SEARCH FOR THE DECAY $B \rightarrow K^*\gamma$

ARGUS Collaboration

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Received 24 May 1988

For footnotes see next page.

Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY, a search for the decays $B \to K^* \gamma$ has been made. The following upper limits were derived at 90% CL: $BR(B \to K^*(892)\gamma) < 2.4 \times 10^{-4}$, $BR(B \to K_1(1400)\gamma) < 4.1 \times 10^{-4}$, $BR(B \to K_2^*(1430)\gamma) < 8.3 \times 10^{-4}$ and $BR(B \to K_3^*(1780)\gamma) < 3.0 \times 10^{-3}$.

Searches for radiative B decays of the penguin type $b \to s\gamma$ have recently attracted much interest [1–7]. The reasons for this include

- a strong cross section dependence on the top quark mass m_t,
- a need to directly observe loop effects in the framework of the standard model,
- the sensitivity to the possible existence of a fourth generation.

The lower limit on m_t of 50 GeV/c^2 which is inferred by the observation of a substantial rate of B^0–$\bar{B}^0$ mixing [8], leads to an expected branching ratio for the decay $b \to s\gamma$ of a few times 10^{-4}. Branching ratios of this size are accessible to current experiments.

The predicted branching ratios for inclusive final states receive a substantial enhancement from hard QCD processes, possibly as much as two orders of magnitude for small top quark masses [1]. Including these QCD corrections, the expected branching ratios for the decay $b \to s\gamma$ range from 4.8×10^{-5} [5] to 1.4×10^{-3} [1] for $m_t = 50$ GeV/c^2. Final states are assumed to be dominated by the K* resonances, but the relative importance of the possible exclusive channels is not well understood. For $B \to K^*(892)\gamma$ estimates range from 99.8% of the inclusive rate [2] to as low as 4.5% [4]. The influence of a fourth generation has been discussed [6,7] and increases the range of allowed branching ratios for $b \to s\gamma$ by a further order of magnitude.

The results reported here are based on a data sample of 103 pb^{-1} obtained on the $\Upsilon(4S)$ resonance using the ARGUS detector at the DORIS II storage ring. Searches for radiative B decays have been made in the decay channels [#1]

$$B^0 \longrightarrow K^{*0}\gamma, \quad K^{*0} \longrightarrow K^+\pi^- \;, \qquad B^+ \longrightarrow K^{*+}\gamma, \quad K^{*+} \longrightarrow K_S^0\pi^+ \;,$$

where K* refers to the $K^*(892)$, the $K_2^*(1430)$, or the $K_3^*(1780)$ resonance. In addition, the decay of B mesons into the $K_1(1400)$ resonance with $J^P = 1^+$ has been investigated in the following mode:

$$B \longrightarrow K_1(1400)\gamma, \quad K_1(1400) \longrightarrow K^*(892)\pi$$

for both charged and neutral B mesons.

The ARGUS detector is a 4π spectrometer and has been described in more detail elsewhere [9]. Charged particles are identified on the basis of measurements of both specific ionization and time of flight. For a given track all mass hypotheses are accepted for which the likelihood ratio [10] exceeds 3%. Each $\pi^+\pi^-$ pair forming a secondary vertex, where at least one of the pions is separated from the main vertex by more than 7σ and the invariant mass lies within ± 50 MeV/c^2 of the nominal K_S^0 mass [11], is accepted as a K_S^0 candidate.

All combinations of K^+ and π^- candidates which originate from the main vertex and have an invariant mass within ± 60 MeV/c^2 of the nominal $K^{*0}(892)$ mass are considered as $K^{*0}(892)$ candidates. Likewise, a mass interval of ± 60 MeV/c^2 is used to select $K^{*+}(892)$ candidates from $K_S^0\pi^+$ combinations. $K_2^*(1430)$ and $K_3^*(1780)$ candidates are selected using the mass intervals ± 120 MeV/c^2 and ± 180 MeV/c^2 respectively, accounting the larger width of these resonances. $K_1(1400)$ candidates are obtained by combining a $K^*(892)$ with a charged pion and us-

[1] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P.
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[8] Supported by the US National Science Foundation.
[9] Supported by Raziskovalna skupnost Slovenije and the Internationales Büro KfA, Jülich.
[10] Supported by the Swedish Research Council.
[11] Supported by the US Department of Energy, under contract DE-AS09-80ER10690.

[#1] References in this paper to a specific charged state are to be interpreted as also implying the charge conjugate state.

ing a mass interval of ± 220 MeV/c^2 around the nominal mass value. The mass intervals have been adjusted to accept about 90% for each of the different K* resonances.

Photons are reconstructed in a fine-grained electromagnetic calorimeter [12], made of lead-scintillator sandwich modules with wavelength shifter readout. The energy resolutions is approximately

$$\frac{\sigma_E}{E} = \sqrt{\frac{0.07^2}{E\ [\mathrm{GeV}]} + 0.07^2}\ .$$

In order to reduce backgrounds from showering neutral hadrons or from fast neutral pions where the two decay photons overlap in the calorimeter, a cut on the lateral shape of the energy deposition [12] is applied. Using a sample of radiative Bhabha events, the efficiency of this cut for photons is determined to be 95%.

