Inclusive ϕ Production in B-Meson Decay

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We have measured the inclusive branching ratio for $B \to \phi X$ to be $0.023 \pm 0.006 \pm 0.005$. The momentum distribution of the ϕ mesons is compared with that expected from the cascade decays $B \to F \to \phi$ and $B \to D \to \phi$.

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Weak decays of B mesons are a rich ground for testing various theoretical models of heavy-flavor decays. Measurements of the B-meson decay parameters are consistent with the spectator picture of heavy-flavor-meson decay.[1] In this model the b quark decays into a c or u quark and a virtual W^- while the light quark remains a spectator. The W^- converts into a quark-antiquark or lepton-antilepton pair (Fig. 1). The rate at which lepton-antilepton pairs are produced has been determined from measurements of the semileptonic decays of B mesons.[2] It is of considerable interest to determine the coupling of the virtual W to $c\bar{s}$ in the decay of B mesons. A final-state result of this process is F-meson production in B decay. It is suggested that a less effective mechanism for $B \to FX$ is the fragmentation of the c quark from the diagram $b \to cW^-$,

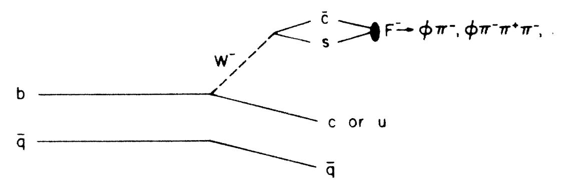

FIG. 1. The spectator diagram for the decay $B \to FX$.

where an $\bar{s}$ is picked up from the sea to form an F meson.[3] The F meson has been observed in the exclusive final states $\phi\pi$ and $\phi\pi\pi\pi$ with a combined estimated branching ratio of about 10%.[4] While the experimental sensitivity for direct observation of F's from B decay is low, the sizable branching ratio of F to ϕ allows one to use the ϕ yield as a measure of F production in B-meson decay.

In this work we have studied ϕ production in B decay using electron-positron annihilation data taken with the CLEO detector at the Cornell Electron Storage Ring. The CLEO detector has been described in detail elsewhere.[5] The upgraded inner tracking system consists of a ten-layer cylindrical precision drift chamber followed by a larger drift chamber which is now instrumented to provide a maximum of seventeen measurements of the energy lost (dE/dx) by charged particles. The momentum resolution for high-momentum particles is $\Delta p/p = [0.007\ (\mathrm{GeV}/c)^{-1}]p$ while for particles with momenta below 1.0 GeV/c the resolution is dominated by multiple scattering. Charged particles in the momentum interval of 200–600 MeV/c were identified as π's, K's, or p's by means of dE/dx measurements in the drift chamber. Time-of-flight and dE/dx measurements in the CLEO octant detectors, which are located outside the CLEO solenoid, were also used to identify K's and π's in the momentum range from 450 to 1000 MeV/c.[6] The data used in this analysis consisted of 30.4 pb^{-1} on the $\Upsilon(4S)$ resonance and 12.8 pb^{-1} on the continuum at an energy below the $\Upsilon(4S)$.

ϕ mesons were identified by computing the invariant mass of oppositely charged tracks, where at least one of the particles was positively identified as a kaon and the other track was only required to be consistent with a kaon hypothesis. Positively identified kaons were those tracks whose dE/dX or time-of-flight measurements were within 3 standard deviations of a kaon hypothesis and 3 standard deviations away from a pion hypothesis. The resulting mass spectra are shown in Figs. 2(a) and 2(b) for the $\Upsilon(4S)$ and continuum data, respectively. The spectra were fitted with a Gaussian signal and a polynomial background. We obtained a mean ϕ mass of 1019.3 ± 0.5 MeV/c^2 and a width (FWHM) of 6.0 ± 1.0 MeV/c^2 which is consistent with the estimated resolution of the CLEO detector.

