Three-body charmless baryonic $\bar{B}_s^0$ decays

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Abstract

We study for the first time the three-body charmless baryonic decays $\bar{B}_s^0 \to \bar{p}\Lambda M^+(p\bar{\Lambda}M^-)$, with $M = \pi, K$. We find that the branching ratios of $\bar{B}_s^0 \to (\bar{p}\Lambda K^+ + p\bar{\Lambda}K^-)$ and $\bar{B}_s^0 \to p\bar{\Lambda}\pi^-$ are $(5.1 \pm 1.1) \times 10^{-6}$ and $(2.8 \pm 1.5) \times 10^{-7}$, respectively, which agree with recent experimental results reported by the LHCb collaboration. In addition, we derive the relations $B(\bar{B}_s^0 \to \bar{p}\Lambda K^+) \simeq (f_K/f_\pi)^2(\tau_{B^0}/\tau_{B^0})B(\bar{B}_s^0 \to \bar{p}\Lambda\pi^+)$ and $B(\bar{B}_s^0 \to p\bar{\Lambda}\pi^-)/B(\bar{B}_s^0 \to p\bar{\Lambda}K^-) \simeq B(B^- \to pp\pi^-)/B(B^- \to ppK^-)$ to be confronted to future experimental measurements. The fact that all four processes $B_s^0, \bar{B}_s^0 \to p\bar{\Lambda}K^-, \bar{p}\Lambda K^+$ can occur opens the possibility of decay-time-dependent CP violation measurements in baryonic $B$ decays, something that had not been realised before.
I. INTRODUCTION

In contrast with mesonic $B$ decays, the decays of $B$ mesons to baryonic final states have been observed to have unique signatures due to the baryon-pair ($B_1 \bar{B}_2$) formations, which reflect rich mechanisms for the hadronizations of the spinors. For example, the BaBar and Belle experiments at the $B$ factories \cite{1} reported typical three-body charmless baryonic $B$ decay branching ratios $\mathcal{B}(B \to B_1 \bar{B}_2 M) \simeq \mathcal{O}(10^{-6})$, and provided evidence for prominent peaks around $m_{B_1 \bar{B}_2} \simeq m_B + m_{\bar{B}}$ in the baryon-antibaryon spectra of baryonic $B$ decays \cite{2}, which show that the $B_1 \bar{B}_2$ formations favour the threshold area. However, in two-body decays $B \to B_1 \bar{B}_2$, there is no large energy release from the recoiled meson \cite{3}, such that the total energy of $B_1 \bar{B}_2$ is at the $m_B$ scale, which definitely deviates from the threshold area \cite{4}. As a result, $\mathcal{B}(B \to B_1 \bar{B}_2)$ are seen to be small, around $10^{-8} - 10^{-7}$ \cite{5–7}.

Furthermore, the angular distribution asymmetry $A_\theta$ of $\bar{B}_0 \to \bar{p} \Lambda \pi^+$ has been measured to have an unexpectedly large value of $(−41 \pm 11 \pm 3)\%$, indicating significant interference as a result of the baryonic form factors \cite{9, 10}. The same behaviour has been observed in decays to final states with open charm, for example

$$A_\theta(\bar{B}_0 \to \Lambda \bar{p} \pi^+) = (55 \pm 17)\%$$ \cite{8}.

The aforementioned observations in $\bar{B}_0 / B^- \to B_1 \bar{B}_2 (M)$ decays may also hold for $\bar{B}_s^0 \to B_1 \bar{B}_2 (M)$ decays now experimentally accessible to the LHCb collaboration \cite{11, 12}. Nonetheless, baryonic $\bar{B}_s^0$ decays are not trivially related to baryonic $\bar{B}_0$ and $B^-$ decays. For example, replacing $(\bar{u}, \bar{d})$ by $\bar{s}$ in $\bar{B}_0 / B^-$, one may approximately infer that

