

Charmless B decays at the LHCb experiment

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Abstract. Recent measurements of charmless B meson decays using proton-proton collision data collected by the LHCb experiment are presented here. Branching fraction measurements of the $B_{d,s}^0 \rightarrow K^{*\pm} K^\mp$ decays have been made, as well as measurements of CP asymmetry in both the $B^\pm \rightarrow h^\pm h^+ h^-$ and $B^\pm \rightarrow h^\pm p \bar{p}$ decays. In addition, the forward-backward asymmetry in the $B^\pm \rightarrow h^\pm p \bar{p}$ decays was measured.

1. Introduction

One of the most important areas in quark flavour physics is the study of the so-called “charmless” B meson decays. These are decays of B mesons to hadronic final states which do not contain charm quarks or antiquarks. As shown in Fig. 1, these decays will in general have contributions from both “tree” and “loop” diagrams. When there is a phase difference between the CP even (“strong”) and CP odd (“weak”) phases of the contributing diagrams, CP violation may occur.

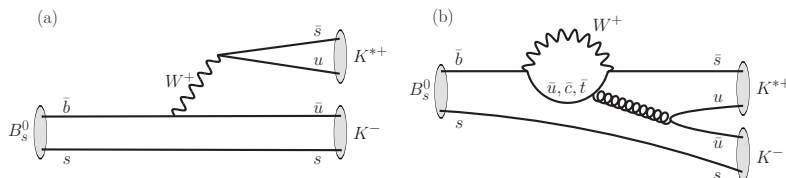


Figure 1: (a) Tree and (b) loop diagrams for the decay $B_s^0 \rightarrow K^{*+} K^-$.

It is possible that beyond Standard Model (SM) particles could participate in the loop contribution, causing a deviation from the SM expectation of branching fractions or CP asymmetry. For decays containing three or more final state particles, a Dalitz plot analysis [1] allows the study of the weak and strong phases and the variation of the CP asymmetries across the phase space of the decay.

The analyses presented here are based on two data samples recorded at the LHCb detector at CERN [2]. The 2011 data sample corresponding to an integrated luminosity of 1.0 fb^{-1} of proton-proton collisions at a centre-of-mass energy of 7 TeV, and the 2012 data sample with an integrated luminosity of 2.0 fb^{-1} at 8 TeV.

2. $B_{d,s}^0 \rightarrow K^{*\pm} h^\mp$ branching fractions [3]

Previous measurements have been made at LHCb of the inclusive branching fractions of $B_{d,s}^0 \rightarrow K_s^0 h^\pm h'^\mp$ decays [4]. The $B_{d,s}^0 \rightarrow K^{*\pm} h^\mp$ decays are intermediate resonances of the

$B_{d,s}^0 \rightarrow K_s^0 h^\pm h'^\mp$ ones, where the $K^{*\pm}$ decays to a K_s^0 and a π^\pm . This analysis aimed to measure the branching fractions of the three unobserved $B_{d,s}^0 \rightarrow K^{*\pm} h^\mp$ modes with respect to the previously measured $B^0 \rightarrow K^{*+} \pi^-$ normalisation mode.

Using the 2011 data sample $B_{d,s}^0 \rightarrow K^{*\pm} h^\mp$ events were selected using a method based on the $B_{d,s}^0 \rightarrow K_s^0 h^\pm h'^\mp$ analysis. Each B candidate was formed from three tracks, a K_s^0 candidate and two charged tracks. The K_s^0 candidates were reconstructed by combining $\pi^+ \pi^-$ tracks and assigning them (and the B candidate they form) one of two categories, “long” and “downstream”. Long K_s^0 candidates come from pion tracks which have hits in both the VELO subdetector [5] and the tracking systems downstream of the magnet. Downstream candidates do not have tracks in the VELO and consequently have worse mass, momentum and vertex resolution. Due to this there were slightly different selection requirements on the long and downstream candidates, and until the final calculation of branching fractions the analyses of the two categories were completely separate.

To extract the yields of the different decays separate 2D fits for the $B_{d,s}^0 \rightarrow K^{*\pm} K^\mp$ and $B_{d,s}^0 \rightarrow K^{*\pm} \pi^\mp$ final state were created. These fits used the m_B and $m_{K_s^0 \pi}$ mass combination variables and fit simultaneously between the two K_s^0 categories. Figs. 2-3 show the results of these fits.

