On the η' gluonic admixture

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The η' which is an $SU(3)_F$ singlet state can contain a pure gluon component, gluonium. We examine this possibility by analyzing all available experimental data. It is pointed out that the η' gluonic component may be as large as 26%. We also show that the amplitude for $J/\psi \to \eta' \gamma$ decay obtains a notable contribution from gluonium.

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I. INTRODUCTION

The CLEO Collaboration reported an unexpectedly large branching ratio for $B \to \eta' X_s$ [1]. One of the suggested mechanisms [2–13] to explain this problem considers the process $b \to sg$, $g \to \eta' g$ [2–7]. This mechanism is based on the anomalous coupling of $gg \to \eta'$ which accounts for the large branching ratio for $J/\psi \to \eta' \gamma$ decay. It should be noted that the gluonic component of η' has been studied extensively in the literature [14–21]. We shall determine the gluonic component of η' considering all known experimental data.

It is believed that η' consists of the $SU(3)_F$ singlet and octet $q\bar{q}$ states which we denote as η_1 and η_8, respectively, and is dominated by the singlet state. The $SU(3)_F$ singlet state, differing from the octet state, can be composed of pure gluon states. Therefore, we examine another singlet state in η' made only of gluons, which we call gluonium.

The remainder of the paper is organized as follows. In Sec. II, we describe our notation and introduce the gluonic component. The formalism for studying the radiative light meson decays is presented in Sec. III. The recent discussions on the definition of the decay constants for η and η' [22–24] are taken into account. We then proceed to obtain the pseudoscalar mixing angle θ_p and the possible gluonic content of η' in Sec. IV. The investigation of the radiative J/ψ decay is performed in Sec. V. A summary and conclusions are given in Sec. VI.

II. NOTATION

$SU(3)_F \times U(1)$ symmetry introduces the pseudoscalar octet state η_8 and singlet state η_1 as

$$\begin{pmatrix} \eta_8 \\ \eta_1 \end{pmatrix} = \begin{pmatrix} \sin\theta_I & -\cos\theta_I \\ \cos\theta_I & \sin\theta_I \end{pmatrix} \begin{pmatrix} \dfrac{u\bar{u}+d\bar{d}}{\sqrt{2}} \\ s\bar{s} \end{pmatrix}, \tag{1}$$

where θ_I is the ideal mixing angle which satisfies $\theta_I = \tan^{-1}(1/\sqrt{2})$. The two physical states η and η' are considered as mixtures of these states with pseudoscalar mixing angle θ_p

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\theta_p & -\sin\theta_p \\ \sin\theta_p & \cos\theta_p \end{pmatrix} \begin{pmatrix} \eta_8 \\ \eta_1 \end{pmatrix}. \tag{2}$$

Combining Eqs. (1) and (2), we rewrite

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\alpha_p & -\sin\alpha_p \\ \sin\alpha_p & \cos\alpha_p \end{pmatrix} \begin{pmatrix} \dfrac{u\bar{u}+d\bar{d}}{\sqrt{2}} \\ s\bar{s} \end{pmatrix} \tag{3}$$

with $\alpha_p = \theta_p - \theta_I + \pi/2$ which represents the discrepancy of the mixing angle from the ideal one. Note that the ϕ and ω in the vector meson system mix almost ideally, that is, $\alpha_v \simeq 0$. This characteristic deviation from the ideal mixing in $\eta - \eta'$ system can be understood in terms of the anomaly. Let us take the derivative of the singlet axial vector current

$$\partial_\mu j^{\mu 5} = 2imq\gamma_5\bar{q} - \frac{3\alpha_s}{4\pi} G_{\alpha\beta}\tilde{G}^{\alpha\beta}, \tag{4}$$

where $G_{\alpha\beta}$ is a gluonic field strength and $\tilde{G}^{\alpha\beta}$ is its dual. The term proportional to $G\tilde{G}$ is coming from the triangle anomaly [25]. It affects neither the octet axial vector nor the vector current. Equation (4) implies that the pseudoscalar singlet state can be composed not only of $q\bar{q}$ but also of gluons. Treating the gluon composite equivalent to the quark composite, the η' which is mostly $SU(3)_F$ singlet may contain the pure gluon state, gluonium. Therefore, we reconstruct $\eta - \eta'$ system by including gluonium. Then Eq. (2) is extended to a 3×3 matrix with three mixing angles

