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Charmless two-body anti-triplet b-baryon decays

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Abstract

We study the charmless two-body decays of b-baryons (Λ_b, Ξ_b^-, Ξ_b^0). We find that $\mathcal{B}(\Xi_b^- \to \Lambda\rho^-) = (2.08^{+0.69}_{-0.51}) \times 10^{-6}$ and $\mathcal{B}(\Xi_b^0 \to \Sigma^+ M^-) = (4.45^{+1.46}_{-1.09}, 11.49^{+3.8}_{-2.9}, 4.69^{+1.11}_{-0.79}, 2.98^{+0.76}_{-0.51}) \times 10^{-6}$ for $M^- = (\pi^-, \rho^-, K^-, K^{*-})$, which are compatible to $\mathcal{B}(\Lambda_b \to p\pi^-, pK^-)$. We also obtain that $\mathcal{B}(\Lambda_b \to \Lambda\omega) = (2.30\pm0.10)\times10^{-6}$, $\mathcal{B}(\Xi_b^- \to \Xi^-\phi, \Xi^-\omega) \simeq \mathcal{B}(\Xi_b^0 \to \Xi^0\phi, \Xi^0\omega) = (5.35\pm0.41, 3.65\pm0.16) \times 10^{-6}$ and $\mathcal{B}(\Xi_b^- \to \Xi^-\eta^{(\prime)}) \simeq \mathcal{B}(\Xi_b^0 \to \Xi^0\eta^{(\prime)}) = (2.51^{+0.70}_{-0.46}, 2.99^{+1.16}_{-0.57}) \times 10^{-6}$. For the CP violating asymmetries, we show that $\mathcal{A}_{CP}(\Lambda_b \to pK^{*-}) = \mathcal{A}_{CP}(\Xi_b^- \to \Sigma^0(\Lambda)K^{*-}) = \mathcal{A}_{CP}(\Xi_b^0 \to \Sigma^+K^{*-}) = (19.7\pm1.4)\%$. Similar to the charmless two-body Λ_b decays, the Ξ_b decays are accessible to the LHCb detector.

I. INTRODUCTION

The charmful and charmless Λ_b decays, such as $\Lambda_b \to pM$ [1, 2], $\Lambda_b \to \Lambda(\eta^{(\prime)}, \phi)$ [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 $\mathcal{B}_b$ decays are worthy of more theoretical and experimental studies, where $\mathcal{B}_b$ denotes one of the anti-triplet b-baryons of Λ_b, Ξ_b^0, and Ξ_b^-. However, it seems more difficult to measure the Ξ_b decays due to $f_{\Xi_b} \simeq 1/10 f_{\Lambda_b}$ with $f_{\mathcal{B}_b} \equiv \mathcal{B}(b \to \mathcal{B}_b)$ as the fragmentation fraction. To one's surprise, apart from the charmful $\Lambda_b \to J/\psi\Lambda$ and $\Xi_b^- \to J/\psi\Xi^-$ decays [1, 11, 12], the three-body Λ_b and Ξ_b modes have been equally observed [5, 13, 14], that is, $\Lambda_b/\Xi_b^0 \to p\bar{K}^0 M$, $\Lambda_b/\Xi_b^0 \to \Lambda\pi^+\pi^-$, $\Lambda_b/\Xi_b^0 \to \Lambda K^+ M$, $\Xi_b^- \to p\bar{K}^- M$, and $\Xi_b^- \to p\pi^-\pi^-$.

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

$$\begin{aligned}
&\mathcal{B}(\Lambda_b \to pK^-, p\pi^-) = (4.9 \pm 0.9, 4.1 \pm 0.8) \times 10^{-6}\,, \\
&\mathcal{B}(\Lambda_b \to \Lambda\eta, \Lambda\eta') = (9.3^{+7.3}_{-5.3}, < 3.1) \times 10^{-6}\,, \\
&\mathcal{B}(\Lambda_b \to \Lambda\phi) = (5.18 \pm 1.04 \pm 0.35^{+0.67}_{-0.62}) \times 10^{-6}\,,
\end{aligned} \tag{1}$$

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 $\mathcal{B}(\Lambda_b \to \Lambda\eta) \simeq \mathcal{B}(\Lambda_b \to \Lambda\eta')$ [15, 16]. As the counterparts of the Λ_b cases, the two-body Ξ_b decays of $\Xi_b^0 \to \Sigma^+ M$, $\Xi_b^- \to \Lambda M$, and $\Xi_b^{0,-} \to \Xi^{0,-}(\eta^{(\prime)}, \phi)$ should be explored experimentally, whereas no such decay has yet been observed. Similar to the experimental situation, theoretically, even though the two-body Λ_b decays have been well studied in Refs. [15–22], the Ξ_b cases are barely explored except those in Refs. [23–25]. In addition, the CP-violating asymmetry (CPA) of $\mathcal{A}_{CP}(\Lambda_b \to pK^{*-})$ predicted to be 20% [21] suggests that there can be large CPAs in the Ξ_b processes due to the same anti-triplet hadronic structure. Moreover, some of the charmless two-body decays of $\mathcal{B}_b \to \mathcal{B}_n M$ with M being π^0, $\eta^{(\prime)}$, ϕ, ρ^0 and ω remain unexplored. To compare with the future data, in this paper we systematically study the charmless two-body $\mathcal{B}_b \to \mathcal{B}_n M$ decays with $\mathcal{B}_n$ 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 $\mathcal{B}_b \to \mathcal{B}_n M$ decays under the factorization approach can be decomposed as the matrix elements of the $\mathcal{B}_b \to \mathcal{B}_n$ 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 π^0, ρ^0, ω and ϕ are given by [16, 26]

