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Mixing of neutral charmed mesons and tests for CP violation in their decays

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The reactions $e^+e^- \to D^0\bar{D}^0 + m(\pi^0) + n(\gamma)$, followed by decays of the charmed mesons to eigenstates of CP, satisfy selection rules which allow tests of CP invariance. When the e^+e^- reactions proceed through one virtual photon and n is even (odd), the decay products of the two neutral charmed mesons will have opposite (equal) CP to the approximation in which CP is conserved. Final states with even CP include $\pi\pi$ and, approximately, $K_L^0\pi^0$; the final state $K_S^0\pi^0$ is nearly CP-odd. It is shown that when both neutral charmed mesons decay to *identical* final states, the signal for CP violation always contains a factor related to the amount of D^0-$\bar{D}^0$ mixing, and hence is small if this mixing is small (as in the standard charm model). When two *different* final states are observed, the signal for CP violation contains such a factor only in certain models, of which the superweak model is an example.

I. INTRODUCTION

The charm hypothesis[1] predicts the existence of neutral, weakly decaying, spinless mesons D^0 and $\bar{D}^0$,[1,2] which can mix with one another via the weak interactions.[2-6] They may then display some of the remarkable features of the K^0-$\bar{K}^0$ system, including CP violation.[7] In this note we wish to describe a class of tests for CP violation in the D^0-$\bar{D}^0$ system as produced in electron-positron annihilations.[8]

The tests we shall discuss, in contrast to many proposed earlier,[4] involve the experimental search for signals which are forbidden in the CP-conserving limit. Such selection rules are achieved by producing a $D^0\bar{D}^0$ pair in a state of definite C. (For an early discussion of similar effects for kaons, see Ref. 9.) Singly produced D^0 or $\bar{D}^0$ mesons are not expected to give rise to easily separated CP eigenstates D_1^0 and D_2^0. In contrast to the situation for kaons, where K_S^0 and K_L^0 can be separated on the basis of their vastly differing lifetimes, the D_1^0 and D_2^0 both are expected to have lifetimes of the order of 10^{-13} sec,[2] and hence to be very difficult to separate from one another on the basis of lifetimes alone.

The tests make use of the fact that a virtual photon produces states of odd C. Thus in reactions

$$e^+e^- \to D^0\bar{D}^0 + m(\pi^0) + n(\gamma), \quad m \geq 0, \; n \geq 0, \tag{1}$$

the $D^0\bar{D}^0$ system will be in a state of definite C to the extent that the reactions proceed through an intermediate state of one virtual photon. This fact entails selection rules (in the CP-invariant limit) affecting the subsequent decays of D^0 and $\bar{D}^0$. When n is even (odd), $C(D^0\bar{D}^0)$ is odd (even), and the decay products of D^0 and $\bar{D}^0$ will have opposite (equal) CP.

We first prove the above statements (Sec. II). The results for reactions (1) then are applied in Sec. III to specific decays like $D^0 \to \pi\pi$, $D^0 \to \bar{K}^0\pi^0$, and to production processes in which the neutral pions or photons in (1) arise from the decays

$$D^{*0} \to D^0 + \pi^0 \tag{2}$$

or

$$D^{*0} \to D^0 + \gamma. \tag{3}$$

Both (2) and (3) are expected to occur with reasonable rates,[10] and both have probably been observed.[11] Section IV is devoted to a discussion of possible CP-violating effects. The observed signals are first calculated as a function of the times at which the two charmed particles decay, and some interesting correlations pointed out. (Similar correlations were discussed earlier for neutral kaons.[12,13]) We then integrate over the time dependences to obtain intensities of signals for CP violation. When each charmed particle decays to the *same* CP eigenstate (such as $\pi^+\pi^-$), the signal is found to be proportional to a quantity related to the D^0-$\bar{D}^0$ mixing. Such signals hence may be fairly small, as D^0-$\bar{D}^0$ mixing is anticipated to be relatively weak in most theories.[2-5] However, since large mixing effects still are not ruled out,[6] we quote[5] a simple means of estimating them. If mixing effects indeed are small, we point out that decays of the charmed particles to *different* CP eigenstates still can lead in principle to signals for CP violation not sensitive to mixing effects. Section V summarizes our results.

