b semi-leptonic weak decays postprint

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Full Text

Preamble

Semileptonic Weak Decays of Ω_b

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Abstract

Semileptonic decays are studied in detail. 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 from large N_c heavy quark effective theory.

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INTRODUCTION

Heavy baryons provide an excellent testing ground for QCD and reveal important features of heavy quark physics. Data on heavy baryons have been accumulating from experiments at LHC and Tevatron, as well as from earlier LEP, LEPII, and B-factories. Detailed theoretical analyses are necessary. The Λ_b baryon has been studied considerably; for 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 QCD has been established for over 35 years, its nonperturbative aspects remain poorly understood, preventing precise calculations in hadron physics. For heavy hadrons containing a single heavy quark, heavy quark effective theory (HQET) [5, 6] provides the correct framework, which systematically factorizes the perturbatively calculable part from hadronic matrix elements of weak currents. The truly challenging task lies in calculating the nonperturbative part, which manifests as universal Isgur-Wise functions. These can only be computed through nonperturbative QCD methods, such as large N_c QCD [7].

In this paper, we study semileptonic weak decays of the Ω_b baryon. The Ω_b baryon was discovered by Tevatron experiments [8] via its two-body nonleptonic decay $\Omega_b \to J/\Psi\Omega^-$. In terms of valence quark content, it consists of bss. Unlike B-mesons or charm hadrons, b-baryons cannot be produced at B-factories; they have only been 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 most appropriate for determining the Ω_b mass, the weak interaction properties of the Ω_b baryon cannot be precisely extracted because nonleptonic decays are subject to large nonperturbative QCD uncertainties. They are much cleaner in the semileptonic decays $\Omega_b \to \Omega_c^{(*)}\ell\bar{\nu}$, which are not CKM suppressed. In the near future, more data on Ω_b will be obtained by Tevatron and LHCb experiments. Furthermore, the proposed Z factory [9] can also produce a large amount of Ω_b data. At the Z factory, the Z boson is polarized, and Ω_b produced from Z decays will also be polarized. All these developments make it viable to analyze Ω_b semileptonic decays experimentally.

Theoretically, semileptonic decays are simply parameterized in terms of form factors that contain all nonperturbative QCD effects. With the help of HQET, there are only two universal Isgur-Wise functions at leading order in the heavy quark expansion for $\Omega_b \to \Omega_c^{(*)}$ transitions [10]. These Isgur-Wise functions can be further calculated in large N_c QCD [12, 13], partly based on the observation of light-quark spin-flavor symmetry in the large N_c limit [14].

We perform a detailed analysis including polarization effects of the decays. Our analysis follows the approach of Körner and Krämer [1], who analyzed Λ_b semileptonic decays. The technique of helicity amplitudes is adopted, as described in [15, 16]. To obtain detailed information about Ω_b decays, we calculate all kinds of observables, although some are not practically measurable at the current stage. Nevertheless, through this systematic approach, we also obtain the semileptonic decay branching ratio and spectrum. In Section II, helicity amplitudes are written down for analyzing $\Omega_b \to \Omega_c^{(*)}$ weak decays. Decay distributions and various asymmetry parameters are calculated in Section III. The decay rates are presented in Section IV. In Section V, we summarize our 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 fourteen form factors defined as follows [17]:

$$
\begin{aligned}
\langle\Omega_c(v',s')|V_\mu|\Omega_b(v)\rangle &= \bar{u}(v',s')(F_1\gamma_\mu + F_2 v_\mu + F_3 v'_\mu)u(v,s),\\
\langle\Omega_c(v',s')|A_\mu|\Omega_b(v)\rangle &= \bar{u}(v',s')(G_1\gamma_\mu + G_2 v_\mu + G_3 v'_\mu)\gamma_5 u(v,s),\\
\langle\Omega_c^*(v',s')|V_\mu|\Omega_b(v)\rangle &= \bar{u}_\lambda(v',s')(N_1 v^\lambda\gamma_\mu + N_2 v^\lambda v_\mu + N_3 v^\lambda v'_\mu + N_4 g_\mu^\lambda)\gamma_5 u(v,s),\\
\langle\Omega_c^*(v',s')|A_\mu|\Omega_b(v)\rangle &= \bar{u}_\lambda(v',s')(K_1 v^\lambda\gamma_\mu + K_2 v^\lambda v_\mu + K_3 v^\lambda v'_\mu + K_4 g_\mu^\lambda)u(v,s).
\end{aligned}
$$

