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Estimated of CP violation in B^0 meson decays into D^{*+} and D^- mesons

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Abstract The decay $B^0 \to D^{*+}D^-$ is favorable mode for studying CP violation in the interference between mixing and decay for B^0 and $\bar{B}^0$ mesons. The latest analysis of the CP parameters has been performed by the LHCb Collaboration values of $S_{D^*D} = -0.861 \pm 0.077 \pm 0.019$, $C_{D^*D} = -0.059 \pm 0.092 \pm 0.020$, $\triangle S_{D^*D} = 0.019 \pm 0.075 \pm 0.012$, $\triangle C_{D^*D} = -0.031 \pm 0.092 \pm 0.016$, and $\mathcal{A}^{CP}_{D^*D} = 0.008 \pm 0.014 \pm 0.006 \pm 0.003$. We have been estimated the parameters S_{D^*D} and C_{D^*D} of the $B^0 \to D^{*+}D^-$ decay as -0.709 ± 0.024 and -0.051 ± 0.004. In the following, we have obtained the values of $\triangle S_{D^*D} = 0.054 \pm 0.003$ and $\triangle C_{D^*D} = 0.020 \pm 0.001$ and direct CP violation of 0.008 ± 0.001. Also, we have calculated the branching ratio of $B^0 \to D^{*+}D^-$ decay. The values obtained in this work are comparable with the corresponding experimental values.

1 Introduction

The standard model (SM) is a relativistic quantum field theory that involves the search for fundamental particles and the fundamental interactions that occurring among them. To perform such searches through high-precision measurements of the parameters of the quark-flavour of the SM sector with b- and c-hadron decays is developed. In this way, possible inconsistencies with the SM predictions are revealed. The increasing amount of data makes it necessary to consider higher-order the SM corrections [1]. One way to do this is to examine decays that involve $b \to c\bar{c}d$ transitions, such as $B^0 \to D^{*+}D^-$. Neutral meson mixing is one important effect that allows access to parameters in the flavour sector [2]. The mesons composed of a different quarks and antiquarks type decay weakly, allowing CP violation and mixing. Mixing describes the transformation of a neutral meson into an antiparticle state and vice versa, and is also called meson oscillation. The time-dependent oscillation between the particle and antiparticle states appears [3]. CP violation in general could lead to the excess of a matter–antimatter in our universe, but the smallness of the observed CP violation is not sufficient to explain the observations [4]. Nevertheless, the fact that the CP violation is a relatively small non-zero value is interesting and allows for further studies on its properties. Also, new sources of CP violation beyond the SM that account for the difference between measured values and SM predictions can be considered as a research idea for the yet-undiscovered physics [5]. In the case of CP symmetry in the B meson system, we can study the processes in which the B mesons decay into a CP-eigenstate state. In a general way, we can compare the rate at which a B meson decays into a CP-eigenstate with the rate at which a B meson decays into a CP-conjugate final state ($\bar{f}$), to the rate at which a $\bar{B}$ meson decays into the CP final state (f) and to the rate at which a $\bar{B}$ meson decays into the $\bar{f}$. These different final states provide additional information about the system, and only by combining such information from different measurements can we get a complete picture of the subject as well as accurate results. The difference between the B^0 and $\bar{B}^0$ meson decays appears only in the time-dependent decay rate, and this time corresponds to the time when the B meson freely propagates before it decays to the CP-eigenstate [6]. In Tables 1 and 2 an overview of existing measurements and the world average is provided for the $B^0 \to D^{*\pm}D^{\mp}$ decays by the different collaborations.

Recently, the first measurement of CP violation in the $B^0 \to D^{*\pm}D^{\mp}$ decay has been reported in the LHCb experiment. They have measured the CP parameters as $S_{D^*D} = -0.861 \pm 0.077 \pm 0.019$, $\triangle S_{D^*D} = 0.019 \pm 0.075 \pm 0.012$, $C_{D^*D} = -0.059 \pm 0.092 \pm 0.020$, $\triangle C_{D^*D} = -0.031 \pm 0.092 \pm 0.016$ and $\mathcal{A}^{CP}_{D^*D} = 0.008 \pm 0.014 \pm 0.006 \pm 0.003$ [9]. In this work, we have estimated the CP parameters and

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Table 1 Experimentally values CP violation parameters for $B^0 \to D^{*\pm}D^{\mp}$ decay

