Ω_b semileptonic weak decays

Ming-Kai Du[*] and Chun Liu[†]

Institute of Theoretical Physics, Chinese Academy of Sciences, and State Key Laboratory of Theoretical Physics, P. O. Box 2735, Beijing 100190, China

(Received 26 January 2011; revised manuscript received 15 July 2011; published 12 September 2011)

$\Omega_b \to \Omega_c^{(*)}$ semileptonic decays are studied in details. Relevant helicity amplitudes are written down. Both unpolarized and polarized Ω_b cases are considered. Decay angular distributions, asymmetry parameters and semileptonic decay rates are calculated, with numerical results using leading order results of the large N_c heavy quark effective theory.

DOI: 10.1103/PhysRevD.84.056007 PACS numbers: 11.80.Cr, 12.39.Hg, 14.20.Mr

I. INTRODUCTION

Heavy baryons can be a good application ground of QCD. They reveal some important features of the heavy quark physics. Data on heavy baryons have been accumulating by experiments of LHC and Tevatron, as well as by previously LEP, LEPII and B-factories. Detailed theoretical analysis are necessary. The Λ_b baryon has been studied considerably. For an example, the $\Lambda_b \to \Lambda_c$ semileptonic decay was analyzed thoroughly in Refs. [1–4] in terms of decay rates, distributions and various asymmetry parameters.

Although established for over 35 years, QCD's nonperturbative aspects are still not fully understood, which renders us from precise calculations for the hadron physics. For heavy hadrons containing a single heavy quark, the heavy quark effective theory (HQET) [5,6] is the right QCD, which correctly factorizes the perturbatively calculable part out from hadronic matrix elements of weak currents in a simple and systematic way. The really tough task lies in calculating the nonperturbative part which is the universal Isgur-Wise functions. They can only be calculated by some nonperturbative methods of QCD, like the large N_c QCD [7].

In this paper, Ω_b baryon semileptonic weak decays are studied. The Ω_b baryon was discovered by Tevatron experiments [8], via its 2-body nonleptonic decay $\Omega_b \to J/\Psi\Omega^-$. In terms of the valence quark content, it is made of $b - s - s$. Unlike B mesons or charm hadrons, b baryons cannot be produced at B-factories, they have been only produced at LEP, Tevatron and LHC. It would be a stable particle if the electroweak interaction were shut down. While the process $\Omega_b \to J/\Psi\Omega^-$ is the most appropriate for determining the Ω_b mass, the weak interaction properties of the Ω_b baryon cannot be precisely extracted out, because nonleptonic decays are subjected to a large nonperturbative QCD uncertainty. They are a lot cleaner in the semileptonic decays $\Omega_b \to \Omega_c^{(*)} l\nu$ which are not CKM suppressed. In the near future, more data on Ω_b will be obtained by the Tevatron and LHCb experiments. Furthermore, the planning Z factory [9] can also produce a large amount of Ω_b data. In the Z factory, Z is polarized, Ω_b coming out from Z is also polarized. All these make it viable to analyze the Ω_b semileptonic decays experimentally. Theoretically semileptonic decays are simply parameterized in terms of form factors which contain all the nonperturbative QCD effects. With the help of the HQET, there are only two universal Isgur-Wise functions at the leading order of heavy quark expansion in the $\Omega_b \to \Omega_c^{(*)}$ transitions [10]. These Isgur-Wise functions can be further calculated in the large N_c QCD [11,12]. This is partly based on the observation of the light-quark spin-flavor symmetry in the large N_c limit [13].

We will perform a detailed analysis considering polarization effects of the decays. Our analysis follows the way of Körner and Krämer [1], who analyzed Λ_b semileptonic decays. The technique of helicity amplitudes is adopted which can be found in [14,15]. For obtaining detailed information of the Ω_b decays, all kinds of observables are calculated, although some of them are not practically measurable in the current stage. Nevertheless in such a systematic way, the semileptonic decay branching ratio and spectrum are also obtained at last. In Sec. II, helicity amplitudes are written down for analyzing the $\Omega_b \to \Omega_c^{(*)}$ weak decays. Decay distributions and various asymmetry parameters are calculated in Sec. III. The decay rates are presented in Sec. IV. In Sec. V, we summarize the results.

