

Factorization and angular distribution asymmetries in charmed baryonic B decays

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We examine the validity of the generalized factorization method and calculate the angular correlations in the charmed three-body baryonic decays of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)+}$. With the timelike baryonic form factors newly extracted from the measured baryonic B decays, we obtain $\mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+, \Lambda \bar{p} D^{*+}) = (1.85 \pm 0.30, 2.75 \pm 0.24) \times 10^{-5}$ to agree with the recent data from the Belle Collaboration, which demonstrates that the theoretical approach based on the factorization still works well. For the angular distribution asymmetries, we find $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+, \Lambda \bar{p} D^{*+}) = (-0.030 \pm 0.002, +0.150 \pm 0.000)$, which are consistent with the current measurements. Moreover, we predict that $\mathcal{A}_\theta(\bar{B}^0 \rightarrow p \bar{p} D^0, p \bar{p} D^{*0}) = +0.04 \pm 0.01$. Future precise explorations of these angular correlations at Belle and LHCb as well as super-Belle are important to justify the present factorization approach in the charmed three-body baryonic decays.

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I. INTRODUCTION

Recently, the Belle Collaboration has reported the branching ratios of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)+}$ along with the first angular distribution asymmetries measured in the charmed three-body baryonic $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M_c$ decays, given by [1]

$$\begin{aligned} \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+) &= (25.1 \pm 2.6 \pm 3.5) \times 10^{-6}, \\ \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*+}) &= (33.6 \pm 6.3 \pm 4.4) \times 10^{-6}, \\ \mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^-) &= -0.08 \pm 0.10, \\ \mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*-}) &= +0.55 \pm 0.17, \end{aligned} \quad (1)$$

with the subscript θ as the angle between the \bar{p} and $D^{(*)-}$ moving directions in the $\Lambda \bar{p}$ rest frame, where $\mathcal{A}_\theta \equiv (\mathcal{B}_+ - \mathcal{B}_-)/(\mathcal{B}_+ + \mathcal{B}_-)$ represents the angular distribution asymmetry, with $\mathcal{B}_{+(-)}$ defined as the branching ratio of the positive (negative) cosine value. The data in Eq. (1) can be important due to the fact that $\bar{B}^0 \rightarrow \Lambda \bar{p} D^+$ and $\Lambda \bar{p} D^{*+}$ are two of the few current-type processes among the richly observed baryonic B decays, connected to the timelike baryonic form factors via the vector and axial-vector quark currents. Note that although $\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^+$ and $B^- \rightarrow \Lambda \bar{p} \rho^0$ are related to the timelike baryonic form factors, they also mix with the contributions from the scalar and pseudoscalar currents via the penguin diagrams.

The decays of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)-}$ have been previously studied in Ref. [2], with the branching ratios predicted to be $(3.4 \pm 0.2) \times 10^{-6}$ and $(11.9 \pm 2.7) \times 10^{-6}$, respectively, which are obviously much lower than the current data in Eq. (1) and regarded as the failure of the theoretical approach based on the factorization in Ref. [1]. To resolve the problem, in this work we will evaluate the hadronic

matrix elements from the observed baryonic B decays directly instead of using the data of $e^+e^- \rightarrow p \bar{p}(n\bar{n})$ ($p \bar{p} \rightarrow e^+e^-$) in Ref. [2].

