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Rates and CP asymmetries of charmless two-body baryonic $B_{u,d,s}$ decays

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With the experimental evidences of $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ decays, it is now possible to extract both tree and penguin amplitudes of the charmless two-body baryonic B decays for the first time. The extracted penguin-tree ratio agrees with the expectation. Using the topological amplitude approach with the experimental results on $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ decay rates as input, predictions on all other $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$, $\mathcal{B}\bar{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$ and $\mathcal{D}\bar{\mathcal{D}}$ decay rates, where $\mathcal{B}$ and $\mathcal{D}$ are the low lying octet and decuplet baryons, respectively, are given. It is nontrivial that the results do not violate any existing experimental upper limit. From the analysis it is understandable that why $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ modes are the first two modes with experimental evidences. Relations on rates are verified using the numerical results. We note that the predicted $B^- \to p\overline{\Delta^{++}}$ rate is close to the experimental bound, which has not been updated in the last ten years. Direct CP asymmetries of all $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$, $\mathcal{B}\overline{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$ and $\mathcal{D}\bar{\mathcal{D}}$ modes are explored. Relations on CP asymmetries are examined using the numerical results. The direct CP asymmetry of $\bar{B}^0 \to p\bar{p}$ decay can be as large as $\pm 50\%$. Some of the CP asymmetries can serve as tests of the Standard Model. Most of them are pure penguin modes, which are expected to be sensitive to new physics contributions. In particular, $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^-}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$, $\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$ and $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$ decays are $\Delta S = -1$ pure penguin modes with unsuppressed rates, which can be searched in the near future. Their CP asymmetries are constrained to be of few % and are good candidates to be added to the list of the tests of the Standard Model.

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I. INTRODUCTION

Recently, the LHCb collaboration reported the evidence for the first penguin dominated charmless two-body baryonic mode, $B^- \to \Lambda\bar{p}$ decay, at 4.1σ level [1], giving

$$\mathcal{B}(B^- \to \Lambda\bar{p}) = (2.4^{+1.0}_{-0.8} \pm 0.3) \times 10^{-7}. \tag{1}$$

The result is consistent with the predictions given in a pole model calculation [2] and a topological amplitude approach [3]. The latter work made use of the large m_B mass, the experimental rate of the tree-dominated $\bar{B}^0 \to p\bar{p}$ decay [4],

$$\mathcal{B}(\bar{B}^0 \to p\bar{p}) = (1.47^{+0.62+0.35}_{-0.51-0.14}) \times 10^{-8}, \tag{2}$$

and a naïve estimation on tree-penguin ratio. In fact, it was advocated in [3] that the $B^- \to \Lambda\bar{p}$ decay mode could be the second charmless two-body baryonic mode to be found experimentally. With both the experimental evidences on $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ decays, it is now possible to extract both tree and penguin amplitudes at the same time.

Most of the decay amplitudes of the two-body baryonic decays are nonfactorizable.[1] Various models, such as the pole model, [2,6–8], sum rule, [9], diquark model, [10,11] and approaches employing flavor symmetry [12–15] were used (for recent reviews, see [16,17]) to calculate the amplitudes. Nevertheless all predictions on the $\bar{B}^0 \to p\bar{p}$ rate are off by several orders of magnitude comparing to the LHCb result [4,16,17].

Indeed, the $B^0 \to p\bar{p}$ decay mode is more suppressed than expected. To see this one scales the $\bar{B}^0 \to \Lambda_c^+\bar{p}$ rate by the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements $|V_{ub}/V_{cb}|^2$ and with a possible dynamical suppression factor $f_{\rm dyn}$ included [18],

$$\mathcal{B}(\bar{B}^0 \to p\bar{p}) = \mathcal{B}(\bar{B}^0 \to \Lambda_c^+\bar{p})|V_{ub}/V_{cb}|^2 \times f_{\rm dyn} \sim 2 \times 10^{-7} \times f_{\rm dyn}. \tag{3}$$

The data demands $f_{\rm dyn} \sim 0.1$. It was pointed out in Ref. [18] that for a given tree operator O_i, one needs to consider additional contributions, which were missed in the literature, from its Fiertz transformed operator O_i'. It was found that there are cancellations of Feynman diagrams induced by O_i by that from O_i' and, consequently, the smallness of the tree-dominated charmless two-body baryonic B decays results from this partial cancellation. Furthermore, as pointed out in Ref. [18], the internal W-emission tree amplitude should be proportional to the Wilson coefficient combination $c_1 + c_2$ rather than $c_1 - c_2$,

[1] For a study on the factorization contributions, see Ref. [5].

where the latter is usually claimed in the literature. We shall adapt this point in the present work.

We can make use of the newly measured $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ rates to give information on other modes in a symmetry related approach. The quark diagram or the so-called topological approach, has been extensively used in mesonic modes [19–24]. In fact, the approach is closely related to the flavor SU(3) symmetry [19,22,25]. In [26] the approach was extended to the charmless two-body baryonic case. It was further developed in [3], where amplitudes for all low lying charmless two-body baryonic modes with full topological amplitudes are obtained. Note that in general a typical amplitude has more than one tree and one penguin amplitude. Asymptotic relations in the large m_B limit [27] can be used to relate various topological amplitudes [3,26].

In this work, using the experimental results on the $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ decay rates, we will extract both tree and penguin amplitudes for the first time. Rates and direct CP asymmetries of all low lying charmless two body baryonic decays can be explored. Rates and CP asymmetries of some modes can be checked experimentally in the near future in LHCb and Belle-II. Note that CP asymmetries of some modes can be added to the list of the tests of the Standard Model. In particular, $\Delta S = -1$ pure penguin modes have small CP asymmetries and they are expected to be sensitive to new physics contributions. These modes are good candidates to be added to the lists of the tests of the Standard Model, especially for those with unsuppressed rates.

The layout of this paper is as follows. In Sec. II, we briefly review and update our formulation for charmless two-body baryonic decays modes. In Sec. III, we present the numerical results on rates and direct CP asymmetries of all low lying baryon modes. Relations on rates and CP asymmetries will also be studied. The conclusion is given in Sec. IV, which is followed by two appendixes.

II. TWO-BODY CHARMLESS BARYONIC B DECAY AMPLITUDES

There are more than 160 $\bar{B} \to \mathcal{B}\bar{\mathcal{B}}$, $\mathcal{B}\bar{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$, $\mathcal{D}\bar{\mathcal{D}}$ decay amplitudes with $\mathcal{B}$ and $\mathcal{D}$ the low lying octet and decuplet baryons, respectively. Their decay amplitudes expressed in terms of topological amplitudes can be found in [3] and are collected in Appendix A, since they will be used extensively in this work. We show a few examples here,

$$\begin{aligned}
A(B^- \to \Lambda\bar{p}) &= \frac{1}{\sqrt{6}}(T'_{1\mathcal{B}\bar{\mathcal{B}}} + 2T'_{3\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{6}}(10P'_{1\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3\sqrt{6}}(P'_{1\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}} \\
&\quad - 4P'_{3\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}} + 4P'_{4\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{6}}(10A'_{1\mathcal{B}\bar{\mathcal{B}}} - A'_{2\mathcal{B}\bar{\mathcal{B}}}), \\
A(\bar{B}^0 \to p\bar{p}) &= -T_{2\mathcal{B}\bar{\mathcal{B}}} + 2T_{4\mathcal{B}\bar{\mathcal{B}}} + P_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{2}{3}P_{2\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}} - 5E_{1\mathcal{B}\bar{\mathcal{B}}} + E_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA_{\mathcal{B}\bar{\mathcal{B}}}, \\
A(B^- \to \Xi^-\bar{\Xi}^0) &= -P_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{3}P_{2\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}} - A_{2\mathcal{B}\bar{\mathcal{B}}}, \\
A(\bar{B}^0_s \to p\bar{p}) &= -5E'_{1\mathcal{B}\bar{\mathcal{B}}} + E'_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},
\end{aligned} \tag{4}$$

$$\begin{aligned}
A(B^- \to p\overline{\Delta^{++}}) &= -\sqrt{6}(T_{1\mathcal{B}\bar{\mathcal{D}}} - 2T_{2\mathcal{B}\bar{\mathcal{D}}}) + \sqrt{6}P_{\mathcal{B}\bar{\mathcal{D}}} + 2\sqrt{\frac{2}{3}}P_{1\mathrm{EW}\mathcal{B}\bar{\mathcal{D}}} + \sqrt{6}A_{\mathcal{B}\bar{\mathcal{D}}}, \\
A(\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}) &= \sqrt{2}P'_{\mathcal{B}\bar{\mathcal{D}}} - \frac{\sqrt{2}}{3}P'_{1\mathrm{EW}\mathcal{B}\bar{\mathcal{D}}},
\end{aligned} \tag{5}$$

$$\begin{aligned}
A(B^- \to \Delta^0\bar{p}) &= \sqrt{2}T_{1\mathcal{D}\bar{\mathcal{B}}} - \sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}} + \frac{\sqrt{2}}{3}(3P_{1\mathrm{EW}\mathcal{D}\bar{\mathcal{B}}} + P_{2\mathrm{EW}\mathcal{D}\bar{\mathcal{B}}}) - \sqrt{2}A_{\mathcal{D}\bar{\mathcal{B}}}, \\
A(\bar{B}^0 \to \Sigma^{*+}\bar{p}) &= \sqrt{2}T'_{2\mathcal{D}\bar{\mathcal{B}}} + \sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} + \frac{2\sqrt{2}}{3}P'_{2\mathrm{EW}\mathcal{D}\bar{\mathcal{B}}},
\end{aligned} \tag{6}$$

$$\begin{aligned}
A(\bar{B}^0 \to \Delta^0\overline{\Delta^0}) &= 2T_{\mathcal{D}\bar{\mathcal{D}}} + 4P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{2}{3}P_{\mathrm{EW}\mathcal{D}\bar{\mathcal{D}}} + 2E_{\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}}, \\
A(B^- \to \Sigma^{*+}\overline{\Delta^{++}}) &= 2\sqrt{3}T'_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{4}{\sqrt{3}}P'_{\mathrm{EW}\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}A'_{\mathcal{D}\bar{\mathcal{D}}},
\end{aligned} \tag{7}$$

where $T^{(\prime)}$, $P^{(\prime)}$, $E^{(\prime)}$, $A^{(\prime)}$, $PA^{(\prime)}$ and $P^{(\prime)}_{\mathrm{EW}}$ are tree, penguin, W-exchange, annihilation, penguin annihilation and electroweak penguin amplitudes, respectively, for $\Delta S = 0(-1)$ decays (see Fig. 1). In most cases we need more than one tree and one penguin amplitude in the baryonic decay amplitudes. Note that from the above amplitudes, $\bar{B}^0 \to p\bar{p}$ decay is expected to be a tree dominated mode, $B^- \to \Lambda\bar{p}$ decay a penguin dominated mode and $\bar{B}^0_s \to p\bar{p}$ decay a suppressed mode.

By considering the chirality nature of weak interaction and asymptotic relations [27] at the large m_B limit ($m_q/m_B, m_{\mathcal{B},\mathcal{D}}/m_B \ll 1$), the number of independent amplitudes is significantly reduced [3,26]:

$$\begin{aligned}
T^{(\prime)} &= T^{(\prime)}_{1\mathcal{B}\bar{\mathcal{B}},2\mathcal{B}\bar{\mathcal{B}},3\mathcal{B}\bar{\mathcal{B}},4\mathcal{B}\bar{\mathcal{B}}} = T^{(\prime)}_{1\mathcal{B}\bar{\mathcal{D}},2\mathcal{B}\bar{\mathcal{D}}} = T^{(\prime)}_{1\mathcal{D}\bar{\mathcal{B}},2\mathcal{D}\bar{\mathcal{B}}} = T^{(\prime)}_{\mathcal{D}\bar{\mathcal{D}}},\\
P^{(\prime)} &= P^{(\prime)}_{1\mathcal{B}\bar{\mathcal{B}},2\mathcal{B}\bar{\mathcal{B}}} = P^{(\prime)}_{\mathcal{B}\bar{\mathcal{D}}} = P^{(\prime)}_{\mathcal{D}\bar{\mathcal{B}}} = P^{(\prime)}_{\mathcal{D}\bar{\mathcal{D}}},\\
P^{(\prime)}_{\rm EW} &= P^{(\prime)}_{1{\rm EW}\mathcal{B}\bar{\mathcal{B}},2{\rm EW}\mathcal{B}\bar{\mathcal{B}},3{\rm EW}\mathcal{B}\bar{\mathcal{B}},4{\rm EW}\mathcal{B}\bar{\mathcal{B}}}\\
&= P^{(\prime)}_{1{\rm EW}\mathcal{B}\bar{\mathcal{D}},2{\rm EW}\mathcal{B}\bar{\mathcal{D}}} = P^{(\prime)}_{1{\rm EW}\mathcal{D}\bar{\mathcal{B}},2{\rm EW}\mathcal{D}\bar{\mathcal{B}}} = P^{(\prime)}_{{\rm EW}\mathcal{D}\bar{\mathcal{D}}},\\
&E_{1\mathcal{B}\bar{\mathcal{B}},2\mathcal{B}\bar{\mathcal{B}},\mathcal{B}\bar{\mathcal{D}},\mathcal{D}\bar{\mathcal{B}},\mathcal{D}\bar{\mathcal{D}}}, A_{1\mathcal{B}\bar{\mathcal{B}},2\mathcal{B}\bar{\mathcal{B}},\mathcal{B}\bar{\mathcal{D}},\mathcal{D}\bar{\mathcal{B}},\mathcal{D}\bar{\mathcal{D}}}, PA_{\mathcal{B}\bar{\mathcal{B}},\mathcal{D}\bar{\mathcal{D}}} \to 0, \qquad (8)
\end{aligned}$$

and there are only one tree, one penguin and one electroweak penguin amplitude, which are estimated to be

$$\begin{aligned}
T^{(\prime)} &= V_{ub}V^*_{ud(s)}\frac{G_f}{\sqrt{2}}(c_1+c_2)\chi\bar{u}'(1-\gamma_5)v,\\
P^{(\prime)} &= -V_{tb}V^*_{td(s)}\frac{G_f}{\sqrt{2}}[c_3+c_4+\kappa_1 c_5+\kappa_2 c_6]\chi\bar{u}'(1-\gamma_5)v,\\
P^{(\prime)}_{\rm EW} &= -\frac{3}{2}V_{tb}V^*_{td(s)}\frac{G_f}{\sqrt{2}}[c_9+c_{10}+\kappa_1 c_7+\kappa_2 c_8]\chi\bar{u}'(1-\gamma_5)v,
\end{aligned} \qquad (9)$$

where c_i are the next-to-leading order Wilson coefficients, given by

$$\begin{aligned}
&c_1 = 1.081, \quad c_2 = -0.190, \quad c_3 = 0.014,\\
&c_4 = -0.036, \quad c_5 = 0.009, \quad c_6 = -0.042,\\
&c_7 = -0.011\alpha_{\rm EM}, \quad c_8 = 0.060\alpha_{\rm EM},\\
&c_9 = -1.254\alpha_{\rm EM}, \quad c_{10} = 0.223\alpha_{\rm EM},
\end{aligned} \qquad (10)$$

in the naive dimensional regularization scheme at scale $\mu = 4.2$ GeV [28]. Note that the relative signs of $c_{1,3,9}$ and $c_{2,4,10}$ in Eq. (9) are determined according to Ref. [18]. Since the Fiertz transformation of $O_{5,6,7,8}$ are different from $O_{1,2,3,4}$, additional coefficients κ_i in front of $c_{5(7)}$ and $c_{6(8)}$ in Eq. (9) are assigned. For simplicity we take $\kappa_1 = \kappa_2 = \kappa$. The parameters χ and κ will be extracted from $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ data. Note that $|\kappa|$ is expected to be of order $\mathcal{O}(1)$.

In reality the m_B mass is finite. The decays amplitudes are not in the asymptotic forms. Some corrections are expected. The correction on $T^{(\prime)}_i$, $P^{(\prime)}_i$ and $P^{(\prime)}_{{\rm EW}i}$ are estimated to be of order $m_\mathcal{B}/m_B$ (the baryon and B meson mass ratio). Hence, we have

$$\begin{aligned}
T^{(\prime)}_i &= (1+r^{(\prime)}_{t,i})T^{(\prime)},\\
P^{(\prime)}_i &= (1+r^{(\prime)}_{p,i})P^{(\prime)}_, P^{(\prime)}_{{\rm EW}i} = (1+r^{(\prime)}_{ewp,i})P^{(\prime)}_{\rm EW},
\end{aligned} \qquad (11)$$

with

$$|r^{(\prime)}_{t,i}|, |r^{(\prime)}_{p,i}|, |r^{(\prime)}_{ewp,i}| \le m_p/m_B, \qquad (12)$$

parametrizing the correction to the asymptotic relations, Eq. (8). Note that the phases of these $r^{(\prime)}$ can be any value. For $P^{(\prime)}_i$, we replace the CKM factor $-V_{tb}V^*_{td(s)}$ by the sum of $V_{ub}V^*_{ud(s)}$ and $V_{cb}V^*_{cd(s)}$. The penguins with $V_{ub}V^*_{ud(s)}$ and $V_{cb}V^*_{cd(s)}$ are u-penguin ($P^{(\prime)u}_i$) and c-penguin ($P^{(\prime)c}_i$), respectively. The $r_{p,i}$ of the u-penguin and the c-penguin are independent. Furthermore, although in the asymptotic limit the $\bar{u}'u$ and $-\bar{u}'\gamma_5 u$ terms have the same coefficients, see Eq. (9), this will no longer be true in the finite m_B case. In other words, the $r^{(\prime)}$ for $\bar{u}'u$ and $-\bar{u}'\gamma_5 u$ terms are independent. For subleading terms, such as exchange, penguin annihilation and annihilation amplitudes, we have

$$\begin{aligned}
E^{(\prime)}_i &\equiv \eta_i\frac{f_B}{m_B}\frac{m_\mathcal{B}}{m_B}T^{(\prime)}, \qquad A^{(\prime)}_j \equiv \eta_j\frac{f_B}{m_B}\frac{m_\mathcal{B}}{m_B}T^{(\prime)},\\
PA^{(\prime)}_k &\equiv \eta_k\frac{f_B}{m_B}\frac{m_\mathcal{B}}{m_B}P^{(\prime)},
\end{aligned} \qquad (13)$$

where the ratio f_B/m_B is from the usual estimation, the factor $m_\mathcal{B}/m_B$ is from the chirality structure. Note that $|\eta_{i,j,k}|$ are estimated to be of order 1 and, explicitly, we take $0 \le |\eta_{i,j,k}| \le |\eta| = 1$, with the bound $|\eta|$ set to 1.

With the above amplitudes and formulas given in Appendixes A and B, we are ready to study the two-body baryonic decay rates. Note that for $\bar{B} \to \mathcal{B}\bar{\mathcal{D}}, \mathcal{D}\bar{\mathcal{B}}$ decays, we need to add a correction factor of $p_{cm}/(m_B/2)$ to the topological amplitudes shown in Eq. (9) with p_{cm} the momentum of the final state baryons in the center-of-mass frame. The factor will further correct the amplitudes from their asymptotic forms.

III. NUMERICAL RESULTS ON RATES AND DIRECT *CP* ASYMMETRIES

A. Tree and penguin amplitudes

Using the recent data on the $\bar{B}^0 \to p\bar{p}$ rate and the $B^- \to \Lambda\bar{p}$ rate, the unknown parameters χ and κ in asymptotic amplitudes, Eq. (9), are fitted to be

$$\chi = (5.08^{+1.12}_{-1.02}) \times 10^{-3}\ {\rm GeV}^2, \qquad \kappa = 1.92^{+0.39}_{-0.46}. \qquad (14)$$

Note that the value of κ is indeed of order 1. The tree-penguin ratio is close to the naïve estimation. The penguin-tree and tree-penguin ratios of the asymptotic amplitudes [see Eq. (8)] for $\Delta S = 0$ and -1 transitions, respectively, can be extracted for the first time to be

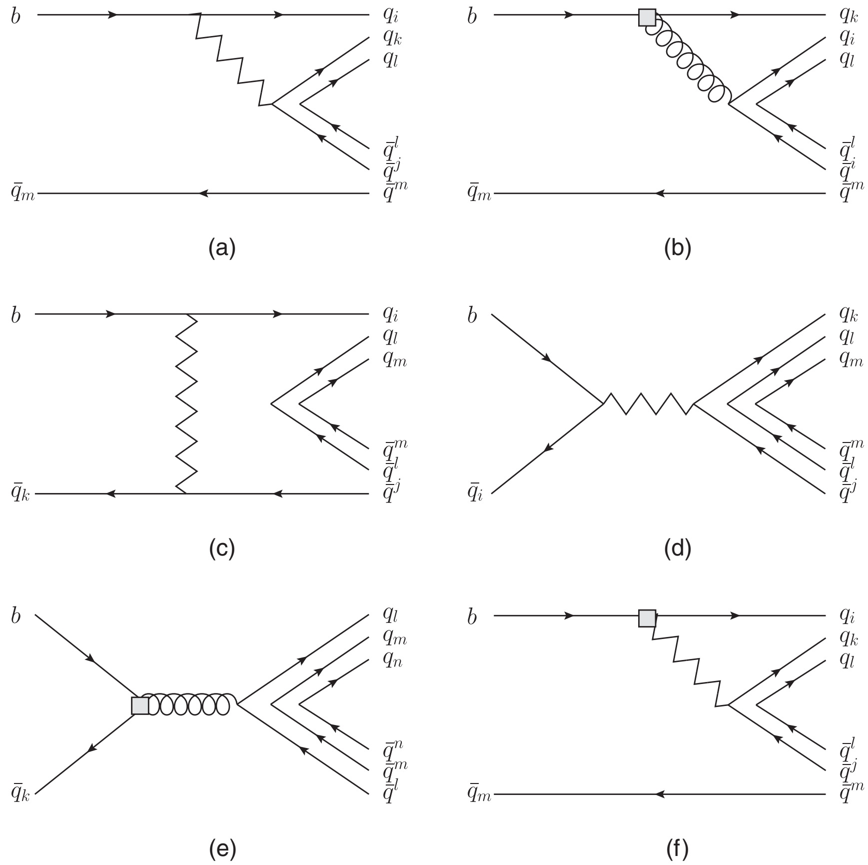

FIG. 1. Flavor flow or topological diagrams of (a) $T^{(\prime)}$ (tree), (b) $P^{(\prime)}$ (penguin), (c) $E^{(\prime)}$ (W-exchange), (d) $A^{(\prime)}$ (annihilation), (e) $PA^{(\prime)}$ (penguin annihilation) and (f) $P_{\rm EW}^{(\prime)}$ (electroweak penguin) amplitudes in $\bar B$ to baryon pair decays for $\Delta S = 0(-1)$ decays.

$$\left|\frac{P}{T}\right| = 0.24 \pm 0.04, \qquad \left|\frac{T'}{P'}\right| = 0.21^{+0.05}_{-0.03}. \tag{15}$$

The above equation is one of the major results of this work.

B. Numerical results on rates

In the following we make use of the $\bar B^0 \to p\bar p$ and $B^- \to \Lambda\bar p$ data as inputs and predict rates of all other $\bar B \to \mathcal{B}\bar{\mathcal{B}}$, $\mathcal{B}\bar{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$, $\mathcal{D}\bar{\mathcal{D}}$ modes. Results are shown in Tables I–VIII. They are major results of this work. A first glimpse on these tables reveals that all experimental upper bounds are satisfied. This is a nontrivial check. We will go through the discussions of the updated results on $\bar B \to \mathcal{B}\bar{\mathcal{B}}$, $\mathcal{B}\bar{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$, $\mathcal{D}\bar{\mathcal{D}}$ decay rates below and make suggestions on future experimental searches. We will give a summary of our suggestions at the end of this subsection.

1. Rates of $\bar B_q \to \mathcal{B}\bar{\mathcal{B}}$ decays

Predictions on $\Delta S = 0$, $\bar B_q \to \mathcal{B}\bar{\mathcal{B}}$ decay rates are shown in Table I. The first uncertainty is from the uncertainties of the χ and κ parameters [see Eq. (14)], reflecting the uncertainties in the measurements of $\mathcal{B}(\bar B^0 \to pp)$ and $\mathcal{B}(B^- \to \Lambda\bar p)$. The second uncertainty is obtained by varying the tree and penguin strong phase ϕ, where we assign to the penguin amplitude[2]:

$$P^{(\prime)} = -V_{tb}V^*_{td(s)}\frac{G_f}{\sqrt{2}}[c_3 + c_4 + \kappa c_5 + \kappa c_6]\chi e^{i\phi}\bar u'(1-\gamma_5)v \tag{16}$$

and a similar expression for $P_{\rm EW}^{(\prime)}$. We use a common strong phase for simplicity. The third uncertainty is from relaxing the asymptotic relations by varying $r_{t,i}, r_{p,i}, r_{ewp,i}$ [see Eqs. (11) and (12)] and the last uncertainty is from subleading contributions, such as annihilation, penguin annihilation and exchange amplitudes [see Eq. (13)].

From the tables we see that errors are reduced at least by a factor of 2 compared to the previous analysis in [3]. These errors can provide useful information: (i) As noted before the first errors reflect the uncertainties in $\mathcal{B}(\bar B^0 \to pp)$ and $\mathcal{B}(B^- \to \Lambda\bar p)$. (ii) The second errors reflect the size of tree-penguin interferences. We can see from the table that in

[2]The strong phase of the tree amplitude is factored out and set to zero. Therefore, the strong phase ϕ is the relative strong phase of penguin and tree amplitudes.

TABLE I. Decay rates of $\Delta S = 0$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ modes. The first uncertainty is from the uncertainties of the χ and κ parameters, reflecting the uncertainties in the measurements of $\mathcal{B}(\bar{B}^0 \to pp)$ and $\mathcal{B}(B^- \to \Lambda\bar{p})$, the second uncertainty is obtained by varying the tree and penguin strong phase ϕ, the third uncertainty is from relaxing the asymptotic relations, by varying $r_{t,i}$, $r_{p,i}$, $r_{ewp,i}$ [see Eqs. (11) and (12)] and the last uncertainty is from subleading contributions, terms with $\eta_{i,j,k}$ [see Eq. (13)]. Occasionally the last uncertainty is shown to a larger decimal place. The latest experimental results are given in parentheses under the theoretical results. The experimental $\bar{B}^0 \to p\bar{p}$ rate is one of the inputs.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to n\bar{p}$	$3.45^{+1.50+0.68+1.99}_{-1.50-1.23-0} \pm 0.09$	$\bar{B}^0_s \to p\overline{\Sigma^+}$	$1.42^{+0.69+0.13+2.01}_{-0.51-0-1.12} \pm 0$
$B^- \to \Sigma^0\overline{\Sigma^+}$	$3.29^{+1.56+0.52+2.09}_{-1.18-0-1.58} \pm 0.11$	$\bar{B}^0_s \to n\overline{\Sigma^0}$	$0.75^{+0.36+0+0.32}_{-0.27-0.05-0.26} \pm 0$
$B^- \to \Sigma^-\overline{\Sigma^0}$	$0.62^{+0.28}_{-0.22} \pm 0^{+0.42+0.006}_{-0.31-0.004}$	$\bar{B}^0_s \to n\bar{\Lambda}$	$2.96^{+1.36+0.57+1.88}_{-1.06-0-1.41} \pm 0$
$B^- \to \Sigma^-\bar{\Lambda}$	$0.47^{+0.21}_{-0.17} \pm 0^{+0.20+0.003}_{-0.17-0.002}$	$\bar{B}^0_s \to \Sigma^0\overline{\Xi^0}$	$10.85^{+5.23+1.22+5.23}_{-3.90-0-4.20} \pm 0$
$B^- \to \Xi^-\overline{\Xi^0}$	$0.07^{+0.03}_{-0.03} \pm 0 \pm 0.03^{+0.0005}_{-0.0003}$	$\bar{B}^0_s \to \Sigma^-\overline{\Xi^-}$	$1.76^{+0.78}_{-0.63} \pm 0^{+0.76}_{-0.63} \pm 0$
$B^- \to \Lambda\overline{\Sigma^+}$	$0.47^{+0.21}_{-0.17} \pm 0^{+0.38+0.003}_{-0.17-0.002}$	$\bar{B}^0_s \to \Lambda\overline{\Xi^0}$	$0.11^{+0.05}_{-0.04} \pm 0^{+0.63}_{-0.08} \pm 0$
$\bar{B}^0 \to p\bar{p}$	$1.47^{+0.71+0.14+2.07}_{-0.53-0-1.16} \pm 0.12$	$\bar{B}^0 \to \Sigma^+\overline{\Sigma^+}$	$0 \pm 0 \pm 0 \pm 0^{+0.003}_{-0}$
	$1.47^{+0.62+0.35}_{-0.51-0.14}$ [4]		
$\bar{B}^0 \to n\bar{n}$	$6.66^{+3.15+1.05+4.25}_{-2.39-0-3.20} \pm 0.07$	$\bar{B}^0 \to \Sigma^0\overline{\Sigma^0}$	$1.52^{+0.72+0.24+0.97}_{-0.55-0-0.73} \pm 0.07$
$\bar{B}^0 \to \Xi^0\overline{\Xi^0}$	$0 \pm 0 \pm 0 \pm 0^{+0.0004}_{-0}$	$\bar{B}^0 \to \Sigma^-\overline{\Sigma^-}$	$1.15^{+0.51}_{-0.41} \pm 0^{+0.78}_{-0.58} \pm 0.04$
$\bar{B}^0 \to \Xi^-\overline{\Xi^-}$	$0.07^{+0.03}_{-0.02} \pm 0^{+0.03}_{-0.02} \pm 0.01$	$\bar{B}^0 \to \Sigma^0\bar{\Lambda}$	$4.10^{+1.98+0.39+1.90}_{-1.47-0-1.54} \pm 0.05$
$\bar{B}^0 \to \Lambda\bar{\Lambda}$	$0 \pm 0 \pm 0^{+0.23+0.0005}_{-0-0}$	$\bar{B}^0 \to \Lambda\overline{\Sigma^0}$	$0.22^{+0.10}_{-0.08} \pm 0^{+0.18}_{-0.08} \pm 0.001$
	(<32) [29]		

general the effects of tree-penguin interference on rates are not sizable. This is consistent with the tree-penguin ratios shown in Eq. (15). (iii) The third errors, which correspond to corrections to amplitudes away from the asymptotic limit, are usually the largest ones. (iv) Occasionally we show the last errors, which are from subleading contributions, to larger decimal places. These terms are with $\eta_{i,j,k}$ [see Eq. (13)]. Note that for modes which only have subleading contributions, the rates are proportional to $|\eta_{i,j,k}|^2$, while for modes having tree and/or penguin terms as well, these (subleading) contributions are roughly proportional to $\eta_{i,j,k}$.

For $\Delta S = 0$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ decays, there are three modes that can decay cascadely to all charged final states, namely $\bar{B}^0 \to p\bar{p}$, $\bar{B}^0 \to \Xi^-\overline{\Xi^-}$ and $\Lambda\bar{\Lambda}$ decays.[3] We see from Table I that among these modes the $\bar{B}^0 \to p\bar{p}$ decay has the highest rate and highest detectability. The rates of the other two modes are, in fact, one or two orders of magnitude smaller than the $p\bar{p}$ rate. In particular, the predicted $\bar{B}^0 \to \Lambda\bar{\Lambda}$ rate is much smaller than the present experimental upper limit [29]. More modes can be searched for with π^0, γ, $\pi^0\pi^0$ and $\pi^0\gamma$ in future experiments, such as in Belle II. For example, with one π^0 or γ, one can search for $\bar{B}^0 \to \Sigma^0\bar{\Lambda}$ and $\bar{B}^0_s \to p\overline{\Sigma^+}$ decays, with $\pi^0\gamma$ one can also search for $\bar{B}^0_s \to \Sigma^0\overline{\Xi^0}$ and $B^- \to \Sigma^0\overline{\Sigma^+}$ decays, while with $\gamma\gamma$ one can search for $\bar{B}^0 \to \Sigma^0\overline{\Sigma^0}$ decays. In fact, the $\bar{B}^0_s \to \Sigma^0\overline{\Xi^0}$ decay rate is of the order of 10^{-7}, which is the highest rate in the table, but the mode is reconstructed through the cascade decay $\bar{B}^0_s \to \Sigma^0\overline{\Xi^0} \to \Lambda\gamma\bar{\Lambda}\pi^0$, which requires both γ and π^0 for the detection. It is understandable why the $\bar{B}^0 \to p\bar{p}$ decay is the first mode with experimental evidence.

