0 K^*$, $B^0 \to \overline{D}^0 K^{*0}$, and $B^0 \to D_{CP}^0 K^{*0}$ decays [6], will give $\sigma(\gamma) = 7° - 8°$. In the presence of new physics, these three different approaches could allow to identify it. In addition, very rare decays like $B_s^0 \to \mu^+\mu^-$ decay, $b \to s$ penguin processes as $B^0 \to \phi K_S^0$, $B_d^0 \to \mu^+\mu^- K^{*0}$, $B_d^0 \to K^{*0}\gamma$, $B_s^0 \to \phi\gamma$ and $B_s^0 \to \phi\phi$ decays, $b \to d$ penguin processes with $B^0 \to \rho\pi$ decay, B_c mesons and b-baryons will be studied in great detail by LHCb.

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