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Charmless Two-body Baryonic $B_{u,d,s}$ Decays

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We study charmless two-body baryonic B decays using the topological amplitude approach. We extend a previous work to include all ground state octet and decuplet final states with full topological amplitudes. Relations on rates and CP asymmetries are obtained. With the long awaited $\overline{B}^0 \to p\bar{p}$ data, we can finally extract information on the topological amplitudes and predict rates of other modes. We point out some modes that will cascadely decay to all charged final states and have large decay rates. We find that the $\overline{B}^0 \to p\bar{p}$ mode is the most accessible one among octet-anti-octet final states in the $\Delta S = 0$ transition. The predicted $\overline{B}^0_s \to p\bar{p}$ rate is several order smaller than the present experimental result. The analysis presented in this work can be systematically improved when more measurements on decay rates become available. The smallness of the $\overline{B}^0 \to p\bar{p}$ rate is studied as well. We point out that for a given tree operator O_i, the contribution from its Fiertz transformed operator, tends to cancel the internal W-emission amplitude induced from O_i. This explains why most previous model calculations predicted too large rates as the above consideration was not taken into account.

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1. Introduction

Recently, LHCb collaboration found the evidence for the charmless two-body baryonic mode, $\overline{B}^0 \to p\bar{p}$, with $\mathscr{B}(\overline{B}^0 \to p\overline{p}) = (1.47^{+0.62+0.35}_{-0.51-0.14}) \times 10^{-8}$ and $\mathscr{B}(\overline{B}^0_s \to p\overline{p}) = (2.84^{+2.03+0.85}_{-1.68-0.18}) \times 10^{-8}$. [1] The two-body baryonic decays are in general non-factorizable, which makes the theoretical study difficult. In general, one has to resort to model calculations. There are pole model, sum rule, model, related studies [2, 3]. Predictions from various models usually differ a lot, and explicit calculations usually give too large rates on the charmless modes. For example, all existing predictions on $\overline{B}^0 \to p\bar{p}$ rate are off by several order of magnitude comparing to the LHCb result [1, 2, 3].

Given that direct computation is not reliable at this moment, it is thus useful to use symmetry related approach to relate modes and make use of the newly measured $B \to p\bar{p}$ rate to give information on other modes. In [4], we use the quark diagram or the so-called topological approach to the charmless two-body baryonic decays and obtained predictions on relative rates. With the evidence on the $\overline{B}^0 \to p\bar{p}$ mode, it is timely to revisit the subject. In [5] we extended the previous work to include all topological amplitudes, where only dominant ones were considered previously [4]. We can now make use of the newly observed $\overline{B}^0 \to p\bar{p}$ rate to extract information on decay amplitudes and proceed to provide predictions on rates of all other charmless two-body baryonic modes of ground state octet and decuplet baryons. The number of independent amplitudes are significantly reduced in the large m_B limit. We will extract the asymptotic amplitude from the $\overline{B}^0 \to p\bar{p}$ data. Furthermore, the results can be systematically improved when the measurements of other modes become available in the future.

2. Results on two-body charmless baryonic B decay amplitudes and rates

There are more than 160 $\overline{B} \to \mathscr{D}\overline{\mathscr{D}}$, $\mathscr{D}\overline{\mathscr{B}}$, $\mathscr{B}\overline{\mathscr{D}}$, $\mathscr{B}\overline{\mathscr{B}}$ decay amplitudes [5]. We show a few of them as examples here:

$$\begin{aligned}
A(\bar{B}^0 \to \Delta^0\overline{\Delta^0}) &= 2T_{\mathscr{D}\overline{\mathscr{D}}} + 4P_{\mathscr{D}\overline{\mathscr{D}}} + \frac{2}{3}P_{EW\mathscr{D}\overline{\mathscr{D}}} + 2E_{\mathscr{D}\overline{\mathscr{D}}} + 18PA_{\mathscr{D}\overline{\mathscr{D}}}, \\
A(B^- \to \Sigma^{*+}\overline{\Delta^{++}}) &= 2\sqrt{3}T'_{\mathscr{D}\overline{\mathscr{D}}} + 2\sqrt{3}P'_{\mathscr{D}\overline{\mathscr{D}}} + \frac{4}{\sqrt{3}}P'_{EW\mathscr{D}\overline{\mathscr{D}}} + 2\sqrt{3}A'_{\mathscr{D}\overline{\mathscr{D}}}, \\
A(B^- \to p\overline{\Delta^{++}}) &= -\sqrt{6}(T_{1\mathscr{B}\overline{\mathscr{D}}} - 2T_{2\mathscr{B}\overline{\mathscr{D}}}) + \sqrt{6}P_{\mathscr{B}\overline{\mathscr{D}}} + 2\sqrt{\frac{2}{3}}P_{1EW\mathscr{B}\overline{\mathscr{D}}} + \sqrt{6}A_{\mathscr{B}\overline{\mathscr{D}}}, \\
A(\bar{B}^0 \to \Xi^-\overline{\Sigma^{*-}}) &= \sqrt{2}P'_{\mathscr{B}\overline{\mathscr{D}}} - \frac{\sqrt{2}}{3}P'_{1EW\mathscr{B}\overline{\mathscr{D}}}, \\
A(B^- \to \Delta^0\overline{p}) &= \sqrt{2}T_{1\mathscr{D}\overline{\mathscr{B}}} - \sqrt{2}P_{\mathscr{D}\overline{\mathscr{B}}} + \frac{\sqrt{2}}{3}(3P_{1EW\mathscr{D}\overline{\mathscr{B}}} + P_{2EW\mathscr{D}\overline{\mathscr{B}}}) - \sqrt{2}A_{\mathscr{D}\overline{\mathscr{B}}}, \\
A(\bar{B}^0 \to \Sigma^{*+}\overline{p}) &= \sqrt{2}T'_{2\mathscr{D}\overline{\mathscr{B}}} + \sqrt{2}P'_{\mathscr{D}\overline{\mathscr{B}}} + \frac{2\sqrt{2}}{3}P'_{2EW\mathscr{D}\overline{\mathscr{B}}}, \\
A(\bar{B}^0 \to p\overline{p}) &= -T_{2\mathscr{B}\overline{\mathscr{B}}} + 2T_{4\mathscr{B}\overline{\mathscr{B}}} + P_{2\mathscr{B}\overline{\mathscr{B}}} + \frac{2}{3}P_{2EW\mathscr{B}\overline{\mathscr{B}}} - 5E_{1\mathscr{B}\overline{\mathscr{B}}} + E_{2\mathscr{B}\overline{\mathscr{B}}} - 9PA_{\mathscr{B}\overline{\mathscr{B}}}, \\
A(\bar{B}^0_s \to p\overline{p}) &= -5E'_{1\mathscr{B}\overline{\mathscr{B}}} + E'_{2\mathscr{B}\overline{\mathscr{B}}} - 9PA'_{\mathscr{B}\overline{\mathscr{B}}}.
\end{aligned} \tag{2.1}$$

