SEARCH FOR HADRONIC b $\to$ u DECAYS

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Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY, we searched for $b \to u$ transitions in exclusive hadronic B meson decays. A systematic analysis of B decays into pions has been performed for decay modes with 2–7 pions in the final state. In none of the decays a positive signal was observed. The upper limits obtained on various branching ratios are consistent with the current model predictions.

The standard model of electroweak interactions allows for $b \to c$ and $b \to u$ transitions. Whereas much information is available on the decay of the b quark into charm [1], very little is known concerning $b \to u$ decays. Evidence for these decays has been observed analyzing semileptonic B decays [2,3]. The attempt to reconstruct hadronic B decays containing neither charm nor strangeness in the final state has not led to conclusive results up to now [4,5]. Therefore a systematic study of B decays into charged and neutral pions has been performed.

The results reported here are based on a data sample of 214 pb^{-1} obtained on the $\Upsilon(4S)$ resonance and 93 pb^{-1} in the continuum using the ARGUS detector at the DORIS II storage ring. Searches for B decays have been made in decay channels [#1] containing charged and neutral pions:

(a) $B^0 \to \pi^+\pi^-$, (b) $B^+ \to \pi^+\pi^0$,
(c) $B^+ \to \pi^+\pi^+\pi^-$, (d) $B^0 \to \pi^+\pi^-\pi^0$, (e) $B^+ \to \pi^+\pi^0\pi^0$,
(f) $B^0 \to \pi^+\pi^+\pi^-\pi^-$, (g) $B^+ \to \pi^+\pi^+\pi^-\pi^0$, (h) $B^0 \to \pi^+\pi^-\pi^0\pi^0$,
(i) $B^+ \to 3\pi^+2\pi^-$, (j) $B^0 \to 2\pi^+2\pi^-\pi^0$,
(k) $B^0 \to 3\pi^+3\pi^-$, (l) $B^+ \to 3\pi^+2\pi^-\pi^0$,
(m) $B^0 \to 3\pi^+3\pi^-\pi^0$,

The ARGUS detector is a 4π spectrometer, which has been described in detail elsewhere [6]. Charged particles are identified on the basis of measurements of both specific ionization and time of flight. Only those charged tracks are accepted as pions, for which the corresponding likelihood ratio exceeds 1%. The two photons from a π^0 decay may either form two separate clusters in the calorimeter or merge into one cluster. In the two-cluster case, the energy of each photon has to be larger than 50 MeV. Each combination of two photons is accepted as a π^0 candidate, if their invariant mass lies within 2.5 standard deviations of the table value. The accepted candidates are subject to a mass constraint fit. To cover the merged cluster case, photons with an energy above 800 MeV are accepted as π^0 candidates.

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[13] 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.

Since B mesons produced in $\Upsilon(4S)$ decays must have the beam energy E_{beam}, which is half of the $\Upsilon(4S)$ mass of 10.580 GeV/c^2 [7], we require the energy of B candidate combinations to satisfy $|E_B - E_{beam}| < 2\sigma_E$. 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 moderate momentum resolution into a mass resolution of a few MeV/c^2. Adding the contribution of the $\Upsilon(4S)$ resonance width and that of the DORIS beam energy spread, we expect a signal to have a width between 3.7 and 5.5 MeV/c^2. The B mesons have a p-wave angular distribution proportional to $\sin^2\theta_B$, where θ_B is the polar angle of the B meson with respect to the beam axis. Taking advantage of this fact, we require $|\cos\theta_B| \leqslant 0.8$. This cut reduces the background by about 20% at an efficiency of 94%.

The background from continuum events is very efficiently reduced by a topological cut, exploiting the fact that B mesons from $\Upsilon(4S)$ 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 $\Upsilon(4S)$ decays there is no correlation between the two axes, while for continuum events there is a strong peaking at $|\cos\alpha_{thrust}| = 1$, where α_{thrust} is the opening angle between the two thrust axes. Therefore, we require that $|\cos\alpha_{thrust}| \leqslant 0.6$.

