PHYSICAL REVIEW D **79**, 034004 (2009)

B_c meson form factors and $B_c \to PV$ decays involving flavor dependence of transverse quark momentum

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(Received 6 October 2008; published 6 February 2009)

We present a detailed analysis of the B_c form factors in the Bauer-Stech-Wirbel framework, by investigating the effects of the flavor dependence on the average transverse quark momentum inside a meson. Branching ratios of two-body decays of B_c mesons to pseudoscalar and vector mesons are predicted.

DOI: 10.1103/PhysRevD.79.034004 PACS numbers: 13.25.Hw, 12.39.Ki

I. INTRODUCTION

The discovery of the B_c meson by the collider detector at Fermilab (CDF) [1] opens up some interesting investigations concerning the structure of strong and weak interactions. The properties of the B_c meson are of special interest [2], since it is the only heavy meson consisting of two heavy quarks with different flavors. This difference of quarks flavor forbids annihilation into gluons. A peculiarity of the B_c decays, with respect to the decays of the B and B_s mesons, is that both the quarks may be involved in their weak decay. There are quite a few theoretical works studying various leptonic, semileptonic, and hadronic decay channels of B_c mesons in different models [3–14]. Their estimates of B_c decay rates indicate that the c quarks give a dominant contribution as compared to b-quark decays. From an experimental point of view, the study of weak decays of B_c mesons is quite important for the determination of Cabibbo-Kobayashi-Maskawa (CKM) elements. More detailed information about their decay properties are expected in the near future at the LHC and in other experiments.

In our recent work [14], we have investigated the effects of flavor dependence on $B_c \to P$ form factors, caused by possible variation of the average transverse quark momentum (ω) in a meson. Employing the Bauer-Stech-Wirbel (BSW) framework [15], we then predicted the branching ratios of a B_c meson decaying into two pseudoscalar mesons. In the present paper, we extend our analysis to investigate such effects on the form factors involving $B_c \to V$ transitions. We also calculate the branching ratios of a B_c meson decaying into a pseudoscalar (P) meson and a vector (V) meson. We observe that the branching ratios of B_c decays get enhanced for both the bottom changing and bottom conserving decay modes of the B_c meson, when such flavor dependent effects are included.

The present paper is organized as follows: In Sec. II, we give the methodology. Section III deals with B_c form factors in the BSW model. We study the effects of the flavor dependence of ω on $B_c \to V$ form factors in Sec. IV. Finally, the branching ratios of $B_c \to PV$ decays are predicted. Section V contains a summary and conclusions.

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II. METHODOLOGY

The decay rate is given by

$$\Gamma(B_c \to PV) = \frac{k^3}{8\pi m_V^2}|A(B_c \to PV)|^2, \tag{1}$$

where in the three-momentum k of the final state particle in the rest frame of B_c is given by

$$k = \frac{1}{2m_{B_c}}\{[m_{B_c}^2 - (m_P + m_V)^2][m_{B_c}^2 - (m_P - m_V)^2]\}^{1/2}. \tag{2}$$

A. Weak Hamiltonian

The QCD modified weak Hamiltonian generating [16] the b-quark decays in CKM enhanced modes ($\Delta b = 1$, $\Delta C = 1$, $\Delta S = 0$; $\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$) is given by

$$H_w^{\Delta b=1} = \frac{G_F}{\sqrt{2}}\{V_{cb}V_{ud}^*[c_1(\mu)(\bar{c}b)(\bar{d}u) + c_2(\mu)(\bar{c}u)(\bar{d}b)] + V_{cb}V_{cs}^*[c_1(\mu)(\bar{c}b)(\bar{s}c) + c_2(\mu)(\bar{c}c)(\bar{s}b)]\}, \tag{3}$$

where $\bar{q}q \equiv \bar{q}\gamma_\mu(1-\gamma_5)q$, G_F is the Fermi constant, V_{ij} are the CKM matrix elements, and c_1 and c_2 are the standard perturbative QCD coefficients.

In addition to the bottom changing decays, the bottom conserving decay channel is also available for the B_c meson, where the charm quark decays to an s or a d quark. The weak Hamiltonian generating the c-quark decays in the CKM enhanced mode ($\Delta b = 0$, $\Delta C = -1$, $\Delta S = -1$) is given by

$$H_w^{\Delta c=-1} = \frac{G_F}{\sqrt{2}}V_{ud}V_{cs}^*[c_1(\mu)(\bar{u}d)(\bar{s}c) + c_2(\mu)(\bar{u}c)(\bar{s}d)]. \tag{4}$$

One naively expects this channel to be suppressed kinematically due to the small phase space available. However, the kinematic suppression is well compensated by the

CKM element V_{cs}, which is larger than V_{cb} appearing in the bottom changing decays [13]. In fact, we shall show later that bottom conserving decay modes are more prominent than the bottom changing ones.

B. Factorization scheme

In the standard factorization scheme, the decay amplitude is obtained by sandwiching the QCD modified weak Hamiltonian which is given below:

$$A(B_c \to PV) \propto \langle P|J^\mu|0\rangle\langle V|J^\dagger_\mu|B_c\rangle + \langle V|J^\mu|0\rangle\langle P|J^\dagger_\mu|B_c\rangle, \tag{5}$$

where the weak current J_μ is given by

$$J_\mu = (\bar{u}\,\bar{c}\,\bar{t})\gamma_\mu(1-\gamma_5)\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}, \tag{6}$$

and d', s', b' are a mixture of the d, s, and b quarks, as given by the CKM matrix [17].

