PROCEEDINGS OF SCIENCE

CP Violating Asymmetries in $D^0 \to PP$ Decays

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Final state interaction accounts for the large $SU(3)_f$ violations in the non leptonic decays of the charmed pseudoscalar mesons into two light pseudoscalars .
This gives information for the phases of the amplitudes proportional to $\sin(\theta)_C$ and on the CP violating asymmetries, which depend on two parameters in the framework of the standard model. To agree with the present experimental infomation one needs a large value of the parameter, which is expected to be small as a consequence of the Zweig selection rule, which would imply smaller values for the three more recent measurements of the CP violating asymmetries at LHC_b.

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1. Introduction

After the challenging research, which has lead to more than five standard deviations for $\Delta A_{CP} = -0.154 \pm 0.029 \times 10^{-2}$ [1], the same collaboration has recently proposed for the CP violating asymmetries for the decays of the charmed neutral pseudoscalar, D^0, into two charged pions, two charged kaons and two K^S's the following values [2]:

$$Asy(D^0 \to \pi^+\pi^-) = (0.22 \pm 0.057) \times 10^{-2} \quad (1)$$

$$Asy(D^0 \to K^+K^-) = (0.077 \pm 0.057) \times 10^{-2} \quad (2)$$

$$Asy(D^0 \to K_S K_S) = -3.1 \pm 1.2 \pm 0.4 \pm 0.2 \times 10^{-2} \quad (3)$$

The last result differs by the measurement performed by Belle [3],

$$0.0 \pm 1.5 \pm 0.2 \times 10^{-2} \quad (4)$$

while the average is:

$$Asy(D^0 \to K_S K_S)_{ave} = (-1.9 \pm 1.0) \times 10^{-2}. \quad (5)$$

CP violating asymmetries have been advocated many years ago [4] as a consequence of the final state interaction needed to account for the large $SU(3)_f$ violations in the amplitudes for the decays of charmed particles into two pseudoscalar mesons and implied by the isospin identities for the Cabibbo allowed amplitudes for the decays of D particles into $\bar{K}\pi$ [5] and Cabibbo forbidden into two pions [6] .

In a previous paper [7] we have written the amplitudes for the decays of the charmed pseudoscalar into two pseudoscalars, assuming $SU(3)_f$ for the non rescattered amplitudes and a final state interaction coming from the presence of a scalar nonet in the region of the masses of the D's .

We kept into account the $SU(3)_f$ violation related to the non conservation of the strangness changing vector currents and introduced two $SU(3)_f$ violating "ad hoc" parameters, since the precision in the measurement of the branching ratios is better than the one expected by $SU(3)_f$.

We have been able to describe the branching ratios for the D decays and the comparison with the values found after our work shows the stability of our predictions. To evaluate the CP violating asymmetries one should compute the $\Delta U = 0$ amplitudes coming for the penguin and pseudopenguin contributions, both proportional to $V_{cb}V^*_{ub}$, which relate the D^0 to the U singlets of the 1, 8 and 27 representations of $SU(3)_f$.

Since the reduced matrix element for the tensor product $\bar{3} \times 15 = 27$ has been fixed from the $\Delta U = 1$ matrix elements only two parameters are needed to fix the non rescattered $\Delta U = 0$ amplitudes, while the phases and the singlet-octet mixing of the isospin 0 states, which are responsible for the final state interaction, have been fixed by the study of th $\Delta U = 1$ matrix elements.

In conclusion the $\Delta U = 0$ amplitudes and the CP violating asymmetries depend only on two parameters, which will allow us to write a relationship between the three CP violating asymmetries measured up to now.

By assuming the Zweig selection rules [8], the CP violating asymmetries would depend only on one parameter .

In the next section we shall write the amplitudes proposed in [7] for the Cabibbo forbidden decays

into two pions or two kaons and the CP violating asymmetries in terms of three parameters, one of them fixed by the fit to the experimental branching ratios .
In the third section we fix the other two parametes to comply with Eqs.(1,2) or with ΔA_{CP} and Eq.(4) .
Finally we shall give our conclusion.

