CP Violation in D meson Decays

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We discuss the direct CP violation in the singly Cabibbo suppressed two body decays of the neutral D mesons. Ascribing the large SU(3) violations to the final state interactions one gets large strong phase differences necessary for substantial direct CP violation. While the absolute value of the CP violating asymmetries depend on the uncertain strength of the penguin contribution, we predict an asymmetry for the decays into charged pions more than twice as large and having opposite sign with respect to that for charged kaons.

1 Introduction

The experimental results on CP violation in singly Cabibbo suppressed (SCS) decays of the D^0 and $\bar{D}^0$ mesons, larger of the common expectation beforehand, published in [1, 2] after the less conclusive results of the beauty factories [3, 4] have recently been contradicted by new analyses by the LHCb Collaboration that gave smaller results and moreover of different signs according to the method used [5, 6]. In the following, we report the analysis made in [7].
Defining the CP violating asymmetries for decay into the final state f as

$$a(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)}$$

the difference of asymmetries, $a(f)$, in the decays into charged kaons and charged pions, $\Delta_{\rm CP} = a(K^+K^-) - a(\pi^+\pi^-)$, has been measured with the following results:

$$\begin{aligned} \Delta_{\rm CP} &= (-0.62 \pm 0.21 \pm 0.10)\% \text{ (CDF)}, & (1)\\ &= (-0.82 \pm 0.21 \pm 0.11)\% \text{ (LHCb1)}, & (2)\\ &= (-0.87 \pm 0.41 \pm 0.06)\% \text{ (Belle)}, & (3)\\ &= (+0.24 \pm 0.62 \pm 0.26)\% \text{ (BaBaR)}, & (4)\\ &= (-0.34 \pm 0.15 \pm 0.10)\% \text{ (LHCb2)}, & (5)\\ &= (+0.49 \pm 0.30 \pm 0.14)\% \text{ (LHCb3)}. & (6) \end{aligned}$$

A naive weighted average [8] would give $\Delta_{\rm CP} = (-0.33 \pm 0.12)\%$, also compatible with a null result. Many authors think that it is a sign of new physics [9], while others think that such results are compatible with the standard model [10, 11]. In [7] we support the second hypothesis.

In [12] we presented a model to evaluate the decay branching ratios of D and D_s mesons. The model was based on factorization and include a way to take into account the rescattering effects through nearby resonances and gives CP violation asymmetries at least one order of magnitude smaller than what was found in [1, 2]. The experimental data however did change in the meantime, so in [7] we have done a new analysis, limiting our consideration to the SCS decays.

In [12] we observed that the large flavor SU(3) violations in the data were mainly due to the rescattering effects (because of the difference in mass of the relevant resonances). Therefore we now assume SU(3) symmetry for the weak decay amplitudes prior to rescattering. Furthermore, we approximate the hamiltonian for D weak decays with its $\Delta U = 1$ part when estimating branching ratios, introducing the $\Delta U = 0$ terms only for the calculation of asymmetries. This is justified by the smallness of the relevant CKM elements, $|V_{\rm ub}V^*_{\rm cb}| << |V_{\rm ud(s)}V^*_{\rm cd(s)}|$.

2 Decay amplitudes and branching ratios

The weak effective hamiltonian for SCS charmed particles decays is:

$$\begin{aligned}
\mathcal{H}_{\rm w} &= \frac{G_F}{\sqrt{2}} V_{ud}\, V^*_{cd}\, [C_1 Q_1^d + C_2 Q_2^d] \;+\; \frac{G_F}{\sqrt{2}} V_{us}\, V^*_{cs}\, [C_1 Q_1^s + C_2 Q_2^s] \\
&- \frac{G_F}{\sqrt{2}} V_{ub}\, V^*_{cb} \sum_{i=3}^{6} C_i Q_i \;+\; h.c.
\end{aligned} \tag{7}$$

where the C_i are Wilson coefficients that multiply the four–fermion operators defined as [13]

