Energy Dependence of the Reaction $\gamma p \to \rho^- \Delta^{++}$ †

J. Ballam, G. B. Chadwick, A. Levy,* M. M. Menke, P. Seyboth,‡ and A. Shapira§
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

Y. Eisenberg, B. Haber, E. E. Ronat, Y. Stahl, and G. Yekutieli
Weizmann Institute of Science, Rehovoth, Israel
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The reaction $\gamma p \to \rho^-\Delta^{++}$ was studied between 4 and 8 GeV using positron-annihilation radiation. Assuming $\sigma \propto E_\gamma^{-a}$ we find that $a = 0.6 \pm 0.2$. With sufficiently large absorption corrections, a one-pion–exchange model can fit this dependence, but requires a width for $\rho \to \pi\gamma$ much in excess of the value predicted by SU(3).

Associated ρ and Δ production in the reaction

$$\gamma p \to \rho^- \Delta^{++} \tag{1}$$

has been observed in several bubble-chamber experiments.[1-5] Since the ρ^- cannot be produced diffractively, the simple assumption that Reaction (1) proceeds mainly through one-pion exchange (OPE) has been made. In this case the $\gamma p \to \rho^-\Delta^{++}$ cross sections are proportional to $\Gamma(\rho \to \pi\gamma)$, the $\rho\pi\gamma$ width, which is small [$\frac{1}{9}$ of the width[6] $\Gamma(\omega \to \pi\gamma)$ according to[7] SU(3)] and difficult to measure directly. Estimates of $\Gamma(\rho \to \pi\gamma)$ have therefore been given[1,2] using the OPE assumption. In this Letter we report on the extension of cross-section measurements for Reaction (1) up to 8.2 GeV. Thus the energy dependence of $\sigma(\gamma p \to \rho^-\Delta^{++})$ could be studied for a wide range of photon energies and serve as a test of the OPE assumption. We find that the variation of $\sigma(\gamma p \to \rho^-\Delta^{++})$ with the increase of the photon energy is smaller than that found for reactions expected to be dominated by an OPE process. This questions the validity of the $\Gamma(\rho\pi\gamma)$ estimates which were based on this assumption. A similar possible discrepancy with an OPE mechanism for Reaction (1) was recently reported by Eisenberg *et al.*,[4] who found that the ratio $\sigma(\gamma p \to \rho^-\Delta^{++})/\sigma(\gamma n \to \omega^0\Delta^0)$ at 4.3 GeV is in disagreement with OPE + SU(3) predictions.

The monochromatic annihilation experiments[4,3] at 4.3 and 5.25 GeV were extended to 7.5 GeV. A total of 1.5 million pictures were taken in the Stanford Linear Accelerator Center (SLAC) 40-in. bubble chamber at the three energies. All the events in the monochromatic peaks as well as the bremsstrahlung events were analyzed, but only the monochromatic events, which give constrained kinematic fits, were used in the study of the energy dependence of the cross sections. To avoid systematic biases, the 4.3- and

