Baryonic $B$ Meson Decays

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Recent results on baryonic $B$ decays from the two $b$-factories, BABAR and Belle, are presented. These include studies of $B^+ \rightarrow p\bar{p}\pi^+$, $B^+ \rightarrow p\Lambda\gamma$ and $B^0 \rightarrow p\Lambda\pi^-$; observations of $B^+ \rightarrow p\Lambda\pi^0$, $B \rightarrow \Lambda^+_c \bar{\Lambda}_c K$, and $B^+ \rightarrow \Xi^0 \Lambda^+_c$; and study of the inclusive $B$ decays to $\Lambda_c$.

1 Introduction

Following the pioneering work done by CLEO, various baryonic $B$ decays with charmed or charmless baryons in the final states have been found recently by the two $b$-factories, BABAR and Belle. The charmed baryonic decays have much larger branching fractions due to the dominant Cabibbo favored $b \rightarrow c$ transition. The charmless modes presumably proceed via the $b \rightarrow s$ penguin or the $b \rightarrow u$ tree processes. The charmed baryonic $B$ decays are observed in four-body, three-body and two-body final states while there are only three-body final states being found for the charmless case. There is a common feature for the charmless decays that the baryon-antibaryon mass spectra peak near threshold. This feature was conjectured in Ref. and has recently aroused much theoretical interest.

In $b$-factory, it is an over-constrained system to determine decays from $B$ mesons since not only the mass but also the energy of the $B$ meson are known in the center-of-mass (CM) frame. One can pick two kinematic variables in the CM frame to identify the reconstructed $B$ meson candidates, for example, the beam energy constrained mass $M_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^2}$, and the energy difference $\Delta E = E_B - E_{\text{beam}}$, where $E_{\text{beam}}$ is the beam energy, and $p_B$ and $E_B$ are the momentum and energy, respectively, of the reconstructed $B$ meson. After performing various selection cuts for background suppression, the $B$ yields can be determined by an unbinned extended likelihood fit using the above two variables as inputs for all candidate events. The signal probability density function (PDF) of the two variables is typically obtained by Monte Carlo samples and the background PDF is determined from sideband (i.e. non-signal region) data.

2 Charmless modes

After the first observation of the charmless baryonic $B$ meson decay, $B^+ \rightarrow p\bar{p}K^+$, many charmless three-body baryonic decays were found. Detailed information from the polar angle distributions and Dalitz plots offer better understanding of the underlying dynamics. We use a data sample consisting of $449 \times 10^6 B\bar{B}$ pairs to study the baryon angular distribution in the
proton-antiproton helicity frame with \( M_{pp} < 2.85 \text{ GeV}/c^2 \) for the decays of \( B^+ \rightarrow p\bar{p}K^+ \) and \( B^+ \rightarrow p\bar{p}\pi^+ \). This angle is defined between the baryon direction and the oppositely charged meson direction in the proton-antiproton pair rest frame. The observed angular distributions for the two modes have opposite trends. Further theoretical investigations are needed to explain the behavior of \( p\bar{p}K^+ \) and \( p\bar{p}\pi^+ \) modes simultaneously.

We also study the decays of \( B^+ \rightarrow p\bar{\Lambda}\gamma \), \( B^+ \rightarrow p\bar{\Lambda}\pi^0 \) and \( B^0 \rightarrow p\bar{\Lambda}\pi^- \). Note that the results include the first observation of \( B^+ \rightarrow p\bar{\Lambda}\pi^0 \). Figure 1 illustrates the fits for the \( B \) yields in a baryon-antibaryon mass region below 2.8 GeV/c^2 for the \( p\bar{\Lambda}\pi^0 \) mode. The ratio of \( B(B^+ \rightarrow p\bar{\Lambda}\pi^0)/B(B^0 \rightarrow p\bar{\Lambda}\pi^-) \) is \( 0.93^{+0.21}_{-0.15} \pm 0.09 \), which is larger than the theoretical prediction of 0.5. We also study the two-body intermediate decays \( B^0 \rightarrow p\Sigma^{*-} \), \( B^0 \rightarrow \Delta^0\bar{\Lambda} \), \( B^+ \rightarrow p\Sigma^{*0} \), and \( B^+ \rightarrow \Delta^+\bar{\Lambda} \), where the \( \Sigma^{*-,s0} \) and \( \Delta^{0,+} \) are reconstructed in the \( \Sigma^{*-,s0} \rightarrow \bar{\Lambda}\pi^-\pi^0 \) and \( \Delta^{0,+} \rightarrow p\pi^0\pi^+ \) channels, respectively. The selection criteria are \( 1.30 \text{ GeV}/c^2 < M_{\Lambda\pi^-,\pi^0} < 1.45 \text{ GeV}/c^2 \) and \( M_{pp\pi^+,\pi^-} < 1.40 \text{ GeV}/c^2 \). No significant signals are found in these decay chains. We set upper limits on the branching fractions at the 90% confidence level using the methods described in Refs.\(^9\)\(^10\), where the systematic uncertainty is taken into account. The results are listed in Table 1.

In the low mass region below 2.8 GeV/c^2, we study the proton angular distribution of the baryon-antibaryon pair system. The angle \( \theta_p \) is defined as the angle between the proton direction and the meson (photon) direction in the baryon-antibaryon pair rest frame. We define the angular asymmetry as \( A_\theta = \frac{Br_+ - Br_-}{Br_+ + Br_-} \), where \( Br_+ \) and \( Br_- \) stand for the measured branching fractions with \( \cos \theta_p > 0 \) and \( \cos \theta_p < 0 \), respectively. The measured results are shown in Table 1. We also measure the charge asymmetry as \( A_{CP} = (N_b - N_\bar{b})/(N_b + N_\bar{b}) \) for these modes, where \( b \) stands for the quark flavor of the \( B \) meson. The results are listed in Table 1. The measured charge asymmetries are consistent with zero within their statistical uncertainties.

