On Two-Body Decays of A Scalar Glueball

K.T. Chao\textsuperscript{1}, Xiao-Gang He\textsuperscript{2,1}, and J.P. Ma\textsuperscript{3,1}
\textsuperscript{1}Department of Physics, Peking University, Beijing
\textsuperscript{2}Department of Physics and Center for Theoretical Sciences, National Taiwan University, Taipei
\textsuperscript{3}Institute Of Theoretical Physics, Academia Sinica, Beijing

Abstract

We study two body decays of a scalar glueball. We show that in QCD a spin-0 pure glueball (a state only with gluons) cannot decay into a pair of light quarks if chiral symmetry holds exactly, i.e., the decay amplitude is chirally suppressed. However, this chiral suppression does not materialize itself at the hadron level such as in decays into $\pi^+\pi^-$ and $K^+K^-$. We show this explicitly in two cases with the glueball to be much lighter and much heavier than the QCD scale using low-energy theorems and perturbative QCD. For a heavy glueball, using QCD factorization based on an effective Lagrangian, we find that the hadronization into $\pi\pi$ and $KK$ leads to a large difference between $\text{Br}(\pi\pi)$ and $\text{Br}(KK)$, even the decay amplitude is not chirally suppressed. Our results can provide some understanding of the partonic contents if $\text{Br}(\pi\pi)$ or $\text{Br}(KK)$ is measured reliably.

It is believed that all hadrons are built with quarks and gluons, which are the dynamical degrees of freedom of QCD. So far all observed hadrons have been shown to contain quarks. In general, it is also possible to have hadrons which contain gluons only, the so called pure glueball states. Experimentally, the existence of glueballs has not been confirmed although there are some indications. Studies with Lattice QCD indicate that the lowest lying glueball is a scalar, $0^{++}$ state, having a mass in the range of $1.5 \sim 2.0$ GeV\textsuperscript{1}. The state $f_0(1710)$ is a promising candidates for a scalar glueball\textsuperscript{2}.

In the framework of QCD a scalar glueball $G_s$ is in general a superposition of many components containing gluons and quarks as partons $a_i (i = 1, \cdots, n)$ which can be schematically represented as

$$|G_s\rangle = \sum_{n=2} \psi_{a_1 \cdots a_n}(a_1, \cdots, a_n) = \psi_{gg}|gg\rangle + \psi_{qq}|q\bar{q}\rangle + \cdots,$$

where $\psi_{a_1 \cdots a_n}$ is the probability amplitude for the component $|a_1, \cdots, a_n\rangle$. It is clear that a state should not be identified as a glueball state, if it has a quark content larger than its gluon content, roughly speaking, if $|\psi_{gg}| < |\psi_{qq}|$. Decay products of a particle can be used to extract crucial information about whether a state is a glueball or not. In this letter we will show that two body decays of a scalar glueball can reveal some important information, and discuss possible experimental implications. Part of our results, in particular the results on pQCD calculation of the leading contribution for glueball decays into two light mesons have been discussed in Ref.\textsuperscript{4}. Here we provide more details including some higher twist effects and also discussions for low-energy theorem implications for light glueball decay into two light mesons.

We will first show in QCD, without any assumption, that a $0^{++}$ glueball $G_s$ cannot decay into a light-quark pair $q\bar{q}$ if $G_s$ is a pure glueball with exact chiral symmetry. The decay is chirally
suppressed. Then we study the two-body hadronic decays, such as $\pi\pi$ and $KK$ and show that the quark level chiral suppression does not materialize itself at hadron level, even for a pure glueball decay. We will show this explicitly in two cases with the glueball to be much lighter and much heavier than the QCD scale. In the case that the glueball is light, the decay products will have small momenta. One can use low-energy theorems to show that even in the chiral limit the glueball still can decay into $\pi\pi$. If the glueball is heavy, one can show based on QCD factorization even for a pure glueball it will mainly couple to two quark pairs $q\bar{q}q\bar{q}$ which hadronize to two light mesons or so at long distances rather than just one quark pair $q\bar{q}$ at short distances (see Fig.2 (a)). Hence, there is no chiral suppression for the $\pi\pi$ mode compared with the $KK$ mode. Taking $f_0(1710)$ as an example, we find that a small decay ratio for $B(\pi^+\pi^-)/B(K^+K^-)$ does not necessarily imply that $f_0(1710)$ is a pure glueball. This is in contrast to the recent result in [3].

