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HADRONIC AND RARE B DECAYS WITH THE BaBar AND BELLE EXPERIMENTS*

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We review recent experimental results on B_d and B_s mesons decays by the BaBar and Belle experiments. These include measurements of the color-suppressed decays $\bar{B}^0 \to D^{(*)0}h^0, h^0 = \pi^0, \eta, \eta', \omega$, observation of the baryonic decay $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-$, measurements of the charmless decays $B \to \eta h, h = \pi, K$, $B \to K\pi$, and observation of CP eigenstates in the B_s decays: $B_s^0 \to J/\psi f_0(980)$, $B_s^0 \to J/\psi f_0(1370)$ and $B_s^0 \to J/\psi \eta$. The theoretical implications of these results will be considered.

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1. Introduction

Given the large mass of the top quark, B mesons are the only weakly decaying mesons containing quarks of the third generation. Their decays are thus a unique window on the Cabibbo–Kobayashi–Maskawa (CKM) matrix elements, describing the couplings of the third generation of quarks to the lighter quarks. Hadronic B mesons decays occur primarily through the Cabibbo favored $b \to c$ transition. In the Standard Model, these decays can also occur through Cabibbo suppressed $b \to u$ transitions or through one loop diagrams, such as penguin diagrams, which involve a virtual $W^\pm$ boson and a heavy quark. This proceeding reviews recent results [1,2,3,4,5,6] from the BaBar [7] and Belle [8] experiments which took data during the past decade at the high luminosity B factories PEP-II [9] and KEKB [10].

2. Color-suppressed decays $\bar{B}^0 \to D^{(*)0}h^0$, $h^0 = \pi^0$, η, η', ω

In such decays, the effect of color suppression is obscured by the exchange of soft gluons (final state interactions), which enhance $W^\pm$ exchange

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diagrams. Previous measurements of the branching fractions of the color-suppressed decays $\bar{B}^0 \to D^{(*)0}h^0$ invalidated the factorization model [11, 12, 13]. However, more precise measurements are needed to confirm that result and to constrain the different QCD models: SCET (Soft Collinear Effective Theory) and pQCD (perturbative QCD). BaBar measured the branching fractions from exclusive reconstruction using a data sample of $454 \times 10^6 B\bar{B}$ pairs [1], the measured values can be found in Table I compared to theoretical predictions. The values measured are higher by a factor of about three to five than the values predicted by factorization. The pQCD predictions are closer to experimental values but are globally higher, except for the $D^{(*)0}\pi^0$ modes. SCET [14, 15, 16] does not give prediction on the branching fractions themselves, but predicts that the ratios $\mathrm{BF}(\bar{B}^0 \to D^{*0}h^0)/\mathrm{BF}(\bar{B}^0 \to D^0h^0)$ are about equal to one for $h^0 = \pi^0, \eta, \eta'$. The ratios of branching fractions are given in Table II and are compatible with one. This SCET prediction holds only for the longitudinal component $\bar{B}^0 \to D^{(*)0}h^0$, in the case of $h^0 = \omega$ nontrivial long-distance QCD interactions may increase the transverse amplitude. The longitudinal fraction f_{L} of B decays to a pair of vector mesons is predicted to be one in the factorization description. The longitudinal fraction of the decay $\bar{B}^0 \to D^{(*)0}\omega$ was measured for the first time in the same data sample, yielding $f_{\mathrm{L}} = (66.5 \pm 4.7(\mathrm{stat.}) \pm 1.5(\mathrm{syst.}))\%$ [1], deviating thus significantly from the factorization's prediction. This reinforces the conclusion drawn from the branching fraction measurements on the validity of factorization in color-suppressed decays and supports expectations from SCET.

TABLE I

Comparison of the measured branching fractions BF, with the predictions by factorization [17, 18, 19, 20] and pQCD [21, 22]. The first quoted uncertainty is statistical and the second is systematic.

