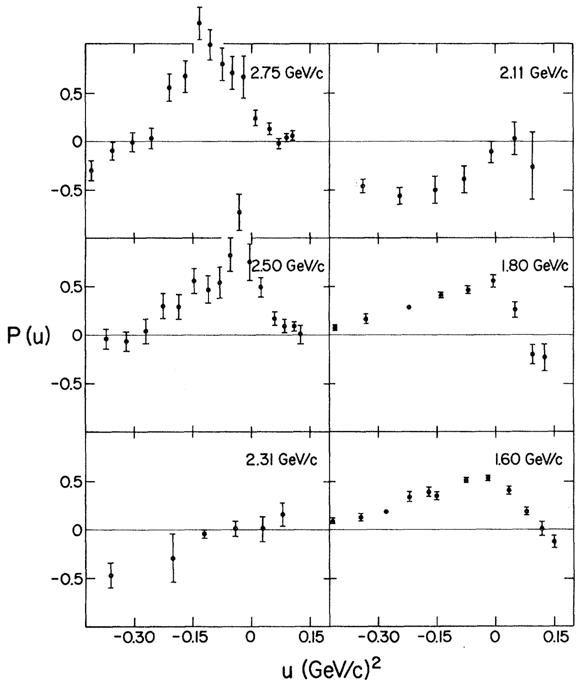

FIG. 2. π^+p polarization as function of $|u|$ for incident momenta of 2.75, 2.50, 2.31, 2.11, 1.80, and 1.60 GeV/c. (The data at 2.75 and 2.50 GeV/c are taken from Ref. 4.)

ward region, in the same energy range.

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γn Partial Cross Sections up to 12 GeV and the Isovector-Isoscalar Interference

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γn reactions are studied in a 40-in. bubble chamber filled with deuterium. Cross sections for channels with no neutral particles in the final state are presented up to a photon energy of 12 GeV. For channels with one neutral particle we present the cross sections at 7.5 GeV only. Comparison of γn reactions with their charge-symmetric γp reactions indicates a considerable isovector-isoscalar interference contribution.

The vector-dominance model (VDM) has been applied successfully to photoproduction interactions. In this model the photon is represented by a combination of a ρ^0 meson (isovector) and an ω and a φ meson (isoscalar). The contribution of the φ meson is believed to be small and therefore often neglected. In some of the calculations using the VDM, the interference between the amplitudes of these mesons is neglected. In some others the interference term is avoided by taking a suitable combination of cross sections so that the term cancels out. A straightforward method to study the magnitude of this interference is a comparison of γn reactions with their γp charge-symmetric ones. This method has already been utilized in the single-pion photoproduction reactions.[1] In this Letter we present results on γn partial cross sections up to 12 GeV which are used for a study of the isovector-isoscalar interference.

The experiment was carried out with the Stanford Linear Accelerator Center (SLAC) annihilation beam[2] in the SLAC 40-in. bubble chamber filled with deuterium. The chamber was exposed to positron-electron annihilation radiation at 7.5 GeV, which was superimposed upon a bremsstrahlung radiation with 12 GeV maximum energy.

We have analyzed about 180 000 pictures which were double scanned for events having three or more prongs. We report here the results on the four- or more-prong events, where the following reactions have been analyzed:

$$\gamma n \rightarrow p\pi^+2\pi^-, \quad (1)$$

$$\rightarrow p\pi^+2\pi^-\pi^0, \quad (2)$$

$$\rightarrow n2\pi^+2\pi^-, \quad (3)$$

$$\rightarrow p2\pi^+3\pi^-, \quad (4)$$

$$\rightarrow p2\pi^+3\pi^-\pi^0, \quad (5)$$

$$\rightarrow n3\pi^+3\pi^-, \quad (6)$$

$$\rightarrow p3\pi^+4\pi^-, \quad (7)$$

$$\rightarrow p3\pi^+4\pi^-\pi^0, \quad (8)$$

$$\rightarrow n4\pi^+4\pi^-. \quad (9)$$

Reactions (1), (4), and (7), where no neutral particles are produced, can be identified up to 12 GeV photon energy. In all the other reactions, where one neutral particle is present in the final state, the identification is possible only at the annihilation peak, namely, at the photon energy interval of 6.9-8.1 GeV. In this interval the photon energy is known for each event with an accuracy of ~2%. Hence one can treat Reactions (2), (3), (5), (6), (8), and (9) as one-constraint (1C) reactions and calculate quantities (e.g., confidence level, missing mass, etc.) which may help to remove the contamination of multineutral particle production in these channels. Another way of minimizing this contamination is to look at the difference between the constrained and nonconstrained photon energy for these reactions. The distribution of this difference peaks around 0 with a typical full width of about 200 MeV. At all other energies these reactions are of a 0C type and therefore are not discussed here.

About $\frac{1}{3}$ of all the events had a visible, short spectator proton which was measured. In all the remaining events, the proton spectator was reconstructed in the fitting process, assuming the unmeasured momentum components to be $p_x = p_y = p_z/1.37 = 0 \pm 30$ MeV/c, z being the direction of the optical axis. To verify this procedure we have studied the momentum distribution of the spectator proton (defined as the proton with the lower momentum) for both the measured and the reconstructed ones. In Fig. 1 we display the spectator momentum distribution in the laboratory system for the reaction

$$\gamma d \rightarrow p_s p\pi^+\pi^-\pi^-.$$

As can be seen, the distribution agrees well with the expected one from the Hulthén wave function. In all the reactions we accepted only events having a spectator momentum in the laboratory system of less than 300 MeV/c. All cross sections were therefore corrected by 2% to account for this cutoff. Glauber corrections were assumed to be the same for all the different channels and extended from 1% at 1 GeV [3] up to 4% at 8 GeV [4] photon energy.

Figure 2 shows the dependence of $\sigma(\gamma n \rightarrow p\pi^+\pi^-\pi^-)$ on the incoming photon energy $E_\gamma{}^n$ in the neutron rest system, up to 12 GeV. The cross-section values in this figure do not include the Glauber corrections. For comparison we have compiled in the same figure the cross-section values measured by the DESY group[5] up to 5.3 GeV, and those measured by the Rehovoth group[6] up to 8

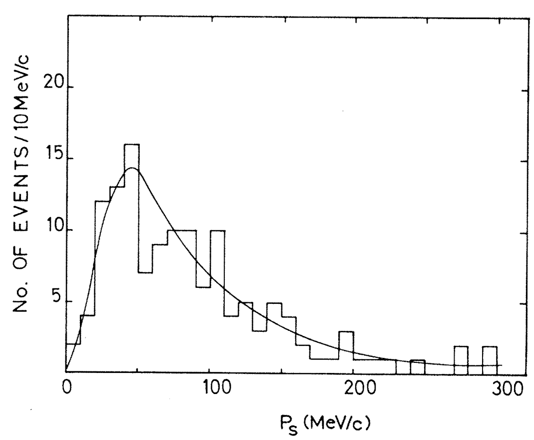

FIG. 1. The momentum distribution, in the laboratory system, of the spectator proton in the reaction $\gamma d \rightarrow p_s p\pi^+\pi^-\pi^-$. The smooth curve is the expected distribution from the Hulthén wave function.

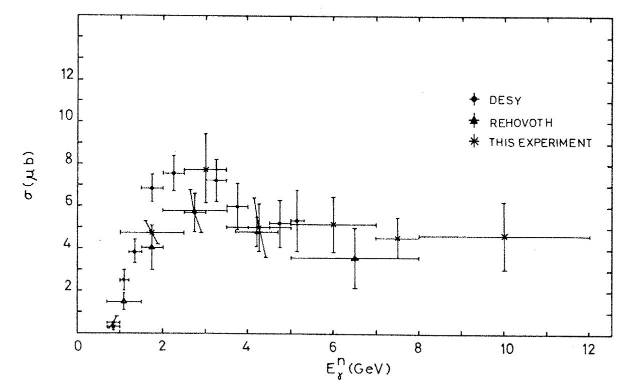

FIG. 2. Compilation of the cross section for the reaction $\gamma n \rightarrow p\pi^+\pi^-\pi^-$ as a function of the photon energy $E_\gamma{}^n$ in the neutron rest system. The cross-section values do not include the Glauber corrections.