Figure 1: A glueball decays into a $q\bar{q}$ pair. (a) The contribution from components containing gluons only. (b) The contribution from components containing a $q\bar{q}$ and gluons when mixing exists.

For the decay of a scalar glueball into $qq$ all components in Eq.(1) may contribute. The contributions from those components only containing gluons can be represented by Fig.1a, where the bulb with $S$ can be defined as a $n$-point Green’s function of gluon fields combined with gluon propagators in the free case, and the other bulb attached with the glueball can be defined with gluon field operators sandwiched between the vacuum and the glueball state. Although a complete calculation for the diagram with the structure given in Fig.1a is not possible at present, some general conclusions can be drawn by using properties of QCD and Lorentz covariance.

The decay amplitude from Fig.1a for $G_s \rightarrow q(p_1)\bar{q}(p_2)$ can be written as a product of a spinor pair $\bar{u}(p_1)$ and $v(p_2)$ with a product of any number of $\gamma$ matrices sandwiched between the spinors.

Because the quark-gluon coupling in QCD is vector-like, the number of the $\gamma$-matrices is an odd number when the quark mass $m_q$ is equal to zero. A product of $\gamma$-matrices with odd number can be reduced to just one $\gamma$-matrix. Therefore the amplitude from Fig.1a can always be written as:

$$T_g(G_s \rightarrow q\bar{q}) = \bar{u}(p_1)\gamma_\mu A^{\mu}v(p_2).$$

(2)

Although we cannot obtain an explicit expression for $A^{\mu}$, we know from Lorentz covariance that it can be written as $A^{\mu}(p_1,p_2) = a_1p_1^{\mu} + a_2p_2^{\mu}$. With this it is easy to find that in the chiral limit $m_q = 0$, the contribution to the decay amplitude $G_s \rightarrow q\bar{q}$ from the pure gluonic components is zero. The result also applies to a pseudoscalar glueball decays into a $q\bar{q}$ pair.

It is clear that the contribution of these pure gluonic components to the decay amplitude in the limit $m_q \rightarrow 0$ is

$$T_g(G_s \rightarrow q\bar{q}) \sim m_q + O(m_q^2),$$

(3)

because the helicity of quarks can be flipped with a finite quark mass $m_q$. By assuming a specific form of the coupling for a scalar glueball with two gluons as given in Eq.(4) in the below the result for $G_s$ is also obtained in Ref.[3], with other assumptions. We emphasis that the above results
can be obtained in QCD without any assumption. The above result is obtained by an analysis in perturbative theory. It is well-known that the chiral symmetry not only can be broken by finite quark masses, but also can be broken spontaneously, the latter is a nonperturbative effect. Therefore the correct statement about the decay should be that the decay is not allowed if the chiral symmetry holds. The \( m_q \) in Eq.(3) should not be understood as a current quark mass, but rather as the scale of chiral symmetry breaking. The effect of spontaneous breaking of chiral symmetry on the decay can only be studied with nonperturbative methods, e.g., in [6] for the case here. Combining the nonperturbative effect the chiral suppression for the ratio \( T_g(G_s \to uu)/T_g(G_s \to ss) \) will be not so strong as suggested by current quark masses ratio \( m_u/m_s \).

For contributions from components containing \( q \bar{q} \) pairs with or without gluons, the situation will be different. The \( q \bar{q} \) in the final state can come from one of the \( q \bar{q} \) pairs through scattering from the already existing quark contents in the glueball state as shown in Fig.1b. In this case one cannot conclude that the contribution from Fig.1b is zero in the limit \( m_q = 0 \). The reason is that the glueball can have components with a \( q \bar{q} \) pair and gluons. If these gluons are in a state like \( J^{PC} = 1^{--} \), the \( q \bar{q} \) pair must also be in a \( 1^{--} \) state. One can show that the contributions from those components are not zero in the chiral limit.

In the above, the results are obtained for the decay of \( G_s \) into a \( q \bar{q} \) pair. For a real decay process one has to work with hadron states. Unfortunately at present the hadronization mechanism is not well understood. To study the hadronic decays we will therefore assume that a scalar glueball dominantly couples to gluons and quarks via the effective Lagrangian [3]:

\[
L_s = G_s \left\{ \frac{f_g}{M} G^a_{\mu\nu} G^{a\mu\nu} + f_q q \bar{q} \right\} + \cdots .
\]

(4)

where \( G_s \) is the extrapolation field of the scalar glueball, \( M \) is its mass. \( f_g \) and \( f_q \) are dimensionless coupling constants. They are related to those probability amplitude in Eq.(1). If \( G_s \) is a pure glueball, the coupling \( f_q \) is chirally suppressed, i.e., \( f_u, d << f_s \), or zero if the chiral symmetry is exact. These couplings are unknown, but important information about them can be extracted from experiment as we will show later.