$$\begin{aligned}
Q_1^d &= \bar{u}^\alpha \gamma_\mu (1-\gamma_5) d_\beta\, \bar{d}^\beta \gamma^\mu (1-\gamma_5)\, c_\alpha\ , \\
Q_2^d &= \bar{u}^\alpha \gamma_\mu (1-\gamma_5) d_\alpha\, \bar{d}^\beta \gamma^\mu (1-\gamma_5)\, c_\beta\ , \\
Q_3 &= \bar{u}^\alpha \gamma_\mu (1-\gamma_5)\, c_\alpha \sum_q \bar{q}^\beta \gamma^\mu (1-\gamma_5)\, q_\beta, \\
Q_4 &= \bar{u}^\alpha \gamma_\mu (1-\gamma_5)\, c_\beta \sum_q \bar{q}^\beta \gamma^\mu (1-\gamma_5)\, q_\alpha, \\
Q_5 &= \bar{u}^\alpha \gamma_\mu (1-\gamma_5)\, c_\alpha \sum_q \bar{q}^\beta \gamma^\mu (1+\gamma_5)\, q_\beta. \\
Q_6 &= \bar{u}^\alpha \gamma_\mu (1-\gamma_5)\, c_\beta \sum_q \bar{q}^\beta \gamma^\mu (1+\gamma_5)\, q_\alpha.
\end{aligned} \tag{8}$$

The operators Q_1^s and Q_2^s are obtained by means of the substitution $d \to s$ in Q_1^d and Q_2^d.

Looking at the U spin transformation properties, the hamiltonian can be decomposed in two parts. The dominant part has $\Delta U = 1$ and it is

$$\begin{aligned}
H_{\Delta U=1} &= \frac{G_F}{2\sqrt{2}} (V_{us}\, V^*_{cs} - V_{ud}\, V^*_{cd}) [C_1 (Q_1^s - Q_1^d) + C_2 (Q_2^s - Q_2^d)] \qquad (9) \\
&\simeq \frac{G_F}{\sqrt{2}} \sin\theta_C \cos\theta_C [C_1 (Q_1^s - Q_1^d) + C_2 (Q_2^s - Q_2^d)].
\end{aligned}$$

The remaining part, that using the unitarity of the CKM matrix can be written in the form

$$H_{\Delta U=0} = -\frac{G_F}{\sqrt{2}} V_{ub}\, V^*_{cb} \left\{ \sum_{i=3}^{6} C_i Q_i + \frac{1}{2} [C_1 (Q_1^s + Q_1^d) + C_2 (Q_2^s + Q_2^d)] \right\}, \tag{10}$$

may be neglected in the calculation of decay branching ratios (even if necessary for CP violation) given that $|V_{\rm ub}V^*_{\rm cb}| << \sin\theta_C \cos\theta_C$. In this approximation, the neutral charmed meson D^0 being a U-spin singlet, only two independent amplitudes are needed for D^0 SCS decays into two pseudoscalars belonging to SU(3) octets. In fact, there are two independent combinations of S-wave states having U=1:

$$\frac{1}{2}\Big\{|K^+ K^- > +|K^- K^+ > -|\pi^+ \pi^- > -|\pi^- \pi^+ > \Big\} \; ; \tag{11}$$
$$\frac{\sqrt{3}}{2\sqrt{2}}\Big\{|\pi^0 \pi^0 > -|\eta_8 \eta_8 > -\frac{1}{\sqrt{3}}(|\pi^0 \eta_8 > +|\eta_8 \pi^0 >)\Big\} \; ,$$

that may be combined in two states with given trasformation properties under SU(3):

$$|8, U = 1 >= \frac{\sqrt{3}}{2\sqrt{5}} \Big\{ |K^+K^- > +|K^-K^+ > -|\pi^+\pi^- > -|\pi^-\pi^+ > \tag{12}$$
$$- \big[|\pi^0\pi^0 > -|\eta_8\eta_8 > -\frac{1}{\sqrt{3}}(|\pi^0\eta_8 > +|\eta_8\pi^0 >)\big]\Big\},$$
$$|27, U = 1 >= \frac{1}{\sqrt{10}} \Big\{ |K^+K^- > +|K^-K^+ > -|\pi^+\pi^- > -|\pi^-\pi^+ > \tag{13}$$
$$+ \frac{3}{2}\big[|\pi^0\pi^0 > -|\eta_8\eta_8 > -\frac{1}{\sqrt{3}}(|\pi^0\eta_8 > +|\eta_8\pi^0 >)\big]\Big\}.$$

Another independent amplitude would appear considering decays to states involving an SU(3) singlet. In order to keep the number of parameters to a minimum we disregard decays to states containing the singlet η_1 meson.

