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ARTICLES

Inelastic ρ^0 photoproduction in the reaction $\gamma p \to \rho^0\pi^+ n$

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Inelastic ρ^0 photoproduction in the reaction $\gamma p \to \rho^0\pi^+ n$ is observed in the peripheral region $| t'_{\gamma,\rho^0} | < 0.12$ GeV^2. The data are consistent with the ρ^0 production being due to a double peripheral mechanism which conserves s-channel helicity. The $\pi^+ n$ produced in association with the ρ^0 is also consistent with the same mechanism, although there is a distortion of the expected angular distributions in the $\pi^+ n$ mass region of 1.3–1.5 GeV/c^2.

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Elastic ρ^0 photoproduction as well as inclusive ρ^0 photoproduction have been exhaustively studied over the years. However, aside from a study [1] of the reaction $\gamma p \to N^\star\rho^0 \to \Delta^{++}\pi^-\rho^0$, there appears to be no other works devoted to specific inelastic ρ^0 photoproduction processes. In this paper we will investigate ρ^0 production in the reaction $\gamma p \to n\pi^+\pi^+\pi^-$. We shall compare our results with calculations of Wolf [2] and with some experimental results [3] from diffractive pion-nucleon interactions.

Our data come from a large triggered hydrogen bubble chamber experiment which was performed at the Stanford Linear Accelerator Center, utilizing incident photons of average energy 19.3 GeV with a full width at half maximum of 1.7 GeV. The photon beam was generated by backscattered laser photons from the SLAC 30 GeV electron beam and had a linear polarization of 0.52. The experimental details have been given in previous publications [4]. In the present work our sample consists of 3782 events of the type: $\gamma p \to n\pi^+\pi^+\pi^-$. The event sample was obtained as follows. Any three-prong event which had a three-constraint fit to any of the hypothesis ($\gamma p \to p\pi^+\pi^-$, pK^+K^-, $\bar{p}pp$) with a fit probability in excess of 10^{-2}% was rejected. Further, any event for which either of the positive tracks was identifiable as a proton on the basis of ionization, curvature, and/or Čerenkov information was rejected. Finally, any event for which the downstream lead-glass wall registered one or more photons was excluded. Throughout this article we treat the $n\pi^+\pi^+\pi^-$ final state in this conservative fashion, excluding events where any evidence for ambiguity exists. The events accepted for this zero-constraint channel were those which survived these cuts and for which energy and momentum balance provided a photon energy between 16.5 and 21.0 GeV. Some results [5] from this reaction have been presented previously in our study of resonances that are produced by peripheral charge exchange processes. Because of the unconstrained nature of our events, the integrity of the data sample deteriorates at larger values of the momentum transfer between the photon beam and the outgoing ρ^0. We shall, in fact, restrict all of our results to events for which $|t'_{\gamma,\pi^+\pi^-}| < 0.12$ GeV^2 where $|t'_{\gamma,\pi^+\pi^-}| = |t_{\gamma,\pi^+\pi^-}| - |t_{\min}|$. With these restrictions the triggering efficiency for dipion systems of mass between 0.5 and 1.0 GeV lies between 0.72 and 0.76 while for the recoiling baryon-pion combination it varies smoothly between 0.68 and 0.74 for $\pi^+ n$ masses between 1.1 and 2.1 GeV. Because of the small variations in these efficiencies we will apply average corrections to the various cross sections.

In Fig. 1(a) we present the neutral dipion spectrum for those events for which the lesser of the two $|t'_{\gamma,\pi^+\pi^-}|$'s is less than 0.12 GeV^2. Clearly this spectrum is dominated by neutral ρ^0 production. Moreover, as has been observed in both elastic ($\gamma p \to \rho^0 p$) [6] and inelastic ρ^0 photoproduction ($\gamma p \to \rho^0 N^\star \to \rho^0\Delta^{++}\pi^-$) [2], the ρ^0 mass spectrum is sharply skewed toward lower mass values than the Particle Data Group [7] value of 767 MeV. In Fig. 1(b) we present the $\pi^+ n$ mass spectrum for those particles recoiling against the dipion systems in Fig. 1(a). Except for the threshold region, this spectrum is quite similar to the one that was presented for the $\Delta^{++}\pi^-$ mass recoiling against the ρ^0 in this same experiment [2]. The overriding feature of both the $\pi^+ n$ and $\Delta^{++}\pi^-$ spectra is a large low mass enhancement falling rapidly to a small background value around 2.1 GeV.

