Observation of Exclusive Decay Modes of b-Flavored Mesons

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(Received 24 January 1983)

B-meson decays to final states consisting of a D^0 or $D^{*\pm}$ and one or two charged pions have been observed. The charged-B mass is $5270.8 \pm 2.3 \pm 2.0$ MeV and the neutral-B mass is $5274.2 \pm 1.9 \pm 2.0$ MeV.

PACS numbers: 14.40.Jz, 13.25.+m, 13.65.+i

The upsilon states[1] are interpreted as q-q resonances of a new quark, the b quark. The first three resonances are narrow,[2,3] implying bound b flavor and a suppressed strong decay. The large width of the $\Upsilon(4S)$ resonance discovered at the e^+e^- storage ring CESR[4] (Cornell Electron Storage Ring) and the observation that the decay products from the $\Upsilon(4S)$ include high-momentum leptons[5] imply that the $\Upsilon(4S)$ decays strongly into $B\bar{B}$ meson pairs, which then decay weakly. Until now, however, the b-flavored mesons themselves had not been found. Here we report that

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discovery.

The b quark has been shown to decay predominantly to the c quark.[6] Thus the principal decay mode of the B meson will be to a charmed meson plus pions. Since the high multiplicity in $\Upsilon(4S)$ decay[7] leads to large combinatorial background, we have restricted our search to low-multiplicity decay modes, D^0 or $D^{*\pm}$ plus one or two charged pions.

The data sample used is 40.7 pb^{-1} of $\Upsilon(4S)$ data and 19.6 pb^{-1} of continuum data taken with the CLEO detector at CESR. The $\Upsilon(4S)$ cross section is a 1.0-nb enhancement above a 2.5-nb continuum contribution. The detector has been described in detail elsewhere.[8] In this work we have used the cylindrical drift chamber inside a 1.0-T solenoid magnet to determine momenta of charged particles. In addition we have used the dE/dx-measuring wire proportional chambers and the time-of-flight scintillation counters located outside the solenoid magnet to identify charged kaons over a momentum range from 0.45 to 1.0 GeV/c.

The two-body decay modes, $D^0 \to K^-\pi^+$ and its charge conjugate, were used to find D^0 mesons. Identified kaons were paired with each oppositely charged particle in the event (assumed to be a pion). The combination was kept only if its momentum was below 2.6 GeV/c, since D^0's from B decay cannot exceed this momentum. The resulting $K^\pm\pi^\mp$ mass distribution is shown in Fig. 1(a). Mass combinations within $\pm$ 40 MeV of the D^0 mass were kept as D^0 candidates.

We looked for charged D^* mesons through the cascade $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ and its charge conjugate. We did not require that the charged kaon be identified as such. Rather we first formed mass combinations of all pairs of oppositely charged particles in an event, assuming that each particle in turn is a kaon. We then added an additional particle (assumed to be a pion) of charge opposite to that of the assumed kaon. We kept as D^* candidates the combinations for which the $[K\pi\pi, K\pi]$ mass difference was within $\pm$ 3.0 MeV of the $[D^{*\pm}, D^0]$ mass difference of 145.4 MeV,[9] and $K\pi$ masses within $\pm$ 80 MeV of the D^0 mass. We further required that the D^* candidate have momentum below 2.6 GeV/c, eliminating the high-momentum D^* contribution from the continuum. With these requirements the $D^{*\pm}$ signal is hidden under considerable background. By demanding a more restrictive set of conditions [see Fig. 1(b)], we demonstrate that the $\Upsilon(4S)$ decays contain a $D^{*\pm}$ signal. Because these latter restrictions lower

