Analysis of #3;b → #3;c weak decays in Heavy Quark Effective Theory (Postprint)

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Date: 2017-09-17T00:00:00+00:00

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Full Text

Analysis of Λb → Λc Weak Decays in Heavy Quark Effective Theory

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Abstract

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I. INTRODUCTION

The weak decays of heavy baryons provide an important testing ground for the Standard Model and reveal crucial features of heavy quark physics. From the study of heavy quark physics, important parameters of the Standard Model such as the Cabibbo-Kobayashi-Maskawa (CKM) matrix element Vcb can be extracted by comparing experimental measurements with theoretical calculations from decay modes like Λb → Λcl^{-} . The main difficulties in Standard Model calculations, however, arise from the poor understanding of the nonperturbative aspects of strong interactions (QCD).

For heavy hadrons containing a single heavy quark, an effective theory of QCD based on heavy quark symmetry in the heavy quark limit [1], known as heavy quark effective theory (HQET), has been proposed [2]. The classification of weak decay form factors for heavy baryons is greatly simplified in HQET [3]. At leading order in the heavy quark expansion, only one universal form factor –the Isgur-Wise function–is required to describe the Λb → Λc semileptonic decay. To order 1/mQ [4], one additional universal function and one mass parameter are introduced [5]. However, heavy quark symmetry alone cannot provide information about the detailed behavior of these universal form factors and the mass parameter. For a complete analysis of heavy baryons, we must employ other nonperturbative methods.

Various nonperturbative methods have yielded interesting results for heavy baryon weak decay form factors, including QCD sum rules [6,7], the large Nc limit [8], lattice simulations [9], dispersion relations and analyticity [10], and quark models [11]. In this paper, we apply the results from QCD sum rules and the large Nc limit to analyze in detail the weak decays Λb → Λc to order 1/mc and 1/mb. This analysis will be useful for comparison with future experimental results. In Sec. II, the Λb → Λc semileptonic decay form factors are discussed. While there is no large Nc calculation available for the universal form factor appearing in 1/mQ corrections, we argue that it vanishes in the large Nc limit. In Sec. III, we calculate numerical results for the decay rates, distributions, and various angular asymmetry parameters. In Sec. IV, we discuss several nonleptonic decay modes of Λb. We summarize our results in Sec. V.

II. FORM FACTORS

The hadronic matrix element of the weak current appearing in the effective Hamiltonian for Λb → Λc is generally parameterized by six form factors Fi and Gi (i = 1, 2, 3):

$$\begin{aligned}\langle\Lambda_c(v')|\bar{c}\gamma_\mu(1-\gamma_5)b|\Lambda_b(v)\rangle &= \bar{u}_{\Lambda_c}(v')(F_1\gamma_\mu + F_2 v_\mu + F_3 v'_\mu)u_{\Lambda_b}(v)\\ &- \bar{u}_{\Lambda_c}(v')(G_1\gamma_\mu + G_2 v_\mu + G_3 v'_\mu)\gamma_5 u_{\Lambda_b}(v),\end{aligned}$$

where v and v denote the four-velocities of Λb and Λc, respectively. Within the framework of HQET, the classification of form factors is greatly simplified. To order 1/mc and 1/mb, they are expressed as:

$$F_1 = C(\mu)\xi(y) + \left(\frac{1}{m_c} + \frac{1}{m_b}\right)\frac{\bar{\Lambda}}{y+1}[2\chi(y) + \xi(y)],$$
$$G_1 = C(\mu)\xi(y) + \left(\frac{1}{m_c} + \frac{1}{m_b}\right)\frac{\bar{\Lambda}y}{y+1}[2\chi(y) + \xi(y)],$$
$$F_2 = G_2 = \frac{\bar{\Lambda}}{m_c(y+1)}\xi(y),$$
$$F_3 = G_3 = \frac{\bar{\Lambda}}{m_b(y+1)}\xi(y),$$

with the perturbative QCD coefficient in the leading logarithmic approximation:

$$C(\mu) = \left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right]^{-6/25}\left[\frac{\alpha_s(m_c)}{\alpha_s(\mu)}\right]^{a_L(y)},$$

where $a_L(y) = \frac{8}{27}[yr(y) - 1]$ and $r(y) = \frac{\ln(y+\sqrt{y^2-1})}{\sqrt{y^2-1}}$.