II. FORM FACTORS AND HELICITY AMPLITUDES

A. Form factors

The hadronic matrix elements of the weak currents $V_\mu \equiv \bar{c}\gamma_\mu b$ and $A_\mu \equiv \bar{c}\gamma_\mu\gamma_5 b$ can be parametrized by 14 form factors which are defined as below [16]:

[*]mkdu@itp.ac.cn
[†]liuc@mail.itp.ac.cn

$$\langle\Omega_c(v',s')|V^\mu|\Omega_b(v)\rangle = \bar{u}(v',s')(F_1\gamma^\mu + F_2 v^\mu + F_3 v'^\mu)u(v,s);$$
$$\langle\Omega_c(v',s')|A^\mu|\Omega_b(v)\rangle = \bar{u}(v',s')(G_1\gamma^\mu + G_2 v^\mu + G_3 v'^\mu)\gamma^5 u(v,s);$$
$$\langle\Omega_c^*(v',s')|V^\mu|\Omega_b(v)\rangle = \bar{u}_\lambda(v',s')(N_1 v^\lambda\gamma^\mu + N_2 v^\lambda v^\mu + N_3 v^\lambda v'^\mu + N_4 g^{\lambda\mu})\gamma^5 u(v,s);$$
$$\langle\Omega_c^*(v',s')|A^\mu|\Omega_b(v)\rangle = \bar{u}_\lambda(v',s')(K_1 v^\lambda\gamma^\mu + K_2 v^\lambda v^\mu + K_3 v^\lambda v'^\mu + K_4 g^{\lambda\mu})u(v,s), \tag{1}$$

where u_λ is the Rarita-Schwinger spinor for the Ω_c^*. It is convenient to redefine some of the form factors as below:

$$F_2' = \frac{1}{2}\left(\frac{F_2}{M_1} + \frac{F_3}{M_2}\right), \qquad F_3' = \frac{1}{2}\left(\frac{F_2}{M_1} - \frac{F_3}{M_2}\right);$$
$$G_2' = \frac{1}{2}\left(\frac{G_2}{M_1} + \frac{G_3}{M_2}\right), \qquad G_3' = \frac{1}{2}\left(\frac{G_2}{M_1} - \frac{G_3}{M_2}\right);$$
$$N_2' = \frac{1}{2}\left(\frac{N_2}{M_1} + \frac{N_3}{M_2'}\right), \qquad N_3' = \frac{1}{2}\left(\frac{N_2}{M_1} - \frac{N_3}{M_2'}\right);$$
$$K_2' = \frac{1}{2}\left(\frac{K_2}{M_1} + \frac{K_3}{M_2'}\right), \qquad K_3' = \frac{1}{2}\left(\frac{K_2}{M_1} - \frac{K_3}{M_2'}\right), \tag{2}$$

where M_1 is the Ω_b mass, M_2 and M_2' masses of Ω_c and Ω_c^* masses, respectively, while $M_1 = 6.071$ GeV, $M_2 = 2.695$ GeV, and $M_2' = 2.770$ GeV [17]. For simplicity, we shall neglect lepton masses. In this case, F_3', G_3', F_3', N_3', and K_3' have no contribution to the decays.

In the HQET, according to the standard tensor method [10], we denote the $\Omega_Q^{(*)}$ states by Ω_Q^M, where $M = 1$ is for Ω_Q, and $M = 2$ for Ω_Q^*. Then the tensor fields describing the Ω_Q^M states are B_μ^M,

$$B_\mu^1(v,s) = \frac{1}{\sqrt{3}}(\gamma_\mu + v_\mu)\gamma^5 u(v,s),$$
$$B_\mu^2(v,s) = u_\mu(v,s). \tag{3}$$

To the leading order of heavy quark expansion, the 14 form factors are reduced into two Isgur-Wise functions [10],

$$\langle\Omega_c^M|\bar{h}^{(c)}\Gamma h^{(b)}|\Omega_b^N\rangle = C\bar{B}_\mu^M\Gamma B^N[-g^{\mu\nu}\xi_1(\omega) + v^\mu v'^\nu\xi_2(\omega)], \tag{4}$$

$$C = \left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right]^{-6/25} = 1.1, \tag{5}$$

where $\omega = v\cdot v'$, and C is the QCD perturbative leading logarithm correction, which has been evaluated at the scale $\mu = m_c$. The 14 form factors are then expressed as below [16]:

$$F_1 = \frac{-\omega}{3}\xi_1 + \frac{\omega^2-1}{3}\xi_2, \quad G_1 = \frac{-\omega}{3}\xi_1 + \frac{\omega^2-1}{3}\xi_2$$
$$F_2 = \frac{2}{3}\xi_1 + \frac{2(1-\omega)}{3}\xi_2, \quad G_2 = \frac{2}{3}\xi_1 + \frac{-2(1+\omega)}{3}\xi_2$$
$$F_3 = \frac{2}{3}\xi_1 + \frac{2(1-\omega)}{3}\xi_2, \quad G_3 = \frac{-2}{3}\xi_1 + \frac{2(1+\omega)}{3}\xi_2$$
$$N_1 = \frac{-1}{\sqrt{3}}\xi_1 + \frac{\omega-1}{\sqrt{3}}\xi_2, \quad K_1 = \frac{-1}{\sqrt{3}}\xi_1 + \frac{\omega+1}{\sqrt{3}}\xi_2$$
$$N_2 = 0\ , \quad K_2 = 0$$
$$N_3 = 0 + \frac{2}{\sqrt{3}}\xi_2, \quad K_3 = 0 + \frac{-2}{\sqrt{3}}\xi_2$$
$$N_4 = \frac{-2}{\sqrt{3}}\xi_1 + 0, \quad K_4 = \frac{2}{\sqrt{3}}\xi_1 + 0; \tag{6}$$