II. PROOF OF SELECTION RULES

To the extent that the final hadronic state h in $e^+e^- \to h$ arises from the matrix element $\langle h|J_\mu^{(\mathrm{e.m.})}|0\rangle$, h must have negative charge conjugation: $C(h)=-$. Since $C(\pi^0)=+$ and $C(\gamma)=-$, the $D^0\bar{D}^0$ system in reaction (1) must then be in a state of definite C as well:

$$C(D^0\bar{D}^0)=(-1)^{n+1}. \tag{4}$$

It is also true that

$$C(D^0\bar{D}^0)=(-1)^l=P(D^0\bar{D}^0), \tag{5}$$

where l is the relative orbital angular momentum of D^0 and $\bar{D}^0$. Hence D^0 and $\bar{D}^0$ are produced in the states

$$D^0\bar{D}^0+\bar{D}^0D^0=D_1^0D_1^0-D_2^0D_2^0 \quad C=P=+, \tag{6}$$

$$D^0\bar{D}^0-\bar{D}^0D^0=D_2^0D_1^0-D_1^0D_2^0 \quad C=P=-. \tag{7}$$

In Eqs. (6) and (7) the first particle has c.m. momentum $\vec{p}$, and the second has $-\vec{p}$. D_1^0 and D_2^0 are states of definite mass and lifetime with $CP=+$ and $CP=-$, respectively. From Eqs. (4), (6), and (7), we see that even n leads to states of opposite CP and odd n to states of the same CP.

III. APPLICATION TO SPECIFIC REACTIONS

The selection rules just derived are useful whenever each charmed meson decays to a final state of easily identified CP. The simplest example is the $\pi\pi$ final state, with $CP=+$. The decay $D^0\to\pi^+\pi^-$ is expected to occur[2,14] at the rate of about 6% of the observed[8] $K^-\pi^+$ decay. However, another simple final state of great potential advantage over $\pi\pi$ is $K_S^0\pi^0$. Neglecting CP violation in the K^0-$\bar{K}^0$ system as well as in the D^0-$\bar{D}^0$ system, we find

$$CP(\pi^0K_S^0)=CP(\pi^0)CP(K_S^0)(-1)^{l_{K\pi}}$$
$$=-\ \text{for}\ l_{K\pi}=0,$$

so that

$$\langle\pi^0K_S^0|H_W|D_1^0\rangle=0. \tag{8}$$

Similarly, one finds

$$\langle\pi^0K_L^0|H_W|D_2^0\rangle=0. \tag{9}$$

Hence the allowed decays in the limit of CP invariance are

$$D_1^0\to K_L^0\pi^0 \quad (CP=+), \tag{10}$$

$$D_2^0\to K_S^0\pi^0 \quad (CP=-). \tag{11}$$

Similar results hold when π^0 is replaced by η or η'.

The ratio $\Gamma(D^0\to\bar{K}^0\pi^0)/\Gamma(D^0\to K^-\pi^+)$ is $\frac{1}{2}$ if the $I=\frac{1}{2}$ final state is dominant, as in the models of Ref. 14. In any event, this ratio is unlikely to experience the suppression expected[2,14] for $\Gamma(D^0\to\pi^-\pi^+)/\Gamma(D^0\to K^-\pi^+)$: A branching ratio $\Gamma(D^0\to\bar{K}^0\pi^0)/\Gamma(D^0\to\text{all})$ in excess of a percent is quite likely in view of present models.[14] [The models[14] also predict $\Gamma(D^0\to\bar{K}^0\eta')\simeq\Gamma(D^0\to K^-\pi^+)$.]

