Testing the $W$-exchange mechanism
with two-body baryonic $B$ decays

Y.K. Hsiao$^*$ and Shang-Yuu Tsai$^†$

School of Physics and Information Engineering,
Shanxi Normal University, Linfen 041004, China

Eduardo Rodrigues$^‡$

Department of Physics, University of Cincinnati, Cincinnati, Ohio 45221, USA

Abstract

The role of $W$-exchange diagrams in baryonic $B$ decays is poorly understood, and often taken as insignificant. We show that charmful two-body baryonic $B \rightarrow B_c \bar{B}'$ decays, where $B_c$ is an antitriplet or a sextet charmed baryon, and $\bar{B}'$ an octet charmless (anti-)baryon, provide a good test-bed for the study of the $W$-exchange topology, whose contribution is found to be non-negligible. The calculated branching ratio of the $\bar{B}^0 \rightarrow \Lambda^+_c \bar{p}$ decay, $\mathcal{B}(\bar{B}^0 \rightarrow \Lambda^+_c \bar{p}) = (1.6^{+0.7}_{-0.7}) \times 10^{-5}$, is in good agreement with experimental data. Its cousin $\bar{B}^0_s$ mode, $\bar{B}^0_s \rightarrow \Lambda^+_c \bar{p}$, is a purely $W$-exchange decay, hence is naturally suited for the study of the role of the $W$-exchange topology. We predict $\mathcal{B}(\bar{B}^0_s \rightarrow \Lambda^+_c \bar{p}) = (1.2^{+0.7}_{-0.5}) \times 10^{-6}$, a relatively large branching ratio to be tested with a future measurement by the LHCb collaboration. Other predictions, such as $\mathcal{B}(\bar{B}^0 \rightarrow \Xi^+_c \bar{\Sigma}^-) = (1.8^{+1.0}_{-0.8}) \times 10^{-5}$, can be tested with future Belle II measurements.

$^*$yukuohsiao@gmail.com
$^†$shangyu@gmail.com
$^‡$eduardo.rodrigues@cern.ch
Decays of \( B \) mesons to multi-body baryonic final states, such as \( B \to B\bar{B}'M \) and \( B\bar{B}'MM' \), where \( B \) (\( M \)) represents a baryon (meson), have been richly studied. Their branching ratios are typically at the level of \( 10^{-6} \) \([1]\). These relatively large branching ratios are due to the fact that the baryon-pair production tends to occur in the threshold region of \( m_{B\bar{B}} \simeq m_B + m_{B'} \), where the threshold effect with a sharply raising peak can enhance the branching ratio \([2–5]\). On the other hand, without the recoiled meson(s) to carry away the large energy release, the two-body \( B \to B\bar{B}' \) decays proceed at the \( m_B \) scale, several \( \text{GeV} \) away from the threshold region, resulting in the suppression of their decay rates \([6, 7]\).

So far, only three charmless modes have been seen experimentally: \( \bar{B}_0 \to p\bar{p} \) \((B \simeq O(10^{-8}))\) and \( B^- \to \Lambda^{(*)}\bar{p} \) \((B \simeq O(10^{-7}))\), with \( \Lambda^{*} \equiv \Lambda(1520) \) \([8–10]\).

The tree-level dominated \( B \to B\bar{B}' \) decays can proceed through the \( W \)-exchange, emission and annihilation diagrams, depicted in Figs. 1(a,b,c), respectively. However, the \( W \)-exchange (annihilation) process is regarded as helicity suppressed \([11, 12]\), and hence neglected in theoretical studies \([13–17]\). Moreover, one also neglects the penguin-level gluon-exchange (annihilation) contributions, which leads to \( \mathcal{B}(\bar{B}_s^0 \to p\bar{p}) \simeq 0 \) \([17]\). Consequently, the observation of the \( \bar{B}_s^0 \to p\bar{p} \) decay would provide valuable information on whether contributions from the exchange (annihilation) processes play a significant role. The smallness of the current upper bound on its branching ratio, \( \mathcal{B}(\bar{B}_s^0 \to p\bar{p}) < 1.5 \times 10^{-8} \) \([8]\), indicates an experimentally difficult decay mode to study the role of \( W \)-exchange diagrams.

