PROCEEDINGS OF SCIENCE

Time-integrated CP violation measurements in $B \to DD$ and $B \to DKK$ decays at LHCb

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Measurements of CP violation are a core part of the LHCb physics program to over constrain the CKM matrix and to understand the differences between matter and antimatter. The worlds most precise measurement of A_{CP} in $B^- \to D^- D^0$ decays is presented alongside the first measurement of A_{CP} in the $B^- \to D_s^- D^0$ channel. Results from $B^0_{(s)} \to \overline{D}^0 KK$ decays are also shown, including the first observation of the $B^0_s \to \overline{D}^0 KK$ channel and inspections of the Dalitz plots.

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

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PoS(ICHEP2018)347

1. Introduction

Precision measurements of *CP* violation to understand the observed matter-antimatter asymmetry in Universe are a core part of the LHCb physics program. The angle γ of the Cabibbo-Kobayashi-Maskawa (CKM) Unitarity Triangle [1, 2] is one of the least known variables of the system and improving its precision will significantly improve our knowledge and help constrain physics beyond the Standard Model (SM). Its determination in tree-level open-charm b-hadron decays is theoretically clean [3, 4]. Various measurements from LHCb and B factories allow the angle γ to be determined with an uncertainty of around 5°. However, no single measurement dominates the world average and alternative methods are therefore important to improve the precision.

2. First observation of $B_s^0 \to \overline{D}^0 K^+ K^-$

A Dalitz plot analysis of $B_s^0 \to \overline{D}^0 K^+ K^-$ decays can be used to determine γ and the *CP*-violating phase ϕ_s [5]. Moreover, rich resonant structures of the decays are also motivating for charm spectroscopy studies. The search for $B_s^0 \to \overline{D}^0 K^+ K^-$ decay modes has been performed by the LHCb collaboration with the observation of $B^0 \to \overline{D}^0 K^+ K^-$ and evidence for $B_s^0 \to \overline{D}^0 K^+ K^-$ using a data sample corresponding to 0.62 fb^{-1} [6].

An improved measurement using a larger data sample corresponding to an integrated luminosity of 3 fb^{-1} is performed with better control of systematic uncertainties [7]. The invariant-mass distribution of $m_{\overline{D}^0 K^+ K^-}$ with different fit components is shown in Fig. 1. The branching fraction ratio between $B^0 \to \overline{D}^0 K^+ K^-$ and $B^0 \to \overline{D}^0 \pi^+ \pi^-$ is measured to be $(6.9 \pm 0.4 \pm 0.3)\%$ and that between $B_s^0 \to \overline{D}^0 K^+ K^-$ and $B^0 \to \overline{D}^0 K^+ K^-$ to be $(93.0 \pm 8.9 \pm 6.9)\%$. In this proceeding, the experimental uncertainties are presents such that the first uncertainties are statistical, the second systematic and the third, if present, due to the normalization channel. Using the branching fraction $\mathscr{B}(B^0 \to \overline{D}^0 \pi^+ \pi^-) = (8.8 \pm 0.5) \times 10^{-4}$ [8], the branching fractions of the $B^0 \to \overline{D}^0 K^+ K^-$ and $B_s^0 \to \overline{D}^0 K^+ K^-$ decays are measured to be $\mathscr{B}(B^0 \to \overline{D}^0 K^+ K^-) = (6.1 \pm 0.4 \pm 0.3 \pm 0.3) \times 10^{-5}$ and $\mathscr{B}(B_s^0 \to \overline{D}^0 K^+ K^-) = (5.7 \pm 0.5 \pm 0.4 \pm 0.5) \times 10^{-5}$, respectively. The measurement of the branching ratios $\mathscr{B}(B_s^0 \to \overline{D}^0 K^+ K^-)$ is the first step towards a Dalitz plot analysis of these modes using the LHCb Run-1 and Run-2 data sample.