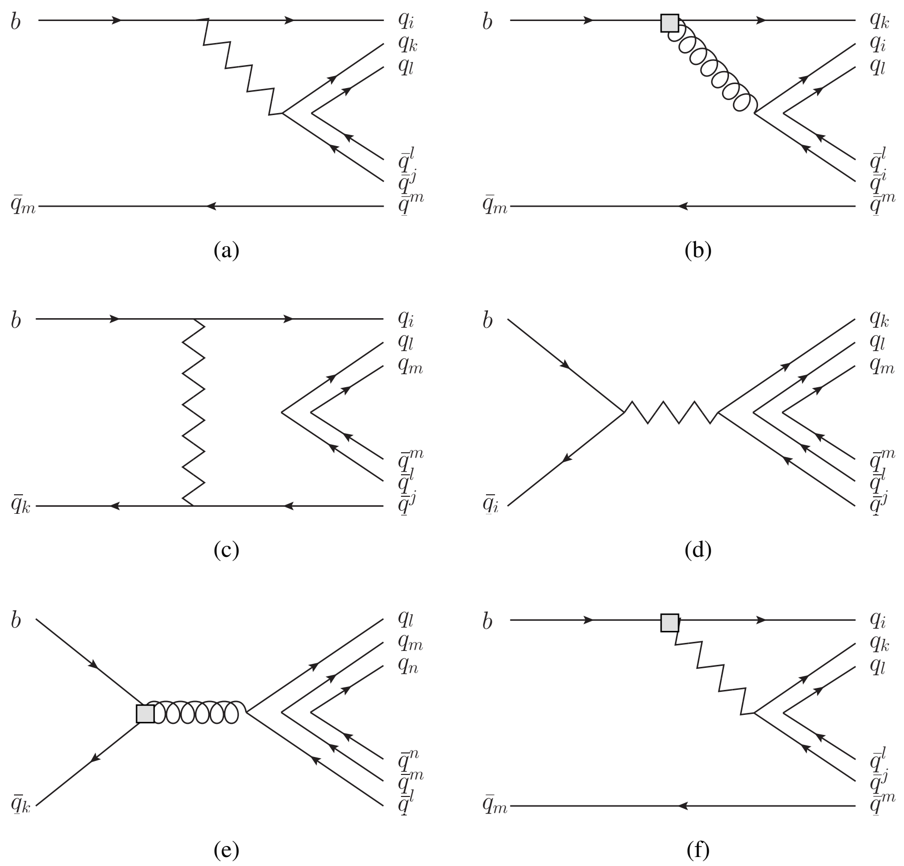

Figure 1: Pictorial representation of (a) T (tree), (b) P (penguin), (c) E (W-exchange), (d) A (annihilation), (e) PA (penguin annihilation) and (f) P_{EW} (electroweak penguin) amplitudes in $\overline{B}$ to baryon pair decays. These are flavor flow diagrams.

Relations on amplitudes, rates and CP violations can be obtained [5]. There are in general more than one tree and one penguin amplitudes in the baryonic decays.

By considering the chirality nature of weak interaction and asymptotic relations [6], the number of independent amplitudes is significantly reduced [4]. Asymptotically, there are only one tree, one penguin and one electroweak penguin amplitudes, which are estimated to be

$$\begin{aligned}
T^{(\prime)} &= V_{ub}V^*_{ud(s)}\frac{G_f}{\sqrt{2}}(c_1+c_2)\chi\bar{u}'(1-\gamma_5)v,\\
P^{(\prime)} &= -V_{tb}V^*_{td(s)}\frac{G_f}{\sqrt{2}}[c_3+c_4+\kappa_1 c_5+\kappa_2 c_6]\chi\bar{u}'(1-\gamma_5)v,\\
P^{(\prime)}_{EW} &= -\frac{3}{2}V_{tb}V^*_{td(s)}\frac{G_f}{\sqrt{2}}[c_9+c_{10}+\kappa_1 c_7+\kappa_2 c_8]\chi\bar{u}'(1-\gamma_5)v. \qquad (2.2)
\end{aligned}$$

Note that the relative signs of $c_{1,3,9}$ and $c_{2,4,10}$ are fixed using the result of a recent study [7]. The unknown amplitude χ are fitted from the recent $\overline{B}^0 \to p\bar{p}$ data to be $\chi = (5.11^{+1.12}_{-1.02}) \times 10^{-3}$ GeV^2.

In reality the topological amplitudes are, however, not in the asymptotic limit. Corrections are expected and can be estimated as following. (i) The correction on $T^{(\prime)}_i$, $P^{(\prime)}_i$ and $P^{(\prime)}_{EWi}$ are

Table 1: Some decay rates for $\Delta S = 0, -1$, $\overline{B}_q \to \mathscr{D}\overline{\mathscr{D}}, \mathscr{B}\overline{\mathscr{D}}, \mathscr{D}\overline{\mathscr{B}}, \mathscr{B}\overline{\mathscr{B}}$ modes. Most of these modes have unsuppressed rates and good detectability, while a few of them are listed as to compare to experimental limits. Note that the $B^0 \to p\bar{p}$ rate is taken as the input of our numerical analysis. For the $B_s \to p\bar{p}$ rate see text for discussion.