$$\mathcal{B}(\bar{B}_s^0 \to \bar{p} \Lambda K^+) \simeq \mathcal{B}(\bar{B}_0 \to \bar{p} \Lambda \pi^+),$$
$$\mathcal{B}(\bar{B}_s^0 \to p \bar{\Lambda} \pi^-) \simeq \mathcal{B}(B^- \to p \bar{p} \pi^-),$$
$$\mathcal{B}(\bar{B}_s^0 \to p \bar{\Lambda} K^-) \simeq \mathcal{B}(B^- \to p \bar{p} K^-),$$ \hspace{1cm} (1)

which will be shown to be mostly incorrect, except for the first relation. We will also demonstrate that the recent first observation, made by the LHCb collaboration, of a baryonic $\bar{B}_s^0$ decay, namely $\bar{B}_s^0 \to p \bar{\Lambda} K^-$, and the measurement of its branching ratio \cite{13}, combines in reality the branching ratios of $\bar{B}_s^0 \to p \bar{\Lambda} K^-$ and $\bar{B}_s^0 \to \bar{p} \Lambda K^+$.

II. FORMALISM

The decay $\bar{B}_0^0 \to \bar{p} \Lambda \pi^+$ is flavour specific, unlike the similar mode of the $\bar{B}_s^0$ meson, which can decay to both $\bar{p} \Lambda K^+$ and $p \bar{\Lambda} K^-$ final states. The latter three-body baryonic $\bar{B}_s^0$
decays proceed through different configurations as demonstrated in the Feynman diagrams in Fig. [1]. Specifically, the baryon pairs involve quark currents and $B$ meson transitions as depicted in Figs. [1(a,b)] and [1(c,d)], respectively.

![Feynman Diagrams](image)

**FIG. 1.** Feynman diagrams for three-body baryonic $\bar{B}_s^0$ decays, where (a,b) depict $\bar{B}_s^0 \to \bar{p}\Lambda K^+$ while (c,d) depict $\bar{B}_s^0 \to p\bar{\Lambda}K^-$.

The amplitudes can be factorized in terms of the effective Hamiltonian at the quark level [14] as [9, 15–18]

\[
A(\bar{B}_s^0 \to \bar{p}\Lambda K^+) = \frac{G_F}{\sqrt{2}} \left\{ \alpha_1 (\bar{p}\Lambda|\bar{s}u)V_{-A}|0\rangle + \alpha_6 (\bar{p}\Lambda|\bar{s}u)S_{+P}|0\rangle \right\},
\]

\[
A(\bar{B}_s^0 \to p\bar{\Lambda}K^-) = \frac{G_F}{\sqrt{2}} \left\{ \alpha_1 (K^-|\bar{s}u)V_{-A}|\bar{B}_s^0\rangle + \alpha_6 (K^-|\bar{s}u)S_{+P}|\bar{B}_s^0\rangle \right\},
\]

with $\alpha_1 = V_{ub}V^*_{us}a_1 - V_{tb}V^*_{ts}a_4$ and $\alpha_6 = V_{tb}V^*_{ts}2a_6$, where $G_F$ is the Fermi constant, $V_{ij}$ are the CKM matrix elements, $(\bar{q}_1 q_2)V_{(A)}$ and $(\bar{q}_1 q_2)S_{(P)}$ stand for $\bar{q}_1 \gamma_\mu(\gamma_5)q_2$ and $\bar{q}_1 (\gamma_5)q_2$, respectively, and $a_{1(4,6)} \equiv c^\text{eff}_{1(4,6)} + c^\text{eff}_{2(3,5)}, N^\text{eff}_c$ are composed of the effective Wilson coefficients $c^\text{eff}_i$ defined in Ref. [14] with $N^\text{eff}_c$ the effective colour number, ranging between 2 and $\infty$ to account for the non-factorizable effects in the generalized factorization approach. The amplitude $A(\bar{B}_s^0 \to p\bar{\Lambda}\pi^-)$ is obtained from $A(\bar{B}_s^0 \to p\bar{\Lambda}K^-)$ of Eq. (2) replacing the strange
quark by the down quark.