2. The strangness conserving amplitudes for D^0 decays into two pions or kaons

One has to consider the matrix elements of the operator

$$\bar{u}_L(x)\gamma_\mu s_L(x)\bar{s}_L(x)\gamma^\mu c_L(x) - \bar{u}_L(x)\gamma_\mu d_L(x)\bar{d}_L(x)\gamma^\mu c_L(x) \tag{6}$$

for the contribution proportional to $\sin\theta_C$ and :

$$\bar{u}_L(x)\gamma_\mu s_L(x)\bar{s}_L(x)\gamma^\mu c_L(x) + \bar{u}_L(x)\gamma_\mu d_L(x)\bar{d}_L(x)\gamma^\mu c_L(x) \tag{7}$$

$$\left[\bar{u}(x)\lambda_a\gamma_\mu u(x) + \bar{d}(x)\lambda_a\gamma_\mu d(x) + \bar{s}(x)\lambda_a\gamma_\mu s(x)\right]\bar{u}_L(x)\lambda_a\gamma^\mu c_L(x) \tag{8}$$

for the contributions proportional to $V_{cb}V^*ub$.

We call $A(D^0 \to f)$ the contributions proportional to $\sin\theta_C$ and $A(D^0 \to f)$ the ones proportional to $-V_{cb}v^*_{ub}$ and write [7] :

$$\begin{aligned} A(D^0 \to \pi^+\pi^-) &= (T - \frac{2}{3}C)[-\frac{3}{10}(\exp i\delta_0' + \exp i\delta_0') \\ &+ (-\frac{3}{10}\cos 2\phi + \frac{3}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0)] \\ &- \frac{2}{5}(T + C) \end{aligned} \tag{9}$$

$$\begin{aligned} A(D^0 \to \pi^0\pi^0) &= (T - \frac{2}{3}C)[-\frac{3}{10}(\exp i\delta_0' + \exp i\delta_0') \\ &+ (-\frac{3}{10}\cos 2\phi + \frac{3}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0)] \\ &+ \frac{3}{5}(T + C) \end{aligned} \tag{10}$$

$$\begin{aligned} A(D^0 \to K^+K^-) &= (T - \frac{2}{3}C)\ [\frac{3}{20}(\exp i\delta_0' + \exp i\delta_0') \\ &+ (\frac{3}{20}\cos 2\phi + \frac{1}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0) \\ &+ \frac{3}{10}\exp i\delta_1] + \frac{2}{5}(T + C) \end{aligned} \tag{11}$$

$$\begin{aligned} A(D^0 \to K^0\bar{K}^0) &= (T - \frac{2}{3}C)[\frac{3}{20}(\exp i\delta_0' + \exp i\delta_0') \\ &+ (\frac{3}{20}\cos 2\phi + \frac{1}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0) \\ &- \frac{3}{10}\exp i\delta_1] \end{aligned} \tag{12}$$

$$
\begin{aligned}
&B(D^0 \to \pi^+\pi^-) = \tilde{P}[\frac{1}{2}(\exp i\delta_0' + \exp i\delta_0) \\
&+ (-\frac{1}{6}\cos 2\phi - \frac{7}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0)] \\
&+ \Delta_4[(-\frac{1}{3}\cos 2\phi - \frac{1}{4\sqrt{10}}\sin 2\phi(\exp i\delta_0' - \exp i\delta_0))] \\
&+ (T+C)[-\frac{3}{20}(\exp i\delta_0' + \exp i\delta_0)(\frac{1}{60}\cos 2\phi - \frac{1}{4\sqrt{10}}\sin 2\phi) \\
&(\exp i\delta_0' - \exp i\delta_0) + \frac{3}{10}]
\end{aligned} \tag{13}
$$

$$
\begin{aligned}
&B(D^0 \to \pi^0\pi^0) = \tilde{P}[\frac{1}{2}(\exp i\delta_0' + \exp i\delta_0) \\
&+ (-\frac{1}{6}\cos 2\phi - \frac{7}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0)] \\
&+ \Delta_4[(-\frac{1}{3}\cos 2\phi - \frac{1}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0)] \\
&+ (T+C)[-\frac{3}{20}(\exp i\delta_0' + \exp i\delta_0)(\frac{1}{60}\cos 2\phi - \frac{1}{4\sqrt{10}}\sin 2\phi) \\
&(\exp i\delta_0' - \exp i\delta_0)] - \frac{7}{10}
\end{aligned} \tag{14}
$$

