Production of neutral strange particles in $\bar{\nu}N$ interactions caused by neutral currents

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The production of neutral strange particles in $\bar{\nu}N$ interactions caused by neutral currents has been studied. Two estimates of the strange neutral current $s_L^2 + s_R^2$ are extracted from the total multiplicity of neutral strange particles and from the multiplicity of K^0 mesons in the current fragmentation region ($z > 0.3$).

Antineutrino experiments are convenient for studying the right and strange weak hadron neutral currents because the relative contribution of these neutral currents to the cross sections for $\bar{\nu}N$ interactions is several times larger than that to the cross section for νN interactions. The results of the measurements of the coupling constants (u_R^2 and d_R^2) for the right neutral current in our antineutrino experiment with the 15-foot bubble chamber have been published previously.[1] In this letter we report a study of the production of neutral strange particles in interactions of neutral currents. This study was carried out to obtain information on the neutral current associated with the strange quark.

The experimental data were obtained from an analysis of 155 000 photographs from a 15-foot bubble chamber bombarded in a wide-band beam of high-energy antineutrinos from the Fermilab accelerator. The bubble chamber was filled with a heavy neon-hydrogen mixture (64% Ne atoms). The energy of the primary protons was 400 GeV. The ν_μ admixture in the antineutrino beam was 6%. In the working volume of the bubble chamber (17 m^3), ~13 000 events initiated by neutral particles and having

TABLE I. Uncorrected and corrected numbers and multiplicities of K^0 mesons and Λ hyperons in the sample of neutral-current interactions with $8 < E_{\text{app}} < 30$ GeV.

	Uncorrected numbers	Corrected numbers	Multiplicities
K^0	126 ± 17	476 ± 66	0,30 ± 0,04
Λ	93 ± 16	192 ± 33	0,12 ± 0,02
V^0	219 ± 23	668 ± 74	0,42 ± 0,05

an apparent energy $E_{\text{app}} > 4$ GeV were detected. The procedure for distinguishing interactions of neutral currents from this complete sample is described in detail in Ref. 1.

In this analysis we used a sample of neutral-current interactions consisting of 1575 ± 73 events with[1] $8 < E_{\text{app}} < 30$ GeV which remained after the interactions of a charged current with a muon momentum[2] $p_\mu > 1$ GeV/c were removed from the total sample. Of the events in the selected sample of neutral-current events, 83% were true neutral-current interactions (70% of $\bar{\nu}_\mu$, 12% of ν_μ, and 1% of $\overset{(-)}{\nu}_e$). The other 17% constituted the background: $11 \pm 4\%$ from the interactions of neutral hadrons (n and K_L^0) and ~6% from the interactions of charged currents with $p_\mu < 1$ GeV/c.

In the neutral-current sample, 200 ± 23 events contained neutral strange particles associated with the primary vertex. Strange particles were identified on the basis of the decays $K_S^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$, as in Ref. 2, where the production of V^0 in a charged current was studied with our statistical base. The first two columns of Table I show the uncorrected numbers of neutral strange particles and the numbers after correction for the detection efficiency and the neutral decay modes (including the K_L^0 loss).

The multiplicities of K^0 mesons and Λ hyperons in the sample of neutral-current interactions are listed in the third column of this table. We did not introduce a correction for the admixture of background interactions in this calculation, since the relative contribution of the background to the neutral-current sample and that to the subsample of neutral-current events with V^0 are comparatively small and approximately equal.[3] Figure 1 shows the distributions of K^0 and Λ in the variable z, defined as the ratio of the hadron energy to the total energy transferred from the lepton to hadrons.

The neutral strange current is responsible for the interactions with the strange (anti) quarks $\overset{(-)}{\nu}\, s \to \overset{(-)}{\nu}\, s$. We used two independent methods to evaluate the ratio of the number of such interactions to the total number of all neutral-current (NC) interactions, $\rho = N^s_{\text{HT}}/N_{\text{HT}}$. a) We used the total multiplicity of neutral strange particles,

$$< n_{\text{NC}}^{V^0} > = 0{,}42 \pm 0.05 \qquad (1)$$

b) We used the K^0 multiplicity in the current fragmentation region ($z > 0.3$),

$$< n_{\text{NC}}^{K^0,\, z > 0{,}3} > = 0.072 \pm 0.016. \qquad (2)$$

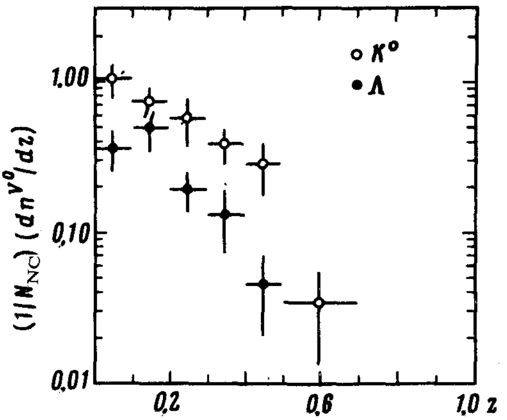

FIG. 1. The z distributions $(1/N_{\rm NC})(dn^{V^0}/dz)$ of K^0 mesons and Λ hyperons in the sample of neutral-current interactions with $8 < E_{\rm app} < 30$ GeV. Here $N_{\rm NC}$ is the number of events in the neutral-current sample.