The eqs.(12,13) imply no decay to neutral kaons ($K^0 \bar{K}^0$) and the decays to charged pions should be more frequent than to charged kaons because of the larger phase space, given the equal and opposite amplitudes. Both predictions are in disagreement with experiment.

The large SU(3) violations have been much discussed in the literature, a general first order analysis was done many years ago [14] and in recent works [9, 10] its relevance to CP violation has been stressed. In our model the necessary SU(3) breaking is determined by the final state interactions, described as the effect of resonances in the scattering of the final particles. Assuming no exotic resonances belonging to the 27 representation, the possible resonances have SU(3) and isospin quantum numbers $(8, I = 1)$, $(8, I = 0)$ and $(1, I = 0)$. Moreover, the two states with $I = 0$ can be mixed, yielding two resonances:

$$|f_0 > \;=\; +\sin\phi \;\; |8, I = 0 > +\cos\phi \;\; |1, I = 0 >, \tag{14}$$
$$|f_0' > \;=\; -\cos\phi \;\; |8, I = 0 > +\sin\phi \;\; |1, I = 0 > . \tag{15}$$

The mixing angle ϕ and the strong phases δ_0, δ_0' and δ_1 are our model parameters, together with the two independent weak decay amplitudes. In principle, the strong phases should be related to the mass M_i and total width Γ_i of the corresponding resonance through the relation

$$\tan\delta_i = \frac{\Gamma_i}{2(M_i - M_{D^0})} \; ,$$

however the experimental data on these scalar resonances are sparse and do not allow a clean determination of the phases. One plausible hypothesis is that the phase $\delta_1 \sim \pi/2$, since the isovector partner of the scalar resonance $K_0^*(1950)$ should have a mass close to the D^0 mass, as it follows deriving it from an equispacing formula [12]. Note also that we are putting to zero the small phase δ_{27}, so that the δ_i parameters actually correspond to the differences with respect to the phase in the non resonant channel.

The two independent and unknown weak amplitudes can be related to the commonly used diagrammatic amplitudes T and C (color connected and color suppressed respectively) [15] in the following way:

$$A_8(U=1) = \langle 8, U=1| H_{\Delta U=1} |D^0\rangle \quad \propto \quad T - \frac{2}{3}C \,, \tag{16}$$

$$A_{27}(U=1) = \langle 27, U=1| H_{\Delta U=1} |D^0\rangle \quad \propto \quad T + C. \tag{17}$$

It is important to stress that in our approach, differently from other authors, both the amplitudes T and C are real numbers, the strong phases being introduced as effects of rescattering. As an example, it is interesting to look at the decay amplitudes in charged pions and kaons including the effects of the final state interactions:

$$\begin{aligned} A(D^0 \to \pi^+\pi^-) &= \left(T - \frac{2}{3}C\right)\left\{-\frac{3}{10}\left(e^{\imath\delta_0} + e^{\imath\delta_0'}\right)\right. \\ &+ \left.\left(-\frac{3}{10}\cos(2\phi) + \frac{3}{4\sqrt{10}}\sin(2\phi)\right)\left(e^{\imath\delta_0'} - e^{\imath\delta_0}\right)\right\} \\ &- \left(T + C\right)\,\frac{2}{5}\,, \end{aligned} \tag{18}$$

$$\begin{aligned} A(D^0 \to K^+K^-) &= \left(T - \frac{2}{3}C\right)\left\{\frac{3}{20}\left(e^{\imath\delta_0} + e^{\imath\delta_0'}\right)\right. \\ &+ \left.\left(\frac{3}{20}\cos(2\phi) + \frac{3}{4\sqrt{10}}\sin(2\phi)\right)\left(e^{\imath\delta_0'} - e^{\imath\delta_0}\right) + \frac{3}{10}e^{\imath\delta_1}\right\} \\ &+ \left(T + C\right)\,\frac{2}{5}\,. \end{aligned} \tag{19}$$

