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Rare B decays in B -factory experiments

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Recent results of the charmless B decays from the two B -factories, BABAR and Belle, are presented. These include studies of $B \rightarrow K\pi$, $B^+ \rightarrow K^+\pi^+\pi^-$, $B^0 \rightarrow \rho^0\rho^0$, $B^0 \rightarrow \omega K^{*0}$, $B \rightarrow K^*l^+l^-$, $B \rightarrow \pi l^+l^-$, $B^+ \rightarrow p\bar{p}K^+$, $B^+ \rightarrow p\bar{p}\pi^+$ and $B \rightarrow p\bar{p}K^*$. Findings for the direct CP violation will be addressed.

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1. Introduction

The information gathered from rare B decays is very useful to determine the elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and is essential to the study of the CP violation mechanism of the Standard Model (SM). It is also sensitive to new physics beyond SM for the additional contributions from the unknown heavy virtual particles in the $b \rightarrow s(d)$ penguin loop. Because there is no dominant $b \rightarrow c$ decay amplitude, large direct CP violation could be expected via the interference between decay amplitudes of comparable size. In this paper, we will report the recent experimental observations in rare B decays from the two B -factories, BABAR [1] and Belle [2]. These results can be categorized into mesonic B decays, B decays with lepton pair in the final state and three-body baryonic B decays.

The challenge of studying rare B decays is the suppression of overwhelmingly large background from the continuum $e^+e^- \rightarrow q\bar{q}$ processes, where q stands for u , d , s , or c quark. One can use the so called event-shape variables to separate the more spherically B events from the jet-like continuum events. In B -factory, it is an over-constrained system to determine decays from B meson since not only the mass but also the energy of the B meson are known in the center-of-mass frame. To determine the B yields, normally an unbinned extended likelihood fit is applied to all candidate event by using the above

two kinematical variables and other useful information. The signal probability density function (PDF) of the two variables is typically obtained by Monte Carlo (MC) simulation and the background PDF can be determined from either MC simulation or sideband (i.e. non-signal region) data. The systematic uncertainty could be studied using high statistics control samples to check the difference between data and MC simulation. Taking the particle identification as an example, for proton selection, one can use the $\Lambda \rightarrow p\pi^-$ sample, while for K/π identification one can use the $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$ sample.

2. Charmless mesonic B decays

The direct CP violation in B decay is well established in the $B^0 \rightarrow K^+\pi^-$ [3,4] process by both BABAR and Belle. The asymmetry CP parameter A_{CP} is defined as $(N_b - N_{\bar{b}})/(N_b + N_{\bar{b}})$ where b stands for the quark flavor of the B meson and $N_b(N_{\bar{b}})$ stands for the efficiency corrected $\bar{B}$ (B) yield. The measured $A_{K^\pm\pi^\mp}$ is about -0.1 with 5σ deviation from null asymmetry. Figure 1 a and b show the two dominant $B \rightarrow K\pi$ processes, color-allowed three and strong penguin, respectively. These two decay amplitudes are of similar magnitude with different weak and strong phases. Therefore, appreciable CP violation could be expected. Recently, Belle published a new result [5] for $B \rightarrow K\pi$ using a data sample of 535 million $B\bar{B}$ pairs. The interesting finding is that the observed A_{CP} parameters for the neutral

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and charged modes seem to have opposite sign. One can tell this by looking at the reconstructed mass spectra of B candidates as shown in Fig. 2. The difference between the asymmetry parameters in charged and neutral modes of $B \rightarrow K\pi$ is: $A_{K^\pm\pi^0} - A_{K^\pm\pi^\mp} = 0.164 \pm 0.037$, which is established at the 4.4σ level. Since both Fig. 1 a and b contribute to $B \rightarrow K^\pm\pi^\mp$ and $B^\pm \rightarrow K^\pm\pi^0$, one would naively think that these two asymmetry parameters should be similar. This intriguing fact may indicate a hint of new physics contribution in the loop of the $b \rightarrow s$ electro-weak penguin as shown in Fig. 1 d, which can only occur in the charged $B^\pm \rightarrow K^\pm\pi^0$ decays. Of course, there is also the possibility that the color-suppressed tree contribution from the SM prediction, shown in Fig. 1 c, has a sizable effect. It is important to gather more information from other rare B decay processes in order to ping down different scenarios.

