Observation of the Decay $B \rightarrow FX$

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(Received 7 April 1986)

We present evidence for inclusive F-meson production in B-meson decay. The product branching fraction $B(B \rightarrow FX)B(F^+ \rightarrow \phi\pi^+)$ is measured to be 0.0038 ± 0.0010. The F momentum spectrum indicates the presence of a large component of two-body final states in the decay $B \rightarrow FX$.

PACS numbers: 13.25.+m, 14.40.Jz

In the spectator picture of B-meson decay the b quark decays to a c or a u quark and a virtual W^-. The decay $B \rightarrow FX$ can occur when the W^- couples to $\bar{c}s$ [Fig. 1(a)]. (Throughout this paper whenever we refer to B meson, it implies both the charged and neutral nonstrange B mesons.) Since the b-to-c coupling is dominant,[1] the final states may be of the form $B \rightarrow FDX$. Theoretical estimates accounting for the phase-space effects predict a rate of 15% for $b \rightarrow cW^- \rightarrow c(\bar{c}s)$.[2] Other possible mechanisms for F production are the fragmentation of the c quark

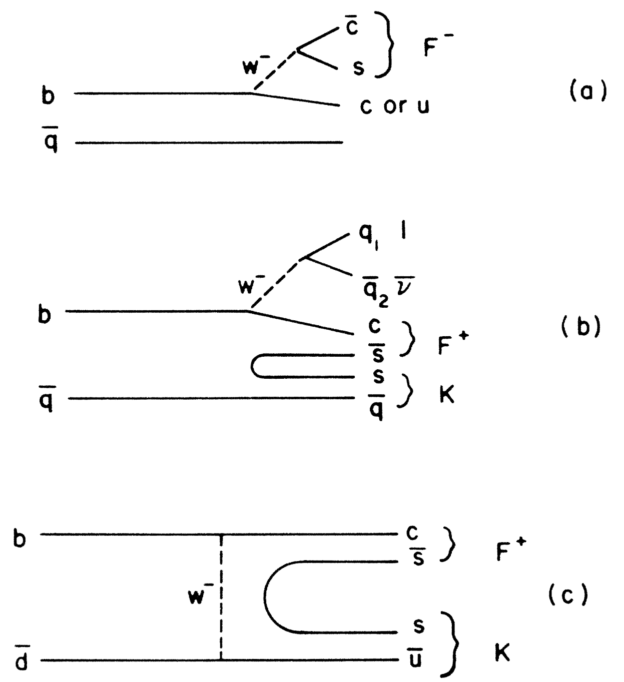

FIG. 1. Possible diagrams for the decay $B \rightarrow FX$.

from $b \rightarrow cW^-$ [Fig. 1(b)], where an $\bar{s}$ is picked up from the sea to form an F meson, and the W-exchange diagram in Fig. 1(c). However, the rate for these processes is expected to be small as a result of the mass suppression in $s\bar{s}$ pair creation from the sea. In this report we show evidence for F-meson production in B decay and present a measurement of its rate and momentum spectrum.

The data sample used in this study was taken with the CLEO detector at the Cornell Electron Storage Ring (CESR) and consisted of 77 pb^{-1} at the $\Upsilon(4S)$ and 36 pb^{-1} on the continuum at an energy just below the $\Upsilon(4S)$. The $\Upsilon(4S)$ is produced with a visible cross section of 1.15 nb and decays exclusively to $B\bar{B}$ pairs,[3] giving 88 550 $B\bar{B}$ events. The CLEO detector has been extensively described elsewhere.[4] The inner tracking system, upgraded in 1984, consists of a new ten-layer cylindrical precision drift chamber followed by a larger drift chamber which is instrumented to provide up to seventeen measurements of the energy deposition rate (dE/dx) by charged particles. The momentum resolution obtained for high-momentum particles is $\Delta p/p = 0.007p$ (p in GeV/c), while for particles with momenta below 1.0 GeV/c the resolution is dominated by multiple scattering. Charged hadron identification was provided by time-of-flight measurements and by dE/dx measurements.

F mesons were identified in the mode $F^+ \rightarrow \phi\pi^+$, $\phi \rightarrow K^+K^-$, where ϕ candidates were reconstructed by computing the invariant mass of oppositely charged tracks whose dE/dx and time-of-flight measurements were consistent with a kaon. In the K^+K^- mass spectrum we observe a ϕ peak at the mass 1019.7 ± 0.5 MeV/c^2 with a width (FWHM) 5.5 ± 1.0 MeV/c^2.[5] A ϕ candidate was required to have $1015.0 < m(K^+K^-) < 1025.0$ MeV/c^2 and was then combined with all other charged tracks in the event to form $\phi\pi$ combinations.

