

Experimental Status and Expectations Regarding Radiative Penguin Decays

G. Eigen*
University of Bergen

Radiative penguin decays provide a hunting ground complementary to direct searches for physics beyond the Standard Model. In the era of B -factories copious production of B mesons permits precision measurements of radiative penguin decays. We present herein the status of radiative penguin processes and expectations at high luminosities, focusing on $b \rightarrow s(d)\gamma$, $b \rightarrow s\ell^+\ell^-$, and $b \rightarrow s\nu\bar{\nu}$ modes.

1. Introduction

Radiative penguin decays are flavor-changing neutral current (FCNC) transitions that are forbidden in the Standard Model (SM) at tree level but occur at the loop level involving electroweak penguin loops or box diagrams. Though suppressed in SM they are relatively large in $b \rightarrow s$ because of the CKM structure and the top-quark dominating the loop. Additional contributions can arise from New Physics effects such as new gauge bosons, charged Higgs bosons or supersymmetric particles. These interfere with the SM processes. Depending on the sign of the interference term enhanced or depleted branching fractions result. In addition, due to the presence of new weak phases CP asymmetries that are small in the SM may be enhanced. In this report we focus on electroweak penguin decays with a photon, a lepton pair or a neutrino pair in the final state. We have chosen five benchmark luminosities \mathcal{L} for our extrapolations: (i) $9.1/20.7 \text{ fb}^{-1}$, integrated luminosity used in present analysis samples by CLEO and BABAR, (ii) 100 fb^{-1} , integrated luminosity expected in BABAR by summer 2002, (iii) 500 fb^{-1} , integrated luminosity expected in BABAR by summer 2005, (iv) 1 ab^{-1} , integrated luminosity expected in BABAR by 2008, and (v) 10 ab^{-1} , annually integrated luminosity of a super B -factory [1], [2]. We use the most precise measurements where available and scale yields linearly with \mathcal{L} and statistical errors by $1/\sqrt{\mathcal{L}}$. For modes that have not been observed yet we use a range of most recent predictions and inflate statistical errors by $\sqrt{2}$ to account conservatively for background subtraction. Systematic errors are a guess assuming that for increased data samples individual systematic uncertainties can be reduced, by obtaining an improved understanding of the detector performance with time and by choosing a set of analysis criteria that yield improved systematic errors even at a cost of reduced statistics.

2. Inclusive and Exclusive $b \rightarrow s(d)\gamma$ Modes

The electromagnetic penguin process $b \rightarrow s\gamma$ is dominated by the magnetic penguin operator $O_{7\gamma}$. The SM decay rate contains the squares of the CKM matrix elements $|V_{ts}|$ and the Wilson coefficient C_7 . The latter accounts for all perturbative QCD contributions. Due to operator mixing an effective coefficient results, which in leading order (LO) takes the value $C_7^{(0)eff} = -0.312^{+0.059}_{-0.034}$. Including the next order and employing a low-energy cut-off on the photon energy in the gluon-bremsstrahlung process yields an effective Wilson coefficient $|D^{eff}| = 0.373$. The non-perturbative contributions are absorbed into the hadronic matrix element of the magnetic dipole operator. Because of large model uncertainties one avoids the calculation of the hadronic matrix element by using the approximation that the ratio of decay rates of $b \rightarrow s\gamma$ and $b \rightarrow c e \bar{\nu}$ at the

*eigen@asfys2.fi.uib.no

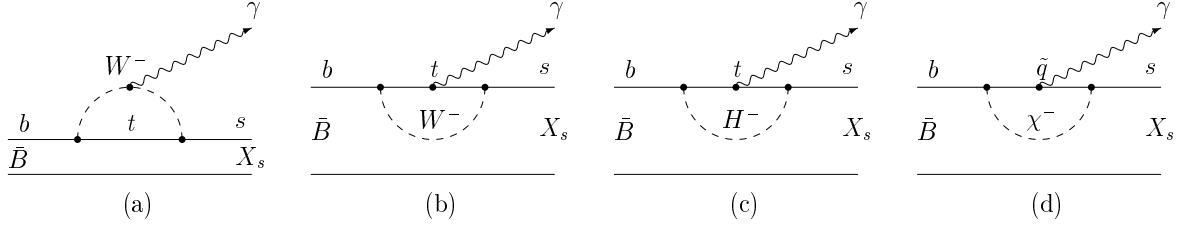


Figure 1: Lowest order Feynman diagrams for $b \rightarrow s\gamma$ decays in the SM (a,b) and for New Physics contributions from a charged Higgs (c) and supersymmetric processes (d).

