The hidden charm decays of X(3915) and Z(3930) as the P-wave charmonia

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We calculate the widths of the hidden charm decay J/ψω on two charmonium-like states X(3915) and Z(3930) for χ′(2P) and χ′(2P) assignments, respectively. Our results indicate that the decay width of Z(3930) → J/ψω is 2 ~ 3 orders smaller than that of X(3915) → J/ψω, which further explains why only one structure X(3915) has been observed in the J/ψω invariant mass spectrum for the process γγ → J/ψω.

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I. INTRODUCTION

The γγ fusion process is an ideal platform to produce the charmonium-like states. In the past years, the Belle and BaBar experiments have reported many charmonium-like states in the γγ fusion processes. Among these observations, X(3915) has mass M_X(3915) = (3915 ± 3(stat) ± 2(syst)) MeV and width Γ_X(3915) = (17 ± 10(stat) ± 3(syst)) MeV. Since X(3915) was observed in the J/ψω invariant mass spectrum of γγ → J/ψω, the possible quantum number should be J^P = 0^+ or J^P = 2^+, which results in the corresponding Belle measurement of Γ_X(3915)γγ = BR(X(3915) → J/ψω) = (61 ± 17(stat) ± 8(syst)) eV or (18 ± 5(stat) ± 2(syst)) eV.

As the candidate of charmonium χ′(2P) (n^2S+1L_J = 2^1P_2), Z(3930) was first observed in the process γγ → DD. The experimental information on Z(3930) gives M_Z(3930) = 3929 ± 5(stat) ± 2(syst) MeV, Γ_Z(3930) = 29 ± 10(stat) ± 2(syst) MeV, and Γ_Z(3930)γγ = BR(Z(3930) → DD) = 0.18 ± 0.05(stat) ± 0.03(syst) keV. Later, the BaBar Collaboration also confirmed the observation of Z(3930) in γγ → DD.

In Ref. [4], the authors indicated that X(3915) and Z(3930) can be explained as χ(2P) and χ′(2P) charmonium states, respectively, by analyzing the mass spectrum and calculating the strong decay of P-wave charmonium. At present, it is an important and interesting topic to search for other approaches to test these assignments. Later, the BaBar collaboration announces that the charmonium like state X(3915) has been confirmed in γγ → χ′(2P) process with a spin-parity J^P = 0^+ [5], which is consistent with the results in Ref. [4].

In this work, we will dedicate ourselves to exploring the hidden charm decays of X(3915) and Z(3930) under χ(2P) and χ′(2P) assignments, respectively. We will give a picture of how X(3915)/Z(3930) → J/ψω occurs via hadronic loop effects with the open-charm decay channels as the intermediate state. This mechanism has been studied in Refs. [2],[3] when calculating the hidden-charm and open-charm decay modes of charmonium and other charmonium-like states. The study of the hidden-charm decays of X(3915) and Z(3930) via hadronic loop effects can be a new approach to test the P-wave charmonium explanations of X(3915) and Z(3930) and shed light on the mechanism of the hidden charm decay of a charmonium.

II. HIDDEN CHARM DECAY OF X(3915) AND Z(3930)

Under the χ(2P) assignment to X(3915), the hidden charm decay X(3915) → J/ψω occurs through the intermediate states DD since X(3915) with J^P = 0^+ dominantly decays into DD as indicated in Ref. [4]. The hadron level descriptions of X(3915) → DD → J/ψω are shown in Fig. 1.

The expression for the decay amplitude of the hidden charm decay X(3915) → DD → J/ψω reads as

$$M[X(3915) \rightarrow J/\psi \omega] = 4[M^{(o)} + M^{(b)}].$$

As the χ′(2P) state, Z(3930) mainly decays into DD and DD^* + h.c. [4]. Thus, its hidden charm decay Z(3930) → J/ψω is shown in Fig. 2. The amplitude for the processes Z(3930) → D^*(s)D^{(*)} → J/ψω can be expressed as

$$M[Z(3930) \rightarrow J/\psi \omega] = 4[M^{(j)} + M^{(t)} + M^{(s)} + M^{(j')} + M^{(t')} + M^{(s)}].$$

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FIG. 1: The schematic diagrams describing the hidden charm decay of $X'_c(2P)$. When taking the charge conjugate transformation $(D^+ \leftrightarrow \bar{D}^0)$ and the isospin transformations $(D^{+0} \leftrightarrow D^{+0})$ and $(D^{00} \leftrightarrow D^{00})$, we can obtain other diagrams from these two diagrams.

where the factor 4 in Eq. (1) and (2) is resulted from the charge conjugate and isospin transformations.

