第 30 卷 第 8 期 高 能 物 理 与 核 物 理 Vol. 30, No. 8
2006 年 8 月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS Aug., 2006

Pseudoscalar-Meson Mixing in $\psi(2S)\to$VP Decays*

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Abstract Based on the branching ratios of $\psi(2S)\to$ VP given by the BES collaboration, we make a new analysis to study the mixing of pseudoscalars. The mixing angle of η and $\eta'_{\rm p}$, $\theta_{\rm p}$ is determined to be $(-7.54\pm 1.52)^\circ$ which is consistent with the value obtained from quadratic Gell-Mann-Okubo formula. From this work we also know that the strength of DOZI to SOZI is about 14% in $\psi(2S)\to$ VP, and the phase angle of electromagnetic amplitude to strong amplitude is $(156\pm 89)^\circ$.

Key words pseudoscalar mixing, mixing angle, $SU(3)$ symmetry breaking

1 Introduction

The masses of η and η' as well as the value of the pseudoscalar mixing angle have long been the subject of discussion from the time that $SU(3)$-flavor symmetry was proposed. There are many researches on the pseudoscalar mixing both in theory and in experiments. Phenomenologically, the situation of the η-η' mixing remains not completely settled up to now.

For the pseudoscalar mesons, the Gell-mann-Okubo formula is given by[1]:

$$m^2_{\eta_8}=\frac{4}{3}m^2_{\rm K}-\frac{1}{3}m^2_{\pi}, \tag{1}$$

assuming no octet-singlet mixing. In the above formula, m_{η_8} is the mass of the octet η_8, $m_{\rm K}$ and m_π are the mass of the pseudoscalar mesons K and π.

However, the octet and singlet can mix because of $SU(3)$ symmetry breaking. Considering the $SU(3)$ symmetry breaking, the Gell-mann-Okubo formula is determined by $m^2_{\eta_8}=\left(\frac{4}{3}m^2_{\rm K}-\frac{1}{3}m^2_{\pi}\right)(1+\varDelta)$ to the first order in $\varDelta$, and the pseudoscalar mixing angle is $\theta_{\rm p}=-10.1^\circ(1+8.5\varDelta)$[2]. From which we can see that the mixing angle of pseudoscalar mesons is related to the mass of η_8. A small breaking of the Gell-Mann-Okubo relation can produce a major modification of the η-η' mixing angle.

Isgur[3] roughly estimated the value of the η-η' mixing angle $\theta_{\rm p}\approx -10^\circ$ in terms of the mass formula firstly. In the simplest possible situation where one assumes the presence of an octet and a singlet, the quadratic Gell-Mann-Okubo mass formula yields a pseudoscalar mixing angle of $\theta_{\rm p}\approx -10^\circ$. With the same assumption a Gell-Mann-Okubo mass formula which is linear in the masses gives $\theta_{\rm p}\approx -23^\circ$. Fritzsch[4] gave the result that the mixing angle was -10° by taking into account $SU(3)$ breaking. For many years most authors believed that the mixing angle is about -10°. With the development of experiment techniques, more and more data has been taken, which can be used to study the mixing of η and η' experimentally. Using the data accumulated from experimental and the phenomenological approaches based on effective field theory, the pseudoscalar mixing has been discussed and the value of the mixing angle tended to -20°. In particular, the

Received 17 December 2005, Revised 13 March 2006
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value of the η-η′ mixing angle, $\theta_{\rm p}$, was deduced from the experiment of electromagnetic decays of pseudoscalar and vector mesons, decays of J/ψ into a vector and a pseudoscalar meson, and some other transitions. An important work was performed by Gilman in which various data, such as J/ψ→η(η′)γ, J/ψ → VP, and πp scattering , are discussed. A value of $\theta_{\rm p} \approx -20^{\circ}$ was obtained from that. The $\theta_{\rm p} = (-16.9 \pm 1.7)^{\circ}$ was extracted by Bramon[5] from the analysis which took into account the non-ideal ω-φ mixing. Besides the previous method, Bramon also obtained the result of $\theta_{\rm p} = (-18.2 \pm 1.4)^{\circ}$ and $\theta_{\rm V} = (-3.4 \pm 0.2)^{\circ}$[6] by not restricting the mixing angle of vector mesons from the radiative decay of vector and pseudoscalar mesons. Li De-Ming[7] investigated two-photo decays of pseudoscalar mesons, radiative decays between pseudoscalar and vector mesons, decays of J/ψ into a vector and a pseudoscalar meson, and radiative decays of J/ψ into a pseudoscalar meson to study the quarkonia-glueball structure of η, η′ and η(1440) and found that η (η′) contains little glueball component and that η(1440) is mainly a glueball states (about 78% glueball component). More recently, many processes are investigated using two mixing angles by Escribano[8].

