International Journal of Modern Physics A

FCNC Decays of B Mesons

PETER KRIŽAN
(for the Belle Collaboration)
University of Ljubljana and J. Stefan Institute, Jadranska 19
SI-1000 Ljubljana, Slovenia

Received (Day Month Year)
Revised (Day Month Year)

The paper reviews recent results from the Belle experiment on the flavor changing neutral current processes $b \to s\gamma$, $b \to d\gamma$ and $b \to s\ell^+\ell^-$. We report on a new measurement of the $b \to s\gamma$ inclusive rate and of the moments of the photon energy distribution. We also present the measurements of rate, isospin asymmetry and CP violation in the $B \to K^*\gamma$ decays, as well as the CP asymmetry measurement in the inclusive $B \to X_s\gamma$ transitions. We report on the evidence for exclusive $b \to d\gamma$ transitions, and finally present the first observation of the $B \to K^*\ell^+\ell^-$ decay and updated measurements of the $B \to K\ell^+\ell^-$ and $B \to X_s\ell^+\ell^-$ branching fractions.

Keywords: Keyword1; keyword2; keyword3.

1. Introduction

Flavor changing neutral current (FCNC) processes $b \to s$ or $b \to d$ are within the Standard Model (SM) forbidden at the tree level. They can only proceed via higher-order loop diagrams. This fact makes them an ideal place to search for new physics. The experimental studies reported in this paper were carried out with the Belle spectrometer at the KEK-B asymmetric e^+e^- collider.[1] The analyses discussed in this paper have mostly used the 140 fb^{-1} data set corresponding to 152 millions of $B\bar{B}$ pairs.

2. Inclusive $b \to s\gamma$ measurement

The inclusive rate of $b \to s\gamma$ decays is sensitive to deviations from the SM, but the present world averaged measured values are in good agreement with the SM predictions.[2] On the other hand, the shape of the photon energy E_γ distribution depends on the b quark mass and on its motion within the B meson. The energy distribution is helpful in extracting the CKM matrix elements V_{cb} and V_{ub} from inclusive semileptonic B decays.[3] To reduce the model dependence of the measurement of the $b \to s\gamma$ rate and E_γ distribution parameters, it is essential to extend the range of photon energies E_γ as low as possible. While the measurement by the

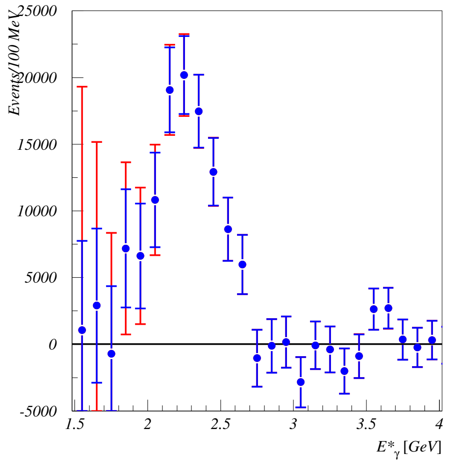

Fig. 1. Energy spectrum of photons from radiative B decays. The error bars indicate the statistical and total error.

CLEO Collaboration covered photon energies above 2.0 GeV,[4] the present analysis extended the range to $E_\gamma > 1.8$ GeV, thus covering $\approx 95\%$ of the total rate.[2]

The central problem of such an inclusive measurement are backgrounds, which in total exceed the signal rate by several orders of magnitude: photons from continuum $e^+e^- \rightarrow q\bar{q}$ events, photons from $\pi^0, \eta \rightarrow \gamma\gamma$ decays from the B decay cascade, misidentified photons, and photons from the beam background. Since the background level becomes higher at lower E_γ, while the signal rate gets lower, it is obvious that extending the range is a difficult task.

