$B_c(B) \rightarrow Dl\bar{\nu}$ form factors in Light-Cone Sum Rules and the $D$-meson distribution amplitude

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Abstract

In this paper we calculate the weak form factors of the decays $B_c(B) \rightarrow Dl\bar{\nu}$ by using the chiral current correlator within the framework of the QCD light-cone sum rules (LCSR). The expressions of the form factors only depend on the leading twist distribution amplitude (DA) of the $D$ meson. Three models of the $D$-meson distribution amplitude are employed and the calculated form factor $F_{B_c \rightarrow D}(0)$ is given. Our prediction, by using the $D$-meson distribution amplitude with the exponential suppression at the end points, is compatible with other approaches, and favors the three-points sum rules (3PSR) approach with the Coulomb corrections included.

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1 Introduction

The CDF Collaboration reported on the observation of the bottom-charm $B_c$ meson at Fermilab [1] in the semileptonic decay mode $B_c \to J/\psi + l + \nu$ with the $J/\psi$ decaying into muon pairs in 1998. Values for the mass and the lifetime of the $B_c$ meson were given as $M(B_c) = 6.40 \pm 0.39 \pm 0.13$ GeV and $\tau(B_c) = 0.46^{+0.18}_{-0.16}$(stat) $\pm 0.03$(syst) ps. Recently, CDF reported first Run II evidence for the $B_c$ meson in the fully reconstructed decay channel $B_c \to J/\psi + \pi$ with $J/\psi \to \mu^+\mu^-$ [2]. The mass value quoted for this decay channel is $6.2857\pm0.0053$(stat)$\pm0.0012$(syst) GeV with errors significantly smaller than in the first measurement. Also D0 has observed the $B_c$ in the semileptonic mode $B_c \to J/\psi + \mu + X$ and reported preliminary evidence that $M(B_c) = 5.95^{+0.14}_{-0.13} \pm 0.34$ GeV and $\tau(B_c) = 0.45^{+0.13}_{-0.10} \pm 0.12$ ps [3].

The $B_c$ decays, at first, calculated in the potential models (PM) [4, 5], wherein the variation of techniques results in close estimates after the adjustment on the semileptonic decays of $B$ mesons. The Operator Product Expansion (OPE) evaluation of inclusive decays gave the lifetime and widths [6], which agree well with PM, if one sums up the dominating exclusive modes. That was quite unexpected, when the sum rules (SR) of QCD results in the semileptonic $B_c$ widths [7], which are one order of magnitude less than those of PM and OPE. The reason may be the valuable role of Coulomb corrections, that implies the summation of $\alpha_s/v$ corrections significant in the heavy quarkonia, i.e. in the $B_c$ [8].

In the recent paper [9], we calculate the form factor for $B\to D l \bar{\nu}$ transitions within the framework of QCD light-cone sum rules (LCSR). In the velocity transfer region $1.14 < v \cdot v' < 1.59$, which renders the OPE near light-cone $x^2 = 0$ go effectively, the yielding behavior of form factor is in agreement with that extracted from the data on $B \to D l \bar{\nu}$, within the error. In the larger recoil region $1.35 < v \cdot v' < 1.59$, the results are observed consistent with those of perturbative QCD (pQCD). In this paper we calculate the form factor of the semileptonic decay $B_c \to D l \bar{\nu}$, which also depends on the $D$-meson DA. However, due to the different feature of the two process, the $c$ quark is a spectator in the decay $B_c \to D l \bar{\nu}$ and the $c$ quark comes from the $b$ quark decay in the process $B \to D l \bar{\nu}$, these two form factors are sensitive to the shape of the DA in two different regions. Combining the information in the two process, we can find which model is more suitable for describing the $D$ meson. Similar to the case of $B \to \pi l \bar{\nu}$, the LCSR approach for the $B_c \to D l \bar{\nu}$ form factor is reliable only in the region $0 < q^2 < 15$ GeV$^2$. we extrapolate the result to the whole region and give the decay width and branching ratio for the semileptonic decay.