If the glueball is light enough, it is easy to show with the above effective Lagrangian that there is no chiral suppression in the sense that in the chiral limit the decay of the glueball into \( \pi^+ \pi^- \) happens. The decay amplitude through the gluonic coupling \( f_g \) in Eq.(4) is given by

\[
T_g(G_s \to \pi^+ \pi^-) = \frac{f_g}{M} \langle \pi^+(p_1) \pi^-(p_2) | G^a_{\mu\nu} G^{a\mu\nu} | 0 \rangle.
\]

(5)

This amplitude is nonperturbative. However, there exist some low-energy theorems which give information about the above amplitude. In the chiral limit one can show [7]:

\[
\langle \pi^+(p_1) \pi^-(p_2) | \left( -\frac{\beta_0 \alpha_s}{8\pi} \right) G^a_{\mu\nu} G^{a\mu\nu} | 0 \rangle = (p_1 + p_2)^2 + \mathcal{O}(p^4),
\]

(6)

where \( \beta_0 = (11 - 2n_f)/3 \) with \( n_f \) the number of light quarks. This result simply tells that the decay can happen in the chiral limit. Therefore, there is no chiral suppression if the glueball is light. Similarly, the direct transmission of \( q \bar{q} \) into \( \pi \pi \) can also be fixed [8]. The same could also be obtained by using a chiral realization of \( L_s \) as described in [9]. One can also work out similar expressions for \( G_s \to KK \) amplitude.

To show that whether there is a chiral suppression in \( G_s \to \pi \pi \) compared with \( G_s \to KK \), one needs to consider the direct hadronization of \( G_s \to q \bar{q} \) to \( G_s \to \pi \pi(KK) \) and also some other
possible contributions. The above discussion indicate that $G_s \rightarrow q\bar{q}$ direct hadronization will not produce chiral suppressions.

We note that the glueball mass is expected to be around 2GeV. Practically, the applicability of the low-energy theorems is questionable at this scale. At this energy scale, perturbative QCD may make some reliable predictions, such as those of the decay of $\tau$-lepton. Therefore one can employ QCD factorization for exclusive processes suggested long time ago in Ref.\[5\], where the hadronization is parameterized with light-cone wave functions. In the following we will consider if there is chiral suppression from pQCD point of view. We will use QCD factorization with $L_s$ to study the decay $G_s \rightarrow \pi^+\pi^-$ in the following.

![Diagram](image)

**Figure 2:** (a) One of the 2 diagrams for the decay through the coupling with gluons. (b) One of the 4 diagrams for the decay through the coupling with quarks.

We first discuss the contributions from the coupling with gluons. To the leading twist-2 order, the contribution comes from diagrams represented by Fig. 2a. A direct calculation gives:

$$T_g = -\alpha_s f_g \frac{8\pi}{9 M^2} f_{\pi}^2 \int_0^1 du_1 du_2 \phi_{\pi^+} (u_1) \phi_{\pi^-} (u_2) \left[ m_u f_u \left( \frac{1}{u_1^2 (1-u_2)} + \frac{1}{u_1 (1-u_2)^2} \right) + m_d f_d \left( \frac{1}{(1-u_1)^2 u_2} + \frac{1}{(1-u_1) u_2^2} \right) \right] + \frac{m_{\pi}^2}{m_u + m_d} \left[ \frac{3 - u_2}{u_1 (1-u_2)^2} f_u + \frac{2 + u_1}{u_1^2 (1-u_2)} f_d \right] \phi_{\pi^+}^{[p]} (u_2) \phi_{\pi^-} (u_1) \right] \right],$$

where $\phi_{\pi}$ is the twist-2 light-cone wave function of $\pi$. $u_i (i=1,2)$ is the momentum fraction carried by the anti-quark in the meson. In the above, $\lambda$ can be any soft scale, such as quark mass, $\Lambda_{QCD}$ and $m_\pi$. The contribution from the coupling with quarks are nonzero if one takes $m_q \neq 0$. Clearly, $T_g$ is not zero in the chiral limit $m_q = 0$.