Figure 1. Decay diagrams for $B \rightarrow K\pi, \pi\pi$. The B^+ (B^0) meson consists of a $\bar{b}$ quark and u (d) quark, while its antiparticle, B^- ($\bar{B}^0$) is made of a b quark and a $\bar{u}$ ($\bar{d}$) quark. Contributions from diagrams a and b are expected to be dominant.

So far, the direct CP violation is only confirmed in the neutral B decays. The most promising channel with large direct CP violation in charged B decays is $B^+ \rightarrow \rho^0 K^+$. Consistent results have been reported by BABAR and Belle [6]. From a detailed Dalitz plot analy-

Figure 2. Beam energy constrained mass plots for (a) $K^-\pi^+$, (b) $K^+\pi^-$, (c) $K^-\pi^0$ and (d) $K^+\pi^0$. Histograms are data, solid lines are the overall fit projections which contain the contributions from signal (as point-dashed lines), continuum background (as dashed lines) and fake $\pi^\pm\pi$ components (as small bumps in the signal region).

sis [7] for $B^+ \rightarrow K^+\pi^+\pi^-$, BABAR has observed a 3.7σ evidence of the direct CP violation in $B^+ \rightarrow \rho^0 K^+$, using a data sample of 383 million $B\bar{B}$ pairs. The CP asymmetry parameter is found to be $A_{CP} = 0.44 \pm 0.17$. Figure 3 shows the B yield distributions for both B^+ and B^- candidates as a function of the $\pi^+\pi^-\pi^0$ invariant mass in the region of the ρ^0 and f_2 resonances. In order to highlight the direct CP violation effect, the projected yields are further subdivided into two groups with positive and negative values of $\cos\theta_H$, where θ_H is the polar angle of π^+ in the helicity frame of the $\pi^+\pi^-\pi^0$ system. The asymmetry in the excess of events above background in the ρ^0 region is quite visible in the distributions with the requirement $\cos\theta_H > 0$.

As stated before, the information from rare B decays is very useful to constrain the CKM matrix elements. One example is the $B \rightarrow \rho\rho$ processes.

Figure 3. Projection plots of the $\pi^+\pi^-$ invariant mass in the region of the ρ^0 and f_2 resonances. The left (right) plots are for B^- (B^+) candidates. The top row shows all candidates, the middle row shows those where $\cos\theta_H > 0$, and the bottom row shows those where $\cos\theta_H < 0$. The data are the black points with statistical error bars, the lower solid dark histogram is the $q\bar{q}$ component, the middle solid light histogram is the $B\bar{B}$ background contribution, while the open histogram shows the total fit result.

From the angular analysis, the polarization of the ρ mesons in $B^0 \rightarrow \rho^+\rho^-$ [8] and $B^+ \rightarrow \rho^+\rho^0$ [9] is found to be almost 100% longitudinal. This indicates that the $b \rightarrow d$ penguin contribution is small and the $\phi_2(\alpha)$ angle of the CKM unitary triangle can be measured well using the three decay amplitudes of $B^0 \rightarrow \rho^+\rho^-$, $B^+ \rightarrow \rho^+\rho^0$ and $B^0 \rightarrow \rho^0\rho^0$ from an isospin analysis [10].

Using a data sample containing 657 million $B\bar{B}$ pairs, Belle reported an upper limit on $\mathcal{B}(B^0 \rightarrow \rho^0\rho^0)$ [11] of 1.0×10^{-6} at the 90% confidence level. Based on this study and the world averages [12] of the branching fractions as well as the

polarization measurements of $B^+ \rightarrow \rho^+\rho^0$ and $B \rightarrow \rho^+\rho^-$, one can constrain the CKM ϕ_2 angle. Fig. 4 shows the difference between one and the confidence level ($1-\text{C.L.}$) as a function of ϕ_2 ; the central value and one sigma interval for ϕ_2 is found to be $(91.7 \pm 14.9)^\circ$.

Figure 4. $1-\text{C.L.}$ vs. $\phi_2(\alpha)$ obtained from the isospin analysis of $B \rightarrow \rho\rho$ decays.

