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Radiative Penguin decays at the BaBar experiment

$B \to K^{*}\gamma,\ B \to \rho\gamma,\ B \to \omega\gamma$ and $B \to X_s\gamma$

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Abstract. A review of the results obtained from the analysis of the B meson decays that involve Radiative Penguin processes, recorded at the BaBar experiment at the Stanford Linear Accelerator Center PEP-II B-Factory, is presented. The physics interest of these processes and their SM prediction are discussed briefly. The most relevant selection techniques used in the analysis are described before quoting the latest results made public by the BaBar collaboration as of July 2003.

1 Introduction

Radiative Penguin B-decays are Flavour Changing Neutral Current (FCNC) decay processes, which though forbiden by the Standard Model (SM) a tree level, they do occur via loop processes involving heavy particles (W, top), as represented in Fig. 1.

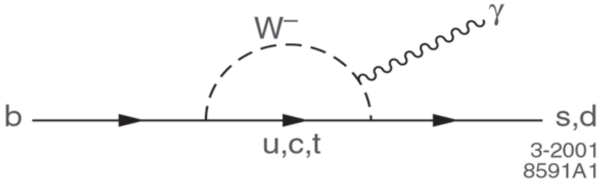

Fig. 1. Radiative Penguin process diagram

The analysis of these FCNC processes can be addressed, on the one hand, studying the decays into inclusive final states, which are theoretically clean to predict but have an experimental background pollution difficult to suppress. On the other hand, the studying exclusive final states involve large theoretical uncertainties (mainly from hadronic form factors) but have clear experimental signatures instead.

The SM prediction for the above different final state decays could be changed dramatically if there where new physics [1]. New particles (like several Higgs bosons and SUSY's) could enhance their otherwise small SM decay rates.

The Branching Fraction (BF) for the process $B \to X_s\gamma$ predicted by the SM assuming a cut below 1.6 GeV in the photon energy (in the B boson rest frame) is of about $(3.60 \pm 0.30) \times 10^{-4}$ [2]. For the exclusive processes the SM predicts that the ratio BF$(B \to \rho\gamma)$/BF$(B \to K^{*}\gamma)$ is proportional to the squared ratio of two the CKM mixing matrix elements, namely $\parallel \mathrm{V}_{td}/\mathrm{V}_{ts} \parallel^2$, which can be used to further constrain the Unitarity triangle. The typical predicted BF's are:

$B^{\pm} \to \rho^{\pm}\gamma = (0.85 \pm 0.34) \times 10^{-6}$ [3]
$B^{0} \to \rho^{0}(\omega)\gamma = (0.49 \pm 0.18) \times 10^{-6}$ [4]
$B \to K^{*}\gamma = (7.1 \pm 2.5) \times 10^{-5}$ [5]

The latter has a small CP asymmetry (of arround ≈1%) and therefore is very sensitive to non-SM contributions that might cause CP-violating charge asymmetries as high as 20%.

2 Event selection and reconstruction

The data selection requires events with an isolated high energy photon, with a centre-of-mass (Υ(4s) rest frame) energy between 1.5 and 3.5 GeV. Its shower lateral profile in the calorimeter must be consitent with being of electro-magnetic nature. In addition, photons are vetoed if when combined with any other photon in the event, the resulting invariant mass is consistent with that of π^0 or η (actually those not properly vetoed constitute a significant background).

The so-called "continuum" background, the $q\bar{q}\gamma$ (where $q = u, d, s, c$ and γ is from Initial State Radiation) underneath the $b\bar{b}$ production, is suppressed using several topological event observables (that exploit the jet-like decay structure of the background against the more isotropic from the signal), shape variables (thrust angle, flavour tag, etc...) and B meson properties.

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3 Exclusive final state decays

Since here the specific final state products are used to reconstruct the B meson, the kinematical signature of the B meson decays can be used. Thus, energy and momentum conservation is expressed in terms of the beam energy substituted invariant mass m_{ES} and ΔE defined as:

$$m_{ES} = \sqrt{E^{*2}_{beam} - P^{*2}_{B}} \quad ; \quad \Delta E = E^{*}_{B} - E^{*}_{beam}$$

Specially challenging is the experimental selection and reconstruction for $B^0 \to \rho^0(\omega)\gamma$, since not only they have the lowest BF, but the ρ resonance is much wider (149 MeV) that the K^*. The ΔE resolution is limited by the photon energy measurement and some B meson background from $B \to K^*\gamma$ and $B \to \rho\pi^0$ processes is very difficult to remove.