Matrix elements of the currents are defined [15] as

$$\begin{aligned}\langle V|J_\mu|B_c\rangle = {}& \frac{2}{m_{B_c}+m_V}\varepsilon_{\mu\nu\rho\sigma}\varepsilon^{*\nu}P^\rho_{B_c}P^\sigma_V V(q^2) \\ &+ i\left\{\varepsilon^*_\mu(m_{B_c}+m_V)A_1(q^2) - \frac{\varepsilon^*\cdot q}{m_{B_c}+m_V}\right. \\ &\left.\times(P_{B_c}+P_V)_\mu A_2(q^2) - \frac{\varepsilon^*\cdot q}{q^2}2m_V q_\mu A_3(q^2)\right\} \\ &+ i\frac{\varepsilon^*\cdot q}{q^2}2m_V q_\mu A_0(q^2),\end{aligned} \tag{7}$$

$$\begin{aligned}\langle P|J_\mu|B_c\rangle = {}& \left(P_{B_c}+P_P-\frac{m^2_{B_c}-m^2_P}{q^2}q\right)_\mu F_1(q^2) \\ &+ \frac{m^2_{B_c}-m^2_P}{q^2}q_\mu F_0(q^2),\end{aligned} \tag{8}$$

$$\langle P|J_\mu|0\rangle = -if_P P_\mu, \tag{9}$$

$$\langle V|J_\mu|0\rangle = \epsilon^*_\mu f_V m_V, \tag{10}$$

where ε_μ denotes the polarization vector of the outgoing vector meson, $q_\mu = (P_{B_c} - P_P)_\mu$, $F_1(0) = F_0(0)$, $A_3(0) = A_0(0)$, and

$$A_3(q^2) = \frac{m_{B_c}+m_V}{2m_V}A_1(q^2) - \frac{m_{B_c}-m_V}{2m_V}A_2(q^2). \tag{11}$$

There are three types of B_c decays:

(i) those caused by a color-favored diagram,
(ii) those caused by a color-suppressed diagram, and
(iii) those caused by both color-favored and color-suppressed diagrams.

In general, the color-favored decay amplitude $A(B_c \to PV)$ can be expressed as

$$\begin{aligned}A(B_c \to PV) = {}& \frac{G_F}{\sqrt{2}}\times(\text{CKM factors}) \\ &\times 2m_V a_1\{(\text{C.G. coeff.})f_V F_1^{B_cP}(m_V^2) \\ &+ (\text{C.G. coeff.})f_P A_0^{B_cV}(m_P^2)\},\end{aligned} \tag{12}$$

where [15] $a_1(\mu) = c_1(\mu) + \frac{1}{N_c}c_2(\mu)$, and N_c is the number of colors. For the color-suppressed modes, the QCD factor a_1 is replaced by a_2 which is given as $a_2(\mu) = c_2(\mu) + \frac{1}{N_c}c_1(\mu)$. However, we follow the convention of the large N_c limit to fix the QCD coefficients $a_1 \approx c_1$ and $a_2 \approx c_2$, where [16]

$$\begin{aligned} c_1(\mu) &= 1.26, \qquad c_2(\mu) = -0.51 \quad \text{at } \mu \approx m_c^2, \\ c_1(\mu) &= 1.12, \qquad c_2(\mu) = -0.26 \quad \text{at } \mu \approx m_b^2. \end{aligned} \tag{13}$$

To evaluate the factorization amplitudes (9) and (10), we use the following decay constants [5,8,17]:

$$\begin{aligned} f_\pi &= 0.131\text{ GeV}, \qquad f_K = 0.160\text{ GeV}, \\ f_D &= 0.208\text{ GeV}, \qquad f_{D_s} = 0.273\text{ GeV}, \\ f_{\eta_c} &= 0.400\text{ GeV}, \end{aligned}$$

and

$$\begin{aligned} f_\rho &= 0.221\text{ GeV}, \qquad f_{K*} = 0.220\text{ GeV}, \\ f_{D*} &= 0.245\text{ GeV}, \qquad f_{D*_s} = 0.273\text{ GeV}, \\ f_{J/\psi} &= 0.411\text{ GeV}. \end{aligned} \tag{14}$$

It has been pointed out in the BSW2 model [18] that consistency with the heavy quark symmetry requires certain form factors such as F_1 and A_0 to have dipole q^2 dependence, i.e.

$$\begin{aligned} F_1(q^2) &= F_1(0)/(1-q^2/m_V^2)^2 \quad \text{and} \\ A_0(q^2) &= A_0(0)/(1-q^2/m_P^2)^2. \end{aligned}$$

Therefore, in this work we have determined the amplitudes using the dipole q^2 dependence for these form factors.

III. FORM FACTORS IN THE BSW MODEL

We employ the BSW model for evaluating the meson form factors. In this model, the initial and final state mesons are given by the relativistic bound states of a quark q_1 and an antiquark in the infinite momentum frame [15],

$$\begin{aligned}|\mathbf{P}, m, j, j_Z\rangle = {}& \sqrt{2}(2\pi)^{3/2}\sum_{S_1S_2}\int d^3p_1 d^3p_2\delta^3(\mathbf{P}-\mathbf{p_1}-\mathbf{p}_2) \\ &\times \psi_m^{j,j_Z}(\mathbf{p_{1T}}, x, s_1, s_2)a_1^{S_1^+}(\mathbf{p_1})b_2^{S_2^+}(\mathbf{p_2})|0\rangle,\end{aligned} \tag{15}$$

where $P_\mu = (P_0, 0, 0, P)$ with $P \to \infty$, x denotes the fraction of the longitudinal momentum carried by the nonspectator quark q_1, and $\mathbf{p_{1T}}$ denotes its transverse

TABLE I. Form factors of the $B_c \to P$ transition (errors shown here are due to uncertainty in $m_{B_c^*} - m_{B_c}$).