In the present analysis all photons with $E_\gamma > 1.5$ GeV were considered.[5] Candidates compatible with $\pi^0, \eta \rightarrow \gamma\gamma$ decays were rejected. Stringent continuum cuts were applied, based on the event shape and energy flow variables. The remaining continuum component was subtracted by using a sample of 15 fb^{-1} of data recorded at a center-of-mass energy 60 MeV below the $\Upsilon(4s)$ resonance. For each of the further background categories, the prediction from MC simulation was scaled according to the measured data wherever possible, e.g. the inclusive $B \rightarrow \pi^0 X$ and $B \rightarrow \eta X$ spectra were measured in data by using photon pairs with well-balanced energies; beam background was measured on random triggered events. For each criterion and each background type the E_γ-dependent selection efficiency was determined using appropriate control channels in the data and MC simulated samples. The MC background samples were then scaled according to the ratio of these efficiencies, and subtracted from the data. Note that the signal selection was optimized in such a way that the significance in the 1.8 GeV$< E_\gamma <$ 1.9 GeV interval was maximized.

The resulting efficiency corrected photon energy spectrum is shown in Fig. 1. The measured branching fraction amounts to $BR(b \rightarrow s\gamma) = (3.55 \pm 0.32^{+0.30+0.11}_{-0.31-0.07}) \cdot 10^{-4}$, where the listed errors are statistical, systematic and theoretical. The two moments

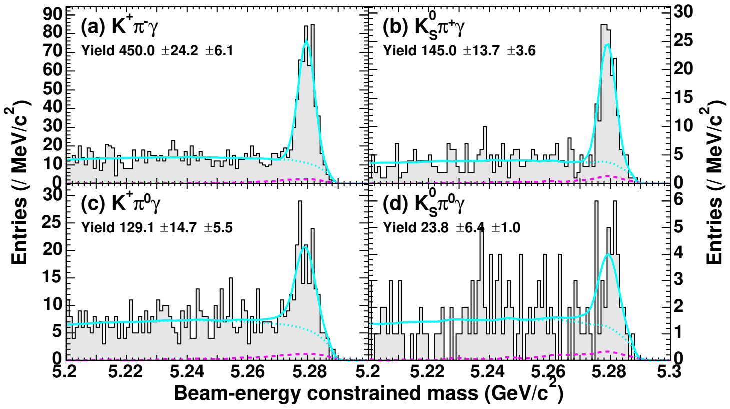

Fig. 2. Beam-energy constrained mass $M_{\rm bc}$ spectrum for $B \to K^*\gamma$ decays.

of the distribution are $< E_\gamma >= (2.292 \pm 0.026 \pm 0.034)$ GeV and $< E_\gamma^2 > - < E_\gamma >^2 = (0.0305 \pm 0.0074 \pm 0.0063)$ (GeV)^2. The systematic errors are dominated by the uncertainty in the ratio of efficiencies on recorded and MC simulated data, and by the energy resolution function (in the case of the first moment).

3. Isospin and CP asymmetry measurements in $B \to K^*\gamma$

By using a data set of 78 fb^{-1}, an updated measurement of $B \to K^*\gamma$ decays was performed.[6] The $K^*(892)$ mesons were reconstructed in 4 final states: $K^+\pi^-$, $K^0_S\pi^0$, $K^+\pi^0$, $K^0_S\pi^+$, all with $|M(K\pi) - M(K^*)| < 75$ MeV/c^2. A photon was added with 1.8 GeV$< E_\gamma < 3.4$ GeV, if it was incompatible with a $\pi^0/\eta \to \gamma\gamma$ decay. For the combined state the beam-energy constrained mass, $M_{\rm bc} = \sqrt{E^{*2}_{\rm beam}/c^4 - p^{*2}_B/c^2}$, and the energy difference, $\Delta E = E^*_B - E^*_{\rm beam}$, were used to identify the B meson decays. Here $E^*_{\rm beam}$ is the beam energy in the center-of-mass system (cms), and E^*_B and p^*_B are the cms energy and momentum of the reconstructed B candidate. The main background component $e^+e^- \to q\bar{q}(\gamma)$ was suppressed by using event shape variables and the B meson direction in the cms with respect to the e^- beam axis. The signal yield is determined from a fit to the $M_{\rm bc}$ distribution, as shown in Fig. 2.

