Next-to-leading Order Calculations of the Radiative and Semileptonic Rare $B$ Decays in the Standard Model and Comparison with Data

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We review some selected rare $B$ decays calculated in next-to-leading order accuracy in the Standard Model (SM). These include the radiative decays $B \to (X_s, K^*, \rho)\gamma$ and the semileptonic decays $B \to (X_s, K, K^*)\ell^+\ell^-$, for which new data from the BABAR and BELLE collaborations have been presented at this conference. SM is in agreement with the current measurements within the theoretical and experimental errors. The impact of rare $B$-decays on the CKM phenomenology is quantitatively discussed.

1. INTRODUCTION AND OVERVIEW

First measurements of rare $B$ decays $B \to K^*\gamma$ [1] and $B \to X_s\gamma$ [2] were reported by CLEO in 1993 and 1995, respectively. Since then, a wealth of data on these decays has become available through the subsequent work of the CLEO collaboration [3,4], the ALEPH collaboration at LEP [5], and more recently from the experiments at the B factories, BABAR [6] and BELLE [7], which now dominate this field. We quantify the impact of $B \to X_s\gamma$ measurement on the CKM phenomenology.

Concerning the exclusive decays $B \to K^*\gamma$, the NLO calculations of the decay widths were completed last year [8–10]. Radiative decays provide a cleaner test of the underlying theoretical framework of perturbative QCD factorization which has been invoked initially to calculate the two-body exclusive non-leptonic $B$ decays, such as $B \to \pi\pi$ [11]. Quantitative rapport of theory and experiment in these decays is on hold at present due to the imprecise knowledge of the form factor, as discussed later in this talk.

A big leap forward has been reported in the experimental study of the Cabibbo-suppressed decays $B \to \rho\gamma$ and $B \to \omega\gamma$ at this conference [6,7]. These decays which enact $b \to d\gamma$ transition at the quark level yield complementary information on the CKM parameters and hence are potentially very important. We work out the constraints following from the current upper limits on the $B \to \rho\gamma$ branching ratios [6,7]. Apart from these, the Cabibbo-suppressed radiative decays $B \to \rho\gamma$ allow us to study isospin- and CP-asymmetries, which in the SM have a sensitive dependence on the angle $\alpha$ of the unitarity triangle [12,8,9]. We present the SM expectations for the decay rates and asymmetries, which are also potentially of interest in searching for physics beyond-the-SM [12,13].

The semileptonic decays $B \to (X_s, K, K^*)\ell^+\ell^-$ ($\ell^\pm = e^\pm, \mu^\pm$) are the new additions to the flavour changing neutral current FCNC decays, where $B$ factories have made first experimental inroads [7,14]. Of particular interest is the inclusive decay $B \to X_s\ell^+\ell^-$, whose measurement has been reported at this conference by the BELLE collaboration [7]. These decays have been calculated in the SM to the same degree of theoretical precision as their radiative counterpart $B \to X_s\gamma$, and take into account the explicit $O(\alpha_s)$ corrections to the dilepton invariant mass distribution [15,16], the forward-backward asymmetry of the charged lepton [17,18] and the leading power corrections in...
1/m_b [19,20] and 1/m_c [21]. Precise measurements of the dilepton invariant mass spectrum and the forward-backward asymmetry would allow to extract the (effective) Wilson coefficients, providing precision tests of the SM and enabling searches for physics beyond-the-SM [22].

What concerns the exclusive decays $B \to (K, K^*)\ell^+\ell^-$, important theoretical progress has been made recently [23,10], using ideas based on the large energy expansion [24]. In particular, both the dilepton invariant mass spectrum and the forward-backward asymmetry in $B \to K^*\ell^+\ell^-$ have been calculated in the lower region of the dilepton invariant mass ($s/m_{\phi,\psi}^2$) to the same accuracy as is the case for $B \to X_s\ell^+\ell^-$, albeit using perturbative QCD factorization. This framework has also been used to carry out a helicity analysis of the decays $B \to K^*\ell^+\ell^-$ and $B \to \rho\nu\ell$ [25]. Data on $B \to (X_s, K^*, K)\ell^+\ell^-$ are compared with the SM estimates [26,27] and the two are found to be compatible with each other.