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

$$
\begin{aligned}
F'_2 = \frac{F_2}{M_2}, \quad F'_3 = \frac{F_3}{M_2}, \quad G'_2 = \frac{G_2}{M_2}, \quad G'_3 = \frac{G_3}{M_2},\\
N'_2 = \frac{N_2}{M'_2}, \quad N'_3 = \frac{N_3}{M'_2}, \quad K'_2 = \frac{K_2}{M'_2}, \quad K'_3 = \frac{K_3}{M'_2}
\end{aligned}
$$

where M_1 is the Ω_b mass, M_2 and M'_2 are the masses of Ω_c and Ω_c^*, respectively, with $M_1 = 6.071$ GeV, $M_2 = 2.695$ GeV, and $M'_2 = 2.770$ GeV [18]. For simplicity, we neglect lepton masses. In this case, F'_3, G'_3, N'_3, and K'_3 have no contribution to the decays.

In 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^*. The tensor fields describing these states are:

$$
\begin{aligned}
B_{M\mu}(v,s) &= (\gamma_\mu + v_\mu)\gamma_5 u(v,s), \quad \text{for } M = 1,\\
B_{M\mu}(v,s) &= u_\mu(v,s), \quad \text{for } M = 2.
\end{aligned}
$$

To leading order in the heavy quark expansion, the fourteen form factors reduce to two Isgur-Wise functions [10]:

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

where $\omega = v \cdot v'$, and C is the QCD perturbative leading logarithm correction:

$$C = \left(\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right)^{-6/25} = 1.1.$$

The fourteen form factors are then expressed as [17]:

$$\begin{aligned}
F_1 &= -\frac{1}{2}(\xi_1+\xi_2), \qquad & F_2' &= \frac{1}{2(1+\omega)}(\xi_1+\xi_2),\\
G_1 &= -\frac{1}{2}(\xi_1-\xi_2), \qquad & G_2' &= \frac{1}{2(1+\omega)}(\xi_1-\xi_2),\\
N_1 &= -\frac{1}{2}\xi_2, \qquad & N_4 &= -\frac{1}{2}\xi_2,\\
K_1 &= -\frac{1}{2(\omega+1)}\xi_2, \qquad & K_2 &= \frac{1}{2(\omega+1)}\xi_2, \quad K_3 = 0, \quad K_4 = \frac{1}{2}\xi_1.
\end{aligned}$$

At this stage, nonperturbative methods are needed. In the large N_c limit, these two Isgur-Wise functions are related to that of $\Lambda_b \to \Lambda_c$ transitions. While $\langle\Lambda_c|\bar{h}^{(c)}\Gamma h^{(b)}|\Lambda_b\rangle = \bar{u}_c\Gamma u_b\eta(\omega)$, the relations are [11, 12]:

$$\eta(\omega) = \xi_1(\omega) = (\omega+1)\xi_2(\omega).$$

Furthermore, in the large N_c limit, η is predicted as [13]:

$$\eta(\omega) = 0.99\exp[1.3(\omega-1)].$$

B. Helicity amplitudes

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

$$H^V_{1/2,0} = \sqrt{Q_-}[(M_1 + M_2)F_1 + F'_2], \qquad H^V_{1/2,1} = \sqrt{2Q_-}F_1,$$
$$H^A_{1/2,0} = \sqrt{Q_+}[(M_1 - M_2)G_1 - G'_2], \qquad H^A_{1/2,1} = \sqrt{2Q_+}G_1,$$
$$H^{V*}_{1/2,0} = \sqrt{Q'_-}\left[(M_1 + M'_2)N_1 - N_4 + \frac{M_1 M'_2}{2}N'_2\right], \qquad H^{V*}_{3/2,1} = \sqrt{Q'_-}N_1,$$
$$H^{A*}_{1/2,0} = \sqrt{Q'_+}\left[(M_1 - M'_2)K_1 + K_4 + \frac{M_1 M'_2}{2}K'_2\right], \qquad H^{A*}_{3/2,1} = \sqrt{Q'_+}K_1,$$
$$H^{V*}_{1/2,1} = \sqrt{Q'_-}\left[-(M_1 + M'_2)K_1 - K_4 + \frac{M_1 M'_2}{2}K'_2\right], \qquad H^{V*}_{-1/2,-1} = \sqrt{Q'_-}K_1,$$
$$H^{A*}_{1/2,1} = \sqrt{Q'_+}\left[-(M_1 - M'_2)N_1 + N_4 + \frac{M_1 M'_2}{2}N'_2\right], \qquad H^{A*}_{-1/2,-1} = \sqrt{Q'_+}N_1,$$

where $Q_\pm = (M_1 \pm M_2)^2 - q^2$ and $Q'_\pm = (M_1 \pm M'_2)^2 - q'^2$, with q^2 and q'^2 being the momentum transfer squared. The momentum of the off-shell W boson is $q^{(\prime)}_\mu = (q^{(\prime)}_0, 0, 0, |\vec{p}^{(\prime)}|)$ while $|\vec{p}^{(\prime)}| = \sqrt{Q^{(\prime)}_\pm}/2M_1$ and $q^{(\prime)}_0 = (M_1^2 - M_{2,3}^2 + q_2^{(\prime)})/2M_1$. Other helicity amplitudes can be obtained via parity relations:

$$H^{V(A)}_{-\lambda_2,-\lambda_W} = \pm(-1)^{\lambda_2-\lambda_W} H^{V(A)}_{\lambda_2\lambda_W}.$$

III. ANGULAR DISTRIBUTIONS AND ASYMMETRY PARAMETERS

We consider both unpolarized and polarized Ω_b decays. For the $\Omega_b \to \Omega_c$ transition, we take into account the cascade nonleptonic weak decay $\Omega_c \to a + b$ [18], where a has spin 1/2 and b is a spin-zero particle. For the $\Omega_b \to \Omega_c^*$ transition, we do not further consider Ω_c^* cascade decays, which proceed via either strong or radiative decays [18] and therefore do not produce asymmetry factors.

A. Unpolarized Ω_b decay

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

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

With this density matrix, using the methods of Refs. [15, 16, 19] and ignoring lepton masses, we obtain the angular distribution for the full decay $\Omega_b \to \Omega_c(\to a + b) + \ell + \bar{\nu}$:

$$\frac{d^4\Gamma}{d\omega d\cos\Theta d\chi d\cos\Theta_\Omega} = \frac{G^2|V_{cb}|^2}{(2\pi)^4}\frac{q^2p}{2M_1^2}\sqrt{\omega^2-1}\times \mathrm{Br}(\Omega_c\to a+b)$$
$$\times \Big\{(1+\cos\Theta)^2|H_{1/2,1}|^2+(1-\cos\Theta)^2|H_{-1/2,-1}|^2$$
$$+\sin^2\Theta|H_{1/2,0}|^2(1+\alpha_\Omega\cos\Theta_\Omega)+\sin^2\Theta|H_{-1/2,0}|^2(1-\alpha_\Omega\cos\Theta_\Omega)$$
$$+2\alpha_\Omega\cos\chi\sin\Theta\sin\Theta_\Omega[(1+\cos\Theta)\mathrm{Re}(H_{-1/2,0}H^*_{1/2,1})$$
$$+(1-\cos\Theta)\mathrm{Re}(H_{1/2,0}H^*_{-1/2,-1})]\Big\},$$

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

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

$$\frac{d^2\Gamma}{d\omega d\cos\Theta_\Omega} \propto 1+\alpha_1\alpha_\Omega\cos\Theta_\Omega,$$

where the asymmetry parameter α_1 is defined as:

$$\alpha_1 = \frac{|H_{1/2,1}|^2-|H_{-1/2,-1}|^2}{|H_{1/2,1}|^2+|H_{-1/2,-1}|^2}.$$

