Search for b→s gluon in B meson decays

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Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY, a search for penguin decays of B mesons involving $b\to s$ gluon has been performed. No evidence for the penguin mechanism was found and a number of upper limits are quoted.

In recent years there has been considerable interest in penguin decays of B mesons and the general $b\to s$ gluon transition. Such transitions are probes of the electroweak interactions and provide a possible window on physics well beyond the directly accessible mass scale [1–12]. A good review may be found in ref. [13]. Penguin decays are also potentially important in gaining an understanding of the $|\Delta I|=\frac{1}{2}$ rule in K decays, as the possibility exists that a mechanism enhancing penguin decays of B mesons might also enhance those of K mesons. Such information is valuable in attempts to understand whether or not *CP* violation in the K^0–$\bar{K}^0$ system can be accommodated by the Kobayashi–Maskawa formalism [14,15]. Many of these decay modes are also of interest as channels to investigate *CP* violation in B meson decays [16–19].

The decay modes searched for were $B\to\pi$, ρ, or ϕ and one of K, $K^*(892)$, $K_1(1400)$, or $K_2^*(1430)$; we will henceforth refer to these K mesons collectively as $K^{(*)}$. Charged and neutral B mesons were handled separately. No evidence of a signal was seen in any of these channels, so the results of this search are 24 upper limits. These form a significant addition to the existing limits on standard and electromagnetic penguin decays [20–24]. While all of these decays can proceed via penguin diagrams, it is perhaps wise to note that some (such as $\bar{B}^0\to K^-\pi^+$) can occur via tree level spectator diagrams which are suppressed by small Kobayashi–Maskawa matrix elements. These mechanisms are illustrated in figs. 1 and 2. It is also conceivable that the decay may occur through flavour-changing neutral currents which are not allowed in the standard model. Standard model predictions of penguin-mediated decay rates involving the nonexcited K meson are about 2 orders of magnitude higher than those of tree level processes. Estimates of the branching ratios of B mesons into exclusive final states mediated by penguin decays lie in the range 10^{-5}–10^{-3}. The most recent predictions are those of Tanimoto [12] of $BR(B_d^0\to K^-\pi^+)\approx BR(B_d^0\to\bar{K}^0\phi)\approx 10^{-5}$ almost independent of the top

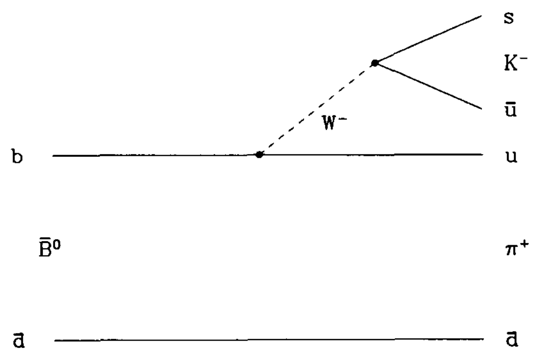

Fig. 1. Quark level diagram depicting a tree level process contributing to $\bar{B}^0\to K^-\pi^+$.

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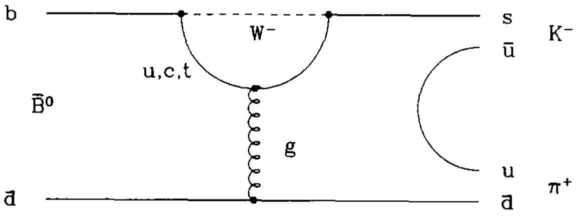

Fig. 2. Penguin diagram contribution to $\bar{B}^0 \to K^- \pi^+$.

quark mass m_t for $m_t > 50$ GeV$/c^2$. This branching ratio is rather low in comparison with earlier expectations and makes the prospect of seeing such decays with existing data rather remote. However, any sign of a significant enhancement over the predicted branching ratios could signal new physics. Interestingly, the branching ratio for the quark level process b→s gluon is expected to be rather large: on the other of a few percent. Unfortunately, the experimental study of this is difficult, due both to background sources, and the fact that this rate is presumably shared among a large number of exclusive final states. There are, to date, no theoretical calculations of the expected rates in channels involving excited states of the K system beyond the K*(892). These channels are studied here in order to extend the search for b→s gluon transitions, and in light of recent interest in $B \to K^* \gamma$ decays involving higher mass K resonances [25–27].

The results reported here are based on a data sample of 162 pb^{-1} taken with the ARGUS detector at the DORIS II storage ring on the $\Upsilon(4S)$ resonance. Assuming that the $\Upsilon(4S)$ always decays into $B\bar{B}$ pairs this corresponds to about 274 000 B mesons. The ARGUS detector is a 4π spectrometer described in more detail elsewhere [28].