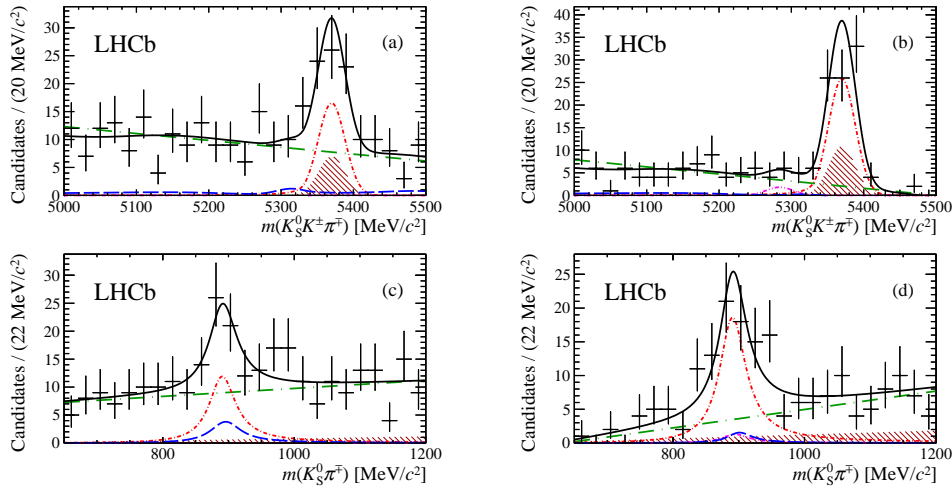


Figure 2: Results of the fit to $K^{*\pm} K^\mp$ candidates projected onto (a,b) B candidate and (c,d) K^* candidate mass distributions, for (a,c) long and (b,d) downstream candidates. The total fit result (solid black line) is shown together with the data points and multiple background components.

The total significances of the $B_s^0 \rightarrow K^{*\pm} K^\mp$ and $B_s^0 \rightarrow K^{*-} \pi^+$ yields were 7.8σ and 3.4σ respectively, the first observation and evidence for these decays. While the significance of the $B^0 \rightarrow K^{*\pm} K^\mp$ was below 2σ . The yields were used to find the branching fractions relative to the $B^0 \rightarrow K^{*+} \pi^-$ mode. Multiplying the relative branching fractions by the world average $\mathcal{B}(B^0 \rightarrow K^{*+} \pi^-) = (8.5 \pm 0.7) \times 10^{-6}$ [6] gave the absolute branching fractions and limits

$$\begin{aligned}
 \mathcal{B}(B_s^0 \rightarrow K^{*\pm} K^\mp) &= (12.7 \pm 1.9(\text{stat}) \pm 1.9(\text{syst})) \times 10^{-6}, \\
 \mathcal{B}(B^0 \rightarrow K^{*\pm} K^\mp) &= (0.17 \pm 0.15(\text{stat}) \pm 0.05(\text{syst})) \times 10^{-6}, \\
 &< 0.4 (0.5) \times 10^{-6} \text{ at } 90\% (95\%) \text{ CL}, \\
 \mathcal{B}(B_s^0 \rightarrow K^{*-} \pi^+) &= (3.3 \pm 1.1(\text{stat}) \pm 0.5(\text{syst})) \times 10^{-6}.
 \end{aligned}$$

