Decay $D^0 \to \phi \bar{K}^0$

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(Received 5 February 1986)

We have observed a signal for the decay $D^0 \to \phi \bar{K}^0$. We find that a broad threshold enhancement in the K^+K^- mass spectrum in the decay $D^0 \to K^+K^-\bar{K}^0$ is the main source of background to the $D^0 \to \phi\bar{K}^0$ signal. Accounting for this background, we obtain the branching fraction $B(D^0 \to \phi\bar{K}^0) = (1.18 \pm 0.40 \pm 0.17)\%$.

PACS numbers: 13.25.+m, 14.40.Jz

In the spectator model of D-meson decay the charged and neutral D mesons are predicted to have equal lifetimes and equal semileptonic branching fractions. However, present data show convincingly that the D^0 has a shorter lifetime than the D^+, indicating that nonspectator effects are present in D decays.[1] Lifetime and semileptonic-branching-fraction differences could result from quark interference in the final state,[2] resulting in a suppression of nonleptonic D^+ decays, or from quark annihilation by W exchange, which would enhance nonleptonic D^0 decay.[3] The W-exchange amplitude is expected to be suppressed as a result of effects involving helicity and color. However, emission of soft gluons in the initial state or explicit presence of gluons in the wave function may remove the helicity suppression. Theoretical predictions for the contribution of the W-exchange mechanism to D^0 decay range from 1% to 60% of the total D^0 width.[4] The decay $D^0 \to \phi \bar{K}^0$ is believed to be a unique mode which occurs predominantly through the W-exchange process (Fig. 1).[5] In the absence of final-state interactions,[6] the spectator mechanism gives a branching fraction below 10^{-5} for this decay mode.[5] Previous experimental investigations of this decay disagreed on the level of the background from the decay $D^0 \to K^+K^-\bar{K}^0$.[7,8] In this report we show positive evidence for the decay $D^0 \to \phi \bar{K}^0$ and present a measurement of its branching fraction after accounting for the background from $D^0 \to K^+K^-\bar{K}^0$.

The results presented here are from a data sample of 94 pb^{-1} and 381 000 hadronic events obtained with the Cornell Electron Storage Ring CLEO detector in the region of the $\Upsilon(4S)$ resonance. The CLEO detector has been extensively described in a previous publication.[9] The inner tracking system, upgraded in 1984, now consists of a new ten-layer cylindrical precision drift chamber followed by the original larger drift chamber which is now instrumented to provide up to seventeen measurements of the energy deposited (dE/dx) by charged particles. The momentum resolution obtained for high-momentum particles is $\Delta p/p = 0.007p$. Charged-hadron identification was provided by time-of-flight measurements and by dE/dx measurements in the CLEO drift chamber and in the octant proportional wire chambers. The decay $K_S^0 \to \pi^+\pi^-$ was identified by the reconstruction of two oppositely charged tracks whose vertex was displaced from the event origin and whose mass was consistent with the K_S^0 mass.

Phi mesons were reconstructed by computation of the invariant mass of oppositely charged particles, each assigned the kaon mass. In this analysis we did not require explicit kaon identification, but rejected tracks identified as pions or protons. In the K^+K^- invariant-mass distribution, we find a ϕ signal at a mass of 1.0197 ± 0.0010 GeV/c^2 and a width (FWHM) of 0.0055 ± 0.0006 GeV/c^2. A ϕ candidate was required to have $1.015 < m(K^+K^-) < 1.025$ GeV/c^2. We then combined ϕ and K_S^0 candidates and required that the momentum of the combination be greater than 1.0 GeV/c. This momentum cut was subsequently applied to all $K^+K^-K_S^0$ mass spectra described in this Letter. The resulting ϕK_S^0 invariant-mass spectrum is shown in Fig. 2(a). Fitting this distribution with a Gaussian and a polynomial background gives a signal of 36.6 ± 8.0 events at the D^0 mass. The observed width (FWHM) of 17.3 ± 3.2 MeV/c^2 is consistent with a Monte Carlo simulation of the decay in the CLEO detector.

The main source of background to this signal is from the decay $D^0 \to K^+K^-K_S^0$. Making no requirement on $m(K^+K^-)$, we observe a signal of 137 ± 39 events at the D^0 mass. Assuming a phase-space distribution for $m(K^+K^-)$ in the decay $D^0 \to K^+K^-K_S^0$, we estimate that this process contributes a background of 2.0 ± 0.7 events to the observed signal in $D \to \phi K_S^0$. In Fig. 3 we show the $m(K^+K^-)$ distribution for the requirement $1.845 < m(K^+K^-K_S^0) < 1.885$ GeV/c^2.

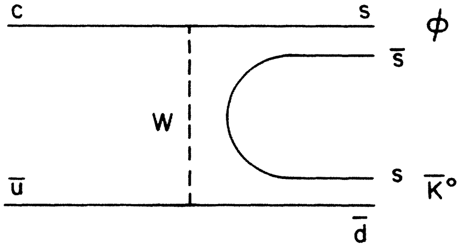

FIG. 1. The W-exchange diagram for $D^0 \to \phi \bar{K}^0$.