Table I. γn partial cross sections with (σ_c) and without (σ) the Glauber correction.

Final State	E_γ^n(GeV)	σ(μb)	σ_c(μb)	Final State	E_γ^n(GeV)	σ(μb)	σ_c(μb)
$p\pi^+2\pi^-$	0.7 - 1.0	.28 ± .12	.28 ± .12	$n2\pi^+2\pi^-$	6.9 - 8.1	6.05 ± .98	6.25 ± 1.01
"	1.0 - 2.5	4.75 ± .54	4.80 ± .55	$p2\pi^+3\pi^-$	4.5 - 7.0	1.54 ± .69	1.60 ± .70
"	2.5 - 3.5	7.75 ± 1.65	7.95 ± 1.70	"	7.0 - 8.0	1.92 ± .50	2.00 ± .50
"	3.5 - 5.0	5.06 ± 1.37	5.21 ± 1.41	$p2\pi^+3\pi^-\pi^0$	6.9 - 8.1	1.95 ± .50	2.02 ± .50
"	5.0 - 7.0	5.16 ± 1.24	5.35 ± 1.28	$n3\pi^+3\pi^-$	6.9 - 8.1	2.54 ± .62	2.63 ± .63
"	7.0 - 8.0	4.56 ± .94	4.73 ± .97	$p3\pi^+4\pi^-$	6.5 - 8.0	.64 ± .32	.66 ± .33
"	8.0 -12.0	4.65 ± 1.58	4.84 ± 1.64	$p3\pi^+4\pi^-\pi^0$	6.9 - 8.1	.42 ± .26	.44 ± .27
$p\pi^+2\pi^-\pi^0$	6.9 - 8.1	4.70 ± .86	4.85 ± .89	$n4\pi^+4\pi^-$	6.9 - 8.1	.21 ± .21	.22 ± .22

GeV. All the measurements are in agreement with each other within statistical errors. The cross section rises rapidly from threshold to a maximum around 3 GeV and then decreases to a constant value of ~4 μb. In Table I we present both the uncorrected (σ) and Glauber-corrected (σ_c) cross sections for all the reactions.

Next we turn to the comparison between the γn reactions and their charge-symmetric γp reactions. In particular we compare Reaction (1) to the reaction

$$\gamma p \to n\pi^-\pi^+\pi^+. \quad (10)$$

If the photon were an eigenstate of isospin, the two cross sections $\sigma(\gamma n \to p\pi^+\pi^-\pi^-)$ and $\sigma(\gamma p \to n\pi^-\pi^+\pi^+)$ would be equal. Since, however, the photon is a mixture of isovector and isoscalar parts, any difference between these two cross sections is a measure of the interference between the isovector and the isoscalar components. In Fig. 3(a) we compare the cross sections for Reaction (1) with those of Reaction (10).[7] The values of the γp cross section are consistently higher than the corresponding charge-symmetric ones where this difference is most noticeable, in the region of 3-5 GeV photon energy. Thus it is clear that the isovector-isoscalar interference is rather large and cannot be neglected.

Both γp and γn reactions may be compared to corresponding πp reactions using a model proposed by Satz.[8] In this model one uses the VDM, the additive quark assumption, and the isospin independence of π-N amplitudes. The predictions for γp and γn cross sections from $\pi^\pm p$ data by use of this method[9] are shown in Fig. 3(a). As can be seen, the values from the $\pi^\pm p$ data are higher than the γn and lower than the γp cross-section values. A possible reason for this poor agreement is the omission of the ρ-ω interference term, which appears with opposite signs in