2. Inclusive Decay $B \to X_s\gamma$

The theoretical framework for analyzing the transition $B \to X_s\gamma$ is provided by the effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{ts} \sum_{i=1}^{8} C_i(\mu) O_i,$$

where $G_F$ is the Fermi coupling constant and $V_{ij}$ are the CKM matrix elements. The effective Hamiltonian is obtained from the SM by integrating out all the particles that are much heavier than the $b$-quark. The Wilson coefficients $C_i(\mu)$ play the role of effective coupling constants for the interaction terms $O_i$. The generic structure of the operators $O_i$ can be seen, for example, in Ref. [27].

Perturbative calculations are used to determine the Wilson coefficients in a given renormalization scheme, such as the $\overline{\text{MS}}$ scheme, at a renormalization scale, typically $\mu_b \sim O(m_b)$.

$$C_i(\mu_b) = C_i^{(0)}(\mu_b) + \frac{\alpha_s(\mu_b)}{4\pi} C_i^{(1)}(\mu_b) + \ldots$$

Here, $C_i^{(n)}(\mu_b)$ depend on $\alpha_s$ only via the ratio $\eta \equiv \alpha_s(\mu_0)/\alpha_s(\mu_b)$, where $\mu_0 \sim m_W$. In the leading order (LO) calculations, everything but $C_i^{(0)}(\mu_b)$ is neglected in Eq. (2). In NLO, one takes in addition $C_i^{(1)}(\mu_b)$ into account.

It has become customary to quote the theoretical branching ratios for $B \to X_s\gamma$ decay with a cut on the photon energy $E_\gamma$. In the $\overline{\text{MS}}$ scheme, the results in the SM (in units of $10^{-4}$) are [28,29]:

$$B(\bar{B} \to X_s\gamma ; E_\gamma > 1.6 \text{ GeV}) = (3.57 \pm 0.30),$$

$$B(\bar{B} \to X_s\gamma ; E_\gamma > \frac{1}{1.5}m_b) = (3.70 \pm 0.31).$$

(3)

The present world averages (also in units of $10^{-4}$)

$$B(\bar{B} \to X_s\gamma ; E_\gamma > 1.6 \text{ GeV}) = (3.28 \pm 0.41),$$

$$B(\bar{B} \to X_s\gamma ; E_\gamma > \frac{1}{1.5}m_b) = (3.40 \pm 0.42).$$

(4)

result from the following four measurements: BABAR [6,30], CLEO [3], BELLE [31], and ALEPH [5]. They are in good agreement with the NLO results in the $\overline{\text{MS}}$ scheme. However, there is a residual theoretical uncertainty on the SM estimates related to the scheme-dependence of the quark masses. This can be judged from the theoretical branching ratios in the $\overline{\text{MS}}$ scheme for which one gets $B(\bar{B} \to X_s\gamma) = (3.73 \pm 0.31) \times 10^{-4}$ [28], and in the pole quark mass scheme yielding $B(\bar{B} \to X_s\gamma) = (3.35 \pm 0.30) \times 10^{-4}$ [32].

Reducing this theoretical uncertainty, which currently represents an error of $O(10\%)$, requires calculation of the next-to-next-to-leading order contribution to the decay width (i.e., explicit $O(\alpha_s^2)$ improvements), which is a formidable but doable task in a concerted theoretical effort [33]. Anticipated experimental precision at the $B$ factories will make it mandatory to undertake this heroic effort.

