W-exchange contribution in hadronic decays of bottom baryon

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August 29, 2023

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The nonleptonic decays of $Λ_b$ that are dominated by $W$ exchange are studied. In particular, the decay modes $Λ_b \to Δ^0 D^0, Δ^− D^+, Λ_b \to Σ^+ Δ^0$, $Σ^+ π^0, Σ^+ K^0$ and $Λ_b \to Σ^+ π^−$ are analyzed. In another aspect, the decay $Λ_b \to Σ^+ cπ^−$ in the factorization ansatz is studied. It is shown that factorization contributes to parity violating (s-wave) amplitude $A$ only. Hence factorization gives asymmetry parameter $α = 0$. However, the dominant contribution to parity conserving (p-wave) amplitude $B$ comes from $W$ exchange, i.e., from baryon pole, giving asymmetry parameter $α = −0.77$.

Introduction

In the standard model (SM), two body hadronic decays for the heavy flavor are analyzed in terms of the effective Hamiltonian \[ H_{\text{eff}} = V_{cb} V^{*}_{cs} [a_1 (\bar{s}c) V_{- A} (\bar{c}b) V_{- A} + a_2 (\bar{c}c) V_{- A} (\bar{s}b) V_{- A}] \] (1)

\[ = V_{cb} V^{*}_{ud} [a_1 (\bar{d}u) V_{- A} (\bar{c}b) V_{- A} + a_2 (\bar{c}u) V_{- A} (\bar{d}b) V_{- A}] \] (2)

where

\[ a_1 = C_1 + \frac{1}{3} C_2 : \text{tree diagram} \]
\[ a_2 = C_2 + \frac{1}{3} C_1 : \text{color suppressed tree diagram} \] (3)

The Hamiltonian (1) arises from the transition $b \to c + s + \bar{c}$ and (2) from the transition $b \to c + d + \bar{u}$. Only the Hamiltonian (1) is relevant for the decays of bottom baryon $Λ_b$ which is studied in this paper. Both these Hamiltonian correspond to the decays which are not Cabibbo suppressed.

It is clear that $(\bar{c}b) V_{- A}$ and $(\bar{s}b) V_{- A}$ in Eq. (1) belong to the singlet and triplet representations of $SU(3)$, respectively. Thus in the factorization ansatz, only possible decays of $Λ_b$ belonging to 3 representation of $SU(3)$ are $Λ_b \to Λ^+ D^−, Λ^+ π^−$ for the first term in Eq. (1). For the second term, since $3 \times 3 = 8 + 1$, the possible decay mode of $Λ_b$ is $Λ_b \to Λ J/ψ$, as $Λ$ belongs to octet representation of $SU(3)$.

Hence for the decay $Λ_b (\frac{1+}{3}) \to Λ^+ c(\frac{3+}{2}) + P_{s}$ and $Λ_b (\frac{1+}{3}) \to Λ^* (\frac{3+}{2}) + P_{D}$, where $B^*_c (\frac{3+}{2})$ and $B^* (\frac{3+}{2})$ belong to sextet and decuplet representations of $SU(3)$, respectively, the above framework is not applicable.

For these decays the dominant contribution comes from $W$ exchange. $W$ exchange in the non-relativistic limit is encoded in the effective Hamiltonian \[ \mathcal{H}_{PC}^W = \frac{G_F}{\sqrt{2}} V_{ud} V_{cb} \sum_{i \neq j} (\alpha_i \gamma^+_{i, j} (1 - \sigma_i \cdot \sigma_j) \delta^3(r), \] (4)

where
\[\alpha_i |u\rangle = |d\rangle, \quad i = 1, 2 \text{ to be summed over } i\]
\[\gamma_j^+ |b\rangle = |c\rangle, \quad j = 3.\]

Note that \(A_b, \Sigma^0_c, \Xi^0_c\) belong to anti-symmetric representation \(\bar{3}\) of \(SU(3)\), with spin wave function
\[
\chi_{MA}^{\pm} = \frac{1}{\sqrt{2}} |(\uparrow \downarrow - \downarrow \uparrow) \uparrow\rangle,\]
(5)

where as \(\Sigma^0_c, \Sigma^+_b\) belong to symmetric representation of 6 of \(SU(3)\) with spin wave function
\[
\chi_{MS}^{\pm} = \frac{1}{\sqrt{6}} |(\uparrow \downarrow + \downarrow \uparrow) \uparrow + 2 \uparrow \downarrow\rangle.\]
(6)

