1. INTRODUCTION

In this talk we would like to give an overview of the experimental and theoretical status of exclusive baryonic $B$ decays. The announcement of the first measurement of the decay modes $pp\pi^\pm$ and $p\bar{p}\pi^+\pi^-$ in $B$ decays by ARGUS [11] has stimulated extensive theoretical studies during the period of 1988-1992. However, experimental and theoretical activities towards baryonic $B$ decays suddenly faded away after 1992. This situation was dramatically changed in the past six years. Interest in this area was revitalized by many new measurements at CLEO, Belle and BaBar followed by active theoretical studies.

### Table 1

<table>
<thead>
<tr>
<th>Decay</th>
<th>Belle [234]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda_c^+\bar{p}$</td>
<td>$2.19^{+0.96}_{-0.90} \pm 0.32 \pm 0.57$</td>
</tr>
<tr>
<td>$\Lambda_c^-\Delta^-$</td>
<td>$&lt; 1.9$</td>
</tr>
<tr>
<td>$\Lambda_c^+\Delta_0(1600)^-$</td>
<td>$5.90^{+1.03}_{-0.96} \pm 0.55 \pm 1.53$</td>
</tr>
<tr>
<td>$\Lambda_c^+\Delta_0(2420)^-$</td>
<td>$4.70^{+0.92}_{-0.74} \pm 0.43 \pm 1.22$</td>
</tr>
<tr>
<td>$\Sigma^0\bar{p}$</td>
<td>$3.67^{+0.74}_{-0.66} \pm 0.36 \pm 0.95$</td>
</tr>
<tr>
<td>$\Sigma_c(2520)^0\bar{p}$</td>
<td>$&lt; 2.7$</td>
</tr>
<tr>
<td>$\Xi_c^0(\Xi^-\pi^\pm)\Lambda_c^-$</td>
<td>$4.8^{+0.9}_{-0.9} \pm 1.1 \pm 1.2$</td>
</tr>
<tr>
<td>$\Xi_c^+(\Xi^-\pi^+\pi^-)\Lambda_c^+$</td>
<td>$9.3^{+2.7}_{-2.8} \pm 1.9 \pm 2.4$</td>
</tr>
</tbody>
</table>

1 The preliminary BaBar result for $\bar{B}^0 \rightarrow \Lambda_c^+\bar{p}$ is $(2.15 \pm 0.36 \pm 0.13 \pm 0.56) \times 10^{-5}$ [6].

### Table 2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp$</td>
<td>$2.7 \times 10^{-7}$</td>
<td>$4.1 \times 10^{-7}$</td>
<td>$1.4 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Delta\Lambda$</td>
<td>$6.9 \times 10^{-7}$</td>
<td>$1.2 \times 10^{-6}$</td>
<td></td>
</tr>
<tr>
<td>$\Delta\bar{p}$</td>
<td>$4.9 \times 10^{-7}$</td>
<td>$1.5 \times 10^{-6}$</td>
<td></td>
</tr>
<tr>
<td>$\Lambda(1520)\bar{p}$</td>
<td>$1.5 \times 10^{-5}$</td>
<td>$1.5 \times 10^{-4}$</td>
<td>$1.5 \times 10^{-4}$</td>
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<tr>
<td>$p\Delta^-$</td>
<td>$3.8 \times 10^{-4}$</td>
<td>$1.1 \times 10^{-4}$</td>
<td>$1.1 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\Delta^0\bar{p}$</td>
<td>$1.5 \times 10^{-4}$</td>
<td>$1.5 \times 10^{-4}$</td>
<td>$1.5 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

