PRODUCTION AND DECAY OF b-FLAVORED HADRONS

Updated December 2003 by Y. Kwon (Yonsei University, Seoul, Korea).

In the summer of 2001—almost four decades after CP violation was first discovered in the decay of neutral kaons—the BABAR and Belle collaborations reported the first observation of CP violation in the B meson system [1,2]. The measurement of the CP-violation parameter $\sin 2\beta (= \sin 2\phi_1)$ [3] marks the culmination of a very significant experimental and theoretical program that started in 1973 when Kobayashi and Maskawa proposed their model of the quark mixing matrix. Other recent developments in the physics of B mesons include new results on penguin decays, improved measurements of rare hadronic B decays, as well as new determinations of the CKM matrix elements V_{cb} and V_{ub} [4,5].

The structure of this mini-review is organized as follows. First, we briefly update the results on b quark production and discuss the spectroscopy and the lifetimes of b-flavored hadrons. Then after a brief description of basic properties of B meson decays, we give a short description of the experimental results on CP violation in B meson decays. More details about formalism and implications of CP violations are described in a separate mini-review [6] in this *Review* . This review closes with a description and update on hadronic and rare decays of B mesons.

Production and spectroscopy: Elementary particles are characterized by their masses, lifetimes, and internal quantum numbers. The bound states with a $\overline{b}$ antiquark and a u or d quark are referred to as the B_d (B^0) and the B_u (B^+) mesons, respectively. The first excitation is called the B^* meson. B^{**} is the generic name for the four orbitally excited $(L = 1)$ B-meson states that correspond to the P-wave mesons in the charm system, D^{**}. Mesons containing an s or a c quark are denoted B_s^0 and B_c^+, respectively.

Although the b quark was discovered in a fixed-target experiment at Fermilab in 1977, most of the experimental information on b-flavored hadrons has come from colliding-beam machines. Currently, experimental studies of b decay are performed at the $\Upsilon(4S)$ resonance near production threshold, as well as at higher energies in proton-antiproton collisions and Z decays. High-energy $p\overline{p}$ collisions at the Tevatron produce b-flavored hadrons with very large cross-section ($\sigma_{bb} \sim 50\mu b$), but it is only possible to trigger on a very small fraction of the decays because of limited acceptance and large background. The bb production cross-section at the Z and $\Upsilon(4S)$ resonances are about 6.6 nb and 1.1 nb, respectively.

By far the largest samples of B mesons have been collected by the e^+e^- collider detectors running at $\Upsilon(4S)$ ("B-Factories"). As of this writing, both Belle and BABAR have accumulated approximately 150 fb^{-1}. The $\Upsilon(4S)$ resonance decays only to $B^0\overline{B}^0$ and B^+B^- pairs, while at high-energy collider experiments, heavier states such as B_s^0 or B_c^+ mesons and b-flavored baryons are produced as well. The current experimental limit for non-$B\overline{B}$ decays of the $\Upsilon(4S)$ is less than 4% at the 95% confidence level (CL) [7]. The $\bar{b}$ (or b) quarks produced at high-energy collider experiments hadronize as B^0, B^+, B_s^0, and B_c^+ mesons (or their antiparticles), or as baryons containing $\bar{b}$ (or b) quarks.

For quantitative studies of B decays, the initial composition of the data sample must be known. In particular, the ratio f_+/f_0 of charged to neutral $\Upsilon(4S)$ decays is crucial to calculate the decay branching fractions for B-factory experiments. CLEO and BABAR have measured the ratio $(f_+/f_0)(\tau_+/\tau_0)$ with exclusive $B \to \psi K^{(*)}$ [8,9] and $B \to D^*\ell\nu$ [10] decays, where τ_+/τ_0 is the B^+/B^0 lifetime ratio (*see next section*). By using the world-average value of τ_+ and τ_0 Belle also extracted the value of f_+/f_0 [11]. Using the current average of τ_+/τ_0, the average becomes $f_+/f_0 = 1.044 \pm 0.050$ [12]. This is consistent with equal production of B^+B^- and $B^0\overline{B}^0$ pairs, and unless explicitly stated otherwise, we will assume $f_+/f_0 = 1$. This assumption is further supported by the near equality of the B^+ and B^0 masses. Again using exclusive $B \to J/\psi K^{(*)}$ decays, CLEO determined these masses to $m(B^0) = 5.2791 \pm 0.0007 \pm$

0.0003 GeV/c^2 and $m(B^+) = 5.2791 \pm 0.0004 \pm 0.0004$ GeV/c^2, respectively [13].

More diverse species of b-flavored hadrons are produced in the experiments at the Z resonance and in the high-energy $p\overline{p}$ collisions. Table 1 shows the fractions f_d, f_u, f_s, and $f_{\rm baryon}$ of B^0, B^+, B^0_s, and b baryons in an unbiased sample of weakly decaying b hadrons produced at the Z resonance and in $p\overline{p}$ collisions [12]. A detailed account can be found elsewhere in this *Review* [14]. The values assume identical hadronization in $p\overline{p}$ collisions and in Z decay, even though these could, in principle, differ because of the different momentum distributions of the b–quark in these processes.

Table 1: Fractions of weakly decaying b-hadron species in $Z \to b\overline{b}$ decay and in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV.

b hadron	Fraction [%]
B^+, B^0	39.7 ± 1.0
B^0_s	10.7 ± 1.1
b baryons	9.9 ± 1.7

To date, the existence of several b-flavored mesons (B^+, B^0, B^0_s, B^+_c, and various excitations), as well as the Λ_b baryon has been established. Using exclusive hadronic decays such as $B^0_s \to J/\psi\phi$ and $\Lambda_b \to J/\psi\Lambda$, the masses of these states are now known with the precision of a few MeV. The current world averages of the B^0_s and the Λ_b mass are 5.3696 ± 0.0024 GeV/c^2 and 5.624 ± 0.009 GeV/c^2, respectively. Clear evidence for the B^+_c, the last weakly decaying bottom meson, has been published by CDF [15]. They reconstruct the semileptonic decay $B^+_c \to J/\psi\ell X$, and extract a B^+_c mass of $6.40 \pm 0.39 \pm 0.13$ GeV/c^2. First indications of Ξ_b production have been presented by the LEP Collaborations [16,17].

