SLAC-PUB-16307

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This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-76SF00515 and HEP.

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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 expeiments. 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.

PACS numbers: 14.20.Mr

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 $\bar{B}^0 \to D^{(*)0}h^0, h^0 = \pi^0, \eta, \eta', \omega$

In such decays, the effect of color suppression is obscured by the exchange of soft gluons (final state interactions), which enhance $W^{\pm}$ exchange diagrams. Previous measurements of the branching fractions of the color-suppressed decays $\bar{B}^0 \to D^{(*)0}h^0$ invalidated the factorization

* Presented at Cracow Epiphany Conference, 9-11 January 2012

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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 the Table 1 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 $BF(\bar{B}^0 \to D^{*0}h^0)/BF(\bar{B}^0 \to D^0h^0)$ are about equal to one for $h^0 = \pi^0, \eta, \eta'$. The ratios of branching fractions are given in Table 2 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 $f_L = (66.5 \pm 4.7(\text{stat.}) \pm 1.5(\text{syst.}))\%$ [1], deviating thus significantly from the factorization's prediction. This reinforces the conclusion drawn from the branching fraction measurements on the validity of factorisation in color-suppressed decays and supports expectations from SCET.

Table 1. 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 2. Ratios of branching fractions $BF(\bar{B}^0 \to D^{*0}h^0)/BF(\bar{B}^0 \to D^0h^0)$. 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 $(6.8 \pm 0.6)\%$ [23] of all B mesons decays, however little is know 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 measurement 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 the Fig. 1. A resonant structure is observed above 3.5 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: $BF(\bar{B}^0 \to \Lambda_c^+\bar{\Lambda}K^-) = (3.8 \pm 0.8(\text{stat.}) \pm 0.2(\text{syst.}) \pm 1.0(\Lambda_c^+)) \times 10^{-5}$ [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:

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

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 preciser 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) has been measured in the final Belle data sample [3], thus $772 \times 10^6 B\bar{B}$, and are given in the Table 3. The first observation of $B^0 \to \eta K^0$ is also reported, with a significance of 5.4σ [3].

Table 3. 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
$BF(B^0 \to \eta K^0)$	$(1.27^{+0.33}_{-0.29} \pm 0.08) \times 10^{-6}$
$BF(B^+ \to \eta K^+)$	$(2.12 \pm 0.23 \pm 0.11) \times 10^{-6}$
$BF(B^+ \to \eta\pi^+)$	$(4.07 \pm 0.26 \pm 0.21) \times 10^{-6}$
$A_{CP}(B^+ \to \eta K^+)$	$-0.38 \pm 0.11 \pm 0.01$
$A_{CP}(B^+ \to \eta\pi^+)$	$-0.19 \pm 0.06 \pm 0.01$

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 assymetry $A_{CP}(K^\pm\pi^\mp)$:

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

Previous measurements of the direct CP asymmetry in $B \to K\pi$ decays by Belle [28] pointed a significant and unexplained difference between $A_{CP}(K^\pm\pi^\mp)$ and $A_{CP}(K^\pm\pi^0)$. 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 4). 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 the Table 5 are consistent with the different theoretical approaches [4].

Table 4. Measured branching fractions BF and direct CP asymmetry A_{CP} of $B \to K\pi$. The first uncertainty is statistical, the second is systematic.

Channel	BF	A_{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 5. Widths Γ ratios derived from the measured branching fractions (see Table 4), 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, occuring 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*→*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*→*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 the Figure 2, where the $f_0(980)$ resonance can be seen, close to another scalar resonance, whose fitted parameters are: $m_0 = (1.405 \pm 0.015(\text{stat.})^{+0.001}_{-0.007}(\text{syst.}))$ GeV/c^2 and $\Gamma_0 = (0.054 \pm 0.033(\text{stat.})^{+0.014}_{-0.003}(\text{syst.}))$ GeV, which are consistent with the $f_0(1370)$ parameters [23]. The measured branching fractions, signal yields and significances are given in the Table 6.

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

Table 6. 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	$0.34^{+0.11+0.03+0.08}_{-0.14-0.02-0.05}$

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 the Figure 3 where the B signal can clearly be seen at $M_{bc} \simeq 5.42$ GeV/c^2 and $\Delta E \simeq 0$ GeV. The measured branching fraction yields:

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

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.