This paper is organized as follows. In the following section we derive the LCSRs for the form factor of $B_c \to D l \bar{\nu}$. A discussion of the DA models for the $D$ meson is given in section 3. Section 4 is devoted to the numerical analysis and comparison with other approaches. The last section is reserved for summary.
2 LCSRs for the $B_c(B) \rightarrow D$ Form Factors

The $B_c \rightarrow D$ weak form factors $f(q^2)$ and $\tilde{f}(q^2)$ are usually defined as:

$$<D(p)|\bar{u}\gamma_{\mu}b|B_c(p+q)> = 2f(q^2)p_{\mu} + \tilde{f}(q^2)q_{\mu}, \quad (1)$$

with $q$ being the momentum transfer.

To achieve a LCSR estimate of $f(q^2)$, we follow Ref.[10] and use the following chiral current correlator $\Pi_\mu(p,q)$:

$$\Pi_\mu(p,q) = i \int d^4xe^{ipx} <D(p)|T\{\bar{u}(x)\gamma_{\mu}(1 + \gamma_5)b(x), \bar{b}(0)i(1 + \gamma_5)c(0)|0>$$

$$= \Pi(q^2, (p+q)^2)p_{\mu} + \tilde{\Pi}(q^2, (p+q)^2)q_{\mu}, \quad (2)$$

First, we express the hadronic representation for the correlator. This can be done by inserting the complete intermediate states with the same quantum numbers as the current meson, we have the hadronic representation in the following:

$$\Pi^H_\mu(p,q) = \Pi^H(q^2, (p+q)^2)p_{\mu} + \tilde{\Pi}^H(q^2, (p+q)^2)q_{\mu}$$

$$= \frac{<D|\bar{u}\gamma_{\mu}b|B_c><B_c|\bar{b}\gamma_5c|0>}{m_{B_c}^2 - (p+q)^2}$$

$$+ \sum_H \frac{<D|\bar{u}\gamma_{\mu}(1 + \gamma_5)b|B^H_c><B^H_c|\bar{b}(1 + \gamma_5)c|0>}{m_{B^H_c}^2 - (p+q)^2}. \quad (3)$$

Note that the intermediate states $B^H_c$ contain not only the pseudoscalar resonance of masses greater than $m_{B_c}$, but also the scalar resonances with $J^P = 0^+$, corresponding to the operator $\bar{b}(1 + \gamma_5)c$. Isolating the pole contribution due to the lowest pseudoscalar $B_c$ meson, we have the hadronic representation in the following:

$$<B_c|\bar{b}\gamma_5c|0> = m_{B_c}^2f_{B_c}/(m_b + m_c), \quad (4)$$

and expressing the contributions of higher resonances and continuum states in a form of dispersion integration, the invariant amplitudes $\Pi^H$ and $\tilde{\Pi}^H$ read,

$$\Pi^H[q^2, (p+q)^2] = \frac{2f(q^2)m_{B_c}^2f_{B_c}}{(m_b + m_c)(m_{B_c}^2 - (p+q)^2)} + \int_{s_0}^{\infty} \frac{\rho^H(s)}{s - (p+q)^2}ds + \text{subtractions}, \quad (5)$$

and

$$\tilde{\Pi}^H[q^2, (p+q)^2] = \frac{\tilde{f}(q^2)m_{B_c}^2f_{B_c}}{(m_b + m_c)(m_{B_c}^2 - (p+q)^2)} + \int_{s_0}^{\infty} \frac{\tilde{\rho}^H(s)}{s - (p+q)^2}ds + \text{subtractions}, \quad (6)$$

where the threshold parameter $s_0$ should be set near the squared mass of the lowest scalar $B_c$ meson, the spectral densities $\rho^H(s)$ and $\tilde{\rho}^H(s)$ can be approximated by invoking the quark-hadron duality ansatz

$$\rho^H(s)(\tilde{\rho}^H(s)) = \rho^{QCD}(s)(\tilde{\rho}^{QCD}(s))\theta(s - s_0). \quad (7)$$
On the other hand, we need to calculate the correlator in QCD theory to obtain the desired sum rule result. In fact, there is an effective kinematical region which makes OPE applicable: \((p + q)^2 - m_b^2 \ll 0\) for the \(bd\) channel and \(q^2 \leq m_b^2 - 2\Lambda_{QCD}m_b\) for the momentum transfer. For the present purpose, it is sufficient to consider the invariant amplitude \(\Pi(q^2, (p + q)^2)\) which contains the desired form factor. The leading contribution is derived easily by contracting the \(b\text{-}quark\) operators to a free propagator:

\[
<0|Tb(x)\bar{u}(0)|0> = \int \frac{d^4k}{(2\pi)^4} e^{-ikx} \frac{k + m_b}{k^2 - m_b^2}.
\]  