The resulting branching fractions are $BR(B^0 \to K^{*0}\gamma) = (4.01 \pm 0.21 \pm 0.17) \cdot 10^{-5}$ and $BR(B^+ \to K^{*+}\gamma) = (4.25 \pm 0.31 \pm 0.24) \cdot 10^{-5}$. The systematic errors in the yield, efficiency, the number of B meson pairs and the model errors are added in quadrature to give the total systematic error. The measured branching fractions are in agreement with the rather uncertain SM predictions, $(6.9 \pm 2.1) \cdot 10^{-5}$ and $(7.4 \pm 2.3) \cdot 10^{-5}$ for the two channels.[7]

From the two branching fractions, the isospin asymmetry, $\Delta_{+0} = (BR(B^0 \to K^{*0}\gamma) - BR(B^+ \to K^{*+}\gamma))/(BR(B^0 \to K^{*0}\gamma) + BR(B^+ \to K^{*+}\gamma))$, is measured to be $\Delta_{+0} = +0.012 \pm 0.044(\text{stat}) \pm 0.026(\text{syst})$, again compatible with SM expectations between 0.05 and 0.10.[7]

From the partial rates into $K^*\gamma$ and $\bar{K}^*\gamma$ final states, the CP asymmetry can be determined $A_{CP} = (\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma))/(\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)) = -0.015 \pm 0.044(\mathrm{stat}) \pm 0.012(\mathrm{syst})$, in agreement with the SM expectation $A_{CP} \ll 0.01$.

4. Search for CP asymmetry in $B \to X_s\gamma$

The CP asymmetry in $b \to s\gamma$ transitions was also measured on a sample of pseudo-reconstructed $B \to X_s\gamma$ decays.[8] Here B is either a B^0 or a B^+, and X_s is a hadronic recoil system that contains an odd number of kaons. The hadronic system is reconstructed from a charged kaon or K_S combined with 1 to 4 pions, out of which up to one π^0 is allowed. We also include combinations with three kaons and up to one charged pion. The yield of $B \to X_s\gamma$ events is determined from the M_{bc} spectrum of combinations of X_s with a high energy photon.

From a data sample corresponding to 140 fb^{-1} the CP asymmetry $A_{CP} = (\Gamma(b \to s\gamma) - \Gamma(\bar{b} \to \bar{s}\gamma))/(\Gamma(b \to s\gamma) + \Gamma(\bar{b} \to \bar{s}\gamma))$ is extracted by properly taking into account the events tagged as B or $\bar{B}$ decays, as well as ambiguous cases. For events with $X_s < 2.1$ GeV/c^2 the asymmetry amounts to $A_{CP} = -0.002 \pm 0.050(\mathrm{stat}) \pm 0.030(\mathrm{syst})$, again consistent with the SM expectation of $A_{CP} = +0.005$.[9]

5. Search for $b \to d\gamma$ transitions

The $b \to d\gamma$ transitions are suppressed with respect to the $b \to s\gamma$ transitions by the square of the ratio of CKM matrix elements $(|V_{td}|/|V_{ts}|)^2$. The SM predictions for the branching fraction of the exclusive $B^+ \to \rho^+\gamma$ decay are around 10^{-6}. No decay of such type has been observed before. Measurements of these transitions would improve the constraints on $|V_{td}|/|V_{ts}|$, and might provide sensitivity to new physics complementary to the $b \to s\gamma$ transitions. In addition, a sizeable CP asymmetry is expected in these processes.[7,10] In our study a search was made for the exclusive channels $B \to \rho^+\gamma, \rho^0\gamma, \omega\gamma$ in a data sample of 140 fb^{-1}.

The main background comes from continuum events and is suppressed with event shape variables, by requiring a common vertex in case of two charged tracks in the final state, and by requiring a valid flavor tag from the associated B meson. The remaining backgrounds include the $B \to K^*\gamma$ decays with a misidentified kaon and the $B \to \rho/\omega\pi^0$ transitions.