The contribution from the coupling with quarks is given by diagrams represented in Fig.2b. It is zero if we only take twist-2 light-cone wave functions. At twist-3 there are two wave functions, but only one leads to a nonzero contributions. It gives:

$$T_q = -\frac{4\pi}{9} f_{\pi}^2 \alpha_s (\mu) \int_0^1 du_1 du_2 \left\{ \phi_{\pi^+} (u_1) \phi_{\pi^-} (u_2) \left[ m_u f_u \left( \frac{1}{u_1^2 (1-u_2)} + \frac{1}{u_1 (1-u_2)^2} \right) + m_d f_d \left( \frac{1}{(1-u_1)^2 u_2} + \frac{1}{(1-u_1) u_2^2} \right) \right] \right\} \left[ \frac{3 - u_2}{u_1 (1-u_2)^2} f_u + \frac{2 + u_1}{u_1^2 (1-u_2)} f_d \right] \phi_{\pi^+}^{[p]} (u_2) \phi_{\pi^-} (u_1) \right],$$

where $\phi_{\pi}$ is the twist-3 light-cone wave function. Definitions of above light-cone wave functions can be found in [11]. It should be noted that the above integration is divergent because of end-point singularities. This is common in an higher-twist calculation for exclusive processes, examples can
be found in $B$-decay and form-factors\cite{13}. These singularities can be regularized as usual by introducing a cut-off scale $\Lambda_c$ or $\epsilon = \Lambda_c/M$ and by changing the integration range from $[0, 1]$ to $[\epsilon, 1 - \epsilon]$. In our later discussions we will use the QCD scale $\Lambda_c = 300$ MeV for illustration.

The amplitude for $G_s \rightarrow K^+K^-$ decay can be obtained by replacing quantities related to $\pi$ by those related to $K$ correspondingly. We now apply the above results to analyze $\pi^+\pi^-$ and $K^+K^-$ decays of $f_0(1710)$ which is a candidate for a scalar glueball. For numerical calculations we take the models for twist-2 light-cone wave functions at the energy scale $1 \text{ GeV}$ in \cite{12} and the asymptotic form of $\phi^{[p]}$, which is 1, and take $M = 1710$ MeV, $m_u = m_d = 4.5$ MeV, $m_s = 120$ MeV, $f_\pi = 132$ MeV and $f_K = 1.27 f_\pi$. We have the amplitudes in unit of GeV with $\Lambda_c = 300$ MeV:

$$T(\pi^+\pi^-) \approx (-1.062 f_g - 0.602 f_u - 0.602 f_d)\alpha_s(\text{GeV}),$$

$$T(K^+K^-) \approx (-1.796 f_g - 1.674 f_u - 1.671 f_s)\alpha_s(\text{GeV}).$$

(9)

With smaller cut-off, $T_q$ becomes bigger. The qualitative features do not change very much.

We note the difference in the coefficients in front of $f_g$ for the amplitude of $\pi\pi$ and $KK$ in Eq.(9). This is mainly due to the difference between $f_{\pi}$ and $f_K$. This tells that the decays into $\pi\pi$ and $KK$ is already significantly different, even if the glueball does not couple to $q\bar{q}$, i.e., $f_q = 0$. With $f_q = 0$ the ratio $R = \text{Br}(\pi^+\pi^-)/\text{Br}(K^+K^-) \approx f_\pi^4/f_K^4 = 0.48$, which is substantially different from 1. This suppression is much milder compared with the one at the quark level. It should be noted that the result $R \approx f_\pi^4/f_K^4$ can be derived without the effective Lagrangian in Eq.(4) if the glueball is purely composed of gluons and the pQCD contribution dominates. This is because that for a pure gluball state, the amplitude of the decay $G_s \rightarrow \pi^+\pi^-$ can always be written with QCD factorization as $T_{\pi\pi} = f_\pi^4 H_g \otimes \phi_{\pi^+} \otimes \phi_{\pi^-}$, where the higher-twist effects related to $\pi$’s are neglected and $H_g$ consists of some perturbative coefficient functions and some quantities related to the structure of $G_s$. $H_g$ does not depend on the hadrons in the final state. Although $H_g$ is unknown, one can easily find the result of $R \approx f_\pi^4/f_K^4$. Hence, even the decay amplitude is not chirally suppressed, the difference of hadronization for the $G_s$-decays into $\pi\pi$ and $KK$ already leads to a large difference between $\text{Br}(\pi^+\pi^-)$ and $\text{Br}(K^+K^-)$. It should be noted that $R \approx 0.48$ is close to the recent experimental central value $0.41^{+0.11}_{-0.17}$ obtained by BES\cite{14}. From Eq.(9) the terms proportional to $f_g$ are sizeable compared with other terms if $f_g$ and $f_q$ are similar in size. Since a gluball should have a larger gluon content than quark content, $f_q$ should not be too much larger than $f_g$ if $f_0(1710)$ can be identified as a gluball.

