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EFFECTS OF THE ρ-NUCLEON TOTAL CROSS SECTION ON PHOTOPION PRODUCTION IN THE FORWARD DIRECTION*

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ABSTRACT

The possible contribution of a ρ-exchange process to the photoproduction of ρ mesons, which subsequently decay to high energy pions at very small angles, is examined when the ρ-nucleon vertex is replaced by the total cross section for ρ induced reactions.

Recent experiments[1] on high energy photoproduction of pions in the very forward directions have indicated a possible large cross section which cannot be explained by the Drell mechanism[2] of single pion exchange. Speculations that a non-vanishing 0° cross section would be possible from a direct $\gamma\rho\rho$ magnetic moment interaction have been considered[3] for the reaction

$$\gamma + N \rightarrow \rho^{\pm} + N, \quad \rho^{\pm} \rightarrow \pi^{\pm} + \pi^{0} \tag{1}$$

as indicated in Fig. 1. The main problem with such a contribution is that the calculated angular distribution must be drastically reduced away from 0° if the ρ-exchange mechanism is to be even in rough agreement with experiment. A possible procedure for making the ρ-exchange process more sharply peaked at very small angles is to assume a Regge pole-like behavior of the exchanged ρ.[4] This procedure brings the angular distribution to a better agreement with experiment, but yields a slow decrease of the calculated 0° cross section with increasing primary energy. The latter result must still be checked by higher energy experiments.

In this note we examine the possible contribution of the ρ-exchange process, where the ρNN vertex is replaced by the total cross section for the reaction $\rho + N \rightarrow$ (all consistent final states), as shown in Fig. 2. Assuming that the ρ-nucleon total cross section is 30 mb and that the ρ is coupled to a conserved current, we conclude that the ρ-exchange process contribution to a final state of a small angle ρ and a nucleon, as calculated in Ref. 3, is always an order of magnitude larger than the contribution to a final state where the ρNN vertex is replaced by the ρ total cross section.

Consider the process where the exchanged ρ interacts with the target nucleon (Fig. 2)

$$\begin{array}{l} \gamma + N \rightarrow \rho^{\pm} + (\text{others}) \\ \qquad\quad \lfloor\!\!\rightarrow \pi^{\pm} + \pi^{0} \end{array} \tag{2}$$

The cross section for this process is given by

$$d\sigma = \frac{K - w_1 - w_2}{K} (4\pi\alpha)(1 + \mu_\rho)^2 \left(\frac{1}{\left|q^2\right| + m_\rho^2} \right)^2 \left| \frac{1}{p^2 - m_\rho^2 - i m_\rho \Gamma_\rho} \right|^2$$

$$g_{\rho\pi\pi}^2 \, \frac{3}{2} \sum_{e\ \text{pol.}} |m|^2 \, \frac{d^3 q_1}{2w_1(2\pi)^3} \, \frac{d^3 q_2}{2w_2(2\pi)^3} \tag{3}$$

where K is the photon energy, w_1, w_2 are the energies of the produced pions, α is the fine structure constant, Γ_ρ is the ρ width and $g_{\rho\pi\pi}$ its coupling constant to the two pions.

The matrix element in Eq. (3) results from the magnetic moment interaction between the photon and the ρ-pair, and the subsequent absorption of the exchanged ρ-meson. Following Ref. 3, the matrix element may be written in the form

$$m = \left[(k\cdot\epsilon)e_\mu - (\epsilon\cdot e)k_\mu \right] \Gamma_\mu \tag{4}$$

where e and ϵ are the photon and ρ-meson linear polarization vectors.

The vector Γ_μ represents the absorption of the exchanged ρ. If we make the assumption that the ρ is coupled to a conserved current, then averaging over all other final particles, except for the exchanged ρ, allows us to write the averaged tensor $\overline{\Gamma_\mu \Gamma_\nu} = T_{\mu\nu}$ in the form[5]

$$T_{\mu\nu} = A_1 \left(\delta_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right) + A_2 \left(p_{1\mu} - \frac{(p_1 \cdot q) q_\mu}{q^2} \right) \left(p_{1\nu} - \frac{(p_1 \cdot q) q_\nu}{q^2} \right) \tag{5}$$

where p_1 and q are the initial nucleon and exchanged ρ momenta, respectively. In order to assure that $T_{\mu\nu}$ will be nonsingular at $q^2 = 0$, A_1 and A_2 must be related near $q^2 \approx 0$ in the form

$$A_2 = \frac{q^2}{(p_1 \cdot q)^2} A_1 \qquad (q^2 \to 0) \tag{6}$$

The total cross section of the virtual ρ, given by $\left[\frac{q_\mu q_\nu}{q^2} - \delta_{\mu\nu} \right] T_{\mu\nu}$, expressed in terms of A_1 and A_2, is