From Eqs. (A1), (A2) and (A3), we see that there are several modes without any tree ($T_{i\mathcal{B}\bar{\mathcal{B}}}$) contribution. These include $B^- \to \Sigma^-\overline{\Sigma^0}$, $B^- \to \Sigma^-\bar{\Lambda}$, $B^- \to \Xi^-\overline{\Xi^0}$, $\bar{B}^0 \to \Xi^-\overline{\Xi^-}$, $\bar{B}^0 \to \Sigma^-\overline{\Sigma^-}$, $\bar{B}^0 \to \Xi^0\overline{\Xi^0}$, $\bar{B}^0 \to \Sigma^+\overline{\Sigma^+}$ and $\bar{B}^0_s \to \Sigma^-\overline{\Xi^-}$ decays. As shown in Table I the second uncertainties of the rates of these modes are vanishing. Note that $\bar{B}^0 \to \Xi^-\bar{\Xi}^-$, $\bar{B}^0 \to \Sigma^-\overline{\Sigma^-}$ and $\bar{B}^0_s \to \Sigma^-\overline{\Xi^-}$ decays are pure penguin modes, which only have $P_{i\mathcal{B}\bar{\mathcal{B}}}$, $P_{i\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}}$ and $PA_{\mathcal{B}\bar{\mathcal{B}}}$ terms, while $\bar{B}^0 \to \Xi^0\overline{\Xi^0}$ and $\bar{B}^0 \to \Sigma^+\overline{\Sigma^+}$ decays only have subleading contributions, namely $E_{i\mathcal{B}\bar{\mathcal{B}}}$ and $PA_{\mathcal{B}\bar{\mathcal{B}}}$. Note that although $B^- \to \Lambda\overline{\Sigma^+}$, $\bar{B}^0_s \to \Lambda\overline{\Xi^0}$, $\bar{B}^0 \to \Lambda\bar{\Lambda}$ and $\bar{B}^0 \to \Lambda\overline{\Sigma^0}$ decays have tree amplitudes $T_{i\mathcal{B}\bar{\mathcal{B}}}$, these tree amplitudes cancel out in the

[3] To study the accessibilities of searching the charmless two-body baryonic modes, we note that (i) $\Delta^{++,0}$, Λ, Ξ^-, $\Sigma^{*\pm}$, Ξ^{*0} and Ω^- have nonsuppressed decay modes of final states with all charged particles, (ii) Δ^+, Σ^+, Ξ^0, Σ^{*0} and Ξ^{*-} can be detected by detecting a π^0, (iii) Σ^0 can be detected by detecting γ, and (iv) one needs n in detecting Δ^- and Σ^- [3,30]. Note that although some particles, such as Ξ^- and Ξ^{*0}, can decay to final states with all charged particles, they may suffer from low reconstruction efficiencies.

asymptotic limit [see Eqs (A1), (A2), (A3) and (8)]. In particular, the tree, penguin, electroweak penguin and exchange amplitudes in the $\bar{B}^0 \to \Lambda\bar{\Lambda}$ amplitude all cancel out in the asymptotic limit. This mode is therefore sensitive to the correction to the asymptotic relations, Eqs. (8), (11) and (12).

Predictions on $\Delta S = -1$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ decay rates are shown in Table II. There are 9 modes that have rates of order 10^{-7}, namely $B^- \to \Xi^0\overline{\Sigma^+}$, $\Xi^-\overline{\Sigma^0}$, $\Lambda\bar{p}$, $\bar{B}^0 \to \Xi^0\overline{\Sigma^0}$, $\Xi^-\overline{\Sigma^-}$, $\Lambda\bar{n}$, $\bar{B}^0_s \to \Xi^0\overline{\Xi^0}$, $\Xi^-\overline{\Xi^-}$ and $\Lambda\bar{\Lambda}$ decays. On the other hand, there are 5 modes that can cascadely decay to all charged final states, namely $B^- \to \Xi^-\bar{\Lambda}$, $\Lambda\bar{p}$, $\bar{B}^0_s \to p\bar{p}$, $\Xi^-\overline{\Xi^-}$ and $\Lambda\bar{\Lambda}$. Comparing these two sets, we see that $B^- \to \Lambda\bar{p}$, $\bar{B}^0_s \to \Lambda\bar{\Lambda}$ and $\Xi^-\overline{\Xi^-}$ decays are the only three modes that have rates of order 10^{-7} and can cascadely decay to all charge final states. In fact, the $B^- \to \Lambda\bar{p}$ has the highest rate among these three modes and has the best detectability as the others need both Λ and $\bar{\Lambda}$ for detections ($\bar{B}^0_s \to \Lambda\bar{\Lambda}$, $\bar{B}^0_s \to \Xi^-\overline{\Xi^-} \to \Lambda\pi^-\bar{\Lambda}\pi^+$). It is understandable that why $B^- \to \Lambda\bar{p}$ is the first penguin mode with experimental evidence. Nevertheless, it is interesting to search for $\bar{B}^0_s \to \Lambda\bar{\Lambda}$ and $\Xi^-\overline{\Xi^-}$ decays as well. One can also search for other modes. For example, the $B^- \to \Xi^-\bar{\Lambda}$ mode can also cascadely decay to all charged final states and its rate is of order 10^{-8}, but this mode suffers from the low reconstruction efficiency of Ξ^-. With γ one can search for $B^- \to \Xi^-\overline{\Sigma^0}$ decay, which has rate of order 10^{-7}. With π^0 one can search for $\bar{B}^0 \to \Xi^0\bar{\Lambda}$ and $\bar{B}^0 \to \Sigma^+\bar{p}$ decays at 10^{-8} level. With $\pi^0\pi^0$ one can search for $B^- \to \Xi^0\overline{\Sigma^+}$, $\bar{B}^0_s \to \Xi^0\overline{\Xi^0}$, and $\bar{B}^0_s \to \Sigma^+\overline{\Sigma^+}$ decays, where the first two modes have rate of order 10^{-7}, while with $\pi^0\gamma$ one can search for $\bar{B}^0 \to \Xi^0\overline{\Sigma^0}$, which has rate of order 10^{-7}, and finally with $\gamma\gamma$ one can search for $\bar{B}^0_s \to \Sigma^0\overline{\Sigma^0}$ decay at 10^{-8} level. Note that with all charged final states, γ, $\pi^0\pi^0$ and $\pi^0\gamma$, most modes having rates of the order of 10^{-7} can be searched for in the future.

From Eqs. (A4), (A5) and (A6), we see that $B^- \to \Sigma^-\bar{n}$, $B^- \to \Xi^-\overline{\Sigma^0}$, $B^- \to \Xi^-\bar{\Lambda}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$, $\bar{B}^0_s \to p\bar{p}$ and $\bar{B}^0_s \to n\bar{n}$ decays do not have any tree ($T'_{i\mathcal{B}\bar{\mathcal{B}}}$) contribution. As shown in Table II the rates of these modes have vanishing second uncertainties. In particular, we note that $\bar{B}^0 \to \Xi^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^-\overline{\Sigma^-}$ and $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$ are pure penguin modes, which only have $P'_{i\mathcal{B}\bar{\mathcal{B}}}$, $P'_{i\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}}$ and $PA'_{\mathcal{B}\bar{\mathcal{B}}}$ terms, while $\bar{B}^0_s \to p\bar{p}$ and $\bar{B}^0_s \to n\bar{n}$ decays only have subleading contributions, the $E'_{i\mathcal{B}\bar{\mathcal{B}}}$ and $PA'_{\mathcal{B}\bar{\mathcal{B}}}$ terms. We will return to these modes later.

The predicted $\bar{B}^0_s \to p\bar{p}$ rate is several orders smaller than the present experimental result, which, however, has large uncertainty. As noted this mode only receives contributions from subleading terms [see Eq. (4)]. One may enhance the subleading contributions, but will soon run into contradictions. For example, after enhancing the subleading contributions in the $\bar{B}^0 \to p\bar{p}$ mode, the so-called "subleading contributions" will oversize the leading tree contribution. Note that, some enhancement on subleading contributions is possible in the presence of final state rescattering (see for example, [31,32]), but it is unlikely that the enhancement be so significant. Note that in Ref. [5], when partial conservation of axial-vector current is relaxed, the calculated $B_s \to p\bar{p}$ rate can be close to data, but the predicted $B^- \to \Lambda\bar{p}$ rate is of the order 10^{-8} and is

TABLE II. Same as Table I, but with $\Delta S = -1$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ modes. The latest experimental result is given in the parentheses under the theoretical results. The experimental $B^- \to \Lambda\bar{p}$ rate is one of the inputs.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to \Sigma^0\bar{p}$	$0.76^{+0.35+0+0.50}_{-0.27-0.19-0.37} \pm 0.001$	$\bar{B}^0 \to \Sigma^+\bar{p}$	$1.83^{+0.76+0.47+0.82}_{-0.65-0-0.61} \pm 0$
$B^- \to \Sigma^-\bar{n}$	$1.67^{+0.74}_{-0.59} \pm 0^{+0.71+0.002}_{-0.58-0.002}$	$\bar{B}^0 \to \Sigma^0\bar{n}$	$1.12^{+0.47+0.52+0.47}_{-0.40-0-0.36} \pm 0$
$B^- \to \Xi^0\overline{\Sigma^+}$	$39.98^{+17.53+2.14+17.06}_{-14.23-0-14.02} \pm 0.03$	$\bar{B}^0 \to \Xi^0\overline{\Sigma^0}$	$18.50^{+8.11+0.99+7.89}_{-6.58-0-6.48} \pm 0$
$B^- \to \Xi^-\overline{\Sigma^0}$	$19.40^{+8.59}_{-6.90} \pm 0^{+8.38}_{-6.88} \pm 0.02$	$\bar{B}^0 \to \Xi^0\bar{\Lambda}$	$2.59^{+1.07+0.67+2.80}_{-0.92-0-1.74} \pm 0$
$B^- \to \Xi^-\bar{\Lambda}$	$2.36^{+1.05}_{-0.84} \pm 0^{+2.65}_{-1.67} \pm 0.005$	$\bar{B}^0 \to \Xi^-\overline{\Sigma^-}$	$35.88^{+15.89}_{-12.77} \pm 0^{+15.50}_{-12.73} \pm 0$
$B^- \to \Lambda\bar{p}$	$24.00^{+10.44+2.13+12.48}_{-8.54-0-9.85} \pm 0.02$	$\bar{B}^0 \to \Lambda\bar{n}$	$23.48^{+10.00+4.12+12.13}_{-8.36-0-9.50} \pm 0$
	$24^{+10}_{-8} \pm 3$ [1]		
$\bar{B}^0_s \to p\bar{p}$	$0 \pm 0 \pm 0^{+0.007}_{-0}$	$\bar{B}^0_s \to \Sigma^+\overline{\Sigma^+}$	$1.76^{+0.73+0.45+0.79+0.21}_{-0.63-0-0.59-0.20}$
	$(2.84^{+2.03+0.85}_{-1.68-0.18})$ [4]		
$\bar{B}^0_s \to n\bar{n}$	$0 \pm 0 \pm 0^{+0.007}_{-0}$	$\bar{B}^0_s \to \Sigma^0\overline{\Sigma^0}$	$1.61^{+0.69+0.21+0.69+0.20}_{-0.57-0-0.55-0.19}$
$\bar{B}^0_s \to \Xi^0\overline{\Xi^0}$	$24.46^{+10.53+3.24+16.28+0.75}_{-8.71-0-12.07-0.74}$	$\bar{B}^0_s \to \Sigma^-\overline{\Sigma^-}$	$1.49^{+0.66}_{-0.53} \pm 0^{+0.63+0.19}_{-0.52-0.18}$
$\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$	$22.63^{+10.02}_{-8.05} \pm 0^{+15.27+0.72}_{-11.36-0.71}$	$\bar{B}^0_s \to \Sigma^0\bar{\Lambda}$	$0.05^{+0.03+0.04+0.06}_{-0.02-0-0.04} \pm 0.001$
$\bar{B}^0_s \to \Lambda\bar{\Lambda}$	$14.90^{+6.42+1.97+7.58+0.61}_{-5.31-0-5.99-0.60}$	$\bar{B}^0_s \to \Lambda\overline{\Sigma^0}$	$0.05^{+0.03+0.04}_{-0.02-0} \pm 0.02 \pm 0.001$

in tension with the data [1]. We need a more precise measurement on the $B_s \to p\bar{p}$ rate to settle the issue.

2. Rates of $\bar{B}_q \to \mathcal{B}\overline{\mathcal{D}}$ decays

Predictions on rates of $\Delta S = 0$, $\bar{B}_q \to \mathcal{B}\overline{\mathcal{D}}$ decays are shown in Table III. Modes that can cascadely decay to all charged final states and with unsuppressed rates are $B^- \to p\overline{\Delta^{++}}$ and $\bar{B}^0_s \to p\overline{\Sigma^{*+}}$ decays. In particular, the predicted rate of $B^- \to p\overline{\Delta^{++}}$ decay is the highest one in the table and is just roughly a factor of 2 smaller than the present experimental upper bound [33], which, however, has not been updated for quite a while. This mode could be just around the corner. On the other hand, four other modes that can cascadely decay to all charged final states, namely $B^- \to \Xi^-\overline{\Xi^{*0}}$, $\Lambda\overline{\Sigma^{*+}}$, $\bar{B}^0_s \to \Xi^-\overline{\Omega^-}$ and $\Lambda\overline{\Xi^{*0}}$ decays, are one or two orders of magnitude more suppressed. Note that with γ one can search for $B^- \to \Sigma^0\overline{\Sigma^{*+}}$ and $\bar{B}^0_s \to \Sigma^0\overline{\Xi^{*0}}$ decays, with π^0 one can search for $\bar{B}^0 \to p\overline{\Delta^+}$ decay, while with $\gamma\pi^0$ one can search for $\bar{B}^0 \to \Sigma^0\overline{\Sigma^{*0}}$ decay in the future. All of these modes have rates of orders 10^{-8}.

From Eqs. (A7), (A8) and (A9), we see that $B^- \to \Sigma^-\overline{\Sigma^{*0}}$, $B^- \to \Xi^-\overline{\Sigma^{*0}}$, $\bar{B}^0_s \to \Sigma^-\overline{\Xi^{*-}}$, $\bar{B}^0 \to \Xi^-\overline{\Xi^{*-}}$, $\bar{B}^0 \to \Sigma^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Xi^-\overline{\Omega^-}$, $\bar{B}^0 \to \Sigma^+\overline{\Sigma^{*+}}$ and $\bar{B}^0 \to \Xi^0\overline{\Xi^{*0}}$ decay amplitudes, do not have any tree ($T_{i\mathcal{B}\overline{\mathcal{D}}}$) contribution. As shown in Table III, the rates of these modes have vanishing second uncertainties. We note that $\bar{B}^0 \to \Xi^-\overline{\Xi^{*-}}$ and $\bar{B}^0 \to \Sigma^-\overline{\Sigma^{*-}}$ decays are pure penguin modes with only $P_{\mathcal{B}\overline{\mathcal{D}}}$ and $P_{i\mathrm{EW}\mathcal{B}\overline{\mathcal{D}}}$ contributions, while $\bar{B}^0 \to \Sigma^+\overline{\Sigma^{*+}}$ and $\bar{B}^0 \to \Xi^0\overline{\Xi^{*0}}$ decays are pure exchange modes with only $E_{\mathcal{B}\overline{\mathcal{D}}}$ contributions. Although $B^- \to \Lambda\overline{\Sigma^{*+}}$, $\bar{B}^0_s \to \Lambda\overline{\Xi^{*0}}$ and $\bar{B}^0 \to \Lambda\overline{\Sigma^{*0}}$ decay amplitudes have tree amplitudes, these tree amplitudes cancel out in the asymptotic limit.

There are relations among rates. Using formulas in Appendixes A and B, we have [3]

$$\begin{aligned}
&\mathcal{B}(B^- \to \Xi^-\overline{\Xi^{*0}}) = 2\mathcal{B}(B^- \to \Sigma^-\overline{\Sigma^{*0}})\left(\frac{p_{\rm cm}(B^- \to \Xi^-\overline{\Xi^{*0}})}{p_{\rm cm}(B^- \to \Sigma^-\overline{\Sigma^{*0}})}\right)^3 \simeq 2\mathcal{B}(B^- \to \Sigma^-\overline{\Sigma^{*0}}),\\
&3\tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Sigma^-\overline{\Sigma^{*-}}) \simeq 3\tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Xi^-\overline{\Xi^{*-}}) \simeq 3\tau_{B_s}\mathcal{B}(\bar{B}^0_s \to \Sigma^-\overline{\Xi^{*-}}) \simeq \tau_{B_s}\mathcal{B}(\bar{B}^0_s \to \Xi^-\overline{\Omega^-}),\\
&\mathcal{B}(\bar{B}^0 \to \Sigma^+\overline{\Sigma^{*+}}) \simeq \mathcal{B}(\bar{B}^0 \to \Xi^0\overline{\Xi^{*0}}).
\end{aligned} \tag{17}$$

One can check from Table III that the rates of these modes roughly satisfy the above relations and the agreement will be improved when the SU(3) breaking effects are taken into account. Note that these relations do not rely on the asymptotic relations.

Predictions on $\Delta S = -1$, $\bar{B}_q \to \mathcal{B}\overline{\mathcal{D}}$ decay rates are shown in Table IV. Both $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$ and $\Lambda\overline{\Delta^0}$ modes can cascadely decay to all charge final states, where only the $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$ rate can reach 10^{-8} level. In principle, this mode can be detected through $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}} \to \Lambda\pi^-\bar{\Lambda}\pi^+$ decay, but may be restricted by the low reconstruction efficiency of Ξ^-. Note that with π^0 one can search for $\bar{B}^0_s \to \Sigma^+\overline{\Sigma^{*+}}$, $B^- \to \Xi^0\overline{\Sigma^{*+}}$, $B^- \to \Sigma^+\overline{\Delta^{++}}$, $\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Xi^0\overline{\Xi^{*0}}$ and $B^- \to \Xi^-\overline{\Sigma^{*0}}$ decays, which have rates of

TABLE III. Same as Table I, but with $\Delta S = 0$, $\bar{B}_q \to \mathcal{B}\overline{\mathcal{D}}$ modes. The latest experimental result is given in the parentheses.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to p\overline{\Delta^{++}}$	$6.21^{+3.01+0.58+8.77}_{-2.23-0-4.89} \pm 0.08$ (<14) [33]	$\bar{B}^0_s \to p\overline{\Sigma^{*+}}$	$1.84^{+0.89+0.17+2.60}_{-0.66-0-1.45} \pm 0$
$B^- \to n\overline{\Delta^+}$	$2.18^{+1.05+0+0.93}_{-0.79-0.15-0.75} \pm 0.03$	$\bar{B}^0_s \to n\overline{\Sigma^{*0}}$	$0.97^{+0.47+0+0.41}_{-0.35-0.07-0.33} \pm 0$
$B^- \to \Sigma^0\overline{\Sigma^{*+}}$	$3.14^{+1.53+0.17+1.34}_{-1.13-0-1.10} \pm 0.02$	$\bar{B}^0_s \to \Sigma^0\overline{\Xi^{*0}}$	$2.77^{+1.35+0.15+1.19}_{-1.00-0-0.97} \pm 0$
$B^- \to \Sigma^-\overline{\Sigma^{*0}}$	$0.04 \pm 0.02 \pm 0 \pm 0.02^{+0.0003}_{-0.0002}$	$\bar{B}^0_s \to \Sigma^-\overline{\Xi^{*-}}$	$0.08 \pm 0.03 \pm 0 \pm 0.03 \pm 0$
$B^- \to \Xi^-\overline{\Xi^{*0}}$	$0.07^{+0.03}_{-0.02} \pm 0^{+0.03+0.0004}_{-0.02-0.0003}$	$\bar{B}^0_s \to \Xi^-\overline{\Omega^-}$	$0.18^{+0.08}_{-0.07} \pm 0^{+0.08}_{-0.06} \pm 0$
$B^- \to \Lambda\overline{\Sigma^{*+}}$	$0.14^{+0.06}_{-0.05} \pm 0^{+0.21}_{-0.05} \pm +0.001$	$\bar{B}^0_s \to \Lambda\overline{\Xi^{*0}}$	$0.12^{+0.05}_{-0.04} \pm 0^{+0.19}_{-0.05} \pm 0$
$\bar{B}^0 \to p\overline{\Delta^+}$	$1.92^{+0.93+0.18+2.71}_{-0.69-0-1.51} \pm 0.02$	$\bar{B}^0 \to \Sigma^+\overline{\Sigma^{*+}}$	$0 \pm 0 \pm 0^{+0.0001}_{-0}$
$\bar{B}^0 \to n\overline{\Delta^0}$	$2.01^{+0.97+0+0.86}_{-0.73-0.14-0.69} \pm 0.03$	$\bar{B}^0 \to \Sigma^0\overline{\Sigma^{*0}}$	$1.45^{+0.71+0.08+0.62}_{-0.52-0-0.51} \pm 0.01$
$\bar{B}^0 \to \Xi^0\overline{\Xi^{*0}}$	$0 \pm 0 \pm 0^{+0.0001}_{-0}$	$\bar{B}^0 \to \Sigma^-\overline{\Sigma^{*-}}$	$0.08^{+0.04}_{-0.03} \pm 0 \pm 0.03 \pm 0$
$\bar{B}^0 \to \Xi^-\overline{\Xi^{*-}}$	$0.06^{+0.03}_{-0.02} \pm 0^{+0.03}_{-0.02} \pm 0$	$\bar{B}^0 \to \Lambda\overline{\Sigma^{*0}}$	$0.06^{+0.03}_{-0.02} \pm 0^{+0.10+0.0004}_{-0.02-0.0003}$

orders 10^{-8}, while with γ one can search for $\bar{B}^0 \to \Sigma^0\overline{\Delta^0}$ decay in the future. In particular, the $B^- \to \Sigma^+\overline{\Delta^{++}}$ decay rate is the highest one in the table. With $\gamma\pi^0$, $\pi^0\pi^0$ or $\gamma\gamma$, one can search for $B^- \to \Sigma^0\overline{\Delta^+}$, $\bar{B}^0 \to \Sigma^+\overline{\Delta^+}$, $\bar{B}^0_s \to \Sigma^0\overline{\Sigma^{*0}}$ and $\bar{B}^0 \to \Xi^0\overline{\Sigma^{*0}}$ decays, which have rates of orders (or close to) 10^{-8}, in the future. Note that the predicted $\bar{B}^0 \to \Lambda\overline{\Delta^0}$ and $B^- \to \Lambda\overline{\Delta^+}$ rates are both roughly two orders of magnitude below the present experimental bounds [34].

From Eqs. (A10), (A11) and (A12), we see that $B^- \to \Sigma^-\overline{\Delta^0}$, $B^- \to \Xi^-\overline{\Sigma^{*0}}$, $\bar{B}^0 \to \Sigma^-\overline{\Delta^-}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Sigma^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to p\overline{\Delta^+}$ and $\bar{B}^0_s \to n\overline{\Delta^0}$ decays do not have any tree ($T'_{i\mathcal{B}\bar{\mathcal{D}}}$) contribution. As shown in Table IV, the rates of these modes have vanishing second uncertainties. Note that $\bar{B}^0 \to \Sigma^-\overline{\Delta^-}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Sigma^-\overline{\Sigma^{*-}}$ and $\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$ decays are pure penguin modes with only $P'_{\mathcal{B}\bar{\mathcal{D}}}$ and $P'_{i\mathrm{EW}\mathcal{B}\bar{\mathcal{D}}}$ contributions, while $\bar{B}^0_s \to p\overline{\Delta^+}$ and $\bar{B}^0_s \to n\overline{\Delta^0}$ are pure exchange modes with only $E'_{\mathcal{B}\bar{\mathcal{D}}}$ contributions.

The rates of some modes are related. From Appendixes A and B, we have [3]

$$\begin{aligned} 2\mathcal{B}(B^- \to \Xi^-\overline{\Sigma^{*0}}) &= \mathcal{B}(B^- \to \Sigma^-\overline{\Delta^0}), \\ 3\tau_{B_s}\mathcal{B}(\bar{B}^0_s \to \Sigma^-\overline{\Sigma^{*-}}) &= 3\tau_{B_s}\mathcal{B}(\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}) \\ &= 3\tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}) \\ &= \tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Sigma^-\overline{\Delta^-}), \\ \mathcal{B}(\bar{B}^0_s \to p\overline{\Delta^+}) &= \mathcal{B}(\bar{B}^0_s \to n\overline{\Delta^0}), \end{aligned} \tag{18}$$

where these relations are subjected to corrections from SU(3) breaking in $|p_{\mathrm{cm}}|^3$. These relations do not rely on the asymptotic relations. As shown in Table III the rates of these modes roughly satisfy the above relations and the agreement will be improved when the SU(3) breaking effects are taken into account.

3. Rates of $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ decays

Predictions on $\Delta S = 0$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ decay rates are shown in Table V. The mode with the highest decay rate is $\bar{B}^0 \to \Delta^0\bar{n}$ decay, which is unfortunately hard to detect. Both $B^- \to \Delta^0\bar{p}$ and $\bar{B}^0_s \to \Delta^0\bar{\Lambda}$ decays can cascadely decay to all charge final states. These two modes both have rates at the order of 10^{-8}, but the $B^- \to \Delta^0\bar{p}$ decay has better detectability. Note that the predicted rate of this mode is roughly two orders of magnitude below the present experimental limit [33], which, however, has not been updated since 2008. With π^0, one can search for $\bar{B}^0 \to \Delta^+\bar{p}$ and $\bar{B}^0 \to \Sigma^{*0}\bar{\Lambda}$ decays, while $\bar{B}^0_s \to \Delta^0\overline{\Sigma^0}$ decay, which has a slightly smaller rate, can be searched for with π^0 in the future. With $\pi^0\pi^0$, one can search for $\bar{B}^0_s \to \Sigma^{*0}\overline{\Xi^0}$, $\bar{B}^0_s \to \Delta^+\overline{\Sigma^+}$, and $B^- \to \Sigma^{*0}\overline{\Sigma^+}$ decays, in the future. These modes all have rates at the level of 10^{-8}.

Note that $B^- \to \Delta^-\bar{n}$, $B^- \to \Sigma^{*-}\overline{\Sigma^0}$, $B^- \to \Xi^{*-}\overline{\Xi^0}$, $B^- \to \Sigma^{*-}\bar{\Lambda}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Xi^-}$, $\bar{B}^0_s \to \Delta^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^-}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^-}$, $\bar{B}^0 \to \Xi^{*0}\overline{\Xi^0}$ and $\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^+}$ decays do not have any tree ($T_{i\mathcal{D}\bar{\mathcal{B}}}$) contribution [see Eqs. (A19), (A20) and (A21)], and, consequently, their rates in Table V have vanishing second uncertainties. In particular, the $\bar{B}^0 \to \Xi^{*-}\overline{\Xi^-}$, $\bar{B}^0_s \to \Delta^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^-}$ and $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^-}$ decays are pure penguin modes, which only have $P_{\mathcal{D}\bar{\mathcal{B}}}$ and $P_{i\mathrm{EW}\mathcal{D}\bar{\mathcal{B}}}$ contributions, while $\bar{B}^0 \to \Xi^{*0}\overline{\Xi^0}$ and $\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^+}$ decays are pure exchange ($E_{\mathcal{D}\bar{\mathcal{B}}}$) modes.

The rates of some modes are related. Using the formulas in Appendixes A and B, we have [3]

TABLE IV. Same as Table I, but with $\Delta S = -1$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{D}}$ modes. The latest experimental results are given in parentheses.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to \Sigma^+\overline{\Delta^{++}}$	$6.99^{+2.90+1.80+3.13}_{-2.49-0-2.33} \pm 0.002$	$\bar{B}^0 \to \Sigma^+\overline{\Delta^+}$	$2.16^{+0.90+0.56+0.97}_{-0.77-0-0.72} \pm 0$
$B^- \to \Sigma^0\overline{\Delta^+}$	$4.25^{+1.83+0.56+1.83}_{-1.51-0-1.46} \pm 0.003$	$\bar{B}^0 \to \Sigma^0\overline{\Delta^0}$	$3.93^{+1.69+0.52+1.69}_{-1.40-0-1.35} \pm 0$
$B^- \to \Sigma^-\overline{\Delta^0}$	$1.96^{+0.87}_{-0.70} \pm 0^{+0.83}_{-0.69} \pm 0.002$	$\bar{B}^0 \to \Sigma^-\overline{\Delta^-}$	$5.46^{+2.42}_{-1.94} \pm 0^{+2.32}_{-1.91} \pm 0$
$B^- \to \Xi^0\overline{\Sigma^{*+}}$	$1.49^{+0.67+0+0.93}_{-0.53-0.38-0.70} \pm 0.002$	$\bar{B}^0 \to \Xi^0\overline{\Sigma^{*0}}$	$0.69^{+0.31+0+0.43}_{-0.24-0.17-0.33} \pm 0$
$B^- \to \Xi^-\overline{\Sigma^{*0}}$	$0.81^{+0.36}_{-0.29} \pm 0^{+0.34}_{-0.28} \pm 0.001$	$\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$	$1.49^{+0.66}_{-0.53} \pm 0^{+0.63}_{-0.52} \pm 0$
$B^- \to \Lambda\overline{\Delta^+}$	$0.15^{+0.07+0.11+0.07}_{-0.05-0-0.05} \pm 0$	$\bar{B}^0 \to \Lambda\overline{\Delta^0}$	$0.14^{+0.07+0.10+0.06}_{-0.05-0-0.05} \pm 0$
	(<82) [34]		(<93) [34]
$\bar{B}^0_s \to p\overline{\Delta^+}$	$0 \pm 0 \pm 0^{+0.000005}_{-0}$	$\bar{B}^0_s \to \Sigma^+\overline{\Sigma^{*+}}$	$2.07^{+0.86+0.53+0.93}_{-0.74-0-0.69} \pm 0.001$
$\bar{B}^0_s \to n\overline{\Delta^0}$	$0 \pm 0 \pm 0^{+0.000005}_{-0}$	$\bar{B}^0_s \to \Sigma^0\overline{\Sigma^{*0}}$	$1.89^{+0.81+0.25+0.81}_{-0.67-0-0.65} \pm 0.001$
$\bar{B}^0_s \to \Xi^0\overline{\Xi^{*0}}$	$1.31^{+0.59+0+0.82}_{-0.47-0.33-0.62} \pm 0.002$	$\bar{B}^0_s \to \Sigma^-\overline{\Sigma^{*-}}$	$1.74^{+0.77}_{-0.62} \pm 0^{+0.74}_{-0.61} \pm 0$
$\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$	$1.42^{+0.63}_{-0.51} \pm 0^{+0.60}_{-0.50} \pm 0$	$\bar{B}^0_s \to \Lambda\overline{\Sigma^{*0}}$	$0.07^{+0.03+0.05+0.03}_{-0.02-0-0.02} \pm 0.001$

TABLE V. Same as Table I, but with $\Delta S = 0$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ modes. The latest experimental result is given in the parentheses.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to \Delta^0 \bar{p}$	$2.19^{+1.05+0+0.92}_{-0.79-0.15-0.74} \pm 0.03$	$\bar{B}^0_s \to \Delta^+ \overline{\Sigma^+}$	$1.70^{+0.82+0.16+0.79}_{-0.61-0-0.64} \pm 0$
	(<138) [33]		
$B^- \to \Delta^- \bar{n}$	$0.33^{+0.15}_{-0.12} \pm 0^{+0.14+0.002}_{-0.12-0.001}$	$\bar{B}^0_s \to \Delta^0 \overline{\Sigma^0}$	$0.96^{+0.46+0.15+0.50}_{-0.34-0-0.40} \pm 0$
$B^- \to \Sigma^{*0} \overline{\Sigma^+}$	$0.85^{+0.41+0+0.36}_{-0.31-0.06-0.29} \pm 0.01$	$\bar{B}^0_s \to \Delta^- \overline{\Sigma^-}$	$0.27^{+0.12}_{-0.10} \pm 0^{+0.11}_{-0.09} \pm 0$
$B^- \to \Sigma^{*-} \overline{\Sigma^0}$	$0.04 \pm 0.02 \pm 0 \pm 0.02^{+0.0003}_{-0.0002}$	$\bar{B}^0_s \to \Sigma^{*0} \overline{\Xi^0}$	$2.73^{+1.33+0.15+1.17}_{-0.98-0-0.96} \pm 0$
$B^- \to \Xi^{*-} \overline{\Xi^0}$	$0.07^{+0.03}_{-0.02} \pm 0^{+0.03+0.0004}_{-0.02-0.0003}$	$\bar{B}^0_s \to \Sigma^{*-} \overline{\Xi^-}$	$0.07 \pm 0.03 \pm 0 \pm 0.03 \pm 0$
$B^- \to \Sigma^{*-} \bar{\Lambda}$	$0.14^{+0.06}_{-0.05} \pm 0^{+0.06}_{-0.05} \pm 0.001$	$\bar{B}^0_s \to \Delta^0 \bar{\Lambda}$	$2.59^{+1.27+0.03+1.01}_{-0.93-0-0.84} \pm 0$
$\bar{B}^0 \to \Delta^+ \bar{p}$	$1.92^{+0.93+0.18+0.89}_{-0.69-0-0.72} \pm 0.02$	$\bar{B}^0 \to \Sigma^{*+} \overline{\Sigma^+}$	$0 \pm 0 \pm 0 \pm 0^{+0.0001}_{-0}$
$\bar{B}^0 \to \Delta^0 \bar{n}$	$7.46^{+3.64+0.40+3.19}_{-2.69-0-2.62} \pm 0.05$	$\bar{B}^0 \to \Sigma^{*0} \overline{\Sigma^0}$	$0.39^{+0.19+0+0.17}_{-0.14-0.03-0.13} \pm 0.005$
$\bar{B}^0 \to \Xi^{*0} \overline{\Xi^0}$	$0 \pm 0 \pm 0 \pm 0^{+0.0001}_{-0}$	$\bar{B}^0 \to \Sigma^{*-} \overline{\Sigma^-}$	$0.08^{+0.04}_{-0.03} \pm 0 \pm 0.03 \pm 0$
$\bar{B}^0 \to \Xi^{*-} \overline{\Xi^-}$	$0.06^{+0.03}_{-0.02} \pm 0^{+0.03}_{-0.02} \pm 0$	$\bar{B}^0 \to \Sigma^{*0} \bar{\Lambda}$	$1.18^{+0.57+0.11+0.55}_{-0.42-0-0.44} \pm 0.02$

$$\begin{aligned}
\mathcal{B}(B^- \to \Delta^0 \bar{p}) &= 2\mathcal{B}(B^- \to \Sigma^{*0}\overline{\Sigma^+}),\\
\mathcal{B}(B^- \to \Delta^- \bar{n}) &= 3\mathcal{B}(B^- \to \Xi^{*-}\overline{\Xi^0}) = 6\mathcal{B}(B^- \to \Sigma^{*-}\overline{\Sigma^0}) = 2\mathcal{B}(B^- \to \Sigma^{*-}\bar{\Lambda}),\\
3\tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^-}) &= 3\tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Xi^{*-}\overline{\Xi^-}) = \tau_{B_s}\mathcal{B}(\bar{B}^0_s \to \Delta^-\overline{\Sigma^-}) = 3\tau_{B_s}\mathcal{B}(\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^-}),\\
\mathcal{B}(\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^+}) &= \mathcal{B}(\bar{B}^0 \to \Xi^{*0}\overline{\Xi^0}),
\end{aligned} \tag{19}$$

where these relations are subjected to corrections from SU(3) breaking in $|p_{\rm cm}|^3$. These relations do not rely on the asymptotic relations. Note that the relations on B^- decay rates are new compared to those in [3]. As shown in Table V the rates of these modes roughly satisfy the above relations and the agreement will be improved when the SU(3) breaking effects are taken into account.

