PROCEEDINGS OF SCIENCE

CP violation in charmless 2-body B-meson decays at LHCb

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Charmless 2-body B-meson decays can present large *CP* asymmetries. The study of *CP* violation in the decay $B^+ \to K^+\pi^0$ can help to better understand the $K\pi$-puzzle. We report here the latest LHCb measurement of the direct *CP* asymmetry, which is the most precise as for now. Observation of *CP* violation in 2-body $B^0_{(s)}$-meson decays to charged pions and kaons can help constraining the CKM unitarity triangle. The study of these observables in LHCb, presented here, results in the first observation of time-dependent *CP* asymmetry in a B^0_s-meson decay.

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1. Introduction

In charmless 2-body B-meson decays, large *CP* asymmetries can occur due to the interference between the tree and loop amplitudes. We should note that the contribution from the latter gives sensitivity to new physics. Recent measurements performed by the b-factories have brought possible hints for new physics in charmless 2-body $B \to K\pi$ decays. It is known as the $K\pi$-puzzle [1–4].

The $B \to K\pi$ decays obey isospin relations [1–10]. The *CP* asymmetry is expected to be comparable in these decays. Though, the recent study of the $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$ *CP* asymmetries has shown inconsistencies with what is expected. Indeed, the difference between $A_{CP}(B^+ \to K^+\pi^0) = 0.040 \pm 0.021$ [11] and $A_{CP}(B^0 \to K^+\pi^-) = -0.084 \pm 0.004$ [11] is non-zero with a 5.5σ significance. Hence, $B \to K\pi$ decay studies are necessary to further investigate the $K\pi$-puzzle.

Measurements of *CP* violation in charmless 2-body $B \to \pi\pi$ decays participate in constraining the CKM angle α [12–14]. The *CP* violation and the branching fraction of $B \to KK$ decays can help constraining $-2\beta_s$ and γ [15, 16]. *CP* asymmetry can arise from the interference between at least 2 diagrams contributing to the amplitude of a decay. We then talk about direct *CP* asymmetry. It is measured as the difference between the rate $\Gamma(A_f)$ of a decay and the rate $\Gamma(\bar{A}_{\bar{f}})$ of its charged conjugate, normalised by their sum:

$$A_{CP} = \frac{\Gamma(A_f) - \Gamma(\bar{A}_{\bar{f}})}{\Gamma(A_f) + \Gamma(\bar{A}_{\bar{f}})}, \tag{1}$$

where A_f denotes the $A \to f$ decay and $\bar{A}_{\bar{f}}$ denotes the $\bar{A} \to \bar{f}$ decay. This type of *CP* violation concerns both charged and neutral B-meson decays.

B^0- and B^0_s-mesons, due to their oscillation, can also present time-dependent *CP* asymmetry, when the final state is accessible to both the B-meson and its charge conjugate. We then have

$$A_{CP}(t) = \frac{\Gamma(A_f)(t) - \Gamma(\bar{A}_f)(t)}{\Gamma(A_f)(t) + \Gamma(\bar{A}_f)(t)} = \frac{-C_f \cos(\Delta m_{d(s)t}) + S_f \sin(\Delta m_{d(s)t})}{\cosh(\frac{\Delta\Gamma_{d(s)}}{2}t) + A_f^{\Delta\Gamma} \sinh(\frac{\Delta\Gamma_{d(s)}}{2}t)}. \tag{2}$$

In this equation, $C_f \equiv \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}$ is the *CP* violation in the decay, $S_f \equiv \frac{2Im\lambda_f}{1+|\lambda_f|^2}$ is the *CP* violation in the mixing and $A_f^{\Delta\Gamma} \equiv \frac{2Re\lambda_f}{1+|\lambda_f|^2}$. Then, Δm and $\Delta\Gamma$ are, respectively, the mass and decay rate differences between the flavour- and the mass-eigenstate. The parameter λ_f is defined as $\lambda_f \equiv \frac{q}{p}\frac{\bar{A}_f}{A_f}$, where q and p are the coefficient that allow to change from the mass basis to the flavour basis.

2. Measurement of *CP* violation in the decay $B^+ \to K^+\pi^0$

The presented measurement of *CP* violation in the decay $B^+ \to K^+\pi^0$ uses the data collected by LHCb from 2016 to 2018 [17]. The data sample has a size of 5.4 fb^{-1}. Figure 1 shows the data distribution and the fit to the data. The raw asymmetry measured by comparing the rates of