### 2. EXPERIMENTAL STATUS

#### 2.1. Two-body decay

The experimental results for two-body baryonic $\bar{B}^0$ and $B^-$ decays are summarized in Tables 1 and 2 for charmful and charmless decays, respectively. It is clear that the present limit on charmless ones has been pushed to the level of $10^{-7}$. In contrast, four of the charmful 2-body baryonic $B$ decays have been observed in recent years; among them $\bar{B}^0 \rightarrow \Lambda_c^+\bar{p}$ is the first observation of the 2-body baryonic $B$ decay mode by Belle [2]. The BaBar’s preliminary result for this mode agrees well with Belle (see [5] for details). The decays with two charm baryons in the final state were measured by Belle recently [11]. Taking the theoretical estimates (see e.g. Table III of [10]), $B(\Xi_c^0 \rightarrow \Xi^-\pi^+) \approx 1.3\%$ and
Table 3
Branching ratios (in units of $10^{-6}$) of charmless three-body baryonic $B$ decays. Except for the $p\bar{p}K^-$ mode, BaBar results are all preliminary.

<table>
<thead>
<tr>
<th>Mode</th>
<th>BaBar [5,7]</th>
<th>Belle [15,16]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p\bar{p}K^-$</td>
<td>$6.7 \pm 0.5 \pm 0.4$</td>
<td>$5.30^{+0.39}_{-0.38} \pm 0.58$</td>
</tr>
<tr>
<td>$p\bar{p}K^0$</td>
<td>$2.95 \pm 0.53 \pm 0.26$</td>
<td>$1.20^{+0.32}_{-0.22} \pm 0.14$</td>
</tr>
<tr>
<td>$p\bar{p}K^-$</td>
<td>$4.94 \pm 1.66 \pm 1.00$</td>
<td>$10.31^{+1.62}_{-1.34} \pm 2.77 \pm 1.65$</td>
</tr>
<tr>
<td>$p\bar{p}K^+$</td>
<td>$1.28 \pm 0.56_{-0.17}^{+0.18}$</td>
<td>$&lt; 7.6$</td>
</tr>
<tr>
<td>$p\bar{p}\pi^-$</td>
<td>$1.24 \pm 0.32 \pm 0.10$</td>
<td>$3.06^{+0.73}_{-0.62} \pm 0.37$</td>
</tr>
<tr>
<td>$\Lambda\bar{p}\pi^+$</td>
<td>$3.30 \pm 0.53 \pm 0.31$</td>
<td>$3.27^{+0.62}_{-0.51} \pm 0.39$</td>
</tr>
<tr>
<td>$\Lambda\bar{K}^-$</td>
<td>$2.91^{+0.90}_{-0.70} \pm 0.38$</td>
<td>$&lt; 2.8$</td>
</tr>
<tr>
<td>$\Lambda\Lambda\pi^+$</td>
<td>$&lt; 0.82$</td>
<td>$&lt; 3.8$</td>
</tr>
<tr>
<td>$\Sigma^0\bar{p}\pi^+$</td>
<td>$&lt; 3.8$</td>
<td></td>
</tr>
</tbody>
</table>

$B(\Xi^+_c \to \Xi^0\pi^+) \approx 3.9\%$ together with the experimental measurement $B(\Xi^+_c \to \Xi^0\pi^+)/B(\Xi^+_c \to \Xi^-\pi^+\pi^+) = 0.55 \pm 0.16$ [11], it follows from Table II that

$$B(B^- \to \Xi^0\bar{\Lambda}_c^-) \approx 4.8 \times 10^{-3},$$
$$B(\bar{B}^0 \to \Xi^+_c\Lambda^-) \approx 1.2 \times 10^{-3}.$$ (1)

Therefore, the two-body doubly charmed baryonic $B$ decay $B \to \bar{B}_c\bar{B}_c$ has a branching ratio of order $10^{-3}$. Hence, we have the pattern

$$B_c\bar{B}_c (\sim 10^{-3}) \gg B_c\bar{B} (\sim 10^{-5})$$
$$\gg B_1\bar{B}_2 (\lesssim 10^{-7})$$ (2)

for two-body baryonic $B$ decays.

2.2. Three-body decay

The measured branching ratios of charmful baryonic decays with one charmed meson or one charmed baryon or two charmed baryons in the final state are summarized in Table IV of [12].