parton level is equal to that at the meson level. New Physics processes yield additional contributions C_7^{new} and C_8^{new} , where the latter arises from SUSY operators that are equivalent to the chromomagnetic dipole operator O_8 . Typical Feynman diagrams for SM and New Physics processes are shown in Figure 1. In next-to-leading order (NLO) the SM inclusive branching fraction is predicted to be $\mathcal{B}(B \rightarrow X_s \gamma) = (3.28 \pm 0.33) \times 10^{-4}$ [3]. Gambino and Misiak [4], however, have recently argued for a different choice of the charm-quark mass, which increases the branching fraction to $\mathcal{B}(B \rightarrow X_s \gamma) = (3.73 \pm 0.3) \times 10^{-4}$. The present theoretical uncertainty of $\sim 10\%$ is dominated by the mass ratio of the c -quark and b -quark and the choice of the scale parameter μ_b .

So far inclusive measurements have been performed by CLEO [5], BELLE [6] and ALEPH [7], of which the CLEO result is the most precise. The analysis is an update extending the observed photon-energy range to 2.0–2.7 GeV (94% of the spectrum). The main backgrounds originate from $q\bar{q}$ continuum processes with either a high-energy photon from initial-state radiation (ISR) or from a π^0 . To reduce these backgrounds, CLEO exploits several event-shape variables, performs B -meson pseudoreconstruction and uses kinematic information of identified leptons. Candidates are sorted into four classes: events selected solely with event-shape variables, those having in addition a B pseudoreconstruction, those with an additional lepton, and those satisfying all three requirements. In each class all variables are combined in a neural net, which computes a weight between 0.0 and 1.0, depending on how much the event is continuum-like or $B \rightarrow X_s \gamma$ signal-like. The observed spectrum containing 1861.7 ± 16.5 weights in the signal region is still dominated by backgrounds (75% continuum, 12.3% $B\bar{B}$). After background subtraction, where the continuum-background spectrum is obtained from data taken below the $\Upsilon(4S)$ resonance and the B -background spectrum is determined from $B\bar{B}$ Monte Carlo, which was tuned to match yields observed in the data, CLEO finds a $B \rightarrow X_s \gamma$ signal yield of $233.6 \pm 31.2 \pm 13.4$ weights in a sample of 9.1 fb^{-1} . With a detection efficiency of $\varepsilon = (3.93 \pm 0.15 \pm 0.17)\%$ CLEO measures a branching fraction of $\mathcal{B}(B \rightarrow X_s \gamma) = (3.21 \pm 0.43_{(stat)} \pm 0.27_{(sys)} {}^{+0.18}_{-0.10}_{(th)}) \times 10^{-4}$, where errors are statistical, systematic and from theory, respectively. This result is consistent with the SM prediction and agrees with the BELLE measurement of $\mathcal{B}(B \rightarrow X_s \gamma) = (3.36 \pm 0.53_{(stat)} \pm 0.42_{(sys)} {}^{+0.50}_{-0.54}_{(th)}) \times 10^{-4}$.

Presently, errors are rather large amounting to a relative statistical (systematic) error of 13.4% (8.4%). They are slightly larger than the present theoretical uncertainty. Using the CLEO measurement, the yields and relative errors obtained from extrapolations to high \mathcal{L} are summarized in Table I. Note that a super B -factory operating at a luminosity of $10^{36} \text{ cm}^{-2} \text{ s}^{-1}$ is expected to produce 2.6×10^5 $B \rightarrow X_s \gamma$ signal weights per year permitting a $B \rightarrow X_s \gamma$ branching-fraction measurement with a relative statistical error of 0.4%. It is expected that with increased statistics the systematic error can be reduced substantially by using appropriate data selections even at the cost of slightly reduced statistics and by improving measurements of tracking efficiency, photon energy, photon efficiency and B counting. The precision of the SM prediction needs to be improved to ascertain a high sensitivity for New Physics processes. In a hadron collider precision measurements are difficult because of high backgrounds.