On the other hand, experimental data show that \( \mathcal{B}(B \to B_c\bar{B}') \simeq (10^2 - 10^3)\mathcal{B}(B \to B\bar{B}') \), where \( B_c \) denotes a charmed baryon \([1]\). The set of measured \( B \to B_c\bar{B}' \) branching ratios is nevertheless scarce \([1, 18, 19]\):

\[
\begin{align*}
\mathcal{B}(B^0 \to \Lambda_c^+\bar{p}) &= (1.55 \pm 0.18) \times 10^{-5}, \\
\mathcal{B}(\bar{B}^0 \to \Sigma_c^+\bar{p}) &< 2.4 \times 10^{-5}, \\
\mathcal{B}(B^- \to \Sigma_0^0\bar{p}) &= (3.0 \pm 0.7) \times 10^{-5}.
\end{align*}
\]

(1)

With significantly larger decay rates, charmful two-body baryonic \( B \) decays offer an interesting and suitable environment in which to study and test the role of the \( W \)-exchange (annihilation) mechanism.

As in the case of the charmless final states considered above, \( B \to B_c\bar{B}' \) decays can
FIG. 1. Feynman diagrams for the $B \rightarrow B_{(c)} B'$ decays, where (a,c) depict the $W$-exchange and annihilation processes, respectively, and (b) depicts the $W$-emission process, with $q = (u,d,s)$ for $B_q \equiv (\bar{B}_0^0, B^-, \bar{B}_s^0)$.

proceed through both the $W$-exchange and $W$-emission diagrams. Again, theoretical studies regard the $W$-exchange diagram as helicity-suppressed, and take the $W$-emission diagram as the dominant contribution [13, 14, 20–22]. With $\mathcal{A}(B \rightarrow \ell \bar{\nu}_\ell) \propto m_\ell \bar{u}(1 + \gamma_5)\nu$, the small $m_\ell$ is responsible for the helicity suppression. On the other hand, the amplitude of Fig. 1(c) for $B \rightarrow B_c \bar{B}'$ can be presented as $\mathcal{A}(B \rightarrow B_c \bar{B}') \propto m_c \langle B_c \bar{B}' | \bar{c}(1 + \gamma_5)q | 0 \rangle$. With $m_c \sim 1.3$ GeV [1], the $W$-exchange (annihilation) process in $B \rightarrow B_c \bar{B}'$ is clearly helicity allowed, indicating that neglecting its contribution may not be a valid assumption to make. For completeness, we note that the theoretical studies in Refs. [23, 26] also considered the exchange and annihilation contributions in $B \rightarrow BB'$ and $D_s^+ \rightarrow p\bar{n}$.

We propose to study the family of charmful two-body baryonic $B \rightarrow B_c \bar{B}'$ decays to improve our knowledge of the role of $W$-exchange diagrams in $B$ decays to baryonic final states. Since modes such as $\bar{B}_0^0 \rightarrow \Xi_c^0 \bar{\Sigma}^-$ and $\bar{B}_s^0 \rightarrow \Lambda_c^0 \bar{p}$ can only proceed via the $W$-exchange diagram, measurements of their branching ratios are direct tests on the exchange mechanism.
II. FORMALISM

We consider the \( W \)-exchange (\( A_{\text{ex}} \)) and \( W \)-emission (\( A_{\text{em}} \)) amplitudes for the charmful two-body baryonic \( \bar{B}^0_{(s)} \to B_c \bar{B}' \) decays, where \( B_c \) denotes the anti-triplet and the sextet charmed baryon states, \((\Xi^{+0}, \Lambda^+_c)\) and \((\Sigma^{++0}, \Xi^{+0}_c, \Omega^{0}_c)\), respectively, and \( \bar{B}' \) an octet charmless (anti-)baryon. The decays with the decuplet charmless (anti-)baryons are excluded from the calculations in this paper due to the lack of the corresponding timelike baryon form factors.

