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CP Violation in Fermion Pair Decays of Neutral Boson Particles

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Abstract

We study CP violation in fermion pair decays of neutral boson particles with spin 0 or 1. We study a new asymmetry to measure CP violation in $\eta, K_L \to \mu^+\mu^-$ decays and discuss the possibility of measuring it experimentally. For the spin-1 particles case, we study CP violation in the decays of J/ψ to $SU(3)$ octet baryon pairs. We show that these decays can be used to put stringent constraints on the electric dipole moments of Λ, Σ and Ξ.

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I. INTRODUCTION

CP violation has only been observed in the neutral Kaon system [1]. In order to isolate the source (or sources) responsible for CP violation, it is important to find CP violation in other systems. In this paper we study CP violation in fermion pair decays of a neutral boson particle, which is a CP eigenstate and has spin-0(S) or spin-1 (V).

a) $S \to f\bar{f}$

The most general decay amplitude for S decays into a pair of spin-1/2 particles $f\bar{f}$ can be parametrized as

$$M(S \to f\bar{f}) = \bar{u}_f(p_1, s_1)(a_S + i\gamma_5 b_S)v_{\bar{f}}(p_2, s_2) , \tag{1}$$

where a_S and b_S are in general complex numbers. If both a_S and b_S are nonzero, CP is violated. One can define a density matrix R for the process $S \to f\bar{f}$, where the $f(\bar{f})$ is polarized and the polarization is described by a unit polarization vector $\mathbf{s}_{1(2)}$ in the $f(\bar{f})$ rest frame. With the amplitude in eq.(1) the CP violating part of the density matrix in the rest frame of S is given by

$$R_{CP} = N_f\{\mathrm{Im}(a_S b_S^*)\mathbf{p} \cdot (\mathbf{s}_1 - \mathbf{s}_2) - \mathrm{Re}(a_S b_S^*)\mathbf{p} \cdot (\mathbf{s}_1 \times \mathbf{s}_2)\} , \tag{2}$$

where N_f is a normalization constant, and $\mathbf{p}$ is the three momentum of the fermion f. R_{CP} contains all information about CP violation in the decay. The CP violating parameter $Im(a_S b_S^*)$ can be measured by the asymmetery

$$A(S) = \frac{N_+ - N_-}{N_+ + N_-} , \tag{3}$$

where $N_{+(-)}$ indicates the decay events with $\mathbf{s}_1 \cdot \mathbf{p} > 0(<)0$. In terms of the parameters in the decay amplitude,

$$\begin{aligned} A(S) &= \beta_f \frac{Im(a_S b_S^*)}{\beta_f^2 |a_S|^2 + |b_S|^2} \\ &= \frac{\beta_f^2 M_S Im(a_S b_S^*)}{8\pi\Gamma_f} , \end{aligned} \tag{4}$$

where Γ_f is the decay width for $S \to f\bar{f}$, $\beta_f = \sqrt{1 - 4m_f^2/M_S}$, and m_f and M_S are the masses of the fermion $f(\bar{f})$ and the scalar S, respectively. This asymmetry is non-zero provided CP is violated and a non-zero absorptive part of the decay amplitude exist because of CPT invariance. The asymmetry A has been studied extensively for $\eta, K_L \to \mu^+\mu^-$ decays [2–5]. Additional CP violating observable can be constructed with $\mathrm{Re}(a_S b_S^*)$. We construct the following asymmetry B to probe this CP violating parameter,

$$B(S) = \frac{N^+ - N^-}{N^+ + N^-} , \tag{5}$$

where N^+ and N^- indicates the decay events with $(\mathbf{s}_1 \times \mathbf{s}_2) \cdot \mathbf{p} > (<)0$. In terms of the parameters in the decay amplitude, we have

$$\begin{aligned} B(S) &= -\frac{\pi}{4}\beta_f \frac{Re(a_S b_S^*)}{\beta_f^2 |a_S|^2 + |b_S|^2} \\ &= -\frac{\beta_f^2 M_S Re(a_S b_S^*)}{32\Gamma_f} . \end{aligned} \tag{6}$$

