$\rho^{\pm}$ Photoproduction at 9.6 GeV*

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$\rho^{\pm}$ photoproduction from hydrogen and deuterium at 9.6 GeV is studied. The reactions $\gamma p \to \rho^+ n$ and $\gamma p \to \rho^- \Delta^{++}(1236)$ have cross sections much larger than expected from pion exchange alone. t distributions do not show the sharp forward peak characteristic of one-pion exchange contributions. Density matrices indicate an isotropic decay distribution. The ratio of ρ^+ to ρ^- production on deuterium differs from unity and by the amount expected from interference between ρ and A_2 exchanges. We conclude that π exchange is unimportant for $\rho^{\pm}$ photoproduction, and infer that ρ exchange dominates.

In sharp contrast to the much studied topic of ρ^0 photoproduction, there has been little work reported on charged-ρ photoproduction, either of an experimental or a theoretical nature. Here we present an experimental survey of $\rho^{\pm}$ photoproduction at 9.6 GeV, using hydrogen and deuterium targets.

The apparatus, described more fully elsewhere,[1,2] consisted of an 8.8- to 10.4-GeV tagged photon beam, incident on a hydrogen or deuterium target, followed by a multiparticle forward spectrometer. The vector momenta of all $\rho^{\pm}$ decay products ($\pi^{\pm}, \gamma, \gamma$) were measured. Target decay products were not detected, but the use of a tagged photon beam enabled the missing mass m in the reaction $\gamma N \to \rho^{\pm} m$ to be determined.

Events with the topology, one charged particle, two γ rays, were reconstructed. The 2γ mass spectrum was dominated by the π^0. The $\pi^{\pm}\pi^0$ mass spectra for two missing-mass intervals are shown in Figs. 1(a) and 1(b). A ρ signal is clearly present. It was extracted from the nonresonant $\pi^{\pm}\pi^0$ background by fitting the mass interval near the ρ with a Ross-Stodolsky-modified p-wave Breit-Wigner form plus a linear background. This procedure is quite adequate for the lower missing-mass interval, but not for the higher one.

The production of ρ^+ and ρ^- on targets of p and n leading to a missing mass m can be written (assuming no $I=2$ exchange)

$$\sigma(\gamma p \to \rho^+ m) = N^*(+,m) + \tfrac{1}{3}\Delta(+,m), \quad (1a)$$

$$\sigma(\gamma p \to \rho^- m) = \Delta(-,m), \quad (1b)$$

$$\sigma(\gamma n \to \rho^+ m) = \Delta(+,m), \quad (1c)$$

$$\sigma(\gamma n \to \rho^- m) = N^*(-,m) + \tfrac{1}{3}\Delta(-,m). \quad (1d)$$

N^* (Δ) refers to an $I=\frac{1}{2}$ ($I=\frac{3}{2}$) baryon state. These expressions assume no N^*-Δ interference. Ignoring Glauber corrections and deuterium-form-factor effects, the cross section on deuterium is just the sum of that on protons and neutrons:

$$\sigma(\gamma d \to \rho^+ m) = N^*(+,m) + \tfrac{4}{3}\Delta(+,m), \quad (1e)$$

$$\sigma(\gamma d \to \rho^- m) = N^*(-,m) + \tfrac{4}{3}\Delta(-,m). \quad (1f)$$