Modes	Transition	This work $F_1^{B_cP}(0)$ ($\omega = 0.40$ GeV)	$F_1^{B_cP}(0)$ (using flavor dependent ω)
$\Delta b = 0$, $\Delta C = -1$, $\Delta S = -1$	$B_c \to B_s$	0.35	$0.55^{+0.02}_{-0.02}$
	$B_c \to B$	0.28	$0.41^{+0.01}_{-0.02}$
$\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$	$B_c \to D$	0.015	$0.075^{+0.06}_{-0.08}$
	$B_c \to D_s$	0.021	$0.15^{+0.01}_{-0.01}$
$\Delta b = 1$, $\Delta C = 1$, $\Delta S = 0$	$B_c \to \eta_c(c\bar{c})$	0.19	$0.58^{+0.02}_{-0.01}$

momentum:

$$x = p_{1Z}/P, \qquad \mathbf{p_{1T}} = (p_{1x}, p_{1y}).$$

Though $B_c \to PV$ decays involve $F_1(q^2)$ and $A_0(q^2)$ only, we calculate all the form factors appearing in the expressions (7) and (8) so that we can later investigate their flavor dependence.

By expressing the current J_μ in terms of the annihilation and creation operators, the form factors are given by the following integrals:

$$\begin{aligned} F_0^{B_cP}(0) &= F_1^{B_cP}(0) \\ &= \int d^2p_T \int_0^1 (\Psi_P^*(\mathbf{p_T}, x)\Psi_{B_C}(\mathbf{p_T}, x))dx, \\ A_0^{B_cV}(0) &= A_3^{B_cV}(0) \\ &= \int d^2\mathbf{p_T} \int_0^1 dx(\Psi_V^{*1,0}(\mathbf{p_T}, x)\sigma_Z^{(1)}\Psi_{B_c}(\mathbf{p_T}, x)), \end{aligned} \tag{16}$$

$$V(0) = \frac{m_{q_1(B_c)} - m_{q_1(V)}}{m_{B_c} - m_V} I, \tag{17}$$

and

$$A_1(0) = \frac{m_{q_1(B_c)} + m_{q_1(V)}}{m_{B_c} + m_V} I, \tag{18}$$

where

$$I = \sqrt{2}\int d^2\mathbf{p_T} \int_0^1 \frac{dx}{x} (\Psi_V^{*1,-1}(\mathbf{p_T}, x) i\sigma_y^{(1)}\Psi_{B_c}(\mathbf{p_T}, x)), \tag{19}$$

and $m_{q_1(B_c)}$ and $m_{q_1(V)}$ denote masses of the nonspectator quarks participating in the quark decay process. The meson wave function is given by

$$\Psi_m(\mathbf{p_T}, x) = N_m\sqrt{x(1-x)}\exp(-\mathbf{p_T^2}/2\omega^2) \times \exp\left(-\frac{m^2}{2\omega^2}\left(x - \frac{1}{2} - \frac{m_{q_1}^2 - m_{q_2}^2}{2m^2}\right)^2\right), \tag{20}$$

where m denotes the meson mass, m_i denotes the ith quark mass, N_m is the normalization factor, and ω is the average transverse quark momentum, $\langle \mathbf{p_T^2} \rangle = \omega^2$.

The form factors are sensitive to the choice of ω, which is treated as a free parameter. In the BSW model [15], the form factors are calculated by taking $\omega = 0.40$ GeV for all the mesons, and $m_u = m_d = 0.35$ GeV, $m_s = 0.55$ GeV, $m_c = 1.7$ GeV, and $m_b = 4.9$ GeV. The $B_c \to P$ form factors thus obtained are given in column 3 of Table I, and $B_c \to V$ form factors are given in Table II. Using these form factors, we obtain the branching ratios for various B_c decays, with $\tau_{Bc} = 0.46$ ps as given in column 2 of Table III. We make the following observations:

(1) Naively, one may expect the bottom conserving modes to be kinematically suppressed. However, the large CKM mixing angle for bottom conserving modes overcomes this suppression. We find that the bottom conserving and charm changing modes are dominant: $B(B_c^+ \to \pi^+ B_s^{*0}) = 1.91\%$, $B(B_c^+ \to B_s^0\rho^+) = 2.75\%$, $B(B_c^+ \to B^+\bar{K}^{*0}) = 0.38\%$, and $B(B_c^+ \to \bar{K}^0 B^{*+}) = 0.38\%$. Among the bottom changing decays, $B(B_c^- \to \eta_c D_s^{*-}) = 0.04\%$, $B(B_c^- \to D_s^- J/\psi) = 0.03\%$, and $B(B_c^- \to \eta_c\rho^-) = 0.04\%$ modes dominate, but are small compared to the bottom conserving modes.

(2) Because there is less overlap of the initial and final state wave functions for $\omega = 0.40$ GeV, as shown in Fig. 1, bottom changing modes are further suppressed due to the small values of the corresponding form factors.