In our calculation, the matrix elements of $\bar{B}_s^0 \rightarrow \bar{p} \Lambda K^+$ in Eq. (2) are expressed as \[15, 16\]

$$
\langle M | \bar{q} \gamma^\mu b | B \rangle = (p_B + p_M)^\mu F_1^{BM} + \frac{m_B^2 - m_M^2}{t} \gamma^\mu (F_0^{BM} - F_1^{BM}) ,
$$

$$
\langle B_1 \bar{B}_2 | \bar{q}_1 \gamma_\mu q_2 | 0 \rangle = \bar{u} \left[ F_1 \gamma_\mu + \frac{F_2}{m_{B_1} + m_{B_2}} i \sigma_{\mu \nu} q_\nu \right] v ,
$$

$$
\langle B_1 \bar{B}_2 | \bar{q}_1 \gamma_\mu \gamma_5 q_2 | 0 \rangle = \bar{u} \left[ g_A \gamma_\mu + \frac{h_A}{m_{B_1} + m_{B_2}} q_\mu \right] \gamma_5 v ,
$$

$$
\langle B_1 \bar{B}_2 | \bar{q}_1 q_2 | 0 \rangle = f_S \bar{u} v , \langle B_1 \bar{B}_2 | \bar{q}_1 | 0 \rangle = g_P \bar{u} v ,
$$

(3)

with $q = p_B - p_M = p_{B_1} + p_{B_2}$, $t \equiv q^2$, $p = p_B - q$, and $u(v)$ the (anti-)baryon spinor, where $F_{0,1}^{BM}$ are the form factors for the $B \rightarrow M$ transition, and $F_{1,2}, g_A, h_A, f_S$, and $g_P$ the timelike baryonic form factors. For $\bar{B}_s^0 \rightarrow \bar{p} \Lambda K^-$, besides $\langle M | \bar{q}_1 \gamma_\mu \gamma_5 q_2 | 0 \rangle = -i f_M p_M^\mu$ with $f_M$ the decay constant, the matrix elements of the $B \rightarrow B_1 \bar{B}_2$ transition are parameterized as \[9, 17\]

$$
\langle B_1 \bar{B}_2 | \bar{q}_1 \gamma_\mu b | B \rangle = i \bar{u} \left[ g_1 \gamma_\mu + g_2 i \sigma_{\mu \nu} p^\nu + g_3 p_\mu + g_4 q_\mu + g_5 (p_{B_2} - p_{B_1}) \gamma_5 v \right] ,
$$

$$
\langle B_1 \bar{B}_2 | \bar{q}_1 \gamma_5 b | B \rangle = i \bar{u} \left[ f_1 \gamma_\mu + f_2 i \sigma_{\mu \nu} p^\nu + f_3 p_\mu + f_4 q_\mu + f_5 (p_{B_2} - p_{B_1}) \gamma_5 v \right] ,
$$

$$
\langle B_1 \bar{B}_2 | \bar{q}_1 b | B \rangle = i \bar{u} \left[ \bar{g}_1 \gamma_\mu + \bar{g}_2 (E_{B_2} + E_{B_1}) + \bar{g}_3 (E_{B_2} - E_{B_1}) \right] \gamma_5 v ,
$$

$$
\langle B_1 \bar{B}_2 | \bar{q}_1 \gamma_5 b | 0 \rangle = i \bar{u} \left[ \tilde{f}_1 \gamma_\mu + \tilde{f}_2 (E_{B_2} + E_{B_1}) + \tilde{f}_3 (E_{B_2} - E_{B_1}) \right] v ,
$$

(4)

where $g_i(f_i)$ ($i = 1, 2, ..., 5$) and $\bar{g}_j(\tilde{f}_j)$ ($j = 1, 2, 3$) are the $B \rightarrow B_1 \bar{B}_2$ transition form factors. The form factors in Eqs. (3) and (4) are momentum dependent. Explicitly, $F_{0,1}^{BM}$ are given by \[19\]

$$
F_1^{BM} (t) = \frac{F_1^{BM} (0)}{(1 - \frac{t}{M_B^2}) (1 - \frac{\sigma_{11} t}{M_V^2} + \frac{\sigma_{12} t^2}{M_V^2})} , \quad F_0^{BM} (t) = \frac{F_0^{BM} (0)}{1 - \frac{\sigma_{01} t}{M_V^2} + \frac{\sigma_{02} t^2}{M_V^2}} .
$$