We show in Table I the amplitudes involved in the interesting \( \bar{B}^0_{(s)} \to B_c \bar{B}' \) modes. The decay rate of modes that can only occur through the \( W \)-exchange diagram would be vanishingly small by construction if the importance of these diagrams was to be insignificant:

\[
\mathcal{B}(\bar{B}^0 \to \Xi^+ \Sigma^-, \Sigma^{++} \tilde{\Delta}^-, \Xi^{+} \tilde{\Sigma}^-, \Omega^{0}_c \Xi^{0}) = 0 ,
\]

\[
\mathcal{B}(\bar{B}^0_s \to \Lambda^+_c \bar{p}, \Lambda^+_c \bar{\Delta}^-, \Sigma^{++} \tilde{\Delta}^-, \Sigma^+ \bar{p}, \Sigma^+ \tilde{\Delta}^-, \Sigma^0_\Lambda \bar{n}, \Sigma^{0}_c \tilde{\Delta}^0) = 0 .
\]  
(2)

None of these relations has yet been verified experimentally.

The relevant part of the Hamiltonian for the \( \bar{B}^0_{(s)} \to B_c \bar{B}' \) decays has the following form \[27\]:

\[
\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_{q=d,s} V_{cb} V_{ub}^* \left[ c_1^{\text{eff}} (\bar{q} u)(\bar{c} b) + c_2^{\text{eff}} (\bar{c} u)(\bar{q} b) \right] ,
\]  
(3)

where \( G_F \) is the Fermi constant, \( V_{ij} \) stand for the CKM matrix elements, and \((\bar{q}_1 q_2)_{V-A} \equiv \bar{q}_1 \gamma^\mu (1 - \gamma_5) q_2\). In the factorization approach, the \( W \)-exchange amplitude of \( \bar{B}^0_{(s)} \to B_c \bar{B}' \) is given by \[20\] \[26\]

\[
\mathcal{A}(\bar{B}^0_{(s)} \to B_c \bar{B}') = \frac{G_F}{\sqrt{2}} a_2 V_{cb} V_{ub}^* (\bar{c} u)(\bar{q} b) \mathcal{B}(\bar{B}^0_{(s)} ) ,
\]  
(4)

where \( q = d(s) \) for \( \bar{B}^0_{(s)} \), and \( a_2 = c_2^{\text{eff}} + c_1^{\text{eff}} / N_c \) consists of the effective Wilson coefficients \((c_1^{\text{eff}}, c_2^{\text{eff}}) = (1.168, -0.365)\) and the color number \( N_c \). The matrix elements in Eq. (4) are defined as \[1\] \[21\] (for simplification, \( B \) denotes \( \bar{B}^0_{(s)} \) in the remainder of this section)

\[
\langle 0 | \bar{q} \gamma^\mu (1 - \gamma_5) b | B \rangle = -i f_B q^\mu ,
\]

\[
\langle B, B' | \bar{c} \gamma^\mu (1 - \gamma_5) u | 0 \rangle \simeq \bar{u} [f_1 (q^2) \gamma^\mu - g_1 (q^2) \gamma^\mu \gamma_5] v ,
\]  
(5)

where \( f_B \) is the \( B \) meson decay constant and \( q^\mu = (p_B + p_{B'})^\mu \) the momentum transfer. In Eq. (5), \( f_1 (q^2) \) and \( g_1 (q^2) \) are the timelike baryonic \((0 \to B_c \bar{B}')\) form factors, whose
TABLE I. Classification for $B \rightarrow \bar{B}c$ decays, where $A_{ex}$ and $A_{em}$ denote the amplitudes through the $W$-exchange and $W$-emission diagrams, respectively.

| $B^0 \rightarrow \bar{B}c\bar{B}'$ Amplitudes | $\bar{B}^0 \rightarrow Bc\bar{B}'$ Amplitudes |
|---------------------------------------------|---------------------------------------------|
| $\Lambda^+_c \bar{p}, \Lambda^+_{c} \bar{\Delta}^- A_{ex} + A_{em}$ | $\Sigma^+_{c} \bar{\Delta}^-- A_{ex}$ |
| $\Xi^+_c \bar{\Sigma}^- A_{ex}$ | $\Sigma^+_c \bar{p}, \Sigma^+_c \bar{\Delta}^- A_{ex} + A_{em}$ |
| $\Xi^0_{c} \bar{0} \Lambda, \Xi^0_{c} \bar{0} \Sigma^0 A_{ex} + A_{em}$ | $\Xi^+_{c} \bar{\Lambda}^- A_{ex}$ |
| $\Xi^0_{c} \bar{0} \Lambda, \Xi^0_{c} \bar{0} \Sigma^0 A_{ex} + A_{em}$ | $\Omega^0_{c} \Xi^0 A_{ex}$ |

