Evidence for two-quark content of $f_0(980)$ in exclusive $b \to c$ decays

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Inspired by a large decay branching ratio (BR) of $B^+ \to f_0(980)K^+$ measured by Belle recently, we propose that a significant evidence of the component of $n\bar{n}$ = $(u\bar{u} + d\bar{d})/\sqrt{2}$ in $f_0(980)$ could be demonstrated in exclusive $b \to c$ decays by the observation of $f_0(980)$ in the final states $B \to D^{(*)0}\pi^+\pi^-(KK)$ and $B \to J/\Psi\pi^+\pi^-(KK)$. We predict the BRs of $B \to D^{(*)0}(J/\Psi)f_0(980)$ to be $\mathcal{O}(10^{-4})$ ($\mathcal{O}(10^{-5})$) while the unknown wave functions of $D^{(*)0}(J/\Psi)$ are chosen to fit the observed decays of $B \to D^{(*)0}\pi^0(J/\Psi K^{(*)})$.

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In spite of the successful quark model and QCD theory for strong interaction, the fundamental questions on the inner structure of lightest scalar mesons, such as $f_0(400 - 1200)$, $f_0(980)$ and $a_0(980)$ etc., are still uncertain, even although it has been over thirty years since $f_0(980)$ was discovered first time in phase shift analysis of elastic $\pi\pi$ scattering [1]. Besides the interpretations of $qq\bar{q}$ four-quark states [2] or $KK$ molecular states [3] or $q\bar{q}$ states [4] etc., the possibilities of gluonium states [5] and scalar glueballs [6] are also proposed. It might be oversimplified to regard them as only one kind of composition.

It is suggested that in terms of $\gamma\gamma$ [7] and radiative $\phi$ [8] $B$ decays, the nature of scalar mesons can be disentangled. However, with these experiments, the conclusions such as given by Refs. [10, 11] and Ref. [12] are not unique. The former prefers $qq\bar{q}$ while the latter is four-quark content. Nevertheless, according to the data of E791 [13] and Focus [14], the productions of scalar mesons which are reconstructed from $D$ and $D_s$ decaying to three-pseudoscalar final states and mainly show $qq\bar{q}$ contents, can provide us a further resolution [15]. In addition, $B_0$ decay data of OPAL [16] also hint that $f_0(980)$, $f_2(1270)$ and $\phi(1020)$ have the same internal structure. Hence, the compositions of light scalar bosons should be examined further.

Recently, the decay of $B^+ \to f_0(980)K^+$ with the BR product of $Br(B^+ \to f_0(980)K^+) \times Br(f_0(980) \to \pi^+\pi^-) = (9.6\pm2.3\pm1.5\pm3.4) \times 10^{-6}$ has been observed in Belle [17]. The observation not only displays in the first time $B$ decay to scalar-pseudoscalar final states but also provides the chance to understand the characteristics of scalar mesons. Since $B$ meson is much heavier than $D(s)$ mesons, in the two-body $B$ decays, the outgoing light mesons will behave as massless particles so that the perturbative QCD (PQCD) approach [18, 19], in which the corresponding bound states are expanded by Fock states, could apply. Therefore, as compared to two-parton states, the contributions of four-parton and gluonium states belong to higher Fock states. Consequently, we think that the effects of $qq\bar{q}$ state are more important than those in $D_s$ decays. In this paper, in order to further understand what the nature of $f_0(980)$ in $B$ decays is, we take it to be composed of $q\bar{q}$ states mainly and use $|f_0(980)> = \cos\phi_s|s\bar{s}> + \sin\phi_s|n\bar{n}>$ with $n\bar{n} = (u\bar{u} + d\bar{d})/\sqrt{2}$ to denote its flavor wave function. We note that so far $\phi_s$ could be $42.14^{+5.80}_{-7.3}$ [7] and $138^{0}\pm 6^{0}$ [8]. With the lowest order criterion, the effects of four-parton and gluonium states are neglected.

