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Non-leptonic rare B-decays from Belle

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Abstract. Recent results of exclusive charmless hadronic B decays with an ω or ϕ meson in the final states from Belle collaboration are reviewd. We present measurements of the branching fations of $B^+ \to \omega K^+, \omega\pi^+$ and $B \to \phi K^{(*)}$. We also report the observation of the decay mode $B \to \phi\phi K$.

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1 Introduction

Charmless hadronic B decays play an important role in the understanding of CP violation in the B system. These decays proceed primarily through $b \to s$ loop penguin diagrams and $b \to u$ tree spectator diagrams with interference effects between them. The branching fractions of $B \to \phi K^{(*)}$ and $B \to \omega K^+(\pi^+)$ have been predicted by QCD-factorization [1] and PQCD [2]. In addition, the $B \to \phi\phi K$ decays may be sensitive to glueball production in B decays, where the glueball decays to $\phi\phi$ [3]. Here, we present the results of a study of B decays to ϕK^*, $\phi\phi K$ and $\omega K(\pi)$. Charge conjugated are implied throughout.

2 Analysis in general

In all the decay modes presented here, the continuum process ($e^+e^- \to q\bar{q}$) is the dominant background. Since $B\bar{B}$ events are spherical while the continuum events are jet-like, we apply cuts on various event shape variables to suppress the background. [4] The data used here contain 85×10^6 $B\bar{B}$ pairs.

B candidates are identified using two kinematic variables: beam constrained mass: $M_B = \sqrt{E_{beam}^2 - p_B^2}$, and the energy difference: $\Delta E = E_B - E_{beam}$. Here E_{beam} is the beam energy, p_B and E_B are the momentum and energy of a reconstructed B candidate, respectively, where all variables are defined in the $\Upsilon(4S)$ rest frame. The yields are obtained from unbin extended Maximun Likelihood (ML) fit on that variables. [4]

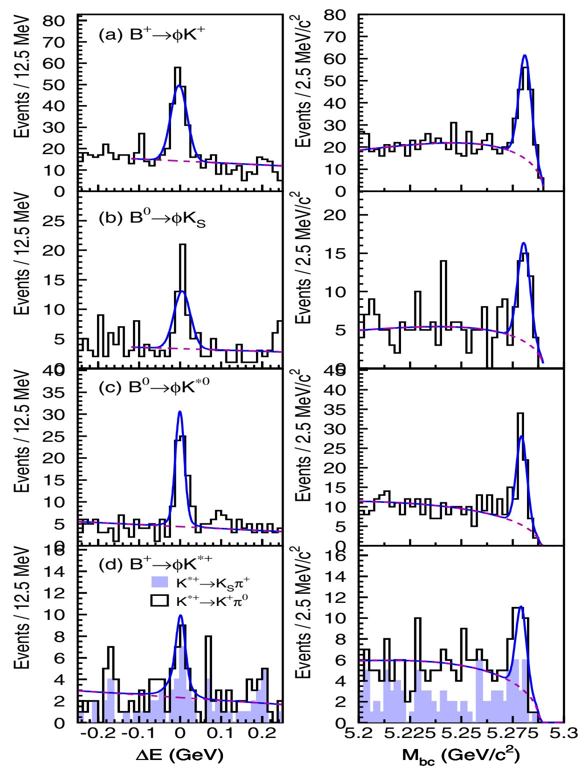

Fig. 1. Distributions of ΔE ($M_{\rm bc}$) with fit results for the events in the M_{bc} (ΔE) signal window. The continuum background component is shown by *dashed curves*

3 $B \to \phi K^{(*)}$ decays

These decays can provide information on the Cabibb0-Maskawa matrix element V_{ts} and can be sensitive to physics beyond the Standard Model [5]. Here, we look for the B decay modes ϕK^+, ϕK^0, ϕK^{*0} and ϕK^{*+}. The daughter particles are reconstructed through $\phi \to K^+K^-$, $K^{*0} \to K^+\pi^-$, $K^{*+} \to K^+\pi^0$ and $K^{*+} \to K_S^0\pi^+$.