it is at this stage that nonperturbation methods are needed. In the large N_c limit, these two Isgur-Wise functions are related to that of $\langle\Lambda_c|\bar{h}^{(c)}\Gamma h^{(b)}|\Lambda_b\rangle$. While $\langle\Lambda_c|\bar{h}^{(c)}\Gamma h^{(b)}|\Lambda_b\rangle = \eta\bar{u}_c\Gamma u_b$, the relations are [11,18]

$$\eta(\omega) = \xi_1(\omega) = (\omega+1)\xi_2(\omega). \tag{7}$$

Furthermore, in the large N_c limit, η is predicted as [12]

$$\eta(\omega) = 0.99\exp[-1.3(\omega-1)]. \tag{8}$$

B. Helicity amplitudes

Following the way of Ref. [1] for $\Lambda_b \to \Lambda_c l\bar{\nu}$ decays, we analyze $\Omega_b \to \Omega_c^{(*)} l\bar{\nu}$ semileptonic decays. It is convenient to regard the decay as two-successive decays $\Omega_1 \to \Omega_2 + W_{\text{off-shell}}$ and $W_{\text{off-shell}} \to \ell + \bar{\nu}$. We denote helicity amplitudes of $\Omega_b \to \Omega_c + \ell + \bar{\nu}$ as $H^{V,A}_{\lambda_2\lambda_W}$ and that of $\Omega_b \to \Omega_c^* + \ell + \bar{\nu}$ as $H'^{V,A}_{\lambda_2\lambda_W}$, where λ_2 and λ_W are helicities of the daughter baryon and the off-shell W boson. These amplitudes can be expressed by our redefined form factors as

$$\sqrt{q^2}H^V_{1/20} = \sqrt{Q_-}[(M_1+M_2)F_1 + F_2'Q_+],$$
$$H^V_{1/21} = -\sqrt{2Q_-}F_1;$$
$$\sqrt{q^2}H^A_{1/20} = \sqrt{Q_+}[(M_1-M_2)G_1 - G_2'Q_-],$$
$$H^A_{1/21} = -\sqrt{2Q_+}G_1; \tag{9}$$

and

$$\sqrt{q'^2}H'^V_{1/20} = \sqrt{\frac{2}{3}}\frac{p'}{M'_2}\sqrt{Q'_+}[(M_1 - M'_2)N_1 - N'_2Q_-] - \sqrt{\frac{2}{3}}\sqrt{Q'_-}\left[\frac{Q_-}{2M'_2} + (M_1 - M'_2)\right]N_4$$

$$\sqrt{q'^2}H'^A_{1/20} = \sqrt{\frac{2}{3}}\frac{p'}{M'_2}\sqrt{Q'_-}[(M_1 + M'_2)K_1 + K'_2Q_+] + \sqrt{\frac{2}{3}}\sqrt{Q'_+}\left[\frac{Q_+}{2M'_2} - (M_1 + M'_2)\right]K_4 \quad (10)$$

$$H'^V_{1/21} = \sqrt{\frac{1}{3}}\sqrt{Q'_-}\left[N_4 - N_1\frac{Q'_+}{M_1M'_2}\right]$$

$$H'^A_{1/21} = \sqrt{\frac{1}{3}}\sqrt{Q'_+}\left[K_4 - K_1\frac{Q'_-}{M_1M'_2}\right]$$

$$H'^V_{3/21} = -N_4\sqrt{Q'_-}$$

$$H'^A_{3/21} = K_4\sqrt{Q'_+},$$

where $Q^{(\prime)}_\pm = (M_1 \pm M^{(\prime)}_2)^2 - q^{(\prime)2}$ and $q^{(\prime)\mu}(W) = (q^{(\prime)0}, 0, 0, -p^{(\prime)})$ while $p^{(\prime)} = \sqrt{Q^{(\prime)}_+Q^{(\prime)}_-}/2M_1$ and $q^{(\prime)0} = (M_1^2 - M_2^{(\prime)2} + q^{(\prime)2})/2M_1$. Other helicity amplitudes can be obtained via using the parity relations:

$$H^{V(A)}_{-\lambda_2-\lambda_W} = +(-)H^{V(A)}_{\lambda_2\lambda_W}. \quad (11)$$

III. ANGULAR DISTRIBUTIONS AND ASYMMETRY PARAMETERS

Unpolarized and polarized Ω_b decays will be considered, respectively. And in case of the $\Omega_b \to \Omega_c$ transition, the cascade nonleptonic weak decay $\Omega_c \to a + b$ (for example $\Omega_c \to \Omega + \pi$ [17]) will be taken into account, where a has spin 1/2, and b is a spin zero particle. While in the case of $\Omega_b \to \Omega_c^*$ transition, we will not further consider Ω_c^* cascade decays which are either strong or radiative decays [17] and therefore will not produce the asymmetry factors.

