IL NUOVO CIMENTO **42 C** (2019) 147
DOI 10.1393/ncc/i2019-19147-1

Colloquia: IFAE 2018

Measurement of CP violation in charmless charged two-body $B^0_{(s)}$-meson decays at LHCb

D. Fazzini([1])([2])

([1]) *INFN, Sezione di Milano-Bicocca - Milano, Italy*
([2]) *Dipartimento di Fisica, Università di Milano-Bicocca - Milano, Italy*

received 31 January 2019

Summary. — Charmless charged two-body b-hadron decays to final states with kaons and pions are good for testing the Standard Model. In addition, they are sensitive to new physics beyond the Standard Model since they occur trough loop diagrams. We report the most recent results on the charmless b-hadron two-body decays obtained by the LHCb experiment using the data collected in the full Run 1 (3 fb^{-1}).

1. – Introduction

The charmless two-body b-hadron decays cover a very important role for testing the Standard Model (SM) and studying the CP violation [1, 2]. The reason is that these decays occur through both tree-level and one-loop processes with competitive amplitudes. Thus, precision measurements of the CP violation on these decay modes could provide useful information regarding the physics beyond the SM, which may enter the loop diagrams modifying the values of several CP parameters [3, 4].

The violation of the CP symmetry in the SM within the weak sector is linked to the existence of at least three flavour families. The only source of CP violation predicted by the SM lies in a complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix. The CKM matrix describes the transitions between the three quark families due to charged current processes. A precise measurement of the CKM elements is extremely important for a complete understanding of the CP violation.

The SM predicts three different ways in which the CP violation can arise. The first is the "CP violation in decays", which occurs when the rate of a process and its own conjugate are different. In this case it is possible measure the time-integrated CP asymmetry defined as

$$A_{CP} = \frac{\Gamma(B \to f) - \Gamma(\overline{B} \to \overline{f})}{\Gamma(B \to f) + \Gamma(\overline{B} \to \overline{f})} = \frac{1 - \left|\frac{\overline{A}_{\overline{f}}}{A_f}\right|^2}{1 + \left|\frac{\overline{A}_{\overline{f}}}{A_f}\right|^2}. \quad (1)$$

The second is the "*CP* violation in mixing", which appears when the probabilities of a $B^0_{d,s}$ and a $\overline{B}^0_{d,s}$ to oscillate to their own antiparticle are different. Finally the third way to violate the *CP* symmetry is called "*CP* violation in interference", which can arise when both B^0 and $\overline{B}^0$ decay to the same final state. In this case it is possible to measure the time-dependent *CP* asymmetry defined as

$$A_{CP}(t) = \frac{C_f \cos(\Delta M t) + S_f \sin(\Delta M t)}{\cosh\left(\frac{\Delta\Gamma}{2}t\right) - A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma}{2}t\right)}, \tag{2}$$

where f represents a certain final state and the three parameters C_f, S_f and $A_f^{\Delta\Gamma}$ satisfy the following relation: $|C_f|^2 + |S_f|^2 + |A_f^{\Delta\Gamma}|^2 = 1$.

2. – Measurement with charmless two-body B decays

In the LHCb experiment a simultaneous analysis of the $\pi^+\pi^-$, K^+K^- and $K^+\pi^-$ final-state hypotheses is performed to measure the time-dependent *CP* asymmetries of the $B^0_d \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ decays, and the time-integrated *CP* asymmetries of the $B^0_d \to K^+\pi^-$ and $B^0_s \to \pi^+K^-$ decays. The values of the *CP* parameters are obtained by means of a simultaneous fit to the three final-state hypotheses. An efficient discrimination between pions and kaons is possible thanks to the information provided by the RICH. However, small contributions due to misidentification between pions and kaons remain at the level of 10% relatively to the signals. These contributions, in addition to the random combination of two tracks and to the partially reconstructed 3-body decays, represent the main contamination to be dealt with. In order to maximize the signal purity in the sample, the event selection is performed both applying a set of particle identification (PID) requirements and using a boosted-decision-tree discriminator based on kinematic and geometrical variables. The final selected sample used in the analysis contains approximately 28600 $B^0_d \to \pi^+\pi^-$, 36800 $B^0_s \to K^+K^-$, 94200 $B^0_d \to K^+\pi^-$, and 7000 $B^0_s \to \pi^+K^-$ signal candidates.