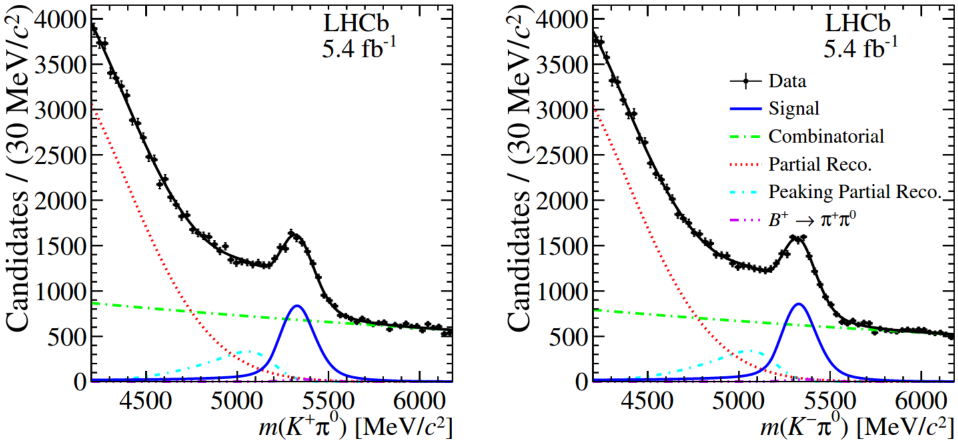

Figure 1: Data distribution and fit to the data for the $B^+ \to K^+\pi^0$ (right) and $B^- \to K^-\pi^0$ (left) decays. The study has been performed on a 5.4 fb^{-1} data sample [17].

the $B^+ \to K^+\pi^0$ and the $B^- \to K^-\pi^0$ decays has to be corrected to take into consideration the asymmetry in the production of B^+ and B^- mesons. It should also be corrected to account for the asymmetry in the detection, in the triggering and in the reconstruction of the charged kaons. The *CP*-violation is then

$$A_{CP}(B^+ \to K^+\pi^0) = A_{\text{raw}}(B^+ \to K^+\pi^0) - A^B_{\text{prod.}} - A^K_{\text{det}}. \tag{3}$$

The nuisance asymmetries are determined thanks to the $B^+ \to (J/\psi \to \mu^+\mu^-)K^+$ control sample. Once the raw asymmetry is corrected, the result is

$$A_{CP}(B^+ \to K^+\pi^0) = 0.025 \pm 0.015 \pm 0.06 \pm 0.003 \text{ [17]}, \tag{4}$$

where the first uncertainty is statistical, the second is systematic and the third is from the uncertainty on $A_{CP}(B^+ \to (J/\psi \to \mu^+\mu^-)K^+)$. This result is compatible with the world average and exceeds its precision. The *CP* anomaly, determined by the difference in *CP* asymmetry between $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$, is computed to be

$$\Delta A_{CP}(K\pi) = 0.115 \pm 0.014 \text{ [17]}, \tag{5}$$

which is non-zero with a significance greater than 8σ.

3. Observation of *CP* violation in 2-body $B^0_{(s)}$-meson decays to charged pions and kaons

In the charmless 2-body decays of neutral B mesons to charged kaons and pions, direct *CP* asymmetry can be measured. A time-dependent study of these decays allows for measurements of time-dependent *CP* violation. In the analysis presented here [18], the *CP* parameters are determined thanks to a simultaneous fit, including the mass distributions of the $B^0_{(s)} \to K\pi$, $B^0 \to \pi\pi$ and $B^0_s \to KK$, together with the neutral B-meson decay times, the tagging decisions and the mis-tag

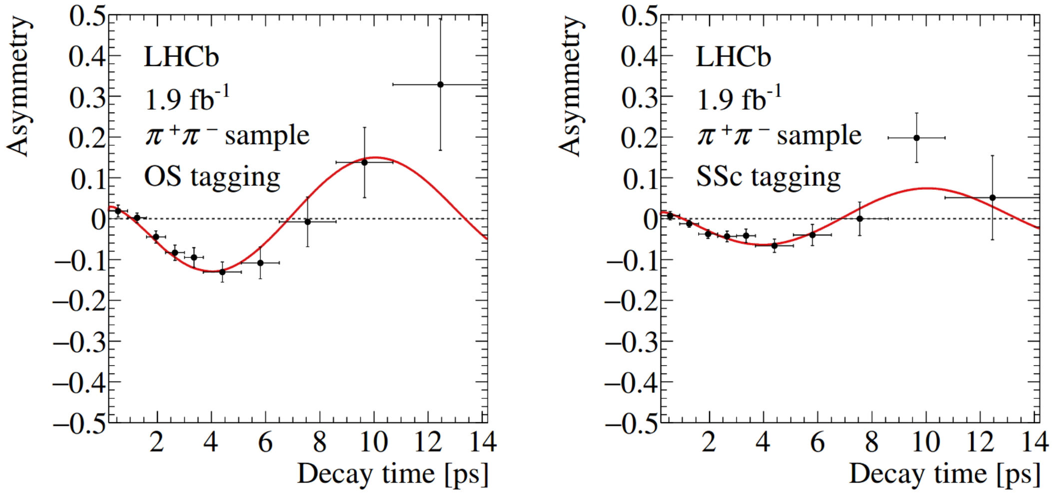

Figure 2: $B^0 \to \pi\pi$ *CP* asymmetry as a function of the decay time. The red line is the fit to the distribution. The study is performed with a 1.9 fb^{-1} data sample [18].

