Experimental Prospects for $B \to X_{s/d}\gamma$ and $B \to X_s\ell^+\ell^-$

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In this report, experimental prospects for the inclusive analysis of the radiative B decays and electroweak penguin decays at the super B factories are presented.

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1 Introduction

Radiative B decay $B \to X_s\gamma$, $X_d\gamma$ and electroweak penguin decay $B \to X_s\ell^+\ell^-$, where X_s (X_d) is the hadronic recoil system including an s (d) quarks, are the flavor changing neutral processes, sensitive to New Physics (NP). After the first measurement of the inclusive branching fraction of $B \to X_s\gamma$ by CLEO [1], several measurements of inclusive $B \to X_{s/d}\gamma$ and $B \to X_s\ell^+\ell^-$ have been performed by BaBar and Belle.

In general, the inclusive measurements are experimentally challenging, but theoretically clean. Therefore, improving existent measurements and exploring new measurements of the inclusive $B \to X_{s/d}\gamma$, $X_s\ell^+\ell^-$ processes with much larger luminosity at the super B factories will provide important test of NP. In this proceedings, experimental prospects of the measurements of branching fractions and other observables, such as CP asymmetry, of the inclusive $B \to X_{s/d}\gamma$, $X_s\ell^+\ell^-$ are reported.

2 Branching fraction of $B \to X_s\gamma$

The experimental analysis of the inclusive $B \to X_s\gamma$ decay has been performed with three methods: (1) fully inclusive, (2) sum of exclusive modes and (3) recoil tag.

In the fully inclusive method, we substract the on-resonance photon energy spectrum by the continuum spectrum. This method is free from the model uncertainty of the hadronic recoil system X_s. However, it sufferes large backgrouds from the continuum process and B decays. Therefore, a lepton from the other side B is sometimes tagged for the continuum background suppression. This lepton tag is also useful for flavor tagging.

In the method using sum of exclusive modes, which are often refered to as semi-inclusive or pseudo-reconstruction method, hadronic system X_s is reconstructed as a sum of exclusive final states. This method provides higher purity than the fully inclusive method, and clear separation between X_s and X_d. On the other hand, it suffers from large model uncertainty of the hadronic system partially because of the modes that are not reconstructed.

In the recoil tag method, one B meson is either fully reconstructed with hadronic final states or is tagged with semi-leptonic B decay, and a high energy photon coming from $B \to X_s\gamma$ is looked for among remaining particles in the event. In this method, signal is very clean and continuum background is negligible. The drawback is very low efficiency ($\sim O(0.1\%)$) that requires huge amount of statistics. When the tag side B meson is fully reconstructed, the photon energy in the B rest frame and flavor information can be obtained.

At present, the most precise measurement of $\mathcal{B}(B \to X_s\gamma)$ is obtained with fully inclusive method. Belle obtained $\mathcal{B}(B \to X_s\gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$ with

$E_\gamma > 1.7$ GeV [2]. The error is already systematic dominated.

Therefore, in the super B factories with more than 10 ab^{-1}, the recoil tag method is most promising. If we scale BaBar's result $\mathcal{B}(B \to X_s\gamma; E_\gamma > 1.9 \text{ GeV}) = (3.66 \pm 0.85 \pm 0.60) \times 10^{-4}$ with 210 fb^{-1} [3], the statistical error at 10 ab^{-1} will be 3%.

The challenge will be to reduce the systematic errors. Fig. 1 shows the breakdown of the background in the fully inclusive decay. In the recoil tag method, background from the continuum process will be negligible, but other contribution is not expected to be significantly smaller. Among the background from B decays, decays of π^0 and η are the major contrinbutions, but they can be calibrated from control samples. However, there are some components difficult to calibrate such as decay of ω, η', J/ψ or hadronic interaction of neutral particle in the calorimeter. According to the inclusive analysis by Belle, around 7% systematic error is assigned to B background except π^0, η decay. These number can be reduced in future, but the systematic error of 3-5% is expected. Nevertheless, this might be adequate given the current theoretical prediction $\mathcal{B}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ [4].