$$
\begin{aligned}
&\mathcal{A}(\mathcal{B}_b \to \mathcal{B}_n M) = \frac{G_F}{\sqrt{2}}\Bigg\{\bigg[\alpha_2\langle M|(\bar{u}u)_{V-A}|0\rangle + \alpha_3\langle M|(\bar{u}u+\bar{d}d)_{V-A}|0\rangle + \alpha_4\langle M|(\bar{q}q)_{V-A}|0\rangle \\
&+\alpha_5\langle M|(\bar{u}u+\bar{d}d)_{V+A}|0\rangle + \alpha_9\langle M|(2\bar{u}u-\bar{d}d)_{V-A}|0\rangle\bigg]\langle\mathcal{B}_n|(\bar{q}b)_{V-A}|\mathcal{B}_b\rangle \\
&+\alpha_6\langle M|(\bar{q}q)_{S+P}|0\rangle\langle\mathcal{B}_n|(\bar{q}b)_{S-P}|\Lambda_b\rangle\Bigg\}\,, \\
&\mathcal{A}(\mathcal{B}_b \to \mathcal{B}_n \phi) = \frac{G_F}{\sqrt{2}}\bar{\alpha}_3\langle\phi|(\bar{s}s)_V|0\rangle\langle\mathcal{B}_n|(\bar{s}b)_{V-A}|\mathcal{B}_b\rangle\,,
\end{aligned} \tag{2}
$$

with $(\bar{q}_i q_j)_{V(A)} = \bar{q}_i\gamma_\mu(\gamma_5)q_j$ and $(\bar{q}_i q_j)_{S(P)} = \bar{q}_i(\gamma_5)q_j$, where $\alpha_2 = V_{ub}V_{uq}^*\,a_2$, $\alpha_3 = -V_{tb}V_{tq}^*\,a_3$, $\alpha_4 = -V_{tb}V_{tq}^*\,a_4$, $\alpha_5 = -V_{tb}V_{tq}^*\,a_5$, $\alpha_6 = V_{tb}V_{tq}^* 2a_6$, $\alpha_9 = -V_{tb}V_{tq}^*\,a_9/2$, and $\bar{\alpha}_3 = -V_{tb}V_{ts}^*\,(a_3 + a_4 + a_5 - a_9/2 - a_{10}/2)$. In the generalized factorization approach [26], the color-singlet currents as in Eq. (2) are kept for the vacuum to meson production and the $\mathcal{B}_b \to \mathcal{B}_n$ transition, such that one derives the parameters $a_i \equiv c_i^{eff} + c_{i\pm1}^{eff}/N_c^{eff}$ 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 $\langle M\mathcal{B}_n|(\bar{q}_\alpha q'_\beta)(q''_\beta b_\alpha)|\mathcal{B}_b\rangle$ with α and β the color indices, which are non-factorizable and disregarded. Nonetheless, by effectively shifting N_c^{eff} from 2 to ∞, 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

$$
\begin{aligned}
&\Lambda_b \to nM,\ \Xi_b^{-,0} \to \Sigma^{-,0}M, && \text{(for q=d)} \\
&\Lambda_b \to (\Lambda,\Sigma^0)M,\ \Xi_b^{-,0} \to \Xi^{-,0}M, && \text{(for q=s)} \\
&\Lambda_b \to (\Lambda,\Sigma^0)\phi,\ \Xi_b^{-,0} \to \Xi^{-,0}\phi\,, &&
\end{aligned} \tag{3}
$$

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

$$\begin{aligned}
&\mathcal{A}(\mathcal{B}_b \to \mathcal{B}_n M) \\
&= \frac{G_F}{\sqrt{2}}\bigg\{(\alpha_1+\alpha_4)\langle M|(\bar{q}u)_{V-A}|0\rangle\langle\mathcal{B}_n|(\bar{u}b)_{V-A}|\mathcal{B}_b\rangle + \alpha_6\langle M|(\bar{q}u)_{S+P}|0\rangle\langle\mathcal{B}_n|(\bar{u}b)_{S-P}|\mathcal{B}_b\rangle\bigg\}\,, \\
&\mathcal{A}(\mathcal{B}_b \to \mathcal{B}_n \bar{K}^{(*)0}) \\
&= \frac{G_F}{\sqrt{2}}\bigg\{\alpha_4\langle \bar{K}^{(*)0}|(\bar{s}d)_{V-A}|0\rangle\langle\mathcal{B}_n|(\bar{d}b)_{V-A}|\mathcal{B}_b\rangle + \alpha_6\langle \bar{K}^{(*)0}|(\bar{s}d)_{S+P}|0\rangle\langle\mathcal{B}_n|(\bar{d}b)_{S-P}|\mathcal{B}_b\rangle\bigg\}\,, \\
&\mathcal{A}(\mathcal{B}_b \to \mathcal{B}_n K^{(*)0}) = -\frac{G_F}{\sqrt{2}}V_{tb}V_{td}^* a_4\langle K^{(*)0}|(\bar{d}s)_{V-A}|0\rangle\langle\mathcal{B}_n|(\bar{s}b)_{V-A}|\mathcal{B}_b\rangle\,, \qquad (4)
\end{aligned}$$

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

$$\begin{aligned}
&\Lambda_b \to pM,\ \Xi_b^- \to (\Lambda, \Sigma^0)M,\ \Xi_b^0 \to \Sigma^+ M, \\
&\Lambda_b \to n\bar{K}^{(*)0},\ \Xi_b^{-,0} \to \Sigma^{-,0}\bar{K}^{(*)0}, \\
&\Lambda_b \to (\Lambda, \Sigma^0)K^{(*)0},\ \Xi_b^{-,0} \to \Xi^{-,0}K^{(*)0}, \qquad (5)
\end{aligned}$$