The limit of exact flavor SU(3) would correspond to $\sin(\phi) = 1$, $\delta_0 = \delta_1$. In this limit the amplitudes do not depend on δ_0' (since in the approximation of keeping only the $\Delta U = 1$ hamiltonian the D^0 meson does not couple to the singlet state) they are of opposite sign and equal respectively to:

$$A[D^0 \to \pi^+\pi^-(K^+K^-)] \quad \to \quad \mp\left[\left(T - \frac{2}{3}C\right)\frac{3}{5}\,e^{\imath\delta_0} + \left(T + C\right)\,\frac{2}{5}\right]\,. \tag{20}$$

The expressions for the remaining amplitudes can be found in [7].

As it can be seen from the above equations, the SU(3) breaking corrections do not change the part of the amplitudes belonging to the 27 representation, but only the octet part, that also acquires a singlet component. Therefore, in our model the SU(3) breaking hamiltonian transforms as a triplet under SU(3), completely analogous to the simplifying hypothesis put forward in [14], first suggested in [16]. However, the number of parameters in our model is six, three of which describe the SU(3) symmetry breaking, while in [14] the symmetry breaking parameters are four.

We note that the experimental results for the decays of neutral and charged D mesons in a pion pair when analyzed in terms of amplitudes of given isospin A_2 and A_0, defined by

$\mathcal{A}(D^0 \to \pi^+\pi^-) = (\sqrt{2}\, A_0 - A_2)/\sqrt{6}$, give [11]:

$$\begin{aligned} |A_2| &= (3.08 \pm 0.08)\, 10^{-7}\ \text{GeV}\,, \\ |A_0| &= (7.6 \pm 0.1)\, 10^{-7}\ \text{GeV}\,, \\ \arg(A_2/A_0) &= \pm(93 \pm 3)^\circ\,. \end{aligned} \tag{21}$$

On the contrary, the presence of two independent amplitudes with isospin 1 in the $K\bar{K}$ channels does not allow a determination of the amplitudes from their decay branching ratios.

We found a good agreement with the experimental data for the rates with the following set of parameters (the upper or lower signs should be taken simultaneously):

$$\begin{array}{rcl} C\ /\ T & = & -\,0.529\,, \\ \sin(2\phi) = 0.701\,, & & \cos(2\phi) = 0.713\ , \\ \sin\delta_0 = \pm\,0.529\,, & & \cos\delta_0 = -\,0.848\ , \\ \sin\delta_0' = \pm\,0.794\,, & & \cos\delta_0' = 0.608\ , \\ \sin\delta_1 = \pm\,0.992\,, & & \cos\delta_1 = 0.126\ . \end{array} \tag{22}$$

In fact, using these values we obtain the following results for the ratios of decay rates:

$$\begin{aligned} \frac{\Gamma(D^0 \to K_S K_S)}{\Gamma(D^0 \to K^+K^-)} &= 0.0429\ , \\ \frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K^+K^-)} &= 0.354\ , \\ \frac{\Gamma(D^0 \to \pi^0\pi^0)}{\Gamma(D^0 \to K^+K^-)} &= 0.202\ , \end{aligned} \tag{23}$$

to be compared to the experimental values [17]: 0.043±0.010, 0.354±0.010, 0.202±0.013, respectively. Moreover, the ratio of the moduli of the two pion isospin amplitudes is $|A_2/A_0| = 0.40$ and its phase is $\mp 87.2^\circ$, in fair agreement with the experimental results reported in eq.(21). The result for the absolute values of the branching ratios, obtained using the experimental lifetime, agree within 20% with the values obtained using naive factorization (that may be derived in the $\pi^+\,\pi^-$ case from eq. (2.16) of [12]).