BF ($\times 10^{-4}$)	This measurement	Factorization	pQCD
$\bar{B}^0 \to D^0\pi^0$	$2.69 \pm 0.09 \pm 0.13$	0.58 [17]; 0.70 [18]	2.3–2.6
$\bar{B}^0 \to D^{*0}\pi^0$	$3.05 \pm 0.14 \pm 0.28$	0.65 [17]; 1.00 [18]	2.7–2.9
$\bar{B}^0 \to D^0\eta$	$2.53 \pm 0.09 \pm 0.11$	0.34 [17]; 0.50 [18]	2.4–3.2
$\bar{B}^0 \to D^{*0}\eta$	$2.69 \pm 0.14 \pm 0.23$	0.60 [18]	2.8–3.8
$\bar{B}^0 \to D^0\omega$	$2.57 \pm 0.11 \pm 0.14$	0.66 [17]; 0.70 [18]	5.0–5.6
$\bar{B}^0 \to D^{*0}\omega$	$4.55 \pm 0.24 \pm 0.39$	1.70 [18]	4.9–5.8
$\bar{B}^0 \to D^0\eta'$	$1.48 \pm 0.13 \pm 0.07$	0.30–0.32 [20]; 1.70–3.30 [19]	1.7–2.6
$\bar{B}^0 \to D^{*0}\eta'$	$1.48 \pm 0.22 \pm 0.13$	0.41–0.47 [19]	2.0–3.2

TABLE II

Ratios of branching fractions $\mathrm{BF}(\bar{B}^0 \to D^{*0}h^0)/\mathrm{BF}(\bar{B}^0 \to D^0h^0)$. The first uncertainty is statistical, the second is systematic.

BF ratio	This measurement
$D^{*0}\pi^0/D^0\pi^0$	$1.14 \pm 0.07 \pm 0.08$
$D^{*0}\eta(\gamma\gamma)/D^0\eta(\gamma\gamma)$	$1.09 \pm 0.09 \pm 0.08$
$D^{*0}\eta(\pi\pi\pi^0)/D^0\eta(\pi\pi\pi^0)$	$0.87 \pm 0.12 \pm 0.05$
$D^{*0}\eta/D^0\eta$ (combined)	$1.03 \pm 0.07 \pm 0.07$
$D^{*0}\omega/D^0\omega$	$1.80 \pm 0.13 \pm 0.13$
$D^{*0}\eta'(\pi\pi\eta)/D^0\eta'(\pi\pi\eta)$	$1.03 \pm 0.22 \pm 0.07$
$D^{*0}\eta'(\rho^0\gamma)/D^0\eta'(\rho^0\gamma)$	$1.06 \pm 0.38 \pm 0.09$
$D^{*0}\eta'/D^0\eta'$ (combined)	$1.04 \pm 0.19 \pm 0.07$

3. Baryonic decay $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-$

Baryonic decays account for (6.8±0.6)% [23] of all B mesons decays, however little is known about these processes. The reconstruction of exclusive final states allow to compare decay rates, and hence to increase our understanding of the fragmentation of B mesons into hadrons. The first measure-

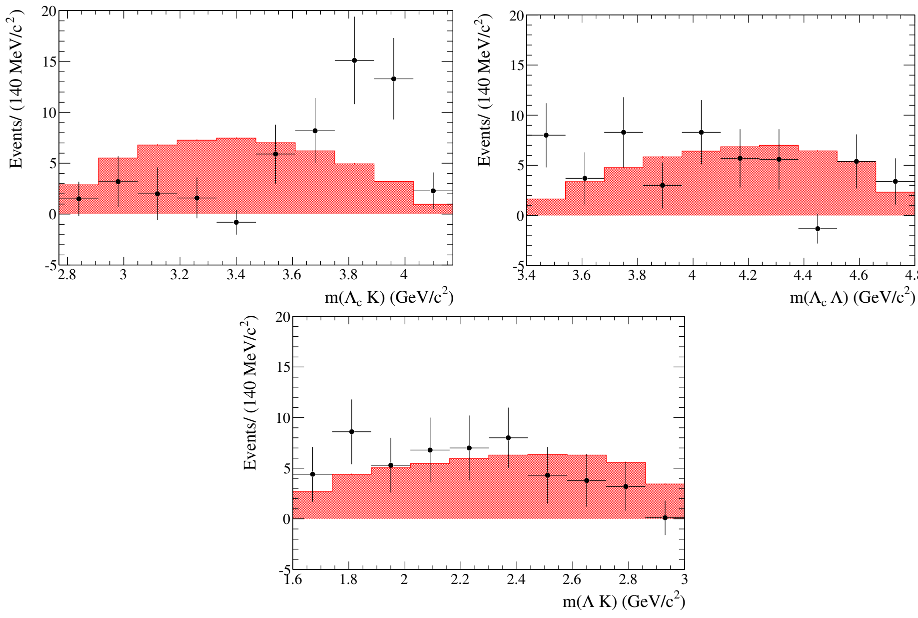

Fig. 1. Background-substracted distributions of the invariant masses $m(\Lambda_c K)$, $m(\Lambda_c \Lambda)$ and $m(\Lambda_K)$ in data (points) and simulated Monte Carlo non-resonant signal sample (full histogram).

