PRODUCTION AND DECAY OF b-FLAVORED HADRONS

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The b quark belongs to the third generation of quarks and is the weak–doublet partner of the t quark. The existence of the third–generation quark doublet was proposed in 1973 by Kobayashi and Maskawa [1] in their model of the quark mixing matrix ("CKM" matrix), and confirmed four years later by the first observation of a $b\bar{b}$ meson [2]. In the KM model, CP violation is explained within the Standard Model (SM) by an irreducible phase of the 3×3 unitary 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 SM, including the fermion masses, and the elements of the CKM matrix.

Since the b quark is the lighter element of the third–generation quark doublet, the decays of b-flavored hadrons occur via generation-changing processes through this matrix. Because of this, and the fact that the CKM matrix is close to a 3×3 unit matrix, many interesting features such as loop and box diagrams, flavor oscillations, as well as large CP asymmetries, can be observed in the weak decays of b-flavored hadrons.

The CKM matrix is parameterized by three real parameters and one complex phase. This complex phase can become a source of CP violation in B meson decays. A crucial milestone was the first observation of CP violation in the B meson system in 2001, by the BaBar [3] and Belle [4] collaborations. They measured a large value for the parameter $\sin 2\beta$ ($= \sin 2\phi_1$) [5], almost four decades after the discovery of a small CP asymmetry in neutral kaons. A more detailed discussion of the CKM matrix and CP violation can be found elsewhere in this *Review* [6,7].

Recent developments in the physics of b-hadrons include the significant improvement in experimental determination of the CKM angle γ, the increased information on B_s, B_c and Λ_b decays, the precise determination of Λ_b lifetime, the wealth of information in the $B^0 \to K^{*0}(892)\ell^+\ell^-$ decays and after many years of search, the observation of $B_s \to \mu^+\mu^-$ decays along with ever increasing precision on the CKM matrix parameters.

The structure of this mini-review is organized as follows. After a brief description of theory and terminology, we discuss b-quark production and current results on spectroscopy and lifetimes of b-flavored hadrons. We then discuss some basic properties of B-meson decays, followed by summaries of hadronic, rare, and electroweak penguin decays of B-mesons. There are separate mini-reviews for $B\overline{B}$ mixing [8] and the extraction of the CKM matrix elements V_{cb} and V_{ub} from B-meson decays [9] in this *Review.*

Theory and terminology: The ground states of b-flavored hadrons decay via weak interactions. In most hadrons, the b-quark is accompanied by light-partner quarks (d, u, or s), and the decay modes are well described by the decay of the b quark (spectator model) [10]. The dominant decay mode of a b quark is $b \to cW^{*-}$ (referred to as a "tree" or "spectator" decay), where the virtual W materializes either into a pair of leptons $\ell\bar{\nu}$ ("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^* to form one of the final state hadrons are suppressed by a factor $\sim (1/3)^2$, because the colors of the two quarks from different sources must match ("color–suppression").

Many aspects of B decays can be understood through the Heavy Quark Effective Theory (HQET) [11]. This has been particularly successful for semileptonic decays. For further discussion of HQET, see for instance Ref. 12. For hadronic decays, one typically uses effective Hamiltonian calculations that rely on a perturbative expansion with Wilson coefficients. In addition, some form of the factorization hypothesis is commonly used, where, in analogy with semileptonic decays, two-body hadronic decays of B mesons are expressed as the product of two independent hadronic currents, one describing the formation of a charm meson (in case of the dominant $b \to cW^{*-}$ decays), 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 (produced as a color singlet) travels fast enough to leave the interaction region without influencing the charm meson. This is known to work well for the dominant spectator decays [13]. There are several common implementations of these ideas for hadronic B decays, the most common of which are QCD factorization (QCDF) [14], perturbative QCD (pQCD) [15], and soft collinear effective theory (SCET) [16].

The transition $b \to u$ is suppressed by $|V_{ub}/V_{cb}|^2 \sim (0.1)^2$ relative to $b \to c$ transitions. The transition $b \to s$ is a flavor-changing neutral-current (FCNC) process, and although not allowed in the SM as a tree-process, can occur via more complex loop diagrams (denoted "penguin" decays). The rates for such processes are comparable or larger than CKM-suppressed $b \to u$ processes. Penguin processes involving $b \to d$ transitions are also possible, and have been observed [17,18]. Other decay processes discussed in this *Review* include W–exchange (a W is exchanged between initial–state quarks), penguin annihilation (the gluon from a penguin loop attaches to the spectator quark, similar to an exchange diagram), and pure–annihilation (the initial quarks annihilate to a virtual W, which then decays).

Production and spectroscopy: The bound states of a $\overline{b}$ antiquark and a u, d, s, or c quark are referred to as the B_u (B^+), B_d (B^0), B_s, and B_c mesons, respectively. The B_c is the heaviest of the ground–state b-flavored mesons, and the most difficult to produce: it was observed for the first time in the semileptonic mode by CDF in 1998 [19], but its mass was accurately determined only in 2006, from the fully reconstructed mode $B_c^+ \to J/\psi\pi^+$ [20]. One of the best determination up to date uses $B_c^+ \to J\psi D_s^+$ decay and yields $M(B_c^+) = 6276.28 \pm 1.44 \pm 0.36$ MeV/c^2 [21]. As this decay has very low energy release, it allows to decrease systematic uncertainty and thus offers prospects for future increase in precision.

The first excited meson is called the B^* meson, while 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^{**}. Excited states of the B_s meson are similarly named B_s^* and B_s^{**}. Of the possible bound $\overline{b}b$ states, the Υ series (S-wave) and the χ_b (P-wave) are well studied.

The pseudoscalar ground state η_b also has been observed by BaBar [22](and confirmed by CLEO [23]) , indirectly through the decay $\Upsilon(3S) \to \gamma\eta_b$. See Ref. 45 for classification and naming of these and other states.

