Why is the $B \to \eta' X$ Decay Width So Large?

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A new mechanism for the observed inclusive $B \to \eta' X$ decay is suggested. We argue that the dominant contribution to this amplitude is due to the Cabibbo favored $b \to \bar{c}cs$ process followed by the transition $\bar{c}c \to \eta'$. A large magnitude of the "intrinsic charm" component of η' is of critical importance in our approach. Our results are consistent with an unexpectedly large $\mathcal{B}(B \to \eta' + X) \sim 10^{-3}$ recently announced by CLEO. We stress the uniqueness of this channel for 0^{-+} gluonia search. [S0031-9007(97)05042-4]

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Recently CLEO has reported [1] a very large branching ratio for the inclusive production of η':

$$\mathcal{B}(B \to \eta' + X;\ 2.2\ \text{GeV} \le E_{\eta'} \le 2.7\ \text{GeV}) = (7.5 \pm 1.5 \pm 1.1) \times 10^{-4}, \quad (1)$$

where the result quoted above contains an acceptance cut intended to reduce the background from events with charmed mesons. To get a feeling of how large this number is, we present for comparison a branching ratio for the inclusive production of J/ψ meson [2]:

$$\mathcal{B}(B \to J/\psi(\text{direct}) + X) = (8.0 \pm 0.8) \times 10^{-3}. \quad (2)$$

This process is due to the Cabibbo favored $b \to \bar{c}cs$ decay which is the largest possible amplitude without charmed hadrons (like $D, D_s, \Lambda_c, \ldots$) in the final state. The comparison of these two numbers shows that the amplitude of process (1) is only by a factor of 3 less than the most Cabibbo favored amplitude $b \to \bar{c}cs \to J/\psi s$. It is clear that the data (1) are in severe contradiction with a standard view of the process at the quark level as a decay of the b quark into light quarks which could be naively suggested keeping in mind the standard picture of η' as a SU(3) singlet meson made of the u, d and s quarks. In this picture the decay (1) must be proportional to the Cabibbo suppression factor V_{ub}, and therefore the standard approach has no chance to explain the data (1); see below for more detail. Once this fact is realized, we should look around and ask the question: Where does the η' come from? We remind the reader that it has been known [3,4] for a long time that η' is a very special meson. It is so special that physicists repeatedly organize workshops with the word η' in the title [5]. The question addressed there can be formulated in the following way: What kind of experiments should be designed to demonstrate the uniqueness of η'?

The aim of this Letter is to argue that one of the crucial experiments establishing the uniqueness of η' was not only designed, but rather it was already successfully completed (1)! The reason why the $b \to \eta'$ transition is so unique for the study of η' can be explained in simple terms as follows. We claim that the η' production is due to the Cabibbo favored $b \to \bar{c}cs$ process followed by the transition $\bar{c}c \to \eta'$. Because of the fact that the c quark could be considered as a heavy particle, one can perform the $1/m_c$ expansion reducing the original problem to the problem of the gluon content of η'. Therefore, in the $B \to \eta'$ decay we have a new local gluon source which has never been available before. We should stress that our mechanism is very different from one proposed recently [6], and distinctions between them will be explained below.

We would like to start our presentation with an estimate of the $B \to \eta' + X$ decay width assuming that the η' is made exclusively of light quarks. To this end, it is convenient to consider the following ratio for two pseudoscalar particles η' and $\eta_c(1S)$:

$$\frac{\Gamma(B \to \eta' + X)}{\Gamma(B \to \eta_c(1S) + X)} \sim \left(\frac{V_{bu}}{V_{bc}}\right)^2 \frac{|\langle \eta' | \bar{u}\gamma_\mu\gamma_5 u|0\rangle \langle X|\bar{d}\gamma_\mu(1+\gamma_5)b|B\rangle|^2}{|\langle \eta_c|\bar{c}\gamma_\mu\gamma_5 c|0\rangle \langle X|\bar{s}\gamma_\mu(1+\gamma_5)b|B\rangle|^2} \frac{\Omega_{B\to\eta'+X}}{\Omega_{B\to\eta_c+X}} \sim \frac{1}{3}\left(\frac{V_{bu}}{V_{bc}}\right)^2 \left(\frac{f_{\eta'}}{f_{\eta_c}}\right)^2 \left(\frac{1 - m_{\eta'}^2/m_b^2}{1 - m_{\eta_c}^2/m_b^2}\right)^2 \sim 3 \times 10^{-4}. \quad (3)$$

