MESON PRODUCTION BY NEUTRINOS INCIDENT ON NUCLEONS

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ABSTRACT

Production and exchange of non-strange pseudoscalar and vector mesons is considered in the peripheral model. For non-strange mesons a consequence of this model is that the corresponding ν and $\bar{\nu}$ cross-sections are equal, assuming that ν and $\bar{\nu}$ couple to the same isospin multiplet. The cross-section for production of ρ and ω with π exchange, with and without simultaneous excitation of the $3/2, 3/2$ resonance, is found to be a fraction (with strong dependence on badly known form factors) of the "elastic" cross-section, $\sigma(\nu + n \rightarrow p + \rho^-)$, at a few GeV incident neutrino energy. Production of π and η mesons with ρ and ω exchange is computed also, and is found to be very small.

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1. INTRODUCTION

It is conceivable that vector mesons play an important role in the inelastic pion production by neutrinos incident on nucleons as observed in the CERN neutrino experiment ¹⁾. Production of single pions ^{2),3)} and kaons ^{4),5)} has been discussed by several authors. Here we consider peripheral meson production involving non-strange vector and pseudoscalar mesons.

In Section 2 we compute cross-sections for events of the type $\nu + N \rightarrow N' + \mu^- + b$ where b is a ρ or ω . In Section 3, cross-sections for events of the type $\nu + N \rightarrow \mu^- + b + X$ are considered, where X represents the final state in the reaction $\pi + N \rightarrow X$. Production of π , η mesons by vector meson exchange is computed in Section 4 and is found to be very small.

2.

2. CROSS-SECTIONS FOR ρ AND ω PRODUCTION

The cross-sections for ρ and ω production are computed according to the peripheral Feynman diagram in Fig. 1a. The four-momentum associated with each particle is indicated in parentheses. Considering only non-strange particles, the possible reactions indicated in graph 1a are:

In these reactions the meson current coupled to the leptons transforms supposedly as the + component of an isovector. The antineutrino reactions are found by replacing ν by $\bar{\nu}$ and taking the isospin - part of the meson current; apart from very small effects of electromagnetic origin (e.g., n, p mass difference, etc.) the corresponding neutrino and antineutrino cross-sections are equal. This is a situation peculiar to this model, and depends entirely on the assumption that ν and $\bar{\nu}$ couple to the same isospin multiplet, or equivalently (if time reversal invariance holds), that the meson current is of the first kind under G parity⁶). From the isospin properties we find, apart from small electromagnetic effects again,

$$\sigma(\nu + p \rightarrow p + \nu^- + \rho^+) = \sigma(\nu + n \rightarrow n + \nu^- + \rho^+) = \frac{1}{2} \sigma(\nu + n \rightarrow p + \nu^- + \rho^0).$$

Thus there are two independent cross-sections which we take to be $\sigma(\nu + n \rightarrow p + \nu^- + \omega)$ and $\sigma(\nu + p \rightarrow p + \nu^- + \rho^+)$.

The lepton-meson vertex of graph 1a is given by:

$$i \bar{U}_\mu(k') \gamma_\alpha (1 + \gamma_5) U_\nu(k) \langle b | J_\alpha^V + J_\alpha^A | B \rangle. \quad (1)$$

The leptonic part is as usual, and J^V and J^A are the vector and axial vector components of the mesonic weak current ^{*)}. Requiring now that $G J^V G^{-1} = J^V$ and $G J^A G^{-1} = -J^A$ (where G is the G-parity operator) implies that either $\langle b | J^V | B \rangle$ or $\langle b | J^A | B \rangle$ is absent, for under G :

$$\langle b | J^V + J^A | B \rangle = g_b g_B \langle b | J^V - J^A | B \rangle \quad (2)$$

where g_b and g_B are the G-parities of b and B (equal to ± 1), and therefore

$$\langle \omega | J^A | \pi \rangle = \langle \rho | J^A | \eta \rangle = \langle \rho | J^V | \pi \rangle = 0.$$

Considering omega production by pion exchange ($b = \omega, B = \pi^-$), the coupling strength of the $\pi - \omega$ current to the lepton current for $(k-k')^2 = 0$ may be found from the observed (purely $\Delta I = 1$) $\omega \rightarrow \pi^0 + \gamma$ decay rate ⁷⁾ and CVC theory ⁸⁾. The lepton-meson vertex is then given by (momenta defined in Fig. 1a):

$$i g_V \bar{U}_\mu \gamma_\alpha (1 + \gamma_5) U_\nu \epsilon_{\alpha\beta\rho\sigma} \frac{S_\beta \not{k}' \not{k} S_\sigma}{F_\ell} F_\ell([k-k']^2) \quad (3)$$

where F_ℓ is a form factor with $F_\ell(0) = 1$. Furthermore, $g_V \equiv \lambda G$ and λ^2