Experimental studies of b decays have been performed in e^+e^- collisions at the $\Upsilon(4S)$ (ARGUS, CLEO, Belle, BaBar) and $\Upsilon(5S)$ (CLEO, Belle) resonances, as well as at higher energies, at the Z resonance (SLC, LEP), in $p\overline{p}$ (Tevatron) and pp collisions (LHC). The $e^+e^- \to b\overline{b}$ production cross-section at the Z, $\Upsilon(4S)$, and $\Upsilon(5S)$ resonances are about 6.6 nb, 1.1 nb, and 0.3 nb respectively. High-energy hadron collisions produce b-flavored hadrons of all species with much larger cross-sections: $\sigma(p\overline{p} \to bX, |\eta| < 1) \sim 30\ \ \mu b$ at the Tevatron ($\sqrt{s} = 1.96$ TeV), and even higher at the energies of the LHC pp collider (at $\sqrt{s} = 7$ TeV, visible b-hadron cross section at the LHCb is $\sim 100\ \ \mu b$).

BaBar and Belle have accumulated respectively 560 fb^{-1} and 1020 fb^{-1} of data, of which 433 fb^{-1} and 710 fb^{-1} respectively are at the $\Upsilon(4S)$ resonance; CDF and D0 have accumulated by the end of their running about 10 fb^{-1} each. At the LHC, CMS and ATLAS have collected 5 fb^{-1} (20 fb^{-1}) of data at $\sqrt{s} = 7$ (8) TeV respectively and LHCb has collected about 1 fb^{-1} and 2 fb^{-1} at the two energies. These numbers indicate that the majority of b-quarks have been produced in hadron collisions, but the large backgrounds cause the hadron collider experiments to have lower selection efficiency. While traditionally only the few decay modes for which triggering and reconstruction are easiest have been studied in hadron collisions, with current experiments at hadron colliders much more is possible. This is due to triggers based on the tracking first introduced in CDF and further improved by LHCb. LHCb experiment has also reasonable capability for detection of neutral pions and photons. While both e^+e^- and hadron colliders have their own strengths and weaknesses, in the domain of decays which involve neutrinos, e^+e^- experiments are in significant advantage.

In hadron collisions, most production happens as $b\overline{b}$ pairs, either via s-channel production or gluon–splitting, with a smaller fraction of single b-quarks produced by flavor excitation. The total b-production cross section is an interesting test of our understanding of QCD processes. For many years, experimental measurements have been several times higher than predictions. With improved measurements [24], more accurate input parameters, and more advanced calculations [25], the discrepancy between theory and data diminished and there is now good agreement between measurements and predictions.

Each quark of a $b\bar{b}$ pair produced in hadron collisions hadronizes separately and incoherently from the other, but it is still possible, although difficult, to obtain a statistical indication of the charge of a produced $b/\bar{b}$ quark ("flavor tag" or "charge tag") from the accompanying particles produced in the hadronization process, or from the decay products of the other quark. The momentum spectrum of produced b-quarks typically peaks near the b-quark mass, and extends to much higher momenta, dropping by about a decade for every ten GeV. This implies typical decay lengths of the order of a millimeter; the resolution for the decay vertex must be more precise than this to resolve the fast oscillations of B_s mesons.

In e^+e^- colliders, since the B mesons are very slow in the $\Upsilon(4S)$ rest frame, asymmetric beam energies are used to boost the decay products to improve the precision of time-dependent measurements that are crucial for the study of CP violation. At KEKB, 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 used a slightly larger boost, $\beta\gamma = 0.55$. The two B mesons produced in $\Upsilon(4S)$ decay are in a coherent quantum state, which makes it easier than in hadron collisions to infer the charge state of one B meson from observation of the other; however, the coherence also requires determination of the decay time of both mesons, rather than just one, in order to perform time–dependent CP–violation measurements. For B_s, which can be produced at $\Upsilon(5S)$ the situation is less favourable, as boost is not high enough to provide sufficient time resolution to resolve the fast B_s oscillations.

For the measurement of branching fractions, the initial composition of the data sample must be known. The $\Upsilon(4S)$

resonance decays predominantly to $B^0\overline{B}^0$ and B^+B^-; the current experimental upper limit for non-$B\overline{B}$ decays of the $\Upsilon(4S)$ is less than 4% at the 95% confidence level (CL) [26]. The only known modes of this category are decays to lower Υ states and a pion pair, observed with branching fractions of order 10^{-4} [27]. The ratio f_+/f_0 of the fractions of charged to neutral B productions from $\Upsilon(4S)$ decays has been measured by CLEO, BaBar, and Belle in various ways. They typically use pairs of isospin-related decays of B^+ and B^0, such that it can be assumed that $\Gamma(B^+ \to x^+) = \Gamma(B^0 \to x^0)$. In this way, the ratio of the number of events observed in these modes is proportional to $(f_+\tau_+)/(f_0\tau_0)$ [28–31]. BaBar has also performed an independent measurement of f_0 with a different method that does not require isospin symmetry or the value of the lifetime ratio, based on the number of events with one or two reconstructed $B^0 \to D^{*-}\ell^+\nu$ decays [32]. The combined result, from the current average of τ_+/τ_0, is $f_+/f_0 = 1.058 \pm 0.024$ [33]. Though the current 2.4σ discrepancy with equal production of B^+B^- and $B^0\overline{B}^0$ pairs is somewhat larger than previous averages, we still assume $f_+/f_0 = 1$ in this mini-review except where explicitly stated otherwise. This assumption is also supported by the near equality of the B^+ and B^0 masses: our fit of CLEO, ARGUS, CDF, and LHCb measurements yields $m(B^0) = 5279.58 \pm 0.17$ MeV/c^2, $m(B^+) = 5279.26 \pm 0.17$ MeV/c^2, and $m(B^0) - m(B^+) = 0.32 \pm 0.06$ MeV/c^2.