Compared to the experimental result of $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^-)$ in Eq. (1), the measured value of $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^-) = -0.41 \pm 0.11 \pm 0.03$ [3] as the charmless counterpart is unexpectedly large. Moreover, the experimental implication of $\mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^-) \sim \mathcal{B}(B^- \rightarrow \Lambda \bar{p} \pi^0) \sim 3 \times 10^{-6}$ [3] looks mysterious as it breaks the isospin symmetry. Since the decays of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)-}$ simply proceed through the (axial-) vector currents from the tree contributions, one suspects that $|\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^-)| \gg |\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^-)|$ is due to the additional (pseudo)scalar currents from the penguin diagrams in $\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^-$. Likewise, the charmless three-body baryonic decays of $B^- \rightarrow p \bar{p}(\pi^-, K^-)$ receive the main contributions from the tree and penguin diagrams, respectively, which may result in the wrong sign of $\mathcal{A}_\theta(B^- \rightarrow p \bar{p} \pi^-) \simeq -\mathcal{A}_\theta(B^- \rightarrow p \bar{p} K^-)$ [4,5]. It is hence expected that $\bar{B}^0 \rightarrow p \bar{p} D^0$ from the tree-level diagrams can be more associated with $B^- \rightarrow p \bar{p} \pi^-$. Clearly, systematic studies of the angular correlations in $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M_c$ are needed.

Most importantly, since the theoretical approach for the three-body baryonic B decays depends on the generalized factorization, according to the comments in Ref. [1], if the calculations fail to explain the data, it will indicate that the model parameters need to be revised and, perhaps, some modification of the theoretical framework is required. Note that it is also commented in Ref. [1] that the factorization fails to provide a satisfactory explanation for the $M-\bar{p}$ angular correlations in $B^- \rightarrow p \bar{p} K^-$, $B^0 \rightarrow p \bar{\Lambda} \pi^-$ and $B \rightarrow p \bar{p} D$. However, this is clearly misleading, as $\mathcal{A}_\theta(B^- \rightarrow p \bar{p} K^-)$ has been well studied in Ref. [6],

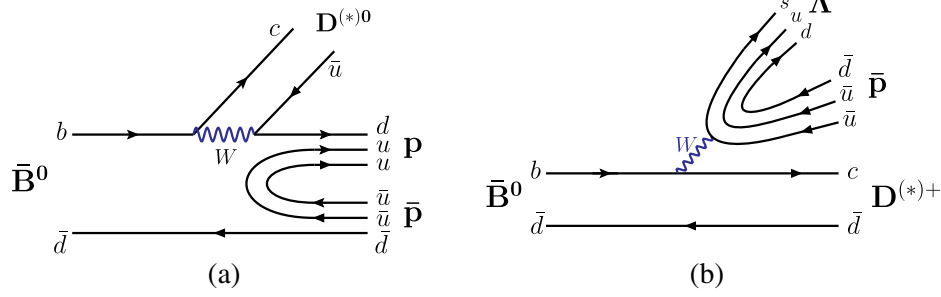


FIG. 1. Feynman diagrams for the three-body baryonic B decays of (a) $\bar{B}^0 \rightarrow p\bar{p}D^{(*)0}$ and (b) $\bar{B}^0 \rightarrow \Lambda\bar{p}D^{(*)+}$.

whereas $\mathcal{A}_\theta(B \rightarrow p\bar{p}D)$ has been neither measured experimentally nor predicted theoretically.

In this report, we will study $\bar{B}^0 \rightarrow p\bar{p}D^{(*)0}$ and $\bar{B}^0 \rightarrow \Lambda\bar{p}D^{(*)-}$ in order to approve the factorization approach. In addition, we will calculate their angular distribution asymmetries to have the first theoretical predictions. Moreover, some of these charming asymmetries will be compared to the charmless counterparts of $B^- \rightarrow p\bar{p}K^-(\pi^-)$ and $\bar{B}^0 \rightarrow \Lambda\bar{p}\pi^-$ ($B^- \rightarrow \Lambda\bar{p}\pi^0$).