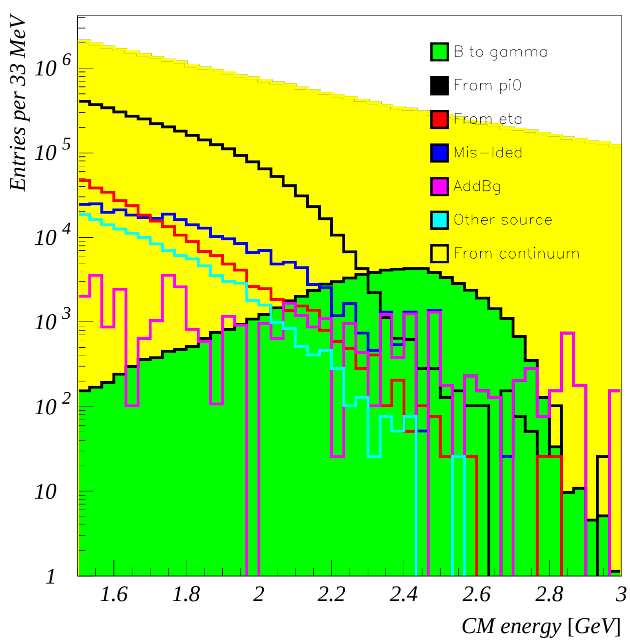

Figure 1: Breakdown of the background component of $B \to X_s\gamma$ analysis with the fully inclusive method. $B \to \gamma$ component is the $B \to X_s\gamma$ signal. The background from continuum will be less significant in the recoil tag method.

3 CP Asymmetry of $B \to X_{s/d}\gamma$

The CP asymmetry of $B \to X_{s/d}\gamma$ is predicted very accurately by theory, and hence will be a sensitive probe to NP in the super B factories.

A prediction [5] shows $A_{CP}(B \to X_s\gamma) = 0.0044\,^{+0.0024}_{-0.0014}$ and $A_{CP}(B \to X_d\gamma) = -0.102\,^{+0.033}_{-0.058}$, while the CP asymmetry for the sum of $B \to X_s\gamma$ and $B \to X_d\gamma$ ($B \to X_{s+d}\gamma$) is essentially zero. On the other hand, some NP models predict larger CP asymmetry for $B \to X_s\gamma$ and $B \to X_{s+d}\gamma$. Therefore, measurement of these asymmetries provide useful information to identify NP models.

The CP asymmetry in $B \to X_s\gamma$ has been performed with analysis using sum of exclusive modes. The advantage of this method is that the flavor information can be obtained from the reconstruction information. Also, the contribution of $B \to X_d\gamma$ is negligible. Belle obtained $A_{CP}(B \to X_s\gamma) = 0.002 \pm 0.050 \pm 0.030$ with 140 fb^{-1} [6] and BaBar obtained $A_{CP}(B \to X_s\gamma) = -0.011 \pm 0.030 \pm 0.014$ with a dataset with 383 M $B\overline{B}$ [7]. Here, most of the systematic errors are limited by the control sample statistics, and can be reduced in future. If we scale the Belle result, the expected statistical and systematic errors are ± 0.009(stat)± 0.006(syst) at 5 ab^{-1} and ± 0.003 (stat) $\pm\, 0.002$ (syst) $\pm\, 0.003$ (model) [8].

In the fully inclusive method, lepton tag is useful to tag the flavor of B meson, though wrong tag happens due to B mixing ($\sim 9\%$) and leptons from non-B ($\sim 3\%$). Since $B \to X_d\gamma$ is inevitably included in the signal, this method is useful to measure the asymmetry for $B \to X_{s+d}\gamma$. By simple extrapolation, 1% statistical error is possible at 10 ab^{-1}.

4 Branching fraction of $B \to X_d\gamma$

Branching fraction of $B \to X_d\gamma$ is useful to constrain $|V_{td}/V_{ts}|$. However, the measurement suffers huge background from $B \to X_s\gamma$ decays. In order to suppress contamination from $B \to X_s\gamma$, analysis with sum of exclusive modes is the most promising.

According to the MC study by Belle [8], one expects 5% statistical errors at 5 ab^{-1} if we sum up 2 to 4 pions including up to 1 π^0 to reconstruct X_d up to 2.0 GeV. However, the systematic error is around 20%, which mainly comes from the normalization of $b \to s\gamma$ components.

BaBar performed the study of $B \to X_d\gamma$ with a dataset with 471 M $B\overline{B}$ [9]. They reconstructed 7 exclusive modes at $0.5 < M_{X_{d(s)}} < 2.0$ GeV for $B \to X_d\gamma$ and $B \to X_s\gamma$, and measured $\mathcal{B}(B \to X_d\gamma) = (9.2 \pm 2.0 \pm 2.3) \times 10^{-6}$ and $\mathcal{B}(B \to X_s\gamma) = (23.0 \pm 0.8 \pm 3.0)$ respectively, obtaining $|V_{td}/V_{ts}| = 0.199 \pm 0.022 \pm 0.024 \pm 0.002$(th.). Again, the key issue in future is the reduction of the systematic error. A large part of it comes from unreconstructed modes and poor knowledge about the final states.