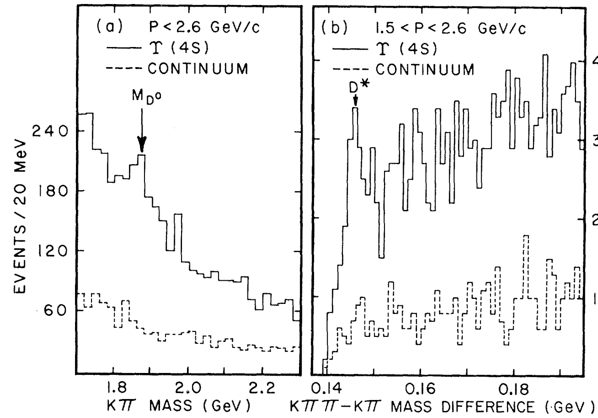

FIG. 1. (a) Mass distribution of $K^\pm\pi^\mp$, for $K\pi$ momenta below 2.6 GeV/c, using identified kaons. The solid line shows data from 40.7 pb^{-1} of $\Upsilon(4S)$ running; the dashed line is from 19.6 pb^{-1} of continuum running at energies just below the $\Upsilon(4S)$. A D^0 signal at 1.86 GeV is evident in the $4S$ data. (b) $(K^\pm\pi^\mp\pi^\mp)-(K^\pm\pi^\mp)$ mass-difference distribution, for $K\pi\pi$ momenta between 1.5 and 2.6 GeV/c and $K\pi$ masses within 20 MeV of the D^0 mass. Kaons were not directly identified. Curves are as in (a). The signal at the $D^{*\pm}-D^0$ mass difference (145.4 MeV) is evidence of $D^{*\pm}$ production in $\Upsilon(4S)$ decay.

the $D^{*\pm}$ detection efficiency they were not used in the search for B mesons.

Each event containing a D^0 or $D^{*\pm}$ candidate was fitted to the following hypotheses[10] (or their charge conjugates):

$$B^- \to D^0\pi^-, \tag{1}$$

$$\bar{B}^0 \to D^0\pi^+\pi^-, \tag{2}$$

$$\bar{B}^0 \to D^{*+}\pi^-, \tag{3}$$

$$B^- \to D^{*+}\pi^-\pi^-. \tag{4}$$

We considered only these charge combinations, since they preserve the quark decay scheme $b \to c \to s$. In making the fit, we constrained the B-meson energy to the beam energy and constrained the D^0 or $D^{*\pm}$ decay products to the known D^0, $D^{*\pm}$ masses, respectively. This fitting procedure measures the B mass relative to the CESR beam energy, which is scaled to agree with the VEPP4 measurement of the $\Upsilon(1S)$ mass.[11] Since the threshold for $B\bar{B}$ production is known to lie between the $\Upsilon(3S)$ and $\Upsilon(4S)$ resonances, we considered B-meson mass combinations between half the $\Upsilon(3S)$ and $\Upsilon(4S)$ resonance masses (i.e., 5180 and 5290 MeV). Candidate fits were required to have a χ^2 value less than 14. If an event had two acceptable fits in this mass interval we took the hypothesis with the lower χ^2. Each successful fit was examined visually to reject B candidates involving incorrectly fitted drift-chamber tracks (a 15% rejection).

The B masses for all successful fits are shown in Fig. 2. The 18 events in the peak near 5275 MeV are divided 2, 5, 5, and 6 for reactions (1)–(4), respectively. The width of the mass peak is consistent with the resolution expected from Monte Carlo studies. We have estimated the background under the mass peak in several ways. (1) We changed our selection criteria to accept $K^{\mp}\pi^{\pm}$ mass combinations that differed from the D^0 mass by $\pm$ 200 MeV. The spectrum of reconstructed "B-meson" masses for this "sideband" search is shown in Fig. 3(a). (2) We considered wrong charge combinations, which corresponded to doubly charged B's, or corresponded to decay sequences other than $b \to c \to s$. The mass spectrum for wrong charge combinations is shown in Fig. 3(b). Both distributions in Fig. 3 have been normalized so that the vertical scales are directly comparable with Fig. 2. (3) We performed Monte Carlo studies of background from $B\bar{B}$ events and from continuum events, to determine how the background in Fig. 2 should be extrapolated from lower masses to the peak region. (4) We searched 19.6 pb^{-1} of data accumulated just below the $\Upsilon(4S)$ for apparent B's, finding two in the region of the mass peak. These studies lead to estimates of the background under the peak at 5275 MeV which lie between 4 and 7 events.

If a B decay contains a low-energy particle that escapes detection, the remaining particles from that B may still be consistent with the beam-energy constraint and give an acceptable fit. We frequently cannot distinguish reactions (1) and (2) from similar reactions with the D^0 replaced by D^{*0}, where $D^{*0} \to D^0\pi^0$ or $D^0\gamma$. Similarly, the decay $\bar{B}^0 \to D^{*+}\pi^-$, $D^{*+} \to D^0\pi^+$ (π^+ not detected), can masquerade as $B^- \to D^0\pi^-$, causing us to assign an incorrect charge to the B. Monte Carlo studies show that the reconstructed mass is shifted down a few megaelectronvolts from the true B mass, and the mass resolution is worsened slightly. The problem of missed low-energy particles is not important for reactions (3) and (4), and therefore we use only these to determine the B mass.