From the above equation, it follows
\[
|\alpha - 1 \gamma_3^+ (1 - \sigma_1 \cdot \sigma_3) + \alpha_2 \gamma_3^+ (1 - \sigma_2 \cdot \sigma_3)\rangle |A_b\rangle = \sqrt{6} |\Sigma^0_c\rangle,\]
(7)
\[
|\alpha_2 \gamma_3^+ (1 - \sigma_2 \cdot \sigma_3) + \alpha_1 \gamma_3^+ (1 - \sigma_1 \cdot \sigma_3)\rangle |\Sigma^+_b\rangle = \sqrt{6} |A^+_c\rangle,\]
(8)
\[
|\alpha_2 \gamma_3^+ (1 - \sigma_2 \cdot \sigma_3) + \alpha_1 \gamma_3^+ (1 - \sigma_1 \cdot \sigma_3)\rangle |\Sigma^+_b\rangle = 3 \sqrt{3} |\Sigma^+_c\rangle.\]
(9)

The following comment is in order with respect to Eq. (8) and Eq. (9): one notes
\[6 \times 8 = \bar{3} + 6 + 15 + 24.\]

\(W\) exchange is relevant when one considers baryon-pole contributions (Born terms) involving the matrix elements of the form \(\langle B_c | \mathcal{H}_W^{PC} | B_b \rangle\), which can be evaluated in the non-relativistic quark model (NQM) by using Eq. (4). The form of Hamiltonian Eq. (4) lead to non-zero matrix elements [3]:
\[
\langle \Sigma^0_c | \mathcal{H}_W^{PC} | \Lambda_b \rangle = \left(\frac{G_F}{\sqrt{2}} V_{ud} V_{cb}\right) \sqrt{d'},\]
(10)
\[
\langle \Lambda^+_c | \mathcal{H}_W^{PC} | \Sigma^+_b \rangle = \left(\frac{G_F}{\sqrt{2}} V_{ud} V_{cb}\right) \sqrt{6d'},\]
(11)
\[
\langle \Sigma^-_c | \mathcal{H}_W^{PC} | \Sigma^+_b \rangle = \left(\frac{G_F}{\sqrt{2}} V_{ud} V_{cb}\right) 3 \sqrt{2d'}.\]
(12)

where [3] [6]
\[d' = \frac{3(m_\Delta - m_N)}{8 \pi \alpha_s} m_{bd}^2 \approx 10^{-2}\text{GeV}^3.\]
(13)

On using the numerical values,
\[\alpha_s = 0.32, m_b = 4.66 \text{ GeV},\]
\[m_d \approx m_u = 0.336 \text{GeV}, m_s = 0.510 \text{ GeV},\]
\[m_c = 1.43 \text{ GeV}, m_{bd} = \frac{m_b m_d}{m_b + m_d} \approx 0.313 \text{ GeV},\]
\[m_{cu} = 0.273 \text{GeV}, m_{bs} \approx 0.460 \text{GeV} .\]

Hence, using \(d'\) given in Eq. (13) and \(V_{cb} \approx 0.040\)
\[\left(\frac{G_F}{\sqrt{2}} V_{ud} V_{cb}\right) \sqrt{6d'} \approx 8.08 \times 10^{-9} \text{GeV}.\]
(14)
2 Hadronic decays of $B'_b\left(\frac{1}{2}^+\right) \rightarrow B^*\left(\frac{3}{2}^+\right) + P_D$

For the decay of above type, the decay rate is given by

$$\Gamma = \frac{1}{6\pi m^2} \frac{|p|^3}{f_D^2} (p_0 + m^*) |C|^2,$$  \hspace{1cm} (15)

where $C$ is the parity conserving (p-wave amplitude). Thus for the decays $\Lambda_b \rightarrow \Delta^0D^0, \Delta^-D^+, \Sigma^*-D^+_s$, Using $f_D \approx 0.207$ GeV, $f_{D^*_s} \approx 0.257$ GeV, from Eq. \hspace{1cm} (15)

$$\Gamma(\Lambda_b \rightarrow \Delta^0D^0) \approx 3.99 \times 10^2 |C|^2 \text{ GeV},$$  \hspace{1cm} (16)

$$\Gamma(\Lambda_b \rightarrow \Delta^-D^+) \approx 3.99 \times 10^2 |C|^2 \text{ GeV},$$  \hspace{1cm} (17)

$$\Gamma(\Lambda_b \rightarrow \Sigma^*-D^+_s) \approx 1.31 \times 10^2 |C|^2 \text{ GeV}.$$  \hspace{1cm} (18)