To experimentally measure A and B, one must know the polarizations of the fermions in the final state. The polarizations can be analysed by using certain decay channels of f and $\bar{f}$. Assuming that the polariztions of f and $\bar{f}$ are analysed by the decays $f \to f'(p_{f'}) + X$ and $\bar{f} \to \bar{f}'(p_{\bar{f}'}) + \bar{X}$, with density matrices given by

$$\begin{aligned} \rho_f &= 1 + \alpha_f \mathbf{s}_1 \cdot \hat{\mathbf{p}}_{f'} , \\ \rho_{\bar{f}} &= 1 - \alpha_{\bar{f}} \mathbf{s}_2 \cdot \hat{\mathbf{p}}_{\bar{f}'} , \end{aligned} \tag{7}$$

where $\alpha_{f(\bar{f})}$ are constants, and the hat on the momentum indicates the unit vector in the direction of the momentum. Using this information, we define a more convenient asymmetry,

$$\begin{aligned} \tilde{A}(S) &= \frac{\tilde{N}_+ - \tilde{N}_-}{\tilde{N}_+ + \tilde{N}_-} = \alpha_f A(S) \\ \tilde{B}(S) &= \frac{\tilde{N}^+ - \tilde{N}^-}{\tilde{N}^+ + \tilde{N}^-} = -\alpha_f \alpha_{\bar{f}} B(S) , \end{aligned} \tag{8}$$

where $\tilde{N}_{+(-)}$ and $\tilde{N}^{+(-)}$ indicate events with $\hat{\mathbf{p}}_{f'} \cdot \hat{\mathbf{p}} > (<)0$ and $(\hat{\mathbf{p}}_{f'} \times \hat{\mathbf{p}}_{\bar{f}'}) \cdot \hat{\mathbf{p}}_f > (<)0$, respectively.

b) $V \to f\bar{f}$

The most general decay amplitude for this decay can be parametrized as

$$M(V \to f\bar{f}) = \varepsilon^{\mu}\bar{u}_f(p_1)[\gamma_\mu(a+b\gamma_5) + (p_{1\mu} - p_{2\mu})(c + id\gamma_5)]v_{\bar{f}}(p_2)\ , \tag{9}$$

where ε^μ is the polarization of V and in its rest frame $\varepsilon_\mu = (0, \vec{\varepsilon})$. If CP is conserved, $d = 0$. The constants a, b, c and d are in general complex numbers.

The density matrix for this decay in the rest frame of V, up to a normalization constant, is given by

$$\begin{aligned} R_{ij} = &[\bar{u}_\Lambda(p_1, \mathrm{s}_1)[\gamma_i(a+b\gamma_5) + (p_{1i} - p_{2i})(c + id\gamma_5)]v_{\bar{\Lambda}}(p_2, \mathrm{s}_2) \\ &\times \bar{v}_{\bar{\Lambda}}(p_2, \mathrm{s}_2)[\gamma_j(a^* + b^*\gamma_5) + (p_{1j} - p_{2j})(c^* + id^*\gamma_5)]u_\Lambda(p_1, \mathrm{s}_1)]\ , \end{aligned} \tag{10}$$

where i and j label three-vector components.

The CP violating part of this density matrix is given by

$$\begin{aligned} R_{ij} &= r_{ij} + r^*_{ji}\ , \\ r_{ij} &= i2ad^* p_j\{\frac{M_V^2}{2}(\mathbf{s}_1 - \mathbf{s}_2)_i - \frac{2M}{M_V + 2m_f}(\mathbf{s}_1 - \mathbf{s}_2)\cdot \mathbf{p}p_i \\ &+ imM_V(\mathbf{s}_1 \times \mathbf{s}_2)_i + i\frac{2M_V}{M_V + 2m_f}(\mathbf{s}_1 \cdot \mathbf{p}(\mathbf{p}\times \mathbf{s}_2)_i - \mathbf{s}_2\cdot\mathbf{p}(\mathbf{p}\times\mathbf{s}_1)_i)\} \\ &+ 2ibd^* M_V p_j\{s_{2i}\mathbf{s}_1\cdot\mathbf{p} - s_{1i}\mathbf{s}_2\cdot\mathbf{p} + i(\mathbf{p}\times(\mathbf{s}_1 - \mathbf{s}_2))_j\} \\ &+ 4icd^* M_V p_i p_j\{-(\mathbf{s}_1 - \mathbf{s}_2)\cdot\mathbf{p} + i(\mathbf{s}_1\times\mathbf{s}_2)\cdot\mathbf{p}\}\ , \end{aligned} \tag{11}$$

where M_V the mass of V. In general, V is produced with polarization, and the polarization depends on how V is produced and is different in different productions. However, we can construct a similar asymmetry as for the spin-0 decay case, which is independent of the polarization due to rotation invariance, to probe the CP violating parameters [6], $Re(da^*)$, $Re(dc^*)$,

$$\begin{aligned} B(V) &= \frac{N^+ - N^-}{N^+ + N^-} \\ &= -\frac{\beta^2 M_V}{96\Gamma_f}(2m_f Re(da^*) + (M_V^2 - 4m_f^2)Re(dc^*))\ , \end{aligned}$$

$$\tilde{B}(V) = \frac{\tilde{N}^+ - \tilde{N}^-}{\tilde{N}^+ + \tilde{N}^-}$$
$$= -\alpha_f \alpha_{\bar{f}} B(V) \ . \qquad (12)$$

