Proceedings of the DIS'2004, Štrbské Pleso, Slovakia

LHCB EXPERIMENT SENSITIVITY TO CKM PHASES AND NEW PHYSICS

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The LHCb detector is being constructed for LHC collider at CERN to study CP violation and other rare phenomena in B meson decays with very high precision. After short description of the detector, few examples of measurements in B_s decays are discussed. Results from Monte Carlo simulations allow to estimate sensitivities for B_s mixing parameters and CKM matrix phases determinations.

1 Introduction

The LHCb experiment is being built at the Large Hadron Collider (LHC) to study CP violation and rare decays in the B system [1]. The collider will work at $\sqrt{s} = 14$ TeV. With a $b\bar{b}$ production cross-section of 0.5 mb and nominal luminosity of $2 \cdot 10^{32} cm^{-2} s^{-1}$, a total amount of 10^{12} $b\bar{b}$ pairs will be produced per year ($10^7 s$). This will allow studies of many rare decays of B_d^0 and B_s^0 mesons and precise determinations of the parameters of the unitary triangles derived from the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix. Precise measurements of the angles β, γ and χ provide powerful tests of the Standard Model and a significant discovery potential for physics beyond the Standard Model. The much larger statistics and in particular the access to B_s decays will allow many cross checks of CP violation that are not possible at the current B factories. In this presentation a few examples of the LHCb physics performance in B_s decays will be discussed.

2 The LHCb detector

The LHCb detector is a single-arm spectrometer with a large dipole magnet for momentum measurement (Fig.1). It is designed to maximize the efficiency for detecting b - hadrons produced in forward directions. The detector covers an angular region approximately between 10 and 250 mrad (300 mrad) in the non-bending (bending) plane [1].

A warm dipole magnet with an aluminium conductor provides about 4 Tm field integral. The silicon Vertex Locator (VELO) surrounds the interaction point. It is built in two halves, placed in "Roman Pots" on both sides of the beam. There are 21 stations of silicon strip detectors (220 μm thick) arranged into independent r and ϕ planes. Typical proper time resolutions are about 40 fs (Fig.2).

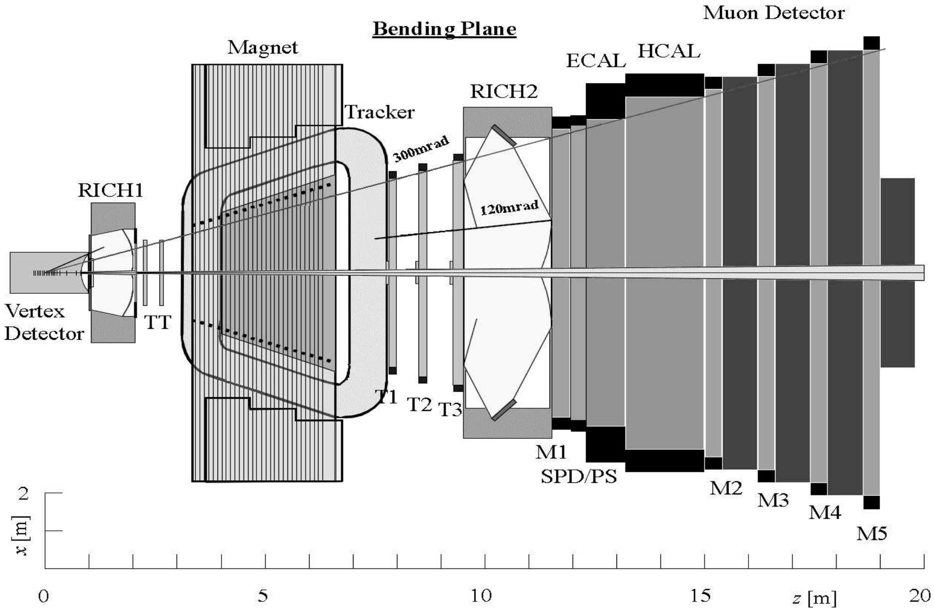

Figure 1. A top view of the LHCb spectrometer

The tracking system comprises two stations (TT) of silicon microstrip detectors with four detection layers and a total surface of $8.3m^2$ in front of the magnet and three large tracking stations ($6 \times 5m^2$) behind the magnet (T1 - T3) (Inner and Outer Trackers). The inner region of each station, close to the beam pipe, is filled with silicon microstrips. The Outer Tracker is built with 5 mm diameter drift straw tubes. The average momentum resolution is $\delta p/p \approx 0.35\%$ up to 150 GeV/c, resulting in typical mass resolutions of 5 MeV/c^2 for D mesons and 14 MeV/c^2 for B mesons (Fig.2). This gives a powerful background suppression in the reconstruction of final states [2].

