PROCEEDINGS OF SCIENCE

Measurements of *CP* violation in charmless 3-body B-meson decays at LHCb

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Charmless 3-body B-meson decays can present significant *CP* asymmetries. Large raw charge asymmetries were observed in $B^+ \to \pi^+ K^+ K^-$ and $B^+ \to \pi^+ \pi^+ \pi^-$ decays by the LHCb collaboration. The most recent results from LHCb are discussed here. They include amplitude analyses of $B^+ \to \pi^+ K^+ K^-$ and $B^+ \to \pi^+ \pi^+ \pi^-$ decays. The study of $B^+ \to \pi^+ K^+ K^-$ reported a large *CP* asymmetry arising from the S-wave. In the case of the $B^+ \to \pi^+ \pi^+ \pi^-$ decay analysis, the first observation of *CP* violation in a process involving a tensor was made.

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1. Introduction

In charmless 3-body B-meson decays, large *CP* asymmetries can occur due to interference between contributions to a single amplitude from penguin and tree diagrams with comparable magnitudes. The LHCb collaboration observed large raw charge asymmetries in $B^+ \to \pi^+ K^+ K^-$ and $B^+ \to \pi^+\pi^+\pi^-$ decays[1] [1], providing a strong motivation to perform amplitude analyses for both $B^+ \to \pi^+ K^+ K^-$ [2] and $B^+ \to \pi^+\pi^+\pi^-$ [3, 4]. These two decays are coupled through the rescattering process $\pi\pi \leftrightarrow KK$. Rescattering allows decays via one channel (e.g. $B \to X\pi^+\pi^-$) to appear as a second, coupled final state (e.g. XK^+K^-). Both of the amplitude analyses have been performed with the Run 1 data sample, corresponding to $3\,\text{fb}^{-1}$ of pp collisions at $\sqrt{s} = 7, 8\,\text{TeV}$ collected by LHCb. One way to describe the effect of interfering amplitudes is based on the isobar model [5, 6]. In this formalism, the overall amplitude is described as a sum of individual contributions with index j, each of which is the product of two terms:

$$A^{\pm}(m_{13}^2, m_{23}^2) = \sum_j^N c_j^{\pm} F_j(m_{13}^2, m_{23}^2), \tag{1}$$

where A^+ and A^- are the amplitudes for B^+ and B^- at a given point in phase space, and $c_j^{\pm}$ is constant over the phase space (the Dalitz plot) and are the free parameters of the model. m_{ab}^2 is the squared invariant mass of particle a and b. $F_j(m_{13}^2, m_{23}^2)$ is a form factor given by

$$F_j(m_{13}^2, m_{23}^2) = R(m_{13}) \times T(\vec{p}, \vec{q}) \times X(|\vec{p}| r_{BW}^P) \times X(|\vec{q}| r_{BW}^R),$$

and is the product of a mass line-shape R (e.g. a Breit-Wigner), an angular dependence T, and the barrier factors X, and does not distinguish between B^+ and B^-. *CP* violation occurs if $c_j^+ \neq c_j^-$ for any of the components.

2. Amplitude analysis of $B^+ \to \pi^+ K^+ K^-$ decays

The isobar model (Eq. 1) is used to describe the charmless three-body decay $B^{\pm} \to \pi^{\pm} K^+ K^-$. The resulting amplitude provides a good description of the data (Fig. 1). To describe the $\pi^+ K^-$ system, the model includes three contributions. They consist of the $K^*(892)^0$ and $K_0^*(1430)^0$ resonances, plus a nonresonant with a single-pole form factor [7] providing a phenomenological description of the partonic interaction. The nonresonant term is the single largest contribution to the amplitude, with a fit fraction of about 32% [2]. Four contributions are used to describe the K^+K^- system, namely three resonances—$\rho(1450)^0$, $f_2(1270)$ and $\phi(1020)$—and a rescattering amplitude. The latter has yielded a *CP* asymmetry of $(-66 \pm 4 \pm 2)\%$ [2], the largest such asymmetry observed for a single contribution in an amplitude analysis.

3. Amplitude analysis of $B^+ \to \pi^+\pi^+\pi^-$ decays

While the isobar formalism is conceptually simple and has been used successfully in numerous past studies, it has some known limitations, particularly when describing multiple overlapping

[1]Charge-conjugate processes are included implicitly.