Here $\Omega_{B\to\eta'+X}$ and $\Omega_{B\to\eta_c+X}$ are the corresponding phase volumes for two inclusive decays; $(V_{bu}/V_{bc}) \simeq 0.08$. The matrix element $\langle \eta'(p)|\bar{u}\gamma_\mu\gamma_5 u|0\rangle = (-i/\sqrt{3}) f_{\eta'} p_\mu \simeq (0.5\text{–}0.8)(-i/\sqrt{3}) f_\pi p_\mu$ is known numerically from [7]. We define the corresponding η_c matrix element in a similar way to the η':

$$\langle \eta_c(p)|\bar{c}\gamma_\mu\gamma_5 c|0\rangle = -i f_{\eta_c} p_\mu . \quad (4)$$

This matrix element can be estimated from the $\eta_c \to \gamma\gamma$ decay: $f_{\eta_c} \simeq 400$ MeV.

To make a prediction for $\Gamma(B \to \eta' + X)$ from Eq. (3), we need to know $\Gamma(B \to \eta_c(1S) + X)$ which, unfortunately, is not presently available. However, as we

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will see in a moment, $\Gamma(B \to \eta_c(1S) + X) \simeq 0.6\Gamma(B \to J/\psi + X)$. The latter number is well known (2). Therefore, the standard mechanism yields a very small contribution in comparison with the data (1):

$$\mathcal{B}(B \to \eta' + X)_{\text{standard}} \sim 1.5 \times 10^{-6}. \tag{5}$$

We should mention that the factorization procedure used in the estimate (3) does not work well. A phase factor introduced into this formula is also a rough simplification: In reality, an inclusive spectrum is a much more complicated function than a simple factor $\Omega_{B\to\eta'+X}$ obtained as a result of two-particle decay of a colorful heavy quark $b \to \eta'(\eta_c) + d(s)$ instead of the physical B meson. Besides, gluon corrections to the Wilson coefficients in front of the operators containing $\bar{c}c$ quarks [denominator in (3)] or light quarks [numerator in (3)] also change the estimate (3). However, it is obvious that all these effects due to a nonfactorizability, gluon corrections, as well as $O(1/m_b, 1/N)$ terms omitted in (3), cannot substantially change our estimate. We therefore conclude that the image of the η' meson as the SU(3) singlet quark state made exclusively of the u, d, s quarks is not adequate to the problem at hand. It is easy to see that the small value for the ratio (3) is a consequence of a small residue of the η' supplemented with the Cabibbo suppression of the $b \to u$ transition.

To conclude the discussion of the standard approach to the $B \to X\eta'$ decay, we should estimate $\mathcal{B}(B \to \eta_c(1S) + X)$ which was not yet measured, but was a relevant element in our calculations (3). To this end, consider the following ratio

$$\begin{aligned}\frac{\Gamma(B \to \eta_c(1S) + X)}{\Gamma(B \to J/\psi + X)} &\sim \frac{|\langle \eta_c|\bar{c}\gamma_\mu\gamma_5 c|0\rangle\langle X|\bar{s}\gamma_\mu(1+\gamma_5)b|B\rangle|^2}{|\langle J/\psi|\bar{c}\gamma_\mu c|0\rangle\langle X|\bar{s}\gamma_\mu(1+\gamma_5)b|B\rangle|^2}\,\frac{\Omega_{B\to\eta_c+X}}{\Omega_{B\to J/\psi+X}} \\ &\sim \frac{1}{1+2m_{J/\psi}^2/m_b^2}\left(\frac{f_{\eta_c}}{f_\psi}\right)^2 \sim 0.6\,. \end{aligned} \tag{6}$$

Here we introduced the constant f_ψ defined by the following matrix element:

$$\langle J/\psi|\bar{c}\gamma_\mu c|0\rangle = \epsilon_\mu f_\psi m_\psi\,. \tag{7}$$

The definition of f_ψ is similar to the definition of f_{η_c} introduced before (4). One can estimate f_ψ independently from $J/\psi \to e^+e^-$ decay: $f_\psi \simeq 400$ MeV. We also note that in the limit $m_b \to \infty$ only the longitudinal polarization of J/ψ meson contributes the decay; see, e.g., [8]. In this case $\epsilon_\mu m_\psi \to p_\mu$, and therefore the matrix elements for longitudinally polarized J/ψ meson (7) and η_c meson (4) are equal, and the ratio (6) should be close to one: $(f_{\eta_c}/f_\psi)^2 \simeq 1$. In reality, m_b is not much heavier than J/ψ, and thus the contribution of two transverse polarizations of J/ψ is not suppressed numerically, and the correction factor due to the transverse polarizations is explicitly taken into account in (6).