II. FORMALISM

As shown in Fig. 1, in terms of the effective Hamiltonian for the quark-level $b \rightarrow cud(\bar{s})$ transition and the generalized factorization approach [7], the amplitudes of the $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M_c$ decays can be written by [2]

$$\begin{aligned} \mathcal{A}(\bar{B}^0 \rightarrow p\bar{p}D^{(*)0}) &= \frac{G_F}{\sqrt{2}} V_{cb} V_{ud}^* a_2 \langle D^{(*)0} | (\bar{c}u)_{V-A} | 0 \rangle \langle p\bar{p} | (\bar{d}b)_{V-A} | \bar{B}^0 \rangle, \\ \mathcal{A}(\bar{B}^0 \rightarrow \Lambda\bar{p}D^{(*)-}) &= \frac{G_F}{\sqrt{2}} V_{cb} V_{us}^* a_1 \langle \Lambda\bar{p} | (\bar{s}u)_{V-A} | 0 \rangle \langle D^{(*)-} | (\bar{c}b)_{V-A} | \bar{B}^0 \rangle, \end{aligned} \quad (2)$$

where G_F is the Fermi constant, V_{ij} are the CKM matrix elements, $(\bar{q}_1 q_2)_{V(A)}$ stands for $\bar{q}_1 \gamma_\mu (\gamma_5) q_2$, and $a_{1(2)} \equiv c_{1(2)}^{\text{eff}} + c_{2(1)}^{\text{eff}} / N_c^{\text{eff}}$ is composed of the effective Wilson coefficients $c_{1,2}^{\text{eff}}$ defined in Ref. [7]. In Eq. (2), the matrix elements for the $D^{(*)}$ -meson productions through the $\bar{c}u$ -quark currents can be written as

$$\langle D | \bar{c} \gamma^\mu \gamma_5 u | 0 \rangle = -i f_D p_D^\mu, \quad \langle D^* | \bar{c} \gamma^\mu u | 0 \rangle = m_{D^*} f_{D^*} \varepsilon^{\mu*}, \quad (3)$$

with $f_{D^{(*)}}$ the decay constant and p_D^μ ($\varepsilon^{\mu*}$) the four-momentum (polarization). The matrix elements of the $B \rightarrow D^{(*)}$ transitions can be parametrized as [8]

$$\begin{aligned} \langle D | \bar{c} \gamma^\mu b | B \rangle &= \left[(p_B + p_D)^\mu - \frac{m_B^2 - m_D^2}{t} q^\mu \right] F_1^{BD}(t) \\ &\quad + \frac{m_B^2 - m_D^2}{t} q^\mu F_0^{BD}(t), \\ \langle D^* | \bar{c} \gamma_\mu b | B \rangle &= \epsilon_{\mu\nu\alpha\beta} \varepsilon^{*\nu} p_B^\alpha p_{D^*}^\beta \frac{2V_1^{BD^*}(t)}{m_B + m_{D^*}}, \\ \langle D^* | \bar{c} \gamma_\mu \gamma_5 b | B \rangle &= i \left[\varepsilon_\mu^* - \frac{\varepsilon^* \cdot q}{t} q_\mu \right] (m_B + m_{D^*}) A_1^{BD^*}(t) \\ &\quad + i \frac{\varepsilon^* \cdot q}{t} q_\mu (2m_{D^*}) A_0^{BD^*}(t) \\ &\quad - i \left[(p_B + p_{D^*})_\mu - \frac{m_B^2 - m_{D^*}^2}{t} q_\mu \right] \\ &\quad \times (\varepsilon^* \cdot q) \frac{A_2^{BD^*}(t)}{m_B + m_{D^*}}, \end{aligned} \quad (4)$$

where $t \equiv q^2$ with $q = p_B - p_{D^{(*)}} = p_{\mathbf{B}} + p_{\bar{\mathbf{B}}'}$. With the $\Lambda\bar{p}$ pair produced from the $s\bar{u}$ -quark currents, $\bar{B}^0 \rightarrow \Lambda\bar{p}D^{(*)-}$ is classified as the current-type decay, such that the matrix elements for the baryon pair production are in the forms of