With the same data set, Belle also searched for a different vector-vector final-state mode, namely, $B^0 \rightarrow \omega K^{*0}$ [13]. There is a hint for such decay with a significance of 3σ . More interestingly, there is an unexpected large non-resonant component, $B^0 \rightarrow \omega K^+\pi^-$, being found. The measured branching fraction is $\mathcal{B}(B^0 \rightarrow \omega K^+\pi^-) = (5.1 \pm 0.7(\text{stat.}) \pm 0.7(\text{syst.})) \times 10^{-6}$ in the $0.755 \text{ GeV}/c^2 < M_{K\pi} < 1.250 \text{ GeV}/c^2$ mass range. Figure 5 shows the B yield distribution in the above mass range. It is clear that the non-resonant component is sizable and the interference effect between K^{*0} and the non-resonant component cannot be neglected.

3. Rare B decays with lepton pair in the final state

In SM, the decays $B \rightarrow K^*\ell^+\ell^-$ are forbidden at tree level, where ℓ stands for either an electron or a muon. These decays are presumably cleaner for theoretical calculations due to lesser hadronic uncertainty. The lowest-order processes contributing to these decays are flavor-changing neutral currents $b \rightarrow s$ penguin diagrams or the W^+W^- box diagram as shown in Fig. 6. From

Figure 5. B yields obtained from 2D fits to ΔE and M_{bc} in bins of $M_{K\pi}$. The curves are for ωK^{*0} (dashed), $\omega K^+ \pi^-$ (dot-dashed), and the total (solid).

the operator product expansion approach, the decay amplitudes can be expressed in terms of effective Wilson coefficients for the electromagnetic penguin, C_7 , and the vector and axial-vector electroweak contributions, C_9 and C_{10} respectively [14].

It is very useful to know f_L , the K^* longitudinal polarization fraction, in $B \rightarrow K^* \ell^+ \ell^-$ in order to understand the underlying decay mechanism. The f_L can be determined from the $\cos \theta_K$ angular distribution, where θ_K is the polar angle of the K meson in the K^* helicity frame. The theoretical PDF for the K^* meson has the form $3/2 \cos^2 \theta_K$ for a pure helicity zero state and $3/4 \sin^2 \theta_K$ for a pure helicity one (± 1) state. Therefore, the longitudinal polarization fraction is obtained by the following PDF: $\frac{3}{2} f_L \cos^2 \theta_K + \frac{3}{4} (1 - f_L) (1 - \cos^2 \theta_K)$. Due to the interference between the γ, Z penguin and $W^+ W^-$ box diagrams, the forward-backward asymmetry, A_{FB} , of the lepton angular distribution in the $\ell^+ \ell^-$ system as a function of $q^2 (= M_{\ell^+ \ell^-}^2)$ is sensitive to many possible new physics contributions. The A_{FB} is defined by $\frac{3}{4} f_L (1 - \cos^2 \theta_\ell) + \frac{3}{8} (1 - f_L) (1 + \cos^2 \theta_\ell) + A_{FB} \cos \theta_\ell$, where θ_ℓ is the angle between the $\ell^+ (\ell^-)$ and the $B(\bar{B})$ direction in the $\ell^+ \ell^-$ rest frame.

Figure 7 shows the results [15] obtained by BABAR using a data sample of 384 million $B\bar{B}$ pairs. The $\ell^+ \ell^-$ contributions from the J/ψ and $\psi(2S)$ resonances are excluded by vetoing

events in the regions $q^2 = 6.25\text{--}10.24 \text{ GeV}^2/c^4$ and $q^2 = 12.96\text{--}14.06 \text{ GeV}^2/c^4$, respectively. In the low q^2 region, the measured values are $A_{FB} = 0.24^{+0.18}_{-0.23} \pm 0.05$ and $f_L = 0.35 \pm 0.16 \pm 0.04$, where the first error is statistical and the second is systematic. For high q^2 region, the values are $A_{FB} = 0.76^{+0.52}_{-0.32} \pm 0.07$ and $f_L = 0.71^{+0.20}_{-0.22} \pm 0.04$. The measured results agree with the SM predictions and are consistent with measurements by Belle [16]. The A_{FB} results disfavor a wrong-sign $C_9 C_{10}$ from purely right-handed weak currents at $\sim 3\sigma$ level. More statistics are needed in order to increase the sensitivity to new physics.