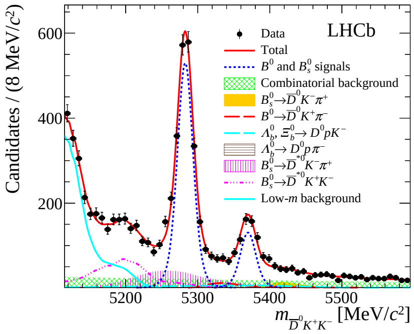

Figure 1: Fit to the $m_{\overline{D}^0 K^+ K^-}$ invariant-mass distribution.

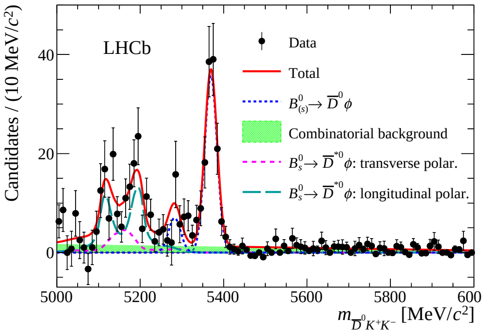

Figure 2: Fit to the $m_{\overline{D}^0 K^+ K^-}$ invariant-mass distribution of $\overline{D}^0 \phi$ candidates obtained using the *sPlot* technique.

3. Studies of the $D^{(*)0}\phi$ system

The decays $B_s^0 \to \overline{D}^{(*)0}\phi$ offer competitive experimental precision on the angle γ where the $\overline{D}^{*0}$ meson can be partially reconstructed. The decay $B_s^0 \to \overline{D}^0\phi$ was first observed by the LHCb collaboration using a data sample corresponding to 1 fb^{-1} [10], while no prior results exist for the $B_s^0 \to \overline{D}^{*0}\phi$ decay. A measurement of the fraction of longitudinal polarization of the $B_s^0 \to \overline{D}^{*0}\phi$ decay is also motivated to constrain QCD models. The $B^0 \to \overline{D}^0\phi$ decay is suppressed by the Okubo-Zweig-Iizuka (OZI) rule and its branching fraction is predicted to be very small. However, it could be enhanced by the ω-ϕ mixing through the $B^0 \to \overline{D}^0\omega$ decay. The observation of this channel has not been claimed yet.

The $D^{(*)0}\phi$ system is studied using the *sPlot* technique to statistically removing non-ϕ contribution using a data sample corresponding to 3 fb^{-1} [9]. The obtained invariant-mass distribution of $\overline{D}^0\phi$ candidates are shown in Fig. 2. The ratio of branching fractions between $B_s^0 \to \overline{D}^0\phi$ and $B^0 \to \overline{D}^0\pi^+\pi^-$ is measured to be $(3.4 \pm 0.4 \pm 0.3)\%$ and $\mathscr{B}(B_s^0 \to \overline{D}^0\phi)$ to be $(3.0 \pm 0.3 \pm 0.2 \pm 0.2) \times 10^{-5}$. The branching fraction is compatible with and more precise than the previous LHCb measurement [10] and supersedes it. The decay $B_s^0 \to \overline{D}^{*0}\phi$ is observed for the first time, with a significance of more than seven standard deviations. The ratio of branching fractions $\mathscr{B}(B_s^0 \to \overline{D}^{*0}\phi)/\mathscr{B}(B_s^0 \to \overline{D}^0\pi^+\pi^-)$ is measured to be $(4.2 \pm 0.5 \pm 0.4)\%$ and the branching fraction $\mathscr{B}(B_s^0 \to \overline{D}^{*0}\phi)$ to be $(3.7 \pm 0.5 \pm 0.3 \pm 0.2) \times 10^{-5}$. The ratio of branching fractions $\mathscr{B}(B_s^0 \to \overline{D}^{*0}\phi)/\mathscr{B}(B_s^0 \to \overline{D}^0\phi)$ is measured to be $1.23 \pm 0.20 \pm 0.08$.