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

$$\begin{aligned}
\mathcal{A}(\mathcal{B}_b \to \mathcal{B}_n \eta^{(\prime)}) = \frac{G_F}{\sqrt{2}}\bigg\{&\Big[\beta_2\langle\eta^{(\prime)}|(\bar{q}'q')_A|0\rangle + \beta_3\langle\eta^{(\prime)}|(\bar{s}s)_A|0\rangle + \beta_4\langle\eta^{(\prime)}|(\bar{q}q)_A|0\rangle\Big] \\
&\times \langle\mathcal{B}_n|(\bar{q}b)_{V-A}|\mathcal{B}_b\rangle + \beta_6\langle\eta^{(\prime)}|(\bar{q}q)_P|0\rangle\langle\mathcal{B}_n|(\bar{q}b)_{S-P}|\mathcal{B}_b\rangle\bigg\}\,, \qquad (6)
\end{aligned}$$

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

$$\begin{aligned}
&\Lambda_b \to n\eta^{(\prime)},\ \Xi_b^{-,0} \to \Sigma^{-,0}\eta^{(\prime)},\ \text{(for q=d)} \\
&\Lambda_b \to (\Lambda, \Sigma^0)\eta^{(\prime)},\ \Xi_b^{-,0} \to \Xi^{-,0}\eta^{(\prime)}.\ \text{(for q=s)} \qquad (7)
\end{aligned}$$

In Eqs. (2), (4), and (6), the matrix elements of the $\mathcal{B}_b \to \mathcal{B}_n$ transitions can be presented as [23, 24]

$$\begin{aligned}
\langle\mathcal{B}_n|(\bar{q}b)_{V-A}|\mathcal{B}_b\rangle &= \bar{u}_{\mathcal{B}_n}(f_1\gamma_\mu - g_1\gamma_\mu\gamma_5)u_{\mathcal{B}_b}\,, \\
\langle\mathcal{B}_n|(\bar{q}b)_{S+P}|\mathcal{B}_b\rangle &= \bar{u}_{\mathcal{B}_n}(f_S + g_P\gamma_5)u_{\mathcal{B}_b}\,, \qquad (8)
\end{aligned}$$

where $f_{1,S}$ and $g_{1,P}$ are the form factors. Note that the parameterizations of the first matrix elements safely ignore the terms of $\bar{u}_{\mathcal{B}_n}\sigma_{\mu\nu}q^\nu(\gamma_5)u_{\mathcal{B}_b}$ and $\bar{u}_{\mathcal{B}_n}q^\mu(\gamma_5)u_{\mathcal{B}_b}$ that flip the helicity of

TABLE I. $\mathcal{B}_b$ to $\mathcal{B}_n$ transition form factors.

$\langle\mathcal{B}_n\|(\bar{q}b)\|\mathcal{B}_b\rangle$	F(0)	$\langle\mathcal{B}_n\|(\bar{q}b)\|\mathcal{B}_b\rangle$	$F(0)$	$\langle\mathcal{B}_n\|(\bar{q}b)\|\mathcal{B}_b\rangle$	$F(0)$
$\langle p\|(\bar{u}b)\|\Lambda_b\rangle$	$\sqrt{\frac{3}{2}}C_{\|\|}$	$\langle\Sigma^+\|(\bar{u}b)\|\Xi_b^0\rangle$	$-\sqrt{\frac{3}{2}}C_{\|\|}$	$\langle\Sigma^-\|(\bar{d}b)\|\Xi_b^-\rangle$	$\sqrt{\frac{3}{2}}C_{\|\|}$
$\langle n\|(\bar{d}b)\|\Lambda_b\rangle$	$\sqrt{\frac{3}{2}}C_{\|\|}$	$\langle\Lambda\|(\bar{d}b)\|\Xi_b^0\rangle$	$-\frac{1}{2}C_{\|\|}$	$\langle\Lambda\|(\bar{u}b)\|\Xi_b^-\rangle$	$\frac{1}{2}C_{\|\|}$
$\langle\Lambda\|(\bar{s}b)\|\Lambda_b\rangle$	$C_{\|\|}$	$\langle\Sigma^0\|(\bar{d}b)\|\Xi_b^0\rangle$	$\sqrt{\frac{3}{4}}C_{\|\|}$	$\langle\Sigma^0\|(\bar{u}b)\|\Xi_b^-\rangle$	$-\sqrt{\frac{3}{4}}C_{\|\|}$
$\langle\Sigma^0\|(\bar{s}b)\|\Lambda_b\rangle$	0	$\langle\Xi^0\|(\bar{s}b)\|\Xi_b^0\rangle$	$-\sqrt{\frac{3}{2}}C_{\|\|}$	$\langle\Xi^-\|(\bar{s}b)\|\Xi_b^-\rangle$	$\sqrt{\frac{3}{2}}C_{\|\|}$

the spinor, whereas the (axial)vector quark currents conserve the helicity. In the equations of motion, (f_S, g_P) are related to (f_1, g_1) as $f_S = (m_{\mathcal{B}_b} - m_{\mathcal{B}_n})/(m_b - m_q)f_1$ and $g_P = (m_{\mathcal{B}_b} + m_{\mathcal{B}_n})/(m_b + m_q)g_1$, respectively, whose momentum dependences are given by [21]

$$f_1(q^2) = \frac{f_1(0)}{(1-q^2/m_{\mathcal{B}_b}^2)^2}\,,\; g_1(q^2) = \frac{g_1(0)}{(1-q^2/m_{\mathcal{B}_b}^2)^2}\,. \tag{9}$$

The $\mathcal{B}_b \to \mathcal{B}_n$ 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 $\mathcal{B}(\Lambda_b \to pK^-)$ and $\mathcal{B}(\Lambda_b \to p\pi^-)$ [21]. For the meson productions, the matrix elements read

$$\begin{aligned}
&\langle P|(\bar{q}_1 q_2)_A|0\rangle = -if_P q_\mu\,,\; (m_{q_1}+m_{q_2})\langle P|(\bar{q}_1 q_2)_P|0\rangle = -if_P m_P^2\,,\\
&\langle V|(\bar{q}_1 q_2)_V|0\rangle = m_V f_V \epsilon_\mu\,,
\end{aligned} \tag{10}$$