^{*)} We use the metric $k'^2 = \vec{k}'^2 + k_4^2 = \vec{k}'^2 - k_0^2 = -m_\mu^2$.

is found ⁵⁾ to be 7.5 GeV^{-2} ; G is the weak coupling constant $G^2_{\text{P}} \approx 10^{-5}$, and S_β is the omega linear polarization vector with $S_\beta q'_\beta = 0$. Note that the meson current is conserved, i.e., $(q'-q)_\alpha \epsilon_{\alpha\beta\mu\nu} S_\beta q'_\mu q_\nu = 0$. Thus, according to Adler ⁹⁾, if the lepton factor is proportional to $(q'-q)$, as happens if the ν (with m_ν taken to be 0) is in the forward direction, the cross-section will be zero. At the nucleon-pion vertex the usual pseudoscalar coupling is used, namely:

$$i\sqrt{2} g_{N\pi} \bar{U}_N \gamma_5 U_N F_B(q^2) \quad (4)$$

where $g_{N\pi}^2/4\pi \approx 15$, and F_B is a form factor with $F_B(0) = 1$.

With these vertices the following differential cross-section is obtained for omega production (averaging over incident spins and summing over outgoing spins):

$$d\sigma = \frac{\lambda^2 G^2 g_{N\pi}^2 F_\pi^2 ([k-k']^2) F_B^2(q^2) (q^2 + \Delta M^2)}{(2\pi)^5 (-P \cdot k) (q^2 + m_\pi^2)^2} \times$$

$$\delta_4(k + q' + P' - P - k) \left\{ k \cdot q' \left[(q \cdot q') (k \cdot q) - q^2 (q' \cdot k) \right] + \right.$$

$$\left. k \cdot q \left[(q \cdot q') (k' \cdot q') + m_\pi^2 (q \cdot k) \right] \right\} \frac{d_3 \vec{q}'}{q'_0} \frac{d_3 \vec{k}'}{k'_0} \frac{d_3 \vec{P}'}{P'_0} \quad (5)$$

where momenta are again defined in Fig. 1a, and $\Delta M = M_N - M_{N'}$. The total cross-section may be trivially reduced to a four-dimensional integral, and it was then numerically integrated. All numerical integrations were done on the CERN 7090 computer.

The form factors were taken to be of the Clementel-Villi type¹⁰⁾:

$$F_\ell(\{k-k'\}^2) = \left[1 + \frac{\{k-k'\}^2}{M_{F\ell}^2} \right]^{-1} ; \quad F_B(q^2) = \left[1 + \frac{q^2}{M_{FB}^2} \right]^{-1} . \quad (6)$$

The total cross-section is very dependent on the choices of $M_{F\ell}$ and M_{FB} . The π -N coupling gives rise to the $(q^2 + \Delta M^2)$ factor in Eq. (5), partly cancelling the $(q^2 + m_B^2)^{-2}$ of the propagator and making high q^2 values more important (which is, in fact, contrary to the spirit of the peripheral model). The strong dependence on $M_{F\ell}$ arises from the fact that σ is zero if the muon is in the forward direction, as noted above. Explicitly this may be verified by observing that the dot products in the $\{ \}$ in Eq. (5) may be reduced to:

$$\{ \} = -\frac{1}{2} (k-k')^2 \left[(k \cdot q')^2 + (k' \cdot q')^2 + \frac{m_b^2}{2} (k-k')^2 \right]$$

where terms in m_μ^2 are neglected. Thus F_ℓ clearly plays an important role in the cross-section obtained from Eq. (5). Table 1 lists the total production cross-section for several choices of form factors. We see that the cross-section is approximately proportional to the lepton form factor mass squared ($\sigma \sim M_{F\ell}^2$).