Our last remark regarding Eq. (6) is that it is very important that this ratio is not sensitive to the problems of nonfactorizability, gluon corrections, and many others we mentioned (and did not mention) earlier. This is because all uncertainties related to those problems are canceled out in the ratio (6).

In view of the failure of the standard approach to the $B \to \eta' + X$ decay which treats the η' as the SU(3) singlet quark state made exclusively of the u, d, s quarks, we suggest an alternative mechanism for the $B \to \eta' + X$ decay which is specific to the uniqueness of the η'. It has been known [3,4] that the η' is *a messenger between two worlds:* the world of light hadrons and a less studied world of gluonia. In other words, it is a very special meson strongly coupled to gluons. We suggest the following picture for the process of interest: The $b \to c\bar{c}s$ decay is followed by the conversion of the $c\bar{c}$ pair into the η'. [The relevance of the process $b \to c\bar{c}s \to$ light hadrons was discussed earlier [9] in connection with the problem of semileptonic branching ratio.] This means that the matrix element

$$\langle 0|\bar{c}\gamma_\mu\gamma_5 c|\eta'(p)\rangle = if_{\eta'}^{(c)} p_\mu \tag{8}$$

is nonzero due to the $c\bar{c} \to$ gluons transition. Of course, since one deals here with virtual c quarks, this matrix element is suppressed by the $1/m_c^2$. However, the c quark is not very heavy, and the suppression $1/m_c^2$ is not large numerically. At the same time, the Cabibbo enhancement of the $b \to c$ transition in comparison to $b \to u$ is a much more important factor which makes this mechanism work.

In our recent paper [10] we estimated the matrix element (8) using a combination of the operator product expansion technique, large N approach, and QCD low energy theorems. The final formula reads

$$\begin{aligned} f_{\eta'}^{(c)} &= -\frac{\langle 0|g^3 f^{abc} G^a_{\mu\nu}\tilde{G}^b_{\nu\alpha}G^c_{\alpha\mu}|\eta'\rangle}{16\pi^2 m_{\eta'}^2 m_c^2} + O\left(\frac{1}{m_c^4}\right) \\ &\simeq \frac{3}{4\pi^2 b}\,\frac{1}{m_c^2}\,\frac{\langle g^3G^3\rangle_{YM}}{\langle 0|\frac{\alpha_s}{4\pi}G_{\mu\nu}\tilde{G}_{\mu\nu}|\eta'\rangle} + O\left(\frac{1}{m_c^4}\right). \end{aligned} \tag{9}$$

Therefore, we have related the residue of the charmed axial current into the η' with apparently completely unrelated quantity which is the value of cubic gluon condensate in pure Yang-Mills theory (we notice that the matrix element of topological density which appears in (9) is known: $\langle 0|(\alpha_s/4\pi)G\tilde{G}|\eta'\rangle \simeq 0.04$ GeV^3 [7]). Using all currently available information regarding the vacuum condensate $\langle g^3G^3\rangle_{YM}$ in gluodynamics, we have arrived at the numerical estimate

$$f_{\eta'}^{(c)} = (50-180)\text{ MeV}\,. \tag{10}$$

Here the uncertainty is mostly due to a poor knowledge of the cubic condensate in gluodynamics. The residue $f_{\eta'}^{(c)}$ has also been calculated numerically [11] within the instanton liquid model, where it was found $f_{\eta'}^{(c)} = (100-120)$ MeV in agreement with (10).