ment of the decay channel $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-$ is reported here [2], using the full BaBar $\Upsilon(4S)$ sample, thus $471 \times 10^6 B\bar{B}$ pairs. The background-substracted distributions of the invariant masses $m(\Lambda_c K)$, $m(\Lambda_c \Lambda)$ and $m(\Lambda_K)$ are given in Fig. 1. A resonant structure is observed above $3.5\,\mathrm{GeV}/c^2$ in $m(\Lambda_c K)$, while no threshold enhancement is observed in $m(\Lambda_c \Lambda)$, in contrary to other three-body baryonic B decays [24]. The branching fraction is measured after rescaling the simulated efficiency to the data distribution, yielding: $\mathrm{BF}(\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-) = (3.8 \pm 0.8(\mathrm{stat.}) \pm 0.2(\mathrm{syst.}) \pm 1.0(\Lambda_c^+)) \times 10^{-5}$ [2], where the third uncertainty arises from uncertainty on the branching fraction of $\Lambda_c^+ \to pK^-\pi^+$. This is the first measurement of this channel, with a significance above seven standard deviations.

4. Charmless decays $B \to \eta h$ $(h = \pi, K)$

Charmless decays are sensitive probes for the measurement of the CP violation. In the Standard Model, the decays $B \to \eta K$ proceed through $b \to s$ penguin and $b \to u$ tree transitions. The interference of these transitions can result in a large direct CP asymmetry A_{CP} [25], defined as

$$A_{\mathrm{CP}} = \frac{\Gamma\left(\bar{B} \to \eta h\right) - \Gamma\left(B \to \eta \bar{h}\right)}{\Gamma\left(\bar{B} \to \eta h\right) + \Gamma\left(B \to \eta \bar{h}\right)}\,, \tag{1}$$

where $\Gamma(B \to \eta h)$ is the partial width obtained for the $B \to \eta h$ decay. Similar non-zero direct CP violation could be observed for $B^+ \to \eta\pi^+$, given to the interference between $b \to d$ penguin and $b \to u$ tree diagrams. Previous measurements by Belle [26] and BaBar [27] pointed to large negative A_{CP}, but more precise measurements are necessary to exclude the non-zero A_{CP} in $B^+ \to \eta\pi^+$. The branching fractions and A_{CP} (for the charged modes) have been measured in the final Belle data sample [3], thus $772 \times 10^6 B\bar{B}$, and are given in Table III. The first observation of $B^0 \to \eta K^0$ is also reported, with a significance of 5.4σ [3].

TABLE III

Measured branching fractions BF and direct CP asymmetry A_{CP} of $B \to \eta h$, $h = K, \pi$. The first uncertainty is statistical, the second is systematic.

Observables	Measured values
$\mathrm{BF}(B^0 \to \eta K^0)$	$(1.27^{+0.33}_{-0.29} \pm 0.08) \times 10^{-6}$
$\mathrm{BF}(B^+ \to \eta K^+)$	$(2.12 \pm 0.23 \pm 0.11) \times 10^{-6}$
$\mathrm{BF}(B^+ \to \eta\pi^+)$	$(4.07 \pm 0.26 \pm 0.21) \times 10^{-6}$
$A_{\mathrm{CP}}(B^+ \to \eta K^+)$	$-0.38 \pm 0.11 \pm 0.01$
$A_{\mathrm{CP}}(B^+ \to \eta\pi^+)$	$-0.19 \pm 0.06 \pm 0.01$

5. Charmless decays $B \to K\pi$

In a similar way as for the $B \to \eta h$ decays (see Section 4), the $B \to K\pi$ channels proceed through two diagrams: $b \to u$ tree and $b \to s$ penguins ones, both color-allowed or color-suppressed [28], whose interference are predicted to lead to a non-null direct CP asymmetry $A_{\rm CP}(K^\pm\pi^\mp)$

$$A_{\rm CP}\left(K^\pm\pi^\mp\right) = \frac{\Gamma\left(\bar{B}^0 \to K^-\pi^+\right) - \Gamma\left(B^0 \to K^+\pi^-\right)}{\Gamma\left(\bar{B}^0 \to K^-\pi^+\right) + \Gamma\left(B^0 \to K^+\pi^-\right)}\,. \qquad (2)$$

