REVIEW OF RADIATIVE PENGUIN MEASUREMENTS

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Belle and BaBar have been extensively exploring radiative penguin B meson decays that are sensitive to physics beyond the Standard Model. Latest results on inclusive and exclusive $b \to s\gamma$ measurements, inclusive and exclusive $b \to d\gamma$ measurements, and exclusive $b \to s\ell^+\ell^-$ measurements are reviewed, and their implications are discussed.

1 Introduction

Radiative $b \to s\gamma$ and $b \to d\gamma$ and electroweak $b \to s\ell^+\ell^-$ penguin B meson decays are sensitive to physics beyond the Standard Model (SM), since they predominantly proceed through processes with at least one loop made of a virtual massive top quark and a W boson or possibly non-SM particles. Photons and leptons are good probes as they bring out information of the short distance processes without being disturbed by hadronic long distance effects, especially in inclusive measurements. Provided that the SM predictions are precisely calculated, they are also sensitive to non-perturbative B decay properties for which calculations from the first principle are practically impossible.

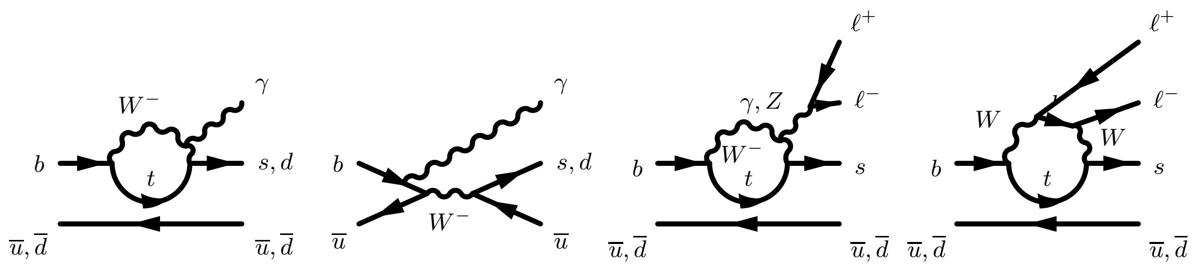

Figure 1: SM diagrams for $b \to s\gamma$ and $b \to d\gamma$ (left) and $b \to s\ell^+\ell^-$ (right). The second left diagram for charged B decays is relevant for isospin asymmetry and is enhanced in $b \to d\gamma$. The second right diagram is similar to the leftmost diagram except for the contribution of the Z boson, while the rightmost diagram is unique to $b \to s\ell^+\ell^-$.

Although all of these decay modes proceed through similar loop processes as shown in Fig. 1, each of the modes has slightly different physics sensitivities. The $b \to s\gamma$ transition has the largest amplitude that leads to the statistically most accurate measurements, and hence provides the most precise tests of the SM. The $b \to d\gamma$ transition is sensitive to the ratio of Cabibbo-Kobayashi-Maskawa (CKM) matrix elements $|V_{td}/V_{ts}|$, and, in addition, isospin asymmetry can be enhanced in $b \to d\gamma$ due to the sizable contribution through the annihilation diagram. The $b \to s\ell^+\ell^-$ transition involves diagrams with Z and W bosons, and, thanks to the three-body kinematics, there is a rich set of observables that are useful to distinguish type of new physics.

The two e^+e^- B-factories, Belle and BaBar, have been extensively exploring the radiative and electroweak penguin B decay modes using their huge data samples taken at the $\Upsilon(4S)$ resonance; especially the huge samples have been indispensable for the very rare $b \to d\gamma$ and $b \to s\ell^+\ell^-$ processes. Belle has analyzed up to 657 million $B\overline{B}$ events, while BaBar has results with 384 or 465 million $B\overline{B}$ events. Both at Belle and BaBar, the CsI calorimeter is the key detector for the photon measurement with typically a 2% photon energy resolution for high energy photons from $b \to s\gamma$ and $b \to d\gamma$. The good resolution of the CsI calorimeter and the clean environment of the e^+e^- collision are the advantages in measuring decay modes with neutral pions. The clean environment also allows an inclusive measurement of radiative penguin decays, fully inclusively for $b \to s\gamma$ or as the sum of exclusive final states for $b \to s\ell^+\ell^-$ and $b \to d\gamma$. The exclusive final states are clearly identified by kinematic variables, the beam-energy constrained (substituted) mass $M_{\rm bc}$ (M_{ES}) and the energy difference ΔE.

Along with the accumulation of the data at Belle and BaBar, more new decay modes have been observed, and new analysis techniques have been developed every year. In this review, recent results on radiative and electroweak penguin decays from Belle and BaBar are presented, and their implications are discussed.