Finally it is now immediately possible to estimate ρ production by η exchange on the basis of graph 1a ^{*)}. Generalizing the Cabibbo weak coupling scheme ¹¹⁾ by requiring that the meson current be an octet ^{**)}, the η , ρ and π , ω couplings to the leptonic current are identical. Therefore Eq. (5) is valid for ρ production by η exchange if we make the substitution $2g_{N\pi}^2 \rightarrow g_{N\eta}^2$ and if we use the masses appropriate to the ρ, η case. The coupling constant $g_{N\eta}^2$ has been estimated by de Swart ¹²⁾ on a unitary symmetry model, and he finds $g_{N\eta}^2 \ll g_{N\pi}^2$. The high mass in the propagator also reduces production. Therefore, ρ production by η exchange is very much smaller than ω production by π exchange.

Graph 1a may also be used to compute ρ production with π exchange. In this case the meson-lepton coupling is pure axial vector, and we take for the lepton vertex

$$ig_A \bar{U}_\nu \gamma_\alpha (1 + \gamma_5) U_\mu S_\alpha F_\ell(\{k, k'\}^2), \quad (7)$$

where S_α is the linear ρ polarization vector ($q'_\alpha S_\alpha = 0$) and derivative couplings are ignored. This interaction is equivalent to the usual β -decay or ρ -capture axial vector interaction in the sense that the quantum numbers of the exchanged systems are the same. In addition there will be a term like the induced

*) We can treat the ρ as a stable particle because:

- a) $\Gamma(\rho \rightarrow \pi + \pi)$ is a slowly varying function of m_ρ ($\Gamma \sim m_\rho$),
- b) $[\Gamma(\rho \rightarrow \pi + \pi)/2m_\rho]^2 \ll 1$, and
- c) $\sigma(\nu + N \rightarrow N + \rho^- + \rho^+)$ can be closely approximated by a linear function of the ρ mass in the interval $0.75 \text{ GeV} - \frac{1}{2} \Gamma_\rho < \rho \text{ mass} < 0.75 \text{ GeV} + \frac{1}{2} \Gamma_\rho$.

**) We are indebted to Professor V. Telegdi for suggesting to us this generalization of the Cabibbo scheme.

pseudoscalar, presumably dominated by the one-pion pole. The coupling constant g_A may now be estimated by a Goldberger-Treiman¹³⁾ argument. In analogy with the β -decay case,

$$\langle \nu | J_\alpha^A | \pi \rangle = g_A S_\alpha + \frac{S_\beta (q' - q)_\beta (q' - q)_\alpha g_{\pi\pi\rho} g_{\pi\ell}}{(q' - q)^2 + m_\pi^2}$$

and

$$\langle \nu | \frac{\partial J_\alpha^A}{\partial x_\alpha} | \pi \rangle = S_\alpha (q' - q)_\alpha \left\{ g_A + g_{\pi\pi\rho} g_{\pi\ell} \left(1 - \frac{m_\pi^2}{(q' - q)^2 + m_\pi^2} \right) \right\}.$$

As usual, the divergence of the axial current is supposed to be dominated by the one-pion pole. Thus, we must have:

$$g_A = -g_{\pi\pi\rho} g_{\pi\ell}$$

where $g_{\pi\pi\rho}$ and $g_{\pi\ell}$ are the coupling constants at the $\rho\pi\pi$ vertex and the $\pi\nu\ell$ vertex. These coupling constants are taken at their values for each particle on the mass shell:

$$\Gamma(\rho \rightarrow \pi_1 + \pi_2) = \left(\frac{g_{\pi\pi\rho}^2}{4\pi} \right) \frac{1}{48 m_\rho^5} \left[(m_\rho^2 - m_{\pi_1}^2 - m_{\pi_2}^2)^2 - 4 m_{\pi_1}^2 m_{\pi_2}^2 \right]^{3/2}$$

and

$$\Gamma(\pi^+ \rightarrow \mu^+ \nu) = \left(\frac{g_{\pi\ell}^2}{4\pi} \right) \left(\frac{m_\mu}{m_\pi} \right)^2 \frac{1}{m_\pi} \left[1 - \frac{m_\mu^2}{m_\pi^2} \right]^2.$$

Using the constants compiled by Roos ⁷⁾, we have

$$g_{\pi\pi\rho}^2 = 114, \quad g_{\pi\ell}^2/m_\pi^2 = 2.21 \times 10^{-14}$$

and,

$$g_A^2 = \lambda^2 G^2 \approx \lambda^2 \frac{10^{-10}}{M_P^4}, \quad \text{with} \quad \lambda^2 = 1.0 \text{ GeV}^2. \quad (8)$$