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$$\begin{pmatrix} \eta \\ \eta' \\ i \end{pmatrix} = \begin{pmatrix} \cos\theta_p \cos\gamma + \sin\theta_p \cos\phi\sin\gamma & -\sin\theta_p\cos\gamma + \cos\theta_p\cos\phi\sin\gamma & \sin\phi\sin\gamma \\ \cos\theta_p\sin\gamma + \sin\theta_p\cos\phi & \sin\theta_p\sin\gamma + \cos\theta_p\cos\phi\cos\gamma & \sin\phi\cos\gamma \\ -\sin\theta_p\sin\phi & -\cos\theta_p\sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} \eta_8 \\ \eta_1 \\ \text{gluonium} \end{pmatrix},$$

where i is a "glueball-like state" which we refrain from discussing here. Since the mass of η is about the mass of η_8 which is obtained from Gell-Mann–Okubo mass formula, we assume that η does not contain the extra singlet state gluonium. Setting $\gamma=0$, we obtain

$$\begin{pmatrix} \eta \\ \eta' \\ i \end{pmatrix} = \begin{pmatrix} \cos\theta_p & -\sin\theta_p & 0 \\ \sin\theta_p\cos\phi & \cos\theta_p\cos\phi & \sin\phi \\ -\sin\theta_p\sin\phi & -\cos\theta_p\sin\phi & \cos\phi \end{pmatrix} \times \begin{pmatrix} \eta_8 \\ \eta_1 \\ \text{gluonium} \end{pmatrix}. \tag{5}$$

It is convenient to write the η and η' states as [14]

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

$$|\eta'\rangle = X_{\eta'} \left| \frac{u\bar{u}+d\bar{d}}{\sqrt{2}} \right\rangle + Y_{\eta'} |s\bar{s}\rangle + Z_{\eta'}|\text{gluonium}\rangle. \tag{7}$$

$X_{\eta(\eta')}$, $Y_{\eta(\eta')}$, and $Z_{\eta'}$ are normalized as

$$X_\eta^2 + Y_\eta^2 = 1, \tag{8}$$

$$X_{\eta'}^2 + Y_{\eta'}^2 + Z_{\eta'}^2 = 1, \tag{9}$$

and relate to the mixing angles

$$X_\eta = \cos\alpha_p, \quad Y_\eta = -\sin\alpha_p, \tag{10}$$

$$X_{\eta'} = \cos\phi\sin\alpha_p, \quad Y_{\eta'} = \cos\phi\cos\alpha_p, \quad Z_{\eta'} = \sin\phi. \tag{11}$$

III. DECAY RATES

We calculate the decay rates by using the vector meson dominance model (VDM) and the $SU(3)_F$ quark model (see, for example, Refs. [26–28]). In this method, the decay rates are expressed in terms of the masses and the decay constants of light mesons. The decay constants for vector mesons which are defined by

$$m_V f_V \epsilon^\mu = \langle 0 | j_V^\mu | V(p,\lambda)\rangle \tag{12}$$

are well determined by their decays into e^+e^- [29] as

$$f_\rho = (216\pm5)\ \text{MeV}, \quad f_\omega = (195\pm3)\ \text{MeV},$$
$$f_\phi = (237\pm4)\ \text{MeV}. \tag{13}$$

