This is the accepted manuscript made available via CHORUS. The article has been published as:

**Charmless two-body antitriplet b-baryon decays**

Y. K. Hsiao, Yu Yao, and C. Q. Geng

*Phys. Rev. D* **95**, 093001 — Published 2 May 2017

DOI: [10.1103/PhysRevD.95.093001](http://10.1103/PhysRevD.95.093001)
Charmless two-body anti-triplet $b$-baryon decays

Y.K. Hsiao$^{1,2}$, Yu Yao$^1$, and C.Q. Geng$^{1,2,3}$

$^1$Chongqing University of Posts & Telecommunications, Chongqing, 400065, China

$^2$Department of Physics, National Tsing Hua University, Hsinchu, Taiwan 300

$^3$Synergetic Innovation Center for Quantum Effects and Applications (SICQEA), Hunan Normal University, Changsha 410081, China

Abstract

We study the charmless two-body decays of $b$-baryons ($\Lambda_b$, $\Xi^-_b$, $\Xi^0_b$). We find that $B(\Xi^-_b \to \Lambda \rho^-) = (2.08^{+0.60}_{-0.51}) \times 10^{-6}$ and $B(\Xi^0_b \to \Sigma^+ \pi^-) = (4.45^{+1.14}_{-1.09}, 11.49^{+3.8}_{-2.9}, 4.69^{+1.11}_{-0.79}, 2.98^{+0.76}_{-0.51}) \times 10^{-6}$ for $M^- = (\pi^-, \rho^-, K^-, K^*_-)$, which are compatible to $B(\Lambda_b \to p \pi^-, pK^-)$. We also obtain that $B(\Lambda_b \to \Lambda \omega) = (2.30 \pm 0.10) \times 10^{-6}$, $B(\Xi^-_b \to \Xi^- \phi, \Xi^- \omega) \simeq B(\Xi^0_b \to \Xi^0 \phi, \Xi^0 \omega) = (5.35 \pm 0.41, 3.65 \pm 0.16) \times 10^{-6}$ and $B(\Xi^-_b \to \Xi^- \eta(0)) \simeq B(\Xi^0_b \to \Xi^0 \eta(0)) = (2.51^{+0.70}_{-0.46}, 2.99^{+1.16}_{-0.97}) \times 10^{-6}$. For the CP violating asymmetries, we show that $A_{CP}(\Lambda_b \to p K^*) = A_{CP}(\Xi^-_b \to \Sigma^0 (\Lambda) K^*) = A_{CP}(\Xi^0_b \to \Sigma^+ K^*) = (19.7 \pm 1.4)\%$. Similar to the charmless two-body $\Lambda_b$ decays, the $\Xi_b$ decays are accessible to the LHCb detector.
I. INTRODUCTION

The charmful and charmless $\Lambda_b$ decays, such as $\Lambda_b \to pM$ [1, 2], $\Lambda_b \to \Lambda(\eta^{(')} , \phi)$ [3, 4], $\Lambda_b \to D_s^- p, \Lambda_c^+ M$ [5], and $\Lambda_b \to pJ/\psi M$ [6, 7] with $M = (K^-, \pi^-)$, have been measured by several experiments. Recently, the LHCb Collaboration discovered the hidden-charm pentaquarks in $\Lambda_b \to J/\psi pM$ [8, 9], and found the evidence of the time-reversal violating asymmetry in $\Lambda_b \to p\pi^-\pi^+\pi^-$ [10], which indicates CP violation. Clearly, the $B_b$ decays are worthy of more theoretical and experimental studies, where $B_b$ denotes one of the anti-triplet $b$-baryons of $\Lambda_b$, $\Xi^0_b$, and $\Xi^-_b$. However, it seems more difficult to measure the $\Xi^+_b$ decays due to $f_{\Xi^+_b} \simeq 1/10 f_{\Lambda_b}$ with $f_{B_b} \equiv B(b \to B_b)$ as the fragmentation fraction. To one’s surprise, apart from the charmful $\Lambda_b \to J/\psi \Lambda$ and $\Xi^- \to J/\psi \Xi^-$ decays [1, 11, 12], the three-body $\Lambda_b$ and $\Xi^-_b$ modes have been equally observed [5, 13, 14], that is, $\Lambda_b/\Xi^0_b \to pK^0 M$, $\Lambda_b/\Xi^0_b \to \Lambda\pi^+\pi^-$, $\Lambda_b/\Xi^0_b \to \Lambda K^+ M$, $\Xi^- \to pK^- M$, and $\Xi^- \to p\pi^-\pi^-$.  

The charmless two-body $\Lambda_b$ decays have been been measured as follows [1–4]:

\begin{align}
B(\Lambda_b \to pK^-, p\pi^-) &= (4.9 \pm 0.9, 4.1 \pm 0.8) \times 10^{-6}, \\
B(\Lambda_b \to \Lambda\eta, \Lambda\eta') &= (9.3^{+7.3}_{-5.3}, < 3.1) \times 10^{-6}, \\
B(\Lambda_b \to \Lambda\phi) &= (5.18 \pm 1.04 \pm 0.35^{+0.67}_{-0.62}) \times 10^{-6},
\end{align}

(1)

where $\Lambda_b \to \Lambda\phi$ can be viewed as the first observed vector mode, while the results of $\Lambda_b \to \Lambda(\eta, \eta')$ are still consistent with the theoretical relation of $B(\Lambda_b \to \Lambda\eta) \simeq B(\Lambda_b \to \Lambda\eta')$ [15, 16]. As the counterparts of the $\Lambda_b$ cases, the two-body $\Xi_b$ decays of $\Xi^0_b \to \Sigma^+ M$, $\Xi^-_b \to \Lambda M$, and $\Xi^0_{b,-} \to \Xi^{0,-}(\eta^{(')} , \phi)$ should be explored experimentally, whereas no such decay has yet been observed. Similar to the experimental situation, theoretically, even though the two-body $\Lambda_b$ decays have been well studied in Refs. [15–22], the $\Xi_b$ cases are barely explored except those in Refs. [23–25]. In addition, the CP-violating asymmetry (CPA) of $A_{CP}(\Lambda_b \to pK^{*-})$ predicted to be $20\%$ [21] suggests that there can be large CPAs in the $\Xi_b$ processes due to the same anti-triplet hadronic structure. Moreover, some of the charmless two-body decays of $B_b \to B_n M$ with $M$ being $\pi^0$, $\eta^{(')}$, $\phi$, $\rho^0$ and $\omega$ remain unexplored. To compare with the future data, in this paper we systematically study the charmless two-body $B_b \to B_n M$ decays with $B_n$ being denoted as the baryon octet and $M$ the pseudoscalar or vector meson.
II. FORMALISM