In general, Belle results are slightly smaller than the CLEO measurements. The decay $B^- \to J/\psi\Lambda\bar{p}$ was first measured by BaBar [13] and confirmed by Belle recently [14]. In general, $B(B \to \bar{B}_c\bar{B}_cM) \sim O(10^{-3})$ and $B(B \to \bar{B}_1\bar{B}_2M) \sim O(10^{-4})$. The decay $B \to J/\psi\Lambda\bar{p}$ with the branching ratio of order $10^{-5}$ is suppressed due to color suppression.

For the charmless case, Belle [15] has observed 6 different modes while BaBar has tried to catch up, see Table 3. The channel $B^- \to p\bar{p}K^-$ announced by Belle nearly four years ago [17] is the first observation of charmless baryonic $B$ decays. Recently Belle has studied the baryon angular distributions in the baryon-antibaryon pair rest frame [13], while BaBar has measured the Dalitz plot asymmetries in the decay $B \to p\bar{p}h$ with $h = K^{(*)-0}, \pi^-$. These measurements provide valuable information on the decay dynamics.

It is naively expected that $p\bar{p}K^{(*)-} < p\bar{p}K^-$ due to the absence of $a_6$ and $a_8$ penguin terms contributing to the former and that $p\bar{p}K^{(*)0} > p\bar{p}K^{(*)0}$ due to the absence of external $W$-emission in the latter. From Table III we see that these expectations are confirmed except that the Belle measurement of $p\bar{p}K^{(*)-}$ seems to be too large.

There are two common and unique features for three-body $B \to \bar{B}_1\bar{B}_2M$ decays: (i) the baryon-antibaryon invariant mass spectrum is peaked near the threshold area, and (ii) many three-body final states have rates larger than their two-body counterparts; that is, $\Gamma(B \to \bar{B}_1\bar{B}_2M) > \Gamma(B \to \bar{B}_1\bar{B}_2)$. The low-mass enhancement effect indicates that the $B$ meson is preferred to decay into a baryon-antibaryon pair with low invariant mass accompanied by a fast recoil meson. As for the above-mentioned second feature, it is now well established experimentally that

$$B(B^- \to p\bar{p}K^-) \gg B(\bar{B}^0 \to p\bar{p}),$$
$$B(\bar{B}^0 \to \Lambda\bar{p}\pi^-) \gg B(B^- \to \Lambda\bar{p}),$$
$$B(B^- \to \Lambda^+_c\bar{p}\pi^-) \gg B(\bar{B}^0 \to \Lambda^+_c\bar{p}),$$
$$B(B^- \to \Sigma^0_c\bar{p}\pi^0) \gg B(B^- \to \Sigma^0_c\bar{p}).$$ (3)

This phenomenon can be understood in terms of the threshold effect, namely, the invariant mass of the dibaryon is preferred to be close to the threshold. The configuration of the two-body decay $B \to \bar{B}_1\bar{B}_2$ is not favorable since its invariant mass is $m_B$. In $B \to \bar{B}_1\bar{B}_2M$ decays, the effective mass of the baryon pair is reduced as the emitted meson can carry away much energies.

An enhancement of the dibaryon invariant mass near threshold has been observed in several charmless and charmful decays. Threshold
enhancement was first conjectured by Hou and Soni [18], motivated by the CLEO measurement of \(B \to D^* \bar{p} n\) and \(D^* p \bar{p} \pi\) [19]. They argued that in order to have larger baryonic \(B\) decays, one has to reduce the energy release and at the same time allow for baryonic ingredients to be present in the final state. This is indeed the near threshold effect mentioned above. Of course, one has to understand the underlying origin of the threshold peaking effect. Hence, the smallness of the two-body baryonic decay \(B \to B_1 \bar{B}_2\) has to do with its large energy release.

