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Time-dependent CP-violation measurements in $B \to DX$ decays at LHCb

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Measurements of the time-dependent CP-violation observables in $B^0 \to D^{\mp}\pi^{\pm}$ and $B_s^0 \to D_s^{\mp}K^{\pm}$ decys are reported. The decays are reconstructed in a dataset collected with the LHCb experiment in pp collisions at centre-of-mass energies of 7 and 8 TeV corresponding to an integrated luminosity of $3\,\mathrm{fb}^{-1}$. For $B^0 \to D^{\mp}\pi^{\pm}$ decays, the CP-observables are measured to be $S_f = 0.058 \pm 0.020 \pm 0.011$ and $S_{\bar{f}} = 0.038 \pm 0.020 \pm 0.007$. For $B_s^0 \to D_s^{\mp}K^{\pm}$ decays, $C_f = 0.730 \pm 0.142 \pm 0.045$, $S_f = -0.519 \pm 0.202 \pm 0.070$, $S_{\bar{f}} = -0.489 \pm 0.196 \pm 0.068$, $A_f^{\Delta\Gamma} = 0.387 \pm 0.277 \pm 0.153$ and $A_{\bar{f}}^{\Delta\Gamma} = 0.308 \pm 0.275 \pm 0.152$ are determined, where the first uncertainties are statistical and the second systematic. Using these observables the CKM angle γ is constrained at 68 % CL to be $[5,86]^{\circ}$ and $\left(128^{+17}_{-22}\right)^{\circ}$ modulo 180° for $B^0 \to D^{\mp}\pi^{\pm}$ and $B_s^0 \to D_s^{\mp}K^{\pm}$ decays, respectively.

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1. Introduction

In the SM, *CP*-violation is possible in the strong and weak interactions, yet it is only observed in the latter, stemming from a single complex phase of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [1, 2]. One important set of measurements is the determination of the CKM angle $\gamma \equiv \arg\left(-V_{ud}V_{ub}^{*}V_{cb}V_{cd}^{*}\right)$, which is the only angle that can be measured using both tree-level and loop-level processes. Time-dependent measurements of *CP*-violation in the interference of mixing and decay in $B^0 \to D^{\mp}\pi^{\pm}$ and $B_s^0 \to D_s^{\mp}K^{\pm}$ decays are sensitive to this angle [3].

The time-dependent decay rates of the $\left|B_q^0(t)\right\rangle$ and $\left|\bar{B}_q^0(t)\right\rangle$ $(q = d, s)$ flavour eigenstates to the final states f and $\bar{f}$ are

$$\left|B_q^0(t)\right\rangle \propto e^{-\Gamma_q t}\left[\cosh\left(\frac{\Delta\Gamma_q}{2}t\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_q}{2}t\right) \mp S_f\sin\left(\Delta m_q t\right) \pm C_f\cos\left(\Delta m_q t\right)\right], \tag{1.1}$$

$$\left|B_q^0(t)\right\rangle \propto e^{-\Gamma_q t}\left[\cosh\left(\frac{\Delta\Gamma_q}{2}t\right) + A_{\bar{f}}^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_q}{2}t\right) \mp S_{\bar{f}}\sin\left(\Delta m_q t\right) \mp C_f\cos\left(\Delta m_q t\right)\right], \tag{1.2}$$

where the upper sign indicates an initial B_q^0 and the lower sign an initial $\bar{B}_q^0$ meson. Here, Γ_q is the decay width of the corresponding B_q^0 meson while $\Delta\Gamma_q$ and Δm_q are the decay-width and mass differences of the corresponding mass eigenstates. The *CP*-violating observables are defined as