In spite of the poor accuracy of our result (10), we concluded in [10] that the gluon mechanism seems to be sufficient to describe the data for exclusive decay $B \to \eta' K$. We came to this conclusion by comparing the theoretical prediction (10) with an "experimental" value of $f^{(c)}_{\eta'}$ obtained under assumption that the above mechanism exhausts the $B \to K\eta'$ decay. From the numerical estimate $\mathcal{B}(B \to K\eta') \simeq 3.92 \times 10^{-3} \times (f^{(c)}_{\eta'}/1\ \mathrm{GeV})^2$ and the CLEO data [1]

$$\mathcal{B}(B \to K\eta') = (7.8^{+2.7}_{-2.2} \pm 1.0) \times 10^{-5}, \qquad (11)$$

we have found the experimental value [we use the central value of the branching ratio (11)]

$$f^{(c)}_{\eta'} \simeq 140\ \mathrm{MeV}\ (\text{"exp"}), \qquad (12)$$

which is within our estimate of $f^{(c)}_{\eta'}$ (10). Bearing in mind that the standard approach to $B \to K\eta'$ yields $\mathcal{B}(B \to K\eta') \simeq 10^{-7}$ [which is extremely small in comparison to (11)], we concluded that the suggested mechanism indeed explains the exclusive decay $B \to K\eta'$, with a reservation for uncertainty of our prediction (10).

Before proceeding with the use of our estimate (10) for the inclusive decay $B \to \eta' + X$, we would like to make a few comments. The obtained result (10) looks very large, as it is only a few times smaller than the analogously normalized residue for η_c meson; see (4). At the same time, $f^{(c)}_{\eta'}$ is a double suppressed amplitude: It is Zweig rule violating and besides contains the $1/m_c^2$ suppression factor. Therefore, presumably, it should be very small. In reality it is not. There are two reasons for this. First, m_c^2 is not very large on the hadronic 1 GeV scale. Second, and more important, the Zweig rule itself is badly broken in vacuum $0^\pm$ channels. Of course, it is in contradiction with a naive large N_c counting where nondiagonal transitions should be suppressed in comparison with diagonal ones. However, a more careful analysis [7,10] reveals that the large N_c picture and the breakdown of the Zweig rule in fact peacefully coexist; while the large N_c description is quite accurate for the η', an extent to which the Zweig rule is violated in η' just suffices to obtain the large residue (10) (see [10] for more details). We stress that the phenomenon of a breakdown of the Zweig rule in vacuum $0^\pm$ channels is well known and understood [7], and many phenomenological examples of corresponding physics have been discussed in the literature; see, e.g., [7,12]. The large residue $f^{(c)}_{\eta'}$ (10) (which is fundamentally important for our estimates) is another manifestation of the same physics. One should expect that the intrinsic charm component of the η' can show up in a number of physical processes. However, in some cases it does not lead to any effects. For instance, the $\eta' \to 2\gamma$ decay is not influenced by the c quark in the η' because the heavy quark contribution to the triangle diagram vanishes when the photons are on-shell [13].

In a number of papers (see, e.g., [6,14]), a much smaller value of the residue $f^{(c)}_{\eta'}$ was suggested, $f^{(c)}_{\eta'} \simeq 5.8$ MeV [14]. These estimates are based on the constituent quark model picture of the η_c-η' mixing

$$|\eta'\rangle = \frac{1}{\sqrt{3}}|u\bar{u} + d\bar{d} + s\bar{s}\rangle\cos\theta + |c\bar{c}\rangle\sin\theta\,,$$

$$|\eta_c\rangle = -\frac{1}{\sqrt{3}}|u\bar{u} + d\bar{d} + s\bar{s}\rangle\sin\theta + |c\bar{c}\rangle\cos\theta\,. \qquad (13)$$

In our opinion, this approach cannot be correct in view of two reasons. First, the quantum mechanical mixing (13) implies that all constituent quarks in (13) are nearly on-shell (with an accuracy $\sim\Lambda_{\mathrm{QCD}}$). Clearly, this cannot be the case for the heavy c quark in the η'. Moreover, this picture completely neglects all gluon Fock components in the $|\eta'\rangle$ state. In particular, one could expect that the matrix element $\langle 0|\alpha_s G\tilde{G}|\eta'\rangle$ should be very small, while we know from QCD that it is actually large. The same is true also for higher gluon Fock states in the η', which are directly related to the residue of interest (9).

