SLAC-PUB-1054
(TH), (EXP)
June 1972

VECTOR MESON PHOTOPRODUCTION, AMPLITUDE STRUCTURE AND S-CHANNEL HELICITY CONSERVATION VIOLATION IN POMERON EXCHANGE REACTIONS*

G. Chadwick, Y. Eisenberg,** and E. Kogan**
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

(Presented by Y. Eisenberg)

ABSTRACT

The experimental data on vector meson photoproduction and Compton scattering is analyzed by utilizing the dual absorptive model. The s-channel helicity conserving (SHC) Pomeron exchange amplitude in ρ^0 and Φ photoproduction is found to shrink with s, in the same way as in π- and K^+-nucleon elastic scattering. The small SHC-violating amplitudes are also studied. The ratio of amplitudes for $|\Delta\lambda| = 1$ to $\Delta\lambda = 0$ at the γ-ρ vertex is shown to be similar to the ratio of corresponding πN amplitudes at the proton vertex and both seem to depend only weakly on s.

INTRODUCTION

My talk will be devoted to discussion of new results on vector meson photoproduction, amplitude structure and the question of s-channel helicity conservation (SHC) in diffractive photon processes as well as to comparison of this data with πN scattering. The experimental photoproduction data is from a SLAC-Berkeley collaboration.[1] The complete amplitude analysis and comparison with πN data will be presented in detail elsewhere.[2]

Photoproduction of ρ^0 mesons is considered to be a good example[3] of a mainly diffractive process at high energies, like πN or γN elastic scattering. Within VDM[3] one pictures the reaction $\gamma p \to \rho^0 p$ as ρ^0 "elastic" scattering. It implies:

$$\frac{d\sigma}{dt}(\gamma p \to \rho^0 p) = \left(\gamma_\rho^2/\alpha\pi\right)^{-1} \frac{d\sigma}{dt}(\rho p \to \rho p) \qquad (1)$$

(The VDM constant $\gamma_\rho^2/4\pi$ from the e^+e^- storage ring experiments[4] is $\simeq 0.64$.) The ρ^0 decay serves as a good analyzer for the polarization state of the "elastically" scattered particle.

The other diffractive-like processes, i.e., $\pi p \to A_1 p$ or $Kp \to Qp$, etc., will not be discussed here. They do not seem to conserve s-channel helicity even approximately, possibly because of the larger backgrounds or because of the required spin changes at the meson vertex, and are clearly in a separate category.

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*Work supported by the U. S. Atomic Energy Commission.
**On leave from the Weizmann Institute, Rehovoth, Israel.

(Presented at The 3rd International Conference on Experimental Meson Spectroscopy at the University of Pennsylvania, Philadelphia, Pennsylvania — April 27-29, 1972.)

In earlier experiments[5] it was shown that s-channel helicity is conserved in reaction (1) to within a very small fraction of the total intensity, for $|t| < .4$ GeV^2. Gilman et al.[6] suggested that SHC is a property of Pomeron exchange. It is therefore of interest to closely examine the amplitude structure of reaction (1), estimate the Pomeron contribution to it and see to what extent the small observed non-SHC amplitudes could be part of the Pomeron exchange process.

AMPLITUDE ANALYSIS

Following the ideas of the Dual Absorptive Model[7] (DAM) the question of the amplitude structure of the Pomeron and Regge exchanges has received considerable attention. In general the SHC Pomeron amplitude was shown[7] to have a flat distribution in impact parameter space and the Regge exchanges (f^0, A_2) to be peripheral (i.e., peaked at radius of $\simeq 1$ fermi). Davier[8] recently analyzed the sum of π^+p and π^-p elastic scattering cross sections and has shown that it is nicely explained by P and f^0 exchanges, within DAM. I would like to show here that also photon initiated processes can be analyzed in the same way and that the resulting[2] SHC-amplitudes look very similar to those obtained[8] for πp scattering.

As a way to estimate the magnitudes of different exchange contributions in photoproduction, we may use the energy dependence of $\sigma_T(\gamma p)$ and $\sigma_T(\gamma n)$ and from it separate the contributing exchanges to forward Compton scattering. By VDM ρ^0 photoproduction in the reaction $\gamma p \to \rho^0 p$ should be related to Compton scattering. A recent compilation of Wolf[3] gave the following results:

$$\mathrm{Im}\, f(\gamma p \to \gamma p)_{t=0} \propto \sigma_T(\gamma p) = C_P + C_{P'} S^{-1/2} + C_{A_2} S^{-1/2} \qquad (2)$$

$$C_P = (97.4 \pm 1.9)\,\mu b, \qquad C_{P'} = (78 \pm 7)\,\mu b\cdot \mathrm{GeV}, \qquad C_{A_2} = (17 \pm 3)\,\mu b \cdot \mathrm{GeV}\ .$$

Since only 1/2 of the A_2 exchange is expected (by SU(3)) to be present in $\gamma p \to \rho^0 p$ we may safely neglect it and analyze reaction (1) in terms of P and $P'(f^0)$ exchanges only.