Previous measurements of the direct CP asymmetry in $B \to K\pi$ decays by Belle [28] pointed a significant and unexplained difference between $A_{\rm CP}(K^\pm\pi^\mp)$ and $A_{\rm CP}(K^\pm\pi^0)$. Using the final sample, thus $772 \times 10^6 B\bar{B}$ pairs plus an improved tracking, Belle measured the branching fractions and the direct asymmetries of $B \to K\pi$ modes [4] (see Table IV). These values are compatible with the previous measurements by BaBar [29], CDF [30] and LHCb [31]. The possible isospin violating in $B \to K\pi$ decays can be investigated comparing the BF ratios between the different modes with the SM prediction from the SU(3) symmetry. The results, given in Table V are consistent with the different theoretical approaches [4].

TABLE IV

Measured branching fractions BF and direct CP asymmetry $A_{\rm CP}$ of $B \to K\pi$. The first uncertainty is statistical, the second is systematic.

Channel	BF	$A_{\rm CP}$
$B^\pm \to K^\pm\pi^0$	$(12.62 \pm 0.31 \pm 0.56) \times 10^{-6}$	$0.043 \pm 0.024 \pm 0.002$
$B^0 \to K^\pm\pi^\mp$	$(20.00 \pm 0.34 \pm 0.63) \times 10^{-6}$	$-0.069 \pm 0.014 \pm 0.007$
$B^\pm \to K^0\pi^\pm$	$(23.97^{+0.53}_{-0.52} \pm 0.69) \times 10^{-6}$	$-0.014 \pm 0.021 \pm 0.006$
$B^0 \to K^0\pi^0$	$(9.66 \pm 0.46 \pm 0.49) \times 10^{-6}$	—

TABLE V

Widths Γ ratios derived from the measured branching fractions (see Table IV), compared to the SM prediction from the SU(3) symmetry. The first uncertainty is statistical, the second is systematic.

Ratio	This measurement	SM
$2\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$	$1.05 \pm 0.03 \pm 0.05$	1.15 ± 0.05
$\Gamma(K^+\pi^-)/2\Gamma(K^0\pi^0)$	$1.04 \pm 0.05 \pm 0.06$	1.12 ± 0.05

6. Observations of $B_s^0 \to J/\psi f_0$ and $B_s^0 \to J/\psi\eta$

The $b \to c\bar{c}s$ transition, occurring for instance in the decay $B_s^0 \to J/\psi\phi$, benefits from a relatively large branching fraction. It has thus been used to extract the B_s^0 decay width difference $\Delta\Gamma$ and the CP violating phase β_s [32, 33], sensitive to potential New Physics. Such study requires however an angular analysis, owing to the *Scalar* $\to$ *Vector Vector* nature of the channel. The same $b \to c\bar{c}s$ transition can lead to the decay channel $B_s^0 \to J/\psi f_0$, thus *Scalar* $\to$ *Vector Scalar*, for which no angular analysis is so needed; furthermore leading order QCD, together with measurements of D_s decays to ϕ and f_0 mesons, predicts its branching fraction to be $(3.1 \pm 2.4) \times 10^{-4}$ [5]. Using its final data sample at $\Upsilon(5S)$, thus 121.4/fb or $(1.24 \pm 0.23) \times 10^7$ $B_s^* \bar{B}_s^*$ pairs, Belle measured the $B_s^0 \to J/\psi f_0$ branching fraction, yielding together with LHCb [34] its first observation [5]. The distributions of the invariant mass of the di-pion system from $f_0 \to \pi^+\pi^-$ are given in figure 2, where the $f_0(980)$ resonance can be seen, close to another scalar resonance, whose fitted parameters are: $m_0 = (1.405 \pm 0.015(\mathrm{stat.})^{+0.001}_{-0.007}(\mathrm{syst.}))$ GeV/c^2 and $\Gamma_0 = (0.054 \pm 0.033(\mathrm{stat.})^{+0.014}_{-0.003}(\mathrm{syst.}))$ GeV, which are consistent with the $f_0(1370)$ parameters [23]. The measured branching fractions, signal yields and significances are given in Table VI.