Once the fundamental parameter $f^{(c)}_{\eta'}$ is fixed, we can estimate the inclusive decay $\mathcal{B}(B \to \eta' + X)$. As before, it is convenient to consider the following ratio for two pseudoscalar particles η' and $\eta_c(1S)$:

$$\frac{\Gamma(B \to \eta' + X)}{\Gamma(B \to \eta_c + X)} \sim \frac{|\langle\eta'|\bar{c}\gamma_\mu\gamma_5 c|0\rangle\langle X|\bar{s}\gamma_\mu(1+\gamma_5)b|B\rangle|^2}{|\langle\eta_c|\bar{c}\gamma_\mu\gamma_5 c|0\rangle\langle X|\bar{s}\gamma_\mu(1+\gamma_5)b|B\rangle|^2}\frac{\Omega_{B\to\eta'+X}}{\Omega_{B\to\eta_c+X}} \sim \left(\frac{f^{(c)}_{\eta'}}{f_{\eta_c}}\right)^2 \sim 0.12\,. \qquad (14)$$

Here $\Omega_{B\to\eta'+X}$ and $\Omega_{B\to\eta_c+X}$ are the corresponding phase volumes for two inclusive decays. As we mentioned earlier, we are quite confident about the ratio for $\mathcal{B}(B \to \eta_c + X) \simeq 0.6\mathcal{B}(B \to J/\psi + X) \sim 5 \times 10^{-3}$; see (6). Therefore, from (14) we expect

$$\mathcal{B}(B \to \eta' + X) \simeq 0.12\mathcal{B}(B \to \eta_c + X) \simeq 6 \times 10^{-4}, \qquad (15)$$

which is our main result. The obtained number is in a good agreement with the data (1). In the course of our estimates (14) and (15) we have used the experimental value for $f^{(c)}_{\eta'}$ (12) rather than our theoretical calculation (10) which has a poor accuracy. By doing so, we essentially assumed that our mechanism is sufficient to describe the experimental data for exclusive decay [10]. The agreement of (15) with the data (1) for inclusive decay serves as a nontrivial test of the suggested mechanism to work also for inclusive decay.

A few words about uncertainties in Eq. (14): The most important ambiguity in our previous Eq. (3) was related to the uncertainty in the Wilson coefficients for operators containing different flavors. We do not have such an uncertainty at all in Eq. (14) because we are discussing one and the same operator with the charmed quarks for both outgoing particles η_c and η'. For the

same reasons, we do not have any uncertainties related to a poor knowledge of V_{ub}/V_{cb}: This factor simply does not appear in (14).

The only important uncertainty in (14) is related to our lack of knowledge of $1/m_b$ corrections. In the limit $m_b \to \infty$ these corrections should disappear. However, in reality they could be large. In fact, the phase volume term alone $\Omega_{B\to\eta'+X}/\Omega_{B\to\eta_c+X}$ calculated on the tree level $b \to \eta_c(\eta') + s$ would bring in the factor $(1 - m^2_{\eta'}/m^2_b)^2/(1 - m^2_{\eta_c}/m^2_b)^2$ which is $\sim 1/m^2_b$, but is not small numerically. Along with these corrections, there are corrections related to the difference in the spectrum for inclusive amplitudes $\langle X|\bar{s}\gamma_\mu(1 + \gamma_5)b|B\rangle$ for different $q^2 = m^2_{\eta_c}$ or $q^2 = m^2_{\eta'}$, respectively. This effect works in the opposite direction than the phase volume effects. A corresponding theoretical analysis of all those corrections is still lacking. Therefore, we neglect these $1/m^2_b$ corrections altogether. We expect that an accuracy of our estimate (14) is rather high and $O(1/m^2_b)$ corrections cannot considerably change our results.

The main result of the present Letter is expressed by the formulas (14) and (15), which agree well with the data (1). We therefore suggest a mechanism which is responsible for both decays: exclusive $B \to \eta' K$ [10] as well as inclusive $B \to \eta' + X$ one (15). The mechanism is based on the Cabibbo favored $b \to \bar{c}cs$ process followed by the transition $\bar{c}c$ into the η'. We believe that all similar modes (as, for example, $B \to \eta' K^*$) will follow the same pattern. Therefore, we expect that the difference between K and K^* modes appears only in the transition form factors $\sim\langle K(K^*)|\bar{s}\gamma_\mu(1 + \gamma_5)b|B\rangle$. At the same time, the part related to the η' remains unchanged. In this case, the corresponding information can be extracted from the analysis of well-known $B \to J/\psi + K(K^*)$ decays and we arrive at the estimate

$$\frac{\Gamma(B \to \eta' + K)}{\Gamma(B \to \eta' + K^*)} \sim \frac{|\langle K|\bar{s}\gamma_\mu(1 + \gamma_5)b|B\rangle|^2}{|\langle K^*|\bar{s}\gamma_\mu(1 + \gamma_5)b|B\rangle|^2} \sim \frac{\Gamma(B \to J/\psi + K)}{\Gamma(B \to J/\psi + K^*)} \sim 0.5\,. \quad (16)$$

We mention that, as before, the main uncertainties, related to the Wilson coefficients, are canceled out in the ratio (16). However, preasymptotic in $1/m_b$ effects in these decays (which can be large; see, e.g., [15]) are not taken into account in (16). Therefore, our prediction (16) should be considered as an order of magnitude estimate only.