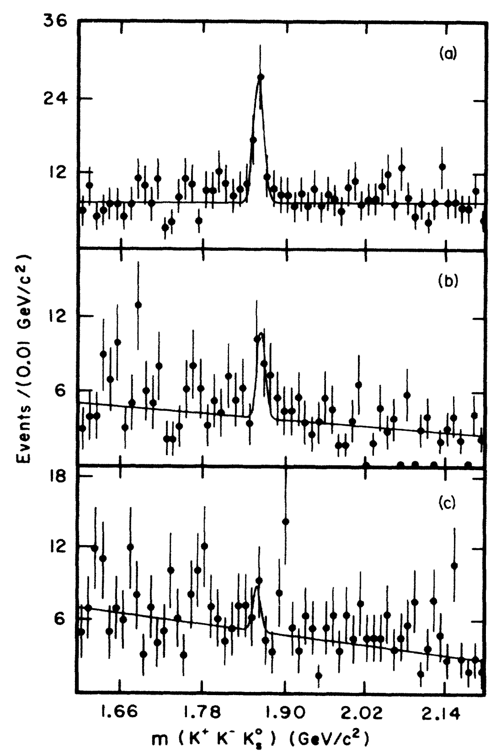

FIG. 2. The $K^+K^-K_S^0$ invariant-mass distribution (a) for $1.015 < m(K^+K^-) < 1.025$ GeV/c^2 (ϕ region), (b) for $1.000 < m(K^+K^-) < 1.010$ GeV/c^2 (low sideband), and (c) for $1.035 < m(K^+K^-) < 1.045$ GeV/c^2 (high sideband).

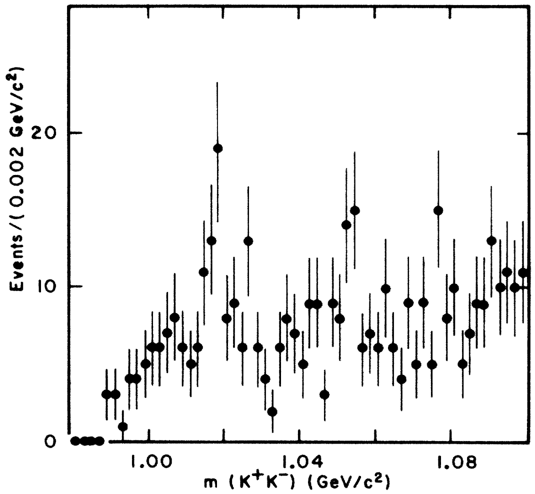

FIG. 3. The K^+K^- invariant-mass distribution for the requirement $1.845 < m(K^+K^-K^0_S) < 1.885$ GeV/c^2.

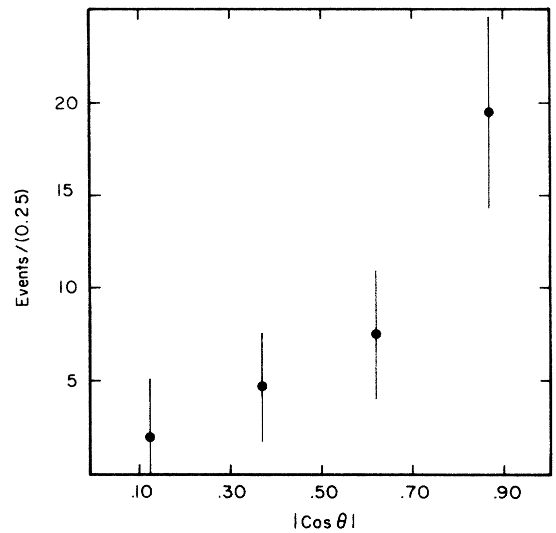

FIG. 4. Distribution of $|\cos(\theta)|$, where θ is the angle of the kaon (K^+) in the ϕ rest frame with respect to the ϕ direction in the D^0 rest frame.

A peak at the ϕ mass is evident. To investigate possible resonant structures in the $m(K^+K^-)$ spectrum near the ϕ region we used two control regions of equal width in $m(K^+K^-)$; a low sideband $1.000 < m(K^+K^-) < 1.010$ GeV/c^2 and a high sideband $1.035 < m(K^+K^-) < 1.045$ GeV/c^2. The high-mass region was chosen farther away from the ϕ mass to reduce the effect of the higher-mass tail of the ϕ peak. Invariant-mass distributions of $K^+K^-K^0_S$ combinations for the low and high sidebands are given in Figs. 2(b) and 2(c), respectively. Fitting these spectra with a Gaussian representing a D^0 signal and a polynomial background, we find a signal of 10.6 ± 4.2 (5.7 ± 4.2) events in the low (high) sideband. This result is inconsistent with a phase-space distribution for $m(K^+K^-)$, indicating the possible existence of resonant enhancement near the threshold in the $m(K^+K^-)$ spectrum from the decay $D^0 \to K^+K^-K^0_S$.