The present $\mathcal{B}(B \rightarrow X_s \gamma)$ measurements already provide a significant constraint on the SUSY parameter space. For example the new physics contributions to $B \rightarrow X_s \gamma$, C_7^{new} and C_8^{new} , have been calculated using the minimal supergravity model (SUGRA) [8]. Many solutions have been generated by varying the input parameters within the ranges $0 < m_0 < 500 \text{ GeV}$, $50 < m_{1/2} <$

Table I Yields Y_B (Y_{CP}), statistical errors $\sigma_{stat}/\mathcal{B}$ (σ_{stat}^{CP}) and systematic errors σ_{sys}/\mathcal{B} (σ_{sys}^{CP}) expected for branching-fraction (CP -asymmetry) measurements of $B \rightarrow X_s \gamma$ and $B^0 \rightarrow K^{*0} \gamma$ for different luminosities.

\mathcal{L} [fb^{-1}/y]	9.1	20.7	100	500	1000	10000
$X_s \gamma$ weights Y_B (Y_{CP})	234 (231)		2570 (2540)	$1.28 (1.27) \times 10^4$	$2.57 (2.54) \times 10^4$	$2.57 (2.54) \times 10^5$
$\sigma_{stat}/\mathcal{B}$ (σ_{stat}^{CP}) [%]	13.4 (10.8)		4.0 (3.3)	1.8 (1.5)	1.3 (1.0)	0.4 (0.33)
σ_{sys}/\mathcal{B} (σ_{sys}^{CP}) [%]	8.4 (2.2)		5 (1.8)	3 (1.5)	2 (1.0)	1-2 (0.5)
$K^{*0} \gamma$ yield Y_B (Y_{CP})		139.2 (139.2)	670 (670)	3360 (3360)	$6.72 (6.72) \times 10^3$	$6.72 (6.72) \times 10^4$
$\sigma_{stat}/\mathcal{B}$ (σ_{stat}^{CP}) [%]		9.3 (9.4)	4.2 (4.3)	1.9 (1.9)	1.3 (1.4)	0.42 (0.43)
σ_{sys}/\mathcal{B} (σ_{sys}^{CP}) [%]		6.2 (1.2)	4 (1.0)	3 (0.8)	2 (0.7)	1? (0.5)

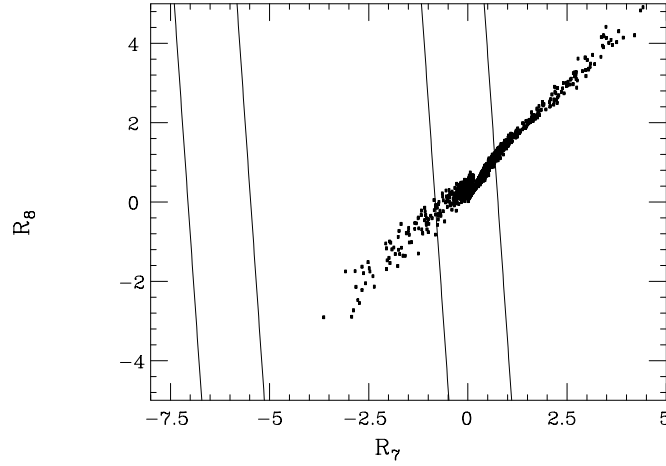


Figure 2: Scatter plot of R_8 versus R_7 for solutions obtained in the SUGRA model. The region allowed by the CLEO measurement lies inside the two sets of solid diagonal bands.

250 GeV, $-3 < A_0/m_0 < 3$ and $2 < \tan \beta < 50$ ¹, while the top-quark mass was kept fixed at $m_t = 175$ GeV. Only solutions were retained that were not in violation with SLC/LEP constraints and Tevatron direct sparticle production limits. For these the ratios $R_7 = C_7^{new}(M_W)/C_7^{SM}(M_W)$ and $R_8 = C_8^{new}(M_W)/C_8^{SM}(M_W)$ were determined. The results are depicted in Figure 2 [9]. The solid bands show the regions allowed by the CLEO measurement. It is interesting to note that many solutions are already in conflict with the data.

The exclusive decay rate for $B \rightarrow K^* \gamma$ involves the hadronic matrix of the magnetic dipole operator, which in general is expressed in terms of three q^2 -dependent form factors $T_i(q^2)$. For on-shell photons T_3 vanishes and T_2 is related to T_1 . For the determination of the form factors various techniques are used, introducing additional theoretical uncertainties. Recently, two NLO calculations were carried out, predicting SM branching fractions of $\mathcal{B}(B \rightarrow K^* \gamma) = (7.1_{-2.3}^{+2.5}) \times 10^{-5}$ [10] and $\mathcal{B}(B \rightarrow K^* \gamma) = (7.9_{-3.0}^{+3.5}) \times 10^{-5}$ [11]. The exclusive $B \rightarrow K^* \gamma$ modes have been studied by BABAR [12], BELLE [13] and CLEO [14], where BABAR used the highest statistics sample. Utilizing kinematic constraints resulting from a full B reconstruction in the B rest frame provides a substantial reduction of the $q\bar{q}$ -continuum background here. We base our extrapolations to high \mathcal{L} on the BABAR $B^0 \rightarrow K^{*0} \gamma$ result in the $K^+ \pi^-$ final state, where a reconstruction efficiency of