	Belle [7]	BABAR [8]	LHCb [9]	HFLAV [10]
S_{D^*D}	$-0.78 \pm 0.15 \pm 0.05$	$-0.68 \pm 0.15 \pm 0.04$	$-0.861 \pm 0.077 \pm 0.019$	-0.73 ± 0.11
C_{D^*D}	$-0.01 \pm 0.11 \pm 0.04$	$+0.04 \pm 0.12 \pm 0.03$	$-0.059 \pm 0.092 \pm 0.020$	0.01 ± 0.09
$\triangle S_{D^*D}$	$-0.13 \pm 0.15 \pm 0.04$	$+0.05 \pm 0.15 \pm 0.02$	$+0.019 \pm 0.075 \pm 0.012$	-0.041 ± 0.11
$\triangle C_{D^*D}$	$+0.12 \pm 0.11 \pm 0.03$	$+0.04 \pm 0.12 \pm 0.03$	$-0.031 \pm 0.092 \pm 0.016$	0.08 ± 0.08
$\mathcal{A}^{CP}_{D^*D}$	$+0.06 \pm 0.05 \pm 0.02$	$+0.008 \pm 0.048 \pm 0.013$	$0.008 \pm 0.014 \pm 0.006$	0.03 ± 0.04

Table 2 Measured results of the time-dependent CP violatin parameters for $B^0 \to D^{*\pm}D^{\mp}$ decay

$B^0 \to D^{*\pm}D^{\mp}$	BABAR [11]	Belle [2]	PDG [2021] . Ave [12]
$S_{D^{*+}D^-}$	$-0.82 \pm 0.75 \pm 0.14$	$-0.55 \pm 0.39 \pm 0.12$	-0.80 ± 0.09
$C_{D^{*+}D^-}$	$-0.47 \pm 0.40 \pm 0.12$	$-0.37 \pm 0.22 \pm 0.06$	-0.03 ± 0.09
$S_{D^{*-}D^+}$	$-0.24 \pm 0.69 \pm 0.12$	$-0.96 \pm 0.43 \pm 0.12$	-0.83 ± 0.09
$C_{D^{*-}D^+}$	$-0.22 \pm 0.37 \pm 0.10$	$+0.23 \pm 0.25 \pm 0.06$	-0.02 ± 0.08

branching ratio for the $B^0 \to D^{*\pm}D^{\mp}$ decay. Under the factorization approach, the amplitudes of $B^0 \to D^{*\pm}D^{\mp}$ decay can be obtained as separate factorizable contributions that include the current–current and penguin contributions. In the case of $\langle B^0 \to D^-\rangle \times \langle 0 \to D^{*+}\rangle$ ($\langle \bar{B}^0 \to D^+\rangle \times \langle 0 \to D^{*-}\rangle$) where the matrix elements B^0 to D^- ($\bar{B}^0$ to D^+) transition multiplying D^{*+} (D^{*-}) arising from the vacuum. We have obtained the branching fraction using the decay amplitude that is to be $\mathcal{B}(B^0 \to D^{*+}D^-) = (5.20 \pm 1.25) \times 10^{-4}$ at $\mu = 2m_b$ scale. This value is well compatible with the value of $\mathcal{B}(B^0 \to D^{*+}D^-) = (6.03 \pm 0.50) \times 10^{-4}$ reported by HFLAV [10]. We have estimated the CP violation as $\mathcal{A}^{CP}_{D^*D} = 0.008 \pm 0.001$ and we have obtained other parameters of CP violation, such as $S_{D^*D} = -0.709 \pm 0.024$, $\triangle S_{D^*D} = 0.054 \pm 0.003$, $C_{D^*D} = -0.051 \pm 0.004$ and $\triangle C_{D^*D} = 0.020 \pm 0.001$.

