Measurements of $A_{CP}(B^0 \to K^+\pi^-)$ and $A_{CP}(B_s \to \pi^+K^-)$ at LHCb

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The LHCb experiment is designed to perform flavour physics measurements at the Large Hadron Collider. Using data collected during the 2010 run, we reconstruct a sample of $H_b \to h^+h'^-$ decays, where H_b can be either a B^0 meson, a B_s^0 meson or a Λ_b baryon, while h and h' stand for π, K or p. We provide preliminary values of the direct CP asymmetries of the neutral B^0 and B_s^0 mesons $A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033\text{(stat.)} \pm 0.008\text{(syst.)}$ and $A_{CP}(B_s^0 \to \pi^+K^-) = 0.15 \pm 0.19\text{(stat.)} \pm 0.02\text{(syst.)}$.

1 Introduction

The family of $H_b \to h^+h'^-$ comprises a large set of decays, namely: $B^0 \to \pi^+\pi^-$, $B^0 \to K^+\pi^-$, $B_s^0 \to K^+K^-$, $B_s^0 \to \pi^+K^-$, $\Lambda_b \to pK^-$, $\Lambda_b \to p\pi^-$, $B^0 \to K^+K^-$, $B_s^0 \to \pi^+\pi^-$ plus their CP-conjugate states. Such decays are matter of great interest, as they are sensitive probes of the Cabibbo-Kobayashi-Maskawa [1,2] matrix and have the potential to reveal the presence of New Physics (NP) [3,4]. NP may alter in a subtle but sizeable way the Standard Model (SM) prediction of the CP asymmetries in these decays. In the following, we will present the preliminary measurements of the direct CP asymmetries in the $B^0 \to K^+\pi^-$ and $B_s^0 \to \pi^+K^-$ decays, obtained using the data collected by LHCb during the 2010 at a centre of mass energy of 7 TeV, corresponding to an integrated luminosity of $\int \mathcal{L}\mathrm{d}t \simeq 37$ pb^{-1}. Such direct CP asymmetries are defined in terms of decay rates of B-hadrons as $A_{CP} = \left[\Gamma\left(\bar{B} \to \bar{f}\right) - \Gamma\left(B \to f\right)\right] / \left[\Gamma\left(\bar{B} \to \bar{f}\right) + \Gamma\left(B \to f\right)\right]$.

2 The LHCb detector

The LHCb detector [5] is a single arm spectrometer in the forward direction. It is composed of a vertex detector around the interaction region, a set of tracking stations in front of and behind a dipole magnet that provides a field integral of 4 Tm, two Ring-Imaging Cherenkov (RICH) detectors, electromagnetic and hadronic calorimeters complemented with pre-shower and scintillating pad detectors, and a set of muon chambers. The two RICH detectors are of particular importance for this analysis, as they provide the particle identification (PID) information needed to disentangle the various $H_b \to h^+h'^-$ final states. They are able to efficiently separate π, K and protons in a momentum range from 2 GeV/c up to and beyond 100 GeV/c. RICH-1 is installed in front of the magnet and uses Areogel and C_4F_{10} as radiators, while RICH-2 is installed behind the magnet and employs CF_4.

3 Events selection

The $H_b \to h^+h'^-$ decays are principally selected by the two-level hadronic trigger of LHCb. The first level (Level 0) is based on custom electronic boards, selecting events with high transverse energy clusters in the hadronic calorimeter. The second level, so called High Level Trigger (HLT), is software-based and selects events with at least one track with high transverse momentum and large impact parameter with respect to all reconstructed primary vertices.

The events used in this analysis are extracted from the triggered data using two different offline selections, each one targeted to achieve the best sensitivity on $A_{CP}(B^0 \to K^+\pi^-)$ and $A_{CP}(B^0_s \to \pi^+K^-)$. The strategy used to optimise the cuts is divided into two steps. In the first step we define the kinematic cuts against the combinatorial background, selecting in an inclusive way the $H_b \to h^+h'^-$ candidates, without using any PID information and assigning by default the pion-mass hypothesis to all charged tracks. The two kinematic selections use the same set of cuts, but with different thresholds. They select pairs of oppositely charged tracks with high transverse momentum and large impact parameter with respect to all reconstructed primary vertices, fitted in a common vertex displaced from the related primary vertex.

In the second step, exploiting the capabilities of the two RICH detectors, two sets of PID cuts are defined (one for each set of optimised kinematic cuts) in order to separate the data into eight mutually exclusive sub-samples corresponding to distinct final state hypothesis ($K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$, K^+K^-, $p\pi^-$, $\bar{p}\pi^+$, pK^- and $\bar{p}K^+$). The guiding principle to identify the PID selection criteria is to limit the total amount of cross-feed backgrounds under the $B^0 \to K^+\pi^-$ and $B^0_s \to \pi^+K^-$ mass peaks to the same level as the corresponding combinatorial background. Such cross-feed backgrounds are due to the other $H_b \to h^+h'^-$ where we mis-identified one or both final state particles.