In order to determine the amplitude $C$, one notes $F_i T_{ijk} S^{jk} \rightarrow [F_i T_{222}] S^{22}$,

$$\approx [F_i T_{222} + F_3 T_{222} + F_3 T_{322}] S^{22},$$

$$\approx \left[ \Delta^0D^0 + \sqrt{3} \Delta^-D^+ + \Sigma^*-D^+_s \right] 2 \Sigma^0_c,$$ (19)

where $F_i = (D^0, D^+, D^+_s)$

Thus for the decays $\Lambda_b \rightarrow \Delta^0D^0, \Delta^-D^+, \Sigma^*-D^+_s$ \hspace{1cm} \hspace{1cm} (3)

$$C = \left(1, \sqrt{3}, 1 \right) 2g^* \frac{\langle \Sigma^0 | H_{\Lambda_b}^{DCF} | \Lambda_b \rangle}{m_{\Lambda_b} - m_{\Sigma^0_c}}.$$ (20)

Hence from Eq. \hspace{1cm} (10) and Eq. \hspace{1cm} (14)

$$C = \left(1, \sqrt{3}, 1 \right) (4.33) \times 10^{-9},$$  \hspace{1cm} (21)

where we have used \hspace{1cm} (3)

$$2g^* = 1.70.$$  \hspace{1cm} (22)

From Eq. \hspace{1cm} (16 \hspace{1cm} 17 \hspace{1cm} 18) and Eq. \hspace{1cm} (21), we get

$$\text{Br}(\Lambda_b \rightarrow \Delta^0D^0) \approx 1.7 \times 10^{-2},$$  \hspace{1cm} (23)

$$\text{Br}(\Lambda_b \rightarrow \Delta^-D^+) \approx 5.0 \times 10^{-2},$$  \hspace{1cm} (24)

$$\text{Br}(\Lambda_b \rightarrow \Sigma^*-D^+_s) \approx 5.4 \times 10^{-3}.$$  \hspace{1cm} (25)

To take into SU(3) breaking, Eq. \hspace{1cm} (25) is multiplied by a factor $\left( \frac{m_{\Lambda_b}}{m_{\Sigma^0_c}} \right)^2 \approx 2.16$. Thus,

$$\text{Br}(\Lambda_b \rightarrow \Sigma^*-D^+_s) \approx 1.2 \times 10^{-2}.$$ (26)

3 Hadronic decays of $B'_b\left(\frac{1}{2}^+\right) \rightarrow B^*\left(\frac{3}{2}^+\right) + P$

For the decays $\Lambda_b \rightarrow \Sigma^+_c\pi^-, \Sigma_c^0\pi^0, \Xi_c^0K^0$, from Eq. \hspace{1cm} (15), using $f_\pi = 0.130$ GeV, $f_K = 0.161$ GeV, we have

$$\Gamma(\Lambda_b \rightarrow \Sigma^+_c\pi^-) = \Gamma(\Lambda_b \rightarrow \Sigma_c^0\pi^0) \approx 2.14 \times 10^2 |C|^2 \text{ GeV,}$$ (27)