$$\begin{aligned} \langle \mathbf{B}\bar{\mathbf{B}}' | \bar{q}_1 \gamma_\mu q_2 | 0 \rangle &= \bar{u} \left\{ F_1 \gamma_\mu + \frac{F_2}{m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}} i \sigma_{\mu\nu} q_\nu \right\} v \\ &= \bar{u} \left\{ [F_1 + F_2] \gamma_\mu + \frac{F_2}{m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}} (p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu \right\} v, \\ \langle \mathbf{B}\bar{\mathbf{B}}' | \bar{q}_1 \gamma_\mu \gamma_5 q_2 | 0 \rangle &= \bar{u} \left\{ g_A \gamma_\mu + \frac{h_A}{m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'}} q_\mu \right\} \gamma_5 v, \end{aligned} \quad (5)$$

where $F_{1,2}$, g_A and h_A are the timelike baryonic form factors, and $u(v)$ is the (anti)baryon spinor. Being classified as the transition-type decays, the study of $\bar{B}^0 \rightarrow p\bar{p}D^{(*)0}$ needs to know the matrix elements for the $\bar{B}^0 \rightarrow p\bar{p}$ transition, which are parameterized as

$$\begin{aligned} \langle \mathbf{B}\bar{\mathbf{B}}' | \bar{q}' \gamma_\mu b | B \rangle &= i \bar{u} [g_1 \gamma_\mu + g_2 i \sigma_{\mu\nu} p^\nu + g_3 p_\mu + g_4 q_\mu \\ &\quad + g_5 (p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu] \gamma_5 v, \\ \langle \mathbf{B}\bar{\mathbf{B}}' | \bar{q}' \gamma_\mu \gamma_5 b | B \rangle &= i \bar{u} [f_1 \gamma_\mu + f_2 i \sigma_{\mu\nu} p^\nu + f_3 p_\mu + f_4 q_\mu \\ &\quad + f_5 (p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu] v, \end{aligned} \quad (6)$$

where $p = p_B - q$ and $g_i(f_i)$ ($i = 1, 2, 3, 4, 5$) are the $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'$ transition form factors. The momentum dependences of the $B \rightarrow D^{(*)}$ transition form factors have been studied in QCD models, given by [9]

$$f(t) = \frac{f(0)}{(1 - t/M_{P(V)}^2)[1 - \sigma_1 t/M_{P(V)}^2 + \sigma_2 t^2/M_{P(V)}^4]} \quad (7)$$

for $f = F_1^{BD}(A_0^{BD*}, V_1^{BD*})$, and by

$$f(t) = \frac{f(0)}{1 - \sigma_1 t/M_V^2 + \sigma_2 t^2/M_V^4} \quad (8)$$

for $f = F_0^{BD}, A_1^{BD*}$ and A_2^{BD*} , while those of F_1 and g_A in pQCD counting rules can be written as [10–12]

$$F_1 = \frac{C_{F_1}}{t^2} \left[\ln\left(\frac{t}{\Lambda_0^2}\right) \right]^{-\gamma}, \quad g_A = \frac{C_{g_A}}{t^2} \left[\ln\left(\frac{t}{\Lambda_0^2}\right) \right]^{-\gamma}, \quad (9)$$

where $\gamma = 2.148$ and $\Lambda_0 = 0.3$ GeV. Note that $h_A = C_{h_A}/t^2$ [13] is in accordance with the violated partial conservation of the axial-vector current, whereas $F_2 = F_1/(t \ln[t/\Lambda_0^2])$ [14,15] is small enough to be safely neglected. According to the principle of pQCD counting rules, one gluon to speed up the spectator quark within the B meson is required in the $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'$ transition, which causes an additional $1/t$ to F_1 and g_A , such that the momentum dependences of $f_i(g_i)$ can be written as [16]

$$f_i(t) = \frac{D_{f_i}}{t^3}, \quad g_i(t) = \frac{D_{g_i}}{t^3}. \quad (10)$$

Furthermore, while the $SU(3)$ flavor symmetry can relate different decay modes, the $SU(2)$ spin symmetry can combine the vector and axial-vector currents to be the chiral currents. Consequently, one gets the baryonic form factors to be [2,10–13,16,17]