TABLE II. Form factors of the $B_c \to V$ transition ($\omega = 0.40$ GeV).

Modes	Transition	$V(0)$	$A_0(0)$	$A_1(0)$	$A_2(0)$
$\Delta b = 0$, $\Delta C = -1$, $\Delta S = -1$	$B_c \to B_s^*$	2.45	0.37	0.40	0.68
	$B_c \to B^*$	2.23	0.31	0.31	0.35
$\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$	$B_c \to D^*$	0.025	0.016	0.015	0.013
	$B_c \to D_s^*$	0.032	0.022	0.020	0.019
$\Delta b = 1$, $\Delta C = 1$, $\Delta S = 0$	$B_c \to J/\psi(c\bar{c})$	0.24	0.17	0.17	0.17

TABLE III. Branching ratios (in $\frac{\tau_{B_c}(\text{ps})}{0.46}\%$) of $B_c \to PV$ decays (errors shown here are due to uncertainty in $m_{B_c^*} - m_{B_c}$).

Decays	This work: Branching ratio (%) ($\omega = 0.40$ GeV)	This work: Branching ratio (%) (using flavor dependent ω)	[4]	[5]	[6]	[7]	[8]	[9]
$\Delta b = 0$, $\Delta C = -1$, $\Delta S = -1$								
$B_c^+ \to \pi^+ B_s^{*0}$	1.91	$4.37^{+0.37}_{-0.33}$	7.33	1.78	3.95	5.73	2.37	1.39
$B_c^+ \to B_s^0 \rho^+$	2.75	$7.00^{+0.60}_{-0.50}$	8.10	1.55	12.22	4.97	2.60	4.35
$B_c^+ \to B^+ \bar{K}^{*0}$	0.38	$0.72^{+0.15}_{-0.00}$	1.14	0.23	$\cdots$	1.24	0.29	0.85
$B_c^+ \to \bar{K}^0 B^{*+}$	0.38	$0.80^{+0.00}_{-0.14}$	4.23	0.28	$\cdots$	1.33	0.23	0.44
$\Delta b = 1$, $\Delta C = 1$, $\Delta S = 0$								
$B_c^- \to D^0 D^{*-}$	2.69×10^{-5}	$6.57^{+1.21}_{-1.26} \times 10^{-4}$	8.50×10^{-3}	$\cdots$	6.89×10^{-3}	3.1×10^{-3}	1.50×10^{-3}	1.36×10^{-3}
$B_c^- \to D^- D^{*0}$	3.53×10^{-5}	$8.34^{+1.52}_{-1.56} \times 10^{-4}$	0.01	$\cdots$	6.14×10^{-4}	3.3×10^{-3}	6.60×10^{-3}	3.60×10^{-3}
$B_c^- \to \eta_c \rho^-$	0.04	$0.39^{+0.01}_{-0.03}$	0.41	0.20	0.07	0.48	0.43	0.33
$B_c^- \to \pi^- J/\psi$	0.01	$0.13^{+0.01}_{-0.01}$	0.13	0.06	0.13	0.17	0.17	0.11
$\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$								
$B_c^- \to \eta_c D_s^{*-}$	0.04	$0.31^{+0.01}_{-0.01}$	0.22	$\cdots$	0.48	0.03	0.33	0.20
$B_c^- \to D_s^- J/\psi$	0.03	$0.28^{+0.01}_{-0.01}$	0.13	$\cdots$	0.33	0.03	0.31	0.13

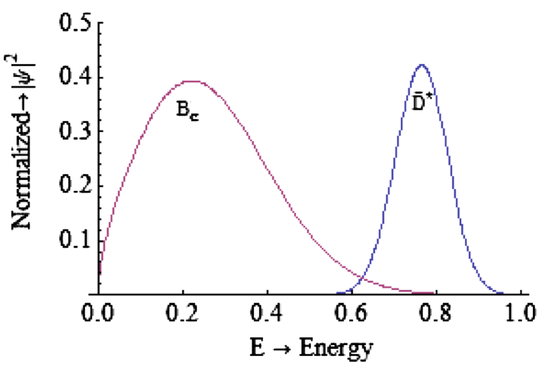

FIG. 1 (color online). Overlap of wave functions for $B_c \to \bar{D}^*$ decays at $\omega_{B_c} = \omega_{D*} = 0.40$ GeV.

(3) Besides $B_c^- \to \eta_c D_s^{*-}$ and $B_c^- \to D_s^- J/\psi$ decays, various decays such as $B_c^- \to K^- \bar{D}^{*0}$, $B_c^- \to \eta' D_s^{*-}$, $B_c^- \to \bar{D}^0 K^{*-}$, $B_c^- \to D_s^- \rho^0$, $B_c^- \to D_s^- \omega$, $B_c^- \to D_s^- \phi$, $B_c^- \to \pi^0 D_s^{*-}$, and $B_c^- \to \eta D_s^{*-}$ are also permitted by the selection rule $\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$. However, their branching ratios are heavily suppressed as they occur through the CKM suppressed weak process involving $b \to u$ transitions.