The success of the Gell-Mann-Okubo mass formula has long been considered as the evidence that the η-η′ mixing angle is small. However, recent experimental results appear to require a different pseudoscalar mixing angle with different methods. It is the purpose of the paper to discuss this experimental evidence and to investigate the pseudoscalar mixing angle via ψ(2S)→VP.

2 The decay mechanism of ψ(2S) → VP

The ψ(2S) is the second c$\bar{\rm c}$ bound state found after J/ψ from the electron-positron collision. J/ψ and ψ(2S) decays are the important source for studying meson spectroscopy in the 1—3GeV region. They have the similar decay mechanism and are suppressed by OZI rule. ψ(2S) and J/ψ decay into a vector and a pseudoscalar meson via three gluon annihilation and electromagnetic decays. Therefore, in this paper, the phenomenological model for J/ψ→VP(V, P are the vector meson and pseudoscalar meson, respectively) is applied in ψ(2S) decays to discuss the pseudoscalar-meson mixing. Fig. 1 is the Feynman diagrams for ψ(2S) → VP, where (a) is the single-OZI-suppression diagram, (b) is the electromagnetic decay diagram, (c) is the double-OZI-suppression diagram connected to q$\bar{\rm q}'$ states and (d) is the double-OZI-suppression diagram connected to a q$\bar{\rm q}'$ state and a glueball state.

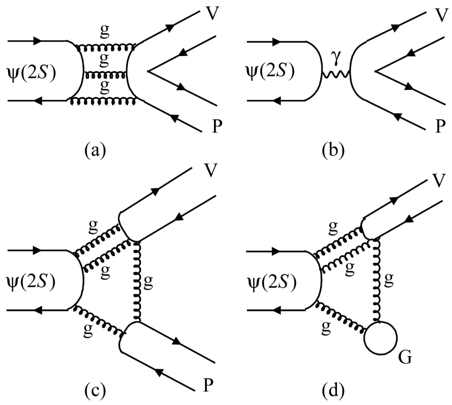

Fig. 1. The Feynman diagrams for ψ(2S)→VP.

3 The mixing of pseudoscalar mesons

3.1 The mixing of mesons

The discovery of quarks is the milestone of particle physics, which helps us to understand the property of hadron. To describe the structure of hadrons, Gell-Mann-Zweig put forward the quark model based on the $SU(3)$ symmetry. In this simple picture, all of the mesons can be understood as bound states consisting of a quark q and an antiquark $\bar{\rm q}$ (the flavors of q and $\bar{\rm q}$ may be different). The nine possible q$\bar{\rm q}'$ combinations containing u, d and s quarks group themselves into an octet and a singlet:

$$\mathbf{3} \otimes \bar{\mathbf{3}} = \mathbf{8} \oplus \mathbf{1}. \qquad (2)$$

States with the same IJ^P and additive quantum numbers can mix(if they are eigenstates of charge conjugation C, they must also have the same value of C). Thus the I=0 member of the ground-state pseudoscalar octet mixes with the corresponding pseudoscalar singlet to yield the η and η′. These appear as members of a nonet. Fig. 2 and Fig. 3 describe the light quark mesons (the ground-state pseudoscalar and vector mesons).

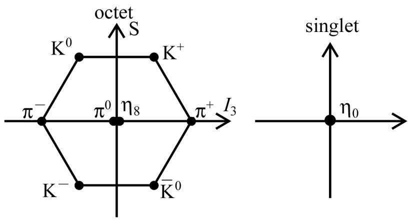

Fig. 2. The nonet of pseudoscalar mesons.

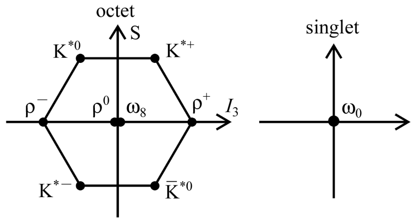

Fig. 3. The nonet of vector mesons.