(5)

In perturbative QCD counting rules, the baryonic form factors depend on $1/t^n$ as the leading-order expansion \[9, 17, 20, 21\], given by

$$
F_1 = \frac{\tilde{C}_{f_1}}{t^2} , \quad g_A = \frac{\tilde{C}_{g_A}}{t^2} , \quad f_S = \frac{\tilde{C}_{f_S}}{t^2} , \quad g_P = \frac{\tilde{C}_{g_P}}{t^2} ,
$$

$$
f_i = \frac{D_{f_i}}{t^3} , \quad g_i = \frac{D_{g_i}}{t^3} , \quad \bar{f}_i = \frac{D_{\bar{f}_i}}{t^3} , \quad \bar{g}_i = \frac{D_{\bar{g}_i}}{t^3} ,
$$

(6)

where $\tilde{C}_i = C_i [\ln (t/\Lambda_0^3)]^{-\gamma}$ with $\gamma = 2.148$ and $\Lambda_0 = 0.3 \text{ GeV}$. 

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III. NUMERICAL RESULTS AND DISCUSSIONS

For the numerical analysis, the theoretical inputs of the CKM matrix elements in the Wolfenstein parameterisation are given by [1]

\[
\begin{align*}
V_{ub} &= A\lambda^3(\rho - i\eta), \quad V_{tb} = 1 - A^2\lambda^4/2, \\
V_{ud} &= 1 - \lambda^2/2, \quad V_{td} = A\lambda^3, \\
V_{us} &= \lambda, \quad V_{ts} = -A\lambda^2 + A\lambda^4[1 + 2(\rho - i\eta)]/2, \\
\end{align*}
\]

(7)

with \((\lambda, A, \rho, \eta) = (0.225, 0.814, 0.120 \pm 0.022, 0.362 \pm 0.013)\). Other parameters are taken to be \[F_{1,0}^{B_s}(0) = 0.31, (\sigma_{11}, \sigma_{12}) = (0.63, 0.33), (\sigma_{01}, \sigma_{02}) = (0.93, 0.70), M_V = 5.32\text{ GeV}, \]
and \((f_K, f_\pi) = (156.2 \pm 0.7, 130.4 \pm 0.2)\text{ MeV} [1]\). Theoretically, the \(B_s^0 \rightarrow \bar{p}\Lambda K^+\) decay is related to \(B^0 \rightarrow n\bar{p}D^{(*)+}, B^0 \rightarrow \Lambda\bar{p}D^{(*)+}, B^0 \rightarrow \bar{p}\Lambda\pi^+, B^{-} \rightarrow \bar{p}\Lambda(\pi^0, \rho^0), B^0_s \rightarrow p\bar{p}, \) and \(B^{-} \rightarrow \bar{p}\Lambda\) through the timelike baryonic form factors, which can be connected by the \(SU(3)\) flavour and \(SU(2)\) spin symmetries \[15, 20], leading to \[10\]

\[
\begin{align*}
C_{F_1} &= \sqrt{\frac{3}{2}C_{||}}, \quad C_{g_A} = \sqrt{\frac{3}{2}(C_{||} + C_2)}, \\
C_{f_3} &= -\sqrt{\frac{3}{2}C_{||}}, \quad C_{g_F} = -\sqrt{\frac{3}{2}(C_{||} + C_2)}, \\
\end{align*}
\]

(8)

where

\[
\begin{align*}
(C_{||}, C_{2}) &= (154.4 \pm 12.1, 19.3 \pm 21.6)\text{ GeV}^4, \\
(C_{||}, \bar{C}_{2}) &= (537.6 \pm 28.7, -342.3 \pm 61.4)\text{ GeV}^4,
\end{align*}
\]