Substituting Eq. (8) into Eq. (2), we have the two-particle contribution to the correlator,

\[
\Pi^{(qq)} = -2m_b i \int \frac{d^4x d^4k}{(2\pi)^4} e^{i(q-k)x} \frac{1}{k^2 - m_b^2} <D(p)|T\bar{c}(x)\gamma_\mu\gamma_5d(0)|0>.
\]  

An important observation, as in Ref. 10, is that only the leading non-local matrix element \(<D(p)|\bar{u}(x)\gamma_\mu\gamma_5c(0)|0>\) contributions to the correlator, while the nonlocal matrix elements \(<D(p)|\bar{u}(x)\gamma_\mu\gamma_5c(0)|0>\) and \(<D(p)|\bar{u}(x)\sigma_{\mu\nu}\gamma_5c(0)|0>\) whose leading terms are of twist 3, disappear from the sum rule. Proceeding to Eq. (9), we can expand the nonlocal matrix element \(<D(p)|T\bar{u}(x)\gamma_\mu\gamma_5c(0)|0>\) as

\[
<D(p)|T\bar{u}(x)\gamma_\mu\gamma_5c(0)|0> = -i p_\mu f_D \int_0^1 du \exp[u p_x]\varphi_D(u) + \text{higher twist terms},
\]  

where \(\varphi_D(u)\) is the twist-2 DA of the \(D\) meson with \(u = 1 - v\) being the longitudinal momentum fraction carried by the \(c\) quark, those DA’s entering the higher-twist terms are of at least twist 4. The use of Eq. (10) yields

\[
\Pi^{(qq)}[q^2, (p + q)^2] = 2f_D m_b \int_0^1 du \frac{\varphi_D(u)}{m_b^2 - (up + q)^2} + \text{higher twist terms}.
\]  

Invoking a correction term due to the interaction of the \(b\) quark with a background field gluon into Eq. (11), the three-particle contribution \(\Pi^{(qq)}\) is achievable. However, the practical calculation shows that the corresponding matrix element whose leading term is of twist 3 also vanishes. Thus, if we work to the twist-3 accuracy, only the leading twist DA \(\varphi_D\) is needed to yield a LCSR prediction.

Furthermore, we carry out the subtraction procedure of the continuum spectrum, make the Borel transformations with respect to \((p + q)^2\) in the hadronic and the QCD expressions, and then equate them. Finally, we get the LCSR for \(f(q^2)\):

\[
f_{B_c \to D}(q^2) = \frac{m_b(m_b + m_c)f_D}{m_{B_c}^2} e^{m_{B_c}^2/M^2} \int_{\Delta_{B_c}}^1 du \exp \left[ -\frac{m_b^2 - (1 - u)(q^2 - u m_b^2)}{u M^2} \right] \varphi_D(u),
\]

where

\[
\Delta_{B_c} = \frac{\sqrt{(s_{B_c}^B - q^2 - m_b^2)^2 + 4m_b^2(m_b^2 - q^2) - (s_{B_c}^B - q^2 - m_b^2)^2}}{2m_D^2}.
\]
and \( p^2 = m_D^2 \) has been used.

The LCSR for the form factor of \( B \to Dl\bar{\nu} \) has been derived in Ref.[9], here we just give the result:

\[
F_{B \to D}(v \cdot v') = \frac{2m_b^2}{(m_B + m_D) m_B} \sqrt{m_D f_D e^{m_b^2/m_D^2}}
\times \int_{\Delta_B}^1 \frac{du}{u} \exp \left[ -\frac{m_b^2 - (1 - u)(q^2 - um_D^2)}{uM^2} \right] \varphi_D(u),
\]

where

\[
\Delta_B = \sqrt{(s_0^R - q^2 - m_D^2)^2 + 4m_D^2(m_b^2 - q^2) - (s_0^R - q^2 - m_D^2)^2} / 2m_D^2.
\]

3 \( D \)-meson Distribution Amplitude

Now let’s do a discussion on an important nonperturbative parameter appearing in the LCSRs, the leading twist DA of \( D \)-meson, \( \varphi_D(x) \). We reexamine the \( D \)-meson distribution amplitude since we missed a factor of \( \sqrt{2} \) for the decay constant \( f_D \) in determining the coefficients of the DA model [9].