2 Inclusive $B \to X_s\gamma$

A new fully inclusive photon spectrum measurement has been performed by Belle,[1] with the photon energy threshold lowered down to 1.7 GeV for the first time. The photon spectrum is measured by subtracting huge backgrounds: the largest one from $e^+e^- \to q\overline{q}$ continuum events using the off-resonance data sample taken below the $\Upsilon(4S)$ resonance, the second largest from $B \to \pi^0 X$ and $B \to \eta X$ using their measured inclusive spectrum, and other backgrounds that are small and described with Monte Carlo (MC) simulation. The result of the background subtraction is shown in Fig. 2. The total branching fraction is measured as an integrated spectrum above 1.7 GeV,

$$\mathcal{B}(B \to X_s\gamma)_{E_\gamma > 1.7\ \mathrm{GeV}} = (3.31 \pm 0.19 \pm 0.37 \pm 0.01) \times 10^{-4}. \tag{1}$$

When the result is compared with theories, the total branching fraction is usually extrapolated for the threshold of 1.6 GeV. Therefore a lower E_γ threshold significantly reduces the extrapolation error. The spectrum also provides information on non-perturbative heavy quark parameters. The mean and width in terms of the moments are used to derive e.g. the b quark mass (m_b) and its Fermi motion (μ_π^2) in a particular theoretical scheme. These quantities are needed to extract the Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$ from inclusive $B \to X_u\ell\nu$ measurements.

The latest HFAG [2] (heavy flavor averaging group) world average of the branching fraction is

$$\mathcal{B}(B \to X_s\gamma)_{E_\gamma > 1.6\ \mathrm{GeV}} = (3.52 \pm 0.25) \times 10^{-4} \tag{2}$$

in which all the available branching fractions are extrapolated down to the photon energy threshold of 1.6 GeV from their original thresholds in the range between 1.7 and 2.2 GeV. This extrapolation is somewhat controversial and hence it strongly motivates us to lower the photon

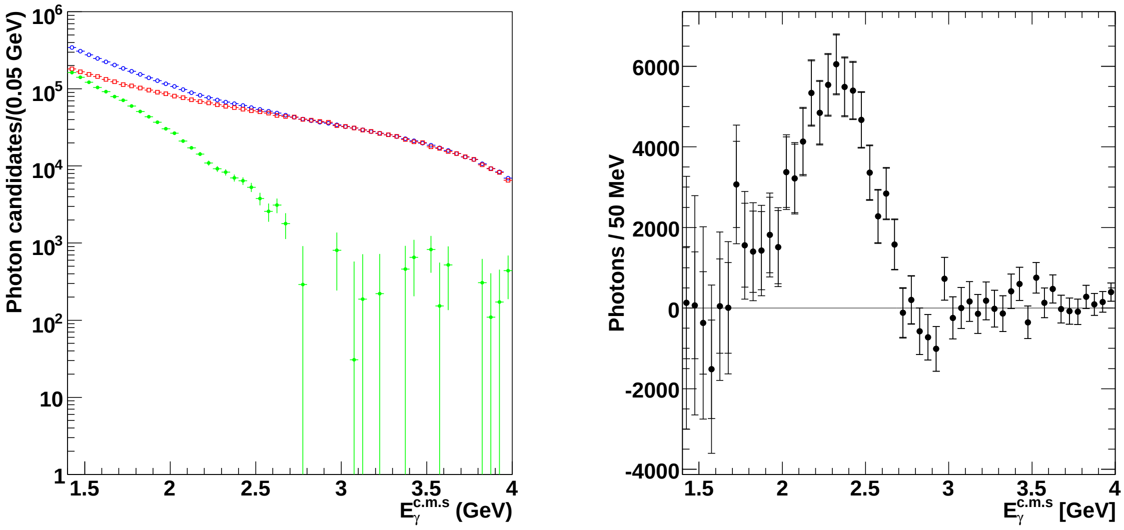

Figure 2: Raw photon spectrum measured in the $\Upsilon(4S)$ data, in the off-resonance data (scaled) and the result of the subtraction (right), and the $B \to X_s\gamma$ spectrum after all the background subtraction steps by Belle.

energy threshold. The result is in agreement with latest theory calculations with next-to-next-to-leading order QCD corrections,[3,4] and puts stringent constraints on various new physics scenarios such as generic two Higgs doublet model (2HDM) or minimum supersymmetric standard model (MSSM).

3 Asymmetries in exclusive $b \to s\gamma$

Exclusive $b \to s\gamma$ modes provide high precision measurements, as they suffer much less from backgrounds after constrained by kinematic variables. Branching fractions for the exclusive modes are unfortunately not very good probes of new physics due to hadronic uncertainties when compared with theories, but these modes are particularly useful in various asymmetry measurements.