CLEO and Belle have also collected some data at the $\Upsilon(5S)$ resonance [34,35]. Belle has accumulated more than 100 fb^{-1} at this resonance. This resonance does not provide the simple final states like the $\Upsilon(4S)$: there are seven possible final states with a pair of non-strange B mesons and three with a pair of strange B mesons ($B_s^*\overline{B}_s^*$, $B_s^*\overline{B}_s$, and $B_s\overline{B}_s$). The fraction of events with a pair of B_s mesons over the total number of events with a pair of b-flavored hadrons has been measured to be $f_s[\Upsilon(5S)] = 0.201^{+0.030}_{-0.031}$, of which 90% is $B_s^*\bar{B}_s^*$ events. A few branching fractions of the B_s have been measured in this way; if the precision of f_s were improved, they would become the most accurate. Belle has observed a few new B_s modes that are difficult to reconstruct in hadron colliders and the most precise mass measurement of the B_s^* meson has been obtained [35,36]. However, the small boost of B_s mesons produced in this way prevents resolution of their fast oscillations for time-dependent measurements; these are only accessible in hadron collisions or at the Z peak.

In high-energy collisions, the produced b or $\bar{b}$ quarks can hadronize with different probabilities into the full spectrum of b-hadrons, either in their ground or excited states. Table 1 shows the measured fractions f_d, f_u, f_s, and f_{baryon} of B^0, B^+, B_s^0, and b baryons, respectively, in an unbiased sample of weakly decaying b hadrons produced at the Z resonance or in $p\overline{p}$ collisions [33]. The results were obtained from a fit where the sum of the fractions were constrained to equal 1.0, neglecting production of B_c mesons. The observed yields of B_c mesons at the Tevatron [19] yields $f_c = 0.2\%$, in agreement with expectations [37], and well below the current experimental uncertainties in the other fractions.

Table 1: Fragmentation fractions of b quarks into weakly-decaying b-hadron species in $Z \to b\overline{b}$ decay, in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

b hadron	Fraction at Z [%]	Fraction at $\overline{p}p$[%]
B^+, B^0	40.4 ± 0.9	33.9 ± 3.9
B_s	10.3 ± 0.9	11.1 ± 1.4
b baryons	8.9 ± 1.5	21.2 ± 6.9

For rather long time, the average of fractions in $p\overline{p}$ collisions and in Z decay was used as it was assumed that the hadronization is identical in the two environments. It was clear that this assumption dost not have to hold in principle, because of the different momentum distributions of the b-quark in these processes; the sample used in the $p\overline{p}$ measurements has momenta close to the b mass, rather than $m_Z/2$. But in the absence of any significant evidence there was also no strong reason against the average. Some discrepancies were observed, but as picture was also obscured by 1.8σ discrepancy in the average time-integrated mixing probability parameter

$\bar{\chi} = f_d\chi_d + f_s\chi_s$ between LEP and Tevatron [8], they were not directly attributed to breakdown of the assumption that hadronization is identical. The first indication that fraction for b-baryons depends on the momentum and thus environment came from CDF [38], but available precision did not allow for firm conclusion. The final evidence for non-universality of hadronization fractions came from LHCb, where strong dependence on the transverse momentum was observed for the Λ_b fraction [39].

Excited B-meson states have been observed by CLEO, LEP, CUSB, D0, and CDF. The current world average of the B^*–B mass difference is 45.78 ± 0.35 MeV/c^2. Evidence for B^{**} (L=1) production has been initially obtained at LEP [40], as a broad resonance in the mass of an inclusively reconstructed bottom hadron candidate combined with a charged pion from the primary vertex. Detailed results from exclusive modes have been obtained at the Tevatron, allowing separation of the narrow states B_1 and B_2^* and also a measurement of the B_2^* width [41].

Also the narrow B_s^{**} states, first sighted by OPAL as a single broad enhancement in the B^+K mass spectrum [42], have now been clearly observed and separately measured at the hadron colliders [43,44]. The measured masses are $M(B_{s1}) = 5828.7 \pm 0.4$ MeV/c^2 and $M(B_{s2}^*) = 5839.96 \pm 0.2$ MeV/c^2.

Baryon states containing a b quark are labeled according to the same scheme used for non-b baryons, with the addition of a b subscript [45]. For many years, the only well-established b baryon was the Λ_b^0 (quark composition udb), with only indirect evidence for Ξ_b (dsb) production from LEP [46]. This situation has changed dramatically in the past few years due to the large samples being accumulated at the Tevatron and LHCb. Clear signals of four strongly–decaying baryon states, Σ_b^+, Σ_b^{*+} (uub), Σ_b^-, Σ_b^{*-} (ddb) have been obtained by CDF in $\Lambda_b^0\pi^\pm$ final states [47]. The strange bottom baryon $\Xi_b^\pm$ was observed in the exclusive mode $\Xi_b^\pm \to J/\psi\Xi^\pm$ by D0 [48], and CDF [49]. More recently CDF has also observed the Ξ_b in the $\Xi_c\pi$ final state [50]. The relative production of Ξ_b and Λ_b baryons has been found to be consistent with the B_s to B_d production ratio [48].

Observation of the doubly–strange bottom baryon Ω_b^- has been published by both D0 [51] and CDF [52]. However the masses measured by the two experiments show a large discrepancy. The resolution is provided by LHCb which measures the Ω_b^- mass consistent with CDF [53]. The CMS experiment added to the list also neutral spin-3/2 Ξ_b^* [54]. The masses of all these new baryons have been measured to a precision of a few MeV/c^2, and found to be in agreement with predictions from HQET.

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 $B_s\overline{B}_s$ mixing parameters. 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. Non–spectator 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 variations in the b system are expected to be only 10% or less [55]. We expect:

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

For the B_c^+, both quarks decay weakly, so the lifetime is much shorter.

Measurements of the lifetimes of the different b-flavored hadrons thus provide a means to determine the importance of non-spectator mechanisms in the b sector. Over the past decade, the precision of silicon vertex detectors and the increasing availability of fully–reconstructed samples has resulted in much-reduced statistical and systematic uncertainties ($\sim$1%). The averaging of precision results from different experiments is a complex task that requires careful treatment of correlated systematic uncertainties; the world averages given in Table 2 have been determined by the Heavy Flavor Averaging Group (HFAG) [33].

Table 2: Summary of inclusive and exclusive world-average b-hadron lifetime measurements. For the two B_s averages, see text below.