Inspired by the large BR of $B^+ \to f_0(980)K^+$, we propose that a significant evidence of the component of $n\bar{n}$ in $f_0(980)$ could be demonstrated by exclusive $B \to D^{(*)0}f_0(980)$ and $B \to J/\Psi f_0(980)$ processes and $f_0(980)$ could be reconstructed from the decays $B \to D^{(*)0}\pi^+\pi^-(KK)$ and $B \to J/\Psi\pi^+\pi^-(KK)$. The results could be as the complement to the three-body decays of $D_s$ that already indicate the existence of $s\bar{s}$ component.

It is known that the exclusive $b \to c$ decays are dominated by the tree contributions and only $(V-A)\otimes(V-A)$ four-fermi interactions need to be considered. The difficulty in our calculations is how to determine the involving wave functions that are sensitive to the nonperturbative QCD effects and are universal objects. In $B$ meson case, one can fix it by $B \to PP$ processes, with $P$ corresponding to light pseudoscalars in which the wave functions are defined in the frame of light-cone and have been derived from QCD sum rule [20]. As to the $D^{(*)0}(J/\Psi)$ wave functions, we can call for the measured BRs of color-suppressed decays $B \to D^{(*)0}\pi^0$ [21] and $B \to J/\Psi K^{(*)}$ [22]. However, it might be questionable to apply the QCD approach for ordinary $PP$ modes to $D^{(*)}(J/\Psi)$ decays because they aren’t light mesons anymore. In the heavy $b$ quark limit, fortunately, the involved scales satisfy $m_b >> m_c >> \Lambda$ with $m_{b(c)}$ being the mass of $b(c)$-quark and $\Lambda = M_B - m_b$ so that the leading power effects in terms of the expansions of $\Lambda/m_c$ and $m_c/m_b$ could be taken as the criterion to estimate the involving processes. We will see later that not only the obtained BRs of $B \to J/\Psi K^{*}$ but also their helicity components of decay amplitudes are consistent with current experimental data. It will guarantee that our predicted results on $f_0(980)$ productions of $B$ decays are reliable.

Since the hadronic transition matrix elements of penguin effects in $B \to J/\Psi M$, $M = K$, $K^*$, and $f_0(980)$,

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can be related to tree ones, we describe the effective Hamiltonian for the $b \to c\bar{q}d$ transition as

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} V_q \left[ C_1(\mu)O_1^{(q)} + C_2(\mu)O_2^{(q)} \right]$$

(1)

with $O_1^{(q)} = \tilde{c}_\alpha q_\beta \tilde{c}_\beta b_\alpha$, and $O_2^{(q)} = \tilde{c}_\alpha q_\beta \tilde{c}_\beta b_\alpha$, where $q_\alpha = q_\alpha \gamma_\mu(1 - \gamma_5)q_\beta$, $\alpha(\beta)$ are the color indices, $V_q = V_{q}\epsilon \epsilon_0$. The products of the CKM matrix elements, and $C_{1,2}(\mu)$ are the Wilson coefficients (WCs). Conventionally, the effective WCs of $a_2 = C_1 + C_2/N_c$ and $a_1 = C_2 + C_1/N_c$ with $N_c = 3$ being color number are more useful. $q = u$ corresponds to $B \to D^{(*)}M$ decays while $q = c$ stands for $B \to J/\Psi M$ decays. According to the effective operators in Eq. (1), we find that only emission topologies contribute to $B \to J/\Psi f_0(980)$, however, the decays of $B \to D^{(*)}f_0(980)$ involve both emission and annihilation topologies. To be more clear, the illustrated diagrams are displayed in Fig. 1. From the figure, we could see obviously that only $u\bar{q}$ content has the contributions and the factorizable emission parts, Fig. (a), are only related to the $B \to f_0(980)$ form factor. We note that in the color-suppressed processes the nonfactorizable effects, shown as Fig. (b) and (d), are important and should be considered.