A. Unpolarized Ω_b decay

For that Ω_b is unpolarized, it is convenient to introduce the correlation density matrix first, which is given by

$$\rho_{\lambda_2\lambda_W;\lambda'_2\lambda'_W} = H_{\lambda_2\lambda_W}H^*_{\lambda'_2\lambda'_W}. \quad (12)$$

With this density matrix, using the methods of Refs. [14,15,19] and ignoring lepton masses, we obtain the angular distribution for the whole decay $\Omega_b \to \Omega_c(\to a + b) + W(\to \ell + \bar{\nu})$:

$$\frac{d\Gamma}{d\omega\, d\cos\Theta\, d\chi\, d\cos\Theta_\Omega} = Br(\Omega_c \to a + b)\frac{G^2}{(2\pi)^4}|V_{cb}|^2q^2\sqrt{\omega^2 - 1}\frac{M_2^2}{24M_1} \times \Big(\frac{3}{8}(1 + \cos\Theta)^2|H_{1/21}|^2(1 + \alpha_\Omega\cos\Theta_\Omega) + \frac{3}{8}(1 - \cos\Theta)^2|H_{-1/2-1}|^2(1 - \alpha_\Omega\cos\Theta_\Omega) + \frac{3}{4}\sin\Theta^2|H_{1/20}|^2(1 + \alpha_\Omega\cos\Theta_\Omega) + \frac{3}{4}\sin\Theta^2|H_{-1/20}|^2(1 - \alpha_\Omega\cos\Theta_\Omega) - \frac{3}{2\sqrt{2}}\alpha_\Omega\cos\chi\sin\Theta\sin\Theta_\Omega[(1 + \cos\Theta)\mathrm{Re}(H_{-1/20}H^*_{1/21}) - \frac{3}{2\sqrt{2}}\alpha_\Omega\cos\chi\sin\Theta\sin\Theta_\Omega[(1 - \cos\Theta)\mathrm{Re}(H_{1/20}H^*_{-1/2-1})]\Big), \quad (13)$$

where the polar angle Θ is for l, Θ_Ω for a, and χ is the azimuthal angle. These angles are illustrated in Fig. 1 and 2. G is the Fermi coupling and V_{cb} is the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix element. The daughter baryon Ω_c decays into a and b with a branching ratio $Br(\Omega_c \to a + b)$ and decay asymmetry parameter α_Ω. p is the momentum of Ω_c in the rest reference frame of Ω_b. According to the results of [20], in Eq. (13) we have assumed all the helicity amplitudes are real, since otherwise we will have to include the effects of CP violation.

Various angular distribution and asymmetry parameters of Ω_b semileptonic decays can now be obtained. First, from Eq. (13), by integrating other angles, the polar angle distribution of the successive decay $\Omega_c \to a + b$ is

$$\frac{d\Gamma}{d\omega\, d\cos\Theta_\Omega} \propto 1 + \alpha_1\alpha_\Omega\cos\Theta_\Omega, \quad (14)$$

where the asymmetry parameter α_1 is defined as

$$\alpha_1 = \frac{|H_{1/21}|^2 - |H_{-1/2-1}|^2 + |H_{1/20}|^2 - |H_{-1/20}|^2}{|H_{1/21}|^2 + |H_{-1/2-1}|^2 + |H_{1/20}|^2 + |H_{-1/20}|^2}, \quad (15)$$

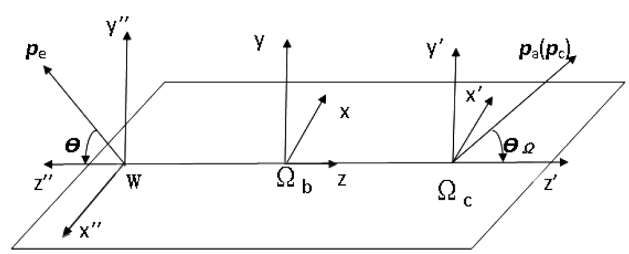

FIG. 1. Definition of polar angles Θ_Ω and Θ, both angles are defined in rest frames of the decaying particles.