Excited B-meson states have been observed by CLEO, LEP, CUSB, and CDF. The current world average of the B^*–B mass difference is 45.78 ± 0.35 MeV/c^2. Evidence for B^{**} production has been presented by the LEP and CDF experiments [18]. Inclusively reconstructing a bottom hadron candidate combined with a charged pion from the primary vertex, they see the B^{**} as a broad resonance around 5.697 ± 0.009 GeV/c^2 in the $M(B\pi) - M(B)$ mass distribution [19]. Due to the inclusive approach, the mass resolution is limited to about 40 MeV, which makes it very difficult to identify the narrow states, B_1^* and B_2^*, separately. The LEP experiments have also provided evidence for excited B_s^{**} states.

Lifetimes: Precise lifetimes are key in extracting the weak parameters that are important for understanding the role of the CKM matrix in CP violation, such as the determination of V_{cb} and $B_s^0\overline{B}_s^0$ mixing measurements. In the naive spectator model, the heavy quark can decay only via the external spectator mechanism, and thus, the lifetimes of all mesons and baryons containing b quarks would be equal. Nonspectator effects, such as the interference between contributing amplitudes, modify this simple picture and give rise to a lifetime hierarchy for b-flavored hadrons similar to the one in the charm sector. However, since the lifetime differences are expected to scale as $1/m_Q^2$, where m_Q is the mass of the heavy quark, the variation in the b system should be significantly smaller, of order 10% or less [20]. For the b system we expect

$$\tau(B^+) \ \geq \ \tau(B^0) \ \approx \ \tau(B_s^0) \ > \ \tau(\Lambda_b^0) \ \gg \ \tau(B_c^+) \ . \qquad (1)$$

In the B_c^+, both quarks can decay weakly, resulting in its much shorter lifetime. Measurements of lifetimes for the various b-flavored hadrons thus provide a means to determine the importance of non-spectator mechanisms in the b sector.

Over the past years, advanced algorithms based on impact parameter or decay length measurements exploiting the potential of silicon vertex detectors resulted in improvement of lifetime measurements. However, in order to reach the precision necessary to test theoretical predictions, the results from different experiments need to be averaged. This is a challenging task that requires detailed knowledge of common systematic uncertainties, and correlations between the results from different experiments. The average lifetimes for b-flavored hadrons given in this edition have been determined by the Heavy Flavor Averaging Group (HFAG) [12]. A detailed description of the procedures and the treatment of correlated and uncorrelated errors can be found in [21]. The asymmetric B factories are now making significant contributions to the B^+ and B^0 lifetime measurements. Their use of fully–reconstructed B decays yield measurements with much reduced statistical and systematic uncertainties. The measurements are free, for example, from systematics associated with modelling of fragmentation. The new world average b-hadron lifetimes are summarized in Table 2.

Table 2: Summary of inclusive and exclusive b-hadron lifetime measurements.

Particle	Lifetime [ps]
B^0	1.536 ± 0.014
B^+	1.671 ± 0.018
B^0_s	1.461 ± 0.057
B^+_c	$0.46^{+0.18}_{-0.16} \pm 0.03$
b baryon	1.208 ± 0.051
Λ_b	1.229 ± 0.080
Ξ_b	$1.39^{+0.34}_{-0.28}$
b hadron	1.564 ± 0.014

For comparison with theory, lifetime ratios are preferred. Experimentally we find

$$\frac{\tau_{B^+}}{\tau_{B^0}} = 1.086 \pm 0.017\,, \ \frac{\tau_{B^0_s}}{\tau_{B^0}} = 0.951 \pm 0.038\,,$$

$$\frac{\tau_{\Lambda_b}}{\tau_{B^0}} = 0.800 \pm 0.053\,,$$

while theory makes the following predictions [22]

$$\frac{\tau_{B^+}}{\tau_{B^0}} = 1 + 0.05 \left(\frac{f_B}{200 \ \mathrm{MeV}}\right)^2 \ , \ \frac{\tau_{B^0_s}}{\tau_{B^0}} = 1 \pm 0.01 \ , \ \frac{\tau_{\Lambda_b}}{\tau_{B^0}} = 0.9 \ .$$

In conclusion, the pattern of measured B-meson lifetimes follows the theoretical expectations, and non-spectator effects are observed to be small. The short B^+_c lifetime has been predicted correctly. However, the Λ_b-baryon lifetime may be somewhat smaller than expected. As has been noted by several authors, the observed value of the Λ_b lifetime is difficult to accommodate theoretically [23–29].

Similar to the kaon system, neutral B mesons contain short- and long-lived components. The Standard Model predicts that the lifetime difference is significantly smaller. The most stringent limit on the lifetime difference of neutral B_d mesons is recently obtained by BABAR: $-0.156 < \Delta\Gamma_d/\Gamma_d < 0.042$ at 90% CL [30] where $\Delta\Gamma_d \equiv \Gamma_H - \Gamma_L$ with $\Gamma_H(\Gamma_L)$ being the decay width of the heavier (lighter) B_d meson. They measure the time-dependence of $\Upsilon(4S)$ decays where one neutral B is fully reconstructed and the other B is identified as being either B^0 or $\overline{B}^0$. In this analysis, possible violations in CP, T, and CPT are fully considered. The limit on the lifetime difference for B_s^0 is $|\Delta\Gamma_s|/\Gamma_s < 0.54$ at 95% CL. This result is based on a combination [12] of the various B_s^0 proper time measurements. A more restrictive limit for the B_s^0 system ($|\Delta\Gamma_s|/\Gamma_s < 0.29$) can be obtained if one assumes $\Gamma_s = \Gamma_d$.

B meson decay properties: B^+ and B^0 mesons are the lightest elements of the b-flavored hadrons, hence they decay via weak interactions. Since the mass of a b-quark is much larger than its partner quark (d or u), B meson decays are mostly described by the decay of the b quark ("spectator model"). The dominant decay mode of a b-quark is $b \to cW^*$ where the virtual W^* eventually materializes either into a pair of leptons, $\ell\nu$ ("semileptonic decay") or into a pair of quarks which then hadronizes. The decays in which the spectator quark combines with one of the quarks from W^* are suppressed because the colors of the quarks from different sources must match ("color-suppression").