2 Branching fraction and CP violation in $B^0 \to D^{*+}D^-$ decay

We explained the theoretical background of CP violation in the B^0 meson system using the SM of particle physics and its constructed theoretical framework. We then presented an overview of the field of flavour physics, including the basic ideas of quark mixing and CP violation in the B meson. Now we want to calculate the direct CP violation. The direct CP violation arises in the ratio of the amplitude $A_f(f = D^{*+}D^-)$ to its conjugate amplitude ($\bar{A}_{\bar{f}}(\bar{f} = D^{*-}D^+)$). In this case, two types of phases occur in these amplitudes [13]. The first type of phase is created in complex parameters in the Lagrangian. In the SM, these phases occur only in the CKM matrix and are called weak phases (ϕ_i) [14]. The CKM matrix elements are in the unitarity triangle relation, $V^*_{ub}V_{uq} + V^*_{cb}V_{cq} + V^*_{tb}V_{tq} = 0$ ($q = d, s$) and weak phases are introduced as $\phi_1 = \arg(V_{cq})$ and $\phi_2 = -\arg(V^*_{tb})$. Another type of phase can appear in the scattering or decay amplitudes that are called the strong phases (δ_i). these phases occur even when the Lagrangian is real. Such phases do not violate CP because they appear in amplitudes (A_f and $\bar{A}_{\bar{f}}$) with the same sign. Their origin is the possible contribution of the mode the intermediates on-shell states in the process of decay. In fact, it is an absorptive part of an amplitude that has contributions from coupled channels. The dominant rescattering is due to strong interactions and this is the reason for naming these phases. The CP violation will not occur unless we have different strong phases in addition to different weak phases [14]. The strong phase δ_1 is obtained from $|\mathcal{A}_1|e^{i\delta_1}$ and δ_2 from $|\mathcal{A}_2|e^{i\delta_2}$. The $B^0 \to D^{*+}D^-$ decay (and $\bar{B}^0 \to D^{*-}D^+$ decay), with two contributing amplitudes $\mathcal{A}_1$ and $\mathcal{A}_2$. This means that the decay can be done by two different paths and those are tree ($\mathcal{A}_1$) and penguin ($\mathcal{A}_2$) diagrams. For the total decay amplitude we have [15]:

$$\mathcal{A}(B^0 \to D^{*+}D^-) = |\mathcal{A}_1|e^{i\delta_1}e^{i\phi_1} + |\mathcal{A}_2|e^{i\delta_2}e^{i\phi_2}, \tag{1}$$

where $|\mathcal{A}_1|$ and $|\mathcal{A}_2|$ represent $|\mathcal{A}_1(B^0 \to D^{*+}D^-)|$ and $|\mathcal{A}_2(B^0 \to D^{*+}D^-)|$. Feynman tree diagrams have the largest amplitude contribution compared to penguin diagrams. The Feynman diagrams of $B^0 \to D^{*+}D^-$ decay are shown in Fig. 1 and the decay amplitude can be expressed as

$$\mathcal{A}(B^0 \to D^{*+}D^-) = \sqrt{2}iG_F f_{D^*} F_1^{B\to D}(m^2_{D^*}) \times \Big(V^*_{cb}V_{cd}a_1 - V^*_{tb}V_{td}(a_4 + a_{10} + (a_6 + a_8)r_\chi^{D^*})\Big), \tag{2}$$

where the tree and penguin level amplitudes are as follows, respectively

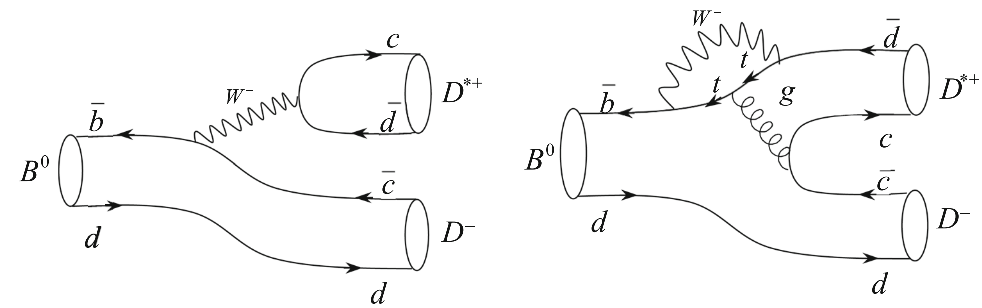

Fig. 1 Feynman diagrams contributing to $B^0 \to D^{*+}D^-$ decay

$$\mathcal{A}_1(B^0 \to D^{*+}D^-) = \sqrt{2} i G_F f_{D^*} F_1^{B\to D}(m_{D^*}^2) V_{cb}^* V_{cd} a_1, \quad (3)$$