In closing, it is important to note that the suggested mechanism for $B \to \eta'$ decay is unique to the special nature of the η', and thus possesses many specific properties which cannot be explained by any other mechanism. It gives a hope that future experiments will support (or reject) the suggested pattern.

In particular, we expect that only 0^{-+} flavor-singlet mesons (similar to η') could contribute on the same level as (1) and (11). (Of course, η will also appear due to the standard mixing with η'.) It is in a big contrast, for example, with the mechanism suggested in [6], where any state with any spin and parity $(0^{++}, 0^{-+}, 2^{++}, 4^{++}, \ldots)$ strongly interacting with two gluons should have, in general, a similar branching ratio. An experience with $J/\psi \to \gamma gg \to \gamma$ + hadrons decays tells us that many states [among them: η', $f_4(2050)$, $f_2(1270)$, $\rho\rho$, and others] have two-gluon coupling constants comparable with the magnitude of $gg \to \eta'$. Therefore, one could expect that within this scenario the same states should appear in B decays also. As we mentioned earlier, we do not expect anything but 0^{-+} mesons.

Moreover, we consider this physics as a new tool for 0^{-+} gluonia search. Such a new gluon color-singlet current produced in $B \to \bar{c}c \to$ glueball decays has never been available for a study before.

In conclusion, we should note that the special quantum numbers 0^{-+} is not the only point which distinguishes our mechanism from all others. A spectrum in the inclusive decay is also very unique: In the $m_b \to \infty$ limit, it is given by the free quark decay result: $b \to \eta' + s$ with the specific two-particle decay spectrum. Physical interactions in $B \to \eta' X$ will smear this spectrum with a width about 1 GeV, however, even in such form it will be very distinguishable from predictions of other mechanisms. Therefore, we suggest that this uniqueness of the spectrum will be helpful for the 0^{-+} glueball search in B decays.

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[1] P. Kim, in Proceedings of FCNC, Santa Monica, California, 1997; F. Würthwein, hep-ex/9706010.
[2] Particle Data Group, R. M. Barnett *et al.*, Phys. Rev. D **54**, 1 (1996).
[3] E. Witten, Nucl. Phys. **B156**, 269 (1979).
[4] G. Veneziano, Nucl. Phys. **B159**, 213 (1979).
[5] Proceedings of the CEBAF Mini-Workshop on the Structure of the Eta-Prime Meson, Las Cruces, New Mexico, 1996, edited by Jose Goity (to be published).
[6] D. Atwood and A. Soni, Phys. Lett. B **405**, 150 (1997).
[7] V. A. Novikov, M. A. Shifman, A. I. Vainshtein, and V. I. Zakharov, Nucl. Phys. **B191**, 301 (1981).
[8] S. J. Brodsky and G. P. Lepage, *Exclusive Processes in Quantum Chromodynamics*, in Perturbative Quantum Chromodynamics, edited by A. H. Mueller (World Scientific Publishing Co., Singapore, 1989); V. L. Chernyak and A. R. Zhitnitsky, Phys. Rep. **112**, 173–318 (1984).
[9] I. Dunietz, J. Incandela, F. D. Snider, and H. Yamatoto, Z. Phys. C **76**, 107 (1997).
[10] I. Halperin and A. Zhitnitsky, hep-ph/9704412.
[11] E. V. Shuryak and A. R. Zhitnitsky, hep-ph/9706316; Phys. Rev. (to be published).
[12] A. R. Zhitnitsky, Phys. Rev. D **55**, 3006 (1997); hep-ph/9611303.
[13] R. D. Carlitz, J. C. Collins, and A. H. Mueller, Phys. Lett. B **214**, 229 (1988).
[14] A. Ali and C. Greub, hep-ph/9707251.
[15] H. J. Lipkin, Phys. Rev. Lett. **46**, 1307 (1981); Phys. Lett. B **254**, 247 (1991).