CLEO SEARCH FOR RARE DECAYS OF THE B MESON

AND

OBSERVATION OF THE DECAY OF THE Y (4s) RESONANCE INTO NON $B\overline{B}$ STATES *

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ABSTRACT

CLEO has set upper limits for rare exclusive decays of B mesons arising from $b \rightarrow u$ transitions and from $b \rightarrow s$ "penquin" processes. We have also observed non-$B\overline{B}$ decays of the Y (4s) resonance into energetic ψ mesons. The measured branching ratio is $0.22 \pm .07\%$. Theoretical implications are discussed and an upper limit is placed on one possible decay mechanism.

Operating on the Y (4s) resonance at the Cornell Electron Storage Ring, CESR, the CLEO collaboration has searched for two different classes of exclusive rare decay modes of the B meson. In one, the b quark decays to a u quark through the ordinary spectator diagram as shown in Fig. 1a. In the second class, the b quark undergoes a flavor changing neutral decay to an s quark via the one loop "penquin" diagram as shown in Fig. 1b. No such decays have been observed and upper limits have been placed on a large number of exclusive channels. In addition, CLEO has observed the unexpected decay of the Y (4s) into a non-$B\overline{B}$ state. This will be discussed in the second part of this paper.

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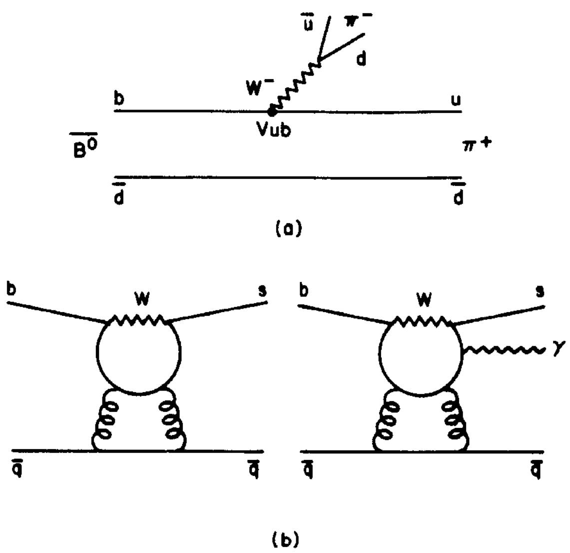

Fig. 1. (a) Spectator diagram for $b \rightarrow u$ decay. (b) Penguin diagrams for $b \rightarrow s$ decay.

In the last few years there has been a great deal of interest in building B factories in order to study CP violation in the B meson system. The Standard Model predicts that CP violation in the decay of the B meson should be significantly larger than for K^0 decay. Unfortunately, the CP violating decays of the B meson are expected to be suppressed due to several mechanisms. For instance, Fig. 2 shows two diagrams leading to $K^+\pi^-$ in the inal state. CP violation comes about due to the inteference between the penquin decay and the doubly suppressed spectator decay. Thus, it is very important to measure these "rare decay" modes to see if it is indeed feasible to measure CP violation in a system other than the neutral K meson.

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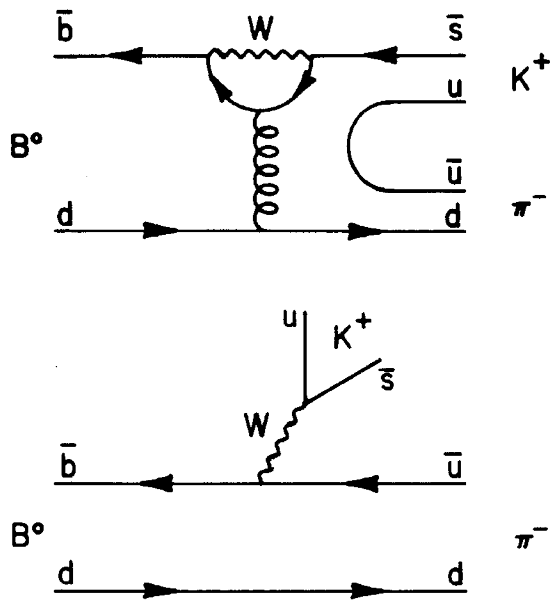

Fig. 2. Upper diagram shows the penguin decay of $B^0 \rightarrow K^+\pi^-$. Lower diagram shows the doubly suppressed spectator decay for $B^0 \rightarrow K^+\pi^-$. Interference between these two diagrams can cause CP Violation in this mode.