We find a mass of $5274.2 \pm 1.9 \pm 2.0$ MeV for the neutral B, and $5270.8 \pm 2.3 \pm 2.0$ MeV for the charged B, where the first error is statistical and the second error systematic. The $[\bar{B}^0, B^-]$ mass difference is $3.4 \pm 3.0 \pm 2.0$ MeV, consistent

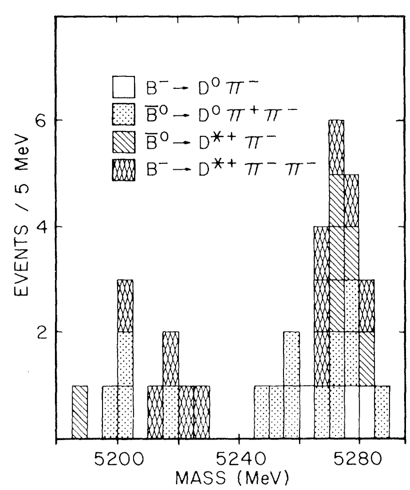

FIG. 2. Mass distribution of B-meson candidates. The $B \to$ final-state decay labels should be interpreted as including the charge-conjugate reaction.

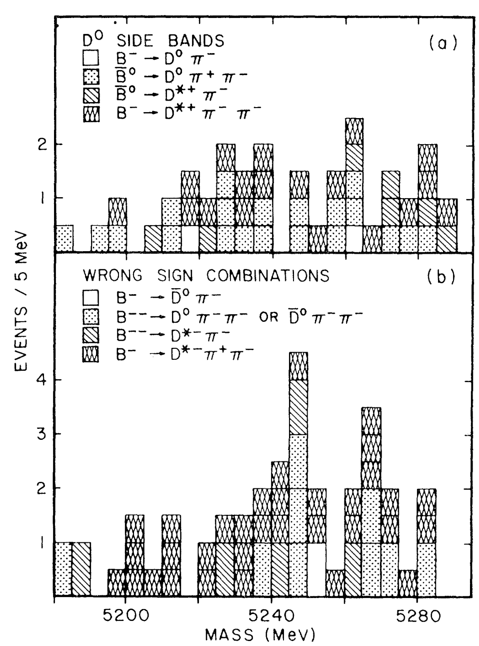

FIG. 3. Mass distribution for two estimates of the background to the B-meson candidates of Fig. 2. (a) D^0's chosen from sidebands. The events shown are plotted with a weight of $\frac{1}{2}$ event, since there are approximately twice as many events in the sidebands as in the D region. (b) Wrong charge combinations. The events shown in this distribution have been scaled to account for the difference in the number of combinations leading to a wrong-sign B compared to those leading to the correct-sign charged B.

with the theoretical prediction[12] of 4.4 MeV. The average of charged and neutral B masses is $5272.3 \pm 1.5 \pm 2.0$ MeV. This corresponds to a mass difference ΔM of $32.4 \pm 3.0 \pm 4.0$ MeV between the mass of the $\Upsilon(4S)$ and twice the B-meson mass. If the $[B^*, B]$ mass difference is ~ 50 MeV as expected theoretically,[12] the $\Upsilon(4S)$ must decay exclusively to $B\bar{B}$, with no contribution from $B^*\bar{B}$. Previous experimental information on ΔM comes from the fact that Schamberger *et al.* do not observe monochromatic photons from $B^* \to \gamma B$ decay.[13] Their experiment sets an upper limit of 50 MeV on ΔM. Theoretical calculations of ΔM using the width and the height of the $\Upsilon(4S)$ fall either above[12] or below[14] our result. Using our measured value for ΔM and the theoretical value of 4.4 MeV for the $[\bar{B}^0, B^-]$ mass difference, we obtain the branching fractions $B(\Upsilon(4S) \to B^+B^-) = 0.60 \pm 0.02$ and $B(\Upsilon(4S) \to B^0\bar{B}^0) = 0.40 \pm 0.02$. We estimate branching ratios of $4.2 \pm 4.2\%$, $13 \pm 9\%$, $2.6 \pm 1.9\%$, and $4.8 \pm 3.0\%$ for reactions (1)–(4), respectively.[15,16]

In conclusion, we have explicitly demonstrated the existence of the B meson through its decay into exclusive final states and have measured its mass.

We gratefully acknowledge the efforts of the CESR staff who made this work possible. We thank H. Tye for useful discussions. This work was supported in part by the National Science Foundation and the U. S. Department of Energy.

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16As noted earlier, the branching ratio for reaction (1) includes a contamination from $B^- \to D^{*0}\pi^-$ and $\bar{B}^0 \to D^{*+}\pi^-$, while reaction (2) includes $\bar{B}^0 \to D^{*0}\pi^+\pi^-$.