

B decays to open charm

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Studies of B meson decays to states involving open charm mesons in data recorded by the LHCb experiment have resulted in first observations of several new decay modes, including $B_s^0 \rightarrow D_s^{*\mp} K^\pm$, $B_s^0 \rightarrow \bar{D}^0 K_S^0$ and $B^+ \rightarrow D^+ K^+ \pi^-$ decays. An upper limit has been placed on the branching fraction of $B_s^0 \rightarrow \bar{D}^0 f_0(980)$ decays. Measurements of other branching fractions, such as those of $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$ decays, are the most precise to date. Additionally, amplitude analyses of $B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-$ and $B^0 \rightarrow \bar{D}^0 K^+ \pi^-$ decays have been performed, alongside the first CP violation analysis using the Dalitz plot of $B^0 \rightarrow DK^+ \pi^-$ decays.

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1. Measurement of the $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$ branching fractions

The branching fractions of $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$ decays¹ provide an important contribution to the inclusive branching fraction for $b \rightarrow c\bar{c}s$ quark transitions. Precise measurements of the branching fractions are therefore vital, allowing model-independent searches for physics beyond the Standard Model to be performed [1]. These measurements can also aid the understanding of hadronisation effects in B_s^0 meson decays via the $b \rightarrow c\bar{c}s$ transition. Measurements of the branching fractions have been made using data recorded at LHCb [2], giving the most precise results to date,

$$\begin{aligned}\mathcal{B}(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}) &= (3.05 \pm 0.10 \pm 0.20 \pm 0.34)\%, \\ \mathcal{B}(B_s^0 \rightarrow D_s^{*\pm} D_s^{\mp}) &= (1.35 \pm 0.06 \pm 0.09 \pm 0.15)\% \text{ and} \\ \mathcal{B}(B_s^0 \rightarrow D_s^{*+} D_s^{*-}) &= (1.27 \pm 0.08 \pm 0.10 \pm 0.14)\%,\end{aligned}$$

where the first uncertainties are statistical, the second are systematic and the third arise from the uncertainty on the branching fraction of the normalisation decay $B^0 \rightarrow D_s^+ D^-$.

2. First observation and measurement of the branching fraction for the decay

$$B_s^0 \rightarrow D_s^{*\mp} K^\pm$$

The decay $B_s^0 \rightarrow D_s^{*\mp} K^\pm$ has been observed for the first time, using data collected at the LHCb experiment [3]. Its branching fraction relative to that for $B_s^0 \rightarrow D_s^{*-} \pi^+$ decays has been measured to be $\mathcal{B}(B_s^0 \rightarrow D_s^{*\mp} K^\pm) / \mathcal{B}(B_s^0 \rightarrow D_s^{*-} \pi^+) = 0.068 \pm 0.005_{-0.002}^{+0.003}$, where the first uncertainty is statistical and the second is systematic. The measured value of the branching fraction ratio is consistent with theoretical predictions [4]. In future, $B_s^0 \rightarrow D_s^{*\mp} K^\pm$ decays could be used to measure the weak phase γ .

3. Observation of $B_s^0 \rightarrow \bar{D}^0 K_S^0$ and evidence for $B_s^0 \rightarrow \bar{D}^{*0} K_S^0$ decays

Using data recorded at LHCb, the decay $B_s^0 \rightarrow \bar{D}^0 K_S^0$ has been observed for the first time, and evidence of the decay $B_s^0 \rightarrow \bar{D}^{*0} K_S^0$ has been found [5]. The measured branching fractions are

$$\begin{aligned}\mathcal{B}(B_s^0 \rightarrow \bar{D}^0 \bar{K}^0) &= (4.3 \pm 0.5 \pm 0.3 \pm 0.3 \pm 0.6) \times 10^{-4} \text{ and} \\ \mathcal{B}(B_s^0 \rightarrow \bar{D}^{*0} \bar{K}^0) &= (2.8 \pm 1.0 \pm 0.3 \pm 0.2 \pm 0.4) \times 10^{-4},\end{aligned}$$

where the first uncertainties are statistical, the second are systematic, the third are due to the ratio of fragmentation fractions (f_s/f_d) and the fourth arise from the uncertainty on the branching fraction of the normalisation decay $B^0 \rightarrow \bar{D}^0 K_S^0$. These values are consistent with theoretical predictions [6]. The normalisation decay is itself of interest because it could be used to measure γ [7], while $B_s^0 \rightarrow \bar{D}^{(*)0} K_S^0$ decays offer sensitivity to the B_s^0 meson mixing phase ϕ_s [8].