Regarding $f_0(980)$ as $q\bar{q}$ contents in $B$ decays, the immediate question is how to write down the corresponding hadronic structures and the associated wave functions for this $^3P_0$ state. What we know is that the spin structures of $f_0(980)$ should satisfy $\langle 0|\bar{q} q|f_0(980)\rangle = 0$ and $\langle 0|\bar{q}\bar{q}|f_0(980)\rangle = m_f f_0^0$ in which $m_f (\bar{f}_0^0 \approx 0.18)$ is the mass ($\gamma$ decay constant) of $f_0(980)$. In order to satisfy these local current matrix elements, the light-cone distribution amplitude for $f_0(980)$ should be given by

$$\langle 0|\bar{q}(0)\gamma_j q(z)|f_0\rangle = \frac{1}{\sqrt{2N_c}} \int_0^1 dx e^{-ixP \cdot z} \left\{ \left[ \hat{p} \right]_j \Phi_{f_0}(x) + m_f \left[ \delta_{ij} \right] \Phi_{f_0}(x) \right\}$$

(2)

where $\Phi_{f_0}(x)$ belong to twist-2(3) wave functions. The charge parity indicates that $\Phi_{f_0}(x) = -\Phi_{f_0}(1-x)$ and $\Phi_{f_0}(x) = \Phi_{f_0}^\ast(1-x)$ so that their normalizations are $\int_0^1 dx \Phi_{f_0}(x) = 0$ and $\int_0^1 dx \Phi_{f_0}^\ast(x) = \bar{f}/2\sqrt{2N_c}$. As usual, we adopt a good approximation that the light-cone wave functions are expanded in Gegenbauer polynomials. Therefore, we choose

$$\Phi_{f_0}^\ast(x) = \frac{\bar{f}}{2\sqrt{2N_c}} \left\{ (3x-1)^2 + C_1^\ast (1-2x)^2 \times \left[ C_2^\ast (1-2x) - 3 \right] + C_3^\ast (1-2x) \right\},$$

$$\Phi_{f_0}(x) = \frac{\bar{f}}{2\sqrt{2N_c}} G \left[ 6x(1-x)C_1^\ast (1-2x) \right],$$

(3)

where $C_n^\alpha$ are the Gegenbauer polynomials and the values of coefficients $\{G\}$ haven’t been determined yet from the first principle QCD approach.

It has been shown that by the employ of hierarchy $M_B >> M_{D^{(*)}} >> \Lambda$, the $D^{(*)}$ meson distribution amplitudes could be described by

$$\langle 0|\bar{d}(0)\gamma_j q(z)|D \rangle = \frac{1}{\sqrt{2N_c}} \int_0^1 dx e^{-ixP \cdot z} \times \left\{ \left[ \hat{p} + M_D \right]_j \gamma_5 \Phi_D(x) \right\},$$

$$\langle 0|\bar{d}(0)\gamma_j q(z)|D^\ast \rangle = \frac{1}{\sqrt{2N_c}} \int_0^1 dx e^{-ixP \cdot z} \times \left\{ \left[ \hat{p} + M_{D^\ast} \right]_j \gamma_5 \Phi_D^\ast(x) \right\},$$

(4)

where $\varepsilon_\mu$ is the polarization vector of $D^\ast$, the normalization of wave functions are taken as $\int_0^1 dx \Phi_{D^{(*)}}(x) = f_{D^{(*)}}/\sqrt{2N_c}$ and $f_{D^{(*)}}$ are the corresponding decay constants. Although the decay constants and wave functions of the $D^{(*)}$ meson for longitudinal and transverse polarizations are different generally, for simplicity, in our estimations we assume that they are the same. Since the hadronic structure of $B$ was studied before, the explicit description can be found in Ref. [23]. In order to fit the measured BR of $B \to D^{(*)}f_0(980)$, the involved $D^{(*)}$ wave functions are modelled simply as

$$\Phi_{D^{(*)}}(x) = \frac{3}{\sqrt{2N_c}} f_{D^{(*)}} x(1-x)[1 + 0.7(1-2x)].$$

(5)

With the same guidance, we also apply the concept to the $J/\Psi$ case. As a detail discussion, one can refer Ref. [26].