Here and are the leading and subleading Isgur-Wise functions, respectively, and the mass parameter $\bar{\Lambda}$ is defined as $\bar{\Lambda} = m_{\Lambda_Q} - m_Q$. Using QCD sum rules, , , and $\bar{\Lambda}$ have been obtained [7]. QCD sum rules are regarded as a nonperturbative method rooted in QCD itself [12]. In a linear approximation, the leading Isgur-Wise function is fitted as:

$$\xi(y) = 1 - \rho^2(y-1), \quad \rho^2 = 0.55.$$

On the other hand, the subleading Isgur-Wise function is negligibly small, $\chi(y) = \mathcal{O}(10^{-2})$, and the parameter $\bar{\Lambda}$ is determined to be $\bar{\Lambda} = 0.79 \pm 0.05$ GeV.

It is interesting to compare these QCD sum rule results with those from the large Nc limit. The large Nc limit is one of the most important model-independent methods of nonperturbative QCD, despite the realistic value Nc = 3 [13]. In this limit, HQET for heavy baryons is often believed to correspond to the heavy quark Skyrme model [14]. The leading Isgur-Wise function is predicted as [8]:

$$\xi(y) = 0.99\exp[1.3(y-1)].$$

The slope of this Isgur-Wise function is steeper than that from the sum rule. In the large Nc limit, the parameter $\bar{\Lambda}$ equals the proton mass [15]. In our analysis, we take $\bar{\Lambda} = 0.87$ GeV [15], which is in agreement with the QCD sum rule result.

However, there is no Skyrme model calculation for the subleading Isgur-Wise function. We will assume that the subleading Isgur-Wise function is negligible in the Skyrme model analysis. In the following, we argue that this assumption holds in the large Nc limit. The subleading Isgur-Wise function (y) is defined by:

$$\langle\Lambda_c(v')|\bar{h}^{(c)}_{v'}\Gamma\frac{(iD)^2}{2m_Q}h^{(b)}_v|\Lambda_b(v)\rangle = \chi(y)\bar{u}_{\Lambda_c}(v')\Gamma u_{\Lambda_b}(v),$$

where $h^{(Q)}_v$ denotes the heavy quark field defined in HQET with velocity v, and Γ is some gamma matrix. The function (y) measures the amplitude of the "brown muck" transfer through strong interactions, described by the above matrix element, from the heavy quark which undergoes a velocity change from v to v due to weak decay. In the Hartree-Fock picture of large Nc HQET, a heavy baryon has Nc−1 light quarks. Any transition that involves changing the momenta of all the light quarks inside the baryon is suppressed when Nc is large. In the limit Nc → ∞, we expect (y) = 0. Furthermore, it is well known that (1) = 0 due to Luke' s theorem [4]. Therefore, we conclude that (y) vanishes in the large Nc limit.

Although the above argument makes our assumption for (y) reasonable, it should be noted that there is still a subtle point distinguishing the Skyrme model from the large Nc limit. For heavy baryon weak decay form factors, the Skyrme model result is not exactly identical to that of the large Nc limit. Consider the leading Isgur-Wise function: our large Nc argument for (y) also applies to (y), which would suggest (y 1) = 0. Because (1) = 1, we might expect the leading Isgur-Wise function to be -function-like in the large Nc limit. However, this result in principle agrees with the Skyrme model result [8] if Nc is taken to be large. The Skyrme model result in Eq. (9) can be obtained by taking Nc = 3. Therefore, (y) = 0 can be understood as the result of the large Nc limit for the Skyrme model.

III. DECAY RATES, DISTRIBUTIONS AND ASYMMETRY PARAMETERS

With the form factors from QCD sum rules and the large Nc limit, we can calculate the rates, distributions, and various asymmetry parameters for the Λb → Λc semileptonic decay. The standard expressions for these observables are given in Ref. [16] in terms of helicity amplitudes. The process Λb → Λc + W(off-shell) → Λc + l +   is considered as a two-step decay. Let ^ (_W) denote the polarization vector of the off-shell W, where _W denotes the helicity state. The longitudinal state corresponds to _W = 0, whereas _W = ±1 corresponds to transverse states.