The missing-mass spectrum for ρ^- produced

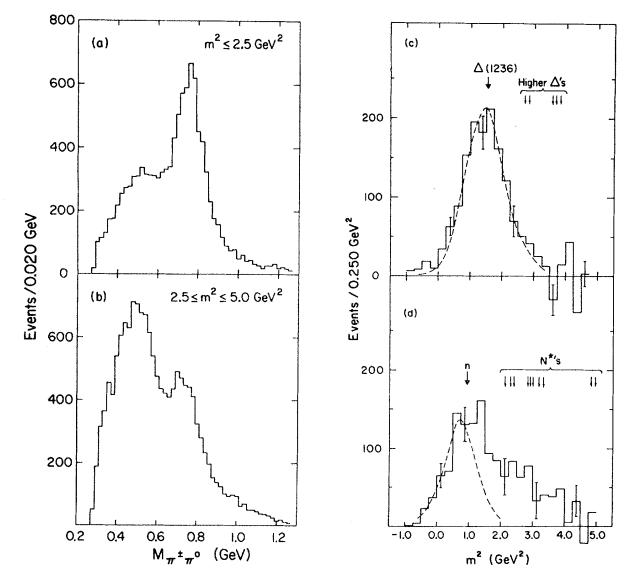

FIG. 1. (a), (b) $\pi^{\pm}\pi^0$ mass distributions for two missing-mass regions. (c), (d) m^2 distributions for (c) ρ^-, pure $I=\frac{3}{2}$, and (d) $\rho^+ - 0.26\rho^-$, predominantly $I=\frac{1}{2}$. The dashed curves on (c) and (d) show the distributions expected for Δ and n final states, respectively. The spectra shown in (c) and (d) are not reliable above 2.5 GeV^2, because of uncertainties in extracting the $\rho^{\pm}$ signal from the nonresonant background.

on hydrogen is shown in Fig. 1(c). It is pure $I=\frac{3}{2}$ [see Eq. (1b)], and is dominated by $\Delta(1236)$; the reaction $\gamma p \rightarrow \rho^- \Delta^{++}(1236)$ is readily extracted. The ρ^+ missing-mass spectrum (not shown) is a mixture of $I=\frac{3}{2}$ and $I=\frac{1}{2}$ [see Eq. (1a)], and the neutron and $\Delta^0(1236)$ peaks are not resolved. However, by subtracting a fraction of the ρ^- missing-mass spectrum, the $\Delta^0(1236)$ contribution can be removed. The appropriate fraction is $(\frac{1}{3})[\Delta(+,m)/\Delta(-,m)]$. In the region of $\Delta(1236)$ the ratio $\Delta(+,m)/\Delta(-,m)$ is to a good approximation just the ρ^+ to ρ^- ratio from deuterium [see Eqs. (1e) and (1f)]. We have measured this ratio to be 0.79 ± 0.07. Therefore in Fig. 1(d) we display the missing-mass spectrum for $\rho^+ - \frac{1}{3}(0.79)\rho^-$. To the extent that $\Delta(+,m)/\Delta(-,m)$ is independent of m and has the value given in the $\Delta(1236)$ region, Fig. 1(d) will be a pure $I=\frac{1}{2}$ spectrum, $N^*(+,m)$. The spectrum is what would be expected for a neutron peak and a continuum of higher N^*'s, all smeared by the experimental resolution. The reaction $\gamma p \rightarrow \rho^+ N$ was extracted by making a cut at a $m^2 = 1.2$ GeV^2; the fraction of the desired reaction lost by this cut was determined from Monte Carlo studies.

In Fig. 2(a) we display the cross section versus square of the momentum transfer for the reactions $\gamma p \rightarrow \rho^+ n$ and $\gamma p \rightarrow \rho^- \Delta^{++}(1236)$. The errors shown allow for the uncertainties in extracting the desired reactions from the nonresonant backgrounds, but do not include an overall normalization uncertainty of ± 15%. The solid curves are the contributions expected from one pion exchange (OPE). They are based on a formulation by Wolf[3] which gives an adequate description of $\gamma p \rightarrow \omega p$ and $\gamma p \rightarrow \omega \Delta^0$. The OPE calculations do *not* give a good representation of the cross sections. The sharp forward peaking of the OPE calculations is not present in the data. The magnitude of the OPE calculations is considerably too small. The calculations account for only 15% of the $\gamma p \rightarrow \rho^+ n$ cross section and only 21% of the $\gamma p \rightarrow \rho^- \Delta^{++}$ cross section in the t interval from 0.0 to 0.2 GeV^2.