(9)

extracted from the data. Here, \(F_2 = F_1/(\text{tln}[t/L_0^2]) [22]\) and \(h_A = C_{h_A}/t^2\) have both been neglected. Note that \(C_{h_A}\) is fitted to be in accordance with \(B(B_0^0 \rightarrow p\bar{p}) = 1.47 \times 10^{-8} [4]\). On the other hand, the \(B_s^0 \rightarrow \bar{p}\Lambda K^-\) decay corresponds to \(B^0 \rightarrow p\bar{p}D^{(*)0}, B^- \rightarrow p\bar{p}(K^{(*)-}, \pi^-), B^0 \rightarrow p\bar{p}K^{(*)0}\), and \(B^- \rightarrow p\bar{p}e^-\bar{\nu}\) through the \(B \rightarrow \bar{B}\bar{B}'\) transition form factors, which are related by the same symmetries \[1, 17\], given by

\[
\begin{align*}
D_{g_1} &= D_{f_1} = -\sqrt{\frac{3}{2}D_{||}}, \quad D_{g_{4,5}} = -D_{f_{4,5}} = -\sqrt{\frac{3}{2}D_{||}^{4,5}}, \\
D_{g_1} &= D_{f_1} = -\sqrt{\frac{3}{2}D_{||}}, \quad D_{g_{2,3}} = -D_{f_{2,3}} = -\sqrt{\frac{3}{2}D_{||}^{2,3}}, \\
\end{align*}
\]

(10)
FIG. 2. Spectra for the three-body baryonic decays (left) \( \bar{B}_s^0 \to (\Lambda\bar{p}K^+, p\Lambda K^-) \) and (right) \( \bar{B}_s^0 \to p\Lambda \pi^- \).

with the vanishing form factors \((g_{2,3}, f_{2,3})\) due to the derivations of \( f_{M\rho\bar{u}}(\sigma_{\mu\nu}p^\nu)\bar{v} = 0 \) for \( g_2(f_2) \) and \( f_{M\rho\bar{u}}\bar{u}p_\mu v \propto m_B^2 \) for \( f_3(g_3) \) in the amplitudes, where

\[
D_\parallel = (45.7 \pm 33.8) \text{ GeV}^5, \quad (D_\perp^1, D_\perp^5) = (6.5 \pm 18.1, -147.1 \pm 29.3) \text{ GeV}^4,
\]

\[
\bar{D}_\parallel = (35.2 \pm 4.8) \text{ GeV}^5, \quad (\bar{D}_\perp^2, \bar{D}_\perp^3) = (-22.3 \pm 10.2, 504.5 \pm 32.4) \text{ GeV}^4. \quad (11)
\]

The effective Wilson coefficients for the \( \bar{B}_s^0(B_s^0) \) decays are given by [14]

\[
\begin{align*}
\epsilon_1^{\text{eff}} &= 1.168, \\
\epsilon_2^{\text{eff}} &= -0.365, \\
10^4\epsilon_3^{\text{eff}} &= -241.9 + 3.2\eta + 1.4\rho + i(31.3 \mp 1.4\eta + 3.2\rho), \\
10^4\epsilon_4^{\text{eff}} &= -508.7 \mp 9.6\eta - 4.2\rho + i(-93.9 \mp 4.2\eta - 9.6\rho), \\
10^4\epsilon_5^{\text{eff}} &= -149.4 \mp 3.2\eta + 1.4\rho + i(31.3 \mp 1.4\eta + 3.2\rho), \\
10^4\epsilon_6^{\text{eff}} &= -645.5 \mp 9.6\eta - 4.2\rho + i(-93.9 \mp 4.2\eta - 9.6\rho). \quad (12)
\end{align*}
\]