The helicity amplitudes are defined by:

$$H^{V(A)}_{\lambda_{\Lambda_c}\lambda_W} = \epsilon_\mu(\lambda_W)\langle\Lambda_c(v';\lambda_{\Lambda_c})|J^{V(A)\mu}|\Lambda_b(v)\rangle,$$

where J^{V(A)} stands for the vector (axial vector) current, and _{Λ_c} in the subscript is the helicity of the daughter baryon Λ_c. They can be expressed in terms of the form factors as:

$$H^{V,A}_{\frac{1}{2}0} = \sqrt{2M_{\Lambda_b}M_{\Lambda_c}(y+1)}\left[(M_{\Lambda_b} \pm M_{\Lambda_c})(F_1,G_1) \mp M_{\Lambda_c}(y-1)(F_2,G_2) \mp M_{\Lambda_b}M_{\Lambda_c}(y-1)(F_3,G_3)\right],$$
$$H^{V,A}_{\frac{1}{2}1} = \sqrt{M_{\Lambda_b}(y+1)}\left[(M_{\Lambda_b} \mp M_{\Lambda_c})(F_1,G_1) + M_{\Lambda_c}(F_2,G_2) + M_{\Lambda_b}(F_3,G_3)\right],$$

where the upper (lower) sign is for the vector (axial vector) current. With the notation for the total helicity amplitude $H_{\pm\frac{1}{2}\lambda_W} = H^V_{\pm\frac{1}{2}\lambda_W} \mp H^A_{\pm\frac{1}{2}\lambda_W}$ and the parity relation $H^{V(A)}_{-\lambda_{\Lambda_c}-\lambda_W} = \pm(-1)^{\lambda_{\Lambda_c}-\frac{1}{2}}H^{V(A)}_{\lambda_{\Lambda_c}\lambda_W}$, the differential decay rate can be expressed as:

$$\frac{d^2\Gamma}{dy\,d\cos\theta} = \frac{G_F^2|V_{cb}|^2M^5_{\Lambda_b}}{192\pi^3}\sqrt{y^2-1}\left[(1+\cos\theta)^2|H_{-\frac{1}{2}-1}|^2 + (1-\cos\theta)^2|H_{\frac{1}{2}1}|^2 + 2\sin^2\theta|H_{\frac{1}{2}0}|^2\right],$$

where   is the angle between the Λ_c momentum and the lepton momentum measured in the off-shell W rest frame. The y distribution of the decay rate is obtained by integrating over cos :

$$\frac{d\Gamma}{dy} = \frac{G_F^2|V_{cb}|^2M^5_{\Lambda_b}}{192\pi^3}\sqrt{y^2-1}\left[|H_{-\frac{1}{2}-1}|^2 + |H_{\frac{1}{2}1}|^2 + 2|H_{\frac{1}{2}0}|^2\right] \equiv \frac{d\Gamma_{T-}}{dy}+\frac{d\Gamma_{T+}}{dy}+\frac{d\Gamma_{L-}}{dy}+\frac{d\Gamma_{L+}}{dy},$$

where T± and L± are defined as the transverse and longitudinal contributions to the decay rate for the final baryon helicity, respectively.

The numerical results are obtained using the form factors discussed in the previous section. We have taken m_c = 1.44 GeV, m_b = 4.83 GeV,   = 0.47 GeV, and |V_{cb}| = 0.04. The partial decay distributions are plotted as functions of y in Fig. 1 and Fig. 2 for both QCD sum rule and large Nc predictions. It is easy to see the dominance of dΓ_{T-}/dy and dΓ_{L-}/dy over the other plus helicity components. As discussed in Ref. [17], this is due to the left-handed V-A current.

From Fig. 2, we can see that the discrepancy between the two models grows larger as y increases. Because the slope of the Isgur-Wise function in the large Nc limit is steeper than that from QCD sum rules, the decay distributions in y predicted by large Nc are explicitly smaller than those from QCD sum rules when y > 1.