| $\bar{B}^0_s \rightarrow Bc\bar{B}'$ Amplitudes | $\bar{B}^0_s \rightarrow Bc\bar{B}'$ Amplitudes |
|---------------------------------------------|---------------------------------------------|
| $\Lambda^+_c \bar{p}, \Lambda^+_{c} \bar{\Delta}^- A_{ex} + A_{em}$ | $\Sigma^+_{c} \bar{\Delta}^-- A_{ex}$ |
| $\Xi^+_c \bar{\Sigma}^- A_{ex} + A_{em}$ | $\Sigma^+_c \bar{p}, \Sigma^+_c \bar{\Delta}^- A_{ex} + A_{em}$ |
| $\Xi^0_{c} \bar{0} \Lambda, \Xi^0_{c} \bar{0} \Sigma^0 A_{ex} + A_{em}$ | $\Xi^+_{c} \bar{\Delta}^-- A_{ex}$ |
| $\Xi^0_{c} \bar{0} \Lambda, \Xi^0_{c} \bar{0} \Sigma^0 A_{ex} + A_{em}$ | $\Omega^0_{c} \Xi^0 A_{ex} + A_{em}$ |

Momentum dependencies can be parameterized as

\[ f_1(q^2) = \frac{C_f}{(1 - q^2/m_V^2)^n}, \quad g_1(q^2) = \frac{C_g}{(1 - q^2/m_A^2)^{n}}, \tag{6} \]

with $(C_f, C_g) \equiv (f_1(0), g_1(0))$ at $q^2 = 0$, and $n = 1(2)$ for the monopole (dipole) behavior. The pole masses $(m_V, m_A) = (m_{D^*(2007)}^v, m_{D_1(2420)}^v)$ are given to match the quantum number of the vector ($V$) and the axial-vector ($A$) current, respectively.

Under the $SU(3)$ flavor symmetry, all the timelike baryonic form factors can be related to each other:

\[ (C_f^{BcB'}, C_g^{BcB'}) = \xi(C_f^{\Lambda^+_c \bar{p}}, C_g^{\Lambda^+_c \bar{p}}), \tag{7} \]
\[ (C_f^{BcB'}, C_g^{BcB'}) = \zeta(C_f^{\Sigma^+ c \bar{p}}, C_g^{\Sigma^+ c \bar{p}}), \tag{8} \]

where $(|\xi|, |\zeta|)$ are given in Table II and $(C_{f,g}^{\Lambda^+_c \bar{p}}, C_{f,g}^{\Sigma^+ c \bar{p}})$ are taken as the theoretical inputs, which can be calculated in QCD models.

We compute the branching ratios from the decay-rate equation for two-body decays, given
TABLE II. The relations between different timelike baryon for $m$ factors. The $\bar{3}_c$ and $6_c$ denote the anti-triplet and the sextet charmed baryons, respectively, and the $8$ denotes the octet charmless baryons.

| $3_c \otimes 8$ | $|\xi|$ | $6_c \otimes 8$ | $|\zeta|$ |
|-----------------|------|-----------------|------|
| $\Lambda_c^+ \bar{p}$ | 1    | $\Sigma_c^+ \bar{p}$ | 1    |
| $\Xi_c^0 \bar{\Sigma}^-$ | 1    | $\Sigma_c^0 \bar{n}$ | $\sqrt{2}$ |
| $\Xi_c^0 \bar{\Lambda}$ | $\frac{1}{\sqrt{6}}$ | $\Xi_c^+ \bar{\Sigma}^-$ | 1    |
| $\Xi_c^0 \bar{\Sigma}^0$ | $\frac{1}{\sqrt{2}}$ | $\Xi_c^0 \bar{\Sigma}^0$ | $\frac{1}{\sqrt{2}}$ |
| $\Xi_c^0 \bar{\Lambda}$ | $\sqrt{\frac{2}{3}}$ | $\Omega_c^0 \bar{\Xi}^0$ | $\frac{1}{\sqrt{2}}$ |

by [1]

$$B(B \rightarrow B_c \bar{B}') = \frac{|\bar{p}_{B_c}| \tau_B}{8\pi m_B^2} |A(B \rightarrow B_c \bar{B}')[|^2,$$

$$|\bar{p}_{B_c}| = \sqrt{(m_B^2 - (m_{B_c} + m_{\bar{B}'})^2)(m_B^2 - (m_{B_c} - m_{\bar{B}'})^2)} / 2m_B,$$

(9)

where $\tau_B$ denotes the $B$ meson lifetime.