$$\begin{aligned} C_{F_1} = C_{g_A} &= -\sqrt{\frac{3}{2}}C_{\parallel}, & C_{h_A} &= -\frac{1}{\sqrt{6}}(C_D + 3C_F), \\ D_{g_1(f_1)} &= \frac{1}{3}D_{\parallel} \mp \frac{2}{3}D_{\parallel}, & D_{g_j(f_j)} &= \mp \frac{1}{3}D_{\parallel}^j, \\ D_{g_1(f_1)} &= -\sqrt{\frac{3}{2}}D_{\parallel}, & D_{g_j(f_j)} &= \mp \sqrt{\frac{3}{2}}D_{\parallel}^j, \end{aligned} \quad (11)$$

with the constants $C_{\parallel}, C_{D(F)}, D_{\parallel(\bar{\parallel})}$, and D_{\parallel}^j ($j = 2, 3, 4, 5$) to be determined. Note that the relation for C_{h_A} is simply from the $SU(3)$ symmetry.

To integrate over the phase space of the three-body $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M_c$ decays, we use [6,18]

$$\Gamma = \int_{-1}^{+1} \int_{(m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'})^2}^{(m_B - m_{M_c})^2} \frac{\beta_t^{1/2} \lambda_t^{1/2}}{(8\pi m_B)^3} |\bar{\mathcal{A}}|^2 dt d\cos\theta, \quad (12)$$

where $\beta_t = 1 - (m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'})^2/t$, $\lambda_t = m_B^4 + m_{M_c}^4 + t^2 - 2m_{M_c}^2 t - 2m_B^2 t - 2m_{M_c}^2 m_B^2$, the angle θ is between the $\bar{\mathbf{B}}'$ and M_c moving directions in the $\mathbf{B}\bar{\mathbf{B}}'$ rest frame, and $|\bar{\mathcal{A}}|^2$ is the squared amplitude of Eq. (2) by summing over all spins. Note that the $\mathbf{B}(\bar{\mathbf{B}}')$ energy is given by

$$E_{\mathbf{B}(\bar{\mathbf{B}}')} = \frac{m_B^2 + t - m_{\mathbf{B}(\bar{\mathbf{B}}')}^2 \mp \beta_t^{1/2} \lambda_t^{1/2} \cos\theta}{4m_B}. \quad (13)$$

From Eq. (12), we define the angular distribution asymmetry:

$$A_{\theta} \equiv \frac{\int_0^{+1} \frac{d\Gamma}{d\cos\theta} d\cos\theta - \int_{-1}^0 \frac{d\Gamma}{d\cos\theta} d\cos\theta}{\int_0^{+1} \frac{d\Gamma}{d\cos\theta} d\cos\theta + \int_{-1}^0 \frac{d\Gamma}{d\cos\theta} d\cos\theta}, \quad (14)$$

where $d\Gamma/d\cos\theta$ is a function of $\cos\theta$ known as the angular distribution, which presents the $M_c - \bar{B}'$ angular correlation in $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M_c$.

III. NUMERICAL ANALYSIS

In our numerical analysis, the theoretical inputs of the CKM matrix elements in the Wolfenstein parameterization and the decay constants for $D^{(*)}$ are given by [19,20]

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

$$(\lambda, A, \rho, \eta) = (0.225, 0.814, 0.120 \pm 0.022, \\ \times 0.362 \pm 0.013),$$

$$(f_D, f_{D^*}) = (204.6 \pm 5.0, 252.2 \pm 22.7) \text{ MeV}.$$

(15)