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DATA

CLEO has searched for these rare decays by collecting $212 pb^{-1}$ of integrated luminosity at the Y (4s) resonance and $101 pb^{-1}$ of continuum data at an energy 60 MeV below the Y (4s). This corresponds to 484,000 B mesons produced on the resonance. Specific event selection depends, of course, on the particular mode of interest [1]. Generally the energy of the B candidate must be within 2σ (σ = 25 - 37 MeV) of the beam energy and pass an event shape cut based on the fact that B events tend to be spherical while the continuum is jet-like.

Each track was required to have specific ionization in the drift chamber within two standard deviations of the expected for that particle assignment. For each candidate B meson, the beam constrained mass was computed. Since the beam energy spread (3.2 Mev r.m.s) is much better then the energy resolution of the detector quoted above, the mass resolution for various modes ranges from 2.5 to 3.0 Mev. Yields were obtained by counting events within 5 Mev of the B mass after continuum subtraction. No signal has been observed in any channel that has been investigated.

$b \to u$ *Decays*

As an example of a $b \to u$ decay, Fig. 3 shows the mass distribution for $\overline{B}^0 \to \pi^+\pi^-$ candidates. The detection efficiency for each mode was estimated from a Monte Carlo simulation of the CLEO detector where one B decays into the mode of interest. Table I gives the 90% confidence - level upper limits for $b \to u$ modes along with the efficiency (including all intermediate branching ratios) for each mode. In addition, the last column shows the branching ratios for modes that can be predicted by the model of Bauer, Stech and Wirbel [2] based on the fact that the ratio of CKM matrix elements, $|V_{ub}/V_{cb}|$, has been measured [3] to have a value of approximately 0.1.

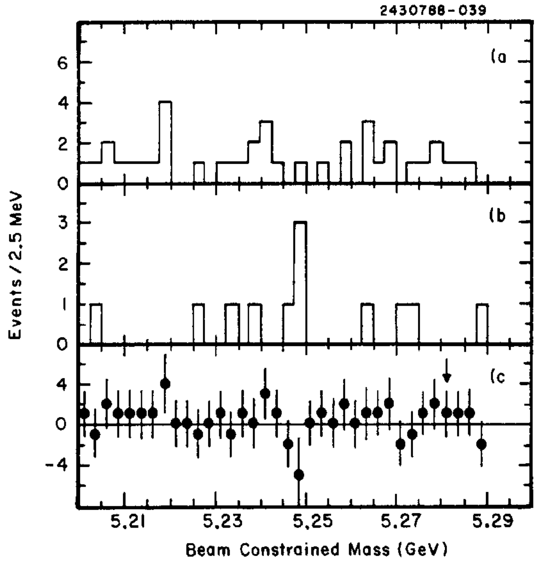

Fig. 3. The mass distribution of $\overline{B}^0 \to \pi^+\pi^-$ candidates: (a) at the Y(4s); (b) in the Continuum below the Y(4s); (c) the net distribution from $B\overline{B}$ events. The arrow indicates where the $\overline{B}^0$ signal should appear.

$b \to s$ *Decays*

The event selection for $b \to s$ decays was basically the same as for $b \to u$ decays except for modes with a photon where a larger difference between the B candidate energy and beam energy was allowed due to poorer photon energy resolution. Also, additional lepton identification cuts were imposed for $b \to sl^+l^-$ modes. Fig. 4 shows four two-body decay modes for $K^-\pi^+\pi^-$ final states. The top three are penquin decays while the bottom graph shows a charged current spectator decay for $B^- \to D^0\pi^-$. A clear peak is seen in this plot which is consistent with the expected yield and resolution.

TABLE I. Upper limits (90% C.L.) for exclusive $b \to u$ decays. The last column is the prdiction is based on the BSW model with $|V_{ub}/V_{cb}| = 0.1$.