In the following we assume P-exchange to be pure imaginary, and write

$$\frac{d\sigma}{dt}(\gamma p \to \rho^0 p) \approx |P(t) + f(t)|^2 \approx |P(t)|^2 + 2P(t)\ \mathrm{Im}\ f(t) \qquad (3)$$

where we have neglected in (3) the $|f(t)|^2$ term (this is justified, by (2) above, for energies above ~ 5 GeV). In the DAM analysis[7-9] P(t) and Im f(t) are approximated to be of the form:

$$P(t) = i\,A_p \exp(B_p t)$$
$$\mathrm{Im}\, f(t) = \frac{A_f}{\sqrt{s}} \exp(B_f t)\ J_0(R\sqrt{-t}) \qquad (4)$$

where the f^0 exchange radius is taken[7,8] to be $r \simeq 1$ fermi (5 GeV^{-1}). s in (4) is expressed in GeV^2. We thus have, within the framework of DAM, a complete description of the s-channel helicity conserving part of reaction (1). As was shown[1] experimentally, reaction (1) is SHC to a 98% level in the intensity. Thus we may fit directly its $d\sigma/dt$ to Eqs. (3) and (4) and obtain the Pomeron and f^0 exchange parameters.

In the analysis[2] we have used the data of the laser[1,5] experiments (parameterization cross sections) and Anderson et al.,[10] which were shown to agree for $E_\gamma \leq 9$ GeV. In the fits A_p and A_f were assumed to be s-independent and B_p and B_f were determined at each E_γ. More details are given in Ref. 2. We obtain excellent fits to all existing data between 5 and 18 GeV and samples of these are shown in Fig. 1. The resulting Pomeron

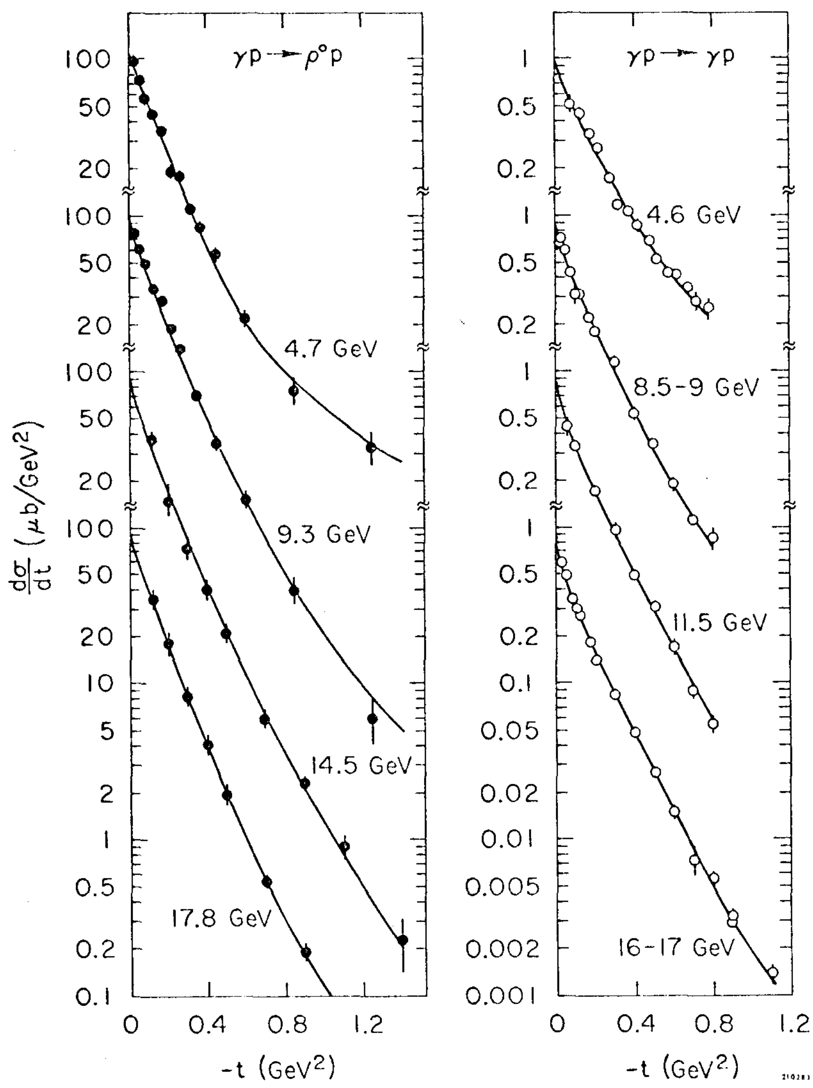

Fig. 1. Fits of $d\sigma/dt$ of ρ^0 photoproduction and Compton scattering to sum of P and f^0 exchange utilizing DAM.