In Fig. 2(a) we further enhance these ρ^0 and $N^\star$ signals by selecting neutral dipions only if the $\pi^+ n$ mass is less than 2.1 GeV [Fig. 2(a)] and by selecting $\pi^+ n$ combinations only if the neutral dipion mass is in the ρ^0 region (0.55–0.90 GeV). It is again seen that the $\pi^+\pi^-$ mass distribution in the ρ^0 region is strongly distorted toward lower mass values. The smooth curve shown in

Fig. 2(a) is a standard Söding model [8] fit over a polynomial background in the dipion mass. The result of such a fit is a mass of 764 ± 15 MeV and a width of 150 ± 20 MeV for the basic ρ^0 parameters. It is interesting to note that there appear to be small enhancements in the mass region of the $f_2(1270)$ and $\rho_3(1690)$. Since there is no firm evidence [9] for either of these states in the reaction $\gamma p \to p\pi^+\pi^-$, it is likely that, if they are present, they result from the decay of a higher mass meson. Figure 3 shows the 3π mass spectrum for those associated $\rho^0 N^*$ events displayed in Fig. 2 which also occur at $|t'_{\gamma,3\pi}| \leq 0.10$ GeV^2. This spectrum contains, at most, marginal evidence for the production of any known 3π resonance and indicates that the events in Fig. 2 are quite free from such contamination.

It is perhaps worthwhile to investigate s-channel helicity conservation for these ρ^0 events. We do this in terms of the conventional decay angles in the helicity frame of the ρ^0. The polar angle of the π^+ in the ρ^0-rest frame relative to the ρ^0 direction of flight is denoted by θ. The difference between the azimuthal angles (Φ, the angle between the photon polarization vector and the production plane in the center-of-mass system, and ϕ, the azimuthal angle of the ρ^0 decay in the ρ^0-rest frame measured as the angle between the decay plane and the production plane) is denoted by Ψ ($\Psi = \phi - \Phi$).

Conservation of s-channel helicity requires the ρ^0 to have helicity of ± 1 so that the decay angular distribution is given by

$$W(\cos\theta, \Psi) = \left(\frac{3}{8\pi}\sin^2\theta\right)(1 + P_\gamma \cos 2\Psi). \qquad (1)$$

Here P_γ is the degree of linear polarization which in this experiment was 0.52. In Figure 4 we present our $\cos\theta$ and Ψ distributions for the ρ^0 mass region (0.55–0.90 GeV) with the t' restrictions mentioned above and with the $\pi^+ n$ mass being less than 2.1 GeV. The solid curve in Fig. 4(a) shows the result of a fit of that distribution to $\sin^2\theta$. It is clear that this distribution represents predominantly