FIG. 2: The typical diagrams relevant to the hidden charm decay of $X'_c(2P)$. After making the charge conjugate transformation $(D^+ \leftrightarrow \bar{D}^0)$ and the isospin transformation $(D^{+0} \leftrightarrow D^{+0})$ and $(D^{00} \leftrightarrow D^{00})$, one gets the rest of 18 diagrams.

To write out the amplitudes corresponding to the diagrams listed in Figs. [1]2 we adopt the effective Lagrangian approach. The effective Lagrangian expressing the interactions of $X(3915)/Z(3930)$ with $D\bar{D}$ or $D\bar{D}^* + h.c.$ is given by [14]

$$\begin{align*}
\mathcal{L}_{\gamma^*D\bar{D}/D\bar{D}^*} &= g_{\gamma^*D\bar{D}} Y_{10} D\bar{D} + g_{\gamma^*D\bar{D}^*} Y_{20} D\bar{D}^* \\
&+ ig_{\gamma^*D\bar{D}} \rho_{\mu} D^{\mu} \bar{D}^{\nu} \delta_{\nu}^{\mu} + D^{\mu} (\partial_{\nu} D^{\nu} - \partial_{\nu} D^{\nu}) \bar{D}^{\nu}. 
\end{align*}$$

The couplings of charmed mesons with the light vector meson $\omega$ or charmonium $J/\psi$ are constructed in Refs. [15,16] paying respect to the heavy quark symmetry and the chiral $SU(3)$ symmetry, and are given below,

$$\begin{align*}
\mathcal{L}_{J/\psi D^0} &= ig_{J/\psi D^0} Y_{10} D^0 + g_{J/\psi D^*} Y_{20} D^* \\
&- ig_{J/\psi D} \rho_{\mu} D^{\mu} \bar{D}^{\nu} \delta_{\nu}^{\mu} + D^{\mu} (\partial_{\nu} D^{\nu} - \partial_{\nu} D^{\nu}) \bar{D}^{\nu}. 
\end{align*}$$

The coupling constants of $X'_c(3915)$ and $X'_c(3930)$ with $D\bar{D}$ and $D\bar{D}^* + h.c.$ are obtained by fitting the total widths of $X(3915)$ and $Z(3930)$, which will be presented in the next section. While the coupling constants of $J/\psi$ interacting with a pair of charmed mesons and a coupling constant of charmed mesons interacting with light vector meson are given in Table II [15–18].

| Coupling constant | Expression | Value |
|------------------|------------|-------|
| $g_{J/\psi D^0}$ | – | 7.71 |
| $g_{J/\psi D^*}$ | $\beta g_{J/\psi D}/\sqrt{2}$ | 3.98 GeV$^{-1}$ |
| $g_{J/\psi D^{*0}}$ | $g_{J/\psi D^0}$ | 7.71 |
| $g_{J/\psi D^{*0}}$ | $\beta g_{J/\psi D}/\sqrt{2}$ | 3.98 GeV$^{-1}$ |

The amplitudes for $X'_c(p_0) \rightarrow [D(p_1)\bar{D}(p_2)]D^{(a)}(q) \rightarrow J/\psi(p_3)\omega(p_4)$ corresponding to Fig. 4 are given by

$$\begin{align*}
\mathcal{M}^{(a)} &= (i)^3 \int \frac{d^4q}{(2\pi)^4} \left[ i \frac{g_{\gamma^*D\bar{D}^*}}{2\sqrt{2}} \epsilon_{\mu\nu} \epsilon_{\rho\sigma} (i\rho_j^{\nu} + i\rho_j^{\nu}) \right. \times \left( -\frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right) \times \left( -\frac{i}{q^2 - m_D^2} \right) \times \left( -\frac{i}{p_3^2 - m_D^2} \right) F^2(q^2), \\
\mathcal{M}^{(b)} &= (i)^3 \int \frac{d^4q}{(2\pi)^4} \left[ -g_{\gamma^*D\bar{D}^*} \rho_{\mu} \epsilon_{\mu\nu} \right. \times \left( -i \frac{g_{\gamma^*D\bar{D}^*}}{2\sqrt{2}} \epsilon_{\mu\nu} \epsilon_{\rho\sigma} (i\rho_j^{\nu} + i\rho_j^{\nu}) \right. \times \left( -\frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right) \times \left( -\frac{i}{q^2 - m_D^2} \right) \times \left( -\frac{i}{p_3^2 - m_D^2} \right) F^2(q^2). 
\end{align*}$$