Each approach is based on the notion that more strange particles are produced in the $\overset{(-)}{\bar{\nu}}\, s \to \overset{(-)}{\bar{\nu}}\, s$ reaction than in interactions with nonstrange quarks. In this reaction, the associative production directly by a pair of "primary" s and $\bar{s}$ quarks of the strange sea of the nucleon is added to the "fragmentation" mechanism for the associative production of strange particles due to the s and $\bar{s}$ pairs produced in the course of the fragmentation of the ejected quark.

A first estimate of ρ was obtained under the assumption that the "primary" $s\bar{s}$ pairs produce, on the average, identical numbers of neutral and charged strange particles, i.e., one of each. The total V^0 multiplicity is then

$$< n^{V^0}_{\rm NC} > \; = \; \rho + < n^{V^0}_{\rm fr} >, \tag{3}$$

where the second term, $\langle n^{V^0}_{\rm fr} \rangle$, corresponds to the "fragmentation" production of V^0. To evaluate this term we used our $\bar{\nu}N$ interactions of charged currents in a region of the apparent hadron energy, $8 < E^H_{\rm app} < 30$ GeV, analogous to that for the sample of neutral-current events. We assumed that the "fragmentation" mechanism in the neutral- and charged-current interactions produces equal numbers of V^0 for a given invariant mass of the hadron system, W. Introducing an additional cutoff in terms of the Bjorken variable[4] $x > 0.2$, to suppress the contribution of interactions with the strange sea, $\bar{\nu}\,\bar{s} \to \mu^+ \bar{c}$, we can write the following expression for the total V^0 multiplicity in charged-current (CC) events:

$$< n^{V^0}_{\rm CC} > \; = \; < n^{V^0}_{\rm fr} > + \; 0{,}5 \sin^2 \theta_C \; = \; 0{,}27 \pm 0{,}03. \tag{4}$$

The second term in (4) allows for the isolated production of V^0 in the transition $\bar{\nu}u \to \mu^+ s$, which is suppressed by the sine of the Cabibbo angle θ_C [as in (3), we have assumed that the s quark produces equal numbers of neutral and charged strange particles].

Substituting $\langle n_{\text{fr}}^{V^0} \rangle$ from (4) into (3), we find

$$\rho = 0{,}18 \pm 0{,}06. \tag{5}$$

In the second approach, which was proposed by Sehgal,[3] we used the K^0 multiplicity in the current fragmentation region ($z > 0.3$). This multiplicity was expressed in terms of ρ and the integrals of the functions representing the fragmentation of the quarks of various types into K^0 ($\overline{K}^0$) mesons, $D_q^{K^0+k^0}(z)$, as follows:

$$< n_{\text{NC}}^{K^0,\, z > 0{,}3} > \; = \; \rho D_s + 0{,}5\,(1-\rho)(D_u + D_d), \tag{6}$$

where $D_q = \int_{0.3}^{1} D_q^{K^0+\overline{K}^0}(z)dz$. The fractions of neutral-current interactions with $\overset{(-)}{u}$ and $\overset{(-)}{d}$ quarks of the nucleon were set equal to each other and to 0.5 $(1-\rho)$.

By measuring the K^0 multiplicities with $z > 0.3$ in our $\bar{\nu}N$ and νN interactions of neutral currents with $W > 3$ GeV and $x > 0.2$ we were able to construct the following combinations of integrals of fragmentation functions:

$$< n_{\text{CC},\,\bar{\nu}}^{K^0,\, z > 0.3} > \; = \; \cos^2\theta_C D_d + \sin^2\theta_C D_s = 0{,}082 \pm 0{,}016, \tag{7}$$

$$< n_{\text{CC},\,\nu}^{K^0,\, z > 0.3} > \; = \; \cos^2\theta_C D_u + \sin^2\theta_C D_c = 0{,}030 \pm 0{,}019. \tag{8}$$