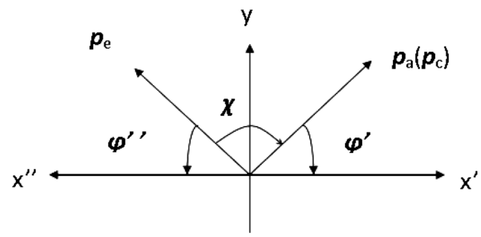

FIG. 2. Definition of the azimuthal angle χ, which is the one between two cascade decay planes.

and the polar angle distribution of the decay $W \to \ell + \bar{\nu}$ is

$$\frac{d\Gamma}{d\omega d\cos\Theta} \propto 1 + 2\alpha_2 \cos\Theta + \alpha_3 \cos^2\Theta, \tag{16}$$

where the parameters α_2 and α_3 are

$$\alpha_2 = \frac{|H_{1/21}|^2 - |H_{-1/2-1}|^2}{|H_{1/21}|^2 + |H_{-1/2-1}|^2 + 2(|H_{1/20}|^2 + |H_{-1/20}|^2)}, \tag{17}$$

$$\alpha_3 = \frac{|H_{1/21}|^2 + |H_{-1/2-1}|^2 - 2(|H_{1/20}|^2 + |H_{-1/20}|^2)}{|H_{1/21}|^2 + |H_{-1/2-1}|^2 + 2(|H_{1/20}|^2 + |H_{-1/20}|^2)}, \tag{18}$$

and the χ distribution is

$$\frac{d\Gamma}{d\omega d\chi} \propto 1 - \frac{3\pi^2}{32\sqrt{2}} \gamma \alpha_\Omega \cos\chi, \tag{19}$$

where

$$\gamma = \frac{2\,\mathrm{Re}(H_{-1/20}H^*_{1/21} + H_{1/20}H^*_{-1/2-1})}{|H_{1/21}|^2 + |H_{-1/2-1}|^2 + |H_{1/20}|^2 + |H_{-1/20}|^2}. \tag{20}$$

Up to now, all of the analysis in this section are model independent. With the help of the large N_c Isgur-Wise function given in Sec. II, we can calculate all these asymmetry parameters numerically, the results are listed in Table I.

Next, let us turn to the analysis of the decay $\Omega_b \to \Omega_c^* + W(\to \ell + \bar{\nu})$, the procedure is analogous to the analysis of $\Omega_b \to \Omega_c(\to a + b) + W(\to \ell + \bar{\nu})$, we can get the angular distribution as the following:

$$\frac{d\Gamma'}{d\omega d\cos\Theta} = \frac{G^2}{(2\pi)^3}|V_{cb}|^2 q'^2 \sqrt{\omega^2 - 1}\frac{M_2'^2}{12M_1} \times \bigg(\frac{3}{8}(1+\cos\Theta)^2|H'_{3/21}|^2 + \frac{3}{8}(1-\cos\Theta)^2|H'_{-3/2-1}|^2 + \frac{3}{8}(1+\cos\Theta)^2|H'_{1/21}|^2 + \frac{3}{8}(1-\cos\Theta)^2|H'_{-1/2-1}|^2 + \frac{3}{4}\sin^2\Theta|H'_{1/20}|^2 + \frac{3}{4}\sin^2\Theta|H'_{-1/20}|^2\bigg), \tag{21}$$

where the angle Θ has the same meaning as before. Again we can get some asymmetry parameters. The polar angular distribution of the cascade decay of $W \to \ell + \bar{\nu}$ is

$$\frac{d\Gamma'}{d\omega d\cos\Theta} \propto 1 + 2\alpha_1' \cos\Theta + \alpha_2' \cos^2\Theta, \tag{22}$$

where

$$\alpha_1' = \frac{|H'_{3/21}|^2 - |H'_{-3/2-1}|^2 + |H'_{1/21}|^2 - |H'_{-1/2-1}|^2}{|H'_{3/21}|^2 + |H'_{-3/2-1}|^2 + |H'_{1/21}|^2 + |H'_{-1/2-1}|^2 + 2(|H'_{1/20}|^2 + |H'_{-1/20}|^2)}, \tag{23}$$

$$\alpha_2' = \frac{|H'_{3/21}|^2 + |H'_{-3/2-1}|^2 + |H'_{1/21}|^2 + |H'_{-1/2-1}|^2 - 2(|H'_{1/20}|^2 + |H'_{-1/20}|^2)}{|H'_{3/21}|^2 + |H'_{-3/2-1}|^2 + |H'_{1/21}|^2 + |H'_{-1/2-1}|^2 + 2(|H'_{1/20}|^2 + |H'_{-1/20}|^2)}. \tag{24}$$

All the numerical results of these asymmetry parameters are listed in Table I.

TABLE I. Asymmetry parameters.

	α_1	α_2	α_3	α_P	γ	γ_P	α_1'	α_2'
$\omega = 1$	0	0	0	0	0.943	$-1/3$	0	0
mean-value	0.522	-0.04	-0.751	-0.626	0.478	0.468	-0.132	-0.363

B. Polarized Ω_b decay

In this subsection, the decays of a polarized Ω_b will be analyzed, since in the proposed Z factory [9], the produced bottom quarks will be polarized. It is reasonable to assume the Ω_b will also be polarized in Z factory. Two new decay angles will be introduced, Θ_P and χ_p, where P denotes the polarization vector of the parent baryon Ω_b, the angles involved are shown in Fig. 3 and 4.