For a B candidate, the total probability obtained from the sum of all χ^2 contributions from particle identification and kinematical fits must exceed 2%. After applying these cuts, the remaining events can contain more than one candidate for a given final state with a mass above 5.15 GeV/c^2. To avoid double counting, the candidate with the largest total probability is chosen. After this selection, the pions were combined to look for hadronic resonances. The invariant mass of the composite system was required to be within the mass range as indicated.

$$\rho^0 \to \pi^+\pi^- \quad \Delta M = \pm 200\ \mathrm{MeV}/c^2\,, \quad \rho^+ \to \pi^+\pi^0 \quad \Delta M = \pm 250\ \mathrm{MeV}/c^2\,,$$

$$a_1^0 \to \rho^+\pi^- \quad \Delta M = \pm 350\ \mathrm{MeV}/c^2\,, \quad a_1^+ \to \rho^+\pi^0 \quad \Delta M = \pm 350\ \mathrm{MeV}/c^2\,, \quad a_1^+ \to \rho^0\pi^+ \quad \Delta M = \pm 350\ \mathrm{MeV}/c^2\,,$$

$$\eta \to \pi^+\pi^-\pi^0 \quad \Delta M = \pm 30\ \mathrm{MeV}/c^2\,, \quad \omega \to \pi^+\pi^-\pi^0 \quad \Delta M = \pm 60\ \mathrm{MeV}/c^2\,.$$

For the decay $B \to \rho\pi$ we use the fact that the ρ is polarized resulting in an angular distribution proportional to $\cos^2\theta_\pi$, where θ_π is the angle between the pion from the B decay and one of the pions from the ρ decay in the ρ rest frame. We cut on $|\cos\theta_\pi| \geqslant 0.5$.

Fig. 1a shows the invariant mass distribution of the decay $B^+ \to \pi^+\pi^0$. There is no evidence for a signal coming from B decays. This conclusion is substantiated by examining the same mass distribution after subtraction of the underlying continuum events. For this purpose, the continuum data has been analyzed in the same way as the $\Upsilon(4S)$ sample, and then scaled according to the luminosities and the $1/s$ dependence of the hadronic cross section. The resulting mass distribution (fig. 1b) shows that the background is dominated by continuum events. The $\Upsilon(4S)$ mass distributions of the individual final states have been fitted with a gaussian distribution of mass 5.279 GeV/c^2 [8] and expected width plus the following function to model the background:

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

The upper limits on the number of events have been derived by integrating the likelihood distributions obtained in the fits over positive values of the number of events. The fit results are summarized in table 1.

To determine the reconstruction efficiency, $\Upsilon(4S)$ decays have been simulated using the LUND 6.2 model [11], which has been adjusted to describe the general properties of B meson decays. The production probabilities of neutral and charged B mesons produced in $\Upsilon(4S)$ decays were assumed to be equal [8]. The generated events have been passed through a detailed detector simulation program [12]. The systematic errors have been taken into account by folding them with the likelihood distributions obtained from the fits to the individual mass distributions.

The 90% confidence level upper limits for the branching ratios are given in table 1. For comparison, the predictions of the two different models [9,10] are included using a ratio $|V_{bu}/V_{bc}| = 0.1$ [2,3]. All of the predicted branching ratios are below the experimental limits. To increase our sensitivity, we added all events with two or three pions in the final state (decay channels a–e). Using the reconstruction efficiencies and the model

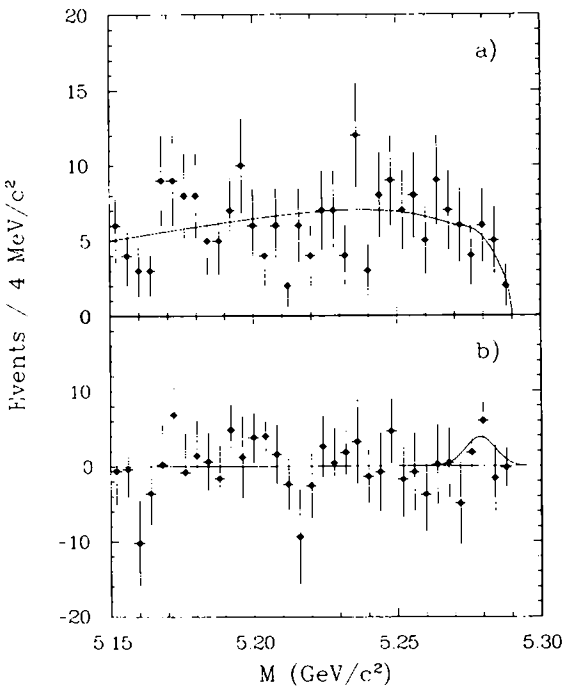

Fig. 1. Invariant mass distribution of the decay $B^+ \to \pi^+\pi^0$. (a) At the $\Upsilon(4S)$; the curve shows the result of the maximum likelihood fit described in the text. (b) After subtraction of the continuum contribution. The gaussian curve represents the 90% CL upper limit on the signal from the above fit (see table 1).