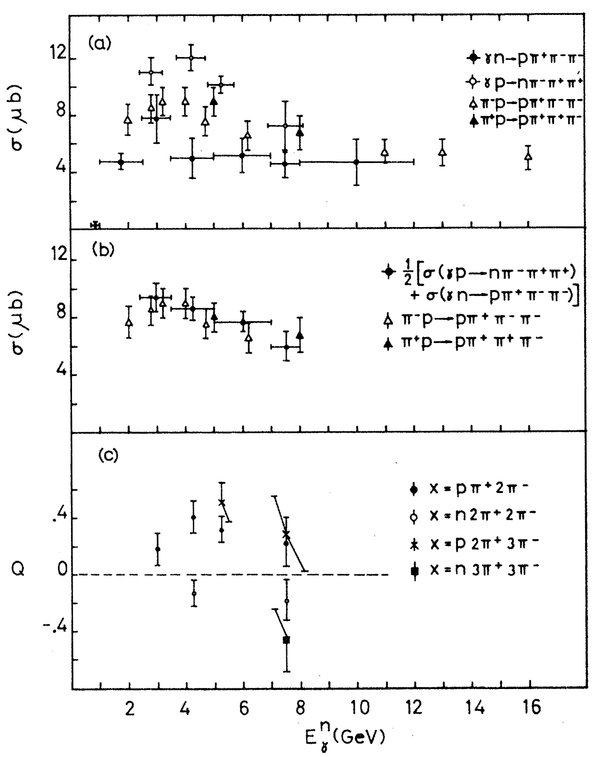

FIG. 3. (a) Comparison of the $\gamma n \to p\pi^+\pi^-\pi^-$ cross section (solid circles) with (1) the charge-symmetric reaction $\gamma p \to n\pi^-\pi^+\pi^+$ (open circles), and (2) the predictions from $\pi^- p$ and $\pi^+ p$ reactions using the Satz model (triangles). (b) Comparison of the sum $S = \frac{1}{2}[\sigma(\gamma p \to n\pi^-\pi^+\pi^+) + \sigma(\gamma n \to p\pi^-\pi^+\pi^+)]$ with the predictions from $\pi^- p$ and $\pi^+ p$ data using the Satz model. (c) Dependence of the relative cross-section difference Q for different final states (see text) as a function of the photon energy E_γ^n.

the γp cross sections.

In the absence of detailed information about the isovector-isoscalar interference, it is useful to consider an average γ-nucleon cross section, which we define as

$$S = \tfrac{1}{2}[\sigma(\gamma n \to x) + \sigma(\gamma p \to x')],$$

where x' is the charge-symmetric final state of x. This sum of cross sections is free of the interference term[10] which is specifically neglected in the Satz model. In Fig. 3(b) we show the comparison between the average γ-nucleon cross section S and the calculated values from $\pi^\pm p$ data. A very good agreement is obtained, suggesting that the other two assumptions used by Satz (isospin independence of π-N amplitudes and additivity of quark scattering amplitudes) are justified.

The γp-γn cross-section difference is a measure of the isovector-isoscalar interference contribution. In Fig. 3(c) we plotted the relative γp-γn cross-section difference, which we define as

$$Q = \frac{\sigma(\gamma p \to x') - \sigma(\gamma n \to x)}{\sigma(\gamma p \to x') + \sigma(\gamma n \to x)},$$

as a function of $E_\gamma^{\,n}$, for several final states[11] for energies above 2 GeV. As seen from this figure, Q is negative for reactions where the initial and final nucleon are identical ("elastic" pion photoproduction) and is positive for "charge-exchange" pion photoproduction. As for energy dependence, there does not seem to be any statistically significant variation. Finally, the isovector-isoscalar interference has recently also been observed in the measurement of the total hadronic γp and γn cross sections for incident energy up to 18 GeV.[12] In that work it was found that $\sigma_T(\gamma p)$ is consistently larger than $\sigma_T(\gamma n)$.

We gratefully acknowledge the cooperation of SLAC in performing this experiment. In particular we are indebted to J. Ballam and G. B. Chadwick for their sincere interest in this experiment. Our thanks are also due to R. Watt and the SLAC Bubble Chamber Operation crew and the SLAC Research Area Division personnel. We also wish to thank the members of our physics department for many helpful discussions. Finally, we would like to acknowledge the valuable help of our technical and scanning staff at Tel-Aviv.

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