Figure 6. Lowest-order Feynman diagrams for $b \rightarrow s \ell \ell$.

In a similar search, Belle looked for $B \rightarrow \pi \ell^+ \ell^-$ [17] with a $657 \times 10^6 B\bar{B}$ data sample. Its branching fraction should be suppressed by roughly a $|V_{td}/V_{ts}|^2$ factor comparing with that of $B \rightarrow K^{(*)} \ell^+ \ell^-$. There are no significant signals found in various $\pi \ell^+ \ell^-$ modes and agree with the SM expectations. Table 1 gives the breakdown list for different $\pi \ell^+ \ell^-$ modes where the upper limit on the isospin-averaged branching fraction is also shown.

4. Charmless baryonic B decays

After the first observation of charmless baryonic B meson decay, $B^+ \rightarrow p \bar{p} K^+$, many other three-body rare baryonic decays were found. Most of the observed decays are presumably via the $b \rightarrow s$ penguin diagrams except $B^+ \rightarrow p \bar{p} \pi^+$

Table 1

A summary of the signal yields (N_s), reconstruction efficiencies (ϵ), statistical significance (Σ), branching fractions ($\mathcal{B}$), and the corresponding upper limits (U.L.) at the 90% confidence level. The errors associated with branching fractions are sequentially statistical errors, systematic errors proportional to the branching fractions, and additive systematic errors related to yield extraction.

Mode	N_s	ϵ (%)	Σ	$\mathcal{B}$ (10^{-8})	U.L. (10^{-8})
$B^+ \rightarrow \pi^+ \mu^+ \mu^-$	$0.5_{-1.9}^{+2.8}$	13.1	0.2σ	$0.6_{-2.2}^{+3.2} \pm 0.0 \pm 0.7$	6.9
$B^+ \rightarrow \pi^+ e^+ e^-$	$1.4_{-2.3}^{+3.2}$	13.8	0.6σ	$1.5_{-2.5}^{+3.5} \pm 0.1 \pm 0.8$	8.0
$B^+ \rightarrow \pi^+ \ell^+ \ell^-$	-	-	0.6σ	$1.0_{-1.8}^{+2.3} \pm 0.1 \pm 0.4$	4.9
$B^0 \rightarrow \pi^0 \mu^+ \mu^-$	$5.1_{-3.3}^{+4.2}$	9.6	1.8σ	$8.1_{-5.2}^{+6.7} \pm 0.8 \pm 1.0$	18.4
$B^0 \rightarrow \pi^0 e^+ e^-$	$2.7_{-4.0}^{+5.2}$	7.4	0.7σ	$5.5_{-8.3}^{+10.7} \pm 0.5 \pm 2.0$	22.7
$B^0 \rightarrow \pi^0 \ell^+ \ell^-$	-	-	2.0σ	$7.4_{-4.5}^{+5.4} \pm 0.7 \pm 0.8$	15.4
$B \rightarrow \pi \ell^+ \ell^-$	-	-	1.2σ	$2.4_{-2.1}^{+2.5} \pm 0.2 \pm 0.2$	6.2

which is believed to be $b \rightarrow u$ tree dominant, as shown in Fig. 8. Nevertheless, all of these decays have a common feature that the baryon-antibaryon mass spectra peak near threshold. This indicates that the baryon-antibaryon pair are likely moving in parallel, and opposite to the direction of the energetic meson in the B rest frame.

Using a $449 \times 10^6 B\bar{B}$ data sample, Belle performed a study of the angular distributions of the proton-antiproton pair system near threshold for both the $p\bar{p}K^+$ and $p\bar{p}\pi^+$ baryonic B decay modes [18]. The angle θ_p is defined as the angle between the baryon direction and the oppositely charged meson direction in the proton-antiproton pair rest frame, i.e. this angle is determined by p and K^-/π^- , or by $\bar{p}$ and K^+/π^+ . The $\cos\theta_p$ distributions, shown in Fig. 9, for the $p\bar{p}K^+$ and $p\bar{p}\pi^+$ modes have different trends. This distribution for the $p\bar{p}\pi^+$ mode does not match the theoretical prediction [19], in which the published $p\bar{p}K^+$ information was used as input and calculations was done under the perturbative QCD framework.