The octet and the singlet are the eigenstates of the $SU(3)$ group and their quark constitution is shown in Table 1.

Table 1. The quark constitution of the octet and the singlet of the pseudoscalar and vector mesons in quark model.

$K^0(K^{*0})=d\bar{s}$		$K^+(K^{*+})=u\bar{s}$
$\pi^-(\rho^-)=d\bar{u}$	$\pi^0(\rho^0)=\sqrt{\frac{1}{2}}(u\bar{u}-d\bar{d})$	$\pi^+(\rho^+)=u\bar{d}$
$K^-(K^{*-})=s\bar{d}$		$\overline{K^0}(\overline{K^{*0}})=s\bar{u}$
$\eta_8=\sqrt{\frac{1}{6}}(u\bar{u}+d\bar{d}-2s\bar{s})$		$\eta_1=\sqrt{\frac{1}{3}}(u\bar{u}+d\bar{d}+s\bar{s})$

In experiment, we observe the mixing of the octet η_8 and the singlet η_0 of the pseudoscalar mesons but not their eigenstates.

3.2 The mixing angle of pseudoscalar-meson

Indeed, the physical eigenstates η, η' maybe are the mixture of octet, singlet and other pseudoscalar components(radially excited quarkonium states, gluonium, or exotics). But we are interested in consistency with the simplest possible situation. Thus we assume a two-state system and neglect possible mixing of the η and η' with other pseudoscalar states and, therefore, we only consider the simplest case and the η-η' mixing is characterized by a single mixing angle $\theta_{\rm P}$. We also assume that the physical states are orthogonal and the physical isoscalar pseudoscalars η and η' are usually given as

$$\begin{pmatrix}\eta\\ \eta'\end{pmatrix}=\begin{pmatrix}\cos\theta_{\rm P} & -\sin\theta_{\rm P}\\ \sin\theta_{\rm P} & \cos\theta_{\rm P}\end{pmatrix}\begin{pmatrix}\eta_8\\ \eta_0\end{pmatrix}, \tag{3}$$

where, $\theta_{\rm P}$ is the mixing angle. η_0 and η_8 are the orthogonal mixture of the respective singlet and octet isospin zero states. η_0 and η_8 are $SU(3)$ quark basis states which are denoted as

$$|\eta_0\rangle=\frac{1}{\sqrt{3}}|u\bar{u}+d\bar{d}+s\bar{s}\rangle, \tag{4}$$

$$|\eta_8\rangle=\frac{1}{\sqrt{6}}|u\bar{u}+d\bar{d}-2s\bar{s}\rangle. \tag{5}$$

In terms of quark basis, the η and η' contain nonstrange and strange contents. In the flavor $SU(3)$ quark model, they are defined through quark-antiquark($q\bar{q}$) basis states as

$$|\eta\rangle=X_\eta\frac{1}{\sqrt{2}}|u\bar{u}+d\bar{d}\rangle+Y_\eta|s\bar{s}\rangle, \tag{6}$$

$$|\eta'\rangle=X_{\eta'}\frac{1}{\sqrt{2}}|u\bar{u}+d\bar{d}\rangle+Y_{\eta'}|s\bar{s}\rangle. \tag{7}$$

Then, we can obtain

$$X_\eta=Y_{\eta'}=\sqrt{\frac{1}{3}}\cos\theta_{\rm P}-\sqrt{\frac{2}{3}}\sin\theta_{\rm P}=\cos\phi_{\rm P}, \tag{8}$$

$$X_{\eta'}=-Y_\eta=\sqrt{\frac{1}{3}}\sin\theta_{\rm P}+\sqrt{\frac{2}{3}}\cos\theta_{\rm P}=\sin\phi_{\rm P}, \tag{9}$$

where, $\theta_{\rm P}=\phi_{\rm P}-54.7^\circ$.

4 The decay amplitude of $\psi(2S)\to$ VP

Fortunately, the full set of $\psi(2S)\to$ VP have been obtained from 14 million $\psi(2S)$ events taken at the BESⅡ and the branching ratios[9—12] are listed in the first column of Table 2. Our discussion will essentially make use of simple and well established arguments based on the quark-model. These arguments will be applied to the set of data describing the $\psi(2S)$ decays into pseudoscalar and vector mesons.