$$C_f = \frac{1-r^2}{1+r^2}, \quad A_f^{\Delta\Gamma} = -\frac{2r\cos(\delta-(\gamma-\phi_q^{\text{mix}}))}{1+r^2}, \quad A_{\bar{f}}^{\Delta\Gamma} = -\frac{2r\cos(\delta+(\gamma-\phi_q^{\text{mix}}))}{1+r^2},$$
$$S_f = -\frac{2r\sin(\delta-(\gamma-\phi_q^{\text{mix}}))}{1+r^2}, \quad S_{\bar{f}} = \frac{2r\sin(\delta+(\gamma-\phi_q^{\text{mix}}))}{1+r^2},$$

where $r = |A(\bar{B}_q^0 \to D_{(s)}^- h^+)/A(B_q^0 \to D_{(s)}^- h^+)|$, δ is a strong phase difference, and $\gamma - \phi_q^{\text{mix}}$ the weak phase difference. Here, the weak phase difference is a combination of the CKM angle γ and the mixing phase ϕ_q^{mix}, which can be identified with -2β $(2\beta_s)$ for B^0 (B_s^0) mesons. Using an independent measurement of the mixing phase as input, the angle γ can be measured with negligible theoretical uncertainties [4]. Due to the small values of $\Delta\Gamma_d$ and r in the B^0 system the measurable *CP*-observables in $B^0 \to D^{\mp}\pi^{\pm}$ decays are reduced to S_f and $S_{\bar{f}}$.

Both measurements are based on a pp collision data sample corresponding to an integrated luminosity of $3\,\text{fb}^{-1}$ collected by the LHCb detector during Run I [5, 6].

2. Analysis of $B^0 \to D^{\mp}\pi^{\pm}$ decays

The selection of $B^0 \to D^{\mp}\pi^{\pm}$ candidates is performed by reconstructing $D^- \to K^+\pi^-\pi^-$ candidates from charged particle tracks with high momentum and transverse momentum, and originating from a common displaced vertex. A combination of PID information and mass-range vetoes is used to suppress cross-feed backgrounds such as $\Lambda_b^0 \to \Lambda_c^0(\to pK^-\pi^+)\pi^-$ and $B_s^0 \to D_s^-(\to K^+K^-\pi^-)\pi^+$, due to the misidentification of protons and kaons as pions, to a negligible level. A boosted decision tree (BDT) is used to increase the signal purity by suppressing background from random combinations of particles. The data sample is further required to consist of B^0 candidates whose initial flavour has been determined by means of the flavour tagging algorithms. After the selection the data sample is split into two disjoint subsets according to the PID information of the companion particle [7]: a sample referred to as pion-like consisting mostly of genuine $B^0 \to D^{\mp}\pi^{\pm}$ decays, and a sample referred to as kaon-like consisting mostly of genuine $B^0 \to D^-K^+$ decays. The binned B^0-mass distributions of these two samples are fitted simultaneously in order to determine the sample compositions. An unbinned maximum-likelihood fit in a smaller mass window, $5220\,\text{MeV}\,\text{c}^{-2}$

to 5600 MeV c^{-2}, to the B^0-mass distribution of the pion-like sample is performed to determine *sWeights* [8], which are used to statistically subtract the background. The $B^0 \to D^{\mp}\pi^{\pm}$ signal yield is found to be $479\,000 \pm 700$ and that of the background to be $34\,400 \pm 300$.

The $B^0 \to D^{\mp}\pi^{\pm}$ decay rates depend on the initially produced flavour eigenstates B^0 and $\bar{B}^0$. The identification of the initial flavour is performed using two classes of flavour-tagging algorithms, referred to as the opposite-side (OS) and same-side (SS) taggers [9, 10, 11]. Each algorithm provides a decision (tag), d, which determines the flavour, and an estimate, η, of the probability that the decision is incorrect (mistag probability). Due to variations in the properties of tagging tracks for different channels, the predicted mistag probability η has to be calibrated using flavour specific, self-tagging, decays to represent the true mistag rate ω. The functional form of this calibration is determined on $B^0 \to J/\psi K^{*0}$ data for the SS taggers and on $B^+ \to D^0\pi^+$ data for the OS algorithms, while the calibration parameters are left free in the fit from which the S_f and $S_{\bar{f}}$ observables are extracted. This is possible because the C_f parameter is a fixed parameter, so that the cosine terms of the decay rates permit the calibration parameters to be measured.