Predictions on $\Delta S = -1$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ decay rates are shown in Table VI. Note that $\bar{B}^0 \to \Omega^-\overline{\Xi^-}$, $\bar{B}^0 \to \Xi^{*0}\bar{\Lambda}$ and $\bar{B}^0 \to \Sigma^{*+}\bar{p}$ decays are the only three modes that can cascadely decay to all charged final states. All of them have rates of order 10^{-8}. We need more data to search for them as the reconstruction efficiencies of the final states of the first two modes are low, while the predicted $\bar{B}^0 \to \Sigma^{*+}\bar{p}$ rate is one order of magnitude below the experimental limit, which has not been updated since 2007 [34]. Note that with one π^0 one can search for $B^- \to \Omega^-\overline{\Xi^0}$, $B^- \to \Xi^{*-}\bar{\Lambda}$, $\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^0}$,

TABLE VI. Same as Table I, but with $\Delta S = -1$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ modes.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to \Sigma^{*0} \bar{p}$	$0.94^{+0.43+0+0.51}_{-0.33-0.24-0.40} \pm 0.001$	$\bar{B}^0 \to \Sigma^{*+} \bar{p}$	$2.25^{+0.93+0.58+0.93}_{-0.80-0-0.75} \pm 0$
	<47 [34]		<26 [34]
$B^- \to \Sigma^{*-} \bar{n}$	$2.05^{+0.91}_{-0.73} \pm 0^{+0.87}_{-0.72} \pm 0.002$	$\bar{B}^0 \to \Sigma^{*0} \bar{n}$	$1.39^{+0.58+0.65+0.54}_{-0.49-0-0.45} \pm 0$
$B^- \to \Xi^{*0} \overline{\Sigma^+}$	$1.44^{+0.65+0+0.78}_{-0.51-0.37-0.61} \pm 0.002$	$\bar{B}^0 \to \Xi^{*0} \overline{\Sigma^0}$	$0.67^{+0.30+0+0.36}_{-0.24-0.17-0.28} \pm 0$
$B^- \to \Xi^{*-} \overline{\Sigma^0}$	$0.78^{+0.35}_{-0.28} \pm 0^{+0.33}_{-0.27} \pm 0.001$	$\bar{B}^0 \to \Xi^{*-} \overline{\Sigma^-}$	$1.45^{+0.64}_{-0.51} \pm 0^{+0.61}_{-0.51} \pm 0$
$B^- \to \Omega^- \overline{\Xi^0}$	$3.77^{+1.67}_{-1.34} \pm 0^{+1.60}_{-1.32} \pm 0.003$	$\bar{B}^0 \to \Omega^- \overline{\Xi^-}$	$3.47^{+1.54}_{-1.24} \pm 0^{+1.47}_{-1.21} \pm 0$
$B^- \to \Xi^{*-} \bar{\Lambda}$	$2.48^{+1.10}_{-0.88} \pm 0^{+1.05}_{-0.87} \pm 0.002$	$\bar{B}^0 \to \Xi^{*0} \bar{\Lambda}$	$2.71^{+1.13+0.70+1.12}_{-0.97-0-0.90} \pm 0$
$\bar{B}^0_s \to \Delta^+ \bar{p}$	$0 \pm 0 \pm 0 \pm 0^{+0.000005}_{-0}$	$\bar{B}^0_s \to \Sigma^{*+} \overline{\Sigma^+}$	$1.98^{+0.82+0.51+0.82}_{-0.71-0-0.66} \pm 0.001$
$\bar{B}^0_s \to \Delta^0 \bar{n}$	$0 \pm 0 \pm 0 \pm 0^{+0.000005}_{-0}$	$\bar{B}^0_s \to \Sigma^{*0} \overline{\Sigma^0}$	$1.81^{+0.78+0.24+0.74}_{-0.64-0-0.61} \pm 0.001$
$\bar{B}^0_s \to \Xi^{*0} \overline{\Xi^0}$	$1.99^{+0.83+0.93+0.78}_{-0.71-0-0.64} \pm 0.0002$	$\bar{B}^0_s \to \Sigma^{*-} \overline{\Sigma^-}$	$1.67^{+0.74}_{-0.59} \pm 0^{+0.71}_{-0.58} \pm 0$
$\bar{B}^0_s \to \Xi^{*-} \overline{\Xi^-}$	$1.36^{+0.60}_{-0.48} \pm 0^{+0.58}_{-0.47} \pm 0$	$\bar{B}^0_s \to \Sigma^{*0} \bar{\Lambda}$	$0.06^{+0.03+0.05}_{-0.02-0} \pm 0.02 \pm 0.001$

$\bar{B}_s^0 \to \Sigma^{*+}\overline{\Sigma^{+}}$, $B^- \to \Xi^{*0}\overline{\Sigma^{+}}$, $\bar{B}_s^0 \to \Xi^{*-}\overline{\Xi^{-}}$ and $B^- \to \Sigma^{*0}\bar{p}$ decays, which have rates of order 10^{-8}, in the future. In particular, the $B^- \to \Omega^-\overline{\Xi^0}$ decay has the highest rate in the table and the predicted $B^- \to \Sigma^{*0}\bar{p}$ rate is more than one order of magnitude below the experimental limit, which has not been updated since 2007 [34]. With $\pi^0\gamma$ one can search for $\bar{B}_s^0 \to \Sigma^{*0}\overline{\Sigma^0}$ and $B^- \to \Xi^{*-}\overline{\Sigma^0}$ decays, which have rates of order (or close to) 10^{-8}, in the future.

Note that $B^- \to \Sigma^{*-}\bar{n}$, $B^- \to \Xi^{*-}\overline{\Sigma^0}$, $B^- \to \Omega^-\overline{\Xi^0}$, $B^- \to \Xi^{*-}\bar{\Lambda}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^-}$, $\bar{B}_s^0 \to \Sigma^{*-}\overline{\Sigma^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^-}$, $\bar{B}_s^0 \to \Xi^{*-}\overline{\Xi^-}$ $\bar{B}_s^0 \to \Delta^+\bar{p}$ and $\bar{B}_s^0 \to \Delta^0\bar{n}$ decays do not have any tree ($T'_{i\mathcal{D}\bar{\mathcal{B}}}$) contribution [see Eqs. (A16), (A17) and (A18)], and, consequently, their rates in Table VI have vanishing second uncertainties. In particular, the $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^-}$ and $\bar{B}_s^0 \to \Xi^{*-}\overline{\Xi^-}$ decays are pure penguin modes, which only have $P'_{\mathcal{D}\bar{\mathcal{B}}}$ and $P'_{i\mathrm{EW}\mathcal{D}\bar{\mathcal{B}}}$ contributions, while $\bar{B}_s^0 \to \Delta^+\bar{p}$ and $\bar{B}_s^0 \to \Delta^0\bar{n}$ decays are pure exchange ($E'_{\mathcal{D}\bar{\mathcal{B}}}$) modes.

The rates of some modes are related. Using the formulas in Appendixes A and B, we have [3]

$$\begin{aligned}
2\mathcal{B}(B^- \to \Sigma^{*0}\bar{p}) &= \mathcal{B}(B^- \to \Xi^{*0}\overline{\Sigma^+}),\\
3\mathcal{B}(B^- \to \Sigma^{*-}\bar{n}) &= 6\mathcal{B}(B^- \to \Xi^{*-}\overline{\Sigma^0}) = \mathcal{B}(B^- \to \Omega^-\overline{\Xi^0}) = 2\mathcal{B}(B^- \to \Xi^{*-}\bar{\Lambda}),\\
3\tau_{B_s}\mathcal{B}(\bar{B}_s^0 \to \Sigma^{*-}\overline{\Sigma^-}) &= 3\tau_{B_s}\mathcal{B}(\bar{B}_s^0 \to \Xi^{*-}\overline{\Xi^-}) = 3\tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^-}) = \tau_{B_d}\mathcal{B}(\bar{B}^0 \to \Omega^-\overline{\Xi^-}),\\
\mathcal{B}(\bar{B}_s^0 \to \Delta^+\bar{p}) &= \mathcal{B}(\bar{B}_s^0 \to \Delta^0\bar{n}),
\end{aligned} \tag{20}$$

where these relations are subjected to corrections from SU(3) breaking in $|p_{\rm cm}|^3$. Note that the relations on B^- decay rates are new compared to those in [3]. These relations do not rely on the asymptotic relations. The rates in Table IV roughly satisfy the above relations and the agreement will be improved when the SU(3) breaking effects are taken into account.

4. Rates of $\bar{B}_q \to \mathcal{D}\bar{\mathcal{D}}$ decays

Predictions on $\Delta S = 0$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{D}}$ decay rates are shown in Table VII. There are six modes that can cascadely decay to all charged final states. They are $\bar{B}^0 \to \Delta^{++}\overline{\Delta^{++}}$, $\Delta^0\overline{\Delta^0}$, $\Omega^-\overline{\Omega^-}$, $\Sigma^{*+}\overline{\Sigma^{*+}}$, $\Sigma^{*-}\overline{\Sigma^{*-}}$ and $\Xi^{*0}\overline{\Xi^{*0}}$ decays. However, most of them have highly suppressed rates, except $\bar{B}^0 \to \Delta^0\overline{\Delta^0}$ and $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$ decays, which have rates of order 10^{-8} and should be searchable. In particular, the bound on $\bar{B}^0 \to \Delta^0\overline{\Delta^0}$ rate has not been updated for almost three decades [35]. Note that with π^0, one can search for plenty of unsuppressed modes. These modes include $B^- \to \Delta^+\overline{\Delta^{++}}$, $B^- \to \Delta^0\overline{\Delta^+}$, $\bar{B}_s^0 \to \Delta^+\overline{\Sigma^{*+}}$, $B^- \to \Sigma^{*0}\overline{\Sigma^{*+}}$, $\bar{B}_s^0 \to \Delta^0\overline{\Sigma^{*0}}$, $\bar{B}_s^0 \to \Sigma^{*0}\overline{\Xi^{*0}}$, $\bar{B}_s^0 \to \Sigma^{*-}\overline{\Xi^{*-}}$, and $\bar{B}_s^0 \to \Xi^{*-}\overline{\Omega^-}$ decays. In

TABLE VII. Same as Table I, but with $\Delta S = 0$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{D}}$ modes.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to \Delta^+\overline{\Delta^{++}}$	$17.15^{+8.31+1.61+7.97}_{-6.17-0-6.45} \pm 0.22$	$\bar{B}_s^0 \to \Delta^+\overline{\Sigma^{*+}}$	$5.18^{+2.51+0.49+2.41}_{-1.86-0-1.95} \pm 0$
$B^- \to \Delta^0\overline{\Delta^+}$	$6.47^{+3.07+1.02+3.39}_{-2.33-0-2.67} \pm 0.14$	$\bar{B}_s^0 \to \Delta^0\overline{\Sigma^{*0}}$	$2.93^{+1.39+0.46+1.53}_{-1.05-0-1.21} \pm 0$
$B^- \to \Delta^-\overline{\Delta^0}$	$0.92^{+0.41}_{-0.33} \pm 0^{+0.39+0.006}_{-0.32-0.004}$	$\bar{B}_s^0 \to \Delta^-\overline{\Sigma^{*-}}$	$0.83^{+0.37}_{-0.29} \pm 0^{+0.35}_{-0.29} \pm 0$
$B^- \to \Sigma^{*0}\overline{\Sigma^{*+}}$	$3.02^{+1.43+0.47+1.58}_{-1.08-0-1.24} \pm 0.07$	$\bar{B}_s^0 \to \Sigma^{*0}\overline{\Xi^{*0}}$	$2.73^{+1.29+0.43+1.43}_{-0.98-0-1.12} \pm 0$
$B^- \to \Sigma^{*-}\overline{\Sigma^{*0}}$	$0.57^{+0.25}_{-0.20} \pm 0^{+0.24}_{-0.20} \pm 0.003$	$\bar{B}_s^0 \to \Sigma^{*-}\overline{\Xi^{*-}}$	$1.03^{+0.46}_{-0.37} \pm 0^{+0.44}_{-0.36} \pm 0$
$B^- \to \Xi^{*-}\overline{\Xi^{*0}}$	$0.26^{+0.12}_{-0.09} \pm 0^{+0.11+0.002}_{-0.09-0.001}$	$\bar{B}_s^0 \to \Xi^{*-}\overline{\Omega^-}$	$0.71^{+0.31}_{-0.25} \pm 0^{+0.30}_{-0.25} \pm 0$
$\bar{B}^0 \to \Delta^{++}\overline{\Delta^{++}}$	$0 \pm 0 \pm 0 \pm 0^{+0.004}_{-0}$	$\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^{*+}}$	$0 \pm 0 \pm 0 \pm 0^{+0.002}_{-0}$
	$<1.1 \times 10^4$ [35]		
$\bar{B}^0 \to \Delta^+\overline{\Delta^+}$	$5.29^{+2.56+0.50+2.46}_{-1.90-0-2.00} \pm 0.16$	$\bar{B}^0 \to \Sigma^{*0}\overline{\Sigma^{*0}}$	$1.40^{+0.66+0.22+0.73}_{-0.50-0-0.58} \pm 0.06$
$\bar{B}^0 \to \Delta^0\overline{\Delta^0}$	$5.99^{+2.83+0.94+3.14}_{-2.15-0-2.47} \pm 0.13$	$\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$	$1.05^{+0.47}_{-0.37} \pm 0^{+0.45}_{-0.37} \pm 0.07$
	$<1.5 \times 10^5$ [35]		
$\bar{B}^0 \to \Delta^-\overline{\Delta^-}$	$2.55^{+1.13}_{-0.91} \pm 0^{+1.08}_{-0.89} \pm 0.11$	$\bar{B}^0 \to \Xi^{*0}\overline{\Xi^{*0}}$	$0 \pm 0 \pm 0 \pm 0^{+0.001}_{-0}$
$\bar{B}^0 \to \Omega^-\overline{\Omega^-}$	$0 \pm 0 \pm 0 \pm 0^{+0.001}_{-0}$	$\bar{B}^0 \to \Xi^{*-}\overline{\Xi^{*-}}$	$0.24^{+0.11}_{-0.09} \pm 0^{+0.10}_{-0.08} \pm 0.03$

particular, the mode with the highest rate (the only one at order 10^{-7}) can be searched through the $B^- \to \Delta^+\overline{\Delta^{++}} \to p\pi^0\bar{p}\pi^-$ decay. With $\pi^0\pi^0$, one can also search for $\bar{B}^0 \to \Delta^+\overline{\Delta^+}$ and $\bar{B}^0 \to \Sigma^{*0}\overline{\Sigma^{*0}}$ decays.

Note that $B^- \to \Delta^-\overline{\Delta^0}$, $B^- \to \Sigma^{*-}\overline{\Sigma^{*0}}$, $B^- \to \Xi^{*-}\overline{\Xi^{*0}}$, $\bar{B}^0 \to \Delta^-\overline{\Delta^-}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Delta^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Omega^-}$, $\bar{B}^0 \to \Delta^{++}\overline{\Delta^{++}}$, $\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^{*+}}$, $\bar{B}^0 \to \Xi^{*0}\overline{\Xi^{*0}}$ and $\bar{B}^0 \to \Omega^-\overline{\Omega^-}$ decays do not have any tree ($T_{\mathcal{D}\bar{\mathcal{D}}}$) contribution [see Eqs. (A19), (A20) and (A21)], and, consequently, their rates in Table VII have vanishing second uncertainties. In particular, the $\bar{B}^0 \to \Delta^-\overline{\Delta^-}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Delta^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^{*-}}$ and $\bar{B}^0_s \to \Xi^{*-}\overline{\Omega^-}$ decays are pure penguin modes, which only have $P_{\mathcal{D}\bar{\mathcal{D}}}$, $P_{\mathrm{EW}\mathcal{D}\bar{\mathcal{D}}}$ and $PA_{\mathcal{D}\bar{\mathcal{D}}}$ contributions, the $\bar{B}^0 \to \Delta^{++}\overline{\Delta^{++}}$, $\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^{*+}}$ and $\bar{B}^0 \to \Xi^{*0}\overline{\Xi^{*0}}$ decays are subleading modes, which only have $E_{\mathcal{D}\bar{\mathcal{D}}}$ and $P_{\mathcal{D}\bar{\mathcal{D}}}$ contributions, while the $\bar{B}^0 \to \Omega^-\overline{\Omega^-}$ decay is a pure penguin annihilation ($PA_{\mathcal{D}\bar{\mathcal{D}}}$) mode.

The rates of some modes are related. Using formulas in Appendixes A and B, we have [3]

$$\begin{aligned}
2\mathcal{B}(B^- \to \Delta^-\overline{\Delta^0}) &= 3\mathcal{B}(B^- \to \Sigma^{*-}\overline{\Sigma^{*0}}) = 6\mathcal{B}(B^- \to \Xi^{*-}\overline{\Xi^{*0}}),\\
\mathcal{B}(B^- \to \Delta^0\overline{\Delta^+}) &= 2\mathcal{B}(B^- \to \Sigma^{*0}\overline{\Sigma^{*+}}),\\
\mathcal{B}(\overline{B^0_s} \to \Delta^0\overline{\Sigma^{*0}}) &= \mathcal{B}(\overline{B^0_s} \to \Sigma^{*0}\overline{\Xi^{*0}}),\\
4\mathcal{B}(\overline{B^0_s} \to \Delta^-\overline{\Sigma^{*-}}) &= 4\mathcal{B}(\overline{B^0_s} \to \Xi^{*-}\overline{\Omega^-}) = 3\mathcal{B}(\overline{B^0_s} \to \Sigma^{*-}\overline{\Xi^{*-}}),
\end{aligned} \tag{21}$$

where these relations are subjected to SU(3) breaking from the phase space factors. These relations do not rely on the asymptotic relations. As shown in Table VII the rates of these modes roughly satisfy the above relations and the agreement will be improved when the SU(3) breaking effects are taken into account.

Predictions on $\Delta S = -1$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{D}}$ decay rates are shown in Table VIII. There are eight modes that can cascadely decay to all charged final states with unsuppressed rates. They are $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$, $B^- \to \Xi^{*0}\overline{\Sigma^{*+}}$, $\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}$, $B^- \to \Sigma^{*+}\overline{\Delta^{++}}$, $B^- \to \Omega^-\overline{\Xi^{*0}}$, $\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}$, $B^- \to \Sigma^{*-}\overline{\Delta^0}$ and $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$ decays. It is interesting that many (the first five) of them have rates of order 10^{-7}. In particular, the $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ decay has the highest rate and good detectability. Note that with one π^0 one can search for $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$, $B^- \to \Sigma^{*0}\overline{\Delta^+}$, $\bar{B}^0 \to \Sigma^{*0}\overline{\Delta^0}$ and $\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^{*0}}$ decays in the future. All of them have rates of order 10^{-7}. With $\pi^0\pi^0$ one can search for $B^- \to \Xi^{*-}\overline{\Sigma^{*0}}$, $\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^{*0}}$ and $\bar{B}^0 \to \Sigma^{*+}\overline{\Delta^+}$ decays, where the first one has rate of order 10^{-7}.

Note that $B^- \to \Sigma^{*-}\overline{\Delta^0}$, $B^- \to \Xi^{*-}\overline{\Sigma^{*0}}$, $B^- \to \Omega^-\overline{\Xi^{*0}}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}}$, $\bar{B}^0_s \to \Delta^+\overline{\Delta^+}$, $\bar{B}^0_s \to \Delta^0\overline{\Delta^0}$ and $\bar{B}^0_s \to \Delta^-\overline{\Delta^-}$ decays do not have any tree ($T'_{\mathcal{D}\bar{\mathcal{D}}}$) contribution [see Eqs. (A22), (A23) and (A24)], and, consequently, their rates in Table VIII have vanishing second uncertainties. The $\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ and $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$ decays are pure penguin modes, which only have $P'_{\mathcal{D}\bar{\mathcal{D}}}$, $P'_{\mathrm{EW}\mathcal{D}\bar{\mathcal{D}}}$ and $PA'_{\mathcal{D}\bar{\mathcal{D}}}$ contributions, the $\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}}$ $\bar{B}^0_s \to \Delta^+\overline{\Delta^+}$ and $\bar{B}^0_s \to \Delta^0\overline{\Delta^0}$ decays are subleading modes, which only have $E'_{\mathcal{D}\bar{\mathcal{D}}}$ and $P'_{\mathcal{D}\bar{\mathcal{D}}}$ contributions, while the $\bar{B}^0_s \to \Delta^-\overline{\Delta^-}$ decay is a pure penguin annihilation ($PA'_{\mathcal{D}\bar{\mathcal{D}}}$) mode.

TABLE VIII. Same as Table I, but with $\Delta S = -1$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{D}}$ modes.

Mode	$\mathcal{B}(10^{-8})$	Mode	$\mathcal{B}(10^{-8})$
$B^- \to \Sigma^{*+}\overline{\Delta^{++}}$	$21.48^{+8.92+5.53+8.86}_{-7.65-0-7.15} \pm 0.007$	$\bar{B}^0 \to \Sigma^{*+}\overline{\Delta^+}$	$6.63^{+2.75+1.71+2.73}_{-2.36-0-2.21} \pm 0$
$B^- \to \Sigma^{*0}\overline{\Delta^+}$	$13.08^{+5.63+1.73+5.32}_{-4.66-0-4.39} \pm 0.008$	$\bar{B}^0 \to \Sigma^{*0}\overline{\Delta^0}$	$12.11^{+5.21+1.60+4.93}_{-4.31-0-4.06} \pm 0$
$B^- \to \Sigma^{*-}\overline{\Delta^0}$	$6.06^{+2.68}_{-2.16} \pm 0^{+2.57}_{-2.12} \pm 0.005$	$\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^-}$	$16.83^{+7.46}_{-5.99} \pm 0^{+7.15}_{-5.88} \pm 0$
$B^- \to \Xi^{*0}\overline{\Sigma^{*+}}$	$24.26^{+10.44+3.21+9.87}_{-8.64-0-8.13} \pm 0.01$	$\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^{*0}}$	$11.23^{+4.83+1.49+4.57}_{-4.00-0-3.77} \pm 0$
$B^- \to \Xi^{*-}\overline{\Sigma^{*0}}$	$11.24^{+4.98}_{-4.00} \pm 0^{+4.77}_{-3.93} \pm 0.01$	$\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$	$20.79^{+9.21}_{-7.40} \pm 0^{+8.83}_{-7.27} \pm 0$
$B^- \to \Omega^-\overline{\Xi^{*0}}$	$15.49^{+6.86}_{-5.51} \pm 0^{+6.57}_{-5.41} \pm 0.01$	$\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$	$14.32^{+6.34}_{-5.10} \pm 0^{+6.08}_{-5.01} \pm 0$
$\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}}$	$0 \pm 0 \pm 0 \pm 0^{+0.02}_{-0}$	$\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}$	$6.49^{+2.69+1.67+2.67+0.77}_{-2.31-0-2.16-0.72}$
$\bar{B}^0_s \to \Delta^+\overline{\Delta^+}$	$0 \pm 0 \pm 0 \pm 0^{+0.02}_{-0}$	$\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^{*0}}$	$5.93^{+2.55+0.79+2.41+0.74}_{-2.11-0-1.99-0.70}$
$\bar{B}^0_s \to \Delta^0\overline{\Delta^0}$	$0 \pm 0 \pm 0 \pm 0^{+0.02}_{-0}$	$\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$	$5.48^{+2.43}_{-1.95} \pm 0^{+2.33+0.72}_{-1.92-0.67}$
$\bar{B}^0_s \to \Delta^-\overline{\Delta^-}$	$0 \pm 0 \pm 0 \pm 0^{+0.02}_{-0}$	$\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}$	$21.92^{+9.44+2.90+8.92+1.36}_{-7.81-0-7.35-1.32}$
$\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$	$41.95^{+18.58}_{-14.93} \pm 0^{+17.81+1.79}_{-14.67-1.75}$	$\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$	$20.29^{+8.99}_{-7.22} \pm 0^{+8.62+1.30}_{-7.10-1.26}$

TABLE IX. Modes with (relatively) unsuppressed rates and (relatively) good detectability are summarized.

	Group I All charged final states	Group II With single π^0/γ	Group III With $\pi^0\pi^0$, $\pi^0\gamma$ or $\gamma\gamma$
$\mathcal{B}\bar{\mathcal{B}}, \Delta S = 0$	$\bar{B}^0 \to p\bar{p}$;	$\bar{B}^0 \to \Sigma^0\bar{\Lambda}$, $\bar{B}^0_s \to p\overline{\Sigma^+}$;	$\bar{B}^0_s \to \Sigma^0\overline{\Xi^0}$, $B^- \to \Sigma^0\overline{\Sigma^+}$, $\bar{B}^0 \to \Sigma^0\overline{\Sigma^0}$
$\mathcal{B}\bar{\mathcal{B}}, \Delta S = -1$	$B^- \to \Lambda\bar{p}$, $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$; $\bar{B}^0_s \to \Lambda\bar{\Lambda}$, $B^- \to \Xi^-\bar{\Lambda}$;	$B^- \to \Xi^-\overline{\Sigma^0}$, $\bar{B}^0 \to \Xi^0\bar{\Lambda}$; $\bar{B}^0 \to \Sigma^+\bar{p}$	$B^- \to \Xi^0\overline{\Sigma^+}$, $\bar{B}^0_s \to \Xi^0\overline{\Xi^0}$, $\bar{B}^0 \to \Xi^0\overline{\Sigma^0}$, $\bar{B}^0_s \to \Sigma^+\overline{\Sigma^+}$, $\bar{B}^0_s \to \Sigma^0\overline{\Sigma^0}$
$\mathcal{B}\bar{\mathcal{D}}, \Delta S = 0$	$B^- \to p\overline{\Delta^{++}}$, $\bar{B}^0_s \to p\overline{\Sigma^{*+}}$;	$B^- \to \Sigma^0\overline{\Sigma^{*+}}$, $\bar{B}^0_s \to \Sigma^0\overline{\Xi^{*0}}$; $\bar{B}^0 \to p\overline{\Delta^+}$	$\bar{B}^0 \to \Sigma^0\overline{\Sigma^{*0}}$
$\mathcal{B}\bar{\mathcal{D}}, \Delta S = -1$	$\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$;	$B^- \to \Sigma^+\overline{\Delta^{++}}$, $\bar{B}^0 \to \Sigma^0\overline{\Delta^0}$; $\bar{B}^0_s \to \Sigma^+\overline{\Sigma^{*+}}$, $B^- \to \Xi^0\overline{\Sigma^{*+}}$; $\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Xi^0\overline{\Xi^{*0}}$, $B^- \to \Xi^-\overline{\Sigma^{*0}}$	$B^- \to \Sigma^0\overline{\Delta^+}$, $\bar{B}^0 \to \Sigma^+\overline{\Delta^+}$, $\bar{B}^0_s \to \Sigma^0\overline{\Sigma^{*0}}$, $\bar{B}^0 \to \Xi^0\overline{\Sigma^{*0}}$
$\mathcal{D}\bar{\mathcal{B}}, \Delta S = 0$	$B^- \to \Delta^0\bar{p}$, $\bar{B}^0_s \to \Delta^0\bar{\Lambda}$;	$\bar{B}^0 \to \Delta^+\bar{p}$, $\bar{B}^0 \to \Sigma^{*0}\bar{\Lambda}$; $\bar{B}^0_s \to \Delta^0\overline{\Sigma^0}$	$\bar{B}^0_s \to \Sigma^{*0}\overline{\Xi^0}$, $\bar{B}^0_s \to \Delta^+\overline{\Sigma^+}$, $B^- \to \Sigma^{*0}\overline{\Sigma^+}$
$\mathcal{D}\bar{\mathcal{B}}, \Delta S = -1$	$\bar{B}^0 \to \Omega^-\overline{\Xi^-}$, $\bar{B}^0 \to \Xi^{*0}\bar{\Lambda}$; $\bar{B}^0 \to \Sigma^{*+}\bar{p}$	$B^- \to \Omega^-\overline{\Xi^0}$, $B^- \to \Xi^{*-}\bar{\Lambda}$; $\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^0}$, $\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^+}$, $B^- \to \Xi^{*0}\overline{\Sigma^+}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^-}$, $B^- \to \Sigma^{*0}\bar{p}$	$\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^0}$, $B^- \to \Xi^{*-}\overline{\Sigma^0}$
$\mathcal{D}\bar{\mathcal{D}}, \Delta S = 0$	$\bar{B}^0 \to \Delta^0\overline{\Delta^0}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$;	$B^- \to \Delta^+\overline{\Delta^{++}}$, $B^- \to \Delta^0\overline{\Delta^+}$; $\bar{B}^0_s \to \Delta^+\overline{\Sigma^{*+}}$, $B^- \to \Sigma^{*0}\overline{\Sigma^{*+}}$, $\bar{B}^0_s \to \Delta^0\overline{\Sigma^{*0}}$, $\bar{B}^0_s \to \Sigma^{*0}\overline{\Xi^{*0}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Omega^-}$	$\bar{B}^0 \to \Delta^+\overline{\Delta^+}$, $\bar{B}^0 \to \Sigma^{*0}\overline{\Sigma^{*0}}$
$\mathcal{D}\bar{\mathcal{D}}, \Delta S = -1$	$\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$, $B^- \to \Xi^{*0}\overline{\Sigma^{*+}}$; $\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}$, $B^- \to \Sigma^{*+}\overline{\Delta^{++}}$; $B^- \to \Omega^-\overline{\Xi^{*0}}$, $\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}$; $B^- \to \Sigma^{*-}\overline{\Delta^0}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$	$\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$; $\bar{B}^0 \to \Sigma^{*0}\overline{\Delta^0}$, $\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^{*0}}$; $\bar{B}^0 \to \Sigma^{*+}\overline{\Delta^+}$	$\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$, $B^- \to \Sigma^{*0}\overline{\Delta^+}$, $B^- \to \Xi^{*-}\overline{\Sigma^{*0}}$, $\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^{*0}}$

The rates of some modes are related. Using formulas in Appendixes A and B, we have [3][4]

$$
\begin{aligned}
6\mathcal{B}(B^-\to\Sigma^{*-}\overline{\Delta^0}) &= 2\mathcal{B}(B^-\to\Omega^-\overline{\Xi^{*0}}) = 3\mathcal{B}(B^-\to\Xi^{*-}\overline{\Sigma^{*0}}),\\
2\mathcal{B}(B^-\to\Sigma^{*0}\overline{\Delta^+}) &= \mathcal{B}(B^-\to\Xi^{*0}\overline{\Sigma^{*+}}),\\
\mathcal{B}(\bar{B}^0\to\Sigma^{*0}\overline{\Delta^0}) &= \mathcal{B}(\bar{B}^0\to\Xi^{*0}\overline{\Sigma^{*0}}),\\
4\mathcal{B}(\bar{B}^0\to\Sigma^{*-}\overline{\Delta^-}) &= 3\mathcal{B}(\bar{B}^0\to\Xi^{*-}\overline{\Sigma^{*-}}) = 4\mathcal{B}(\bar{B}^0\to\Omega^-\overline{\Xi^{*-}}),
\end{aligned}
\tag{22}
$$

where these relations are subjected to SU(3) breaking from the phase space factors. These relations do not relay on the asymptotic relations. The rates in Table VIII roughly satisfy the above relations and the agreement will be improved when the SU(3) breaking effects are taken into account.

