Quasielastic production of Λ hyperon in antineutrino interactions at high energies

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The quasielastic production of a Λ hyperon in antineutrino interactions has been studied experimentally at high energies. The reaction cross section is found to be $(3.4^{+1.1}_{-0.9})\times 10^{-40}$ cm^2, in good agreement with the calculation in the Cabibbo scheme for the value found for the axial mass, $M_A = 1.0 \pm 0.3$ Gev/c^2.

The study of quasielastic antineutrino interactions offers a unique opportunity for direct verification of the Cabibbo scheme[1,2] in the region of spacelike momentum transfer over a broad energy range. In this scheme the ratio R of the cross section for quasielastic reaction proceedings through the charged current with a change in strangeness,

$$\bar{\nu}_\mu p \rightarrow \mu^+ \Lambda , \qquad (1)$$

to the cross section for quasielastic reaction

$$\bar{\nu}_\mu p \rightarrow \mu^+ n \qquad (2)$$

is predicted at the level $0.026 < R < 0.045$. In the GGM-PS bubble chamber experiments,[3,4] this ratio was determined at antineutrino energies in the range $0.5 < E_{\bar{\nu}} < 10$ GeV. In the present letter we report for the first time the determination of reaction yield (1) relative to reaction yield (2), which was studied by us previously,[5] in the energy interval 5–100 GeV.

The experiment was carried out in a 15-foot bubble chamber which was filled with a heavy neon-hydrogen mixture and exposed to broad $\bar{\nu}_\mu$ beam from the Fermilab accelerator. The antineutrino charged-current interactions were identified by an external muon detector. The particular features of the experiment were described in Ref. 6. The events corresponding to reactions (1) and (2) were detected in a special scanning of 71×10^3 photographs. To allow for the rescattering of strange particles by the nucleons of neon nuclei, we included in the sample the events without negatively charged hadrons, which were found in a routine scanning (see Ref. 5 for a more detailed discussion). All V^0 particles were analyzed on the basis of the kinematic-analysis program.[7] The events with V^0 particles, which decay according to the charged modes, were detected with an efficiency of 0.89. We found a total of 14Λ, $1\Sigma^0$, $7\Lambda X^0$, $4\Lambda K^0_S X^0$, $10K^0_S$, $18K^0_S X^0$, $1K^0_S K^0_S$, and $1K^0_S K^0_S X^0$ of the charged-current events, where X^0 are the additional γ rays.

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In our study we have selected events with Λ hyperons and K_S^0 mesons with a mean free path greater than 0.5 cm and less than five decay lengths.[7] The loss of events resulting from the given cutoff, from the inefficiency of scanning and data analysis, from the undetected decay modes (including K_L^0), and from the fact that charged-particle tracks with a range less than 0.5 cm cannot be observed were taken into account by introducing appropriate weights.[7]

The concurrent production of Λ and π^0 mesons and the quasielastic production of a Σ^0 hyperon are responsible in our experiment for the main background in an individual production of a Λ hyperon. For the 14 events of an individual production of a Λ hyperon, observed at a γ-ray detection efficiency[5] of 0.52 ± 0.06, we estimated the background from the production of Λ and π^0 mesons to be 1.8 ± 0.6 events and the background from a quasielastic production of Σ^0 to be $0.7^{+1.0}_{-0.4}$ event. Since we have not detected in our experiment even a single case of associative production of strange neutral particles in the reaction $\bar{\nu}_\mu p \to \mu^+ \Lambda K^0$ [the upper limit of the cross section $\sigma(\bar{\nu}_\mu p \to \mu^+ \Lambda K^0) < 2.3 \times 10^{-40}$ cm^2 at the 90% confidence level], we ignored the background from the associative production of Λ and K^0. The corrected number of events in reaction (1) is $26.9^{+8.6}_{-6.5}$. Using the number of events and the cross section for reaction (2) determined in Ref. 5, we found the ratio $R = 0.038^{+0.012}_{-0.009}$ and the cross section $\sigma(\bar{\nu}_\mu p \to \mu^+ \Lambda) = (3.4^{+1.1}_{-0.9}) \times 10^{-40}$ cm^2. Working in a similar way, we found the cross section for quasielastic reaction $\bar{\nu}_\mu p \to \mu^+ \Sigma^0$ to be $(0.6^{+0.9}_{-0.4}) \times 10^{-40}$ cm^2.

In the Cabibbo scheme, the cross section for reaction (1) can be determined by integrating over the 4-momentum transfer (Q^2) an expression of the type[8]

$$\frac{d\sigma}{dQ^2} = \frac{3G_F^2 \sin^2\theta_C}{4\pi}\left(F_V^2 + F_A^2 + \frac{Q^2}{(m_p + m_\Lambda)^2} F_M^2\right), \qquad (3)$$

which is valid in the limit $E_{\bar{\nu}} m_p$. Here G_F is the Fermi constant; θ_C is the Cabibbo angle; m_p and m_Λ are the masses of the proton and Λ hyperon, respectively; and the form factors F_V, F_M, and F_A are described in the dipole form

$$F_V = \frac{1}{(1 + Q^2/M_V^2)^2}, \qquad F_M = F_M(0) F_V, \quad \text{and} \quad F_A = \frac{F_M(0)}{(1 + Q^2/M_A^2)^2},$$

where $M_V = 0.84$ GeV/c^2, $F_M(0) = 1.79$, and $F_A(0) = 0.70$.