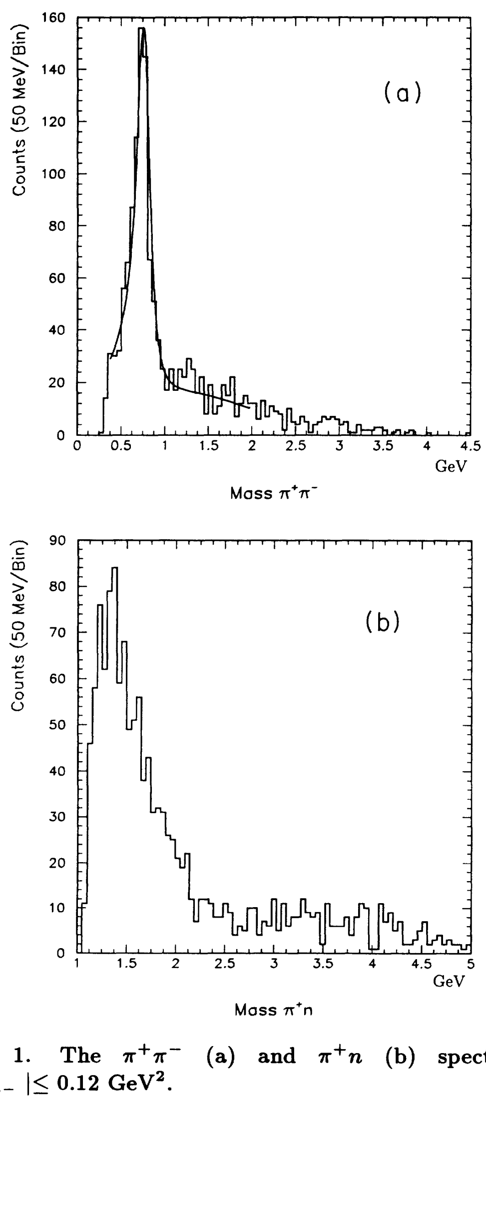

FIG. 1. The $\pi^+\pi^-$ (a) and $\pi^+ n$ (b) spectra for $|t'_{\gamma,\pi^+\pi^-}| \leq 0.12$ GeV^2.

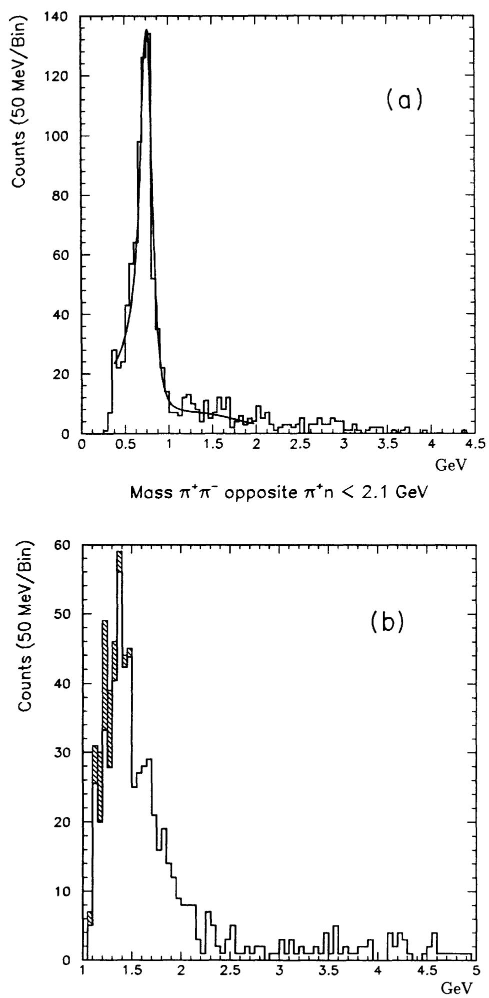

FIG. 2. (a) The $\pi^+\pi^-$ spectrum when $|t'_{\gamma,\pi^+\pi^-}| \leq 0.12$ GeV^2 and when $M(\pi^+ n) < 2.1$ GeV. (b) The $\pi^+ n$ spectrum opposite ρ^0 production when $|t'_{\gamma,\pi^+\pi^-}| \leq 0.12$ GeV^2. The shaded portion represent the expected contributions from $\Delta^+\rho^0$ production.

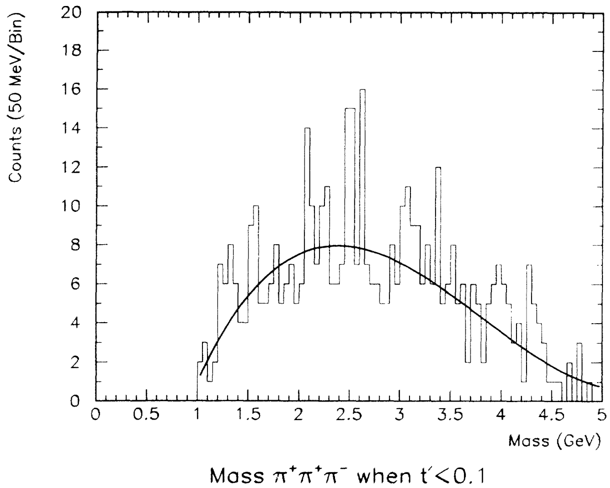

FIG. 3. The $\pi^+\pi^+\pi^-$ spectrum for the $\rho^0 N^*$ events of Fig. 2 which also satisfy $|t'_{\gamma,3\pi}| \leq 0.10$ GeV^2.