With the lepton vertex of expression (7) we find for $\sigma(\nu + p \rightarrow p + \mu^+ + \rho^+)$:

$$d_9\sigma = \frac{g_{\pi\pi}^2 g_A^2 F_B^2(q^2) F_\rho^2(q'^2) (\Delta M^2 + q^2)}{4(2\pi)^5 (-P \cdot K) (q^2 + m_B^2)^2} \delta_4(k + q' + P' - P - k) \times \\ \left\{ -k \cdot k + \frac{2}{m_b^2} (k \cdot q')(k \cdot q') \right\} \frac{d_3 \vec{P}'}{P'_0} \frac{d_3 \vec{k}'}{k'_0} \frac{d_3 \vec{q}'}{q'_0} \quad (9)$$

where the notation of Eq. (5) is followed. The total ρ production cross-section was also computed as a four-fold numerical integral. The results are listed in Table 1. The dependence on form factors is still important, with $\sigma \sim M_{F\ell}$, roughly.

3. CROSS-SECTIONS FOR $\nu + N \rightarrow \nu^- + b + X$

If in the peripheral graph 1a the outgoing nucleon is replaced by a state X (where $B+N \rightarrow X$) we arrive at a new graph (1b) which may also be important for ρ, ω production. Since the most prominent feature of π, N scattering is the $\frac{3}{2} \frac{3}{2}$ resonance (N^*) we are led to consider the special case of graph 1c. This graph is evaluated using the Rarita-Schwinger formalism¹⁴⁾, and following closely the treatment of Ref.³⁾ for the N^* .

The πNN^* interaction is taken to be of the form

$$(g_{\pi NN^*}/m_\pi) N_\alpha^* (\frac{\partial}{\partial x_\alpha} \pi) N, \quad (10)$$

where the form of the interaction and the coupling constant are chosen to yield the observed cross-section for N^* production ($g_{\pi NN^*} = 2.32 = \text{renormalized } \pi NN^*$ coupling constant). The N^* propagator, $D_{\mu\nu}(M')$, is given by³⁾:

$$D_{\mu\nu}(M') = \left[\delta_{\mu\nu} - \frac{i}{3} \gamma_\mu \gamma_\nu - \frac{i}{3M'} (\gamma_\mu P'_\nu - P'_\mu \gamma_\nu) + \frac{2}{3M'^2} P'_\mu P'_\nu \right] (-i \not{P}' + M') (P'^2 - M'^2)^{-1}$$

where a prime refers to the N^* (see Fig. 1c) and

$$M' = M_0 - \frac{i}{2} \Gamma([-P'^2]^{1/2}) (-P'^2)^{1/2} / M_0, \quad M_0 = 1.238 \text{ GeV},$$

and

$$\Gamma(x) = \frac{g_{\pi NN^*}^2}{m_\pi^2} \frac{1}{6\pi(2x)^{1/2}} \left[(x + M_P^2 - m_\pi^2) \right] \left[(x^2 - M_P^2 - m_\pi^2)^2 - 4M_P^2 m_\pi^2 \right]^{3/2}.$$

Since $\Gamma \ll M_0$ for the N^* , we neglect all terms of order Γ/M_0 or smaller everywhere except in the denominator of the N^* propagator where the term of first order in Γ/M_0 is kept. Graph 1c then gives the following cross-section:

$$d\sigma = \frac{2 (g_{\pi NN^*}/m_\pi)^2 |l_\mu J_\mu|^2 k_0 k'_0 F_B(q^2) P'_0 \Gamma}{3 (P \cdot k) (2\pi)^6 (q^2 + m_B^2)^2 [(P'^2 + M_0^2)^2 - P'^2 \Gamma^2]} \times$$

$$\left[q^2 + \left(\frac{q \cdot P'}{M_0} \right)^2 \right] [M_0 M_N - P \cdot P'] \frac{d^3 \vec{k}}{k_0} \frac{d^3 \vec{k}'}{k'_0} \quad (11)$$

where the momenta are defined in Fig. 1c, and $l_\mu J_\mu$ represents the lepton-meson vertex (for π exchange, ω production $l_\mu J_\mu$ is expression 3; for π exchange, ρ production $l_\mu J_\mu$ is expression 7).