To determine the unknown axial mass M_A, we used the Q^2 distribution of the events of the quasielastic production of Λ. In the case of the 14 events of an individual production of a Λ hyperon, found from the known direction of the antineutrino flight path and under the assumption that the interaction between the proton at rest and the target is a quasielastic interaction, we have used the Q_1^2 distribution from the measured muon momentum and the Q_2^2 distribution from the measured Λ momentum to determine the 4-momentum transfer. A comparison of these two quantities for each event showed that all events of the individual production of Λ lie in the region $|Q_1^2 - Q_2^2| < 0.5(\text{GeV}/c)^2$.

A weighted Q_1^2 distribution of the 14 events, corrected for the background, is

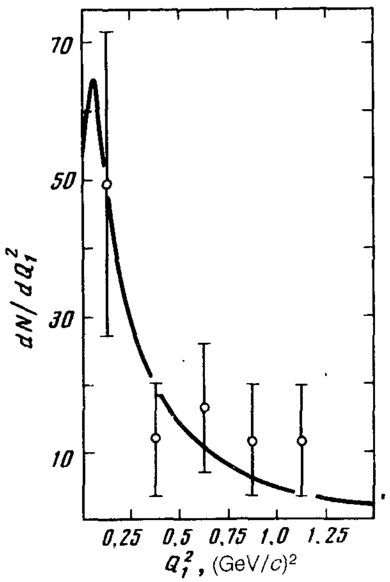

FIG. 1. The weighted Q_1^2 distribution of the events of quasielastic production of a Λ hyperon. The curve was calculated in the Cabibbo scheme with $M_A = 1.0 \pm 0.3$ Gev/c^2 and corrected with allowance for the experimental conditions.

shown in Fig. 1. We have used this distribution, whose shape is not affected by the scattering of Λ by the nucleons of the neon nuclei, to obtain a fit for expression (3) by the maximum-likelihood method. The axial mass was thus found to be $M_A = 1.0 \pm 0.3$ GeV/c^2. The curve in Fig. 1, the result of the fit, was corrected for the anticipated loss of Λ, whose decay products have a less than 0.5-cm mean free path.

The value of M_A which we found is consistent with the value $M_A = 0.92 \pm 0.21$ GeV/c^2 found in Ref. 3. As a result of integrating expression (3) over Q^2, we found the cross section $\sigma(\bar{\nu}_\mu p \to \mu^+ \Lambda) = (3.1^{+0.8}_{-0.6}) \times 10^{-40}$ cm^2, consistent with the value found from the ratio R. Figure 2 is a plot of the cross section for reaction (1) found from the ratio R, along with the experimental data of Refs. 3 and 4. The dependence of the reaction cross section (1) on the antineutrino energy, calculated in the Cabibbo

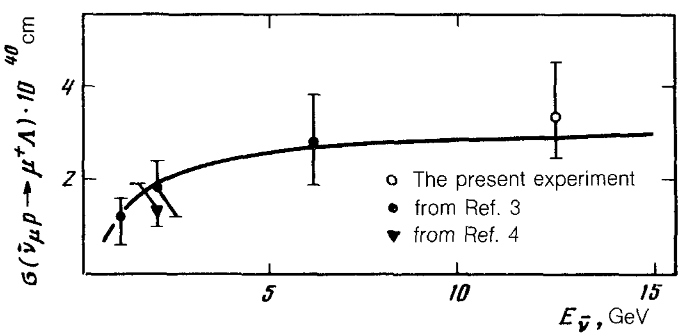

FIG. 2. Cross section for quasielastic production of a Λ hyperon versus antineutrino energy. The curve—calculation in the Cabibbo scheme with $M_A = 1.0 \pm 0.3$ GeV/c^2.

scheme with $M_A = 1.0$ GeV/c^2 (the curve in Fig. 2) is in good agreement with the experimental data.

We wish to note in conclusion that the quasielastic production of a Λ hyperon in antineutrino interactions was studied here for the first time at high energies 5–100 GeV. The value of the ratio of the cross sections for reactions (1) and (2), $R = 0.038^{+0.012}_{-0.009}$, are in good agreement with the predictions of the Cabibbo scheme, which gives for the axial mass $M_A = 1.0 \pm 0.3$ GeV/c^2 found by us the cross section $(3.1^{+0.8}_{-0.6}) \times 10^{-40}$ cm^2 for reaction (1). This cross section coincides, within the error margin, with the cross section $\sigma(\bar{\nu}_\mu p \to \mu^+ \Lambda) = (3.4^{+1.1}_{-0.9}) \times 10^{-40}$ cm^2 found from the ratio R.

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