In terms of the effective Hamiltonian at the quark level, the amplitudes of the charmless two-body $B_b \to B_n M$ decays under the factorization approach can be decomposed as the matrix elements of the $B_b \to B_n$ baryon transitions along with the vacuum to meson productions ($0 \to M$). In our classification, the first types of amplitudes with the unflavored mesons of $\pi^0, \rho^0, \omega$ and $\phi$ are given by [16, 26]

$$
\mathcal{A}(B_b \to B_n M) = \frac{G_F}{\sqrt{2}} \left\{ \alpha_2 \langle M | (\bar{u}u)_{V-A}|0 \rangle + \alpha_3 \langle M | (\bar{u}u + \bar{d}d)_{V-A}|0 \rangle + \alpha_4 \langle M | (\bar{q}q)_{V-A}|0 \rangle + \alpha_5 \langle M | (\bar{u}u + \bar{d}d)_{V+A}|0 \rangle + \alpha_6 \langle M | (\bar{q}q)_{S+P}|0 \rangle \right\} \langle B_n|\bar{q}b|B_b \rangle,
$$

(2)

with $(\bar{q}_i q_j)_{V(A)} = i \gamma_\mu (\gamma_5) q_j$ and $(\bar{q}_i q_j)_{S(P)} = i \gamma_\mu (\gamma_5) q_j$, where $\alpha_2 = V_{ub} V_{ub}^* a_2$, $\alpha_3 = -V_{ub} V_{ub}^* a_3$, $\alpha_4 = -V_{ub} V_{ub}^* a_4$, $\alpha_5 = -V_{ub} V_{ub}^* a_5$, $\alpha_6 = V_{ub} V_{ub}^* 2a_6$, $\alpha_9 = -V_{ub} V_{ub}^* a_9/2$, and $\alpha_3 = -V_{ub} V_{ub}^* (a_3 + a_4 + a_5 - a_9/2 - a_{10}/2)$. In the generalized factorization approach [26], the color-singlet currents as in Eq. (2) are kept for the vacuum to meson production and the $B_b \to B_n$ transition, such that one derives the parameters $a_i \equiv c_i^{eff} + c_i^{eff}/N_c^{eff}$ for $i =$odd (even) with the effective Wilson coefficients $c_i^{eff}$ and color number $N_c^{eff}$. On the other hand, the color-octet currents lead to the amplitudes of $\langle MB_n|(\bar{q}_\alpha q'_\delta)(q'_\beta b_\alpha)|B_b \rangle$ with $\alpha$ and $\beta$ the color indices, which are non-factorizable and disregarded. Nonetheless, by effectively shifting $N_c^{eff}$ from 2 to $\infty$, the non-factorizable contributions have been demonstrated to be well accounted [26]. Note that $\Lambda_b \to \Lambda \phi$ [16] with $a_{3,5}$ is estimated to have the large non-factorizable effect, in which $N_c^{eff}$ is found to be around 2. The relevant decays from the amplitudes in Eq. (2) are

$$
\begin{align*}
\Lambda_b &\to n M, \quad \Xi_b^{-0} \to \Sigma^{-0} M, & (\text{for } q=d) \\
\Lambda_b &\to (\Lambda, \Sigma^0) M, \quad \Xi_b^{-0} \to \Xi^{-0} M, & (\text{for } q=s) \\
\Lambda_b &\to (\Lambda, \Sigma^0) \phi, \quad \Xi_b^{-0} \to \Xi^{-0} \phi,
\end{align*}
$$

(3)
with $M = (\pi^0, \rho^0, \omega)$. The second types of amplitudes with the flavored mesons are given by [21]

$$\mathcal{A}(B_b \to B_n M) = \frac{G_F}{\sqrt{2}} \left\{ \alpha_1 + \alpha_4 \langle M | (\bar{q}u)_{V-A} | 0 \rangle \langle B_n | (\bar{u}b)_{V-A} | B_b \rangle + \alpha_6 \langle M | (\bar{q}u)_{S-P} | 0 \rangle \langle B_n | (\bar{u}b)_{S-P} | B_b \rangle \right\} ,$$

$$\mathcal{A}(B_b \to B_n \bar{K}^{(*)0}) = \frac{G_F}{\sqrt{2}} \left\{ \alpha_4 \langle \bar{K}^{(*)0} | (\bar{s}d)_{V-A} | 0 \rangle \langle B_n | (\bar{d}b)_{V-A} | B_b \rangle + \alpha_6 \langle \bar{K}^{(*)0} | (\bar{s}d)_{S-P} | 0 \rangle \langle B_n | (\bar{d}b)_{S-P} | B_b \rangle \right\} ,$$

$$\mathcal{A}(B_b \to B_n K^{(*)0}) = -\frac{G_F}{\sqrt{2}} V_{tb} V_{td}^{*} a_4 \langle K^{(*)0} | (\bar{d}s)_{V-A} | 0 \rangle \langle B_n | (\bar{s}b)_{V-A} | B_b \rangle ,$$

with $\alpha_1 = V_{ub} V_{uq}^{*} a_1$, where the explicit decay modes are

$$\Lambda_b \to p M, \Xi_b^- \to (\Lambda, \Sigma^0) M, \Xi_b^0 \to \Sigma^+ M,$$

$$\Lambda_b \to n \bar{K}^{(*)0}, \Xi_b^{-0} \to \Sigma^{-0} \bar{K}^{(*)0},$$

$$\Lambda_b \to (\Lambda, \Sigma^0) K^{(*)0}, \Xi_b^{-0} \to \Xi^{-0} K^{(*)0},$$

with $M = (\pi^-, \rho^-)$ for $q = d$ and $M = K^{(*)-}$ for $q = s$. With the mesons of $\eta^{(0)}$, the third types of amplitudes are given by [16]

$$\mathcal{A}(B_b \to B_n \eta^{(0)}) = \frac{G_F}{\sqrt{2}} \left\{ \beta_2 |\eta^{(0)}| (\bar{q}q')_A | 0 \rangle + \beta_3 |\eta^{(0)}| (\bar{s}s)_A | 0 \rangle + \beta_4 |\eta^{(0)}| (\bar{q}q)_A | 0 \rangle \right\} \times \langle B_n | (\bar{q}b)_{V-A} | B_b \rangle + \beta_6 |\eta^{(0)}| (\bar{q}q)_P | 0 \rangle \langle B_n | (\bar{q}b)_{S-P} | B_b \rangle \right\} ,$$

where $q' = u$ or $d$, $\beta_2 = -V_{ub} V_{uq}^{*} a_2 + V_{tb} V_{td}^{*} (2a_3 - 2a_5 + a_9/2)$, $\beta_3 = V_{tb} V_{td}^{*} (a_3 - a_5 - a_9/2)$, $\beta_4 = V_{tb} V_{td}^{*} a_4$, and $\beta_6 = V_{tb} V_{td}^{*} 2a_6$. In Eq. (6), the corresponding decays are

$$\Lambda_b \to n \eta^{(0)}, \Xi_b^{-0} \to \Sigma^{-0} \eta^{(0)}, \text{ (for } q = d)$$

$$\Lambda_b \to (\Lambda, \Sigma^0) \eta^{(0)}, \Xi_b^{-0} \to \Xi^{-0} \eta^{(0)}, \text{ (for } q = s)$$