Naively, the result agrees with the short distance picture for a $b \rightarrow u$ tree diagram. Particles directly associated with b decay are more energetic and the particle containing the spectator quark is generally less energetic. After boosting to the proton-antiproton rest frame, the fast moving anti-protons and π^+ 's are back-to-back most of the time. However, the $b \rightarrow s$ gluon process for

the $p\bar{p}K^+$ case seems to completely disagree with this short distance picture. The baryon with the spectator quark moves faster in the B rest frame. Another theoretical prediction proposes a long distance effect, namely $p\bar{p}$ re-scattering through a hypothetical baryonium bound state [20], in order to explain the violation of the short distance picture for the $p\bar{p}K^+$ mode. Since this long distance effect should also occur for the $p\bar{p}\pi^+$ case, it seems that further theoretical investigations are needed to simultaneously explain the behavior of both the $p\bar{p}K^+$ and $p\bar{p}\pi^+$ modes.

In the study of $B \rightarrow p\bar{p}K^*$ [21], Belle recently reported the observation of $B^0 \rightarrow p\bar{p}K^{*0}$ using a $535 \times 10^6 B\bar{B}$ sample. The measured branching fraction is $(1.18_{-0.25}^{+0.29}(\text{stat.}) \pm 0.11(\text{syst.})) \times 10^{-6}$. The B yield distributions in bins of $\cos\theta_K$ with the corresponding polarization fit curves are shown in Fig 10. The K^{*0} meson has a fraction of $(101 \pm 13 \pm 3)\%$ in the helicity zero state and the K^{*+} meson has a $(32 \pm 17 \pm 9)\%$ fraction in the helicity zero state. It is interesting to note that the helicity zero amplitude is expected to be dominant in the $b \rightarrow s$ penguin transition due to the $(V - A)$ nature of the weak interaction and helicity conservation in the strong interaction. The smaller K^{*+} polarization in the $p\bar{p}K^{*+}$ decay may be attributed to an additional contribution from external W emission. Again, both $B^+ \rightarrow p\bar{p}K^{*+}$ and $B^0 \rightarrow p\bar{p}K^{*0}$ decay modes have threshold enhancements as shown in Fig. 11.

Figure 7. Plots of BABAR results for (a) A_{FB} and (b) F_L for the decay $B \rightarrow K^*\ell^+\ell^-$ showing comparisons with SM (solid); $C_7 = -C_7^{SM}$ (long dash); $C_9C_{10} = -C_9^{SM}C_{10}^{SM}$ (short dash); $C_7 = -C_7^{SM}, C_9C_{10} = -C_9^{SM}C_{10}^{SM}$ (dash-dot). Statistical and systematic errors are added in quadrature. Expected F_L values integrated over each q^2 region are also shown. The F_L curves with $C_9C_{10} = -C_9^{SM}C_{10}^{SM}$ are nearly identical to the two curves shown.

5. Summary

Rare B decays provide a good searching ground for direct CP violation. The first well-established example is in the $B^0 \rightarrow K^+\pi^-$ channel. The observed difference between the A_{CP} parameters for $B^0 \rightarrow K^+\pi^-$ and $B^+ \rightarrow K^+\pi^0$ may indicate a sign of new physics and more investigations are needed. It is quite promising that a large A_{CP} will be observed in the charged B decays to $K^+\rho^0$. There are many progresses in two-body charmless B decays, e.g. $B^0 \rightarrow \rho^0\rho^0$. Informa-

Figure 8. The possible leading (a) $b \rightarrow s$ penguin diagram and (b) $b \rightarrow u$ tree diagram for $B^+ \rightarrow p \bar{p} K^+$ and $B^+ \rightarrow p \bar{p} \pi^+$ decays, respectively.

tion obtained from these decays can be useful to constrain the CKM unitary triangle. The development in the study of $B \rightarrow K^*l^+l^-, \pi l^+l^-$ gives a new direction to test SM. However, the needed statistics can only be realized by super B -factory or at LHCb. For the rare baryonic B decays, it seems that to understand the threshold enhancement and the related decay angular distributions is a key for constructing the proper decay mechanism.