The transition $b \to s\gamma$ is not expected to yield useful information on the CKM-Wolfenstein parameters $\rho$ and $\eta$, which define the apex of the unitarity triangle of current interest. The test of CKM-unitarity for the $b \to s$ transitions in rare $B$-decays lies in checking the relation $\lambda_t \simeq -\lambda_s$, which holds up to corrections of order $\lambda^2$. This is implicit in the theoretical decay rates quoted.
above. Alternatively, one can drop the explicit use of the CKM unitarity and calculate the various contributions in the \( b \to s \gamma \) amplitude from the current knowledge of \( \lambda \) and \( \lambda_\mu \) from PDG [34], which then yields \( \lambda_\mu \approx V_{ts} = -(47 \pm 8) \times 10^{-3} [35] \). This is consistent with \( \lambda_\mu = -\lambda \), but less precise. This is due to the strong mixing of the operator \( O_2 \) with \( O_T \) under QCD renormalization, which enhances the coefficient of the \( \lambda_\mu \) term in the \( b \to s \gamma \) amplitude in comparison with the coefficient of the \( \lambda_\mu \) term, thereby reducing the precision on \( \lambda_\mu \).

3. EXCLUSIVE DECAYS \( B \to (K^*, \rho) \gamma \)

To compute the branching ratios for \( B \to V \gamma \) reliably, one needs to calculate the explicit \( O(\alpha_s) \) improvements to the lowest order decay widths. This requires the calculation of the renormalization group effects in the appropriate Wilson coefficients in the effective Hamiltonian [32], an explicit \( O(\alpha_s) \) calculation of the matrix elements involving the hard vertex corrections [36–38], annihilation contributions [39–41], which are more important in the decays \( B \to \rho \gamma \) but have also been worked out for the \( B \to K^{*\pm} \gamma \) decays [42], and the so-called hard-spectator contributions involving (virtual) hard gluon radiative corrections off the spectator quarks in the \( B \), \( K^{*\pm} \), and \( \rho \)-mesons [8–10]. We discuss the decays \( B \to K^{*\pm} \gamma \) and \( B \to \rho \gamma \) in turn.

3.1. \( B \to K^{*\pm} \gamma \) Decays

The branching ratio for the decays \( B \to K^{*\pm} \gamma \) can be written as [8–10]:

\[
\mathcal{B}(B \to K^{*\pm} \gamma) = \tau_B \frac{G_F^2 |V_{tb} V_{ts}^*|^2 m_{b,\text{pole}} M_B^3}{32\pi^4} \left[ \alpha_F^{(K^\pm)}(0) \right]^2 \left( 1 - \frac{m_{K^\pm}^2}{M_B^2} \right)^3 \left| C_7^{(0)\text{eff}} + A^{(1)}(\mu) \right|^2 .
\]

Here, \( M_B \) is the \( B \)-meson mass and \( \alpha_F^{(K^\pm)}(0) \) is the form factor in the large energy effective theory. It differs from the corresponding form factor in QCD, \( T_1^{K^\pm}(0) \), by \( O(\alpha_s) \) terms calculated in Ref. [23]. Numerically, this relation can be expressed as \( T_1^{K^\pm}(0) \approx 1.08 \alpha_F^{(K^\pm)} \). The effect of the \( O(\alpha_s) \) corrections is encoded in the function \( A^{(1)}(\mu) \) and its numerical value can be expressed in terms of a \( K \)-factor [8–10]:

\[
K = \frac{\left| C_7^{(0)\text{eff}} + A^{(1)}(\mu) \right|^2}{\left| C_7^{(0)\text{eff}} \right|^2} , \quad \text{with} \quad 1.5 \leq K \leq 1.7 .
\]