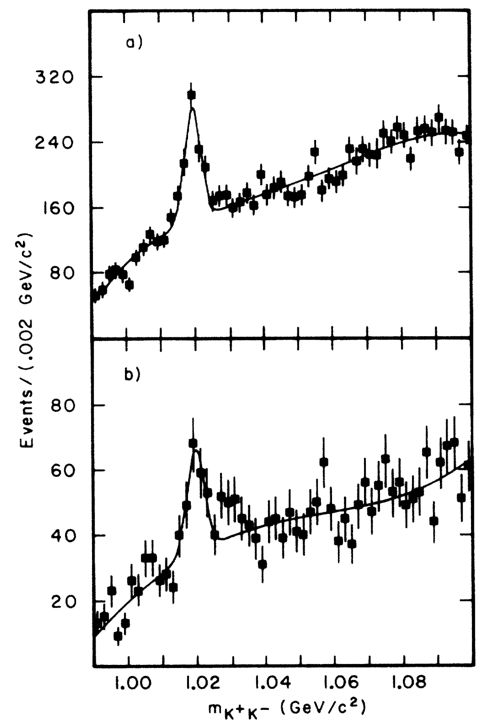

FIG. 2. The K^+K^- mass spectrum for (a) $\Upsilon(4S)$ data and (b) continuum data sample.

We have determined the number of ϕ's as a function of momentum by fitting the K^+K^- mass spectra in the three momentum intervals shown in Table I. The ϕ detection efficiency in the CLEO detector is the product $\epsilon_g \epsilon_l B(\phi \to K^+K^-)$, where ϵ_g is the acceptance and tracking efficiency for finding a kaon pair from ϕ decay, ϵ_l is the probability of identifying at least one of the kaons, and $B(\phi \to K^+K) = 0.49 \pm 0.01$ is the branching ratio of ϕ into the K^+K^- final state.[7] We have evaluated ϵ_g as a function of ϕ momentum using a Monte Carlo method to simulate ϕ production and the performance of the CLEO detector. To estimate $\epsilon_l = 2\epsilon_k - \epsilon_k^2$, where ϵ_k is the efficiency for identifying one kaon, we compared the number

TABLE I. Number of detected ϕ's and efficiencies as a function of momentum.

P_ϕ (GeV/c)	$\epsilon_g \epsilon_l$ efficiency	Number of ϕ's $\Upsilon(4S)$	Continuum	$B\bar{B}$ events
0.5–1.0	0.30 ± 0.02	176 ± 26	47 ± 11	66 ± 36
1.0–1.5	0.36 ± 0.02	197 ± 23	25 ± 10	138 ± 32
1.5–2.0	0.15 ± 0.02	47 ± 12	13 ± 5	17 ± 16

of detected ϕ's when positive identification of only one kaon was required with that when both kaons were identified. Efficiencies are tabulated as a function of ϕ momentum in Table I.

We have estimated the continuum contribution to ϕ production at the $\Upsilon(4S)$ by scaling the number of detected ϕ'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. We have computed the inclusive branching ratio for $B \to \phi X$ by summing the corrected number of ϕ's in all momentum intervals and dividing by twice the number of $B\bar{B}$ events. The number of $B\bar{B}$ events is the product of the visible $\Upsilon(4S)$ resonant cross section, the total integrated luminosity, and the inverse of the Monte Carlo-estimated acceptance of the CLEO detector for $B\bar{B}$ events. This gives 69 970 B's in our data sample. We obtain a value of 0.021 ± 0.0056 for the inclusive branching ratio of B to ϕ mesons in the momentum range 0.5–2.0 GeV/c.

To estimate the systematic error due to uncertainty in the kaon identification efficiency, we carried out the above analysis without requiring the positive identification of kaons but rejecting tracks which were positively identified as π's or p's. We obtained a value of 0.018 ± 0.006 for the branching ratio ($P_\phi > 0.5$ GeV/c) which is consistent with the value obtained above. We used the average of the two results for the branching ratio and estimated a 10% systematic error due to the kaon identification efficiency. We have also estimated a 10% systematic error resulting from the small momentum dependence of the width of the ϕ signal.