4 Calibration of particle indentification

The calibration of the PID observables is a crucial aspect of this analysis, as it is the only variable allowing us to discriminate between the various decay modes. Hence, in order to determine the amount of cross-feed backgrounds for a given channel, the relative efficiencies of the PID selection cuts, employed to identify the specific final state of interest, play a key role.

Thanks to the high production rate of D^* mesons at LHC and to the kinematic characteristics of $D^{*+} \to D^0(K^-\pi^+)\pi^+$ decay chain (and its charge conjugate), samples of large statistcs and high purity of π and K can be extracted from these events without any use of PID information. The same consideration holds for protons obtained from $\Lambda \to p\pi^-$ decays.

Since production and decay kinematics of $D^0 \to K^-\pi^+$ and $\Lambda \to p\pi^-$ channels differ from those of $H_b \to h^+h'^-$, the distributions of PID observables are reweighted in momentum p and transverse momentum p_T, in order to match the corresponding distributions of particles from two-body B-hadron decays. The efficiencies for each set of PID cuts are evaluated from the reweighted distributions.

5 Fits to the $H_b \to h^+h'^-$ mass spectra

We perform unbinned maximum likelihood fits to the mass spectra of events passing the optimised offline selections for the measurements of $A_{CP}(B^0 \to K^+\pi^-)$ or $A_{CP}(B^0_s \to K^-\pi^+)$. The fits are performed simultaneously on all the eight categories defined by means of the PID selection criteria. The signals, identified as the channels where both tracks are identified with the right mass hypothesis, are parameterized with a single Gaussian function convolved with a component accounting for final state QED radiation [6]. The combinatorial background is mod-
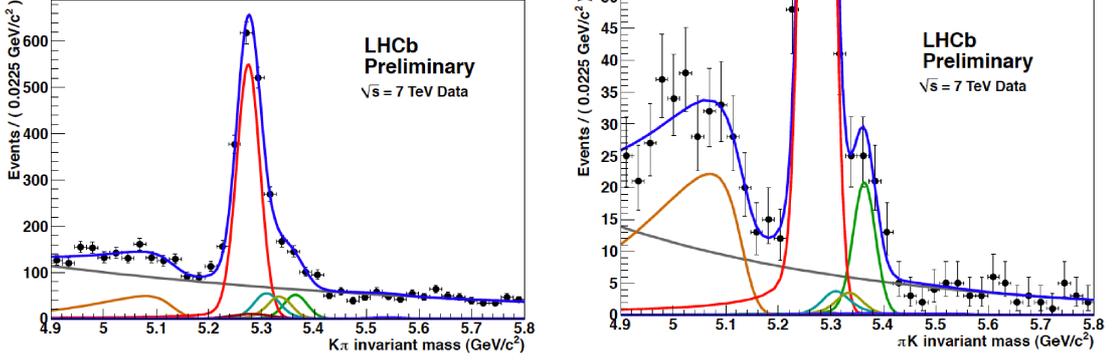
Figure 1: $K^+\pi^-$ (plus charge conjugate) invariant mass spectrum for events surviving the event selection optimised for the best sensitivity on $A_{CP}(B^0 \to K^+\pi^-)$ (left) and $A_{CP}(B^0 \to K^+\pi^-)$ (right). The result of the unbinned maximum likelihood fit is superimposed. The main components contributing to the fit model explained in the text are also visible: $B^0 \to K\pi$ (red), wrong sign $B^0 \to K\pi$ combination (dark red), $B^0 \to \pi^+\pi^-$ (light blue), $B_s^0 \to K^+K^-$ (dark yellow), $B_s^0 \to \pi K$ (green), combinatorial background (grey), 3-body partially reconstructed decays (orange).

eled with an exponential function. The invariant mass shapes of cross-feed backgrounds are parameterized by means of full simulated events, while the normalization of each mis-identified channel is determined multiplying the yield obtained from the right mass hypothesis fit by the ratio between PID efficiencies for the wrong and right final state hypothesis. For the $K^\pm\pi^\mp$ and $\pi^+\pi^-$ categories it is necessary to model also a component due to partially reconstructed 3-body B-hadron decays, while in the other final state categories such a contribution is found to be negligible.

The results of the fits superimposed to the $K^\pm\pi^\mp$ mass spectra (seperately for the samples obtained using the two optimised selections) are shown in Fig. 1. The asymmetries obtained from the fits are respectively: $A_{CP}^{RAW}(B^0 \to K^+\pi^-) = 0.086 \pm 0.033$(stat.) and $A_{CP}^{RAW}(B_s^0 \to K^-\pi^+) = 0.15 \pm 0.19$(stat.). The systematic errors due to the fit model and PID calibration are estimated to be respectively 0.002 and 0.004 for $A_{CP}(B^0 \to K^+\pi^-)$ and 0.021 and 0.001 for $A_{CP}(B_s^0 \to K^+\pi^-)$.