Substituting (7) and (8) into (6), taking $D_s = 0.48 \pm 0.10$ from Ref. 4, and assuming $D_c = D_s$, we find the second estimate

$$\rho = 0{,}09 \pm 0{,}05. \tag{9}$$

These values of ρ are related in the following way to the strange neutral current $g_s^2 = s_L^2 + s_R^2$:

$$\rho = N_{\text{NC}}^s / N_{\text{NC}} = (1/\bar{R})(\sigma_{\text{NC}}^s / \sigma_{\text{CC}}) = (a/\bar{R}) g_s^2 \alpha_{s\bar{s}}, \tag{10}$$

where σ_{NC}^s is the cross section for neutral-current interactions in the strange sea of the nucleon, σ_{CC} is the cross section for charged-current interactions, and $\bar{R}$ is the ratio of the cross sections for the neutral-current and charged-current interactions in the nucleon. Here $\alpha_{s\bar{s}} = \int_0^1 x[s(x) + \bar{s}(x)]dx / \int_0^1 x[q(x) + \bar{q}(x)]dx$ is the momentum of the strange sea divided by the total momentum of all of the (anti) quarks of the nucleon, and the parameter a depends on $\alpha = \int_0^1 x[\bar{u}(x) + \bar{d}(x) + 2\bar{s}(x)]dx / \int_0^1 x[q(x) + \bar{q}(x)]dx$. If we do not introduce a cutoff for the energy and the neutrino admixture we have $a = 4/(1 + 2\alpha)$.

Under our experimental conditions, we have[1] $\bar{R} = 0.41 \pm 0.04$ and $a = 3.6 \pm 0.1$. In calculating a we used our value[5] $\alpha = 0.131 \pm 0.010$.

We use the result $\beta = \int_0^1 x[s(x) + \bar{s}(x)]dx / \int_0^1 x[\bar{u}(x) + \bar{d}(x)]dx = 0.52 \pm 0.09$ obtained by the CDHS group[6] to determine $\alpha_{s\bar{s}}$: $\alpha_{s\bar{s}} = \alpha\beta/(1+\beta) = 0.045 \pm 0.006$. We then find two estimates of g_s^2:

$$g_s^2 = 0{,}45 \pm 0{,}17 \text{ from (5) and } g_s^2 = 0{,}22 \pm 0{,}12 \text{ from (9)}. \tag{11}$$

Using the average value $\rho = 0.12 \pm 0.04$ from our two measurements, we find $g_s^2 = 0.30 \pm 0.11$.

These values of the strange neutral current agree with the measurements by the CHARM group,[7] $g_s^2 = 0.26 \pm 0.06$, and with the prediction of the standard model of the electroweak interaction,(6) $g_s^2 = g_d^2 = d_L^2 + d_R^2 = 0.185$ at $\sin^2\theta_W = 0.23$.

We wish to thank our colleagues at Fermilab and at the University of Michigan for processing and analyzing part of the statistical base of this experiment. We also wish to thank the technical and service staffs of our own institutes for assistance in this experiment.

1) In contrast with Ref. 1, we have not introduced an additional cutoff at a total momentum $P_{T\text{-app}} > 1$ GeV/c for the particles of the event in the direction transverse with respect to the beam. Our intention was to avoid losing interactions of neutral currents involving the strange sea.

2) To distinguish the muons we used an external muon identifier and a kinematic method. Corrections for unobserved charged-current events and for neutral-current events, falsely identified as charged-current events, were made by weighing the observed events. This method made it possible to not only calculate the integral corrections but also to correct the differential distributions.

3) The contribution of the background of neutral hadrons to the subsample of neutral-current interactions with a V^0 ($8 \pm 6\%$) was estimated from the spatial distribution of events with a V^0 in the bubble chamber, in the same manner as for the complete sample of neutral-current events.

4) The average values of W in the sample of charged-current events with $x > 0.2$ and in the sample of neutral-current events were 5.5 and 5.9 GeV, respectively.

5) If we substitute this value of g_s^2 into (10), we find $\alpha_{S\bar{S}} = 0.07 \pm 0.03$ from the average value of ρ.

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[1] P. A. Gorichev *et al.*, Preprint ITÉF-72, Institute of Theoretical and Experimental Physics, Moscow, 1983; V. V. Ammosov *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **39**, 99 (1984) [JETP Lett. **39**, 000 (1984)].

[2] V. Ammosov *et al.*, Nucl. Phys. **B162**, 205 (1980); V. V. Ammosov *et al.*, Nucl. Phys. **B177**, 365 (1981).

[3] L. M. Sehgal, Preprint CERN/SPSC 78-153,SPSC/G 22, 1978.

[4] I. Cohen *et al.*, Phys. Rev. Lett. **40**, 1614 (1978).

[5] V. V. Ammosov *et al.*, Nucl. Phys. **B199**, 399 (1982).

[6] H. Abramowicz *et al.*, Z. Phys. **C15**, 19 (1982).

[7] M. Jonker *et al.*, Phys. Lett. **102B**, 67 (1981).

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