A key ingredient to measure the time-dependent *CP* asymmetries of the $B^0_d \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ decays is the flavour tagging (FT), that is the determination of the flavour of the neutral B meson at the production. The FT algorithms are able to predict, with a certain probability, the B flavour at production exploiting the other particles in the event. In this analysis both the "Opposite Side" algorithms, using particles coming from the decay of the other B in the event, and the "Same Side" algorithms, exploiting the particle generated in the B-signal fragmentation, are employed. The effective tagging efficiency provided by the FT algorithms can be evaluated as

$$\varepsilon_{eff} = \varepsilon_{tag} \cdot (1 - 2\omega)^2, \tag{3}$$

where ε_{tag} stands for the the fraction of the events for which the algorithm is able to provide a response and ω represents the mistag probability. The amount of tagging power available in a certain dataset is a very important parameter in order to obtain precise measurements, since it is inversely proportional to the statistic uncertainty of the *CP* parameters.

The time-integrated asymmetry of the $B^0_d \to K^+\pi^-$ and $B^0_s \to \pi^+K^-$ decays determined from the fit (A_{raw}) does not correspond to the effective *CP* asymmetry (A_{CP}), but needs to be corrected for other nuisance asymmetries arising from experimental effects. These are the production asymmetry (A_P) and the detection asymmetry (A_D):

$$A_{raw}(t) \approx A_{CP} + A_D + A_P \cos(\Delta m_{d(s)} t). \tag{4}$$

On the one hand the production asymmetry can be extracted directly from the fit along with the *CP* asymmetry. On the other hand, the detection asymmetry is determined using high-statistics samples of Cabibbo-favoured decays of charmed mesons [5], and taking into account the kinematic difference with respect to the B signals.

3. – Results

The final values of the time-dependent *CP* parameters obtained by LHCb are reported in eq. (5) while the time-integrated *CP* asymmetries are shown in eq. (6). All the measurements have been performed using the full Run 1 data sample, corresponding to $3\,\text{fb}^{-1}$. Since the value of $\Delta\Gamma_d$ is small, the *CP* parameter $A^{\Delta\Gamma}_{\pi^+\pi^-}$ cannot be determined. All the results obtained are in very good agreement with the previous results obtained by BaBar [6], Belle [7, 8], CDF [9] and LHCb [10, 11]. The measurements of $A_{CP}(B^0 \to K^+\pi^-)$, $A_{CP}(B_s \to \pi^+K^-)$, $C_{\pi^+\pi^-}$ and $S_{\pi^+\pi^-}$ are the most precise obtained by a single experiment. Regarding the *CP* parameters of the $B^0_s \to K^+K^-$ decay, from the evaluation of a χ^2 test the results obtained turn out to deviate from $(0, 0, -1)$, *i.e.*, the no *CP* violation hypothesis, by more than 4 standard deviations. It represents the strongest evidence of *CP* violation in the B^0_s system:

$$\begin{aligned} C_{\pi^+\pi^-} &= -0.34 \pm 0.06 \pm 0.01,\\ S_{\pi^+\pi^-} &= -0.63 \pm 0.05 \pm 0.01,\\ C_{K^+K^-} &= 0.20 \pm 0.06 \pm 0.02,\\ S_{K^+K^-} &= 0.18 \pm 0.06 \pm 0.02,\\ A^{\Delta\Gamma}_{K^+K^-} &= -0.79 \pm 0.07 \pm 0.10, \end{aligned} \tag{5}$$

$$\begin{aligned} A_{CP}(B^0 \to K^+\pi^-) &= (-8.4 \pm 0.4 \pm 0.3)\%,\\ A_{CP}(B_s \to \pi^+K^-) &= (21.3 \pm 1.5 \pm 0.3)\%. \end{aligned} \tag{6}$$

REFERENCES

[1] Fleischer R., *Eur. Phys. J. C*, **52** (2007) 267, arXiv:0705.1121.
[2] Ciuchini M. *et al.*, *JHEP*, **10** (2012) 29, arXiv:1205.4948.
[3] Fleischer R., *Phys. Lett. B*, **459** (1999) 306, arXiv:hep-ph/9903456.
[4] Fleischer R., Jaarsma R. and Vos K. K., *JHEP*, **03** (2017) 55, arXiv:1612.07342.
[5] Aaij R. *et al.*, *JHEP*, **07** (2014) 041, arXiv:1405.2797.
[6] Lees J. P. *et al.*, *Phys. Rev. D*, **87** (2013) 052009, arXiv:1206.3525.
[7] Adachi I. *et al.*, *Phys. Rev. D*, **88** (2013) 092003, arXiv:1302.0551.
[8] Duh Y. T. *et al.*, *Phys. Rev. D*, **87** (2013) 031103, arXiv:1210.1348.
[9] Aaltonen T. *et al.*, *Phys. Rev. Lett.*, **113** (2014) 242001, arXiv:1403.5586.
[10] Aaij R. *et al.*, *JHEP*, **10** (2013) 183, arXiv:1308.1428.
[11] Aaij R. *et al.*, *Phys. Rev. Lett.*, **110** (2013) 221601, arXiv:1304.6173.