The energy dependence of the reaction $\gamma p \rightarrow \rho^- \Delta^{++}(1236)$, obtained from this experiment and earlier experiments,[4] is displayed in Fig. 2(b). The curve is a fit of the form CE_γ^{-n}, with $C = 4.7 \pm 0.4$ μb and $n = 0.81 \pm 0.18$. Reactions dominated by pion exchange have larger n values, in the range[5] 1.6–2.5.

In Fig. 3 we display the density matrices for the reactions $\gamma p \rightarrow \rho^+ n$ and $\gamma p \rightarrow \rho^- \Delta^{++}(1236)$, evaluated in the Gottfried-Jackson frame. Deviations from t-channel helicity conservation ($\rho_{00} = \rho_{10} = \rho_{1-1} = 0$) are large. The data more nearly approximate an isotropic decay distribution ($\rho_{00} = \frac{1}{3}$,

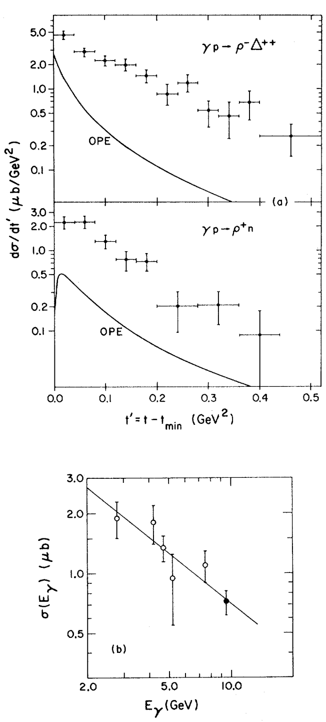

FIG. 2. (a) Differential cross sections for the reactions $\gamma p \rightarrow \rho^- \Delta^{++}(1236)$ and $\gamma p \rightarrow \rho^+ n$. The curves are from a OPE calculation. (b) Energy dependence of the cross section for $\gamma p \rightarrow \rho^- \Delta^{++}(1236)$. Open circles represent data from Ref. 4, filled circle represents this experiment.

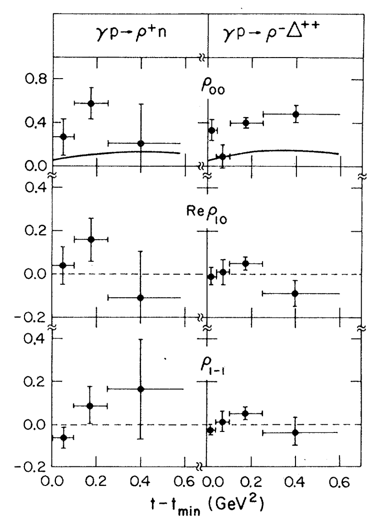

FIG. 3. Density matrices for the reactions $\gamma p \rightarrow \rho^+ n$ and $\gamma p \rightarrow \rho^- \Delta^{++}(1236)$ in the Gottfried-Jackson frame. The curve on the ρ_{00} plots is a smooth fit to measurements of ρ_{00} for the reaction $\gamma p \rightarrow \omega \Delta^0$ (Ref. 6).

$\rho_{10}=\rho_{1-1}=0$). The curve on the ρ_{00} plots is a smooth curve through the measurements[6] of ρ_{00} for the reaction $\gamma p \to \omega\Delta^0$, believed to be dominantly OPE. They do not agree with the values of ρ_{00} reported here.

We conclude from the t dependence, energy dependence, and absolute magnitude of the cross sections, and from the density matrices, that pion exchange plays at most a minor role in the reactions $\gamma p \to \rho^+ n$ and $\gamma p \to \rho^- \Delta^{++}(1236)$.