In Table I, we adopt the $B \rightarrow D^{(*)}$ transition form factors from Ref. [9], in which no uncertainty has been included. As mentioned earlier, the decays of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^+$ and $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*+}$ belong to the current-type modes, described by the timelike baryonic form factors via the vector and axial-vector quark currents. Note that $\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^+$ and $B^- \rightarrow \Lambda \bar{p} \rho^0$ are also connected to the timelike baryonic form factors, but dominated by the additional ones via the scalar and pseudoscalar currents. With the extraction by the data from the current-type baryonic B decays [13], F_1 and g_A as the timelike baryonic form factors can be given. Because the $\bar{B}^0 \rightarrow p \bar{p}$ transition form factors in $\bar{B}^0 \rightarrow p \bar{p} D^{(*)0}$ are related to those of the charmless $B \rightarrow p \bar{p} M$ with $M = K^{(*)}, \pi(\rho)$ and the semileptonic $B^- \rightarrow p \bar{p} e^- \bar{\nu}_e$ decay, the extractions of $f_i(g_i)$ are also available [2]. It is hence determined that

TABLE I. The form factors of $B \rightarrow D^{(*)}$ at $t = 0$ in Ref. [9] with $M_p \simeq M_V = 6.4$ GeV.

$B \rightarrow D^{(*)}$	F_1^{BD}	F_0^{BD}	$V_1^{BD^*}$	$A_0^{BD^*}$	$A_1^{BD^*}$	$A_2^{BD^*}$
f(0)	0.67	0.67	0.76	0.69	0.66	0.62
σ_1	0.57	0.78	0.57	0.58	0.78	1.40
σ_2	...	...	...	...	...	0.41

$$\begin{aligned}
(C_{\parallel}, C_D, C_F) &= (111.4 \pm 14.6, -6.8 \pm 2.0, \\
&\quad \times 2.3 \pm 0.9) \text{ GeV}^4, \\
(D_{\parallel}, D_{\parallel}) &= (36.9 \pm 45.9, -348.2 \pm 18.7) \text{ GeV}^5, \\
(D_{\parallel}^2, D_{\parallel}^3, D_{\parallel}^4, D_{\parallel}^5) &= (-44.7 \pm 30.4, -426.7 \pm 182.5, \\
&\quad \times 4.3 \pm 20.2, 135.2 \pm 29.4) \text{ GeV}^4.
\end{aligned} \tag{16}$$

In addition, a_1 and a_2 are fitted to be

$$a_1 = 1.15 \pm 0.04, \quad a_2 = 0.40 \pm 0.04. \tag{17}$$

As a result, we can reproduce the branching ratios shown in Table II. It should be pointed out that the main reason for the underestimated breaching ratios of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)-}$ in Ref. [2] is due to the small values of F_1 and g_A extracted from the data of $e^+e^- \rightarrow p\bar{p}(n\bar{n})$ ($p\bar{p} \rightarrow e^+e^-$), which are in fact related to the electromagnetic form factors of the proton (neutron) pair without taking into account the timelike axial structures, induced from the weak currents due to W and Z bosons. However, in this work, we take the data from the current-type baryonic B decays as used in Ref. [13], which explains why the data in Eq. (1) of $\mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)-})$ can be explained. With the current precise data for the axial-vector current already, future new data should not change our present fitting parameters very much.

In the table, we also show our predictions of the angular distribution asymmetries. In particular, our result of $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^-) = -0.030 \pm 0.002$ is consistent with the data in Eq. (1) [1], which shows that the unexpected large center number of $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^-) = -30\%$ either will be a much smaller value in future measurements or is due to some unknown sources through the (pseudo)scalar

TABLE II. Our results for the decay branching ratios and angular distribution asymmetries, where the data are from Refs. [1,20,21].

Decay mode	Data	Our results
$10^4 \mathcal{B}(\bar{B}^0 \rightarrow p\bar{p}D^0)$	1.04 ± 0.07	1.04 ± 0.12
$10^4 \mathcal{B}(\bar{B}^0 \rightarrow p\bar{p}D^{*0})$	0.99 ± 0.11	0.99 ± 0.09
$10^5 \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^-)$	2.51 ± 0.44	1.85 ± 0.30
$10^5 \mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*-})$	3.36 ± 0.77	2.75 ± 0.24
$\mathcal{A}_\theta(\bar{B}^0 \rightarrow p\bar{p}D^0)$	...	$+0.04 \pm 0.01$
$\mathcal{A}_\theta(\bar{B}^0 \rightarrow p\bar{p}D^{*0})$	...	$+0.04 \pm 0.01$
$\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^-)$	-0.08 ± 0.10	-0.030 ± 0.002
$\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*-})$	$+0.55 \pm 0.17$	$+0.150 \pm 0.000$