Selection rules such as Eqs. (8) or (9) hold for other final states: e.g.,

$$\langle 2\pi^0K_L^0|H_W|D_1^0\rangle=0, \tag{12}$$

$$\langle 2\pi^0K_S^0|H_W|D_2^0\rangle=0, \tag{13}$$

again in the limit of CP invariance. The proof of Eqs. (12) and (13) is similar to that of Eqs. (8) and (9), but relies on the added fact that the $2\pi^0$ system must have even l, and hence must be in a state of even l with respect to the neutral kaon.

The selection rules, along with their application to some specific final states, are listed in Table I.

The rates for

$$e^+e^-\to D^0\bar{D}^0, \tag{14}$$

$$e^+e^-\to D^0\bar{D}^{*0}+D^{*0}\bar{D}^0, \tag{15}$$

$$e^+e^-\to D^{*0}\bar{D}^{*0} \tag{16}$$

are expected to be in the ratios 1 : 4 : 7 very near threshold.[10,15] Present data, interpreted in terms of a D^0 near 1866 MeV and a D^{*0} near 2005 MeV,[11] are consistent with the copious production of vector mesons. These may then decay via Eqs. (2) or (3), rendering reactions of the type (1) of particular interest.

We reiterate that the selection rules of Table I are useful because they involve processes which are *forbidden* in the limit of CP conservation. By contrast, many of the CP tests proposed earlier for neutral charmed mesons[4] rely on rather precise measurements of relative rates or spectral shapes.

The results of Table I are valid only to the degree that the reactions proceed through a single-virtual-photon state [Fig. 1(a)]. A specific example of this situation is shown in Fig. 1(b). When the final state contains a photon, one must make sure that this photon was not emitted by the initial electron or positron [Fig. 1(c)]. The fractional radiative correction associated with Fig. 1(c) is

TABLE I. Summary of CP selection rules for $e^+e^-\to D^0\bar{D}^0+m(\pi^0)+n(\gamma)$. Entries show $n(\gamma)$ for CP-allowed processes for final states of even CP (e.g., $\pi\pi$, $K_L^0\pi^0$, $K_S^0 2\pi^0$) or odd CP (e.g., $K_S^0\pi^0$, $K_L^0 2\pi^0$).

$\bar{D}^0$ final state	D^0 final state: Even CP	Odd CP
Even CP	n odd	n even
Odd CP	n even	n odd

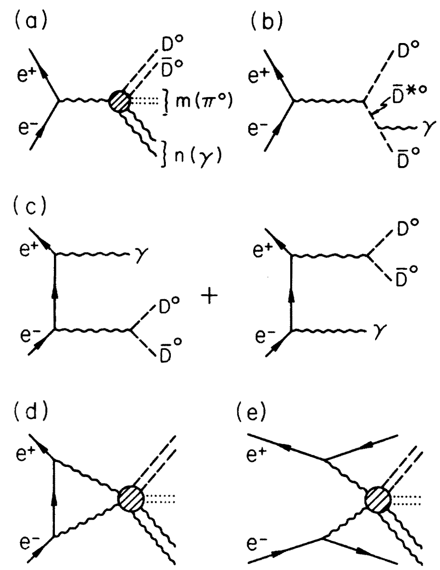

FIG. 1. (a) One-photon e^+e^- annihilation processes for which selection rules of Table I are valid in the limit of CP invariance [see Eq. (1)]. (b) Example of (a) involving radiative decay of a charmed vector meson. (c) A source of possible confusion with (b). (d) "Box"-type annihilation process. (e) Two-photon process not involving annihilation.

$$\frac{d\sigma}{\sigma} \cong \frac{2\alpha}{\pi} \frac{dE_\gamma}{E_\gamma} \frac{d\theta_\gamma}{\sin\theta_\gamma} \tag{17}$$

for $m_e \ll E_\gamma \ll E_{\text{beam}}$ and $\theta_\gamma \gg m_e/E_e$. Here σ is the cross section in the absence of the photon, and θ_γ and E_γ are the laboratory angle and energy of the photon.

