Quasielastic $\nu_\mu + n \to \mu^- + p$ scattering of neutrinos at 2 to 20 GeV in the SKAT bubble chamber

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The cross section and differential distribution dN/dq^2 of the reaction $\nu_\mu n \to \mu^- p$ have been measured at muon-neutrino energies of 2–20 GeV. A value of the parameter $M_A = 0.90 \pm 0.08$ has been determined from the dependence of the quasielastic-reaction cross section on the neutrino energy and a value $M_A = 0.86 \pm 0.18$ has been determined from the analysis of the distribution dN/dq^2.

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The data on quasielastic neutrino scattering

$$\nu_\mu + n \to \mu^- p \tag{1}$$

have been obtained in the SKAT bubble chamber filled with freon bromide (CF_3Br). The bubble chamber was exposed to a wide-band neutrino beam of the IHEP (Institute of High Energy Physics) accelerator. The total discharge of the neutrino channel to the target in the experiment comprised 1.44×10^{17} protons. A total of 1560 neutrino *CC* events (in 80 000 photographs) were recorded in the bubble chamber. We have selected the following events as candidates for the quasielastic reaction:

$$\nu_\mu + A \to \mu^- + mp + np_s + ln_s + A^*, \tag{2}$$

where A and A' are the original and final nucleus, p is the fast proton ($T_{kin} \geqslant 30$ MeV, p_s and n_s are the slow protons and neutrons ($T_{kin} < 30$ MeV), $m = 0.1$, and n, $l = 0, 1, 2 \cdots$.

A negative particle, which did not interact in the visible volume of the bubble chamber, was considered a candidate for the μ^- meson. The positively charged, stopped particles were unambiguously identified as π^+ mesons or protons. The positively charged, interacting particles or those leaving the visible part of the chamber were assumed to be protons.

The following constraints were imposed on the events under investigation.

1. The visible energy E_{vis} of the event must be 3 GeV (in order to eliminate the neutron background).

2. The total longitudinal momentum of the visible reaction products is $P_{vis} > 0.6$ GeV/c.

3. The square of the effective mass of the hadronic component $w_s^2 = M^2 + 2M(E_\nu - E_\mu) - q^2$ must be within the limits $0.2 < w_s^2 < 1.5$ (GeV)^2 (M is the nucleon mass, $E_\nu E_\mu$ is the energy of a neutrino and a muon, and q^2 is the transferred 4-momentum squared).

4. The frame under consideration must have only one event.

Incorporating these constraints, we have selected 121 events to be analyzed as candidates in the reaction (1).

The following processes are the main background sources for the reaction in question. (a) The process $\nu_\mu n \to \mu^- p \pi^\circ$. To estimate the background from this reaction, we have selected the events $\gamma A \to \mu^- p \gamma(\gamma)$, which satisfy the criteria 1-4. After analyzing these events, we were able to estimate this background, which is equal to 1 ± 0.15 event. (b) The reaction $\nu_\mu n \to \mu^- n \pi^+$ (a neutron was not recorded; π^+ meson traversed the visible part of the bubble chamber without an interaction). An estimate of this background from the experimental data gives a value of 3 ± 1 events. (c) Interactions such as $\nu_\mu n \to \nu_\mu p \pi^-$ and $nn \to np\pi^-$ occur when a π^- meson leaves the visible part of the bubble chamber without an interaction. The magnitude of this background is equal to 1 ± 1 event.

Losses occurring in a quasielastic reaction.

1. As in other experiments with complex targets, the largest losses of events in the reaction under investigation are attributable to nuclear effects. Monte Carlo calculations show that protons are rescattered in the nucleus in 29.5% of the cases of a quasielastic scattering. As a result, there are events which do not correpond to the topology of a quasielastic process.

2. Elimination of events with two interactions per frame gives a correction of 11.2%.

3. A single scanning of the reactions with the topology (2) has been achieved with 85% efficiency and double scanning, with 98% efficiency. The total correction is equal to 8 events.