The deuterium data are conveniently presented in the form of a ρ^+-ρ^- charge asymmetry:

$$\epsilon_d(m) \equiv \frac{\sigma(\gamma d \to \rho^+ m) - \sigma(\gamma d \to \rho^- m)}{\sigma(\gamma d \to \rho^+ m) + \sigma(\gamma d \to \rho^- m)}. \qquad (2)$$

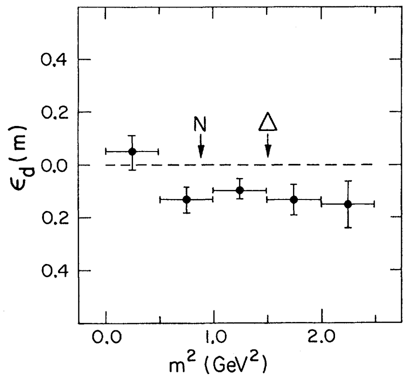

FIG. 4. Charge asymmetry for $\rho^\pm$ photoproduction from deuterium as a function of m^2.

$\epsilon_d(m)$ is plotted in Fig. 4. (We have integrated over the t range 0.0 to 0.4 GeV.) $\epsilon_d(m)$ is significantly different from zero and shows little mass dependence. Its mean value is -0.11 ± 0.03.

Within the framework of a Regge-pole model, a nonzero charge asymmetry implies interference between exchanged trajectories of opposite G parity. Having shown that π exchange is small, the best candidate for the dominant term is ρ exchange. The asymmetry could be produced by ρ-π interference or by ρ-A_2 interference (or both). To leading order in s, and neglecting absorption, ρ and π exchanges will be orthogonal, since the former is a natural-parity exchange and the latter an unnatural-parity exchange. Similarly, ρ and A_2 exchanges will be orthogonal if the ρ and A_2 trajectories are exchange degenerate ($\alpha_\rho = \alpha_{A_2}$). One therefore expects the charge asymmetry to be small, consistent with what we find.

In a model with only ρ and A_2 exchanges, the charge asymmetry can be shown[7] to be

$$\epsilon \equiv \frac{6\,\mathrm{Re}\{[\exp(-i\pi\alpha_\rho)-1][\exp(i\pi\alpha_{A_2})+1]\}s^{(\alpha_{A_2}-\alpha_\rho)}}{9|\exp(-i\pi\alpha_\rho)-1|^2+|\exp(-i\pi\alpha_{A_2})+1|^2 s^{2(\alpha_{A_2}-\alpha_\rho)}}. \qquad (3)$$

For $\alpha_\rho \approx \alpha_{A_2} \approx \frac{1}{2}$, this yields $\epsilon \approx \frac{1}{3}\sin\pi(\alpha_{A_2}-\alpha_\rho)$. The ρ-A_2 trajectory difference has recently been determined by Johnson[8] for the reactions $\pi^- p \to \pi^0 n$ and $\pi^- p \to \eta n$. Using their values in Eq. (3), and appropriately averaging over t, we find $\epsilon = -0.11$, in good agreement with our measurement. This supports the interpretation that the charged ρ reactions are dominated by ρ exchange.

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[1]J. Abramson *et al.*, preceding paper [Phys. Rev. Lett. 36, 1428 (1976)].

[2]Edward N. May, Ph.D. thesis, University of Rochester, 1976 (unpublished).

[3]G. Wolf, Phys. Rev. 182, 1538 (1966), and private communications. We have used the SU(3) value for the ratio of $\rho\pi\gamma$ to $\omega\pi\gamma$ couplings (1:9). Had we used the measured $\rho \to \pi\gamma$ decay width, the calculated cross section would have been lower by a factor near 3.

[4]J. Ballam *et al.*, Phys. Rev. Lett. 26, 995 (1971); Y. Eisenberg *et al.*, Phys. Rev. D 5, 15 (1972).

[5]Martin Perl, *High Energy Hadron Physics* (Wiley, New York, 1974), p. 153.

[6]C. A. Nelson, Jr., *et al.*, to be published.

[7]See Ref. 2. Equation (3) assumes equal residues for ρ and A_2 exchanges, as required by strong exchange degeneracy. The result changes very little for small departures from this assumption.

[8]R. A. Johnson, Ph.D. thesis, University of California, Berkeley, 1975 (unpublished).