Clearly the bremsstrahlung process described by Eq. (17) will not be comparable to the *CP-allowed* process involving the radiative decay of the charmed vector meson: This last reaction probably occurs with an appreciable branching ratio.[10,11] However, the bremsstrahlung process of Fig. 1(c) may be important in comparison with *CP-forbidden* processes. Now, the photon from $D^{*0} \to D^0\gamma$ will be monochromatic in the c.m. system, unlike the bremsstrahlung photon. Moreover, the photon in Eq. (17) is strongly peaked at $\theta_\gamma = 0$ and π, while that from D^{*0} decay is not. By improving energy resolution and by making angular cuts, one can probably reduce the effects of Eq. (17) below the level of 10^{-3}.

Processes containing subgraphs of the form

$$\gamma\gamma \to D^0\bar{D}^0 + (\text{possible detected neutrals}) \tag{18}$$

also can invalidate the selection rules. They include $O(\alpha/\pi)$ processes in which a single soft (undetected) photon is radiated by the final state. The effects of such processes can be limited by improving energy resolution. "Box"-type annihilation graphs [Fig. 1(d)] are of order $(\alpha/\pi)^2$ (logarithms) with respect to the one-photon process. So are the reactions, discussed by many authors,[16] in which the electron and positron do not annihilate one another but emit nearly real photons in each other's electromagnetic field [Fig. 1(c)]. The effects of these last processes can be limited by working close to threshold.[17]

One more possible source of background would be final states which *simulated* D^0 decays. However, certain of these final states, such as

$$e^+e^- \to (K_S^0\pi^0) + (K_S^0\pi^0), \tag{19}$$

while allowed by CP invariance for some configurations of angular momenta, cannot be produced by a C-invariant electromagnetic interaction.

IV. EFFECTS OF *CP* VIOLATION

In this section we shall estimate the intensity of signals for CP violation, assuming CPT invariance holds. The states of definite mass and lifetime then may be written as

$$D_1^0 = [2(1+|\epsilon_C|^2)]^{-1/2}[(1+\epsilon_C)D^0 + (1-\epsilon_C)\bar{D}^0], \tag{20a}$$

$$D_2^0 = [2(1+|\epsilon_C|^2)]^{-1/2}[(1+\epsilon_C)D^0 - (1-\epsilon_C)\bar{D}^0], \tag{20b}$$

where ϵ_C is a parameter describing the CP impurities of both states.[4,18]

At the time of production, the states of $D^0\bar{D}^0$ with $C = P = \pm$ may be written with the help of Eqs. (20) in terms of D_1^0 and D_2^0. The expressions are very similar to Eqs. (6) and (7). Such expressions allow one to discuss time evolution. Let t and t' label the proper times of the charmed mesons with c.m. momenta $\vec{p}$ and $-\vec{p}$, as defined below Eqs. (6) and (7). Then the systems of definite C and P evolve into states:

$C = P = +$:

$$(D^0\bar{D}^0 + \bar{D}^0D^0)/\sqrt{2} \to \mathfrak{N}[D_1^0D_1^0 e^{-i\tilde{m}_1(t+t')} - D_2^0D_2^0 e^{-i\tilde{m}_2(t+t')}]/\sqrt{2}, \tag{21a}$$

$C = P = -$:

$$(D^0\bar{D}^0 - \bar{D}^0D^0)/\sqrt{2} \to \mathfrak{N}[D_2^0D_1^0 e^{-i(\tilde{m}_2 t + \tilde{m}_1 t')} - D_1^0D_2^0 e^{-i(\tilde{m}_1 t + \tilde{m}_2 t')}]/\sqrt{2}. \tag{21b}$$