Particle	Lifetime [ps]
B^+	1.638 ± 0.004
B^0	1.519 ± 0.005
B_s (flavor-specific)	1.465 ± 0.031
B_s $(1/\Gamma_s)$	1.512 ± 0.007
B_c^+	0.500 ± 0.013
Λ_b^0	1.451 ± 0.013
Ξ_b^-	$1.56^{+0.27}_{-0.25}$
Ω_b^-	$1.13^{+0.53}_{-0.40}$
Ξ_b mixture	$1.49^{+0.19}_{-0.18}$
b-baryon mixture	1.449 ± 0.015
b-hadron mixture	1.568 ± 0.009

The short B_c^+ lifetime is in good agreement with predictions [56]. With large samples of B_c^+ mesons at the LHCb precision on the lifetimes should significantly improve. First measurement using semileptonic decays gives $\tau_{B_c^+} = 0.509 \pm 0.008 \pm 0.012$ [57], which is already more precise than combination of all previous experiment. For precision comparisons with theory, lifetime ratios are more sensitive. Experimentally we find:

$$\frac{\tau_{B^+}}{\tau_{B^0}} = 1.076 \pm 0.004\,, \quad \frac{\tau_{B_s}}{\tau_{B^0}} = 0.995 \pm 0.006\,,$$

$$\frac{\tau_{\Lambda_b}}{\tau_{B^0}} = 0.955 \pm 0.009\,,$$

while theory makes the following predictions [55,58]

$$\frac{\tau_{B^+}}{\tau_{B^0}} = 1.06 \pm 0.02\ , \quad \frac{\tau_{B_s}}{\tau_{B^0}} = 1.00 \pm 0.01\ , \quad \frac{\tau_{\Lambda_b}}{\tau_{B^0}} = 0.88 \pm 0.05.$$

The ratio of B^+ to B^0 lifetimes has a precision of better than 1%, and is significantly different from 1.0, in agreement with predictions [55]. The ratio of B_s to B^0 lifetimes is expected to be very close to 1.0. While early measurements were in mild tension with theory, the high precision measurements using fully reconstructed decays and clear definition of lifetime (see below) are in good agreement with theory [59,60,61]. The Λ_b lifetime has a history of discrepancies. Predictions were higher than data before the introduction of higher-order effects lowered them. The first indication that early measurements of the Λ_b are on low side came from the CDF data [62,63]. The recent measurements from LHC experiments [64,65,66,67] significantly improve precision and favour higher lifetime, much closer to the lifetime of B^0 meson. The most precise measurement of the Λ_b lifetime performed by LHCb uses $\Lambda_b \to J/\psi p K^-$ decays and finds $\tau_{\Lambda_b} = 1.482 \pm 0.018 \pm 0.012$ ps [66]. With new results, the discrepancy between theory and experiment on the Λ_b lifetime can be considered resolved.

Neutral B mesons are two-component systems similar to neutral kaons, with a light (L) and a heavy (H) mass eigenstate, and independent decay widths Γ_L and Γ_H. The SM predicts a non-zero width difference $\Delta\Gamma = \Gamma_L - \Gamma_H > 0$ for both B_s and B_d. For B_d, $\Delta\Gamma_d/\Gamma_d$ is expected to be $\sim$0.2%. Analysis of BaBar and DELPHI data on CP-specific modes of the B^0 yield a combined result: $\Delta\Gamma_d/\Gamma_d = 0.015 \pm 0.018$ [33]. Very recently LHCb determined value of $\Delta\Gamma_d/\Gamma_d = -0.044 \pm 0.025 \pm 0.011$ [67], which is based on the comparison of lifetimes in the $B^0 \to J/\psi K^{*0}(892)$ and $B^0 \to J/\psi K_S$ decays. Average including latest LHCb measurement yields $\Delta\Gamma_d/\Gamma_d = 0.001 \pm 0.010$. The issue is much more interesting for the B_s, since the SM expectation for $\Delta\Gamma_s/\Gamma_s$ is of order 10%. This potentially non-negligible difference requires care when defining the B_s lifetime. As indicated in Table 2, two different lifetimes are defined for the B_s meson: one is defined as $1/\Gamma_s$, where Γ_s is the average width of the two mass eigenstates $(\Gamma_L + \Gamma_H)/2$; the other is obtained from "flavor-specific" (*e.g.*, semileptonic) decays and depends both on Γ_s and $\Delta\Gamma_s$. Experimentally, the quantity $\Delta\Gamma_s$ can be accessed by measuring lifetimes in decays into CP eigenstates, which in the SM are expected to be close approximations to the mass eigenstates. This has been done with the $J/\psi\phi$ mode, where the two CP eigenstates are distinguished by angular distributions, and in $B_s \to K^+K^-$ or $B_s \to J/\psi f_0(980)$ which are CP-eigenstates. The current experimental information is dominated by measurements on the $J/\psi\phi$ mode performed by CDF, D0, ATLAS and LHCb experiments. By appropriately combining all published measurements of $J/\psi\phi$ lifetimes, flavor-specific lifetimes and effective lifetimes in CP eigenstates, the HFAG group obtains a world-average $\Delta\Gamma_s/\Gamma_s = 0.138 \pm 0.012$ [33]; the latest theoretical predictions yield $\Delta\Gamma_s/\Gamma_s = 0.133 \pm 0.032$ [68], in agreement with measurements within the uncertainties. The constraint from measurements of lifetimes in CP eigenstates is based on the notion of effective lifetime introduced in Ref. [69]. In this class, measurements in decays $B_s \to J/\psi f_0(980)$ [70], $B_s \to K^+K^-$ [71] decays are used currently. From the theoretical point of view, the best quantity to use is $\Delta\Gamma_s/\Delta M_s$, which is much less affected by hadronic uncertainties [68]. Exploiting the accurate measurement of ΔM_s available [72], this can be turned into a SM prediction with an uncertainty of only 20%: $\Delta\Gamma_s/\Gamma_s = 0.137 \pm 0.027$. This is likely to be of importance in future comparisons, as the experimental precision improves with the growth of LHC samples. Historically, branching fraction of the decay $B_s \to D_s^{(*)+}D_s^{(*)-}$ was used to set an bound on $\Delta\Gamma_s/\Gamma_s$, but the method is highly model–dependent and with increased precision of direct determinations it stops to be useful.