This yields a charge-conjugate averaged branching ratio

\[
\langle \mathcal{B}(B \to K^{*\pm} \gamma) \rangle \approx (7.2 \pm 1.1) \times 10^{-5}
\]

\[
\times \left( \frac{m_{b,\text{pole}}}{4.65 \text{ GeV}} \right)^2 \left( \frac{\xi_\perp^{(K^\pm)}(0)}{0.35} \right)^2 ,
\]

where the default values of the most sensitive parameters are indicated. The value given for \( \xi_\perp^{(K^\pm)}(0) \) is based on using the light-cone QCD sum rules. Varying the parameters within reasonable ranges (see, for example, [8]) and adding the errors in quadrature, one gets

\[
\langle \mathcal{B}(B \to K^{*\pm} \gamma) \rangle \approx (7.2 \pm 2.7) \times 10^{-5} ,
\]

to be compared with the corresponding experimental measurement [4,6,7]:

\[
\langle \mathcal{B}(B \to K^{*\pm} \gamma) \rangle \approx (4.22 \pm 0.28) \times 10^{-5} .
\]

Given the large theoretical errors, there is agreement between theory and experiment. Since there exists good agreement between the SM and experiment in the inclusive decay \( B \to X_s \gamma \), one could use the measured branching ratios for \( B \to K^{* \gamma} \) to determine the form factor \( T_1^{K^\pm}(0) \), which in the stated theoretical context yields \( T_1^{K^\pm}(0) = 0.27 \pm 0.04 \). This is to be compared with the lightcone QCD sum rule result \( T_1^{K^\pm}(0) = 0.38 \pm 0.05 [43,26] \), and with \( T_1^{K^\pm}(q^2 = 0) = 0.32^{+0.04}_{-0.02} [44] \), obtained by using the lattice UKQCD simulations combined with a LC-QCD-sum-rule inspired input for extrapolation from \( q^2 \gg 0 \), where the lattice simulations are actually done, to the physical value \( q^2 = 0 \). A preliminary result on \( T_1^{K^\pm}(0) \) using Lattice-QCD has also been reported at this conference [45]. Due to the spread in the theoretical estimates it is too early to draw a quantitative conclusion on the precise value of the form factor, and hence on the perturbative QCD factorization method underlying the theoretical estimates in \( B \to K^{*\gamma} \).
3.2. $B \to \rho \gamma$ Decays

The effective Hamiltonian for the radiative decays $B \to (\rho, \omega)\gamma$ can be seen for the SM in [8]. These transitions involve the CKM matrix elements in the first and third column, with the unitarity constraints taking the form $\sum_{u,c,t} \xi_i = 0$, with $\xi_i = V_{ib} V_{id}^\ast$. All three matrix elements are of order $\lambda$, with $\xi_u \simeq A\lambda^3(-\bar{\rho} - i\bar{\eta})$, $\xi_c \simeq -A\lambda^3$, and $\xi_t \simeq A\lambda^3(1 - \bar{\rho} - i\bar{\eta})$. This equation leads to the same unitarity triangle as studied through the constraints $V_{ub}/V_{cb}$, $\Delta M_{B_s}$ (or $\Delta M_{B_d}/\Delta M_{B_s}$).

We shall concentrate here on $B \to \rho\gamma$ decays. As the absolute values of the form factors in this decay and in $B \to K^\ast\gamma$ decays discussed earlier are quite uncertain, it is advisable to calculate instead the ratios of the branching ratios

$$R^\pm(\rho / K^\ast \gamma) = \frac{\mathcal{B}(B^\pm \to \rho^\pm \gamma)}{\mathcal{B}(B^\pm \to K^\ast \rho \gamma)} ,$$

$$R^0(\rho / K^\ast \gamma) = \frac{\mathcal{B}(B^0 \to \rho^0 \gamma)}{\mathcal{B}(B^0 \to K^\ast \rho \gamma)} .$$