We have shown that $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ decays have a better chance to be found experimentally. We have identified several modes that can cascadely decay to all charged final states with (relatively) unsuppressed rates. They will be searchable in the near future. In particular, we note that the predicted $B^- \to p\overline{\Delta^{++}}$ rate is close to the experimental bound, which has not been updated in the last ten years [33]. Furthermore, the bounds on $B^- \to \Delta^0\bar{p}$ and $\bar{B}^0 \to \Sigma^{*+}\bar{p}$ rates have not been updated in the last ten years [33,34] and the bound on $\bar{B}^0 \to \Delta^0\overline{\Delta^0}$ rate was last given in 1989 [35], while their rates are predicted to be of the order of 10^{-8}. Also note that the $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ rate is predicted to be the highest rate. It will also be interesting for Belle-II, which will be turned on soon, to search for baryonic modes, as there are many modes having unsuppressed rates but require π^0 or γ for detection. We pointed out several modes without tree amplitudes. Some of them are pure penguin modes. As we shall see in the next subsection, these will affect their CP asymmetries. We summarize our suggestions for experimental searches in Table IX. These modes have (relatively) unsuppressed rates and better detectability. Modes are arranged according to their quantum numbers, detection and rates (in descending order) and they are assigned into groups I, II and III accordingly, where group I modes are modes that have unsuppressed rates and can cascadely decay to all charged final states, group II modes are modes that can be searched with π^0 or γ and group III modes are modes that can be searched with $\pi^0\pi^0$, $\pi^0\gamma$ or $\gamma\gamma$.

[4]A typo in the last relation is corrected.

TABLE X. Direct *CP* asymmetries ($\mathcal{A}$ in %) of $\Delta S = 0$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ modes for $\phi = 0$, $\pm\pi/4$ and $\pm\pi/2$. The uncertainties are from varying the strong phases of $r^{(\prime)}_{t,i}$, $r^{(\prime)}_{p,i}$, $r^{(\prime)}_{\mathrm{ewp},i}$ and $\eta_{i,j,k}$ [see Eqs. (11) and (13)].

Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$	Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$
$B^- \to n\bar{p}$	0 ± 32.1	$\mp(74.0^{+19.7}_{-25.6})$	$\mp(97.9^{+2.1}_{-15.6})$	$\bar{B}^0_s \to p\overline{\Sigma^+}$	0 ± 21.2	$\mp(36.0^{+21.2}_{-17.7})$	$\mp(49.3^{+20.2}_{-15.2})$
$B^- \to \Sigma^0\overline{\Sigma^+}$	0 ± 31.2	$\mp(59.3^{+23.4}_{-27.2})$	$\mp(79.5^{+16.1}_{-22.4})$	$\bar{B}^0_s \to n\overline{\Sigma^0}$	0 ± 14.9	$\pm(26.7^{+14.6}_{-13.8})$	$\pm(38.8^{+13.9}_{-12.8})$
$B^- \to \Sigma^-\overline{\Sigma^0}$	0 ± 54.6	0 ± 54.6	0 ± 54.6	$\bar{B}^0_s \to n\bar{\Lambda}$	0 ± 31.0	$\mp(71.6^{+19.3}_{-25.4})$	$\mp(94.9^{+5.1}_{-16.3})$
$B^- \to \Sigma^-\bar{\Lambda}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s \to \Sigma^0\overline{\Xi^0}$	0 ± 15.4	$\mp(42.8^{+14.1}_{-13.9})$	$\mp(58.3^{+12.9}_{-12.6})$
$B^- \to \Xi^-\overline{\Xi^0}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s \to \Sigma^-\overline{\Xi^-}$	0 ± 30.0	0 ± 30.0	0 ± 30.0
$B^- \to \Lambda\overline{\Sigma^+}$	0 ± 70.7	0 ± 70.7	0 ± 70.7	$\bar{B}^0_s \to \Lambda\overline{\Xi^0}$	0 ± 100	0 ± 100	0 ± 100
$\bar{B}^0 \to p\bar{p}$	0 ± 26.9	$\mp(36.0^{+26.8}_{-22.0})$	$\mp(49.3^{+25.2}_{-18.3})$	$\bar{B}^0 \to \Sigma^+\overline{\Sigma^+}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$
$\bar{B}^0 \to n\bar{n}$	0 ± 31.6	$\mp(59.3^{+23.5}_{-27.9})$	$\mp(79.5^{+16.0}_{-23.2})$	$\bar{B}^0 \to \Sigma^0\overline{\Sigma^0}$	0 ± 33.6	$\mp(59.3^{+24.8}_{-29.6})$	$\mp(79.5^{+16.7}_{-24.4})$
$\bar{B}^0 \to \Xi^0\overline{\Xi^0}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$	$\bar{B}^0 \to \Sigma^-\overline{\Sigma^-}$	0 ± 47.1	0 ± 47.1	0 ± 47.1
$\bar{B}^0 \to \Xi^-\overline{\Xi^-}$	0 ± 32.1	0 ± 32.1	0 ± 32.1	$\bar{B}^0 \to \Sigma^0\bar{\Lambda}$	0 ± 13.3	$\mp(36.0^{+12.8}_{-12.1})$	$\mp(49.3^{+12.1}_{-11.2})$
$\bar{B}^0 \to \Lambda\bar{\Lambda}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$	$\bar{B}^0 \to \Lambda\overline{\Sigma^0}$	0 ± 70.7	0 ± 70.7	0 ± 70.7

C. Numerical results on direct *CP* asymmetries

In this subsection, we will give results of direct *CP* asymmetries of all modes and plot asymmetries of several interesting modes. Note that this study becomes possible as we now have the information of the tree-penguin ratio, Eq. (15).

1. *CP* asymmetries of $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ decays

In Table X we give results of direct *CP* asymmetries of $\Delta S = 0$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ modes. The central values are the asymmetries generated from tree-penguin interference where only the asymptotic amplitudes and Eq. (16) are used. We show results for $\phi = 0$, $\pm\pi/4$ and $\pm\pi/2$. The uncertainties are from relaxing the asymptotic relation by using Eq. (11) and varying the strong phases of $r^{(\prime)}_{t,i}$, $r^{(\prime)}_{p,i}$, $r^{(\prime)}_{ewp,i}$ and from subleading terms Eq. (13) with strong phases from $\eta_{i,j,k}$. Note that to satisfy the experimental $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ rates, the sizes of $|r^{(\prime)}|$ are reduced by 60% in all $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ modes.

Now we discuss the *CP* asymmetries of group I, II, III modes, according to their rates and detectability as noted in Table IX. For the group I mode, the *CP* asymmetry of the $\bar{B}^0 \to p\bar{p}$ decay can be as large as $\mp 49\%$. For the group II modes, $\mathcal{A}(\bar{B}^0 \to \Sigma^0\bar{\Lambda})$ and $\mathcal{A}(\bar{B}^0_s \to p\overline{\Sigma^+})$ are similar to $\mathcal{A}(\bar{B}^0 \to p\bar{p})$. For the group III modes, the *CP* asymmetries of $B^- \to \Sigma^0\overline{\Sigma^+}$ and $\bar{B}^0 \to \Sigma^0\overline{\Sigma^0}$ decays are similar and can reach $\mp 80\%$, while the *CP* asymmetry of the $\bar{B}^0_s \to \Sigma^0\overline{\Xi^0}$ decay is smaller then these two modes, but can still reach $\mp 58\%$. The *CP* asymmetries of these modes basically all have the same sign when $|\phi|$ is large enough.

As noted in the previous subsection, $B^- \to \Sigma^-\overline{\Sigma^0}$, $B^- \to \Sigma^-\bar{\Lambda}$, $B^- \to \Xi^-\overline{\Xi^0}$, $\bar{B}^0 \to \Xi^-\overline{\Xi^-}$, $\bar{B}^0_s \to \Sigma^-\overline{\Xi^-}$ and $\bar{B}^0 \to \Sigma^-\overline{\Sigma^-}$ decays do not have any tree ($T_{i\mathcal{B}\bar{\mathcal{B}}}$) contribution. Although the $\bar{B}^0 \to \Xi^-\overline{\Xi^-}$, $\bar{B}^0 \to \Sigma^-\overline{\Sigma^-}$ and $\bar{B}^0_s \to \Sigma^-\overline{\Xi^-}$ decays are pure penguins modes, which only have $P_{i\mathcal{B}\bar{\mathcal{B}}}$, $P_{i\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}}$ and $PA_{\mathcal{B}\bar{\mathcal{B}}}$ contributions, it is still possible for these modes to have sizable *CP* asymmetries. Since the sizes of u-penguin (P^u) and c-penguin (P^c) in $\Delta S = 0$ modes are not very different, as their ratio can be estimated as

$$\left|\frac{P^u}{P^c}\right| \simeq \left|\frac{V_{ub}V^*_{ud}}{V_{cb}V^*_{cd}}\right| \simeq 0.38, \tag{23}$$

and they can have different strong phases to produce *CP* asymmetries.[5] For subleading modes, $\bar{B}^0 \to \Xi^0\overline{\Xi^0}$ and $\bar{B}^0 \to \Sigma^+\overline{\Sigma^+}$ decays, which only have $E_{i\mathcal{B}\bar{\mathcal{B}}}$ and $PA_{\mathcal{B}\bar{\mathcal{B}}}$ contributions, their *CP* asymmetries can be any value. Note that $B^- \to \Lambda\overline{\Sigma^+}$, $\bar{B}^0_s \to \Lambda\overline{\Xi^0}$, $\bar{B}^0 \to \Lambda\bar{\Lambda}$ and $\bar{B}^0 \to \Lambda\overline{\Sigma^0}$ decay with tree amplitudes $T_{i\mathcal{B}\bar{\mathcal{B}}}$ canceled in the asymptotic limits, and have large uncertainties on *CP* asymmetries, which mostly come from the corrections to the asymptotic relations. Measuring *CP* asymmetries of these modes can give information on the corrections to the asymptotic relations.

In Table XI we give results of direct *CP* asymmetries of $\Delta S = -1$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ modes. The *CP* asymmetries of the group I modes are as follows. The *CP* asymmetries of the $B^- \to \Lambda\bar{p}$ and $\bar{B}^0_s \to \Lambda\bar{\Lambda}$ decays are similar reaching $\pm 13\%$ and $\pm 19\%$, respectively, and their signs are opposite to the sign of $\mathcal{A}(\bar{B}^0 \to p\bar{p})$. The *CP* asymmetries of $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$

[5] Similarly the sizable *CP* asymmetry of a pure penguin mode $\mathcal{A}(\bar{B}^0 \to K^0\bar{K}^0) = -16.7^{+4.7+4.5+1.5+4.6}_{-3.7-5.1-1.7-3.6}\%$ as predicted in a QCD factorization (QCDF) calculation [36] can be understood.

TABLE XI. Same as Table X, but with $\Delta S = -1$, $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$ modes.

Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$	Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$
$B^- \to \Sigma^0 \bar{p}$	0 ± 20.9	$\mp(28.9^{+22.1}_{-18.6})$	$\mp(45.0^{+23.0}_{-16.7})$	$\bar{B}^0 \to \Sigma^+ \bar{p}$	0 ± 16.4	$\pm(27.1^{+16.6}_{-13.6})$	$\pm(35.3^{+15.5}_{-11.9})$
$B^- \to \Sigma^- \bar{n}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Sigma^0 \bar{n}$	0 ± 29.0	$\pm(47.8^{+23.8}_{-23.1})$	$\pm(58.6^{+19.5}_{-17.8})$
$B^- \to \Xi^0 \overline{\Sigma^+}$	0 ± 2.6	$\pm(5.8^{+3.4}_{-2.3})$	$\pm(8.1^{+3.9}_{-2.8})$	$\bar{B}^0 \to \Xi^0 \overline{\Sigma^0}$	0 ± 2.3	$\pm(5.8^{+3.0}_{-2.1})$	$\pm(8.1^{+3.6}_{-2.5})$
$B^- \to \Xi^- \overline{\Sigma^0}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Xi^0 \bar{\Lambda}$	0 ± 24.5	$\pm(27.1^{+28.3}_{-16.2})$	$\pm(35.3^{+27.2}_{-13.0})$
$B^- \to \Xi^- \bar{\Lambda}$	0 ± 5.5	0 ± 5.5	0 ± 5.5	$\bar{B}^0 \to \Xi^- \overline{\Sigma^-}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$B^- \to \Lambda \bar{p}$	0 ± 4.8	$\pm(9.6^{+5.9}_{-4.0})$	$\pm(13.2^{+6.5}_{-4.3})$	$\bar{B}^0 \to \Lambda \bar{n}$	0 ± 8.4	$\pm(18.7^{+9.6}_{-6.9})$	$\pm(24.9^{+9.8}_{-6.6})$
$\bar{B}^0_s \to p\bar{p}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$	$\bar{B}^0_s \to \Sigma^+ \overline{\Sigma^+}$	0 ± 21.0	$\pm(27.1^{+21.6}_{-16.7})$	$\pm(35.3^{+20.1}_{-14.1})$
$\bar{B}^0_s \to n\bar{n}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$	$\bar{B}^0_s \to \Sigma^0 \overline{\Sigma^0}$	0 ± 11.1	$\pm(14.2^{+12.5}_{-8.9})$	$\pm(19.2^{+12.7}_{-8.2})$
$\bar{B}^0_s \to \Xi^0 \overline{\Xi^0}$	0 ± 8.4	$\pm(14.2^{+10.4}_{-6.5})$	$\pm(19.2^{+11.1}_{-6.3})$	$\bar{B}^0_s \to \Sigma^- \overline{\Sigma^-}$	0 ± 1.6	0 ± 1.6	0 ± 1.6
$\bar{B}^0_s \to \Xi^- \overline{\Xi^-}$	0 ± 2.5	0 ± 2.5	0 ± 2.5	$\bar{B}^0_s \to \Sigma^0 \bar{\Lambda}$	0 ± 46.4	$\pm(74.3^{+21.7}_{-33.6})$	$\pm(84.7^{+13.8}_{-19.7})$
$\bar{B}^0_s \to \Lambda\bar{\Lambda}$	0 ± 7.0	$\pm(14.2^{+8.3}_{-5.7})$	$\pm(19.2^{+8.8}_{-5.6})$	$\bar{B}^0_s \to \Lambda \overline{\Sigma^0}$	0 ± 42.8	$\pm(74.3^{+19.7}_{-33.2})$	$\pm(84.7^{+12.5}_{-20.9})$

and $B^- \to \Xi^- \bar{\Lambda}$ decays are vanishingly small. We will return to these modes later. From the table we see that for the group II modes, $\mathcal{A}(B^- \to \Xi^- \overline{\Sigma^0})$ is vanishingly small, while $\mathcal{A}(\bar{B}^0 \to \Xi^0 \bar{\Lambda})$ and $\mathcal{A}(\bar{B}^0 \to \Sigma^+ \bar{p})$ are similar and can be as large as $\pm 35\%$. For the group III modes, $\mathcal{A}(\bar{B}^0_s \to \Sigma^+ \overline{\Sigma^+})$ is the largest one reaching $\pm 35\%$, $\mathcal{A}(\bar{B}^0_s \to \Xi^0 \overline{\Xi^0})$ and $\mathcal{A}(\bar{B}^0_s \to \Sigma^0 \overline{\Sigma^0})$ are similar and can be as large as $\pm 19\%$, while $\mathcal{A}(B^- \to \Xi^0 \overline{\Sigma^+})$ and $\mathcal{A}(\bar{B}^0 \to \Xi^0 \overline{\Sigma^0})$ are similar and are not sizable, but can reach $\pm 8\%$. Some of the above modes have rates of orders 10^{-7} (see Table II) and with unsuppressed CP asymmetries.

From Table XI, we see that the CP asymmetries of $B^- \to \Sigma^- \bar{n}$, $B^- \to \Xi^- \overline{\Sigma^0}$, $B^- \to \Xi^- \bar{\Lambda}$, $\bar{B}^0 \to \Xi^- \overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^- \overline{\Sigma^-}$ and $\bar{B}^0_s \to \Xi^- \overline{\Xi^-}$ decays have vanishing central values as they do not have any tree ($T'_{i\mathcal{B}\bar{\mathcal{B}}}$) contribution. In particular, $\bar{B}^0 \to \Xi^- \overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^- \overline{\Sigma^-}$ and $\bar{B}^0_s \to \Xi^- \overline{\Xi^-}$ decays are pure penguin modes, which only have $P'_{i\mathcal{B}\bar{\mathcal{B}}}$, $P'_{i\mathrm{EW}\mathcal{B}\bar{\mathcal{B}}}$ and $PA'_{\mathcal{B}\bar{\mathcal{B}}}$ terms. Their CP asymmetries are small. This can be understood as P'^u is much smaller than P'^c. We can estimate the CP asymmetry as follows:

$$|\mathcal{A}| \simeq 2\left|\frac{P'^u}{P'^c}\right| \sin\gamma |\sin\delta| \lesssim 2\left|\frac{V_{ub}V^*_{us}}{V_{cb}V^*_{cs}}\right| \sin\gamma \simeq 3.8\%, \quad (24)$$

where δ is the strong phase difference of the penguins.[6] The smallness of the direct CP reflects the fact that in $\Delta S = -1$ decays, the c-penguin is much larger than the u-penguin as their CKM factors are off by about a factor of 50. They can be tests of the Standard Model. In particular, the $\bar{B}^0_s \to \Xi^- \overline{\Xi^-}$ decay being a group I mode, can cascadely decay to all charged final states and with unsuppressed rate ($\sim 2 \times 10^{-7}$, see Table II). The CP asymmetry of this mode can be searched for. Nevertheless the search is quite demanding as it requires tagging of B_s and suffers from low efficiency of Ξ^- reconstruction. Subleading modes, $\bar{B}^0_s \to p\bar{p}$ and $\bar{B}^0_s \to n\bar{n}$ decays with $E'_{i\mathcal{B}\bar{\mathcal{B}}}$ and $PA'_{\mathcal{B}\bar{\mathcal{B}}}$ contributions, can have any value on their CP asymmetries.

There are relations on direct CP asymmetries between $\Delta S = 0$ and $\Delta S = -1$ modes by using the so-called U-spin symmetry [37,38]. With

$$\Delta_{CP}(\bar{B}_q \to f) \equiv \Gamma(\bar{B}_q \to f) - \Gamma(B_q \to \bar{f}) = \frac{2}{\tau(B_q)} \mathcal{A}(\bar{B}_q \to f)\mathcal{B}(\bar{B}_q \to f), \quad (25)$$

we have [3]

$$\begin{aligned}
\Delta_{CP}(B^- \to n\bar{p}) &= -\Delta_{CP}(B^- \to \Xi^0 \overline{\Sigma^+}),\\
\Delta_{CP}(B^- \to \Xi^- \overline{\Xi^0}) &= -\Delta_{CP}(B^- \to \Sigma^- \bar{n}),\\
\Delta_{CP}(\bar{B}^0 \to p\bar{p}) &= -\Delta_{CP}(\bar{B}^0_s \to \Sigma^+ \overline{\Sigma^+}),\\
\Delta_{CP}(\bar{B}^0 \to n\bar{n}) &= -\Delta_{CP}(\bar{B}^0_s \to \Xi^0 \overline{\Xi^0}),\\
\Delta_{CP}(\bar{B}^0 \to \Sigma^+ \overline{\Sigma^+}) &= -\Delta_{CP}(\bar{B}^0_s \to p\bar{p}),\\
\Delta_{CP}(\bar{B}^0 \to \Sigma^- \overline{\Sigma^-}) &= -\Delta_{CP}(\bar{B}^0_s \to \Xi^- \overline{\Xi^-}),\\
\Delta_{CP}(\bar{B}^0 \to \Xi^0 \overline{\Xi^0}) &= -\Delta_{CP}(\bar{B}^0_s \to n\bar{n}),\\
\Delta_{CP}(\bar{B}^0 \to \Xi^- \overline{\Xi^-}) &= -\Delta_{CP}(\bar{B}^0_s \to \Sigma^- \overline{\Sigma^-}),\\
\Delta_{CP}(\bar{B}^0_s \to p\overline{\Sigma^+}) &= -\Delta_{CP}(\bar{B}^0 \to \Sigma^+ \bar{p}),\\
\Delta_{CP}(\bar{B}^0_s \to \Sigma^- \overline{\Xi^-}) &= -\Delta_{CP}(\bar{B}^0 \to \Xi^- \overline{\Sigma^-}).
\end{aligned} \quad (26)$$

The minus signs in the above relations are from $\mathrm{Im}(V_{ub}V^*_{ud}V^*_{tb}V_{td}) = -\mathrm{Im}(V_{ub}V^*_{us}V^*_{tb}V_{ts})$. Note that these

[6] It is useful to compare to the CP asymmetry of the $\Delta S = 1$ pure penguin PP mode: $\mathcal{A}(\bar{B}^0_s \to K^0 \bar{K}^0) = 0.9^{+0.2+0.2+0.1+0.2}_{-0.2-0.2-0.2-0.3}\%$ in a QCDF calculation [36].

TABLE XII. Same as Table X, but with $\Delta S=0$, $\bar{B}_q\to\mathcal{B}\bar{\mathcal{D}}$ modes.

Mode	$\phi=0$	$\phi=\pm\pi/4$	$\phi=\pm\pi/2$	Mode	$\phi=0$	$\phi=\pm\pi/4$	$\phi=\pm\pi/2$
$B^-\to p\overline{\Delta^{++}}$	0 ± 48.7	$\mp(36.0^{+49.3}_{-33.9})$	$\mp(49.3^{+44.8}_{-22.0})$	$\bar{B}^0_s\to p\overline{\Sigma^{*+}}$	0 ± 47.9	$\mp(36.0^{+48.6}_{-33.4})$	$\mp(49.3^{+44.3}_{-21.9})$
$B^-\to n\overline{\Delta^{+}}$	0 ± 19.9	$\pm(26.7^{+20.5}_{-17.3})$	$\pm(38.8^{+20.1}_{-15.2})$	$\bar{B}^0_s\to n\overline{\Sigma^{*0}}$	0 ± 19.6	$\pm(26.7^{+20.1}_{-17.1})$	$\pm(38.8^{+19.7}_{-15.0})$
$B^-\to\Sigma^0\overline{\Sigma^{*+}}$	0 ± 11.5	$\mp(20.8^{+12.4}_{-9.9})$	$\mp(28.9^{+12.5}_{-9.0})$	$\bar{B}^0_s\to\Sigma^0\overline{\Xi^{*0}}$	0 ± 11.4	$\mp(20.8^{+12.3}_{-9.8})$	$\mp(28.9^{+12.4}_{-8.9})$
$B^-\to\Sigma^-\overline{\Sigma^{*0}}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s\to\Sigma^-\overline{\Xi^{*-}}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$B^-\to\Xi^-\overline{\Xi^{*0}}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s\to\Xi^-\overline{\Omega^-}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$B^-\to\Lambda\overline{\Sigma^{*+}}$	0 ± 100	0 ± 100	0 ± 100	$\bar{B}^0_s\to\Lambda\overline{\Xi^{*0}}$	0 ± 100	0 ± 100	0 ± 100
$\bar{B}^0\to p\overline{\Delta^{+}}$	0 ± 48.7	$\mp(36.0^{+49.3}_{-33.9})$	$\mp(49.4^{+44.8}_{-22.0})$	$\bar{B}^0\to\Sigma^+\overline{\Sigma^{*+}}$	0	0	0
$\bar{B}^0\to n\overline{\Delta^{0}}$	0 ± 19.9	$\pm(26.7^{+20.5}_{-17.3})$	$\pm(38.8^{+20.1}_{-15.2})$	$\bar{B}^0\to\Sigma^0\overline{\Sigma^{*0}}$	0 ± 11.5	$\mp(20.8^{+12.4}_{-9.9})$	$\mp(28.9^{+12.5}_{-9.0})$
$\bar{B}^0\to\Xi^0\overline{\Xi^{*0}}$	0	0	0	$\bar{B}^0\to\Sigma^-\overline{\Sigma^{*-}}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$\bar{B}^0\to\Xi^-\overline{\Xi^{*-}}$	0 ± 29.9	0 ± 29.9	0 ± 29.9	$\bar{B}^0\to\Lambda\overline{\Sigma^{*0}}$	0 ± 100	0 ± 100	0 ± 100

relations do not rely on the large m_B limit but are subjected to corrections from SU(3) breaking in the phase space factors and topological amplitudes. Some relations are satisfied trivially as all the related *CP* asymmetries are always vanishing. We can checked that the results shown in Tables X and XI roughly satisfy these relations and the agreement can be improved when SU(3) breaking effects are taken into account.[7] For example, using the first three relations of the above equation and the corresponding rates from Tables I and II, we have

$$\begin{aligned}\mathcal{A}(B^-\to\Xi^0\overline{\Sigma^+}) &= -\mathcal{A}(B^-\to n\bar{p})\frac{\mathcal{B}(B^-\to n\bar{p})}{\mathcal{B}(B^-\to\Xi^0\overline{\Sigma^+})}\\ &\simeq -(0.087)\mathcal{A}(B^-\to n\bar{p}),\\ \mathcal{A}(B^-\to\Xi^-\overline{\Xi^0}) &= -\mathcal{A}(B^-\to\Sigma^-\bar{n})\frac{\mathcal{B}(B^-\to\Sigma^-\bar{n})}{\mathcal{B}(B^-\to\Xi^-\overline{\Xi^0})}\\ &\simeq -(23.9)\mathcal{A}(B^-\to\Sigma^-\bar{n}).\\ \mathcal{A}(\bar{B}^0_s\to\Sigma^+\overline{\Sigma^+}) &= -\mathcal{A}(\bar{B}^0\to p\bar{p})\frac{\tau(B^0_s)}{\tau(B^0)}\frac{\mathcal{B}(\bar{B}^0\to p\bar{p})}{\mathcal{B}(\bar{B}^0_s\to\Sigma^+\overline{\Sigma^+})}\\ &\simeq -(0.8)\mathcal{A}(\bar{B}^0\to p\bar{p}),\end{aligned} \tag{27}$$

which are roughly satisfied compared to results of the *CP* asymmetries in Tables X and XI. Note that the rate ratios in the above relations are not fixed. For example, they can change with ϕ. The values of the rate ratios used are just rough estimations using the center values of rates in Tables I and II.

[7] Note that the values and signs of $\Delta_{CP}(\bar{B}^0\to\Sigma^+\overline{\Sigma^+})$, $\Delta_{CP}(\bar{B}^0\to\Xi^0\overline{\Xi^0})$, $\Delta_{CP}(\bar{B}^0_s\to p\bar{p})$ and $\Delta_{CP}(\bar{B}^0_s\to n\bar{n})$ cannot be read out from the tables. The relative signs of modes in the sixth, eighth and tenth relations cannot be read out from the tables.

Some of these relations are useful for constraining the sizes of *CP* asymmetries of the $\Delta S=-1$ pure penguin modes model independently. From the sixth, eighth and tenth relations we have

$$\begin{aligned}|\mathcal{A}(\bar{B}^0_s\to\Xi^-\overline{\Xi^-})| &= |\mathcal{A}(\bar{B}^0\to\Sigma^-\overline{\Sigma^-})|\frac{\tau(B^0_s)}{\tau(B^0)}\frac{\mathcal{B}(\bar{B}^0\to\Sigma^-\overline{\Sigma^-})}{\mathcal{B}(\bar{B}^0_s\to\Xi^-\overline{\Xi^-})}\\ &\le\frac{\tau(B^0_s)}{\tau(B^0)}\frac{\mathcal{B}(\bar{B}^0\to\Sigma^-\overline{\Sigma^-})}{\mathcal{B}(\bar{B}^0_s\to\Xi^-\overline{\Xi^-})}\simeq 6.5\%,\\ |\mathcal{A}(\bar{B}^0_s\to\Sigma^-\overline{\Sigma^-})| &= |\mathcal{A}(\bar{B}^0\to\Xi^-\overline{\Xi^-})|\frac{\tau(B^0_s)}{\tau(B^0)}\frac{\mathcal{B}(\bar{B}^0\to\Xi^-\overline{\Xi^-})}{\mathcal{B}(\bar{B}^0_s\to\Sigma^-\overline{\Sigma^-})}\\ &\le\frac{\tau(B^0_s)}{\tau(B^0)}\frac{\mathcal{B}(\bar{B}^0\to\Xi^-\overline{\Xi^-})}{\mathcal{B}(\bar{B}^0_s\to\Sigma^-\overline{\Sigma^-})}\simeq 4.6\%,\\ |\mathcal{A}(\bar{B}^0\to\Xi^-\overline{\Sigma^-})| &= |\mathcal{A}(\bar{B}^0_s\to\Sigma^-\overline{\Xi^-})|\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar{B}^0_s\to\Sigma^-\overline{\Xi^-})}{\mathcal{B}(\bar{B}^0\to\Xi^-\overline{\Sigma^-})}\\ &\le\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar{B}^0_s\to\Sigma^-\overline{\Xi^-})}{\mathcal{B}(\bar{B}^0\to\Xi^-\overline{\Sigma^-})}\simeq 5.0\%.\end{aligned} \tag{28}$$

We see from Table XI that the above inequalities are all satisfied. Note that the constraining powers of these inequalities are similar to the one in Eq. (24).

2. *CP* asymmetries of $\bar{B}_q\to\mathcal{B}\overline{\mathcal{D}}$ decays

In Table XII we give results of direct *CP* asymmetries of $\Delta S=0$, $\bar{B}_q\to\mathcal{B}\overline{\mathcal{D}}$ modes. The *CP* asymmetries of group I modes, $B^-\to p\overline{\Delta^{++}}$ and $\bar{B}^0_s\to p\overline{\Sigma^{*+}}$ decays, are similar and can be as large as $\mp 49\%$. For group II modes, $\mathcal{A}(B^-\to\Sigma^0\overline{\Sigma^{*+}})$ and $\mathcal{A}(\bar{B}^0_s\to\Sigma^0\overline{\Xi^{*0}})$ are similar and can be as large as $\mp 29\%$, while $\mathcal{A}(\bar{B}^0\to p\overline{\Delta^+})$ is more sizable and is similar to the *CP* asymmetries of $B^-\to p\overline{\Delta^{++}}$ and $\bar{B}^0_s\to p\overline{\Sigma^{*+}}$ decays, reaching $\mp 49\%$. The *CP* asymmetry of the group III mode, $\mathcal{A}(\bar{B}^0\to\Sigma^0\overline{\Sigma^{*0}})$, is similar to $\mathcal{A}(B^-\to\Sigma^0\overline{\Sigma^{*+}})$ and $\mathcal{A}(\bar B^0_s\to\Sigma^0\overline{\Xi^{*0}})$, reaching $\mp 29\%$. The CP asymmetries of these modes basically all share the sign of $\mathcal{A}(\bar B^0\to p\bar p)$ for large enough $|\phi|$.

From Eqs. (A7), (A8) and (A9), we can easily identify the following relations:

$$\begin{aligned}\mathcal{A}(B^-\to\Xi^-\overline{\Xi^{*0}})&=\mathcal{A}(B^-\to\Sigma^-\overline{\Sigma^{*0}}),\\ \mathcal{A}(\bar B^0\to\Sigma^-\overline{\Sigma^{*-}})&=\mathcal{A}(\bar B^0\to\Xi^-\overline{\Xi^{*-}})=\mathcal{A}(\bar B^0_s\to\Sigma^-\overline{\Xi^{*-}})\\ &=\mathcal{A}(\bar B^0_s\to\Xi^-\overline{\Omega^-}),\\ \mathcal{A}(\bar B^0\to\Sigma^+\overline{\Sigma^{*+}})&=\mathcal{A}(\bar B^0\to\Xi^0\overline{\Xi^{*0}})=0.\end{aligned}\tag{29}$$

We see from Table XII that these relations are satisfied. Note that these relations do not rely on the asymptotic limit, while the first relation is subjected to corrections from SU(3) breaking in the topological amplitudes.