The signal yield is extracted with a 2-dimensional unbinned maximum likelihood fit in two variables, M_{bc} and ΔE. The fit is carried out simultaneously to the three signal channels and two $K^*\gamma$ background channels assuming isospin relations $Br(B^+ \to \rho^+\gamma) = 2\frac{\tau(B^+)}{\tau(B^0)}Br(B^0 \to \rho^0\gamma) = 2\frac{\tau(B^+)}{\tau(B^0)}Br(B^0 \to \omega\gamma)$. From the fit the signal yield of 27.4 is extracted, corresponding to a 3.5σ significance (including the systematic error). This is the first evidence for a $b \to d\gamma$ process. The resulting (pre-

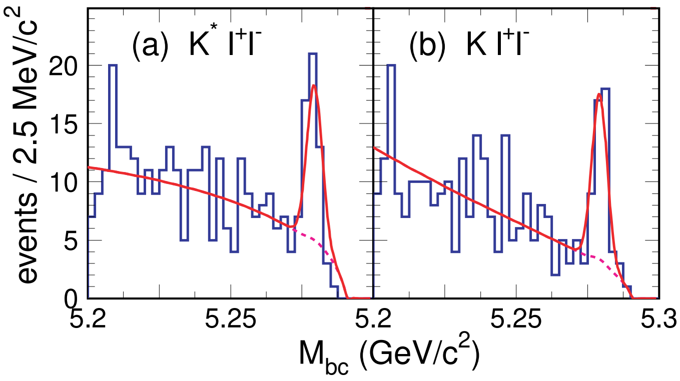

Fig. 3. Beam-energy constrained mass $M_{\rm bc}$ spectrum for $B \to K^*\ell^+\ell^-$ and $B \to K\ell^+\ell^-$ decays.

liminary) branching fraction $BF(B \to \rho^+\gamma) = (1.8^{+0.6}_{-0.5} \pm 0.1) \cdot 10^{-6}$ is in agreement with two SM predictions, $(0.90 \pm 0.34) \cdot 10^{-6}$ and $(1.58^{+0.53}_{-0.46}) \cdot 10^{-6}$.[7,10]

6. Observation of $B \to K^*\ell^+\ell^-$ and an update of $B \to X_s\ell^+\ell^-$

The $b \to s\ell^+\ell^-$ transitions proceed in the Standard Model via an additional box diagram of a virtual top quark and a weak boson, which makes them particularly interesting for searches of deviations from the SM. The $B \to K\ell^+\ell^-$ and the pseudo-reconstructed $B \to X_s\ell^+\ell^-$ decays were first measured by Belle two years ago. With 140 fb^{-1} of data, a search was carried out for the exclusive $K^*\ell^+\ell^-$ transition.[11] This decay channel is particularly important in further searches for the physics beyond SM through the backward-forward asymmetry A_{FB} of leptons in the final state.

In the present analysis, K^* mesons were reconstructed in three channels, $K^+\pi^-$, $K^0_S\pi^+$, $K^+\pi^0$, with $|M(K\pi) - M(K^*)| < 75$ MeV/c^2. For leptons (e^+e^- or $\mu^+\mu^-$) we required $p(e) > 0.4$ GeV/c, $p(\mu) > 0.7$ GeV/c; pairs compatible with two-lepton decays of J/ψ or $\psi(2S)$ were rejected. The continuum background is again rejected by using event shape variables, the B meson direction and the direction of the sphericity axis.

The yield was determined from the $M_{\rm bc}$ distribution of the candidate events (Fig. 3). The resulting measurement of the branching fraction $BR(B \to K^*\ell^+\ell^-) = (11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2) \cdot 10^{-7}$ represents the first observation of this decay channel. The measured branching fraction is in good agreement with theoretical expectation.[12] From the recorded data we have also updated the branching fraction of the $B \to K\ell^+\ell^-$ decay, $BR(B \to K\ell^+\ell^-) = (4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1) \cdot 10^{-7}$.