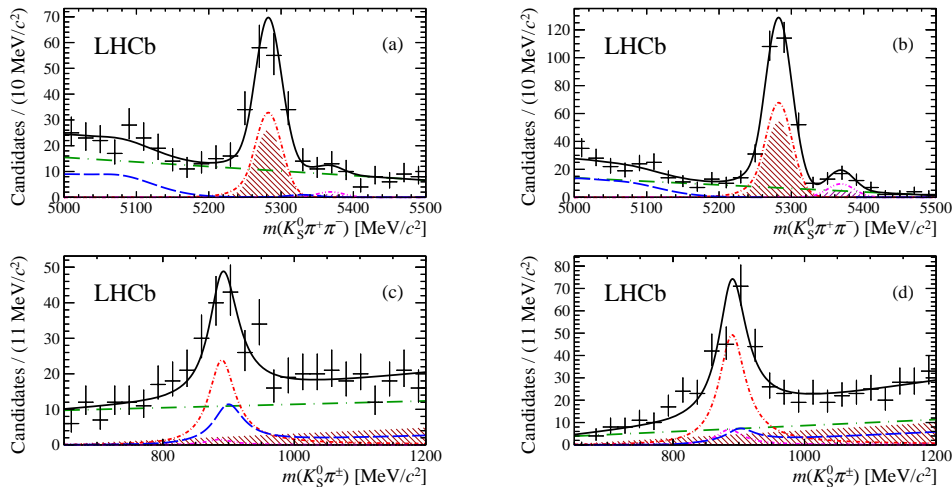


Figure 3: Results of the fit to $K^{*\pm}\pi^\mp$ candidates projected onto (a,b) B candidate and (c,d) K^* candidate mass distributions, for (a,c) long and (b,d) downstream candidates. The total fit result (black solid line) is shown together with the data points and multiple background components.

3. $B^\pm \rightarrow h^\pm h^+ h^-$ CP asymmetries [7]

This analysis supersedes those of Ref. [8] and Ref. [9] using the full data sample of 2011 and 2012 and an updated selection of events. The inclusive CP asymmetries were measured for all four $B^\pm \rightarrow h^\pm h^+ h^-$ decay modes. Raw asymmetries between the B^+ and B^- candidates were extracted from fits to the mass spectra of the selected B candidates. These were then corrected by the detector and production asymmetries to find the final CP asymmetry (\mathcal{A}^{CP}) using

$$\mathcal{A}^{\text{CP}} = \mathcal{A}^{\text{raw}} - \mathcal{A}^{\text{D}}(h) - \mathcal{A}^{\text{P}}(B^\pm). \quad (1)$$

The production asymmetry, $\mathcal{A}^{\text{P}}(B^\pm)$, was calculated from $B^\pm \rightarrow J/\psi K^\pm$ decays and the world average of $\mathcal{A}^{\text{CP}}(B^\pm \rightarrow J/\psi K^\pm)$. The detector asymmetries are different for the $B^\pm \rightarrow K^\pm h^+ h^-$ and $B^\pm \rightarrow \pi^\pm h^+ h^-$ modes. The $\mathcal{A}^{\text{D}}(\pi)$ has been previously measured [10] and the value of $\mathcal{A}^{\text{D}}(K)$ was determined from $D^{*+} \rightarrow \pi^+ D^0$ decays.

The final values and significances for the inclusive CP asymmetries were

$$\begin{aligned} \mathcal{A}^{\text{CP}}(B^\pm \rightarrow K^\pm \pi^+ \pi^-) &= +0.025 \pm 0.004 \pm 0.004 \pm 0.007 \quad (2.8\sigma), \\ \mathcal{A}^{\text{CP}}(B^\pm \rightarrow K^\pm K^+ K^-) &= -0.036 \pm 0.004 \pm 0.002 \pm 0.007 \quad (4.3\sigma), \\ \mathcal{A}^{\text{CP}}(B^\pm \rightarrow \pi^\pm \pi^+ \pi^-) &= +0.058 \pm 0.008 \pm 0.009 \pm 0.007 \quad (4.2\sigma), \\ \mathcal{A}^{\text{CP}}(B^\pm \rightarrow \pi^\pm K^+ K^-) &= -0.123 \pm 0.017 \pm 0.012 \pm 0.007 \quad (5.6\sigma), \end{aligned}$$

where the first uncertainty is statistical, the second systematic and the third is from the uncertainty on $\mathcal{A}^{\text{CP}}(B^\pm \rightarrow J/\psi K^\pm)$.

An investigation was also performed into the CP asymmetries in different regions of the Dalitz plot. Specifically in the mass regions where $KK \leftrightarrow \pi\pi$ rescattering and intermediate resonances are favoured. The results suggested that both rescattering and interference between the P-wave and S-wave contributions around the $\rho^0(770)$ could be important sources to the strong phase difference in these decays. However, a full Dalitz plot amplitude analysis is required to gain a full understanding of these results.