As shown in Table XII, the CP asymmetries of $B^-\to\Sigma^-\overline{\Sigma^{*0}}$, $B^-\to\Xi^-\overline{\Xi^{*0}}$, $\bar B^0_s\to\Sigma^-\overline{\Xi^{*-}}$, $\bar B^0\to\Xi^-\overline{\Xi^{*-}}$, $\bar B^0\to\Sigma^-\overline{\Sigma^{*-}}$, $\bar B^0_s\to\Xi^-\overline{\Omega^-}$, $\bar B^0\to\Sigma^+\overline{\Sigma^{*+}}$ and $\bar B^0\to\Xi^0\overline{\Xi^{*0}}$ decays have vanishing central values, as they do not have any tree ($T_{i\mathcal{B}\bar{\mathcal{D}}}$) contribution. In particular, $\bar B^0\to\Xi^-\overline{\Xi^{*-}}$ and $\bar B^0\to\Sigma^-\overline{\Sigma^{*-}}$ decays are $\Delta S=0$ pure penguin modes with only $P_{\mathcal{B}\bar{\mathcal{D}}}$ and $P_{i\mathrm{EW}\mathcal{B}\bar{\mathcal{D}}}$ contributions, while $\bar B^0\to\Sigma^+\overline{\Sigma^{*+}}$ and $\bar B^0\to\Xi^0\overline{\Xi^{*0}}$ decays are pure exchange modes with only $E_{\mathcal{B}\bar{\mathcal{D}}}$ contributions. The CP asymmetries of the former two modes need not be vanishing [see discussion around Eq. (23)], while the CP asymmetries of the latter two modes are always vanishing. Note that although $B^-\to\Lambda\overline{\Sigma^{*+}}$, $\bar B^0_s\to\Lambda\overline{\Xi^{*0}}$ and $\bar B^0\to\Lambda\overline{\Sigma^{*0}}$ decays have vanishing tree contributions in the asymptotic limit, resulting in their CP asymmetries having vanishing center values, their uncertainties, mostly from corrections to the asymptotic relations, are sizable, however. Measuring the CP asymmetries of these modes can give information on the breaking of the asymptotic relations.

In Table XIII we give results of direct CP asymmetries of $\Delta S=-1$, $\bar B_q\to\mathcal{B}\bar{\mathcal{D}}$ modes. The CP asymmetry of the group I mode $\bar B^0\to\Xi^-\overline{\Sigma^{*-}}$ is vanishing. We will return to this later. For group II modes, $\mathcal{A}(B^-\to\Sigma^+\overline{\Delta^{++}})$ and $\mathcal{A}(\bar B^0_s\to\Sigma^+\overline{\Sigma^{*+}})$ are similar reaching $\pm 35\%$, $\mathcal{A}(B^-\to\Xi^0\overline{\Sigma^{*+}})$ and $\mathcal{A}(\bar B^0_s\to\Xi^0\overline{\Xi^{*0}})$ are similar and sizable reaching $\mp 45\%$, but with sign opposite to most modes in Table XIII, $\mathcal{A}(\bar B^0\to\Sigma^0\overline{\Delta^0})$ can reach $\pm 19\%$, while $\mathcal{A}(\bar B^0_s\to\Xi^-\overline{\Xi^{*-}})$ and $\mathcal{A}(B^-\to\Xi^-\overline{\Sigma^{*0}})$ are vanishingly small. In the group III modes, $\mathcal{A}(\bar B^0\to\Xi^0\overline{\Sigma^{*0}})$ is the largest one reaching $\mp 45\%$ and is similar to $\mathcal{A}(B^-\to\Xi^0\overline{\Sigma^{*+}})$ and $\mathcal{A}(\bar B^0_s\to\Xi^0\overline{\Xi^{*0}})$, $\mathcal{A}(\bar B^0\to\Sigma^+\overline{\Delta^+})$ can be as large as $\pm 35\%$, while $\mathcal{A}(B^-\to\Sigma^0\overline{\Delta^+})$ and $\mathcal{A}(\bar B^0_s\to\Sigma^0\overline{\Sigma^{*0}})$ are similar and can be as large as $\pm 19\%$. Note that for large enough $|\phi|$ most modes in the table have signs basically equal to the sign of $\mathcal{A}(B^-\to\Lambda\bar p)$.

From Eqs. (A10), (A11) and (A12), we can easily identify the following relations:

$$\begin{aligned}\mathcal{A}(B^-\to\Xi^-\overline{\Sigma^{*0}})&=\mathcal{A}(B^-\to\Sigma^-\overline{\Delta^0}),\\ \mathcal{A}(\bar B^0_s\to\Sigma^-\overline{\Sigma^{*-}})&=\mathcal{A}(\bar B^0_s\to\Xi^-\overline{\Xi^{*-}})=\mathcal{A}(\bar B^0\to\Xi^-\overline{\Sigma^{*-}})\\ &=\mathcal{A}(\bar B^0\to\Sigma^-\overline{\Delta^-}),\\ \mathcal{A}(\bar B^0_s\to p\overline{\Delta^+})&=\mathcal{A}(\bar B^0_s\to n\overline{\Delta^0})=0.\end{aligned}\tag{30}$$

We see from Table XIII that these relations are satisfied. Note that these relations do not relay on the asymptotic limit but are subjected to SU(3) breaking in the topological amplitudes.

As shown in Table XIII, the CP asymmetries of $B^-\to\Sigma^-\overline{\Delta^0}$, $B^-\to\Xi^-\overline{\Sigma^{*0}}$, $\bar B^0\to\Sigma^-\overline{\Delta^-}$, $\bar B^0\to\Xi^-\overline{\Sigma^{*-}}$, $\bar B^0_s\to\Sigma^-\overline{\Sigma^{*-}}$, $\bar B^0_s\to\Xi^-\overline{\Xi^{*-}}$, $\bar B^0_s\to p\overline{\Delta^+}$ and $\bar B^0_s\to n\overline{\Delta^0}$ decays have vanishing central values, as they do not have any tree ($T'_{i\mathcal{B}\bar{\mathcal{D}}}$) contribution. In particular, $\bar B^0\to\Sigma^-\overline{\Delta^-}$,

TABLE XIII. Same as Table X, but with $\Delta S=-1$, $\bar B_q\to\mathcal{B}\bar{\mathcal{D}}$ modes.

Mode	$\phi=0$	$\phi=\pm\pi/4$	$\phi=\pm\pi/2$	Mode	$\phi=0$	$\phi=\pm\pi/4$	$\phi=\pm\pi/2$
$B^-\to\Sigma^+\overline{\Delta^{++}}$	0 ± 30.3	$\pm(27.1^{+29.0}_{-25.9})$	$\pm(35.3^{+26.4}_{-21.8})$	$\bar B^0\to\Sigma^+\overline{\Delta^+}$	0 ± 30.1	$\pm(27.1^{+28.8}_{-25.7})$	$\pm(35.3^{+26.2}_{-21.6})$
$B^-\to\Sigma^0\overline{\Delta^+}$	0 ± 16.1	$\pm(14.2^{+17.1}_{-13.7})$	$\pm(19.2^{+16.9}_{-12.6})$	$\bar B^0\to\Sigma^0\overline{\Delta^0}$	0 ± 15.8	$\pm(14.2^{+16.8}_{-13.5})$	$\pm(19.2^{+16.6}_{-12.3})$
$B^-\to\Sigma^-\overline{\Delta^0}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar B^0\to\Sigma^-\overline{\Delta^-}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$B^-\to\Xi^0\overline{\Sigma^{*+}}$	0 ± 21.3	$\mp(28.9^{+22.9}_{-18.5})$	$\mp(45.0^{+24.0}_{-16.3})$	$\bar B^0\to\Xi^0\overline{\Sigma^{*0}}$	0 ± 21.0	$\mp(28.9^{+22.6}_{-18.2})$	$\mp(45.0^{+23.7}_{-16.0})$
$B^-\to\Xi^-\overline{\Sigma^{*0}}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar B^0\to\Xi^-\overline{\Sigma^{*-}}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$B^-\to\Lambda\overline{\Delta^+}$	0 ± 52.9	$\pm(74.3^{+22.9}_{-41.7})$	$\pm(84.7^{+14.4}_{-25.1})$	$\bar B^0\to\Lambda\overline{\Delta^0}$	0 ± 52.9	$\pm(74.3^{+22.9}_{-41.7})$	$\pm(84.7^{+14.4}_{-25.1})$
$\bar B^0_s\to p\overline{\Delta^+}$	0	0	0	$\bar B^0_s\to\Sigma^+\overline{\Sigma^{*+}}$	0 ± 30.3	$\pm(27.1^{+29.0}_{-25.9})$	$\pm(35.3^{+26.4}_{-21.8})$
$\bar B^0_s\to n\overline{\Delta^0}$	0	0	0	$\bar B^0_s\to\Sigma^0\overline{\Sigma^{*0}}$	0 ± 16.0	$\pm(14.2^{+17.0}_{-13.6})$	$\pm(19.2^{+16.7}_{-12.4})$
$\bar B^0_s\to\Xi^0\overline{\Xi^{*0}}$	0 ± 21.3	$\mp(28.9^{+22.9}_{-18.5})$	$\mp(45.0^{+24.0}_{-16.3})$	$\bar B^0_s\to\Sigma^-\overline{\Sigma^{*-}}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$\bar B^0_s\to\Xi^-\overline{\Xi^{*-}}$	0 ± 1.5	0 ± 1.5	0 ± 1.5	$\bar B^0_s\to\Lambda\overline{\Sigma^{*0}}$	0 ± 53.6	$\pm(74.3^{+23.1}_{-42.3})$	$\pm(84.7^{+14.5}_{-25.4})$

$\bar B^0\to\Xi^-\overline{\Sigma^{*-}}$, $\bar B^0_s\to\Sigma^-\overline{\Sigma^{*-}}$ and $\bar B^0_s\to\Xi^-\overline{\Xi^{*-}}$ decays are pure penguin modes with only $P'_{\mathcal{B}\overline{\mathcal{D}}}$ and $P'_{iEW\mathcal{B}\overline{\mathcal{D}}}$ contributions, while $\bar B^0_s\to p\overline{\Delta^+}$ and $\bar B^0_s\to n\overline{\Delta^0}$ are pure exchange modes with only $E'_{\mathcal{B}\overline{\mathcal{D}}}$ contributions. The CP asymmetries of the $\Delta S=-1$ pure penguin modes are small [see Eq. (24)], while the CP asymmetries of pure exchange modes are always vanishing. These can be tests of the Standard Model. In particular, the $\bar B^0\to\Xi^-\overline{\Sigma^{*-}}$ decay can cascadely decay to all charged final states and have unsuppressed decay rate (see Table IV), but may suffer from low reconstruction efficiencies of the final state particles. Nevertheless, it is still interesting to search for this mode and its CP asymmetry.

The U-spin relations for octet-antidecuplet modes are given by [3]

$$\begin{aligned}
\Delta_{CP}(B^-\to n\overline{\Delta^+})&=-\Delta_{CP}(B^-\to\Xi^0\overline{\Sigma^{*+}}),\\
\Delta_{CP}(B^-\to\Xi^-\overline{\Xi^{*0}})&=2\Delta_{CP}(B^-\to\Sigma^-\overline{\Sigma^{*0}})=-2\Delta_{CP}(B^-\to\Xi^-\overline{\Sigma^{*0}})=-\Delta_{CP}(B^-\to\Sigma^-\overline{\Delta^0}),\\
\Delta_{CP}(B^-\to p\overline{\Delta^{++}})&=-\Delta_{CP}(B^-\to\Sigma^+\overline{\Delta^{++}}),\\
\Delta_{CP}(\bar B^0\to n\overline{\Delta^0})&=-\Delta_{CP}(\bar B^0_s\to\Xi^0\overline{\Xi^{*0}}),\\
3\Delta_{CP}(\bar B^0\to\Sigma^-\overline{\Sigma^{*-}})&=3\Delta_{CP}(\bar B^0\to\Xi^-\overline{\Xi^{*-}})=3\Delta_{CP}(\bar B^0_s\to\Sigma^-\overline{\Xi^{*-}})=\Delta_{CP}(\bar B^0_s\to\Xi^-\overline{\Omega^-})=-3\Delta_{CP}(\bar B^0_s\to\Sigma^-\overline{\Sigma^{*-}})\\
&=-3\Delta_{CP}(\bar B^0_s\to\Xi^-\overline{\Xi^{*-}})=-3\Delta_{CP}(\bar B^0\to\Xi^-\overline{\Sigma^{*-}})=-\Delta_{CP}(\bar B^0\to\Sigma^-\overline{\Delta^-}),\\
\Delta_{CP}(\bar B^0\to\Sigma^+\overline{\Sigma^{*+}})&=\Delta_{CP}(\bar B^0\to\Xi^0\overline{\Xi^{*0}})=-\Delta_{CP}(\bar B^0_s\to p\overline{\Delta^+})=-\Delta_{CP}(\bar B^0_s\to n\overline{\Delta^0})=0,\\
\Delta_{CP}(\bar B^0\to p\overline{\Delta^+})&=-\Delta_{CP}(\bar B^0_s\to\Sigma^+\overline{\Sigma^{*+}}),\\
\Delta_{CP}(\bar B^0_s\to n\overline{\Sigma^{*0}})&=-\Delta_{CP}(\bar B^0\to\Xi^0\overline{\Sigma^{*0}})\\
\Delta_{CP}(\bar B^0_s\to p\overline{\Sigma^{*+}})&=-\Delta_{CP}(\bar B^0\to\Sigma^+\overline{\Delta^+}).
\end{aligned}\tag{31}$$

These relations are subjected to corrections from SU(3) breaking in the $|p_{\rm cm}|^3$ factors and topological amplitudes. The above relations are roughly satisfied by the results shown in Tables XII and XIII and the agreement can be improved when SU(3) breaking effects are taken into account. One can make a quick but nontrivial check on the relative signs of these asymmetries and see that they are indeed in agreement with the above relations.[8] Note that several vanishing CP asymmetries as discussed previously are related to each other. The fifth relation can be used to constrain the sizes of CP asymmetries of $\Delta S=-1$ pure penguin modes model independently. For example, from the relation we can have

$$\begin{aligned}
&|\mathcal{A}(\bar B^0\to\Xi^-\overline{\Sigma^{*-}})|\\
&\quad=\frac{1}{3}|\mathcal{A}(\bar B^0_s\to\Xi^-\overline{\Omega^-})|\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar B^0_s\to\Xi^-\overline{\Omega^-})}{\mathcal{B}(\bar B^0\to\Xi^-\overline{\Sigma^{*-}})}\\
&\quad\le\frac{1}{3}\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar B^0_s\to\Xi^-\overline{\Omega^-})}{\mathcal{B}(\bar B^0\to\Xi^-\overline{\Sigma^{*-}})}\simeq4.1\%,
\end{aligned}\tag{32}$$

which is satisfied by $\mathcal{A}(\bar B^0\to\Xi^-\overline{\Sigma^{*-}})$ shown in Table XIII. Note that the above inequalities are generic and can be tested experimentally as the quantities on the both sides are measurable.

[8]Note that for the second relation, the CP asymmetries of these modes all have vanishing central values; their relative signs cannot be read out from Tables XII and XIII.

3. CP asymmetries of $\bar B_q\to\mathcal{D}\bar{\mathcal{B}}$ decays

In Table XIV we give results of direct CP asymmetries of $\Delta S=0$, $\bar B_q\to\mathcal{D}\bar{\mathcal{B}}$ modes. The CP asymmetries of two group I modes, $B^-\to\Delta^0\bar p$ and $\bar B^0_s\to\Delta^0\bar\Lambda$ decays, are opposite in signs, while the former can reach $\pm39\%$ and is more sizable than the latter. For group II modes, $\mathcal{A}(\bar B^0\to\Delta^+\bar p)$ and $\mathcal{A}(\bar B^0\to\Sigma^{*0}\bar\Lambda)$ are similar reaching $\mp49\%$, while $\mathcal{A}(\bar B^0_s\to\Delta^0\overline{\Sigma^0})$ can be as large as $\mp80\%$. For group III modes, $\mathcal{A}(\bar B^0_s\to\Sigma^{*0}\overline{\Xi^0})$ and $\mathcal{A}(\bar B^0_s\to\Delta^+\overline{\Sigma^+})$ can reach $\mp29\%$ and $\mp49\%$, respectively, and have the same sign, while $\mathcal{A}(B^-\to\Sigma^{*0}\overline{\Sigma^+})$ can be as large as $\pm39\%$, but with sign opposites to the other two.

From Eqs. (A13), (A14) and (A15), we can easily identify the following relations:

$$\begin{aligned}
\mathcal{A}(B^-\to\Delta^0\bar p)&=\mathcal{A}(B^-\to\Sigma^{*0}\overline{\Sigma^+}),\\
\mathcal{A}(B^-\to\Delta^-\bar n)&=\mathcal{A}(B^-\to\Xi^{*-}\overline{\Xi^0})=\mathcal{A}(B^-\to\Sigma^{*-}\overline{\Sigma^0})\\
&=\mathcal{A}(B^-\to\Sigma^{*-}\bar\Lambda),\\
\mathcal{A}(\bar B^0\to\Sigma^{*-}\overline{\Sigma^-})&=\mathcal{A}(\bar B^0\to\Xi^{*-}\overline{\Xi^-})=\mathcal{A}(\bar B^0_s\to\Delta^-\overline{\Sigma^-})\\
&=\mathcal{A}(\bar B^0_s\to\Sigma^{*-}\overline{\Xi^-}),\\
\mathcal{A}(\bar B^0\to\Sigma^{*+}\overline{\Sigma^+})&=\mathcal{A}(\bar B^0\to\Xi^{*0}\overline{\Xi^0})=0.
\end{aligned}\tag{33}$$

TABLE XIV. Same as Table X, but with $\Delta S = 0$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ modes.

Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$	Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$
$B^- \to \Delta^0\bar{p}$	0 ± 18.5	$\pm(26.7^{+19.1}_{-16.0})$	$\pm(38.8^{+18.7}_{-14.0})$	$\bar{B}^0_s \to \Delta^+\overline{\Sigma^+}$	0 ± 19.0	$\mp(36.0^{+18.8}_{-16.2})$	$\mp(49.3^{+17.9}_{-14.2})$
$B^- \to \Delta^-\bar{n}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s \to \Delta^0\overline{\Sigma^0}$	0 ± 30.9	$\mp(59.3^{+23.6}_{-25.6})$	$\mp(79.5^{+16.2}_{-19.3})$
$B^- \to \Sigma^{*0}\overline{\Sigma^+}$	0 ± 18.5	$\pm(26.7^{+19.1}_{-16.0})$	$\pm(38.8^{+18.7}_{-14.0})$	$\bar{B}^0_s \to \Delta^-\overline{\Sigma^-}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$B^- \to \Sigma^{*-}\overline{\Sigma^0}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s \to \Sigma^{*0}\overline{\Xi^0}$	0 ± 11.0	$\mp(20.8^{+11.8}_{-9.5})$	$\mp(28.9^{+12.0}_{-8.6})$
$B^- \to \Xi^{*-}\overline{\Xi^0}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^-}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$B^- \to \Sigma^{*-}\bar{\Lambda}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s \to \Delta^0\bar{\Lambda}$	0 ± 2.3	$\mp(4.4^{+2.6}_{-2.0})$	$\mp(6.2^{+2.7}_{-1.9})$
$\bar{B}^0 \to \Delta^+\bar{p}$	0 ± 19.4	$\mp(36.0^{+19.3}_{-16.5})$	$\mp(49.3^{+18.3}_{-14.4})$	$\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^+}$	0	0	0
$\bar{B}^0 \to \Delta^0\bar{n}$	0 ± 11.1	$\mp(20.8^{+12.0}_{-9.6})$	$\mp(28.9^{+12.1}_{-8.7})$	$\bar{B}^0 \to \Sigma^{*0}\overline{\Sigma^0}$	0 ± 18.5	$\pm(26.7^{+19.1}_{-16.0})$	$\pm(38.8^{+18.7}_{-14.0})$
$\bar{B}^0 \to \Xi^{*0}\overline{\Xi^0}$	0	0	0	$\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^-}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$\bar{B}^0 \to \Xi^{*-}\overline{\Xi^-}$	0 ± 29.9	0 ± 29.9	0 ± 29.9	$\bar{B}^0 \to \Sigma^{*0}\bar{\Lambda}$	0 ± 19.4	$\mp(36.0^{+19.3}_{-16.5})$	$\mp(49.3^{+18.3}_{-14.4})$

We see from Table XIV that these relations are satisfied. Note that these relations do not rely on the asymptotic limit but are subjected to SU(3) breaking in the topological amplitudes.

Note that the central values of the CP asymmetries of $B^- \to \Delta^-\bar{n}$, $B^- \to \Sigma^{*-}\overline{\Sigma^0}$, $B^- \to \Xi^{*-}\overline{\Xi^0}$, $B^- \to \Sigma^{*-}\bar{\Lambda}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Xi^-}$, $\bar{B}^0_s \to \Delta^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^-}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^-}$, $\bar{B}^0 \to \Xi^{*0}\overline{\Xi^0}$ and $\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^+}$ decays are vanishing, as they do not have any tree ($T_{i\mathcal{D}\bar{\mathcal{B}}}$) contribution. The $\bar{B}^0 \to \Xi^{*-}\overline{\Xi^-}$, $\bar{B}^0_s \to \Delta^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^-}$ and $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^-}$ decays are pure penguin modes, which only have $P_{\mathcal{D}\bar{\mathcal{B}}}$ and $P_{iEW\mathcal{D}\bar{\mathcal{B}}}$ contributions, while $\bar{B}^0 \to \Xi^{*0}\overline{\Xi^0}$ and $\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^+}$ decays are pure exchange ($E_{\mathcal{D}\bar{\mathcal{B}}}$) modes, the CP asymmetries of the $\Delta S = 0$ pure penguin modes need not be vanishing [see Eq. (23)], while the CP asymmetries of the pure exchange modes are always vanishing.

In Table XV we give results of direct CP asymmetries of $\Delta S = -1$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ modes. In the group I modes, $\mathcal{A}(\bar{B}^0 \to \Xi^{*0}\bar{\Lambda})$ and $\mathcal{A}(\bar{B}^0 \to \Sigma^{*+}\bar{p})$ are similar and sizable reaching $\pm 35\%$, while $\mathcal{A}(\bar{B}^0 \to \Omega^-\overline{\Xi^-})$ is vanishing and will be discussed later. For group II modes, $\mathcal{A}(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^0})$, $\mathcal{A}(\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^+})$, $\mathcal{A}(B^- \to \Xi^{*0}\overline{\Sigma^+})$ and $\mathcal{A}(B^- \to \Sigma^{*0}\bar{p})$ are sizable reaching $\pm 59\%$, $\pm 35\%$, $\mp 45\%$ and $\mp 45\%$, respectively, and the signs of the first two asymmetries are opposite to the last two, while $\mathcal{A}(B^- \to \Omega^-\overline{\Xi^0})$, $\mathcal{A}(B^- \to \Xi^{*-}\bar{\Lambda})$ and $\mathcal{A}(\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^-})$ are vanishingly small and will be discussed later. For the group III modes, $\mathcal{A}(\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^0})$ can be as large as $\pm 19\%$, but $\mathcal{A}(B^- \to \Xi^{*-}\overline{\Sigma^0})$ is highly suppressed.

From Eqs. (A10), (A11) and (A12), we can easily identify the following relations:

TABLE XV. Same as Table X, but with $\Delta S = -1$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{B}}$ modes.

Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$	Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$
$B^- \to \Sigma^{*0}\bar{p}$	0 ± 19.4	$\mp(28.9^{+20.6}_{-17.2})$	$\mp(45.0^{+21.5}_{-15.4})$	$\bar{B}^0 \to \Sigma^{*+}\bar{p}$	0 ± 14.8	$\pm(27.1^{+15.2}_{-12.3})$	$\pm(35.3^{+14.2}_{-10.8})$
$B^- \to \Sigma^{*-}\bar{n}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Sigma^{*0}\bar{n}$	0 ± 26.4	$\pm(47.8^{+22.0}_{-20.8})$	$\pm(58.6^{+18.1}_{-16.1})$
$B^- \to \Xi^{*0}\overline{\Sigma^+}$	0 ± 19.4	$\mp(28.9^{+20.6}_{-17.2})$	$\mp(45.0^{+21.5}_{-15.4})$	$\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^0}$	0 ± 19.2	$\mp(28.9^{+20.4}_{-16.9})$	$\mp(45.0^{+21.3}_{-15.2})$
$B^- \to \Xi^{*-}\overline{\Sigma^0}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^-}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$B^- \to \Omega^-\overline{\Xi^0}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Omega^-\overline{\Xi^-}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$B^- \to \Xi^{*-}\bar{\Lambda}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Xi^{*0}\bar{\Lambda}$	0 ± 14.8	$\pm(27.1^{+15.2}_{-12.3})$	$\pm(35.3^{+14.2}_{-10.8})$
$\bar{B}^0_s \to \Delta^+\bar{p}$	0	0	0	$\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^+}$	0 ± 15.1	$\pm(27.1^{+15.5}_{-12.5})$	$\pm(35.3^{+14.5}_{-11.0})$
$\bar{B}^0_s \to \Delta^0\bar{n}$	0	0	0	$\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^0}$	0 ± 7.9	$\pm(14.2^{+8.8}_{-6.7})$	$\pm(19.2^{+9.0}_{-6.5})$
$\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^0}$	0 ± 26.7	$\pm(47.8^{+22.1}_{-21.0})$	$\pm(58.6^{+18.2}_{-16.2})$	$\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^-}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^-}$	0 ± 1.5	0 ± 1.5	0 ± 1.5	$\bar{B}^0_s \to \Sigma^{*0}\bar{\Lambda}$	0 ± 41.6	$\pm(74.3^{+20.0}_{-29.8})$	$\pm(84.7^{+12.8}_{-17.9})$

$$\begin{aligned}
\mathcal{A}(B^-\to\Sigma^{*0}\bar{p}) &= \mathcal{A}(B^-\to\Xi^{*0}\overline{\Sigma^+}),\\
\mathcal{A}(B^-\to\Sigma^{*-}\bar{n}) &= \mathcal{A}(B^-\to\Xi^{*-}\overline{\Sigma^0}) = \mathcal{A}(B^-\to\Omega^-\overline{\Xi^0})\\
&= \mathcal{A}(B^-\to\Xi^{*-}\bar{\Lambda}),\\
\mathcal{A}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Sigma^-}) &= \mathcal{A}(\bar{B}^0_s\to\Xi^{*-}\overline{\Xi^-}) = \mathcal{A}(\bar{B}^0\to\Xi^{*-}\overline{\Sigma^-})\\
&= \mathcal{A}(\bar{B}^0\to\Omega^-\overline{\Xi^-}),\\
\mathcal{A}(\bar{B}^0_s\to\Delta^+\bar{p}) &= \mathcal{A}(\bar{B}^0_s\to\Delta^0\bar{n}) = 0. \qquad (34)
\end{aligned}$$

We see from Table XV that these relations are satisfied. Note that these relations do not rely on the asymptotic limit but are subjected to SU(3) breaking in the topological amplitudes.

The central values of *CP* asymmetries of $B^-\to\Sigma^{*-}\bar{n}$, $B^-\to\Xi^{*-}\overline{\Sigma^0}$, $B^-\to\Omega^-\overline{\Xi^0}$, $B^-\to\Xi^{*-}\bar{\Lambda}$, $\bar{B}^0\to\Omega^-\overline{\Xi^-}$, $\bar{B}^0_s\to\Sigma^{*-}\overline{\Sigma^-}$, $\bar{B}^0\to\Xi^{*-}\overline{\Sigma^-}$, $\bar{B}^0_s\to\Xi^{*-}\overline{\Xi^-}$, $\bar{B}^0_s\to\Delta^+\bar{p}$ and $\bar{B}^0_s\to\Delta^0\bar{n}$ decays are vanishing, as they do not have any tree ($T'_{i\mathcal{D}\bar{\mathcal{B}}}$) contribution. Since $\bar{B}^0\to\Omega^-\overline{\Xi^-}$, $\bar{B}^0_s\to\Sigma^{*-}\overline{\Sigma^-}$, $\bar{B}^0\to\Xi^{*-}\overline{\Sigma^-}$ and $\bar{B}^0_s\to\Xi^{*-}\overline{\Xi^-}$ decays are pure penguin modes, which only have $P'_{\mathcal{D}\bar{\mathcal{B}}}$ and $P'_{iEW\mathcal{D}\bar{\mathcal{B}}}$ contributions, while $\bar{B}^0_s\to\Delta^+\bar{p}$ and $\bar{B}^0_s\to\Delta^0\bar{n}$ decays are pure exchange ($E'_{\mathcal{D}\bar{\mathcal{B}}}$) modes, the *CP* asymmetries of the $\Delta S=-1$ pure penguin modes are small [see Eq. (24)], while the *CP* asymmetries of the pure exchange modes are always vanishing. These can be tests of the Standard model. In particular, $\bar{B}^0\to\Omega^-\overline{\Xi^-}$ and $\bar{B}^0_s\to\Xi^{*-}\overline{\Xi^-}$ belonging to group I and II modes, respectively, have decay rates that are unsuppressed (see Table VI). These modes should be searched for, but the latter mode requires B_s tagging to search for its *CP* asymmetry.

The *U*-spin relations for decuplet-antioctet modes are given by [3]

$$\begin{aligned}
\Delta_{CP}(B^-\to\Delta^0\bar{p}) &= 2\Delta_{CP}(B^-\to\Sigma^{*0}\overline{\Sigma^+}) = -2\Delta_{CP}(B^-\to\Sigma^{*0}\bar{p}) = -\Delta_{CP}(B^-\to\Xi^{*0}\overline{\Sigma^+}),\\
\Delta_{CP}(B^-\to\Delta^-\bar{n}) &= 3\Delta_{CP}(B^-\to\Xi^{*-}\overline{\Xi^0}) = 6\Delta_{CP}(B^-\to\Sigma^{*-}\overline{\Sigma^0}) = 2\Delta_{CP}(B^-\to\Sigma^{*-}\bar{\Lambda}) = -3\Delta_{CP}(B^-\to\Sigma^{*-}\bar{n})\\
&= -6\Delta_{CP}(B^-\to\Xi^{*-}\overline{\Sigma^0}) = -\Delta_{CP}(B^-\to\Omega^-\overline{\Xi^0}) = -2\Delta_{CP}(B^-\to\Xi^{*-}\bar{\Lambda}),\\
\Delta_{CP}(\bar{B}^0\to\Delta^+\bar{p}) &= -\Delta_{CP}(\bar{B}^0_s\to\Sigma^{*+}\overline{\Sigma^+}),\\
3\Delta_{CP}(\bar{B}^0\to\Sigma^{*-}\overline{\Sigma^-}) &= 3\Delta_{CP}(\bar{B}^0\to\Xi^{*-}\overline{\Xi^-}) = \Delta_{CP}(\bar{B}^0_s\to\Delta^-\overline{\Sigma^-}) = 3\Delta_{CP}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^-}) = -3\Delta_{CP}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Sigma^-})\\
&= -3\Delta_{CP}(\bar{B}^0_s\to\Xi^{*-}\overline{\Xi^-}) = -3\Delta_{CP}(\bar{B}^0\to\Xi^{*-}\overline{\Sigma^-}) = -\Delta_{CP}(\bar{B}^0\to\Omega^-\overline{\Xi^-}),\\
\Delta_{CP}(\bar{B}^0\to\Sigma^{*+}\overline{\Sigma^+}) &= \Delta_{CP}(\bar{B}^0\to\Xi^{*0}\overline{\Xi^0}) = -\Delta_{CP}(\bar{B}^0_s\to\Delta^+\bar{p}) = -\Delta_{CP}(\bar{B}^0_s\to\Delta^0\bar{n}) = 0,\\
\Delta_{CP}(\bar{B}^0\to\Delta^0\bar{n}) &= -\Delta_{CP}(\bar{B}^0_s\to\Xi^{*0}\overline{\Xi^0}),\\
\Delta_{CP}(\bar{B}^0_s\to\Delta^+\overline{\Sigma^+}) &= -\Delta_{CP}(\bar{B}^0\to\Sigma^{*+}\bar{p}),\\
\Delta_{CP}(\bar{B}^0_s\to\Sigma^{*0}\overline{\Xi^0}) &= -\Delta_{CP}(\bar{B}^0\to\Sigma^{*0}\bar{n}). \qquad (35)
\end{aligned}$$

These relations are subjected to corrections from SU(3) breaking in $|p_{cm}|^2$ and topological amplitudes. They are roughly satisfied by the results shown in Tables XIV and XV and the agreement can be improved when SU(3) breaking effects are taken into account. One can make a quick but nontrivial check on the relative signs of these asymmetries and see that they are indeed agreed with the above relations.[9] The forth relation can be used to constrain the size of *CP* asymmetries of $\Delta S=-1$ pure penguin modes model independently. For example, we can have

$$\begin{aligned}
&|\mathcal{A}(\bar{B}^0\to\Omega^-\overline{\Xi^-})|\\
&= 3|\mathcal{A}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^-})|\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^-})}{\mathcal{B}(\bar{B}^0\to\Omega^-\overline{\Xi^-})}\\
&\leq 3\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^-})}{\mathcal{B}(\bar{B}^0\to\Omega^-\overline{\Xi^-})}\simeq 6.1\%, \qquad (36)
\end{aligned}$$

which is satisfied by the result shown in Table XV. Note that the two modes in the above inequality have final states that can cascadely decay to all charged particles. The inequality is generic and can be verified experimentally.