Couplings of quarks to the W boson are described by the Cabibbo-Kobayashi-Maskawa (CKM) matrix. The regular pattern of the three lepton and quark families is one of the most intriguing puzzles in particle physics. The existence of families gives rise to many of the free parameters in the Standard Model, in particular the fermion masses, and the elements of the CKM matrix. In the Standard Model (SM) of three generations, the CKM matrix is parameterized by three real parameters and one complex phase. This complex phase can become a source of CP

violations in B meson decays. A more detailed discussion of the CKM matrix and CP violation can be found elsewhere in this *Review* [6,31].

Semileptonic B decays $B \to X_c \ell \nu$ and $B \to X_u \ell \nu$ provide an excellent laboratory to measure CKM elements $|V_{cb}|$ and $|V_{ub}|$ respectively, because the strong interaction effects are much simplified due to the two leptons in the final state. Both exclusive decays and inclusive decays can be used and the nature of uncertainties are quite complimentary. For exclusive decay analysis a knowledge about the form factors for the exclusive hadronic system $X_{c(u)}$ is required. For inclusive analysis, it is usually required to restrict the available phase-space of the decay products to suppress backgrounds; subsequently uncertainties are introduced in the extrapolation to the full phase-space. Moreover, restriction to a small corner of the phase-space may result in break-down of the operator product expansion scheme, thus making theoretical calculations unreliable. A more detailed discussion of the B semileptonic decays and extraction of $|V_{cb}|$ and $|V_{ub}|$ are described elsewhere in the *Review* [4,5].

On the other hand, hadronic decays of B are complicated because of strong interaction effects caused by the surrounding cloud of light quarks and gluons. While this complicates the extraction of CKM matrix elements, it also provides a great opportunity to study perturbative and non-perturbative QCD, hadronization, and Final State Interaction (FSI) effects, etc.

Other (non-spectator) decay processes include W-exchange and annihilation decays both of which occur at tree level processes. Higher-order loop-induced flavor-changing neutral current (FCNC) decay processes ("Penguin decays") are also available. In the Standard Model, these decays are much suppressed in comparison to the spectator decays. Penguin decays are experimentally established by observations of $B \to K^* \gamma$ and recently $B \to K^{(*)} \ell^+ \ell^-$. Some observed decay modes such as $B^0 \to D_s^- K^+$ may be interpreted as a W-exchange process. There has not been any experimental evidence for annihilation decays of B.

Experimental results on CP violation in B decays: The determination of all the parameters of the CKM matrix is required to fully define the Standard Model, and is central to the experimental program in heavy-flavor physics. In the framework of the Standard Model, the CKM matrix must be unitary, *i.e.* $VV^\dagger = 1$. This gives rise to relationships between the matrix elements that can be visualized as triangles in the complex plane, for example

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0\,.$$

The interior angles of the triangle can be expressed in terms of the CKM elements

$$\alpha = \phi_2 = arg(-\frac{V_{ud}V_{ub}^*}{V_{td}V_{tb}^*})\,,$$

$$\beta = \phi_1 = arg(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*})\,,$$

$$\gamma = \phi_3 = arg(-\frac{V_{cd}V_{cb}^*}{V_{ud}V_{ub}^*})\,.$$

The most precise measurements of the angle β have come from the two energy-asymmetric B-factories running at $\Upsilon(4S)$, KEKB and PEP-II, by analyzing time-dependent CP asymmetries in $b \to c\bar{c}s$ decay modes including $B \to J/\psi K_S$. Given the tiny boost the B mesons receive in the $\Upsilon(4S)$ rest frame, asymmetric beam energies are required to improve the precision of time-dependence measurement. At KEKB, for example, the boost is $\beta\gamma = 0.43$, and the typical B meson decay length is dilated from $\approx 20\ \mu m$ to $\approx 200\ \mu m$. PEP-II uses a slightly larger boost, $\beta\gamma = 0.55$.

In the decay chain $\Upsilon(4S) \to B^0\overline{B}^0 \to f_{CP} f_{\rm tag}$, in which one of the B mesons decays at time t_{CP} to f_{CP} and the other decays at time $t_{\rm tag}$ to a final state $f_{\rm tag}$ that distinguishes between B^0 and $\overline{B}^0$, the decay rate has a time dependence given by [6]

$$\mathcal{P}^q_{f_{CP}}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left[1 + q\cdot\{S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)\}\right],$$

where τ is the B^0 lifetime, Δm_d is the mass difference between the two B^0 mass eigenstates, and $\Delta t = t_{CP} - t_{\rm tag}$. The parameter q is determined by identifying the b-quark flavor of the accompanying B meson ("flavor tagging") using inclusive features of the charged particles in $f_{\rm tag}$. For instance, $q = +1(-1)$ when the tagging B meson is a B^0 ($\overline{B}^0$). The CP-violating parameters S and C are expressed as

$$C = \frac{1-|\lambda|^2}{1+|\lambda|^2}, \qquad S = \frac{2Im\lambda}{1+|\lambda|^2},$$

where λ is a complex parameter that depends on both B^0-$\overline{B}^0$ mixing and on the amplitudes for B^0 and $\overline{B}^0$ decay to f_{CP}. In the SM, to a good approximation, $|\lambda|$ is equal to the absolute value of the ratio of the $\overline{B}^0$ to B^0 decay amplitudes. In the absence of direct CP violation, $|\lambda| = 1$. For $b \to c\bar{c}s$ transition, the SM predicts $S = -\xi \sin 2\beta$, where $\xi = +1(-1)$ for CP-even (-odd) final states, and $C = 0$.

In the summer of 2001, both BABAR [1] and Belle [2] reported first significant measurements of $\sin 2\beta$, thereby establishing CP violation in the B^0 meson decays. Both experiments have updated their results recently. Using a data sample of 88 million $B\overline{B}$ pairs, BABAR [32] obtained $\sin 2\beta = 0.741 \pm 0.067 \pm 0.034$, while with 152 million $B\overline{B}$ pairs, Belle [33] reported $\sin 2\beta = 0.733 \pm 0.057 \pm 0.028$. Averaging the latest results from the two experiments we find

$$\sin 2\beta = \sin 2\phi_1 = 0.736 \pm 0.049.$$

This value is consistent with CKM expectations.