3. Theoretical Progress

3.1. Two-body decay

The quark diagrams for two-body baryonic \(B\) decays consist of internal \(W\)-emission diagram, \(b \to d(s)\) penguin transition, \(W\)-exchange for the neutral \(B\) meson and \(W\)-annihilation for the charged \(B\). Just as mesonic \(B\) decays, \(W\)-exchange and \(W\)-annihilation are expected to be helicity suppressed. Therefore, the two-body baryonic \(B\) decay \(B \to B_1 \bar{B}_2\) receives the main contributions from the internal \(W\)-emission diagram for tree-dominated modes and the penguin diagram for penguin-dominated processes. It should be stressed that, contrary to mesonic \(B\) decays, internal \(W\) emission in baryonic \(B\) decays is not necessarily color suppressed. This is because the baryon wave function is totally anti-symmetric in color indices.

Consider the charmed modes \(\bar{B} \to \Xi_c \bar{L}_c\) and \(\bar{B} \to \Lambda_c \bar{p}\). They have the same CKM angles apart from a sign difference. Therefore, it is expected that

\[
B(\bar{B}^0 \to \Lambda_c^+ \bar{p}) = B(\bar{B}^0 \to \Xi_c^+ \bar{L}_c^-) \times (\text{dynamical suppression}),
\]

where CKM stands for the relevant CKM angles and the dynamical suppression arises from the larger c.m. momentum in \(\Lambda_c^+ \bar{p}\) than in \(\Xi_c \bar{L}_c\). Eq. 4 implies that the dynamical suppression effect is of order \(10^{-2}\). Likewise,

\[
\mathcal{B}(B^- \to \Lambda \bar{p}) = \frac{\mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{p})|V_{ub}/V_{cb}|^2}{(\text{dynamical suppression})^3} \sim 2 \times 10^{-7} (\text{dynamical suppression})^3.
\]

If the dynamical suppression of \(\Lambda \bar{p}\) relative to \(\Lambda_c \bar{p}\) is similar to that of \(\Lambda_c \bar{p}\) relative to \(\Xi_c \bar{L}_c\), the branching ratio of the charmless two-body baryonic \(B\) decays can be even as small as \(10^{-9}\). If this is the case, then it will be hopeless to see any charmless two-body baryonic \(B\) decays.

Earlier calculations based on QCD sum rules [20] or the diquark model [21] all predict that \(\mathcal{B}(\bar{B} \to \Xi_c \bar{L}_c) \approx \mathcal{B}(\bar{B} \to \Xi_c \bar{N})\), which is in strong disagreement with experiment. This implies that some important dynamical suppression effect for the \(\Xi_c \bar{N}\) production with respect to \(\Xi_c \bar{L}_c\) is missing in previous studies. Recently, this issue was investigated in [22]. Since the energy release is relatively small in charmful baryonic \(B\) decay, the \(3\,P_0\) model for \(q \bar{q}\) production is more relevant.

In the work of [22], the possibility that the \(q \bar{q}\) pair produced via light meson exchanges such as \(\sigma\) and pions is considered. The \(q \bar{q}\) pair created from soft nonperturbative interactions tends to be soft. For an energetic proton produced in 2-body \(B\) decays, the momentum fraction carried by its quark is large, \(\sim \mathcal{O}(1)\), while for an energetic charmed baryon, its momentum is carried mostly by the charmed quark. As a consequence, the doubly charmed baryon state such as \(\Xi_c \bar{L}_c\) has a configuration more favorable than \(\Lambda_c \bar{p}\). For the latter, two hard gluons are needed to produce an energetic antiproton as noticed before: one hard gluon for kicking the spectator quark of the \(B\) meson to make it energetic and the other for producing the hard \(q \bar{q}\) pair. It is thus expected that \(\Gamma(\bar{B} \to B_c \bar{N}) \ll \Gamma(\bar{B} \to \Xi_c \bar{L}_c)\) as the former is suppressed by order of \(\alpha_s^4\). This accounts for the dynamical suppression of the \(\Lambda_c \bar{p}\) production relative to \(\Xi_c \bar{L}_c\).