The specific decay chains of the excited K systems studied were those in which the $K^{(*)}$ decays were one of the following [#1]:

$K^{*0}(892) \to K^+ \pi^-$,

$K^{*+}(892) \to K^0_S \pi^+$,

$K^0_1(1400) \to K^{*+}(892) \pi^-$,

$K^+_1(1400) \to K^{*0}(892) \pi^+$,

$K^{*0}_2(1430) \to K^+ \pi^-$.

$K^{*+}_2(1430) \to K^0_S \pi^+$.

Candidate particle combinations were accepted as K*, K_1, or K^*_2 mesons if their invariant masses were within $\pm\Gamma$ (one width) of their nominal masses [29]. The ARGUS detector has a mass resolution of about 9 MeV$/c^2$ for these decays, which is small relative to the natural widths of these particles. The ϕ mesons were taken from K^+K^- combinations within ± 0.006 GeV$/c^2$ of the nominal ϕ mass [29]. The ρ mesons were all neutral and taken from $\pi^+\pi^-$ combinations with a mass lying between -1.0Γ and $+1.2\Gamma$ of the nominal ρ^0 mass [29]. This slightly asymmetric cut was adopted in order to account for the fact that the $\pi^+\pi^-$ invariant mass distribution corresponding to ρ mesons should properly be described by a Breit–Wigner function. Note that, in order to suppress background, no decay channels involving neutral pions were used.

The details of how B meson candidates were handled are the same as those used in the companion paper [21]. The techniques are now well-understood and have been successfully used by the ARGUS Collaboration both in the study of upper limits on rare B meson decays [20,21], and in the reconstruction of B mesons in known channels such as $B \to D + n\pi$ [30]. In addition, for decays of a B meson into a spin-1 and a spin-0 particle, we note that the spin-1 particle must be in a helicity-0 state. If we define α_v as the angle between the decay axis of the spin-1 particle in its rest frame, and its direction of motion, one expects a $\cos^2\alpha_v$ distribution for signal events. Requiring $|\cos\alpha_v| \geq 0.5$ rejects 50% of background events while retaining some 85% of the signal. Further details may be found in ref. [31]. The results are summarized in tables 1-3. They include the most recent results from the CLEO Collaboration as they appear in ref. [24]. Invariant mass distributions for two representative channels (after cuts) are shown in figs. 3 and 4.

As mentioned earlier in this paper, direct interpretation of these results is difficult. Given the quark-level process b→s gluon, it is unknown to what degree each possible final state is to be expected. This, however, is not the only source of theoretical uncertainty. The process b→s gluon itself is expected to be subject to large QCD corrections. In addition, it is sensitive to unknown parameters in the standard

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

Table 1
Summary of the results on $B \to K^{(*)}\pi$.

Decay mode	N_{events} (90% CL)	BR (90% CL)	BR (90% CL) (CLEO)
$B_d^0 \to K^+\pi^-$	<9.4	$<1.8\times10^{-4}$	$<9.0\times10^{-5}$
$B_u^+ \to K_S^0\pi^+$	<3.2	$<9.6\times10^{-5}$	$<1.8\times10^{-4}$
$B_d^0 \to K^{*+}(892)\pi^-$	<2.3	$<6.2\times10^{-4}$	$<4.4\times10^{-4}$
$B_u^+ \to K^{*0}(892)\pi^+$	<3.6	$<1.7\times10^{-4}$	$<1.3\times10^{-4}$
$B_d^0 \to K_1^+(1400)\pi^-$	<8.9	$<1.1\times10^{-3}$	
$B_u^+ \to K_1^0(1400)\pi^+$	<4.3	$<2.6\times10^{-3}$	
$B_d^0 \to K_2^{*+}(1430)\pi^-$	<4.6	$<2.6\times10^{-3}$	
$B_u^+ \to K_2^{*0}(1430)\pi^+$	<8.3	$<6.8\times10^{-4}$	

Table 2
Summary of the results on $B \to K^{(*)}\rho^0$.