The decay amplitude and the corresponding branching ratio have the relation

$$Br(\psi(2S)\to {\rm VP})=|A|^2\times P_{\rm V}^3, \tag{10}$$

where, A is the amplitude, $P_{\rm V}$ is the momentum of the vector mesons and $Br(\psi(2S)\to{\rm VP})$ is the branching ratio of $\psi(2S)\to$ VP.

Table 2.　The branching ratios and the reduced branching ratios of $\psi(2S)\to$VP.

decay mode	branching ratio ($\times10^{-5}$)	reduced branching ratios($\times10^{-5}$)	Ref.
$\rho\pi$	$5.1\pm0.7\pm1.1$	0.313 ± 0.065	[9]
$K^{*-}K^{+}+c.c.$	$3.1^{+1.8}_{-1.9}$	0.296 ± 0.178	[10]
$K^{*0}\bar{K}^{0}+c.c.$	$13.7^{+1.8}_{-9.0}$	1.363 ± 0.327	[10]
$\omega\eta$	<3.1	$<0.614\pm0.0$	[11]
$\omega\eta'$	$3.2^{+2.4}_{-2.0}\pm0.7$	0.749 ± 0.585	[11]
$\phi\eta$	$3.3\pm1.1\pm0.5$	0.729 ± 0.267	[11]
$\phi\eta'$	$3.1\pm1.4\pm0.7$	0.824 ± 0.416	[11]
$\phi\pi^0$	<0.40	<0.082	[11]
$\rho\eta$	$1.78^{+0.67}_{-0.62}\pm0.17$	0.352 ± 0.137	[12]
$\rho\eta'$	$1.87^{+1.64}_{-1.11}\pm0.33$	0.436 ± 0.390	[12]
$\omega\pi^0$	$1.87^{+0.68}_{-0.62}\pm0.28$	0.344 ± 0.136	[12]

The amplitudes[5] of $\psi(2S)\to$ VP are shown in Table 3. The amplitude A, which has contributions from both the three gluon annihilation and the electromagnetic processes, can be expressed in terms of a $SU(3)$ symmetric single-OZI amplitude g, an electromagnetic amplitude e(the coupling strength e has relative phase to the strength g because they are produced from different origins) and the nonet-symmetry-breaking DOZI amplitude r, relative to g. The $SU(3)$ symmetry violation has been accounted for by a pure octet $SU(3)$ breaking term. The $SU(3)$ breaking term in strong interaction and electromagnetic process are expressed by $(1-s)$ and $(1-s_{\rm e})$, respectively. The $s_{\rm e}$ can be determined as the ratio of the quark magnetic moment $\mu_{\rm s}$ and $\mu_{\rm u}$ for the strange and nostrange quarks, $1-s_{\rm e}=\dfrac{\mu_{\rm s}}{\mu_{\rm u}}\sim\dfrac{m_{\rm u}}{m_{\rm s}}$, where $m_{\rm u}$ and $m_{\rm s}$ are the nonstrange and strange quark masses. $\theta_{\rm e}$ is the phase angle of the electromagnetic amplitude to the strong amplitude.

Table 3.　The decay amplitudes of $\psi(2S)\to$VP.

	SOZI	DOZI
$\rho\pi$	$g+e$	
$K^{*\pm}K^{\mp}$	$g(1-s)+e(1+s_{\rm e})$	
$K^{*0}\overline{K^0}$	$g(1-s)-e(2-s_{\rm e})$	
$\omega\eta$	$(g+e)X_\eta$	$\sqrt{2}rg(\sqrt{2}X_\eta+Y_\eta)$
$\omega\eta'$	$(g+e)X_{\eta'}$	$\sqrt{2}rg(\sqrt{2}X_{\eta'}+Y_{\eta'})$
$\phi\eta$	$(g(1-2s)-2e(1-s_{\rm e}))Y_\eta$	$rg(\sqrt{2}X_\eta+Y_\eta)$
$\phi\eta'$	$(g(1-2s)-2e(1-s_{\rm e}))Y_{\eta'}$	$rg(\sqrt{2}X_{\eta'}+Y_{\eta'})$
$\rho^0\eta$	$3eX_\eta$	
$\rho^0\eta'$	$3eX_{\eta'}$	
$\omega\pi^0$	$3e$	
$\phi\pi^0$	0	

5　The result and analysis

With the MINUIT package[13] in CERN library, the parameters are obtained by least χ squares fitting. The reduced branching ratio is defined as

$$\widetilde{B_r}(\psi(2S)\to{\rm VP})=\frac{(B_r(\psi(2S)\to{\rm VP})}{P_{\rm V}^3},\qquad(11)$$

here $P_{\rm V}$ is the momentum of the vector meson.