In Eqs. (2), (4), and (6), the matrix elements of the $B_b \to B_n$ transitions can be presented as [23, 24]

$$\langle B_n | (\bar{q}b)_{V-A} | B_b \rangle = \bar{u}_{B_n} (f_1 \gamma_\mu - g_1 \gamma_\mu \gamma_5) u_{B_b} ,$$

$$\langle B_n | (\bar{q}b)_{S-P} | B_b \rangle = \bar{u}_{B_n} (f_S + g_P \gamma_5) u_{B_b} ,$$

where $f_{1,5}$ and $g_{1,5}$ are the form factors. Note that the parameterizations of the first matrix elements safely ignore the terms of $\bar{u}_{B_n} \sigma_{\mu\nu} q^\nu (\gamma_5) u_{B_b}$ and $\bar{u}_{B_n} q^\mu (\gamma_5) u_{B_b}$ that flip the helicity of
The $B_b \to B_n$ transition form factors for different decay modes can be related by the $SU(3)$ flavor and $SU(2)$ spin symmetries [24, 27], resulting in the connection of $F(0) \equiv g_1(0) = f_1(0)$ and the relations given in Table I, where $C_{||}$ has been extracted from the data of $B(A_b \to pK^-)$ and $B(A_b \to p\pi^-)$ [21]. For the meson productions, the matrix elements read

$$
\langle P|\bar{q}_1q_2|0\rangle = -i f_P q_\mu, \quad (m_{q_1} + m_{q_2}) \langle P|\bar{q}_1q_2P|0\rangle = -i f_P m_P^2,
$$

$$
\langle V|\bar{q}_1q_2V|0\rangle = m_V f_V \epsilon_\mu,
$$

(10)

where $M = (P, V)$ are denoted as the pseudoscalar and vector mesons, respectively, and [29]

$$
\langle \eta^{(0)}|(\bar{s}s)_A|0\rangle = -i f_{\eta^{(0)}}^s q_\mu, \quad \langle \eta^{(0)}|(\bar{q}q)_A|0\rangle = -\frac{i q_\mu^\eta}{\sqrt{2}} h_{\eta^{(0)}}^q,
$$

$$
2m_s \langle \eta^{(0)}|(\bar{s}s)_P|0\rangle = -i h_{\eta^{(0)}}^s, \quad 2m_q \langle \eta^{(0)}|(\bar{q}q)_P|0\rangle = -\frac{i q_\mu^\eta}{\sqrt{2}} h_{\eta^{(0)}}^q,
$$

(11)

with $(f_P, f_V, f_{\eta^{(0)}}^s, f_{\eta^{(0)}}^q, h_{\eta^{(0)}}^s, h_{\eta^{(0)}}^q)$ decay constants, $q_\mu(\epsilon_\mu)$ the four-momentum (-vector polarization), and $\bar{q}q = (\bar{u}u, \bar{d}d)$. The direct CP-violating asymmetry is defined by

$$
A_{CP}(B_b \to B_n M) \equiv \frac{\Gamma(B_b \to B_n M) - \Gamma(\bar{B}_b \to \bar{B}_n M)}{\Gamma(B_b \to B_n M) + \Gamma(\bar{B}_b \to \bar{B}_n M)},
$$

(12)

where $\Gamma(B_b \to B_n M)$ and $\Gamma(\bar{B}_b \to \bar{B}_n \bar{M})$ are the decay widths from the particle and antiparticle decays, respectively.

| TABLE I. $B_b$ to $B_n$ transition form factors. |
|--------------------------------------------------|
| $\langle B_n|(\bar{q}b)|B_b\rangle$ | $F(0)$ | $\langle B_n|(\bar{q}b)|B_b\rangle$ | $F(0)$ | $\langle B_n|(\bar{q}b)|B_b\rangle$ | $F(0)$ |
|------------------------------------------|--------|------------------------------------------|--------|------------------------------------------|--------|
| $\langle p|\bar{u}b|\Lambda_b\rangle$  | $\sqrt{2} C_{||}$ | $\langle \Sigma^+|(\bar{u}b)|\Xi^+_b\rangle$ | $-\sqrt{\frac{3}{2}} C_{||}$ | $\langle \Sigma^-|(db)|\Xi^-_b\rangle$ | $\sqrt{\frac{3}{2}} C_{||}$ |
| $\langle n|(db)|\Lambda_b\rangle$     | $\sqrt{2} C_{||}$ | $\langle \Lambda|(db)|\Xi^+_b\rangle$ | $-\frac{1}{2} C_{||}$ | $\langle \Lambda|(\bar{u}b)|\Xi^-_b\rangle$ | $\frac{1}{2} C_{||}$ |
| $\langle \Lambda|(\bar{s}b)|\Lambda_b\rangle$ | $C_{||}$ | $\langle \Sigma^0|(\bar{s}b)|\Xi^+_b\rangle$ | $\sqrt{\frac{3}{2}} C_{||}$ | $\langle \Sigma^0|(\bar{u}b)|\Xi^-_b\rangle$ | $-\sqrt{\frac{3}{2}} C_{||}$ |
| $\langle \Sigma^0|(\bar{s}b)|\Lambda_b\rangle$ | $0$     | $\langle \Xi^0|(\bar{s}b)|\Xi^+_b\rangle$ | $-\sqrt{\frac{3}{2}} C_{||}$ | $\langle \Xi^0|(\bar{s}b)|\Xi^-_b\rangle$ | $\sqrt{\frac{3}{2}} C_{||}$ |
III. NUMERICAL RESULTS AND DISCUSSIONS

For our numerical analysis, we use the CKM matrix elements in the Wolfenstein parameterization, given by [1]

\[
\begin{align*}
(V_{ub}, V_{tb}) &= (A\lambda^3 (\rho - i\eta), 1), \\
(V_{ud}, V_{td}) &= (1 - \lambda^2/2, A\lambda^3), \\
(V_{us}, V_{ts}) &= (\lambda, -A\lambda^2),
\end{align*}
\tag{13}
\]

with \((\lambda, A, \rho, \eta) = (0.225, 0.814, 0.120 \pm 0.022, 0.362 \pm 0.013)\). The effective Wilson coefficients \(c_i^{\text{eff}}\) are adopted as [26]