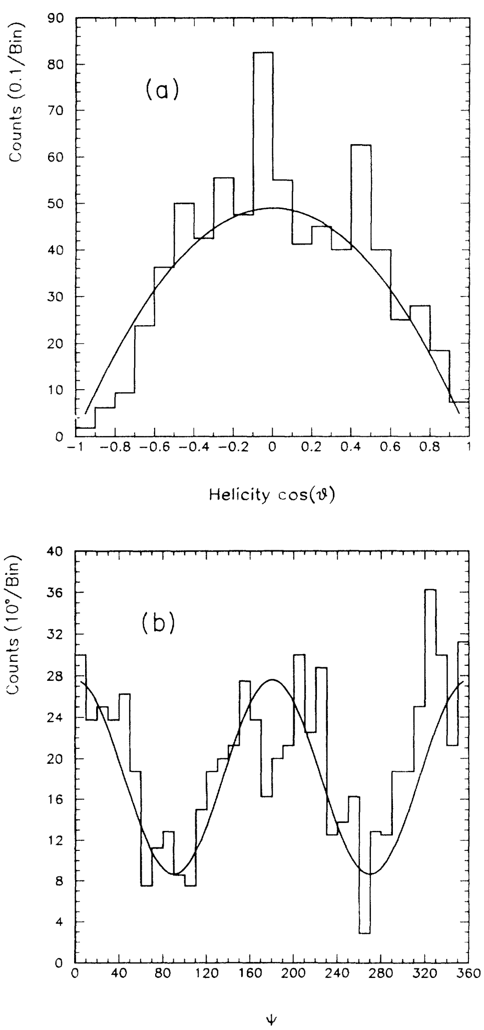

FIG. 4. The ρ^0 decay angular distributions in the helicity system: (a) $\cos\theta$; (b) Ψ.

ρ^0 mesons of helicity ± 1. There does appear to be a relative dearth of events in the region $-1 \leq \cos\theta \leq -0.7$. We do not understand the origin of this effect although that is the region where our calculated efficiencies are smallest. If we fit the data in Fig. 4(b) to the form $1 + P_\gamma \cos 2\Psi$ and determine P_γ from the fit, we find $P_\gamma = 0.53 \pm 0.05$ which is quite consistent with the expected value of 0.52. We thus can confirm that, in the main, s-channel helicity is conserved for the peripheral photoproduction reaction, $\gamma p \to \rho^0 \pi^+ n$, when the $\pi^+ n$ mass is less than 2.1 GeV. This is consistent with the conclusion reached above that the $\rho^0 N^*$ events considered here are produced directly and are not a feature of the decay of a 3π state.

The cross section for the reaction $\gamma p \to \rho^0 \pi^+ n$, at $|t'_{\gamma,\rho^0}| \leq 0.12$ GeV^2 is obtained from the data in Fig. 1, where there is no constraint on the recoiling $\pi^+ n$ mass. A Söding model fit to the data in Fig. 1(a) yields 632 ± 48 ρ^0 mesons. Figure 5 shows the $|\, t'_{\gamma,\rho^0} \,|$ distribution for the ρ^0 mass region ($0.6 \leq M_{\rho^0} \leq 0.9$ GeV). The smooth curve is a fit of the form $e^{-bt'}$ with b determined to be 8.9 ± 1.1 GeV^{-2}. Correcting for our triggering efficiency, acceptance, and the t' distribution yields a full diffractive, inelastic ρ^0 production cross section ($\gamma p \to \rho^0 \pi^+ n$), at 20 GeV, of $0.75 \pm 0.11\,\mu$b. At 9.3 GeV, Kogan [10], reported a cross section for diffractive ρ^0 production, in the same reaction, of $0.7 \pm 0.2\,\mu$b. Both experimental values are somewhat less than indicated by the calculations of Wolf [2] for ρ^0 production via a double peripheral process (Pomeron plus pion exchange) for which he finds a cross section of 1.0–1.2 μb in the photon energy range of 10–20 GeV.