For the decay $\Omega_b \to \Omega_c(\to a + b) + W(\to \ell + \bar{\nu})$, the density matrix is now the following:

$$\begin{aligned}\rho_{1/21/2} &= |H_{1/21}|^2(1 - P\cos\Theta_P) \\ &\quad + |H_{1/20}|^2(1 + P\cos\Theta_P), \\ \rho_{1/2-1/2} &= \rho_{-1/21/2} = P\sin\Theta_P \mathrm{Re}(H_{1/20}H^*_{-1/20}), \\ \rho_{-1/2-1/2} &= |H_{-1/2-1}|^2(1 + P\cos\Theta_P) \\ &\quad + |H_{-1/20}|^2(1 - P\cos\Theta_P).\end{aligned} \tag{25}$$

After integrating the angles of the leptons out, the whole angle distribution is obtained:

$$\begin{aligned}\frac{d\Gamma}{d\omega d\cos\Theta_P d\chi_P d\cos\Theta_\Omega} &= Br(\Omega_c \to a + b)\frac{G^2}{(2\pi)^4}|V_{cb}|^2 q^2\sqrt{\omega^2 - 1}\frac{M_2^2}{48M_1} \times (|H_{1/21}|^2 + |H_{-1/2-1}|^2 + |H_{1/20}|^2 \\ &\quad + |H_{-1/20}|^2 + \alpha_\Omega \cos\Theta_\Omega(|H_{1/21}|^2 - |H_{-1/2-1}|^2 + |H_{1/20}|^2 - |H_{-1/20}|^2)x \\ &\quad + P\alpha_\Omega \cos\Theta_P(-|H_{1/21}|^2 + |H_{-1/2-1}|^2 + |H_{1/20}|^2 - |H_{-1/20}|^2) \\ &\quad + P\alpha_\Omega \cos\Theta_\Omega \cos\Theta_P(-|H_{1/21}|^2 - |H_{-1/2-1}|^2 + |H_{1/20}|^2 + |H_{-1/20}|^2) \\ &\quad + P\alpha_\Omega \sin\Theta_\Omega \sin\Theta_P \cos\chi_P 2\,\mathrm{Re}(H_{1/20}H^*_{-1/20})).\end{aligned} \tag{26}$$

Then the Θ_P angle distribution is

$$\frac{d\Gamma}{d\omega d\cos\Theta_P} \propto 1 - \alpha_P P\cos\Theta_P, \tag{27}$$

where

$$\alpha_P = \frac{|H_{1/21}|^2 - |H_{-1/2-1}|^2 - |H_{1/20}|^2 + |H_{-1/20}|^2}{|H_{1/21}|^2 + |H_{-1/2-1}|^2 + |H_{1/20}|^2 + |H_{-1/20}|^2}. \tag{28}$$

And the χ_P distribution is

$$\frac{d\Gamma}{d\omega d\chi} \propto 1 - \frac{\pi^2}{16}P\gamma_P\alpha_P\cos\chi, \tag{29}$$

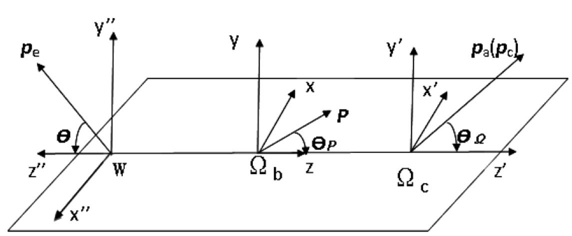

FIG. 3. Definition of polar angles Θ_Ω and Θ_P, where the polarization vector P is in the y–z plane.

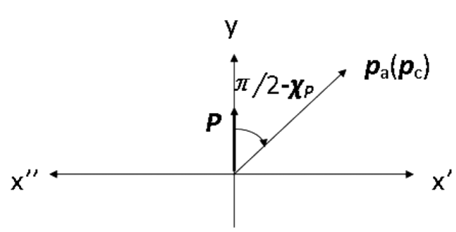

FIG. 4. Definition of azimuthal angle χ_P.

where

$$\gamma_P = \frac{2\mathrm{Re}(H_{1/20}H^*_{-1/20})}{|H_{1/21}|^2 + |H_{-1/2-1}|^2 + |H_{1/20}|^2 + |H_{-1/20}|^2}. \tag{30}$$

The numerical results of these asymmetry parameters are shown in Table I.

For the decay $\Omega_b \to \Omega_c^* + W(\to \ell + \bar{\nu})$, after integrating the lepton angles out, there are no such two asymmetry factors.