Here $\beta = \sqrt{1 - 4m_f^2/M_V^2}$. $N^{+(-)}$ and $\tilde{N}^{+(-)}$ are defined in the same way as for the spin-zero case.

II. CP VIOLATION IN $S \to F\bar{F}$

In this section we study the asymmetry B for $\eta, K_L \to \mu^+\mu^-$ decays. CP violating tests in these systems have been studied before [2,3]. All of them concentrated on the asymmetry A. Here we show that the asymmetry B is also a good quantity to study CP violation. It reveals information not contained in A.

$\eta \to \mu^+\mu^-$.

Because η is a pseudo-scalar, if CP is conserved, $a_\eta = 0$. The CP violating contributions are expected to be small. We can use the decay width to determine b_η. Imb_η is determined from $\eta \to \gamma\gamma \to \mu^+\mu^-$ with the two intermediate photons on-shell. Using experimental data for $\eta \to \gamma\gamma$ [7], one obtains

$$|\mathrm{Im}b_\eta| = \frac{\alpha_{em}}{4\beta}\frac{m_\mu}{m_\eta}\ln\frac{1+\beta}{1-\beta}[64\pi\Gamma(\eta \to 2\gamma)/m_\eta]^{1/2}$$
$$= 1.59 \times 10^{-5} \ . \qquad (13)$$

This amplitude is close to the experimental amplitude determined from $Br(\eta \to \mu^+\mu^-) = (5 \pm 1) \times 10^{-6}$ [8]. The real part of the amplitude is $|\mathrm{Re}b| \approx 0.7 \times 10^{-5}$. Using these numbers we find

$$|B(\eta)| = 2 \times 10^4 |\mathrm{Re}a_\eta + 2.3\mathrm{Im}a_\eta| \ . \qquad (14)$$

Here we have assumed that $\mathrm{Re}b_\eta$ and $\mathrm{Im}b_\eta$ have the same sign. The asymmetry A is $5.8 \times 10^4(\mathrm{Re}a_\eta - 0.44\mathrm{Im}a_\eta)$.

The parameter a_η is model dependent. In many model a_η is very small [2,3]. In lepton-quark models, the constraint on a_η is from the neutron electric dipole moment. If one assumes no cancellations among different contributions to the neutron electric dipole moment, a_η is constrained to be less than 2×10^{-9}. However, if one allows cancellations between different contributions, it is possible to have relatively large a_η [3]. The asymmetry B can reach 10^{-3} or even larger. The polarization of the muons from $\eta \to \mu^+\mu^-$ can be analysed by $\mu \to e\bar{\nu}_e\nu_\mu$. In this case $\alpha_e = 1/3$. The η factory at SACLAY can reach a sensitivity for A and B at the level a few % in the near future [9]. It may provide interesting information about CP violation.

$K_L \to \mu^+\mu^-$.

Using data from $K_L \to 2\gamma$ and $K_L \to \mu^+\mu^-$, we obtain, $|\text{Im}b_K| = 2\times10^{-12}$, and $|\text{Re}b_K| = (0.14\pm0.16)\times10^{-12}$. The contributions to the asymmetries A and B from direct CP violation are given by

$$|A(K_L)| = 3.6\times10^{11}|\text{Re}a_K - 0.07\text{Im}a_K|\ ,$$
$$|B(K_L)| = 2\times10^{11}|0.1\text{Re}a_K + 1.4\text{Im}a_K|\ . \tag{15}$$