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

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

where the parameters α_2 and α_3 are:

$$\alpha_2 = \frac{|H_{1/2,1}|^2-|H_{-1/2,-1}|^2}{|H_{1/2,1}|^2+|H_{-1/2,-1}|^2+2(|H_{1/2,0}|^2+|H_{-1/2,0}|^2)},$$

$$\alpha_3 = \frac{|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 - 2(|H_{1/2,0}|^2 + |H_{-1/2,0}|^2)}{|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 + 2(|H_{1/2,0}|^2 + |H_{-1/2,0}|^2)}.$$

The χ distribution is:

$$\frac{d^2\Gamma}{d\omega d\chi} \propto \gamma \alpha_\Omega \cos\chi,$$

where:

$$\gamma = \frac{\mathrm{Re}(H_{-1/2,0}H^*_{1/2,1} + H_{1/2,0}H^*_{-1/2,-1})}{|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2}.$$

Up to now, all the analysis in this section is model-independent. With the help of the large N_c Isgur-Wise function given in Section II, we can calculate all these asymmetry parameters numerically; the results are listed in [TABLE:N].

Next, we turn to the analysis of the decay $\Omega_b \to \Omega_c^* \ell \bar{\nu}$. The procedure is analogous to the analysis of $\Omega_b \to \Omega_c \ell \bar{\nu}$. We can obtain the angular distribution as:

$$\begin{aligned}\frac{d^2\Gamma}{d\omega d\cos\Theta} = {} & \frac{G^2|V_{cb}|^2}{(2\pi)^3}\frac{q'^2 p'}{2M_1^2}\sqrt{\omega^2-1} \\ & \times \Big\{(1+\cos\Theta)^2|H_{3/2,1}|^2 + (1-\cos\Theta)^2|H_{-3/2,-1}|^2 \\ & + \sin^2\Theta|H_{1/2,0}|^2 + \sin^2\Theta|H_{-1/2,0}|^2\Big\},\end{aligned}$$

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

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

where:

$$\alpha_1' = \frac{|H_{3/2,1}|^2 - |H_{-3/2,-1}|^2}{|H_{3/2,1}|^2 + |H_{-3/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2},$$

$$\alpha_2' = \frac{|H_{3/2,1}|^2 + |H_{-3/2,-1}|^2 - 2(|H_{1/2,0}|^2 + |H_{-1/2,0}|^2)}{|H_{3/2,1}|^2 + |H_{-3/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2}.$$

All numerical results of these asymmetry parameters are listed in [TABLE:N].

B. Polarized Ω_b decay

In this subsection, we analyze decays of a polarized Ω_b, since at the proposed Z factory [9], the produced bottom quarks will be polarized. It is reasonable to assume the Ω_b will also be polarized at the Z factory. Two new decay angles are introduced, Θ_P and χ_P, where P denotes the polarization vector of the parent baryon Ω_b. The angles involved are shown in [Figure 3: see original paper] and [Figure 4: see original paper].

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

$$\begin{aligned}
\rho_{1/2,1/2} &= |H_{1/2,1}|^2(1+P\cos\Theta_P) + |H_{1/2,0}|^2(1-P\cos\Theta_P),\\
\rho_{1/2,-1/2} &= \rho_{-1/2,1/2} = P\sin\Theta_P \mathrm{Re}(H_{1/2,0}H^*_{-1/2,0}),\\
\rho_{-1/2,-1/2} &= |H_{-1/2,-1}|^2(1+P\cos\Theta_P) + |H_{-1/2,0}|^2(1-P\cos\Theta_P).
\end{aligned}$$