The reduced branching ratios of $\psi(2S)\to$ VP measured from the BES experiment are shown in the second column in Table 2.

The χ^2 is defined as following

$$\chi^2=\sum_{i=1}^{9}\left(\frac{\tilde{B}r_{\rm expc}-\tilde{B}r_{\rm meas}}{\sigma_{\tilde{B}r_{\rm meas}}}\right)^2,\qquad(12)$$

where, $\tilde{B}r$ is the reduced branching ratio, σ is the fitting uncertainty, expc and meas are the expectation value and the measurement value, respectively.

We first present the relevant set of data and briefly discuss their main features. The previously available information of the $\psi(2S)\to$ VP branching ratios have been summarized in the first column of Table 1. We have omitted the known upper limits for the $\psi(2S)\to\phi\pi^0$ and $\psi(2S)\to\omega\eta$ branching ratios in our analysis because they are the upper limits at 90% confidence level rather than precise branching ratios. As previously stated, we just consider the mixing angle between η and η' and assume the mixing of ω and ϕ is ideal. In spite of these simplifying assumptions this phenomenological model contains a rather large number of parameters. The g, e, r, s, $s_{\rm e}$, $\theta_{\rm e}$ and $\theta_{\rm p}$ are 7 parameters.

In order to determine the parameters, we fit the parameters in two conditions.

Fitting Ⅰ: In order to determine the $SU(3)$ symmetry breaking caused by mass effect in electromagnetic process, we fit the parameters with $s_{\rm e}$ in the range of [0—1.0]. The fitting result is shown in Table 4.

From fitting result Ⅰ, we can find that $\theta_{\rm p}$, $\theta_{\rm e}$, s and $s_{\rm e}$ are relevant to each other. The change of $s_{\rm e}$ has little effect on the other parameters except s. We can think the $SU(3)$ symmetry breaking caused by $s_{\rm e}$ can be ignored in $\psi(2S)$ strong decays. From fitting result, the change of $\chi^2/_{\rm n.o.d}$ with $s_{\rm e}$ can be neglected. When $s_{\rm e}$ equals zero, the fitting result is $g=0.76\pm0.20$, $s=0.01\pm0.23$, $e=0.22\pm0.03$, $\theta_{\rm e}=(156\pm89)^\circ$, $\theta_{\rm p}=(-7.77\pm1.68)^\circ$, $r=0.14\pm0.22$.

Table 4. Fitting result Ⅰ.