BaBar [5] reported new results on branching fractions, direct CP asymmetry and isospin asymmetry for $B \to K^*\gamma$,

$$\begin{aligned}
\mathcal{B}(B^0 \to K^{*0}\gamma) &= (4.58 \pm 0.10 \pm 0.16) \times 10^{-5}, \\
\mathcal{B}(B^+ \to K^{*+}\gamma) &= (4.73 \pm 0.15 \pm 0.17) \times 10^{-5}, \\
A_{CP}(B \to K^*\gamma) &= -0.009 \pm 0.017 \pm 0.011, \\
\Delta_{0-}(B \to K^*\gamma) &= 0.029 \pm 0.019 \pm 0.016 \pm 0.018,
\end{aligned} \tag{3}$$

where direct CP asymmetry is defined as $A_{CP} = [\Gamma(\overline{B} \to \overline{K}^*\gamma) - \Gamma(B \to K^*\gamma)]/[\Gamma(\overline{B} \to \overline{K}^*\gamma) + \Gamma(B \to K^*\gamma)]$ and isospin asymmetry is defined as $\Delta_{0-} = [\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)]/[\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)]$. In the SM, direct CP asymmetry is much smaller than the current experimental sensitivity, and isospin asymmetry is also small. These asymmetries are useful to constrain new physics: e.g. the region of mSUGRA masses $m_{1/2}$-m_0 constrained by Δ_{0-} can be more stringent in some parameter space than that allowed by the $B \to X_s\gamma$ branching fraction.[6]

BaBar [7] has also updated time-dependent CP asymmetry in $B \to K^0_S\pi^0\gamma$, measured as the coefficient of the sine term $\mathcal{S}$ in asymmetry of the Δt distribution, where Δt is the time difference between the two B decays. In the SM, the sine term is suppressed by the quark mass ratio $m_s/2m_b$ because a helicity flip is necessary to induce the interference between the decay amplitudes to the same final state through the $b \to s\gamma$ transition and the $\overline{b} \to \overline{s}\gamma$ transition. This constraint is relaxed if there is a sizable non-SM right-handed current contribution in the $b \to s\gamma$ transition. Therefore, a non-zero sine term is a sign of such new physics. The coefficient of the cosine term $\mathcal{C}$ indicates direct CP violation and is expected to be even smaller. The events are divided into two $K_S^0\pi^0$ mass ranges: between 0.8 and 1.0 GeV where $B \to K^*\gamma$ is dominant, and between 1.1 and 1.8 GeV where other contributions are dominant. The results are,

$$\begin{aligned}
\mathcal{S}_{K^*\gamma} &= -0.03 \pm 0.29 \pm 0.03, \\
\mathcal{C}_{K^*\gamma} &= -0.14 \pm 0.16 \pm 0.03, \\
\mathcal{S}_{K_S^0\pi^0} &= -0.78 \pm 0.59 \pm 0.09, \\
\mathcal{C}_{K_S^0\pi^0} &= -0.36 \pm 0.33 \pm 0.04.
\end{aligned} \tag{4}$$

Both $\mathcal{S}$ and $\mathcal{C}$ values are consistent with zero, with the error of $\mathcal{S}$ around 0.3 for $B \to K^*\gamma$, similarly to the previous Belle results. After combined for the entire mass range and averaged with Belle, HFAG [2] calculated $\mathcal{S} = -0.15 \pm 0.20$. This is not precise enough to constrain the size of possible right-handed current contribution yet.

One of the directions to overcome the statistical limitation is to study other similar decay modes. It is known that any B meson decay modes into two self-conjugate neutral mesons (one of them has to be a pseudoscalar) and a photon are similarly sensitive to the right-handed current contribution.

BaBar [8] has performed a measurement using $B \to K_S^0\eta\gamma$ decays in the mass range $M(K\eta) <$ 3.25 GeV,

$$\begin{aligned}
\mathcal{S}_{K_S^0\eta\gamma} &= -0.18\,^{+0.49}_{-0.46} \pm 0.12, \\
\mathcal{C}_{K_S^0\eta\gamma} &= -0.32\,^{+0.40}_{-0.39} \pm 0.07, \\
\mathcal{B}(B^0 \to K^0\eta\gamma) &= (7.1\,^{+2.1}_{-2.0} \pm 0.4) \times 10^{-6}, \\
\mathcal{B}(B^+ \to K^+\eta\gamma) &= (7.7 \pm 1.0 \pm 0.4) \times 10^{-6}, \\
A_{CP}(K^+\eta\gamma) &= (-9.0\,^{+10.4}_{-9.8} \pm 1.4) \times 10^{-2}.
\end{aligned} \tag{5}$$

The size of the error is still larger than the $K_S^0\pi^0\gamma$ mode, but it will be useful with more data. A similar analysis is in principle possible with the decay mode $B \to K_S^0\eta'\gamma$, if there are sufficient events. Belle [9] has found the $B^+ \to K^+\eta'\gamma$ signal at a 3σ significance for the first time, but the $B^0 \to K_S^0\eta'\gamma$ mode is not significant yet. The results are

$$\begin{aligned}
\mathcal{B}(B \to K^+\eta'\gamma) &= (3.2\,^{+1.2}_{-1.1} \pm 0.3) \times 10^{-6}, \\
\mathcal{B}(B \to K^0\eta'\gamma) &< 6.3 \times 10^{-6} \quad (90\%\ \text{CL}).
\end{aligned} \tag{6}$$