The \( D \) meson is composed of the heavy quark \( c \) and the light anti-quark \( \bar{q} \). The longitudinal momentum distribution should be asymmetry and the peak of the distribution should be approximately at \( x \approx m_c/m_D \approx 0.7 \). According to the definition in Eq.(10), \( \varphi_D(x) \) satisfies the normalization condition

\[
\int_0^1 dx \varphi_D(x) = 1.
\]

In the pQCD calculations [11], a simple model (we call model I) is adopted as

\[
\varphi_D^{(I)}(x) = 6x(1 - x)(1 - C_d(1 - 2x))
\]

which is based on the expansion of the Gegenbauer polynomials. Eq.(17) has a free parameter \( C_d \) which ranges from 0 to 1, and is supposed to approximate 0.7 in order to get consistent results with experiments [11]. Thus we simply take \( C_d = 0.7 \).

On the other hand, it was suggested in [12] that the light-cone wave function of the \( D \)-meson be taken as:

\[
\psi_D(x, k_\perp) = A_D \exp \left[ -b_D^2 \left( \frac{k_\perp^2 + m_c^2}{x} + \frac{k_\perp^2 + m_d^2}{1 - x} \right) \right]
\]

which is derived from the Brosky-Huang-Lepage(BHL) prescription [13]. One constraint on the wave function is from the leptonic decay process \( D \to \mu \nu \):

\[
\int_0^1 \int \frac{d^2k_\perp}{16\pi^3} \psi_D(x, k_\perp) = f_D/2\sqrt{6}.
\]
Here the conventional definition of the decay constant $f_D$ has been used, so Eq.(19) differs from that in Ref.[12] by a factor of $\sqrt{2}$. Another constraint comes from an estimation of the probability of finding the $|q\bar{q} >$ Fock state in the $D$ meson:

$$P_D = \int_0^1 dx \int \frac{d^2k_\perp}{16\pi^3} |\psi_D(x, k_\perp)|^2. \quad (20)$$

As discussed in Ref.[12], $P_D \approx 0.8$ is a good approximation for the $D$ meson. Based on these two constraints, the parameters $A_D$ and $b_D^2$ can be fixed. Taking $P_D \approx 0.8$, $f_D = 222.6$MeV, $m_c = 1.3$GeV and $m_d = 0.35$GeV, we have $A_D = 225$GeV$^{-1}$, $b_D^2 = 0.580$GeV$^{-2}$. $\psi_D(x, k_{\perp})$ can be related to the normalized DA $\varphi_D(x)$ by the definition:

$$\varphi_D(x) = \frac{2\sqrt{6}}{f_D} \int \frac{d^2k_\perp}{16\pi^3} \psi_D(x, k_\perp). \quad (21)$$

Substituting Eq.(18) into Eq.(21), we have a model of the DA(model II)

$$\varphi_D^{(II)}(x) = \frac{\sqrt{6}A_D}{8\pi^2 f_D b_D^2} x(1-x) \exp \left[ -b_D^2 \frac{xm_d^2 + (1-x)m_c^2}{1-x} \right]. \quad (22)$$

Furthermore, as argued in Ref.[14], a more complete form of the light-cone wave function should include the Melosh rotation effect in spin space:

$$\psi_D^f(x, k_{\perp}) = \chi_D(x, k_{\perp}) A_D^f \exp \left[ -b_D^f \frac{(k_{\perp}^2 + m_c^2) + (k_{\perp}^2 + m_d^2)}{1-x} \right] \quad (23)$$

with the Melosh factor,

$$\chi_D(x, k_{\perp}) = \frac{(1-x)m_c + x m_d}{\sqrt{k_{\perp}^2 + ((1-x)m_c + x m_d)^2}}. \quad (24)$$