We have used the central values for Reb_K and Imb_K. In the above analysis we have assumed that K_L is a pure CP egeinstate. This is, however, not the whole story. K_L is not a pure CP eigenstate,

$$K_L = \frac{1}{\sqrt{1+|\epsilon|^2}}(|K_2> +\epsilon|K_1>)\ , \tag{16}$$

where $CP|K_2>=-|K_2>$, $CP|K_1>=|K_1>$ and the mixing parameter ϵ is measured to be $2.27\times10^{-3}e^{i\pi/4}$. The asymmetries A and B are related to $\text{Im}(b_2(a_2+\epsilon b_1))$ and $\text{Re}(b_2(a_2+\epsilon b_1))$, respectively. Here a_i and b_i are the amplitudes for $K_i \to \mu^+\mu^-$. The parameter b_1 is not zero. Using the values for the real and the imaginary parts of b_1 determined in Ref. [10], and set $a_2 = 0$, we obtain

$$B(K_L)|_{a_2=0} \approx 0.3\times10^{-3}\ . \tag{17}$$

The asymmetry $A(K_L)|_{a_2} \approx 10^{-3}$. If experiments measure larger value for A and B, there must be new physics due to large a_2. In many models the paramter a_2 is predicted to be very small. However there are models which can produce large a_2 [4]. B can be as large as 10^{-2}. A Kaon factory may be able to see CP violation.

In both $\eta \to \mu^+\mu^-$ and $K_L \to \mu^+\mu^-$ decays, the experimental sensitivities for the asymmetry A is better than for B. For the asymmetry A, It will be sufficient to just measure the polarization of μ^+. For the asymmetry B it is necessary to measure the polarizations of μ^+ and μ^-. In principle this can be done by stopping muons in some materials and analyse their decays. However the measurement of the μ^- polarization is more difficult than that of μ^+ because there are additional depolarization mechanisms for μ^- when it is stope [11]. Extra care must be taken when carry out this analysis. If Rea is larger than or the same order of magnitude as Ima, the asymmetry A is a better quantity to measure. However, if it turns out that $\mathrm{Im}a > \mathrm{Re}a$, the asymmetry B may be the better one. This situation may happen if there is significant CP violation in the decay amplitude for $K_L \to 2\gamma$.

The decay $B_d(B_s) \to \mu^+\mu^-$ can be used to study CP violation also. However in the standard model, the branching ratios for these decays are very small [12]. If the standard model prediction is correct, it is very difficult to test CP violation using these decay modes. One, of cause, should keep in mind that should this decay be discovered with a branching ratio larger than the standard model predictions, there must be new physics and large CP violation may be observed. The same comments apply to $D^0 \to \mu^+\mu^-$. The same analysis can also be carried out for Higgs particle decays [13].

III. $V \to F\bar{F}$

The decays $V \to f\bar{f}$ provide new tests for CP violation. In a previous paper we have studied a particular case, $J/\psi \to \Lambda\bar{\Lambda}$, and shown that this is a good place to look for CP violation [6]. In this section we will carry out a more detailed analysis by including more decay channels.

$J/\psi \to B_8\bar{B}_8$.

The branching ratio for J/ψ decays into baryon pairs B_8 and $\bar{B}_8$ of the $SU(3)$ octet is typically 10^{-3}. With enough J/ψ decay events, we may obtain useful information about CP violation. In Eq.(9), the b-term is a P violating amplitude and is expected to be significantly smaller than the P conserving a- and c- amplitudes. We will therefore neglect the contribution to the branching ratio from b. The relative strength of the amplitude a and c can be determined by studying angular correlations between the polarization of J/ψ and the direction of B_8 momentum. Due to large experimental uncertainties associated with the constants which determine the angular distribution, a and c can not be reliably determined separately at present [7]. In our numerical estimates we will consider two cases where the decay ampiltudes are dominated by 1) the a-term, and 2) the c-term, respectively. Assuming a and b are real and using the experimental branching ratios compiled by the particle data group, we obtain numerical values for the asymmetry B. The results are given in Table I.

The CP violating d-term can receive contributions from different sources, the electric dipole moment, the CP violating Z -B_8 coupling, etc. In the following we estimate the contribution from the electric dipole moment d_{B_8} of B_8. Here d_{B_8} is defined as

$$L_{dipole} = i\frac{d_{B_8}}{2}\bar{B}_8\sigma_{\mu\nu}\gamma_5 B_8 F^{\mu\nu} \ , \tag{18}$$

where $F^{\mu\nu}$ is the field strength of the electromagnetic field. Exchanging a photon between B_8 and a c-quark, we have the CP violating c-B_8 interaction

$$L_{c-\Lambda} = -\frac{2}{3M^2}ed_\Lambda(p_1^\mu - p_2^\mu)\bar{c}\gamma_\mu c\bar{B}_8 i\gamma_5 B_8 \ . \tag{19}$$

