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Recent LHCb results related to the measurement of the CKM phase γ

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Summary. — Using data collected during 2011 at a center-of-mass energy of 7 TeV LHCb selected samples of $B^{\pm} \to Dh^{\pm}$ and $H_b \to h^+h'^-$ decays. Using these samples the measurement of the full set of partial widths and $\mathcal{CP}$ asymmetries of $B^{\pm} \to Dh^{\pm}$ decays has been performed. From the analysis of the selected charmless charged two-body hadronic B decays LHCb measured the direct $\mathcal{CP}$ asymmetries $A_{\mathcal{CP}}(B^0 \to K\pi)$ and $A_{\mathcal{CP}}(B_s^0 \to \pi K)$, the branching ratios $\mathcal{BR}(B^0 \to K^+K^-)$ and $\mathcal{BR}(B_s^0 \to \pi^+\pi^-)$ and the time-dependent $\mathcal{CP}$ asymmetries of $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ decays

PACS 12.15.Hh – Determination of Cabibbo-Kobayashi & Maskawa (CKM) matrix elements.
PACS 13.25.Hw – Decays of bottom mesons.

1. – Introduction

In this paper we present the results obtained by the LHCb experiment based on the reconstruction of $B^{\pm} \to Dh^{\pm}$ decays (where the D signifies a D^0 or $\bar{D}^0$ meson and h can be either a kaon or a pion) and charmless charged two-body hadronic B decays, $H_b \to h^+h'^-$ (where $H_b = B^0, B_s^0, \Lambda_b$ and $h, h' = \pi, K, p$). All the results are obtained analysing data collected during 2011 at a center-of-mass energy of 7 TeV.

The measurement of partial widths and $\mathcal{CP}$ asymmetries of $B^{\pm} \to Dh^{\pm}$ decays presented here (in the cases of D mesons decaying into K^+K^-, $\pi^+\pi^-$, $K^-\pi^+$ and $K^+\pi^-$) is one of the most powerful ways [1, 2] for determining the complex phase γ of the Cabibbo-Kobayashi-Maskawa matrix [3] using tree-level processes. For this analysis the full data sample has been used, corrisponding to an integrated luminosity of $\int \mathcal{L} dt = 1\,\text{fb}^{-1}$. Also $H_b \to h^+h'^-$ decays provide sensitivity to γ and even have potential to reveal New Physics thanks to the presence of loop topologies inside the decay diagrams [4]. Here we present the measurement of the direct $\mathcal{CP}$ asymmetries $A_{\mathcal{CP}}(B^0 \to K\pi)$ and $A_{\mathcal{CP}}(B_s^0 \to \pi K)$ (using $\int \mathcal{L} dt = 0.32\,\text{fb}^{-1}$), the measurement of the branching fractions $\mathcal{BR}(B^0 \to K^+K^-)$ and $\mathcal{BR}(B_s^0 \to \pi^+\pi^-)$ (using $\int \mathcal{L} dt = 0.37\,\text{fb}^{-1}$) and the measurement of the direct and mixing-induced components of time-dependent $\mathcal{CP}$ asymmetries of $B^0 \to \pi^+\pi^-$ ($A^{dir}_{\pi\pi}$ and $A^{mix}_{\pi\pi}$) and $B^0_s \to K^+K^-$ (A^{dir}_{KK} and A^{mix}_{KK}) decays (using $\int \mathcal{L}\mathrm{d}t = 0.69\,\mathrm{fb}^{-1}$).

2. – Analysis strategy

The decays $B^\pm \to Dh^\pm$ and $H_b \to h^+h'^-$ are mainly selected by the two-level hadronic trigger of LHCb [5] that exploits the high transverse momentum and impact parameter with respect to primary vertices typical of B hadron decay products. Two different kinds of offline selections have been used to extract the final samples in the analyses shown in this paper: $B^\pm \to Dh^\pm$ have been discriminated from combinatorial background using a boosted decision tree algorithm, while for $H_b \to h^+h'^-$ a cut based selection has been applied. In both cases different sets of selection criteria have been optimized depending on the measurement of interest.

A crucial point of both analyses is the calibration of the particle identification (PID), needed to discriminate between the various final states and to estimate the relative fractions of correctly identified or mis-identified decays. The two Ring Imaging Cherenkov detectors of LHCb (RICH1 and RICH2) allow to distinguish charged hadrons in a wide momentum range (between few GeV/c up to and beyond 100 GeV/c). The response of these detectors has been calibrated using large and pure samples of pions, kaons and protons selected from $D^{*+} \to D^0(K^-\pi^+)\pi^+$ and $\Lambda \to p\pi^-$ decays (plus their charge conjugates).