Another decay mode, $B \to K_S^0\rho^0\gamma$, has an advantage for the time dependent CP asymmetry measurement, since the decay vertex can be reconstructed from the $\rho^0 \to \pi^+\pi^-$ decay tracks, while the decay vertex of the $K_S^0\pi^0\gamma$ and $K_S^0\eta\gamma$ final states has to be reconstructed by extrapolating the momentum vector from the $K_S^0 \to \pi^+\pi^-$ vertex point with a constraint on the interaction region. The branching fraction for $B \to K_S^0\rho^0\gamma$ is also relatively large. The only drawback is that the final state is a mixture of $K_S^0\rho^0\gamma$ and $K^{*\pm}\pi^{\mp}\gamma$, where the latter dilutes the CP asymmetry measurement. Fortunately, Belle [10] has found using the isospin-related decay mode, $B^+ \to K^+\pi^+\pi^-\gamma$, that the $B \to K\pi^+\pi^-\gamma$ decay mode is dominated by the decay chain $B \to K_1(1270)\gamma \to K\rho^0\gamma$. The correction to the sine term due to dilution is calculated to be $\mathcal{D} = 0.83\,^{+0.19}_{-0.03}$, and the $\mathcal{S}$ and $\mathcal{A}$ values are measured to be

$$\begin{aligned}
S_{K_S^0\rho^0\gamma} &= +0.11 \pm 0.33\,^{+0.05}_{-0.09}, \\
A_{K_S^0\pi^+\pi^-\gamma} &= +0.05 \pm 0.18 \pm 0.06.
\end{aligned} \tag{7}$$

Here, the cosine term is not corrected for dilution and hence quoted for the entire $K_S^0\pi^+\pi^-$ final state. The size of the error in the $\mathcal{S}$ result is competitive to $K_S^0\pi^0\gamma$. The decomposition of the $K\pi^+\pi^-\gamma$ final state and the result of the time-dependent CP fit are shown in Fig. 3.

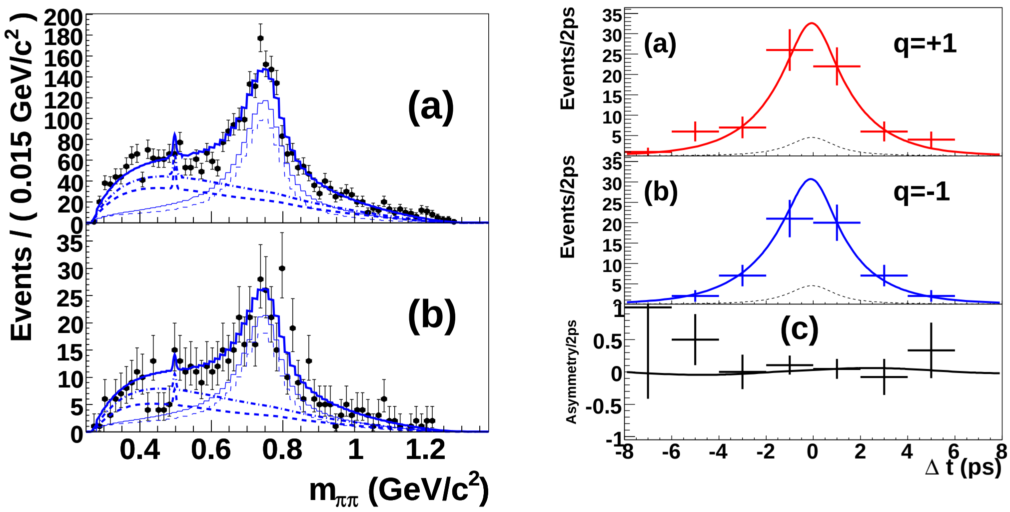

Figure 3: Decomposition of the $K\pi^+\pi^-\gamma$ final state in $\pi^+\pi^-$ invariant mass for $B^+ \to K^+\rho^0\gamma$ candidates (left-top) and $B^+ \to K^+\rho^0\gamma$ candidates (left-bottom), and the result of the time-dependent CP fit (right).

4 $b \to d\gamma$ measurements

The $b \to d\gamma$ modes are now measured in the exclusive modes $B \to \rho\gamma$ and $B \to \omega\gamma$ by Belle [11] and BaBar [12], and in a semi-inclusive way by summing up exclusive modes by BaBar.[13] The combined $B \to (\rho,\omega)\gamma$ branching fraction has been measured to be

$$\begin{array}{ll} \mathcal{B}(B \to (\rho,\omega)\gamma) = (11.4 \pm 2.0\,^{+1.0}_{-1.2}) \times 10^{-7} & \text{(Belle)} \\ \mathcal{B}(B \to (\rho,\omega)\gamma) = (16.3\,^{+3.0}_{-2.8} \pm 1.6) \times 10^{-7} & \text{(BaBar)} \end{array} \quad (8)$$