Again there are only two independent cross-sections, taken as

$$\begin{aligned} \sigma(\nu + p \rightarrow \mu^- + \rho^0 + N^{*++}) &= \\ 3/2 \sigma(\nu + p \rightarrow \mu^- + \rho^+ + N^{*+}) &= \\ 3/2 \sigma(\nu + n \rightarrow \mu^- + \rho^+ + N^{*0}) &= \\ 3 \sigma(\nu + n \rightarrow \mu^- + \rho^0 + N^{*+}) & \end{aligned}$$

and

$$\sigma(\nu + p \rightarrow \mu^- + \omega + N^{*++}) = 3 \sigma(\nu + n \rightarrow \mu^- + \omega + N^{*+}).$$

The corresponding antineutrino reactions are obtained as before.

From Eq. (11) the total production cross-sections were computed as five-fold numerical integrals; they are listed in Table 2.

Equation (11), as can be seen from graph 1b, entails the cross-section $B+N \rightarrow X$ (i.e., here $\pi + N \rightarrow N^*$) where, however, B is virtual. The fact that the π is virtual necessitates the use of an explicit formula for the cross-section rather than directly the experimental π, N cross-section since in the latter case one neglects important kinematical effects. For a given pion energy (in the N^* rest system) a virtual pion may have as compared to a real pion considerably higher three momentum and it therefore penetrates the angular momentum barrier more easily and has relatively a higher cross-section than a physical pion. Using the experimental π, N cross-section with the same form factors as before, and without allowance for the angular momentum barrier, leads to an underestimate of graph 1c by roughly a factor of 4 for neutrino energies of a few GeV.

4. PRODUCTION OF π , η MESONS BY ρ , ω EXCHANGE

Production of π , η mesons by ρ , ω exchange has been computed on the basis of the graph in Fig. 2. All of these cross-sections are small because of the weak coupling of the vector mesons to nucleons and the high masses in the propagators. The three independent cross-sections are:

$$\begin{aligned}\sigma(\nu + p \rightarrow p + \nu^- + \pi^+) &= & (\omega \text{ exchanged}) \\ \sigma(\nu + n \rightarrow n + \nu^- + \pi^+) &= & (\omega \text{ exchanged}), \\ \sigma(\nu + n \rightarrow p + \nu^- + \eta) &= & (\rho^- \text{ exchanged}),\end{aligned}$$

$$\begin{aligned}\text{and } \sigma(\nu + p \rightarrow p + \nu^- + \pi^+) &= & (\rho^0 \text{ exchanged}) \\ \sigma(\nu + n \rightarrow n + \nu^- + \pi^+) &= & (\rho^0 \text{ exchanged}) \\ \frac{1}{2} \sigma(\nu + n \rightarrow p + \nu^- + \pi^0) &= & (\rho^- \text{ exchanged}).\end{aligned}$$

The matrix element for graph 2 may be written:

$$M = \frac{-i(2\pi)^4}{(2f_0')^{1/2}} (q^2 + m_B^2)^{-1} \bar{U}_N \gamma_\alpha (1 + \gamma_5) U_N F_\ell([k-k']^2) F_B(q^2) X$$

$$\bar{U}_N f_V (\tau_{\alpha\beta} [\gamma_\beta + \lambda_m \gamma_{\beta\sigma} \not{q}_\sigma] + \frac{i g_A}{m_B^2} \Delta M \not{q}_\alpha) U_N$$

where $T_{\alpha\beta} \equiv g_A \delta_{\alpha\beta} + g_V \epsilon_{\alpha\rho\sigma\beta} q'_\rho q_\sigma$, with g_A and g_V as defined above. For a given reaction, of course, either g_A or $g_V \equiv 0$, according to Eq. (2). $\sigma_{\alpha\beta} \equiv \frac{i}{2}(\gamma_\alpha \gamma_\beta - \gamma_\beta \gamma_\alpha)$, and f_V and λ_m are coupling constants for the BNN' vertex. These coupling constants have been estimated by Liu and Singer¹⁵⁾, namely:

Vertex	$f_V^2/4$	λ_m
$\omega_{N,N}$	1.0	0
$\rho^-_{n,P}$	0.2	-1.5 GeV^{-1}
$\rho^0_{N,N}$	0.1	-1.5 GeV^{-1}

in units where $g_{N\pi}^2/4\pi \approx 15$.

The production cross-section is now given by:

$$d\sigma = \frac{1}{(2\pi)^3} (Flux)^{-1} \delta_4(P'+k'+q'-P-k) d_3\vec{P}' d_3\vec{q}' d_3\vec{k} |m|^2$$

where $|m|^2$ is averaged over initial spins and summed over final spins. The traces in $|m|^2$ are easily evaluated, but the tensor inner products lead to a large number of terms. In Table 3 are listed the computed cross-sections for pseudo-scalar meson production with vector meson exchange.