$$\sigma_\rho = 3A_1 - A_2 \left(p_1^2 - \frac{(p_1 \cdot q)^2}{q^2} \right) = -2A_1 - p_1^2 A_2 \tag{7}$$

and for small $|q^2|$ approaches

$$\sigma_\rho = -2A_1 \tag{8}$$

In integrating Eq. (3) over some narrow range of $|q^2|$ near $|q^2| \approx 0$ we are confronted with the problem of whether there is a possible rapid variation of A_1 with $|q^2|$. To this end we note that the assumption that the ρ is coupled to a conserved vector current, and the additional assumption that there is a direct gauge invariant ρ-γ coupling, leads to the relation

$$\sigma_{(\text{virtual } \gamma)} = \left[\alpha - \frac{\beta|q^2|}{|q^2| + m_\rho^2} \right] \sigma_{(\text{virtual } \rho)} \tag{9}$$

where α and β are constants. The observed inelastic electroproduction[6] is compatible with the above equation for a nearly constant $\sigma_{(\text{virtual } \rho)}$ as a function of $|q^2|$. Therefore in the following considerations we use Eq. (9) to support the assumption that $\sigma_{(\text{virtual } \rho)}$ is constant in the region of $|q^2| \approx 0$ to $|q^2| \approx 30\ m_\pi^2$.

Within these assumptions it is possible to calculate cross section (3). In the limit of $\Gamma_\rho \to 0$ we get

$$d\sigma = \frac{3}{8} \frac{\sigma_\rho}{K}\ 4\pi\alpha(1 + \mu_\rho)^2 \left(\frac{1}{|q^2| + m_\rho^2} \right)^2 \frac{48\pi^2}{m_\rho^2}\ \delta(p^2 - m_\rho^2)\ F(K,w_1,w_2,q^2)$$

$$\frac{d^3q_1}{2w_1(2\pi)^3} \frac{d^3q_2}{2w_2(2\pi)^3} \tag{10}$$

where for small $|q^2|$ values $F(K,w_1,w_2,q^2)$ is given by

$$F(K,w_1,w_2,q^2) = K\left[4Kw_1(1 - \beta_1 \cos\theta_1) - (|q^2| + m_\rho^2)\right]^2$$

$$- (w_1 - w_2)(|q^2| + m_\rho^2)\left[4Kw_1(1 - \beta_1 \cos\theta_1) - (|q^2| + m_\rho^2)\right]$$

$$- 2Km_\rho^2(|q^2| + m_\rho^2) \qquad (11)$$

This result depends crucially on the assumption that reaction (2) is dominated by small momentum and energy transfers. Unless we are limited to small momentum transfers there is no justification for neglecting the form factor A_2. In evaluating $F(K,w_1,w_2,q^2)$ we have neglected terms linear in $q^4(K - w_1 - w_2)$.

Photo ρ production via a ρ exchange process is best detected if one of the high energy final pions is produced at 0°, where other calculated contributions are either zero or negligible. In calculating the cross section for reaction (2) at $\theta_1 = 0^{\circ}$, we have neglected the mass of the produced high energy pion and have approximated $\cos\theta_2 \approx 1$. The integration over q^2 was taken over an interval $\Delta q^2 \approx 30\ m_\pi^2$. As the actual damping of momentum transfers in this reaction is probably very strong,[4] our result may be overestimated. Within these approximations the cross section to photoproduce a high energy pion at $\theta_1 = 0^{\circ}$ from reaction (2) will be given by

$$\left(\frac{d^2\sigma}{d\Omega_1 dw_1}\right)_{\theta_1=0^\circ} = \frac{9}{16}\left(\frac{1}{2\pi}\right)^2 \alpha \frac{(1+\mu_\rho)^2}{m_\rho^2} \sigma_\rho \Delta q^2 \frac{\beta_2}{(1-\beta_2)K^2}$$

$$\times \left(K + w_1 - \frac{m_\rho^2}{2w_1(1-\beta_2)}\right) \tag{12}$$

Some immediate consequences follow from this result: The cross section to photoproduce a high energy pion at $\theta_1 = 0^\circ$ in the BeV region from reaction (1) was shown[3] to be of the order of 10^{-28} cm^2/BeV-sr. With the assumption that σ_ρ is 30 mb, the equivalent cross section from reaction (2) is one order of magnitude smaller. The differential cross section $\left(\frac{d^2\sigma}{d\Omega_1 dw_1}\right)_{\theta_1=0^\circ}$ was shown[3] to behave like $(w_1/K)w_1$, whereas (12) yields a dependence of $(w_1/K)^2 w_1$ which is slightly weaker. We are led to the conclusion that at any accessible photon energy reaction (1) is dominating reaction (2) by an order of magnitude as a possible source for high energy pion production at $\theta_1 = 0^\circ$. This result can be readily checked experimentally since it implies that the great majority of charged pions photoproduced at very small angles in a hydrogen bubble chamber experiment should belong to one-prong events independent of the primary photon energy.