The inclusive $B \to X_s\ell^+\ell^-$ measurement is a model independent probe for new physics. A new measurement was carried out on a data sample of 140 fb^{-1} as an update of the first observation with about twice the statistics, following a very similar analysis.[13] In this measurement a pseudo-reconstruction of $B \to X_s\ell^+\ell^-$ is performed. The hadronic system X_s is reconstructed from a charged kaon or K_S combined with up to four pions, of which up to one π^0 is allowed. The signal yield is determined from an unbinned maximum likelihood fit to the $M_{\rm bc}$ distribution. The resulting (preliminary) branching fraction is $BR(B \to X_s \ell^+\ell^-) = (4.39 \pm 0.84^{+0.78}_{-0.73}) \cdot 10^{-6}$ for $M_{\ell\ell} > 0.2$ GeV$/c^2$. The systematic errors in the yield, efficiency, the number of B meson pairs and the model errors are added in quadrature to give the total systematic error. The result is in agreement with the SM prediction of $(4.2 \pm 0.7) \cdot 10^{-6}$.[12]

7. Summary

We report on a new measurement of the $b \to s\gamma$ inclusive rate and of the moments of the photon energy distribution with an extended energy range, $E_\gamma > 1.8$ GeV. We also present the results of rate, isospin asymmetry and CP violation in the $B \to K^*\gamma$ decays, as well as of the CP asymmetry measurement in the inclusive $B \to X_s\gamma$ transitions. We report on the evidence for exclusive $b \to d\gamma$ transitions in the decay channels $B \to \rho^+\gamma$, $B \to \rho^0\gamma$ and $B \to \omega\gamma$. Finally we present the first observation of the $B \to K^*\ell^+\ell^-$ decay and updated measurements of the $B \to K\ell^+\ell^-$ and $B \to X_s\ell^+\ell^-$branching fractions.

The measured branching fractions in $b \to s\gamma$, $b \to d\gamma$ and $b \to s\ell^+\ell^-$ transitions and asymmetries in $b \to s\gamma$ decays are in good agreement with the Standard Model, but some interesting results are statistically limited. We are entering an exciting phase of precision measurements (e.g. A_{FB} and q^2 dependence in $B \to K^*\ell^+\ell^-$). It is worth noting that by this summer the available data sample will be doubled with respect to the one which was available for the presented analyses.

Acknowledgments

References

1. A. Abashian *et al.* (Belle Collaboration), *Nucl. Instrum. Meth.* **A479** 117 (2002).
2. P. Gambino and M. Misiak, *Nucl. Phys.* **B611** 338 (2001); T. Hurth, E. Lunghi, W. Porod, arXiv: hep-ex/0312260, and references therein.
3. M. Neubert, *Phys. Rev.* **D49** 4623 (1994); M. Neubert, *Phys. Lett.* **B513** 88 (2001).
4. S. Chen *et al.* (CLEO Collaboration), *Phys. Rev. Lett.* **87** 251807 (1978).
5. P. Koppenburg *et al.* (BELLE Collaboration), to be published in *Phys. Rev. Lett.*; arXiv: hep-ex/0403004.
6. M. Nakao *et al. Phys. Rev.* **D69** 112001 (2004).
7. A. Ali and A. Ya. Parkhomenko, *Eur. Phys.* **C23** 89 (2002).
8. S. Nishida *et al.* (BELLE Collaboration), to be published in *Phys. Rev. Lett.*; arXiv: hep-ex/0308038.
9. J. M. Soares, *Nucl.Phys.* **B367** 575 (1991); A. Kagan, M. Neubert, *Phys. Rev.* **D58** 094012 (1998); K. Kiers, A. Soni, G.H. Wu *Phys. Rev.* **D62** 116004 (2000).
10. S. Bosch and G. Buchalla *Nucl. Phys.* **B621** 459 (2002).
11. A. Ishikawa *et al.* (BELLE Collaboration), *Phys. Rev. Lett.* **91** 261601 (2003).
12. A. Ali *et al.*, *Phys. Rev.* **D66** 034002 (2002).
13. J. Kaneko *et al.* (BELLE Collaboration), *Phys. Rev. Lett.* **90** 021801 (2003).