Further results from charge-exchange photoproduction

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It is shown that the energy dependence of charge-exchange a_2^+ photoproduction ($\gamma p \to n a_2^+$) agrees with a one-pion exchange mechanism. No evidence for the photoproduction of the $a_1^+(1260)$ is observed. If the dynamics of a_1 and a_2 photoproduction are assumed to be the same, the absence of evidence for the a_1 is shown to be consistent with either an extremely large a_1 hadronic width or with an a_1 of mass somewhat less than 1260 MeV.

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Since the earliest photoproduction experiments, it has been known that the dominant reaction is the diffractive photoproduction of vector mesons. Arguments based on the vector meson dominance model have often been used to exclude anything but a minor amount of particle exchange as a mechanism for photoproduction [1]. Perhaps the most dramatic evidence of this is the unnatural parity-exchange contribution to ω photoproduction [2] ($\gamma p \to \omega p$) where the cross section falls from 1.3 ± 0.3 μb at 4.7 GeV to 0.1 ± 0.2 μb at 9.3 GeV. Since the radiative width of the ω is large [$\Gamma(\omega \to \pi^0 \gamma) = 850 \pm 50$ keV], such a drop in the unnatural parity-exchange ω production cross section leads to the conclusion that one-pion exchange (OPE) rapidly becomes an ineffectual production mechanism as E_γ increases. Complications in this interpretation do arise, however. Some years ago the reaction $\gamma p \to \rho^- \Delta^{++}$ was observed to persist to rather large energies. At 19.5 GeV this reaction was clearly evident with a production cross section [3] of 0.224 ± 0.045 μb. While it was natural to assume that the reaction was mediated by OPE [$\Gamma(\rho^- \to \pi^- \gamma) = 71 \pm 12$ keV], the decay angular distributions, the t' dependence of the production cross section, and its E_γ dependence all indicated difficulties in the interpretation of the reaction as evidence for OPE. Similar data and arguments had been noted previously at lower energies [4].

Recently, in a study of the reaction [5] $\gamma p \to a_2^- \Delta^{++} \to \pi^+ \pi^- \pi^- \pi^+ p$ at 19.5 GeV; it was observed that the decay angular distributions of the Δ^{++} and a_2^- as well as the t' distribution showed good agreement with OPE. Since this was the initial quantitative report of $a_2^- \Delta^{++}$ associated photoproduction at any energy, we could obviously not study its E_γ dependence. The purpose of this paper is to present our evidence for a_2^+ photoproduction from the reaction $\gamma p \to n \pi^+ \pi^+ \pi^-$, which we will compare with lower-energy data. We shall also comment on the significance of this result as regards to the photoproduction of the $a_1(1260)$.

Our data derive from a high-statistics hydrogen bubble chamber experiment which was performed at the Stanford Linear Accelerator Center with the primary purpose of studying open charm photoproduction. The experimental details regarding the data-taking phase of the experiment may be gleaned from prior publications [6]. The photon beam, produced by backscattering laser light from SLAC 30-GeV electron beam had an average energy of 19.3 GeV with a full width at half maximum of 1.7 GeV. The event sample for the $n \pi^+ \pi^+ \pi^-$ final state was determined as follows. Any event which had a three-constraint fit to any of the reactions $\gamma p \to p \pi^+ \pi^-$, pK^+K^-, or $pp\bar{p}$ with a probability greater than 10^{-4} was rejected. We also rejected all events for which either of the positive tracks was identifiable as a proton on the basis of ionization and curvature measurements or on the basis of Cherenkov information. Additionally, any event for which the downstream Pb-glass wall contained a γ was rejected. The present report is based on those 3781 events which survived these cuts and for which energy and momentum balance was attainable for the hypothesis $\gamma p \to n \pi^+ \pi^+ \pi^-$, with the energy of the incident photon lying between 16.5 and 21.0 GeV.