$\phi$ and $\bar{\phi}$ denote the light vector nonet meson formed from the 3 x 3 matrix $\mathcal{V}$.

$\mathcal{V} = \begin{pmatrix} \frac{\rho^{\theta+\phi}}{\sqrt{2}} & \rho^{\phi} & K^{*+} \\ \rho^{\phi} & K^0 & K^{*0} \\ K^{*0} & K^{0} & \phi \end{pmatrix}.$

$\mathcal{V}$, $\rho$, $\phi$, $K$, and $K^*$ are obtained by fitting the total widths of $X(3915)$ and $Z(3930)$, which will be presented in the next section. While the coupling constants of $J/\psi$ interacting with a pair of charmed mesons and a coupling constant of charmed mesons interacting with light vector meson are given in Table II [15–18].
The decay amplitudes for $\chi_{cJ}^+ \to [D^{(*)}(p_1)\bar{D}^{(*)}(p_2)]D^{(*)}(q) \to J/\psi(p_3)\omega(p_4)$, corresponding to Fig. 2 and denoted as $\mathcal{M}^{(i)}$ ($i = 1, \cdots, 6$), read as

$$
\mathcal{M}^{(1)} = (i)^3 \int \frac{d^4 q}{(2\pi)^4} \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(p_1\mu_\alpha)(ip_2\nu) \right] \times \left[ \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] - g_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(-ip_2\tau) + iq_2 \epsilon_\omega^\alpha \left[ \frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right] \times \frac{1}{q^2 - m_D^2} \mathcal{F}\left(q^2\right),
$$

(7)

$$
\mathcal{M}^{(2)} = (i)^3 \int \frac{d^4 q}{(2\pi)^4} \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(p_1\mu_\alpha)(ip_2\nu) \right] \times \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] - g_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(-ip_2\tau) + i \epsilon_\omega^\alpha \left[ \frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right] \times \frac{1}{q^2 - m_D^2} \mathcal{F}\left(q^2\right),
$$

(8)

$$
\mathcal{M}^{(3)} = (i)^3 \int \frac{d^4 q}{(2\pi)^4} \left[ ig_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(p_1\mu_\alpha)(ip_2\nu) \right] \times (ip_1\nu) \left[ ig_{\chi_{cJ}^+\omega} \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] \times \left[ -2f_{\chi_{cJ}^+\omega} \epsilon_{\omega\omega\omega}(ip_1^\nu) \epsilon_\omega^\alpha(-ip_2^\nu + iq^\nu) \right] \times \left[ \frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right] \times \frac{1}{q^2 - m_D^2} \mathcal{F}\left(q^2\right),
$$

(9)

$$
\mathcal{M}^{(4)} = (i)^3 \int \frac{d^4 q}{(2\pi)^4} \left[ ig_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(p_1\mu_\alpha)(ip_2\nu) \right] \times (ip_1\nu) \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] \times \left[ -2f_{\chi_{cJ}^+\omega} \epsilon_{\omega\omega\omega}(ip_1^\nu) \epsilon_\omega^\alpha(-ip_2^\nu + iq^\nu) \right] \times \left[ \frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right] \times \frac{1}{q^2 - m_D^2} \mathcal{F}\left(q^2\right),
$$

(10)

$$
\mathcal{M}^{(5)} = (i)^3 \int \frac{d^4 q}{(2\pi)^4} \left[ ig_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(p_1\mu_\alpha)(ip_2\nu) \right] \times (ip_1\nu) \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] \times \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] \times \left[ \frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right] \times \frac{1}{q^2 - m_D^2} \mathcal{F}\left(q^2\right),
$$