Here $\mathfrak{N} \equiv (1+|\epsilon_C|^2)/(1-\epsilon_C^2)$ is a factor, presumably close to 1, which will be omitted in what follows, while the $\tilde{m}_i$ $(i = 1, 2)$ are complex parameters incorporating both mass m_i and inverse lifetime $\tau_i^{-1}=\gamma_i$:

$$\tilde{m}_i = m_i - \tfrac{1}{2} i\gamma_i, \quad i=1,2. \tag{22}$$

If we denote the final state of one charmed meson by α and that of the other by β, the pairs of decay modes $D^0\bar{D}^0 \to \alpha\beta$ may be grouped into three classes: (A) $\alpha=\beta$; (B) $\alpha\neq\beta$, $CP(\alpha)=CP(\beta)$; (C) $\alpha\neq\beta$, $CP(\alpha)=-CP(\beta)$. The CP-violating signals are somewhat different for each class, so we discuss them separately.

A. Identical D^0 and $\bar{D}^0$ final states: $\alpha=\beta$

Denote

$$A(D_i^0 \to \alpha) \equiv a_i, \quad i=1,2. \tag{23}$$

The intensities of the signals arising from Eqs. (21) are then

$C=P=+$:

$$I_+(t,t') = \tfrac{1}{2} \left| a_1^2 e^{-i\tilde{m}_1(t+t')} - a_2^2 e^{-i\tilde{m}_2(t+t')} \right|^2, \tag{24a}$$

$C=P=-$:

$$I_-(t,t') = \tfrac{1}{2} |a_1 a_2|^2 \left| e^{-i(\tilde{m}_1 t + \tilde{m}_2 t')} - e^{-i(\tilde{m}_2 t + \tilde{m}_1 t')} \right|^2. \tag{24b}$$

When CP is conserved and $CP(\alpha)=+\,(-)$, a_2 (a_1) and hence I_- must vanish, and $I_+(t,t')$ will be the product of two uncorrelated exponential decays. When both a_1 and a_2 are nonvanishing, implying CP violation, Eqs. (24) acquire periodic modulations and correlations between t and t'. For example, the CP-forbidden signal still vanishes when $t=t'$.[19] Its time integral is

$$\int_0^\infty dt \int_0^\infty dt' I_-(t,t') = |a_1 a_2|^2 \rho/\gamma_1\gamma_2: \tag{25}$$

$$\rho \equiv \frac{\Delta^2+y^2}{\Delta^2+\gamma^2}, \quad \Delta \equiv m_1 - m_2,$$

$$y \equiv \tfrac{1}{2}(\gamma_1-\gamma_2), \quad \gamma \equiv (\gamma_1+\gamma_2)/\Delta.$$

The CP-allowed signal is

$$\int_0^\infty dt \int_0^\infty dt' I_+(t,t')$$

$$\simeq \frac{1}{2}\frac{|a_1^2|^2}{\gamma_1^2} \quad [CP(\alpha)=+,\ |a_2| \ll |a_1|] \tag{26a}$$

$$\simeq \frac{1}{2}\frac{|a_2^2|^2}{\gamma_2^2} \quad [CP(\alpha)=-,\ |a_1| \ll |a_2|]. \tag{26b}$$

Let us now assume each of the states on the left-hand sides of Eqs. (21) is prepared with known probability. This requires some auxiliary measurements, for example of the ratio of

$$\sigma(e^+e^- \to D^0\bar{D}^{*0} \to D^0\bar{D}^0\gamma) \quad [C(D^0\bar{D}^0)=+]$$

to

$$\sigma(e^+e^- \to D^0\bar{D}^{*0} \to D^0\bar{D}^0\pi^0) \quad [C(D^0\bar{D}^0)=-].$$

Assuming that the even- and odd-C states of $D^0\bar{D}^0$ have been prepared with equal probability, the ratio of the α-α signal from the CP-forbidden state [21(b)] to that from the CP-allowed state [21(a)] is then

$$\frac{I(\alpha\alpha,\ \text{forbidden})}{I(\alpha\alpha,\ \text{allowed})} = 2\rho \times \begin{cases} \gamma_1|a_2|^2/\gamma_2|a_1|^2 & CP(\alpha)=+,\ |a_2| \ll |a_1| \\ \gamma_2|a_1|^2/\gamma_1|a_2|^2 & CP(\alpha)=-,\ |a_1| \ll |a_2|. \end{cases} \tag{27}$$