Mode	$\mathscr{B}(10^{-8})$	Mode	$\mathscr{B}(10^{-8})$
$\overline{B}^0 \to \Delta^0\overline{\Delta^0}$	$5.64^{+6.42+2.03}_{-3.33-0.49}\pm 0.17$	$\overline{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$	$0.41^{+0.50+1.84}_{-0.25-0.41}\pm 0.03$
$B^- \to \Sigma^{*+}\overline{\Delta^{++}}$	$9.68^{+11.59+34.86}_{-5.74\ -8.94}\pm 0.04$	$B^- \to \Sigma^{*-}\overline{\Delta^0}$	$2.46^{+3.07+11.20}_{-1.53-2.46}\pm 0.01$
$B^- \to \Omega^-\overline{\Xi^{*0}}$	$6.30^{+7.84+28.62}_{-3.90-6.30}\pm 0.03$	$\overline{B}^0_s \to \Sigma^{*+}\overline{\Sigma^{*+}}$	$2.92^{+3.50+10.53+0.35}_{-1.73-2.70\ -0.33}$
$\overline{B}^0_s \to \Sigma^{*-}\overline{\Sigma^{*-}}$	$2.23^{+2.78+10.14+0.30}_{-1.38-2.23\ -0.28}$	$\overline{B}^0_s \to \Xi^{*0}\overline{\Xi^{*0}}$	$9.32^{+11.12+38.27+0.59}_{-5.61\ -9.08\ -0.58}$
$\overline{B}^0_s \to \Omega^-\overline{\Omega^-}$	$17.06^{+21.23+77.53+0.75}_{-10.58-17.06-0.73}$		
$B^- \to p\overline{\Delta^{++}}$	$7.50^{+20.65+0.73}_{-6.66\ -0.19}\pm 0.10$	$\overline{B}^0_s \to p\overline{\Sigma^{*+}}$	$2.28^{+6.28+0.22}_{-2.03-0.06}\pm 0$
	(< 14) [10]		
$\overline{B}^0 \to \Xi^-\overline{\Sigma^{*-}}$	$0.82^{+1.02+3.74}_{-0.51-0.82}\pm 0$		
$B^- \to \Lambda\overline{\Delta^+}$	$0.17^{+0.22+0.02}_{-0.11-0.01}\pm 0$	$\overline{B}^0 \to \Lambda\overline{\Delta^0}$	$0.16^{+0.20+0.02}_{-0.10-0.01}\pm 0$
	(< 82) [9]		(< 93) [9]
$B^- \to \Delta^0\overline{p}$	$2.48^{+2.84+0.22}_{-1.47-0.04}\pm 0.03$	$\overline{B}^0_s \to \Delta^0\overline{\Lambda}$	$3.20^{+3.65}_{-1.89}\pm 0.00\pm 0$
	(< 138) [10]		
$\overline{B}^0 \to \Sigma^{*+}\overline{p}$	$1.27^{+1.52+4.56}_{-0.75-1.17}\pm 0$	$\overline{B}^0 \to \Omega^-\overline{\Xi^-}$	$2.01^{+2.60+9.50}_{-1.30-2.09}\pm 0$
$\overline{B}^0 \to \Xi^{*0}\overline{\Lambda}$	$1.64^{+1.97+5.92}_{-0.98-1.52}\pm 0$		
$\overline{B}^0 \to p\overline{p}$	$1.47^{+4.05+0.14+0.15}_{-1.31-0.04-0.14}$	$\overline{B}^0 \to \Lambda\overline{\Lambda}$	$0^{+0.33}_{-0}\pm 0^{+0.0006}_{-0}$
	$(1.47^{+0.62+0.35}_{-0.51-0.14})$ [1]		(< 32) [8]
$B^- \to \Lambda\overline{p}$	$10.03^{+14.14+42.79}_{-6.62\ -9.91}\pm 0.05$	$\overline{B}^0_s \to p\overline{p}$	$0\pm 0\pm 0^{+0.004}_{-0}$
	(< 32) [8]		$(2.84^{+2.03+0.85}_{-1.68-0.18})$ [1]
$\overline{B}^0_s \to \Lambda\overline{\Lambda}$	$6.33^{+8.71+26.02}_{-4.11-6.17}\pm 0.27$		

