Search for new charmed strange states in $\tilde{\nu}_\mu N$ and $\nu_\mu N$ interactions

A. É. Asratyan, V. S. Burtovoĭ,[1)] V. A. Gapienko,[1)] G. S. Gapienko,[1)] P. A. Gorichev, A. G. Denisov,[1)] V. G. Zaets, V. I. Klyukhin,[1)] V. I. Koreshev,[1)] S. P. Kruchinin, M. A. Kubantsev, I. V. Makhlyueva, P. V. Pitukhin,[1)] V. I. Sirotenko,[1)] Z. U. Usubov,[1)] A. V. Fedotov, V. G. Shevchenko, and V. I. Shekelyan
Institute of Theoretical and Experimental Physics

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The neutrino production of a new charmed strange state with a mass of 2563.5 ± 5.2 MeV, which decays by the D^*K hadronic channel, has been observed.

Previous studies by our group[1,2] have revealed a low-lying vector state (F_V^*) and pseudovector state (F_A^*) of the charmed strange system ($\bar{c}s$), which form in $\nu_\mu N$ interactions by a vector-dominance mechanism.[3] The states F_V^* and F_A^* lie below the corresponding lower hadronic thresholds DK and D^*K and decay by a radiative mechanism.

In this letter we are reporting a search for the D^*K decays of the new charmed strange states in $\tilde{\nu}_\mu N$ and $\nu_\mu N$ interactions in a 15-foot bubble chamber.[2)]

The method involves analyzing the mass spectra of the systems

$$D^{*+}K^0, \quad D^{*0}K^+$$

with $z > 0.6$, where z is the fraction of the hadronic energy E_H which is carried off by the D^*K system (here and below, we will not write out explicitly the charge-conjugate states). The D^* mesons are identified by a combinatorial approach on the basis of the decays

$$D^{*+} \to \pi^+ D^0,\ \pi^0 D^+,\ \gamma D^+ ; \qquad D^{*0} \to \pi^0 D^0,\ \gamma D^0 \tag{1}$$

with the subsequent D-meson decays

$$\begin{aligned} D^0 &\to K^-\pi^+,\ K^-\pi^+\pi^-\pi^+,\ K^-\pi^+\pi^0,\ K_s^0\pi^+\pi^-, \\ D^+ &\to K^-\pi^+\pi^+,\ K_s^0\pi^+,\ K_s^0\pi^+\pi^0. \end{aligned} \tag{2}$$

The first step is to identify the D mesons on the basis of the invariant mass of the secondary particles in decay channels[3)] (2). Combination (2) is regarded as a candidate for the decay of D (and is designated D_c) if its invariant mass differs from the tabulated mass of the D meson by no more than 1.5 standard deviations:

$$\Delta m \equiv |m(D_c) - m(D)| < 1.5\sigma ,$$

where σ is calculated individually for each combination through a transfer of the measurement errors ($\sigma \sim 50$ MeV). The kaon mass is arbitrarily assigned to the charged meson tracks. In the case $D_c^0 = K^-\pi^+\pi^-\pi^+$, the background is suppressed by imposing the additional cutoff $\cos\theta_K > 0.4$ on the K^- emission angle in the rest frame of D_c^0 with respect to the direction in which D_c^0 is moving in the laboratory frame (an acceptance of 30%). The π^0 mesons are reconstructed as pairs of γ rays with a mass in the interval[2] 135 ± 30 MeV.

In the second step, the D^* mesons are reconstructed from decays (1). Here we make use of the fact that the energy released in the decays $D^* \to \pi D$ is small (~ 6 MeV) and that the γ rays are monochromatic in the decays $D^* \to \gamma D$ (the energy is ~ 150 MeV in the rest frame of the D meson). Designating the candidate combinations by D_c^*, and allowing for the experimental resolutions, we assume

1) $\pi^+ D_c^0$, if $m(\pi^+ D_c^0) - m(D_c^0) - m(\pi^+) < 12$ MeV (acceptance $\sim 90\%$);

2) $\pi^0 D_c^0 = D_c^{*0}$, $\pi^0 D_c^+ = D_c^{*+}$, if $m(\gamma\gamma D_c) - m(D_c) - m(\gamma\gamma) < 20$ MeV (acceptance $\sim 90\%$);

3) $\gamma D_c^0 = D_c^{*0}$, $\gamma D_c^+ = D_c^{*+}$, if the energy of the single γ ray (not combined into a π^0) in the rest frame of D_c lies in the interval 147 ± 44 MeV (~ 1.5 standard deviations).