The width difference $\Delta\Gamma_s$ is connected to the B_s mixing phase ϕ_s by $\Delta\Gamma_s = \Gamma_{12}\cos\phi_s$, where Γ_{12} is the off–diagonal element of the decay matrix [6,8,68]. The early measurements by CDF [73] and D0 [74] have produced CL contours in the $(\phi_s, \Delta\Gamma)$ plane, and both observed a mild deviation, in the same direction, from the expectation of the SM of the phase ϕ_s near $\Delta\Gamma = 0$. The possibility of a large value of ϕ_s has attracted significant interest, as it would be very clean evidence for the existence of new sources of CP violation beyond the SM. However the latest measurements from CDF [59], D0 [75], ATLAS [60] and LHCb [61], which provide significant improvements over initial measurements, show good agreement with the SM. While most experiments use up to now only $B_s \to J/\psi\phi$ decay, LHCb also exploits $B_s \to J/\psi\pi^+\pi^-$ decays, which are experimentally determined to be pure CP-odd and therefore in $B_s \to J/\psi\pi^+\pi^-$ decays no angular analysis is needed. It should be noted that in pure $B_s \to J/\psi\phi$ decay, there is an two-fold ambiguity in the sign of $\Delta\Gamma_s$ and ϕ_s. This can be resolved using the interference between the decays to $J/\psi\phi$ and $J/\psi K^+K^-$, where K^+K^- is in relative S-wave state. This has been used by LHCb experiment to determine the sign of $\Delta\Gamma_s$ to be positive [76] in accordance with SM. The world average value of the CP violating phase is $\phi_s = 0.04^{+0.10}_{-0.13}$ [33] without any tension with the SM.

B meson decay properties: Semileptonic B decays $B \to X_c\ell\nu$ and $B \to X_u\ell\nu$ provide an excellent way to measure the magnitude of the 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 and inclusive decays can be used with dominant uncertainties being complementary. For exclusive decay analysis, knowledge of the form factors for the exclusive hadronic system $X_{c(u)}$ is required. For inclusive analysis, it is usually necessary 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 breakdown of the operator-product expansion scheme, thus making theoretical calculations unreliable. A more detailed discussion of B semileptonic decays and the extraction of $|V_{cb}|$ and $|V_{ub}|$ is given elsewhere in this *Review* [9].

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. Pure–penguin decays were first established by the observation of $B \to K^*\gamma$ [77]. Some observed decay modes such as $B^0 \to D_s^- K^+$, may be interpreted as evidence of a W-exchange process [78]. The evidence for the decay $B^+ \to \tau^+\nu$ from Belle [79] and BaBar [80] is the first sign of a pure annihilation decay. There is growing evidence that penguin annihilation processes may be important in decays with two vector mesons in the final state [81].

Hadronic decays: Most of the hadronic B decays involve $b \to c$ transition at the quark level, resulting in a charmed hadron or charmonium in the final state. Other types of hadronic decays are very rare and will be discussed separately in the next section. The experimental results on hadronic B decays have steadily improved over the past few years, and the measurements have reached sufficient precision to challenge our understanding of the dynamics of these decays. With the 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 for suppressing 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.

The kinematically clean environment of B meson decays provides an excellent opportunity 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. In 2003, BaBar discovered a new narrow charm-strange state $D^*_{sJ}(2317)$ [82], and CLEO observed a similar state $D_{sJ}(2460)$ [83]. The properties of these new states were studied in the B meson decays, $B \to DD^*_{sJ}(2317)$ and $B \to DD_{sJ}(2460)$ by Belle [84]. Further studies of $D^{(*)}_{sJ}$ meson production in B decays have been made by Belle [85] and BaBar [86]. Now these charm-strange meson states are identified as $D^*_{s0}(2317)$ and $D_{s1}(2460)$, respectively.

More recently, Belle observed a new D_{sJ} meson produced in $B^+ \to \bar{D}^0 D_{sJ} \to \bar{D}^0 D^0 K^+$ [87]. Combined with a subsequent measurement by BaBar [88], the mass and width of this state are determined to be 2709^{+9}_{-6} MeV/c^2 and 125 ± 30 MeV, respectively. An analysis of the helicity angle distribution determines its spin-parity to be 1^-.

A variety of exotic particles have been discovered in B decays. Belle found the $X(3872)$ state [89], which is confirmed by CDF [90] and BaBar [91]. Analyzing their full $\Upsilon(4S)$ data sample, Belle finds a new upper limit on the width of $X(3872)$ to be $\Gamma_{X(3872)} < 1.2$ MeV [92], improving on the existing limit by nearly a factor of 2. Radiative decays of $X(3872)$ can play a crucial role in understanding the nature of the particle. For example, in the molecular model the decay of $X(3872)$ to $\psi'\gamma$ is expected to be highly suppressed in comparison to the decay to $J/\psi\gamma$ [93]. BaBar has seen the evidence for the decay to $J/\psi\gamma$ [94]. The ratio $R \equiv \mathcal{B}(X(3872) \to \psi'\gamma)/\mathcal{B}(X(3872) \to J/\psi\gamma)$ is measured to be 3.4 ± 1.4 by BaBar [95], while Belle obtains $R < 2.1$ at 90% CL [96].

Belle has observed a near-threshold enhancement in the $J/\psi\omega$ invariant mass for $B \to J/\psi\omega K$ decays [97]. BaBar has studied $B \to J/\psi\pi^+\pi^- K$, finding an excess of $J/\psi\pi^+\pi^-$ events with a mass just above 4.2 GeV/c^2; this is consistent with the $Y(4260)$ that was observed by BaBar in ISR (Initial State Radiation) events [98]. A Belle study of $B \to \psi' K\pi^\pm$ [99] finds a state called $X(4430)^\pm$ that decays to $\psi'\pi^\pm$. Since it is charged, it could not be a charmonium state. This state was searched for by BaBar with similar sensitivity but was not found [100]. In a Dalitz plot analysis of $\overline{B}^0 \to \chi_{c1}K^-\pi^+$, Belle has observed two resonance-like structures in the $\chi_{c1}\pi^+$ mass distribution [101], labelled as $X(4050)^\pm$ and $X(4250)^\pm$ in this *Review*, while no evidence is found by BaBar in a search with similar sensitivity [102].