In Fig. 1 we present the $\pi^+ \pi^+ \pi^-$ mass spectrum for those peripheral events ($|t'_{\gamma,3\pi}| < 0.12$ Gev^2) where either

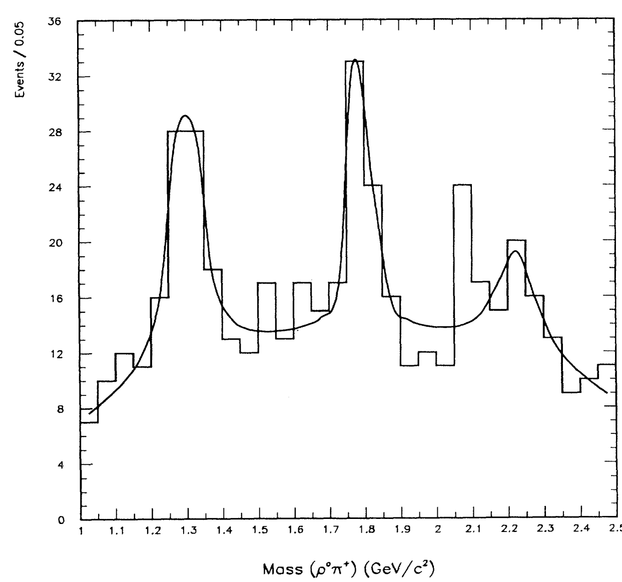

FIG. 1. $\pi^+ \pi^+ \pi^-$ mass spectrum from the reaction $\gamma p \to n \pi^+ \pi^+ \pi^-$ when either neutral dipion combination is a ρ^0 and when $|t'_{\gamma,3\pi}| < 0.12$ GeV^2.

$\pi^+\pi^-$ mass combination is a ρ^0 (0.55–0.90 GeV). Because of the somewhat uncertain nature of the efficiencies associated with this channel when the $\pi^+\pi^+\pi^-$ mass is large, we truncate our spectrum at 2.5 GeV. For the region $1.0 \leq M_{3\pi} \leq 2.5$ GeV, our efficiencies, determined by Monte Carlo procedures, do not depart from the values 0.72 ± 0.03. While the relative production cross sections vary, Fig. 1 contains evidence for the same resonances that were present in the reaction [5], $\gamma p \to \Delta^{++}\rho^0\pi^-$, which has been published and which we reproduce in Fig. 2. This "symmetry" would clearly be expected for isovector exchange. The fit in Fig. 1 is to a third-order polynomial background with simple Breit-Wigner resonances representing the $a_2(1320)$, a state of mass 1775 MeV, and a higher-mass state. The fit shown indicates an a_2 signal of greater than five standard deviation significance and corresponds to an a_2 production cross section of 0.29 ± 0.06 μb. We have assumed that all a_2 decays into 3π occur via $\rho\pi$ and that the t' dependence of the cross section is the same ($e^{-10|t'|}$) as we observed for the reaction $\gamma p \to \Delta^{++}a_2^-$. We have also included the effects of our efficiencies as well as the non-3π-decay modes of the a_2. It should perhaps be pointed out that neither the $a_1^0(1260)$, $a_2^0(1320)$, nor the $\pi_2^0(1670)$ has ever been observed in peripheral γp interactions, which is, again, consistent with OPE since the production of states with even C parity such as these are prohibited by charge conjugation invariance at the photon-meson vertex. The a_2 mass and width determined from the fit in Fig. 1 are 1305 ± 14 and 120 ± 40 MeV, respectively. These values are quite consistent with the parameters given for the $a_2(1320)$ in the Particle Data Group (PDG) tables [7].