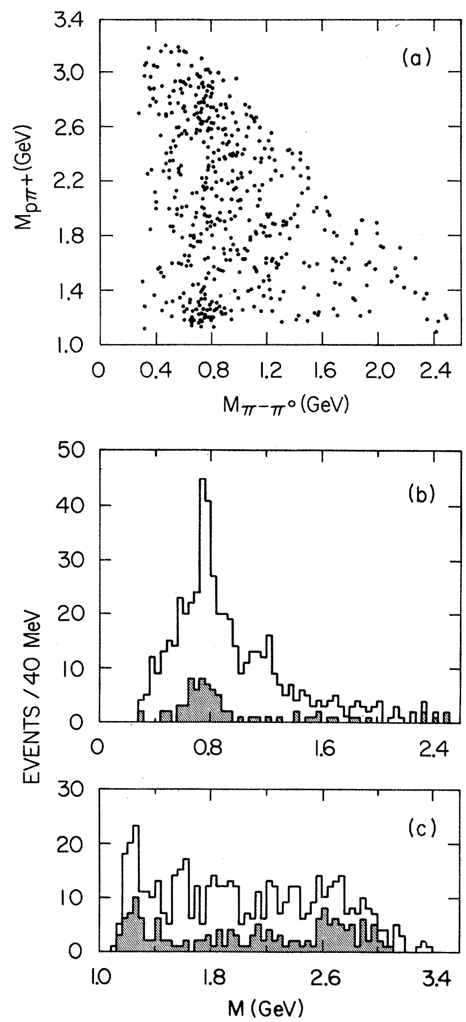

FIG. 1. (a) Scatter plot of $M(p\pi^+)$ versus $M(\pi^-\pi^0)$ for $\gamma p \to p\pi^+\pi^-\pi^0$ at 7.5 GeV. (b), (c) The $M(\pi^-\pi^0)$ and $M(p\pi^+)$ mass distributions, respectively. The shaded areas are $M(\pi^-\pi^0)$ distributions for Δ^{++} events ($1.12 < M_{p\pi^+} < 1.32$ GeV) in (b), and the $M(p\pi^+)$ distributions for ρ^- events ($0.66 < M_{\pi^-\pi^0} < 0.86$ GeV) in (c). Events with $M(\pi^+\pi^-\pi^0) < 0.81$ GeV were removed from the plot to exclude ω events.

Table I. Cross sections, momentum-transfer slopes B, and density-matrix elements obtained in this experiment. $\sigma(\gamma p \to p\pi^+\pi^-\pi^0)$ is the total channel cross section including $\omega \to \pi^+\pi^-\pi^0$, while $\sigma(\gamma p \to \rho\Delta)$ is the associated resonance-production cross section times the branching ratio for the protonic decay of the $\Delta(1236)$. B is the slope of the t distribution, ρ_{00}^{ρ} and ρ_{11}^{Δ} the diagonal elements for ρ and Δ, all for Reaction (1). Errors in the latter include an uncertainty from the unknown background decay distribution.

E_γ (GeV)	$\sigma(\gamma p \to p\pi^+\pi^-\pi^0)$ (μb)	$\sigma(\gamma p \to \Delta^{++}\rho^-)$ (μb)	$\sigma(\gamma p \to \Delta^+\rho^0)$ $(\Delta^+ \to p\pi^0)$ (μb)	$\sigma(\gamma p \to \Delta^0\rho^+)$ $(\Delta^0 \to p\pi^-)$ (μb)	B (GeV^{-2})	ρ_{00}^{ρ}	ρ_{11}^{Δ}
3.7–4.7	18.2 ±2.0	1.80 ±0.40	0.27 ±0.27	0.27 ±0.25	7.7 ±1.1	0.28 ±0.13	0.26 ±0.10
4.7–5.8	13.5 ±1.5	0.9 ±0.35	0.8 ±0.3	0.3 ±0.3	6.4 ±3.1	0.64 ±0.27	0.41 ±0.18
6.8–8.2	11.8 ±1.2	1.1 ±0.2	0.25 ±0.15	0.25 ±0.15	7.6 ±2.5	0.60 ±0.22	0.21 ±0.13

5.25-GeV data were reanalyzed and the same selection criteria, cuts, resonance shapes, and fitting procedures were used for all experiments.

A scatter plot of $M(p\pi^+)$ versus $M(\pi^-\pi^0)$ for final state

$$\gamma p \to p\pi^+\pi^-\pi^0 \qquad (2)$$

at 7.5 GeV with ω events removed is shown on Fig. 1(a) together with the $p\pi^+$ and $\pi^-\pi^0$ mass projections [Figs 1(b) and 1(c)]. The shaded areas correspond to Δ^{++} events in Fig. 1(b) and to ρ^- events in Fig. 1(c). Similar $\rho\Delta$ signals are obtained at 4.3 and 5.25 GeV with a somewhat larger background.[8] The signals become more pronounced when cuts are introduced on the γ-ρ four-momentum transfer t (e.g., $|t| < 0.6$ GeV^2).

The fractions of $\Delta\rho$ events in channel (2) were obtained by a multidimensional maximum-likelihood fit to the states $\Delta^{++}\rho^-$, $\Delta^+\rho^0$, $\Delta^0\rho^+$, $\Delta^{++}\pi^-\pi^0$, $\Delta^+\pi^+\pi^-$, $\Delta^0\pi^+\pi^0$, $\rho^-p\pi^+$, $\rho^0p\pi^0$, $\rho^+p\pi^-$, and $p\pi^+\pi^-\pi^0$ after the $\gamma p \to p\omega$ events had been removed. Fits were also done to final states including A_2^0; however, this did not affect the $\Delta\rho$ fractions. A detailed description of the cross-section determination for the enitre channel $\gamma p \to p\pi^+\pi^-\pi^0$ has been given elsewhere.[9] The cross sections for $\gamma p \to p\pi^+\pi^-\pi^0$ and for the various charge configurations of $\gamma p \to \rho\Delta$ are presented in Table I for all three energies. In the same table we also present the t slopes B for ρ^- production in Reaction (1) where a momentum-transfer distribution of the form $d\sigma/dt = A\exp(-B|t|)$ was assumed. Finally, the diagonal density-matrix elements, in the Jackson system, for the ρ^- and Δ^{++} were evaluated and are also given in Table I.