\[
\begin{align*}
c_1^{\text{eff}} &= 1.168, \\
c_2^{\text{eff}} &= -0.365, \\
10^4 \epsilon_1 c_3^{\text{eff}} &= 64.7 + 182.3\epsilon_1 + 20.2\eta - 92.6\rho + 27.9\epsilon_2 \\
&\quad + i(44.2 - 16.2\epsilon_1 + 36.8\eta - 108.6\rho + 64.4\epsilon_2), \\
10^4 \epsilon_1 c_4^{\text{eff}} &= -194.1 - 329.8\epsilon_1 + 60.7\eta + 277.8\rho - 83.7\epsilon_2 \\
&\quad + i(-132.6 + 48.5\epsilon_1 + 110.4\eta + 325.9\rho - 193.3\epsilon_2), \\
10^4 \epsilon_1 c_5^{\text{eff}} &= 64.7 + 89.8\epsilon_1 + 20.2\eta - 92.6\rho + 27.9\epsilon_2 \\
&\quad + i(44.2 - 16.2\epsilon_1 + 36.8\eta - 108.6\rho + 64.4\epsilon_2), \\
10^4 \epsilon_1 c_6^{\text{eff}} &= -194.1 - 466.7\epsilon_1 + 60.7\eta + 277.8\rho - 83.7\epsilon_2 \\
&\quad + i(-132.6 + 48.5\epsilon_1 + 110.4\eta + 325.9\rho - 193.3\epsilon_2), \\
10^4 \epsilon_1 c_9^{\text{eff}} &= -3.0 - 109.5\epsilon_1 + 0.9\eta + 4.3\rho - 1.3\epsilon_2 \\
&\quad + i(-2.0 + 1.7\eta + 5.0\rho - 3.0\epsilon_2), \\
10^4 \epsilon_1 c_{10}^{\text{eff}} &= 37.5,
\end{align*}
\tag{14}
\]
for the $b \to d$ ($\bar{b} \to \bar{d}$) transition, and
\[
\begin{align*}
c_1^{\text{eff}} &= 1.168, \quad c_2^{\text{eff}} = -0.365, \\
10^4 c_3^{\text{eff}} &= 241.9 \pm 3.2\eta + 1.4\rho + i(31.3 \mp 1.4\eta + 3.2\rho), \\
10^4 c_4^{\text{eff}} &= -508.7 \mp 9.6\eta - 4.2\rho + i(-93.9 \pm 4.2\eta - 9.6\rho), \\
10^4 c_5^{\text{eff}} &= 149.4 \pm 3.2\eta + 1.4\rho + i(31.3 \mp 1.4\eta + 3.2\rho), \\
10^4 c_6^{\text{eff}} &= -645.5 \mp 9.6\eta - 4.2\rho + i(-93.9 \pm 4.2\eta - 9.6\rho), \\
10^4 c_7^{\text{eff}} &= -112.2 \mp 0.1\eta - 0.1\rho + i(-2.2 \pm 0.1\eta - 0.1\rho), \\
10^4 c_8^{\text{eff}} &= 37.5,
\end{align*}
\]  
(15)
for the $b \to s$ ($\bar{b} \to \bar{s}$) transition, where $\epsilon_1 = (1 - \rho)^2 + \eta^2$ and $\epsilon_2 = \rho^2 + \eta^2$. The meson decay constants are taken to be [1, 28–30]
\[
\begin{align*}
(f_\pi, f_K, f_\rho, f_{K^*}, f_\omega, f_\phi) &= (0.130, 0.156, 0.205, 0.217, 0.195, 0.231) \text{ GeV}, \\
(f_\eta^q, f_{\eta^q}, f_\phi^q, f_{\phi^q}) &= (0.108, 0.089, -0.111, 0.136) \text{ GeV}, \\
(h_\eta^q, h_{\eta^q}, h_\phi^q, h_{\phi^q}) &= (0.001, 0.001, -0.055, 0.068) \text{ GeV}.
\end{align*}
\]  
(16)
In addition, the extraction from the data gives $|C_1| = 0.111 \pm 0.007$ [21, 24] in Table I. Subsequently, we obtain the branching ratios and direct CPAs for the two-body charmless $\Lambda_b$, $\Xi_b^-$ and $\Xi_b^0$ decays, shown in Tables II, III and IV, respectively.

For the $\Lambda_b$ decays, it is interesting to note that all $\Lambda_b \to \Sigma^0 M$ decays, such as $\Lambda_b \to \Sigma^0(\pi^0, \eta^0, \phi, \rho^0, \omega)$, have zero branching ratios, which are not listed in Table II. This is due to $\langle \Sigma^0|\bar{s}b|\Lambda_b\rangle = 0$, where the $b$ to $s$ transition currents transform $\Lambda_b$ to $\Lambda = (ud - du)s$ that does not correlate to $\Sigma^0 = (ud + du)s$. It is clear that these nonexistent decays with $\mathcal{B} = 0$ can test the theory based on the factorization approach. To get the values of $\mathcal{B}(\Lambda_b \to p\pi^-, p\rho^-)$ in Table II, we have used $a_1 \approx 1.0$ as the input in the amplitudes. In contrast, though being the tree-dominated modes also, we take $a_2 = 0.18 \pm 0.05$ ($N^{\text{eff}}_c \approx 2$) [23, 24] to calculate the decays of $\Lambda_b \to n(\pi^0, \rho^0, \omega)$. While $\langle \pi^0(\rho^0)|(\bar{u}u + \bar{d}d)|0\rangle = 0$ with $(\pi^0, \rho^0) = u\bar{u} - d\bar{d}$ makes the $\alpha_{3,5}$ terms disappear in the first amplitude in Eq. (2), one obtains $\mathcal{B}(\Lambda_b \to \Lambda\pi^0, \Lambda\rho^0) \simeq \mathcal{O}(10^{-8} - 10^{-7})$. On the other hand, $\Lambda_b \to \Lambda\omega$ with $\omega = u\bar{u} + d\bar{d}$ enhances its contribution from the $\alpha_{3,5}$ terms in Eq. (2), resulting in $\mathcal{B}(\Lambda_b \to \Lambda\omega) > \mathcal{B}(\Lambda_b \to \Lambda\rho^0)$. Note that $\mathcal{B}(\Lambda_b \to n\bar{K}^0, n\bar{K}^{*0}) = (4.61^{+1.48}_{-0.90}, 3.09^{+1.64}_{-0.81}) \times 10^{-6}$ are as large as the counterparts of $\mathcal{B}(\Lambda_b \to \Lambda K^-, \Lambda K^{*-}) = (4.49^{+1.06}_{-0.76}, 2.86^{+0.73}_{-0.49}) \times 10^{-6}$, whereas $\mathcal{B}(\Lambda_b \to \Lambda K^0, \Lambda K^{*0}) = \mathcal{O}(10^{-8}, 10^{-7})$ are mainly due to the CKM suppression of $|V_{td}/V_{ts}| = 0.225$, respectively.
For the $\Xi_b$ decays, we obtain

$$
\mathcal{B}(\Xi_b^{-} \to \Lambda \pi^-, \Lambda \rho^-) = (0.80^{+0.26}_{-0.20}, 2.08^{+0.69}_{-0.51}) \times 10^{-6},
$$
$$
\mathcal{B}(\Xi_b^{-} \to \Lambda K^{(*)-}) = (0.85^{+0.20}_{-0.14}, 0.54^{+0.14}_{-0.09}) \times 10^{-6},
$$
$$
\mathcal{B}(\Xi_b^{0} \to \Lambda \bar{K}^{(*)0}) = (0.82^{+0.26}_{-0.16}, 0.54^{+0.29}_{-0.14}) \times 10^{-6}.
$$

(17)