As mentioned before, due to a large energy transfer in heavy $B$ meson decays, we can utilize the factorization theorem, in which decay amplitudes can be calculated by the convolution of hard parts and wave functions [13][19], to describe the hadronic effects. Although vector $D^{(*)}$ and $J/\Psi$ mesons carry the spin degrees of freedom, in the $B \to D^{(*)}\bar{J}/\Psi f_0(980)$ decays only longitudinal polarization is involved. Expectably, the results should be similar to the $D_0 f_0(980)$ mode. Hence, we only present the representative formulas for $B \to D_0 f_0(980)$ at the amplitude level but give the predicted BRs for all considered processes. From Fig. 1 and the effective interactions of Eq. (1), the decay amplitude for $B \to D_0 f_0(980)$ is written by

$$A_{Bn} = \frac{\sin \phi_n}{\sqrt{2}} V_n \left[ f_{D_0} F_c + M_c + f_{D_0} F_a + M_a \right]$$
where $F_c(M_e)$ and $F_a(M_a)$ are the factorized (non-factorized) emission and annihilation hard amplitudes, respectively. According to Eqs. 2 and 1, the typical hard functions are expressed as

$$F_c = \zeta \int_0^1 dx_1 dx_3 \int_0^\infty b_1 b_2 b_3 \Phi_B(x_1, b_1)$$

$$\left\{ (1 + x_3) \Phi_{f_0}(x_3) + r_f (1 - 2x_3) \Phi_{f_0}^*(x_3) \right\} \mathcal{E}_c(t_e^2)$$

$$+ 2r_f \Phi_{f_0}^*(x_3) \mathcal{E}_c(t_e^2),$$

(6)

$$M_e = 2 \zeta \int_0^1 d[x] \int_0^\infty b_1 b_2 b_3 \Phi_B(x_1, b_1) \Phi_{D_0}(x_2)$$

$$\left\{ - (x_2 + x_3) \Phi_{f_0}(x_3) + r_f x_3 \Phi_{f_0}^*(x_3) \right\} \mathcal{E}_c(t_e^2)$$

$$+ (1 - x_2) \Phi_{f_0}(x_3) - r_f x_3 \Phi_{f_0}^*(x_3) \mathcal{E}_c(t_e^2),$$

(7)

with $\zeta = 8\pi C_F M_B^2$, $r_f = m_{f_0} M_{B}$, $\mathcal{E}_c(t_e^2) = \alpha_e (t_e^2) a_2 (t_e^2) S_{u_B + f_0(980)}(t_e^2)$, $h_e \{x\}, \{b\}$ and $\mathcal{E}_c(t_e^2) = \alpha_e (t_e^2) (C_2(t_e^2) / N_c)$ $S_u(t_e^2) S_B + D + f_0(980)$ $h_d \{x\}, \{b\}$. $t_{e,d}$, $S_u$ and $h_{e,d}$ denote the hard scales of $B$ decays, Sudakov factors and hard functions arising from the propagators of gluon and internal valence quark, respectively. Their explicit expressions can be found in Ref. 27. With the same procedure, the other hard functions can be derived.

So far, the still uncertain values are the $\{G\}$ parameters of the $f_0(980)$ wave functions. By the identity of $<0|\bar{q}_\mu \gamma^\mu V_T|T> = M_{f_0} \mathcal{V}_{f_0} \mathcal{E}_c(t_e^2)$ for the $V-$meson transverse polarization, we find that except the Dirac matrices $\gamma_\mu$ and the associated polarization vector $\mathcal{E}_c$, it is similar to the scalar meson case. Inspired by the similarity, we adopt $\Phi_{f_0}^*(x)$ to be a $\rho$-meson like wave function and take $G_1^\rho \approx 1.5$ and $G_2^\rho \approx 1.8$ 28. As to the value of $G$, we use the corresponding value in $a_0(980)$ given by the second reference of 22 and get $G \approx 1.11$. By the chosen values and using Eq. 8 with excluding WC of $a_2$, we immediately get the $B \rightarrow f_0(980)$ form factor to be 0.38. Is it a reasonable value? In order to investigate that the obtained value is proper, we employ the relationship $F^{B \rightarrow f_0(980)} \sim (M_{f_0}/M_B)^{1/2} F^{D_0 \rightarrow f_0(980)}$, which comes from the heavy quark symmetry limit 24, 29, as a test. According to the calculation of Ref. 30, we know $F^{D_0 \rightarrow f_0(980)} \approx 0.6$; and then, we have $F^{B \rightarrow f_0(980)} \approx 0.36$. Clearly, it is quite close to what we obtain. Hence, with the taken values of parameters, the magnitudes of hard functions are given in Table I. We note that the complex values come from the on-shell internal quark and all of hard functions are the same in order of magnitude.