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

$$\begin{aligned}
&\langle\eta^{(\prime)}|(\bar{s}s)_A|0\rangle = -if^s_{\eta^{(\prime)}} q_\mu\,, \langle\eta^{(\prime)}|(\bar{q}q)_A|0\rangle = -i\frac{f^q_{\eta^{(\prime)}}}{\sqrt{2}} q_\mu\,,\\
&2m_s\langle\eta^{(\prime)}|(\bar{s}s)_P|0\rangle = -ih^s_{\eta^{(\prime)}}\,, 2m_q\langle\eta^{(\prime)}|(\bar{q}q)_P|0\rangle = -i\frac{h^q_{\eta^{(\prime)}}}{\sqrt{2}}\,,
\end{aligned} \tag{11}$$

with $(f_P, f_V, f^s_{\eta^{(\prime)}}, f^q_{\eta^{(\prime)}}, h^s_{\eta^{(\prime)}}, h^q_{\eta^{(\prime)}})$ 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

$$\mathcal{A}_{CP}(\mathcal{B}_b \to \mathcal{B}_n M) \equiv \frac{\Gamma(\mathcal{B}_b \to \mathcal{B}_n M) - \Gamma(\bar{\mathcal{B}}_b \to \bar{\mathcal{B}}_n \bar{M})}{\Gamma(\mathcal{B}_b \to \mathcal{B}_n M) + \Gamma(\bar{\mathcal{B}}_b \to \bar{\mathcal{B}}_n \bar{M})}\,, \tag{12}$$

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

III. NUMERICAL RESULTS AND DISCUSSIONS

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

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

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^{eff} are adopted as [26]

$$\begin{aligned}
c_1^{eff} &= 1.168, \quad c_2^{eff} = -0.365\,, \\
10^4 \epsilon_1 c_3^{eff} &= 64.7 + 182.3\epsilon_1 \mp 20.2\eta - 92.6\rho + 27.9\epsilon_2 \\
&\quad + i(44.2 - 16.2\epsilon_1 \mp 36.8\eta - 108.6\rho + 64.4\epsilon_2), \\
10^4 \epsilon_1 c_4^{eff} &= -194.1 - 329.8\epsilon_1 \pm 60.7\eta + 277.8\rho - 83.7\epsilon_2 \\
&\quad + i(-132.6 + 48.5\epsilon_1 \pm 110.4\eta + 325.9\rho - 193.3\epsilon_2), \\
10^4 \epsilon_1 c_5^{eff} &= 64.7 + 89.8\epsilon_1 \mp 20.2\eta - 92.6\rho + 27.9\epsilon_2 \\
&\quad + i(44.2 - 16.2\epsilon_1 \mp 36.8\eta - 108.6\rho + 64.4\epsilon_2), \\
10^4 \epsilon_1 c_6^{eff} &= -194.1 - 466.7\epsilon_1 \pm 60.7\eta + 277.8\rho - 83.7\epsilon_2 \\
&\quad + i(-132.6 + 48.5\epsilon_1 \pm 110.4\eta + 325.9\rho - 193.3\epsilon_2), \\
10^4 \epsilon_1 c_9^{eff} &= -3.0 - 109.5\epsilon_1 \pm 0.9\eta + 4.3\rho - 1.3\epsilon_2 \\
&\quad + i(-2.0 \pm 1.7\eta + 5.0\rho - 3.0\epsilon_2), \\
10^4 c_{10}^{eff} &= 37.5,
\end{aligned} \tag{14}$$

for the $b \to d$ ($\bar{b} \to \bar{d}$) transition, and

$$
\begin{aligned}
& c_1^{eff} = 1.168,\; c_2^{eff} = -0.365\,, \\
& 10^4 c_3^{eff} = 241.9 \pm 3.2\eta + 1.4\rho + i(31.3 \mp 1.4\eta + 3.2\rho), \\
& 10^4 c_4^{eff} = -508.7 \mp 9.6\eta - 4.2\rho + i(-93.9 \pm 4.2\eta - 9.6\rho), \\
& 10^4 c_5^{eff} = 149.4 \pm 3.2\eta + 1.4\rho + i(31.3 \mp 1.4\eta + 3.2\rho), \\
& 10^4 c_6^{eff} = -645.5 \mp 9.6\eta - 4.2\rho + i(-93.9 \pm 4.2\eta - 9.6\rho), \\
& 10^4 c_9^{eff} = -112.2 \mp 0.1\eta - 0.1\rho + i(-2.2 \pm 0.1\eta - 0.1\rho), \\
& 10^4 c_{10}^{eff} = 37.5,
\end{aligned} \tag{15}
$$

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]

$$
\begin{aligned}
& (f_\pi, f_K, f_\rho, f_{K^*}, f_\omega, f_\phi) = (0.130,\ 0.156,\ 0.205,\ 0.217,\ 0.195,\ 0.231)\,\text{GeV}\,, \\
& (f_\eta^q, f_{\eta'}^q, f_\eta^s, f_{\eta'}^s) = (0.108,\ 0.089,\ -0.111,\ 0.136)\,\text{GeV}\,, \\
& (h_\eta^q, h_{\eta'}^q, h_\eta^s, h_{\eta'}^s) = (0.001,\ 0.001,\ -0.055,\ 0.068)\,\text{GeV}\,.
\end{aligned} \tag{16}
$$

In addition, the extraction from the data gives $|C_{||}| = 0.111 \pm 0.007$ [21, 24] in Table I. Subsequently, we obtain the branching ratios and direct CPAs for the two-body charmless Λ_b, Ξ_b^- and Ξ_b^0 decays, shown in Tables II, III and IV, respectively.