3.2. Three-body decay

Contrary to the two-body baryonic \(B\) decay, the three-body decays do receive factorizable contributions that fall into two categories: (i) the transition process with a meson emission, \(\langle M | \bar{q}_3 q_2 | 0 \rangle \langle B_1 \bar{B}_2 | \bar{q}_1 b | B \rangle\), and (ii) the current-induced process governed by the factorizable amplitude \(\langle B_1 \bar{B}_2 | \bar{q}_1 q_2 | 0 \rangle \langle M | \bar{q}_3 b | B \rangle\). The two-body matrix element \(\langle B_1 \bar{B}_2 | \bar{q}_1 q_2 | 0 \rangle\) in the latter process can be either related to some measurable quantities or calculated using the quark model.
The current-induced contribution to three-body baryonic $B$ decays has been discussed in various publications \cite{23,24,25}. On the contrary, it is difficult to evaluate the three-body matrix element in the transition process and in this case one can appeal to the pole model \cite{20,21,22}.

Current-induced three-body baryonic $B$ decays such as $B^0 \to \Lambda \bar{p} \pi^+$ provide an ideal place for understanding the threshold enhancement effects. It receives the dominant factorizable contributions from tree and penguin diagrams with the amplitude

$$A(B^0 \to \Lambda \bar{p} \pi^+) = \frac{G_F}{\sqrt{2}} \langle \pi^+ | (\bar{u}b) | B^0 \rangle \int \left( V_{ub} V_{ts}^* a_1 - V_{tb} V_{ts}^* a_4 \right) \langle \Lambda | (\bar{s}u) | 0 \rangle + 2 a_6 V_{tb} V_{ts}^* \left( \frac{p_{\Lambda} + p_{\bar{p}}}{m_b - m_u} \right) \langle \Lambda | \bar{s}(1 + \gamma_5) u | 0 \rangle \right).$$

Based on the pQCD counting rule, the vacuum to $\Lambda p$ form factor has the asymptotic form

$$F(t) \to \frac{a}{t^2} + \frac{b}{t^3}$$

in the limit of large $t$. The threshold enhancement effect is thus closely related to the asymptotic behavior of various form factors, namely, they fall off fast with the dibaryon invariant mass. A detailed study in \cite{25} shows that the differential decay rate for $\Lambda \bar{p} \pi^+$ should be in the form of a parabola that opens downward. This is indeed confirmed by experiment \cite{10} the pion has no preference for its correlation with the $\Lambda$ or the $\bar{p}$.

The fragmentation picture advocated in \cite{21} provides some qualitative descriptions of the correlation in three-body baryonic $B$ decays. However, some of the predictions based on the fragmentation mechanism are not borne out by experiment. For example, the argument in \cite{21} that the $\bar{p}$ and $\pi^+$ are neighbors in the fragmentation chain of $B^0 \to \Lambda \bar{p} \pi^+$ so that the $\pi^+$ is correlated more strongly to the $\bar{p}$ than to the $\Lambda$ will lead to an asymmetric angular distribution which is opposite to what is seen experimentally.

Apart from the purely transition-induced decays such as $B^0 \to D^{*(+)0} \bar{p} p, B^0 \to \Sigma^{(*)0} + \bar{p} \pi^-$, most other decays receive both current- and transition-induced contributions. In the absence of theoretical guidance for the form factors in the three-body matrix element $(B_1 B_2 | (\bar{q}_1 b) | B)$, one may consider a phenomenological pole model at the hadron level as put forward in \cite{20}. The meson pole diagrams are usually related to the vacuum to $B_1 B_2$ transition form factors and hence responsible for threshold enhancement, whereas the baryon pole diagrams account for the correlation of the outgoing meson with the baryon. Indeed, a detailed analysis indicates that the baryon pole diagram always leads to an antibaryon tendency to emerge parallel to the outgoing meson in $B \to B_1 B_2 M$ decays \cite{12,30}. This feature has been confirmed in $\Lambda^+_c \bar{p} \pi^-$ \cite{3}, $p \bar{p} \pi^-$ \cite{31} and $\Lambda \bar{p} \gamma$ \cite{32} modes. However, the measured angular distribution in $B^- \to ppK^-$ turns out to be astonishing.