The results of the branching fraction measurements ($\mathcal{B}$) are summarized in Table 1. The ΔE and $M_{\rm bc}$ projections are shown in Fig. 1. Our results [6] are in agreement

Table 1. Signal yields (N_s) obtained by fits after background subtraction, total efficiency (ϵ), statistical significance ($\Sigma \equiv \sqrt{2\ln[\mathcal{L}(N_s)/\mathcal{L}(0)]}$), and measured branching fraction ($\mathcal{B}$). The intermediate branching fractions are taken from [9]

Mode	N_s	ϵ (%)	Σ	$\mathcal{B}(10^{-6})$
$B^+ \to \phi K^+$	136^{+16}_{-15}	16.9	16.5	$9.4 \pm 1.1 \pm 0.7$
$B^0 \to \phi K^0$	$35.6^{+8.4}_{-7.4}$	4.6	8.7	$9.0^{+2.2}_{-1.8} \pm 0.7$
$B^0 \to \phi K^{*0}$	$58.5^{+9.1}_{-8.1}$	6.9	11.3	$10.0^{+1.6}_{-1.5}{}^{+0.7}_{-0.8}$
$B^+ \to \phi K^{*+}$	–	–	4.9	$6.7^{+2.1}_{-1.9}{}^{+0.7}_{-1.0}$
$K^{*+} \to K^+\pi^0$	$8.0^{+4.3}_{-3.5}$	1.4	2.8	$6.9^{+3.8}_{-3.2}{}^{+0.9}_{-1.0}$
$K^{*+} \to K^0_S\pi^+$	$11.3^{+4.5}_{-3.8}$	2.1	4.0	$6.5^{+2.6}_{-2.3}{}^{+0.6}_{-0.9}$

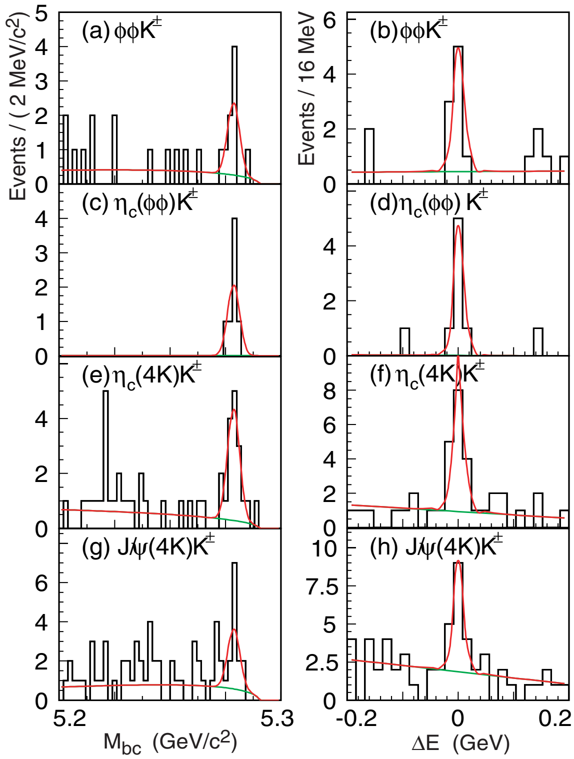

Fig. 2. Projections of $M_{\rm bc}$ and ΔE overlaid with the fitted curves for (a, b) $B^+ \to \phi\phi K^+$ with $M_{\phi\phi} < 2.85$ GeV/c^2, (c, d) $B^+ \to \eta_c K^+$ and $\eta_c \to \phi\phi$, (e, f) $B^+ \to \eta_c K^+$ and $\eta_c \to 2(K^+K^-)$, and (g, h) $B^+ \to J/\psi K^+$ and $J/\psi \to 2(K^+K^-)$

with measurements by BaBar [7] and CLEO [8], and the predictions by PQCD [2].

4 $B \to \phi\phi K$ decays

The decay mode $B \to \phi\phi K$ is an example of a $b \to s\bar{s}s\bar{s}s$ transition, which requires the creation of an additional final $s\bar{s}$ quark pair than in $b \to s\bar{s}s$ processes such as $B \to \phi K$ decay. Here, we look for the B decay modes $\phi\phi K^+$, $\phi\phi K^0$ with $M(\phi\phi) < 2.85$ GeV/c^2. We also look for decays to charmonium states. For charmonium states, we reconstruct them through $\eta_c \to \phi\phi$, $\eta_c \to \phi K^+K^-$, $\eta_c \to 2(K^+K^-)$, $J/\psi \to \phi K^+K^-$ and $J/\psi \to 2(K^+K^-)$.