On the other hand, the decay constants for η and η' are not well defined because of the anomaly. Recently, there has been considerable progress on the parametrization of the decay constants of $\eta-\eta'$ system [22–24]. Following Ref. [24], we utilize the decay constants defined by

$$i f_x p_\mu = \left\langle 0 \left| u\gamma^\mu\gamma_5\bar{u} + d\gamma^\mu\gamma_5\bar{d} \right| \frac{u\bar{u}+d\bar{d}}{\sqrt{2}} \right\rangle, \tag{14}$$

$$i f_y p_\mu = \langle 0 | s\gamma^\mu\gamma_5\bar{s} | s\bar{s}\rangle, \tag{15}$$

which are considered as the decay constants for the $SU(3)_F$ singlet states at nonanomaly limit. Since the state $|(u\bar{u}+d\bar{d})/\sqrt{2}\rangle$ in Eq. (14) is equivalent to π^0 but an isospin singlet, we can approximately have the following relation by assuming that the isospin breaking effect is not large:

$$f_x = f_\pi.$$

When $SU(3)_F$ symmetry is exact f_y in Eq. (15) is equal to f_x. However, the mass difference between the u and d quarks and the s quark is notable. The Gell-Mann–Okubo mass formula gives a quantitative estimate of the s quark mass breaking effect. Similarly, this breaking effect for our decay constants can be included through

$$f_y = \sqrt{2f_K^2 - f_\pi^2}.$$

The known values for $f_\pi = 131$ MeV and $f_K = 160$ MeV lead to

$$f_x = 131\ \text{MeV}, \quad f_y = 1.41\times 131\ \text{MeV}. \tag{16}$$

It is shown in Ref. [24] that the approximate values in Eq. (16) are justified phenomenologically and also satisfy the result of chiral perturbation theory in Ref. [22].

Using these decay constants, the radiative decay rates of the light mesons can be written in terms of $X_{\eta(\eta')}$, $Y_{\eta(\eta')}$ and $Z_{\eta'}$ in the VDM as follows:

$$\Gamma(\omega\to\eta\gamma) = \frac{\alpha}{24}\left(\frac{m_\omega^2 - m_\eta^2}{m_\omega}\right)^3 \left(\frac{m_\omega}{f_\omega \pi^2}\right)^2 \left(\frac{X_\eta}{4f_x}\right)^2, \tag{17}$$

$$\Gamma(\phi\to\eta\gamma) = \frac{\alpha}{24}\left(\frac{m_\phi^2 - m_\eta^2}{m_\phi}\right)^3 \left(\frac{m_\phi}{f_\phi \pi^2}\right)^2 \left(-2\frac{Y_\eta}{4f_y}\right)^2, \tag{18}$$

$$\Gamma(\eta\to\gamma\gamma)=\frac{\alpha^2}{288\pi^3}m_\eta^3\left(\frac{5X_\eta}{f_x}+\frac{\sqrt{2}Y_\eta}{f_y}\right)^2, \quad (19)$$

$$\Gamma(\eta'\to\omega\gamma)=\frac{\alpha}{8}\left(\frac{m_{\eta'}^2-m_\omega^2}{m_{\eta'}}\right)^3\left(\frac{m_\omega}{f_\omega\pi^2}\right)^2\left(\frac{X_{\eta'}}{4f_x}\right)^2, \quad (20)$$

$$\Gamma(\eta'\to\rho\gamma)=\frac{\alpha}{8}\left(\frac{m_{\eta'}^2-m_\rho^2}{m_{\eta'}}\right)^3\left(\frac{m_\rho}{f_\rho\pi^2}\right)^2\left(\frac{3X_{\eta'}}{4f_x}\right)^2, \quad (21)$$

$$\Gamma(\phi\to\eta'\gamma)=\frac{\alpha}{24}\left(\frac{m_\phi^2-m_{\eta'}^2}{m_\phi}\right)^3\left(\frac{m_\phi}{f_\phi\pi^2}\right)^2\left(-2\frac{Y_{\eta'}}{4f_y}\right)^2, \quad (22)$$

$$\Gamma(\eta'\to\gamma\gamma)=\frac{\alpha^2}{288\pi^3}m_{\eta'}^3\left(\frac{5X_{\eta'}}{f_x}+\frac{\sqrt{2}Y_{\eta'}}{f_y}\right)^2, \quad (23)$$

where the OZI suppressed process occurring from ϕ-ω mixing violation is ignored. In fact this breaking effect is expected to be very small; for example, in the case of the $\phi\to\pi^0\gamma$ decay, $\sin\alpha_V$ is estimated to be less than 0.02.