$$
\begin{aligned}
&B(D^0 \to K^+K^-) = \tilde{P}[\frac{1}{4}(\exp i\delta_0' + \exp i\delta_0) \\
&+ (-\frac{5}{12}\cos 2\phi + \frac{1}{4\sqrt{10}}\sin 2\phi)(\exp i\delta_0' - \exp i\delta_0) \\
&+ \frac{!}{2}\exp i\delta_1] + \Delta_4[\frac{1}{4}(\exp i\delta_0' + \exp i\delta_0) \\
&(-\frac{1}{12}\cos 2\phi + \frac{3}{4\sqrt{10}}(\exp i\delta_0' - \exp i\delta_0) - \frac{1}{2}\exp i\delta_1] \\
&+ (T+C)[-\frac{1}{20}(\exp i\delta_0' + \exp i\delta_0) \\
&+ \frac{7}{60}\cos 2\phi(\exp i\delta_0' - \exp i\delta_0) \\
&+ \frac{3}{10} - \frac{1}{5}\exp i\delta_1]
\end{aligned} \tag{15}
$$

$$B(D^0 \to K^0\bar{K}^0) = \tilde{P}[\frac{1}{4}(\exp i\delta'_0 + \exp i\delta_0)$$
$$+ (-\frac{5}{12}\cos 2\phi + \frac{1}{4\sqrt{10}}\sin 2\phi)(\exp i\delta'_0 - \exp i\delta_0)$$
$$- \frac{!}{2}\exp i\delta_1] + \Delta_4[\frac{1}{4}(\exp i\delta'_0 + \exp i\delta_0)$$
$$(-\frac{1}{12}\cos 2\phi + \frac{3}{4\sqrt{10}}\sin 2\phi)(\exp i\delta'_0 - \exp i\delta_0) + \frac{1}{2}\exp i\delta_1] \tag{16}$$
$$+ (T + C)[-\frac{1}{20}(\exp i\delta'_0 + \exp i\delta_0)$$
$$+ \frac{7}{60}\cos 2\phi(\exp i\delta'_0 - \exp i\delta_0) + \frac{3}{10} + \frac{1}{5}\exp i\delta_1]$$

With the central values of the parameters fixed by the experimental branching ratios, $T = 0.424$, $C = -0.211$, $\delta'_0 = -0.84$, $\delta_0 = -2.373$, $\delta_1 = -1.085$ and$\phi = 0.435$ we get ;

$$A(D^0 \to \pi^+\pi^-) = -0.086 + 0.244i \tag{17}$$
$$A(D^0 \to \pi^0\pi^0) = 0.127 + 0.244i \tag{18}$$
$$A(D^0 \to K^+K^-) = 0.378 - 0.279i \tag{19}$$
$$A(D^0 \to K^0\bar{K}^0) = 0.134 + 0.02i \tag{20}$$
$$B(D^0 \to \pi^+\pi^-) = (-0.76 - 0.69i)\tilde{P} + (-0.38 - 0.014i)\Delta_4 + (0.49 + 0.21i)(T + C) \tag{21}$$

$$B(D^0 \to \pi^0\pi^0) = (-0.76 - 0.69i)\tilde{P} + (-0.38 - 0.014i)\Delta_4 + (0.51 + 0.21i)((T + C) \tag{22}$$
$$B(D^0 \to K^+K^-) = (-0.68 - 0.79i)\tilde{P} + (-0.069 - 0.076i)\Delta_4 + (0.31 + 0.255i)(T + C) \tag{23}$$
$$B(D^0 \to K^0\bar{K}^0) = (-0.535 + 0.09i)\tilde{P} + (0.40 - 0.81i)\Delta_4 + (0.1 - 0.145i)(T + C) \tag{24}$$

Neglecting the contrbutions to the denominator of the contributions proportional to

$$|V_{cb}V^*_{cu}|^2$$

the CP violating asymmetries are given by:

$$A_{Asy}(D \to f) = Im\left[2\frac{V_{ub}V^*_{cb}}{V_{cs}V^*_{us} - V_{cd}V^*_{ud}}\right]\frac{Im[A(D \to f)B^*(D \to f)]}{|A(D \to f)|^2} \tag{25}$$