For the Λ_b decays, it is interesting to note that all $\Lambda_b \to \Sigma^0 M$ decays, such as $\Lambda_b \to \Sigma^0(\pi^0, \eta^{(\prime)}, \phi, \rho^0, \omega)$, 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 Λ_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 $a_1 \simeq 1.0$ as the input in the amplitudes. In contrast, though being the tree-dominated modes also, we take $a_2 = 0.18 \pm 0.05$ ($N_c^{eff} \simeq 2$) [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 $\mathcal{B}(\Lambda_b \to pK^-, pK^{*-}) = (4.49^{+1.06}_{-0.76}, 2.86^{+0.73}_{-0.49}) \times 10^{-6}$, 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 Ξ_b decays, we obtain

$$\mathcal{B}(\Xi_b^- \to \Lambda\pi^-, \Lambda\rho^-) = (0.80^{+0.26}_{-0.20}, 2.08^{+0.69}_{-0.51}) \times 10^{-6}\,,$$
$$\mathcal{B}(\Xi_b^- \to \Lambda K^{(*)-}) = (0.85^{+0.20}_{-0.14}, 0.54^{+0.14}_{-0.09}) \times 10^{-6}\,,$$
$$\mathcal{B}(\Xi_b^0 \to \Lambda \bar{K}^{(*)0}) = (0.82^{+0.26}_{-0.16}, 0.54^{+0.29}_{-0.14}) \times 10^{-6}\,. \tag{17}$$

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 Σ modes can be larger than the Λ ones in the Ξ_b decays. Explicitly, we have

$$\mathcal{B}(\Xi_b^0 \to \Sigma^+\pi^-, \Sigma^+\rho^-) = (4.45^{+1.46}_{-1.09}, 11.49^{+3.8}_{-2.9}) \times 10^{-6}\,,$$
$$\mathcal{B}(\Xi_b^0 \to \Sigma^+ K^{(*)-}) = (4.69^{+1.11}_{-0.79}, 2.98^{+0.76}_{-0.51}) \times 10^{-6}\,,$$
$$\mathcal{B}(\Xi_b^- \to \Sigma^- \bar{K}^{(*)0}) = (5.14^{+2.52}_{-1.70}, 3.43^{+1.81}_{-0.90}) \times 10^{-6}\,, \tag{18}$$

where the relation of $\mathcal{B}(\Xi_b^0 \to \Sigma^+ M^-) \simeq \mathcal{B}(\Lambda_b \to pM^-)$ 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 $\eta^{(\prime)}$, the branching fractions are given by

$$\mathcal{B}(\Xi_b^- \to \Xi^-\eta^{(\prime)}) = (2.67^{+0.74}_{-0.49}, 3.19^{+1.24}_{-0.61}) \times 10^{-6}\,,$$
$$\mathcal{B}(\Xi_b^0 \to \Xi^0\eta^{(\prime)}) = (2.51^{+0.70}_{-0.46}, 2.99^{+1.16}_{-0.57}) \times 10^{-6}\,, \tag{19}$$

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

$$\mathcal{B}(\Lambda_b \to \Lambda\omega) = (2.30 \pm 0.10) \times 10^{-6}\,,$$
$$\mathcal{B}(\Xi_b^{-,0} \to \Xi^{-,0}\phi) = (5.70 \pm 0.43, 5.35 \pm 0.41) \times 10^{-6}\,,$$
$$\mathcal{B}(\Xi_b^{-,0} \to \Xi^{-,0}\omega) = (3.85 \pm 0.17, 3.62 \pm 0.16) \times 10^{-6}\,, \tag{20}$$

which can be used to test the non-factorizable effects.

For the CPAs, since the Λ_b and $\Xi_b^{-,0}$ decays are associated with the same amplitudes, we obtain

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

where $\mathcal{A}_{CP}(M^-) = (-3.9\pm0.4, -3.8\pm0.4, 6.7\pm0.4, 19.7\pm1.4)\%$ 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 $\mathcal{A}_{CP}(K^{*-})$ is around 20%, which is large and should be measurable by the LHCb experiment. We remark that the large non-factorizable effects in $\mathcal{B}_b \to \mathcal{B}_n(\omega, \phi)$ would flip the signs of uncertainties in the corresponding CPAs.

IV. CONCLUSIONS

We have systematically examined all possible two-body $\mathcal{B}_b \to \mathcal{B}_n M$ decays with $\mathcal{B}_b = (\Lambda_b, \Xi_b^-, \Xi_b^0)$, $\mathcal{B}_n = (p, n, \Lambda, \Xi^{-,0}, \Sigma^{\pm,0})$ and $M = (\pi^{-,0}, K^{-,0}, \bar{K}^0, \rho^{-,0}, \omega, \phi, K^{*-,0}, \bar{K}^{*0})$. Explicitly, we have found that $\mathcal{B}(\Xi_b^- \to \Lambda\rho^-) = (2.08^{+0.69}_{-0.51}) \times 10^{-6}$, $\mathcal{B}(\Xi_b^0 \to \Sigma^+ M^-) = (4.45^{+1.46}_{-1.09}, 11.49^{+3.8}_{-2.9}, 4.69^{+1.11}_{-0.79}, 2.98^{+0.76}_{-0.51}) \times 10^{-6}$ for $M^- = (\pi^-, \rho^-, K^-, K^{*-})$, $\mathcal{B}(\Lambda_b \to \Lambda\omega) = (2.30 \pm 0.10) \times 10^{-6}$, $\mathcal{B}(\Xi_b^- \to \Xi^-\phi, \Xi^-\omega) \simeq \mathcal{B}(\Xi_b^0 \to \Xi^0\phi, \Xi^0\omega) = (5.35 \pm 0.41, 3.65 \pm 0.16) \times 10^{-6}$, and $\mathcal{B}(\Xi_b^- \to \Xi^-\eta^{(\prime)}) \simeq \mathcal{B}(\Xi_b^0 \to \Xi^0\eta^{(\prime)}) = (2.51^{+0.70}_{-0.46}, 2.99^{+1.16}_{-0.57}) \times 10^{-6}$. For CP violation, we have obtained $\mathcal{A}_{CP}(\Lambda_b \to pK^{*-}) = \mathcal{A}_{CP}(\Xi_b^- \to \Sigma^0(\Lambda)K^{*-}) = \mathcal{A}_{CP}(\Xi_b^0 \to \Sigma^+ K^{*-}) = (19.7 \pm 1.4)\%$. 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.