![Graph](image_url)

Figure 3: The solid, long-dashed, and short-dashed lines are for $f_s/f_g$ vs. $f_u/f_g$ with $R = 0.2$, 0.1, 0.05, respectively. Lines labelled with positive and negative are according to the sign of $T(\pi^+\pi^-)/T(K^+K^-)$.

If the ratio $R$ is significantly smaller than $f_\pi^4/f_K^4$, it is an indication that there are other non-


gluon content in it. Previous measurements\cite{2} gave smaller values compared with recent BES data\cite{14}. We therefore also studied the influence of a non-zero $f_q$ on $R$. In Fig.3, we show the correlation of $f_u/f_g$ and $f_s/f_g$ for several given values of $R$, where we assume $f_u = f_d$. From Fig.3, we can see that the measured ratio $R = 0.2$ does not necessarily imply $f_u/f_s \ll 1$, or the chiral suppression, as discussed after Eq.(4). Experimental data on $R$ can be explained even if $f_u$ is at the same order of magnitude as $f_s$, e.g., $f_s/f_g \approx 2f_u/f_g \approx 1$. Since the couplings $f_q$ are determined by quark contents, the current experimental data does not exclude the possibility that $f_0(1710)$ has large quark contents. Combining experimental data of decays and production in radiative decay of $J/\psi$, the study in\cite{15} also shows that $f_0(1710)$ not only has gluon content but also large $s\bar{s}$-content and sizeable $u\bar{u} + d\bar{d}$-content. With the effective Lagrangian $L_s$ one can also approximate the total decay width to be $\Gamma = \Gamma(gg) + \sum_q \Gamma(q\bar{q})$. If we take the ratio $R$ to be known, the branching ratio of $\text{Br}(K\bar{K})$ can be expressed as a function of $f_s/f_g$ or $f_u/f_g$. In Fig.4 we show the branching ratio as a function of $f_s/f_g$ for several different $R$. Reliable experimental data on the branching ratios can provide crucial information about the constituent contents in $f_0(1710)$.

![Figure 4: The branching ratio of the decay into $K^+K^-$ as a function of $f_s/f_g$ with cut-off $\Lambda_c = 0.3$ GeV.](image)

Our results are different from those in\cite{3}. In\cite{3} it is assumed that the decays of $G_s$ into two light mesons goes like the following, $G_s$ first decays into a $q\bar{q}$ pair and then the pair is hadronized into the two light mesons. Because the decay amplitude into one $q\bar{q}$ pair is chirally suppressed, it can result in the chiral suppression at hadron level. The hadronization is a complicated process, one should not take directly the quark level picture. We have shown that if the glueball is light, the low-energy theorems tells us that there is no chiral suppression. For a heavy glueball, one can use pQCD to study its decay. In this case the two quark decay picture is also problematic. In general one needs at least two $q\bar{q}$ pairs to form two light mesons. Perturbatively another $q\bar{q}$ pair can be produced, e.g., through emission of an extra gluon from the quark line in Fig.1a and the gluon annihilates into the pair. In this case the decay amplitude into two $q\bar{q}$ pairs is not chirally suppressed.

Using the methods in previous discussions, the coupling of $G_s$ to a proton-antiproton system can also be studied. The coupling is fixed at certain level by trace-anomaly, the $\sigma$-term and the strange-quark content of proton. With this approximation we have considered the possibility if the enhancement in $J/\psi \rightarrow \gamma p\bar{p}$ at BES\cite{16} is due to a glueball. We find that the possible state $X(1876)$ causing the enhancement is unlikely a scalar glueball\cite{16}. The coupling of a pseudoscalar glueball with $p\bar{p}$ can also be related to the spin content of the proton as an approximation\cite{17}. Detailed analysis of the coupling to a $p\bar{p}$ system will be presented elsewhere.