From this we obtain

$$d = -\frac{2}{3}\frac{g_V}{M^2_{J/\psi}}ed_{B_8} \ . \tag{20}$$

Here we have used the parametrization, $< 0|\bar{c}\gamma_\mu c|J/\psi >= \varepsilon_\mu g_V$. The value $|g_V|$ is determined to be 1.25 GeV^2 from $J/\psi \to \mu^+\mu^-$. There are additional contributions to d, for example, exchanging a photon between the final B_8 and $\bar{B}_8$. We have checked several contributions of this type and find them to be small if electric dipole moment is the only source of CP violation. Using the above information, we can express the asymmetry B in terms of the electric dipole moment of the baryons. The asymmetry B can be used to put constraints on the electric dipole moment. In Table II we give the asymmetry B in terms of the electric dipole moment of B_8. Note that because photons are off-shell, d_{B_8} is measured at $q^2 = M^2_{J/\psi}$ from the measurement of B. If we assume that the extrapolation follow the same q^2 dependence as the magnetic dipole moment of B_8, $d_{B_8}(q^2 = M^2_{J/\psi})$ is smaller than $d_{B_8}(q^2 = 0)$. However, the q^2 dependence of the electric dipole moment may be completely different from the magnetic dipole moment. It is possible that d_{B_8} does not change very much from $q^2 = 0$ to $q^2 = M^2_{J/\psi}$.

The polarizations of B_8 and $\bar{B}_8$ in $J/\psi \to B_8\bar{B}_8$, can be analysed by certain decay channels of B_8 and $\bar{B}_8$. There are many decay channels available to carry out such analysis [7]. The neutron polarization can be analysed by $n \to pe\bar{\nu}_e$. The proton polarization may be analysed by rescattering. It may be difficulty to carry out such analysis. We list it here for completeness. The polarization of Λ can be analysed by, for example, $\Lambda \to p\pi^-$. This decay mode has a large branching ratio (64%) and a large α_Λ (0.642). The polarization of Σ can also be analysed. For Σ^-, one can use $\Sigma^- \to n\pi^-$. This decay mode has large branching ratio (99.85%) with $\alpha_{\Sigma^-} = -0.068$. The polarization of Σ^0 can be analysed by $\Sigma^0 \to \Lambda\gamma$. This is the dominant decay channel for Σ^0 (100%). The polarization of Σ^+ can be analysed by $\Sigma^+ \to p\pi^0$. The branching ratio is 51.6% and has a large value for α_{Σ^+} (-0.98). The polarization of Ξ^0 can be analysed by $\Xi^0 \to \Lambda\pi^0$. This is the main decay channel (100%) and the parameter $\alpha_{\Xi^0} = -0.411$. The polarization of Ξ^- can be analysed by $\Xi^- \to \Lambda\pi^-$, again this decay mode is the dominant one (100%) and has a large vaule for α_{Ξ^-} (-0.456).

The asymmetry B may not be useful in providing upper bounds for the electric dipole moment for neutron and proton because their electric dipole moments have been constrained to be very small, $d_n < 1.2 \times 10^{-26} ecm$ [14] and $d_p < 10^{-22} ecm$ [15]. However useful information about the electric dipole moments for Λ, Σ and Ξ can be extracted. The experimental upper bound on d_Λ is 1.5×10^{-16}ecm [7]. There are constraints on the strange quark electric dipole moment and colour dipole moment from the neutron electric dipole moment d_n , which follow if one assumes that the contributions to d_n do not cancel against each other

[16]. There may be constraints also from $SU(3)$ chiral peturbative theory [17]. However it is possible that cancellations do occur for d_n but not d_Λ and the constraints from d_n do not necessarily lead to strong constraints on d_Λ. Alternative experimental approaches to d_Λ, such as that presented here, should therefore be pursued. If d_Λ indeed has a value close to its experimental upper bound, the asymmetry B can be as large as $O(10^{-2})$. Using $\Lambda \to p\pi^-$ to analyse the polarization, we can obtain $\tilde{B}$ as large as 10^{-2}. With 10^7 J/ψ, it is already possible to obtain some interesting results. This experiment can be performed with the Beijing e^+ e^- machine. If 10^9 J/ψ can be produced, one can improve the upper bound on d_Λ by an order of magnitude. This can be achieved in future J/ψ factories. There is not much information about the electric dipole moment of Σ and Ξ. The observable B can thus be used to put upper bound on the electric dipole moments of Σ and Ξ. With 10^9 J/ψ decays, the sensitivity for the elelctric dipole moment is typically $10^{-17} ecm$.