where $B \to \rho\gamma$ and $B \to \omega\gamma$ modes are combined assuming their quark contents. These branching fractions are used to extract $|V_{td}/V_{ts}|$ by using the more precisely determined $B \to K^*\gamma$ branching fractions and theoretical corrections due to the form factor ratio between $B \to K^*\gamma$ and $B \to (\rho,\omega)\gamma$ and isospin violation. Belle measures $|V_{td}/V_{ts}| = 0.195\,^{+0.020}_{-0.019} \pm 0.015$, while BaBar gives $|V_{td}/V_{ts}| = 0.233\,^{+0.025}_{-0.024}\,^{+0.022}_{-0.021}$. Here, the second error is due to theoretical assumptions and may not be significantly reduced in the near future. The results are consistent with $|V_{td}/V_{ts}|$ obtained from other measurements, and provide non-trivial constraints to the physics beyond the SM.

An inclusive measurement of the $b \to d\gamma$ process is a way to overcome the irreducible theoretical uncertainties, although a fully inclusive $B \to X_d\gamma$ measurement is extremely challenging because of the huge $B \to X_s\gamma$ background with similar kinematics.

BaBar [13] has performed a semi-inclusive $b \to d\gamma$ measurement by summing up exclusive modes in the mass range between 0.6 and 1.8 GeV. A similar semi-inclusive $b \to s\gamma$ measurement with the same mass range has been performed at the same time in order to calculate the ratio of branching fractions. The included modes are $\pi^+\pi^-\gamma$, $\pi^+\pi^0\gamma$, $\pi^+\pi^-\pi^0\gamma$, $\pi^+\pi^-\pi^+\gamma$, $\pi^+\pi^-\pi^+\pi^-\gamma$, $\pi^+\pi^-\pi^+\pi^0\gamma$ and $\pi^+\eta\gamma$ for $b \to d\gamma$, and the modes where the first π^+ is replaced by a K^+ are used for $b \to s\gamma$. Distributions of the events in the mass range between 1.0 and 1.8 GeV are shown in Fig. 4. The measured branching fraction is

$$\mathcal{B}(B \to X_d\gamma)_{[0.6,1.8]\mathrm{GeV}} = (7.2 \pm 2.7 \pm 2.3) \times 10^{-6}, \quad (9)$$

and this gives $|V_{td}/V_{ts}| = 0.177 \pm 0.043$. Since not all modes are included, a large correction factor of ~ 2 is estimated using JETSET with a large uncertainty. Otherwise the measurement of $|V_{td}/V_{ts}|$ is almost free from theory errors.

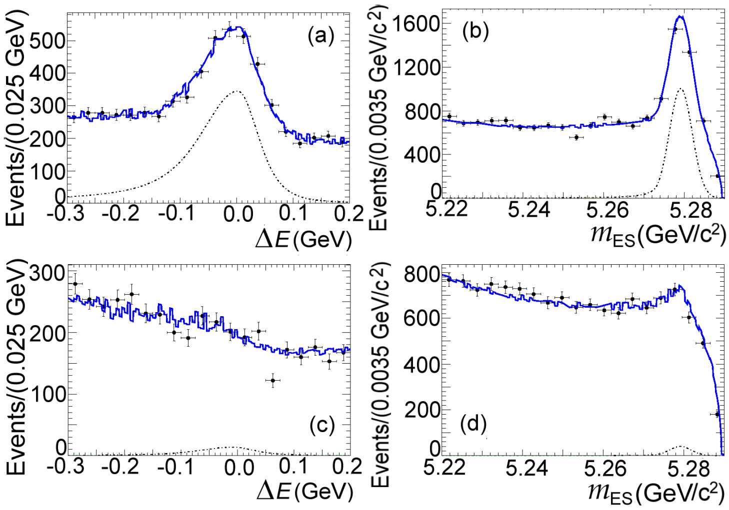

Figure 4: $B \to X_d\gamma$ (top) and $B \to X_d\gamma$ (bottom) events in the X_s/X_d mass ranges of $[1.0, 1.8]$ GeV in the ΔE (left) and M_{ES} (right) distributions.

Asymmetries for $B \to \rho\gamma$ and $B \to \omega\gamma$ are also good probes for physics beyond the SM. Direct CP asymmetry for $B^+ \to \rho^+\gamma$ has been measured by Belle,[11]

$$A_{CP}(B^+ \to \rho^+\gamma) = -0.11 \pm 0.32 \pm 0.09, \tag{10}$$

and isospin asymmetry between $B^0 \to \rho^0\gamma$ and $B^+ \to \rho^+\gamma$, defined as $\Delta(\rho\gamma) = \Gamma(B^+ \to \rho^+\gamma)$ / $[2\Gamma(B^0 \to \rho^0\gamma)] - 1$, has been measured by Belle [11] and BaBar,[12]

$$\begin{aligned} \Delta(\rho\gamma) &= -0.48\,^{+0.21}_{-0.19}\,^{+0.08}_{-0.09} \quad \text{(Belle)}, \\ \Delta(\rho\gamma) &= -0.43\,^{+0.25}_{-0.22} \pm 0.10 \quad \text{(BaBar)}. \end{aligned} \tag{11}$$

