D^0 Spectrum from B-Meson Decay

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The inclusive branching fraction for B-meson decay into D^0 mesons and the momentum spectrum of the D^0's have been measured. $0.8 \pm 0.2 \pm 0.2$ D^0 per B decay was found. The shape of the spectrum suggests an interesting picture of B-meson decay.

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Weak decays of B mesons provide an excellent way of confronting theoretical ideas about heavy-meson and heavy-quark decay. Since the dominant mode of b-quark decay is to c quarks,[1] D mesons should be produced when B mesons decay. We have investigated D^0 yields using 40.8 pb^{-1} of data taken on the $\Upsilon(4S)$ resonance, which decays into $B\overline{B}$ meson pairs.[2] The cross section for $\Upsilon(4S)$ production is 1 nb and the continuum cross section at this energy is 2.5 nb. The data come from the CLEO detector at the Cornell Electron Storage Ring (CESR). The CLEO detector has been described in detail elsewhere.[3] For this analysis we used only the inner drift chamber of 1.0-m radius situated in a 1.0-T magnetic field with momentum resolution $\Delta P/P = 0.012P$ (P in GeV/c).

B-meson decays may be usefully viewed in the spectator model (see Fig. 1). Here the b quark decays into a virtual W^- and a c or u quark. The virtual W^- decays into the lepton-antilepton or quark-antiquark pairs shown in Fig. 1. The spec-

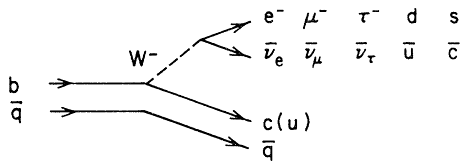

FIG. 1. Spectator model of B-meson decay.

tator does not participate directly in the decay, but joins with the c or u quark or other quarks produced by the virtual W to form an outgoing hadronic system. The c quark may take the form of a D or D^* meson.[4] Since the D^0 carries most of the momentum of a parent D^*, the D^0 momentum spectrum reflects the motion of the c quarks produced in the B decay and provides insight into the dynamics of these decays.

We identify D^0 ($\bar{D}^0$) through their decay into $K^-\pi^+$ ($K^+\pi^-$). The branching ratio for this decay has been measured[5] as $(3.0 \pm 0.6)\%$. In order to maximize our detection efficiency, we eschew particle identification and form mass combinations of all oppositely charged tracks, interchanging the kaon and pion mass hypotheses. The combinatorial background in the $K\pi$ mass plot is substantial. We use two additional criteria to suppress this background. First, we require the Fox-Wolfram parameter R_2 of the event[6] be less than 0.3. This requirement selects "spherical" events as opposed to "jetlike" events. We lose ~25% of the $B\bar{B}$ events while rejecting ~60% of the continuum events. Second, a requirement based on a difference between D^0 decay kinematics and background combinations is imposed on the data. The direction of the D^0 candidate in the laboratory defines a direction in the D^0 candidate rest frame. The cosine of the angle between this direction and the momentum vector of the kaon in the D^0 rest frame ($\cos\theta_K$) is isotropic for the decay of a spin-0 object, such as a D^0. Studies of background $K\pi$ mass distributions show that the $\cos\theta_K$ distribution peaks at values near ± 1. In