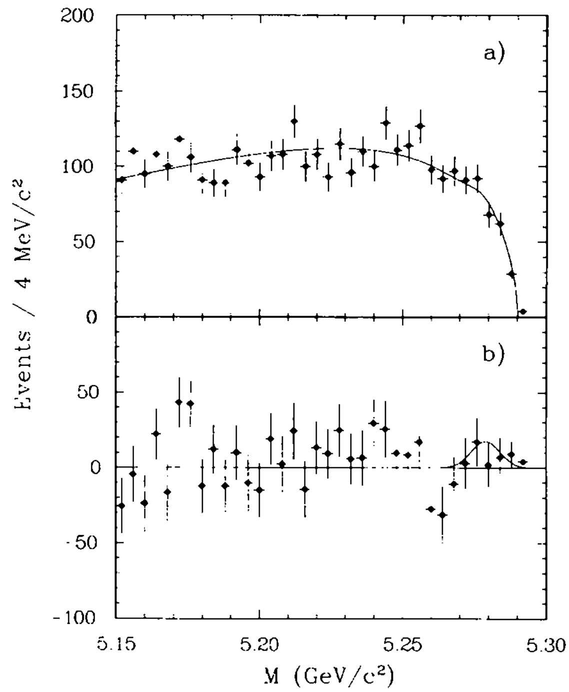

Fig. 2. Invariant mass distribution of all B candidates with two or three pions in the final state (decay channels a–c). (a) At the $\Upsilon(4S)$; the curve shows the result of the maximum likelihood fit described in the text. (b) After subtraction of the continuum contribution. The gaussian curve represents the 90% CL upper limit on the signal from the above fit.

Table 1
Summary of the limits at the 90% confidence level on the number of events and corresponding branching ratios. For comparison, the model predictions for two-body [11] and multibody [12] decays are given. The first two decay modes have been investigated by both models.

Decay mode	Upper limits (90% CL) events	Upper limits (90% CL) BR	Br [a] ($\lvert V_{bu}/V_{bc}\rvert=0.1$)	Decay mode	Upper limits (90% CL) events	Upper limits (90% CL) BR	Br [a] ($\lvert V_{bu}/V_{bc}\rvert=0.1$)
$\pi^+\pi^0$	12.5	2.4×10^{-4}	$0.6(1.3)\times10^{-5}$	$\omega\pi^+$	5.0	4.0×10^{-4}	2×10^{-6}
$\pi^+\pi^-$	8.8	1.3×10^{-4}	$2.0(2.5)\times10^{-5}$	$\eta\pi^+$	2.3	7.0×10^{-4}	3×10^{-6}
$\pi^+\pi^+\pi^-$	23.8	4.5×10^{-4}	6×10^{-5}	$\pi^+\pi^-\pi^0\pi^0$	35.3	3.1×10^{-3}	5×10^{-4}
$\rho^0\pi^+$	5.5	1.5×10^{-4}	2×10^{-6}	$\rho^+\rho^-$	12.5	2.2×10^{-3}	5×10^{-5}
$\pi^+\pi^-\pi^0$	25.0	7.2×10^{-4}	2×10^{-4}	$a_1^0\pi^0$	10.7	1.1×10^{-3}	7×10^{-7}
$\rho^0\pi^0$	10.0	4.0×10^{-4}	2×10^{-6}	$\omega\pi^0$	3.9	4.6×10^{-4}	1×10^{-7}
$\rho^+\pi^-$	11.4	5.2×10^{-4}	6×10^{-5}	$\eta\pi^0$	3.9	1.8×10^{-3}	–
$\pi^+\pi^0\pi^0$	19.3	8.9×10^{-4}	6×10^{-5}	$3\pi^+2\pi^-$	25.0	8.6×10^{-4}	2×10^{-4}
$\rho^+\pi^0$	8.2	5.5×10^{-4}	2×10^{-5}	$a_1^+\rho^0$	5.5	6.0×10^{-4}	3×10^{-5}
$\pi^+\pi^+\pi^-\pi^-$	26.4	6.7×10^{-4}	1×10^{-4}	$2\pi^+2\pi^-\pi^0$	100.0	9.0×10^{-3}	6×10^{-4}
$\rho^0\rho^0$	5.9	2.8×10^{-4}	1×10^{-6}	$a_1^+\rho^-$	11.0	3.4×10^{-3}	7×10^{-5}
$a_1^+\pi^-$	10.4	6.3×10^{-4}	6×10^{-5}	$a_1^0\rho^0$	17.6	2.4×10^{-3}	8×10^{-7}
$\pi^+\pi^+\pi^-\pi^0$	83.0	4.0×10^{-3}	4×10^{-4}	$3\pi^+3\pi^-$	68.5	3.0×10^{-3}	2×10^{-4}
$\rho^+\rho^0$	11.3	1.0×10^{-3}	1×10^{-5}	$a_1^+a_1^-$	24.8	6.0×10^{-3}	–
$a_1^+\pi^0$	14.4	1.7×10^{-3}	3×10^{-5}	$3\pi^+2\pi^-\pi^0$	47.8	6.3×10^{-3}	7×10^{-4}
$a_1^0\pi^-$	17.6	9.0×10^{-4}	–	$a_1^+a_1^0$	37.0	1.3×10^{-2}	–
				$3\pi^+3\pi^-\pi^0$	79.1	1.1×10^{-2}	7×10^{-4}