In conclusion, we have studied several two body decay modes of a scalar glueball. Without any
assumption we have shown that a pure spin-0 glueball can not decay into a $q\bar{q}$ pair in QCD if the chiral symmetry is exact. Hence the decay is chirally suppressed. However, this chiral suppression does not materialize itself at the hadron level such as in $G_s \rightarrow \pi^+\pi^-$ and $G_s \rightarrow K^+K^-$. This can be shown in the two cases with the glueball is much lighter and much heavier than the QCD scale. One expects that the decay amplitude should not have drastic changes in between and therefore that the chiral suppression is unlikely materialized in some intermediate range of the glueball mass. Using QCD factorization based on an effective Lagrangian for scalar glueball coupling to two gluons and a quark pair, we have found that even if the decay amplitude is not chirally suppressed, only from the difference of hadronization into $\pi\pi$ and $KK$, it already leads to a large difference between $\text{Br}(\pi^+\pi^-)$ and $\text{Br}(K^+K^-)$. The current experimental data of a small ratio $\text{Br}(\pi^+\pi^-)/\text{Br}(K^+K^-)$ for $f_0(1710)$ does not necessarily imply that $f_0(1710)$ is a pure glueball, but it also allows a sizable $q\bar{q}$ content. The gluon and quark contents of $f_0(1710)$ can be better understood if reliable $\text{Br}(\pi^+\pi^-,K^+K^-)$ are measured.

Acknowledgments:
We thank helpful discussions with Profs. H.-Y. Cheng, X.D. Ji, H.Y. Jin, Y.P. Kuang and H.-n. Li. This work was supported in part by grants from NSC and NNSFC (10421003).

References

[1] C. Morningstar and M.J. Peardon, Phys. Rev. D56 (1997) 3043, Phys. Rev. D60 (1999) 034509; C. Liu, Chin. Phys. Lett. 18 (2001) 187, Commun. Theor. Phys. 35 (2001) 288.

[2] S. Eidelman et al. Particle Data Group, Phys. Lett. B592, 1 (2004); W.-M. Yao et al. Particle Data Group, J. Phys. G33, 1(2006).

[3] M.S. Chanowitz, Phys. Rev. Lett. 95 (2005) 172001, hep-ph/0506125

[4] K.-T. Chao, X.-G. He and J.P. Ma, Phys.Rev.Lett. 98 (2007) 149103, arXiv:0704.1061

[5] S.J. Brodsky and G.P. Lepage, Phys. Rev. D24 (1981) 2848, Phys. ReV. D22 (1980) 2157.

[6] Z.F. Zhang and H.Y. Jin, hep-ph/0511252

[7] M.A. Shifman, Phys. Rept. 209 (1991) 341.

[8] X.D. Ji, Phys. Rev. Lett. 74 (1995) 1071, Phys. Rev. D52 (1995) 271.

[9] J. Gunion, H. Habar, G. Kane and S. Dawson, The Higgs Hunter’s Guide, Addison-Wesley Publishing Company (1990), J. Donoghue, E. Golowich and B. Holstein, Dynamics of the Standard Model, Cambridge University Press (1992), X.-G. He, J. Tandean and G. Valencia, Phys. Lett. B631, 100(2005) hep-ph/0509041.

[10] M. Chanowitz, Phys. Rev. Lett. 98, 149104 (2007).

[11] V.M. Braun and I.B. Filyanov, Z. Phys. C48 (1990) 239.

[12] P. Ball, JHEP 9901:010,1999, hep-ph/9812375, P. Ball and M. Boglione, Phys. Rev. D68 (2003) 094006, hep-ph/0307337, P. Ball and R. Zwicky, hep-ph/0510338
[13] M. Beneke et al., Nucl. Phys. B606 (2001) 245, Z.Z. Song and K.T. Chao, Phys. Lett. B568 (2003) 127, hep-ph/0206253, J.P. Ma and Z.G. Si, Phys. Rev. D70 (2004) 074007, hep-ph/0405111.

[14] M. Ablikim et al. (BES Collaboration), Phys. Lett. B642, 441(2006).

[15] F. Close and Q. Zhao, Phys. Rev. D71 (2005) 094022; S. Narison, hep-ph/0512256.

[16] J.Z. Bai et al., BES Collaboration, Phys. Rev. Lett. 91 (2003) 022001.

[17] B.A. Li, Phys.Rev. D74 (2006) 034019, hep-ph/0510093.