The ratio of branching fractions of $\mathscr{B}(B^0 \to \overline{D}^0\phi)/\mathscr{B}(B^0 \to \overline{D}^0\pi^+\pi^-)$ is measured to be $(1.2 \pm 0.7 \pm 0.4) \times 10^{-3}$ and the branching fraction $\mathscr{B}(B^0 \to \overline{D}^0\phi)$ to be $(1.1 \pm 0.6 \pm 0.3 \pm 0.1) \times 10^{-6}$. The significance for the W-exchange OZI-suppressed decay $B^0 \to \overline{D}^0\phi$ is about two standard deviations. Since there is no significant signal, an upper limit is set as $\mathscr{B}(B^0 \to \overline{D}^0\phi) < 2.0\ (2.3) \times 10^{-6}$ at 90% (95%) confidence level (CL), which improves a factor of six over the previous limit by the BaBar collaboration [11]. The upper limit obtained here is compatible with the theoretical prediction. Further studies with more data are therefore motivated. These results are used to constrain the $\omega - \phi$ mixing angle $|\delta| < 5.2^\circ\ (5.5^\circ)$ at 90% (95%) CL assuming the dominant contribution to the $B^0 \to \overline{D}^0\phi$ decay is through $\omega - \phi$ mixing.

4. Search for B_c^+ mesons decaying to two charmed mesons

Decays of B_c^+ mesons into two charm mesons, $B_c^+ \to D_{(s)}^{(*)}D^{(*)}$ have been proposed to measure the angle γ [13]. Their branching fractions are predicted to be within the range of 10^{-5}–10^{-6} [14]. The large B_c^+ samples collected by the LHCb experiment open possibilities to use these decays to probe γ. Despite the smaller yields, the ratio of amplitudes, $r_{B_c^+} = |A(B_c^+ \to D^0D_s^+)/A(B_c^+ \to \overline{D}^0D_s^+)|$ is around 1, compared to that of $B^+ \to DK^+$ which is around 0.1. This results in a large *CP* asymmetry and thus better sensitivity to γ.

Using a data sample corresponding to 3 fb^{-1}, searches for $B_c^+ \to D_{(s)}^{(*)}D^{(*)}$ decays are performed. For decays with excited $D_{(s)}$ states, the signal candidates are considered without reconstructing the neutral decay products (γ, π^0). No signals are found for these decays and upper limits are set (see Ref. [15] for detailed results on each channel).

5. *CP* violation measurements for $B^- \to D_s^- D^0$ and $B^- \to D^- D^0$ decays

The *CP* asymmetries in decays of B^- meson into two charmed mesons are defined as $A^{CP}(B^- \to D^-_{(s)}D^0) = \frac{\Gamma(B^-\to D^-_{(s)}D^0)-\Gamma(B^+\to D^+_{(s)}\overline{D}^0)}{\Gamma(B^-\to D^-_{(s)}D^0)+\Gamma(B^+\to D^+_{(s)}\overline{D}^0)}$. Nonzero *CP* asymmetries are expected due to interference between tree-level and loop-level amplitudes. In the SM, the values of A_{CP} are expected to be small, with an order of 10^{-2}, however, physics beyond SM can significantly enhance them. Previous measurements of $B^- \to D^- D^0$ decays from the Belle and Babar experiments gave $A^{CP} = (0 \pm 8 \pm 2)\%$ and $A^{CP} = (-13 \pm 14 \pm 2)\%$ respectively. No prior *CP* measurement has been performed for $B^- \to D_s^- D^0$ decay.

Using a data sample corresponding to 3 fb^{-1}, the *CP* asymmetries are measured to be $A^{CP}(B^- \to D_s^- D^0) = (-0.4 \pm 0.5 \pm 0.5)\%$ and $A^{CP}(B^- \to D^- D^0) = (2.3 \pm 2.7 \pm 0.4)\%$ [16]. The uncertainty on the *CP* asymmetry in $B^- \to D^- D^0$ decay has been reduced by more than a factor two with respect to previous measurements and the *CP* asymmetry in $B^- \to D_s^- D^0$ has been measured for the first time. The measurements are consistent with no *CP* violation.

6. Conclusion

CP violation measurements in *B* decays are part of the LHCb core physics program. The LHCb experiment is continuously exploring its potential in the field, especially in the measurements of γ. With the full Run 2 and upgrade statistics the future is very bright for decay modes like these.

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