and

$$\mathcal{A}_2(B^0 \to D^{*+}D^-) = \sqrt{2} i G_F f_{D^*} F_1^{B\to D}(m_{D^*}^2) V_{tb}^* V_{td} \times \Big(a_4 + a_{10} + (a_6 + a_8) r_\chi^{D^*}\Big), \quad (4)$$

the quantity of $r_\chi^{D^*}$ is equal to $(2m_{D^*}/m_b)(f_{D^*}^\perp/f_{D^*})$, where $f_{D^*}^\perp/f_{D^*} = 0.9 \pm 0.1$ [16]. The form factor F_1 is obtained form [17]

$$F_1(q^2) = \frac{m_B + m_D}{2\sqrt{m_B m_D}}\Big[\xi_+(\omega) - \frac{m_B - m_D}{m_B + m_D}\xi_-(\omega)\Big] \quad (5)$$

here the $\xi_+(\omega)$ and $\xi_-(\omega)$ are under the heavy quark symmetry to be equal $\xi(\omega)$ and zero respectively. We use the Isgur-Wise function $\xi(\omega) = 1 - \rho_D^2(\omega - 1)$ for the transition $B \to D$, where $\omega = (m_B^2 + m_D^2 - q^2)/(2m_B m_D)$ and $\rho_D^2 = 0.90 \pm 0.06$. The ρ_D^2 is called the slope parameter. The basis of QCD lagrangian is quark mass, although it cannot be directly related to measurable physical quantities. The masses depend on the renormalization scheme and, in a given scheme, on the renormalization scale μ. The most important issue in obtaining the amplitude is the calculation of the Wilson coefficients in the NLO or LO approximation. Therefore, we must know the appropriate value of Wilson's coefficients (C_j) in $\mu = O(M_W)$. Also, the C_j's are quantities dependent on the renormalization scheme. The dependence of the renormalization scheme is felt in next-to-leading order (NLO) but not significant in the leading order (LO). In this calculation, the evolution of the renormalization group to the low energy scales $\mu \ll M_W$ related to the decays is considered. In fact, the Wilson coefficients are the coupling constants for the interaction terms of the effective Hamiltonian operators, transformed into non-computable functions α_s, M_W and the renormalization scale μ [18].

For the Wilson parameter a_j (j = 1, ..., 10), we have

$$a_{2j-1} = C_{2j-1} + \frac{1}{3}C_{2j}, \quad a_{2j} = C_{2j} + \frac{1}{3}C_{2j-1}, \quad j = 1, 2, 3, 4, 5. \quad (6)$$

Table 3 Wilson coefficients C_j in the NDR scheme ($\alpha = 1/129$) [19]

NLO	$\mu = m_b/2$	$\mu = m_b$	$\mu = 2m_b$
C_1	1.137	1.081	1.045
C_2	− 0.295	− 0.190	− 0.113
C_3	0.021	0.014	0.009
C_4	− 0.051	− 0.036	− 0.025
C_5	0.010	0.009	0.007
C_6	− 0.065	− 0.042	− 0.027
C_7/α	− 0.024	− 0.011	0.011
C_8/α	0.096	0.060	0.039
C_9/α	− 1.325	− 1.254	− 1.195
C_{10}/α	0.331	0.223	0.144

We used the next-to-leading logarithm in the naive dimensional regularization (NDR) scheme for the Wilson coefficients $C_j(\mu)$ at the scale μ that are shown in Table 3.

In this paper, we take the decay constants, quark, and meson masses (in units of MeV) [12]

$$\begin{aligned} m_{D^*} &= 2010.26 \pm 0.05, \quad m_{B^0} = 5279.65 \pm 0.12, \\ m_{D^\pm} &= 1869.66 \pm 0.05, \quad f_{D^*} = 230 \pm 20 \\ m_b &= 4180^{+40}_{-30}, \quad m_d = 4.67^{+0.48}_{-0.17}, \quad m_c = 1270 \pm 20. \end{aligned} \quad (7)$$