6 Correction to the A_{CP}^{RAW}

The physical $\mathcal{CP}$ asymmetries we want to measure are related to the raw asymmetries obtained from the invariant mass fit by:

$$A_{CP} = A_{CP}^{RAW} - A_D(K\pi) - \kappa A_P \tag{1}$$

where $A_D(K\pi)$ is the detector induced asymmetry in reconstructing $K^+\pi^-$ and $K^-\pi^+$ final states, A_P is the production asymmetry of B mesons and κ is a factor that takes into account the $B - \bar{B}$ oscillation. The production asymmetry is defined in terms of the B and $\bar{B}$ production rates $A_P = (R_{\bar{B}} - R_B)/(R_{\bar{B}} + R_B)$. The κ factor is given by

$$\kappa = \frac{\int (e^{-\Gamma t'} \cos \Delta m t')\varepsilon(t)dt}{\int (e^{-\Gamma t'} \cosh \frac{\Delta\Gamma}{2} t')\varepsilon(t)dt}, \tag{2}$$

where $\varepsilon(t)$ is the acceptance for the decay of interest, as function of the proper decay time t. The detector induced asymmetry $A_D(K\pi)$ is determined using high statistics samples of tagged $D^{*+} \to D^0(K^-\pi^+)\pi^+$, $D^{*+} \to D^0(K^+K^-)\pi^+$ and $D^{*+} \to D^0(\pi^+\pi^-)\pi^+$, and untagged $D^0 \to$

$K^-\pi^+$ decays (plus their charge conjugates). Combining the integrated raw asymmetries obtained from the invariant mass fit of all these decay modes and employing the current world average of the integrated $\mathcal{CP}$ asymmetries for the two modes $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ [8], we determine $A_D(K\pi) = -0.004 \pm 0.004$ (the direct $\mathcal{CP}$ asymmetry of $D^0 \to K^-\pi^+$ is considered negligible).

The production asymmetry A_P is determined by means of a reconstructed sample of $B^\pm \to J/\psi(\mu^+\mu^-)K^\pm$ decays. Correcting the raw asymmetry measured from data by the current world average of the direct $\mathcal{CP}$ asymmetry $A_{CP}(B^+ \to J/\psi K^+) = 0.009 \pm 0.008$ [10], and taking into account the reconstruction asymmetry between K^+ and K^- we measure $A_P(B^+) = -0.024 \pm 0.013$. We assume $A_P(B^+)$ equal to $A_P(B^0)$, but introducing a systematic error of 0.01 to account for possible differences, obtaining $A_P(B^0) = -0.024 \pm 0.013 \pm 0.010$. Such a systematic uncertainty has been determined by studying the predictions of different fragmentation models [7].

For the evaluation of the κ factors, $\varepsilon(t)$ is determined from full simulated events using the selections optimised for the respective $A_{CP}(B^0 \to K^+\pi^-)$ and $A_{CP}(B_s^0 \to K^+\pi^-)$ measurements. The values of the parameters controlling the time evolution of neutral B mesons, namely Γ_d, Γ_s, Δm_d, Δm_s and $\Delta\Gamma_s$, are taken from the current world averages [10], but assuming $\Delta\Gamma_d = 0$. The κ factors, computed respectively for the B^0 and B_s^0, are $\kappa_d = 0.33$ and $\kappa_s = 0.015$. For the case of the $B_s^0 \to K^-\pi^+$ decay, even assuming conservatively $A_P(B_s^0) = A_P(B^0)$, the correction to the $A_{CP}^{RAW}(B_s^0 \to K^-\pi^+)$ results to be negligible.

Using Eq. (1) the central values of the direct $\mathcal{CP}$ asymmetries are $A_{CP}(B^0 \to K^+\pi^-) = -0.074$ and $A_{CP}(B_s^0 \to K^+\pi^-) = 0.15$. The statistical errors of $A_D(K\pi)$ and κA_P are considered as systematic uncertainties contributing to $A_{CP}(B^0 \to K^+\pi^-)$ and $A_{CP}(B_s^0 \to K^+\pi^-)$.

7 Final result

Using data collected by the LHCb detector during the 2010 run we provide preliminary values of the direct CP asymmetries:

$$A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033(\text{stat.}) \pm 0.008(\text{syst.}) \tag{3}$$

$$A_{CP}(B_s^0 \to \pi^+K^-) = 0.15 \pm 0.19(\text{stat.}) \pm 0.02(\text{syst.}). \tag{4}$$

The current HFAG average [9] $A_{CP}(B^0 \to K^+\pi^-) = -0.098^{+0.012}_{-0.11}$ and the CDF measurement [11] $A_{CP}(B_s^0 \to K^-\pi^+) = 0.39 \pm 0.15(\text{stat.}) \pm 0.08(\text{syst.})$ are in agreement with our values.

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