HYPERON PRODUCTION BY ANTINEUTRINOS AND SELECTION-RULE TESTS

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ABSTRACT

Rates are estimated for hyperon production in antineutrino experiments in the 25-ft bubble chamber (hydrogen target surrounded by neon). Possible tests of the weak-interaction selection rules in antineutrino interactions are enumerated.

I. HYPERON PRODUCTION

A major aim of future antineutrino experiments is to establish the hyperon production processes

$$\begin{aligned} &\bar{\nu} + p \to \mu^+ + \Lambda \quad &(a)\\ &\bar{\nu} + p \to \mu^+ + \Sigma^0 \quad &(b)\\ &\bar{\nu} + p \to \mu^+ + \Sigma^- \quad &(c) \end{aligned} \qquad (1)$$

to measure their rates and test thereby the Cabibbo theory, and to measure the form factors determining these $\Delta S = \Delta Q = 1$ processes. The cross sections for (1) have been calculated by Cabibbo and Chilton[1] based on the SU_3 model of weak interactions proposed by Cabibbo.[2] For reference the baryon matrix elements for (1) in the exact SU_3 limit may be given here:

$$\left\langle p \middle| J_\alpha \middle| \Lambda \right\rangle = \frac{-G}{\sqrt{2}} \cdot \sqrt{\frac{3}{2}} \cdot \sin\theta \cdot \left[\gamma_\alpha + \frac{\mu p}{2M} \sigma_{\alpha\beta} \, q_\beta + \frac{1+2x}{3} \lambda \gamma_\alpha \gamma_5 \right] F\,(q^2)\,,$$

$$\left\langle n \middle| J_\alpha \middle| \Sigma^- \right\rangle = \frac{G}{\sqrt{2}} \sin\theta \cdot \left[\gamma_\alpha + \frac{\mu_p + 2\mu_n}{2M} \sigma_{\alpha\beta} \, q_\beta - (1-2x) \lambda \gamma_\alpha \gamma_5 \right] F(q^2)\,.$$

μ_p, μ_n are the anomalous magnetic moments of proton and neutron, x is the ratio of f to d coupling and has been taken from Σ^- decay to be 0.25, λ is the ratio of axial to vector coupling constant ($\lambda = 1.2$). The q^2 dependence of the axial vector form factor has been assumed to be the same as for the vector form factor:

$$F(q^2) = \left(1 + \frac{q^2}{M^2}\right)^{-2} .$$

The cross-section curves calculated from this theory are shown in Fig. 1. [They differ from the ones given in Ref. 1 where the interference term in Eq. (28) has the wrong sign.[3]]

Assuming M = 0.89 GeV and the antineutrino spectrum of Fig. 1 of the group D1b report, the following rates can be predicted: In a 10-foot H or D target using $2 \cdot 10^{19}$ protons, $520\,\Lambda^o$, $320\,\Sigma^-$, and $160\,\Sigma^o$ could be produced.

In order to obtain an estimate of Y_1^* production by antineutrinos, the calculations of Albright and Liu[4] represented in Fig. 2 have been used together with the predictions by Adler[5] for the process $\bar{\nu} + N \rightarrow N^* + \mu^+$ of $\sigma = 0.6 \times 10^{-38}\,cm^2$, yielding 200 Y_1^*'s.

It may be noted that these rates could actually be up to 10 times larger in special low-energy-enhanced antineutrino beams. Then tests of the form-factor assumptions or even separate determination of several form factors will become possible.

II. TESTS OF SELECTION RULES

The ratios and/or the absence of certain antineutrino reaction rates can be used to test whether selection rules derived from the absence of corresponding hyperon decays are also valid in production processes and at higher energy. The importance of this question is obvious, since the whole Cabibbo scheme is based on the empirical pair of selection rules

a) $\Delta S = 0, \ \Delta T = 1$

b) $\Delta S = 1, \ \Delta T = 1/2$

which imply

c) $\Delta S \leq 1$ and

d) $\Delta S = \Delta Q$.

Rule a) can be tested in

$$\frac{\bar{\nu} p \rightarrow \mu^+ N^{*o}}{\bar{\nu} n \rightarrow \mu^+ N^{*-}} = \frac{1}{3} ,$$

rule b) in

$$\frac{\bar{\nu} n \rightarrow \mu^+ \Sigma^-}{\bar{\nu} p \rightarrow \mu^+ \Sigma^o} = \frac{1}{2} ,$$

rule c) by the absence of

$$\left.\begin{array}{l}\bar{\nu}n \to \mu^+ \Xi^- \\ \bar{\nu}p \to \mu^+ \Xi^o \\ \bar{\nu}p \to \mu^+ + (\Sigma^+ + K^-) \\ \bar{\nu}p \to \mu^+ + (\Omega^- + K^+)\end{array}\right\} \Delta S = 2$$

or

$$\bar{\nu}n \to \mu^+ + \Omega^- \qquad \Delta S = 3;$$

rule d) comparison of ν and $\bar{\nu}$ production of $S = -1$ hyperons, which is forbidden for neutrinos by rule d). Another possible test of $\Delta S = \Delta Q$ and $\Delta S \leq 2$ using K^o production by antineutrinos is described by Roe.[6]

III. EXPERIMENTAL REQUIREMENTS

Beam: Since the cross-section curves for all the reactions considered are predicted to level off above about 2-GeV antineutrino energy, a study of hyperon production by antineutrinos will preferably be performed in a low-energy-enhanced neutrino beam and could be combined with the form factor studies of the other quasi-elastic neutrino and antineutrino interactions.