It may appear that describing four experimental data (the three ratios in eq.(23) and the analogous ratio for the two pion decay of a D^+, or equivalently the relative phase of the two pionic amplitudes with given isospin) with five parameters is trivial. However, four of these parameters are angles, and sines or cosines may only vary between -1 and 1, so that formulae like those given in the Appendix are not capable of describing any number. The result presented in eq.(22) has not been obtained with a least squares fit, and not every parameter has been taken as really free. In fact, we required $|\sin(\delta_1)| \simeq 1$ (as already said above) and $C\ /\ T \sim -\,0.5$, similar to the results of our old fits [12].

Finally, we note that identifying the η meson with η_8 the branching ratios to final states would come out

$$\begin{aligned} \frac{\Gamma(D^0 \to \pi^0\eta)}{\Gamma(D^0 \to K^+K^-)} &= 0.216 \\ \frac{\Gamma(D^0 \to \eta\eta)}{\Gamma(D^0 \to K^+K^-)} &= 0.250, \end{aligned} \tag{24}$$

to be compared to the experimental values (0.172±0.018, 0.422±0.051) respectively. Also in this case, the final state rescattering is helpful in allowing a decay rate to $\eta\eta$ larger than to $\pi^0\pi^0$, albeit to an insufficient level, in spite of the phase space difference.

3 CP asymmetries

A nonzero direct CP asymmetry is present only when the decay amplitude is a sum of two amplitudes with different weak phases and having also two different strong phases. If the amplitude for D decay is

$$\mathcal{A} = A\, e^{\imath\delta_A} + B\, e^{\imath\delta_B}\ ,$$

the CP conjugate amplitude would be

$$\bar{\mathcal{A}} = A^*\, e^{\imath\delta_A} + B^*\, e^{\imath\delta_B}\ ,$$

and the CP asymmetry is:

$$a_{\rm CP} = \frac{|\mathcal{A}|^2 - |\bar{\mathcal{A}}|^2}{|\mathcal{A}|^2 + |\bar{\mathcal{A}}|^2} = \frac{2\,\Im(A^*\,B)\ \sin(\delta_A - \delta_B)}{|A|^2 + |B|^2 + 2\,\Re(A^*\,B)\ \cos(\delta_A - \delta_B)}. \tag{25}$$

In our case the amplitude B is provided by the matrix elements of the $\Delta U = 0$ hamiltonian, eq.(10), that contains both $Q_{1(2)}$ and "penguin" operators. In this case, there are three independent symmetric states of two pseudoscalar mesons:

$$\begin{aligned}
&\frac{1}{2}\Big\{|K^+\,K^- > +|K^-\,K^+ > +|\pi^+\,\pi^- > +|\pi^-\,\pi^+ >\Big\}\ ; \qquad (26)\\
&\frac{1}{4}\left\{3\,|\pi^0\,\pi^0 > +|\eta_8\,\eta_8 > +\sqrt{3}\,(|\pi^0\,\eta_8 > +|\eta_8\,\pi^0 >)\right\}\ ;\\
&\frac{1}{\sqrt{3}}\left\{\frac{1}{4}|\pi^0\,\pi^0 > +\frac{3}{4}\,|\eta_8\,\eta_8 > -\frac{\sqrt{3}}{4}\,(|\pi^0\,\eta_8 > +|\eta_8\,\pi^0 >) + |K^0\,\bar{K^0} > +|\bar{K^0}\,K^0 >\right\}\ ,
\end{aligned}$$

that give rise to three amplitudes transforming as 27, 8 and 1 under SU(3) (for the $Q_{1(2)}$ part) and to two amplitudes transforming as 8 and 1 (for the penguin part). In the framework of quark diagrams (and neglecting annihilation) the third state in eq.(26) decouples, both for penguins and for the other terms. Moreover, the $\Delta I = 1/2$ property of the penguin selects one combination of the first two states. Taking into account that now also the singlet components of the resonances couple to the D^0 meson state, after rescattering the relevant amplitudes become:

$$\begin{aligned}
B(D^0 \to \pi^+\pi^-) &= \left(P + \frac{T'}{2}\right)\left\{\frac{1}{2}\left(e^{\imath\delta_0} + e^{\imath\delta_0'}\right)\right. \\
&+ \left.\left(-\frac{1}{6}\cos(2\phi) - \frac{7}{4\sqrt{10}}\sin(2\phi)\right)\left(e^{\imath\delta_0'} - e^{\imath\delta_0}\right)\right\} \\
&+ (T' + C')\left\{\frac{3}{20} - \frac{3}{40}\left(e^{\imath\delta_0} + e^{\imath\delta_0'}\right)\right. \\
&+ \left.\left[\frac{1}{120}\cos(2\phi) + \frac{1}{4\sqrt{10}}\sin(2\phi)\right]\left(e^{\imath\delta_0'} - e^{\imath\delta_0}\right)\right\}\ ,
\end{aligned} \tag{27}$$

$$\begin{aligned}
B(D^0 \to K^+K^-) &= \left(P + \frac{T'}{2}\right)\left\{\frac{1}{4}\left(e^{\imath\delta_0} + e^{\imath\delta_0'}\right)\right. \\
&+ \left.\left(-\frac{5}{12}\cos(2\phi) + \frac{1}{4\sqrt{10}}\sin(2\phi)\right)\left(e^{\imath\delta_0'} - e^{\imath\delta_0}\right) + \frac{1}{2}e^{\imath\delta_1}\right\} \\
&+ (T' + C')\left\{\frac{3}{20} - \frac{1}{40}\left(e^{\imath\delta_0} + e^{\imath\delta_0'}\right) + \frac{7}{120}\cos(2\phi)\left(e^{\imath\delta_0'} - e^{\imath\delta_0}\right) - \frac{1}{10}e^{\imath\delta_1}\right\}.
\end{aligned} \tag{28}$$

The parameter P represents, in eqs.(27,28), the "penguin" diagram, while with T' and C' we indicate the color connected and color suppressed contributions (we are neglecting annihilations) and them are related to T and C by

$$T' = -\,T\,\frac{V_{ub}\,V_{cb}^*}{\sin\theta_C\cos\theta_C} \quad \text{and} \quad C' = -\,C\,\frac{V_{ub}\,V_{cb}^*}{\sin\theta_C\cos\theta_C}\ . \tag{29}$$

We note that if $T' + C' = 0$ the terms containing these amplitudes have the same structure of the penguin term, and that therefore could be reabsorbed in the uncertainty of the penguin contribution. In our phase convention the amplitudes T and C are real, while T', C' and P are complex, having the phase $\pi - \gamma = (111 \pm 4)^\circ$ [17, 18].

The numerical value of the ratios $|T'/T|$ and $|C'/C|$ being $(6.6\pm0.9)\cdot10^{-4}$, they would result in a CP asymmetry of this order. A large asymmetry may only be due to the penguin contribution. We recall that the penguin diagrams were introduced as a possible explanation of the "octet enhancement" by Shifman, Vainshtein and Zacharov [19] many years ago. A large matrix element for these operators could successfully describe both the kaon and the hyperon non–leptonic decays. There has not been a general consensus on this approach, and in particular a recent lattice calculation [20] seems to indicate a different origin for the $\Delta I = 1/2$ dominance in kaon decays.

Using the expressions in equations (19,28) and neglecting the contribution of the terms containing T' and C', the $\mathcal{A}(K^+K^-)$ can be approximated by the

$$\mathcal{A}(K^+K^-) \simeq T\ f_T(\delta_i, \phi, C/T)\ +\ P\ f_P(\delta_i, \phi)\ ,$$

and equation (25) gives

$$a_{CP}(K^+K^-) \simeq \frac{2\,T\,\Im(P)\,\Im(f_T\,f_P^*)}{T^2\,|f_T|^2 + ...} \tag{30}$$

where we neglected terms of order $|P|/T$ in the denominator, an approximation already made in the calculation of the decay rates.