IV. EFFECTS OF FLAVOR DEPENDENCE ON $B_c \to V/P$ FORM FACTORS

In the previous work [14], we have investigated the possible flavor dependence in $B_c \to P$ form factors and consequently in $B_c \to PP$ decay widths. We wish to point out that the parameter ω, which is a dimensional quantity, may show flavor dependence. Therefore, it may not be justified to take the same ω for all the mesons. Following the analysis described in [14], we estimate ω for different mesons from $|\Psi(0)|^2$, i.e. the square of the wave function at the origin, using the following relation based on the dimensionality arguments:

$$|\Psi(0)|^2 \propto \omega^3. \tag{21}$$

$|\Psi(0)|^2$ is obtained from the hyperfine splitting term for the meson masses [19],

$$|\Psi(0)|^2 = \frac{9m_i m_j}{32\alpha_s \pi}(m_V - m_P), \tag{22}$$

where m_V and m_P, respectively, denote the masses of vector and pseudoscalar mesons composed of i and j quarks. The meson masses fix quark masses (in GeV) to be $m_u = m_d = 0.31$, $m_s = 0.49$, $m_c = 1.7$, and $m_b = 5.0$ for $\alpha_s(m_b) = 0.19$, $\alpha_s(m_c) = 0.25$, and $\alpha_s = 0.48$ (for light flavors u, d, and s).

Except for B_c^*, all the meson masses required are available experimentally. Theoretical estimates for the hyperfine splitting $m_{B_c^*} - m_{B_c}$ obtained in different quark models [20,21] range from 65 to 90 MeV. For the present work, we take $m_{B_c^*} - m_{B_c} = 73 \pm 15$ MeV obtained in [20], which has been quite successful in giving charmonium and bottomonium mass spectra. Calculated numerical values of $|\Psi(0)|^2$ are listed in column 2 of Table V. Variation in ω_{B_c} with hyperfine splitting $m_{B_c^*} - m_{B_c}$ is shown in Fig. 2. We use the well-measured form factor [22] $F_0^{DK}(0) = 0.78 \pm 0.04$ to determine $\omega_D = 0.43$ GeV, which in turn yields ω for other mesons given in column 3 of Table II. The form factors obtained for $B_c \to P$ transitions are given in column 4 of Table I, and for $B_c \to V$ transitions are given in Table IV. We find that all the form factors get significantly enhanced due to the large overlap of B_c and the final state meson as shown in Fig. 3. In Figs. 4 and 5, we show the dependence of various $B_c \to B^*$ and $B_c \to D*$ form factors on ω_{B_c} and ω_F in the range 0 to 1, where ω_F is for the final state meson.

TABLE IV. Form factors of the $B_c \to V$ transition using flavor dependent ω (errors shown here are due to uncertainty in $m_{B_c^*} - m_{B_c}$).

Modes	Transition	$V(0)$	$A_0(0)$	$A_1(0)$	$A_2(0)$
$\Delta b = 0$, $\Delta C = -1$, $\Delta S = -1$	$B_c \to B_s^*$	$5.19^{+0.08}_{-0.11}$	$0.57^{+0.02}_{-0.03}$	$0.79^{+0.01}_{-0.02}$	$3.24^{+0.04}_{-0.09}$
	$B_c \to B^*$	$4.77^{+0.07}_{-0.10}$	$0.42^{+0.02}_{-0.02}$	$0.63^{+0.01}_{-0.01}$	$2.74^{+0.04}_{-0.07}$
$\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$	$B_c \to D^*$	$0.16^{+0.02}_{-0.02}$	$0.081^{+0.07}_{-0.08}$	$0.095^{+0.013}_{-0.015}$	$0.11^{+0.01}_{-0.02}$
	$B_c \to D_s^*$	$0.29^{+0.02}_{-0.03}$	$0.16^{+0.01}_{-0.01}$	$0.18^{+0.01}_{-0.02}$	$0.20^{+0.02}_{-0.03}$
$\Delta b = 1$, $\Delta C = 1$, $\Delta S = 0$	$B_c \to J/\psi(c\bar{c})$	$0.91^{+0.04}_{-0.05}$	$0.58^{+0.01}_{-0.03}$	$0.63^{+0.03}_{-0.03}$	$0.74^{+0.05}_{-0.06}$

A. Numerical branching ratios

Using the flavor dependent form factors, we finally predict the branching ratios, which are given in column 3 of Table III. We observe the following:

(1) The branching ratios get enhanced significantly for both bottom changing and for bottom conserving modes. However, the bottom conserving and charm changing modes still remain dominant with $B(B_c^+ \to \pi^+ B_s^{*0}) = 4.37^{+0.37}_{-0.33}\%$, $B(B_c^+ \to B_s^0 \rho^+) = 7.00^{+0.60}_{-0.50}\%$, $B(B_c^+ \to \bar{K}^0 B^{*+}) = 0.80^{+0.00}_{-0.14}\%$, and $B(B_c^+ \to B^+ \bar{K}^{*0}) = 0.72^{+0.15}_{-0.00}\%$.

(2) Among the bottom changing modes, higher branching ratios are $B(B_c^- \to D_s^- J/\psi) = 0.28^{+0.01}_{-0.01}\%$, $B(B_c^- \to \eta_c D_s^{*-}) = 0.31^{+0.01}_{-0.01}\%$, $B(B_c^- \to \pi^- J/\psi) = 0.13^{+0.01}_{-0.01}\%$, and $B(B_c^- \to \eta_c \rho^-) = 0.39^{+0.01}_{-0.03}\%$. For the sake of comparison, we list results of other models in Table III for branching ratios of B_c mesons.