One challenging question is that how reliable our results are. In order to investigate this point, besides the $B \rightarrow D^{(*)0} f_0(980)$ decays, we also calculate $B \rightarrow D^{0} \pi^0$, $J/\Psi(K^+)$ and $B \rightarrow f_0(980) K^+$ processes. All of them are already measured at B factories 31, 32. Due to the calculations and formalisms being similar to $D^{0} f_0(980)$, we directly present the predicted BRs in Table II by taking $\phi_s = 45^0$, $f_{D^*} = 0.22$.

### Table I: Hard functions (in units of $10^{-2}$) for $\bar{B} \rightarrow D^{0} f_0(980)$ decay with $f = 0.18$, $f_D = 0.2$ GeV, $G = 1.11$, $G_1^\rho = 1.5$ and $G_2^\rho = 1.8$.

| Amp. | $F_c$ | $M_e$ | $F_a$ | $M_a$ |
|------|-------|-------|-------|-------|
| $D^0 f_0(980)$ | $-5.95$ | $-2.66 + i1.56$ | $1.83 - i3.60$ | $0.20 + i1.12$ |

### Table II: BRs (in units of $10^{-4}$) with $\phi_s = 45^0$, $f_{D^*} = 0.22$, $f_J/\Gamma = 0.405$ GeV and the same taken values of Table I.

| Mode | Belle [31] | BaBar [32] | This work |
|------|------------|-------------|-----------|
| $D^0 f_0(980)$ | $2.28$ | $2.46$ | $0.10$ |
| $J/\Psi f_0(980)$ | $0.01$ | $0.01$ | $0.01$ |
| $K^+ f_0(980)$ | $3.1 \pm 0.4 \pm 0.5$ | $2.89 \pm 0.29 \pm 0.38$ | $2.60$ |
| $J/\Psi K^0$ | $7.9 \pm 0.4 \pm 0.9$ | $8.3 \pm 0.4 \pm 0.5$ | $8.3$ |
| $J/\Psi K^{*0}$ | $12.9 \pm 0.5 \pm 1.3$ | $12.4 \pm 0.5 \pm 0.9$ | $13.37$ |

Table I: Hard functions (in units of $10^{-2}$) for $\bar{B} \rightarrow D^{0} f_0(980)$ decay with $f = 0.18$, $f_D = 0.2$ GeV, $G = 1.11$, $G_1^\rho = 1.5$ and $G_2^\rho = 1.8$. GeV, $f_J/\Gamma = 0.405$ GeV and the same taken values of Table I. As to the $J/\Psi$ wave functions, we model it as $\Phi_{J/\Psi}(x) = f_{J/\Psi} / \sqrt{x} (x^2 + 2)^2$. The BRs of charged $B^+ \rightarrow J/\Psi M^+$ modes can be obtained from neutral modes by using $Br(B^0 \rightarrow J/\Psi M^0) \gamma_B / \gamma_{B^+}$. Hence, from the Table II, we clearly see that our predictions are consistent with experimental data. Moreover, it is worthwhile to mention that in addition to the BR of $B \rightarrow J/\Psi K^*$ decay, the squared helicity amplitudes $|A_0|^2$, $|A_1|^2$ and $|A_\perp|^2$ with the normalization of $|A_0|^2 + |A_1|^2 + |A_\perp|^2 = 1$ are also given as 0.59, 0.24 and 0.17, respectively. They are all comparable with the measured values 0.60 ± 0.05(0.60 ± 0.04), 0.21 ± 0.08(0.24 ± 0.04) and 0.19 ± 0.06(0.16 ± 0.03) of Belle (BaBar) 31, 32. In order to further understand the dependence of the effects of $n\bar{n}$ content, the BRs as a function of mixing angle $\phi_s$ are shown in Fig. 2. We note that with including the twist-2 wave function for $f_0(980)$, our previous result of $B^+ \rightarrow K^+ f_0(980)$ in the small $\phi_s$ region 28 becomes insensitive to $\phi_s$.