By inputing the form factors of $F(0)^2 = (3/4, 1/4)C^2_{||}$ for the $\Xi_b^{-} \to \Sigma^0$ and $\Xi_b^{-} \to \Lambda$ transitions, we get $\mathcal{B}(\Xi_b^{-} \to \Sigma^0 M^-) \simeq 3\mathcal{B}(\Xi_b^{-} \to \Lambda M^-)$ for $M^- = (\pi^-, \rho^-, K^{(*)-})$, respectively, indicating that the $\Sigma$ modes can be larger than the $\Lambda$ ones in the $\Xi_b$ decays. Explicitly, we have

$$
\mathcal{B}(\Xi_b^{0} \to \Sigma^+ \pi^-, \Sigma^+ \rho^-) = (4.45^{+1.46}_{-1.09}, 11.49^{+3.8}_{-2.9}) \times 10^{-6},
$$
$$
\mathcal{B}(\Xi_b^{0} \to \Sigma^+ K^{(*)-}) = (4.69^{+1.11}_{-0.79}, 2.98^{+0.76}_{-0.61}) \times 10^{-6},
$$
$$
\mathcal{B}(\Xi_b^{-} \to \Sigma^- \bar{K}^{(*)0}) = (5.14^{+2.52}_{-1.70}, 3.43^{+1.81}_{-1.90}) \times 10^{-6},
$$

(18)

where the relation of $\mathcal{B}(\Xi_b^{0} \to \Sigma^+ M^-) \simeq \mathcal{B}(\Lambda_b \to p M^-)$ with $M^- = (\pi^-, \rho^-, K^{(*)-})$ can be traced back to the same amplitudes in Eq. (4) with the identical inputing form factors. On the other hand, with $F(0)^2 = (3/4, 3/2)C^2_{||}$ for $\Xi_b^{-} \to \Sigma^0$ and $\Xi_b^{0} \to \Sigma^+$, we find $\mathcal{B}(\Xi_b^{-} \to \Sigma^0 K^{(*)-}) \simeq \mathcal{B}(\Xi_b^{0} \to \Sigma^+ K^{(*)-})/2$ and $\mathcal{B}(\Xi_b^{0} \to \Sigma^0 \bar{K}^{(*)0}) \simeq \mathcal{B}(\Xi_b^{-} \to \Sigma^- \bar{K}^{(*)0})/2$. For the decays with $\eta^{(*)}$, the branching fractions are given by

$$
\mathcal{B}(\Xi_b^{-} \to \Xi^- \eta^{(*)}) = (2.67^{+0.74}_{-0.49}, 3.19^{+1.24}_{-0.61}) \times 10^{-6},
$$
$$
\mathcal{B}(\Xi_b^{0} \to \Xi^0 \eta^{(*)}) = (2.51^{+0.70}_{-0.46}, 2.99^{+1.16}_{-0.57}) \times 10^{-6},
$$

(19)

with $\mathcal{B}(\Xi_b^{-} \to \Xi^- \eta^{(*)}) \simeq \mathcal{B}(\Xi_b^{0} \to \Xi^0 \eta^{(*)})$ to obey the isospin symmetry. Note that the branching ratios of these $\eta^{(*)}$ modes in Eq. (19) are about 1.5 times larger than $\mathcal{B}(\Lambda_b \to \Lambda \eta^{(*)})$ (see Table II). As a result, the decays of $\Xi_b \to \Xi \eta^{(*)}$ are promising to be measured.

The $\Lambda_b \to \Lambda \phi$ decay is sensitive to $N_{c}^{eff}$ (see Table II). To explain the data in Eq. (1), we fix $N_{c}^{eff} = 2$ to get $\mathcal{B}(\Lambda_b \to \Lambda \phi) = (3.42 \pm 0.26) \times 10^{-6}$, which implies the sizeable non-factorizable effects for $\mathcal{B}_b \to \mathcal{B}_b(\omega, \phi)$. Explicitly, we predict that

$$
\mathcal{B}(\Lambda_b \to \Lambda \omega) = (2.30 \pm 0.10) \times 10^{-6},
$$
$$
\mathcal{B}(\Xi_b^{-0} \to \Xi^- 0 \phi) = (5.70 \pm 0.43, 5.35 \pm 0.41) \times 10^{-6},
$$
$$
\mathcal{B}(\Xi_b^{-0} \to \Xi^- 0 \omega) = (3.85 \pm 0.17, 3.62 \pm 0.16) \times 10^{-6},
$$

(20)

which can be used to test the non-factorizable effects.
For the CPAs, since the $\Lambda_b$ and $\Xi_b^{0,-}$ decays are associated with the same amplitudes, we obtain

$$A_{CP}(M^-) \equiv A_{CP}(\Lambda_b \to pM^-) = A_{CP}(\Xi_b^- \to \Sigma^0(\Lambda)M^-) = A_{CP}(\Xi_b^0 \to \Sigma^+M^-), \quad (21)$$

where $A_{CP}(M^-) = (-3.9 \pm 0.4, -3.8 \pm 0.4, 6.7 \pm 0.4, 19.7 \pm 1.4)$% for $M^- = (\pi^-, \rho^-, K^-, K^{*-})$, respectively. Note that both uncertainties from the non-factorizable effects and form factors have been eliminated in Eq. (12) due to the ratios, leading to small errors for the CPAs in Tables II and III. It is interesting to see that $A_{CP}(K^{*-})$ is around 20%, which is large and should be measurable by the LHCb experiment. We remark that the large non-factorizable effects in $B_b \to B_n(\omega, \phi)$ would flip the signs of uncertainties in the corresponding CPAs.

IV. CONCLUSIONS

We have systematically examined all possible two-body $B_b \to B_n M$ decays with $B_b = (\Lambda_b, \Xi_b^-, \Xi_b^0)$, $B_n = (p, n, \Lambda, \Xi^{-,0}, \Sigma^{+,0})$ and $M = (\pi^{-0}, K^{*-0}, K^0, \rho^{0}, \omega, \phi, K^{*-0}, K^{*0})$. Explicitly, we have found that $B(\Xi_b^- \to \Lambda \rho^-) = (2.08^{+0.69}_{-0.51}) \times 10^{-6}$, $B(\Xi_b^0 \to \Sigma^+M^-) = (4.45_{-1.09}^{+1.46}, 11.49_{-2.9}^{+3.8}, 4.69_{-0.79}^{+1.11}, 2.98_{-0.51}^{+0.76}) \times 10^{-6}$ for $M^- = (\pi^-, \rho^-, K^-, K^{*-})$, $B(\Lambda_b \to \Lambda \omega) = (2.30 \pm 0.10) \times 10^{-6}$, $B(\Xi_b^- \to \Xi^- \phi, \Xi^- \omega) \simeq B(\Xi_b^0 \to \Xi^0 \phi, \Xi^0 \omega) = (5.35 \pm 0.41, 3.65 \pm 0.16) \times 10^{-6}$, and $B(\Xi_b^- \to \Xi^- \eta^{(')}) \simeq B(\Xi_b^0 \to \Xi^0 \eta^{(')}) = (2.51_{-0.46}^{+0.70}, 2.99_{-0.57}^{+1.16}) \times 10^{-6}$. For CP violation, we have obtained $A_{CP}(\Lambda_b \to pK^{*-}) = A_{CP}(\Xi_b^- \to \Sigma^0(\Lambda)K^{*-}) \equiv A_{CP}(\Xi_b^0 \to \Sigma^+K^{*-}) = (19.7 \pm 1.4)$%. We urge to have some dedicated experiments to confirm these large CP asymmetries. In sum, we have demonstrated that most of the charmless two-body anti-triplet $b$-baryon decays are accessible to the LHCb detector.