[a] Refs. [9,10].

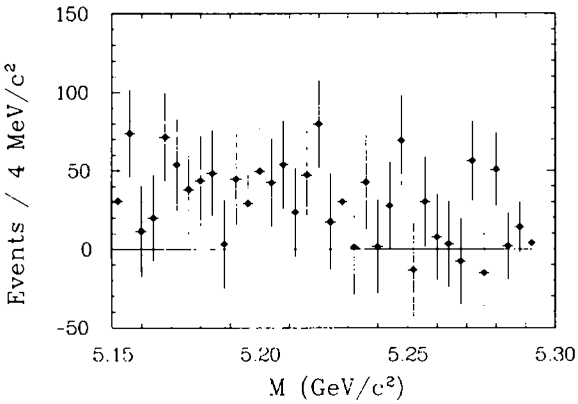

Fig. 3. Invariant mass distribution of all B candidates with four pions in the final state (decay channels f–h). The continuum contribution has been subtracted.

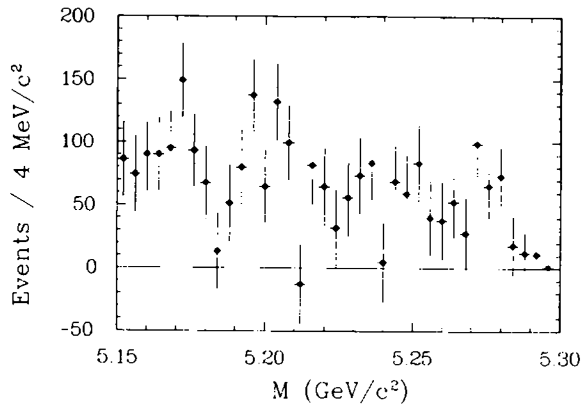

Fig. 4. Invariant mass distribution of all B candidates with five pions in the final state (decay channels i, j). the continuum contribution has been subtracted.

calculations (table 1), we expect a signal of 13 events, which is too small to be observed in fig. 2. The fit to fig. 2a results in 55 events at 90% CL. The mass distribution of B decays into four and five pions are plotted in fig. 3 and 4 respectively after subtraction of the scaled continuum. With increasing decay multiplicity, the mass distributions show a rising contribution from $\Upsilon(4S)$ decays. The number of signal events expected is about 17 (fig. 3) and 11 (fig. 4). The huge combinatorial background does not allow to observe such small signals coming from hadronic $b\to u$ decays.

In summary, an extensive search for B decays into pions has been performed. No evidence for hadronic $b\to u$ transitions has been observed. The upper limits obtained are consistent with the model predictions.

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