Large $\Delta(\rho\gamma)$ could be sign of new physics, e.g. MSSM,[14] although the measurement errors are still large and the results are also consistent with null asymmetry. Within the SM, $O(10\%)$ $\Delta(\rho\gamma)$ is possible e.g. by a non-perturbative charming penguin contribution.[15]

5 $b \to s\ell^+\ell^-$ measurements

Radiative and electroweak decays are often described using effective operators, where the size of each contribution is expressed by a Wilson coefficient. In $b \to s\ell^+\ell^-$, three Wilson coefficients, C_7 for the magnetic penguin operator, C_9 for the vector electroweak operator, and C_{10} for the axial-vector electroweak operator, are relevant. These Wilson coefficients are precisely calculated for the SM, and a deviation is an indication of physics beyond the SM in each type of interaction.

Inclusive and exclusive $b \to s\ell^+\ell^-$ modes are especially useful to measure the Wilson coefficients, because of the three-body nature of the final state where the contributions can be separated in the dilepton mass (or $q^2 = m^2_{\ell^+\ell^-}$) dependence. This is contrary to the $B \to X_s\gamma$ measurement which is sensitive only to the size of C_7, whose sign can be measured in $b \to s\ell^+\ell^-$.

Branching fractions for $B \to K\ell^+\ell^-$ and $B \to K^*\ell^+\ell^-$ are now measured precisely in the range of $O(10^{-6})$. Belle [16] has updated the branching fractions,

$$\begin{aligned} \mathcal{B}(B \to K\ell^+\ell^-) &= (4.8\,^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}, \\ \mathcal{B}(B \to K^*\ell^+\ell^-) &= (10.7\,^{+1.1}_{-1.0} \pm 0.9) \times 10^{-7}, \end{aligned} \tag{12}$$

that are consistent with earlier Belle and BaBar results. Experimental precision has already been better than theory predictions which suffer from form-factor uncertainties. CDF [18] also

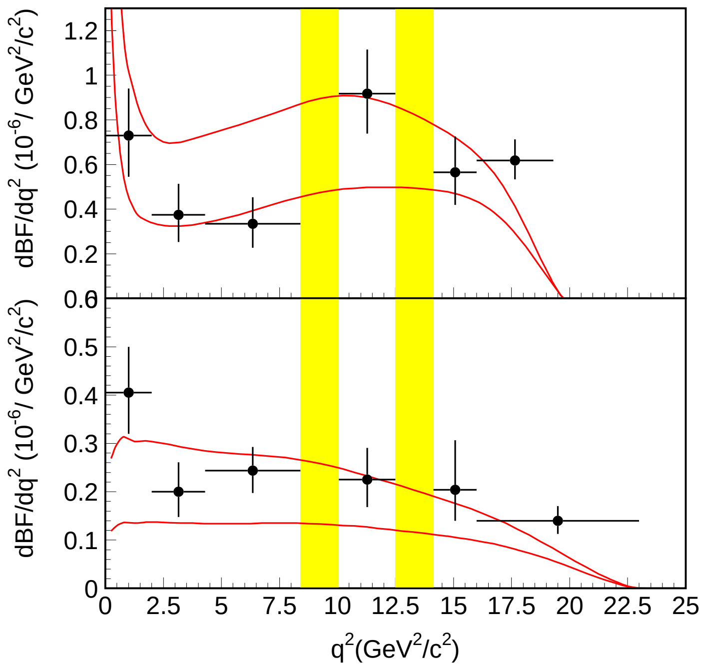

Figure 5: Differential branching fraction for $B \to K\ell^+\ell^-$ (top) and $B \to K^*\ell^+\ell^-$ (bottom) by Belle.

measured the $B^+ \to K^+\mu^+\mu^-$ and $B^0 \to K^{*0}\mu^+\mu^-$ modes, demonstrating future sensitivities in hadron collider experiments.

Differential branching fraction has been measured by Belle in 6 bins of q^2 as shown in Fig. 5. The dilepton mass regions for $J/\psi \to \ell^+\ell^-$ and $\psi' \to \ell^+\ell^-$ are excluded since $B \to J/\psi K^{(*)}$ and $B \to \psi' K^{(*)}$ have the same final states as $B \to K^{(*)}\ell^+\ell^-$, larger branching fraction and different underlying processes. The differential branching fractions are sensitive to Wilson coefficients, but for the moment they also suffer from the form-factor uncertainties.