The hadronic decays $\overline{B}^0 \to D^{(*)0}h^0$, where h^0 stands for light neutral mesons such as $\pi^0, \eta^{(\prime)}, \rho^0, \omega$, proceed through color-suppressed diagrams, hence they provide useful tests on the factorization models. Both Belle and BaBar have made comprehensive measurements of such color-suppressed hadronic decays of $\overline{B}^0$ [103].

Information on B_s and Λ_b decays is limited, though improving with recent studies of large samples at the Tevatron and LHC experiments. Recent additions are decays of $B_s \to J/\psi f_0(980)$ [70,104], $B_s \to J/\psi f_2'(1525)$ [105], and $\Lambda_b \to \Lambda_c\pi^+\pi^-\pi^-$ [106]. For the later, not only the total rate is measured, but also structure involving decays through excited Λ_c and Σ_c baryons.

There have been hundreds of publications on hadronic B decays to open-charm and charmonium final states mostly from the B-factory experiments. These results are nicely summarized in a recent report by HFAG [33].

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

Charmless B meson decays into two-body hadronic final states such as $B \rightarrow \pi\pi$ and $K\pi$ are experimentally clean, and provide good opportunities to probe new physics and search for indirect and direct CP violations. Since the final state particles in these decays tend to have larger momenta than average B decay products, the event environment is cleaner than for $b \rightarrow c$ decays. Branching fractions are typically around 10^{-5}. Over the past decade, many such modes have been observed by BaBar, Belle, and CLEO. More recently, comparable samples of the modes with all charged final particles have been reconstructed in $p\bar{p}$ collisions by CDF and pp collisions by LHCb by triggering on the impact parameter of the charged tracks. This has also allowed observation of charmless decays of the B_s, in final states such as $\phi\phi$ [107], K^+K^- [108], and $K^-\pi^+$ [109], and of charmless decays of the Λ_b^0 baryon [109]. Charmless B_s modes are related to corresponding B^0 modes by U-spin symmetry, and are determined by similar amplitudes. Combining the observables from B_s and B^0 modes is a further way of eliminating hadronic uncertainties and extracting relevant CKM information [110].

Because of relatively high-momenta for final state particles, the dominant source of background in e^+e^- collisions is $q\bar{q}$ continuum events; sophisticated background suppression techniques exploiting event shape variables are essential for these analyses. In hadron collisions, the dominant background comes from QCD or partially reconstructed heavy flavors, and is similarly suppressed by a combination of kinematic and isolation requirements. The results are in general consistent among the experiments.

BaBar [111] and Belle [112] have observed the decays $B^+ \to \overline{K}^0 K^+$ and $B^0 \to K^0\overline{K}^0$. The world-average branching fractions are $\mathcal{B}(B^0 \to K^0\overline{K}^0) = (0.96^{+0.20}_{-0.18}) \times 10^{-6}$ and $\mathcal{B}(B^+ \to \overline{K}^0 K^+) = (1.36 \pm 0.27) \times 10^{-6}$. These are the first observations of hadronic $b \to d$ transitions, with significance $> 5\sigma$ for all four measurements. CP asymmetries have even been measured for these modes, though with large errors.

Most rare decay modes including $B^0 \to K^+\pi^-$ have contributions from both $b \to u$ tree and $b \to sg$ penguin processes. If the size of the two contributions are comparable, the interference between them may result in direct CP violation, seen experimentally as a charge asymmetry in the decay rate measurement. BaBar [113], Belle [114], and CDF [108] have measured the direct CP violating asymmetry in $B^0 \to K^+\pi^-$ decays. The BaBar and Belle measurements constitute observation of direct CP violation with a significance of more than 5σ. The world average for this quantity is now rather precise, -0.098 ± 0.013. There are sum rules [115] that relate the decay rates and decay-rate asymmetries between the four $K\pi$ charge states. The experimental measurements of the other three modes are not yet precise enough to test these sum rules.

There is now evidence for direct CP violation in three other decays: $B^+ \to \rho^0 K^+$ [116], $B^+ \to \eta K^+$ [117], and $B^0 \to \eta K^{*0}$ [118]. The significance is typically 3–4σ, though the significance for the $B^+ \to \eta K^+$ decay is now nearly 5σ with the recent Belle measurement [117]. In at least the first two cases, a large direct CP violation might be expected since the penguin amplitude is suppressed so the tree and penguin amplitudes may have comparable magnitudes.

The decay $B^0 \to \pi^+\pi^-$ can be used to extract the CKM angle α. This is complicated by the presence of significant contributions from penguin diagrams. An isospin analysis [119] can be used to untangle the penguin complications. The decay $B^0 \to \pi^0\pi^0$, which is now measured by both BaBar and Belle, is crucial in this analysis. Unfortunately the amount of penguin pollution in the $B \to \pi\pi$ system is rather large. In the past few years, measurements in the $B^0 \to \rho\rho$ system have produced more precise values of α, since penguin amplitudes are generally smaller for decays with vector mesons. An important ingredient in the analysis is the $B^0 \to \rho^0\rho^0$ branching fraction. The average of measurements from BaBar and Belle BaBar [120] yields a branching fraction of $(0.73 \pm 0.28) \times 10^{-6}$. This is only 3% of the $\rho^+\rho^-$ branching fraction, much smaller than the corresponding ratio in the $\pi\pi$ system.

The decay $B \to a_1\pi$ has been seen by BaBar. An analysis of the time evolution of this decay [121] together with measurements of other related decays has been used to measure the CKM angle α [122] in agreement with the more precise measurements from the $\rho\rho$ system.