Systematic error can be reduced by adding more reconstruction modes and more statistics, but will remain the dominant source of the error at the super B factories.

Another possibility for the study of $B \to X_d\gamma$ is to use the recoil tag method and apply strangeness tag to remove $B \to X_s\gamma$ component. However, the strangeness tag is not straightforward because of the neutral kaons, baryons and possible $s\bar{s}$ popping. However the method can be only used with 50 ab^{-1} or more [10].

5 $B \to X_s\ell^+\ell^-$

The inclusive analysis of $B \to X_s\ell^+\ell^-$ is more challenging than $B \to X_{s/d}\gamma$ because of two orders of magnitudes lower branching fraction. Similarly to exclusive analyses like $B \to K^*\ell^+\ell^-$, there exist many observables to be measured in addition to the branching fraction, such as CP asymmetry, forward-backward asymmetry. The inclusive modes are theoretically clean compared to exclusive modes. For example, the zero-crossing point of the q^2 distribution of the forward backward aymmetry q_0^2 is predicted to 3.50 ± 0.12 GeV^2 (3.38 ± 0.11 GeV^2) for $B \to X_s\mu^+\mu^-$ ($X_se^+e^-$) [11] and 4.2 ± 0.6 GeV^2 for $B \to K^*\ell^+\ell^-$ [12]. Experimentally, the analysis is very challenging, but is possible only in e^+e^- B factories.

So far, all the analyses at BaBar and Belle are with the sum of exclusive modes. Figure 2 shows the result of $B \to X_s\ell^+\ell^-$ by Belle with 605 fb^{-1}. Belle observed $238.3\pm26.4\pm2.3$ events, resulting the branching fraction of $(3.33\pm0.80\,^{+0.19}_{-0.24})\times10^{-6}$. The result is consistent with the SM prediction of $(4.2\pm0.7)\times10^{-6}$ [13]. The M_{X_s} and q^2 dependence for a few bins are obtained. Although the error is still dominated by the statistical error at present, it will be important to reduce the systematic error at the super B factories. According to the study for SuperB [14], the statistical error can be reduced to a few percent with 75 ab^{-1}. One of the main source of the systematic error is the uncertainty of the hadronic system and the unreconstructed modes, which may be reduced by comparing with $B \to X_s\gamma$ decays.

The next step is to measure the forward backward asymmetry for $B \to X_s\ell^+\ell^-$. Unfortunately, the sensitivity of the forward backward asymmetry is not estimated yet for inclusive $B \to X_s\ell^+\ell^-$. In the exclusive $B \to K^*\ell^+\ell^-$ mode, q_0^2 is expepected to be measurable with the precision of 5% at 50 ab^{-1}. However, the precision for the inclusive modes is expected to be significantly worse than for the exclusive modes. Considering the theoretical precision, forward backward asymmetry of the inclusive $B \to X_s\ell^+\ell^-$ is not competitive to exclusive modes at early stage of the super B factories.

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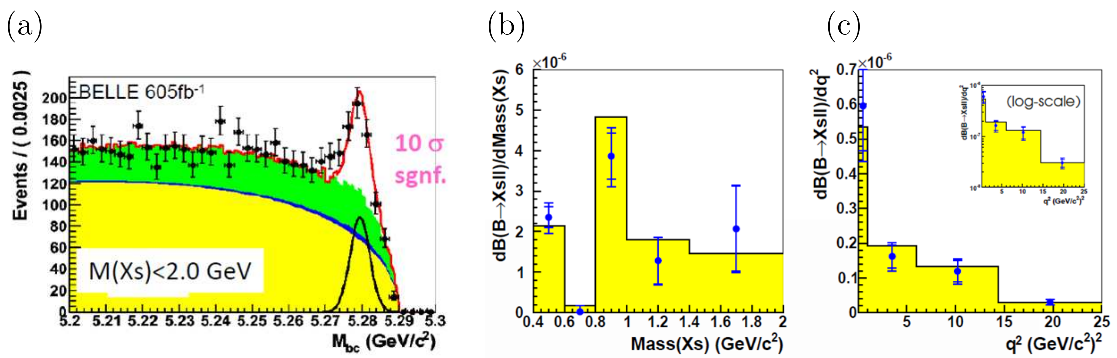

Figure 2: Inclusive $B \to X_s \ell^+ \ell^-$ analysis at Belle with 605 fb^{-1}. (a) $M_{\rm bc}$ distribution for $M_{X_s} < 2.0$ GeV (b) M_{X_s} dependence of the branching fraction (c) q^2 dependence of the branching fraction.

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