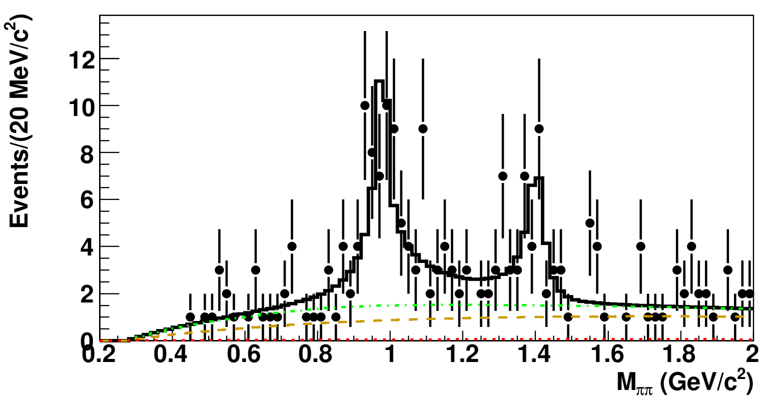

Fig. 2. Invariant mass of the di-pion system in data (points). The total fitted distribution is given by the solid line, the dash-dotted curves give the total background, the dashed curves other J/ψ background, and the dotted curves show the non-resonant component.

Belle also observed for the first time the decay $B_s^0 \to J/\psi\eta$ using its full $\Upsilon(5S)$ dataset [6]. The distributions in data of the beam-constrained mass M_{bc} and of the energy difference ΔE [5] for the sub-channel $B_s^0 \to J/\psi\eta$ with $\eta \to \pi^+\pi^-\pi^0$ are given in figure 3, where the B signal can clearly be seen at $M_{\mathrm{bc}} \simeq 5.42$ GeV/c^2 and $\Delta E \simeq 0$ GeV. The measured branching fraction yields

$$\mathrm{BF}\left(B_s^0 \to J/\psi\eta\right) = \left(5.11 \pm 0.50(\mathrm{stat.}) \pm 0.35(\mathrm{syst.}) \pm 0.68(f_s) \times 10^{-4}\right), \quad (3)$$

where the last uncertainty accounts for the $B_s^{(*)}\bar{B}_s^{(*)}$ production fraction at the $\Upsilon(5S)$.

The observation of these channels offers new CP channels for the study of the B_s mixing property, paving the way for LHC experiments.

TABLE VI

Branching fractions, fitted signal yields and significance S of the measurements performed in data on the $B_s^0 \to J/\psi f_0(X)$ channels. The quoted uncertainties account for, respectively, the statistics, systematics and the number of $B_s^{(*)}\bar{B}_s^{(*)}$ in the data sample.

Mode	Yield	S	BF$\times 10^{-4}$
$B_s^0 \to J/\psi f_0(980)$	63^{+16}_{-10}	8.4σ	$1.16^{+0.31+0.15+0.26}_{-0.19-0.17-0.18}$
$B_s^0 \to J/\psi f_0(1370)$	19^{+6}_{-8}	4.2σ	$0.34^{+0.11+0.03+0.08}_{-0.14-0.02-0.05}$

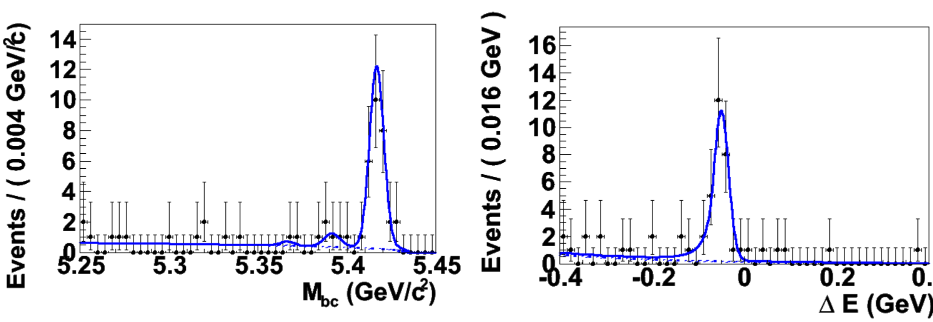

Fig. 3. The distributions in data (points) of the beam-constrained mass M_{bc} and of the energy difference ΔE for the sub-channel $B_s^0 \to J/\psi\eta$ with $\eta \to \pi^+\pi^-\pi^0$. The total fit function is given by the solid line, the total background contribution by the dotted line, and the continuum background is represented by the dashed line.

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