$s_{\rm e}$	$\theta_{\rm p}$	$\theta_{\rm e}$	g	s	e	r	$\chi^2/_{\rm n.o.d}$
0	$(-7.77\pm1.68)^\circ$	$(156\pm89)^\circ$	0.76 ± 0.20	0.01 ± 0.23	0.22 ± 0.03	0.14 ± 0.22	2.3016/3
0.1	$(-7.77\pm1.69)^\circ$	$(157\pm87)^\circ$	0.76 ± 0.19	-0.02 ± 0.21	0.22 ± 0.03	0.14 ± 0.22	2.3021/3
0.2	$(-7.76\pm1.69)^\circ$	$(158\pm84)^\circ$	0.76 ± 0.18	-0.04 ± 0.20	0.22 ± 0.03	0.14 ± 0.22	2.3026/3
0.3	$(-7.75\pm1.69)^\circ$	$(159\pm81)^\circ$	0.76 ± 0.17	-0.07 ± 0.19	0.22 ± 0.03	0.14 ± 0.21	2.3029/3
0.4	$(-7.74\pm1.69)^\circ$	$(160\pm78)^\circ$	0.76 ± 0.16	-0.09 ± 0.18	0.22 ± 0.03	0.14 ± 0.21	2.3031/3
0.5	$(-7.74\pm1.70)^\circ$	$(160\pm76)^\circ$	0.76 ± 0.15	-0.12 ± 0.17	0.22 ± 0.03	0.14 ± 0.21	2.3032/3
0.6	$(-7.73\pm1.70)^\circ$	$(161\pm74)^\circ$	0.77 ± 0.15	-0.15 ± 0.17	0.22 ± 0.03	0.14 ± 0.21	2.3032/3
0.7	$(-7.72\pm1.70)^\circ$	$(161\pm70)^\circ$	0.77 ± 0.14	-0.17 ± 0.16	0.22 ± 0.03	0.14 ± 0.21	2.3032/3
0.8	$(-7.72\pm1.70)^\circ$	$(162\pm70)^\circ$	0.77 ± 0.14	-0.20 ± 0.16	0.22 ± 0.03	0.14 ± 0.21	2.3031/3
0.9	$(-7.72\pm1.70)^\circ$	$(162\pm66)^\circ$	0.77 ± 0.13	-0.23 ± 0.16	0.22 ± 0.03	0.14 ± 0.21	2.3030/3
1.0	$(-7.71\pm1.70)^\circ$	$(163\pm65)^\circ$	0.77 ± 0.13	-0.25 ± 0.15	0.22 ± 0.03	0.14 ± 0.21	2.3028/3

Table 5. Fitting result Ⅱ.

$s_{\rm e}$	$\theta_{\rm p}$	$\theta_{\rm e}$	g	s	e	$\chi^2/_{\rm n.o.d}$
0	$(-13.09\pm2.43)^\circ$	$(179\pm221)^\circ$	0.78 ± 0.08	-0.02 ± 0.13	0.22 ± 0.03	2.6039/4
0.1	$(-13.07\pm2.43)^\circ$	$(179\pm206)^\circ$	0.78 ± 0.08	-0.05 ± 0.13	0.22 ± 0.03	2.6039/4
0.2	$(-13.07\pm2.43)^\circ$	$(179\pm188)^\circ$	0.78 ± 0.08	-0.08 ± 0.13	0.22 ± 0.03	2.6039/4
0.3	$(-13.07\pm2.43)^\circ$	$(179\pm176)^\circ$	0.78 ± 0.08	-0.10 ± 0.13	0.22 ± 0.03	2.6039/4
0.4	$(-13.07\pm2.43)^\circ$	$(179\pm163)^\circ$	0.78 ± 0.08	-0.13 ± 0.13	0.22 ± 0.03	2.6039/4
0.5	$(-13.07\pm2.43)^\circ$	$(179\pm154)^\circ$	0.78 ± 0.08	-0.16 ± 0.13	0.22 ± 0.03	2.6039/4
0.6	$(-13.07\pm2.43)^\circ$	$(179\pm146)^\circ$	0.78 ± 0.08	-0.19 ± 0.13	0.22 ± 0.03	2.6039/4
0.7	$(-13.07\pm2.43)^\circ$	$(179\pm139)^\circ$	0.78 ± 0.08	-0.22 ± 0.13	0.22 ± 0.03	2.6039/4
0.8	$(-13.07\pm2.43)^\circ$	$(179\pm134)^\circ$	0.78 ± 0.08	-0.24 ± 0.14	0.22 ± 0.03	2.6039/4
0.9	$(-13.06\pm2.43)^\circ$	$(179\pm126)^\circ$	0.78 ± 0.08	-0.27 ± 0.14	0.22 ± 0.03	2.6039/4
1.0	$(-13.07\pm2.43)^\circ$	$(179\pm124)^\circ$	0.78 ± 0.08	-0.30 ± 0.14	0.22 ± 0.03	2.6039/4

Fitting Ⅱ: If we ignore the DOZI contribution, the fitting result is shown in Table 5. From fitting result Ⅱ, we find that the DOZI contribution makes large effect on the fitting results especially to the mixing angle of pseudoscalar mesons. The phase angle of the electromagnetic amplitude to the strong amplitude has large error if we ignore the DOZI contribution. However, the other parameters have little effect from this hypothesis.