$$\Gamma(\Lambda_b \rightarrow \Xi_c^0K^0) \approx 1.00 \times 10^2 |C|^2 \text{ GeV.}$$ (28)
In order to determine the amplitude \( C \), note that
\[
S^*_{ij} P^I_k S^{ik} \rightarrow \left[ S^*_{2j} P^j_2 \right] S^{22} = \left[ \Sigma^{*+}_c \pi^- - \Sigma^{*0}_c \pi^0 + \Xi^{*0}_c K^0 \right] \sqrt{2} \Sigma^{*0}_c. \tag{29}
\]
Thus the amplitude \( C \) for the decays \( \Lambda_b \rightarrow \Sigma^{*+}_c \pi^- , \Sigma^{*0}_c \pi^0 , \Xi^{*0}_c K^0 \) is given by \[3\]
\[
C = (1, -1, 1) (2.55 \times 10^{-9}). \tag{30}
\]
Now the decay rate for the decay \( S^* \rightarrow A \pi \) is given by
\[
\Gamma \left( S^* \rightarrow A \pi \right) = \frac{1}{2\pi m^2_S} \frac{1}{f^2_S} \left( \sqrt{2} g^*_c \right)^2 (p_0 + m_A) |p|^3. \tag{31}
\]
The \( SU(3) \) symmetry gives: \( \sqrt{2} g^*_c \left[ \Sigma^{*+}_c \pi^+ - \Sigma^{*+}_c \pi^0 \right] \Lambda^+_c. \)
From Eq. \[31\], we get
\[
\Gamma \left( \Sigma^{*+}_c \rightarrow \Lambda^+_c \pi^+ \right) = (\sqrt{2} g^*_c)^2 (1.673), \tag{30}
\]
From the experimental value for this decay
\[
\sqrt{2} g^*_c \approx 0.94. \tag{32}
\]
Thus from Eq. \[30\] and Eq. \[32\],
\[
C = (1, -1, 1) (2.40 \times 10^{-9}), \tag{33}
\]
Hence from Eq. \[27\] \[28\] and Eq. \[33\]
\[
\text{Br} (\Lambda_b \rightarrow \Sigma^{*+}_c \pi^-) = \text{Br} (\Lambda_b \rightarrow \Sigma^{*0}_c \pi^0) \approx 2.74 \times 10^{-3}, \tag{34}
\]
\[
\text{Br} (\Lambda_b \rightarrow \Xi^{*0}_c K^0) \approx 1.28 \times 10^{-3}, \tag{35}
\]
\[
\rightarrow (1.28 \times 10^{-3}) \left( \frac{m_{b}}{m_{d}} \right)^2, \tag{36}
\]
\[
\approx 2.76 \times 10^{-3}. \tag{36}
\]

4 Hadronic Weak Decays \[7\]

For the hadronic weak decay \( B' (p') \rightarrow B (p) + \pi (k) \), with \( p' = p + k \), the transition matrix can be written as
\[
T = \frac{1}{(2\pi)^2} \sqrt{\frac{m m'}{2 k_0 p_0 p'_0}} u (p) (A - B_{\gamma_5}) u (p') \tag{37}
\]
where \( A \) and \( B \) are the parity violating (s-wave) and parity conserving (p-wave) amplitudes, respectively. The Decay rate is given by
\[
\Gamma = \frac{k}{4\pi m} \left[ (p_0 + m) |A|^2 + (p_0 - m) |B|^2 \right], \tag{38}
\]
and the asymmetry parameter
\[
\alpha = \frac{2kA^* B}{[ (p_0 + m) |A|^2 + (p_0 - m) |B|^2 ]}. \tag{39}
\]

4.1 Factorization

For the decay \( \Lambda_b (p') \rightarrow \Lambda^+_c (p) \pi^- (k) \), the factorization gives
\[
\left( \frac{G_F}{\sqrt{2}} V_{ud} V_{cb} \right) a_1 (-f_\pi) k^\mu \bar{u} (p) \gamma_\mu (g_V - g_A \gamma_5) u (p'). \tag{40}
\]
Thus

\[ A_{\text{fact}} = - \left( \frac{G_F}{\sqrt{2}} V_{ud} V_{cb} \right) a_1 f_\pi \left( m_{\Lambda_b} - m_{\Lambda_c} \right) g_V, \]  

(41)

\[ B_{\text{fact}} = \left( \frac{G_F}{\sqrt{2}} V_{ud} V_{cb} \right) a_1 f_\pi \left( m_{\Lambda_b} + m_{\Lambda_c} \right) g_A. \]  

(42)

The quark model gives \( g_V = 1, \) \( g_A = 0, \) implying \( B_{\text{fact}} = 0. \) Now \( a_1 = C_1 + \frac{1}{3} C_2, \) \( C_1 = 1.009, \) \( C_2 = -0.257, \)
giving \( a_1 = 0.92. \) The \( g_V = 1, \) is in the limit \( m \to 0, \) i.e., \( g_V(0) = 1. \) To get \( g_V \) for finite masses, the following prescription is used

\[ g_V = \left( 1 + \frac{m_d}{m_b} \right) \left( 1 - \frac{m_c}{m_b} \right) g_V(0) = 0.739 \]  

(43)

and

\[ a_1 g_V = 0.680 \]  

(44)

by using \( m_d = 0.336 \text{ GeV}, \) \( m_c = 1.45 \text{ GeV}, \) \( m_b = 4.66 \text{ GeV}. \) Hence from Eqs. (41) and (43), we have

\[ A = A_{\text{fact}} = -9.47 \times 10^{-8}, \]  

(45)

and from Eqs. (38), using \( k = 2.342 \text{ GeV}, \) \( p_0 + m_{\Lambda_c} = 5.558 \text{ GeV}, \) we have

\[ \text{Br} \left( \Lambda_b \to \Lambda_c^+ \pi^- \right) = 4.0 \times 10^{-3}, \]  