**III. NUMERICAL ANALYSIS**

In the numerical analysis, we use the Wolfenstein parameterization for the CKM matrix elements, given by [1]

$$(V_{cb}, V_{ud}, V_{us}) = (A\lambda^2, 1 - \lambda^2/2, \lambda),$$

(10)

where $\lambda = 0.22453 \pm 0.00044$ and $A = 0.836 \pm 0.015$, together with the $B$ meson decay constants $(f_B, f_{B_c}) = (0.19, 0.23)$ GeV [1]. For the form factors in Eqs. (5) and (6) and (7) [8], we adopt the ones for $0 \rightarrow \Lambda_c^+ \bar{p}, \Sigma_c^+ \bar{p}$ from the QCD light-cone sum rules [28]:

$$(C_{f^{\Lambda_c^+ \bar{p}}}, C_{g^{\Lambda_c^+ \bar{p}}}) = (0.59^{+0.15}_{-0.16}, 0.55^{+0.14}_{-0.15}),$$

$$(C_{f^{\Sigma_c^+ \bar{p}}}, C_{g^{\Sigma_c^+ \bar{p}}}) = (-0.23^{+0.04}_{-0.05}, 0.06 \pm 0.01),$$

(11)

where the dominant uncertainties come from the parameters input in QCD, such as the $\Lambda_c^+ (\Sigma_c^+)$ decay constant. In the generalized edition of the factorization approach [29], $N_c$ is
TABLE III. The branching ratios for the $\bar{B}^0_{(s)} \to B_c \bar{B}'$ decays. The uncertainties come from the form factors in Eq. (11).

| Decay modes $\mathcal{B} \times 10^5$ | Data | Decay modes $\mathcal{B} \times 10^7$ | Data |
|------------------------------------|------|------------------------------------|------|
| $\bar{B}^0 \to \Lambda_c^+ \bar{p}$ | $1.6^{+0.9}_{-0.7}$ | $1.55 \pm 0.18$ | $1\bar{B}^0 \to \Sigma_c^+ \bar{p}$ | $3.2^{+0.8}_{-0.6}$ | $< 240$ |
| $\bar{B}^0 \to \Xi_c^+ \bar{\Sigma}^-$ | $1.8^{+1.0}_{-0.8}$ | | $\bar{B}^0 \to \Sigma_c^0 \bar{n}$ | $6.4^{+1.6}_{-1.3}$ | |
| $\bar{B}^0 \to \Xi_c^0 \bar{\Sigma}$ | $0.9^{+0.5}_{-0.4}$ | | $\bar{B}^0 \to \Xi_c^+ \bar{\Sigma}^-$ | $3.0^{+0.7}_{-0.6}$ | |
| $\bar{B}^0 \to \Xi_c^0 \bar{\Lambda}$ | $0.3^{+0.2}_{-0.1}$ | | $\bar{B}^0 \to \Xi_c^0 \bar{\Sigma}$ | $1.5^{+0.3}_{-0.3}$ | |
| $\bar{B}^0 \to \Xi_c^0 \bar{\Lambda}$ | $4.6^{+1.0}_{-0.9}$ | | $\bar{B}^0 \to \Omega_c^0 \bar{\Xi}^0$ | $5.9^{+1.3}_{-1.2}$ | |