4. Search for the decay $B_s^0 \rightarrow \bar{D}^0 f_0(980)$

A search for $B_s^0 \rightarrow \bar{D}^0 f_0(980)$ decays has been performed using LHCb data [9]. Measurements of the relative production of scalar mesons in $B_{(s)}^0$ meson decays provide insight into their substructure [10]; $\mathcal{B}(B^0 \rightarrow \bar{D}^0 f_0(980))$ has already been measured [11, 12]. Additionally, $B_s^0 \rightarrow \bar{D}^0 f_0(980)$ decays could be used to measure γ , under the assumption that the $f_0(980)$ meson has a predominant $s\bar{s}$ component [7, 13]. No significant signal is observed in the data, so upper limits on the branching fraction of $\mathcal{B}(B_s^0 \rightarrow \bar{D}^0 f_0(980)) < 3.1(3.4) \times 10^{-6}$ are set at 90% (95%) confidence level.

¹The inclusion of charge conjugate processes is implied throughout this contribution.

5. First observation of the rare $B^+ \rightarrow D^+ K^+ \pi^-$ decay

Using data collected at LHCb, the decay $B^+ \rightarrow D^+ K^+ \pi^-$ has been observed for the first time [14] with a branching fraction of $\mathcal{B}(B^+ \rightarrow D^+ K^+ \pi^-) = (5.31 \pm 0.90 \pm 0.48 \pm 0.35) \times 10^{-6}$, where the uncertainties are statistical, systematic and due to the uncertainty on the branching fraction of the normalisation decay $B^+ \rightarrow D^- K^+ \pi^+$ [15], respectively. Figure 1 shows the corresponding weighted invariant mass distribution for the candidate decays. The Dalitz plot, also shown in Figure 1, appears to be dominated by broad structures; angular distributions are used to search for quasi-two-body contributions from $B^+ \rightarrow D_2^*(2460)^0 K^+$ and $B^+ \rightarrow D^+ K^*(892)^0$ decays, but no significant signals are seen and upper limits are therefore set on their branching fractions. In future, decays of the type $B^+ \rightarrow D^{**} K^+$, where D^{**} represents an excited state such as $D_2^*(2460)^0$ that can decay to both $D^\pm \pi^\mp$ and $D\pi^0$, could be used to measure γ [16]².

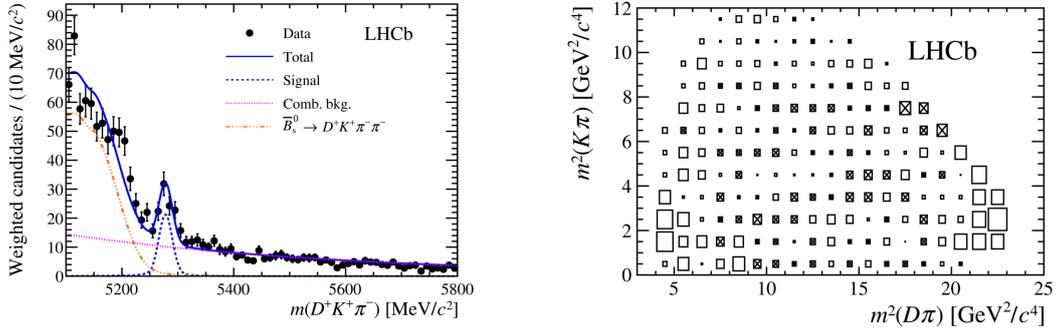


Figure 1: Weighted invariant mass distribution (left) and background-subtracted Dalitz plot distribution (right) of candidate $B^+ \rightarrow D^+ K^+ \pi^-$ decays [14]. Areas of boxes in the Dalitz plot are proportional to signal yields.

6. Dalitz plot analysis of $B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-$ decays

An amplitude analysis of the decay $B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-$ has been performed using LHCb data [12]. In the phase-space region $m(\bar{D}^0 \pi^\pm) > 2.1 \text{ GeV}/c^2$, the branching fraction of the decay is measured to be $\mathcal{B}(B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-) = (8.46 \pm 0.14 \pm 0.29 \pm 0.40) \times 10^{-4}$, where the first uncertainty is statistical, the second is systematic and the third arises from the uncertainty on the branching fraction of the normalisation decay $B^0 \rightarrow D^*(2010)^- \pi^+$. The Dalitz plot, shown in Figure 2, is analysed using a model with four components for $\bar{D}^0 \pi^-$ resonances, four P-wave $\pi^+ \pi^-$ resonances, one D-wave $\pi^+ \pi^-$ resonance and two alternative model contributions for the $\pi^+ \pi^-$ S-wave components. The complex coefficients and fit fractions for the components of the model are determined from the data. The presence of a resonant structure is confirmed at $m(\bar{D}^0 \pi^-) \approx 2.8 \text{ GeV}/c^2$, with its spin-parity of $J^P = 3^-$ established for the first time; the branching fractions, masses and widths of this resonant structure and the $D_0^*(2400)^-$ and $D_2^*(2460)^-$ resonances are determined. The branching fractions of $B^0 \rightarrow \bar{D}^0 h^0 (\rightarrow \pi^+ \pi^-)$ decays are also measured, many with the highest precision to date, and several decays are observed for the first time. As well as studying the rich resonant structure of the $B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-$ decay, the amplitude analysis is an initial step towards a measurement of the CKM angle β [17]. Furthermore, $B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-$ decays offer sensitivity to physics beyond the Standard Model [18].