¹In SUGRA one assumes a common scalar mass m_0 for squarks and sleptons, a common gaugino mass $m_{1/2}$ and a common trilinear scalar coupling A_0 . As usual the ratio of vacuum expectation values of the neutral components of the two Higgs doublets is parameterized by $\tan \beta$.

14% is achieved. In a sample of $\mathcal{L} = 20.7 \text{ fb}^{-1}$ a yield of 139.2 ± 13.1 events is observed, resulting in a branching fraction of $\mathcal{B}(B^0 \rightarrow K^{*0}\gamma) = (4.39 \pm 0.41_{(stat)} \pm 0.27_{(sys)}) \times 10^{-5}$. Due to the large theoretical errors of 35 – 40% the BABAR measurement is still consistent with the NLO SM predictions. Note that the combined statistical and systematic error is already more than a factor of three smaller than the theoretical uncertainty. The results of our extrapolations to high \mathcal{L} are also shown in Table I. Expected precisions are similar to those in $B \rightarrow X_s\gamma$. In hadron colliders $B \rightarrow K^{*0}\gamma$ is also measurable. CDF expects to observe 170 ± 40 events per 2 fb^{-1} , while BTeV [15] and LHCb [16] estimate yields of 27000 and 26000 events per $10^7 s$ ($\sim 2 \text{ fb}^{-1}$), respectively.

CP asymmetries provide another test of the SM. While small in the SM ($\leq 1\%$) [17] they may be as large as 20% [18] in SUSY models. So far all observed CP asymmetries are consistent with zero. In the inclusive mode we base our extrapolations on a recent result from CLEO [19], yielding $\mathcal{A}_{CP}(B \rightarrow X_s\gamma) = (-0.079 \pm 0.108 \pm 0.022) \times (1.0 \pm 0.03)$. The first error is statistical, while the second and third errors represent additive and multiplicative systematic uncertainties, respectively. For extrapolating CP asymmetries of the exclusive $B^0 \rightarrow K^{*0}\gamma$ modes to high \mathcal{L} , we use the BABAR result of $\mathcal{A}_{CP}(B \rightarrow K^{*0}\gamma) = -0.035 \pm 0.094_{(stat)} \pm 0.012_{(sys)}$ obtained in the $K^+\pi^-$ final state [12]. The extrapolated yields and errors are listed in Table I in parentheses. Adding the $K^+\pi^0$ and $K_S^0\pi^+$ final states increases the yield to 225.2 ± 17.9 events. The asymmetry remains unchanged, just the statistical error is reduced to 7.6%. While New Physics at the 20% level should be visible in BABAR by next summer, a super B -factory is needed to uncover New Physics at the few % level.

Both inclusive and exclusive $b \rightarrow d\gamma$ decays, which are suppressed by $|V_{td}/V_{ts}|^2$ with respect to corresponding $b \rightarrow s\gamma$ modes, have not been seen yet. A branching-fraction measurement of $B \rightarrow X_d\gamma$ provides a determination of $|V_{td}/V_{ts}|$ with small theoretical uncertainties. However, backgrounds are expected to be huge, since this mode is CKM-suppressed and $u\bar{u}, d\bar{d}$ continuum processes are enhanced compared to $s\bar{s}$ continuum processes. An NLO calculation, which includes long-distance effects of u quarks in the penguin loop, predicts a range of $6.0 \times 10^{-6} \leq \mathcal{B}(B \rightarrow X_d\gamma) \leq 2.6 \times 10^{-5}$ [20] for the inclusive branching fraction. The uncertainty is dominated by imprecisely known CKM parameters. Due to the enormous backgrounds a full or at least partial reconstruction of the other B-meson is probably needed. Using the above range of branching-fraction predictions and assuming a reconstruction efficiency of 0.1% we estimate luminosities in the range of $\mathcal{L} = 20 - 4.7 \text{ ab}^{-1}$ to achieve a 6.5 % statistical accuracy on $|V_{td}/V_{ts}|$, thus requiring 2-0.5 years of running at a super B factory. A determination of $|V_{td}/V_{ts}|$ in the exclusive modes $B \rightarrow \rho(\omega)\gamma$ bears enhanced model uncertainties, since form factors are not precisely known. The branching fraction for $B \rightarrow \rho(\omega)\gamma$ is reduced by a factor ~ 20 with respect to $B \rightarrow K^*\gamma$. In addition, long-distance effects may increase branching fractions by a factor of two [21]. For $\mathcal{B}(B \rightarrow \rho\gamma)/\mathcal{B}(B \rightarrow K^*\gamma) = 0.05$ and an efficiency of 7% we would need $\mathcal{L} = 0.72$ (18) ab^{-1} to obtain a 10 (2)% statistical accuracy in the branching fraction. The CP asymmetry predicted in SM for $B \rightarrow \rho\gamma$ is of the order of 10% [22].