(46)

to be compared with the experimental value

\[ \text{Br} \left( \Lambda_b \to \Lambda_c^+ \pi^- \right) = (4.9 \pm 0.4) \times 10^{-3}. \]  

(47)

For the decay \( \Lambda_b \to \Lambda_c^+ D_s^- \), we can write

\[ A = A_{\text{fact}} = - \left( \frac{G_F}{\sqrt{2}} V_{ud} V_{cb} \right) a_1 g_V f_{D_s} \left( m_{\Lambda_b} - m_{\Lambda_c} \right) = 1.92 \times 10^{-7} \]  

(48)

on using \( f_{D_s} = 0.257 \text{ GeV}. \)

Hence, from Eq. (38), using \( k = 1.833 \text{ GeV}, \) \( p_0 + m_{\Lambda_c} = 5.216 \text{ GeV}, \) we have

\[ \text{Br} \left( \Lambda_b \to \Lambda_c^+ D_s^- \right) = 1.11 \times 10^{-2} = 1.11\% \]  

(49)

in remarkable agreement with the experimental value

\[ \text{Br} \left( \Lambda_b \to \Lambda_c^+ D_s^- \right) = (1.10 \pm 0.10)\%. \]  

(50)

Although, \( B_{\text{fact}} = 0 \) for \( \Lambda_b \to \Lambda_c^+ \pi^- \) - but there is a dominant contribution for the amplitude \( B \) from W exchange, i.e., from the baryon pole:

\[ B = B(\text{pole}) = g_{\Lambda_b \pi^-} \Sigma_b^+ \frac{1}{m_{\Sigma_b^+} - m_{\Lambda_c^+}} \langle \Lambda_c^+ | H_W^{PC} | \Sigma_b^+ \rangle. \]  

(50)

The Goldberger-Treiman (GT) relation gives

\[ g_{\Lambda_b \pi^-} \Sigma_b^+ = \frac{m_{\Lambda_b} + m_{\Sigma_b^+}}{f_\pi} g_A, \]  

(51)

The quark model gives

\[ g_A = \sqrt{\frac{2}{3}} \]  

(52)
and from Eqs. (11, 14) 
\[
\langle \Lambda^+_c \mid \mathcal{H}^{PC}_W \mid \Sigma^+_b \rangle = (8.08 \times 10^{-9}) \text{ GeV},
\]
hence
\[
B(\text{pole}) = \left( \frac{m_{\Lambda_b} + m_{\Sigma^+_b}}{m_{\Sigma^+_b} - m_{\Lambda^+_c}} \right) \frac{g_A}{f_\pi} (8.08 \times 10^{-9} \text{ GeV}),
\]
\[
= 1.67 \times 10^{-7} \text{GeV}. \tag{53}
\]
Again, the quark model value \( g_A = \sqrt{\frac{2}{3}} \) is in the limit \( m \to 0 \). To get \( g_A \) for the finite mass, the following parameterization is used:
\[
g_A = \left( 1 - \frac{m_c}{m_b} \right) g_A(0) = 0.689 \sqrt{\frac{2}{3}}. \tag{54}
\]
Thus
\[
B(\text{pole}) = (1.67 \times 10^{-7}) 0.689 \text{ GeV} = 1.10 \times 10^{-7} \text{GeV}.
\]
Hence, from Eq. (58), using \( p_0 + m_{\Lambda_c} = 0.99 \text{ GeV} \), we have
\[
\text{Br} (\Lambda_b \to \Lambda^+_c \pi^-) = 4.9 \times 10^{-3}, \tag{55}
\]
in remarkable agreement with the corresponding experimental value
\[
\text{Br} (\Lambda_b \to \Lambda^+_c \pi^-) = (4.9 \pm 0.4) \times 10^{-3}. \tag{56}
\]
From Eq. (59), the asymmetry parameter \( \alpha = -0.77 \).