One explanation for the sideband effect would be the presence of the decay $D^0 \to \delta(980)K^0_S$, $\delta \to K^+K^-$. We have used a Monte Carlo simulation of this decay in the detector, incorporating the Flatte parametrization of $\delta(980)$.[10] Integrating the resulting $m(K^+K^-)$ distribution over the three regions of interest, we find the relative weight of the expected signals from the δ channel to be 0.8 for the low sideband, 1.0 for the ϕ region, and 0.9 for the high sideband. Using the weighted average of the observed sideband effects, we predict a background of 9.8 ± 3.5 events from the δ channel in the observed signal of 36.6 ± 8.0 events, indicating a significant signal of 26.8 ± 8.7 $D^0 \to \phi K^0_S$ decays.

However, given the theoretical uncertainties in the shape of the δ and the present limited data sample, the δ hypothesis for the background cannot be accurately tested. We have therefore chosen simply to use the average of the two sideband effects for background subtraction in computing the branching fraction for $D^0 \to \phi \bar{K}^0$. This is nonetheless statistically consistent with our δ analysis.

The angular distribution of kaons from ϕ decay provides additional evidence for the presence of the decay $D^0 \to \phi K^0_S$ in the observed D^0 signal. For the decay $D^0 \to \phi K^0_S$, $\phi \to K^+K^-$, the angular distribution (θ) of the kaons (K^+) in the ϕ rest frame with respect to the ϕ direction in the D^0 rest frame should exhibit a $\cos^2(\theta)$ dependence.[11] A uniform distribution in $\cos(\theta)$ is expected for the kaons (K^+) from the decay $D^0 \to \delta K^0_S$, $\delta \to K^+K^-$. In Fig. 4 the quadratic dependence is evident in the $\cos(\theta)$ distribution for the observed D^0 signal.

In order to compute the branching fraction for $D^0 \to \phi \bar{K}^0$, we have compared the signal in this channel to the signal observed in the $D^0 \to \bar{K}^0 \pi^+\pi^-$ mode, which has a well-established branching fraction. In the $K^0_S\pi^+\pi^-$ invariant-mass distribution we observe a signal of 820 ± 145 events at the D^0 mass. A Monte Carlo simulation of the decays $D^0 \to K^0_S\pi^+\pi^-$ and $D^0 \to \phi K^0_S$ was used to determine the detection efficiencies. This yields efficiencies of 0.157 and 0.038, respectively, for the $D^0 \to K^0_S\pi^+\pi^-$ and $D^0 \to \phi K^0_S$ modes. Subtraction of the above estimate of the background (8.1 ± 3.0 events) from the observed D^0 signal gives a net signal of 28.5 ± 8.5 events. Correcting for efficiencies we obtain

$$B(D^0 \to \phi K^0_S)/B(D^0 \to K^0_S\pi^+\pi^-) = 0.142 \pm 0.049.$$

Using the measured branching fraction $B(D^0 \rightarrow \bar{K}^0\pi^+\pi^-) = (8.3 \pm 0.9 \pm 0.8)\%$ [12] gives $B(D^0 \rightarrow \phi\bar{K}^0) = (1.18 \pm 0.40 \pm 0.17)\%$, where the second error is systematic, resulting from the uncertainty in the branching fraction for $D^0 \rightarrow \bar{K}^0\pi^+\pi^-$. This result is consistent with predictions of the W-exchange models in Ref. 5. We note that the branching fraction into this mode is of the order of the branching fraction for the decay $D^0 \rightarrow \rho^0\bar{K}^0$, $(1.3 \pm 0.4 \pm 0.3)\%$,[12] which is expected to receive a contribution from the spectator diagram as well as the W-exchange process.

Using our signal in $D^0 \rightarrow K^+K^-K_S^0$ and a Monte Carlo–estimated detection efficiency for this decay mode yields the branching fraction $B(D^0 \rightarrow K^+K^-\bar{K}^0) = (2.03 \pm 0.68 \pm 0.28)\%$ in agreement with previous measurements.[7,8] This includes the contribution from $D^0 \rightarrow \phi\bar{K}^0$.

In summary, we have observed a signal for the decay $D^0 \rightarrow \phi\bar{K}^0$ which is evidence for the contribution of a W-exchange diagram to D^0 decay. We attribute about 25% of the observed signal to the background from the enhancement near threshold in the K^+K^- mass distribution from $D^0 \rightarrow K^+K^-K_S^0$.

We gratefully acknowledge the effort of the Cornell Electron Storage Ring staff. Thanks are also due to the Alfred P. Sloan Foundation (from M.G.D.G.), 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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