Since $B \to \rho\rho$ has two vector mesons in the final state, the CP eigenvalue of the final state depends on the longitudinal polarization fraction f_L for the decay. Therefore, a measurement of f_L is needed to extract the CKM angle α. Both BaBar and Belle have measured f_L for the decays $\rho^+\rho^-$ and $\rho^+\rho^0$ and in both cases the measurements show $f_L > 0.9$, making a complete angular analysis unnecessary.

By analyzing the angular distributions of the B decays to two vector mesons, we can learn a lot about both weak- and strong-interaction dynamics in B decays. Decays that are penguin-dominated surprisingly have values of f_L near 0.5. The list of such decays has now grown to include $B \to \phi K^*$, $B \to \rho K^*$, and $B \to \omega K^*$. The reasons for this "polarization puzzle" are not fully understood. A detailed description of the angular analysis of B decays to two vector mesons can be found in a separate mini-review [123] in this *Review* .

There has been substantial progress in measurements of many other rare-B decays. The decay $B \to \eta' K$ stood out as the largest rare-B decay for many years. The reasons for the large rate are now largely understood [14,124]. However, there are now measurements of several 3-body or quasi-3-body modes with similarly large branching fractions. States seen so far include $K\pi\pi$ (three charge states) [125], KKK (four charge states) [126], and $K^*\pi\pi$ (two charged states) [127]. Many of these analyses now include Dalitz plot treatments with many intermediate resonances. There has also been an observation of the decay $B^+ \to K^+K^-\pi^+$ by BaBar [128], noteworthy because an even number of kaons is typically indicative of suppressed $b \to d$ transitions as discussed above.

Belle [79] and BaBar [80] have found evidence for $B^+ \to \tau^+\nu$; the average branching fraction, with a significance of nearly 5σ is $(165 \pm 34) \times 10^{-6}$. This is somewhat larger than, though consistent with, the value expected in the SM. This is the first observation of a pure annihilation decay. A substantial region of parameter space of charged Higgs mass vs. $\tan\beta$ is excluded by the measurements of this mode.

Electroweak penguin decays: More than 20 years have passed since the CLEO experiment first observed an exclusive radiative $b \to s\gamma$ transition, $B \to K^*(892)\gamma$ [77], thus providing the first evidence for the one-loop FCNC electromagnetic penguin decay. Using much larger data samples, both Belle and BaBar have updated this analysis [129] with an average branching fraction $\mathcal{B}(B^0 \to K^{*0}\gamma) = (43.3 \pm 1.5) \times 10^{-6}$, and have added several new decay modes such as $B \to K_1\gamma$, $K_2^*(1430)\gamma$, *etc.* [130]. With a sample of 24 fb^{-1} at $\Upsilon(5S)$, Belle observed the radiative penguin decay of $B_s \to \phi\gamma$ [131]. The decay $B_s \to \phi\gamma$ was also seen at LHCb with higher statistics [132]. The two measurements give average branching fraction of $(36 \pm 4) \times 10^{-6}$.

Compared to $b \to s\gamma$, the $b \to d\gamma$ transitions such as $B \to \rho\gamma$, are suppressed by the small CKM element V_{td}. Both Belle and BaBar have observed these decays [17,18]. The world average $\mathcal{B}(B \to (\rho,\omega)\gamma) = (1.30 \pm 0.23) \times 10^{-6}$. This can be used to calculate $|V_{td}/V_{ts}|$ [133]; the measured values are $0.233^{+0.033}_{-0.032}$ from BaBar [18] and $0.195^{+0.025}_{-0.024}$ from Belle [17].

The observed radiative penguin branching fractions can constrain a large class of SM extensions [134]. 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. By combining the measurements of $B \to X_s\gamma$ from CLEO, BaBar, and Belle experiments [135,136,137], HFAG obtains the new average: $\mathcal{B}(B \to X_s\gamma) = (3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$ [33] for $E_\gamma \geq 1.6$ GeV, which averages over B^+ and B^0. Consistent but less precise results have been reported by ALEPH for inclusive b–hadrons produced at the Z, which includes also small fraction of B_s and Λ_b hadrons. The measured branching fraction can be compared to theoretical calculations. Recent calculations of $\mathcal{B}(b \to s\gamma)$ at NNLO level predict the values of $(3.15 \pm 0.23) \times 10^{-4}$ [138] and $(2.98 \pm 0.26) \times 10^{-4}$ [139], where the latter is calculated requiring $E_\gamma \geq 1.6$ GeV.

The CP asymmetry in $b \to s\gamma$ is extensively studied theoretically both in the SM and beyond [140]. According to the SM, the CP asymmetry in $b \to s\gamma$ is smaller than 1%, but some non-SM models allow significantly larger CP asymmetry ($\sim 10\%$) without altering the inclusive branching fraction. The current world average is $A_{CP} = -0.008 \pm 0.029$, again dominated by BaBar and Belle [141,136]. In addition to the CP asymmetry, BaBar also measured the isospin asymmetry $\Delta_{0-} = -0.01 \pm 0.06$ in $b \to s\gamma$ measured using sum of exclusive decays [142]. Alternative measurement using full reconstruction of the companion B in the hadronic decay modes yields consistent, but less precise result [143].

In addition, all three experiments have measured the inclusive photon energy spectrum for $b \to s\gamma$, and by analyzing the shape of the spectrum they obtain the first and second moments for photon energies. Belle has measured these moments covering the widest range in the photon energy ($1.7 < E_\gamma < 2.8$ GeV) [137]. The measurement by BaBar has slightly smaller range with lower limit at 1.8 GeV [144]. These results can be used to extract non-perturbative HQET parameters that are needed for precise determination of the CKM matrix element V_{ub}.