Our analysis can also be used for $J/\psi \to l^+l^-$. Assuming that the d-term is mainly due to the electric dipole moment d_l of the lepton, we have

$$B = \frac{d_l}{e}\frac{\pi}{4} m_l \frac{\sqrt{1 - 4m_l^2/M^2}}{1 + 2m_l/M} , \tag{21}$$

where m_l is the lepton mass. For $J/\psi \to \mu^+\mu^-$, we have, $B = 4 \times 10^{-7}(d_\mu/10^{-19}$ ecm) which may be too small to be measured experimentally.

$\Upsilon \to f\bar{f}$.

In principle the asymmetry B can be used to probe CP violation in $\Upsilon \to B_8\bar{B}_8$. For these decays the branching ratios are not measured yet. They are smaller than the branching ratios for $J/\psi \to B_8\bar{B}_8$, e.g. $Br(\Upsilon \to p\bar{p}) < 9 \times 10^{-4}$. In order to reach the same sensitivity for CP violating parameters as for $J/\psi \to B_8\bar{B}_8$, more Υ events are needed. It may not be practical to study CP violation using these decay modes.

It may be possible to observe CP violation in $\Upsilon \to l\bar{l}$. One particular interesting decay mode is $\Upsilon \to \tau^+\tau^-$. The tauon polarization can be analysed by the decays $\tau \to \pi\nu$,$2\pi\nu$,$3\pi\nu$,$e\nu\bar{\nu}$ and $\mu\nu\bar{\nu}$. It has been shown that these decay channels provide reasonable sensitivity for tauon polarization analysis [18]. Assuming the electric dipole moment of the tauon is the source for CP violation in this decay, $B = 7 \times 10^{-3} d_\tau/(10^{-16}$ ecm). The experimetal upper bound on d_τ is 1.6×10^{-16} ecm, so the asymmetry B can be as large as 10^{-2}. Values of d_τ as large as 10^{-16}ecm can be obtained in model calculations. The leptoquark model is one of them. In this model there is a scalar which can couple to leptons and quarks. The couplings of the leptoquark scalar to the third generation are weakly constrained [19]. It is possible to generate a large d_τ by exchanging a leptoquark at the one loop level.

Similar experiments can be carried out for other systems, for example, ρ , $\phi \to \mu^+\mu^-$ and $Z \to l\bar{l}$ [20]. In particular the ϕ factory may provide useful information about CP violation in $\phi \to \mu^+\mu^-$.

IV. CONCLUSION

We studied CP violation in fermion pair decays of spin-0 and spin-1 particles using a CP odd and CPT even observable. The asymmetry B studied in this paper provides another test for CP violation in $\eta, K_L \to \mu^+\mu^-$ decays. This asymmetry can reveal new information which is not contained in the asymmetry A studied previously in the liturature. For spin-1 particle case, we studied CP violation in the decays of J/ψ to the $SU(3)$ octet baryon pairs. We showed that these decays can be used to put stringent constraints on the electric dipole moments of Λ, Σ and Ξ. Using the J/ψ events accumulated at the Beijing e^+e^- collider, one may already obtain interesting information about CP violation. We encourage our experimental collegaues to carry out such analysis.

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TABLES

TABLE I. The asymmetry B.

Decay Mode	a-term Dominates (in unit d(GeV))	b-term Dominates (in unit d(GeV)
$n\bar{n}$	3.5×10^2	9.0×10^2
$p\bar{p}$	3.2×10^2	8.2×10^2
$\Lambda\bar{\Lambda}$	3.8×10^2	8.4×10^2
$\Sigma\bar{\Sigma}$	3.7×10^2	7.6×10^2
$\Xi\bar{\Xi}$	3.1×10^2	6.1×10^2

TABLE II. The asymmetry B in terms of the electric dipole moment of B_8.

Decay Mode	a-term Dominates (in unit $10^{14}/ecm$)	b-term Dominates (in unit $10^{14}/ecm$)
$n\bar{n}$	$1.38d_n$	$3.5d_n$
$p\bar{p}$	$1.25d_p$	$3.2d_p$
$\Lambda\bar{\Lambda}$	$1.48d_\Lambda$	$3.3d_\Lambda$
$\Sigma\bar{\Sigma}$	$1.46d_\Sigma$	$2.9d_\Sigma$
$\Xi\bar{\Xi}$	$1.22d_\Xi$	$2.4d_\Xi$