The factor depending on the matrix elements of the Cabibbo Kobayashi Maskawa matrices is given in terms of the approximate parametrization proposed by Wolfenstein :

$$|A|^2(\lambda_C)^4\eta = 6.085 \times 10^{-4} \tag{26}$$

One gets the following CP violating asymmetries in terms of $\tilde{P}$, Δ_4 and $T + C$:

$$Asy(D^0 \to \pi^+\pi^-) = 6.085 \times 10^{-4}(-3.68\tilde{P} - 1.43\Delta_4 + 1.05(T + C) \tag{27}$$

$$\begin{aligned} Asy(D^0 \to K^+K^-) &= 6.085 \times 10^{-4}(2.22\tilde{P} - 0.043\Delta_4 \\ &- 0.83(T + C) = 6.085 \times 10^{-4} \end{aligned} \tag{28}$$

$$\begin{aligned} Asy(D^0 \to K^S K^S) &= 6.085 \times 10^{-4}(-1.26\tilde{P} + 6.43\Delta_4 \\ &+ 1.019(T + C)|A|^2(\lambda_C)^4\eta = 6.085 \times 10^{-4} \end{aligned} \tag{29}$$

3. Comparison with experiments

From the central values of the asymmetries given in Eqs.(1,2) we get :

$$\tilde{P} = 0.454 \tag{30}$$

$$\Delta_4 = -3 \tag{31}$$

which imply for the asymmetry for the decay into two K^S

$$Asy(D^0 \to K^S K^S) = -1.2 \times 10^{-2} \tag{32}$$

in reasonable agreement with the experimental value written in Eq.(5) . A large asymmetry into two K^S may be expected , since at difference from the $\Delta U = 1$ ampòitude the $\Delta U = 0$ amplitude does not violate $SU(3)_f$. However the final state interaction advocated to comply with the experimental branching ratio into two K^S gives rise to a not so small amplitude $A(D^0 \to K^S K^S)$. Also $B(D^0 \to K^S K^S)$ violates the Zweig selection rule [8], since both the penguin and pseudopenguin operators contain either the product of fields $s(x)\bar{s}(x)$ or $d(x)\bar{d}(x)$ and therefore to create a $K^0\bar{K}^0$ pair requires a higher order in α_s . Indeed the parameter Δ, which appears in the amplitudes for the decays of the charged D, is allowed by $SU(3)_f$, but violates the Zweig selection rule and takes the value -0.026, an order of magnitude smaller than T and C . Let us remember that the Zweig selection rule accounts for the narrow width of the J/ψ . To look for a small value of Δ_4 we fix the parameters from the most precise measurement, ΔA_{CP}, and the Belle vanishing result and find :

$$\tilde{P} = -0.345 \tag{33}$$

$$\Delta_4 = -0.025 \tag{34}$$

which would imply a different sign for the asymmetries for the charged final states :

$$Asy(D^0 \to \pi^+\pi^-) = 0.93 \times 10^{-3} \tag{35}$$

$$Asy(D^0 \to K^+K^-) = - - 0.58 \times 10^{-3} \tag{36}$$

The Zweig selection rule relates the amplitudes of the pseudopenguin to the $A(D^0 \to PP)$ and would imply a contribution $-T = -0.424$ to $\tilde{P}$ and a small value for the contribution of the penguin, 0.079 . Also the value for Δ_4 in Eq.(29) is almost equal to Δ .

4. Conclusion

The parametrization proposed in [7] for the amplitudes $A(D^0 \to PP)$ to describe the experimental branching ratios into two pseudoscalar mesons of the D's, which depend on the $\Delta U = 1$ terms proportional to λ_C, allow to describe the CP violating asymmetries of the Cabibbo forbidden decays into two pions and into two kaons in terms of two parameters, $\tilde{P}$ and Δ_4 . By fixing them to get the central values of the asymmetries found for the charged final states one finds a large negative value for Δ_4 and an asymmetry for the final state with two K^S consistent with the average of the LHC_b and Belle measurements . Since the Zweig selection rule imples a small value for that parameter we have fixed the two parameters to agree with the most precise measurement, ΔA_{CP}, and with the vanishing result of Belle . With this choice the asymmetries into the cherged final states are predicted to be opposite and less than 10^{-3} . The high value of Δ_4 necessary to comply with the central values of the three recent measurements at LHC_b may suggest an effective operator proportional to $\bar{d}(x)\gamma_5 s(x)\bar{s}(x)\gamma_5 d(x)\bar{u}(x)\gamma_5 c(x)$ containing the fields able to destroy the initial D^0 and to create the $K^0\bar{K}^0$ pair . This conclusion depends on the parametrization proposed in [7] : indeed Schacht and Sony [9] have been able to find a large nagative asymmetry into two K^S in the framework of the standard model .

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