One of the useful observable is the lepton flavor ratio, $R_{K^{(*)}} = \mathcal{B}(B \to K^{(*)}\mu^+\mu^-)/\mathcal{B}(B \to K^{(*)}e^+e^-)$. In the SM, $R_K = 1$ and $R_{K^*} = 0.75$, while they can be significantly enhanced due to neutral Higgs in a scenario of MSSM with large $\tan\beta$. The results,

$$\begin{array}{ll} R_K = 1.03 \pm 0.19 \pm 0.06 & \text{(Belle)}, \\ R_{K^*} = 0.83 \pm 0.17 \pm 0.05 & \text{(Belle)}, \\ R_K = 0.96\,^{+0.44}_{-0.34} \pm 0.05 & \text{(Belle)}, \\ R_{K^*} = 1.10\,^{+0.42}_{-0.32} \pm 0.07 & \text{(BaBar)}, \end{array} \tag{13}$$

are all consistent with the SM expectations.

Isospin asymmetry in $B \to K^{(*)}\ell^+\ell^-$ is another good probe for non-SM physics. It is defined as $A_I^{K^{(*)}} = [\Gamma(B^0 \to K^{(*)0}\ell^+\ell^-) - \Gamma(B^\pm \to K^{(*)+}\ell^+\ell^-)]/[\Gamma(B^0 \to K^{(*)0}\ell^+\ell^-) + \Gamma(B^\pm \to K^{(*)+}\ell^+\ell^-)]$, and is a function of q^2. BaBar has observed a deficit of neutral $B^0 \to K^{(*)0}\ell^+\ell^-$ at small q^2 and hence a large isospin asymmetry, but Belle's results with more q^2 bins are consistent with null isospin asymmetry, although they are consistent with BaBar, too.

The best observable is the forward-backward asymmetry (A_{FB}) of the lepton direction, which has a strong Wilson coefficient dependence,

$$A_{\rm FB}(q^2) = -C_{10}^{\rm eff}\xi(q^2)\left[Re(C_9^{\rm eff})F_1 + \frac{1}{q^2}C_7^{\rm eff}F_2\right], \tag{14}$$

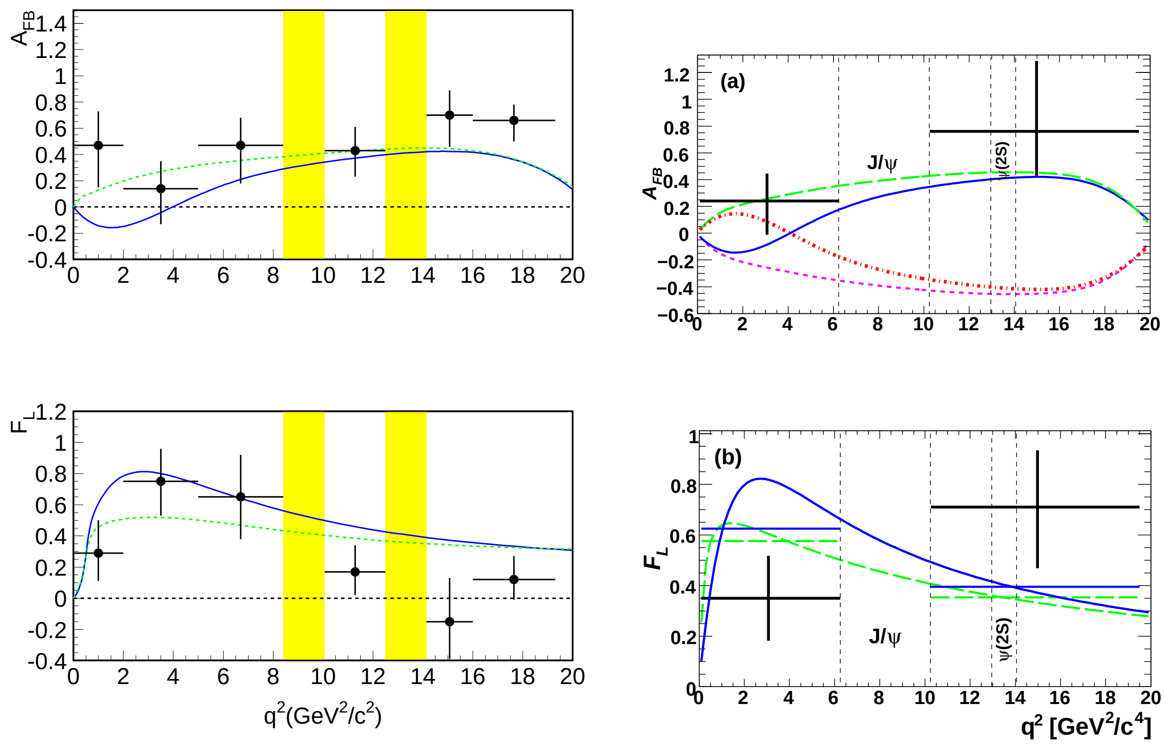

Figure 6: $A_{\rm FB}$ (top) and F_L (bottom) distributions as functions of q^2 measured by Belle (left) and BaBar (right), compared with the SM (solid) and non-SM (others) curves.

where ξ is a function of q^2, $F_{1,2}$ are factors besides q^2 and Wilson coefficients, and the superscript "eff" denotes that corrections to the Wilson coefficients are included. This forward-backward asymmetry is a similar effect to the forward-backward asymmetry in the e^+e^- differential cross-section due to the γ-Z interference near the Z resonance.