They have been calculated in the NLO accuracy and the result can be expressed as [8]:

$$R^\pm(\rho / K^\ast \gamma) = \frac{|V_{td}|^2}{|V_{ts}|^2} [\text{PS}] \zeta^2 (1 + \Delta R^\pm) ,$$

$$R^0(\rho / K^\ast \gamma) = \frac{1}{2} \frac{|V_{td}|^2}{|V_{ts}|^2} [\text{PS}] \zeta^2 (1 + \Delta R^0) ,$$

where $[\text{PS}] = (M^2_{B_s} - M^2_{B_d})/3(M^2_{B_s} - M^2_{B_d})^3$ represents a kinematic factor, which is 1 to a good approximation, and $\zeta = \xi^\pm_+ (0)/\xi^0_+ (0)$, with $\xi^\pm_+ (0)/\xi^0_+ (0)$ being the form factors (at $q^2 = 0$) in the effective heavy quark theory for the decays $B \to \rho(K^\ast)\gamma$. Noting that in the SU(3) limit one has $\zeta = 1$, we take $\zeta = 0.76 \pm 0.10$ - a range which straddles various theoretical estimates of this quantity [39,43,46,47]. The functions $\Delta R^\pm$ and $\Delta R^0$, appearing on the r.h.s. of the above equations and whose parametric dependence is suppressed here for ease of writing, encode both the $O(\alpha_s)$ and annihilation contributions. They have been evaluated as [8,13]: $\Delta R^\pm = 0.055 \pm 0.130$ and $\Delta R^0 = 0.015 \pm 0.110$, where the errors also include the effect of varying the angle $\alpha$ in the currently allowed region.

There are two more observables of interest, namely the isospin-violating ratio $\Delta(\rho \gamma)$ defined as

$$\Delta(\rho \gamma) \equiv \frac{\Gamma^\pm(B \to \rho \gamma)}{2 \Gamma^0(B \to \rho \gamma)} - 1 ,$$

and the CP asymmetry in the decay rates, which for $B^\pm \to \rho \pm \gamma$ decays is defined as

$$A_{CP}(\rho \gamma) \equiv \frac{\mathcal{B}(B^- \to \rho^- \gamma) - \mathcal{B}(B^+ \to \rho^+ \gamma)}{\mathcal{B}(B^- \to \rho^- \gamma) + \mathcal{B}(B^+ \to \rho^+ \gamma)} .$$

The expected values of the observables in the $B \to \rho \gamma$ system defined in Eqs. (7) - (10) and $A_{CP}(\rho \gamma)$, the CP asymmetry in the neutral modes, have been recently updated in Ref. [13]. Including the errors on the current determination of the CKM parameters, the results are:

$$R^\pm(\rho / K^\ast \gamma) = 0.023 \pm 0.012 ,$$

$$R^0(\rho / K^\ast \gamma) = 0.011 \pm 0.006 ,$$

$$\Delta(\rho \gamma) = 0.04^{+0.14}_{-0.07} ,$$

$$A_{CP}(\rho \gamma) = 0.10^{+0.03}_{-0.02} ,$$

$$A_{CP}^0(\rho \gamma) = 0.06 \pm 0.02 .$$

At this conference, the BABAR collaboration has reported a significant improvement on the upper limits of the branching ratios for the decays $B^0(B^0) \to \rho^0 \gamma$ and $B^\pm \to \rho^\pm \gamma$. Averaged over the charge conjugated modes, the current 90% C.L. upper limits are [6]:

$$\mathcal{B}(B^0 \to \rho^0 \gamma) < 1.4 \times 10^{-6} ,$$

$$\mathcal{B}(B^\pm \to \rho^\pm \gamma) < 2.3 \times 10^{-6} ,$$

$$\mathcal{B}(B^0 \to \omega \gamma) < 1.2 \times 10^{-6} .$$

They have been combined, using isospin weights for $B \to \rho \gamma$ decays and assuming $\mathcal{B}(B^0 \to \omega \gamma) = \mathcal{B}(B^0 \to \rho^0 \gamma)$, to yield the improved upper limit [6]

$$\mathcal{B}(B \to \rho \gamma) < 1.9 \times 10^{-6} .$$

Together with the current measurements of the branching ratios for $B \to K^\ast \gamma$ decays by BABAR, this yields a 90% C.L. upper limit [6]