probabilities. Direct *CP* asymmetries in the $B^0_{(s)} \to K\pi$ decays are measured. After a correction to take into consideration any selection asymmetries, they were found to be

$$A_{CP}^{B^0} = -0.0824 \pm 0.0033 \pm 0.0033, \tag{6}$$

$$A_{CP}^{B^0_s} = 0.236 \pm 0.013 \pm 0.011 \text{ [18]}, \tag{7}$$

where the first uncertainty is statistical and the second is systematic. The time-dependent *CP* parameters of the $B^0 \to \pi\pi$ and $B^0_s \to KK$ decays are also extracted from the simultaneous fit. In the case of $B^0 \to \pi\pi$ decays, the result is

$$C_{\pi\pi} = -0.320 \pm 0.038, \tag{8}$$

$$S_{\pi\pi} = -0.672 \pm 0.034 \text{ [18]}. \tag{9}$$

The *CP* asymmetry in the $B^0 \to \pi\pi$ decays as a function of the decay time is shown in Fig. 2, where the red line represents the fit to this distribution. The $A^{\Delta\Gamma}_{\pi\pi}$ coefficient is not measured, as in the case of the B^0 meson Δm_d is negligible. It is clear from Eq. 2 that $A^{\Delta\Gamma}_{\pi\pi}$ then vanishes.

As for the $B^0_s \to KK$ decays, the time-dependent *CP*-asymmetry parameters are measured to be

$$C_{KK} = 0.172 \pm 0.031, \tag{10}$$

$$S_{KK} = 0.139 \pm 0.032, \tag{11}$$

$$A^{\Delta\Gamma}_{KK} = -0.897 \pm 0.087 \text{ [18]}. \tag{12}$$

Figure 3 shows the *CP* asymmetry in $B^0 \to KK$ decays as a function of the decay time. The red line represents the fit to this distribution. In both sets of results, the uncertainty is statistical only. This result is the first observation of time-dependent *CP* violation in B^0_s-meson decays

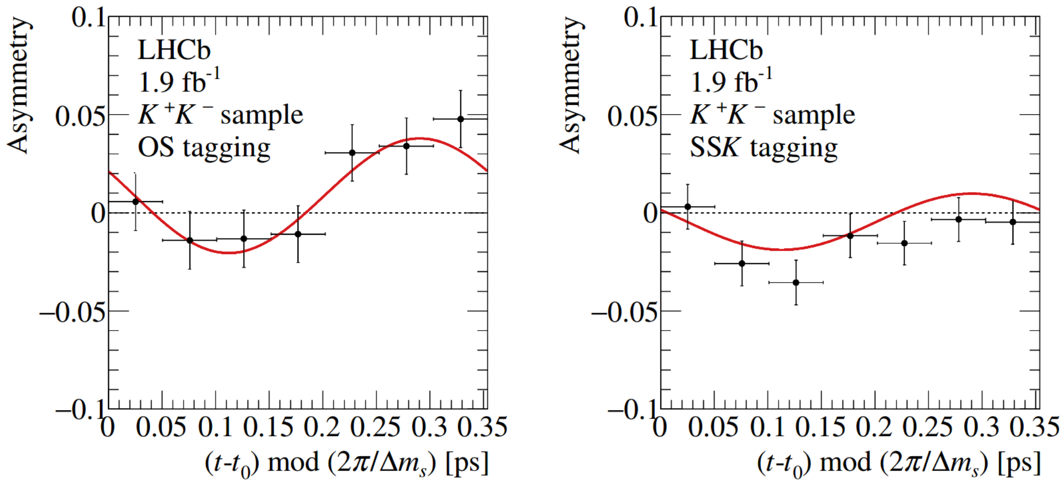

Figure 3: $B_s^0 \to KK$ *CP* asymmetry as a function of the decay time. The red line is the fit to the distribution. The study is performed with a 1.9 fb^{-1} data sample [18].

4. Conclusion

Challenging time-dependent and time-integrated analyses were performed to better understand *CP* violation in charmless 2-body B-meson decays. The measurement of *CP* violation in the decay $B^+ \to K^+\pi^0$ is the most precise measurement of the direct *CP* symmetry in these decays. The result is compatible with the world average and it confirms the anomaly that was observed in the difference between $A_{CP}(B^+ \to K^+\pi^0)$ and $A_{CP}(B^0 \to K^+\pi^-)$. The study of *CP* violation in 2-body $B^0_{(s)}$-meson decays to charged pions and kaons resulted in the most precise measurements from a single experiment of the $B^0 \to \pi\pi$ time-dependent *CP* violation parameters and of the $B^0 \to K\pi$ and $B_s^0 \to K\pi$ direct *CP*-asymmetry. This study observed for the first time time-dependent *CP* violation in B_s^0-meson decays. The upcoming Run 3 of the LHC, with the LHCb upgraded detector, should bring new insights and exciting results on *CP* violation in charmless 2-body *B*-meson decays. It could also give new hints on understanding the $K\pi$-puzzle.

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