(11)

$$
\mathcal{M}^{(6)} = (i)^3 \int \frac{d^4 q}{(2\pi)^4} \left[ ig_{\chi_{cJ}^+\omega} \epsilon_{\chi_{cJ}^+}^\alpha(p_1\mu_\alpha)(ip_2\nu) \right] \times (ip_1\nu) \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] \times \left[ -g_{\chi_{cJ}^+\omega} \epsilon_{\omega}^\beta (iq^\nu + ip_1^\nu) \right] \times \left[ \frac{i}{p_1^2 - m_D^2} + \frac{i}{p_2^2 - m_D^2} \right] \times \frac{1}{q^2 - m_D^2} \mathcal{F}\left(q^2\right),
$$

(12)

In the above expressions, we take $g_{\chi_{cJ}^+\omega} = g_{\chi_{cJ}^+\omega} / \sqrt{2}$ and $f_{\chi_{cJ}^+\omega} = f_{\chi_{cJ}^+\omega} / \sqrt{2}$, where the factor $1 / \sqrt{2}$ comes from the coefficient relevant to the $\omega$ meson in the light vector meson matrix. $e^{\mu\nu}$ is the polarization tensor of $\chi_{cJ}^+$, $\epsilon_j$ ($j = \psi, \omega$) are the polarization vectors of charmonium $J/\psi$ and $\omega$ meson. $\mathcal{F}\left(q^2\right)$ is the form factor, which is introduced not only to compensate the off-shell effects of the charmed meson but also to describe the structure effects of the vertex of a charmed meson pair interacting with $J/\psi$ or $\omega$. In this work, we adopt [19]

$$
\mathcal{F}\left(q^2\right) = \frac{m_E^2 - \Lambda^2}{q^2 - \Lambda^2},
$$

(13)

where $q$ and $m_E$ are the momentum and the mass of the exchanged charmed meson, respectively. $\Lambda$ can be parameterized as $\Lambda = m_E + \alpha \Lambda_{QCD}$ with a dimensionless parameter $\alpha$ and $\Lambda_{QCD} = 220$ MeV. The parameter $\alpha$ is of order unity and depends on the specific process [13][18].

With the above elaborate expressions for the amplitudes, one can obtain the partial decay width for $\chi_{cJ}^+ \to J/\psi(\omega)\chi_{cJ}^-$, and $\tilde{p}$ indicates the three momentum of $\psi$ in the initial state at rest.

### III. NUMERICAL RESULTS

If $X(3915)$ is a $\chi_{c0}^+(2P)$ state, $\bar{D}D$ is its dominant decay. Hence, we can use the experimental width of $X(3915)$ [1] to determine the coupling constant of $\chi_{c0}^+ \to \bar{D}D$ interaction, i.e., $g_{\chi_{c0}^+\bar{D}D} = 2.37$ GeV. However, for $Z(3930)$, there exist two main decay modes $\bar{D}D$ and $D\bar{D} + h.c.$, so the experiments did not give the ratio of $BR(Z(3930))$ to $BR(Z(3930)) \to D\bar{D} + h.c.)$, we must determine these corresponding coupling constants from the theoretical results estimated by quark pair creation model in Ref. [4]. Since $\chi_{c0}^+$ and $\chi_{c2}^+$ have the same spatial wave functions, one can
determine the parameter value $R$ in the spatial wave function from the partial decay width of $X(3915)$, under the assumption $\Gamma_{3915}^{\pi^0} \approx \Gamma_{3915}^{\pi^0}$. With the parameter $R$ estimated by the center value of $\Gamma_{3915}^{\pi^0}$, we obtain $|g_{\chi'_{3915}}^{DD}| = 11.69 \text{ GeV}^{-1}$ and $|g_{\chi'_{3915}}^{D'D}| = 7.83 \text{ GeV}^{-2}$.

With the above preparation, we present the results of $X(3915) \to J/\psi \omega$ and $Z(3930) \to J/\psi \omega$ in Fig. 3 which shows the $\alpha$ dependence of these decay widths. For $X(3915)$ with the assignment $\chi'_{3915}$, its predicted two photon decay width varies with different models. In Ref. [20–23], the two-photon decay width is about $1 \sim 2 \text{ keV}$ in the relativistic quark model. While the Salpeter method indicates that the decay width for $\chi'_{3915}$ can be larger than $3 \text{ keV}$ in a relativistic form and about $5.47 \text{ keV}$ in a non-relativistic form [24]. With the above theoretical predictions, one can conclude the decay width of $X(3915) \to J/\psi \omega$ ranges from $0.19 \text{ MeV}$ to $1 \text{ MeV}$. Our estimate of the decay width for $X(3915) \to J/\psi \omega$ is about $0.15 \text{ MeV}$ for $\alpha = 4$, which is of the same order of the one abstracted from experimental measurements together the theoretical estimations of the two-photon decay width.