4. *CP* asymmetries of $\bar{B}_q\to\mathcal{D}\bar{\mathcal{D}}$ decays

In Table XVI, we give results of direct *CP* asymmetries of $\Delta S=0$, $\bar{B}_q\to\mathcal{D}\bar{\mathcal{D}}$ modes. For group I modes, $\mathcal{A}(\bar{B}^0\to\Delta^0\overline{\Delta^0})$ is sizable and can reach $\mp 80\%$, but $\mathcal{A}(\bar{B}^0\to\Sigma^{*-}\overline{\Sigma^{*-}})$ is vanishing and will be discussed later. For group II modes, $\mathcal{A}(B^-\to\Delta^0\overline{\Delta^+})$, $\mathcal{A}(B^-\to\Sigma^{*0}\overline{\Sigma^{*+}})$, $\mathcal{A}(\bar{B}^0_s\to\Delta^0\overline{\Sigma^{*0}})$, $\mathcal{A}(\bar{B}^0_s\to\Sigma^{*0}\overline{\Xi^{*0}})$ and $\mathcal{A}(\bar{B}^0\to\Sigma^{*0}\overline{\Sigma^{*0}})$ are similar and sizable, reaching $\mp 80\%$, $\mathcal{A}(B^-\to\Delta^+\overline{\Delta^{++}})$ and $\mathcal{A}(\bar{B}^0_s\to\Delta^+\overline{\Sigma^{*+}})$ are similar and sizable, reaching $\mp 49\%$, but $\mathcal{A}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^{*-}})$ and $\mathcal{A}(\bar{B}^0_s\to\Xi^{*-}\overline{\Omega^-})$ are vanishing and will be discussed later. The group III mode, the $\bar{B}^0\to\Delta^+\overline{\Delta^+}$ decay, has sizable *CP* asymmetry, reaching $\mp 49\%$. Most of these *CP* asymmetries basically share the sign of $\mathcal{A}(\bar{B}^0\to p\bar{p})$.

[9] Note that for the second and fourth relations, the *CP* asymmetries of these modes all have vanishing central values; their relative signs cannot be read out from Tables XIV and XV.

TABLE XVI. Same as Table X, but with $\Delta S=0$, $\bar{B}_q\to\mathcal{D}\bar{\mathcal{D}}$ modes.

Mode	$\phi=0$	$\phi=\pm\pi/4$	$\phi=\pm\pi/2$	Mode	$\phi=0$	$\phi=\pm\pi/4$	$\phi=\pm\pi/2$
$B^-\to\Delta^+\overline{\Delta^{++}}$	0 ± 19.4	$\mp(36..0^{+19.3}_{-16.5})$	$\mp(49.3^{+18.3}_{-14.4})$	$\bar{B}^0_s\to\Delta^+\overline{\Sigma^{*+}}$	0 ± 19.0	$\mp(36.0^{+18.8}_{-16.2})$	$\mp(49.3^{+17.9}_{-14.2})$
$B^-\to\Delta^0\overline{\Delta^{+}}$	0 ± 32.1	$\mp(59.3^{+24.4}_{-26.5})$	$\mp(79.5^{+16.7}_{-19.9})$	$\bar{B}^0_s\to\Delta^0\overline{\Sigma^{*0}}$	0 ± 30.9	$\mp(59.3^{+23.6}_{-25.6})$	$\mp(79.5^{+16.2}_{-19.3})$
$B^-\to\Delta^-\overline{\Delta^{0}}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s\to\Delta^-\overline{\Sigma^{*-}}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$B^-\to\Sigma^{*0}\overline{\Sigma^{*+}}$	0 ± 32.1	$\mp(59.3^{+24.4}_{-26.5})$	$\mp(79.5^{+16.7}_{-19.9})$	$\bar{B}^0_s\to\Sigma^{*0}\overline{\Xi^{*0}}$	0 ± 30.9	$\mp(59.3^{+23.6}_{-25.6})$	$\mp(79.5^{+16.2}_{-19.3})$
$B^-\to\Sigma^{*-}\overline{\Sigma^{*0}}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^{*-}}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$B^-\to\Xi^{*-}\overline{\Xi^{*0}}$	0 ± 35.7	0 ± 35.7	0 ± 35.7	$\bar{B}^0_s\to\Xi^{*-}\overline{\Omega^{-}}$	0 ± 29.9	0 ± 29.9	0 ± 29.9
$\bar{B}^0\to\Delta^{++}\overline{\Delta^{++}}$	$-100\sim100$	$-100\sim100$	$-100\sim100$	$\bar{B}^0\to\Sigma^{*+}\overline{\Sigma^{*+}}$	$-100\sim100$	$-100\sim100$	$-100\sim100$
$\bar{B}^0\to\Delta^{+}\overline{\Delta^{+}}$	0 ± 22.9	$\mp(36.0^{+22.4}_{-19.4})$	$\mp(49.3^{+21.1}_{-16.8})$	$\bar{B}^0\to\Sigma^{*0}\overline{\Sigma^{*0}}$	0 ± 37.1	$\mp(59.3^{+27.1}_{-31.2})$	$\mp(79.5^{+17.9}_{-23.4})$
$\bar{B}^0\to\Delta^{0}\overline{\Delta^{0}}$	0 ± 34.0	$\mp(59.3^{+25.4}_{-28.4})$	$\mp(79.5^{+17.1}_{-21.4})$	$\bar{B}^0\to\Sigma^{*-}\overline{\Sigma^{*-}}$	0 ± 30.6	0 ± 30.6	0 ± 30.6
$\bar{B}^0\to\Delta^{-}\overline{\Delta^{-}}$	0 ± 30.6	0 ± 30.6	0 ± 30.6	$\bar{B}^0\to\Xi^{*0}\overline{\Xi^{*0}}$	$-100\sim100$	$-100\sim100$	$-100\sim100$
$\bar{B}^0\to\Omega^{-}\overline{\Omega^{-}}$	0	0	0	$\bar{B}^0\to\Xi^{*-}\overline{\Xi^{*-}}$	0 ± 32.1	0 ± 32.1	0 ± 32.1

From Eqs. (A19), (A20) and (A21), we can easily identify the following relations:

$$\begin{aligned}
&\mathcal{A}(B^-\to\Delta^-\overline{\Delta^0})=\mathcal{A}(B^-\to\Sigma^{*-}\overline{\Sigma^{*0}})=\mathcal{A}(B^-\to\Xi^{*-}\overline{\Xi^{*0}}),\\
&\mathcal{A}(B^-\to\Delta^0\overline{\Delta^+})=\mathcal{A}(B^-\to\Sigma^{*0}\overline{\Sigma^{*+}}),\\
&\mathcal{A}(\overline{B^0_s}\to\Delta^0\overline{\Sigma^{*0}})=\mathcal{A}(\overline{B^0_s}\to\Sigma^{*0}\overline{\Xi^{*0}}),\\
&\mathcal{A}(\overline{B^0_s}\to\Delta^-\overline{\Sigma^{*-}})=\mathcal{A}(\overline{B^0_s}\to\Xi^{*-}\overline{\Omega^-})=\mathcal{A}(\overline{B^0_s}\to\Sigma^{*-}\overline{\Xi^{*-}}).
\end{aligned}\tag{37}$$

We see from Table XVI that these relations are satisfied. These relations do not rely on the asymptotic limit and are not corrected from the phase space ratio but are subjected to SU(3) breaking in the topological amplitudes. Note that the *CP* asymmetries of several group I modes, $B^-\to\Delta^0\overline{\Delta^+}$, $B^-\to\Sigma^{*0}\overline{\Sigma^{*+}}$, $\overline{B^0_s}\to\Delta^0\overline{\Sigma^{*0}}$ and $\overline{B^0_s}\to\Sigma^{*0}\overline{\Xi^{*0}}$ decays, are related.

The central values of the *CP* asymmetries of $B^-\to\Delta^-\overline{\Delta^0}$, $B^-\to\Sigma^{*-}\overline{\Sigma^{*0}}$, $B^-\to\Xi^{*-}\overline{\Xi^{*0}}$, $\bar{B}^0\to\Delta^-\overline{\Delta^-}$, $\bar{B}^0\to\Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0\to\Xi^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s\to\Delta^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s\to\Xi^{*-}\overline{\Omega^-}$, and $\bar{B}^0\to\Omega^-\overline{\Omega^-}$ decays are vanishing, as they do not have any tree ($T_{\mathcal{D}\bar{\mathcal{D}}}$) contribution. The $\bar{B}^0\to\Delta^{++}\overline{\Delta^{++}}$, $\bar{B}^0\to\Sigma^{*+}\overline{\Sigma^{*+}}$ and $\bar{B}^0\to\Xi^{*0}\overline{\Xi^{*0}}$ decays are subleading modes, which only have $E_{\mathcal{D}\bar{\mathcal{D}}}$ and $P_{\mathcal{D}\bar{\mathcal{D}}}$ contributions. Their *CP* asymmetries can be any value. The $\bar{B}^0\to\Delta^-\overline{\Delta^-}$, $\bar{B}^0\to\Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0\to\Xi^{*-}\overline{\Xi^{*-}}$, $\bar{B}^0_s\to\Delta^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^{*-}}$ and $\bar{B}^0_s\to\Xi^{*-}\overline{\Omega^-}$ decays are $\Delta S=0$ pure penguin modes, which only have $P_{\mathcal{D}\bar{\mathcal{D}}}$, $P_{EW\mathcal{D}\bar{\mathcal{D}}}$ and $PA_{\mathcal{D}\bar{\mathcal{D}}}$ contributions, while the $\bar{B}^0\to\Omega^-\overline{\Omega^-}$ decay is a pure penguin annihilation ($PA_{\mathcal{D}\bar{\mathcal{D}}}$) mode. The *CP* asymmetries of the $\Delta S=0$ penguin modes need not be vanishing [see Eq. (23)], while the *CP* asymmetry of the pure penguin annihilation mode is always vanishing.

In Table XVII we give results of direct *CP* asymmetries of $\Delta S=-1$, $\bar{B}_q\to\mathcal{D}\bar{\mathcal{D}}$ modes. For group I modes, $\mathcal{A}(B^-\to\Sigma^{*+}\overline{\Delta^{++}})$ and $\mathcal{A}(\bar{B}^0_s\to\Sigma^{*+}\overline{\Sigma^{*+}})$ are similar and can be as large as $\pm35\%$, $\mathcal{A}(B^-\to\Xi^{*0}\overline{\Sigma^{*+}})$ and $\mathcal{A}(\bar{B}^0_s\to\Xi^{*0}\overline{\Xi^{*0}})$ are similar and can be as large as $\pm19\%$, but $\mathcal{A}(\bar{B}^0_s\to\Omega^-\overline{\Omega^-})$, $\mathcal{A}(B^-\to\Omega^-\overline{\Xi^{*0}})$, $\mathcal{A}(B^-\to\Sigma^{*-}\overline{\Delta^0})$ and $\mathcal{A}(\bar{B}^0_s\to\Sigma^{*-}\overline{\Sigma^{*-}})$ are vanishingly small and will be discussed later. For group II modes, $\mathcal{A}(\bar{B}^0\to\Sigma^{*+}\overline{\Delta^+})$ can reach $\pm35\%$, $\mathcal{A}(\bar{B}^0\to\Sigma^{*0}\overline{\Delta^0})$ and $\mathcal{A}(\bar{B}^0\to\Xi^{*0}\overline{\Sigma^{*0}})$ are similar and can be $\pm19\%$, but $\mathcal{A}(\bar{B}^0\to\Xi^{*-}\overline{\Sigma^{*-}})$ and $\mathcal{A}(\bar{B}^0\to\Omega^-\overline{\Xi^{*-}})$ are vanishing. For group III modes, $\mathcal{A}(B^-\to\Sigma^{*0}\overline{\Delta^+})$ and $\mathcal{A}(\bar{B}^0_s\to\Sigma^{*0}\overline{\Sigma^{*0}})$ are similar and can be $\pm19\%$, but $\mathcal{A}(\bar{B}^0_s\to\Xi^{*-}\overline{\Xi^{*-}})$ and $\mathcal{A}(B^-\to\Xi^{*-}\overline{\Sigma^{*0}})$ are vanishingly small and will be discussed later.

From Eqs. (A22), (A23) and (A24), we can easily identify the following relations:

$$\begin{aligned}
&\mathcal{A}(B^-\to\Sigma^{*-}\overline{\Delta^0})=\mathcal{A}(B^-\to\Omega^-\overline{\Xi^{*0}})=\mathcal{A}(B^-\to\Xi^{*-}\overline{\Sigma^{*0}}),\\
&\mathcal{A}(B^-\to\Sigma^{*0}\overline{\Delta^+})=\mathcal{A}(B^-\to\Xi^{*0}\overline{\Sigma^{*+}}),\\
&\mathcal{A}(\bar{B}^0\to\Sigma^{*0}\overline{\Delta^0})=\mathcal{A}(\bar{B}^0\to\Xi^{*0}\overline{\Sigma^{*0}}),\\
&\mathcal{A}(\bar{B}^0\to\Sigma^{*-}\overline{\Delta^-})=\mathcal{A}(\bar{B}^0\to\Xi^{*-}\overline{\Sigma^{*-}})=\mathcal{A}(\bar{B}^0\to\Omega^-\overline{\Xi^{*-}}).
\end{aligned}\tag{38}$$

We see from Table XVII that these relations are satisfied. Note that these relations do not rely on the asymptotic limit but are subjected to SU(3) breaking in the topological amplitudes.

The central values of the *CP* asymmetries of $B^-\to\Sigma^{*-}\overline{\Delta^0}$, $B^-\to\Xi^{*-}\overline{\Sigma^{*0}}$, $B^-\to\Omega^-\overline{\Xi^{*0}}$, $\bar{B}^0\to\Sigma^{*-}\overline{\Delta^-}$,

$\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$ and $\bar{B}^0_s \to \Delta^-\overline{\Delta^-}$ decays are vanishing, as they do not have any tree ($T'_{\mathcal{D}\bar{\mathcal{D}}}$) contribution. The subleading modes, $\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}}$ $\bar{B}^0_s \to \Delta^+\overline{\Delta^+}$ and $\bar{B}^0_s \to \Delta^0\overline{\Delta^0}$ decays, have $E'_{\mathcal{D}\bar{\mathcal{D}}}$ and $P'_{\mathcal{D}\bar{\mathcal{D}}}$ contributions. Their *CP* asymmetries can be any value. Since the $\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ and $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$ decays are $\Delta S = -1$ pure penguin modes, which only have $P'_{\mathcal{D}\bar{\mathcal{D}}}$, $P'_{EW\mathcal{D}\bar{\mathcal{D}}}$ and $PA'_{\mathcal{D}\bar{\mathcal{D}}}$ contributions, and the $\bar{B}^0_s \to \Delta^-\overline{\Delta^-}$ decay is a pure penguin annihilation ($PA'_{\mathcal{D}\bar{\mathcal{D}}}$) mode, their *CP* asymmetries are small [see Eq. (24)] or always vanishing. These can be tests of the Standard Model. Note that some of these modes have relatively good detectability. These include two group I modes, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ and $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$ decays, two group II modes, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$ and $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$ decays, and a group III mode, the $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$ decay, where all have rates of orders 10^{-7} (see Table VIII). It will be interesting to search for these modes and use their *CP* asymmetries as the null tests of the Standard Model.

The *U*-spin relations for decuplet-antidecuplet modes are given by [3][10]

$$
\begin{aligned}
2\Delta_{CP}(B^- \to \Delta^-\overline{\Delta^0}) &= 3\Delta_{CP}(B^- \to \Sigma^{*-}\overline{\Sigma^{*0}}) = \Delta_{CP}(B^- \to \Xi^{*-}\overline{\Xi^{*0}})\\
&= -6\Delta_{CP}(B^- \to \Sigma^{*-}\overline{\Delta^0}) = -2\Delta_{CP}(B^- \to \Omega^-\overline{\Xi^{*0}}) = -3\Delta_{CP}(B^- \to \Xi^{*-}\overline{\Sigma^{*0}}),\\
\Delta_{CP}(B^- \to \Delta^0\overline{\Delta^+}) &= 2\Delta_{CP}(B^- \to \Sigma^{*0}\overline{\Sigma^{*+}}) = -2\Delta_{CP}(B^- \to \Sigma^{*0}\overline{\Delta^+}) = -\Delta_{CP}(B^- \to \Xi^{*0}\overline{\Sigma^{*+}}),\\
\Delta_{CP}(B^- \to \Delta^+\overline{\Delta^{++}}) &= -\Delta_{CP}(B^- \to \Sigma^{*+}\overline{\Delta^{++}}),\\
\Delta_{CP}(\overline{B^0_s} \to \Delta^0\overline{\Sigma^{*0}}) &= \Delta_{CP}(\overline{B^0_s} \to \Sigma^{*0}\overline{\Xi^{*0}}) = -\Delta_{CP}(\bar{B}^0 \to \Sigma^{*0}\overline{\Delta^0}) = -\Delta_{CP}(\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^{*0}}),\\
4\Delta_{CP}(\overline{B^0_s} \to \Delta^-\overline{\Sigma^{*-}}) &= 4\Delta_{CP}(\overline{B^0_s} \to \Xi^{*-}\overline{\Omega^-}) = 3\Delta_{CP}(\overline{B^0_s} \to \Sigma^{*-}\overline{\Xi^{*-}})\\
&= -4\Delta_{CP}(\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^-}) = -3\Delta_{CP}(\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}) = -4\Delta_{CP}(\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}),\\
\Delta_{CP}(\overline{B^0_s} \to \Delta^+\overline{\Sigma^{*+}}) &= -\Delta_{CP}(\bar{B}^0 \to \Sigma^{*+}\overline{\Delta^+}),\\
\Delta_{CP}(\overline{B^0} \to \Xi^{*0}\overline{\Xi^{*0}}) &= -\Delta_{CP}(\bar{B}^0_s \to \Delta^0\overline{\Delta^0}),\\
\Delta_{CP}(\overline{B^0} \to \Xi^{*-}\overline{\Xi^{*-}}) &= -\Delta_{CP}(\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}),\\
\Delta_{CP}(\overline{B^0} \to \Sigma^{*0}\overline{\Sigma^{*0}}) &= -\Delta_{CP}(\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^{*0}}),\\
\Delta_{CP}(\overline{B^0} \to \Omega^-\overline{\Omega^-}) &= -\Delta_{CP}(\bar{B}^0_s \to \Delta^-\overline{\Delta^-}) = 0,\\
\Delta_{CP}(\overline{B^0} \to \Delta^{++}\overline{\Delta^{++}}) &= -\Delta_{CP}(\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}}),\\
\Delta_{CP}(\overline{B^0} \to \Sigma^{*+}\overline{\Sigma^{*+}}) &= -\Delta_{CP}(\bar{B}^0_s \to \Delta^+\overline{\Delta^+}),\\
\Delta_{CP}(\overline{B^0} \to \Delta^-\overline{\Delta^-}) &= -\Delta_{CP}(\bar{B}^0_s \to \Omega^-\overline{\Omega^-}),\\
\Delta_{CP}(\overline{B^0} \to \Sigma^{*-}\overline{\Sigma^{*-}}) &= -\Delta_{CP}(\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}),\\
\Delta_{CP}(\overline{B^0} \to \Delta^+\overline{\Delta^+}) &= -\Delta_{CP}(\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}),\\
\Delta_{CP}(\overline{B^0} \to \Delta^0\overline{\Delta^0}) &= -\Delta_{CP}(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}).
\end{aligned}
\tag{39}
$$

These relations are roughly satisfied by the results shown in Tables XVI and XVII and the agreement can be improved when SU(3) breaking effects are taken into account. For example, one can make a quick but nontrivial check on the relative signs of these asymmetries and see that they indeed agree with the above relations.[11] Note that several vanishing *CP* asymmetries as discussed previously are related to each other. For example, from the last relation of the above equation, we have

[10]A typo in the fifth relation is corrected.

[11]Note that for the first relation, the *CP* asymmetries of these modes all have vanishing central values; their relative signs cannot be read out from Tables XVI and XVII. The relative signs of $\Delta_{CP}(\overline{B^0} \to \Xi^{*0}\overline{\Xi^{*0}}$ and $\Delta_{CP}(\bar{B}^0_s \to \Delta^0\overline{\Delta^0})$ $\Delta_{CP}(\overline{B^0} \to \Delta^{++}\overline{\Delta^{++}})$ and $\Delta_{CP}(\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}})$, $\Delta_{CP}(\overline{B^0} \to \Sigma^{*+}\overline{\Sigma^{*+}})$ and $\Delta_{CP}(\bar{B}^0_s \to \Delta^+\overline{\Delta^+})$ cannot be read out from Tables XVI and XVII. The signs of modes in the fifth, eighth, thirteenth and fourteenth relations cannot be read out from the tables.

TABLE XVII. Same as Table X, but with $\Delta S = -1$, $\bar{B}_q \to \mathcal{D}\bar{\mathcal{D}}$ modes.

Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$	Mode	$\phi = 0$	$\phi = \pm\pi/4$	$\phi = \pm\pi/2$
$B^- \to \Sigma^{*+}\overline{\Delta^{++}}$	0 ± 15.1	$\pm(27.1^{+15.5}_{-12.5})$	$\pm(35.3^{+14.5}_{-11.0})$	$\bar{B}^0 \to \Sigma^{*+}\overline{\Delta^{+}}$	0 ± 14.8	$\pm(27.1^{+15.2}_{-12.3})$	$\pm(35.3^{+14.2}_{-10.8})$
$B^- \to \Sigma^{*0}\overline{\Delta^{+}}$	0 ± 8.0	$\pm(14.2^{+8.9}_{-6.8})$	$\pm(19.2^{+9.1}_{-6.6})$	$\bar{B}^0 \to \Sigma^{*0}\overline{\Delta^{0}}$	0 ± 7.7	$\pm(14.2^{+8.6}_{-6.6})$	$\pm(19.2^{+8.8}_{-6.4})$
$B^- \to \Sigma^{*-}\overline{\Delta^{0}}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^{-}}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$B^- \to \Xi^{*0}\overline{\Sigma^{*+}}$	0 ± 8.0	$\pm(14.2^{+8.9}_{-6.8})$	$\pm(19.2^{+9.1}_{-6.6})$	$\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^{*0}}$	0 ± 7.7	$\pm(14.2^{+8.6}_{-6.6})$	$\pm(19.2^{+8.8}_{-6.4})$
$B^- \to \Xi^{*-}\overline{\Sigma^{*0}}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$B^- \to \Omega^{-}\overline{\Xi^{*0}}$	0 ± 1.8	0 ± 1.8	0 ± 1.8	$\bar{B}^0 \to \Omega^{-}\overline{\Xi^{*-}}$	0 ± 1.5	0 ± 1.5	0 ± 1.5
$\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$	$\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}$	0 ± 18.3	$\pm(27.1^{+19.0}_{-14.4})$	$\pm(35.3^{+17.8}_{-12.3})$
$\bar{B}^0_s \to \Delta^{+}\overline{\Delta^{+}}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$	$\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^{*0}}$	0 ± 9.6	$\pm(14.2^{+11.0}_{-7.7})$	$\pm(19.2^{+11.2}_{-7.2})$
$\bar{B}^0_s \to \Delta^{0}\overline{\Delta^{0}}$	$-100 \sim 100$	$-100 \sim 100$	$-100 \sim 100$	$\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$	0 ± 1.6	0 ± 1.6	0 ± 1.6
$\bar{B}^0_s \to \Delta^{-}\overline{\Delta^{-}}$	0	0	0	$\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}$	0 ± 8.6	$\pm(14.2^{+9.8}_{-7.2})$	$\pm(19.2^{+10.0}_{-6.8})$
$\bar{B}^0_s \to \Omega^{-}\overline{\Omega^{-}}$	0 ± 1.5	0 ± 1.5	0 ± 1.5	$\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$	0 ± 1.6	0 ± 1.6	0 ± 1.6

$$\mathcal{A}(\bar{B}^0 \to \Delta^0\overline{\Delta^0}) = -\mathcal{A}(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}})\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}})}{\mathcal{B}(\bar{B}^0 \to \Delta^0\overline{\Delta^0})}$$
$$\simeq -(3.7)\mathcal{A}(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}). \quad (40)$$

The results in Tables XVI and XVII agree with it. Note that these two modes are both group I modes. We will return to this later. The fifth, eighth, thirteenth and fourteenth relations can be used to constrain the sizes of CP asymmetries of the $\Delta S = -1$ pure penguin modes model independently. For example, using the fifth relation we can have

$$|\mathcal{A}(\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}})|$$
$$= \frac{3}{4}|\mathcal{A}(\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^{*-}})|\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^{*-}})}{\mathcal{B}(\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}})}$$
$$\leq \frac{3}{4}\frac{\tau(B^0)}{\tau(B^0_s)}\frac{\mathcal{B}(\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^{*-}})}{\mathcal{B}(\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}})} \simeq 5.5\%, \quad (41)$$

which is satisfied by the result shown in Table XVII. Note that the above two modes are both group II modes and one does not need B_s tagging to test the inequality experimentally.

In Tables X to XVII, we show results of CP asymmetries for some specify values of the penguin-tree relative strong phase ϕ (0, $\pm\pi/4$ and $\pm\pi/2$). It will be useful to plot the CP asymmetries of some interesting modes in the full range of ϕ. In Fig. 2, we plot the CP asymmetries of $\bar{B}^0 \to p\bar{p}$, $B^- \to \Lambda\bar{p}$, $\bar{B}^0_s \to \Lambda\bar{\Lambda}$, $B^- \to p\overline{\Delta^{++}}$, $\bar{B}^0_s \to p\overline{\Sigma^{*+}}$, $B^- \to \Delta^0\bar{p}$ and $\bar{B}^0_s \to \Delta^0\bar{\Lambda}$ decays. In Fig. 3, we plot the CP asymmetries of $\bar{B}^0 \to \Xi^{*0}\bar{\Lambda}$, $\bar{B}^0 \to \Sigma^{*+}\bar{p}$, $\bar{B}^0 \to \Delta^0\overline{\Delta^0}$, $B^- \to \Sigma^{*+}\overline{\Delta^{++}}$, $\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}$, $B^- \to \Xi^{*0}\overline{\Sigma^{*+}}$ and $\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}$ decays. These are direct CP asymmetries of several group I modes, which have unsuppressed rates and can cascadely decay to all charged final states. The solid lines are from tree-penguin interferences using the asymptotic relation. The bands between the dashed (dotted) lines in the figures are with contributions from corrections to the asymptotic relation without (with) contributions from subleading terms. For the figures we see that corrections to the asymptotic relation dominate the uncertainties.

Note that the remaining group I modes, including $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$, $B^- \to \Xi^-\bar{\Lambda}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^-}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$, $B^- \to \Omega^-\overline{\Xi^{*0}}$, $B^- \to \Sigma^{*-}\overline{\Delta^0}$ and $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$ decays do not depend on ϕ; hence, their CP asymmetries are not plotted. In particular, as noted before, $\mathcal{A}(\bar{B}^0_s \to \Xi^-\overline{\Xi^-})$, $\mathcal{A}(\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}})$, $\mathcal{A}(\bar{B}^0 \to \Omega^-\overline{\Xi^-})$, $\mathcal{A}(\bar{B}^0_s \to \Omega^-\overline{\Omega^-})$, and $\mathcal{A}(\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}})$ are small and can be used to test the Standard Model; especially these modes have good detectability in rates.

We now return to Figs. 2 and 3. Most of these asymmetries are sizable. We can classify these modes, according to the dependence of ϕ, into two groups. The $\mathcal{A}(\bar{B}^0 \to p\bar{p})$, $\mathcal{A}(B^- \to p\overline{\Delta^{++}})$, $\mathcal{A}(\bar{B}^0_s \to p\overline{\Sigma^{*+}})$, $\mathcal{A}(\bar{B}^0_s \to \Delta^0\bar{\Lambda})$ and $\mathcal{A}(\bar{B}^0 \to \Delta^0\overline{\Delta^0})$ have similar behavior, while $\mathcal{A}(B^- \to \Lambda\bar{p})$, $\mathcal{A}(\bar{B}^0_s \to \Lambda\bar{\Lambda})$, $\mathcal{A}(B^- \to \Delta^0\bar{p})$, $\mathcal{A}(\bar{B}^0 \to \Xi^{*0}\bar{\Lambda})$, $\mathcal{A}(\bar{B}^0 \to \Sigma^{*+}\bar{p})$, $\mathcal{A}(B^- \to \Sigma^{*+}\overline{\Delta^{++}})$, $\mathcal{A}(\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}})$, $\mathcal{A}(B^- \to \Xi^{*0}\overline{\Sigma^{*+}})$ and $\mathcal{A}(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}})$ have similar behavior, but different from the first group. The asymmetries in these two groups basically have opposite signs for ϕ away from 0, π, 2π. Note that through U-spin relation, $\mathcal{A}(\overline{B^0} \to \Delta^0\overline{\Delta^0})$ and $\mathcal{A}(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}})$ are related by Eq. (39). We see from Figs. 3(c) and 3(g) that they indeed respect the relation.

It will be interesting to measure the CP asymmetries of these group I modes and compare to the predictions plotted in Figs. 2 and 3. Measuring these asymmetries can provide useful information on the decay amplitudes.

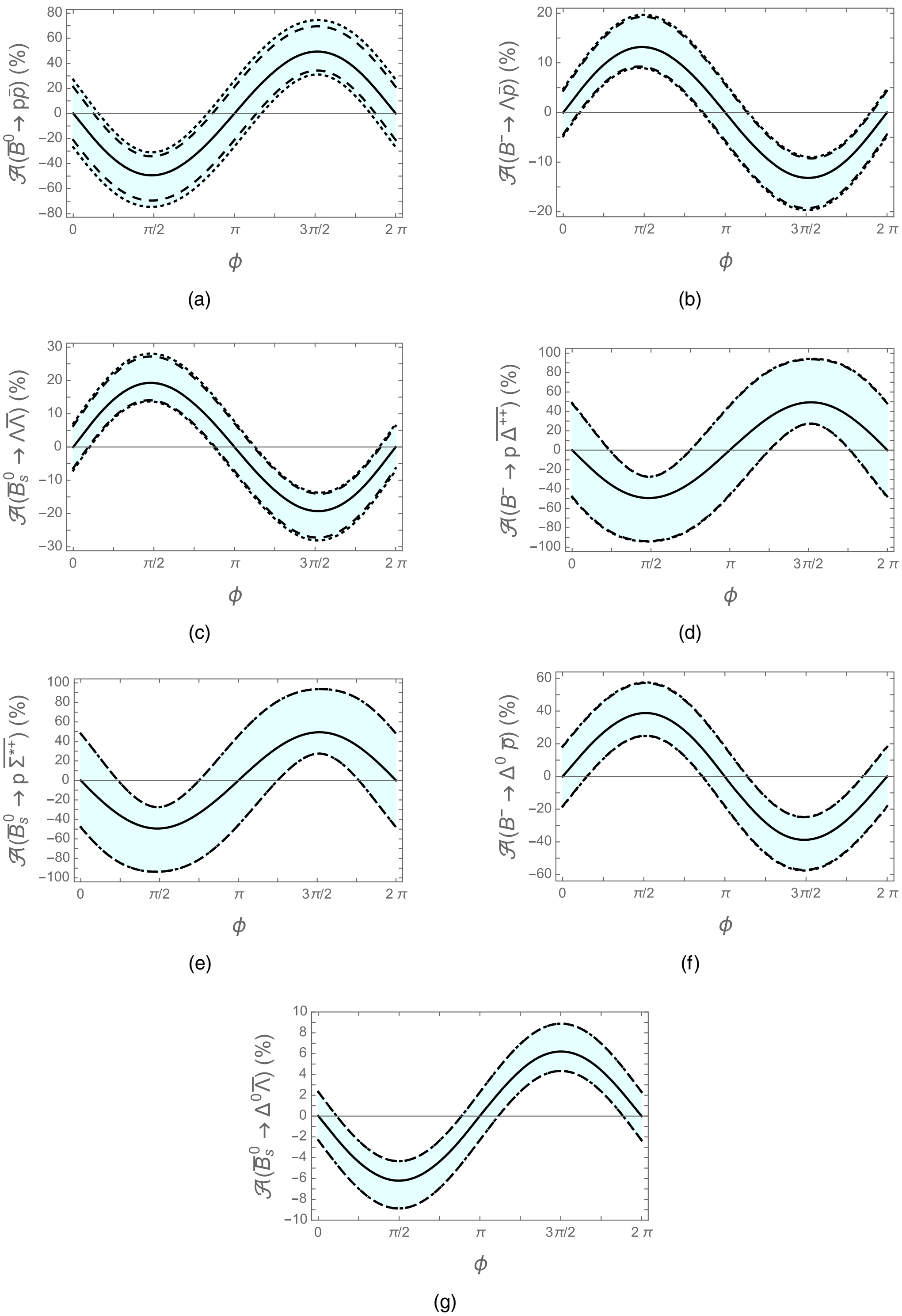

FIG. 2. Direct *CP* asymmetries of some interesting modes are plotted with respect to the penguin-tree relative strong phase ϕ. The solid lines are from tree-penguin interferences using the asymptotic relation. The bands between the dashed (dotted) lines are with contributions from corrections to the asymptotic relation without (with) contributions from subleading terms.