Similarly, $\mathcal{A}_{1,2}(\bar{B}^0 \to D^{*-}D^+)$ is calculated. The decay rates corresponding to the $\mathcal{A}(B^0 \to D^{*+}D^-)$ and $\mathcal{A}(\bar{B}^0 \to D^{*-}D^+)$ amplitudes which are defined as [20]

$$\begin{aligned} \Gamma(B^0 \to D^{*+}D^-) &= \Big||\mathcal{A}_1| e^{i(\delta_1+\phi_1)} + |\mathcal{A}_2| e^{i(\delta_2+\phi_2)}\Big|^2, \\ \Gamma(\bar{B}^0 \to D^{*-}D^+) &= \Big||\mathcal{A}_1| e^{i(\delta_1-\phi_1)} + |\mathcal{A}_2| e^{i(\delta_2-\phi_2)}\Big|^2. \end{aligned} \quad (8)$$

We calculated the branching fractions for the $B^0 \to D^{*+}D^-$ decay is written as

$$\mathcal{B}(B^0 \to D^{*+}D^-) = \frac{\Gamma(B^0 \to D^{*+}D^-)}{\Gamma_{B^0}^{tot}}, \quad (9)$$

here the $\Gamma^{tot}_{B^0}$ is $(4.33 \pm 0.01) \times 10^{-13}$ GeV. The direct CP violation can be expressed as [21]

$$\mathcal{A}^{CP}_{D^*D} = \frac{\Gamma(B^0 \to D^{*+}D^-) - \Gamma(\bar{B}^0 \to D^{*-}D^+)}{\Gamma(B^0 \to D^{*+}D^-) + \Gamma(\bar{B}^0 \to D^{*-}D^+)} = \frac{2|\mathcal{A}_2/\mathcal{A}_1|\sin(\delta_1-\delta_2)\sin(\phi_1-\phi_2)}{1+|\mathcal{A}_2/\mathcal{A}_1|^2+2|\mathcal{A}_2/\mathcal{A}_1|\cos(\delta_1-\delta_2)\cos(\phi_1-\phi_2)}. \tag{10}$$

We obtained the strong phases with values $\delta_1 = -90.01°$ and $\delta_2 = 67.47°$. Also, we calculated for weak phases $\phi_1 = 0.03°$ and $\phi_2 = 22.58°$. In the SM, CP violation occurs when more than one of the Cabibbo–Kobayashi–Maskawa (CKM) quark mixing matrix elements is complex. Here, we use the CKM matrix elements at order λ^5 that is [10]

$$V = \begin{pmatrix} 1-1/2\lambda^2-1/8\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+1/2A^2\lambda^5[1-2(\rho+i\eta)] & 1-1/2\lambda^2-1/8\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-1/2\lambda^2)(\rho+i\eta)] & -A\lambda^2+1/2A\lambda^4[1-2(\rho+i\eta)] & 1-1/2A^2\lambda^4 \end{pmatrix} \tag{11}$$

We adopt the Wolfenstein parameterization and choose the parameters A, ρ, η and λ as [12]

$$\lambda = 0.22650 \pm 0.00048, \quad A = 0.790^{+0.017}_{-0.012},$$
$$\bar{\rho} = 0.141^{+0.016}_{-0.017}, \quad \bar{\eta} = 0.357 \pm 0.011, \tag{12}$$

with $\bar{\rho} = \rho(1-1/2\lambda^2)$ and $\bar{\eta} = \eta(1-1/2\lambda^2)$. Therefore, the CKM matrix elements are obtained as follows (in units of 10^{-3})

$$V_{cb} = 40.529, \quad V_{cd} = -226.368 - 0.136i,$$
$$V_{tb} = 999.179, \quad V_{td} = 7.885 - 3.277i. \tag{13}$$

Another type of CP violation that occurs in the B^0 meson decay, is the violation from interference between decay with and without mixing (without any of the other types of CP violation). We have [6]

$$\lambda_{D^*D} = \frac{q}{p}\frac{\bar{\mathcal{A}}}{\mathcal{A}}. \tag{14}$$

where $A(\bar{A})$ is the decay amplitude for $B^0(\bar{B}^0)$ and q/p is the ratio of the flavor contributions to the mass eigenstates. Since the t quark has more mass, only hadrons with c or u quarks are allowed to transition to physical states. In this case, we have two probability restrictions for these transitions: first, the decay of both B^0 and $\bar{B}^0$ are Cabibbo-suppressed, second, the decay for B^0 is Cabibbo-allowed, and for $\bar{B}^0$ mesons doubly Cabibbo-suppressed, or vice versa. Therefore, the decay width difference is small compared to the mass difference, which allows us to express q/p in terms of CKM matrix elements as

$$\frac{q}{p} \approx \sqrt{\frac{M^*_{12}}{M_{12}}} = \frac{V^*_{tb}V_{td}}{V_{tb}V^*_{td}}. \tag{15}$$