After integrating out the lepton angles, the full angular distribution is:

$$\begin{aligned}
\frac{d^4\Gamma}{d\omega d\cos\Theta_P d\chi_P d\cos\Theta_\Omega} &= \frac{G^2|V_{cb}|^2}{(2\pi)^4}\frac{q^2 p}{2M_1^2}\sqrt{\omega^2-1}\times \mathrm{Br}(\Omega_c\to a+b)\\
&\times \Bigg\{ |H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2\\
&+ \alpha_\Omega\cos\Theta_\Omega(|H_{1/2,1}|^2 - |H_{-1/2,-1}|^2 + |H_{1/2,0}|^2 - |H_{-1/2,0}|^2)\\
&+ P\cos\Theta_P(|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 - |H_{1/2,0}|^2 - |H_{-1/2,0}|^2)\\
&+ P\alpha_\Omega\cos\Theta_\Omega\cos\Theta_P(|H_{1/2,1}|^2 - |H_{-1/2,-1}|^2 - |H_{1/2,0}|^2 + |H_{-1/2,0}|^2)\\
&+ 2P\alpha_\Omega\sin\Theta_\Omega\sin\Theta_P\cos\chi_P\mathrm{Re}(H_{1/2,0}H^*_{-1/2,0})\Bigg\}.
\end{aligned}$$

The Θ_P angular distribution is:

$$\frac{d^2\Gamma}{d\omega d\cos\Theta_P} \propto 1 + \alpha_P P\cos\Theta_P,$$

where:

$$\alpha_P = \frac{|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 - |H_{1/2,0}|^2 - |H_{-1/2,0}|^2}{|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2}.$$

The χ_P distribution is:

$$\frac{d^2\Gamma}{d\omega d\chi_P} \propto P\gamma_P\alpha_\Omega \cos\chi_P,$$

where:

$$\gamma_P = \frac{2\mathrm{Re}(H_{1/2,0}H^*_{-1/2,0})}{|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2}.$$

The numerical results of these asymmetry parameters are shown in [TABLE:N].

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

IV. THE DECAY RATES

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

$$\frac{d\Gamma}{d\omega} = \frac{G^2|V_{cb}|^2}{(2\pi)^3}\frac{q^2 p}{2M_1^2}\sqrt{\omega^2-1}\left[|H_{1/2,1}|^2 + |H_{-1/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2\right],$$

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

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

$$\frac{d\Gamma'}{d\omega} = \frac{G^2|V_{cb}|^2}{(2\pi)^3}\frac{q'^2 p'}{2M_1^2}\sqrt{\omega^2-1}\left[|H_{3/2,1}|^2 + |H_{-3/2,-1}|^2 + |H_{1/2,0}|^2 + |H_{-1/2,0}|^2\right],$$

where $q'^2 = M_1^2 + M_3^2 - 2M_1M_3\omega$. The above distributions are plotted in [Figure 5: see original paper] and [Figure 6: see original paper]. All results are consistent with [21-23] when expressed in terms of form factors.

By inputting the form factors discussed in Section II, numerical results can be obtained. We have taken $G = 1.16637 \times 10^{-5}$ GeV^{-2} and $|V_{cb}| = 40.6 \times 10^{-3}$ [18]. The results are:

$$\begin{aligned} \Gamma(\Omega_b \to \Omega_c \ell\bar{\nu}) &= 1.686 \times 10^{-14}\ \text{GeV}, \qquad \mathcal{B}(\Omega_b \to \Omega_c \ell\bar{\nu}) = 2.82\%, \\ \Gamma(\Omega_b \to \Omega_c^* \ell\bar{\nu}) &= 3.482 \times 10^{-14}\ \text{GeV}, \qquad \mathcal{B}(\Omega_b \to \Omega_c^* \ell\bar{\nu}) = 5.82\%. \end{aligned}$$

The second width is about twice as large as the first one, which can be easily understood when considering the Clebsch-Gordan coefficients. Note that we have obtained these results using two approximations: the heavy quark limit and the 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 from HQET. The large N_c QCD results for Isgur-Wise functions have been used. The numerical results (especially the zero-recoil values) can be checked by experiments at LHCb.