Note that the factor ρ, an indicator of D^0-$\bar{D}^0$ mixing effects [see Eq. (25)], appears in Eq. (27). Standard charm models[2-5] predict ρ to be small. Since the partial decay rates of D_1^0 and D_2^0 will differ signifcantly only in nonstrange CP eigenstates, and since such channels are Cabibbo-suppressed, one expects $y/\gamma \equiv (\gamma_1-\gamma_2)/(\gamma_1+\gamma_2)$ to be of order $\tan^2\theta_C \simeq \frac{1}{18}$. The ratio Δ/γ may be even smaller: it is nominally of order $\tan^2\theta_C$, but is subject to an additional exact suppression in the SU(3) limit.[3] Hence a value $\rho \lesssim \frac{1}{300}$ is not at all unlikely, if the standard model is correct.

Information on the magnitude of ρ will be forthcoming in the near future. For example, the ratio

$$r \equiv \frac{\sigma(e^+e^- \to D^0\bar{D}^0 \to K^\pm\pi^\mp K^\pm\pi^\mp)}{\sigma(e^+e^- \to D^0\bar{D}^0 \to K^\pm\pi^\mp K^\mp\pi^\pm)} \tag{28}$$

is a direct measure of D^0-$\bar{D}^0$ mixing,[5] and is given in terms of parameters defined in Eq. (25) by

$$r = \frac{\Delta^2+y^2}{2\gamma^2+\Delta^2-y^2} = \frac{\rho}{2-\rho}. \tag{29}$$

Neutrino-induced events leading to pairs of leptons of equal sign, i.e.,[20]

$$\nu(\bar{\nu}) + N \to \mu^\mp l^\mp + \cdots, \tag{30}$$

also are a potential source of information on D^0-$\bar{D}^0$ mixing.[3,21]

Unless D^0-$\bar{D}^0$ mixing turns out to be fairly large, it will prove difficult to observe the signal for CP violation when the two neutral charmed mesons decay to identical final states $\alpha=\beta$.

B. Different final states of same CP: $CP(\alpha)=CP(\beta)$

Examples of this situation are $\alpha=\pi^+\pi^-$ and $\beta=\pi^0\pi^0$ or $K_L^0\pi^0$. (We neglect CP violation in the K^0-$\bar{K}^0$ system.) Recall Eq. (23) and define

$$A(D_i^0 \to \beta) \equiv b_i, \quad i=1,2. \tag{31}$$

The intensities of the signals are then:

$C = P = +$:

$$I'_+(t,t') = \tfrac{1}{2}\left|a_1 b_1 e^{-i\tilde{m}_1(t+t')} - a_2 b_2 e^{-i\tilde{m}_2(t+t')}\right|^2, \tag{32a}$$

$C = P = -$:

$$I'_-(t,t') = \tfrac{1}{2}\left|a_2 b_1 e^{-i(\tilde{m}_2 t+\tilde{m}_1 t')} - a_1 b_2 e^{-i(\tilde{m}_1 t+\tilde{m}_2 t')}\right|^2. \tag{32b}$$

Here t and t' refer to states α and β, respectively. The CP-allowed signal (32a) is very similar to Eq. (24a); its time integrals are similar to Eq. (26). However, the CP-forbidden signal (32b) will have in general a different time dependence from Eq. (24b). (For example, the CP-forbidden signal no longer need vanish when $t=t'$.[19]) As a consequence, the smallness of mixing effects no longer need suppress the CP-forbidden signal when $\alpha \neq \beta$.

An exception occurs when $a_2 b_1 = a_1 b_2$, as in superweak models. Equation (32b) then reduces to a form similar to Eq. (24b), and the intensity of the CP-violating signal contains the factor ρ as for case (A).