The *CP*-asymmetries S_f and $S_{\bar{f}}$ are determined from a multidimensional maximum-likelihood fit to the unbinned distributions of the decay time t, the tags d and mistag probabilities η of the signal candidates. The finite decay-time resolution is determined from a sample of fake B^0 candidates formed from a genuine D^- meson and a charged track originating from the same primary vertex and consistent with being a pion of opposite charge. The fit yields $S_f = 0.058 \pm 0.020\,(\text{stat.}) \pm 0.011\,(\text{syst.})$ and $S_{\bar{f}} = 0.038 \pm 0.020\,(\text{stat.}) \pm 0.007\,(\text{syst.})$, where the systematic uncertainties are estimated with Gaussian constraints, pseudoexperiments and variations of the mass fit model. These values result in a significance of $2.7\,\sigma$ for the *CP*-violation hypothesis, according to Wilks' theorem.

3. Analysis of $B_s^0 \to D_s^{\mp} K^{\pm}$ decays

The $B_s^0 \to D_s^{\mp} K^{\pm}$ decay is reconstructed using three different D_s^- final states: $D_s^- \to K^+K^-\pi^-$, $D_s^- \to K^+\pi^-\pi^-$, and $D_s^- \to \pi^+\pi^-\pi^-$. The flavour-specific Cabibbo-favoured decay mode $B_s^0 \to D_s^-\pi^+$ is used as a control channel. The selection features similar steps as for the $B^0 \to D^{\mp}\pi^{\pm}$ decay: cross-feed backgrounds due to the misidentification of protons and kaons as pions are suppressed by a combination of PID information and mass-range vetoes, while a BDT is used to increase the signal purity by suppressing background from random combinations of particles. The signal and background component yields in the samples of $B_s^0 \to D_s^{\mp} K^{\pm}$ and $B_s^0 \to D_s^-\pi^+$ candidates are obtained from a three-dimensional simultaneous extended maximum-likelihood fit in the B_s^0 mass, the D_s^- mass, and the log-likelihood difference $L(K/\pi)$ between the pion and kaon hypotheses for the companion particle. The fit results in a signal yield of 5955 ± 90 $B_s^0 \to D_s^{\mp} K^{\pm}$ candidates.

The calibration functions for the flavour tagging algorithms are determined for both the OS and SS taggers [9, 12] on the $B_s^0 \to D_s^-\pi^+$ control channel. The fast $B_s^0 - \bar{B}_s^0$ oscillations require a per-event decay-time resolution model. The per-event decay time uncertainty σ_t is therefore calibrated using prompt D_s^- mesons combined with a random track yielding fake B_s^0 with a known lifetime of zero.

The determination of the *CP*-parameters is performed using an unbinned maximum-likelihood yielding

$$C_f = 0.730 \pm 0.142 \pm 0.045, \quad A_f^{\Delta\Gamma} = 0.387 \pm 0.277 \pm 0.153, \quad A_{\bar{f}}^{\Delta\Gamma} = 0.308 \pm 0.275 \pm 0.152,$$
$$S_f = -0.519 \pm 0.202 \pm 0.070, \quad S_{\bar{f}} = -0.489 \pm 0.196 \pm 0.068,$$

where the first uncertainties are statistical and the second systematic.