Charmless B decays mediated by the $b \to s$ penguin transition are potentially sensitive to new CP-violating phases from physics beyond the SM [34]. In the SM, measurement of S in the $b \to s\bar{s}s$ transition should yield approximately the same value ($-\xi \sin 2\beta$) as in the $b \to c\bar{c}s$ modes. Both BABAR and Belle measured S for $B \to \eta' K_S$ and ϕK_S. Both final states are CP-odd ($\xi = -1$). Belle also measured S for $B \to K^+K^-K_S$ (non-resonant). From an angular analysis, Belle concludes that $K^+K^-K_S$ is primarily CP-even [35]. The average value of effective $\sin 2\beta (\equiv \sin 2\beta_{\rm eff})$ for $b \to s$ penguin transitions calculated by HFAG is 0.24 ± 0.15 where the error is dominantly statistical. The largest deviation from $b \to c\bar{c}s$ result ($\sin 2\beta = 0.736$) comes from Belle's $B \to \phi K_S$ mode where they measure $\sin 2\beta_{\rm eff} = -0.96 \pm 0.50^{+0.09}_{-0.11}$. For the same mode, BABAR measures $\sin 2\beta_{\rm eff} = +0.45 \pm 0.43 \pm 0.07$. There is a 2.1 σ discrepancy between Belle and BABAR.

Experimental work on the determination of the other two angles of the unitarity triangle is also underway. Much larger data samples will be needed to obtain precision results and to challenge the Standard Model. Information on $\sin 2\alpha$ can be extracted from $B \to \pi^+\pi^-$ decays following a procedure similar to the one outlined above. Unfortunately, these decays suffer from fairly small branching fractions ($\mathcal{O}(10^{-6})$) and sizeable contributions from penguin diagrams that complicate the extraction of the CP phases. Because of this, the time-dependent asymmetry in $B \to \pi^+\pi^-$ will not be proportional to $\sin\alpha$, but to $\sin 2\alpha_{\rm eff}$, with an unknown correction to α. Despite these difficulties, attempts to measure CP asymmetries in the $\pi^+\pi^-$ mode have been reported. Using 113 fb^{-1}, BABAR [36] extracts $S(= \sqrt{1-C^2} \times \sin 2\alpha_{\rm eff}) = -0.40 \pm 0.22 \pm 0.03$ and Belle [37] finds $S = -1.23 \pm 0.41^{+0.08}_{-0.07}$ with 78 fb^{-1}. The contribution from direct CP violation in the $B \to \pi^+\pi^-$ decay shows up as a nonzero amplitude C. Both experiments have determined C simultaneously with S. BABAR finds $C = -0.19 \pm 0.19 \pm 0.05$, while Belle measures $C = -0.77 \pm 0.27 \pm 0.08$. BABAR also measured CP-violation parameters in the related mode $B^0 \to \rho^\pm\pi^\mp$ and obtained $S_{\rho\pi} = -0.13 \pm 0.18 \pm 0.04$ and $C_{\rho\pi} = 0.35 \pm 0.13 \pm 0.05$ [38]. The time- and flavor-integrated charge asymmetry $A^{\rho\pi}_{CP}$ is also measured as $-0.114 \pm 0.062 \pm 0.027$. The decay $B^0 \to \rho^+\rho^-$ is another promising mode for measuring α and has the advantage of a larger expected decay rate and smaller uncertainty in penguin contaminations. Based on the recent limit on $B^0 \to \rho^0\rho^0$ and the measurements of $B^+ \to \rho^+\rho^0$ branching fraction [79], BABAR sets an upper limit on the penguin pollution to $B^0 \to \rho^+\rho^-$ [81].

Several methods have been suggested to measure the third angle, $\gamma \approx \arg(V_{ub})$ [39]. However, they require very large data samples (such as for $B \to DK$), measurements of B^0_s decays or suffer from large theoretical uncertainties, rendering γ particularly difficult to measure.

Gronau and Wyler [40] first suggested that decays of the type $B \to DK$ can be used to extract the angle γ. An example of such Cabibbo–suppressed modes, $B^- \to D^0 K^-$ was first observed by CLEO [41] and later confirmed by Belle [42] and BABAR [43]. By selecting CP eigenstates for the D^0 meson decay mode, both Belle and BABAR have limited direct CP violation in these decays [43,44].

The decay amplitudes for $B^+ \to D^0 K^+$ and $B^+ \to \overline{D}^0 K^+$ can interfere if the D^0 and $\overline{D}^0$ decay to a common final state, such as $K_S \pi^+\pi^-$. Since the Cabibbo-suppressed $B^+ \to D^0 K^+$ amplitude involves V_{ub}, the phase difference measures the angle γ. Belle made a preliminary attempt of a $D^0 \to K_S \pi^+\pi^-$ Dalitz plot analysis for this channel to simultaneously determine γ and an unknown strong phase [45].

The Cabibbo-favoured $B^0 \to D^{(*)-}\pi^+$ amplitude can have interference with the doubly Cabibbo-suppressed amplitude of $\overline{B}^0 \to D^{(*)-}\pi^+$. The relative weak phase between these two amplitudes is γ and, when combined with the $B^0\overline{B}^0$ mixing phase, the total phase difference is $-(2\beta + \gamma)$. Therefore $B^0 \to D^{(*)\pm}\pi^\mp$ decays can provide sensitivity to γ. The interpretation of the observables in terms of unitarity angles requires external input on the ratio of magnitude of the two amplitudes. Due to the disparate strength of the two interfering amplitudes, CP asymmetry is expected to be small, hence the possible occurrence of CP violation on the tag side may become an important obstacle. Preliminary results on measuring the CP-violating amplitudes in the partially and fully reconstructed $B^0 \to D^{(*)\pm}\pi^\mp$ decays have been made by BABAR [46,47] and Belle [48].

Hadronic B decays: The experimental results on hadronic B decays have steadily improved over the past years and the measurements have reached a sufficient precision to challenge our understanding of the dynamics of these decays. It has been suggested that in analogy to semileptonic decays, two-body hadronic decays of B mesons can be expressed as the product of two independent hadronic currents, one describing the formation of a charm meson, and the other the hadronization of the remaining $\overline{u}d$ (or $\overline{c}s$) system from the virtual W^-.

Qualitatively, for a B decay with a large energy release, the $\overline{u}d$ pair, which is produced as a color singlet, travels fast enough to leave the interaction region without influencing the second hadron formed from the c quark and the spectator antiquark. The assumption that the amplitude can be expressed as the product of two hadronic currents is called "factorization" in this paper. Recent theoretical work has provided a more solid foundation for this hypothesis [49,50].

