Observation of a cascade radiative decay of a charmed strange pseudovector meson

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The antineutrino production and cascade radiative decay of a charmed strange pseudovector meson have been observed. The measured masses of the pseudovector meson and of the vector F meson are 2547 ± 60 MeV and 2123 ± 15 MeV, respectively.

As expected,[1,2] the weak transitions $W^{\pm} \to F_V^{*\pm}$, $F_A^{*\pm}$, followed by the scattering of the vector (F_V^*) or pseudovector (F_A^*) charmed strange meson by a nucleon, play an important role in the neutrino production of $F(c\bar{s})$ mesons. This vector-dominance mechanism for F_V^* production was first detected experimentally in Ref. 3, where we observed the radiative decays $F_V^* \to \gamma F^-$ (see also Ref. 4). In the present letter we report a search for radiative decays of pseudovector ($\bar{c}s$) mesons produced in $\bar{\nu}_\mu N$ interactions by the vector-dominance mechanism.

The data which were analyzed were obtained in the antineutrino bombardment of the Fermilab 15-foot bubble chamber with a heavy neon-hydrogen filling. Over the antineutrino energy range 10–200 GeV, the apparatus detected ~ 6600 $\bar{\nu}_\mu N$ interactions with a charged current with an average energy of 34 GeV (the data are described in more detail in Ref. 5).

The method used in this study is a reconstruction of the F^- (1970) meson from the decay products and an analysis of the momentum spectrum of the γ rays in the rest frame of the F^- meson; here the "reconstructed" F^- meson is understood as a set of particles with an invariant mass close to the F mass (the F lifetime is too short for observation of a track in the chamber). The reconstruction of F is carried out on the basis of the decay modes

$$F^- \to \Phi\pi^-,\ \Phi\pi^-\pi^0,\ \Phi\pi^-\pi^+\pi^- \ (\Phi \to K^+K^-,\ K_S^0K_L^0\ ),$$

$$F^- \to K_S^0K^-, K_S^0K^-\pi^0,\ K_S^0K^-\pi^+\pi^-,\ K_S^0K^+\pi^-\pi^-\ .$$

In this connection we note the following: (a) The kaon and pion masses are arbitrarily assigned to charged tracks (not identified as protons or electrons). (b) K^+K^- pairs with masses in the interval 1020 ± 15 MeV (~ 2 calculated standard deviations) are selected in order to find decays $\Phi \to K^+K^-$. (c) In the case of the decay $F^- \to \Phi X$, $\Phi \to K_S^0 K_L^0$, we reconstruct the (spatial) momentum of Φ by simply multiplying the momentum of K_S^0 by a factor $m(\Phi)/m(K^0)$ (K_L^0 is not detected in the chamber).

This approximation is valid because of the small phase space in the decay $\Phi \to K_S^0 K_L^0$. According to calculatons, this approximation leads to "kinematic" errors ~ 95, 75, and 50 MeV for the decay channels $F^- \to \Phi\pi^-$, $\Phi\pi^-\pi^0$, and $\Phi\pi^-\pi^+\pi^-$, respectively, in the reconstruction of the F^- mass. (d) To reconstruct the neutron pions, we select pairs of γ rays with masses in the interval 135 ± 20 MeV, corresponding to the apparent width of the π^0 peak in the $m_{\gamma\gamma}$ distribution. In reconstructing the F^- we require that the mass of the decay system, m differs from $m(F) = 1970$ MeV by no more than one standard deviation: $\Delta m < \sigma$. The latter is calculated for each individual system, through a transfer of the errors in the measurement of the momenta and emission angles of all the particles; it also incorporates in a quadratic manner the "kinematic" error associated with $\Phi \to K_S^0 K_L^0$. The typical values of σ are ~ 100 MeV for the decays $F^- \to \Phi_{00} X^-$ and ~ 50 MeV for the decays $F^- \to \Phi_{+-} X^-$, $K_S^0 K^\pm X$ (Φ_{+-} and Φ_{00} correspond to the decays $\Phi \to K^+ K^-$ and $\Phi \to K_S^0 K_L^0$).

In the rest frame of the F^- meson we analyze the momenta E'_γ of the single γ rays (not combined in π^0), using two selection rules. The first rule (at the event level) is a limitation on the square of the momentum transferred from leptons to hadrons: $Q^2 < 2\ \text{GeV}^2$. The reason for this limitation is that in the vector-dominance model Q^2 is cut off at a level on the order of the square of the meson mass. The second rule (at the combination level) is a cutoff $z > 0.7$ on that fraction of the apparent hadronic energy of the event which corresponds to the γF^- system. This cutoff is aimed at transitions $F^*N \to F^*N$, with a small inelasticity.

