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Direct CP violation at LHCb

R. Cardinale on behalf of the LHCb Collaboration

Abstract

During 2011, LHCb has collected an integrated luminosity of 1.0 fb^{-1} giving rise to a large variety of measurements. Among these, measurements of direct CP violation in B decays play a central role. Three different analyses are presented: the first evidence of CP violation in the B_s^0 system and the observation of CP violation in the B^0 system, using $B^0 \to K\pi$ and $B_s^0 \to \pi K$ decay channels; the evidence of CP violation in $B^\pm \to DK^\pm$ decays with the first observation of the suppressed ADS mode; and a preliminary result showing the evidence of CP asymmetry in charmless three-body charged B decays.

Keywords: LHCb, flavour physics, CP violation, beauty hadrons

1. Charmless two-body decays

The study of charmless two-body decays is of fundamental importance since they are potentially sensitive to new physics beyond the Standard Model. Charmless two-body decays have been extensively studied at the B factories [1, 2] and at the Tevatron [3] where CP violation has been well established in the $B^0 \to K^+\pi^-$ decay channel while for the B_s^0 system, no evidence of CP violation has been found.

The measurements of the direct CP violating asymmetries in $B^0 \to K^+\pi^-$ and $B_s \to K^-\pi^+$ have been performed using data collected with the LHCb detector corresponding to an integrated luminosity of 0.35 fb^{-1} [4].

The direct CP asymmetry in the $B_{(s)}^0$ decay rate to the final state $f_{(s)}$ with $f = K^+\pi^-$ and $f_s = K^-\pi^+$ is defined as:

$$A_{\rm CP} = \Phi[\Gamma(\bar{B}_{(s)}^0 \to \bar{f}_{(s)}), \Gamma(B_{(s)}^0 \to f_{(s)})], \qquad (1)$$

where $\Phi[X, Y] = (X - Y)/(X + Y)$ and $\bar{f}_{(s)}$ is the charge-conjugate state of $f_{(s)}$.

1.1. Selection Procedure

The online selection is based on a hadronic hardware trigger that selects high transverse energy clusters in the calorimeters and on a dedicated two-body software selection imposing requirements on the quality of the reconstructed tracks, their transverse momenta and their impact parameters; the distance of closest approach of the decay products of the B meson candidate, its transverse momentum, its impact parameter and the decay time in its rest frame. Two different sets of offline criteria have been optimized to maximise the sensitivity to the $A_{\rm CP}(B^0 \to K\pi)$ and to the $A_{\rm CP}(B_s^0 \to K\pi)$ measurements. For the B_s^0 decay a tighter selection is needed since the decay rate and the production rate are lower with respect to the B^0. The two selection criteria sets can be found in [4].

The selected candidates are reconstructed under the same pion mass hypothesis and then subdivided into different final states using the Particle Identification information (PID) provided by two RICH detectors. The PID information is a crucial aspect of the analysis. In order to estimate the background from other two-body B decays, a PID calibration procedure has been performed. The PID efficiency and the mis-ID rate have been estimated from data using a calibration sample of $D^{*+} \to D^0(K^-\pi^+)\pi^+$ for pions and kaons and $\Lambda \to p\pi^-$ for protons. The PID information is not used in these calibration samples since the final state can be correctly reconstructed using only kinematic criteria. Since the

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PID performance is momentum dependent, the distributions have been reweighted according to the momentum distribution of the B decay products. The typical PID efficiency for the $A_{\rm CP}(B^0 \to K\pi)$ selection is ~69% and ~38% for the $A_{\rm CP}(B_s^0 \to K\pi)$.

An unbinned maximum likelihood fit has been performed to the selected events (Figure 1). From the mass fits the signal yields and the "raw" asymmetries have been determined.

1.2. Instrumental and production asymmetries

Corrections to the raw asymmetries have been introduced to account for detection and production asymmetries in order to extract the physical asymmetry $A_{\rm CP}$:

$$A_{\rm CP} = A_{\rm raw} - A_\Delta, \tag{2}$$

where A_Δ is the correction factor defined as:

$$A_\Delta = \zeta_{d(s)} A_D(K\pi) + \kappa_{d(s)} A_P(B^0_{(s)}), \tag{3}$$

where A_D is the instrumental asymmetry and A_P is the production asymmetry. The instrumental asymmetry A_D takes into account the effects induced by the different reconstruction and detection efficiencies and different cross sections in the interactions of oppositely charged particle with the detector material. The factors $\zeta_d = 1$ and $\zeta_s = -1$ follow the sign convention for f and f_s defined in Equation 1. The instrumental asymmetries are measured from data using a sample of tagged D^{*+} and untagged two-body D^0 decays. The production asymmetry has been estimated using a sample of $B^0 \to J/\psi K^{*0}$ decays assuming no CP violation. The factor $\kappa_{d(s)}$ takes into account the dilution due to neutral $B^0_{(s)}$ mixing. Since the B^0_s has no valence quark in common with the incoming proton the production asymmetry is expected to be small. Assuming conservatively the same value as for B^0, the effect of $A_P(B^0_s)$ is negligible since κ_s is small due to the fast B^0_s oscillations. Combining the instrumental and production asymmetries, the two correction factor $A_\Delta(B^0 \to K\pi) = (-0.7 \pm 0.6)\%$ and $A_\Delta(B^0_s \to \pi K) = (1.0 \pm 0.2)\%$ have been obtained.

1.3. Systematic Uncertainties

The dominant systematics are linked to the PID calibration procedure, to the modeling of the signal and of the background in the fit procedure and to the instrumental and production asymmetries due to differences in the kinematic properties of B decays with respect to charm control samples, as well as different trigger and offline selections [4].

1.4. Results

Corrected for detection and production asymmetries, the following measurements have been obtained:

$$A_{\rm CP}(B^0 \to K\pi) = -0.088 \pm 0.011_{\rm stat} \pm 0.008_{\rm syst}$$

$$A_{\rm CP}(B^0_s \to \pi K) = 0.27 \pm 0.08_{\rm stat} \pm 0.02_{\rm syst}.$$

The measurement of $A_{\rm CP}(B^0 \to K\pi)$ is in good agreement with the world average, $A_{\rm CP}^{PDG}(B^0 \to K\pi) = -0.097 \pm 0.012$ [5], and it constitutes the most precise measurement available to date. With a significance greater than 6σ, it is the first observation of CP violation in the B meson sector at a hadron collider. The significance for $A_{\rm CP}(B^0_s \to \pi K)$ of 3.3σ makes it the first evidence for CP violation in the decays of B^0_s mesons. The measurement is in good agreement with the only available measurement [3].

2. CP violation in $B^\pm \to DK^\pm$

The $B^\pm \to DK^\pm$ decays allow a theoretically clean extraction of the weak phase γ since they proceed only through tree diagrams. The strategy is to exploit the interference between the $b \to u$ and $b \to c$ transitions. In fact since the amplitude for the $B^- \to D^0K^-$ contribution is proportional to V_{cb} whilst the $B^- \to \bar{D}^0K^-$ amplitude depends on V_{ub}, if the D final state is accessible for both D^0 and $\bar{D}^0$, the interference of these two processes is sensitive to γ and may exhibit direct CP violation. The D final state can be a CP eigenstates: K^+K^- and $\pi^+\pi^-$ (GLW) or the so called ADS modes $D \to \pi^-K^+$. The interesting observables are partial widths and CP asymmetries for a total of 13 observables. There are three ratios of partial widths

$$R^f_{K/\pi} = \frac{\Gamma(B^- \to [f]_D K^-) - \Gamma(B^+ \to [f]_D K^+)}{\Gamma(B^- \to [f]_D \pi^-) - \Gamma(B^+ \to [f]_D \pi^+)}, \tag{4}$$

where f represents KK, $\pi\pi$ and the favoured $K\pi$ mode, six CP asymmetries:

$$A^f_h = \frac{\Gamma(B^- \to [f]_D h^-) - \Gamma(B^+ \to [f]_D h^+)}{\Gamma(B^- \to [f]_D h^-) - \Gamma(B^+ \to [f]_D h^+)}, \tag{5}$$

where h can be a K or a π, and four charge-separated partial widths of the suppressed mode relative to the favoured:

$$R^\pm_h = \frac{\Gamma(B^\pm \to [\pi^\pm K^\mp]_D h^\pm)}{\Gamma(B^\pm \to [K^\pm \pi^\mp]_D h^\pm)}. \tag{6}$$

The measurements of the $B^\pm$ decays in the CP modes $[K^+K^-]_D h^\pm$ and $[\pi^\pm\pi^\mp]_D h^\pm$, the suppressed ADS mode $[\pi^\pm K^\mp]_D h^\pm$ and the favoured mode $[K^\pm\pi^\mp]_D h^\pm$ where h can be a pion or a kaon are presented using $1.0\,{\rm fb}^{-1}$ of data collected by LHCb [6].