Particle identification is provided by two RICH detectors with 2σ $\pi - K$ separation over the momentum range $1 - 150$ GeV/c. In RICH1, photons from two radiators (silica aerogel and C_4F_{10} gas) are registered by the same photodetectors. RICH2 uses CF_4 gas extending particle identification to fast particles. In both RICH detectors the readout is based on hybrid photodiodes (HPD) with 1024 pixels silicon detector.

Electromagnetic (ECAL) and Hadron (HCAL) Calorimeters provide electron, photon and hadron identification. They are crucial for triggering. The ECAL is the Pb - scintillator shashlik type with a preshower (PS). Almost 6000 cells have a depth of $25X_0(1.1\lambda)$ and energy resolution of $\sigma_E = 0.10/\sqrt{E} \bigoplus 0.01$. The HCAL is built with the Fe - scintillator tiles. The depth is 5.6λ and the energy resolution is $\sigma_E/E = 0.80/\sqrt{E} \bigoplus 0.1$.

The Muon Detector consists of five stations (M1 - M5) of multiwire proportional chambers embedded in iron absorbers. The detector provides efficient muon

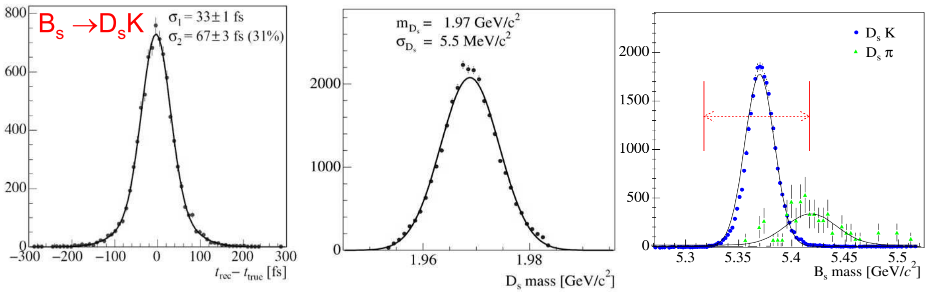

Figure 2. Examples of expected time and mass resolutions in the LHCb detector

identification and is used in the trigger system.

The LHCb trigger has to efficiently select interesting B - decays from inelastic pp interactions. The estimated inelastic pp cross-section is about 80 mb and the ratio of the $b\bar{b}$ cross-section to the inelastic pp cross-section is expected to be $\simeq 1/160$. This corresponds to a rate of 16 MHz of pp interactions at the preferred LHCb luminosity of $2 \cdot 10^{32} cm^{-2} s^{-1}$ and a rate of 100 kHz of $b\bar{b}$ events. With such high rate it is impossible to record all the $b\bar{b}$ events and the trigger system must be designed to enrich the sample with the desired B decay modes. The LHCb trigger is based on three levels. The first trigger level reduces the rate to 1 MHz using large p_T triggers. At the second level all data are digitised and limited tracking information is used to reduce the rate to 40 kHz. The next High Level Trigger performs further software selections rejecting uninteresting $b\bar{b}$ events to achieve a final output rate of 200 Hz for events written to storage.

3 ΔM_s limits from $B_s - \bar{B}_s$ mixing

Mixing parameter ΔM_s and $\Delta\Gamma_s$ for $B_s - \bar{B}_s$ mixing can be measured in many B_s decay channels. In LHCb experiment the channel with largest sensitivity is $B_s \to D_s^- \pi^+$ due to its high branching ratio and fully reconstructed decay $D_s^- \to K^- K^+ \pi^-$. Since decays $B_s^0 \to D_s^- \pi^+$ and $\bar{B}_s^0 \to D_s^+ \pi^-$ are flavour specific, there is no CP asymmetry in this channel. Measurements of time dependent rates:

$$\Gamma_{D_s^- \pi^+} \sim \frac{\mid A_{D_s^- \pi^+} \mid^2}{2} e^{-\Gamma t} \left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) \pm \cosh\left(\Delta m_s t\right) \right] \tag{1}$$

can be used to extract ΔM_s and $\Delta\Gamma_s/\Gamma_s$. $A_{D_s \pi}$ is an amplitude of the decay and + or - sign corresponds to the decays tagged as not mixed or mixed respectively.