The branching ratios $\psi(2S)\to {\rm K}^{*-}{\rm K}^{+}+c.c.$ and $\psi(2S)\to {\rm K}^{*0}\overline{{\rm K}^0}+c.c.$ used to fit the parameters come from the Ref. [10] where the phase between the electromagnetic amplitude and three-gluon amplitude of the $\psi(2S)$ decay is constrained in the range from 95° to 304° which disfavors the positive solution of the phase 90° determined from J/ψ decays. It is coincident with our result. If we ignore the phase, the branching ratios $\psi(2S)\to {\rm K}^{*-}{\rm K}^{+}+c.c.$ and $\psi(2S)\to {\rm K}^{*0}\overline{{\rm K}^0}+c.c.$ are $2.9^{+1.3}_{-1.7}\pm0.4$ and $13.3^{+2.4}_{-2.7}\pm1.7$, respectively. Together with the other seven branching ratios, we fit the parameters with the same method and find the parameters change a little except s. When $s_{\rm e}$ equals zero, the fitting result is $g=0.76\pm0.13$, $s=0.02\pm0.19$, $e=0.22\pm0.03$, $\theta_{\rm e}=(160\pm69)^\circ$, $\theta_{\rm p}=(-7.53\pm1.51)^\circ$, $r=0.15\pm0.18$ with $\chi^2=2.2984$. If we ignore the DOZI contribution, the fitting result is $g=0.76\pm0.12$, $s=-0.02\pm0.18$, $e=0.22\pm0.03$, $\theta_{\rm e}=(160\pm64)^\circ$, $\theta_{\rm p}=(-12.77\pm2.45)^\circ$ with $\chi^2=2.7160$.

From above analysis, we can make the conclusion that the phase between the electromagnetic amplitude and three-gluon amplitude has little effect on the fitting result.

6 The summary and discussion

In this paper, the $SU(3)$ symmetry breaking term is introduced, which is the origin of η-η' mixing. In other words, there exists a sizable difference between effective masses of the strange and nonstrange quarks, which is especially conspicuous in the pseudoscalar mesons states. This mass difference is the eventual origin of all the $SU(3)$ symmetry breaking effects including the octet-singlet mixing. The characteristics of the obtained results are as follows.

1) The mixing angle is estimated to be $-7.5^\circ \sim -13.1^\circ$ after taking into account different cases. The result is consistent with the value obtained from the quadratic Gell-Mann-Okubo mass formula.

2) The $SU(3)$ symmetry breaking factor s_e caused by mass effect in the electromagnetic process has little effect on the other parameters except s. We can think $SU(3)$ symmetry breaking caused by s_e can be ignored in $\psi(2S)$ strong decays.

3) From the fitting result of r, the strength of DOZI to SOZI is about 14% which is consistent with the result from $J/\psi \to VP, \gamma P$.

4) The phase angle of the electromagnetic amplitude to the strong amplitude is in the range from 155° to 180° which is different from the result[14, 15] of J/ψ decays but is consistent with the result[10, 16] obtained from fitting the cross sections in $\psi(2S)$ decays.

5) All the rates are reasonably consistent with each other and with the model.

From the above analysis we have obtained many significant conclusions. However, there are some problems need to be further studied. Our result is different from the other's in some aspects. This work is based on the branching ratios of $\psi(2S) \to VP$ measured by the BES collaboration and the branching ratios are provided with statistical and systematic errors which can affect the fitting result. The radiative correction is not considered in our analysis. Also, we need to consider the continuum contribution and their interference[17] fully.

Up to now, the most precise measurements of the $\psi(2S)$ decays are by e^+e^- colliding experiments, where the production of $\psi(2S)$ is accompanied by $e^+e^- \to \gamma^* \to$ hadrons[18], in which e^+e^- pair annihilates into a virtual photon without going through the intermediate resonance state. Hence there are two sort of Feynman diagrams. One is through the $\psi(2S)$ and the other is through the one-photon annihilation, as shown in Fig. 4.

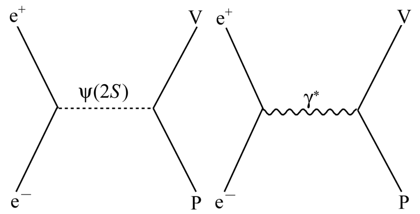

Fig. 4. The Feynman diagrams for $e^+e^- \to VP$ near $\psi(2S)$.