With a good neutral particle detection and hadron identification capabilities of B-factory detectors, a substantial fraction of hadronic B decay events can be fully reconstructed. Because of the kinematic constraint of $\Upsilon(4S)$, the energy sum of the final-state particles of a B meson decay is always equal to one half of the total energy in the center of mass frame. As a result, the two variables, ΔE (energy difference) and M_B (B candidate mass with a beam-energy constraint) are very effective to suppress combinatorial background both from $\Upsilon(4S)$ and $e^+e^- \to q\bar{q}$ continuum events. In particular, the energy-constraint in M_B improves the signal resolution by almost an order of magnitude.

Such a kinematically clean environment of B meson decays provides a very nice laboratory to search for new states. For instance, quark-level $b \to c\bar{c}s$ decays have been used to search for new charmonium and charm-strange mesons and study their properties in detail. Recently, BABAR discovered a new narrow charm-strange state $D_{sJ}(2317)$ [51] and CLEO observed a similar state $D_{sJ}(2460)$ [52]. But the properties of these new states were largely unknown. Belle later observed $B \to DD_{sJ}(2317)$ and $B \to DD_{sJ}(2460)$, which helped identify some quantum numbers of $D_{sJ}(2460)$ [53].

In the $B \to$ charmonium mode, several new modes have been added. In particular, Belle studied $B \to \{J/\psi\pi^+\pi^-\}K^+$ decays and looked for new states that decay to $J/\psi\pi^+\pi^-$. A new very narrow state was discovered at 3.872 GeV which approximately coincides with the sum of D^0 and D^{*0} masses [54]. This state was also confirmed by CDF [55]. The detailed properties of this new state are not known yet.

Most branching fractions for exclusive $B \to J/\psi K^{(*)}$ transitions are updated. Being a vector-vector final state, the CP eigenvalue of $J/\psi K^*$ depends on its polarization state. Therefore, the polarization needs to be measured in order to extract CP violation parameters from this decay. Updated measurements of the polarization in $B \to J/\psi K^*$ have been made by Belle, BABAR, CDF and CLEO and an outstanding discrepancy between theory and experiment [56] is resolved. The decay amplitudes for $B \to \phi K^*$ are also measured and the fraction of longitudinal polarization is $0.41 \pm 0.10 \pm 0.04$ [57].

$B^0 \to D^{(*)+} D^{(*)-}$ decays are also sensitive to the CKM unitarity angle β. However, the theoretically uncertain penguin contribution with different weak phases may shift the observed asymmetry by an amount that depends on the penguin/tree ratio. This shift is expected to be small in models based on factorization and heavy-quark symmetry. $B^0 \to D^{*+} D^{*-}$ decays have been observed by CLEO [58] and BABAR [59] with an average branching fraction of $(8.7 \pm 1.8) \times 10^{-4}$. By studying the polarization of this mode, BABAR determines the CP-odd fraction as $0.063 \pm 0.055 \pm 0.09$ as well as the CP-violating parameter $Im(\lambda) = 0.05 \pm 0.29 \pm 0.10$ [60] which the SM predicts to be $-\sin 2\beta$ in the absence of penguin contamination. $B^0 \to D^{*-} D^+$ decay is first observed by Belle [61] and confirmed by BABAR [62]. The average branching fraction for this mode is $(9.3 \pm 1.5) \times 10^{-4}$. BABAR also set bounds on the CP-violating parameters for this mode.

Angular distributions have been studied for other B decays to two vector mesons, in $B \to D^* \rho$ [63] and $B \to D^* D_s^*$ [64,65]. These results can be used to test the factorization hypothesis as suggested by Körner and Goldstein [66] by comparing exclusive hadronic B decays to the corresponding semileptonic modes. For certain $b \to c$ decays with large energy release it is expected that factorization works well. An example is given by the longitudinal polarization of ρ mesons in $B \to D^* \rho$ decays. CLEO's result of $\Gamma_L/\Gamma = 0.885 \pm 0.016 \pm 0.012$ [63] agrees well with the factorization expectation, 0.85 – 0.88 [67–70]. Within the experimental precision (10 – 30%) and over the limited q^2 range ($\sim M_\rho^2$) probed so far, the measurements agree with factorization predictions. The average fraction of longitudinal polarization for $B \to D^* D_s^*$ is determined as 0.52 ± 0.05 which is again consistent with predictions based on factorization.

The $B^0 \to \overline{D}^{(*)0} h^0$ decay modes, where h^0 is a light neutral meson, are expected to proceed via an internal spectator diagram and to be color-suppressed relative to external spectator decays such as $B^0 \to \overline{D}^{(*)-} \pi^+$. The contribution of the W-exchange diagram is usually assumed to be negligible [71]. In the charm meson decays, the effect of color suppression is obscured by effects of final state interactions, or reduced by non-factorizable contributions. Color suppression is, however, believed to be operative in the B meson system. Until recently, the $B \to$ charmonium transitions were the only identified color-suppressed B decays. Belle, CLEO and BABAR have now reported the observations of $B^0 \to \overline{D}^0 \pi^0$ and $D^{*0}\pi^0$ [73–74]. Belle and BABAR also observed many other color-suppressed modes including $B^0 \to D^0 \rho^0$ [75], $B^0 \to D^0 \eta$, $D^0 \omega$ [74,75] and $B^0 \to D^{*0}\eta$, $D^{*0}\omega$ [74]. The measured branching fractions are consistently higher than recent theoretical predictions based on naive factorization hypothesis [71]. Combining these results with previous measurements of other $B \to D^{(*)}\pi$ final states, it is possible to extract the strong interaction phase δ_I between the isospin 1/2 and 3/2 amplitudes in the $D\pi$ and $D^*\pi$ final states. The results from all three experiments are consistent with δ_I being approximately 30°. These results suggest the possibility of significant nonfactorizable effects such as final-state re-scattering.

The decay $B^0 \to D_s^- K^+$ is expected to occur either via a W exchange diagram or via final-state rescattering process. Because of uncertainties in final-state interaction effects, predictions for its branching fraction vary over a wide range. Therefore measurement of this decay can provide a useful probe of B decay dynamics. Belle [82] observed this decay and BABAR [83] also found an evidence for it. The average branching fraction is $\mathrm{B}(B^0 \to D_s^- K^+) = (3.8 \pm 1.3) \times 10^{-5}$.