Table 2. Signal yields, efficiencies (ϵ) including secondary branching fractions, statistical significances(σ) and branching fractions of B related decays. The branching fractions for modes with K^+K^- pairs include contributions from $\phi \to K^+K^-$

Mode	Yield	ϵ(%)	(σ)	$\mathcal{B}$ ($\times 10^{-6}$)
$\phi\phi K^+$	$7.3\ ^{+3.2}_{-2.5}$	3.3	5.1	$2.6\ ^{+1.1}_{-0.9} \pm 0.3$
$\phi\phi K$	$8.7\ ^{+3.6}_{-2.9}$	2.2	5.3	$2.3\ ^{+0.9}_{-0.8} \pm 0.3$
$f_J(2220)(\phi\phi)K^+$	< 3.7	3.6	.	< 1.2
$\eta_c(\phi\phi)K^+$	$7.0\ ^{+3.0}_{-2.3}$	3.7	8.8	$2.2\ ^{+1.0}_{-0.7} \pm 0.5$
$\eta_c(\phi K^+K^-)K^+$	$14.1\ ^{+4.4}_{-3.7}$	4.6	7.7	$3.6\ ^{+1.1}_{-0.9} \pm 0.8$
$\eta_c(2(K^+K^-))K^+$	$14.6\ ^{+4.6}_{-3.9}$	9.6	6.6	$1.8\ ^{+0.6}_{-0.5} \pm 0.4$
$J/\psi(\phi K^+K^-)K^+$	$9.0\ ^{+3.7}_{-3.0}$	4.4	5.3	$2.4\ ^{+1.0}_{-0.8} \pm 0.3$
$J/\psi(2(K^+K^-))K^+$	$11.0\ ^{+4.3}_{-3.5}$	9.2	4.8	$1.4\ ^{+0.6}_{-0.4} \pm 0.2$

Table 3. Measured branching fractions of secondary charmonium decays and the world averages [9]. The branching fractions for modes with K^+K^- pairs include contributions from $\phi \to K^+K^-$

Decay mode	$\mathcal{B}$ (this work)($\times 10^{-3}$)	$\mathcal{B}$ (PDG)($\times 10^{-3}$)
$\eta_c \to \phi\phi$	$(1.8\ ^{+0.8}_{-0.6} \pm 0.7)$	(7.1 ± 2.8)
$\eta_c \to \phi K^+K^-$	$(2.9\ ^{+0.9}_{-0.8} \pm 1.1)$	–
$\eta_c \to 2(K^+K^-)$	$(1.4\ ^{+0.5}_{-0.4} \pm 0.6)$	(21 ± 12)
$J/\psi \to \phi K^+K^-$	$(2.4\ ^{+1.0}_{-0.8} \pm 0.3)$	(0.74 ± 0.11)
$J/\psi \to 2(K^+K^-)$	$(1.4\ ^{+0.5}_{-0.4} \pm 0.2)$	(0.7 ± 0.3)

We also search for the possible gluball candidate $f_J(2220)$ through $B^+ \to f_J(2220)K^+$, $f_J(2220) \to K^+K^-K^+K^-$.

For $B^+ \to \phi\phi K^+$ with $M(\phi\phi) < 2.85$ GeV/c^2, the ML fit gives an event yield of $7.3^{+3.2}_{-2.5}$. Projections of the ΔE distribution and of the $M_{\rm bc}$ distribution are shown in Figs. 2(a,b). For the $B^0 \to \phi\phi K^0$ mode, there are only four signal candidates. We combine the $B^+ \to \phi\phi K^+$ and $B^0 \to \phi\phi K^0$ modes and perform a ML fit and obtain a signal event yield of $8.7^{+3.6}_{-2.9}$. The final results for $\mathcal{B}(B \to \phi\phi K)$ are obtained assuming isospin symmetry.

Contributions to the systematic error include the uncertainties due to the tracking efficiency (5.4%), particle identification efficiency (5%), the modeling of the likelihood ratio cut (2%), the modeling of the 2-D ML fit PDF functions and possible contamination by non-resonant ϕ $(K^+K^-)_{\rm NR}K^+$ or $2(K^+K^-)_{\rm NR}K^+$ decays (< 5%). The results are summarized in Table 2 [10].

Clear signals have observed for $B^+ \to \eta_c K^+$ and $B^+ \to J/\psi K^+$ with $\eta_c \to \phi\phi, \eta_c(J/\psi) \to \phi K^+K^-$ and $\eta_c(J/\psi) \to 2(K^+K^-)$. Projections of the ΔE distribution and of the $M_{\rm bc}$ distribution are shown in Figs. 2(c–h). Results of the fits are summarized in Table 2. Using the measured branching fraction $\mathcal{B}(B^\pm \to \eta_c K^\pm) = (1.25 \pm 0.42) \times 10^{-3}$ [11] and the known $\mathcal{B}(B^\pm \to J/\psi K^\pm) = (1.01 \pm 0.05) \times 10^{-3}$[9], we obtain the secondary branching fractions for $\eta_c \to \phi\phi$ and $\eta_c(J/\psi)$ decays to $2(K^+K^-)$ and ϕK^+K^- listed in Table 3. No signals have been found for the decay $B^+ \to f_J(2220)K^+$ with $f_J(2220) \to K^+K^-\ K^+\ K^-$ and an upper limit have been set (Table 3).