Decay Mode	Efficiency	Upper Limits Events	BR $[10^{-4}]$	BSW $|V_{ub}/V_{cb}| = 0.1$
$B^0 \to \pi^+\pi^-$	0.45	8.9	0.9	0.20
$B^- \to \rho^0\pi^-$	0.22	8.9	1.5	0.06
$B^- \to f_0\pi^-$	0.06	3.9	2.4	0.04
$B^- \to f_2\pi^-$	0.06	6.9	4.1	
$B^0 \to a_1^+\pi^-$	0.06	6.9	5.1	0.63
$B^- \to a_2^0\pi^-$	0.08	4.1	2.6	
$B^- \to \rho^0 a_1^-$	0.08	8.2	3.8	0.36
$B^- \to \rho^0 a_2^-$	0.07	3.9	1.9	
$B^0 \to a_1^+ a_2^-$	0.03	19.7	32.4	0.74
$B^0 \to \rho^0\rho^0$	0.09	9.3	5.1	
$B^- \to \pi^-\pi^+\pi^-$	0.26	13.5	1.9	
$B^0 \to p\overline{p}$	0.45	3.9	0.4	
$B^+ \to \overline{\Delta}^0 p$	0.08	7.3	3.3	
$B^+ \to \Delta^{++}\overline{p}$	0.25	8.3	1.3	
$B^0 \to \Delta^0\overline{\Delta}^0$	0.01	4.8	17.6	
$B^0 \to \Delta^{++}\overline{\Delta}^{--}$	0.12	3.2	1.3	

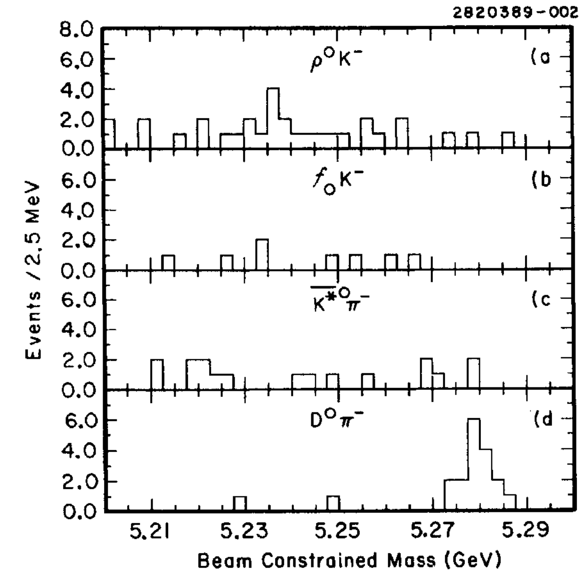

Fig. 4. Mass distributions for the decay $B^- \to K^-\pi^+\pi^-$ for the channels (a) $\rho^o K^-$, (b) $f_o K^-$, (c) $\overline{K}^{*o}\pi^-$ and $D^o\pi^-$

Again there is no evidence of any peak at the B mass for any penquin or leptonic mode investigated. The 90% confidence-level upper limits are given in Table II along with the theoretical predictions.

We see, for both $b \to u$ and $b \to s$ modes, with the possible exception of the $K^-\pi^+$ channel, the measured upper limits are well above the theoretical predictions. It should be noted, that for the $b \to s$ decays, there are large theoretical uncertainties such that for some channels there are order-or-magnitude disagreements between different authors.

$\Upsilon(4s) \to$ Non $- B\overline{B}$ Final States

Earlier this year, CLEO reported on the observation of ψ mesons from the $\Upsilon(4s)$ which were too energetic to come from B meson decays [8]. The existence of this non-$B\overline{B}$ decay could have important implications. For example, if the rate into these states is substantial, all B decay branching ratios are significantly higher than originally reported. In addition, it could be an indication of new physics associated with the b quark system.

The data sample was the same as reported above with the addition of 116 pb^{-1} taken at the $\Upsilon(5s)$ resonance. A minimum of five charged tracks were required. The ψ mesons were identified via their leptonic decay modes. The maximum possible Ψ momentum from B decay is 1.94 GeV/c and comes from the Cabbibo suppressed mode $B \to \psi\pi$. Therefore, to insure that there were no ψ's from B decay, the ψ momentum was required to be greater than 2.0 GeV/c. This corresponds to a minimum allowed $x_B = 0.378$ at the $\Upsilon(4s)$, where x is the momentum divided by the beam energy.