| Decay modes $\mathcal{B} \times 10^6$ | Decay modes $\mathcal{B} \times 10^8$ |
|------------------------------------|------------------------------------|
| $\bar{B}^0 \to \Lambda_c^+ \bar{p}$ | $1.2^{+0.7}_{-0.5}$ |
| $\bar{B}^0 \to \Xi_c^+ \bar{\Sigma}^-$ | $1.4^{+0.8}_{-0.7}$ |
| $\bar{B}^0 \to \Xi_c^0 \bar{\Sigma}^0$ | $0.7^{+0.4}_{-0.3}$ |
| $\bar{B}^0 \to \Xi_c^0 \bar{\Lambda}$ | $0.2^{+0.1}_{-0.1}$ |
| $\bar{B}^0 \to \Sigma_c^+ \bar{p}$ | $2.5^{+0.6}_{-0.5}$ |
| $\bar{B}^0 \to \Xi_c^0 \bar{\Sigma}^0$ | $1.2^{+0.3}_{-0.2}$ |
| $\bar{B}^0 \to \Xi_c^0 \bar{\Lambda}$ | $3.7^{+0.9}_{-1.0}$ |
| $\bar{B}^0 \to \Omega_c^0 \bar{\Xi}^0$ | $4.7^{+1.0}_{-0.9}$ |

a floating number from 2 to $\infty$, in order to account for the non-factorizable effects. With $N_c \simeq 2$, we obtain $a_2 = 0.22$; $a_2 \simeq \mathcal{O}(0.2 - 0.3)$ commonly appears in the interpretation of charmful $b$-hadron decays [21, 30–32]. All predicted $\bar{B}^0_{(s)} \to B_c \bar{B}'$ branching ratios are given in Table III with $n = 1$ assigned for the monopole behavior.

IV. DISCUSSIONS AND CONCLUSIONS

One of the theoretical supports to neglect the $W$-exchange mechanism is in analogy with the $B \to \ell \bar{\nu}_\ell$ decays [12], which are helicity suppressed. In fact, we obtain

$$
\mathcal{B}(B \to \mu \bar{\nu}_\mu) = \frac{G_F^2 m_B \tau_B}{8\pi} |V_{ub}|^2 f_B^2 m_{\mu}^2 \left( 1 - \frac{m_{\mu}^2}{m_B^2} \right)^2,
$$

$$
\mathcal{B}(B \to B_c \bar{B}') = \frac{G_F^2 |F_{B_c}| \tau_B}{8\pi} a_2 V_{ub} V_{ud}^* |f_B^2 m_{\mu}^2 \left[ \mathcal{R} m_{\mu}^2 \left( 1 - \frac{m_{\mu}^2}{m_B^2} \right) + g_1 \left( 1 - \frac{m_{\mu}^2}{m_B^2} \right) \right], (12)
$$
where $m_{\mu}^2 \simeq 0.01 \text{ GeV}^2$ corresponds to $\mathcal{B}(B \to \mu \nu_\mu) = (5.3 \pm 2.0 \pm 0.9) \times 10^{-7}$ [33, 34]. Nonetheless, with $m_{+, -} \equiv m_{B_s, \pm} \pm m_{B_s'}$ and $\mathcal{R}_m \equiv (m_-/m_+)^2$, $m_{+, -}^2$ in $B \to B_s B_s'$ causes no suppression, while $m_{B_s}$ can be as large as $(2.3-2.5) \text{ GeV}$. As a consequence, the $W$-exchange contribution in $B \to B_s B_s'$ decays is not necessarily negligible.

With the $W$-exchange contribution alone, the branching ratio of $\bar{B}^0 \to \Lambda_c^+ \bar{p}$ was once calculated to be as small as $4.6 \times 10^{-7}$ [35], which has been taken as theoretical support for neglecting the $W$-exchange diagram. Note that the calculation used $N_c = 3$ in the naive factorization and $n = 2$ for baryon form factors with dipole behavior, whereas $C_{f,g}^{\Delta \Lambda \bar{p}}$ are not clearly given. However, being sensitive to the color number, $a_2$ with $N_c = 3$ has been shown to fail to accommodate the non-factorizable effects [29]; besides, while it is poorly understood whether $n = 1$ or $n = 2$ is preferred [21], $n = 1$ is most often used in recent QCD models [28, 36, 37]. In the generalized factorization, together with $n = 1$ for the monople-type form factors, we obtain

$$
\mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{p}) = (1.6^{+0.9}_{-0.7}) \times 10^{-5},
$$

$$
\mathcal{B}(\bar{B}^0 \to \Sigma_c^+ \bar{p}) = (3.2^{+0.8}_{-0.6}) \times 10^{-7},
$$

(13)

which are consistent with the current data, cf. Eq. (11). Note that $\mathcal{B}(\bar{B}^0 \to \Sigma_c^+ \bar{p})$ is much smaller than $\mathcal{B}(B^0 \to \Lambda_c^+ \bar{p})$ due to the small $C_{f,g}^{\Sigma \Delta \bar{p}}$ in Eq. (11).