currents from the penguin diagrams. It is interesting to note that our prediction of $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*-}) = 0.150 \pm 0.000$ is large, but it is still lower than the data of $(55 \pm 17)\%$ in Ref. [1]. Note that the small uncertainty of our prediction results from the elimination of the timelike form factors by Eq. (14). The reason why the decay of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{*-}$ can lead to a considerably large $\mathcal{A}_\theta \simeq 15\%$ is that, being one of the $B \rightarrow D^*$ transition form factors in Eq. (4), the $V_1^{BD^*}$ term with $\epsilon_{\mu\nu\alpha\beta}$ is able to relate F_1 and g_A from different currents, such that $V_1^{BD^*} A_1^{BD^*} F_1 g_A (E_{\bar{p}} - E_p)$ can arise with $E_{\bar{p}} - E_p \propto \cos \theta$. It is important to point out that in future experiments, our prediction of $\mathcal{A}_\theta(\bar{B}^0 \rightarrow p\bar{p}D^0) = 0.04 \pm 0.01$ can be used to check if there is a simple relation between $\bar{B}^0 \rightarrow p\bar{p}D^0$ and $B^- \rightarrow p\bar{p}\pi^-$, which are both dominated by the tree-level contributions. In addition, we remark that our results are based on the form factors in Table I without any uncertainty included. If there are some possible errors, our fitting values for the angular distributions could change.

IV. CONCLUSIONS

We have revisited the charmful three-body baryonic decays of $\bar{B}^0 \rightarrow \Lambda \bar{p} D^{(*)+}$. With the timelike baryonic form factors newly extracted from the baryonic B decays instead of $e^+e^- \rightarrow p\bar{p}(n\bar{n})$ ($p\bar{p} \rightarrow e^+e^-$), we have found that $\mathcal{B}(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+, \Lambda \bar{p} D^{*+}) = (1.85 \pm 0.30, 2.75 \pm 0.24) \times 10^{-5}$, which agrees with the data in Eq. (1) from the Belle Collaboration [1]. This agreement has demonstrated that our theoretical approach based on the factorization is still valid. Clearly, the revision of model parameters and the modification of the factorization approach are not required, unlike the statement in Ref. [1].

We have also studied the M_c - $\bar{\mathbf{B}}'$ angular distribution asymmetries in the charmful baryonic B decays of $B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M_c$. Explicitly, we have obtained $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^+, \Lambda \bar{p} D^{*+}) = (-0.030 \pm 0.002, +0.150 \pm 0.000)$, which are consistent with the current data. In addition, we have predicted that $\mathcal{A}_\theta(\bar{B}^0 \rightarrow p\bar{p}D^0, p\bar{p}D^{*0}) = +0.04 \pm 0.01$. We believe that future precision measurements of $\mathcal{A}_\theta(B \rightarrow p\bar{p}D^{(*)}, \Lambda \bar{p} D^{(*)})$ could be used to compare with the charmless counterparts of $\mathcal{A}_\theta(B^- \rightarrow p\bar{p}K^-(\pi^-))$ and $\mathcal{A}_\theta(B \rightarrow \Lambda \bar{p}\pi)$. It is expected that the differences between the charmful and charmless cases, such as $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p}\pi^-) \simeq -41\%$ and $\mathcal{A}_\theta(\bar{B}^0 \rightarrow \Lambda \bar{p} D^-)$, would originate from different contributions at tree and penguin levels. Clearly, it is worth closely examining $\mathcal{A}_\theta(B \rightarrow \mathbf{B}\bar{\mathbf{B}}'M_c)$ at Belle and LHCb, as well as at the future super-Belle facilities.

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