In both $B^\pm \to Dh^\pm$ and $H_b \to h^+h'^-$ analyses, direct raw asymmetries and signal yields are obtained from a simultaneous maximum-likelihood fit of all the possible final states. Further details on the fit models can be found in [6-8].

The measurements of $\mathcal{CP}$ asymmetries are affected by two main sources of biases: detection asymmetry and B hadron production asymmetry. The former is mainly due to the different magnitude of the strong interaction of charge conjugate final states (*e.g.* $K^+\pi^-$ and $K^-\pi^+$) with the detector material, and has been studied using D^*-tagged and untagged two-body hadronic D meson decays. The latter is due to the initial quark flavour imbalance in the proton-proton interaction. This has been studied by measuring the charge asymmetry of $B^\pm \to J/\psi K^\pm$ and $B^0 \to J/\psi K^{*0}(K^+\pi^-)$ respectively for charged and neutral B mesons.

In order to measure the time-dependent $\mathcal{CP}$ asymmetries of $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ a central rôle is played by the tagging of the initial flavour of the B meson. By means of a multivariate algorithm the initial flavour of the B meson is determined by analyzing the decay products of the other B hadron in the event. The response of the tagging algorithm is calibrated measuring the oscillation amplitude of the flavour specific decay $B^0 \to K^\pm\pi^\mp$ that results proportional to the effective tagging power. Using the measured effective tagging power as an external input to a two dimensional (invariant mass and decay time) maximum likelihood fit of the K^+K^- and $\pi^+\pi^-$ spectra, the direct and mixing-induced $\mathcal{CP}$ asymmetry terms $A^{dir}_{\pi\pi}$, $A^{mix}_{\pi\pi}$, A^{dir}_{KK} and A^{mix}_{KK} have been measured [9].

3. – Results

Using the full data sample collected during 2011 LHCb measured of 3 partial widths [6]:

$$R^f_{K/\pi} = \frac{\Gamma(B^- \to [f]_D K^-) + \Gamma(B^+ \to [f]_D K^+)}{\Gamma(B^- \to [f]_D \pi^-) + \Gamma(B^+ \to [f]_D \pi^+)}\,, \tag{1}$$

where f represents KK, $\pi\pi$ and the favoured $K\pi$ modes; 6 $\mathcal{CP}$ asymmetries:

$$A_h^f = \frac{\Gamma(B^- \to [f]_D h^-) - \Gamma(B^+ \to [f]_D h^+)}{\Gamma(B^- \to [f]_D h^-) + \Gamma(B^+ \to [f]_D h^+)}\,, \tag{2}$$

and 4 charge-separated partial widths:

$$R_h^{\pm} = \frac{\Gamma(B^{\pm} \to [\pi^{\pm} K^{\mp}]_D h^{\pm})}{\Gamma(B^{\pm} \to [K^{\pm}\pi^{\mp}]_D h^{\pm})}\,. \tag{3}$$

Using such measurements the following quantities sensitive to γ have been computed:

$$R_{\mathcal{CP}+} \approx \left\langle R_{K/\pi}^{KK}, R_{K/\pi}^{\pi\pi} \right\rangle \Big/ R_{K/\pi}^{K\pi} = 1.007 \pm 0.038 \pm 0.012, \tag{4}$$

$$A_{\mathcal{CP}+} = \left\langle A_K^{KK}, A_K^{\pi\pi} \right\rangle = 0.145 \pm 0.032 \pm 0.010, \tag{5}$$

$$R_{ADS(K)} = \left(R_K^- + R_K^+\right)/2 = 0.0152 \pm 0.0020 \pm 0.0004, \tag{6}$$

$$A_{ADS(K)} = \left(R_K^- - R_K^+\right) / \left(R_K^- + R_K^+\right) = -0.52 \pm 0.15 \pm 0.02, \tag{7}$$

$$R_{ADS(\pi)} = \left(R_\pi^- + R_\pi^+\right)/2 = 0.00410 \pm 0.00025 \pm 0.00005, \tag{8}$$

$$A_{ADS(\pi)} = \left(R_\pi^- - R_\pi^+\right) / \left(R_\pi^- + R_\pi^+\right) = 0.143 \pm 0.062 \pm 0.011. \tag{9}$$

Such measurements are the most precise to date and are compatible with previous results [10]. In particular the suppressed mode $B^{\pm} \to [K\pi]_D K^{\pm}$ (with D decaying through the doubly Cabibbo suppressed transition) is observed for the first time with a $\sim 10\sigma$ statistical significance. In addition $A_{ADS(K)}$ and $A_{\mathcal{CP}+}$ show evidence of direct $\mathcal{CP}$ violation with a statistical significance of 4.0σ and 4.5σ respectively. Finally, comparing the maximum likelihood of the fit to that of the non-$\mathcal{CP}$ violation hypothesis, direct $\mathcal{CP}$ violation in $B^{\pm} \to DK^{\pm}$ decays is observed with a 5.8σ statistical significance.