ACKNOWLEDGMENTS

We would like to thank Dr. Eduardo Rodrigues for useful discussions. This work was supported in part by National Center for Theoretical Sciences, MoST (MoST-104-2112-M-007-003-MY3), and National Science Foundation of China (11675030).

[1] K.A. Olive et al. [Particle Data Group Collaboration], Chin. Phys. C 38, 090001 (2014).
[2] T. Aaltonen et al. [CDF Collaboration], Phys. Rev. Lett. 103, 031801 (2009).
[3] R. Aaij et al. [LHCb Collaboration], JHEP 1509, 006 (2015).
[4] R. Aaij et al. [LHCb Collaboration], Phys. Lett. B 759, 282 (2016).
[5] R. Aaij et al. [LHCb Collaboration], JHEP 1404, 087 (2014).
[6] R. Aaij et al. [LHCb Collaboration], Phys. Rev. Lett. 115, 072001 (2015).
[7] R. Aaij et al. [LHCb Collaboration], JHEP 1407, 103 (2014).
[8] R. Aaij et al. [LHCb Collaboration], Chin. Phys. C 40, 011001 (2016).
[9] R. Aaij et al. [LHCb Collaboration], Phys. Rev. Lett. 117, 082003 (2016).
[10] R. Aaij et al. [LHCb Collaboration], Nature Phys. (2017) [arXiv:1609.05216 [hep-ex]].
[11] V.M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 99, 052001 (2007).
[12] T. Aaltonen et al. [CDF Collaboration], Phys. Rev. D 80, 072003 (2009).
[13] R. Aaij et al. [LHCb Collaboration], JHEP 1605, 081 (2016).
[14] R. Aaij et al. [LHCb Collaboration], arXiv:1612.02244 [hep-ex].
[15] M.R. Ahmady, C.S. Kim, S. Oh and C. Yu, Phys. Lett. B 598, 203 (2004).
[16] C.Q. Geng, Y.K. Hsiao, Y.H. Lin and Y. Yu, Eur. Phys. J. C 76, 399 (2016).
[17] C.D. Lu, Y.M. Wang, H. Zou, A. Ali and G. Kramer, Phys. Rev. D 80, 034011 (2009).
[18] S.W. Wang et al., Chin. Phys. C 37, 063103 (2013).
[19] Z.T. Wei, H.W. Ke and X.Q. Li, Phys. Rev. D 80, 094016 (2009).
[20] J. Zhu, H.W. Ke and Z.T. Wei, Eur. Phys. J. C 76, 284 (2016).
[21] Y.K. Hsiao and C.Q. Geng, Phys. Rev. D 91, 116007 (2015); PoS FPCP 2015, 073 (2015).
[22] Y. Liu, X.H. Guo and C. Wang, Phys. Rev. D 91, 016006 (2015).
[23] Y.K. Hsiao, P.Y. Lin, L.W. Luo and C.Q. Geng, Phys. Lett. B 751, 127 (2015).
[24] Y.K. Hsiao, P.Y. Lin, C.C. Lih and C.Q. Geng, Phys. Rev. D 92, 114013 (2015).
[25] X.G. He and G.N. Li, Phys. Lett. B 750, 82 (2015).
[26] A. Ali, G. Kramer and C.D. Lu, Phys. Rev. D 58, 094009 (1998).
[27] G.P. Lepage and S.J. Brodsky, Phys. Rev. Lett. 43, 545 (1979) [Erratum-ibid. 43, 1625 (1979)].
[28] D. Becirevic et. al., Nucl. Phys. B 883, 306 (2014).
[29] M. Beneke and M. Neubert, Nucl. Phys. B 651, 225 (2003).
[30] P. Ball and R. Zwicky, Phys. Rev. D 71, 014029 (2005).
TABLE II. Two-body $\Lambda_b$ decays, where the first two errors for $(B, A_{CP})$ come from the non-factorizable effects and CKM matrix elements, respectively, while the third error for $B$ is due to the form factors.

| $B_b \rightarrow B_n M$ | $B \times 10^6$ | $A_{CP} \times 10^2$ |
|-------------------------|-----------------|---------------------|
| $\Lambda_b \rightarrow p\pi^-$ | $4.25^{+1.04}_{-0.48} \pm 0.74 \pm 0.56$ | $-3.9^{+0.0}_{-0.0} \pm 0.4$ |
| $\Lambda_b \rightarrow pK^-$ | $4.49^{+0.84}_{-0.39} \pm 0.26 \pm 0.59$ | $6.7^{+0.3}_{-0.2} \pm 0.3$ |
| $\Lambda_b \rightarrow n\pi^0$ | $0.10^{+0.03}_{-0.03} \pm 0.01 \pm 0.01$ | $8.0^{+1.2}_{-1.4} \pm 0.3$ |
| $\Lambda_b \rightarrow n\bar{K}^0$ | $4.61^{+1.31}_{-0.58} \pm 0.31 \pm 0.61$ | $1.1^{+0.0}_{-0.0} \pm 0.0$ |
| $\Lambda_b \rightarrow \Lambda n^0$ | $(3.4^{+0.8}_{-0.4} \pm 0.1 \pm 0.4) \times 10^{-2}$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Lambda_b \rightarrow \Lambda K^0$ | $(9.4^{+2.3}_{-3.8} \pm 0.4 \pm 1.3) \times 10^{-3}$ | $0.2^{+0.1}_{-0.0} \pm 0.0$ |
| $\Lambda_b \rightarrow p\rho^-$ | $11.03^{+2.72}_{-1.25} \pm 1.97 \pm 1.46$ | $-3.8^{+0.9}_{-0.0} \pm 0.4$ |
| $\Lambda_b \rightarrow pK^{*-}$ | $2.86^{+0.62}_{-0.29} \pm 0.11 \pm 0.51$ | $19.7^{+0.4}_{-0.3} \pm 1.4$ |
| $\Lambda_b \rightarrow n\rho^0$ | $0.18^{+0.09}_{-0.09} \pm 0.02 \pm 0.02$ | $14.0^{+1.8}_{-1.8} \pm 1.0$ |
| $\Lambda_b \rightarrow n\omega$ | $0.22^{+0.16}_{-0.10} \pm 0.03 \pm 0.03$ | $-18.2^{+24.4}_{-4.2} \pm 1.6$ |
| $\Lambda_b \rightarrow n\phi$ | $0.02^{+0.17}_{-0.02} \pm 0.00 \pm 0.00$ | $-8.8^{+7.4}_{-5.1} \pm 0.3$ |
| $\Lambda_b \rightarrow n\bar{K}^{*0}$ | $3.09^{+1.57}_{-0.67} \pm 0.21 \pm 0.41$ | $1.3^{+0.1}_{-0.1} \pm 0.0$ |
| $\Lambda_b \rightarrow \Lambda\rho^0$ | $(9.5^{+3.0}_{-1.3} \pm 0.4 \pm 1.3) \times 10^{-2}$ | $2.3^{+0.7}_{-0.8} \pm 0.2$ |
| $\Lambda_b \rightarrow \Lambda\omega$ | $0.71^{+0.59}_{-0.70} \pm 0.04 \pm 0.09$ | $3.6^{+4.8}_{-4.0} \pm 0.2$ |
| $\Lambda_b \rightarrow \Lambda\phi$ | $1.77^{+1.65}_{-1.68} \pm 0.12 \pm 0.23$ | $1.4^{+0.7}_{-0.1} \pm 0.1$ |
| $\Lambda_b \rightarrow \Lambda\bar{K}^{*0}$ | $(9.2^{+4.7}_{-2.6} \pm 0.4 \pm 1.2) \times 10^{-2}$ | $1.3^{+0.1}_{-0.1} \pm 0.0$ |
| $\Lambda_b \rightarrow nn\eta$ | $(6.9^{+2.7}_{-2.4} \pm 0.9 \pm 0.9) \times 10^{-2}$ | $-16.8^{+2.1}_{-2.1} \pm 1.3$ |
| $\Lambda_b \rightarrow nn\eta'$ | $(4.2^{+1.8}_{-1.5} \pm 0.6 \pm 0.6) \times 10^{-2}$ | $-15.7^{+4.0}_{-5.6} \pm 1.3$ |
| $\Lambda_b \rightarrow \Lambda\eta$ | $1.59^{+0.38}_{-0.17} \pm 0.11 \pm 0.21$ | $0.4^{+0.2}_{-0.2} \pm 0.0$ |
| $\Lambda_b \rightarrow \Lambda\eta'$ | $1.90^{+0.68}_{-0.23} \pm 0.13 \pm 0.25$ | $1.6^{+0.1}_{-0.1} \pm 0.1$ |
TABLE III. Two-body $\Xi_b^-$ decays with the error descriptions being the same as Table II.