Figure 1a shows the momentum distribution of the "single" γ rays. In addition to the enhancement at 100–200 MeV, due to the decay[3,4] $F_V^{*-} \to \gamma F^-$, we observe a cluster in the region 400–600 MeV. This cluster might in principle be due to either a direct radiative decay ($F_A^* \to \gamma F$) or cascade radiative decay ($F_A^* \to \gamma F_V^*, F_V^* \to \gamma F$) or F_A^*. In evaluating the background, we consider the following: (1) a distribution with a "shifted" mass, $1.5 < \Delta m/\sigma < 2.5$ (Fig. 1b); (2) a distribution with the opposite sign ($\Phi\pi^+$, etc.; Fig. 1c).

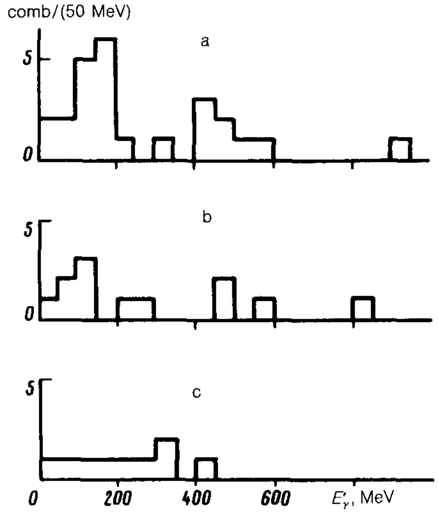

FIG. 1. Momentum spectra of the single γ rays in the c.m. frame. a—For systems of the correct sign with $\Delta m/\sigma < 1$; b—for systems of the correct sign with $1.5 < \Delta m/\sigma < 2.5$; c—for systems of the opposite sign with $\Delta m/\sigma < 1$.

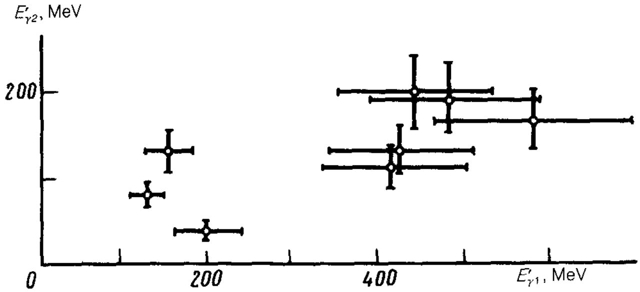

FIG. 2. Two-dimensional distribution in the $E'_{\gamma_1}, E'_{\gamma_2}$ plane for events with two γ rays which contribute to the one-dimensional distribution in Fig. 1a.

A joint analysis of the one-dimensional distributions does not lead to any statistically significant results.

Figure 2 shows a two-dimensional distribution in the plane $(E'_{\gamma_1}, E'_{\gamma_2})$, where $E'_{\gamma_1} > E'_{\gamma_2}$, for events with two single γ rays contributing to the one-dimensional distribution in Fig. 1a. In the two-dimensional region, $400 < E'_{\gamma_1} < 600$ MeV, $100 < E'_{\gamma_2} < 200$ MeV, we observe an isolated group of five "cascade" events. The apparent width of the signal along each of the variables agrees with the resolution (the error in the measurement of the momentum of the γ ray is $\sim 20\%$). Of the two-dimensional background distributions corresponding to Figs. 1b and 1c, the first contains a single point (123 and 67 MeV), while the second contains no point, telling us that the background is low.

Table I shows some characteristics of the "cascade" events (all quantities are expressed in units of megaelectron volts). The most probable interpretation of these events is a cascade radiative decay $F_A^{*-} \to \gamma_1 F_V^{*-}$, $F_V^{*-} \to \gamma_2 F^-$ of a pseudovector $(\bar{c}s)$ meson produced in $\bar{\nu}_\mu N$ interactions by the vector-dominance model along with a vector meson.[3]

The cascade events which are observed make it possible to simultaneously measure the masses of the pseudovector and vector mesons:

$$m(F_A^*) = 2547 \pm 60\,\text{MeV}, \qquad m(F_V^*) = 2123 \pm 15\,\text{MeV}.$$

TABLE I

Decay	$m \pm \sigma$	$E'_{\gamma 2}$	$E'_{\gamma 1}$	$m(F^- \gamma_2)$	$m(F^- \gamma_1 \gamma_2)$
$\Phi_{+-} \pi^- \pi^0$	1994 ± 40	196	447	2157	2549
$\Phi_{+-} \pi^- \pi^+ \pi^-$	1946 ± 26	193	486	2154	2630
$\Phi_{+-} \pi^- \pi^+ \pi^-$	1961 ± 17	131	427	2097	2489
$\Phi_{00} \pi^- \pi^+ \pi^-$	1925 ± 125	165	580	2129	2632
$K_S^0 K^- \pi^+ \pi^-$	1958 ± 24	111	418	2078	2436

Under the condition $m(F_A^*) \gtrsim 2500$ MeV, the strong *s*-wave decay of D^*K should be the absolutely dominant channel for the decay of F_A^*. On the whole, our results show that the mass of F_A^* lies just below the threshold for the D^*K channel ($\simeq$2500 MeV).

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