It can be seen from Eq.(24) that $\chi_D(x, k_{\perp}) \to 1$ as $m_c \to \infty$, since there is no spin interaction between the two quarks in the heavy-flavor meson, i.e., the spin of the heavy constituent decouples from the gluon field, in the heavy quark limit [15]. However the $c$-quark is not heavy enough to neglect the Melosh factor. After integration over $k_{\perp}$ the full form of $D$ meson DA can be achieved (model III):

$$\varphi_D^{(III)}(x) = \frac{A_D^f \sqrt{6x(1-x)}}{8\pi^3/2 f_D b_D^f} \left[ 1 - Erf \left( \frac{b_D^f y}{\sqrt{x(1-x)}} \right) \right] \exp \left[ -b_D^f \frac{xm_d^2 + (1-x)m_c^2 - y^2}{x(1-x)} \right], \quad (25)$$

where $y = x m_d + (1-x)m_c$ and the error function $Erf(x)$ is defined as $Erf(x) = \frac{2}{\pi} \int_0^x \exp(-t^2)dt$. Using the same constraints as in Eq.(19) and (20), the parameters $A_D^f$ and $b_D^f$ are fixed as $A_D^f = 209$GeV$^{-1}$ and $b_D^{f,2} = 0.540$GeV$^{-2}$.

In this paper we will employ the above three kinds of models to do numerical calculation. All these DA’s of the $D$-meson are plotted in Fig.(1) for a comparison. It can be seen that although they all have a maximum at $x \approx 0.65$, the shape of them are rather different, especial in the region $0 < x < 0.3$ and $0.5 < x < 0.8.
Table 1: Parameter sets for $f_{B_c}$ and $f_B$, $s_{0_c}$ and $s_0$ for $f_{B_c}$ and $f_B$ respectively; $m_b$, $f_{B_c}$ and $f_B$ are given in GeV, $s_{0_c}$ and $s_0$ in GeV².

|        | $m_b$ | $s_{0_c}$ | $f_{B_c}$ | $s_0$  | $f_B$  |
|--------|-------|-----------|-----------|-------|-------|
| set 1  | 4.6   | 43.0      | 0.243     | 30.7  | 0.145 |
| set 2  | 4.7   | 42.0      | 0.189     | 30.2  | 0.117 |
| set 3  | 4.8   | 41.2      | 0.137     | 29.8  | 0.090 |

4 Numerical Results and Discussion

Apart from the DA of the $D$ meson, the decay constant of $B_c$-meson $f_{B_c}$ is among the important nonperturbative inputs. For consistency, we use the following corrector

$$K(q^2) = i \int d^4xe^{iqx} < 0|\bar{c}(x)(1 + \gamma_5)b(x), \bar{b}(0)(1 - \gamma_5)c(0)|0 >,$$  \hspace{1cm} (26)

to recalculate it in the two-point sum rules. The calculation should be limited to leading order in QCD, since the QCD radiative corrections to the sum rule for $f_{B_c \to D}(q^2)$ are not taken into account. The value of the threshold parameter $s_{0_c}$ is determined by a best fit requirement in the region $8\text{GeV}^2 \leq M^2 \leq 12\text{GeV}^2$, where $M^2$ is the corresponding Borel parameter. The same procedure is performed for $f_B$, in almost the same Borel “window”. The results are listed in Tab.1. As we have ignored all the radiation corrections, we don’t expect our values of $f_{B_c}$ and $f_B$ to be good predictions of that quantity. We use the same threshold parameters for the corresponding form factors in the LCSRs, except for the Borel parameter $M_{2LC}$, which is taken as $M_{2LC}^2 \approx M^2/\langle u \rangle$, with $\langle u \rangle$ been the average momentum faraction involved. It turns out that the form factors depend little on $M_{2LC}^2$ in the region $15 < M_{2LC}^2 < 20$. The other input parameters are taken as $m_B = 5.279\text{GeV}$, $m_D = 1.869\text{GeV}$, $m_{B_c} = 6.286\text{GeV}$.