Rare B decays: All B-meson decays that do not occur through the usual $b \to c$ transition are known as rare B decays. These include both semileptonic and hadronic $b \to u$ decays that are suppressed at leading order by the small CKM matrix element V_{ub}, as well as higher order processes such as electromagnetic and gluonic penguin decays.

Charmless B meson decays into two-body hadronic final states such as $B \to \pi\pi$ and $K\pi$ are experimentally clean and provide good opportunities to probe new physics and search for indirect and direct CP violations. The final state particles in these decays tend to have larger momenta than average B decay products, therefore the event environment is cleaner than $b \to c$ decays. Over the past years, many such modes have been observed by BABAR, Belle and CLEO. Branching fractions are typically around 10^{-5}, for exclusive channels. Because of high-momenta for final state particles, the dominant source of background is from $e^+e^- \to q\bar{q}$ continuum events and sophisticated background suppression techniques exploiting the event shape variables are essential for these analyses. The results are in general consistent between the three experiments and confirm the larger than expected rate for gluonic penguin decays such as $B \to K\pi$.

Several rare decay modes such as $B^0 \to K^+\pi^-$ have contributions from both $b \to u$ tree diagram and $b \to sg$ penguin diagram processes. If the size of each contribution is comparable to each other, the interference between them may cause direct CP violation which may show up as a charge asymmetry in time-independent decay rate measurement. The average charge asymmetry in the $K^+\pi^-$ mode is -0.095 ± 0.028 [12]. No clear evidence for direct CP violation have been found in other modes.

The fact that $B^0 \to \pi^+\pi^-$ also can have interference between tree and penguin processes makes it difficult to extract a unitarity angle α from time-dependent CP asymmetry measurements. In order to extract α unambiguously, an isospin analysis has been suggested [76]. A crucial element for the isospin analysis is a flavor-specific measurement of $B^0 \to \pi^0\pi^0$ and $\overline{B}^0 \to \pi^0\pi^0$. Recently BABAR observed the $B^0 \to \pi^0\pi^0$ decays and measured the flavor-averaged branching fraction

$B(B^0 \to \pi^0\pi^0) = (2.1 \pm 0.6 \pm 0.3) \times 10^{-6}$ [77]. Belle also reported evidence for the same mode and measured the flavor-averaged branching fraction $(1.7 \pm 0.6 \pm 0.2) \times 10^{-6}$ [78]. The decays $B \to \rho\rho$ are also expected to provide important information on CP violation. Both BABAR [79] and Belle [80] have observed $B^+ \to \rho^+\rho^0$ and measured its polarization. BABAR have observed $B^0 \to \rho^+\rho^-$ and measured its polarization as well [81].

The decay $B^0 \to D_s^+\pi^-$ proceeds via $b \to u$ tree diagram where D_s is produced from the vertex of virtual W hadronization. Therefore, it is sensitive to $|V_{ub}|$, although actual extraction of $|V_{ub}|$ becomes obscured by unknown non-factorizable strong-interaction effects. Both Belle [82] and BABAR [83] found evidences for this mode, and the average branching fraction is $B(B^0 \to D_s^+\pi^-) = (2.7 \pm 1.0) \times 10^{-5}$.

Electroweak penguin decays:

The observation of the decay $B \to K^*(892)\gamma$, reported in 1993 by the CLEO experiment, provided first evidence for the one-loop FCNC penguin diagram [84]. Using larger data samples, CLEO, Belle and BABAR have updated this analysis and have added several new decay modes such as $B \to K_2^*(1430)\gamma$. So far no evidence for the decays $B \to \rho\gamma$ and $B \to \omega\gamma$ has been found. BABAR obtained the most stringent upper limit for the ratio $B(B \to (\rho/\omega)\gamma)/B(B \to K^*\gamma) < 0.047$ at 90% CL [85]. The limit on the ratio of branching fractions implies that $|V_{td}/V_{ts}| < 0.34$ at 90% CL.

The observed branching fractions were used to constrain a large class of Standard Model extensions [86]. However, due to the uncertainties in the hadronization, only the inclusive $b \to s\gamma$ rate can be reliably compared with theoretical calculations. This rate can be measured from the endpoint of the inclusive photon spectrum in B decay. The current PDG average of the CLEO [87] and the Belle [88] measurements for the B meson is $B(B \to X_s\gamma) = (3.3 \pm 0.4) \times 10^{-4}$. Consistent results have been reported by ALEPH for inclusive b–hadrons produced at the Z. The measured branching fraction can be compared to recent theoretical calculations by Chetyrkin, Misiak, Munz and by Kagan and Neubert which predict B($b \to s\gamma$) = $(3.29 \pm 0.33) \times 10^{-4}$ [89–91].

According to the SM, the CP asymmetry in $b \to s\gamma$ is smaller than 1 %, but some non-SM models allow significanly larger CP asymmetry ($\sim$ 10 %) without altering the inclusive branching fraction [92–94]. CLEO has searched for CP violation in this mode, and set a range on $A_{CP}(b \to s\gamma)$ at 90 % CL as $-0.27 < A_{CP} < 0.10$ [95]. Belle also set a preliminary range as $-0.107 < A_{CP} < 0.099$ at 90 % CL [96]. CP asymmetry in the exclusive $B \to K^*\gamma$ mode is also searched for by CLEO [97] and BABAR [98]. The PDG average of the asymmetry is $A_{CP}(B \to K^*\gamma) = -0.01 \pm 0.07$.

In addition, CLEO has measured the inclusive photon energy spectrum for $b \to s\gamma$ [99]. Analyzing the shape of the spectrum they obtained the first and second moment for photon energies above 2 GeV:

$$< E_\gamma >= 2.346 \pm 0.032 \pm 0.011 \text{ GeV} \tag{2}$$

and

$$< E_\gamma^2 > - < E_\gamma >^2 = 0.0226 \pm 0.0066 \pm 0.0020 \text{ GeV}^2 \,. \tag{3}$$

These results can be used to extract non-perturbative HQET parameters that are needed for the determination of the CKM matrix element V_{ub}.