The only other measurement of a_2^+ photoproduction was presented by Eisenberg *et al.* [8] nearly 25 years ago. Those authors segregated their data into two parts, at 4.3

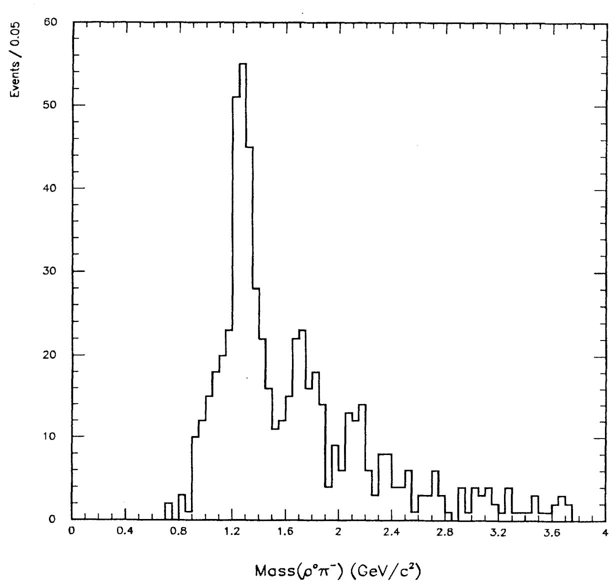

FIG. 2. $\rho^0\pi^-$ mass spectrum from the reaction $\gamma p \to \Delta^{++}\rho^0\pi^-$ at $|t'_{\gamma,\rho^0\pi^-}| < 0.2$ GeV^2. Details for the generation of this spectrum can be found in Ref. [5].

and 5.25 GeV, and they presented their cross sections for $\pi^+\pi^+\pi^-$ decays only. We have taken the liberty of refitting their combined data and applying corrections for other a_2^+ decay modes, from which we find $\sigma=2.6\pm0.6$ μb at an average photon energy of 4.8 GeV. If we assume an E_γ^{-n} energy dependence, a comparison of this result with our value of $\sigma=0.29\pm0.06$ μb at 19.5 GeV yields $n=1.57\pm0.22$, which is again quite consistent with other processes for which OPE is the likely dominant production mechanism [9].

The consistency of charge exchange a_2 photoproduction with one-pion exchange suggests that any isovector odd-G-parity state with a sufficiently large decay width to $\pi^\pm\gamma$ should be present in the $n\pi^+\pi^+\pi^-$ final state (and $\Delta^{++}\pi^+\pi^-\pi^-$). The Particle Data Group tables contain only two confirmed states [$a_1(1260)$, $a_2(1320)$] which are known to satisfy these requirements. Our spectra (Figs. 1 and 2) clearly show an $a_2(1320)$; however, neither spectrum contains an identifiable enhancement indicative of $a_1^\pm$ production. (States are observed in both spectra at $\sim$1775 MeV [10] and at $\sim$2200 MeV which will not be discussed here.) The absence of the a_1 is surprising in that the $\pi\gamma$ radiative width [11] of the a_1 has been measured to be 640 ± 290 keV as compared to the a_2 measurement [12] of 295 ± 60 keV. A variety of theoretical calculations also exists [13], all of which predict the a_1 radiative width to be at least as large as that of the a_2 and some of which find it to be much greater. Since our measurements are restricted to observations of the 3π decays of these states, the presence of substantial non-3π decays [7] for the a_2 and not for the a_1 indicate that the OPE cross sections should be in the ratio

$$R=\frac{\sigma(a_1^\pm \to \rho^0\pi^\pm \to \pi^+\pi^+\pi^-)}{\sigma(a_2^\pm \to \rho^0\pi^\pm \to \pi^+\pi^+\pi^-)} \geq \frac{3}{2},$$