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References

[1] J. G. Körner and M. Krämer, Phys. Lett. B 275 (1991) 495.
[2] P. Bialas, J. G. Körner, M. Krämer and K. Zalewski, Z. Phys. C 57 (1993) 115; B. König, J. G. Körner and M. Krämer, and P. Kroll, Phys. Rev. D 56 (1997) 4282; M. A. Ivanov, V. E. Lyubovitskij, J. G. Körner and P. Kroll, Phys. Rev. D 56 (1997) 348.
[3] Y.-B. Dai, C.-S. Huang, M.-Q. Huang and C. Liu, Phys. Lett. B 387 (1996) 379; J.-P. Lee, C. Liu and H. S. Song, Phys. Rev. D 58 (1998) 014013; M.-Q. Huang, H.-Y. Jin, J. G. Körner and C. Liu, Phys. Lett. B 629 (2005) 27.
[4] C. Albertus, E. Hernandez, J. Nieves, Phys. Rev. D 71 (2005) 014012; M. Pervin, W. Roberts and S. Capstick, Phys. Rev. C 72 (2005) 035201; D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Rev. D 73 (2006) 094002; P. Guo, H.-W. Ke, X.-Q. Li, C.-D. Lü, and Y.-M. Wang, Phys. Rev. D 75, (2007) 054017; H.-W. Ke, X.-Q. Li, Z.-T. Wei, Phys. Rev. D 77 (2008) 014020; Z.-G. Wang, arXiv:0906.4206.
[5] N. Isgur and M. B. Wise, Phys. Lett. B 232 (1989) 113; B 237 (1990) 527; M. B. Voloshin and M. A. Shifman, Yad. Fiz. 45 (1987) 463; 47 (1988) 801; E. V. Shuryak, Phys. Lett. B 93 (1980) 134; E. Eichten and B. Hill, Phys. Lett. B 234 (1990) 511.
[6] H. Georgi, Phys. Lett. B 240 (1990) 447; A. F. Falk, H. Georgi, B. Grinstein and M. B. Wise, Nucl. Phys. B343 (1990) 1.
[7] G. ’ t Hooft, Nucl. Phys. B 72 (1974) 461; E. Witten, Nucl. Phys. B 160

(1979) 57.
[8] D0 Collaboration (V. M. Abazov et al.), Phys. Rev. Lett. 101 (2008) 232002; CDF Collaboration (T. Aaltonen et al.), Phys. Rev. D 80 (2009) 072003.
[9] Sci. Chin. Phys. Mech. Astron. 53 (2010) No. 11 (Special Topics on Z-factory Physics, edited by J.-P. Ma and Z.-X. Zhang).
[10] N. Isgur and M. B. Wise, Nucl. Phys. B 348 (1991) 276; H. Georgi, Nucl. Phys. B 348 (1991) 293.
[11] F. Hussain, J. G. Körner, M. Krämer, G. Thompson, Z. Phys. C51 (1991) 321-328.
[12] C. K. Chow, Phys. Rev. D 51 (1995) 1224; C. K. Chow, Phys. Rev. D 54 (1996) 873.
[13] E. Jenkins, A. V. Manohar and M. B. Wise, Nucl. Phys. B 396 (1993) 38.
[14] R. F. Dashen and A. V. Manohar, Phys. Lett. B 315 (1993) 425; C. Carone, H. Georgi and S. Osofsky, Phys. Lett. B 322 (1994) 227; M. A. Luty and J. March-Russell, Nucl. Phys. B 426 (1994) 71; J.-L. Gervais and B. Sakita, Phys. Lett. B 52 (1984) 87.
[15] M. Jacob and G. C. Wick, Ann. Phys., 7 (1959) 404.
[16] J. D. Jackson, in: High energy physics, eds. C. de Witt and R. Gatto (Gordon and Breach, New York, 1965) p. 325.
[17] C. G. Boyd and D. E. Brahm, Phys. Lett. B 254 (1991) 468.
[18] K. Nakamura et al. (Particle Data Group), J. Phys. G 37 (2010) 075021.
[19] J. G. Körner and G. A. Schuler, Z. Phys. C 46 (1990) 93.
[20] J. G. Körner, K. Schilcher and Y. L. Wu, Phys. Lett. B 242 (1990) 119.
[21] Y.-B. Dai, C. S. Huang, C. Liu and C.-D. Lü, Phys. Lett. B 371 (1996) 99.
[22] J. G. Körner, M. Krämer and D. Pirjol, Prog. Part. Nucl. Phys. 33 (1994) 787.
[23] A. K. Leibovich and I. W. Stewart, Phys. Rev. D57 (1998) 5620.

Note: Figure translations are in progress. See original paper for figures.