(3) It may be noted that the decay widths of $B_c^- \to \eta_c D_s^{*-}$ and $B_c^- \to D_s^- J/\psi$ involve contributions from both the color-favored and the color-suppressed diagrams. In B meson decays, the experimental data favor constructive interference [16], in contrast to the charm meson sector, between the color-favored and color-suppressed diagrams, thereby yielding $a_1 = 1.10 \pm 0.08$ and $a_2 = 0.20 \pm 0.02$. Taking $a_1 = 1.10$ and $a_2 = 0.20$ for the constructive interference case, we obtain larger values, $B(B_c^- \to D_s^- J/\psi) = 0.49^{+0.02}_{-0.03}\%$ and $B(B_c^- \to \eta_c D_s^{*-}) = 0.51^{+0.03}_{-0.03}\%$ in comparison to $0.28^{+0.01}_{-0.01}\%$ and $0.31^{+0.01}_{-0.01}\%$, respectively, which were obtained for the destructive interference.

TABLE V. $|\Psi(0)|^2$ and ω for vector and pseudoscalar mesons (errors shown here are due to uncertainty in $m_{B_c^*} - m_{B_c}$).

Meson	$|\Psi(0)|^2$ (in GeV^3)	Parameter ω (in GeV)
$\rho(\pi)$	0.011	0.33
$K^*(K)$	0.011	0.33
$D^*(D)$	0.026	0.43
$D_s^*(D_s)$	0.041	0.51
$J/\psi(\eta_c)$	0.115	0.71
$B^*(B)$	0.033	0.47
$B_s^*(B_s)$	0.053	0.55
B_c	$0.281^{+0.077}_{-0.060}$	$0.96^{+0.08}_{-0.07}$

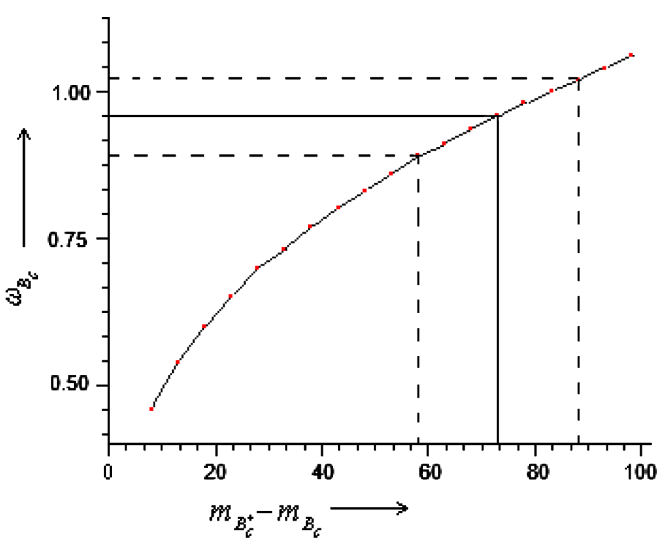

FIG. 2 (color online). Variation in ω_{B_c} with hyperfine splitting $m_{B_c^*} - m_{B_c}$.

V. SUMMARY AND CONCLUSIONS

In this paper, we have employed the BSW relativistic quark model to study the hadronic weak decays of a B_c meson decaying into a pseudoscalar and a vector meson in the CKM enhanced mode. We have also investigated the flavor dependence of ω and, hence, consequently, of the form factors and the branching ratios for bottom changing

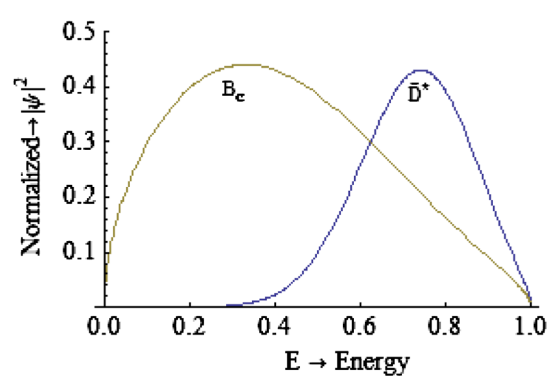

FIG. 3 (color online). Overlap of wave functions for $B_c \to \bar{D}^*$ decays at $\omega_{B_c} = 0.96$ GeV and $\omega_{D*} = 0.43$ GeV.