About 80 000 reconstructed events per year are expected in LHCb experiment with signal to background ratio $S/B \sim 3$. Decay length resolution of $\sim 200\ \mu m$ in the vertex detector results in proper time resolution of $\sim$ 40 fs.

To observe mixing, the flavour of originally produced B_s^0 meson has to be known and therefore tagging of production state is required. Efficiency of the tagging is $\sim$ 55% with a mistag rate of 30%.

One year of data taking in LHCb experiment will allow 5σ measurement for ΔM_s up to 68 ps^{-1} far beyond the present limit and the Standard Model prediction $(14.4 - 26\ ps^{-1})$ [3].

4 CP asymmetries in $B_s \to D_s^{\pm} K^{\pm}$

With the same topology, $B_s \to D_s\pi$ is a background for $B_s \to D_s K$ decays with about 12 - 15 times higher branching ratio. This background can be eliminated by a cut on difference in log-likelihood between K and π hypotheses in RICH detectors [3].

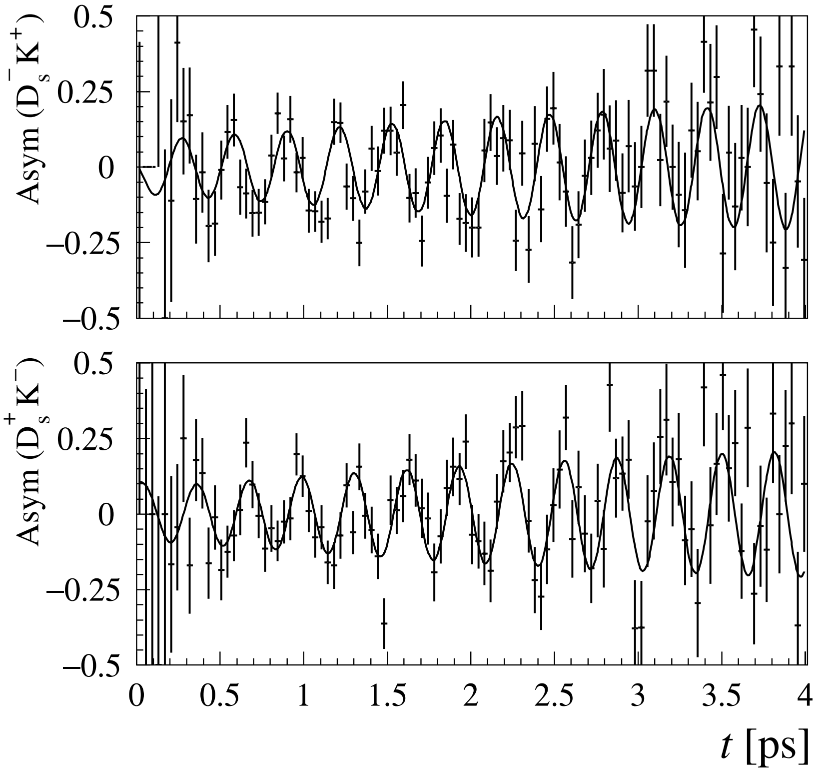

Figure 3. The simulated $B_s^0 \to D_s^{\pm} K^{\mp}$ asymmetries for 5 years of data taking in the LHCb experiment

Four distinct decay modes: $B_s \to D_s^{\pm} K^{\mp}$ and $\bar{B}_s \to D_s^{\pm} K^{\mp}$ can be used to measure γ - the phase of V_{ub} CKM matrix element.

CP-violation asymmetry arises here from the interference between two tree diagrams via B_s mixing: $B_s \to D_s^+ K^-$ interferes with $B_s \to \bar{B}_s^0 \to D_s^+ K^-$ and $B_s \to D_s^- K^+$ interferes with $B_s \to \bar{B}_s \to D_s^- K^+$. Since both tree diagrams amplitudes are of the same order we expect large CP asymmetries which measure $\gamma - 2\chi$ (χ - is a small $B_s - \bar{B}_s$ mixing phase).