When calculating the branching ratios, the continuum contribution and their interference should be considered fully. However, the branching ratios used in this work ignore the continuum contribution except $\psi(2S) \to \rho\eta$, $\psi(2S) \to \rho\eta'$, $\psi(2S) \to \omega\pi^0$, $\psi(2S) \to K^{*-}K^+ + c.c.$ and $\psi(2S) \to K^{*0}\overline{K^0} + c.c.$ and all the decay modes ignore the interference when calculating the branching ratios.

After all, the $\psi(2S)$ sample from the BESⅡ collaboration is not enough and the performance of the detector need to be improved(e.g. energy resolution, momentum resolution and particle identification). To achieve high precision physics results, not only the sample statistics is required to be increased significantly, but also the excellent detector is needed. Therefore a modern detector, BESⅢ, has to be built to meet the above requirements[19]. Comparing with BESⅡ, BESⅢ has very good photon energy resolution, good hadron identification capabilities, accurate 4-momentum measurement of low-momentum charged particles and the largest luminosity in the tau-charm region ever planed. Based on BESⅢ, the large $\psi(2S)$ sample will provide a better chance to study the pseudoscalar mixing and further improve these measurements with much higher sensitivities. It is suggested that it is necessary to obtain much more $\psi(2S)$ data in energy range of continuum contribution except for in energy range of $\psi(2S)$.

We wish to thank Shen Xiao-Yan and Li Hai-Bo for useful communication.

References

1 Gilman F J, Kauffman R. Phys. Rev., 1987, **D36**: 2761
2 Amsler C, Wohl C J. Phys. Rev., 2002, **D66**: 120
3 Isgur N. Phys. Rev., 1975, **D12**: 3770
4 Fritzsch H, Jackson J D. Phys. Lett., 1977, **B66**: 365
5 Bramon A, Escribano R, Scadron M D. Phys. Lett., 1997, **B403**: 339
6 Bramon A, Escribano R, Scadron M D. Eur. Phys. J., 1999, **C7**:271
7 LI D M, MA B, YU H. International Journal of Modern Physics, 2003, **A18**(19): 3335
8 Escribano R, Frère Jean-Marie. JHEP., 2005, **0506**: 029
9 Ablikim M et al. Phys. Lett., 2005, **B619**: 247
10 Ablikim M et al. Phys. Lett., 2005, **B614**: 37
11 Ablikim M et al. Phys. Rev., 2004, **D70**: 112003
12 Ablikim M et al. Phys. Rev., 2004, **D70**: 112007
13 James F. MINUIT Reference Manual. Version 94.1. Genava: CERN Program Library Entry D506, 1994
14 Jousset J, Ajaltouni Z, Falvard A et al. Phys. Rev., 1990, **D41**: 1389
15 Coffman D, Dubois G P, Hauser J et al. Phys. Rev., 1988, **D38**: 2695
16 WANG P, YUAN C Z, MO X H et al. Phys. Rev., 2004, **D69**: 057502
17 WANG P, YUAN C Z, MO X H et al. Phys. Lett., 2004, **B593**: 89
18 WANG P, MO X H, YUAN C Z. Phys. Lett., 2003, **B557**: 192
19 BAI J Z et al. Nucl. Instrum. Methods, 2001, **A458**: 627

$\psi(2S)\to$ VP 衰变中赝标量介子混合的研究*

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摘要　利用BES合作组给出的$\psi(2S)\to$ VP各个衰变道的分支比, 对赝标量介子混合的问题做了分析, 利用$\psi(2S)$数据来研究赝标量介子的混合尚属首次. 通过参数拟合, 可以得到η和η'的混合角$\theta_{\rm p}=(-7.54\pm1.52)^{\circ}$, 这个结果与由二次Gell-Mann-Okubo质量公式所得出的结果相符. 另外, 通过分析还可以得到在$\psi(2S)\to$ VP中DOZI过程相对于SOZI过程的贡献约为14%; 电磁衰变振幅和强相互作用振幅之间的相角$\theta_{\rm e}=(156\pm89)^{\circ}$.

关键词　赝标量混合　混合角　$SU(3)$对称性破坏

2005 – 12 – 17 收稿,　2006 – 03 – 13 收修改稿

*国家自然科学基金(10491300)资助

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