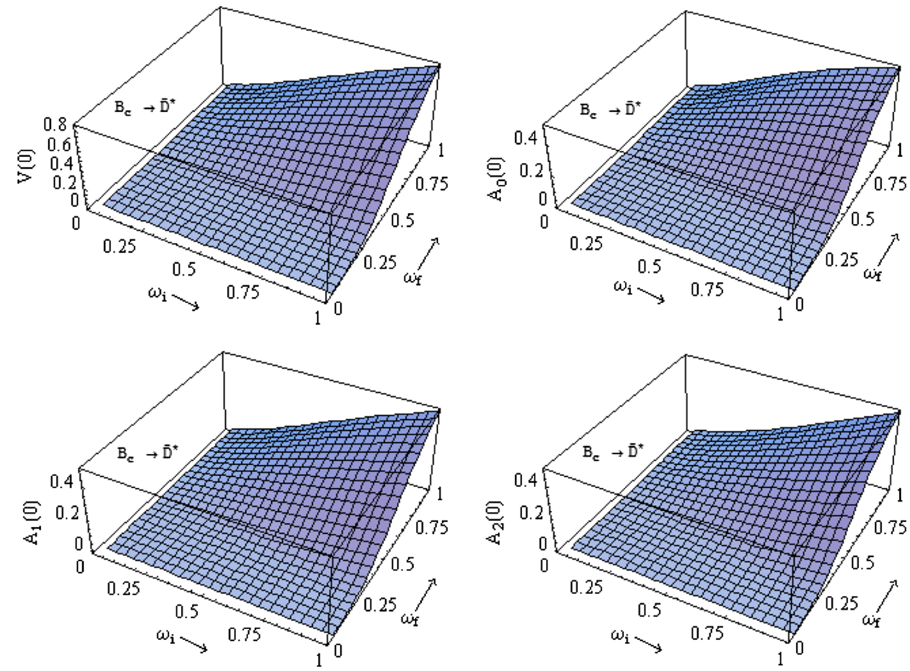

FIG. 4 (color online). Variation of $B_c \to \bar{D}^*$ form factors $V(0)$, $A_0(0)$, $A_1(0)$, and $A_2(0)$ with ω's for initial and final state mesons.

as well as bottom conserving decay modes. We draw the following conclusions.

(1) One naively expects the bottom conserving modes to be kinematically suppressed; however, the large CKM angle involved overly compensates the suppression. Because there is less overlap of the initial and final state wave functions, the form factors involving the bottom changing transitions are small compared to those of the bottom conserving transitions. As a result, bottom changing decays get suppressed in comparison to bottom conserving decays.

(2) Initially, form factors for both the modes are obtained by taking the usual value of $\omega = 0.40$ GeV for all the mesons. For bottom conserving and charm changing modes, their form factors yield $B(B_c^+ \to \pi^+ B_s^{*0}) = 1.91\%$, $B(B_c^+ \to B_s^0 \rho^+) = 2.75\%$,

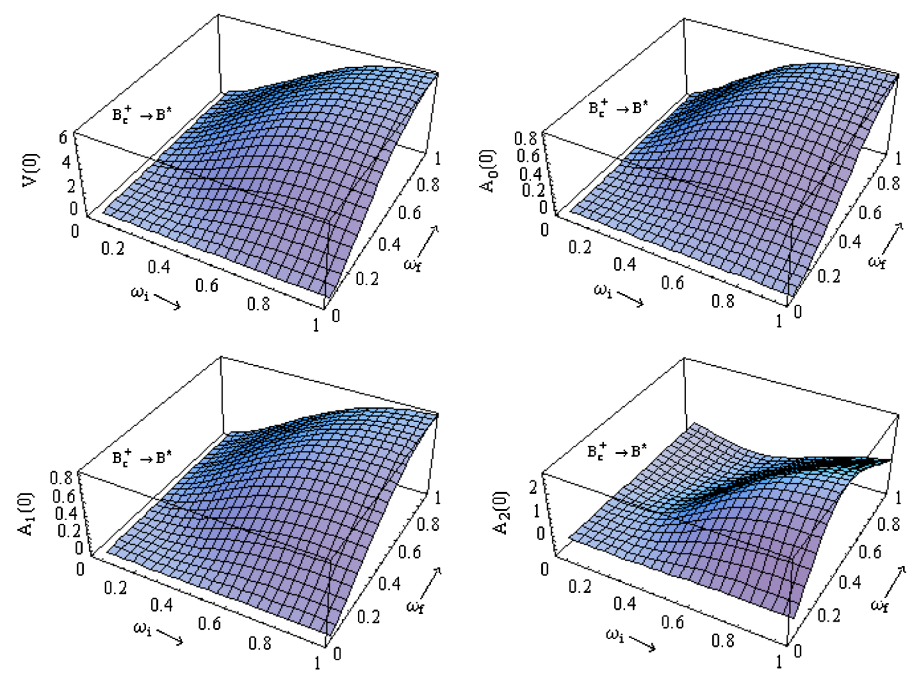

FIG. 5 (color online). Variation of $B_c \to B^*$ form factors $V(0)$, $A_0(0)$, $A_1(0)$, and $A_2(0)$ with ω's for initial and final state mesons.

$B(B_c^+ \to B^+ \bar{K}^{*0}) = 0.38\%$, and $B(B_c^+ \to \bar{K}^0 B^{*+}) = 0.38\%$. Among the bottom changing decays, the dominant branching ratios are $B(B_c^- \to D_s^- J/\psi) = 0.03\%$, $B(B_c^- \to \eta_c D_s^{*-}) = 0.04\%$, and $B(B_c^- \to \eta_c \rho^-) = 0.04\%$.

(3) We then investigate the effects of the possible flavor dependence of ω. Determining $|\Psi(0)|^2$ from the meson masses to fix ω for each meson, we calculate various form factors for B_c transitions which get significantly enhanced for bottom changing as well as for bottom conserving transitions. However, bottom conserving decays remain dominant with higher branching ratios: $B(B_c^+ \to \pi^+ B_s^{*0}) = 4.37^{+0.37}_{-0.33}\%$, $B(B_c^+ \to B_s^0 \rho^+) = 7.00^{+0.60}_{-0.50}\%$, $B(B_c^+ \to \bar{K}^0 B^{*+}) = 0.80^{+0.00}_{-0.14}\%$, and $B(B_c^+ \to B^+ \bar{K}^{*0}) = 0.72^{+0.15}_{-0.00}\%$, while branching ratios of bottom changing modes are also increased to $B(B_c^- \to D_s^- J/\psi) = 0.28^{+0.01}_{-0.01}\%$, $B(B_c^- \to \eta_c D_s^{*-}) = 0.31^{+0.01}_{-0.01}\%$, $B(B_c^- \to \pi^- J/\psi) = 0.13^{+0.01}_{-0.01}\%$, and $B(B_c^- \to \eta_c \rho^-) = 0.39^{+0.01}_{-0.03}\%$. Errors in the predictions are due to the uncertainty in the theoretical estimate of the hyperfine splitting $m_{B_c^*} - m_{B_c} = 73 \pm 15$ MeV.