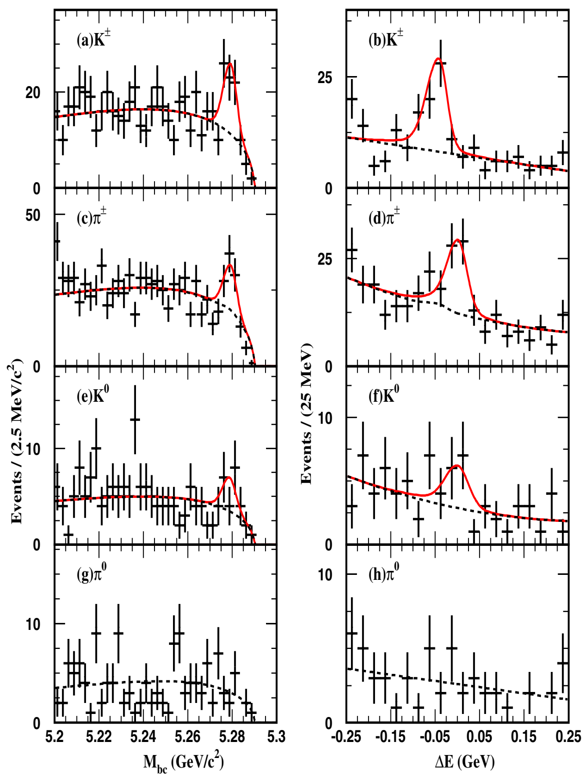

Fig. 3. Projection of 2D ML fits to $M_{\rm bc}$ and ΔE for ωK^+, $\omega\pi^+$, ωK^0 and $\omega\pi^0$ with the fit results displayed. The solid curve shows the fit result with background components represented by the dashed curve. In (d) the small enhancement in the background near −50 MeV is from misidentified $B^+ \to \omega K^+$ decays

5 $B \to \omega K/\pi$ decays

$B \to \omega h$, where h denotes K^+, π^+, K^0, and π^0, are important examples of charmless hadronic B decays, which have a history of controversial results [12,13,14,15]. Naive factorization and QCD factorization approaches [1,2] yield values of $\mathcal{B}(B^+ \to \omega\pi^+)$ consistent with the experimental results. However, these approaches predict $\mathcal{B}(B^+ \to \omega\pi^+)$ to be a factor of two larger than $\mathcal{B}(B^+ \to \omega K^+)$, which is not supported by the previous experimental results from Belle.

Candidate ω meson is reconstructed through $\pi^+\pi^-\pi^0$. Signal yields are obtained using $M_{\rm bc}$ and ΔE as independent variables in an extended unbinned Maximum Likelihood (2D ML) after event shape cuts are applied to suppress the continuum background. The total observed yields from fits are $N_{\omega K^+} = 46.1^{+9.1}_{-8.4}$, $N_{\omega\pi^+} = 42.1^{+10.1}_{-9.3}$ and $N_{\omega K^0} = 11.1^{+5.2}_{-4.4}$. Figure 3 shows projection of the M_{bc} and ΔE distributions. The results from the fits are shown in Table 4.

Table 4. Signal yields(N_s), efficiencies(ϵ) including secondary decay branching fractions, fitting significance(Σ), branching fractions($\mathcal{B}$), and the 90% confidence level upper limits (UL) on the branching fractions for ωK^0 and $\omega\pi^0$

Mode	N_s	ϵ(%)	Σ	$\mathcal{B}(\times 10^{-6})(UL)$
ωK^+	$46.1^{+9.1}_{-8.4}$	8.1	7.8σ	$6.7^{+1.3}_{-1.2} \pm 0.6$
$\omega\pi^+$	$42.1^{+10.1}_{-9.3}$	8.7	6.0σ	$5.7^{+1.4}_{-1.3} \pm 0.6$
ωK^0	$11.1^{+5.2}_{-4.4}$	3.3	3.2σ	$4.0^{+1.9}_{-1.6} \pm 0.5 (< 7.6)$
$\omega\pi^0$	$0^{+2.1}_{-0.0}$	5.2	-	(< 1.9)

6 Summary

We have measured the branching fractions of $B \to \phi K^{(*)}$. The updated measurement of the branching fration for $B^+ \to \omega K^+/\pi^+$ confirm our previous measurement of the large branching fractions for $B^+ \to \omega K^+$. We also make the first observation of the decay $B \to \phi\phi K$, which give the first measuremnt of $b \to s\bar{s}s\bar{s}s$ decays.

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