C. Final states of opposite CP: $CP(\alpha) = +$, $CP(\beta) = -$

Here the CP-allowed signal is (32b), while the CP-forbidden one is (32a). Again, as in case (B), the CP-forbidden signal need not contain any suppression due to mixing effects. However, if $a_1 b_1 = a_2 b_2$, as in superweak models, the CP-forbidden signal contains the factor

$$\rho'/\gamma_1\gamma_2 \equiv \int_0^\infty dt \int_0^\infty dt' \tfrac{1}{2}\left|e^{-i\tilde{m}_1(t+t')} - e^{-i\tilde{m}_2(t+t')}\right|^2, \tag{33}$$

$$\rho' = 3\rho[1 + O(\Delta^2/\gamma^2) + O(y^2/\gamma^2)], \tag{34}$$

and hence is expected to be small if D^0-$\bar{D}^0$ mixing is weak.

V. SUMMARY AND CONCLUSIONS

We have shown that a number of experimentally feasible e^+e^- reactions produce $D^0\bar{D}^0$ states of definite C, thus permitting simple tests of CP invariance in decays of charmed mesons. These reactions are ones in which only neutral pions or photons are produced in addition to $D^0\bar{D}^0$. Such reactions are known to occur quite often,[11] as a result of $e^+e^- \to D^0\bar{D}^{*0}$, $D^{*0}\bar{D}^0$, $D^{*0}\bar{D}^{*0}$ followed by $D^{*0} \to D^0\pi^0$ or $D^0\gamma$. The number $n(\gamma)$ of additional photons in $e^+e^- \to D^0\bar{D}^0 + m(\pi^0) + n(\gamma)$ controls the charge-conjugation eigenvalue of $D^0\bar{D}^0$: if $n(\gamma) =$ even, $C(D^0\bar{D}^0) = -$; if $n(\gamma) =$ odd, $C(D^0\bar{D}^0) = +$. These selection rules hold only to the extent that the e^+e^- annihilation proceeds through a single virtual photon.

The CP tests rely on the decays of D^0 and $\bar{D}^0$ to final states of easily identifiable CP: $CP(\pi\pi) = +$, and, if CP violation in the K^0-$\bar{K}^0$ system is neglected, $CP(K_L^0\pi^0) = CP(K_S^0\pi^0\pi^0) = +$, $CP(K_S^0\pi^0) = CP(K_L^0\pi^0\pi^0) = -$. (These last properties hold for the final states of a zero-spin particle such as D^0 or $\bar{D}^0$.)

If the final states α and β of the two charmed mesons are identical, $\alpha = \beta$, any CP-violating signal always will appear multiplied by a factor ρ which vanishes in the limit of small D^0-$\bar{D}^0$ mixing. In the standard charm model, ρ is expected to be $\lesssim \frac{1}{300}$. However, when $\alpha \neq \beta$, factors such as ρ appear in the CP-violating intensity only in some cases such as superweak models. Consequently, one will be led to search for CP violation in final states $\alpha \neq \beta$ if mixing effects turn out to be small. An example of such a final state (relying rather heavily on detection of neutral pions) would be $\alpha = K_S^0\pi^0$, $\beta = K_S^0\pi^0\pi^0$; another would be $\alpha = K_S^0\eta'$, $\beta = \pi^+\pi^-$.

Our discussion has neglected possible radiative corrections and (for tests involving neutral kaons) the CP impurities of K_S^0 and K_L^0. These are unimportant for the "interesting" case, not yet ruled out, of CP violations in the D^0-$\bar{D}^0$ system substantially larger than those in the K^0-$\bar{K}^0$ system. Indeed, it has even been suggested[4] that the small CP impurities of neutral kaons could originate in "maximal" CP-violating effects associated with charmed mesons.

The D^0 and $\bar{D}^0$ are the only known weakly decaying[22] mesons besides neutral kaons which are not their own charge conjugates. In this respect they can shed valuable light on the mechanism of CP violation. We have indicated some ways in which electron-positron annihilations are particularly suited to such studies.

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