3. Inclusive and exclusive $b \rightarrow s\ell^+\ell^-$ Modes

The radiative decays $b \rightarrow s\ell^+\ell^-$ are suppressed with respect to $b \rightarrow s\gamma$ by about two orders of magnitude. The suppression by α is compensated partially by additional contributions from the Z^0 -penguin diagram and a box diagram that involves the semileptonic operators, O_{9V} and O_{10A} . Each of them can receive additional SUSY contributions. Characteristic Feynman diagrams are depicted in Figure 3. New Physics processes may enhance or deplete decay rates with respect to predictions in SM. Models are characterized in terms of ratios of Wilson coefficients $R_i = 1 + C_i^{NP}/C_i^{SM}$ for $i = 7, 9, 10$. As an example Figure 4 depicts the dilepton-mass-squared spectrum for $B \rightarrow K^*\mu^+\mu^-$ calculated in SM, SUGRA models and minimal-insertion-approach SUSY models (MIA) [23]. The SM prediction is the lowest. However, due to form-factor related uncertainties it may be difficult to uncover New Physics effects unless they are huge. It is interesting to point out that due to interference effects between the penguin process and the long distance processes $B \rightarrow \psi(nS)K^*$ an enhanced (depleted) rate is observed below (above) each $\psi(nS)$ resonance. This in fact may be a useful tool to extract the penguin contribution from an observed dilepton-mass-squared spectrum.

For inclusive modes the SM predicts in NLO branching-fractions of $\mathcal{B}(B \rightarrow X_S e^+e^-) = (6.3_{-0.9}^{+1.0}) \times 10^{-6}$ and $\mathcal{B}(B \rightarrow X_S \mu^+\mu^-) = (5.7 \pm 0.8) \times 10^{-6}$ [24], [25], [26]. So far only CLEO [27] has searched

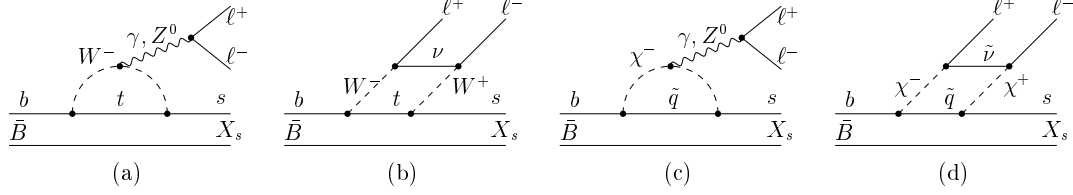


Figure 3: Feynman diagrams for $b \rightarrow s \ell^+ \ell^-$ decay in the SM (a,b), and for supersymmetry contributions (c,d).