estimated to be of order $m_{\mathscr{B}}/m_B$ (the baryon and B meson mass ratio), which is roughly, 0.2. (ii) Furthermore, since the Fierz transformation of $O_{5,6,7,8}$ are different from $O_{1,2,3,4}$, the relation of the contributions from these two sets of operators may be distorted when we move away from the asymptotic limit. We assign a coefficient κ in front of $c_{5(7)}$ and $c_{6(8)}$ in Eq. (2.2) with κ having a $-200 \sim +100\%$ uncertainty: $\kappa_{1,2} = 1^{+1}_{-2}$, to model the correction. (iii) For subleading terms, such as annihilation, penguin annihilation, exchange amplitude, we have $E_i^{(\prime)} \equiv \eta_i \frac{f_B}{m_B}\frac{m_{\mathscr{B}}}{m_B}T^{(\prime)}$, $A_j^{(\prime)} \equiv \eta_j \frac{f_B}{m_B}\frac{m_{\mathscr{B}}}{m_B}T^{(\prime)}$, $PA_k^{(\prime)} \equiv \eta_k \frac{f_B}{m_B}\frac{m_{\mathscr{B}}}{m_B}P^{(\prime)}$, where the ratio f_B/m_B is from the usual estimation, the factor $m_{\mathscr{B}}/m_B$ is from the chirality structure, and $|\eta_{i,j,k}|$ are estimated to be of order 1. Explicitly, we take $0 \leq |\eta_{i,j,k}| \leq |\eta| = 1$, where we set the bound $|\eta|$ to 1 in our numerical results.

In Table 1 rates of some modes that will cascadely decay to all charged final states and have large decay rates are shown. First of all it is interesting to note that all of the predicted rates satisfy existing data. This is a non-trivial fact as we only make use of $B^0 \to p\bar{p}$ rate. (i) For $\overline{B}_q \to \mathscr{D}\overline{\mathscr{D}}$, $\Delta S = 0$ decays, we have $\overline{B}^0 \to \Delta^0\overline{\Delta^0}$ and $\overline{B}^0 \to \Sigma^{*-}\overline{\Sigma^{*-}}$ having rates at or close to 10^{-8} level. (ii) For $\Delta S = -1$, $\overline{B}_q \to \mathscr{D}\overline{\mathscr{D}}$ decays, $B^- \to \Sigma^{*+}\overline{\Delta^{++}}$, $\Sigma^{*-}\overline{\Delta^0}$, $\Omega^-\overline{\Xi^{*0}}$ and $\overline{B}^0_s \to \Omega^-\overline{\Omega^-}$, $\Xi^{*0}\overline{\Xi^{*0}}$, $\Sigma^{*0}\overline{\Sigma^{*-}}$, $\Sigma^{*+}\overline{\Sigma^{*+}}$ decays have rates ranging from 10^{-8} to 10^{-7}, where the $\overline{B}^0_s \to \Omega^-\overline{\Omega^-}$ decay has the largest rate. (iii) For $\Delta S = 0$, $\overline{B}_q \to \mathscr{B}\overline{\mathscr{D}}$ decays, $\overline{B}^0_s \to p\overline{\Sigma^{*+}}$ has rate at 10^{-8} order, while the predicted