## 3 Charmed Modes

The \( b \rightarrow c \) process is the dominant process for \( B \) decays. Many decay modes with \( \Lambda^+_c \) in the final states have been found, including the first observation of a two-body decay: \( \bar{B}^0 \rightarrow \Lambda^+_c p \)\(^11\). It is interesting to see that the two-body baryonic decay is suppressed in exclusive \( B \) decays in contrast to mesonic \( B \) decays where two-body and three-body decays are comparable. This indicates that, for the formation of a baryon-antibaryon pair, giving off extra energy is much favored. Similar decay processes via the \( b \rightarrow c\bar{c}s \) transition and limited phase space have been

![Figure 1: The (a) \( \Delta E \) and (b) \( M_{bc} \) distributions for the \( p\bar{\Lambda}\pi^0 \) mode with the requirement of baryon-antibaryon mass < 2.8 GeV/c^2. The solid curve represents the fit projection, which is the sum of signal (dash-dotted peak) and background (dashed curve) estimations.](image-url)
found for $B^+ \rightarrow \Lambda_c^+ \Lambda_c^- K^+$ and $B^0 \rightarrow \Lambda_c^+ \Lambda_c^- K^0$ in a $386 \times 10^6 B\bar{B}$ data sample. The measured branching fractions are unexpectedly large: $\mathcal{B}(B^+ \rightarrow \Lambda_c^+ \Lambda_c^- K^+) = (6.5^{+1.0}_{-0.5} \pm 1.1 \pm 3.4) \times 10^{-4}$ and $\mathcal{B}(B^0 \rightarrow \Lambda_c^+ \Lambda_c^- K^0) = (7.9^{+1.0}_{-0.9} \pm 1.2 \pm 4.1) \times 10^{-4}$, where the first error represents the statistical uncertainty, the second error is the systematic error and the last error is due to the 52% uncertainty in the absolute branching fraction of $\Lambda_c^+ \rightarrow pK^-\pi^+$. This large rate might be understood by the threshold enhancement phenomenon. Observation of this kind of decay is important for the determination of the charm particle yield per $B$ decay. Decays like $B \rightarrow \Lambda_c^+ \Lambda_c^- K$ would give a wrong-sign $\Lambda_c^+$, where for most cases only $\Lambda_c^-$’s are present in the final state from $B$ decays.

Another doubly charmed baryonic two-body decay, $B^+ \rightarrow \Xi_c^0 \Lambda_c^+$, has been found in the same data set. Judging from the similarity between $b \rightarrow \bar{c}s s$ and $b \rightarrow \bar{c}d u$, one would expect these two decay modes, $B^+ \rightarrow \Xi_c^0 \Lambda_c^+$ and $B^0 \rightarrow \Lambda_c^+ \bar{p}$, to have similar branching fractions. However, the measured branching fraction product $\mathcal{B}(B^+ \rightarrow \Xi_c^0 \Lambda_c^+) \times \mathcal{B}(\Xi_c^0 \rightarrow \Xi^+ \pi^-) = (4.8^{+1.0}_{-0.9} \pm 1.1 \pm 1.2) \times 10^{-4}$ is too big. Assuming $\mathcal{B}(\Xi_c^0 \rightarrow \Xi^+ \pi^-)$ is at 1% level, then $\mathcal{B}(B^+ \rightarrow \Xi_c^0 \Lambda_c^+) \sim 10^{-3}$. This is about 100 times bigger than that of $B^0 \rightarrow \Lambda_c^+ \bar{p}$. This is another example of a large enhancement for smaller available energy in the baryon-antibaryon system. Fig. 2 shows the observed signals.

The question of charm counting for $B$ decays is a fundamental issue to be addressed. Using fully reconstructed $B$ sample (flavor tagging), one can study the correlated ($b \rightarrow \bar{c}c s$) and anti-correlated ($b \rightarrow \bar{c}d u$) charm production. Presumably the correlated charm production is dominant and the anti-correlated is suppressed with a phase space factor. Experimentally, one can determine the correlated/anti-correlated charm production by studying the inclusive $B$ decay rates to a limited charm hadrons, e.g. $\Lambda_c^+$, $D^0$, etc., because all other heavier charm particles decay into one of these special cases. Recently, BABAR used a $231 \times 10^6 B\bar{B}$ event sample and made the measurement. The charm yield per $B$ decay is around 1.2.

4 Summary

The exclusive baryonic $B$ decays are well established after a few years running of the two b-factories. One important thing for baryonic $B$ meson decays is to understand the threshold enhancement mechanism. The study of baryonic $B$ decays is booming with rapidly accumulating data samples. Many new results including CP violation measurements can be expected in the very near future.

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Figure 2: The (a) $\Delta E$ and (b) $M_{bc}$ distributions for the $B^+ \to \Xi^0 \Lambda^+_c$ candidates. The hatched histograms show the combined $\Xi^0$ and $\Lambda^+_c$ mass sidebands normalized to the signal region. The excess around low $\Delta E$ region maybe be due to decays with extra final state particle, e.g. $\Xi^0 \Lambda^+_c \pi^0$. The (c) $\Xi^0$ and (d) $\Lambda^+_c$ mass distributions for candidates taken from the $B$-signal region. The overlaid curves are the fit results.

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