The subsequent question is how to search the events for $B \rightarrow D^{(*)0} f_0(980)$ and $B \rightarrow J/\Psi f_0(980)$ decays. From particle data group of Ref. 22, we know that $f_0(980)$ mainly decays to $\pi \pi$ and $K K$ and $R = \Gamma(\pi \pi) / \Gamma(\pi \pi + \Gamma(K K)) = 0.68$. Therefore, we suggest that the candidates could be found in $B \rightarrow D^{(*)0} (J/\Psi) \pi \pi (K K)$ three-body decay samples. For an illustration, according to the values of Table II, we can estimate that the BR product of $Br(B \rightarrow D^{0} f_0(980)) \times Br(f_0(980) \rightarrow \pi^+ \pi^-) \approx 1.0 \times 10^{-4}$ with $Br(f_0(980) \rightarrow \pi^+ \pi^-) = 2R / 3$. The result is consistent with the measured value of $(8.0 \pm 0.6 \pm 1.5) \times 10^{-4}$ for $B \rightarrow D^{0} \pi^+ \pi^-$ decay while that of $B \rightarrow D^{0} \rho^0$ is determined to be $(2.9 \pm 1.0 \pm 0.4) \times 10^{-4}$ 34.
We have investigated the possibility to extract the existence of $n\bar{n}$ component of $f_0(980)$ in terms of $B \to D^{(*)0} f_0(980)$ and $\bar{B} \to J/\Psi f_0(980)$ decays. Based on the comparable values between the BRs of $\bar{B} \to D^{(*)0}$ and $\bar{B} \to J/\Psi M$ decays and current experimental data, our predictions on the BRs of $\bar{B} \to D^{(*)0}(J/\Psi) f_0(980)$ decays are reliable and can be tested at $B$ factories.

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FIG. 2: BRs as a function of angle $\phi_\psi$. (a) the solid (dashed) lines are for $\bar{B} \to D^0(D^{*0}) f_0(980)$ decays while (b) they express $\bar{B} \to J/\Psi f_0(980)$ and $B^+ \to K^+ f_0(980)$ decays.