Since B mesons produced in Υ(4S) decays must have the beam energy, we require the energy of K*γ combinations to satisfy $|E_B - E_{\mathrm{beam}}| < 2\sigma_E$, where E_B is the measured energy of the B candidate and σ_E the corresponding error. An energy constraint fit is then performed which transforms the momentum resolution into a mass resolution of a few MeV/c^2. Adding the contribution of the Υ(4S) resonance width and of the DORIS beam energy spread, we expect a signal to have a width of $\sigma = 4.5$ MeV/c^2.

The background from continuum events is very efficiently reduced by a topological cut, exploiting the fact that B mesons from Υ(4S) decays have small momenta and decay isotropically. Two thrust axes are calculated for each event, one for the B candidate and one for the remaining particles. For Υ(4S) decays there is no correlation between the two axes, while for continuum events there is a strong peaking of the opening angle, α_{thrust}, between the two axes (fig. 1). Therefore, we require that $|\cos\alpha_{\mathrm{thrust}}| \leq 0.8$.

After applying these cuts, 10% of the remaining events contain more than one candidate with a mass above 5.1 GeV/c^2. To avoid double counting, the candidate with the smallest χ^2 for the beam energy constraint fit is selected.

Fig. 2 shows the invariant mass distribution of the K*(892)γ combinations. There is no evidence for a signal from B decays. This conclusion is substantiated by examining the same mass distribution, but using a sideband of the K*(892) centered at 1.05 GeV/c^2. Clearly the observed entries in the mass distribution are fully explained as combinatorial background. The mass distribution has been fitted with a gaussian of mass 5.278 GeV/c^2 and width 4.5 MeV/c^2, plus a function to model the background

$$\frac{\mathrm{d}N}{\mathrm{d}M} \sim M\sqrt{1 - \frac{M^2}{E_{\mathrm{beam}}^2}}\,\exp\left[-a\left(1 - \frac{M}{E_{\mathrm{beam}}}\right)\right].$$

The fit yields a signal of $-2.5^{+2.7}_{-2.4}$ events. Using a gaussian plus a constant background leads to an even smaller number of signal events.

The mass distributions for the combinations K*^{0}(892)γ and K*$^+$(892)γ were also fitted separately. The results can be found in table 1. There were only 6 events visible in the positive charge state, which means that we can increase our sensitivity by combining charged and neutral states.

The search for decays involving the higher mass K*

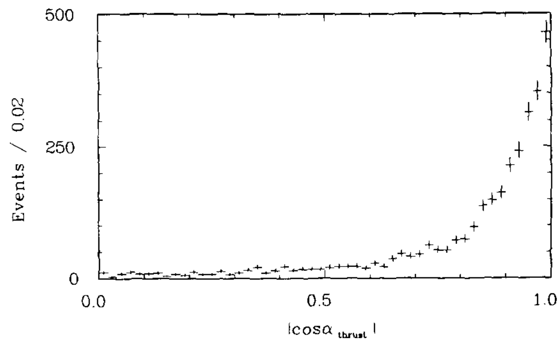

Fig. 1. Opening angle between the thrust axis of the B candidate and the thrust axis of the rest of the event.

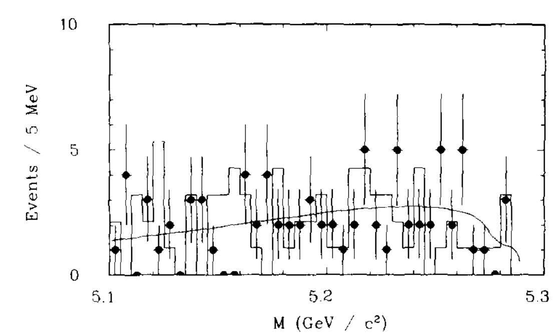

Fig. 2. K*(892)γ invariant mass distribution along with the sideband distribution (histogram). The curve shows the result of the maximum likelihood fit described in the text.

Table 1
Summary of the results on $B\to K^*\gamma$.

Decay mode	N_{events} (fit result)	N_{events} (90% CL)	BR (90% CL)
$B\to K^*(892)\gamma$	$-2.5^{+2.7}_{-2.4}$	<4.1	$<2.4\times10^{-4}$
$B^0\to K^{*0}(892)\gamma$	$-1.8^{+2.2}_{-1.7}$	<3.9	$<2.9\times10^{-4}$
$B^+\to K^{*+}(892)\gamma$	$+0.3^{+1.4}_{-0.8}$	<3.4	$<8.5\times10^{-4}$
$B\to K_1(1400)\gamma$	$-1.3^{+3.2}_{-2.6}$	<4.4	$<4.1\times10^{-4}$
$B\to K_2^*(1430)\gamma$	$+0.6^{+3.1}_{-2.4}$	<6.4	$<8.3\times10^{-4}$
$B\to K_3^*(1780)\gamma$	$+1.6^{+3.8}_{-3.2}$	<9.1	$<3.0\times10^{-3}$

resonances has been performed in the same way. In all cases the invariant mass distribution is well described by a background distribution obtained from a sideband of the K*. The fit to the invariant mass distribution for the decay $B\to K_1(1400)\gamma$ (fig. 3) yields $-1.3^{+3.2}_{-2.6}$ signal events. Fits to the corresponding mass distributions for the $K_2^*(1430)\gamma$ (fig. 4) and $K_3^*(1780)\gamma$ (fig. 5) searches find $0.6^{+3.1}_{-2.4}$ and $1.6^{+3.8}_{-3.2}$ signal events, respectively.