With these inputs, we can carry out the numerical analysis. In particular, we redo the previous calculation for $B \to Dl\bar{\nu}$ in Ref.[9] and show the corresponding form factor $F_{B \to D}(v \cdot v')$ in Fig.(2). The result for the form factor of $B_c \to Dl\bar{\nu}$ is given in Fig.(3). For $F_{B \to D}(v \cdot v')$, similar results can be obtained by applying the various model DA’s at large recoil region $v \cdot v' \approx 1.59$, i.e., $q^2 \approx 0$, but rather different values at the zero recoil point $q^2 = q_{max}^2$. It can be understander easily from the involved region of the DA. While $q^2 = 0$ corresponds to $\Delta_B \approx 0.75$ according to Eq.(15), $q^2 = q_{max}^2$ corresponds to $\Delta_B \approx 0.6$, and the models of the $D$-meson DA in the region $0.5 < x < 0.8$ are rather different. However, the LCSR result at the zero recoil point ($q^2 = q_{max}^2$) is less reliable, we cannot get a final conclusion from the difference of the form factor at this point. Fortunately, the case for $B_c \to Dl\bar{\nu}$ is just opposite, which can be seen from Fig.(3). There is a big difference of the form factor at the point $q^2 = 0$. A detailed comparison for the form factor at this point with other approaches is shown in Tab.2. The big difference between model I and others comes from the different contributions of the DA’s in the involved region $0 < x < 0.45$. Due to the exponential suppression at the
Table 2: Form factor $f_{B_c \to D}(0)$ of $B_c \to Dl\bar{\nu}$ calculated with different kinds of $D$-meson DA’s, in comparison with that of the 3-Points Sum Rule (3PSR) without \cite{7} and with \cite{16} the Coulomb corrections and Potential Model (PM) \cite{16}.

|          | model I | model II | model III | 3PSR \cite{7} | 3PSR \cite{16} | PM \cite{16} |
|----------|---------|---------|-----------|---------------|---------------|--------------|
| $f_{B_c \to D}(0)$ | 0.55    | 0.25    | 0.28      | 0.13 ± 0.05   | 0.32          | 0.29         |

Table 3: Form factor $f_{B_c \to D}(q^2)$ in a three-parameter fit \cite{27}. The three rows correspond to the calculated form factors using different sets of parameters, respectively.

|          | $f(0)$ | $a_f$ | $b_f$ |
|----------|--------|-------|-------|
| set 1    | 0.288  | 3.79  | 4.23  |
| set 2    | 0.283  | 3.92  | 4.47  |
| set 3    | 0.288  | 4.03  | 4.77  |

The calculated form factor for $B_c \to Dl\bar{\nu}$ can be fitted excellently in the calculated region $0 < q^2 < 15\text{GeV}^2$ by the parametrization:

$$f_{B_c \to D}(q^2) = \frac{f(0)}{1 - a_f q^2 / m_{B_c}^2 + b_f (q^2 / m_{B_c}^2)^2}. \quad (27)$$

The values of $f_{B_c \to D}(0)$, $a_f$ and $b_f$ are listed in Table 3.

Extrapolating the form factor to the whole kinetic region $0 < q^2 < (m_{B_c} - m_D)^2 \approx 19.5\text{GeV}^2$ using this parametrization, we get:

$$\Gamma(B_c \to Dl\bar{\nu}) = (0.197 \pm 0.013) \times 10^{-15}\text{GeV}, \quad (28)$$

and

$$BR(B_c \to Dl\bar{\nu}) = (1.35 \pm 0.05) \times 10^{-4}. \quad (29)$$

where $\tau(B_c) = 0.45\text{ps}$ and $V_{ub} = 0.0037$ have been used. The central values are calculated by using the parameters set 2, while the upper and lower bounds are given by using set 3 and set 1 respectively. Our result for the branching ratio is much larger than $BR(B_c \to Dl\bar{\nu}) = 0.4 \times 10^{-4}$ from Ref.\cite{16}, they employed a simple pole approximation to extrapolate the form factor to the whole region. It is also much larger that the PM result $BR(B_c \to Dl\bar{\nu}) = 0.35 \times 10^{-4}$ \cite{17}, and the result $BR(B_c \to Dl\bar{\nu}) = 0.6 \times 10^{-4}$ from Ref.\cite{18}.


Figure 1: Different kinds of $D$-meson DA’s, solid and dashed curves correspond to model III and II, while the dotted line expresses model I.

Figure 2: $\mathcal{F}_{B \to D}$ as a function of the velocity transfer (with the parameters in the set 2). The thin lines express the experiment fits results, the solid line represents the central values, the dashed(dash-dotted) lines give the bounds from the linear(quadratic) fits. The thick lines correspond to our results, with the solid, dashed and dash-dotted lines for model III, II and I respectively.
5 Summary

The $B_c$ meson has been observed by the CDF and D0 groups in the different channels. In this paper we study the weak form factor of the decay process $B_c(B)\rightarrow Dl\bar{\nu}$ by using the chiral current correlator within the framework of the QCD light-cone sum rules, which is similar to the approach for the weak form factor $f_{B\pi}(q^2)$ in Ref.[10]. The calculated form factors depend on the distribution amplitude of the $D$ meson, and we employ the three different models for the $D$ meson. It has been shown that the results using the model with a exponential suppression at the end points are consistent with other approaches. Our results can also confirm the including of the Coulomb corrections in the 3PSR calculations for the semileptonic decay $B_c \rightarrow Dl\bar{\nu}$. In the LCSRs for the form factors of $B_c(B)\rightarrow Dl\bar{\nu}$, the involved region of the $D$ meson distribution amplitude is rather different. Combining the information in the two process, we can find which model is more suitable for describing the $D$ meson.