Detector: Since the interactions should occur on free or quasi-free neucleons and since the observation of vertex details is essential for event identification, a H_2 or D_2 bubble chamber is the most suitable detector. Many of the hyperon decay products are neutrals requiring a high-density liquid for their detection. Hence, it is highly recommended to use the proposed two-liquid bubble-chamber technique: to use a large H_2 or D_2 target inside the Ne-filled "25-foot" bubble chamber.

REFERENCES

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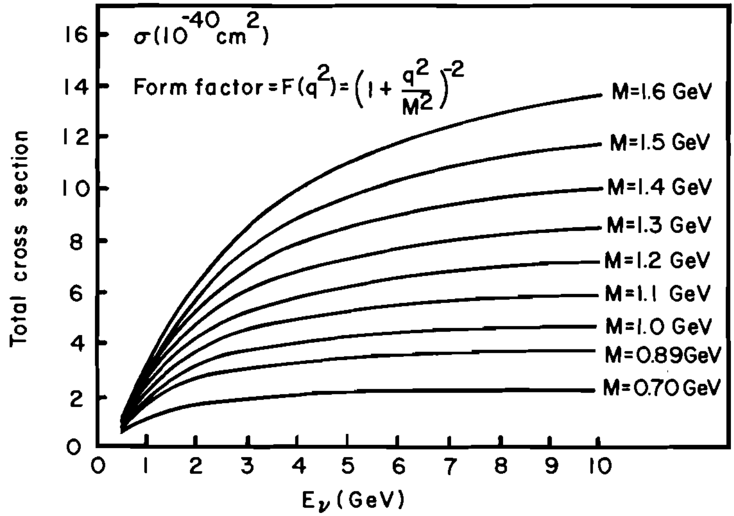

Fig. 1(a). Total cross section for $\overline{\nu} + p \rightarrow \Lambda^{0} + \mu^{+}$ as a function of antineutrino energy E_{ν}.

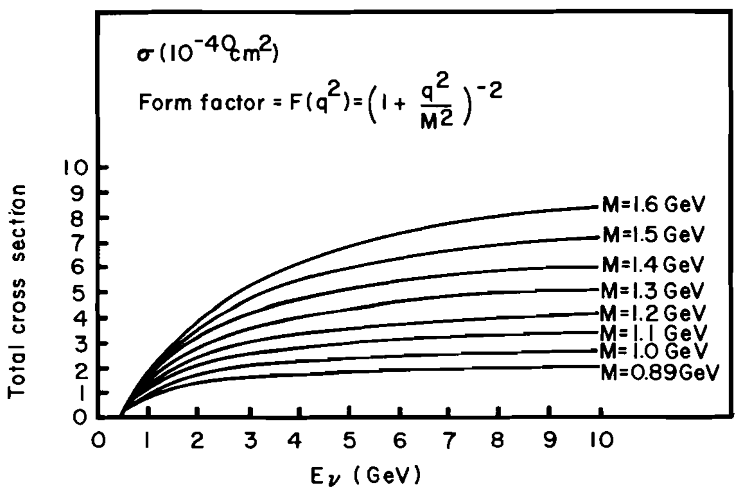

Fig. 1(b). Total cross section for $\nu + n \rightarrow \Sigma^{-} + \mu^{+}$ as function of antineutrino energy E_{ν}.

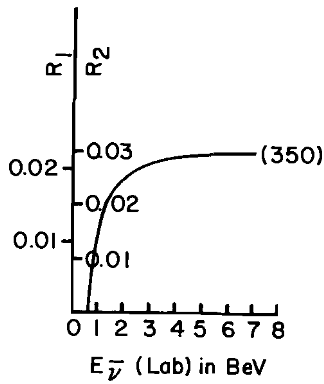

Fig. 2. Anti-neutrino cross-section ratios for Y_1^* compared to N^* production. Here

$$R_1 = \frac{\sigma(\bar{\nu}_\mu + N \rightarrow Y_1^{*-} + \mu^+)}{\sigma(\bar{\nu}_\mu + N \rightarrow N^{*-} + \mu^+)} \quad \text{and} \quad R_2 = \frac{\sigma(\bar{\nu}_\mu + p \rightarrow Y_1^{*o} + \mu^+)}{\sigma(\bar{\nu}_\mu + p \rightarrow N^{*o} + \mu^+)} .$$