For $Z(3930)$ with the assignment of $\chi'_{3930}$, it dominantly decays into $D\bar{D}$ and $D'\bar{D} + h.c.$ The absolute values of the coupling constants between $\chi'_{3930}$ and charmed meson pairs are evaluated by the quark pair creation model. However, the relative sign of coupling constants $g_{\chi'_{3930}}^{DD}$ and $g_{\chi'_{3930}}^{D'D}$ in Eq. (3) can be either positive or negative, which corresponds to the subscripts $++$ and $+-$ shown in Fig. 5 respectively. Thus we discuss two cases for $Z(3930) \to J/\psi \omega$.

In Fig. 4 we also give the ratio of the width of $X(3915) \to J/\psi \omega$ to that of $Z(3930) \to J/\psi \omega$. This result shows that the width of $X(3915) \to J/\psi \omega$ is about $2 \sim 3$ orders of magnitude larger than that of $Z(3930) \to J/\psi \omega$ in two cases (see Fig. 4 for more details). The decay width for $\chi'_{3915}/\chi'_{3930} \to J/\psi \omega$ estimated in the present work strongly depends on the parameter $\alpha$, which is introduced in the form factor. However, what we emphasize in this work is that the ratio of the width of $X(3915) \to J/\psi \omega$ to that of $Z(3930) \to J/\psi \omega$ is very large but very weakly dependent on this parameter as can be seen from Fig. 3(b). Such a large ratio explains the reason why Belle only reported one enhancement structure $X(3915)$ in the $J/\psi \omega$ invariant mass spectrum of the $\gamma \gamma \to J/\psi \omega$ process.

IV. CONCLUSIONS AND DISCUSSION

$X(3915)$ reported by the Belle Collaboration is the second enhancement observed in the $\gamma \gamma$ fusion process. As indicated in Ref. [4]. $X(3915)$ is a good candidate of $\chi'_{3915}(2P)$, i.e., the first radial excitation of $\chi_{3414}$. Besides its open charm decay, study of the hidden charm decay of $X(3915)$ will provide a key hint to understand the properties of $X(3915)$ and further test P-wave charmonium explanation to $X(3915)$ in Ref. [4]. Since the mass of $X(3915)$ is above the threshold of $D\bar{D}$ and dominantly decays into $D\bar{D}$, hadronic loop effects will play an important role to the hidden charm decay $X(3915) \to J/\psi \omega$, which in fact is resulted from the coupled channel effects. In this work, we have performed the calculation of the $X(3915) \to J/\psi \omega$ processes.

Before the observation of $X(3915)$, Belle once reported a state named as $Z(3930)$ in the $\gamma \gamma$ fusion [2, 6], which is also a P-wave charmonium state of the first radial excitation. $Z(3930)$ should decay into $J/\psi \omega$, which seems to indicate that there should exist two peaks being close to each other in the $J/\psi \omega$ invariant mass spectrum given by Belle [1]. However, presently only one structure corresponding to $X(3915)$ was observed [1]. In order to explain this contradiction, in this work we have further studied $Z(3930) \to J/\psi \omega$ by the intermediate states $D\bar{D}$ and $D\bar{D}$ h.c.. The results illustrated in Fig. 4 show that the branching ratio of $Z(3930) \to J/\psi \omega$ is suppressed when compared with that of $X(3915) \to J/\psi \omega$, which explains why $Z(3930)$ can not be observed in the $J/\psi \omega$
invariant mass spectrum.