Based on the pole model and the intuitive argument, the $K^-$ in the $pp$ rest frame is expected to emerge parallel to $\bar{p}$. However, the Belle observation is other around \cite{10}: the $K^-$ is preferred to move collinearly with the proton in the $pp$ rest frame. BaBar \cite{7} has studied the Dalitz plot asymmetry in the invariant masses $m_{pK}$ and $m_{\bar{p}K}$ and found a result consistent with Belle. This puzzle could indicate that the $pp$ system is produced from some intermediate states, such as the glueball and the baryonium, a $pp$ bound state, which may change the correlation pattern. This possibility is currently under study in \cite{30}. (For a different treatment of the correlation puzzle in $B^- \to ppK^-$ decay, see \cite{33}.)

The three-body doubly charmed baryonic decay $B \to \Lambda_c \bar{\Lambda_c} K$ has been observed recently by Belle with the branching ratio of order $7 \times 10^{-4}$ \cite{34}. Since this mode is color-suppressed and its phase space is highly suppressed, the naive estimate of $B \sim 10^{-8}$ is too small by four to five orders of magnitude compared to experiment. It was originally conjectured in \cite{22} that the great suppression for the $\Lambda_c^+ \bar{\Lambda_c^-} K$ production can be alleviated provided that there exists a narrow hidden charm bound state with a mass near the $\Lambda_c \bar{\Lambda_c}$ threshold. This possibility is plausible, recalling

\footnote{A recent study of angular distributions in $B^- \to pp \pi^-$ \cite{35} indicates a correlation of the pion with the proton. This is opposite to what we expect. This has to be checked by future experiments at BaBar and Belle.}
that many new charmonium-like resonances with masses around 4 GeV starting with $X(3872)$ and so far ending with $Y(4260)$ have been recently observed by BaBar and Belle. This new state that couples strongly to the charmed baryon pair can be searched for in $B$ decays and in $p p$ collisions by studying the mass spectrum of $D^{(*)}D^{(*)}$ or $\Lambda_c\bar{\Lambda}_c$. However, no new resonance with a mass near the $\Lambda_c\bar{\Lambda}_c$ threshold was found by Belle (see Fig. 3 in version 2 of [34]). This implies the failure of naive factorization for this decay mode and may hint at the importance of nonfactorizable contributions such as final-state effects. For example, the weak decay $B \rightarrow D^{(*)}D^{(*)}$ followed by the rescattering $D^{(*)}D^{(*)} \rightarrow \Lambda_c\bar{\Lambda}_c K$ [35] or the decay $B \rightarrow \Xi\bar{\Lambda}_c$ followed by $\Xi\bar{\Lambda}_c \rightarrow \Lambda_c\bar{\Lambda}_c K$ may explain the large rate observed for $B \rightarrow \Lambda_c\bar{\Lambda}_c K$.

4. Radiative baryonic $B$ decays

Naively it appears that the bremsstrahlung process will lead to $\Gamma(B \rightarrow B s\gamma) \sim O(\alpha em)\Gamma(B \rightarrow B s\gamma) B$ with $\alpha em$ being an electromagnetic fine-structure constant and hence the radiative baryonic $B$ decay is further suppressed than the two-body counterpart, making its observation very difficult at the present level of sensitivity for $B$ factories. However, there is an important short-distance electromagnetic penguin transition $b \rightarrow s\gamma$. Owing to the large top quark mass, the amplitude of $b \rightarrow s\gamma$ is neither quark mixing nor loop suppressed. Moreover, it is largely enhanced by QCD corrections. As a consequence, the short-distance contribution due to the electromagnetic penguin diagram dominates over the bremsstrahlung.