The M_{12} and M^*_{12} are denote mass matrices. If $|\lambda| \neq 1$, CP violation is manifest through either decay or mixing, but if $Im\lambda \neq 0$, CP violation is manifest through the interference between decays with and without mixing. The decay time-dependent CP asymmetry, $\mathcal{A}^{CP}_{D^*D}(t)$, can be defined [22]

$$\mathcal{A}^{CP}_{D^*D}(t) = \frac{S_{D^{*+}D^-}\sin(\Delta m_d t) - C_{D^{*+}D^-}\cos(\Delta m_d t)}{\cosh(\Delta\Gamma t/2) - A^{\Delta\Gamma}_{D^{*+}D^-}\sinh(\Delta\Gamma t/2)} \tag{16}$$

where $\Delta m_d = 0.510\hbar\, ps^{-1}$ and with [23].

$$S_{D^{*+}D^-} = \frac{2Im\lambda_{D^{*+}D^-}}{1+|\lambda_{D^{*+}D^-}|^2},$$

$$C_{D^{*+}D^-} = \frac{1-|\lambda_{D^{*+}D^-}|^2}{1+|\lambda_{D^{*+}D^-}|^2},$$
$$A^{\Delta\Gamma}_{D^{*+}D^-} = -\frac{2Re\lambda_{D^{*+}D^-}}{1+|\lambda_{D^{*+}D^-}|^2}, \tag{17}$$

For them also applies [24]

$$(S_{D^{*+}D^-})^2 + (C_{D^{*+}D^-})^2 + (A^{\Delta\Gamma}_{D^{*+}D^-})^2 = 1, \tag{18}$$

and this constraint may or may not imposed to fits. To calculate the mixing-induced and direct CP violation, we use $S_{D^{*+}D^-}$ and $C_{D^{*+}D^-}$ parameters, respectively. parameter $|A^{\Delta\Gamma}_{D^{*+}D^-}|$ introduces another observable for neutral meson systems. In the B^0 decay, the expression for the time-dependent amplitude $\mathcal{A}^{CP}_{D^*D}(t)$ is simplified because of the low oscillation frequency. Therefore, the Eq. (16) becomes [25]

$$\mathcal{A}^{CP}_{D^*D}(t) = S_{D^{*+}D^-}\sin(\Delta m_d t) - C_{D^{*+}D^-}\cos(\Delta m_d t) \tag{19}$$

By changing the final state ($D^{*+}D^-$ to $D^{*-}D^+$), the values of $S_{D^{*-}D^+}$, $C_{D^{*-}D^+}$ and $A^{\Delta\Gamma}_{D^{*-}D^+}$ are obtained. From the combination of final states $D^{*+}D^-$ and $D^{*-}D^+$, the following CP parameters for the $B^0 \to D^{\pm*}D^{\mp}$ decay can be defined [26]

$$S_{D^*D} = \frac{1}{2}(S_{D^{*+}D^-} + S_{D^{*-}D^+}),$$
$$\Delta S_{D^*D} = \frac{1}{2}(S_{D^{*+}D^-} - S_{D^{*-}D^+}),$$
$$C_{D^*D} = \frac{1}{2}(C_{D^{*+}D^-} + C_{D^{*-}D^+}),$$
$$\Delta C_{D^*D} = \frac{1}{2}(C_{D^{*+}D^-} - C_{D^{*-}D^+}). \tag{20}$$

Table 4 The CP violation parameters and branching ratio for $B^0 \to D^{*+}D^-$ decay at three different choices of μ scale