We have made a parametrization (27) to the form factor by fitting our calculation in the region $0 < q^2 < 15\text{GeV}^2$, and the decay width and the branching ratio of the process $B_c \rightarrow Dl\bar{\nu}$ have been calculated. It has been shown that $\Gamma(B_c \rightarrow Dl\bar{\nu}) = (0.197 \pm 0.013) \times 10^{-15}\text{GeV}$ and $BR(B_c \rightarrow Dl\bar{\nu}) = (1.35 \pm 0.05) \times 10^{-4}$. The results are different from other approaches. It will be expected to test the different predictions in the coming LHC experiments.

References

[1] F. Abe et al. (CDF Collaboration), Phys. Rev. D58, 112004 (1998); ibid., Phys. Rev. Lett. 81, 2432 (1998).
[2] D. Acosta et al. (CDF Collaboration), hep-ex/0505076.
[3] M.D. Corcoran (CDF Collaboration), hep-ex/0506061.
[4] M. Lusignoli, M. Masetti, Z. Phys. C51, 549 (1991).
[5] V.V. Kiselev, Mod. Phys. Lett. A10, 1049 (1995); V.V. Kiselev, Int. J. Mod. Phys. A9, 4987 (1994).
[6] I. Bigi, Phys. Lett. B371, 105 (1996); M.beneke, G.Buchalla, Phys. Rev. D53, 4991 (1996).
[7] P. Colangelo, G. Nardulli, N. Paver, Z.Phys. C57, 43 (1993); E. Bagan et al., Z.Phys. C64, 57 (1994).
[8] V.V. Kiselev, A.K. Likhoded, A.V. Tkabladze, Phys. Atom. Nucl. 56, 643 (1993), Yad. Fiz. 56, 128 (1993); V.V. Kiselev, A.V. Tkabladze, Phys. Rev. D48, 5208 (1993); V.V. Kiselev, A.K. Likhoded, A.I. Onishchenko, Nucl.Phys. B569, 473 (2000).
[9] F. Zuo, Z.H. Li, T. Huang, Phys. Lett. B641, 177 (2006).

[10] T. Huang, Z. H. Li, and X. Y. Wu, Phys. Rev. D63, 094991 (2001).

[11] T. Kurimoto, H. N. Li and A. I. Sanda, Phys. Rev. D67, 054028 (2003).

[12] X. H. Guo and T. Huang, Phys. Rev. D43, 2931 (1991).

[13] S. J. Brodsky, T. Huang and G. P. Lepage, in Particles and Fields-2, Proceedings of the Banff Summer Institute, Banff, Alberta, 1981, edited by A. Z. Capri and A. N. Kamal (Plenum, New York, 1983), P143; G. P. Lepage, S. J. Brodsky, T. Huang, and P. B. Mackenzie, ibid., p83; T. Huang, in Proceedings of XXth International Conference on High Energy Physics, Madison, Wisconsin, 1980, edited by L. Durand and L. G. Pondrom, AIP Conf. Proc. No. 69 (AIP, New York, 1981), p1000.

[14] T. Huang, B. Q. Ma, and Q. X. Shen, Phys. Rev. D49, 1490 (1994).

[15] N. Isgur and M. B. Wise, Phys. Lett. B232, 113 (1989); ibid. 237, 527 (1989).

[16] V.V. Kiselev, hep-ph/0211021.

[17] M.A.Ivanov, J.G. Körner, P. Santorelli, Phys. Rev. D73, 054024 (2006).

[18] C.H. Chang and Y.Q. Chen, Phys. Rev. D49, 3399 (1994).
Figure 3: $f_{B_c \rightarrow D}(q^2)$ calculated by using different kinds of DA models. The solid, dashed and dash-dotted lines correspond to Model III, II and I respectively. Here the threshold parameter set 2 has been used.