TABLE II: Upper limits (90% C.L.) for exclusive penguin and leptonic decays. The last two columns give the theoretical prediction for the indicated authors.

Decay Mode	Detection Efficiency	Upper Limits (90% CL) Number of Events	Branching Ratio [X 10^{-4}]	Theory Prediction [X 10^{-4}]	Author(s)	
$\overline{B}^o \to K^-\pi^+$	0.45	8.9	0.9	1.0	CC	[4]
				0.7	GYO	[5]
$\overline{B}^o \to \overline{K}^o\rho^o$	0.045	5.3	5.8	0.04	CC	
$\overline{B}^o \to \overline{K}^o f_o$	0.027	2.3	4.2			
$\overline{B}^o \to K^{*-}\pi^+$	0.026	2.3	4.4	1.0	CC	
$\overline{B}^o \to \overline{K}^o\phi$	0.023	2.3	4.9	0.5	GYO	
				0.4	CC	
$\overline{B}^o \to \overline{K}^{*o}\rho^o$	0.087	11.8	6.7			
$\overline{B}^o \to \overline{K}^{*o} f_o$	0.058	2.3	2.0			
$\overline{B}^o \to \overline{K}^{*o}\phi$	0.044	3.9	4.4	0.5	CC	
$B^- \to \overline{K}^o\pi^-$	0.10	2.3	0.9	0.6	CC	
$B^- \to K^-\pi^+\pi^-_{\text{no charm}}$	0.32	14.4	1.7			
$B^- \to K^-\rho^o$	0.22	4.1	0.7	0.1	CC	
$B^- \to K^- f_o$	0.13	2.3	0.7			
$B^- \to \overline{K}^{*o}\pi^-$	0.15	5.3	1.3	0.5	CC	
$B^- \to K^-\phi$	0.11	2.3	0.8	0.4	CC	
$B^- \to \Lambda\overline{p}$	0.19	2.3	0.5			
$\overline{B}^o \to \overline{K}^{*o}\gamma$	0.090	5.3	2.8	0.2	DLT	[6]
$B^- \to K^{*-}\gamma$	0.015	2.3	5.5	0.2	DLT	
$B^- \to K^- e^+ e^-$	0.30	4.1	0.5	0.006	DT	[7]
$B^- \to K^-\mu^+\mu^-$	0.21	8.3	1.5	0.006	DT	
$\overline{B}^o \to \overline{K}^{*o} e^+ e^-$	0.15	2.3	0.8	0.02	DT	
$\overline{B}^o \to \overline{K}^{*o}\mu^+\mu^-$	0.10	3.9	1.9	0.02	DT	

The l^+l^- mass spectrum for the Y(4s) sample is shown in Fig. 5(a) for $x>x_B$ and in Fig. 5(b) for $x<x_B$. The peaks are fitted with a Gaussian centered at the ψ mass. For $x>x_B$ there are 15 ± 4.7 events in the peak. The probability that this is caused by a background fluctuation is 2×10^{-5}.

Fig. 5(c) and Fig. 5 (d) show the corresponding distributions for the continuum 60 MeV below the Y(4s) resonance. There is no signal in either x range. Taking into account that the continuum sample is approximately one half that of the Y(4s) sample, there is a 2.8% probability that the excess in the Y(4s) data is due to a continuum fluctuation.

In order to improve the continuum statistics, the 116 pb^{-1} of Y(5s) data was also used. Here, the x cut had to be increased to 0.48 to eliminate ψ mesons from Doppler-shifted B decays. Fig. 5(e) and 5(f) show the relevant ψ mass distributions. No peak is seen for the $x > 0.48$ data. The signal of 22 ± 6 events in the low x region is in very good agreement with 19 ± 2 events expected from B decays as obtained by scaling the observed Y(4s) signal. If the Y(5s) and continuum data are combined, this sample is equal in size to the Y(4s) sample. In Fig. 6, the Y(4s) dilepton mass distribution is compared to that for the combined sample for $x>0.48$. The probability that the excess as shown in Fig. 6(a) is due to a fluctuation in the summed sample is 1.4%.