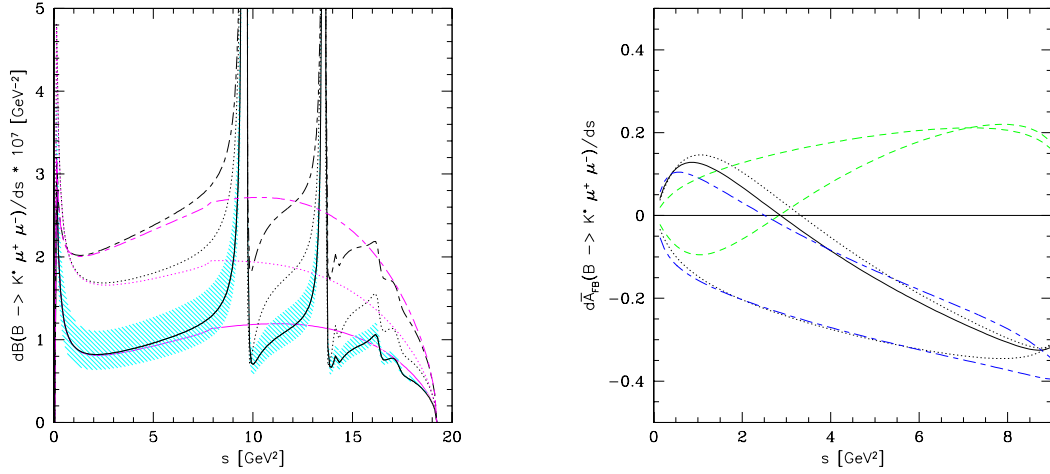


Figure 4: The dilepton invariant mass-squared spectrum (left) and the normalized forward-backward asymmetry (right) as a function of $s = m_{\mu\mu}^2$ in $B \rightarrow K^* \mu^+ \mu^-$ [23]. The solid lines denote the SM prediction. The shaded region depicts form-factor related uncertainties. The dotted lines correspond to a SUGRA model ($R_7 = -1.2, R_9 = 1.03, R_{10} = 1$) and the dash-dotted lines to a MIA model ($R_7 = -0.83, R_9 = 0.92, R_{10} = 1.61$). In the $m_{\mu\mu}^2$ spectrum both the pure penguin contribution and the distribution including long-distance effects are shown. In the \mathcal{A}_{fb} plot the upper and lower sets of curves show the difference between $C_7^{(0)eff} < 0$ and $C_7^{(0)eff} > 0$, while the dashed curves give results for another MIA model ($R_7 = \mp 0.83, R_9 = 0.79, R_{10} = -0.38$).

for $B \rightarrow X_s \ell^+ \ell^-$ setting branching-fraction upper limits that are almost an order of magnitude above the SM predictions. For our extrapolations shown in Table II, we use the range of the SM predictions and efficiencies measured by CLEO of $\varepsilon(X_s e^+ e^-) = 5.2\%$ and $\varepsilon(X_s \mu^+ \mu^-) = 4.5\%$. We have assumed a 1.1 nb $b\bar{b}$ cross section and an equal amount of B^0 and B^+ production. High luminosities are required to accumulate a reasonably large sample, thus emphasizing the need for a super B -factory. At hadron machines also large $X_s \ell^+ \ell^-$ samples are produced. The main issue, however, is whether backgrounds can be reduced sufficiently to make competitive measurements.

Branching fractions of the exclusive modes are further suppressed. Using predictions from a quark model [28] and light cone sum rules [23] we obtain the following ranges of SM predictions: $\mathcal{B}(B \rightarrow K \ell^+ \ell^-) = (4.7 - 7.5) \times 10^{-7}$, $\mathcal{B}(B \rightarrow K^* e^+ e^-) = (1.4 - 3.0) \times 10^{-6}$, and $\mathcal{B}(B \rightarrow K^* \mu^+ \mu^-) = (0.9 - 2.4) \times 10^{-6}$. BABAR [12], BELLE [13] and CLEO [29] have performed studies of the exclusive modes. Except for an unconfirmed signal seen by BELLE in the $K \mu^+ \mu^-$ final state with $\mathcal{B}(B \rightarrow K \mu^+ \mu^-) = (0.99^{+0.40}_{-0.32} (stat) {}^{+0.13}_{-0.14} (sys)) \times 10^{-6}$ [30], which is barely consistent with the BABAR limits, no other signals have been observed yet. Using $\mathcal{L} = 20.7 \text{ fb}^{-1}$ BABAR has obtained the lowest 90% CL branching-fraction upper limits: $\mathcal{B}(B \rightarrow K \ell^+ \ell^-) < 0.6 \times 10^{-6}$, $\mathcal{B}(B \rightarrow K^* e^+ e^-) < 5.0 \times 10^{-6}$, and $\mathcal{B}(B \rightarrow K^* \mu^+ \mu^-) < 3.6 \times 10^{-6}$. While the $B \rightarrow K \ell^+ \ell^-$ branching fraction upper limit lies amidst the SM predictions, the $B \rightarrow K^* e^+ e^-$ ($K^* \mu^+ \mu^-$) branching fraction upper limits are less

Table II Event yields and relative statistical and relative systematic errors of branching fractions in $b \rightarrow se^+e^-$ ($b \rightarrow s\mu^+\mu^-$) modes expected for different luminosities. Statistical errors include a factor of $\sqrt{2}$ to account for background subtraction. Systematic errors are guesses based on CLEO and BABAR.