$$R(\rho / K^\ast \gamma) \equiv \frac{\mathcal{B}(B \to \rho \gamma)}{\mathcal{B}(B \to K^\ast \gamma)} < 0.047 .$$
Thus, we see that the current experimental upper limit on the ratio \( R(\rho\gamma/K^*\gamma) \) is typically a factor 2 away from the central values of the SM. This can be seen graphically in Fig. 1, where we show the fit of the unitarity triangle resulting from the various direct and indirect measurements, including the CP asymmetry \( a_{\psi KS} \), reported by the BABAR and BELLE collaboration at this conference, with the current world average being \( a_{\psi KS} = 0.734 \pm 0.054 \) [48]. The (almost concentric) constraints in the \((\rho, \eta)\) plane from the measured value \( \Delta M_{B_d} = 0.503 \pm 0.006 \) ps\(^{-1}\) [49], and the two competing bounds \( \Delta M_{B_s} > 14.4 \) ps\(^{-1}\) [49], and \( R(\rho\gamma/K^*\gamma) < 0.047 \) [6] are also shown. The two set of curves for the constraints following from \( \Delta M_{B_d} \) and \( \Delta M_{B_s} \), shown with and without the chiral logs, reflect the current uncertainty inherent in Lattice calculations due to chiral extrapolations from the region \( m_s \) to \( m_d \) [50]. We see that the quantity \( R(\rho\gamma/K^*\gamma) \) is not yet competitive with the other two constraints from either \( \Delta M_{B_s} \) or \( \Delta M_{B_s} \). However, this sure will change as the B factory experiments will soon reach the SM-sensitivity on the decay mode \( B \to \rho\gamma \), and hence on \( R(\rho\gamma/K^*\gamma) \).

4. THE DECAYS \( B \to (X_s, K, K^*)\ell^+\ell^- \)

To discuss the FCNC semileptonic decays in the SM, one has to extend the operator basis given in Eq. (1) by adding two semileptonic operators:

\[
O_9 = \frac{e^2}{g_s^2} (\bar{s}L \gamma_\mu b_L) \sum_\ell (\ell \mu)^\ell, \\
O_{10} = \frac{e^2}{g_s^2} (\bar{s}L \gamma_\mu b_L) \sum_\ell (\ell \gamma_\mu \gamma_5 \ell),
\]

where \( e \) (\( g_s \)) is the QED (QCD) coupling constant and the subscript \( L \) refers to the left-handed components of the fermion fields. There are additional non-local contributions, which can be added to \( C_9 \), defining an effective Wilson coefficient, which is a misnomer as it actually a function of the dilepton mass squared \( \hat{s} = s/M_B^2 \): \( C_9^{\text{eff}}(\hat{s}) = C_9 \eta(\hat{s}) + Y(\hat{s}) \), where \( \eta(\hat{s}) = (1+O(\alpha_s)) \) includes the real gluon bremsstrahlung and virtual contributions to the matrix element of the operator \( O_9 \) [51], and \( Y(\hat{s}) \) contains perturbative charm loops and Charmonium resonances (\( J/\psi, \psi', \ldots \)).

Concentrating on the perturbative contribution only, which is expected to be the dominant contribution away from the resonances, and including the leading power corrections in \( 1/m_b \) and \( 1/m_c \), the dilepton invariant mass distribution for \( B \to X_s \ell^+\ell^- \) can be written as [27]:

\[
d\Gamma(b \to s\ell^+\ell^-) = \frac{\alpha_{em}}{4\pi} \left( \frac{G_F^2 m_b \text{pole}}{4\pi^3} \right) \lambda_{ts} \sqrt{\hat{s}} \times \left[ (1 - \hat{s})^2 \left( \frac{\bar{C}_9^{\text{eff}}}{C_9^0} \right)^2 + \left| \bar{C}_9^{\text{eff}} \left\{ \left( G_1(\hat{s}) + 12 \Re \left( \bar{C}_7^{\text{eff}} C_9^{\text{eff}} \right) \right) \times G_3(\hat{s}) + G_c(\hat{s}) \right) \right] \right],
\]

where the functions \( G_i(\hat{s}) \) \((i = 1, 2, 3)\) encode the \( 1/m_b \) corrections [19,20] and the function \( G_c(\hat{s}) \) the corresponding \( 1/m_c \) corrections [21]. Their explicit forms as well as of the other effective coefficients in the above equation can be seen in Ref. [27]. As noted in Ref. [16], inclusion of the explicit \( O(\alpha_s) \) corrections reduces the branching ratio for \( B \to X_s \ell^+\ell^- \), compared to the partial