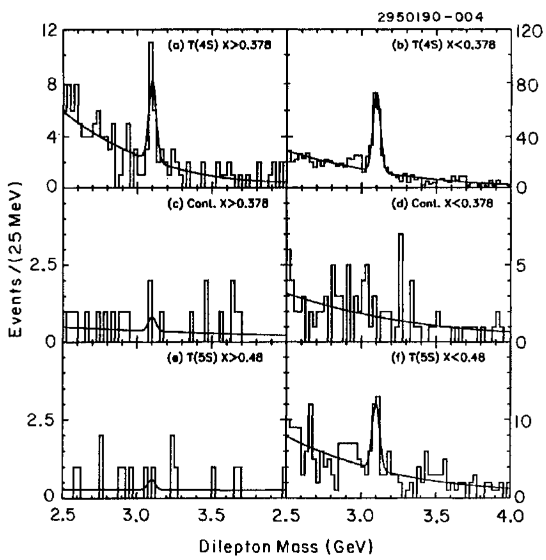

Fig. 5. Dilepton mass distribution. For Y(4s) data (a) $x > 0.378$ and (b) $x < 0.378$. For continuum data (c) $x > 0.378$ and (d) $x < 0.378$. For Y(5s) data (e) $x > 0.48$ and (f) $x < 0.48$.

As further evidence for the significance of the signal, the Fox-Wolfram moment, R_2, has been investigated [9]. This quantity is a measure of the global event shape where spherical events tend to have a small value of R_2 and jet-like events have a large value. The Y(4s) ψ events with large x have a R_2 distribution that peaks at low R_2, consistent with the distribution from B meson decays. On the other hand, the two continuum events near the ψ mass in Fig. 6(b) have only a 6% probability of coming from the same R_2 distribution as the Y(4s) ψ's, but a 95% probability of coming from a sample of dilepton continuum events. This gives further confidence that the signal is not due to a continuum fluctation.

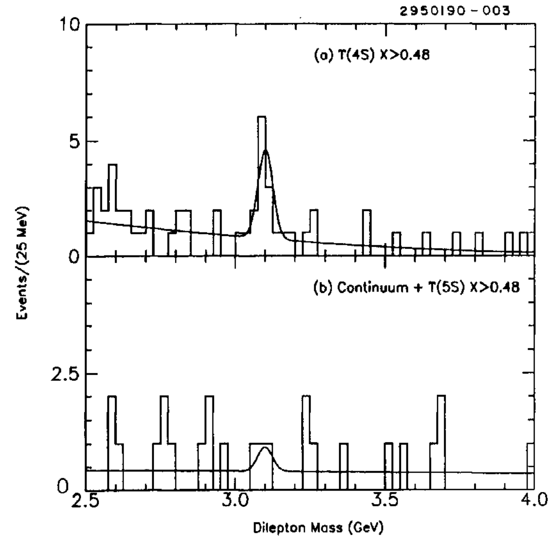

Fig. 6. Dilepton mass distribution for $x > 0.48$ (a) on Y(4s) and (b) continuum plus Y(5s).

Could these ψ's above the kinematic limit for B decay be due to momentum mismeasurement? Fig. 7 shows the ψ momentum spectrum for all Y(4s) decays. The high momentum events appear to be unformally distributed and certainly do not concentrate near x_B, the kinematic limit. Thus there is very strong evidence that the signal is real indicating that the Y(4s) decays into non-$B\bar{B}$ states.

After correcting for acceptances, ψ detection efficiencies and the $\psi \to l^+l^-$ branching ratio we find $B(Y(4s) \to \psi X) = (0.22 \pm 0.06 \pm 0.04)\%$. Searches have also been made looking for Y(4s) production of D^{*+}, ϕ and the Y(1s) above the kinenatic limit for B decay. No signal has been observed for any of these modes.