In Fig. 2 we have plotted the $\gamma p \to \rho^-\Delta^{++}$ cross sections for the three energies together with two recent cross-section determinations at 2.8 and 4.7 GeV.[5] The events in these experiments have much less background because of the energy constraint than was the case for the bremsstrahlung events used in earlier experiments.[1,2] Also, the same resonance parameters, resonance shapes, and fitting programs were used for both the present experiments and that of Ref. 5, minimizing systematic errors. A least-squares fit of the five cross sections by the form

$$\sigma(\gamma p \to \rho^-\Delta^{++}) = CE_\gamma^{-a} \qquad (3)$$

gave $C = 3.5 \pm 1.2$ and $a = 0.6 \pm 0.2$, where σ is expressed in microbarns and E_γ in GeV.

There is no unique prescription for relating the energy exponent a in Eq. (3) to the production mechanism. We therefore choose two approaches: (a) comparing with similarly obtained exponents for reactions believed dominated by OPE; (b) attempting to fit the data with a specif-

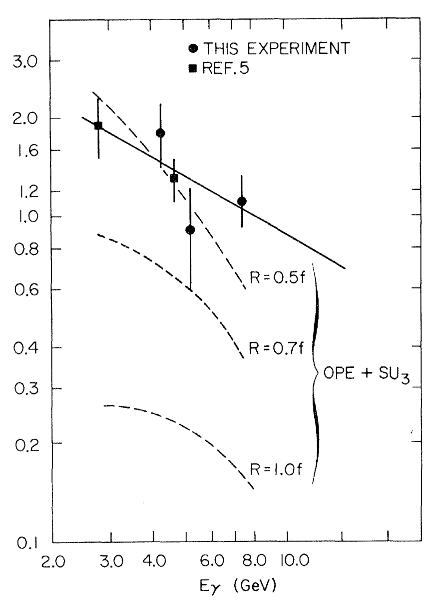

FIG. 2. $\gamma p \to \rho^-\Delta^{++}$ cross sections, determined in this experiment and from Ref. 5, versus the photon energy E_γ. The full line is the best fit of the cross sections by Eq. (3). The dashed lines are the calculated OPE cross sections (see text).

ic OPE model.

In approach (a) it has been noted[10,11] that for our energy range, reactions believed to be OPE dominated have a in the range 1.6-2.5. In particular, the reaction $NN \to \Delta\Delta$, an especially likely OPE candidate which has been studied up to 30 GeV, has been shown to have an energy dependence with $a = 2.5 \pm 0.3$.[10] Clearly the dependence of Reaction (1) falls far outside this range. However, the effects of the kinematic boundaries may be substantial, as will be shown below, so no firm conclusion may be reached.

In approach (b) we use the OPE model with absorption introduced, with a sharp cutoff.[12] This model gives a fair description of other quasi-two-body photoproduction reactions.[9] It has two parameters: $\Gamma(\rho\pi\gamma)$, the ρ radiative width; and R, the cutoff radius. The latter is usually determined by a fit to the t dependence of the reaction studied, and in hadron-induced reactions is about 1 fm. In Fig. 2 the broken lines show the cross sections obtained with this model for R $=0.5$, 0.7, and 1.0 fm, all assuming $\Gamma(\rho\pi\gamma)$ $=\frac{1}{9}\Gamma(\omega\pi\gamma)=0.134$ MeV, the SU(3) value.[6,7] As R increases, the t dependence becomes steeper, and the low-energy cross sections are depressed more than the high by the effects of the kinematic boundaries. Hence the energy dependence found can indeed be reproduced by OPE, but only if $\Gamma(\rho\pi\gamma) \gtrsim 0.5$ MeV ($R \sim 0.8$ fm). The same conclusion is reached when the OPE model of Wolf[13] is applied. Such a large value is in contradiction with the result of a search for the process $\rho \to \pi\gamma$ which found $\Gamma(\rho\pi\gamma) < 0.6$ MeV at the 97% confidence level.[14]

In conclusion we find that the cross sections for the reaction $\gamma p \to \rho^- \Delta^{++}$ in the energy range 3-8 GeV cannot be reproduced using an OPE process and the SU(3) value of $\Gamma(\rho\pi\gamma)$. Similar indications that other processes are important were found by comparing γp and γd reactions.[4]

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*Present address: Physics Department, Tel-Aviv University, Tel-Aviv, Israel.

‡On leave from Max Planck Institute, Munich, Germany.

§Present address: The Weizmann Institute of Science, Rehovoth, Israel.

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