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T A B L E 1

$$\sigma(\nu+n \rightarrow p+\mu^-+\omega) \text{ and } \sigma(\nu+p \rightarrow p+\mu^-+\rho^+)$$

in units of 10^{-40} cm^2

		$\sigma(\nu+n \rightarrow p+\mu^-+\omega)$			$\sigma(\nu+p \rightarrow p+\mu^-+\rho^+)$		
FORM FACTOR MASSES, GeV	$M_{F\ell}$	0.66	0.75	0.66	0.66	0.75	0.66
	M_{FB}	0.939	0.939	1.2	0.939	0.939	1.2
$E_\nu(\text{LAB}), \text{ GeV}$							
2		1.0	1.25	1.39	0.40	0.47	0.53
3		3.76	4.93	5.34	1.15	1.39	1.57
5		9.3	12.8	13.4	2.22	2.71	3.06
7		14.0	19.7	20.4	2.90	3.54	4.02
10		19.7	28.4	28.8	3.56	4.38	4.97

$$\sigma(\nu+p \rightarrow p+\mu^-+\rho^+) = \sigma(\nu+n \rightarrow n+\mu^-+\rho^+) = \frac{1}{2}\sigma(\nu+n \rightarrow p+\mu^-+\rho^0).$$

TABLE 2

$\sigma(\nu+p \rightarrow N^{*++}\mu^{-}+\omega)$ and $\sigma(\nu+p \rightarrow N^{*++}\mu^{-}+\rho^0)$
in units of 10^{-40} cm^2

		$\sigma(\nu+p \rightarrow N^{*++}\mu^{-}+\omega)$			$\sigma(\nu+p \rightarrow N^{*++}\mu^{-}+\rho^0)$		
FORM FACTOR MASSES, GeV	$M_F \ell$ M_{FB}	0.66 0.939	0.75 0.939	0.66 1.2	0.66 0.939	0.75 0.939	0.66 1.2
$E_\nu(\text{LAB}), \text{ GeV}$							
3		1.1	1.37	1.71	0.58	0.697	0.876
5		5.5	7.48	9.26	2.43	2.96	3.81
7		10.8	15.1	18.7	4.34	5.29	6.89
10		19.1	27.2	33.8	7.21	8.75	11.5

$$\sigma(\nu+p \rightarrow N^{*++}\mu^{-}+\omega) = 3 \sigma(\nu+n \rightarrow N^{*++}\mu^{-}+\omega)$$

$$\sigma(\nu+p \rightarrow N^{*++}\mu^{-}+\rho^0) = \frac{3}{2} \sigma(\nu+p \rightarrow N^{*++}\mu^{-}+\rho^+) = \frac{3}{2} \sigma(\nu+n \rightarrow N^{*0}\mu^{-}+\rho^+) = 3 \sigma(\nu+n \rightarrow N^{*++}\mu^{-}+\rho^0).$$

TABLE 3

CROSS-SECTIONS FOR PSEUDOSCALAR MESON PRODUCTION

BY VECTOR MESON EXCHANGE

in units of 10^{-40} cm^2 FORM FACTOR MASSES : $M_{F\ell} = 0.66 \text{ GeV}$, $M_{FB} = 0.939 \text{ GeV}$

	ω exchange	ρ exchange	
Reaction	$\nu + p \rightarrow p + \mu^- + \pi^+$	$\nu + p \rightarrow p + \mu^- + \pi^+$	$\nu + n \rightarrow p + \mu^- + \eta$
$E_\nu(\text{LAB}), \text{ GeV}$			
3	0.422	0.267	0.243
5	0.95	0.415	0.664
7	1.47	0.543	1.11
10	2.15	0.711	1.74

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FIGURE CAPTIONS

Figure 1a Peripheral Feynman diagram for $\nu + N \rightarrow N' + \nu^- + b$. The four-momenta of the particles are indicated in parentheses; dotted lines correspond to pseudoscalar mesons, wavy lines to vector mesons.

Figure 1b Peripheral diagram for $\nu + N \rightarrow \nu^- + b + X$.

Figure 1c Diagram for N^* production with vector meson production; expected to be a major contributor to diagram 1b.

Figure 2 Diagram for pseudoscalar meson production by vector meson exchange.

FIG. 2