where we have used $\Gamma(a_1^\pm \to \pi^\pm\gamma) \geq \Gamma(a_2^\pm \to \pi^\pm\gamma)$ and ignored any difference in mass between the a_1 and a_2. Because of the constrained nature of the $\rho^0\pi^-$ events in the spectrum of Fig. 2, we can use it to set an upper limit to the amount of a_1 present. If we make the extreme assumption that all events not contained in any of the resonant peaks between $\rho^0\pi^-$ masses of 1.0–1.6 GeV correspond to a_1 production, we find the above cross-section ratio R to be less than 0.5, indicating much less a_1 production than estimated above. Precisely why the a_1 is not observed in these data (or in the reaction $\gamma p \to n\pi^+\pi^+\pi^-$) could have several origins. The dynamics of the charge-exchange a_1 photoproduction process could be such as to depress the a_1 cross section relative to that of the a_2. Further, the hadronic width of the a_1 may also be so large that our experiment lacks sensitivity to the a_1. A width in excess of 450 MeV has been suggested by Törnqvist [14] and Bowler [14]. However, Longacre [15] was able to explain all of the hadronic data extant in 1982, including backward a_1 production, with an a_1 of mass 1230 ± 30 MeV and a width of 330 ± 60 MeV. Another possible reason could be that the $\pi^\pm\gamma$ radiative width of the $a_1^\pm$ is, at least, somewhat smaller than that of the a_2. This could be accommodated if the

a_1 mass is somewhat less than the PDG value. If the a_1 mass were as small as 1080 MeV, the experimental *upper limit* for the radiative width of the a_1, obtained by reanalysis of the original data [16], would fall to 240±90 keV. Furthermore, since all calculations of the radiative width involve factors of (q_γ^n) where q_γ is the magnitude of the three-momentum of the decay photon in the a_1 rest frame and n is a positive exponent, a reduction in the a_1 mass will lead to a decrease in the calculated radiative width of the a_1. Ishida *et al.* [13] find that the radiative width of the a_1 is reduced to 125 keV if the a_1 mass is 1056 MeV. Thus the lack of evidence for an a_1 in either of the spectra of Fig. 1 and 2 also can be explained if its mass is somewhat less than the value given by the PDG. This is consistent with the recent hadronic experiment [17] performed at KEK where the mass and hadronic width of the a_1 have been reported as 1122±17 and 254±11 MeV, respectively. A further indication that the PDG value for the a_1 mass may be too high can be gleaned from the observation of Kamal and Verma [18] that the experimental branching fractions for the decays $D^0 \rightarrow K^- a_1^+$ and $D^+ \rightarrow \bar{K}^0 a_1^+$ are factors of 6 and 2, respectively, greater than their calculated values. Since the decay probability for the D is proportional to $P_{a_1}^3$, where P_{a_1} is the a_1 momentum in the D rest frame, it is clear that a lower a_1 mass could result in a significant enhancement of the calculated $(\overline{K}^0 a_1^+)$ decay mode of the D, which would bring theory and experiment into better agreement (the difference between $K^- a_1^+$ and $\bar{K}^0 a_1^+$ decay modes can be understood [18] by including quark annihilation diagrams in the calculations). Finally, it can be recalled that some years ago Peaslee [19] observed that the width nominally assigned to the $a_1(1260)$ was anomalously large for an ordinary $q\bar{q}$ meson. Subsequently, this idea was utilized by Iizuka, Koibuchi, and Masuda [20] in a reanalysis of τ-lepton-decay data, to show that agreement could be obtained with a light relatively narrow a_1 ($M \approx 1.1$ GeV, $\Gamma \leq 0.4$ GeV) together with a heavier a_1'.

In summary, we have observed the photoproduction of the a_2^+ in the reaction $\gamma p \rightarrow n\pi^+\pi^+\pi^-$. At 19.5 GeV/$c$ photon energy, the a_2 production cross section is 0.29 ± 0.06 μb, which is consistent, when compared with previous data, with the energy dependence expected for a one-pion-exchange mechanism. The absence of an identifiable $a_1(1260)$ in either this reaction or in $\gamma p \rightarrow \Delta^{++}\pi^+\pi^-\pi^-$ can be reconciled with either an extremely large a_1 hadronic width or with an a_1 mass of somewhat less than 1260 MeV.

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