The non-leptonic decay \( \Lambda_b \to \Sigma^+_c \pi^- \) is of considerable interest. Factorization does not contribute to this decay and only baryon pole contributes:
\[
g_{\Lambda_b \Sigma^+_c \pi^-} = \frac{1}{m_{\Lambda_b} - m_{\Sigma^+_c}} \langle \Sigma^+_c \mid \mathcal{H}^{PC}_W \mid \Sigma^+_b \rangle. \tag{57}
\]
GT relation gives
\[
g_{\Lambda_b \Sigma^+_c \pi^-} = \frac{m_{\Lambda_b} + m_{\Sigma^+_c}}{f_\pi} g_A, \quad g_A = \sqrt{\frac{2}{3}}. \tag{58}
\]
Thus
\[
B = B(\text{pole}) = \left( \frac{m_{\Lambda_b} + m_{\Sigma^+_c}}{m_{\Lambda_b} - m_{\Sigma^+_c}} \right) \frac{g_A}{f_\pi} \langle \Sigma^+_c \mid \mathcal{H}^{PC}_W \mid \Sigma^+_b \rangle. \tag{59}
\]
From Eqs. (12) and (14):
\[
\langle \Sigma^+_c \mid \mathcal{H}^{PC}_W \mid \Sigma^+_b \rangle = \sqrt{3} (8.08 \times 10^{-9}) \text{ GeV}. \tag{60}
\]
By using \( m_{\Sigma^+_c} = 2.45 \text{ GeV} \), from Eq. (59), we have
\[
B = B(\text{pole}) = 3.12 \times 10^{-7}, \quad p_0 - m_{\Sigma^+_c} = 0.89 \text{ GeV}.
\]
Hence, from Eq. (58), one gets
\[
\text{Br} (\Lambda_b \to \Sigma^+_c \pi^-) = 2.9 \times 10^{-3}. \tag{61}
\]
To conclude: in this work, the formalism developed in [3] is extended to \( \Lambda_b \) decays
\[
\Lambda_b \to \Delta^0 D^0, \Delta^- D^+, S^+_c D^+_s
\]
\[
\Lambda_b \to S^+_c \pi^-, S^*_c \pi^0, S^*_c K^0.
\]
The experimental data is not available to check our results. The most interesting decay in this category is

$$\Lambda_b \rightarrow \Delta^0 D^0 \rightarrow p\pi^- D^0,$$

The experimental value for the branching ratio for the decay $\Lambda_b \rightarrow p\pi^- D^0$ [8] is

$$\text{Br} (\Lambda_b \rightarrow p\pi^- D^0) = (6.4 \pm 0.7) \times 10^{-4},$$

where as, our result of the branching ratio is

$$\text{Br} (\Lambda_b \rightarrow \Delta^0 D^0) \approx 1.7 \times 10^{-2}.$$ 

Thus

$$\frac{\text{Br} (\Lambda_b \rightarrow p\pi^- D^0)}{\text{Br} (\Lambda_b \rightarrow \Delta^0 D^0)} \approx 3.9 \times 10^{-2}.$$ (63)

One notes

$$\Gamma(\Delta^0 \rightarrow p\pi^-) \approx 39 \text{ MeV}.$$ 

For the decay

$$\Lambda_b \rightarrow \Lambda^+_c D^-_s$$

$B_{\text{fact}} = 0$ and $B_{\text{pole}} = 0$. Thus for this decay only factorization contributes. The branching ratio

$$\text{Br} (\Lambda_b \rightarrow \Lambda^+_c D^-_s) = 1.11\%$$

is in agreement with the experimental value, where as, for the decay $\Lambda_b \rightarrow \Lambda^+_c \pi^-$, the factorization gives

$$\text{Br} (\Lambda_b \rightarrow \Lambda^+_c \pi^-) = 4.0 \times 10^{-3}, \text{ and } \alpha = 0,$$

which is not in agreement with the experimental value. However, after including the baryon pole contribution to the amplitude $B$, gives the branching ratio

$$\text{Br} (\Lambda_b \rightarrow \Lambda^+_c \pi^-) = 4.9 \times 10^{-3}$$

and the asymmetry parameter to be

$$\alpha = -0.77.$$ 

This result of the branching ratio is in agreement with the experimental value. 

The branching ratio for the decay $\Lambda_b \rightarrow \Sigma^+_c \pi^- \rightarrow \Lambda^+_c \pi^0 \pi^-$ is

$$\text{Br} (\Lambda_b \rightarrow \Sigma^+_c \pi^-) \approx 2.9 \times 10^{-3}$$

and may be of an interest for the experimentalists.

The decays for which the experimental data is available, our results for the branching ratios are in agreement with them. The experimental verification of our results for the asymmetry parameter $\alpha$ and the branching ratio for the decay $\Lambda_b \rightarrow \Sigma^+_c \pi^-$, would give an important boost to the formalism developed in [3] for the non-leptonic decays of $\Lambda_b$. 
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