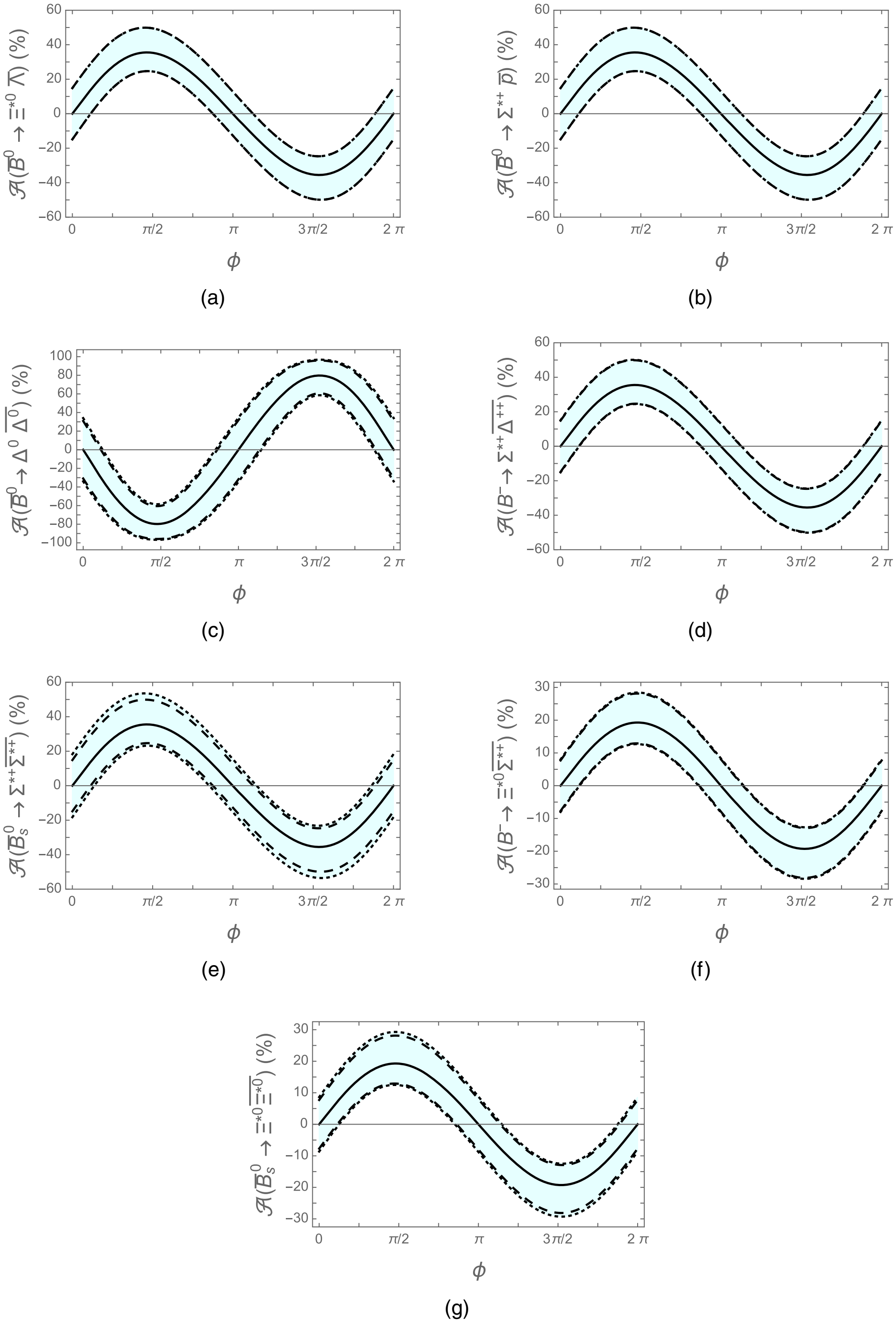

FIG. 3. Direct *CP* asymmetries of some interesting modes are plotted with respect to the penguin-tree relative strong phase ϕ. The solid lines are from tree-penguin interferences using the asymptotic relation. The bands between the dashed (dotted) lines are with contributions from corrections to the asymptotic relation without (with) contributions from subleading terms.

IV. CONCLUSION

With the experimental evidences of $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ decays, it is now possible to extract both tree and penguin amplitudes of charmless two-body baryonic decays for the first time. The extracted penguin-tree ratio agrees with the expectation. Predictions on all $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$, $\mathcal{B}\bar{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$ and $\mathcal{D}\bar{\mathcal{D}}$ decay rates are given. It is nontrivial that the results do not violate any existing experimental upper limit. From the results, it is understandable why $\bar{B}^0 \to p\bar{p}$ and $B^- \to \Lambda\bar{p}$ modes are the first two modes with experimental evidences. Relations on rates are verified. There are 23 modes that have relatively sizable rates and can cascadely decay to all charged final states, including $\bar{B}^0 \to p\bar{p}$, $B^- \to \Lambda\bar{p}$, $\Xi^-\bar{\Lambda}$, $\bar{B}^0_s \to \Lambda\bar{\Lambda}$, $\Xi^-\overline{\Xi^-}$; $B^- \to p\overline{\Delta^{++}}$, $\bar{B}^0_s \to p\overline{\Sigma^{*+}}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$; $B^- \to \Delta^0\bar{p}$, $\bar{B}^0_s \to \Delta^0\bar{\Lambda}$, $\bar{B}^0 \to \Sigma^{*-}\bar{p}$, $\Omega^-\overline{\Xi^-}$, $\Xi^{*0}\bar{\Lambda}$; $\bar{B}^0 \to \Delta^0\overline{\Delta^0}$, $\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $B^- \to \Sigma^{*+}\overline{\Delta^{++}}$, $\Xi^{*0}\overline{\Sigma^{*+}}$, $\Omega^-\overline{\Xi^{*0}}$, $\Sigma^{*-}\overline{\Delta^0}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$, $\Xi^{*0}\overline{\Xi^{*0}}$, $\Sigma^{*+}\overline{\Sigma^{*+}}$ and $\Sigma^{*-}\overline{\Sigma^{*-}}$ decays. With π^0 and γ another 38 modes can be searched for, while with $\pi^0\pi^0$, $\pi^0\gamma$ and $\gamma\gamma$38 more modes can be searched for in the future. In particular, we note that the predicted $B^- \to p\overline{\Delta^{++}}$ rate is close to the experimental bound, which has not been updated in the last ten years [33]. The bounds on $B^- \to \Delta^0\bar{p}$ and $\bar{B}^0 \to \Sigma^{*+}\bar{p}$ rates have not been updated in the last ten years [33,34] and the bound on $\bar{B}^0 \to \Delta^0\overline{\Delta^0}$ rate has not been updated in about three decades [35], while their rates are predicted to be of the order of 10^{-8}. Also note that the $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ rate is predicted to be the highest rate. The analysis of this work can be improved systematically when more modes are measured.

Direct *CP* asymmetries of all $\bar{B}_q \to \mathcal{B}\bar{\mathcal{B}}$, $\mathcal{B}\bar{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$ and $\mathcal{D}\bar{\mathcal{D}}$ modes are explored. Relations on *CP* asymmetries are verified. Results of *CP* asymmetries for modes with relatively good detectability in rates are highlighted. In particular, the direct *CP* asymmetry of $\bar{B}^0 \to p\bar{p}$ decay can be as large as $\pm 50\%$. Some of the *CP* asymmetries are small or vanishing. For $\bar{B} \to \mathcal{B}\bar{\mathcal{B}}$, $\Delta S = -1$ decays, $\bar{B}^0 \to \Xi^-\overline{\Sigma^-}$, $\bar{B}^0_s \to \Sigma^-\overline{\Sigma^-}$ and $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$ decays are pure penguin modes. For $\bar{B} \to \mathcal{B}\bar{\mathcal{D}}$, $\Delta S = 0$ decays, $\bar{B}^0 \to \Sigma^+\overline{\Sigma^{*+}}$ and $\bar{B}^0 \to \Xi^0\overline{\Xi^{*0}}$ decays are pure exchange modes. For $\bar{B} \to \mathcal{B}\bar{\mathcal{D}}$, $\Delta S = -1$ decays, $\bar{B}^0 \to \Sigma^-\overline{\Delta^-}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Sigma^-\overline{\Sigma^{*-}}$ and $\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$ decays are pure penguin modes and $\bar{B}^0_s \to p\overline{\Delta^+}$ and $\bar{B}^0_s \to n\overline{\Delta^0}$ decays are pure exchange modes. For $\bar{B} \to \mathcal{D}\bar{\mathcal{B}}$, $\Delta S = 0$ decays, $\bar{B}^0 \to \Xi^{*0}\overline{\Xi^0}$ and $\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^+}$ decays are pure exchange modes. For $\bar{B} \to \mathcal{D}\bar{\mathcal{B}}$, $\Delta S = -1$ decays, $\bar{B}^0 \to \Omega^-\overline{\Xi^-}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^-}$ and $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^-}$ decays are pure penguin modes, while $\bar{B}^0_s \to \Delta^+\bar{p}$ and $\bar{B}^0_s \to \Delta^0\bar{n}$ decays are pure exchange modes. For $\bar{B} \to \mathcal{D}\bar{\mathcal{D}}$, $\Delta S = 0$ decays, $\bar{B}^0 \to \Omega^-\overline{\Omega^-}$ decay is a pure penguin annihilation mode. For $\bar{B} \to \mathcal{D}\bar{\mathcal{D}}$, $\Delta S = -1$ decays, $\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$, $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ and $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$ decays are pure penguin modes, and the $\bar{B}^0_s \to \Delta^-\overline{\Delta^-}$ decay is a pure penguin annihilation mode. The *CP* asymmetries of the above modes are small, following the hierarchy of the CKM factors, or vanishing. They can be added to the list of the tests of the Standard Model. Note that some of these modes have relatively good detectability in rates. These include 5 group I modes, $\bar{B}^0_s \to \Xi^-\overline{\Xi^-}$, $\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$, $\bar{B}^0 \to \Omega^-\overline{\Xi^-}$, $\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$ and $\bar{B}^0_s \to \Omega^-\overline{\Omega^-}$ decays, 4 group II modes, $\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}$, $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^-}$, $\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}$ and $\bar{B}^0 \to \Omega^-\overline{\Xi^{*-}}$ decays, and a group III mode, the $\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}$ decay, but some require B_s tagging to search for its *CP* asymmetry. It will be interesting to search for these modes and use their *CP* asymmetries to search for new physics. Furthermore, since these modes are rare decay modes and all of them are pure penguin modes, they are expected to be sensitive to new physics contributions.

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APPENDIX A: TOPOLOGICAL AMPLITUDES OF TWO-BODY CHARMLESS BARYONIC *B* DECAYS

We collect all the $\bar{B} \to \mathcal{D}\bar{\mathcal{D}}$, $\mathcal{D}\bar{\mathcal{B}}$, $\mathcal{B}\bar{\mathcal{D}}$, $\mathcal{B}\bar{\mathcal{B}}$ decay amplitudes obtained in Ref. [3]. Note that Eq. (A23) is the corrected version.

1. $\bar{B}$ to octet-anti-octet baryonic decays

The full $\bar{B} \to \mathcal{B}\bar{\mathcal{B}}$ decay amplitudes for $\Delta S = 0$ processes are given by

$$
\begin{aligned}
A(B^- \to n\bar{p}) &= -T_{1\mathcal{B}\bar{\mathcal{B}}} - 5P_{1\mathcal{B}\bar{\mathcal{B}}} + \frac{2}{3}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} - P_{3EW\mathcal{B}\bar{\mathcal{B}}} + P_{4EW\mathcal{B}\bar{\mathcal{B}}}) - 5A_{1\mathcal{B}\bar{\mathcal{B}}},\\
A(B^- \to \Sigma^0\overline{\Sigma^+}) &= \sqrt{2}T_{3\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{\sqrt{2}}(5P_{1\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{3\sqrt{2}}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}} + 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{4EW\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{2}}(5A_{1\mathcal{B}\bar{\mathcal{B}}} - A_{2\mathcal{B}\bar{\mathcal{B}}}),\\
A(B^- \to \Sigma^-\overline{\Sigma^0}) &= -\frac{1}{\sqrt{2}}(5P_{1\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3\sqrt{2}}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 4P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{2}}(5A_{1\mathcal{B}\bar{\mathcal{B}}} - A_{2\mathcal{B}\bar{\mathcal{B}}}),\\
A(B^- \to \Sigma^-\bar{\Lambda}) &= -\frac{1}{\sqrt{6}}(5P_{1\mathcal{B}\bar{\mathcal{B}}} + P_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3\sqrt{6}}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} - P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 4P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{6}}(5A_{1\mathcal{B}\bar{\mathcal{B}}} + A_{2\mathcal{B}\bar{\mathcal{B}}}),\\
A(B^- \to \Xi^-\overline{\Xi^0}) &= -P_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{3}P_{2EW\mathcal{B}\bar{\mathcal{B}}} - A_{2\mathcal{B}\bar{\mathcal{B}}},\\
A(B^- \to \Lambda\overline{\Sigma^+}) &= -\sqrt{\frac{2}{3}}(T_{1\mathcal{B}\bar{\mathcal{B}}} - T_{3\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{6}}(5P_{1\mathcal{B}\bar{\mathcal{B}}} + P_{2\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{3\sqrt{6}}(5P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}}\\
&\quad - 4P_{3EW\mathcal{B}\bar{\mathcal{B}}} + 2P_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{6}}(5A_{1\mathcal{B}\bar{\mathcal{B}}} + A_{2\mathcal{B}\bar{\mathcal{B}}}),
\end{aligned} \tag{A1}
$$

$$
\begin{aligned}
A(\bar{B}^0 \to p\bar{p}) &= -T_{2\mathcal{B}\bar{\mathcal{B}}} + 2T_{4\mathcal{B}\bar{\mathcal{B}}} + P_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{2}{3}P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 5E_{1\mathcal{B}\bar{\mathcal{B}}} + E_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to n\bar{n}) &= -(T_{1\mathcal{B}\bar{\mathcal{B}}} + T_{2\mathcal{B}\bar{\mathcal{B}}}) - (5P_{1\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}}) + \frac{2}{3}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}} - P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{4EW\mathcal{B}\bar{\mathcal{B}}}) + E_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Sigma^+\overline{\Sigma^+}) &= -5E_{1\mathcal{B}\bar{\mathcal{B}}} + E_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Sigma^0\overline{\Sigma^0}) &= -T_{3\mathcal{B}\bar{\mathcal{B}}} - \frac{1}{2}(5P_{1\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{6}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}} + 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{4EW\mathcal{B}\bar{\mathcal{B}}})\\
&\quad - \frac{1}{2}(5E_{1\mathcal{B}\bar{\mathcal{B}}} - E_{2\mathcal{B}\bar{\mathcal{B}}}) - 9PA_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Sigma^0\bar{\Lambda}) &= \frac{1}{\sqrt{3}}(T_{3\mathcal{B}\bar{\mathcal{B}}} + 2T_{4\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{2\sqrt{3}}(5P_{1\mathcal{B}\bar{\mathcal{B}}} + P_{2\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{6\sqrt{3}}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} - P_{2EW\mathcal{B}\bar{\mathcal{B}}}\\
&\quad + 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} + 10P_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{2\sqrt{3}}(5E_{1\mathcal{B}\bar{\mathcal{B}}} + E_{2\mathcal{B}\bar{\mathcal{B}}}),\\
A(\bar{B}^0 \to \Sigma^-\overline{\Sigma^-}) &= -(5P_{1\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 4P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{4EW\mathcal{B}\bar{\mathcal{B}}}) - 9PA_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Xi^0\overline{\Xi^0}) &= E_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Xi^-\overline{\Xi^-}) &= P_{2\mathcal{B}\bar{\mathcal{B}}} - \frac{1}{3}P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 9PA_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Lambda\overline{\Sigma^0}) &= \frac{1}{\sqrt{3}}(T_{1\mathcal{B}\bar{\mathcal{B}}} - T_{3\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{2\sqrt{3}}(5P_{1\mathcal{B}\bar{\mathcal{B}}} + P_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{6\sqrt{3}}(5P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} + 2P_{4EW\mathcal{B}\bar{\mathcal{B}}})\\
&\quad - \frac{1}{2\sqrt{3}}(5E_{1\mathcal{B}\bar{\mathcal{B}}} + E_{2\mathcal{B}\bar{\mathcal{B}}}),\\
A(\bar{B}^0 \to \Lambda\bar{\Lambda}) &= -\frac{1}{3}(T_{1\mathcal{B}\bar{\mathcal{B}}} + 2T_{2\mathcal{B}\bar{\mathcal{B}}} - T_{3\mathcal{B}\bar{\mathcal{B}}} - 2T_{4\mathcal{B}\bar{\mathcal{B}}}) - \frac{5}{6}(P_{1\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}})\\
&\quad + \frac{1}{18}(5P_{1EW\mathcal{B}\bar{\mathcal{B}}} + 7P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 10P_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{5}{6}(E_{1\mathcal{B}\bar{\mathcal{B}}} - E_{2\mathcal{B}\bar{\mathcal{B}}}) - 9PA_{\mathcal{B}\bar{\mathcal{B}}},
\end{aligned} \tag{A2}
$$

and

$$A(\bar{B}_s^0 \to p\overline{\Sigma^+}) = T_{2\mathcal{B}\bar{\mathcal{B}}} - 2T_{4\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}} - \frac{2}{3}P_{2EW\mathcal{B}\bar{\mathcal{B}}},$$

$$A(\bar{B}_s^0 \to n\overline{\Sigma^0}) = -\frac{1}{\sqrt{2}}T_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{\sqrt{2}}P_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{\sqrt{2}}{3}(P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 3P_{4EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}_s^0 \to n\bar{\Lambda}) = \frac{1}{\sqrt{6}}(2T_{1\mathcal{B}\bar{\mathcal{B}}} + T_{2\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{6}}(10P_{1\mathcal{B}\bar{\mathcal{B}}} - P_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3}\sqrt{\frac{2}{3}}(2P_{1EW\mathcal{B}\bar{\mathcal{B}}} + P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} - P_{4EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}_s^0 \to \Sigma^0\overline{\Xi^0}) = \sqrt{2}(T_{3\mathcal{B}\bar{\mathcal{B}}} + T_{4\mathcal{B}\bar{\mathcal{B}}}) + \frac{5}{\sqrt{2}}P_{1\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{3\sqrt{2}}(P_{1EW\mathcal{B}\bar{\mathcal{B}}} + 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} + 4P_{4EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}_s^0 \to \Sigma^-\overline{\Xi^-}) = -5P_{1\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{3}(-P_{1EW\mathcal{B}\bar{\mathcal{B}}} + 4P_{3EW\mathcal{B}\bar{\mathcal{B}}} + 2P_{4EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}_s^0 \to \Lambda\overline{\Xi^0}) = -\sqrt{\frac{2}{3}}(T_{1\mathcal{B}\bar{\mathcal{B}}} + T_{2\mathcal{B}\bar{\mathcal{B}}} - T_{3\mathcal{B}\bar{\mathcal{B}}} - T_{4\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{6}}(5P_{1\mathcal{B}\bar{\mathcal{B}}} - 2P_{2\mathcal{B}\bar{\mathcal{B}}})$$
$$+ \frac{1}{3\sqrt{6}}(5P_{1EW\mathcal{B}\bar{\mathcal{B}}} + 4P_{2EW\mathcal{B}\bar{\mathcal{B}}} - 2P_{3EW\mathcal{B}\bar{\mathcal{B}}} - 4P_{4EW\mathcal{B}\bar{\mathcal{B}}}), \tag{A3}$$

while those for $\Delta S = 1$ transitions are given by

$$A(B^- \to \Sigma^0\bar{p}) = -\frac{1}{\sqrt{2}}(T'_{1\mathcal{B}\bar{\mathcal{B}}} - 2T'_{3\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{2}}P'_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{3\sqrt{2}}(3P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + P'_{2EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{2}}A'_{2\mathcal{B}\bar{\mathcal{B}}},$$

$$A(B^- \to \Sigma^-\bar{n}) = -P'_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{3}P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - A'_{2\mathcal{B}\bar{\mathcal{B}}},$$

$$A(B^- \to \Xi^0\overline{\Sigma^+}) = -T'_{1\mathcal{B}\bar{\mathcal{B}}} - 5P'_{1\mathcal{B}\bar{\mathcal{B}}} + \frac{2}{3}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} - P'_{3EW\mathcal{B}\bar{\mathcal{B}}} + P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) - 5A'_{1\mathcal{B}\bar{\mathcal{B}}},$$

$$A(B^- \to \Xi^-\overline{\Sigma^0}) = -\frac{5}{\sqrt{2}}P'_{1\mathcal{B}\bar{\mathcal{B}}} - \frac{1}{3\sqrt{2}}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} - 4P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{5}{\sqrt{2}}A'_{1\mathcal{B}\bar{\mathcal{B}}},$$

$$A(B^- \to \Xi^-\bar{\Lambda}) = -\frac{1}{\sqrt{6}}(5P'_{1\mathcal{B}\bar{\mathcal{B}}} - 2P'_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3\sqrt{6}}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + 2P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - 4P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{6}}(5A'_{1\mathcal{B}\bar{\mathcal{B}}} - 2A'_{2\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(B^- \to \Lambda\bar{p}) = \frac{1}{\sqrt{6}}(T'_{1\mathcal{B}\bar{\mathcal{B}}} + 2T'_{3\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{6}}(10P'_{1\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3\sqrt{6}}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} - P'_{2EW\mathcal{B}\bar{\mathcal{B}}}$$
$$- 4P'_{3EW\mathcal{B}\bar{\mathcal{B}}} + 4P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{6}}(10A'_{1\mathcal{B}\bar{\mathcal{B}}} - A'_{2\mathcal{B}\bar{\mathcal{B}}}), \tag{A4}$$

$$A(\bar{B}^0 \to \Sigma^+\bar{p}) = T'_{2\mathcal{B}\bar{\mathcal{B}}} - 2T'_{4\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathcal{B}\bar{\mathcal{B}}} - \frac{2}{3}P'_{2EW\mathcal{B}\bar{\mathcal{B}}},$$

$$A(\bar{B}^0 \to \Sigma^0\bar{n}) = -\frac{1}{\sqrt{2}}(T'_{1\mathcal{B}\bar{\mathcal{B}}} + T'_{2\mathcal{B}\bar{\mathcal{B}}} - 2T'_{3\mathcal{B}\bar{\mathcal{B}}} - 2T'_{4\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{2}}P'_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{3\sqrt{2}}(3P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + 2P'_{2EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}^0 \to \Xi^0\overline{\Sigma^0}) = \frac{1}{\sqrt{2}}T'_{1\mathcal{B}\bar{\mathcal{B}}} + \frac{5}{\sqrt{2}}P'_{1\mathcal{B}\bar{\mathcal{B}}} - \frac{\sqrt{2}}{3}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} - P'_{3EW\mathcal{B}\bar{\mathcal{B}}} + P'_{4EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}^0 \to \Xi^0\bar{\Lambda}) = -\frac{1}{\sqrt{6}}(T'_{1\mathcal{B}\bar{\mathcal{B}}} + 2T'_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{6}}(5P'_{1\mathcal{B}\bar{\mathcal{B}}} - 2P'_{2\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{3}\sqrt{\frac{2}{3}}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + 2P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 5P'_{4EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}^0 \to \Xi^-\overline{\Sigma^-}) = -5P'_{1\mathcal{B}\bar{\mathcal{B}}} - \frac{1}{3}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} - 4P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P'_{4EW\mathcal{B}\bar{\mathcal{B}}}),$$

$$A(\bar{B}^0 \to \Lambda\bar{n}) = \frac{1}{\sqrt{6}}(T'_{1\mathcal{B}\bar{\mathcal{B}}} + T'_{2\mathcal{B}\bar{\mathcal{B}}} + 2T'_{3\mathcal{B}\bar{\mathcal{B}}} + 2T'_{4\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{\sqrt{6}}(10P'_{1\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathcal{B}\bar{\mathcal{B}}})$$
$$- \frac{1}{3\sqrt{6}}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + 2P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - 4P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 8P'_{4EW\mathcal{B}\bar{\mathcal{B}}}), \tag{A5}$$

and

$$
\begin{aligned}
A(\bar{B}_s^0 \to p\bar{p}) &= -5E'_{1\mathcal{B}\bar{\mathcal{B}}} + E'_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}_s^0 \to n\bar{n}) &= E'_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}_s^0 \to \Sigma^+\overline{\Sigma^+}) &= -T'_{2\mathcal{B}\bar{\mathcal{B}}} + 2T'_{4\mathcal{B}\bar{\mathcal{B}}} + P'_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{2}{3}P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - 5E'_{1\mathcal{B}\bar{\mathcal{B}}} + E'_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}_s^0 \to \Sigma^0\overline{\Sigma^0}) &= -\frac{1}{2}(T'_{2\mathcal{B}\bar{\mathcal{B}}} - 2T'_{4\mathcal{B}\bar{\mathcal{B}}}) + P'_{2\mathcal{B}\bar{\mathcal{B}}} + \frac{1}{6}P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - \frac{1}{2}(5E'_{1\mathcal{B}\bar{\mathcal{B}}} - E'_{2\mathcal{B}\bar{\mathcal{B}}}) - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}_s^0 \to \Sigma^0\bar{\Lambda}) &= \frac{1}{2\sqrt{3}}(2T'_{1\mathcal{B}\bar{\mathcal{B}}} + T'_{2\mathcal{B}\bar{\mathcal{B}}} - 4T'_{3\mathcal{B}\bar{\mathcal{B}}} - 2T'_{4\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{2\sqrt{3}}(2P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + P'_{2EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{2\sqrt{3}}(5E'_{1\mathcal{B}\bar{\mathcal{B}}} + E'_{2\mathcal{B}\bar{\mathcal{B}}}),\\
A(\bar{B}_s^0 \to \Sigma^-\overline{\Sigma^-}) &= P'_{2\mathcal{B}\bar{\mathcal{B}}} - \frac{1}{3}P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}_s^0 \to \Xi^0\overline{\Xi^0}) &= -T'_{1\mathcal{B}\bar{\mathcal{B}}} - T'_{2\mathcal{B}\bar{\mathcal{B}}} - (5P'_{1\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathcal{B}\bar{\mathcal{B}}}) + \frac{2}{3}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) + E'_{2\mathcal{B}\bar{\mathcal{B}}} - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}_s^0 \to \Xi^-\overline{\Xi^-}) &= -(5P'_{1\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3}(P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - 4P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 2P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) - 9PA'_{\mathcal{B}\bar{\mathcal{B}}},\\
A(\bar{B}_s^0 \to \Lambda\overline{\Sigma^0}) &= \frac{1}{2\sqrt{3}}(T'_{2\mathcal{B}\bar{\mathcal{B}}} + 2T'_{4\mathcal{B}\bar{\mathcal{B}}}) + \frac{1}{2\sqrt{3}}(-P'_{2EW\mathcal{B}\bar{\mathcal{B}}} + 4P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{2\sqrt{3}}(5E'_{1\mathcal{B}\bar{\mathcal{B}}} + E'_{2\mathcal{B}\bar{\mathcal{B}}}),\\
A(\bar{B}_s^0 \to \Lambda\bar{\Lambda}) &= -\frac{1}{6}(2T'_{1\mathcal{B}\bar{\mathcal{B}}} + T'_{2\mathcal{B}\bar{\mathcal{B}}} + 4T'_{3\mathcal{B}\bar{\mathcal{B}}} + 2T'_{4\mathcal{B}\bar{\mathcal{B}}}) - \frac{1}{3}(10P'_{1\mathcal{B}\bar{\mathcal{B}}} - P'_{2\mathcal{B}\bar{\mathcal{B}}})\\
&\quad + \frac{1}{18}(2P'_{1EW\mathcal{B}\bar{\mathcal{B}}} + P'_{2EW\mathcal{B}\bar{\mathcal{B}}} - 8P'_{3EW\mathcal{B}\bar{\mathcal{B}}} - 4P'_{4EW\mathcal{B}\bar{\mathcal{B}}}) - \frac{5}{6}(E'_{1\mathcal{B}\bar{\mathcal{B}}} - E'_{2\mathcal{B}\bar{\mathcal{B}}}) - 9PA'_{\mathcal{B}\bar{\mathcal{B}}}. \qquad \text{(A6)}
\end{aligned}
$$