It is known that the VDM works quite well in describing the decay modes (see, for example, Refs. [30–32]). This is supported by performing the computation of the decay rates $\omega\to\pi^0\gamma$ and $\pi^0\to\gamma\gamma$ which do not depend on $X_{\eta(\eta')}$, $Y_{\eta(\eta')}$, and $Z_{\eta'}$:

$$\Gamma(\omega\to\pi^0\gamma)=\frac{\alpha}{24}\left(\frac{m_\omega^2-m_{\pi^0}^2}{m_\omega}\right)^3\left(\frac{m_\omega}{f_\omega\pi^2}\right)^2\left(\frac{3}{4f_{\pi^0}}\right)^2 = 0.72\ \text{MeV}, \quad (24)$$

$$\Gamma(\pi^0\to\gamma\gamma)=\frac{\alpha^2}{288\pi^3}m_{\pi^0}^3\left(\frac{3}{f_{\pi^0}}\right)^2=0.0077\ \text{KeV}, \quad (25)$$

which are rather consistent with the experimental data [29]

$$\Gamma(\omega\to\pi^0\gamma)=(0.72\pm0.043)\ \text{MeV},$$

$$\Gamma(\pi^0\to\gamma\gamma)=(0.0077\pm0.00055)\ \text{KeV},$$

respectively. Here we used $f_{\pi^0}=131$ MeV. In the case of the $\rho^0\to\pi^0\gamma$ decay, the model calculation gives $\Gamma(\rho^0\to\pi^0\gamma)=0.06$ MeV which is small compared to the experimental value $\Gamma(\rho^0\to\pi^0\gamma)=(0.10\pm0.026)$ MeV. We note, however, that $\rho^0\to\pi^0\gamma$ decay rate still has a large error. It will be discussed in detail as more data are available. We expect that the theoretical uncertainty occurring from the VDM is less than 15%. This number is within the range of the error estimated in Ref. [33] according to a QCD-based method.

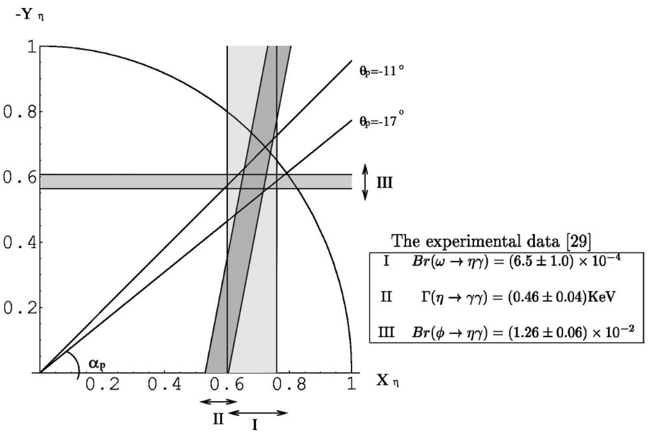

FIG. 1. The experimental bounds for $\omega\to\eta\gamma$ (I), $\eta\to\gamma\gamma$ (II), and $\phi\to\eta\gamma$ (III) obtained by inputing the PDG average. The condition for X_η and Y_η in Eq. (8) is shown as a circumference. We use $-17°\leqslant\theta_p\leqslant-11°$ as a preferable region in the following sections.

IV. RESULTS

A. Results for X_η and Y_η (determination of θ_p)

First, we analyze $\omega\to\eta\gamma$, $\eta\to\gamma\gamma$, and $\phi\to\eta\gamma$ decays. Substituting the left-hand side of Eqs. (17)–(19) for the experimental data, we obtain the constraint on X_η and Y_η and consequently, θ_p via Eq. (10). The result obtained by inputting the average in Ref. [29] is shown in Fig. 1. The circumference denotes the constraint for X_η and Y_η in Eq. (8). As we estimated in the previous section, the theoretical error of 15% is included.

In Fig. 1, we have plotted the average of several experiments for each process taken by Particle Data Group in [29], however, we claim that some inconsistent data are included when averaged. Therefore, we compute averages by excluding those data and give constraints on θ_p below. Our final results obtain slight differences from those shown in Fig. 1 due to this change of inputs.