In order to suppress the combinatorial background in the $\phi\pi$ mass spectrum, we exploited the difference between the angular distribution of the signal and background. For the decay $F^+ \rightarrow \phi\pi^+$, $\phi \rightarrow K^+K^-$ the pion has an isotropic distribution in the rest frame of the F meson; and the distribution in θ_K, where θ_K is the angle between the K^+ and F directions in the ϕ rest frame, is $\cos^2\theta_K$. The random background near the F mass is uniformly distributed in $\cos\theta_K$ and its distribution of $\cos\theta_\pi$, where θ_π is the angle between the pion and the direction of motion of the laboratory in the F rest frame, peaks near the value of -1. Requiring $\cos\theta_\pi > -0.8$ and $|\cos\theta_K| > 0.6$, we find the $\phi\pi$ mass spectra shown in Figs. 2(a)–2(c). Clear F signals are evident in Figs. 2(a) and 2(b). At the $\Upsilon(4S)$ the F-meson momentum from B decay is limited to less than 2.5 GeV/c, while the continuum F production extends over the entire kinematic region up to 5.0 GeV/c.

Fitting the mass spectrum for F momentum greater than 2.5 GeV/c [Fig. 2(a)] to a second-order polynomial background and a Gaussian signal gives an F signal with a mass 1971.0 ± 2.0 MeV/c^2 and a width (FWHM) 25.0 ± 4.0 MeV/c^2. These are consistent with a Monte Carlo simulation of F-meson decay in the CLEO detector. Over the entire F momentum range the expected width varied from 20 to 25 MeV/c^2 and the mass was constant to ± 3 MeV/c^2 of the nominal F mass. We obtained the number of F's in smaller momentum intervals by fitting each corresponding mass spectrum to a polynomial background plus a Gaussian representing the F signal with the Monte Carlo–estimated width and mass.

The number of F's in the $\Upsilon(4S)$ and continuum data samples are given in Table I. The continuum contribution to the F signal at the $\Upsilon(4S)$ is determined by scaling the number of detected F's in the continuum data sample by the ratio of the resonance and continuum integrated luminosities and the small correction for the energy dependence of the continuum cross section. Accounting for this background, we obtain the direct F signal from $B\bar{B}$ events (Table I).

The detection efficiency for the decay $F^+ \rightarrow \phi\pi^+$, $\phi \rightarrow K^+K^-$, is the product $\epsilon_g\epsilon_i$, where ϵ_g contains the effects of geometrical acceptance, tracking efficiency, and kinematic cuts and ϵ_i is the probability that both tracks from the ϕ decay pass the kaon selection criteria. The latter is determined by studying the ef-