IV. THE DECAY RATES

To be more concrete, we can now calculate the differential decay rates. Neglecting the lepton mass, the $\Omega_b \to \Omega_c l\bar{\nu}$ differential decay rate can be expressed in terms of the helicity amplitudes as

$$\begin{aligned}\frac{d\Gamma(\omega)}{d\omega} &= \frac{G^2}{(2\pi)^3}|V_{cb}|^2 q^2\sqrt{\omega^2 - 1}\frac{M_2^2}{12M_1}C^2 \\ &\quad \times [|H_{1/21}|^2 + |H_{-1/2-1}|^2 + |H_{1/20}|^2 + |H_{-1/20}|^2],\end{aligned} \tag{31}$$

where $q^2 = M_1^2 + M_2^2 - 2M_1M_2\omega$.

For the decay of $\Omega_b \to \Omega_c^* l\bar{\nu}$, we have

$$\begin{aligned}\frac{d\Gamma'(\omega)}{d\omega} &= \frac{G^2}{(2\pi)^3}|V_{cb}|^2 q'^2\sqrt{\omega^2 - 1}\frac{M_2'^2}{12M_1}C^2 \\ &\quad \times [|H'_{3/21}|^2 + |H'_{-3/2-1}|^2 + |H'_{1/21}|^2 \\ &\quad + |H'_{-1/2-1}|^2 + |H'_{1/20}|^2 + |H'_{-1/20}|^2],\end{aligned} \tag{32}$$

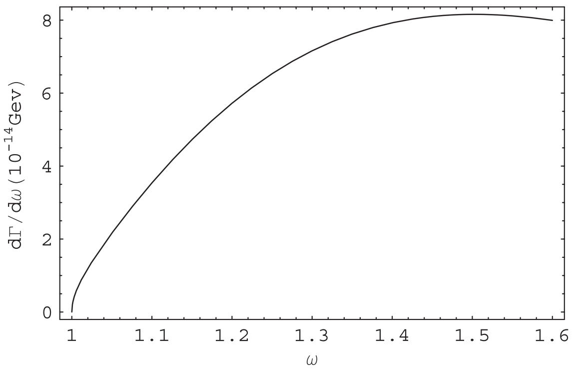

FIG. 5. The differential decay rate of $\Omega_b \to \Omega_c l\bar{\nu}$.

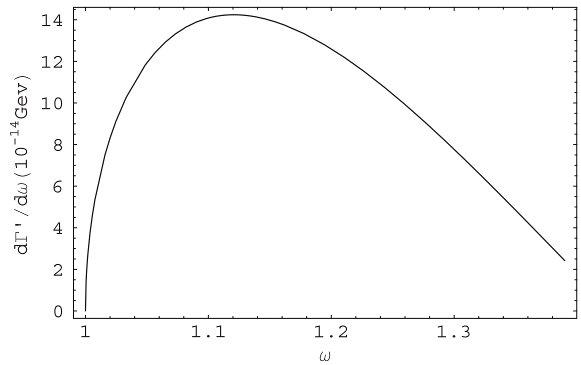

FIG. 6. The differential decay rate of $\Omega_b \to \Omega_c^* l\bar{\nu}$.

where $q'^2 = M_1^2 + M_3^2 - 2M_1M_3\omega$, and the above distributions are plotted in Fig. 5 and 6. All the results are consistent with [21–23] when expressed in terms of form factors.

By inputting the form factors discussed in Sec. II, numerical results can be obtained. We have taken $G = 1.16637 \times 10^{-5}$ GeV^{-2} and $|V_{cb}| = 40.6 \times 10^{-3}$ [17]. The results are

$$\Gamma(\Omega_b \to \Omega_c l\bar{\nu}) = 1.686 \times 10^{-14}\ \text{GeV},\qquad \text{B}(\Omega_b \to \Omega_c l\bar{\nu}) = 2.82\%. \tag{33}$$

$$\Gamma(\Omega_b \to \Omega_c^* l\bar{\nu}) = 3.482 \times 10^{-14}\ \text{GeV},\qquad \text{B}(\Omega_b \to \Omega_c^* l\bar{\nu}) = 5.82\%. \tag{34}$$

The second width is about twice as large as the first one, this can be understood easily when we consider the Clebsch-Gordan coefficients. Note that we have obtained the above results by taking two approximations: heavy quark limit and large N_c limit. In the near future, these results can be tested at the LHCb experiment.

V. SUMMARY

In this paper, we have calculated $\Omega_b \to \Omega_c^{(*)}$ semileptonic decays. Relevant helicity amplitudes have been written down. Both unpolarized and polarized Ω_b baryon cases have been considered. Decay angular distributions, asymmetry parameters, and semileptonic decay rates have been calculated, with numerical results using leading order results of HQET. The large N_c QCD result for Isgur-Wise functions have been used. The numerical results (especially the zero-recoil values) can be checked by the experiment at the LHCb.

ACKNOWLEDGMENTS

This work was supported in part by the National Natural Science Foundation of China under Grant Nos. 11075193 and 10821504, and by the National Basic Research Program of China under Grant No. 2010CB833000.