We now examine, in some detail, the baryonic ($\pi^+ n$) spectrum recoiling from the ρ^0 at $|t'_{\gamma,\rho^0}| < 0.12$ GeV^2. We first note that this spectrum should contain a small signal corresponding to Δ^+ production. That such events should be present is apparent from the fact that in this experiment the cross section for the reaction $\gamma p \to \Delta^{++}\rho^-$ has been measured [11] to be $0.224 \pm 0.040\,\mu$b. After correction for the relative efficiencies in the two

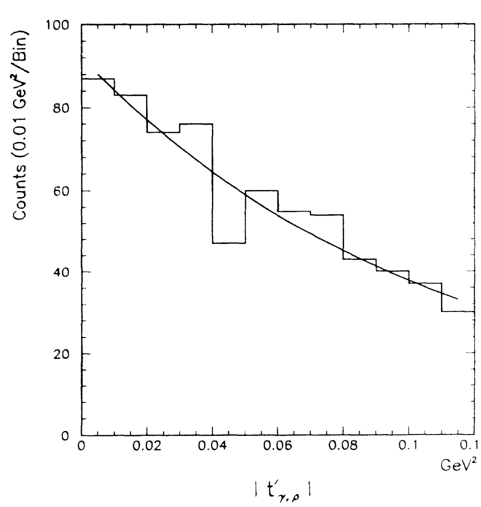

FIG. 5. $|\, t'_{\gamma,\rho^0} \,|$ distribution for peripheral ρ^0 production.

channels and the selection criteria imposed on the events appearing in Fig. 2(b) we expect approximately 56 events in that spectrum to correspond to $\Delta^+\rho^0 \to n\pi^+\rho^0$ production. These events are shaded in Fig. 2(b).

The principal feature of this surviving $\pi^+ n$ spectrum is that it is primarily confined to the region of $\pi^+ n$ mass less than 2.1 GeV. There also appear to be enhancements at masses of $\sim$1.4 GeV and, to a lesser extent, at 1.6 GeV. This is quite similar to the corresponding spectra observed in pion-induced diffraction [3]. It is also quite consistent with the calculated results of Wolf [2] who finds that, at energies and momentum transfers similar to ours, the largest contributors to the cross section derive from the double peripheral production of $\rho^0\pi^+ n$ and to $\rho^0 N^*(1470)$ resonance production. Although many N^* states could contribute to this spectrum, the narrow momentum transfer selection essentially excludes all but minimal contributions from other N^*'s.

To further investigate the baryon spectrum, we examine the decay angular distributions, in the Gottfried-Jackson frame, of the recoiling $\pi^+ n$ system as a function of mass. In this system, the angle θ is defined as the angle between the incident proton and outgoing neutron in the $\pi^+ n$ rest system. This polar angular distribution is shown for four $\pi^+ n$ mass regions, < 1.3 GeV, 1.3–1.5 GeV, 1.5–1.8 GeV, and 1.8–2.1 GeV in Figs. 6(a)–6(d), respectively. Aside from the mass region, 1.3–1.5 GeV, these distributions are quite similar to those presented by Wolf for the double peripheral production of the final state $\rho^0\pi^+$n. However, in the 1.4 GeV mass region [Fig. 6(b)], our $\cos\theta$ distribution is relatively symmetric as opposed to the double peripheral calculation of Wolf [2] which shows a forward-backward asymmetry intermediate between those found for the lower and higher mass regions. Since our data agree qualitatively with the double peripheral calculations, in both the low and high mass regions, we also expect a contribution from this origin in the 1400 MeV mass region. Thus most of the backward enhancement in the 1400 MeV angular distribution must be due to a process other than the double peripheral mechanism (events with $1.2 \le M_{3\pi} \le 2.0$ GeV, which also have $|t'_{\gamma,3\pi}| \le 0.10$ GeV^2 appear in Fig. 6 only