It was noted that the ρ exchange process cross sections calculated in the pole approximation do not fit the known experimental results, and a Regge pole behavior was suggested[4] to overcome this difficulty. This suggestion does not change the qualitative results of the present calculation. A Regge pole calculation would change the normalization, energy dependence, and angular distributions of the individual cross sections concerned, but will not change the approximate ratio of the contributions from reactions (1) and (2) at $\theta_1 = 0^\circ$ within the assumptions stated here.

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FIGURE CAPTIONS

1. $\gamma + N \rightarrow \rho^{\pm} + N$ via a ρ exchange process.

2. $\gamma + N \rightarrow \rho^{\pm} + (\text{others})$ via a ρ exchange process. The photon is denoted by the polarization e and momentum k, the produced ρ by ϵ, p. The ρ-N vertex is denoted by Γ.

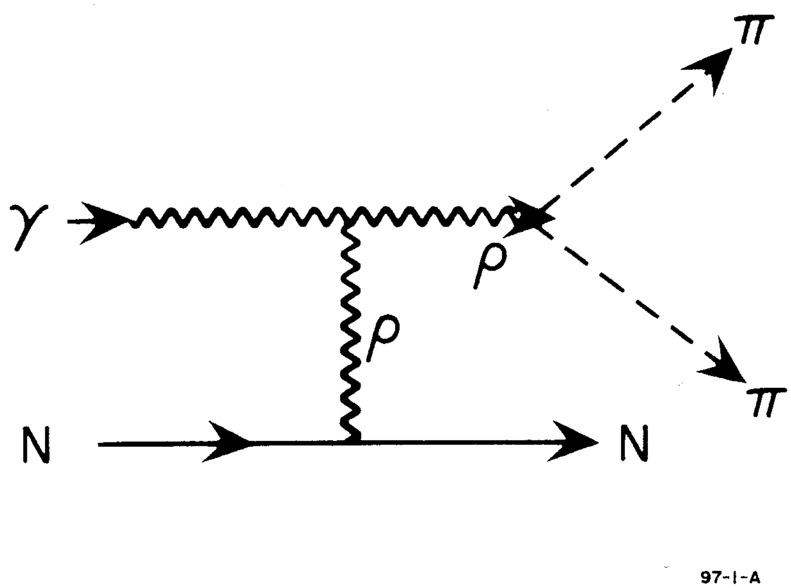

FIGURE 1

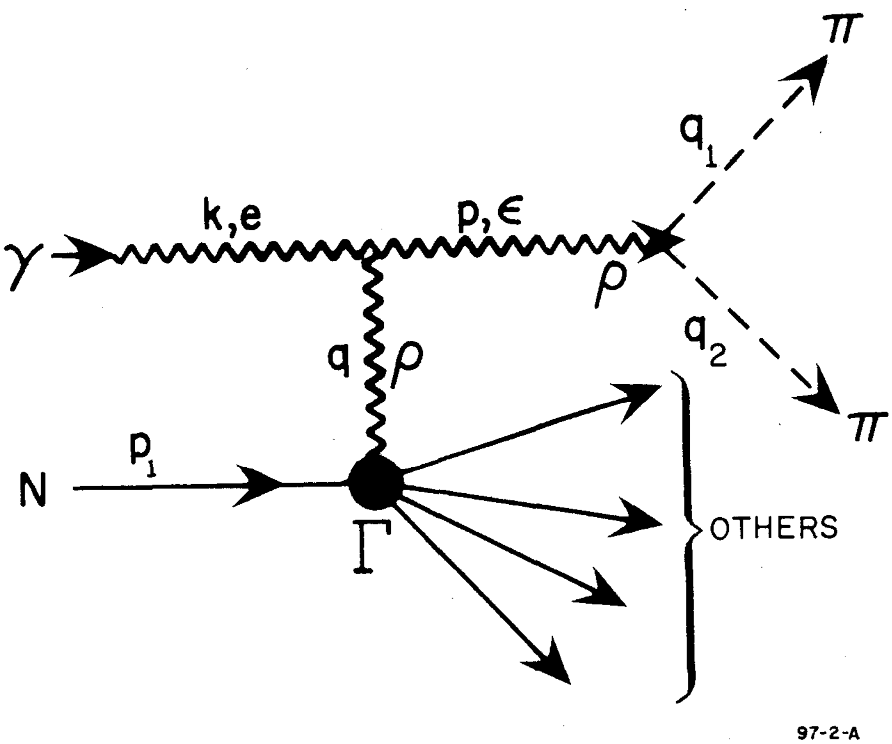

FIGURE 2