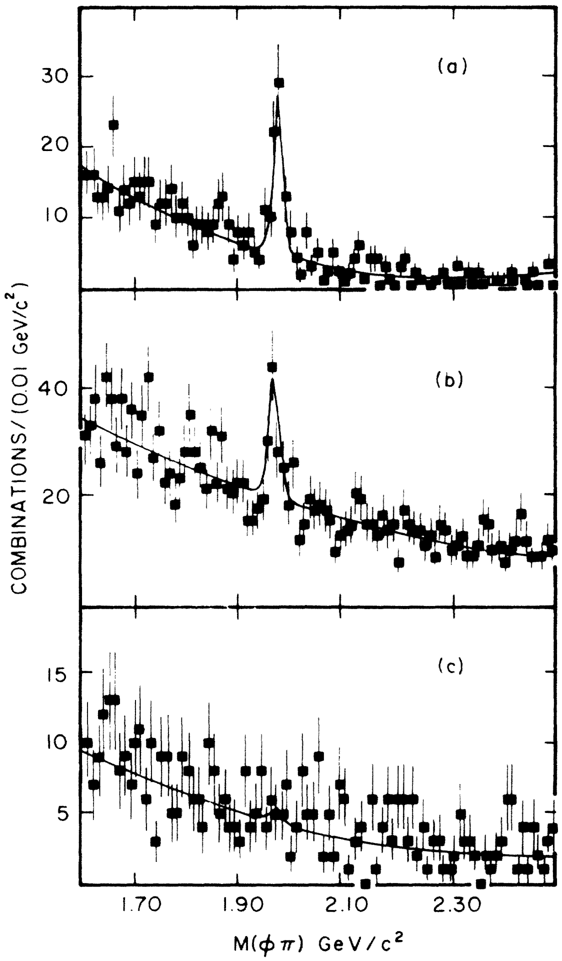

FIG. 2. (a) The $\phi\pi$ mass spectrum for $P_{\phi\pi} > 2.5$ GeV/c for the combined $\Upsilon(4S)$ and continuum data samples. (b) The $\phi\pi$ mass spectrum for $P_{\phi\pi} < 2.5$ GeV/c for the $\Upsilon(4S)$ sample. (c) The $\phi\pi$ mass spectrum for $P_{\phi\pi} < 2.5$ GeV/c for the continuum sample.

fect of the kaon selection requirements on the full sample of detected ϕ's. A Monte Carlo procedure was used to determine ϵ_g as a function of the F momentum. Finally, the acceptance factor includes the correction for the branching fraction $B(\phi \to K^+ + K^-) = 0.49 \pm 0.01$.[6] In Table I, we give the detection efficiency as a function of momentum.

Applying these corrections to the observed number of F's in the $\Upsilon(4S)$ and continuum data samples gives the distribution $d\sigma/dp = (1/L)dN/dp$ [Fig. 3(a)], where L is the total integrated luminosity for the combined data sample. Integrating this spectrum above 2.5 GeV/c gives $B(F^+ \to \phi\pi^+)\sigma_F(p_F > 2.5$ GeV/$c) = 6.0 \pm 0.9$ pb, where σ_F is the continuum F-meson production cross section.[7] The total continuum electron-positron-annihilation cross section in this energy region is 3 nb. The shape of the spectrum in Fig. 3(a) is indicative of a contribution from B-meson decays in the F momentum region below 2.5 GeV/c.

Using the direct F signal from $B\bar{B}$ events (Table I), correcting for the efficiencies and dividing by twice the number of $B\bar{B}$ events, we find the F momentum spectrum shown in Fig. 3(b). Summing the number of F's in this plot gives the product branching fraction $B(B \to FX)B(F^+ \to \phi\pi^+) = 0.0038 \pm 0.0010$.

To determine the branching fraction $B(B \to FX)$ one requires the value of $B(F^+ \to \phi\pi^+)$ which is not yet measured. However, using $B(F^+ \to \phi\pi^+) = \Gamma(F^+ \to \phi\pi^+)\tau_F$, where $\Gamma(F^+ \to \phi\pi^+) = 11.24 \times 10^{10}$ s^{-1} is the theoretical estimate of the rate[8] and $\tau_F = (3.5 \pm 1.2) \times 10^{-13}$ s is the measured F lifetime,[9] we find a value of $\sim 3.5\%$ for $B(F^+ \to \phi\pi^+)$. Estimates using the measurement of the product $\sigma_F B(F^+ \to \phi\pi^+)$ and a simple quark counting model suggest a value of several percent for the F branching fraction.[10] Using $B(F^+ \to \phi\pi^+) = 3.5\%$, we find $B(B \to FX) \sim 11\%$, consistent with the theoretical estimate of 9%.[11]

The diagram $B \to (c\bar{q})W^- \to (c\bar{q})\bar{c}s$ [Fig. 1(a)] requires final states containing two charmed particles. For the B meson at rest, a two-body decay such as $B \to FD$ yields a monochromatic F momentum distribution at $P_F = 1.8$ GeV/c. In the $\Upsilon(4S)$ decays, however, the B meson has a momentum of 0.4 GeV/c which results in a Doppler-broadened momentum spectrum. In Fig. 3(b), we show the curve representing the F momentum distribution for an equal combination of four possible two-body final states $B \to FD$, $B \to FD^*$, $B \to F^*D$, and $B \to F^*D^*$. A Monte Carlo model was used to obtain the curves

TABLE I. The $F \to \phi\pi^+$ signal and detection efficiencies as a function of momentum. The signal from $B\bar{B}$ events is obtained using (No. of F from $B\bar{B}$) = [No. of F from $\Upsilon(4S)$ data] $- 2.13 \times$ (No. of F from continuum data).