In the $B \to K^*\ell^+\ell^-$ mode, the forward-backward asymmetry is related to the K^* polarization and extracted through the angular distribution of the kaon (θ_K) which follows $\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$, and that of the lepton (θ_ℓ) which follows $\frac{3}{4}F_L(1-\cos^2\theta_\ell)+\frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell)+A_{\rm FB}\cos\theta_\ell$. The former determines the K^* polarization, and the latter determines $A_{\rm FB}$.

The measured forward-backward asymmetry by Belle [16] and BaBar [19] are shown in Fig. 6, compared with the SM prediction and extreme cases of the non-SM Wilson coefficients. For example, the opposite sign combination for the product C_9C_{10} is disfavored as $A_{\rm FB}$ is positive at large q^2. The sign of C_7 can be determined by whether the $A_{\rm FB}$ crosses zero or not, i.e., it becomes negative or not at small q^2. In the SM the sign of C_7 is negative and there is a zero-crossing point. Current data shows no indication of zero-crossing, but statistics is not enough to exclude zero-crossing, either. It was reported that BaBar has an anomaly in F_L in the small q^2 bin, but Belle did not observe such an effect.

6 Summary

Progress in the studies of radiative and electroweak penguin B meson decay modes by Belle and BaBar has been remarkable since the beginning of these two experiments, and has never slowed down until now. The measurement of the branching fraction for $B \to X_s\gamma$ by Belle has become more and more precise. After establishing the $B \to (\rho,\omega)\gamma$ decay modes, BaBar has made a new step in measuring $b \to d\gamma$ modes using a semi-inclusive method. The number of $B \to K^{(*)}\ell^+\ell^-$

Table 1: Summary of branching fractions for radiative and electroweak penguin decay modes by Belle and BaBar, and the world averages by HFAG which also include other experiments where available.

	Belle	BaBar	HFAG
$B \to X_s\gamma$ (10^{-4})			3.52 ± 0.25
inclusive	$3.31 \pm 0.19 \pm 0.37 \pm 0.01$	$3.67 \pm 0.29 \pm 0.34 \pm 0.29$	
sum-of-exclusive	$3.36 \pm 0.53 \pm 0.42\,^{+0.50}_{-0.54}$	$3.27 \pm 0.18\,^{+0.55}_{-0.40}\,^{+0.04}_{-0.09}$	
$B \to X_d\gamma$ (10^{-6})		$7.2 \pm 2.7 \pm 2.3$	
$B \to X_s\ell^+\ell^-$ (10^{-6})	$4.11 \pm 0.83\,^{+0.85}_{-0.81}$	$5.6 \pm 1.5 \pm 0.6 \pm 1.1$	4.5 ± 1.0
$B^0 \to K^{*0}\gamma$ (10^{-5})	$4.01 \pm 0.21 \pm 0.17$	$4.58 \pm 0.10 \pm 0.16$	4.40 ± 0.15
$B^+ \to K^{*+}\gamma$ (10^{-5})	$4.25 \pm 0.31 \pm 0.24$	$4.73 \pm 0.15 \pm 0.17$	4.57 ± 0.19
$B \to (\rho,\omega)\gamma$ (10^{-7})	$11.4 \pm 2.0\,^{+1.0}_{-1.2}$	$16.3\,^{+3.0}_{-2.8} \pm 1.6$	$13.0\,^{+1.8}_{-1.9}$
$B \to K\ell^+\ell^-$ (10^{-7})	$4.8\,^{+0.5}_{-0.4} \pm 0.3$	$3.4 \pm 0.7 \pm 0.2$	4.3 ± 0.4
$B \to K^*\ell^+\ell^-$ (10^{-7})	$10.7\,^{+1.1}_{-1.0} \pm 0.9$	$7.8\,^{+1.9}_{-1.7} \pm 1.1$	10.0 ± 1.1

events have increased dramatically to allow us studying the forward-backward asymmetry and other observables in bins of q^2. A list of branching fractions for representative decay modes is given in Table 1; the full list of measured radiative and electroweak penguin decays is getting longer and longer, e.g. by a new addition of $B^+ \to K^+\eta'\gamma$ mode found by Belle. Some of the results, in particular isospin asymmetry in $B \to (\rho,\omega)\gamma$ and the forward-backward asymmetry in $B \to K^*\ell^+\ell^-$, are already interesting in terms of searches for physics beyond the SM, and a larger data sample from the next generation e^+e^- B-factory will bring a bright future in studies of radiative and electroweak penguin decays.

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