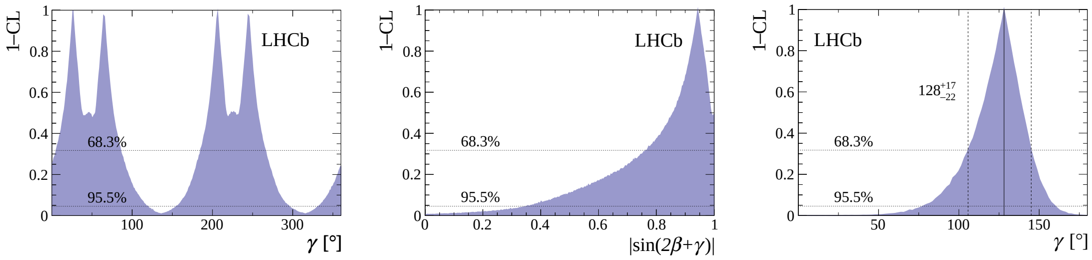

Figure 1: Distribution of $1-\mathrm{CL}$ for (left) γ from $B^0 \to D^{\mp}\pi^{\pm}$ decays, (middle) $|\sin(2\beta+\gamma)|$ from $B^0 \to D^{\mp}\pi^{\pm}$ decys and (right) γ from $B_s^0 \to D_s^{\mp}K^{\pm}$ decays.

4. Interpretation

Using a frequentist approach [13], the measurement of the *CP*-sensitive parameters is interpreted in terms of the angle γ and for both $B^0 \to D^{\mp}\pi^{\pm}$ and $B_s^0 \to D_s^{\mp}K^{\pm}$ decays, and in terms of the quantity $|\sin(2\beta+\gamma)|$ for $B^0 \to D^{\mp}\pi^{\pm}$ decays. The resulting confidence intervals from $B^0 \to D^{\mp}\pi^{\pm}$ decays at 68 % CL are

$$\gamma = [5,86]^\circ \cup [185,266]^\circ, \quad \delta_{D^{\mp}\pi^{\pm}} = [-41,41]^\circ \cup [140,220]^\circ, \quad |\sin(2\beta+\gamma)| = [0.77,1.0],$$

where the value of r is determined assuming SU(3) following the procedure presented in Refs. [14, 15]. For $B_s^0 \to D_s^{\mp}K^{\pm}$ decays the confidence intervals at 68 % CL are

$$\gamma = \left(128^{+17}_{-22}\right)^\circ, \quad \delta_{D_s^{\mp}K^{\pm}} = \left(358^{+13}_{-14}\right)^\circ, \quad r_{D_s^{\mp}K^{\pm}} = 0.37^{+0.10}_{-0.09},$$

where the intervals for the angles are expressed modulo 180°. All results are shown in Fig. 1.

References

[1] N. Cabibbo, Phys. Rev. Lett. **10** (1963) 531

[2] M Kobayashi and T. Maskawa, Prog. Theor. Phys. **49** (1973) 652

[3] R. Fleischer, Nucl. Phys. **B671** (2003) 459, `arXiv:hep-ph/0304027`

[4] J Brod and J. Zupan, JHEP **1401** (2014) 051, `arXiv:1308.5663`

[5] LHCb Collaboration, JHEP **1806** (2018) 084, `arXiv:1805.03448`

[6] LHCb collaboration, JHEP **1803** (2018) 059, `arXiv:1712.07428`

[7] LHCb collaboration, Int. J. Mod. Phys **A30** (2015) 1530022, `arXiv:1412.6352`

[8] M. Pivk and F. R. Le Diberder, Nucl. Instrum. Meth. **A555** (2005) 356, `arXiv:physics/0402083`

[9] LHCb collaboration, Eur. Phys. J. **C72** (2012) 2022, `arXiv:1202.4979`

[10] LHCb collaboration, JINST **10** (2015) P10005, `arXiv:1507.07892`

[11] LHCb collaboration, Eur. Phys. J. **C77** (2017) 238, `arXiv:1610.06019`

[12] LHCb collaboration, JINST **11** (2016) P05010, `arXiv:1602.07252`

[13] LHCb collaboration, JHEP **12** (2016) 087, `arXiv:1611.03076`

[14] BaBar collaboration, Phys. Rev. **D78** (2008) 032005, `arXiv:0803.4296`

[15] Belle collaboration, Phys. Rev. **D82** (2010) 051103, `arXiv:1007.4619`