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TABLE II. Two-body Λ_b decays, where the first two errors for $(\mathcal{B}, \mathcal{A}_{CP})$ come from the non-factorizable effects and CKM matrix elements, respectively, while the third error for $\mathcal{B}$ is due to the form factors.

$\mathcal{B}_b \to \mathcal{B}_n M$	$\mathcal{B} \times 10^6$	$\mathcal{A}_{CP} \times 10^2$
$\Lambda_b \to p\pi^-$	$4.25^{+1.04}_{-0.48} \pm 0.74 \pm 0.56$	$-3.9^{+0.0}_{-0.0} \pm 0.4$
$\Lambda_b \to pK^-$	$4.49^{+0.84}_{-0.39} \pm 0.26 \pm 0.59$	$6.7^{+0.3}_{-0.2} \pm 0.3$
$\Lambda_b \to n\pi^0$	$0.10^{+0.03}_{-0.03} \pm 0.01 \pm 0.01$	$8.0^{+1.2}_{-1.4} \pm 0.3$
$\Lambda_b \to n\bar{K}^0$	$4.61^{+1.31}_{-0.58} \pm 0.31 \pm 0.61$	$1.1^{+0.0}_{-0.0} \pm 0.0$
$\Lambda_b \to \Lambda\pi^0$	$(3.4^{+0.8}_{-0.4} \pm 0.1 \pm 0.4) \times 10^{-2}$	$0.0^{+0.0}_{-0.0} \pm 0.0$
$\Lambda_b \to \Lambda K^0$	$(9.4^{+2.3}_{-3.8} \pm 0.4 \pm 1.3) \times 10^{-3}$	$0.2^{+0.1}_{-0.0} \pm 0.0$
$\Lambda_b \to p\rho^-$	$11.03^{+2.72}_{-1.25} \pm 1.97 \pm 1.46$	$-3.8^{+0.0}_{-0.0} \pm 0.4$
$\Lambda_b \to pK^{*-}$	$2.86^{+0.62}_{-0.29} \pm 0.11 \pm 0.51$	$19.7^{+0.4}_{-0.3} \pm 1.4$
$\Lambda_b \to n\rho^0$	$0.18^{+0.09}_{-0.09} \pm 0.02 \pm 0.02$	$14.0^{+1.8}_{-1.8} \pm 1.0$
$\Lambda_b \to n\omega$	$0.22^{+0.16}_{-0.10} \pm 0.03 \pm 0.03$	$-18.2^{+24.4}_{-\ \ 4.2} \pm 1.6$
$\Lambda_b \to n\phi$	$0.02^{+0.17}_{-0.02} \pm 0.00 \pm 0.00$	$-8.8^{+7.4}_{-5.1} \pm 0.3$
$\Lambda_b \to n\bar{K}^{*0}$	$3.09^{+1.57}_{-0.67} \pm 0.21 \pm 0.41$	$1.3^{+0.1}_{-0.1} \pm 0.0$
$\Lambda_b \to \Lambda\rho^0$	$(9.5^{+3.0}_{-1.3} \pm 0.4 \pm 1.3) \times 10^{-2}$	$2.3^{+0.7}_{-0.8} \pm 0.2$
$\Lambda_b \to \Lambda\omega$	$0.71^{+1.59}_{-0.70} \pm 0.04 \pm 0.09$	$3.6^{+4.8}_{-4.0} \pm 0.2$
$\Lambda_b \to \Lambda\phi$	$1.77^{+1.65}_{-1.68} \pm 0.12 \pm 0.23$	$1.4^{+0.7}_{-0.1} \pm 0.1$
$\Lambda_b \to \Lambda K^{*0}$	$(9.2^{+4.7}_{-2.0} \pm 0.4 \pm 1.2) \times 10^{-2}$	$1.3^{+0.1}_{-0.1} \pm 0.0$
$\Lambda_b \to n\eta$	$(6.9^{+2.7}_{-2.4} \pm 0.9 \pm 0.9) \times 10^{-2}$	$-16.8^{+2.1}_{-2.1} \pm 1.3$
$\Lambda_b \to n\eta'$	$(4.2^{+1.8}_{-1.8} \pm 0.6 \pm 0.6) \times 10^{-2}$	$-15.7^{+4.0}_{-5.6} \pm 1.3$
$\Lambda_b \to \Lambda\eta$	$1.59^{+0.38}_{-0.17} \pm 0.11 \pm 0.21$	$0.4^{+0.2}_{-0.2} \pm 0.0$
$\Lambda_b \to \Lambda\eta'$	$1.90^{+0.68}_{-0.23} \pm 0.13 \pm 0.25$	$1.6^{+0.1}_{-0.1} \pm 0.1$

TABLE III. Two-body Ξ_b^- decays with the error descriptions being the same as Table II.

