

# Radiative Penguin decays at the BaBar experiment

$B \rightarrow K^*\gamma$ ,  $B \rightarrow \rho\gamma$ ,  $B \rightarrow \omega\gamma$  and  $B \rightarrow X_s\gamma$

Eugeni Graugés (*BaBar* collaboration)<sup>a</sup>

University of Barcelona (UB) and Stanford Linear Accelerator Center (SLAC)

Received: 7 November 2003 / Accepted: 17 November 2003 /  
Published Online: 2 December 2003 – © Springer-Verlag / Società Italiana di Fisica 2003

**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 forbidden by the Standard Model (SM) a tree level, they do occur via loop processes involving heavy particles ( $W$ , top), as represented in Fig. 1.

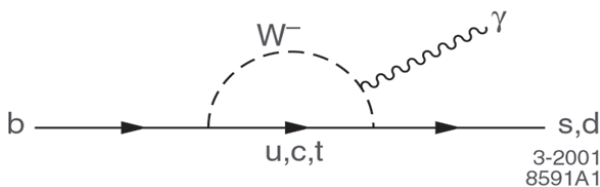


Fig. 1. Radiative Penguin process diagram

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 were 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  $B \rightarrow X_s\gamma$  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  $\text{BF}(B \rightarrow \rho\gamma)/\text{BF}(B \rightarrow K^*\gamma)$  is proportional to the squared ratio of two the CKM mixing matrix elements, namely  $\|V_{td}/V_{ts}\|^2$ , which can be used to further constrain the Unitarity triangle. The typical predicted BF's are:

$$B^\pm \rightarrow \rho^\pm\gamma = (0.85 \pm 0.34) \times 10^{-6} \text{ [3]}$$

$$B^0 \rightarrow \rho^0(\omega)\gamma = (0.49 \pm 0.18) \times 10^{-6} \text{ [4]}$$

$$B \rightarrow K^*\gamma = (7.1 \pm 2.5) \times 10^{-5} \text{ [5]}$$

The latter has a small CP asymmetry (of around  $\approx 1\%$ ) 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 ( $\Upsilon(4s)$  rest frame) energy between 1.5 and 3.5 GeV. Its shower lateral profile in the calorimeter must be consistent 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  $\pi^0$  or  $\eta$  (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  $\gamma$  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.

<sup>a</sup> Address: Departament E.C.M. (Física) U. de Barcelona, Diagonal 647, E-08028 Barcelona (Catalonia) Spain

### 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  $\Delta E$  defined as:

$$m_{ES} = \sqrt{E_{beam}^{*2} - P_B^{*2}} \quad ; \quad \Delta E = E_B^* - E_{beam}^*$$

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

#### 3.1 Results

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

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

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

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  $B^0 \rightarrow \rho^0(\omega)\gamma$ , based on a data sample of  $78 \text{ fb}^{-1}$ , 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):

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

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

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

If isospin asymmetry is assumed then

$BF(B \rightarrow \rho\gamma) = BF(B^\pm \rightarrow \rho^\pm\gamma) = 2 \times BF(B^0 \rightarrow \rho^0\gamma)$   
therefore, the following upper limit can be obtained

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

From [3] we have that

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

$$\|1 + \Delta R\|\zeta^2\|V_{td}/V_{ts}\|^2(1 - m_\rho^2/M_B^2)^3/(1 - m_{K^*}^2/M_B^2)^3$$

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

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

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  $B \rightarrow X_d\gamma$  processes are subtracted using a theoretical prediction of  $(4.0 \pm 1.6)\%$ . 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  $54 \text{ pb}^{-1}$ )

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

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

#### 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  $E_\gamma = (m_B^2 - m_{X_s}^2)/2m_B$ . 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  $20 \text{ pb}^{-1}$ , the first moment is calculated to be:

$$\langle E_\gamma \rangle = 2.35 \pm 0.04(stat) \pm 0.04(sys)$$

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

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

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

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:

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

*Acknowledgements.* The author is grateful for the extraordinary contributions of the PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support BaBar. Special thanks to SLAC for its support and kind hospitality to the author both as a user and as an employee.

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