Analyzing $0.32\,\text{fb}^{-1}$ of data collected during 2011 LHCb measured $A_{\mathcal{CP}}\left(B^0 \to K\pi\right) = -0.088 \pm 0.011 \pm 0.008$ and $A_{\mathcal{CP}}(B_s^0 \to \pi K) = 0.27 \pm 0.08 \pm 0.02$ [7]. The former is the most precise measurement ever of this quantity [10] and the latter represents the first evidence of direct $\mathcal{CP}$ violation in the B_s^0 sector with a significance of more that 3σ and is compatible with previous measurements [11].

Using $0.37\,\text{fb}^{-1}$ LHCb observed for the first time the decay $B_s^0 \to \pi^+\pi^-$ with a 5.3σ significance and measured $\mathcal{BR}(B^0 \to K^+K^-) = (0.11^{+0.05}_{-0.04} \pm 0.06) \times 10^{-6}$ and $\mathcal{BR}(B_s^0 \to \pi^+\pi^-) = (0.95^{+0.21}_{-0.17} \pm 0.13) \times 10^{-6}$ (see figs. 1). Values are compatible with previous results [11].

Finally using $0.69\,\text{fb}^{-1}$ of data LHCb measured the time-dependent $\mathcal{CP}$ asymmetries of the $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ decays [9]:

$$A_{\pi\pi}^{dir} = 0.11 \pm 0.21 \pm 0.03, \qquad A_{\pi\pi}^{mix} = -0.56 \pm 0.17 \pm 0.03, \tag{10}$$

$$A_{KK}^{dir} = 0.02 \pm 0.18 \pm 0.04, \qquad A_{KK}^{mix} = 0.17 \pm 0.18 \pm 0.05 \tag{11}$$

with correlations $\rho(A_{\pi\pi}^{dir}, A_{\pi\pi}^{mix}) = -0.34$ and $\rho(A_{KK}^{dir}, A_{KK}^{mix}) = -0.10$. $A_{\pi\pi}^{dir}$ and $A_{\pi\pi}^{mix}$ are compatible with results from the B-Factories [12]; A_{KK}^{dir} and A_{KK}^{mix} are measured for the first time ever and are compatible with theoretical expectations [13].

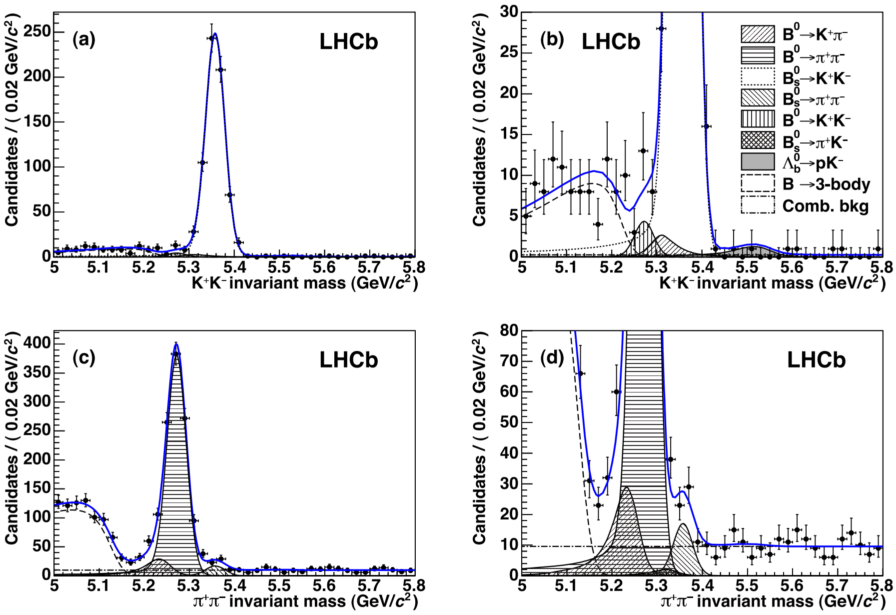

Fig. 1. – Invariant mass spectra for the mass hypotheses (a, b) K^+K^- and (c, d) $\pi^+\pi^-$. Plots (b) and (d) are the same as (a) and (c), respectively, but magnified to focus on the rare $B^0 \to K^+K^-$ and $B_s^0 \to \pi^+\pi^-$ signals. The results of the unbinned maximum-likelihood fits are overlaid. The main components contributing to the fit model are also shown.

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