[1] J. G. Körner and M. Krämer, Phys. Lett. B **275**, 495 (1992).
[2] P. Bialas, J. G. Körner, M. Krämer, and K. Zalewski, Z. Phys. C **57**, 115 (1993); B. König, J. G. Körner, M. Krämer, and P. Kroll, Phys. Rev. D **56**, 4282 (1997); M. A. Ivanov, V. E. Lyubovitskij, J. G. Körner, and P. Kroll, Phys. Rev. D **56**, 348 (1997).
[3] Y.-B. Dai, C.-S. Huang, M.-Q. Huang, and C. Liu, Phys. Lett. B **387**, 379 (1996); J.-P. Lee, C. Liu, and H. S. Song, Phys. Rev. D **58**, 014013 (1998); M.-Q. Huang, H.-Y. Jin, J. G. Körner, and C. Liu, Phys. Lett. B **629**, 27 (2005).
[4] C. Albertus, E. Hernandez, and J. Nieves, Phys. Rev. D **71**, 014012 (2005); M. Pervin, W. Roberts, and S. Capstick, Phys. Rev. C **72**, 035201 (2005); D. Ebert, R. N. Faustov, and V. O. Galkin, Phys. Rev. D **73**, 094002 (2006); P. Guo, H.-W. Ke, X.-Q. Li, C.-D. Lü, and Y.-M. Wang, Phys. Rev. D **75**, 054017 (2007); H.-W. Ke, X.-Q. Li, and Z.-T. Wei, Phys. Rev. D **77**, 014020 (2008); Z.-G. Wang, arXiv:0906.4206.
[5] N. Isgur and M. B. Wise, Phys. Lett. B **232**, 113 (1989); **237**, 527 (1990); M. B. Voloshin and M. A. Shifman, Yad. Fiz. **45**, 463 (1987); [Sov. J. Nucl. Phys. **45**, 292 (1987)];**47**, 801 (1988); [Sov. J. Nucl. Phys. **47**, 511 (1988)];E. V. Shuryak, Phys. Lett. B **93**, 134 (1980); E. Eichten and B. Hill, Phys. Lett. B **234**, 511 (1990).
[6] H. Georgi, Phys. Lett. B **240**, 447 (1990); A. F. Falk, H. Georgi, B. Grinstein, and M. B. Wise, Nucl. Phys. B **343**, 1 (1990).
[7] G. 't Hooft, Nucl. Phys. B **72**, 461 (1974); E. Witten, Nucl. Phys. B **160**, 57 (1979).
[8] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **101**, 232002 (2008); T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. D **80**, 072003 (2009).

[9] "*Special Topics on Z-factory Physics,*," Sci. Chin. Phys. Mech. Astron. 53, Edited by J.-P. Ma and Z.-X. Zhang, 2010.
[10] N. Isgur and M. B. Wise, Nucl. Phys. B **348**, 276 (1991); H. Georgi, Nucl. Phys. B **348**, 293 (1991).
[11] C. K. Chow, Phys. Rev. D **51**, 1224 (1995); C. K. Chow, Phys. Rev. D **54**, 873 (1996).
[12] E. Jekins, A. V. Manohar, and M. B. Wise, Nucl. Phys. B **396**, 38 (1993).
[13] R. F. Dashen and A. V. Manohar, Phys. Lett. B **315**, 425 (1993); C. Carone, H. Georgi, and S. Osofsky, Phys. Lett. B **322**, 227 (1994); M. A. Luty and J. March-Russell, Nucl. Phys. B **426**, 71 (1994); J.-L. Gervais and B. Sakita, Phys. Lett. B **52**, 87 (1984).
[14] M. Jacob and G. C. Wick, Ann. Phys. (N.Y.) **7**, 404 (1959).
[15] J. D. Jackson, in *High Energy Physics*, edited by C. de Witt and R. Gatto (Gordon and Breach, New York, 1965) p. 325.
[16] C. G. Boyd and D. E. Brahm, Phys. Lett. B **254**, 468 (1991).
[17] K. Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010).
[18] F. Hussain, J. G. Körner, M. Krämer, and G. Thompson, Z. Phys. C **51**, 321 (1991).
[19] J. G. Körner and G. A. Schuler, Z. Phys. C **46**, 93 (1990) 93.
[20] J. G. Körner, K. Schilcher, and Y. L. Wu, Phys. Lett. B **242**, 119 (1990).
[21] Y.-B. Dai, C. S. Huang, C. Liu, and C.-D. Lü, Phys. Lett. B **371**, 99 (1996).
[22] J. G. Körner, M. Krämer, and D. Pirjol, Prog. Part. Nucl. Phys. **33**, 787 (1994).
[23] A. K. Leibovich and I. W. Stewart, Phys. Rev. D **57**, 5620 (1998).