\mathcal{L} [fb $^{-1}$ /y]	20	100	500	1000	10000
$X_s\ell^+\ell^-$ Yield	12-17 (10-13)	62-84 (49-64)	310-420 (240-320)	620-835 (490-640)	6180-8350 (4850-6440)
$\sigma_{stat}/\mathcal{B}$ [%]	40-35 (45-39)	18.0-15.5 (20-17.6)	8.0-6.9 (9.1-7.9)	5.7-4.9 (6.4-5.6)	1.8-1.5 (2.0-1.8)
σ_{sys}/\mathcal{B} [%]	15 (25)	10 (17)	7 (12)	6 (10)	4 (7)?
$K^+\ell^+\ell^-$ Yield	1.8-2.9 (1.1-1.7)	9-14 (5-9)	45-72 (27-43)	90-144 (54-87)	905-1440 (540-870)
$\sigma_{stat}/\mathcal{B}$ [%]	105-83 (136-107)	47-37 (61-48)	21-17 (27-21)	14.9-11.8 (19.2-15.2)	4.7-3.7 (6.1-4.8)
σ_{sys}/\mathcal{B} [%]	14 (15)	10 (12)	8 (10)	6 (7)	3-4 (4-5)
$K^{*0}\ell^+\ell^-$ Yield	3.1-6.7 (1.6-4.2)	16-34 (8-21)	80-170 (40-106)	160-340 (80-210)	1570-3370 (790-2110)
$\sigma_{stat}/\mathcal{B}$ [%]	80-55 (112-69)	36-24 (50-31)	16.0-10.9 (22.5-13.8)	11.3-7.7 (15.9-9.7)	3.6-2.4 (5.0-3.1)
σ_{sys}/\mathcal{B} [%]	14 (15)	10 (12)	7 (9)	5 (7)	3 (4)

than a factor of two above the SM predictions. For our extrapolations presented in Table II we use efficiencies measured in BABAR: $\varepsilon(K^+ee) = 17.5\%$, $\varepsilon(K^+\mu\mu) = 10.5\%$, $\varepsilon(K^{*0}ee) = 10.2\%$ and $\varepsilon(K^{*0}\mu\mu) = 8.0\%$. At the Tevatron CDF and D0 expect to observe the $K^{*0}\mu^+\mu^-$ final state in a sample of 2 fb $^{-1}$ [15]. Yield estimates are of the order of 59 events for CDF and $\sim 310 - 130$ events for D0 depending on the lepton momentum requirement, where D0 makes more optimistic assumptions than CDF. BTeV expects $K^{*0}\mu^+\mu^-$ signal yields of 2240 events for 2 fb $^{-1}$ [15]. At LEP ATLAS, CMS and LHCb expect to observe 665, 4200 and 4500 events per 10^7 s (~ 2 fb $^{-1}$), respectively [16].

The lepton forward-backward asymmetry $\mathcal{A}_{fb}(s)$ as a function of $s = m_{\ell\ell}^2$ is an observable that is very sensitive to SUSY contributions. It reveals characteristic shapes in the SM both for inclusive and exclusive final states. With sufficient statistics this asymmetry is a powerful tool to discriminate between SM and New Physics. To avoid complications from the ψ resonances one restricts the range to masses below the J/ψ , which accounts for $\sim 40\%$ of the entire spectrum. Figure 4 shows $\mathcal{A}_{fb}(q^2)$ for the $B \rightarrow K^{*0}\mu^+\mu^-$ mode [23]. In SM the position s_0 of $\mathcal{A}_{fb}(s_0) = 0$ is predicted to lie at $s_0 = 2.88^{+0.44}_{-0.28}$ GeV 2 . Both, the shape and s_0 are expected to differ significantly in New Physics models. The shape is very sensitive to the sign of R_7 and varies from model to model. Thus, a precise measurement of $\mathcal{A}_{fb}(q^2)$ may permit an extraction of the coefficients R_i . The extrapolated yields in Table II indicate that a yearly luminosity of 10 ab $^{-1}$ is needed to determine $\mathcal{A}_{fb}(s)$ with reasonable precision. For Measuring 18 data points below $s = 9$ GeV 2 with 100 events each in the $B \rightarrow X_s\ell^+\ell^-$ ($B \rightarrow K^{*0}\ell^+\ell^-$) modes at a super B factory (10 ab $^{-1}$ /y) requires a run period of 0.3-0.4 (0.8-1.3) years.