[1] S.D. Protopopescu et al., Phys. Rev. D7, 1279 (1973); B. Hyams et al., Nucl. Phys. B64, 4 (1973).
[2] R.L. Jaffe, Phys. Rev. D15, 267 (1977); ibid, 281 (1997); M. Alford and R.L. Jaffe, Nucl. Phys. B578, 367 (2000).
[3] J. Weinstein and N. Isgur, Phys. Rev. Lett. 48, 659 (1982); Phys. Rev. D27, 588 (1983); Phys. Rev. D41, 2236 (1990); M.P. Locher et al., Eur. Phys. J. C4, 317 (1998).
[4] N.A. Tornqvist, Phys. Rev. Lett. 49, 624 (1982); N.A. Tornqvist and M. Roos, Phys. Rev. Lett. 76, 1575 (1996).
[5] P. Minkowski and W. Ochs, Eur. Phys. J. C9, 283 (1999); hep-ph/0209223.
[6] A.V. Anisovich, V.V. Anisovich and V.A. Nikonorov, hep-ph/0011191.
[7] D. Robson, Nucl. Phys. B130, 328 (1977); E. Klempt, PSI Zuoz Summer School on Phenomenology of Gauge Interactions, 13-19, 2000, hep-ex/010131.
[8] A. Antonelli, invited talk at the XXII Physics in Collisions Conference (PIC02), Stanford, Ca, USA, June 2002, hep-ph/0209069.
[9] A. Bramon et al., Eur. Phys. J. C26, 253 (2002).
[10] R. Delbourgo et al., Phys. Lett. B446, 332 (1999); F. De Fazio and M.R. Pennington, Phys. Lett. B521, 15 (2001); F. Kleefeld et al., Phys. Rev. D66, 034007 (2002).
[11] F. De Fazio and M.R. Pennington, Phys. Lett. B521, 15 (2001).
[12] N.N. Achasov and V.V. Gubin, Phys. Rev. D63, 094007 (2001); P.E. Close and N.A. Tornqvist, J. Phys. G28, R249 (2002).
[13] E791 Collaboration, E.M. Aitala et al., Phys. Rev. Lett. 86, 765 (2000); ibid, 770 (2000); ibid 89, 121801 (2002).
[14] FOCUS Collaboration, K. Stenson, presented at Proc. Heavy Flavour 9, Pasadena, CA, Sep. 10-13, 2001, hep-ex/0111083.
[15] B.T. Meadows, invited talk at the XXII Physics in Collisions Conference (PIC02), Stanford, Ca, USA, June 2002, hep-ex/0210065.
[16] OPAL Collaboration, K. Ackerstaff et al., Eur. Phys. J. C4, 19 (1998).
[17] Belle Collaboration, A. Garmash et al., Phys. Rev. D 65, 092005 (2002).
[18] G.P. Lepage and S.J. Brodsky, Phys. Lett. B87, 359 (1979); Phys. Rev. D22, 2157 (1980).
[19] H.N. Li, Phys. Rev. D64, 014019 (2001).
[20] P. Ball, JHEP 01, 100 (1999).
[21] Belle Collaboration, K. Abe et al., Phys. Rev. Lett. 88, 052002 (2002); CLEO Collaboration, T. E. Coan et al., ibid, 062001 (2002); Babar Collaboration, B. Aubert et al., contributed to ICHEP2002, hep-ex/0207092.
[22] Particle Data Group, K. Hagiwara et al., Phys. Rev. D66, 010001 (2002); Belle Collaboration, K. Abe et al., Phys. Lett. B538, 11 (2002); Babar Collaboration, B. Aubert et al., Phys. Rev. Lett. 87, 241801 (2001).
[23] G. Buchalla et al., Rev. Mod. Phys. 68, 1230 (1996).
[24] V.L. Chernyak and A.R. Zhitnitsky, Phys. Rep. 112, 173 (1984); M. Diehl and G. Hiller, JHEP 060, 067 (2001).
[25] H.N. Li, presented at FPCP, Philadelphia, Pennsylvania, 16-18 May 2002, hep-ph/0201019.
[26] T.K. Kurimoto et al., hep-ph/0210289.
[27] T.W. Yeh and H.N. Li, Phys. Rev. D56, 1615 (1997).
[28] C.H. Chen and H.N. Li, Phys. Rev. D63, 014003 (2001).
[29] C.H. Chen, Phys. Rev. D67, 014012 (2003).
[30] N. Isgur and M.B. Wise, Phys. Rev. D42, 2388 (1990); H.Y. Cheng, hep-ph/0121117, to appear in PRD.
[31] A. Deandrea et al., Phys. Lett. B502, 79 (2001).
[32] Belle Collaboration, K. Abe et al., Phys. Rev. Lett. 88, 052002 (2002); Phys. Lett. B538, 11 (2002) and hep-ex/0211047.
[33] A. Garmash et al., Phys. Rev. D 65, 092005 (2002).
[34] BaBar Collaboration, B. Aubert et al., hep-ex/0207092 and Phys. Rev. D65, 032001 (2002).
[35] C.H. Chen et al., Phys. Rev. D66, 054013 (2002).
[36] Belle Collaboration, K. Abe et al., hep-ex/0211022.