A result for $\eta\to\gamma\gamma$ decay in 1974, $\Gamma(\eta\to\gamma\gamma)=(0.32\pm0.046)$ KeV, is inconsistent with all other experiments so that we exclude this result and take the average again. Consequently, the central value of $\Gamma(\eta\to\gamma\gamma)$ gets an increase of 5%, which leads the bound II in Fig. 1 to shift to the right by about 0.03. After the shift, the bound II intersects the circle between $\alpha_p\simeq-44°$ and $-41°$ and we obtain the result from the $\eta\to\gamma\gamma$ decay as $\theta_p\simeq-14°\sim-11°$. Similarly, a result for $\omega\to\eta\gamma$ in 1977, which is $Br(\omega\to\eta\gamma)=(3.0^{+2.5}_{-1.8})\times10^{-4}$, is small compared to other data and in fact, it has a 70% error. Exclusion of this value leads to a 6% increase of the center value and about a 0.04 shift to the right of the bound I in Fig. 1. As a result, the bound I intersects the circle at $\theta_p\simeq-17°\sim-8°$. Finally, the experiment in 1983 of $\phi\to\eta\gamma$ reports a branching ratio $\mathrm{Br}(\phi\to\eta\gamma)=(0.88\pm0.20)\times10^{-2}$ which is smaller than any other value. We exclude this result and obtain a 0.01 upward shift of the bound III in Fig. 1. Then the result for θ_p from $\phi\to\eta\gamma$ is $-20°\sim-17°$. We here summarize the constraints on θ_p: $-14°\sim-11°$ from $\eta\to\gamma\gamma$, $-17°\sim-8°$ from $\omega\to\eta\gamma$ and $-20°\sim-17°$ from $\phi\to\eta\gamma$. Unfortunately, we do not ob-

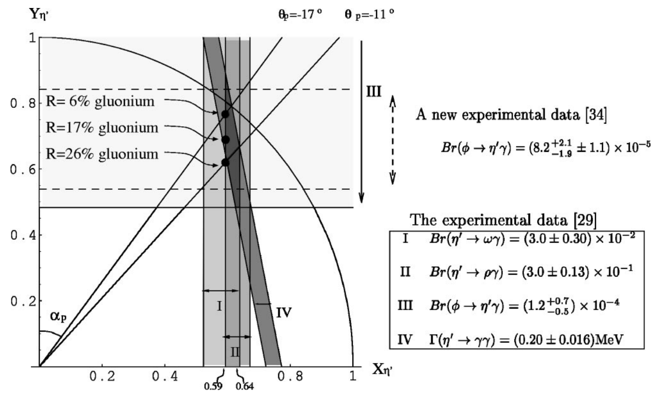

FIG. 2. The experimental bounds for $\eta'\to\omega\gamma$ (I), $\eta'\to\rho\gamma$ (II), $\phi\to\eta'\gamma$ (III), and $\eta'\to\gamma\gamma$ (IV). The dashed line shows the bound for $\phi\to\eta'\gamma$ from new experimental data [34]. Taking the value of θ_p to be $-11°$, we observe the maximum 26% of the gluonic component in η'.

serve any region where all three constraints overlap. We would not like to conclude so far that this is a serious problem since the experimental errors are still large for these processes. We expect that experimental improvements will solve this problem in the near future.

Although we could not obtain a consistent result on θ_p, it is more convenient for the following analysis to have a preferable region of θ_p. Looking back on the summary of our results above, both $\eta\to\gamma\gamma$ and $\omega\to\eta\gamma$ processes determine $-14°\sim11°$ as an allowed region. On the other hand, $-17°$ is allowed from both $\omega\to\eta\gamma$ and $\phi\to\eta\gamma$ processes. Consequently, we try to use $-11°\leqslant\theta_p\leqslant-17°$ as a preferable region in the following sections.

