Production of $N^*$ in Neutrino Reactions (*)

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Summary. — The production cross-section of the $N^*$ pion-nucleon isobar in neutrino-reactions is calculated. In order to determine the values of some of the form factors, the conserved vector current theory and the Goldberger-Treiman relation have been used. The high-energy behavior of the total cross-section is shown to depend rather sensitively on the high-momentum transfer behavior of the form factors.

1. — Introduction.

Recently, a considerable number of single-pion production events have been observed in the neutrino-nucleon collision experiment. These events are now believed to be predominantly associated with the production of the $N^*$ pion-nucleon isobar ($T=J=\frac{3}{2}$) which decays into a pion and a nucleon. While the calculations of the production cross-section of the isobar have been reported in the past (1-3), their authors, obeying either simplicity or considerations based on specific models, have retained only a few of the possible form factors. In contrast, our calculation retains all form factors consistent with Lorentz invariance and the notion of the current $\times$ current structure of leptonic weak interactions. We shall discuss the behavior of the pion production total cross-section for several alternative behaviors of the form

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(1) M. Veltman: Proceedings S.I.F., Course XXXII (1964) (to be published); S. Berman and M. Veltman: preprint.

(2) R. H. Good jr., et al.: preprint.

factors at high momentum transfers. As expected, the high-energy behavior of the total cross-section is shown to depend rather sensitively on the high momentum transfer behavior of the form factors.

2. - Calculation of the production cross-section.

The matrix element for the reaction $\nu^+ N \rightarrow l^- + N^{*}$ may be written as

$$\mathcal{M} = \frac{G}{\sqrt{2}} \bar{u}_f \gamma_\mu (1 + \gamma_5) u_\nu \langle N^{*} | V_\mu + A_\mu | N \rangle,$$

where $G$ is the universal Fermi coupling constant. The matrix elements of the vector and axial vector currents $V_\mu, A_\mu$ are

$$\langle N^{*} | V_\mu | N \rangle = \bar{\omega}_v(p') \left\{ (\delta_{\mu\nu} - q_\mu q_\nu / q^2) F_v(q^2) + \right.$$  
$$+ i q_\mu [\gamma_\mu - i (m + m')q_\mu / q^2] G_v(q^2) / m + i q_\mu q_\nu H_v(q^2) / m^2 \right\} \gamma_u u(p),$$

$$\langle N^{*} | A_\mu | N \rangle = \bar{\omega}_v(p') \left\{ \delta_{\mu\nu} F_a(q^2) + i q_\mu \gamma_\mu G_a(q^2) / m + 
$$  
$$+ q_\mu (p' - p')_\nu H_a(q^2) / m^2 + q_\mu q_\nu F_a(q^2) / m^2 \right\} u(p),$$

where $\omega_v(p')$ is the Rarita-Schwinger wave function (1) for the isobar and $u(p)$ is the nucleon spinor, $q = p' - p$ is the momentum transfer and $m$ and $m'$ are masses of the nucleon and isobar, respectively. The form factors $F_v(q^2)$ are relatively real on the basis of the time reversal invariance. In deriving eq. (2) we have used the conserved current hypothesis. Since $V_\mu$ is assumed to be the conserved isotopic spin current, $F_v(0), G_v(0)$ and $H_v(0)$ may be determined from the analysis of photoproduction of the isobar. From the analysis of Gourdin and Salin (6), we obtain

$$\begin{align*}
F_v(0) &= \sqrt{3} F_{1}^{(\text{em})}(0) \approx 9.70, \\
G_v(0) &= -\sqrt{3} F_{2}^{(\text{em})}(0) \approx 4.33, \\
H_v(0) &\approx 0.
\end{align*}$$

Further, the usual argument (8) used in deriving the Goldberger-Treiman rela-

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