²Here, and in Section 8, D denotes a superposition of the D^0 and \bar{D}^0 states decaying to the same final state (in Section 5, specifically a CP eigenstate).

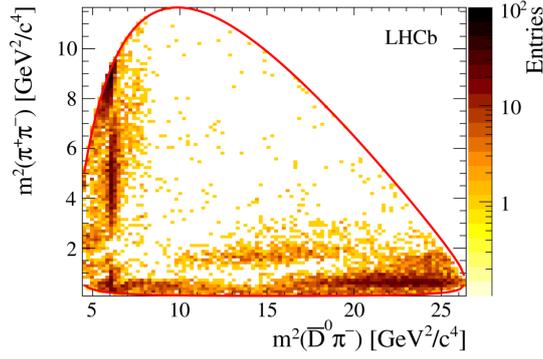


Figure 2: Dalitz plot distribution of candidate $B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-$ decays [12]. The red line indicates the kinematic boundary of the Dalitz plot.

7. Amplitude analysis of $B^0 \rightarrow \bar{D}^0 K^+ \pi^-$ decays

An amplitude analysis of $B^0 \rightarrow \bar{D}^0 K^+ \pi^-$ decays in LHCb data has also been performed [19]. The Dalitz plot is analysed using an amplitude model with components for $K^*(892)^0$, $K^*(1410)^0$, $K_2^*(1430)^0$ and $D_2^*(2460)^-$ resonances, a $K\pi$ S-wave component, and $D\pi$ S- and P-wave components. The masses and widths of the $D_0^*(2400)^-$ and $D_2^*(2460)^-$ resonances are measured and are found to be consistent with those determined in the analysis of $B^0 \rightarrow \bar{D}^0 \pi^+ \pi^-$ decays described in Section 6; the complex amplitudes and fit fractions for all amplitude model components are also determined.

8. Constraints on the unitarity triangle angle γ from Dalitz plot analysis of $B^0 \rightarrow DK^+ \pi^-$ decays

Using an amplitude model derived from the results of Ref. [19], described in Section 7, the first CP violation analysis using the Dalitz plot of $B^0 \rightarrow D(\rightarrow K^+ \pi^-, K^+ K^-, \pi^+ \pi^-) K^+ \pi^-$ decays to measure γ [20] has been performed with data recorded at LHCb [21]. Due to the ability to exploit interference between different contributions to the decay, this method obtains additional sensitivity compared to the quasi-two-body analysis, where only the $K^*(892)^0$ resonance region of the Dalitz plot is used. No significant CP violation effect is observed; constraints are placed on γ using the $B^0 \rightarrow DK^*(892)^0$ contribution to the decay, with no value of γ excluded at 95% confidence level, as shown in Figure 3. Hadronic parameters required to determine γ from quasi-two-body analyses of $B^0 \rightarrow DK^*(892)^0$ decays are also measured. These measurements provide important input to the determination of γ from a combination of $B \rightarrow DK$ analyses using LHCb data [22].

9. Conclusions and prospects

Many recent studies of B meson decays to open charm have been performed using data recorded by the LHCb experiment, resulting in first observations of several decay modes and world-best measurements of others. There are also excellent prospects for the future use of some of these decays for CP violation measurements, including measurements of the CKM angles γ and β . Studies of further decay modes and analysis updates to include new data collected at the LHCb experiment will provide additional and improved measurements in the near future.

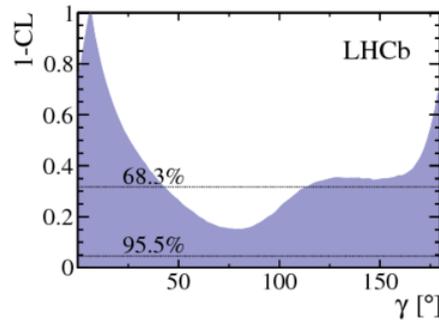


Figure 3: Constraints on γ from the $B^0 \rightarrow DK^*(892)^0$ contribution to $B^0 \rightarrow DK^+\pi^-$ decays [21].

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