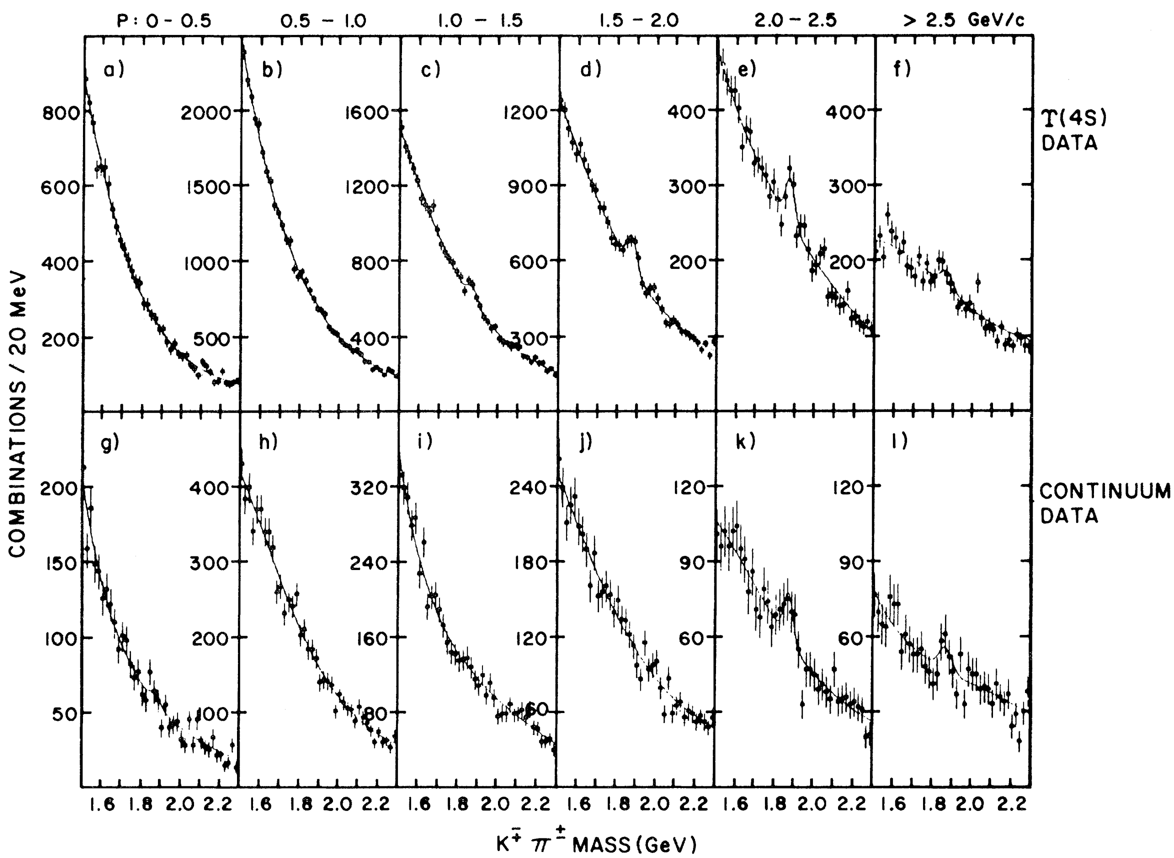

FIG. 2. Invariant-mass distributions of oppositely signed charged track pairs interpreted as $K^{\pm}\pi^{\mp}$ for different $K\pi$ momentum intervals. The curves are fits by a Gaussian centered at the D^0 mass and a slowly falling background. The $\Upsilon(4S)$ data (40.8 pb^{-1}) are shown in (a)–(f) and the continuum data (17.1 pb^{-1}) are shown in (g)–(l).

TABLE I. Number of D^0 events.

P (GeV/c)	ϵ (%)	Detected on the $\Upsilon(4S)$	Detected on continuum	Corrected D^0's from $B\bar{B}$
0–0.5	36±2	12±36	14±18	4±153
0.5–1.0	38±2	55±65	−3±31	118±257
1.0–1.5	35±2	236±60	3±26	644±244
1.5–2.0	35±2	383±61	4±25	1077±243
2.0–2.5	29±2	178±40	57±20	156±212
>2.5	35±5	92±39	36±20	26±171

order to reduce the background, we insist that the absolute value of $\cos\theta_K$ be less than 0.5 for $K\pi$ momenta less than 1.5 GeV/c and less than 0.75 for momenta above 1.5 GeV/c. The data have been grouped in several $K\pi$ momentum intervals between 0 and 2.5 GeV/c and in one interval above 2.5 GeV/c. The kinematic limit for D^0's from B decay at the $\Upsilon(4S)$ is 2.5 GeV/c. The $K\pi$ mass distribution for these momentum bins is shown in Figs. 2(a)–(f). A peak due to D^0 is apparent at momenta above 1.0 GeV/c. We extract the number of $D^0 \to K\pi$ decays by fitting the mass spectrum with a Gaussian at the D^0 mass and a slowly varying background term. The variance of the Gaussian is fixed at 23 MeV, as determined by a Monte Carlo simulation described below. The curves in Fig. 2 are the result of these fits.

The efficiency of D^0 detection was evaluated by use of Monte Carlo techniques. We generated 150 000 $B\bar{B}$ events and passed these through our detector simulation programs which have been adjusted to reproduce the track-finding efficiency and momentum resolution of the drift chamber. We then fitted the resultant mass distributions of the generated D^0's. We considered both the correct mass assignment and the one with the K and π identities switched. Note that when the K and π momenta are equal, the mass of a $K^-\pi^+$ or π^-K^+ combination are identical.

Since a large fraction of the cross section at the $\Upsilon(4S)$ arises from continuum events we must subtract D^0's from this source. In Fig. 2(g)–(l) we show the $K\pi$ mass distributions for 17.1 pp^{-1} of continuum data taken between the $\Upsilon(3S)$ and the $\Upsilon(4S)$. A signal is evident only in the momentum range above 2.0 GeV/c.