Decay mode	N_{events} (90% CL)	BR (90% CL)	BR (90% CL) (CLEO)
$B_d^0 \to K_S^0\rho^0$	<2.3	$<1.6\times10^{-4}$	$<11.6\times10^{-4}$
$B_u^+ \to K^+\rho^0$	<6.4	$<1.8\times10^{-4}$	$<7.0\times10^{-5}$
$B_d^0 \to K^{*0}(892)\rho^0$	<7.7	$<4.6\times10^{-4}$	$<6.7\times10^{-4}$
$B_u^+ \to K^{*+}(892)\rho^0$	<3.4	$<9.0\times10^{-4}$	
$B_d^0 \to K_1^0(1400)\rho^0$	<3.2	$<3.0\times10^{-3}$	
$B_u^+ \to K_1^+(1400)\rho^0$	<5.6	$<7.8\times10^{-4}$	
$B_d^0 \to K_2^{*0}(1430)\rho^0$	<8.2	$<1.1\times10^{-3}$	
$B_u^+ \to K_2^{*+}(1430)\rho^0$	<2.3	$<1.5\times10^{-3}$	

Table 3
Summary of the results on $B \to K^{(*)}\phi$.

Decay mode	N_{events} (90% CL)	BR (90% CL)	BR (90% CL) (CLEO)
$B_d^0 \to K_S^0\phi$	<2.3	$<3.6\times10^{-4}$	$<9.2\times10^{-4}$
$B_u^+ \to K^+\phi$	<2.9	$<1.8\times10^{-4}$	$<8.0\times10^{-5}$
$B_d^0 \to K^{*0}(892)\phi$	<2.3	$<3.2\times10^{-4}$	$<4.4\times10^{-4}$
$B_u^+ \to K^{*+}(892)\phi$	<2.3	$<1.3\times10^{-3}$	
$B_d^0 \to K_1^0(1400)\phi$	<2.3	$<5.0\times10^{-3}$	
$B_u^+ \to K_1^+(1400)\phi$	<3.6	$<1.1\times10^{-3}$	
$B_d^0 \to K_2^{*0}(1430)\phi$	<5.1	$<1.4\times10^{-3}$	
$B_u^+ \to K_2^{*+}(1430)\phi$	<2.3	$<3.4\times10^{-3}$	

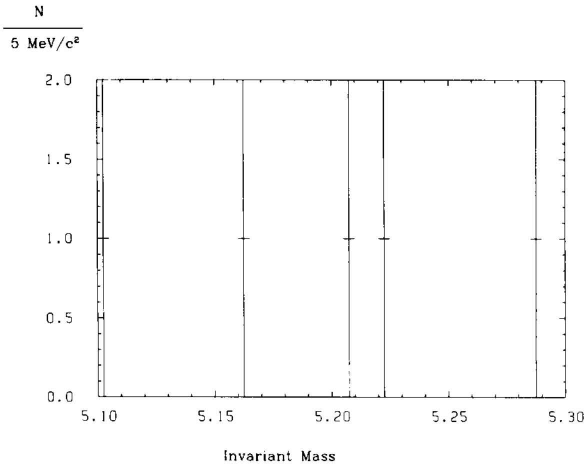

Fig. 3. $K^+\phi$ invariant mass distribution.

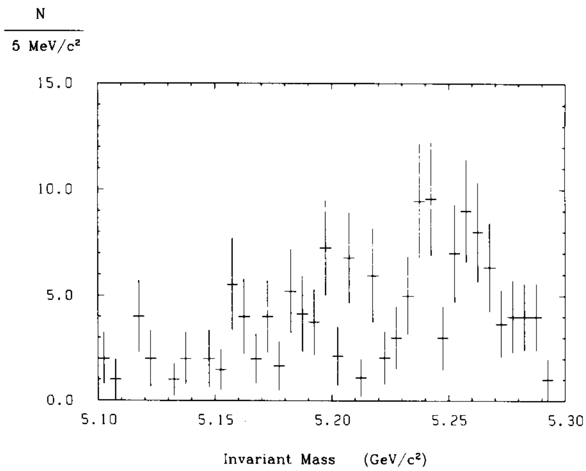

Fig. 4. $K^+\pi^-$ invariant mass distribution.

model (the top quark mass, weak mixing angles, and details of the Higgs sector) and possible physics beyond (such as a fourth generation or supersymmetry). We refer the reader at this point to the rather extensive theoretical literature (see refs. [1–12] and the summary [13]) for more detailed descriptions of how a positive signal might be interpreted.

In summary, no evidence for penguin decays of B mesons has been found. The data presented here constitute the most comprehensive limits to date on exclusive processes involving the $b \to s$ gluon transition. The values are not in contradiction with expectations based on the standard model, but may serve to constrain some models involving more exotic phenomena. There can be no doubt that the experimental and theoretical study of these decays will continue to test the standard model and provide a window into physics beyond.

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