Integrating over the phase space of the three-body decays [1] we obtain the spectra for \( \bar{B}_s^0 \to (\bar{p}\Lambda K^+, p\Lambda K^-) \) and \( \bar{B}_s^0 \to p\Lambda \pi^- \) in Fig. 2, which clearly present the threshold enhancement observed in a multitude of baryonic \( \bar{B}_s^0 \) and \( B_s^0 \) decays. The branching ratios are predicted to be

\[
\begin{align*}
\mathcal{B}(\bar{B}_s^0 \to \bar{p}\Lambda K^+) &= (3.75 \pm 0.81^{+0.67}_{-0.31} \pm 0.01) \times 10^{-6}, \\
\mathcal{B}(\bar{B}_s^0 \to p\Lambda K^-) &= (1.31 \pm 0.32^{+0.22}_{-0.10} \pm 0.01) \times 10^{-6}, \\
\mathcal{B}(\bar{B}_s^0 \to p\Lambda \pi^-) &= (2.79 \pm 1.37^{+0.64}_{-0.30} \pm 0.17) \times 10^{-7}, \quad (13)
\end{align*}
\]
with the uncertainties from the form factors, non-factorizable effects, and CKM matrix elements in order. The $\mathcal{B}(B_s^0 \to \bar{p}\Lambda K^+)$ is calculated to be close to the observed $\mathcal{B}(\bar{B}^0 \to \bar{p}\Lambda \pi^+) = (3.14 \pm 0.29) \times 10^{-6}$ \cite{1}, which confirms the first relation in Eq. \cite{1}. Nonetheless, using the experimental measurements of $\mathcal{B}(B^- \to p\bar{p}M) \ (M = K^-, \pi^-)$ \cite{1}, we find that $\mathcal{B}(\bar{B}_s^0 \to p\Lambda M) \approx 0.2 \times \mathcal{B}(B^- \to p\bar{p}M)$, which disproves the other relations in Eq. \cite{1}. The reason for this is that $\bar{B}_s^0 \to p\Lambda$ and $B^- \to p\bar{p}$ transitions give different contributions. Consequently, we should revise the relations in Eq. \cite{1} to be

$$
\frac{\mathcal{B}(\bar{B}_s^0 \to \bar{p}\Lambda K^+)}{\mathcal{B}(\bar{B}_s^0 \to \bar{p}\Lambda K^-)} \approx (\frac{f_K/f_\pi}{\tau_{f \bar{p}}/\tau_{f \bar{p}}}) \mathcal{B}(\bar{B}^0 \to \bar{p}\Lambda \pi^+),
$$

$$
\mathcal{B}(\bar{B}_s^0 \to \bar{p}\Lambda \pi^-) \approx \mathcal{B}(B^- \to p\bar{p} \pi^-) \times \mathcal{B}(\bar{B}_s^0 \to \bar{p}\Lambda K^-) / \mathcal{B}(B^- \to p\bar{p}K^-). \quad (14)
$$

From an experimental perspective, the measured branching ratio is $\mathcal{B}(B_s^0 \to \bar{p}\Lambda K^- + \bar{B}_s^0 \to p\Lambda K^-)$, given that the flavour of the reconstructed $B_s^0$ meson at production is not determined – the identification of the flavour at production, a procedure known as flavour tagging, requires a decay-time-dependent analysis. Assuming negligible CP violation, $\mathcal{B}(B_s^0 \to \bar{p}\Lambda K^- + \bar{B}_s^0 \to p\Lambda K^-)$ is equivalent to the combination of the two branching ratios $\mathcal{B}(\bar{B}_s^0 \to \bar{p}\Lambda K^+ + \bar{B}_s^0 \to \bar{p}\Lambda K^-) = (5.1 \pm 1.1) \times 10^{-6}$. This calculation agrees well with the experimental measurement, $\mathcal{B}(B_s^0 \to \bar{p}\Lambda K^- + \bar{B}_s^0 \to \bar{p}\Lambda K^-) = (5.48^{+0.82}_{-0.80} \pm 0.60 \pm 0.51 \pm 0.32) \times 10^{-6}$, reported by the LHCb collaboration \cite{13}. In contrast, $\mathcal{B}(\bar{B}_s^0 \to p\Lambda \pi^-)$ is estimated to be of order $10^{-7}$, consistent with its non-observation with the present data sample \cite{13}.