P_F (GeV/c)	ϵ efficiency	No. of observed $F \to \phi\pi^+$ decays $\Upsilon(4S)$	Continuum	$B\bar{B}$
0.0–1.0	0.093 ± 0.01	14.0 ± 6.0	−0.6 ± 2.6	14.0 ± 8.5
1.0–1.5	0.097 ± 0.01	12.0 ± 5.2	1.0 ± 2.9	9.8 ± 8.0
1.5–2.0	0.085 ± 0.01	31.7 ± 7.0	−0.1 ± 2.2	31.7 ± 8.4
2.0–2.5	0.088 ± 0.01	4.5 ± 3.9	−0.1 ± 2.0	4.5 ± 6.0
> 2.5	0.087 ± 0.01	37.4 ± 7.2	14.5 ± 4.5	6.4 ± 12.0

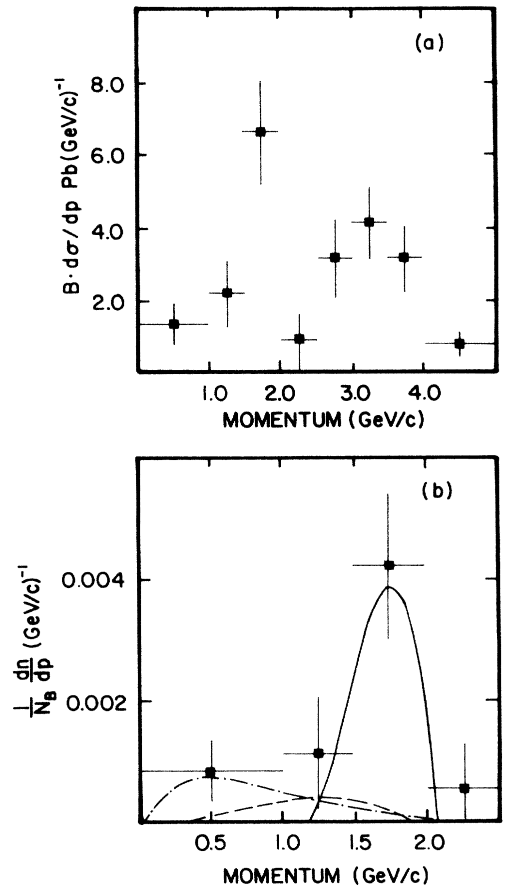

FIG. 3. (a) The distribution of $B(F^+ \rightarrow \phi\pi^+)d\sigma/dp$ for the combined data sample. (b) The momentum distribution of the F yield per B meson decay. The solid curve is the Doppler-broadened F momentum spectrum for two-body decays $B \rightarrow FD$, $B \rightarrow FD^*$, $B \rightarrow F^*D$, and $B \rightarrow F^*D^*$. The dashed and dash-dotted curves are respectively the Monte Carlo–simulated F momentum distribution for decays $B \rightarrow FD\pi$ and $B \rightarrow FKW^- \rightarrow FK(q_1\bar{q}_2)$. Normalization of the curves is determined by the fit to the data.

representing the F momentum distribution for decays $B \rightarrow FD\pi$ and $B \rightarrow (c\bar{q})W^- \rightarrow FKW^-$ [Fig. 1(b)].[12] Comparing these distributions with the observed spectrum indicates the existence of two-body final states in the decay $B \rightarrow FX$. The spectrum is clearly inconsistent with a combination of only the latter two alternative processes. Fitting the observed distribution to a linear combination of the three functions gives the two-body component of the decay $B \rightarrow FX$ to be $(64 \pm 22)\%$. This is consistent with theoretical predictions,[13] where two-body decays are expected to dominate the decay $B \rightarrow FX$.[14] The present limited data sample does not, however, allow the exclusive reconstruction of the two-body modes. We find no significant signal in the momentum region from 2.0 to 2.5 GeV/c where the contribution from the W-exchange decays $B \rightarrow FK$ and $B \rightarrow FK^*$ are expected.

In conclusion, we have observed the production of F mesons in B decay. The product branching fraction $B(B \rightarrow FX)B(F^+ \rightarrow \phi\pi^+)$ and the F momentum spectrum are determined. The momentum spectrum indicates the presence of a large component of two-body decays $B \rightarrow FD$, $B \rightarrow FD^*$, $B \rightarrow F^*D$, and $B \rightarrow F^*D^*$ in the decay $B \rightarrow FX$, consistent with the theoretical predictions.

We gratefully acknowledge the effort of the CESR staff. Thanks are also due to the U.S. Department of Energy Outstanding Junior Investigator program (from H.K. and R.K.) and the Bunting Institute (from K.K.). This work was funded by both the National Science Foundation and the U.S. Department of Energy.

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