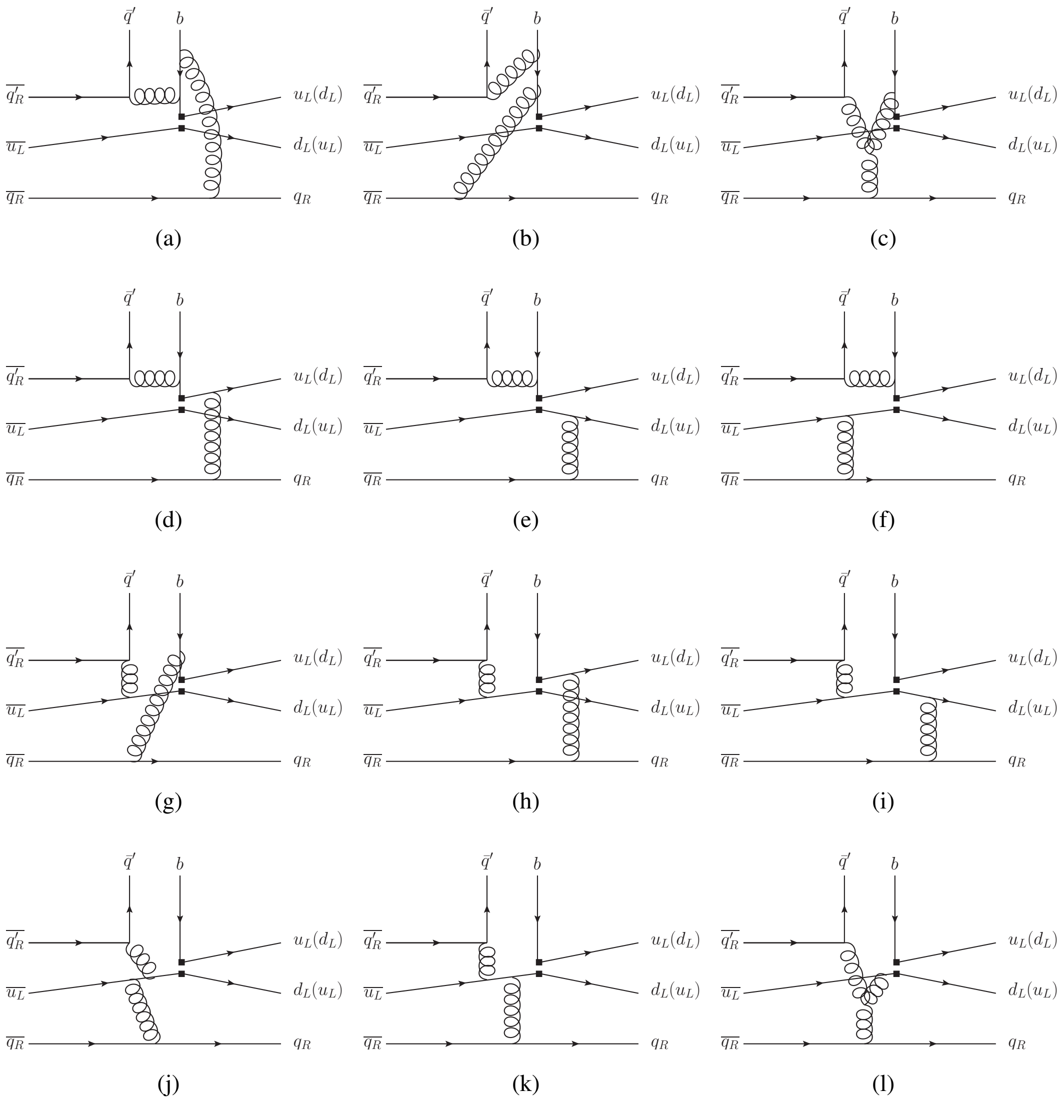

Figure 2: (a) to (l): Feynman diagrams of internal W-emission induced by O_1^u. Those in parenthesis are the corresponding diagrams using the Fiertz transformed O_1^u (i.e. O'^u_1). These diagrams canceled.