It is experimentally useful to calculate the lepton energy distribution. We obtain:

$$\frac{d^2\Gamma}{dE_l\, d\cos\theta} = \frac{G_F^2 |V_{cb}|^2 M_{\Lambda_b}^5}{32\pi^3} \left[(1+\cos\theta)^2 |H_{-\frac{1}{2}-1}|^2 + (1-\cos\theta)^2 |H_{\frac{1}{2}1}|^2 + 2\sin^2\theta |H_{\frac{1}{2}0}|^2 \right],$$

where $\cos\theta = \frac{2E_l + M_{\Lambda_c}(y_{\max}-y)}{\sqrt{y^2-1}M_{\Lambda_b}}$, $y_{\max} = \frac{M_{\Lambda_b}^2 + M_{\Lambda_c}^2}{2M_{\Lambda_b}M_{\Lambda_c}}$, and $y_{\min}(E_l) = y_{\max} - \frac{2E_l}{M_{\Lambda_b}}$.

The lepton energy spectra for the decay rates are given in Fig. 3 and Fig. 4 for the QCD sum rule and large Nc Isgur-Wise functions. As in the case of the y distribution, the helicity minus components dominate over the plus components. The decay distributions in E_l from large Nc are always smaller than those from QCD sum rules.

The decay rates are obtained from Eq. (15) by integrating over y, or from Eq. (16) by integrating over E_l. The numerical results for the partial decay rates into given helicity states are listed in Table 1 , where quark model results [17] are also included for comparison. The total decay rate is obtained by summing all contributions:

For QCD sum rule linear fitting:

$$\Gamma = 6.17 \times 10^{-14}\,\text{GeV}, \quad \text{Br.}(\Lambda_b \to \Lambda_c l\bar{\nu}) = 11.5\% \times \frac{1.23\times10^{-12}\,\text{sec}}{\tau(\Lambda_b)}.$$

For large Nc approximation:

$$\Gamma = 4.51 \times 10^{-14}\,\text{GeV}, \quad \text{Br.}(\Lambda_b \to \Lambda_c l\bar{\nu}) = 8.43\% \times \frac{1.23\times10^{-12}\,\text{sec}}{\tau(\Lambda_b)}.$$

The quark model results from Ref. [17] are $\Gamma = 4.28 \times 10^{-14}$ GeV and Br. $=$ 7.99% for $\tau(\Lambda_b) = 1.23 \times 10^{-12}$ sec. The QCD sum rule predicts a larger decay branching ratio than the large Nc model, as expected. We also see that both QCD sum rules and large Nc predict larger results for the decay than the quark model of Ref. [17]. Up to leading order, we have $\Gamma = 5.52\times10^{-14}$ GeV for QCD sum rules and $\Gamma = 4.00 \times 10^{-14}$ GeV for the large Nc limit. This means that 1/m_c and 1/m_b corrections yield about an 11% enhancement for the total decay rate.

Now we turn to the various asymmetry parameters. The polarization effects in the process Λb → Λc are revealed in various angular distributions. First, from Eq. (14), the polar angle distribution is:

$$\frac{d\Gamma}{dy\, d\cos\theta} \propto 1 + 2\alpha' \cos\theta + \alpha'' \cos^2\theta,$$

where the asymmetry parameters and can be expressed as:

$$\alpha' = \frac{|H_{\frac{1}{2}1}|^2 - |H_{-\frac{1}{2}-1}|^2}{|H_{\frac{1}{2}1}|^2 + |H_{-\frac{1}{2}-1}|^2 + 2|H_{\frac{1}{2}0}|^2}, \quad \alpha'' = \frac{|H_{\frac{1}{2}1}|^2 + |H_{-\frac{1}{2}-1}|^2 - 2|H_{\frac{1}{2}0}|^2}{|H_{\frac{1}{2}1}|^2 + |H_{-\frac{1}{2}-1}|^2 + 2|H_{\frac{1}{2}0}|^2}.$$

Additional asymmetry parameters can be introduced if the successive hadronic cascade decay Λc → a + b is considered, where a and b are some hadrons. Two more angles are involved: Θ_Λ and . Θ_Λ is the angle between the Λ_c momentum in the Λ_b rest frame and the momentum of particle a in the Λ_c rest frame, assuming J_a = 1/2 and J_b = 0. is the relative azimuthal angle between the decay planes defined by (l,) and (a, b). The Θ_Λ and distributions of the decay are [16]:

$$\frac{d\Gamma}{dy\, d\cos\Theta_\Lambda} \propto 1 + \alpha\alpha_\Lambda \cos\Theta_\Lambda, \quad \frac{d\Gamma}{dy\, d\chi} \propto \gamma\alpha_\Lambda \cos\chi,$$

where _Λ is the asymmetry parameter in the Λ_c hadronic decay. In this case, the related asymmetry parameters and are given by:

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

When Λ_b polarization is further considered, additional asymmetry parameters can be introduced. The new decay angles are Θ_P and _P. Θ_P is the angle between the Λ_b polarization and Λ_c momentum, and _P is the azimuthal angle between the plane of Λ_b polarization and Λ_c momentum and that of a, b momenta. The decay distributions are [16]:

$$\frac{d\Gamma_{\mathrm{pol}}}{dy\, d\cos\Theta_P} \propto \alpha_P P \cos\Theta_P, \quad \frac{d\Gamma_{\mathrm{pol}}}{dy\, d\chi_P} \propto P\alpha_\Lambda\gamma_P \cos\chi_P,$$

where P is the degree of polarization of Λ_b. The asymmetry parameters _P and _P are:

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

These asymmetry parameters are functions of y. When averaging over y, the numerators and denominators are integrated separately with proper weight

$(y_{\max} - y)\sqrt{y^2 - 1}$. Our numerical results for the mean values of the asymmetry parameters are listed in Table 2 , where both QCD sum rule and large Nc results are given. Note that these results include 1/m_c and 1/m_b corrections. Quark model results [17] are also listed for comparison.

IV. NONLEPTONIC DECAYS

In this section, we consider the two-body nonleptonic decay modes Λ_b → Λ_c ( ) and Λ_cK(∗). All these decays involve external W-emission diagrams that can be analyzed using the factorization approximation [18,19]. The decays Λ_b → Λ_c ( ) also receive contributions from internal W-emission, which is non-factorizable and difficult to calculate reliably. We simply neglect this contribution in our analysis. Penguin diagrams do not contribute to these decays. There are contributions from W-exchange diagrams in both Λ_b → Λ_c ( ) and Λ_b → Λ_cK(∗) channels. Because such diagrams involve two valence quark lines meeting in the region of 1/M_W, they are suppressed and neglected. This is also justified by detailed quark model analyses for b-baryon nonleptonic decays [20]. In short, the decays will be analyzed using the factorization assumption, which is expected to be reliable except for the Λ_c ( ) channels. In a recent study [21], the non-factorizable effect in the decay Λ_c was estimated to be about 30% of the factorizable contribution. Although sizable, the factorizable effect remains dominant.

After factorization, the amplitude of the process can be expressed as the product of two matrix elements to which the form factors given in Sec. II can be applied, just as in the semileptonic case. With the definition of the Λ_b → Λ_c matrix element in Eq. (1), the widths for decays into pseudoscalar meson (P) and vector meson (V) can be easily calculated:

$$\Gamma(P) = \frac{G_F^2 |V_{cb}V_{ij}|^2}{16\pi} |\mathbf{p}_{\Lambda_c}| \left[(1-r)^2 \kappa_P^2 A^2 + (1+r)^2 \kappa_P^2 B^2\right],$$

where

$$A = (1{+}r)F_1 {+} (1{-}r)F_2, \quad B = (1{+}r)G_1 {-} (1{-}r)G_2, \quad \kappa_P = \frac{1}{1+r}F_2 {+} \frac{1}{1-r}G_2.$$

For vector meson decays:

$$\Gamma(V) = \frac{G_F^2 |V_{cb}V_{ij}|^2}{16\pi} |\mathbf{p}_{\Lambda_c}| \frac{M_V^2}{M_{\Lambda_b}^2} \left[2t_V^2 \kappa_V^2 C^2 + \kappa_V^2 D^2\right],$$

where

$$C=(1+r)F_1+\frac{1-r^2-t_V^2}{t_V}F_2,\quad D=(1-r)G_1-\frac{1+r^2-t_V^2}{t_V}G_2,\quad \kappa_V=\frac{1}{1+r}F_2+\frac{1}{1-r}G_2.$$

Here V_{ij} denotes V_{ud} for ( ) and V_{us} for K(∗), and $r = M_{\Lambda_c}/M_{\Lambda_b}$, $t_{P(V)} \equiv m_{P(V)}/M_{\Lambda_b}$ where $m_{P(V)}$ is the mass of the pseudoscalar (vector) meson. And $y = v\cdot v' = \frac{1+r^2-t^2}{2r}$. The QCD coefficient a_1 is taken as a free parameter in the discussion of nonleptonic decays [18,19].