$\mathcal{B}_b \to \mathcal{B}_n M$	$\mathcal{B} \times 10^6$	$\mathcal{A}_{CP} \times 10^2$
$\Xi_b^- \to \Xi^- \pi^0$	$(5.7^{+1.3}_{-0.6} \pm 0.2 \pm 0.7) \times 10^{-2}$	$0.0^{+0.0}_{-0.0} \pm 0.0$
$\Xi_b^- \to \Sigma^- \pi^0$	$0.11^{+0.04}_{-0.04} \pm 0.01 \pm 0.01$	$8.0^{+1.2}_{-1.4} \pm 0.3$
$\Xi_b^- \to \Sigma^0 K^-$	$2.50^{+0.47}_{-0.22} \pm 0.15 \pm 0.33$	$6.7^{+0.3}_{-0.2} \pm 0.3$
$\Xi_b^- \to \Lambda K^-$	$0.85^{+0.16}_{-0.07} \pm 0.05 \pm 0.11$	$6.7^{+0.3}_{-0.2} \pm 0.3$
$\Xi_b^- \to \Sigma^- \bar{K}^0$	$5.14^{+1.46}_{-0.64} \pm 0.35 \pm 0.68$	$1.1^{+0.0}_{-0.0} \pm 0.0$
$\Xi_b^- \to \Sigma^0 \pi^-$	$2.37^{+0.58}_{-0.27} \pm 0.41 \pm 0.31$	$-3.9^{+0.0}_{-0.0} \pm 0.4$
$\Xi_b^- \to \Lambda \pi^-$	$0.80^{+0.20}_{-0.09} \pm 0.14 \pm 0.11$	$-3.9^{+0.0}_{-0.0} \pm 0.4$
$\Xi_b^- \to \Xi^- K^0$	$(1.6^{+0.3}_{-0.6} \pm 0.1 \pm 0.2) \times 10^{-2}$	$0.2^{+0.1}_{-0.0} \pm 0.0$
$\Xi_b^- \to \Xi^- \rho^0$	$0.16^{+0.05}_{-0.02} \pm 0.01 \pm 0.02$	$2.3^{+0.7}_{-0.8} \pm 0.2$
$\Xi_b^- \to \Xi^- \omega$	$1.18^{+2.67}_{-1.17} \pm 0.07 \pm 0.16$	$3.6^{+4.8}_{-4.0} \pm 0.2$
$\Xi_b^- \to \Xi^- \phi$	$2.95^{+2.75}_{-2.80} \pm 0.20 \pm 0.39$	$1.4^{+0.7}_{-0.1} \pm 0.1$
$\Xi_b^- \to \Sigma^- \rho^0$	$0.20^{+0.10}_{-0.10} \pm 0.03 \pm 0.03$	$14.0^{+1.8}_{-1.8} \pm 1.0$
$\Xi_b^- \to \Sigma^- \omega$	$0.24^{+0.17}_{-0.11} \pm 0.04 \pm 0.03$	$-18.2^{+24.4}_{-\ 4.2} \pm 1.6$
$\Xi_b^- \to \Sigma^- \phi$	$0.02^{+0.19}_{-0.02} \pm 0.00 \pm 0.00$	$-8.8^{+7.4}_{-5.1} \pm 0.3$
$\Xi_b^- \to \Sigma^0 K^{*-}$	$1.59^{+0.34}_{-0.16} \pm 0.06 \pm 0.21$	$19.7^{+0.4}_{-0.3} \pm 1.4$
$\Xi_b^- \to \Lambda K^{*-}$	$0.54^{+0.12}_{-0.05} \pm 0.02 \pm 0.07$	$19.7^{+0.4}_{-0.3} \pm 1.4$
$\Xi_b^- \to \Sigma^- \bar{K}^{*0}$	$3.43^{+1.75}_{-0.74} \pm 0.23 \pm 0.45$	$1.3^{+0.1}_{-0.1} \pm 0.0$
$\Xi_b^- \to \Sigma^0 \rho^-$	$6.12^{+1.51}_{-0.69} \pm 1.09 \pm 0.81$	$-3.8^{+0.0}_{-0.0} \pm 0.4$
$\Xi_b^- \to \Lambda \rho^-$	$2.08^{+0.51}_{-0.23} \pm 0.37 \pm 0.27$	$-3.8^{+0.0}_{-0.0} \pm 0.4$
$\Xi_b^- \to \Xi^- K^{*0}$	$0.15^{+0.08}_{-0.03} \pm 0.01 \pm 0.02$	$1.3^{+0.1}_{-0.1} \pm 0.0$
$\Xi_b^- \to \Xi^- \eta$	$2.67^{+0.63}_{-0.29} \pm 0.19 \pm 0.35$	$0.4^{+0.2}_{-0.2} \pm 0.0$
$\Xi_b^- \to \Xi^- \eta'$	$3.19^{+1.14}_{-0.38} \pm 0.21 \pm 0.42$	$1.6^{+0.1}_{-0.1} \pm 0.1$
$\Xi_b^- \to \Sigma^- \eta$	$(7.6^{+3.0}_{-2.7} \pm 1.0 \pm 1.0) \times 10^{-2}$	$-16.8^{+2.1}_{-2.1} \pm 1.3$
$\Xi_b^- \to \Sigma^- \eta'$	$(4.7^{+2.0}_{-2.0} \pm 0.6 \pm 0.6) \times 10^{-2}$	$-15.7^{+4.0}_{-5.6} \pm 1.3$

TABLE IV. Two-body Ξ_b^0 decays with the error descriptions being the same as Table II.