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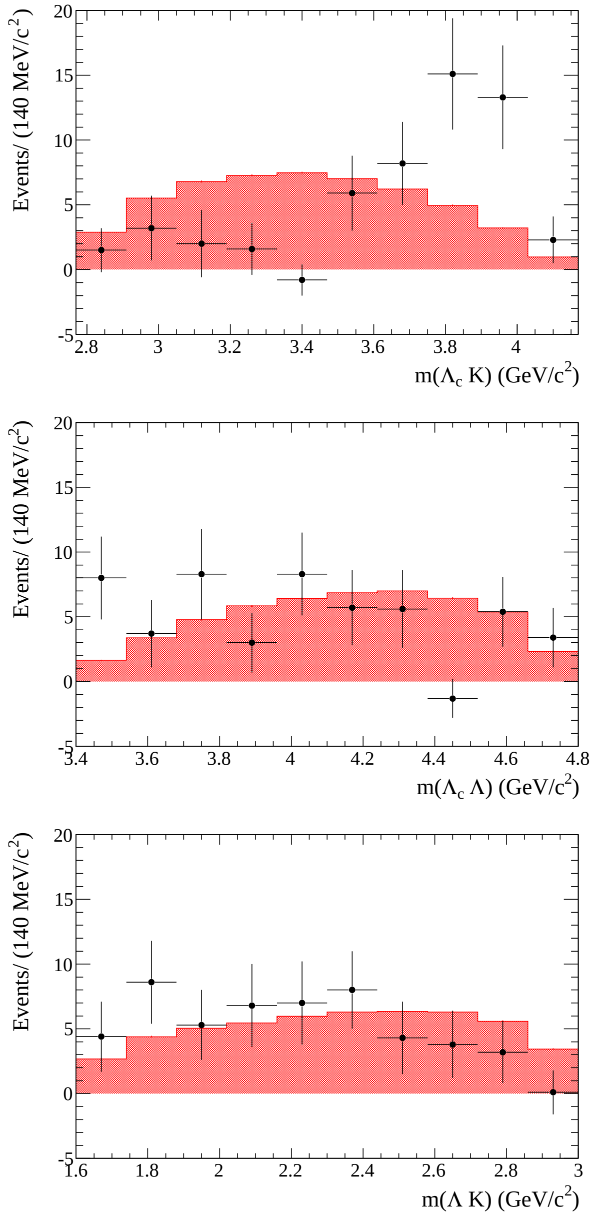

Fig. 1. Background-substracted distributions of the invariant masses $m(\Lambda_c K)$, $m(\Lambda_c \Lambda)$ and $m(\Lambda_K)$ in data (points) and simulated Monte Carlo non-resonant signal sample (full histogram)

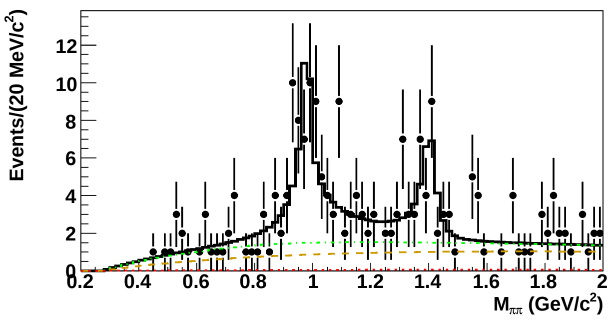

Fig. 2. Invariant mass of the di-pion system in data (points). The total fitted distribution is given by the solid line, the dash-dotted cuvred give the total background, the dashed curves other J/ψ background, and the dotted curves show the non-resonant component.

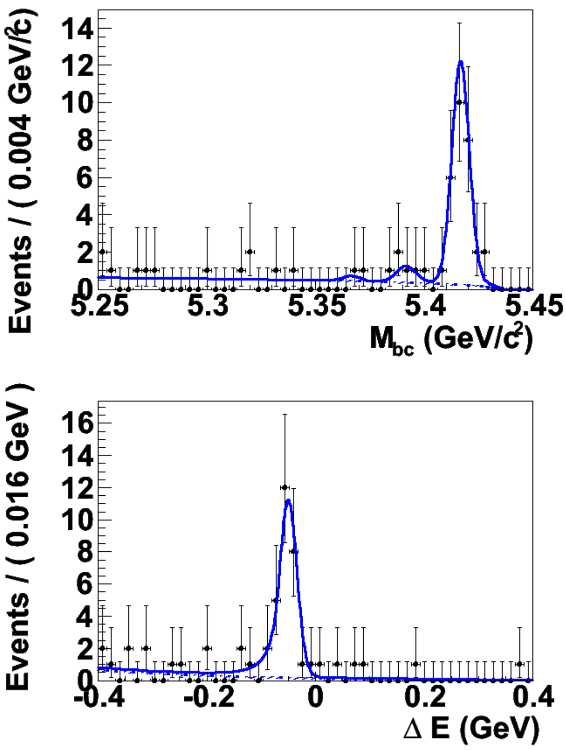

Fig. 3. The distributions in data (points) of the beam-constrained mass M_{bc} and of the energy difference ΔE for the sub-channel $B_s^0 \to J/\psi\eta$ with $\eta \to \pi^+\pi^-\pi^0$. The total fit function is given by the solid line, the total background contribution by the dotted line, and the continuum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