In summary, as more charmonium-like states are observed in the $\gamma\gamma$ fusion process [1–3, 25], they provide us a better chance to explore the property of these states, especially P-wave charmonium states [4]. The study of the hidden charm and the open charm decays of $X(3915)$ to test the $J^{PC}$ quantum number of $X(3915)$ must be 0++. Although $Z(3930)$ is well established as $X'(2S)$ state [2, 3], its hidden charm decay behavior is unclear before this work. Performing the calculation of $Z(3930) \rightarrow J/\psi\omega$ by the hadronic loop mechanism, we further learn that the branching ratio of $Z(3930) \rightarrow J/\psi\omega$ is $2 \sim 3$ orders smaller than that of $X(3915) \rightarrow J/\psi\omega$, which not only successfully explains only one enhancement $X(3915)$ appearing in the $J/\psi\omega$ invariant mass spectrum but also tests the hadronic loop effects which is an important non-perturbative mechanism on the decays of charmonium or charmonium-like state [6–13].

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1. S. Uehara [The Belle Collaboration], Phys. Rev. Lett. 104 092001 (2010) [arXiv: 0912.4451 [hep-ex]].
2. S. Uehara et al., [Belle Collaboration], Phys. Rev. Lett. 96, 082003 (2006) [arXiv:hep-ex/0512035].
3. B. Aubert et al., [BABAR Collaboration], Phys. Rev. D 81, 092003 (2010) [arXiv:1002.0281 [hep-ex]].
4. X. Liu, Z. G. Luo and Z. F. Sun, Phys. Rev. Lett. 104, 122001 (2010) [arXiv:0911.3694 [hep-ph]].
5. J. P. Lees et al., [BABAR Collaboration], arXiv:1207.2651 [hep-ex].
6. X. Liu, B. Zhang and S. L. Zhu, Phys. Lett. B 645, 185 (2007) [arXiv:hep-ph/0610278].
7. X. Liu, Eur. Phys. J. C 54, 471 (2008) [arXiv:0708.4167 [hep-ph]].
8. X. Liu, B. Zhang and S. L. Zhu, Phys. Rev. D 77, 114021 (2008) [arXiv:0803.4270 [hep-ph]].
9. X. Liu, Phys. Lett. B 680, 137 (2009) [arXiv:0904.0136 [hep-ph]].
10. C. Meng and K. T. Chao, arXiv:0708.4222 [hep-ph].
11. X. Liu, X. Q. Zeng and X. Q. Li, Phys. Rev. D 74, 074003 (2006) [arXiv:hep-ph/0606191].
12. X. Liu, B. Zhang and X. Q. Li, Phys. Lett. B 675, 441 (2009) [arXiv:0902.0480 [hep-ph]].
13. D. -Y. Chen, J. He, X. -Q. Li and X. Liu, Phys. Rev. D 81, 074006 (2010) [arXiv:0912.4860 [hep-ph]].
14. P. Colangelo, F. De Fazio and T. N. Pham, Phys. Rev. D 69, 054023 (2004) [arXiv:hep-ph/0310084].
15. R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, R. Gatto, F. Feruglio and G. Nardulli, Phys. Rept. 281, 145 (1997) [arXiv:hep-ph/9605342].
16. Y. S. Oh, T. Song and S. H. Lee, Phys. Rev. C 63, 034901 (2001) [arXiv:nucl-th/0010064].
17. C. Isola, M. Ladisa, G. Nardulli and P. Santorelli, Phys. Rev. D 68, 114001 (2003) [arXiv:hep-ph/0307367].
18. H. Y. Cheng, C. K. Chua and A. Soni, Phys. Rev. D 71, 014030 (2005) [arXiv:hep-ph/0409317].
19. X. H. Liu and Q. Zhao, Phys. Rev. D 81, 014017 (2010) [arXiv:0912.1508 [hep-ph]].
20. S. Godfrey and N. Isgur, Phys. Rev. D 32, 189 (1985).
21. C. R. Munz, Nucl. Phys. A 609, 364 (1996) [hep-ph/9601206].
22. D. Ebert, R. N. Faustov and V. O. Galkin, Mod. Phys. Lett. A 18 (2003) 601 [hep-ph/0302044].
23. C. -W. Hwang and R. -S. Guo, Phys. Rev. D 82 (2010) 034021 [arXiv:1005.2811 [hep-ph]].
24. G. -L. Wang, Phys. Lett. B 653, 206 (2007) [arXiv:0708.3516 [hep-ph]].
25. C. P. Shen et al., [Belle Collaboration], Phys. Rev. Lett. 104, 112004 (2010) [arXiv:0912.2383 [hep-ex]].