To determine the reconstruction efficiency, $\Upsilon(4S)$ decays have been simulated using the LUND 6.2 model [13], which has been adjusted to describe the general properties of B meson decays. The ratio of neutral and charged B mesons produced in $\Upsilon(4S)$ decays is assumed to be 0.45/0.55. The generated events have been passed through a detailed detector simulation program [14], where the description of the electromagnetic calorimeter has been carefully checked. The upper limits on the number of events have been obtained by integrating the likelihood distributions over positive values of the number of events obtained in the fits. Errors on the efficiency

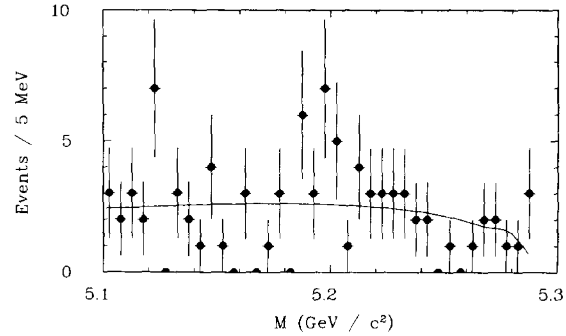

Fig. 4. $K_2^*(1430)\gamma$ invariant mass distribution. The curve shows the result of the maximum likelihood fit described in the text.

and the K* branching ratios were also folded in. From this, we obtain the following upper limits at 90% CL:

$$BR(B\to K^*(892)\gamma)<2.4\times10^{-4},$$

$$BR(B\to K_1(1400)\gamma)<4.1\times10^{-4},$$

$$BR(B\to K_2^*(1430)\gamma)<8.3\times10^{-4},$$

$$BR(B\to K_3^*(1780)\gamma)<3.0\times10^{-3}.$$

Our limit for the $B\to K^*(892)\gamma$ decay represents an improvement by an order of magnitude over the previous limit [15]. The results for the other reactions are the first to be reported.

In summary, no evidence for radiative B decays $b\to s\gamma$ has been found. If the fraction of $B\to K^*(892)\gamma$ decays is 7% [1] of the inclusive rate, we derive an upper limit of

$$BR(b\to s\gamma)<3.4\times10^{-3}.$$

This is just at the limit of sensitivity for constraining

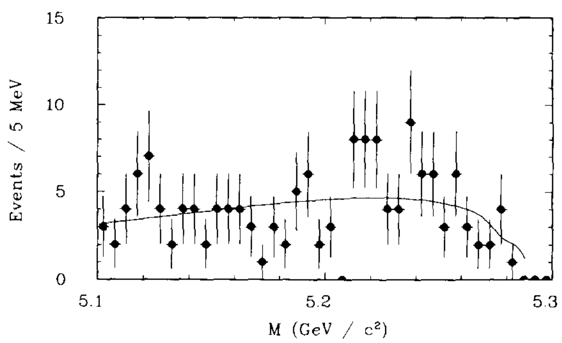

Fig. 3. $K_1(1400)\gamma$ invariant mass distribution. The curve shows the result of the maximum likelihood fit described in the text.

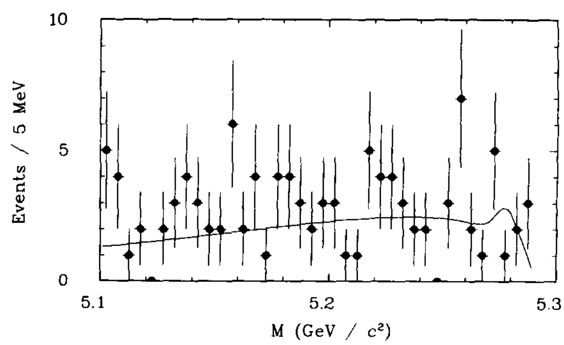

Fig. 5. $K_3^*(1780)\gamma$ invariant mass distribution. The curve shows the result of the maximum likelihood fit described in the text.

the top quark mass. The same conclusion holds for the influence of a possible fourth generation, where a slightly improved sensitivity would allow the exclusion of a wide range of values for coupling with a new generation.

It is a pleasure to thank U. Djuanda, E. Konrad, E. Michel, and W. Reinsch for their competent technical help in running the experiment and processing the data. We thank Dr. H. Nesemann, B. Sarau, and the DORIS group for the excellent operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

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