Additional information on FCNC processes can be obtained from $B \to X_s\ell^+\ell^-$ decays which are mediated by electroweak penguin and W-box diagrams. Exclusive $B \to K\ell^+\ell^-$ decay was first observed by Belle [100]. Recently, both BABAR [101] and Belle [102] updated the measurments and the PDG average of the branching fraction is

$$\text{B}(B \to K\ell^+\ell^-) = (0.54 \pm 0.08) \times 10^{-6}.$$

The branching fraction for $B \to K^*(892)\ell^+\ell^-$ is also measured by both experiments and the average value is

$$\text{B}(B \to K^*\ell^+\ell^-) = (1.05 \pm 0.20) \times 10^{-6}.$$

The branching fraction of inclusive $B \to X_s \ell^+\ell^-$ decays is measured by Belle [103]:

$$\mathrm{B}(B \to X_s \ell^+\ell^-) = (6.1 \pm 1.4^{+1.4}_{-1.1}) \times 10^{-6}.$$

These results are consistent with SM expectations.

Summary and Outlook: The study of B mesons continues to be one of the most productive fields in particle physics. CP violation has been observed for the first time outside the kaon system. Many hadronic $b \to u$ transitions and gluonic penguin decays have been observed, and the emerging pattern is still full of surprises. The coming years look equally promising. Each of the asymmetric B-factory experiments, Belle and BABAR, has accumulated data samples well over 100 fb^{-1}. Run II at Fermilab has begun and new results from CDF and D0 can be expected soon. These experiments promise a rich spectrum of rare and precision measurements that have the potential to affect fundamentally our understanding of the Standard Model and CP-violating phenomena.

References

1. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **87**, 091801 (2001).
2. Belle Collab., K. Abe *et al.*, Phys. Rev. Lett. **87**, 091802 (2001).
3. Currently two different notations (ϕ_1, ϕ_2, ϕ_3) and (α, β, γ) are used in the literature for CKM unitarity angles. In this mini-review, we use the latter notation following the other mini-reviews in this *Review* . The two notations are related by $\phi_1 = \beta$, $\phi_2 = \alpha$ and $\phi_3 = \gamma$.
4. See the "Status of $|V_{ub}|$ Measurements" by L. Gibbons and M. Battaglia in this *Review* .
5. See the "Status of $|V_{cb}|$ Measurements" by M. Artuso and E. Barberio in this *Review* .
6. See the "CP Violation in Meson Decays" by D. Kirby and Y. Nir in this *Review* .
7. CLEO Collab., B. Barish *et al.*, Phys. Rev. Lett. **76**, 1570 (1996).
8. CLEO Collab., J.P. Alexander *et al.*, Phys. Rev. Lett. **86**, 2737 (2001).

9. BABAR Collab., B. Aubert *et al.*, Phys. Rev. **D65**, 032001 (2002).
10. CLEO Collab., S.B. Athar *et al.*, Phys. Rev. **D66**, 052003 (2002).
11. Belle Collab., N.C. Hastings *et al.*, Phys. Rev. **D67**, 052004 (2003).
12. Heavy Flavor Averaging Group, `http://www.slac.stanford.edu/xorg/hfag/`.
13. CLEO Collab., S.E. Csorna *et al.*, Phys. Rev. **D61**, 111101 (2000).
14. See the "Review on B–$\overline{B}$ Mixing" by O. Schneider in this *Review* .
15. CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **81**, 2432 (1998);
    CDF Collab., F. Abe *et al.*, Phys. Rev. **D58**, 112004 (1998).
16. ALEPH Collab., D. Buskulic *et al.*, Phys. Lett. **B384**, 449 (1996).
17. DELPHI Collab., P. Abreu *et al.*, Z. Phys. **C68**, 541 (1995).
18. F. Ukegawa, "Spectroscopy and lifetime of bottom and charm hadrons", `hep-ex/0002031`, *Proceedings of 3rd International Conference on B Physics and CP Violation*, (BCONF99), Taipei, Taiwan, (1999).
19. V. Ciulli, "Spectroscopy of excited b and c states", `hep-ex/9911044`, *Proceedings of the 8th International Conference on Heavy Flavours*, Southampton (1999).
20. I.I. Bigi, UND-HEP-99-BIG07, `hep-ph/0001003`, *Proceedings of the 3rd International Conference on B Physics and CP Violation*, Taipei (1999).
21. D. Abbaneo *et al.*, "Combined results on b-hadron production rates and decay properties" CERN EP-2001/050 (2001).
22. I.I. Bigi *et al.*, in "B Decays," 2nd edition, S. Stone (ed.), World Scientific, Singapore, 1994.
23. N. Uraltsev, Phys. Lett. **B376**, 303 (1996).
24. M. Neubert and C.T. Sachrajda, Nucl. Phys. **B483**, 339 (1997).
25. J.L. Rosner, Phys. Lett. **B379**, 267 (1996).
26. M. Voloshin, Phys. Reports **320**, 275 (1999).
27. B. Guberina, B. Melic, and H. Stefancic, Phys. Lett. **B469**, 253 (1999).

28. P. Colangelo and F. De Fazio, Phys. Lett. **B387**, 371 (1996);
P. Colangelo, *Proceedings of the 28th International Conference on High Energy Physics*, Warsaw (1996).
29. G. Altarelli *et al.*, Phys. Lett. **B382**, 409 (1996).
30. BABAR Collab., B. Aubert *et al.*, `hep-ex/0311037`, submitted to Phys. Rev. Lett.
31. See the "CKM Quark Mixing Matrix" by F.J. Gilman, K. Kleinknecht, and B. Renk in this *Review* .
32. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **89**, 201802 (2002).
33. Belle Collab., K. Abe *et al.*, Belle-CONF-0353 (2003).
34. Y. Grossman and M.P. Worah, Phys. Lett. **B395**, 241 (1997).
35. Belle Collab., K. Abe *et al.*, Belle-CONF-0344 (2003).
36. BABAR Collab., Preliminary result presented at Lepton-Photon 2003 (2003).
37. Belle Collab., K. Abe *et al.*, Phys. Rev. **D68**, 012001 (2003).
38. The results originally published in Phys. Rev. Lett. **91**, 201802 (2003) are updated at Lepton-Photon 2003 (2003).
39. See, for example, "The BABAR Physics Book", SLAC-R-504, P.F. Harrison and H.R. Quinn, Ed., and references therein.
40. M. Gronau and D. Wyler, Phys. Lett. **B265**, 172 (1991).
41. CLEO Collab., M. Athanas *et al.*, Phys. Rev. Lett. **80**, 5493 (1998).
42. Belle Collab., K. Abe *et al.*, Phys. Rev. Lett. **87**, 111801 (2001).
43. BABAR Collab., B. Aubert *et al.*, `hep-ex/0207087`.
44. Belle Collab., S. Swain *et al.*, Phys. Rev. **D68**, 051101 (2003).
45. Belle Collab., K. Abe *et al.*, Belle-CONF-0343 (2003).
46. BABAR Collab., B. Aubert *et al.*, `hep-ex/0310037`, submitted to Phys. Rev. Lett.
47. BABAR Collab., B. Aubert *et al.*, BABAR-CONF-03/022 (2003).
48. Belle Collab., K. Abe *et al.*, Belle-CONF-0341 (2003).
49. M. Neubert, "Aspects of QCD Factorization", `hep-ph/0110093` *Proceedings of HF9*, Pasadena (2001) and references therein.