4. Inclusive and Exclusive $b \rightarrow s\nu\bar{\nu}$ Modes

The processes $b \rightarrow s\nu\bar{\nu}$ result from the Z^0 penguin or box diagrams by replacing ℓ^+ , ℓ^- , ν in Figure 3 with ν , $\bar{\nu}$, ℓ^+ , respectively. The branching fraction predictions are expected to bear the smallest model dependence among all radiative penguin decays, since long distance effects are absent and QCD corrections are small. The largest error results from the uncertainty of the t -quark mass. Thus, these modes have the highest sensitivity to search for New Physics contributions. The inclusive branching fraction in SM is predicted to be $\mathcal{B}(B \rightarrow X_s\nu\bar{\nu}) = (4.1^{+0.8}_{-1.0}) \times 10^{-5}$ [31], [32]. The branching fractions for exclusive modes lie in the range $\mathcal{B}(B \rightarrow K\nu\bar{\nu}) = (2.4 - 9.2) \times 10^{-6}$ and $\mathcal{B}(B \rightarrow K^*\nu\bar{\nu}) = (0.8 - 2.6) \times 10^{-5}$ [33], [28]. So far, none of these modes has been observed. ALEPH has set a limit of $\mathcal{B}(B \rightarrow X_s\nu\bar{\nu}) < 7.7 \times 10^{-4}$ @90%CL, which is more than an order of magnitude above the SM prediction. Due to the two unobserved neutrinos one strategy of controlling backgrounds consists of a full reconstruction of the other B meson. Presently, the efficiency of fully-reconstructed B 's is $\sim 0.075\%$. Assuming that this can be increased by a factor of two by partial reconstruction, and assuming detection efficiencies of 80%/43%/33% for $K^+/K^\pm/\pi^\pm/X_s$ reconstruction, we obtain the extrapolated yields shown in Table III. Since these modes are not accessible in hadron machines, a super B -factory is needed to observe them and

measure their properties. In a sample of 10 ab^{-1} the statistical error for the $X_s \nu \bar{\nu}$ final state in the optimistic case is still 6%.

Table III Expected event yields for $B \rightarrow X_s \nu \bar{\nu}$ and $B \rightarrow K^{(*)} \nu \bar{\nu}$ modes for different luminosities.

$\mathcal{L} [\text{fb}^{-1}/\text{y}]$	efficiency $[10^{-4}]$	20	100	500	1000	10000
$K^+ \nu \bar{\nu}$ Yield	12.0	0.06-0.24	0.3-1.2	1.6-6.1	3.2-12	32-120
$K^{*0} \nu \bar{\nu}$ Yield	6.5	0.1-0.4	0.6-1.9	2.9-9.3	5.7-19	57-186
$X_s \nu \bar{\nu}$ Yield	5.0	0.7-1.1	3.4-5.4	17-27	34-54	340-540

5. Conclusion

Present asymmetric B -factories will accumulate sufficient luminosities to achieve precise branching-fraction and CP -asymmetry measurements in inclusive and exclusive $b \rightarrow s \gamma$ decays allowing searches for physics beyond the SM. These measurements are complementary to direct searches and may yield positive results before the start of the LHC. The data samples in present asymmetric B factories will be sufficiently large to allow for a discovery of inclusive and exclusive $b \rightarrow s \ell^+ \ell^-$ modes. Precision measurements of branching fractions and the lepton forward-backward asymmetries in $B \rightarrow X_s \mu^+ \mu^-$, $B \rightarrow K^+ \mu^+ \mu^-$ and $B \rightarrow K^{*0} \mu^+ \mu^-$ can be achieved in hadron colliders. A super B factory with an annual luminosity of $10^{36} \text{ cm}^{-2} \text{ s}^{-1}$, however, is competitive in $\mu^+ \mu^-$ final states and, in addition, can measure these quantities in $e^+ e^-$ final states. Such a machine would also allow for precise measurements of $B \rightarrow \rho(\omega) \gamma$, and yield an observation of $B \rightarrow X_d \gamma$. Furthermore, one would have a unique opportunity to detect the $B \rightarrow X_s \nu \bar{\nu}$ and $B \rightarrow K^+(K^{*0}) \nu \bar{\nu}$ modes and measure their properties, since due to $q\bar{q}$ continuum and $B\bar{B}$ backgrounds these rare B decays are not accessible in hadron machines.

Acknowledgments

This work has been supported by NFR.

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