$\mathcal{B}_b \to \mathcal{B}_n M$	$\mathcal{B} \times 10^6$	$\mathcal{A}_{CP} \times 10^2$
$\Xi_b^0 \to \Xi^0 \pi^0$	$(5.3^{+1.2}_{-0.6} \pm 0.2 \pm 0.7) \times 10^{-2}$	$0.0^{+0.0}_{-0.0} \pm 0.0$
$\Xi_b^0 \to \Sigma^0 \pi^0$	$(5.1^{+1.8}_{-1.7} \pm 0.5 \pm 0.6) \times 10^{-2}$	$8.0^{+1.2}_{-1.4} \pm 0.3$
$\Xi_b^0 \to \Lambda \pi^0$	$(1.7^{+0.6}_{-0.5} \pm 0.1 \pm 0.2) \times 10^{-2}$	$8.0^{+1.2}_{-1.4} \pm 0.3$
$\Xi_b^0 \to \Sigma^0 \bar{K}^0$	$2.41^{+0.68}_{-0.30} \pm 0.16 \pm 0.32$	$1.1^{+0.0}_{-0.0} \pm 0.0$
$\Xi_b^0 \to \Lambda \bar{K}^0$	$0.82^{+0.23}_{-0.10} \pm 0.06 \pm 0.11$	$1.1^{+0.0}_{-0.0} \pm 0.0$
$\Xi_b^0 \to \Sigma^+ K^-$	$4.69^{+0.87}_{-0.41} \pm 0.27 \pm 0.62$	$6.7^{+0.3}_{-0.2} \pm 0.3$
$\Xi_b^0 \to \Sigma^+ \pi^-$	$4.45^{+1.09}_{-0.50} \pm 0.77 \pm 0.59$	$-3.9^{+0.0}_{-0.0} \pm 0.4$
$\Xi_b^0 \to \Xi^0 K^0$	$(1.5^{+0.4}_{-0.6} \pm 0.1 \pm 0.2) \times 10^{-2}$	$0.2^{+0.1}_{-0.0} \pm 0.0$
$\Xi_b^0 \to \Xi^0 \rho^0$	$0.15^{+0.05}_{-0.02} \pm 0.01 \pm 0.02$	$2.3^{+0.7}_{-0.8} \pm 0.2$
$\Xi_b^0 \to \Xi^0 \omega$	$1.11^{+2.51}_{-1.10} \pm 0.07 \pm 0.15$	$3.6^{+4.8}_{-4.0} \pm 0.2$
$\Xi_b^0 \to \Xi^0 \phi$	$2.77^{+2.58}_{-2.63} \pm 0.19 \pm 0.37$	$1.4^{+0.7}_{-0.1} \pm 0.1$
$\Xi_b^0 \to \Sigma^0 \rho^0$	$(9.5^{+4.6}_{-4.5} \pm 1.3 \pm 1.3) \times 10^{-2}$	$14.0^{+1.8}_{-1.8} \pm 1.0$
$\Xi_b^0 \to \Sigma^0 \omega$	$0.11^{+0.08}_{-0.05} \pm 0.02 \pm 0.01$	$-18.2^{+24.4}_{-\ 4.2} \pm 1.6$
$\Xi_b^0 \to \Sigma^0 \phi$	$(1.0^{+8.7}_{-0.8} \pm 0.0 \pm 0.1) \times 10^{-2}$	$-8.8^{+7.4}_{-5.1} \pm 0.3$
$\Xi_b^0 \to \Lambda \rho^0$	$(3.2^{+1.6}_{-1.6} \pm 0.4 \pm 0.4) \times 10^{-2}$	$14.0^{+1.8}_{-1.8} \pm 1.0$
$\Xi_b^0 \to \Lambda \omega$	$(3.8^{+2.8}_{-1.8} \pm 0.6 \pm 0.5) \times 10^{-2}$	$-18.2^{+24.4}_{-\ 4.2} \pm 1.6$
$\Xi_b^0 \to \Lambda \phi$	$(0.3^{+3.0}_{-0.3} \pm 0.0 \pm 0.0) \times 10^{-2}$	$-8.8^{+7.4}_{-5.1} \pm 0.3$
$\Xi_b^0 \to \Sigma^0 \bar{K}^{*0}$	$1.61^{+0.82}_{-0.35} \pm 0.11 \pm 0.21$	$1.3^{+0.1}_{-0.1} \pm 0.0$
$\Xi_b^0 \to \Lambda \bar{K}^{*0}$	$0.54^{+0.28}_{-0.12} \pm 0.04 \pm 0.07$	$1.3^{+0.1}_{-0.1} \pm 0.0$
$\Xi_b^0 \to \Sigma^+ K^{*-}$	$2.98^{+0.64}_{-0.30} \pm 0.11 \pm 0.39$	$19.7^{+0.4}_{-0.3} \pm 1.4$
$\Xi_b^0 \to \Sigma^+ \rho^-$	$11.49^{+2.83}_{-1.30} \pm 2.05 \pm 1.52$	$-3.8^{+0.0}_{-0.0} \pm 0.4$
$\Xi_b^0 \to \Xi^0 K^{*0}$	$0.14^{+0.07}_{-0.03} \pm 0.01 \pm 0.02$	$1.3^{+0.1}_{-0.1} \pm 0.0$
$\Xi_b^0 \to \Xi^0 \eta$	$2.51^{+0.59}_{-0.27} \pm 0.17 \pm 0.33$	$0.4^{+0.2}_{-0.2} \pm 0.0$
$\Xi_b^0 \to \Xi^0 \eta'$	$2.99^{+1.07}_{-0.36} \pm 0.20 \pm 0.40$	$1.6^{+0.1}_{-0.1} \pm 0.1$
$\Xi_b^0 \to \Lambda \eta$	$(1.2^{+0.5}_{-0.4} \pm 0.2 \pm 0.2) \times 10^{-2}$	$-16.8^{+2.1}_{-2.1} \pm 1.3$
$\Xi_b^0 \to \Lambda \eta'$	$(7.4^{+3.2}_{-3.1} \pm 1.0 \pm 1.0) \times 10^{-3}$	$-15.7^{+4.0}_{-5.6} \pm 1.3$
$\Xi_b^0 \to \Sigma^0 \eta$	$(3.6^{+1.4}_{-1.3} \pm 0.5 \pm 0.5) \times 10^{-2}$	$-16.8^{+2.1}_{-2.1} \pm 1.3$
$\Xi_b^0 \to \Sigma^0 \eta'$	$(2.2^{+0.9}_{-0.9} \pm 0.3 \pm 0.3) \times 10^{-2}$	$-15.7^{+4.0}_{-5.6} \pm 1.3$