The above expressions are spin-averaged results. If we consider spin effects, the spin up-down asymmetry of Λ_b is a good parameter to analyze Λ_b → Λ_c nonleptonic decays. In this case, the decay rates are [3,20]:

$$\Gamma(P)=\Gamma_0(P)\left[1+\alpha(P)(S_{\Lambda_c}+S_{\Lambda_b})\cdot\hat{p}_{\Lambda_c}\right],\quad \alpha(P)=\frac{2\kappa_P\mathrm{Re}(A^*B)}{A^2+\kappa_P^2B^2},$$

$$\Gamma(V)=\Gamma_0(V)\left[1+\alpha(V)S_{\Lambda_b}\cdot\hat{p}_{\Lambda_c}\right],\quad \alpha(V)=\frac{2\kappa_V\mathrm{Re}(8t_V^2C^*D)}{2t_V^2\kappa_V^2C^2+\kappa_V^2D^2},$$

where S_{Λ_Q} is the spin vector of Λ_Q and $\hat{p}_{\Lambda_c}$ is the unit vector of the Λ_c momentum. _{P(V)} is the spin up-down asymmetry parameter of Λ_b.

The numerical results from QCD sum rules and the large Nc limit are given in Table 3 . Because y is near 1.45, in the QCD sum rule case we used the nonlinear fitting of the Isgur-Wise function $\xi(y) = \left(\frac{2}{y+1}\right)^{0.5}\exp\left[0.8\frac{y-1}{y+1}\right]$ [7]. The value of a_1 is taken to be 0.98, obtained from the decay B → D [19]. Various decay constants are taken as: $f_\pi = 131$ MeV, $f_\rho = 210$ MeV, $f_K = 158$ MeV, and $f_{K^*} = 214$ MeV. Quark model results from Ref. [20] are also listed for comparison.

V. SUMMARY

We have analyzed the Λ_b → Λ_c semileptonic decay in the framework of HQET to order 1/m_c and 1/m_b. We used predictions for the Isgur-Wise functions and mass parameters from QCD sum rules and the large Nc method. In the large Nc limit, we argued that the subleading Isgur-Wise function vanishes. The decay rates, distributions, and various asymmetry parameters were calculated numerically. Some Λ_b nonleptonic decays were also calculated. The numerical results can be checked by experiments in the near future.

ACKNOWLEDGMENTS

We would like to thank Jungil Lee for helpful discussions. This work was supported in part by KOSEF through the SRC program, and in part by the Korean Ministry of Education, Project No. BSRI-97-2418. After finishing this work, we

noticed a paper [22] that calculated nonleptonic Λ_b decays in the large Nc and heavy quark limits.

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FIGURE CAPTIONS

Fig. 1 [Figure 1: see original paper]. y distribution of the decay rates for (a) QCD sum rule and (b) large Nc limit. T± and L± denote the transverse and longitudinal contributions to the decay rate for the final baryon helicity, respectively.

Fig. 2 [Figure 2: see original paper]. Comparison of the two models in the helicity component y distribution of the decay rates: (a) dΓ_{T-}/dy, (b) dΓ_{T+}/dy, (c) dΓ_{L-}/dy, (d) dΓ_{L+}/dy, (e) dΓ/dy.

Fig. 3 [Figure 3: see original paper]. Lepton energy distribution of the decay rates for (a) QCD sum rule and (b) large Nc limit.

Fig. 4 [Figure 4: see original paper]. Comparison of the two models in the helicity component lepton energy distribution of the decay rates: (a) dΓ_{T-}/dE_l, (b) dΓ_{T+}/dE_l, (c) dΓ_{L-}/dE_l, (d) dΓ_{L+}/dE_l, (e) dΓ/dE_l.

TABLE CAPTIONS

Table 1 . The partial decay rates (in 10^{1} GeV).

Table 2 . Asymmetry parameters.

Table 3 . Numerical results for Λ_b two-body nonleptonic decays. The QCD coefficient a is taken to be 0.98 [19].

FIGURES

[Figure 1: see original paper]
[Figure 2: see original paper]
[Figure 3: see original paper]
[Figure 4: see original paper]

TABLES

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

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