A correction of 15% was applied to the data to account for the unobserved momentum intervals of less than 0.5 GeV/c and greater than 2.0 GeV/c. This was calculated with use of a Monte Carlo model of the spectator diagram to simulate the ϕ momentum distribution for the processes $B \to F \to \phi\pi, \phi\pi\pi\pi$, $B \to D^0 \to \phi K^0$, and $B \to D^+ \to \phi\pi^+$.[4] The curve for $B \to FX$ represents the contribution from the diagram in Fig. 1. Applying this correction we obtain a value of $0.023 \pm 0.006 \pm 0.005$ for the inclusive branching ratio of B to ϕ, where the second error is the combined systematic error.

In Fig. 3 we show the corrected momentum distribution of the ϕ's from B decay. The spectrum is somewhat harder than that expected from $B \to F \to \phi X$ and $B \to D \to \phi X$.

To relate this result to F production in B decay, one requires the inclusive rates for decays $D \to \phi X$ and $F \to \phi X$, which have not yet been measured, and the rate for ϕ production from sources other than D or F. The contribution from the latter is expected to be small since it requires the creation of two $s\bar{s}$ pairs from the sea which, according to the conventional ideas on the fragmentation processes, suffers strong mass suppression. Using the rates for the observed exclusive decay modes of D to ϕ meson we can estimate a lower bound on the contribution of $B \to D \to \phi X$ to the ϕ yield. Measurements of the semileptonic decays of B mesons and of the yield of D^0 and D^{*+} in B decay[8] have shown that the b quark couples predominantly to c. Therefore, we assume a value of 1 for $B(B \to DX)$ and a lower bound of 0.01 for $B(D \to \phi X)$,[9] which results in a lower limit of 0.01 for the rate of the process $B \to D \to \phi X$. This gives an upper bound of 2.7% for $B(B \to FX)B(F \to \phi X)$ at 90% confidence level.

In summary, we have observed ϕ production in the weak decays of B mesons at a rate of $0.023 \pm 0.006 \pm 0.005$ per B. The momentum spectrum of ϕ's from B decay is measured.

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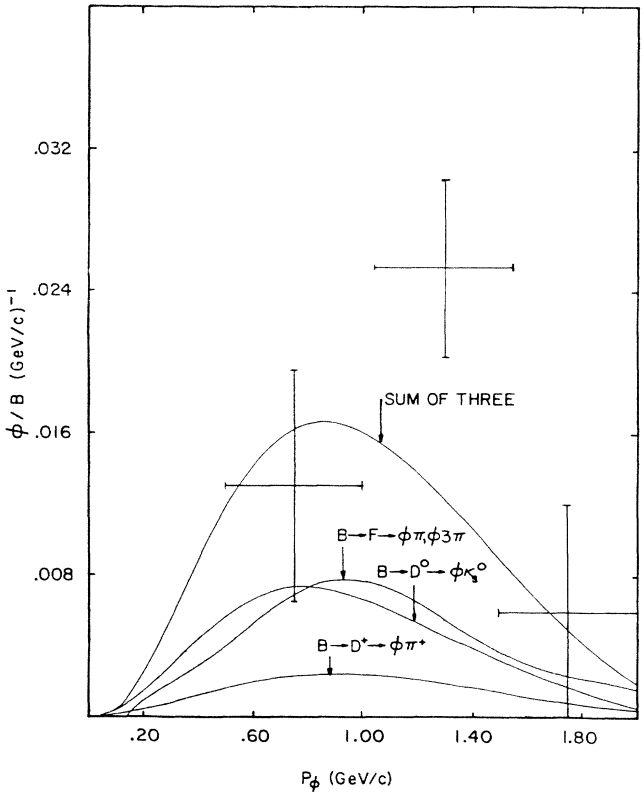

FIG. 3. The momentum distribution of ϕ's from B decay. Curves correspond to Monte Carlo-simulated contributions from $B \to F \to \phi$, $B \to D^+ \to \phi\pi^+$, and $B \to D^0 \to \phi K^0$, where we have used $B(B \to FX)B(F \to \phi X) = 1\%$ and $B(B \to D^+ + D^0)B(D^+ + D^0 \to \phi X) = 1\%$.

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