Additional information on FCNC processes can be obtained from $b \to s\ell^+\ell^-$ decays, which are mediated by electroweak penguin and W-box diagrams. Measurements at Belle and BaBar suffered from low statistics and therefore they typically provide average between charged and neutral B mesons as well as between e^+e^- and $\mu^+\mu^-$ finals states [145,146]. The total branching fraction measured at B-factories for $B \to K\ell^+\ell^-$ is $(0.45 \pm 0.04) \times 10^{-6}$ and for $B \to K^*(892)\ell^+\ell^-$ is $(1.05 \pm 0.10) \times 10^{-6}$. Measurements at B-factories were complemented by CDF [147], which used only muons in the final state. While precision at CDF was similar to B-factories, it had access also to $B_s \to \phi\mu^+\mu^-$ and $\Lambda_b \to \Lambda\mu^+\mu^-$ decays, which were observed for the first time [147,148] and confirmed by LHCb [149,150]. B-factory experiments also measured the branching fractions for inclusive $B \to X_s\ell^+\ell^-$ decays [151], with an average of $(3.66^{+0.76}_{-0.77}) \times 10^{-6}$ [152]. In $b \to s\ell^+\ell^-$ decays, the angular analysis provides several interesting observables, which can be studied as function of dilepton invariant mass squared, q^2. While first measurements were done by Belle, Babar and CDF, real advance of these measurements came with LHC experiments, where samples available are significantly larger than before. The best known of angular observables is forward-backward asymmetry, which was measurement in $B \to K^*(892)\ell^+\ell^-$ by several experiments having access to the decay [145,153,154,155] with most precise measurement coming from LHCb [156]. Measurements of the CP asymmetries [146,157,158], the isospin asymmetry [145,146,159] and several other angular observables [156,160] are possible in this class of decays. While most of the measurements agree with the SM, isospin asymmetry in $B \to K\mu^+\mu^-$ and one of the other angular observables measured by the LHCb exhibit small tension with the SM expectation. While the angular analysis was up to recently mainly concentrating on the decay $B \to K^*(892)\ell^+\ell^-$, with samples available at LHC, also first angular analysis of the $B_s \to \phi\mu^+\mu^-$ decay was performed [149] with its results being consistent with the SM.

Finally the decays $B^0_{(s)} \to e^+e^-$ and $\mu^+\mu^-$ are interesting since they only proceed at second order in weak interactions in the SM, but may have large contributions from supersymmetric loops, proportional to $(\tan\beta)^6$. First limits were published 30 years ago and since then experiments at Tevatron, B-factories and LHC gradually improved those and effectively excluded whole models of new physics and significantly constrained allowed parameter space of others. For the decays to $\mu^+\mu^-$, Tevatron experiments pushed the limits down to roughly factor of 5-10 above the SM expectation [161,162]. The long journey in the search for these decays culminated in 2012, when first evidence for $B_s \to \mu^+\mu^-$ decay was seen [163]. Currently LHCb [164] and CMS [165] observe this decay with significance between 4 and 5 standard deviations. The measured branching fraction is $(2.9^{+1.1}_{-1.0})\times 10^{-9}$ at LHCb and $(3.0^{+1.0}_{-0.9})\times 10^{-9}$ at CMS, both in agreement with the SM expectation. The best limit for $B^0 \to \mu^+\mu^-$ is obtained by LHCb with value $< 7.4 \times 10^{-10}$ at 95% confidence level. The limits for the e^+e^- modes are: $< 2.8\times 10^{-7}$ and $< 8.3\times 10^{-8}$, respectively, for B_s and B^0 [166]. The searches were also performed for lepton flavour violating decays to two leptons with best limits in $e^\pm\mu^\mp$ channel, where limits are $< 3.7 \times 10^{-9}$ for B^0 and $< 1.4 \times 10^{-8}$ at 95% confidence level [167].

Summary and Outlook: The study of B mesons continues to be one of the most productive fields in particle physics. With the two asymmetric B-factory experiments Belle and BaBar, we now have a combined data sample of well over 1 ab^{-1}. CP violation has been firmly established in many decays of B mesons. Evidence for direct CP violation has been observed. Many rare decays resulting from hadronic $b \to u$ transitions and $b \to s(d)$ penguin decays have been observed, and the emerging pattern is still full of surprises. Despite the remarkable successes of the B-factory experiments, many fundamental questions in the flavor sector remain unanswered.

At Fermilab, CDF and D0 each has accumulated about 10 fb^{-1}, which is the equivalent of about 10^{12} b-hadrons produced. In spite of the low trigger efficiency of hadronic experiments, a selection of modes have been reconstructed in large quantities, giving a start to a program of studies on B_s and b-flavored baryons, in which a first major step has been the determination of the B_s oscillation frequency.

As Tevatron and B-factories stop their taking data, the new experiments at the LHC have become very active. The LHC accelerator performed very well in 2011 and 2012. The general purpose experiments ATLAS and CMS collected about

25 fb^{-1} while LHCb collected about 3 fb^{-1}. LHCb, which is almost fully dedicated to the studies of b- and c-hadrons, has a data sample that is for many decays larger than the sum of all previous experiments. Of particular note is the first evidence of the decay $B_s \to \mu^+\mu^-$ by LHCb and CMS experiments in 2013.

In addition, the preparation of the next generation high-luminosty B-factory at KEK is ongoing with first physics data taking expected in 2016. The aim to increase sample to $\sim 50\ \mathrm{ab}^{-1}$ will make it possible to explore the indirect evidence of new physics beyond the SM in the heavy-flavor particles (b, c, and τ), in a way that is complementary to the LHC. In the same time, LHCb Collaboration is working on the upgrade of its detector, which should be installed in 2018 and 2019. Aim of the upgrade is to increase flexibility of trigger, which will allow to significantly increase instantaneous luminosity and possibly integrate about 50 fb^{-1} of data.

These experiments promise a rich spectrum of rare and precise measurements that have the potential to fundamentally affect our understanding of the SM and CP-violating phenomena.

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6. See the "CP Violation in Meson Decays" by D. Kirkby and Y. Nir in this *Review*.
7. See the "CKM Quark Mixing Matrix," by A. Cecucci, Z. Ligeti, and Y. Sakai, in this *Review*.
8. See the "Review on B-$\overline{B}$ Mixing," by O. Schneider in this *Review*.

9. See the "Determination of $|V_{cb}|$ and $|V_{ub}|$," by R. Kowalewski and T. Mannel in this *Review*.
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