$B^- \to p\overline{\Delta^{++}}$ rate is close to the experimental upper bound and should be searchable in the near future. (iv) For $\Delta S = -1$, $\overline{B}_q \to \mathscr{B}\overline{\mathscr{D}}$ decays, $\overline{B}^0 \to \Xi^- \overline{\Sigma^{*-}}$ decay rate is at 10^{-8} order. (v) For $\Delta S = 0$, $\overline{B}_q \to \mathscr{D}\overline{\mathscr{B}}$ decays, $B^- \to \Delta^0 \overline{p}$ and $\overline{B}{}^0_s \to \Delta^0 \overline{\Lambda}$ decays have rates of order 10^{-8}. (vi) For $\Delta S = -1$, $\overline{B}_q \to \mathscr{D}\overline{\mathscr{B}}$ decays, $\overline{B}^0 \to \Sigma^{*-}\overline{p}$, $\Omega^- \overline{\Xi^-}$ and $\Xi^{*0}\overline{\Lambda}$ rates are at the order of 10^{-8}. (vii) For $\Delta S = 0$, $\overline{B}_q \to \mathscr{B}\overline{\mathscr{B}}$ decays, $\overline{B}^0 \to p\bar{p}$ is the most accessible mode. It is not surprise that it is the first $\overline{B}_q \to \mathscr{B}\overline{\mathscr{B}}$ mode being found. (viii) For $\Delta S = -1$, $\overline{B}_q \to \mathscr{B}\overline{\mathscr{B}}$ decays, $B^- \to \Lambda\bar{p}$ and $\overline{B}{}^0_s \to \Lambda\overline{\Lambda}$ have rates at 10^{-7} level and do not lost much in cascade decays. They are interesting modes to search for. In fact, the $B^- \to \Lambda\overline{p}$ decay could be the second $\overline{B} \to \mathscr{B}\overline{\mathscr{B}}$ mode to be observed as its rate is close to the present experimental upper limit. The predicted $\overline{B}{}^0_s \to p\bar{p}$ rate is several order smaller than the present experimental result. The central value of the experimental result can be reproduced only with a unnaturally scaled up $|\eta|$. By naively scaling up $|\eta|$, we find that the contribution of the "subleading terms" (term with η) will give rate five time of the tree contribution in $\overline{B}^0 \to p\bar{p}$ rate. We need more data to clarify the situation. The analysis presented in this work can be systematically improved when more measurements on decay rates become available.

3. Smallness of Tree-dominated Charmless Two-body Baryonic B Decay Rates

All the earlier model predictions on $B^0 \to p\bar{p}$ rates are too large compared with experiment [2, 3]. This charmless decay is suppressed relative to $\bar{B}^0 \to \Lambda_c^+ \bar{p}$ by the Cabibbo-Kobayashi-Maskawa matrix elements $|V_{ub}/V_{cb}|^2$ and is subject to a possible dynamical suppression, $\mathscr{B}(\overline{B}^0 \to p\bar{p}) = \mathscr{B}(\overline{B}^0 \to \Lambda_c^+ \bar{p})|V_{ub}/V_{cb}|^2 \times f_{dyn} \sim 2\times 10^{-7} \times f_{dyn}$. The data demands a suppression factor of $f_{dyn} \sim 0.1$. In [7], we pointed out that for a given tree operator O_i, the contribution from its Fiertz transformed operator O_i', an effect missed in the literature, has to be taken into account. Feynman diagrams responsible for internal W-emission can be classified into two categories. We found that diagrams in the first category (see Fig. 2) induced by O_i are completely canceled by that from O_i', while no cancellation occurs for diagrams in the second category. The cancellation is ascribed to the fact that the wave function of low-lying baryons are symmetric in momenta and the quark flavor with the same chirality, but antisymmetric in color indices. We advocate that the partial cancellation accounts for the smallness of the tree-dominated charmless two-body baryonic B decays which can be checked by realistic pQCD calculations. A by product of the study is that, contrary to the claim in the literature, the internal W-emission tree amplitude should be proportional to the Wilson coefficient combination $c_1 + c_2$ rather than $c_1 - c_2$.

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