Since a direct evaluation of this radiative decay is difficult as it involves an unknown 3-body matrix element $M_{\mu\nu} = \langle \Lambda p | s\bar{\mu}(1+\gamma_5)b | B^- \rangle$, we shall instead evaluate the corresponding diagrams known as pole diagrams at the hadron level (see Fig. 1). For $B^- \rightarrow \Lambda\bar{p}\gamma$, the relevant intermediate states are $\Lambda_b^{(s)}$, $\Sigma_b^{(s)}$, and $K^*$.

The predicted branching ratios for $B^- \rightarrow \Sigma^0\bar{p}\gamma$, $\Xi^0\Sigma^-\gamma$ and $\Xi^-\bar{\Lambda}\gamma$ decays are summarized in Table I [36]. For the decay rates of other modes, see [37]. It is interesting to notice that the $\Sigma^0\bar{p}\gamma$ mode, which was previously argued to be very suppressed due to the smallness of the strong coupling $g_{\Sigma_b}\rightarrow B^- p$ [37], receives the dominant contribution from the $K^*$ pole diagram and its branching ratio is consistent with that obtained in [38]. In contrast, the mode $\Xi^0\Sigma^-\gamma$ is dominated by the baryon pole contribution. Meson and baryon intermediate state contributions are comparable in $\Lambda\bar{p}\gamma$ and $\Xi^-\bar{\Lambda}\gamma$ modes except that they interfere constructively in the former but destructively in the latter. Recently, Belle [32] has made the first observation of radiative hyperon $B$ decay $B^- \rightarrow \Lambda\bar{p}\gamma$ with the result

$$B(B^- \rightarrow \Lambda\bar{p}\gamma) = (2.16^{+0.58}_{-0.20} \pm 0.20) \times 10^{-6}. \quad (8)$$

In addition to the first observation of $\Lambda\bar{p}\gamma$, the decay $B^- \rightarrow \Xi^0\Sigma^-\gamma$ at the level of $6 \times 10^{-7}$ may be accessible to $B$ factories in the future.

Besides the threshold enhancement effect observed in the differential branching fraction of $\Lambda\bar{p}\gamma$, Belle has also measured the angular distribution of the antiproton in the $\Lambda\bar{p}$ system and found that the $\Lambda$ tends to emerge opposite the direction of the photon. The angular asymmetry is measured by Belle to be $A = 0.36^{+0.23}_{-0.20}$ for $B^- \rightarrow \Lambda\bar{p}\gamma$ [32]. The meson pole diagram is responsible for low-mass enhancement and does not show a preference for the correlation between the baryon pair and the photon. Our prediction $A = 0.25$ (see Table I) is consistent with experiment.

Acknowledgement: I’m grateful to the organizers for this wonderful conference.

REFERENCES

Table 4
Branching ratios and angular asymmetries for radiative baryonic $B$ decays [36].

<table>
<thead>
<tr>
<th>Mode</th>
<th>Baryon pole</th>
<th>Meson pole</th>
<th>$\text{Br}(\text{total})$</th>
<th>Angular asymmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^- \to \Lambda p \gamma$</td>
<td>$7.9 \times 10^{-7}$</td>
<td>$9.5 \times 10^{-7}$</td>
<td>$2.1 \times 10^{-6}$</td>
<td>0.25</td>
</tr>
<tr>
<td>$B^- \to \Sigma^0 \pi^- \gamma$</td>
<td>$4.6 \times 10^{-9}$</td>
<td>$2.5 \times 10^{-7}$</td>
<td>$2.9 \times 10^{-7}$</td>
<td>0.07</td>
</tr>
<tr>
<td>$B^- \to \Xi^- \Lambda \gamma$</td>
<td>$1.6 \times 10^{-7}$</td>
<td>$2.4 \times 10^{-7}$</td>
<td>$2.2 \times 10^{-7}$</td>
<td>0.13</td>
</tr>
</tbody>
</table>

3. Belle Collaboration, N. Gabyshev et al., hep-ex/0409005
4. Belle Collaboration, R. Chistov et al., hep-ex/0510074
34. Belle Collaboration, N. Gabyshev et al., hep-ex/0508015