Inserting in the relevant formulae the parameter values previously determined from the branching ratios and choosing the lower signs in eq.(22), the CP asymmetries for decays in charged mesons turn out to be

$$\begin{aligned} a_{CP}(K^+K^-) &= \frac{\Im(P)}{T} \cdot (+1.469) \,, \qquad (31) \\ a_{CP}(\pi^+\pi^-) &= \frac{\Im(P)}{T} \cdot (-3.362) \,. \end{aligned}$$

The sign would be opposite if one chooses instead the upper signs in eq.(22). Our choice is suggested by the fact that apparently the resonance $f_0(1710)$ - that has a lower mass - prefers to decay in a pair of kaons [17] and should therefore be identified with f_0'.

We also report the prediction for CP asymmetries for decays in final states with neutral mesons, although it will probably be difficult to test them by experiment:

$$\begin{aligned} a_{CP}(K^0\bar{K}^0) &= \frac{\Im(P)}{T} \cdot (-1.217) \,, \qquad (32) \\ a_{CP}(\pi^0\pi^0) &= \frac{\Im(P)}{T} \cdot (-1.668) \,. \end{aligned}$$

We note that our parameters predict an asymmetry in the decay to charged pions that is of opposite sign with respect to the asymmetry for decays to charged kaons, and more than twice as large. Assuming instead equal values for the phases δ_0, δ_0' and δ_1, the asymmetries would be equal and opposite, but of considerable less magnitude (even for a maximal strong phase). Therefore, the SU(3) breaking in rescattering favors, in a sense, a larger Δ_{CP}. Taking into account the CKM elements entering in the definition of T and P, one has

$$\begin{aligned} \frac{\Im(P)}{T} &= \frac{|V_{ub}\,V_{cb}|}{\sin\theta_C \cos\theta_C} \sin\gamma \frac{< K^+\,K^-|\ \sum_{i=3}^{6}\ C_i Q_i + \frac{1}{2}[C_1\{Q_1^s + Q_1^d\} + C_2\{Q_2^s + Q_2^d\}]\ |D^0 >}{< K^+\,K^-|\,C_1(Q_1^s - Q_1^d) + C_2(Q_2^s - Q_2^d)\,|D^0 >} \\ &= 6.3\,10^{-4}\kappa \,, \qquad (33) \end{aligned}$$

where the notation $< K^+\,K^-|\ \{Q_i\}\ |D^0>$ indicates the matrix element evaluated with a penguin contraction of the operator. One obtains therefore:

$$\Delta_{\text{CP}} = 3.03\ 10^{-3}\kappa \,. \qquad (34)$$

A value of κ around three gives asymmetries at the percent level. Concerning the sign of Δ_{CP}, we note that if one uses factorization κ would be negative and Δ_{CP} would therefore be negative, in agreement with the majority of experimental results. We note however that if one uses factorization a considerably smaller value for κ would be expected, due to the smallness of the Wilson coefficients of QCD penguin operators.

Let us compare this result to what has been found in [11], where an analysis of the bounds imposed by unitarity on the final state interactions of the isospin zero amplitudes was pursued, both in a two–channel and in a three–channel situation. We note that the enhancement factor κ required is similar to what was found there in the three channel case, and that, in our SU(3) based scheme, the channels are in fact three (1, 8, 27).

4 Conclusion

We studied the singly Cabibbo suppressed decays of neutral D mesons by assuming that all the SU(3) violations are due to the final state interactions. Large values of the strong phases are necessary to predict consistent CP violation in the decay amplitudes. In our framework we were able to give an accurate description of decay branching ratios and of the isospin structure of the amplitudes for pionic decays.

The experimental situation regarding the CP violating asymmetries is at present rather confused, but we think anyhow of interest to have shown that large asymmetries can be obtained, considering the uncertainties of long distance contributions and with some stretching of the parameters, even without invoking New Physics.

A rather large value of the "penguin" matrix element would be needed to obtain asymmetries as large as in [1, 2, 3]. We recall that large "penguin" contributions were also suggested to reproduce rates and isospin structure of the decays of K mesons and hyperons [19], although it is not evident that the analogy can be pursued [16]. While the absolute value of the CP violating asymmetries cannot be safely predicted, we obtain an asymmetry for the decays into charged pions more than twice as large and having opposite sign with respect to that for charged kaons.

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