50. Z. Ligeti, M. Luke, and M. Wise, Phys. Lett. **B507**, 142 (2001).
51. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **90**, 242001 (2003).
52. CLEO Collab., D. Besson *et al.*, Phys. Rev. **D68**, 032002 (2003).
53. Belle Collab., P. Krokovny *et al.*, `hep-ex/0308019`, to be published in Phys. Rev. Lett.
54. Belle Collab., S.-K. Choi *et al.*, `hep-ex/0309032`, to be published in Phys. Rev. Lett.
55. CDF II Collab., D. Acosta *et al.*, `hep-ex/0312021`, submitted to Phys. Rev. Lett.
56. K. Honscheid, *Proceedings of the International b20 Symposium*, Chicago (1997).
57. Belle Collab., K.-F. Chen *et al.*, Phys. Rev. Lett. **91**, 201801 (2003).
58. CLEO Collab., E. Lipeles *et al.*, Phys. Rev. **D62**, 032005 (2003).
59. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **89**, 061801 (2002).
60. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **91**, 131801 (2003).
61. Belle Collab., K. Abe *et al.*, Phys. Rev. Lett. **89**, 122001 (2003).
62. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **90**, 221801 (2003).
63. S.E. Csorna *et al.*, CLEO Collab., Phys. Rev. **D67**, 112002 (2003).
64. BABAR Collab., B. Aubert *et al.*, Phys. Rev. **D67**, 092003 (2003).
65. CLEO Collab., S. Ahmed *et al.*, Phys. Rev. **D62**, 112003 (2003).
66. J. Körner and G. Goldstein Phys. Lett. **B89**, 105 (1979).
67. J.L. Rosner, Phys. Rev. **D42**, 3732 (1990).
68. M. Neubert, Phys. Lett. **B264**, 455 (1991).
69. G. Kramer, T. Mannel, and W.F. Palmer, Z. Phys. **C55**, 497 (1992).
70. A. Dighe, I. Dunietz, and R.Fleischer, Eur. Phys. J. **C6**, 647 (1999).
71. M. Neubert and B. Stech, in *Heavy Flavors II*, ed. by A.J. Buras and M. Lindner (World Scientific, Singapore, 1998).

72. CLEO Collab., T. Coan *et al.*, Phys. Rev. Lett. **88**, 062001, (2002).
73. Belle Collab., K. Abe *et al.*, Phys. Rev. Lett. **88**, 052002 (2002).
74. BABAR Collab., B. Aubert *et al.*, `hep-ex/0310028`, submitted to Phys. Rev. **D**.
75. Belle Collab., A. Satpathy *et al.*, Phys. Lett. **B553**, 159 (2003).
76. M. Gronau and D. London, Phys. Rev. Lett. **65**, 3381 (1990).
77. BABAR Collab., B. Aubert *et al.*, `hep-ex/0308012`, to be published in Phys. Rev. Lett.
78. Belle Collab., S.H. Lee *et al.*, `hep-ex/0308040`, to be published in Phys. Rev. Lett.
79. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **91**, 171802 (2003).
80. Belle Collab., J. Zhang *et al.*, Phys. Rev. Lett. **91**, 221801 (2003).
81. BABAR Collab., B. Aubert *et al.*, `hep-ex/0311017`, to be published in Phys. Rev. **D**.
82. Belle Collab., P. Krokovny *et al.*, Phys. Rev. Lett. **89**, 231804 (2002).
83. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **90**, 181803 (2003).
84. CLEO Collab., R. Ammar *et al.*, Phys. Rev. Lett. **71**, 674 (1993).
85. BABAR Collab., B. Aubert *et al.*, `hep-ex/0306038`, to be published in Phys. Rev. Lett.
86. J.L. Hewett, Phys. Rev. Lett. **70**, 1045 (1993).
87. CLEO Collab., S. Chen *et al.*, Phys. Rev. Lett. **87**, 251807 (2001).
88. Belle Collab., K. Abe *et al.*, Phys. Lett. **B511**, 151 (2001).
89. K. Chetyrkin, M. Misiak, and M. Münz, Phys. Lett. **B400**, 206 (1997);
    Erratum-ibid, Phys. Lett. **B425**, 414 (1998).
90. A.J. Buras, A. Kwiatkowski, and N. Pott, Phys. Lett. **B414**, 157 (1997);
    Erratum-ibid, Phys. Lett. **B434**, 459 (1998).
91. A.L. Kagan and Matthias Neubert, Eur. Phys. J. **C7**, 5 (1999).

92. K. Kiers, A. Soni and G. Wu, Phys. Rev. **D62**, 116004 (2000).
93. A.L. Kagan and M. Neubert, Phys. Rev. **D58**, 094012 (1998).
94. S. Baek and P. Ko, Phys. Rev. Lett. **83**, 488 (1998).
95. CLEO Collab., T.E. Coan *et al.*, Phys. Rev. Lett. **86**, 5661 (2001).
96. Belle Collab., K. Abe *et al.*, Belle-CONF-0348 (2003).
97. CLEO Collab., T.E. Coan *et al.*, Phys. Rev. Lett. **84**, 5283 (2000).
98. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **88**, 101805 (2002).
99. CLEO Collab., S. Chen *et al.*, Phys. Rev. Lett. **87**, 251807 (2001).
100. Belle Collab., K. Abe *et al.*, Phys. Rev. Lett. **88**, 021801 (2001).
101. BABAR Collab., B. Aubert *et al.*, Phys. Rev. Lett. **91**, 221802 (2003).
102. Belle Collab., A. Ishikawa *et al.*, Phys. Rev. Lett. **91**, 261601 (2003).
103. Belle Collab., J. Kaneko *et al.*, Phys. Rev. Lett. **90**, 021801 (2003).