REFERENCES

1. B. Aubert *et al.* (BABAR Collaboration), Nucl. Instr. and Meth. A **479**, 1 (2002).
2. A. Abashian *et al.* (Belle Collaboration), Nucl. Instr. and Meth. A **479**, 117 (2002).
3. B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **93**, 131801 (2004); Y. Chao *et al.* (Belle Collaboration) Phys. Rev. Lett. **93**, 191802 (2004).
4. Throughout this report, inclusion of charge

conjugate mode is always implied unless otherwise stated.

5. S.-W. Lin *et al.* (Belle Collaboration), *Nature* **452**, 332 (2008).
6. B. Aubert *et al.* (BABAR Collaboration), *Phys. Rev. D* **72**, 072003 (2005), (Erratum-*ibid.* **74**, 099903 (2006)); A. Garmash *et al.* (Belle Collaboration) *Phys. Rev. Lett.* **96**, 251803 (2006).
7. B. Aubert *et al.* (BABAR Collaboration), *Phys. Rev. D* **78**, 012004 (2008).
8. A. Somov *et al.* (Belle Collaboration), *Phys. Rev. D* **76**, 011104 (2007); B. Aubert *et al.* (BaBar Collaboration), *Phys. Rev. D* **76**, 052007 (2007).
9. J. Zhang *et al.* (Belle Collaboration), *Phys. Rev. Lett.* **91**, 221801 (2003); B. Aubert *et al.* (BaBar Collaboration), *Phys. Rev. Lett.* **97**, 261801 (2006).
10. M. Gronau and D. London, *Phys. Rev. Lett.* **65**, 3381 (1990).
11. C.-C. Chiang (Belle Collaboration), arXiv:0808.2576[hep-ex].
12. W.-M. Yao *et al.* (Particle Data Group), *J. Phys. G* **33**, 1 (2006).
13. P. Goldenzweig *et al.* (Belle Collaboration), arXiv:0807.4271[hep-ex].
14. G. Buchalla, A.J. Buras and M.E. Lautenbacher, *Rev. Mod. Phys.* **68**, 1125 (1996).
15. B. Aubert *et al.* (BABAR Collaboration), arXiv:0804.4412[hep-ex].
16. A. Ishikawa *et al.* (Belle Collaboration) *Phys. Rev. Lett.* **96**, 251801 (2006).
17. J.-T. Wei *et al.* (Belle Collaboration), arXiv:0804.3656[hep-ex].
18. J.-T. Wei *et al.* (Belle Collaboration), *Phys. Lett. B* **659**, 80 (2008).
19. C.Q. Geng and Y.K. Hsiao, *Phys. Rev. D* **74**, 094023 (2006).
20. M. Suzuki, *J. Phys. G* **34**, 283 (2007).
21. J.-H. Chen *et al.* (Belle Collaboration) *Phys. Rev. Lett.* **100**, 251801 (2008).

Figure 9. Differential branching fractions *vs.* $\cos\theta_p$ in the proton-antiproton pair system for (a) $B^+ \rightarrow p\bar{p}K^+$ and (b) $B^+ \rightarrow p\bar{p}\pi^+$. The solid curve is the theoretical prediction.

Figure 10. B yield distributions as functions of $\cos\theta_K$ with fit curves overlaid for (a) the $p\bar{p}K^{*0}$ mode and (b) the $p\bar{p}K^{*+}$ mode. The fraction of the signal in the helicity zero state is the fit parameter and is denoted by H_0 . The asymmetries in the fit curves are due to detection efficiencies. The underlying theoretical distributions are symmetric.

Figure 11. Differential branching fractions for (a) the $p\bar{p}K^{*0}$ and (b) the $p\bar{p}K^{*+}$ modes as a function of proton-antiproton invariant mass. Note that the two shaded mass bins contain charmonium events and are excluded from the charmless signal yields. The data points for the $2.85 \text{ GeV}/c^2 < M_{p\bar{p}} < 3.128 \text{ GeV}/c^2$ mass region are off-scale.