Our calculation of $\mathcal{B}(B^0 \to \Lambda_c^+ \bar{p}) \simeq 1.6 \times 10^{-5}$ is as large as the values of $(2.3-5.1) \times 10^{-5}$ and $1.1 \times 10^{-5}$ from the perturbative QCD approach and pole model, respectively [20-22], which only take into account the $W$-emission contribution. This causes the confusion that, if the $W$-exchange and emission contributions are compatible, the combination of the branching ratios should exceed the experimental data. For clarification, we study decays other than $\bar{B}^0 \to \Lambda_c^+ \bar{p}, \Sigma_c^+ \bar{p}$, which receive contributions from both $A_{ex}$ and $A_{em}$. By taking $A_{ex}$ as the primary contribution, we predict

$$
\mathcal{B}(\bar{B}^0 \to \Xi^0 \Sigma^0, \Xi^0 \Lambda) = (0.9^{+0.5}_{-0.4}, 0.3^{+0.2}_{-0.1}) \times 10^{-5},
$$

$$
\mathcal{B}(B_s^0 \to \Xi^0 \Sigma^0, \Xi^0 \Lambda) \simeq \mathcal{R}_{B_s} \times \mathcal{B}(B^0 \to \Xi^0 \Sigma^0, \Xi^0 \Lambda),
$$

(14)

with $\mathcal{R}_{B_s} \equiv |(V_{us}f_{B_s})/(V_{ud}f_B)|^2 = 0.075$. In future measurements, the deviation of $\mathcal{R}_{B_s}$ from the theoretical prediction can be used to evaluate the size of $A_{em}$ in the decays.

Being pure $W$-exchange processes, $\bar{B}^0 \to \Xi^+_c \Xi^-_c, \Xi^+_c \Xi^-_c, \Omega^0_c \Xi^0_c$ and $\bar{B}_s^0 \to \Sigma^0_c \bar{n}, \Lambda_c^+ \bar{p}, \Sigma_c^+ \bar{p}$...
can be excellent probes for the examination of the $W$-exchange mechanism. We predict that

$$B(\bar{B}^0 \to \Xi^+_c \bar{\Sigma}^-) = (1.8^{+1.0}_{-0.8}) \times 10^{-5},$$

$$B(\bar{B}^0_s \to \Lambda_c^+ \bar{p}) = (1.2^{+0.7}_{-0.5}) \times 10^{-6},$$

which are all within the capability of the current $B$ factories.

In summary, we have studied the charmful two-body baryonic $B^0_{(s)} \to B_c B'$ decays, with $B_c = (\Xi^+_c, \Lambda_c^+) \text{ or } (\Sigma^{++}_c, \Xi^{'+}_c, \Omega^0_c)$. We have found that the $W$-exchange contribution is not negligible. We have calculated that $B(\bar{B}^0 \to \Lambda_c^+ \bar{p}) = (1.6^{+0.9}_{-0.7}) \times 10^{-5}$, which is different from the previously estimated value of $4.6 \times 10^{-7}$. In addition, $B(\bar{B}^0 \to \Sigma^+_c \bar{p}) = (3.2^{+0.8}_{-0.6}) \times 10^{-7}$, compatible with the current data. For decays that only proceed via a $W$-exchange diagram, we predict $B(\bar{B}^0_s \to \Lambda_c^+ \bar{p}) = (1.2^{+0.7}_{-0.5}) \times 10^{-6}$ and $B(\bar{B}^0 \to \Xi^+_c \bar{\Sigma}^-) = (1.8^{+1.0}_{-0.8}) \times 10^{-5}$, which provide an excellent window for the LHCb and Belle II experiments to look into the long-ignored $W$-exchange mechanism.

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