4. The loss of single μ^- mesons comprised 5 events.

The number of candidates for the reaction (1) was estimated to be 198 ± [illegible] (the systematic error of Monte Carlo calculations was 10% of the given number of events), after all the aforementioned factors were taken into account.

The differential cross section for the reaction (1) in the context of the V–A theory of weak interactions is given by (Ref. 1)

$$\frac{d\sigma}{dq^2} = \frac{G^2 \cos\theta_C M^2}{8\pi E_\nu^2}\left\{A(q^2) - \frac{s-u}{M^2} B(q^2) + \left(\frac{s-u}{M}\right)^2 C(q^2)\right\}, \tag{3}$$

where M is the nucleon mass, G is the weak interaction constant, θ_C is the Cabibbo angle, $s-u = 4E_\nu M - q^2 - m_\mu^2$,

$$A(q^2) = \frac{q^2 + m_\mu^2}{4M^2}\left\{F_v^2\left(\frac{q^2}{M^2} - 4\right) + F_M^2\left(1 - \frac{q^2}{M^2}\right)\frac{q^2}{M^2} + 4F_A F_M \frac{q^2}{M^2} + F_A\left(4 + \frac{q^2}{M^2}\right) - \frac{m_A^2}{M^2}\left|(F_v + F_A)^2 + F_A^2\right|\right\};$$

$$B(q^2) = q^2(F_v + F_A)F_A/M^2;$$

$$C(q^2) = \frac{1}{4}\,(F_v^2 + q^2 F_M^2/4M^2 + F_A^2);$$

F_v and F_A are the vector and axial-vector nucleon form factors, and F_M is the weak-magnetism form factor induced by a virtual strong interaction. The effect of a pseudoscalar form factor is ignored. The F_v, F_A, and F_M form factors are generally parametrized in a dipolar manner,

$$F_i = F_i(0)/(1 + q^2/M_i^2)^2. \tag{4}$$

Here $F_v(0) = 1$, $F_M(0) = 3.71$, and $F_A(0) = 1.26$.[2]

We assume that the values of M_v and M_M, which were measured in the electron experiments, are equal to 0.84.

Under the assumptions made above the value of M_A can be determined from the energy dependence of the total cross section for the process (1) (Fig. 1) and from the

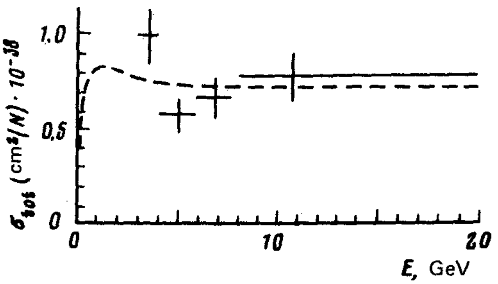

FIG. 1. Transverse cross section of the reaction $\nu_\mu n \rightarrow \mu^- p$, plotted as a function of the neutrino energy. The curve corresponds to $M_A = 0.90$.

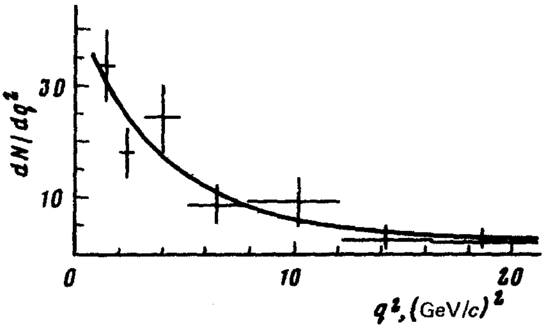

FIG. 2. Differential distribution dN/dq^2 integrated over the neutrino energy spectrum. The theoretical curve corresponds to $M_A = 0.86$.

differential distribution dN/dq^2 (Fig. 2). After fitting these distributions to the appropriate dependences in (3), we obtain the following values of M_A (the errors are statistical):

$$M_A = 0.90 \pm 0.08,$$

$$M_A = 0.86 \pm 0.18.$$

These results are in good agreement with the predictions of the V–A theory and with the results of bubble-chamber experiments carried out at other energies.[3–7]

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