2. $\bar{B}$ to octet-anti-decuplet baryonic decays

The full $\bar{B} \to \mathcal{B}\overline{\mathcal{D}}$ decay amplitudes for $\Delta S = 0$ processes are given by

$$
\begin{aligned}
A(B^- \to p\overline{\Delta^{++}}) &= -\sqrt{6}(T_{1\mathcal{B}\overline{\mathcal{D}}} - 2T_{2\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{6}P_{\mathcal{B}\overline{\mathcal{D}}} + 2\sqrt{\frac{2}{3}}P_{1EW\mathcal{B}\overline{\mathcal{D}}} + \sqrt{6}A_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to n\overline{\Delta^{+}}) &= -\sqrt{2}T_{1\mathcal{B}\overline{\mathcal{D}}} + \sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{2\sqrt{2}}{3}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 3P_{2EW\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{2}A_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Sigma^0\overline{\Sigma^{*+}}) &= -2T_{2\mathcal{B}\overline{\mathcal{D}}} - P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{1}{3}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 6P_{2EW\mathcal{B}\overline{\mathcal{D}}}) - A_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Sigma^-\overline{\Sigma^{*0}}) &= -P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{1}{3}P_{1EW\mathcal{B}\overline{\mathcal{D}}} - A_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Xi^-\overline{\Xi^{*0}}) &= -\sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{\sqrt{2}}{3}P_{1EW\mathcal{B}\overline{\mathcal{D}}} - \sqrt{2}A_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Lambda\overline{\Sigma^{*+}}) &= \frac{2}{\sqrt{3}}(T_{1\mathcal{B}\overline{\mathcal{D}}} - T_{2\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{3}P_{\mathcal{B}\overline{\mathcal{D}}} - \frac{1}{\sqrt{3}}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 2P_{2EW\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{3}A_{\mathcal{B}\overline{\mathcal{D}}}, \qquad \text{(A7)}
\end{aligned}
$$

$$
\begin{aligned}
A(\bar{B}^0 \to p\overline{\Delta^+}) &= -\sqrt{2}(T_{1\mathcal{B}\overline{\mathcal{D}}} - 2T_{2\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{2\sqrt{2}}{3}P_{1EW\mathcal{B}\overline{\mathcal{D}}} - \sqrt{2}E_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to n\overline{\Delta^0}) &= -\sqrt{2}T_{1\mathcal{B}\overline{\mathcal{D}}} + \sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{2\sqrt{2}}{3}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 3P_{2EW\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{2}E_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^+\overline{\Sigma^{*+}}) &= \sqrt{2}E_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^0\overline{\Sigma^{*0}}) &= -\sqrt{2}T_{2\mathcal{B}\overline{\mathcal{D}}} - \frac{1}{\sqrt{2}}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{1}{3\sqrt{2}}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 6P_{2EW\mathcal{B}\overline{\mathcal{D}}}) - \frac{1}{\sqrt{2}}E_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^-\overline{\Sigma^{*-}}) &= -\sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{\sqrt{2}}{3}P_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Xi^0\overline{\Xi^{*0}}) &= \sqrt{2}E_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Xi^-\overline{\Xi^{*-}}) &= -\sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{\sqrt{2}}{3}P_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Lambda\overline{\Sigma^{*0}}) &= \sqrt{\frac{2}{3}}(T_{1\mathcal{B}\overline{\mathcal{D}}} - T_{2\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{\frac{3}{2}}P_{\mathcal{B}\overline{\mathcal{D}}} - \frac{1}{\sqrt{6}}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 2P_{2EW\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{\frac{3}{2}}E_{\mathcal{B}\overline{\mathcal{D}}},
\end{aligned}
\tag{A8}
$$

and

$$
\begin{aligned}
A(\bar{B}^0_s \to p\overline{\Sigma^{*+}}) &= -\sqrt{2}(T_{1\mathcal{B}\overline{\mathcal{D}}} - 2T_{2\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{2\sqrt{2}}{3}P_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to n\overline{\Sigma^{*0}}) &= -T_{1\mathcal{B}\overline{\mathcal{D}}} + P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{2}{3}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 3P_{2EW\mathcal{B}\overline{\mathcal{D}}}),\\
A(\bar{B}^0_s \to \Sigma^0\overline{\Xi^{*0}}) &= -2T_{2\mathcal{B}\overline{\mathcal{D}}} - P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{1}{3}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 6P_{2EW\mathcal{B}\overline{\mathcal{D}}}),\\
A(\bar{B}^0_s \to \Sigma^-\overline{\Xi^{*-}}) &= -\sqrt{2}P_{\mathcal{B}\overline{\mathcal{D}}} + \frac{\sqrt{2}}{3}P_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Xi^-\overline{\Omega^-}) &= -\sqrt{6}P_{\mathcal{B}\overline{\mathcal{D}}} + \sqrt{\frac{2}{3}}P_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Lambda\overline{\Xi^{*0}}) &= \frac{2}{\sqrt{3}}(T_{1\mathcal{B}\overline{\mathcal{D}}} - T_{2\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{3}P_{\mathcal{B}\overline{\mathcal{D}}} - \frac{1}{\sqrt{3}}(P_{1EW\mathcal{B}\overline{\mathcal{D}}} - 2P_{2EW\mathcal{B}\overline{\mathcal{D}}}),
\end{aligned}
\tag{A9}
$$

while those for $\Delta S = 1$ transitions are given by

$$
\begin{aligned}
A(B^- \to \Sigma^+\overline{\Delta^{++}}) &= \sqrt{6}(T'_{1\mathcal{B}\overline{\mathcal{D}}} - 2T'_{2\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{6}P'_{\mathcal{B}\overline{\mathcal{D}}} - 2\sqrt{\frac{2}{3}}P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - \sqrt{6}A'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Sigma^0\overline{\Delta^+}) &= -T'_{1\mathcal{B}\overline{\mathcal{D}}} + 2T'_{2\mathcal{B}\overline{\mathcal{D}}} + 2P'_{\mathcal{B}\overline{\mathcal{D}}} + \frac{1}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}} + 2A'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Sigma^-\overline{\Delta^0}) &= \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{\sqrt{2}}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}} + \sqrt{2}A'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Xi^0\overline{\Sigma^{*+}}) &= \sqrt{2}T'_{1\mathcal{B}\overline{\mathcal{D}}} - \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{2\sqrt{2}}{3}(P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - 3P'_{2EW\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{2}A'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Xi^-\overline{\Sigma^{*0}}) &= P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{1}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}} + A'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(B^- \to \Lambda\overline{\Delta^+}) &= \frac{1}{\sqrt{3}}(T'_{1\mathcal{B}\overline{\mathcal{D}}} + 2T'_{2\mathcal{B}\overline{\mathcal{D}}}) - \frac{1}{\sqrt{3}}(P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - 4P'_{2EW\mathcal{B}\overline{\mathcal{D}}}),
\end{aligned}
\tag{A10}
$$

$$
\begin{aligned}
A(\bar{B}^0 \to \Sigma^+\overline{\Delta^+}) &= \sqrt{2}(T'_{1\mathcal{B}\overline{\mathcal{D}}} - 2T'_{2\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{2\sqrt{2}}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^0\overline{\Delta^0}) &= -T'_{1\mathcal{B}\overline{\mathcal{D}}} + 2T'_{2\mathcal{B}\overline{\mathcal{D}}} + 2P'_{\mathcal{B}\overline{\mathcal{D}}} + \frac{1}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^-\overline{\Delta^-}) &= \sqrt{6}P'_{\mathcal{B}\overline{\mathcal{D}}} - \sqrt{\frac{2}{3}}P'_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Xi^0\overline{\Sigma^{*0}}) &= T'_{1\mathcal{B}\overline{\mathcal{D}}} - P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{2}{3}(P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - 3P'_{2EW\mathcal{B}\overline{\mathcal{D}}}),\\
A(\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}) &= \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{\sqrt{2}}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0 \to \Lambda\overline{\Delta^0}) &= \frac{1}{\sqrt{3}}(T'_{1\mathcal{B}\overline{\mathcal{D}}} + 2T'_{2\mathcal{B}\overline{\mathcal{D}}}) - \frac{1}{\sqrt{3}}(P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - 4P'_{2EW\mathcal{B}\overline{\mathcal{D}}}),
\end{aligned} \tag{A11}
$$

and

$$
\begin{aligned}
A(\bar{B}^0_s \to p\overline{\Delta^+}) &= -\sqrt{2}E'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to n\overline{\Delta^0}) &= -\sqrt{2}E'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^+\overline{\Sigma^{*+}}) &= \sqrt{2}(T'_{1\mathcal{B}\overline{\mathcal{D}}} - 2T'_{2\mathcal{B}\overline{\mathcal{D}}}) - \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{2\sqrt{2}}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}} + \sqrt{2}E'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^0\overline{\Sigma^{*0}}) &= -\frac{1}{\sqrt{2}}(T'_{1\mathcal{B}\overline{\mathcal{D}}} - 2T'_{2\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} + \frac{1}{3\sqrt{2}}P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - \frac{1}{\sqrt{2}}E'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^-\overline{\Sigma^{*-}}) &= \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{\sqrt{2}}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Xi^0\overline{\Xi^{*0}}) &= \sqrt{2}T'_{1\mathcal{B}\overline{\mathcal{D}}} - \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{2\sqrt{2}}{3}(P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - 3P'_{2EW\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{2}E'_{\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Xi^-\overline{\Xi^{*-}}) &= \sqrt{2}P'_{\mathcal{B}\overline{\mathcal{D}}} - \frac{\sqrt{2}}{3}P'_{1EW\mathcal{B}\overline{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Lambda\overline{\Sigma^{*0}}) &= \frac{1}{\sqrt{6}}(T'_{1\mathcal{B}\overline{\mathcal{D}}} + 2T'_{2\mathcal{B}\overline{\mathcal{D}}}) - \frac{1}{\sqrt{6}}(P'_{1EW\mathcal{B}\overline{\mathcal{D}}} - 4P'_{2EW\mathcal{B}\overline{\mathcal{D}}}) + \sqrt{\frac{3}{2}}E'_{\mathcal{B}\overline{\mathcal{D}}}.
\end{aligned} \tag{A12}
$$

3. $\bar{B}$ to decuplet-anti-octet baryonic decays

The full $\bar{B} \to \mathcal{D}\bar{\mathcal{B}}$ decay amplitudes for $\Delta S = 0$ processes are given by

$$
\begin{aligned}
A(B^- \to \Delta^0\bar{p}) &= \sqrt{2}T_{1\mathcal{D}\bar{\mathcal{B}}} - \sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}} + \frac{\sqrt{2}}{3}(3P_{1EW\mathcal{D}\bar{\mathcal{B}}} + P_{2EW\mathcal{D}\bar{\mathcal{B}}}) - \sqrt{2}A_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^- \to \Delta^-\bar{n}) &= -\sqrt{6}P_{\mathcal{D}\bar{\mathcal{B}}} + \sqrt{\frac{2}{3}}P_{2EW\mathcal{D}\bar{\mathcal{B}}} - \sqrt{6}A_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^- \to \Sigma^{*0}\overline{\Sigma^+}) &= -T_{1\mathcal{D}\bar{\mathcal{B}}} + P_{\mathcal{D}\bar{\mathcal{B}}} - \frac{1}{3}(3P_{1EW\mathcal{D}\bar{\mathcal{B}}} + P_{2EW\mathcal{D}\bar{\mathcal{B}}}) + A_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^- \to \Sigma^{*-}\overline{\Sigma^0}) &= -P_{\mathcal{D}\bar{\mathcal{B}}} + \frac{1}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}} - A_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^- \to \Xi^{*-}\overline{\Xi^0}) &= \sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}} - \frac{\sqrt{2}}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}} + \sqrt{2}A_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^- \to \Sigma^{*-}\bar{\Lambda}) &= \sqrt{3}P_{\mathcal{D}\bar{\mathcal{B}}} - \frac{1}{\sqrt{3}}P_{2EW\mathcal{D}\bar{\mathcal{B}}} + \sqrt{3}A_{\mathcal{D}\bar{\mathcal{B}}},
\end{aligned} \tag{A13}
$$

$$
\begin{aligned}
A(\bar{B}^0\to\Delta^+\bar{p}) &= \sqrt{2}T_{2\mathcal{D}\bar{\mathcal{B}}}+\sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}}+\frac{2\sqrt{2}}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}}-\sqrt{2}E_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0\to\Delta^0\bar{n}) &= \sqrt{2}(T_{1\mathcal{D}\bar{\mathcal{B}}}+T_{2\mathcal{D}\bar{\mathcal{B}}})+\sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}}+\frac{\sqrt{2}}{3}(3P_{1EW\mathcal{D}\bar{\mathcal{B}}}+2P_{2EW\mathcal{D}\bar{\mathcal{B}}})-\sqrt{2}E_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0\to\Sigma^{*+}\overline{\Sigma^+}) &= \sqrt{2}E_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0\to\Sigma^{*0}\overline{\Sigma^0}) &= \frac{1}{\sqrt{2}}T_{1\mathcal{D}\bar{\mathcal{B}}}-\frac{1}{\sqrt{2}}P_{\mathcal{D}\bar{\mathcal{B}}}+\frac{1}{3\sqrt{2}}(3P_{1EW\mathcal{D}\bar{\mathcal{B}}}+P_{2EW\mathcal{D}\bar{\mathcal{B}}})-\frac{1}{\sqrt{2}}E_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0\to\Sigma^{*-}\overline{\Sigma^-}) &= -\sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}}+\frac{\sqrt{2}}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0\to\Xi^{*0}\overline{\Xi^0}) &= \sqrt{2}E_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0\to\Xi^{*-}\overline{\Xi^-}) &= -\sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}}+\frac{\sqrt{2}}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0\to\Sigma^{*0}\bar{\Lambda}) &= -\frac{1}{\sqrt{6}}(T_{1\mathcal{D}\bar{\mathcal{B}}}+2T_{2\mathcal{D}\bar{\mathcal{B}}})-\sqrt{\frac{3}{2}}P_{\mathcal{D}\bar{\mathcal{B}}}-\frac{1}{\sqrt{6}}(P_{1EW\mathcal{D}\bar{\mathcal{B}}}+P_{2EW\mathcal{D}\bar{\mathcal{B}}})+\sqrt{\frac{3}{2}}E_{\mathcal{D}\bar{\mathcal{B}}},
\end{aligned}
\tag{A14}
$$

and

$$
\begin{aligned}
A(\bar{B}^0_s\to\Delta^+\overline{\Sigma^+}) &= -\sqrt{2}T_{2\mathcal{D}\bar{\mathcal{B}}}-\sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}}-\frac{2\sqrt{2}}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s\to\Delta^0\overline{\Sigma^0}) &= T_{2\mathcal{D}\bar{\mathcal{B}}}+2P_{\mathcal{D}\bar{\mathcal{B}}}+\frac{1}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s\to\Delta^-\overline{\Sigma^-}) &= \sqrt{6}P_{\mathcal{D}\bar{\mathcal{B}}}-\sqrt{\frac{2}{3}}P_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s\to\Sigma^{*0}\overline{\Xi^0}) &= -(T_{1\mathcal{D}\bar{\mathcal{B}}}+T_{2\mathcal{D}\bar{\mathcal{B}}})-P_{\mathcal{D}\bar{\mathcal{B}}}-\frac{1}{3}(3P_{1EW\mathcal{D}\bar{\mathcal{B}}}+2P_{2EW\mathcal{D}\bar{\mathcal{B}}}),\\
A(\bar{B}^0_s\to\Sigma^{*-}\overline{\Xi^-}) &= \sqrt{2}P_{\mathcal{D}\bar{\mathcal{B}}}-\frac{\sqrt{2}}{3}P_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s\to\Delta^0\bar{\Lambda}) &= -\frac{1}{\sqrt{3}}(2T_{1\mathcal{D}\bar{\mathcal{B}}}+T_{2\mathcal{D}\bar{\mathcal{B}}})-\frac{1}{\sqrt{3}}(2P_{1EW\mathcal{D}\bar{\mathcal{B}}}+P_{2EW\mathcal{D}\bar{\mathcal{B}}}),
\end{aligned}
\tag{A15}
$$

while those for $\Delta S=1$ transitions are given by

$$
\begin{aligned}
A(B^-\to\Sigma^{*0}\bar{p}) &= T'_{1\mathcal{D}\bar{\mathcal{B}}}-P'_{\mathcal{D}\bar{\mathcal{B}}}+\frac{1}{3}(3P'_{1EW\mathcal{D}\bar{\mathcal{B}}}+P'_{2EW\mathcal{D}\bar{\mathcal{B}}})-A'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^-\to\Sigma^{*-}\bar{n}) &= -\sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}}+\frac{\sqrt{2}}{3}P'_{2EW\mathcal{D}\bar{\mathcal{B}}}-\sqrt{2}A'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^-\to\Xi^{*0}\overline{\Sigma^+}) &= -\sqrt{2}T'_{1\mathcal{D}\bar{\mathcal{B}}}+\sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}}-\frac{\sqrt{2}}{3}(3P'_{1EW\mathcal{D}\bar{\mathcal{B}}}+P'_{2EW\mathcal{D}\bar{\mathcal{B}}})+\sqrt{2}A'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^-\to\Xi^{*-}\overline{\Sigma^0}) &= -P'_{\mathcal{D}\bar{\mathcal{B}}}+\frac{1}{3}P'_{2EW\mathcal{D}\bar{\mathcal{B}}}-A'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^-\to\Omega^-\overline{\Xi^0}) &= \sqrt{6}P'_{\mathcal{D}\bar{\mathcal{B}}}-\sqrt{\frac{2}{3}}P'_{2EW\mathcal{D}\bar{\mathcal{B}}}+\sqrt{6}A'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(B^-\to\Xi^{*-}\bar{\Lambda}) &= \sqrt{3}P'_{\mathcal{D}\bar{\mathcal{B}}}-\frac{1}{\sqrt{3}}P'_{2EW\mathcal{D}\bar{\mathcal{B}}}+\sqrt{3}A'_{\mathcal{D}\bar{\mathcal{B}}},
\end{aligned}
\tag{A16}
$$

$$
\begin{aligned}
A(\bar{B}^0 \to \Sigma^{*+}\bar{p}) &= \sqrt{2}T'_{2\mathcal{D}\bar{\mathcal{B}}} + \sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} + \frac{2\sqrt{2}}{3}P'_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Sigma^{*0}\bar{n}) &= T'_{1\mathcal{D}\bar{\mathcal{B}}} + T'_{2\mathcal{D}\bar{\mathcal{B}}} + P'_{\mathcal{D}\bar{\mathcal{B}}} + \frac{1}{3}(3P'_{1EW\mathcal{D}\bar{\mathcal{B}}} + 2P'_{2EW\mathcal{D}\bar{\mathcal{B}}}),\\
A(\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^0}) &= T'_{1\mathcal{D}\bar{\mathcal{B}}} - P'_{\mathcal{D}\bar{\mathcal{B}}} + \frac{1}{3}(3P'_{1EW\mathcal{D}\bar{\mathcal{B}}} + P'_{2EW\mathcal{D}\bar{\mathcal{B}}}),\\
A(\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^-}) &= -\sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} + \frac{\sqrt{2}}{3}P'_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Omega^{-}\overline{\Xi^-}) &= -\sqrt{6}P'_{\mathcal{D}\bar{\mathcal{B}}} + \sqrt{\frac{2}{3}}P_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0 \to \Xi^{*0}\bar{\Lambda}) &= -\frac{1}{\sqrt{3}}(T'_{1\mathcal{D}\bar{\mathcal{B}}} + 2T'_{2\mathcal{D}\bar{\mathcal{B}}}) - \sqrt{3}P'_{\mathcal{D}\bar{\mathcal{B}}} - \frac{1}{\sqrt{3}}(P'_{1EW\mathcal{D}\bar{\mathcal{B}}} + P'_{2EW\mathcal{D}\bar{\mathcal{B}}}),
\end{aligned} \tag{A17}
$$

and

$$
\begin{aligned}
A(\bar{B}^0_s \to \Delta^{+}\bar{p}) &= -\sqrt{2}E'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s \to \Delta^{0}\bar{n}) &= -\sqrt{2}E'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^+}) &= -\sqrt{2}T'_{2\mathcal{D}\bar{\mathcal{B}}} - \sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} - \frac{2\sqrt{2}}{3}P'_{2EW\mathcal{D}\bar{\mathcal{B}}} + \sqrt{2}E'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^0}) &= \frac{1}{\sqrt{2}}T'_{2\mathcal{D}\bar{\mathcal{B}}} + \sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} + \frac{1}{3\sqrt{2}}P'_{2EW\mathcal{D}\bar{\mathcal{B}}} - \frac{1}{\sqrt{2}}E'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^-}) &= \sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} - \frac{\sqrt{2}}{3}P'_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^0}) &= -\sqrt{2}(T'_{1\mathcal{D}\bar{\mathcal{B}}} + T'_{2\mathcal{D}\bar{\mathcal{B}}}) - \sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} - \frac{\sqrt{2}}{3}(3P'_{1EW\mathcal{D}\bar{\mathcal{B}}} + 2P'_{2EW\mathcal{D}\bar{\mathcal{B}}}) + \sqrt{2}E'_{\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^-}) &= \sqrt{2}P'_{\mathcal{D}\bar{\mathcal{B}}} - \frac{\sqrt{2}}{3}P'_{2EW\mathcal{D}\bar{\mathcal{B}}},\\
A(\bar{B}^0_s \to \Sigma^{*0}\bar{\Lambda}) &= -\frac{1}{\sqrt{6}}(2T'_{1\mathcal{D}\bar{\mathcal{B}}} + T'_{2\mathcal{D}\bar{\mathcal{B}}}) - \frac{1}{\sqrt{6}}(2P'_{1EW\mathcal{D}\bar{\mathcal{B}}} + P'_{2EW\mathcal{D}\bar{\mathcal{B}}}) + \sqrt{\frac{3}{2}}E'_{\mathcal{D}\bar{\mathcal{B}}}.
\end{aligned} \tag{A18}
$$

4. $\bar{B}$ to decuplet-anti-decuplet baryonic decays

The full $\bar{B} \to \mathcal{D}\bar{\mathcal{D}}$ decay amplitudes for $\Delta S = 0$ processes are given by

$$
\begin{aligned}
A(B^- \to \Delta^{+}\overline{\Delta^{++}}) &= 2\sqrt{3}T_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{4}{\sqrt{3}}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}A_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Delta^{0}\overline{\Delta^{+}}) &= 2T_{\mathcal{D}\bar{\mathcal{D}}} + 4P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{2}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 4A_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Delta^{-}\overline{\Delta^{0}}) &= 2\sqrt{3}P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{\sqrt{3}}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}A_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Sigma^{*0}\overline{\Sigma^{*+}}) &= \sqrt{2}T_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{\sqrt{2}}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}A_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Sigma^{*-}\overline{\Sigma^{*0}}) &= 2\sqrt{2}P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2\sqrt{2}}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}A_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Xi^{*-}\overline{\Xi^{*0}}) &= 2P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 2A_{\mathcal{D}\bar{\mathcal{D}}},
\end{aligned} \tag{A19}
$$

$$
\begin{aligned}
A(\bar{B}^0 \to \Delta^{++}\overline{\Delta^{++}}) &= 6E_{\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Delta^{+}\overline{\Delta^{+}}) &= 2T_{\mathcal{D}\bar{\mathcal{D}}} + 2P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{4}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 4E_{\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Delta^{0}\overline{\Delta^{0}}) &= 2T_{\mathcal{D}\bar{\mathcal{D}}} + 4P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{2}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 2E_{\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Delta^{-}\overline{\Delta^{-}}) &= 6P_{\mathcal{D}\bar{\mathcal{D}}} - 2P_{EW\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^{*+}\overline{\Sigma^{*+}}) &= 4E_{\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^{*0}\overline{\Sigma^{*0}}) &= T_{\mathcal{D}\bar{\mathcal{D}}} + 2P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{1}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 2E_{\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}) &= 4P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{4}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Xi^{*0}\overline{\Xi^{*0}}) &= \frac{1}{3}E_{\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Xi^{*-}\overline{\Xi^{*-}}) &= 2P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}} + 18PA_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Omega^{-}\overline{\Omega^{-}}) &= 18PA_{\mathcal{D}\bar{\mathcal{D}}},
\end{aligned}
\tag{A20}
$$

and

$$
\begin{aligned}
A(\bar{B}^0_s \to \Delta^{+}\overline{\Sigma^{*+}}) &= 2T_{\mathcal{D}\bar{\mathcal{D}}} + 2P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{4}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Delta^{0}\overline{\Sigma^{*0}}) &= \sqrt{2}T_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{\sqrt{2}}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Delta^{-}\overline{\Sigma^{*-}}) &= 2\sqrt{3}P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{\sqrt{3}}P_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^{*0}\overline{\Xi^{*0}}) &= \sqrt{2}T_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}P_{\mathcal{D}\bar{\mathcal{D}}} + \frac{\sqrt{2}}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^{*-}\overline{\Xi^{*-}}) &= 4P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{4}{3}P_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Xi^{*-}\overline{\Omega^{-}}) &= 2\sqrt{3}P_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{\sqrt{3}}P_{EW\mathcal{D}\bar{\mathcal{D}}},
\end{aligned}
\tag{A21}
$$

while those for $\Delta S = 1$ transitions are given by

$$
\begin{aligned}
A(B^- \to \Sigma^{*+}\overline{\Delta^{++}}) &= 2\sqrt{3}T'_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{4}{\sqrt{3}}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}A'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Sigma^{*0}\overline{\Delta^{+}}) &= \sqrt{2}T'_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{\sqrt{2}}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}A'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Sigma^{*-}\overline{\Delta^{0}}) &= 2P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 2A'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Xi^{*0}\overline{\Sigma^{*+}}) &= 2T'_{\mathcal{D}\bar{\mathcal{D}}} + 4P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{2}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 4A'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Xi^{*-}\overline{\Sigma^{*0}}) &= 2\sqrt{2}P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2\sqrt{2}}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}A'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(B^- \to \Omega^{-}\overline{\Xi^{*0}}) &= 2\sqrt{3}P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{\sqrt{3}}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{3}A'_{\mathcal{D}\bar{\mathcal{D}}},
\end{aligned}
\tag{A22}
$$

$$
\begin{aligned}
A(\bar{B}^0 \to \Sigma^{*+}\overline{\Delta^{+}}) &= 2T'_{\mathcal{D}\bar{\mathcal{D}}} + 2P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{4}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^{*0}\overline{\Delta^{0}}) &= \sqrt{2}T'_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{\sqrt{2}}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Sigma^{*-}\overline{\Delta^{-}}) &= 2\sqrt{3}P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{\sqrt{3}}P'_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Xi^{*0}\overline{\Sigma^{*0}}) &= \sqrt{2}T'_{\mathcal{D}\bar{\mathcal{D}}} + 2\sqrt{2}P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{\sqrt{2}}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Xi^{*-}\overline{\Sigma^{*-}}) &= 4P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{4}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0 \to \Omega^{-}\overline{\Xi^{*-}}) &= 2\sqrt{3}P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{\sqrt{3}}P'_{EW\mathcal{D}\bar{\mathcal{D}}},
\end{aligned}
\tag{A23}
$$

and

$$
\begin{aligned}
A(\bar{B}^0_s \to \Delta^{++}\overline{\Delta^{++}}) &= 6E'_{\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Delta^{+}\overline{\Delta^{+}}) &= 4E'_{\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Delta^{0}\overline{\Delta^{0}}) &= 2E'_{\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Delta^{-}\overline{\Delta^{-}}) &= 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}) &= 2T'_{\mathcal{D}\bar{\mathcal{D}}} + 2P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{4}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 4E'_{\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^{*0}\overline{\Sigma^{*0}}) &= T'_{\mathcal{D}\bar{\mathcal{D}}} + 2P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{1}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 2E'_{\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}) &= 2P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{2}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}) &= 2T'_{\mathcal{D}\bar{\mathcal{D}}} + 4P'_{\mathcal{D}\bar{\mathcal{D}}} + \frac{2}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 2E'_{\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Xi^{*-}\overline{\Xi^{*-}}) &= 4P'_{\mathcal{D}\bar{\mathcal{D}}} - \frac{4}{3}P'_{EW\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}},\\
A(\bar{B}^0_s \to \Omega^{-}\overline{\Omega^{-}}) &= 6P_{\mathcal{D}\bar{\mathcal{D}}} - 2P_{EW\mathcal{D}\bar{\mathcal{D}}} + 18PA'_{\mathcal{D}\bar{\mathcal{D}}}.
\end{aligned}
\tag{A24}
$$

APPENDIX B: FORMULAS FOR DECAY AMPLITUDES AND RATES

In general the decay amplitudes of $\bar{B}$ to final states with octet baryon ($\mathcal{B}$) and decuplet baryons ($\mathcal{D}$) can be expressed as [7]

$$
\begin{aligned}
A(\bar{B} \to \mathcal{B}_1\bar{\mathcal{B}}_2) &= \bar{u}_1(A_{\mathcal{B}\bar{\mathcal{B}}} + \gamma_5 B_{\mathcal{B}\bar{\mathcal{B}}})v_2,\\
A(\bar{B} \to \mathcal{D}_1\bar{\mathcal{B}}_2) &= i\frac{q^\mu}{m_B}\bar{u}^\mu_1(A_{\mathcal{D}\bar{\mathcal{B}}} + \gamma_5 B_{\mathcal{D}\bar{\mathcal{B}}})v_2,\\
A(\bar{B} \to \mathcal{B}_1\bar{\mathcal{D}}_2) &= i\frac{q^\mu}{m_B}\bar{u}_1(A_{\mathcal{B}\overline{\mathcal{D}}} + \gamma_5 B_{\mathcal{B}\overline{\mathcal{D}}})v^\mu_2,\\
A(\bar{B} \to \mathcal{D}_1\bar{\mathcal{D}}_2) &= \bar{u}^\mu_1(A_{\mathcal{D}\bar{\mathcal{D}}} + \gamma_5 B_{\mathcal{D}\bar{\mathcal{D}}})v_{2\mu} + \frac{q^\mu q^\nu}{m_B^2}\bar{u}^\mu_1(C_{\mathcal{D}\bar{\mathcal{D}}} + \gamma_5 D_{\mathcal{D}\bar{\mathcal{D}}})v_{2\nu},
\end{aligned}
\tag{B1}
$$

where $q = p_1 - p_2$ and u^μ, v^μ are the Rarita-Schwinger vector spinors for a spin-$\frac{3}{2}$ particle, where [39]

$$u_\mu\left(\pm\frac{3}{2}\right)=\epsilon_\mu(\pm1)u\left(\pm\frac{1}{2}\right)u_\mu\left(\pm\frac{1}{2}\right)$$
$$=\left(\epsilon_\mu(\pm1)u\left(\mp\frac{1}{2}\right)+\sqrt{2}\epsilon_\mu(0)u\left(\pm\frac{1}{2}\right)\right)\Big/\sqrt{3}, \tag{B2}$$

with $\epsilon_\mu(\lambda)$ the usual polarization vector and $u(s)$ the spinor. Note that

$$q\cdot\epsilon(\lambda)_{1,2}=\mp\,\delta_{\lambda,0}m_Bp_c/m_{1,2}, \tag{B3}$$

where p_c is the baryon momentum in the B rest frame and $\epsilon_1^*(0)\cdot\epsilon_2(0)=(m_B^2-m_1^2-m_2^2)/2m_1m_2$ is the largest product among $\epsilon_1^*(\lambda_1)\cdot\epsilon_2(\lambda_2)$. We can now express the amplitudes in Eq. (B1) as

$$A(\bar B\to\mathcal{D}_1\bar{\mathcal{B}}_2)=-i\sqrt{\frac{2}{3}}\frac{p_{cm}}{m_1}\bar u_1(A_{\mathcal{D}\bar{\mathcal{B}}}+\gamma_5B_{\mathcal{D}\bar{\mathcal{B}}})v_2,$$
$$A(\bar B\to\mathcal{B}_1\bar{\mathcal{D}}_2)=i\sqrt{\frac{2}{3}}\frac{p_{cm}}{m_2}\bar u_1(A_{\mathcal{B}\overline{\mathcal{D}}}+\gamma_5B_{\mathcal{B}\overline{\mathcal{D}}})v_2,$$
$$A(\bar B\to\mathcal{D}_1\bar{\mathcal{D}}_2)\simeq\frac{m_B^2}{3m_1m_2}\bar u_1(A'_{\mathcal{D}\bar{\mathcal{D}}}+\gamma_5B'_{\mathcal{D}\bar{\mathcal{D}}})v_2, \tag{B4}$$

where $A'_{\mathcal{D}\bar{\mathcal{D}}}=A_{\mathcal{D}\bar{\mathcal{D}}}-2(p_{cm}/m_B)^2C_{\mathcal{D}\bar{\mathcal{D}}}$ and $B'_{\mathcal{D}\bar{\mathcal{D}}}=B_{\mathcal{D}\bar{\mathcal{D}}}-2(p_{cm}/m_B)^2D_{\mathcal{D}\bar{\mathcal{D}}}$ and decuplets are only or dominantly in the $\pm\frac{1}{2}$-helicity states. All four $\bar B\to\mathbf{B}_1\bar{\mathbf{B}}_2$ ($\mathbf{B}\bar{\mathbf{B}}=\mathcal{B}\bar{\mathcal{B}},\mathcal{D}\bar{\mathcal{B}},\mathcal{B}\overline{\mathcal{D}},\mathcal{D}\bar{\mathcal{D}}$) decays can be effectively expressed as

$$A(\bar B\to\mathbf{B}_1\bar{\mathbf{B}}_2)=\bar u_1(\mathbf{A}+\gamma_5\mathbf{B})v_2, \tag{B5}$$

and the rates are given by

$$\Gamma(\bar B\to\mathbf{B}_1\bar{\mathbf{B}}_2)=\frac{p_{cm}}{8\pi m_B^2}[(2m_B^2-2(m_{\mathbf{B}_1}+m_{\mathbf{B}_1})^2)\mathbf{A}^2+(2m_B^2-2(m_{\mathbf{B}_1}-m_{\mathbf{B}_1})^2)\mathbf{B}^2], \tag{B6}$$

where

$$\mathbf{A}_{\mathcal{B}\bar{\mathcal{B}}}=A_{\mathcal{B}\bar{\mathcal{B}}},\qquad \mathbf{A}_{\mathcal{B}\bar{\mathcal{D}}}=i\sqrt{\frac{2}{3}}\frac{p_{cm}}{m_{\bar{\mathcal{D}}}}A_{\mathcal{D}\bar{\mathcal{B}}},$$
$$\mathbf{A}_{\mathcal{D}\bar{\mathcal{B}}}=-i\sqrt{\frac{2}{3}}\frac{p_{cm}}{m_{\mathcal{D}}}A_{\mathcal{B}\bar{\mathcal{D}}},\qquad \mathbf{A}_{\mathcal{D}\bar{\mathcal{D}}}=\frac{m_B^2}{3m_{\mathcal{D}}m_{\bar{\mathcal{D}}}}A'_{\mathcal{D}\bar{\mathcal{D}}}, \tag{B7}$$

and

$$\mathbf{B}_{\mathcal{B}\bar{\mathcal{B}}}=B_{\mathcal{B}\bar{\mathcal{B}}},\qquad \mathbf{B}_{\mathcal{B}\bar{\mathcal{D}}}=i\sqrt{\frac{2}{3}}\frac{p_{cm}}{m_{\bar{\mathcal{D}}}}B_{\mathcal{D}\bar{\mathcal{B}}},$$
$$\mathbf{B}_{\mathcal{D}\bar{\mathcal{B}}}=-i\sqrt{\frac{2}{3}}\frac{p_{cm}}{m_{\mathcal{D}}}B_{\mathcal{B}\bar{\mathcal{D}}},\qquad \mathbf{B}_{\mathcal{D}\bar{\mathcal{D}}}=\frac{m_B^2}{3m_{\mathcal{D}}m_{\bar{\mathcal{D}}}}B'_{\mathcal{D}\bar{\mathcal{D}}}. \tag{B8}$$

Note that in the asymptotic limit, $m_B\gg m_{\mathcal{B}}$, one has $p_{cm}\to m_B/2$.

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