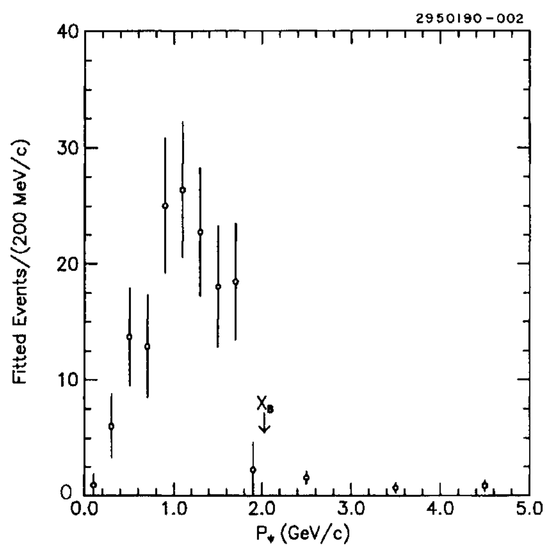

Fig. 7. The ψ momentum distribution for all Y(4s) decays.

Theoretical Speculation

In 1986, Lipkin [10] predicted that non-$B\overline{B}$ decays were to be expected due to a similar mechanism that causes $\phi \to \rho\pi$ and $\psi'' \to$ non $- D\overline{D}$ states. Atwood, Soni and Wyler [11] attempt to explain the non-$B\overline{B}$ states by conventional quarkonium spectroscopy. They find two possible candidate decays: $Y(4s) \to h_b(1P) + \eta$ and $Y(4s) \to \eta_b + h_1(1170)$ The former mode would produce monoenergetic η's which could be detected in a high resolution electromagnetic detector such as CLEO II. Ono, Sanda and Tornquist [12] have suggested that the Y(4s) is made up of an admixture bb quarks and so- called hybrid states of quarks and gluons. None of these papers make quantative predictions.

Khodjamirian, Rudaz and Voloshin (KRV) [13] also have a model based on the Y(4s) containing a light admixture of hybrid states in addition to $b\overline{b}$. With such a compound structure, $b\overline{b}$ could be in a color octet. In this case, $b\overline{b}$ could then annihilate into one photon and one gluon yielding an almost monochromatic photon of energy between 4 and 5 GeV with a branching ratio that is 2.6% of all non-$B\overline{B}$ decays. They argue this is equivalent to a width that could be as large as 0.5% of the total Y(4s) width. For the data sample of 212 pb^{-1} at the Y(4s), this corresponds to 1200 produced photons. With a detection efficiency of about 0.2, CLEO should observe 240 photons.

CLEO has searched for these photons. Fig. 8(a) shows the high energy photon spectrum for both Y(4s) and continuum events while Fig. 8(b) shows the continuum subtracted spectrum. No statistically significant peak is observed. The 95% confidence-level upper limit branching ratio is .26%. Thus the KRV mechanism can contribute no more than 10% to the non-$B\overline{B}$ decays of the Y(4s).

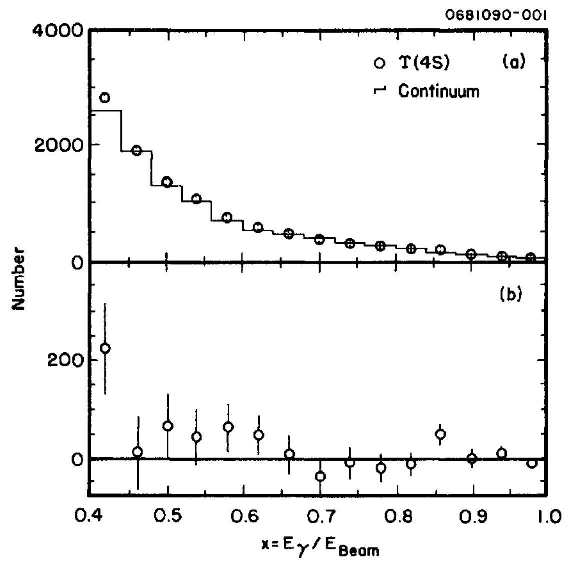

Fig. 8. (a) Photons from Y(4s) and continuum events (b) continuum subtracted photon spectrum.

At this point in time, we have no real understanding as to the source of the observed non-$B\overline{B}$decay. It could certainly imply new and interesting physics. In addition, if the branching ratio for this decay is substantial, it would cause a re-evaluation of all B meson branching ratios. In particular this could bring the measured semi-leptonic branching ratio of 10% into closer agreement with the theoretical lower limit of 12% [13]. Within the next year, CLEO using the new high resolution CLEO II detector, could shed new light on this process.

References

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