All four processes $B_s^0, \bar{B}_s^0 \to \bar{p}\Lambda K^-$, $\bar{p}\Lambda K^+$ are possible, just as in the case of the $\bar{B}_s^0 \to D_s^+ K^- \pm$ decays \cite{23}. A $B$-flavour tagged decay-time-dependent analysis of these baryonic decay modes is necessary to disentangle all contributions. As the ratio of the $\bar{B}_s^0 \to \bar{p}\Lambda K^+$ and $B_s^0 \to \bar{p}\Lambda K^+$ branching ratios is predicted to be rather large, cf. Eq. \cite{13}, sizeable interference due to $B_s^0$-$\bar{B}_s^0$ mixing is expected, which hints at possibly large time-dependent CP violating asymmetries. Time-dependent analyses require a typical minimum data sample of order 1000 to 1500 signal candidates, see for example the LHCb analysis presented in Ref. \cite{23}. Extrapolating from the $260 \pm 21 \ B_s^0, \bar{B}_s^0 \to \bar{p}\Lambda K^- \bar{p}\Lambda K^+$ candidates selected in the recent LHCb analysis \cite{13}, assuming (as done in LHCb extrapolations) a two-fold increase in the $b\bar{b}$ production cross-section between the first data taking period of the LHC, and the present second period started in 2015, we conclude that such an analysis will require the full data sample to be collected by 2018.

Based on the observation of $\bar{B}_s^0 \to (\bar{p}\Lambda K^+, \bar{p}\Lambda K^-)$, it is promising to study other charm-
less baryonic $B^0_s$ decays such as $B^0_s \rightarrow \bar{p}\Lambda K^+\phi$, $B^0_s \rightarrow \Lambda\Lambda K^*$, $B^0_s \rightarrow \Lambda\Lambda\phi$, $B^0_s \rightarrow \Sigma\Lambda\phi$, $B^0_s \rightarrow (\Sigma^\prime\Lambda, \Lambda\Sigma^\prime, \Sigma\Sigma^\prime)\phi$, $B^0_s \rightarrow \bar{p}\Sigma^0 K^+$, $p\Sigma^0 K^-$, and $B^0_s \rightarrow p\Sigma^0 \pi^-$. The presence of extra resonances or neutral particles in the final states of these decay modes makes the experimental searches more demanding, though feasible by both the LHCb experiment and the future Belle II experiment.

IV. CONCLUSIONS

We have studied the three-body charmless baryonic decays $\bar{B}^0_s \rightarrow \bar{p}\Lambda M^+$ and $p\Lambda M^-$, with $M = \pi, K$. We have predicted the combined branching ratio of $\bar{B}^0_s \rightarrow (\bar{p}\Lambda K^+ \text{ and } p\Lambda K^-)$ to be $(5.1 \pm 1.1) \times 10^{-6}$, in good agreement with the recently presented experimental result by the LHCb collaboration [13]. We further obtained $\mathcal{B}(\bar{B}^0_s \rightarrow p\Lambda\pi^-) = (2.8 \pm 1.5) \times 10^{-7}$, which is below the current experimental sensitivity of the LHCb analysis. We have also presented useful relations between the three-body baryonic decays of $\bar{B}^0_s$ and $B^0/B^-$, such as $\mathcal{B}(\bar{B}^0_s \rightarrow \bar{p}\Lambda K^+) \simeq (f_K/f_\pi)^2(\tau_B/\tau_{B^0})\mathcal{B}(\bar{B}^0 \rightarrow \bar{p}\Lambda\pi^+) \text{ and } \mathcal{B}(\bar{B}^0_s \rightarrow p\Lambda\pi^-)/\mathcal{B}(\bar{B}^0_s \rightarrow p\Lambda K^-) \simeq \mathcal{B}(B^- \rightarrow p\bar{p}\pi^-)/\mathcal{B}(B^- \rightarrow p\bar{p}K^-)$, which can be tested by the future experiments at LHCb. The fact that all four processes $B^0_s, \bar{B}^0_s \rightarrow p\Lambda K^-, \bar{p}\Lambda K^+$ can occur opens the possibility of decay-time-dependent CP violation measurements in baryonic decays, something that had not been realised before.

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