4. $B^\pm \rightarrow h^\pm p\bar{p}$ asymmetries [11]

This analysis is an update to Ref. [12] with the full data sample, focused on the $B^\pm \rightarrow h^\pm p\bar{p}$ decays. These are similar to the previous $B^\pm \rightarrow h^\pm h^+ h^-$ decays but with a proton-antiproton

pair rather than a $\pi^+\pi^-$ or KK pair in the final state.

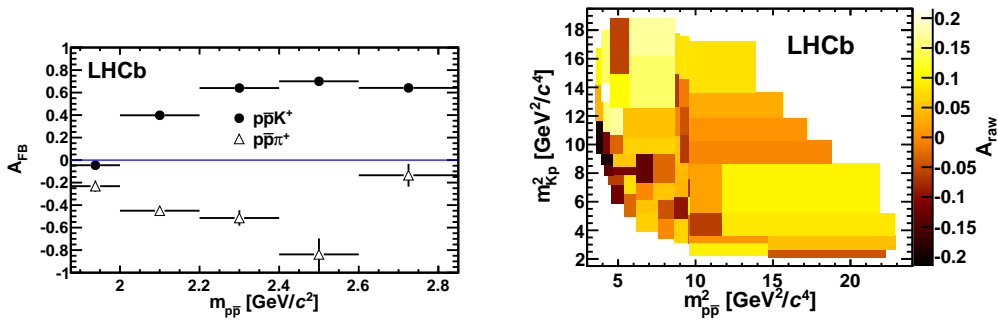
The first measurement was of the forward-backward asymmetry in the $m_{p\bar{p}} < 2.85 \text{ GeV}/c^2$ region of the Dalitz plot. The forward-backward asymmetry is defined as

$$\mathcal{A}^{\text{FB}} = \frac{N_{\text{pos}} - N_{\text{neg}}}{N_{\text{pos}} + N_{\text{neg}}}, \quad (2)$$

where N_{pos} and N_{neg} are the efficiency corrected yields for the $\cos\theta_p > 0$ and $\cos\theta_p < 0$ regions respectively. Here θ_p is the angle between the charged meson and the oppositely charged baryon in the rest frame of the $p\bar{p}$ system. The obtained values of \mathcal{A}^{FB} for both decay modes were

$$\begin{aligned} \mathcal{A}^{\text{FB}}(B^\pm \rightarrow K^\pm p\bar{p}) &= +0.495 \pm 0.012(\text{stat}) \pm 0.007(\text{syst}), \\ \mathcal{A}^{\text{FB}}(B^\pm \rightarrow \pi^\pm p\bar{p}) &= -0.409 \pm 0.033(\text{stat}) \pm 0.006(\text{syst}). \end{aligned}$$

Additionally, Fig. 4a shows the dependence of \mathcal{A}^{FB} on $m_{p\bar{p}}$. These results indicate a strong dependence on $m_{p\bar{p}}$ and a sign flip between the kaon and pion decay modes.



(a) Forward-backward asymmetry in bins of $m_{p\bar{p}}$ for $B^\pm \rightarrow K^\pm p\bar{p}$ and $B^\pm \rightarrow \pi^\pm p\bar{p}$ decays. The data points are shown with their total uncertainties.

(b) Asymmetries of the number of signal events in bins of the Dalitz plot variables for $B^\pm \rightarrow K^\pm p\bar{p}$. The number of events in each bin is approximately 300.

The \mathcal{A}^{CP} was also measured for various regions of the Dalitz plot for the $B^\pm \rightarrow K^\pm p\bar{p}$ decay mode. The method to obtain \mathcal{A}^{CP} was very similar to that of the $B^\pm \rightarrow h^\pm h^+ h^-$ analysis above and the raw asymmetries across the Dalitz plot can be seen in Fig. 4b. A positive \mathcal{A}^{CP} of nearly 4σ was found in the region $m_{p\bar{p}} < 2.85 \text{ GeV}/c^2$, $m_{Kp}^2 > 10 \text{ GeV}^2/c^4$ with a value of $0.096 \pm 0.024(\text{stat}) \pm 0.004(\text{syst})$. This is the first evidence of CP violation in B decays with baryons in the final state.

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