In the final step we analyze the $D_c^* K$ system. Specifically, we analyze its "modified" invariant mass

$$M = m(D_c^* K) - m(D_c^*) + m(D^*) ,$$

which can be measured considerably more accurately than the "actual" mass $m(D_c^* K)$ can be because the measurement errors cancel out (the respective errors are on the order of 10 and 70 MeV). Figure 1a shows a two-dimensional distribution of $D_c^* K$ combinations with $z > 0.6$ in the variables M and Q^2, where Q^2 is the square of the momentum transfer from the leptons to the hadrons (the filled points correspond to antineutrinos, and the open points to neutrinos).

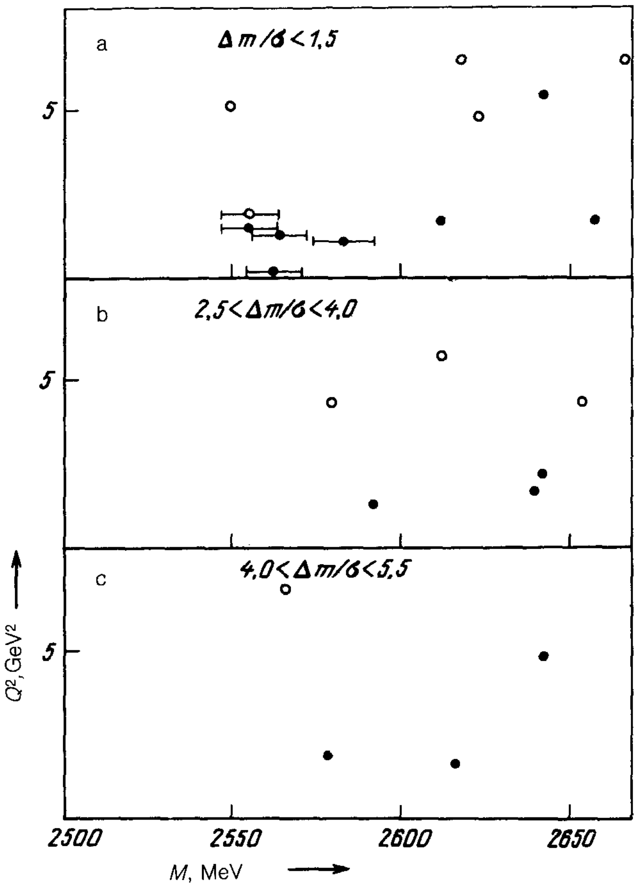

FIG. 1. a—Two-dimensional distributions of D^*K candidates in the variables M and Q^2; b,c—background distributions (explained in the text proper).

In the two-dimensional region $Q^2 < 2$ GeV^2, $2545 < M < 2585$ MeV we observe a cluster of five events with a mean mass $\langle M \rangle = 2563.5$ MeV and a standard deviation of 10 MeV, which is close to the experimental resolution in this region (8 MeV). As backgrounds we consider distributions with a mass of the D_c combination "shifted"

TABLE I.

	E_ν	E_H	Q^2	M	Decay
ν	46.6	12.0	1.97	2.554	$[(K^-\pi^+)\gamma]K^+$
$\tilde{\nu}$	30.9	21.4	0.21	2.562	$[(K^+\pi^-\pi^+\pi^-)\pi^0]K^-$
$\tilde{\nu}$	17.5	8.0	1.50	2.555	$[(K^+\pi^-\pi^0)\gamma]K^-$
$\tilde{\nu}$	30.4	6.1	1.28	2.564	$[(K^+\pi^-\pi^+\pi^-)\pi^0]K^-$
$\tilde{\nu}$	31.6	8.8	1.07	2.583	$[(K^+\pi^-\pi^-)\gamma]K_s^0$

with respect to $m(D)$: $2.5 < \Delta m/\sigma < 4.0$ and $4.0\ \Delta m/\sigma < 5.5$ (Fig. 1, b and c). We see that the background in the vicinity of this cluster is insignificant.

We interpret the observed cluster as D^*K decays of a new $(c\tilde{s})$ state with a mass of 2563.5 ± 5.2 MeV. The small value of Q^2 points to a vector-dominance mechanism for the formation of this state.[3] Despite the strong decays, the decay width of this state is small: $\Gamma < 25$ MeV.

Table I lists some characteristics of the events in the cluster (all quantities are expressed in units of GeV or GeV^2; the combination D_c is given in parentheses, while D_c^* is given in square brackets).

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[1)]Institute of the High-Energy Physics, Serpukhov.
[2)]The sample being analyzed consists of $\sim 5300\ \tilde{\nu}_\mu N$ interactions and $4600\ \nu_\mu N$ interactions of a charged current in the energy interval 10–200 GeV with mean values of 34 and 43 GeV, respectively. The muons are detected by an external muon identifier ($p_\mu > 4$ GeV).
[3)]The lifetime of the D mesons is too short for direct observation of the range in the chamber.

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