If χ will be determined from e.g. $B_s \to J/\psi\phi$ decays, measurements of these asymmetries provide a clean method to measure γ. Since only tree diagrams contribute, the method is expected to be insensitive to New Physics contributions - new particles appear only in loops.

Branching ratio for $D_s^- \to K^- K^+ \pi^-$ gives $\sim$ 5400 events per year in LHCb detector [3].

To eliminate unknown strong phase difference $\Delta_{T1/T2}$ between tree diagrams both $D_s^- K^+$ and $D_s^+ K^-$ asymmetry phases have to be measured. The asymmetries are shown in Fig.2. With fits to two time-dependent asymmetries it is possible to extract both $\Delta_{T1/T2}$ and $\gamma - 2\chi$.

The expected error on γ is about 14^o in one year of data taking [4].

5 CP asymmetry in $B_s \to J/\psi\phi$

Dominated by a single amplitude the $B_s^0 \to J/\psi\phi$ decay is a strange counterpart of the golden mode decay $B^0 \to J/\psi K_s^0$. In both decays no CP violation in decay is expected and CP asymmetry arises from the interference of $B_s \to J/\psi\phi$ and $B_s \to \bar{B}_s \to J/\psi\phi$. In the Standard Model the asymmetry, proportional to $sin2\chi = 2\eta\lambda^2 \sim 0.04$, is very small and therefore it is a sensitive probe for contributions from New Physics.

Complication of the analysis arises from the fact that since both J/ψ and ϕ are vector mesons, two orbital states can occur and the final state is an admixture of CP-even and CP-odd contributions. Separation of these contributions requires angular analysis of decay products.

The unbinned likelihood fit is performed to the decay time distribution as well as to the transversity angle distribution. Likelihood function is a sum of CP - odd and CP - even terms:

$$L(t) = R_- L_-(t)(1 + cos^2\Theta_{tr})/2 + (1 - R_-)L_+(t)(1 - cos^2\Theta_{tr}) \qquad (2)$$

where Θ_{tr} is the transversity angle defined in the rest frame of the J/ψ as the angle between the z - axis and the positive lepton. The z - axis is perpendicular to the plane made up by two kaons from the ϕ. R_- is the fraction of CP - odd component.

In LHCb experiment $\sim$ 120 000 events per year will be reconstructed with $J/\psi \to \mu^+\mu^-$ or e^+e^- and $\phi \to K^+K^-$ [5]. The expected resolution for $sin2\chi$ is $\sigma(sin2\chi) \sim 0.06$. $\Delta\Gamma_s/\Gamma_s$ can also be extracted from the time-dependent fit with $\sigma(\Delta\Gamma_s/\Gamma_s) \sim 0.02$ [6].

6 Physics performance of the LHCb experiment

The physics performance of LHCb in one year of running ($10^7 s$) is summarized in Table 1.

	Channel	Yield	Precision
β	$B_d \to J/\psi\, K_s$	240 000	$\sigma(\beta) \approx 0.6^o$
γ	$B_s \to D_s K$	5400	$\sigma(\gamma) \approx 14^o$
	$B_d \to \pi\pi$, $B_s \to KK$	26000, 37000	$\sigma(\gamma) \approx 6^o$
	$B_d \to D^0\, K^*$	500	$\sigma(\gamma) \approx 8^o$
	$B_d \to \bar{D}^0\, K^*$	3400	
	$B_d \to D_{CP}{}^0\, K^*$	600	
χ	$B_s \to J/\psi\, \phi$	120 000	$\sigma(\chi) \approx 2^o$
$\lvert V_{td}/V_{ts} \rvert$	$B_s \to D_s \pi$	80 000	Δm_s up to 68 ps^{-1}
rare decays	$B_d \to K^* \gamma$	35 000	$\sigma(A_{CP}{}^{dir}) \approx 0.01$

Figure 4. LHCb physics performance for few selected B decay channels for one year of data taking at $L = 2 \cdot 10^{32} cm^{-2} s^{-1}$

7 Conclusions

The LHCb experiment will be ready for first LHC collisions in 2007. To discover New Physics or to help in the interpretation of New Physics discovered in other experiments a comprehensive study of heavy flavour physics will be needed by this time. This requires high precision measurements of CKM matrix angles: β, γ and χ in as many B decays as possible, also looking at rare decays and mixing.

The LHCb experiment will be able to explore flavour physics with the required sensitivity allowing precise tests of the Standard Model and physics beyond.

References

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