B. Result for $X_{\eta'}$, $Y_{\eta'}$, and $Z_{\eta'}$ (determination of $Z_{\eta'}$)

Now we analyze $\eta'\to\omega\gamma$, $\eta'\to\rho\gamma$, $\eta'\to\gamma\gamma$, and $\phi\to\eta'\gamma$ decays. Constraints on $X_{\eta'}$, $Y_{\eta'}$, and $Z_{\eta'}$ can be obtained by using Eqs. (20)–(23). The experimental bounds [29,38] for these decays are shown in Fig. 2. As in the case of η, a 15% theoretical error is taken into account. As mentioned in Sec. IV A, we use a constraint on the pseudoscalar mixing angle $-17°\leqslant\theta_p\leqslant-11°$. Since we have a relation $X^2_{\eta'}+Y^2_{\eta'}+Z^2_{\eta'}=1$, the result $X^2_{\eta'}+Y^2_{\eta'}<1$ represents η' having a gluonic component.

We have the following observations.

(1) The maximum gluonic admixture in η' is obtained to be 6% for $\theta_p=-17°$, 17% for $\theta_p=-14°$, and 26% for $\theta_p=-11°$, where the percentage is computed by

$$R=\frac{Z_{\eta'}}{X_{\eta'}+Y_{\eta'}+Z_{\eta'}}. \tag{26}$$

(2) If future experiments show an increase of 10% in the central values of the $\eta'\to\rho\gamma$ or $\eta'\to\gamma\gamma$ decay rate, the existence of the gluonic content in η' will be excluded for large $|\theta_p|$.

(3) The CMD-2 Collaboration observed $\phi\to\eta'\gamma$ in 1999. Using their new result [34]

$$\mathrm{Br}(\phi\to\eta'\gamma)=\left(8.2^{+2.1}_{-1.9}\pm1.1\right)\times10^{-5},$$

the dashed bound in Fig. 2 is obtained. The new data show that the observation of the maximum gluonic admixture described above is still allowed. A more stringent constraint is expected once the data from the ϕ factory at DAΦNE come out.

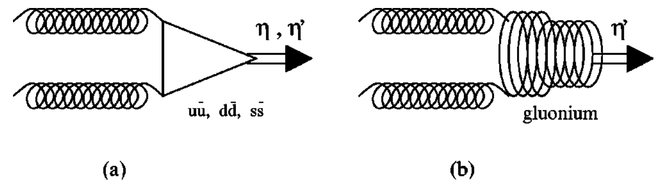

FIG. 3. Coupling of η and η' to two gluons through quark and antiquark triangle loop (a) and through gluonic admixture (b).

V. J/ψ DECAYS

Now we analyze the radiative J/ψ decays into η and η' and see the influence of the allowed amount of gluonic admixture in Sec. IV B on the amplitudes. The ratio of the two decay rates $R_{J/\psi}$ can be written as [24,35–37]

$$R_{J/\psi}=\frac{\Gamma(J/\psi\to\eta\gamma)}{\Gamma(J/\psi\to\eta'\gamma)}=\left(\frac{1-m^2_{\eta}/m^2_{J/\psi}}{1-m^2_{\eta'}/m^2_{J/\psi}}\right)^3\left|\frac{\sqrt{2}\xi X_\eta-\zeta(-Y_\eta)}{(\sqrt{2}\xi X_{\eta'}+\zeta Y_{\eta'})+g'_r Z_{\eta'}}\right|^2, \tag{27}$$

where ξ, ζ, and g'_r are f_π/f_x, f_π/f_y, and the coupling of two gluons to gluonium, respectively. Using the average of Ref. [29], we have

$$R_{J/\psi}=\frac{\Gamma(J/\psi\to\eta\gamma)}{\Gamma(J/\psi\to\eta'\gamma)}=0.20\pm0.02. \tag{28}$$

The terms $\sqrt{2}\xi X_{\eta^{(\prime)}}$ and $\zeta Y_{\eta^{(\prime)}}$ in Eq. (27) represent the contributions from such intermediate processes as $gg\to(u\bar{u},d\bar{d}$ triangle loop$)\to\eta^{(\prime)}$ and $gg\to(s\bar{s}$ triangle loop$)\to\eta^{(\prime)}$, respectively [see Fig. 3(a)], and the term $g'_rZ_{\eta'}$ from $gg\to$(gluonium)$\to\eta'$ [see Fig. 3(b)]. We define the ratio between the amplitudes for the process Fig. 3(b) and Fig. 3(a) by r:

$$r=\frac{g'_rZ_{\eta'}}{(\sqrt{2}\xi X_{\eta'}+\zeta Y_{\eta'})}. \tag{29}$$

First, we examine the case of $r=0$ which means that gluonium does not contribute to $J/\psi\to\eta'\gamma$ amplitude. In this case, the right-hand side of Eq. (27) depends on only one parameter α_p, so using Eq. (28), θ_p can be determined. The result is shown in Fig. 4. We observe that for $g'_rZ_{\eta'}=0$, the θ_p angle is determined in a region $\theta_p=-13°\pm1.0°$. On the other hand, in the analysis of the glue content in Sec. IV B,

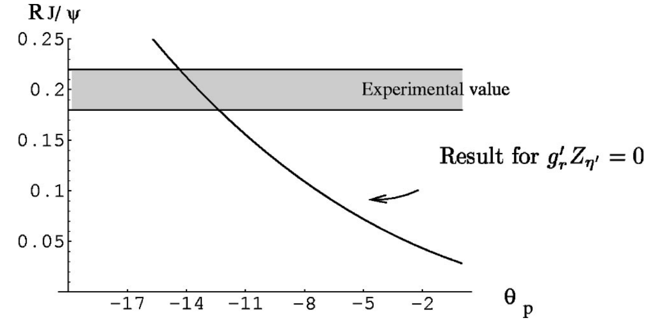

FIG. 4. The determination of θ_p, putting $g_r' Z_{\eta'} = 0$ (no gluonic admixture in η'). The result conflicts with the observation in Sec. IV B when $g_r' \neq 0$.

$Z_{\eta'} = 0$ is allowed only when θ_p is in a narrow region around $-17°$ (see Fig. 2). This disagreement indicates that $Z_{\eta'} = 0$ should be excluded.

Now let us examine the case of $g_r' Z_{\eta'} \neq 0$ in Eq. (27). Since we do not know the value of g_r' which denotes the coupling of two gluons to gluonium we fix the θ_p angle at $-17°$, $-14°$, and $-11°$, and examine each case. We set the value of $Z_{\eta'}$ at the maximum which is allowed in Sec. IV B. Substituting the left hand side of Eq. (27) for the experimental data, we determine the r value for each θ_p angle. The result is shown in Fig. 5. We observe that r reaches a maximum of 0.3 when θ_p is $-17°$ with 6% of the glue content. That is, the amplitude of the process $J/\psi \to \eta' \gamma$ has a maximum contribution of 20% from gluonium in η'.

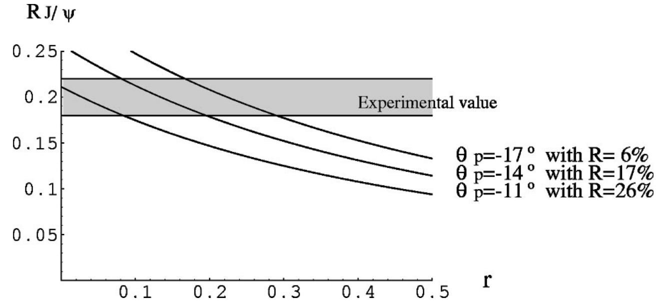

FIG. 5. The amplitude of the process $J/\psi \to \eta' \gamma$ has a maximum 20% of contribution from gluonium in η' when we choose $\theta_p = -17°$ with $R = 6\%$.

VI. CONCLUSION

We have examined the gluonic component of η' and the contributions to the process $gg \to \eta'$. By analyzing the latest experimental data on the radiative light meson decays, we have observed that the maximum 26% of the gluonic component in η' is possible at $\theta_p = -11°$. Further investigation will be done once the data from DAΦNE have come out. We have also studied the contributions of gluonium to the radiative J/ψ decays. Combining the obtained result from the analysis on the radiative light meson decays, we found that the J/ψ decays also demand gluonium in η'. In a case when we choose $\theta_p = -17°$ with 6% of gluonium in η', we have observed that the 20% of the amplitude of $J/\psi \to \eta' \gamma$ comes from gluonium.

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