3.1 Results

Already published in [6], the measurement of the BF($B \to K^*\gamma$), based on a data sample of 20 pb^{-1}, is performed separatedly for the neutral and charged B meson to be able to compute the charge asymmetry:

$$BF(B^0 \to K^{*^0}\gamma) = (4.23 \pm 0.40(stat) \pm 0.22(sys)) \times 10^{-5}$$

$$BF(B^{\pm} \to K^{*\pm}\gamma) = (3.83 \pm 0.62(stat) \pm 0.22(sys)) \times 10^{-5}$$

which restrict the CP-violating charge asymmetry to be, at a 90% confidence level, between:

$$-0.170 < A_{CP} < 0.082$$

The results for the $B^0 \to \rho^0(\omega)\gamma$, based on a data sample of 78 fb^{-1}, are obtained after a multi-dimensional maximum likelihood fit is used to extract the signal yields. No evidence of signal is found, and therefore the following upper limit to the BF are set at a 90% confidence level (see [7] for more details):

$$BF\ (B^0 \to \rho^0\gamma) < 1.2 \times 10^{-6}$$

$$BF\ (B^{\pm} \to \rho^{\pm}\gamma) < 2.1 \times 10^{-6}$$

$$BF\ (B^0 \to \omega\gamma) < 1.0 \times 10^{-6}$$

If isospin asymmetry is assumed then
BF($B \to \rho\gamma$) = BF($B^{\pm} \to \rho^{\pm}\gamma$) = 2 × BF($B^0 \to \rho^0\gamma$)
therefore, the following upper limit can be obtained

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

From [3] we have that

$$BF(B \to \rho\gamma)/BF(B \to K^*\gamma) =$$

$$\|1 + \Delta R\|\zeta^2\|V_{td}/V_{ts}\|^2(1 - m^2_{\rho}/M^2_B)^3/(1 - m^2_{K^*}/M^2_B)^3$$

and assuming the values of $\zeta = 0.76 \pm 0.10$ and $\Delta R = 0.0 \pm 0.2$, an upper limit is obtained at 90% confidence level

$$\|V_{td}/V_{ts}\| < 0.34$$

4 Inclusive final state decays

The measurement of the inclusive final state BF is based on the Quark-Hadron duality given by Heavy Quark Effective Theory (HQET) that yields to the following identification

$$BF(b \to s\gamma) = BF(B \to X_s\gamma)$$

Experimentally after the signal photon is pre-selected the remaining background is still a factor 10^3 larger. That challenge is tackled by two different approaches: Fully Inclusive and Semi-Inclusive analysis.

4.1 Fully inclusive

Mainly lepton tags are used to reject background leading to a signal selection efficiency of around 1%. Signal events are integrated between 2.1 and 2.7 GeV range in the photon energy (in the B boson rest frame). An advantage of this analysis is that all final states are included in the data sample and only through the photon energy cut a moderate model dependence is introduced; being the main source of systematic error the subtraction of BB background. Events from the $B \to X_d\gamma$ processes are subtracted using a theoretical prediction of (4.0 ± 1.6)%. A disadvantage is here is that the photon resolution is limited by the calorimeter experimental performance.

The resulting BF [8] is measured to be (based on a data sample of 54 pb^{-1})

$$BF(B \to X_s\gamma) =$$

$$= (3.88 \pm 0.36(stat) \pm 0.37(syst)^{+0.43}_{-0.23}(model)) \times 10^{-4}$$

4.2 Semi-inclusive

The Inclusive BF is here computed as the sum of different exclusive final states. Those can have in their final state a kaon plus up to three pions, of which only one can be a neutral pion. That leads to a total of 12 exclusive final states. The signal yields are extracted in bins of hadronic invariant mass m_{X_s} related to the photon energy by $E\gamma = (m^2_B\text{-}m^2_{X_s})/2m_B$. The unmeasured exclusive decays channels are parametrized using Monte Carlo simulations. That is indeed an important source of systematic errors specially for high hadronic invariant mass events (or equivalently low energy photon events).

From the measured photon spectrum, based on a data sample of 20 pb^{-1}, the first moment is calculated to be:

$$< E_{\gamma} >= 2.35 \pm 0.04(stat) \pm 0.04(sys)$$

That quantity can be used to compute the Λ and m_b parameters of HQET (see [9] for details) resulting in:

$$\Lambda = 0.37 \pm 0.09(stat) \pm 0.07(sys) \pm 0.10(th)GeV$$

$$m_b = 4.79 \pm 0.08(stat) \pm 0.10(sys) \pm 0.10(th)GeV$$

Assuming the measured value for m_b=4.79, the inclusive BF is extracted from a fit to the spectrum using the parameterization suggested in [10], and is measured to be:

$$BF(B \to X_s\gamma) =$$

$$= (4.3 \pm 0.5(stat) \pm 0.8(sys) \pm 1.3(model)) \times 10^{-4}$$

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