| $B_{b} \rightarrow B_{n}M$ | $B \times 10^6$ | $A_{CP} \times 10^2$ |
|---------------------------|-----------------|----------------------|
| $\Xi_b^+ \rightarrow \Xi^- \pi^0$ | $(5.7^{+1.3}_{-0.6} \pm 0.2 \pm 0.7) \times 10^{-2}$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi_b^+ \rightarrow \Sigma^- \pi^0$ | $0.11^{+0.04}_{-0.03} \pm 0.01 \pm 0.01$ | $8.0^{+1.2}_{-1.4} \pm 0.3$ |
| $\Xi_b^- \rightarrow \Sigma^0 K^-$ | $2.50^{+0.47}_{-0.22} \pm 0.15 \pm 0.33$ | $6.7^{+0.3}_{-0.2} \pm 0.3$ |
| $\Xi_b^- \rightarrow \Lambda K^-$ | $0.85^{+0.16}_{-0.07} \pm 0.05 \pm 0.11$ | $6.7^{+0.3}_{-0.2} \pm 0.3$ |
| $\Xi_b^- \rightarrow \Sigma^- \bar{K}^0$ | $5.14^{+1.46}_{-0.64} \pm 0.35 \pm 0.68$ | $1.1^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi_b^- \rightarrow \Sigma^0 \pi^-$ | $2.37^{+0.58}_{-0.27} \pm 0.41 \pm 0.31$ | $-3.9^{+0.0}_{-0.0} \pm 0.4$ |
| $\Xi_b^- \rightarrow \Lambda \pi^-$ | $0.80^{+0.20}_{-0.09} \pm 0.14 \pm 0.11$ | $-3.9^{+0.0}_{-0.0} \pm 0.4$ |
| $\Xi_b^+ \rightarrow \Xi^- K^0$ | $(1.6^{+0.3}_{-0.6} \pm 0.1 \pm 0.2) \times 10^{-2}$ | $0.2^{+0.1}_{-0.0} \pm 0.0$ |
| $\Xi_b^- \rightarrow \Xi^- \rho^0$ | $0.16^{+0.05}_{-0.02} \pm 0.01 \pm 0.02$ | $2.3^{+0.7}_{-0.8} \pm 0.2$ |
| $\Xi_b^- \rightarrow \Xi^- \omega$ | $1.18^{+2.67}_{-1.17} \pm 0.07 \pm 0.16$ | $3.6^{+4.8}_{-4.0} \pm 0.2$ |
| $\Xi_b^- \rightarrow \Xi^- \phi$ | $2.95^{+2.75}_{-2.80} \pm 0.20 \pm 0.39$ | $1.4^{+0.7}_{-0.1} \pm 0.1$ |
| $\Xi_b^- \rightarrow \Sigma^- \rho^0$ | $0.20^{+0.10}_{-0.10} \pm 0.03 \pm 0.03$ | $14.0^{+1.8}_{-1.8} \pm 1.0$ |
| $\Xi_b^- \rightarrow \Sigma^- \omega$ | $0.24^{+0.17}_{-0.11} \pm 0.04 \pm 0.03$ | $-18.2^{+24.4}_{-42.6} \pm 1.6$ |
| $\Xi_b^- \rightarrow \Sigma^- \phi$ | $0.02^{+0.09}_{-0.02} \pm 0.00 \pm 0.00$ | $-8.8^{+7.4}_{-5.1} \pm 0.3$ |
| $\Xi_b^- \rightarrow \Sigma^0 K^{*+}$ | $1.59^{+0.34}_{-0.16} \pm 0.06 \pm 0.21$ | $19.7^{+0.4}_{-0.3} \pm 1.4$ |
| $\Xi_b^- \rightarrow \Lambda K^{*+}$ | $0.54^{+0.12}_{-0.05} \pm 0.02 \pm 0.07$ | $19.7^{+0.4}_{-0.3} \pm 1.4$ |
| $\Xi_b^- \rightarrow \Sigma^- \bar{K}^{*0}$ | $3.43^{+1.75}_{-0.74} \pm 0.23 \pm 0.45$ | $1.3^{+0.1}_{-0.1} \pm 0.0$ |
| $\Xi_b^- \rightarrow \Sigma^0 \rho^-$ | $6.12^{+1.51}_{-1.09} \pm 1.09 \pm 0.81$ | $-3.8^{+0.0}_{-0.0} \pm 0.4$ |
| $\Xi_b^- \rightarrow \Lambda \rho^-$ | $2.08^{+0.51}_{-0.23} \pm 0.37 \pm 0.27$ | $-3.8^{+0.0}_{-0.0} \pm 0.4$ |
| $\Xi_b^- \rightarrow \Xi^- K^{*0}$ | $0.15^{+0.08}_{-0.03} \pm 0.01 \pm 0.02$ | $1.3^{+0.1}_{-0.1} \pm 0.0$ |
| $\Xi_b^- \rightarrow \Xi^- \eta$ | $2.67^{+0.63}_{-0.29} \pm 0.19 \pm 0.35$ | $0.4^{+0.2}_{-0.2} \pm 0.0$ |
| $\Xi_b^- \rightarrow \Xi^- \eta'$ | $3.19^{+1.14}_{-0.38} \pm 0.21 \pm 0.42$ | $1.6^{+0.1}_{-0.1} \pm 0.1$ |
| $\Xi_b^- \rightarrow \Sigma^- \eta$ | $(7.6^{+3.0}_{-2.7} \pm 1.0 \pm 1.0) \times 10^{-2}$ | $-16.8^{+2.1}_{-2.1} \pm 1.3$ |
| $\Xi_b^- \rightarrow \Sigma^- \eta'$ | $(4.7^{+2.0}_{-2.0} \pm 0.6 \pm 0.6) \times 10^{-2}$ | $-15.7^{+4.0}_{-5.6} \pm 1.3$ |
TABLE IV. Two-body $\Xi^0_b$ decays with the error descriptions being the same as Table II.