The efficiency ϵ[7] and the number of detected D^0's for each D^0 momentum bin are given in Table I. The detected numbers for $\Upsilon(4S)$ and continuum correspond to 40.8 pb^{-1} and 17.1 pb^{-1} of luminosity, respectively. To obtain the number of detected D^0's from $B\bar{B}$ events, we have subtracted the continuum contribution to the $\Upsilon(4S)$ data by using the number of D^0's found in the continuum data and correcting for the difference in luminosity. For the subtraction, the continuum data have been averaged in the momentum range 0 to 2.0 GeV/c in order to smooth the positive and negative fluctuations. The corrected numbers of D^0's from $B\bar{B}$ decay shown in Table I are obtained by dividing the detected numbers by the listed efficiencies. As expected, no D^0 signal from the $B\bar{B}$ events exists above 2.5 GeV/c.

The total number of D^0's per B decay corrected for efficiencies and the measured $D^0 \to K\pi$ branching ratio is $0.8 \pm 0.2 \pm 0.2$. The systematic error is dominated by the uncertainty in the $D^0 \to K\pi$ branching ratio.

The corrected D^0 momentum spectrum from B decay is shown in Fig. 3. Most of the D's are at

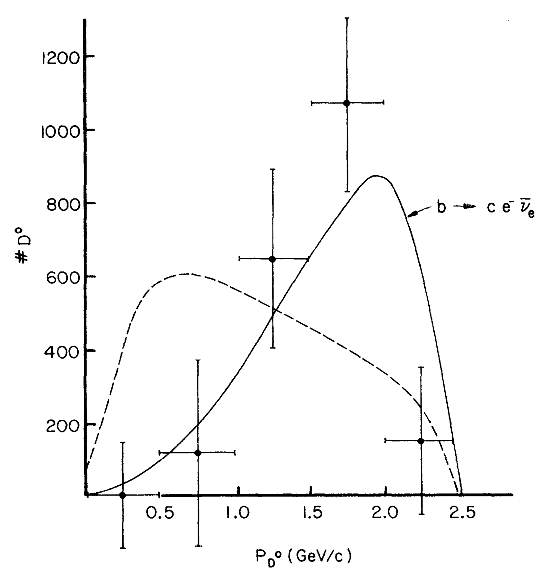

FIG. 3. D^0 momentum distribution from B-meson decay. The solid curve is the theoretical expectation for the semileptonic decay $b \to ce^-\bar{\nu}_e$, where the decay proceeds via $V-A$. The dashed curve is the result of a phase-space model (see text).

large momenta. Current theoretical descriptions of B-meson decay within the framework of the spectator model are not able to make firm predictions about how the final-state quarks produce hadrons. In one extreme, the two quarks and two antiquarks in a nonleptonic decay or the quark and antiquark in a semileptonic decay (see Fig. 1) are combined with additional $q\bar{q}$ pairs from the vacuum to make hadrons. The pairing of a quark and antiquark is selected at random and the final meson momenta are distributed according to the available phase space. The parameters of this model can be adjusted to give an acceptable description of the inclusive charged-particle momentum spectrum, the charged multiplicity, the number of kaons, and the lepton momentum spectrum in semileptonic decays. The dashed curve in Fig. 3 illustrates the results of such a model. The spectrum is softer than the data.

An alternative scheme would have the c quark and the spectator not interacting with the other quarks but merely "dressing" themselves. Therefore, in this scheme, one expects the D^0 spectrum in nonleptonic decay to be similar to that in semileptonic decay. Since the number of hadrons that the c quark and the spectator quark will produce is not known *a priori*, this scheme does not lead to a unique prediction for the D^0 momentum spectrum. The measured lepton spectrum[1] is consistent with an equal mixture of $B \to l\nu D$ and $B \to l\nu D^*$ indicating that the c quark and spectator usually produce a D or D^*. Furthermore, the measured charged multiplicity of 4.1 ± 0.4 in semileptonic B decay[8] supports this picture. The solid curve in Fig. 3 is a calculation of $b \to ce^- \bar{\nu}_e$ for a $V-A$ current and a c quark mass of 1.86 GeV.[9] It is in better agreement with the data.

We have measured $0.8 \pm 0.2 \pm 0.2$ D^0 per B decay. The D^0 momentum spectrum for all B decays resembles that for D mesons from semileptonic B decay as inferred from the lepton spectra.

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