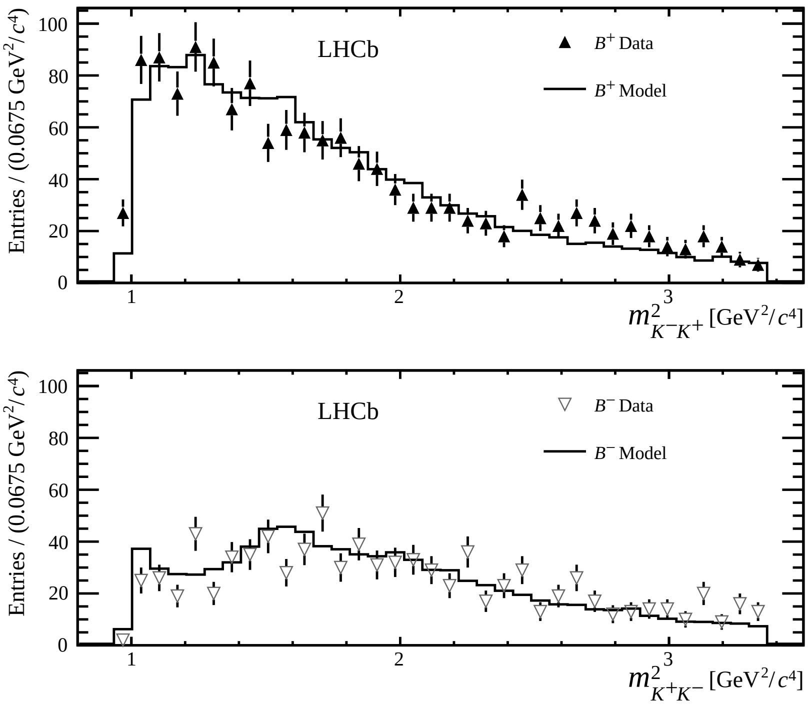

Figure 1: Distribution of $m^2_{K^+K^-}$ up to 3.5 GeV^2/c^4. Data are represented by points for B^+ and B^- separately, with the result of the fit overlaid [2].

contributions (in which case it can violate unitarity). This is a particular concern for the $\pi^+\pi^-$ S-wave component. Therefore, to complement the result, this component was described with three different approaches: the isobar model, the K-matrix formalism [8–10] and a quasi-model-independent (QMI) procedure [11–16]. The fits obtained with all three approaches are in good agreement with the data and with each other (Fig. 2). In the fits, it is found that the $\rho(770)^0$ resonance has a *CP* asymmetry compatible with 0. By contrast, significant *CP* violation was observed in the interference between the $\rho(770)^0$ P-wave and the S-wave contribution. All three approaches gave a good description of this effect, which marks the first time that *CP* violation in an amplitude analysis has been observed originating purely in the interference between two components (as opposed to asymmetries in the components themselves). In addition, a clear *CP* asymmetry, around 15% [3, 4], which is not associated with the interference process described above, is seen below the K^+K^- threshold. The $f_2(1270)$ resonance also exhibited significant *CP* violation of about 40% [3, 4]; this is the first time that *CP* violation linked to a tensor tensor has been reported.

4. Conclusion

Challenging amplitude analyses were performed to better understand the *CP* violation observed in $B^+ \to \pi^+K^+K^-$ and $B^+ \to \pi^+\pi^+\pi^-$ decays. In the $B^+ \to \pi^+K^+K^-$ amplitude analysis, large *CP* violation was observed in the S-wave contribution. This is consistent with what is observed

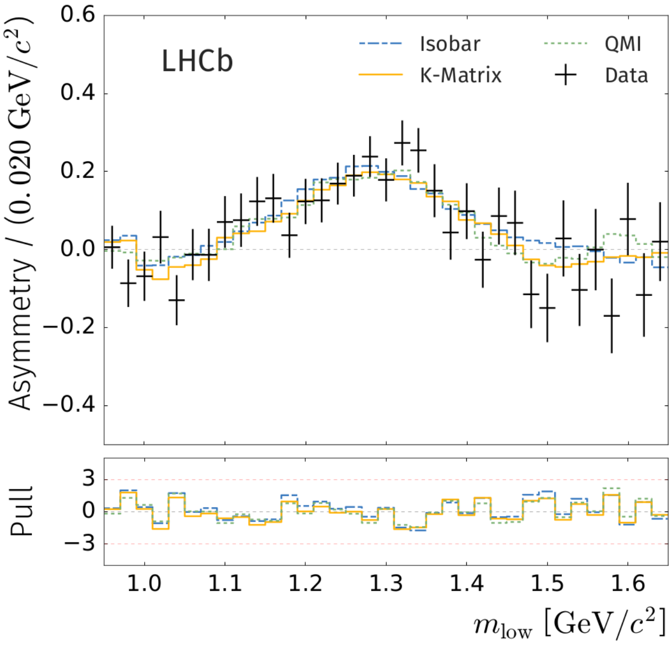

Figure 2: Fitted asymmetry projected on m_{low}, the lower of the two $\pi^+\pi^-$ invariant masses, in the region around the $f_2(1270)$ resonance [3, 4].

in the coupled channel $B^+ \to \pi^+\pi^+\pi^-$. In the $B^+ \to \pi^+\pi^+\pi^-$ amplitude analysis, consistent descriptions of the S-wave contribution were obtained with three different frameworks. Significant *CP* violation was observed in the S-wave component, and in the interference between the S- and P-wave components. For the first time, *CP* violation was observed in a process involving a tensor.

Further, exciting results can be expected for these and other multi-body charmless b-hadron decays with the addition of the Run 2 data sample (which has both an integrated luminosity and a b-hadron production cross-section two times larger). The upgraded LHCb detector will collect data with even greater luminosity and efficiency from Run 3.

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