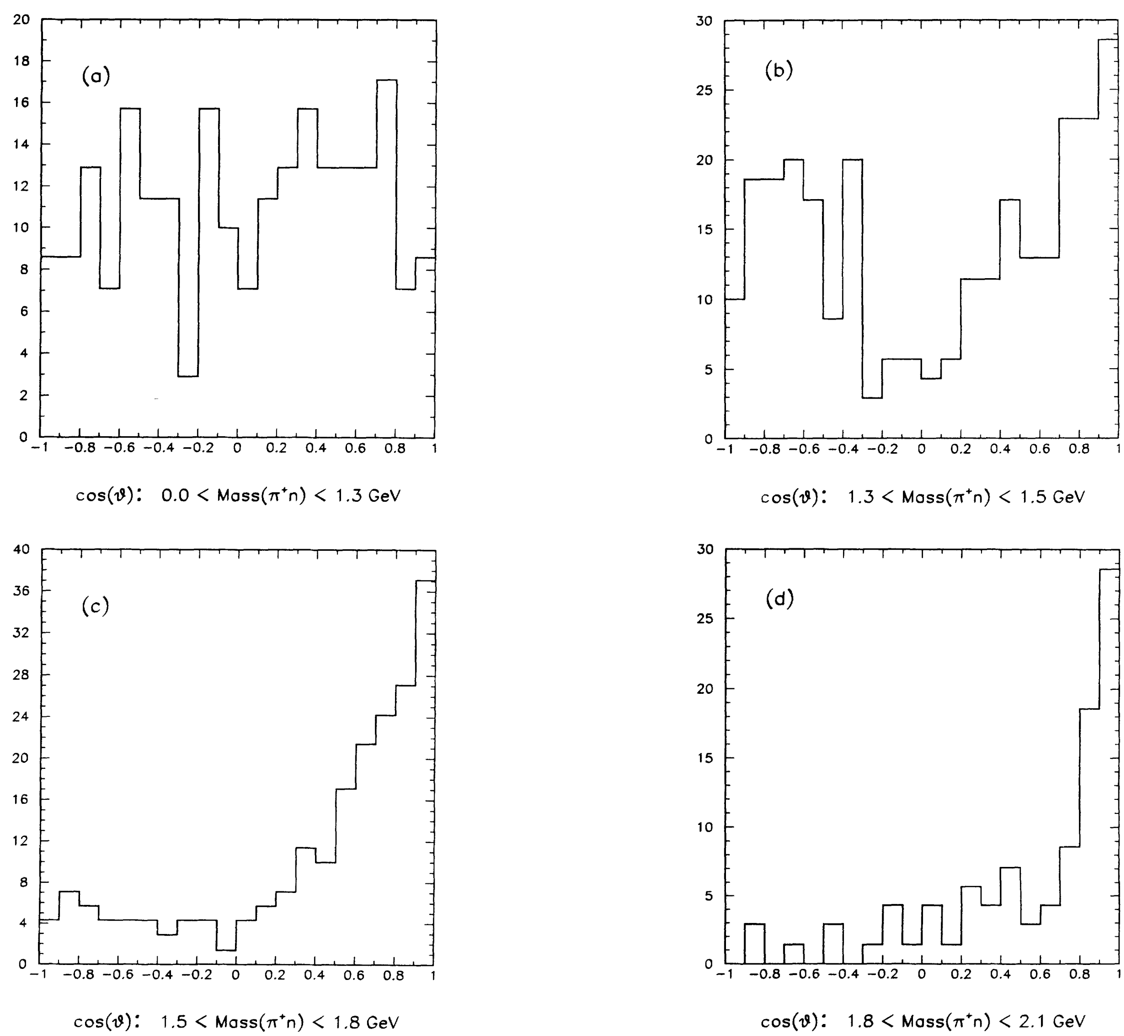

FIG. 6. The polar angle distributions in the Gottfried-Jackson system as a function of mass: (a) $0.0 \le M(\pi^+ n) \le 1.3$ GeV; (b) $1.3 \le M(\pi^+ n) \le 1.5$ GeV; (c) $1.5 \le M(\pi^+ n) \le 1.8$ GeV; (d) $1.8 \le M(\pi^+ n) \le 2.1$ GeV.

at positive values of $\cos\theta$). Whatever this process may be, its strong backward-forward asymmetry suggests it is unlikely to be N^* resonance production. The situation is similar to that observed by Chadwick *et al.* [3] for the reaction $\pi N \rightarrow \pi\pi N$ where the anomaly in the 1.4 GeV region in that experiment also appears as a backward asymmetry. These authors present cogent arguments that their 1.4 GeV enhancement is also not due to resonance production. They suggest that the origin is baryon exchange. While we cannot exclude baryon exchange as the causative agent in the photoproduction of the 1.4 GeV enhancement, we are aware of no peripheral photoproduction data which is not explicable on the basis of either Pomeron or meson exchange. In particular, we are aware of no instance where nucleon exchange has been invoked to explain forward photoproduction data.

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