| $B_b \rightarrow B_n M$ | $B \times 10^6$ | $A_{CP} \times 10^2$ |
|--------------------------|-----------------|---------------------|
| $\Xi^0_b \rightarrow \Xi^0 \pi^0$ | $(5.3^{+1.2}_{-0.6} \pm 0.2 \pm 0.7) \times 10^{-2}$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Sigma^0 \pi^0$ | $(5.1^{+1.8}_{-1.7} \pm 0.5 \pm 0.6) \times 10^{-2}$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Lambda \pi^0$ | $(1.7^{+0.6}_{-0.5} \pm 0.1 \pm 0.2) \times 10^{-2}$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Sigma^0 K^0$ | $2.41^{+0.68}_{-0.30} \pm 0.16 \pm 0.32$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Lambda K^0$ | $0.82^{+0.23}_{-0.16} \pm 0.06 \pm 0.11$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Sigma^+ K^-$ | $4.69^{+0.87}_{-0.41} \pm 0.27 \pm 0.62$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Sigma^+ \pi^-$ | $4.45^{+1.00}_{-0.50} \pm 0.77 \pm 0.59$ | $0.0^{+0.0}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Xi^0 K^0$ | $(1.5^{+0.4}_{-0.6} \pm 0.1 \pm 0.2) \times 10^{-2}$ | $0.2^{+0.1}_{-0.0} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Xi^0 \rho^0$ | $0.15^{+0.05}_{-0.02} \pm 0.01 \pm 0.02$ | $2.3^{+0.7}_{-0.8} \pm 0.2$ |
| $\Xi^0_b \rightarrow \Xi^0 \omega$ | $1.11^{+2.51}_{-1.10} \pm 0.07 \pm 0.15$ | $3.6^{+4.8}_{-4.0} \pm 0.2$ |
| $\Xi^0_b \rightarrow \Xi^0 \phi$ | $2.77^{+2.58}_{-2.63} \pm 0.19 \pm 0.37$ | $1.4^{+0.7}_{-0.1} \pm 0.1$ |
| $\Xi^0_b \rightarrow \Sigma^0 \rho^0$ | $(9.5^{+4.6}_{-4.5} \pm 1.3 \pm 1.3) \times 10^{-2}$ | $14.0^{+1.8}_{-1.8} \pm 1.0$ |
| $\Xi^0_b \rightarrow \Sigma^0 \omega$ | $0.11^{+0.08}_{-0.05} \pm 0.02 \pm 0.01$ | $-18.2^{+24.4}_{-4.2} \pm 1.6$ |
| $\Xi^0_b \rightarrow \Sigma^0 \phi$ | $(1.0^{+8.7}_{-0.8} \pm 0.0 \pm 0.1) \times 10^{-2}$ | $-8.8^{+7.4}_{-5.1} \pm 0.3$ |
| $\Xi^0_b \rightarrow \Lambda \rho^0$ | $(3.2^{+1.6}_{-1.6} \pm 0.4 \pm 0.4) \times 10^{-2}$ | $14.0^{+1.8}_{-1.8} \pm 1.0$ |
| $\Xi^0_b \rightarrow \Lambda \omega$ | $(3.8^{+2.8}_{-1.8} \pm 0.6 \pm 0.5) \times 10^{-2}$ | $-18.2^{+24.4}_{-4.2} \pm 1.6$ |
| $\Xi^0_b \rightarrow \Lambda \phi$ | $(0.3^{+3.0}_{-0.3} \pm 0.0 \pm 0.0) \times 10^{-2}$ | $-8.8^{+7.4}_{-5.1} \pm 0.3$ |
| $\Xi^0_b \rightarrow \Sigma^0 K^{*0}$ | $1.61^{+0.82}_{-0.35} \pm 0.11 \pm 0.21$ | $1.3^{+0.1}_{-0.1} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Lambda K^{*0}$ | $0.54^{+0.28}_{-0.12} \pm 0.04 \pm 0.07$ | $1.3^{+0.1}_{-0.1} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Sigma^+ K^{*-}$ | $2.98^{+0.64}_{-0.30} \pm 0.11 \pm 0.39$ | $19.7^{+0.4}_{-0.3} \pm 1.4$ |
| $\Xi^0_b \rightarrow \Sigma^+ \rho^-$ | $11.49^{+2.83}_{-1.30} \pm 2.05 \pm 1.52$ | $-3.8^{+0.0}_{-0.0} \pm 0.4$ |
| $\Xi^0_b \rightarrow \Xi^0 K^{*-}$ | $0.14^{+0.07}_{-0.03} \pm 0.01 \pm 0.02$ | $1.3^{+0.1}_{-0.1} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Xi^0 \eta$ | $2.51^{+0.59}_{-0.27} \pm 0.17 \pm 0.33$ | $0.4^{+0.2}_{-0.2} \pm 0.0$ |
| $\Xi^0_b \rightarrow \Xi^0 \eta'$ | $2.99^{+1.07}_{-0.36} \pm 0.20 \pm 0.40$ | $1.6^{+0.1}_{-0.1} \pm 0.1$ |
| $\Xi^0_b \rightarrow \Lambda \eta$ | $(1.2^{+0.5}_{-0.4} \pm 0.2 \pm 0.2) \times 10^{-2}$ | $-16.8^{+2.1}_{-2.1} \pm 1.3$ |
| $\Xi^0_b \rightarrow \Lambda \eta'$ | $(7.4^{+3.2}_{-3.1} \pm 1.0 \pm 1.0) \times 10^{-3}$ | $-15.7^{+4.0}_{-5.6} \pm 1.3$ |
| $\Xi^0_b \rightarrow \Sigma^0 \eta$ | $(3.6^{+1.4}_{-1.3} \pm 0.5 \pm 0.5) \times 10^{-2}$ | $-16.8^{+2.1}_{-2.1} \pm 1.3$ |
| $\Xi^0_b \rightarrow \Sigma^0 \eta'$ | $(2.2^{+0.9}_{-0.9} \pm 0.3 \pm 0.3) \times 10^{-2}$ | $-15.7^{+4.0}_{-5.6} \pm 1.3$ |