**Figure 1. Unitary triangle fit in the SM and the resulting 95\% C.L. contour in the \( \rho - \eta \) plane. The impact of the \( R(\rho\gamma/K^*\gamma) < 0.047 \) constraint is also shown. (From Ref. [13].)**
$O(\alpha_s)$-corrected result [19] and its scale dependence is considerably reduced.

Data from the BELLE collaboration on the dilepton invariant mass spectrum has been analyzed using Ref. [27], which incorporates all the explicit $O(\alpha_s)$ and power corrections mentioned above. The hadron invariant mass spectrum in $B \to X_s \ell^+\ell^-$, calculated in the heavy quark effective theory (HQET) and in a phenomenological Fermi motion model [52], has been used to estimate the effect of the experimental cuts on $M_{X_S}$. The results are given in Table 1, and are to be understood with a cut on the dilepton invariant mass $M_{\ell^+\ell^-} > 0.2$ GeV. Given the current experimental errors, the agreement with the SM-based estimates is reasonably good.

The corresponding results for the exclusive decays $B \to K\ell^+\ell^-$, averaged over $\ell = e, \mu$, and for $B \to K^*\ell^+\ell^-$, with $\ell = e, \mu$, presented at this conference [7,14] are also given in Table 1 and compared with the SM-based estimates [26,27]. One notes the comparatively larger theoretical uncertainty in the exclusive decay rates due to the form factors. However, within the theoretical and experimental errors, SM accounts well the current data on all the inclusive and exclusive rare $B$ decays. This can be used to constrain models of physics beyond-the-SM [27].

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Table 1
SM predictions ($O(\alpha_s)$ and leading power corrected) and comparison with data (in units of $10^{-6}$)

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<tr>
<td>$B \rightarrow K\ell^+\ell^-$</td>
<td>$0.35 \pm 0.12$</td>
<td>$0.58^{+0.17}_{-0.15} \pm 0.06$</td>
<td>$0.78^{+0.24}_{-0.20}+0.11$</td>
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<tr>
<td>$B \rightarrow K^+e^+e^-$</td>
<td>$1.58 \pm 0.52$</td>
<td>$&lt; 5.1$</td>
<td>$1.68^{+0.68}_{-0.58} \pm 0.28$</td>
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<tr>
<td>$B \rightarrow K^+\mu^+\mu^-$</td>
<td>$1.2 \pm 0.4$</td>
<td>$&lt; 3.0$</td>
<td>$&lt; 3.0$; weighted $e^+e^-, \mu^+\mu^-$</td>
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<tr>
<td>$B \rightarrow X_s\ell^+\ell^-$</td>
<td>$4.15 \pm 0.70$</td>
<td>$7.9 \pm 2.1^{+1.5}_{-1.1}$</td>
<td>$-$</td>
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<tr>
<td>$B \rightarrow X_s e^+e^-$</td>
<td>$4.2 \pm 0.7$</td>
<td>$5.0 \pm 2.3^{+1.2}_{-1.1}$</td>
<td>$-$</td>
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<tr>
<td>$B \rightarrow X_s \ell^+\ell^-$</td>
<td>$4.18 \pm 0.70$</td>
<td>$6.1 \pm 1.4^{+1.3}_{-1.1}$</td>
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The inclusive measurements and the corresponding SM rates are given with a cut on the dilepton mass, $M_{\ell^+\ell^-} > 0.2 \text{ GeV}$.

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