Parameters	$\mu = m_b/2$	$\mu = m_b$	$\mu = 2m_b$	Exp.
$S_{D^{*+}D^-}$	-0.630 ± 0.021	-0.655 ± 0.021	-0.673 ± 0.022	-0.80 ± 0.09 [12]
$C_{D^{*+}D^-}$	-0.025 ± 0.015	-0.031 ± 0.016	-0.029 ± 0.015	-0.03 ± 0.09 [12]
$S_{D^{*-}D^+}$	-0.734 ± 0.031	-0.763 ± 0.031	-0.748 ± 0.031	-0.83 ± 0.09 [12]
$C_{D^{*-}D^+}$	-0.036 ± 0.006	-0.071 ± 0.008	-0.080 ± 0.009	-0.02 ± 0.08 [12]
S_{D^*D}	-0.707 ± 0.022	-0.709 ± 0.024	-0.710 ∓ 0.024	$-0.861 \pm 0.077 \pm 0.019$ [9]
C_{D^*D}	-0.030 ± 0.003	-0.051 ± 0.004	-0.054 ± 0.004	$-0.059 \pm 0.092 \pm 0.020$ [9]
$\triangle S_{D^*D}$	0.076 ± 0.004	0.054 ± 0.003	0.037 ± 0.002	$+0.019 \pm 0.075 \pm 0.012$ [9]
$\triangle C_{D^*D}$	0.005 ± 0.000	0.020 ± 0.001	0.026 ± 0.002	$-0.031 \pm 0.092 \pm 0.016$ [9]
$\mathcal{A}^{CP}_{D^*D}$	0.011 ± 0.001	0.008 ± 0.001	0.005 ± 0.001	$0.008 \pm 0.014 \pm 0.006$ [9]
$\mathcal{B}(\times 10^{-4})$	4.65 ± 1.12	4.98 ± 1.20	5.25 ± 1.26	6.03 ± 0.50 [10]

The S_{D^*D} is mixing induced CP violation However $\triangle S_{D^*D}$ is insensitive to CP violation because is related to the strong phase. In the case of CP invariance, $S_{D^{*+}D^-} = -S_{D^{*-}D^+}$ is fulfilled. The C_{D^*D} is direct CP violation and $\triangle C_{D^*D}$ define the asymmetry between the rates $\Gamma(B^0 \to D^{*+}D^-) + \Gamma(\bar{B}^0 \to D^{*-}D^+)$ and $\Gamma(B^0 \to D^{*-}D^+) + \Gamma(\bar{B}^0 \to D^{*+}D^-)$ [27]. The $\triangle C_{D^*D} = \pm 1$ denotes a flavour-specific decay, where no CP violation in the interference between decay and decay after mixing is feasible, while decays with $\triangle C_{D^*D} = 0$ have the highest sensitivity to mixing induced CP violation.

3 Numerical results and conclusion

The CP parameters resulting from the fit to the decay time, direct CP violation and branching ratio for the $B^0 \to D^{*+}D^-$ decay are shown in Table 4.

The main our goal of the analysis of $B^0 \to D^{*+}D^-$ decay was to calculate the CP parameters (S_{D^*D}, C_{D^*D}, $\triangle S_{D^*D}$, $\triangle C_{D^*D}$, and $\mathcal{A}^{CP}_{D^*D}$). Studying decays that involve CP violation is a good way to verify the theoretical principles in the quark-flavour of the SM. The $B^0 \to D^{*+}D^-$ decay, involves $b \to c\bar{c}d$ transitions, which are CKM suppressed. The contributions of higher-order are not Cabibbo-suppressed so the analysis of the $B^0 \to D^{*+}D^-$ decay helps to constrain these contributions in order to distinguish them from the effects of new physics. Here we have obtained the direct CP violation and parameters CP violation from interference between decay with and without mixing. The uncertainty of the calculated parameters is due to the mass of quarks and mesons, the decay constant and CKM matrix elements. The most important value in the theoretical uncertainty is related to the decay constant. We have calculated the CP parameters as $\mathcal{A}^{CP}_{D^*D} = 0.008 \pm 0.001$. Also, we have found $S_{D^*D} = -0.709 \pm 0.024$, $\triangle S_{D^*D} = 0.054 \pm 0.003$, $C_{D^*D} = -0.051 \pm 0.004$ and $\triangle C_{D^*D} = 0.020 \pm 0.001$. From the sum of the amplitudes, we have calculated the total amplitude and obtained comparable result with experimental value for the branching ratio as $\mathcal{B}(B^0 \to D^{*+}D^-) = (5.20 \pm 1.25) \times 10^{-4}$ at $\mu = 2m_b$ scale.

Data Availability Statement This manuscript has no associated data or the data will not be deposited. [Authors' comment: This work is purely theoretical. Therefore, no data has been used except experimental results. The results obtained in this article are theoretical values and can be used by the public.]

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