(4) Taking into account the constructive interference observed for B meson decays involving both the color-favored and color-suppressed diagrams [15], we find that $B(B_c^- \to D_s^- J/\psi)$ and $B(B_c^- \to \eta_c D_s^{*-})$ get further enhanced to $0.49^{+0.02}_{-0.03}\%$ and $0.51^{+0.03}_{-0.03}\%$, respectively. From the experimental point of view, measurements of these branching ratios present an interesting test for the interference between color-favored and color-suppressed processes in B_c meson decays.

[1] F. Abe *et al.* (CDF Collaboration), Phys. Rev. Lett. **81**, 2432 (1998); Phys. Rev. D **58**, 112004 (1998); P. Ball *et al.*, Report No. CERN-TH/2000-101.
[2] M. D. Corcoran (CDF Collaboration), arXiv:hep-ex/0506061v1; A. Abulencia *et al.*, Phys. Rev. Lett. **96**, 082002 (2006).
[3] S. S. Gershtein *et al.*, Usp. Fiz. Nauk **165**, 3 (1995) [Phys. Usp. **38**, 1 (1995)]; N. Brambilla *et al.*, CERN Yellow Report No. CERN-2005-005, 2005, p. 487.
[4] W. Wang, Y. L. Shen, and C. D. Lü, Eur. Phys. J. C **51**, 841 (2007).
[5] E. Hernánder *et al.*, Phys. Rev. D **74**, 074008 (2006); J. F. Sun *et al.*, Phys. Rev. D **77**, 074013 (2008); **77**, 114004 (2008); arXiv:0808.3619v2.
[6] V. V. Kiselev *et al.*, Nucl. Phys. **B585**, 353 (2000); J. Phys. G **28**, 595 (2002); arXiv:hep-ph/0211021v2.
[7] D. Ebert *et al.*, Eur. Phys. J. C **32**, 29 (2003); Phys. Rev. D **68**, 094020 (2003);
[8] P. Colangelo and F. De Fazio, Phys. Rev. D **61**, 034012 (2000).
[9] C. H. Chang and Y. Q. Chen, Phys. Rev. D **49**, 3399 (1994).
[10] M. A. Ivanov *et al.*, Phys. Lett. B **555**, 189 (2003); Phys. Rev. D **73**, 054024 (2006); Report No. DSF-2006-27-NAPOLI.
[11] A. Abd El-Hady *et al.*, Phys. Rev. D **59**, 094001 (1999); Phys. Rev. D **62**, 014019 (2000); T. Mannel and S. Wolf, Phys. Rev. D **65**, 074012 (2002).
[12] M. T. Choi and J. K. Kim, Phys. Rev. D **53**, 6670 (1996); M. A. Nobes and R. M. Woloshyn, J. Phys. G **26**, 1079 (2000).
[13] R. C. Verma and A. Sharma, Phys. Rev. D **65**, 114007 (2002).
[14] R. Dhir, N. Sharma, and R. C. Verma, J. Phys. G **35**, 085002 (2008).
[15] M. Wirbel, B. Stech, and M. Bauer, Z. Phys. C **29**, 637 (1985); M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C **34**, 103 (1987); M. Wirbel, Prog. Part. Nucl. Phys. **21**, 33 (1988).
[16] T. E. Browder and K. Honscheid, Prog. Part. Nucl. Phys. **35**, 81 (1995); M. Neubert, V. Rieckert, B. Stech, and Q. P. Xu, in *Heavy Flavours*, edited by A. J. Buras and H. Lindner (World Scientific, Singapore, 1992), and references therein.
[17] C. Amsler *et al.* (Particle Data Group), Phys. Lett. B **667**, 1 (2008).
[18] M. Neubert *et al.*, *Exclusive Weak Decays of B-mesons*, edited by A. J. Buras and H. Linder (World Scientific, Singapore, 1992), p. 28; H. Y. Cheng, Phys. Rev. D **67**, 094007 (2003); **69**, 074025 (2004), and references therein.
[19] D. H. Perkins, *Introduction to High Energy Physics* (Cambridge University Press, Cambridge, England, 2000), 4th ed.
[20] E. J. Eichten and C. Quigg, Phys. Rev. D **49**, 5845 (1994), and references therein.
[21] M. Baldicchi and G. M. Prosperi, Phys. Rev. D **62**, 114024 (2000); N. Brambilla and A. Vairo, Phys. Rev. D **62**, 094019 (2000); S. M. Ikhdair and R. Sever, Int. J. Mod. Phys. A **18**, 4215 (2003); **20**, 6509 (2005).
[22] M. Ablikim *et al.* (BES), Phys. Lett. B **597**, 39 (2004); D. Y. Kim, Nucl. Phys. **B167**, 75 (2007); R. Dhir, and R. C. Verma, J. Phys. G **34**, 637 (2007), and references therein.