exchange slopes B_p are given in Fig. 2 and one clearly observes the shrinkage of the Pomeron amplitude with s in a way similar to the results of Davier.[8] We have repeated the analysis also for Compton scattering,[11] $\gamma p \to \gamma p$, utilizing C_p, $C_{p'}$ and C_{A_2} of relation (2) for the coefficients A in (4) and combining the A_2 and f^0 exchange contributions (both are expected[7] to have similar shapes). Some of the Compton fits are also shown in Fig. 1 and the corresponding slopes in Fig. 2. Again we notice good fits to the data and agreements between the resulting P-exchange slopes of ρ^0 photoproduction and Compton scattering. Note also that the Pomeron slopes calculated[8] for πN elastic scattering (dashed line in Fig. 2) are close to those we obtain* and all clearly suggest a shrinkage of the Pomeron production distribution. Finally, we show in Fig. 2 the experimental slope parameters[1,3] of Φ^0 photoproduction in the reaction $\gamma p \to \Phi^0 p$, obtained by fitting

$$\frac{d\sigma}{dt}(\gamma p \to \Phi p) \propto e^{2B_p t} \quad .$$

As was pointed out by Avni,[9] again good agreement is obtained with a shrinking Pomeron alone and thus apparently we find an explanation to the known[3] observation that Φ^0 photoproduction has smaller $d\sigma/dt$ slopes as compared with those of ρ^0 and ω.

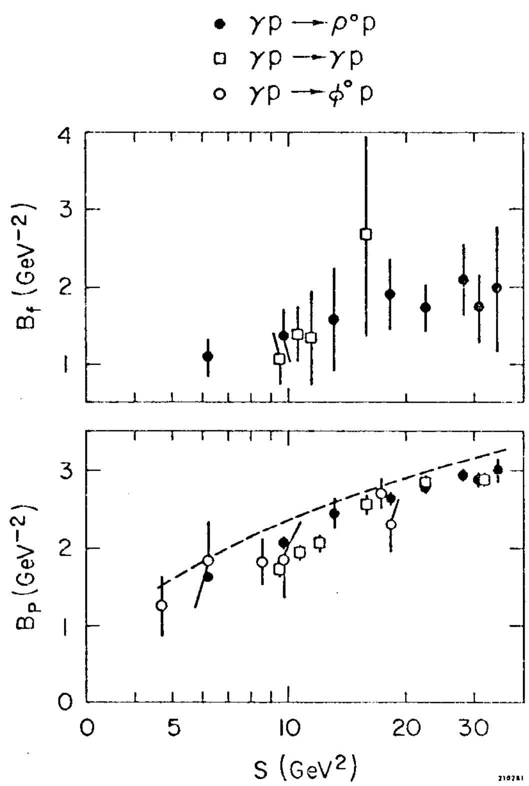

Fig. 2. P and f^0 exchange amplitude slopes as obtained from fits of $d\sigma/dt$. Also shown Φ^0 photoproduction slopes and the P-exchange slopes in πN scattering (dashed line) from Ref. 8.

The fits are not very sensitive to the f-exchange slopes, B_f, and thus the latter have large errors (see Fig. 2). Generally, also here we obtain[2] good agreement with the corresponding πN results[8] and the resulting slopes are consistent with being linear in ln s.

Finally, it is interesting to point out that the parameters A_p and A_f that we obtain for reaction (1), $7.6 \pm .5$ and $10.7 \pm 1\ \mu b^{1/2}\ \mathrm{GeV}^{-1}$ respectively, agree with the corresponding[8] πN values when multiplied by the VDM constant $\gamma_\rho/\sqrt{\alpha\pi}$ with $\gamma_\rho^2/4\pi = .64$. (For $\rho^0 p$ A_p and A_f become $4.6 \pm .3$ and $6.4 \pm .6\ \mathrm{mb}^{1/2}\ \mathrm{GeV}^{-1}$ and for πp (Ref. 8) they are $4.82 \pm .14$ and $5.4 \pm .5\ \mathrm{mb}^{1/2}\ \mathrm{GeV}^{-1}$ respectively.) Thus the analogy between photon induced processes and πN scattering is rather complete as long as we concern ourselves with the SHC-amplitudes.

*The uncertainty in determining ρ^0 photoproduction[1] cross sections brings about a 10% systematic error in the ρ^0 slopes.

THE SHC VIOLATING AMPLITUDES

The recent experimental results[1] on ρ^0 photoproduction in the polarized photon experiments indicate clearly deviations from pure SHC at the large $|t|$. The natural parity exchange part of the density matrix elements for $\gamma p \to \rho^0 p$ are shown in Fig. 3 for three photon energies. Even in the earlier

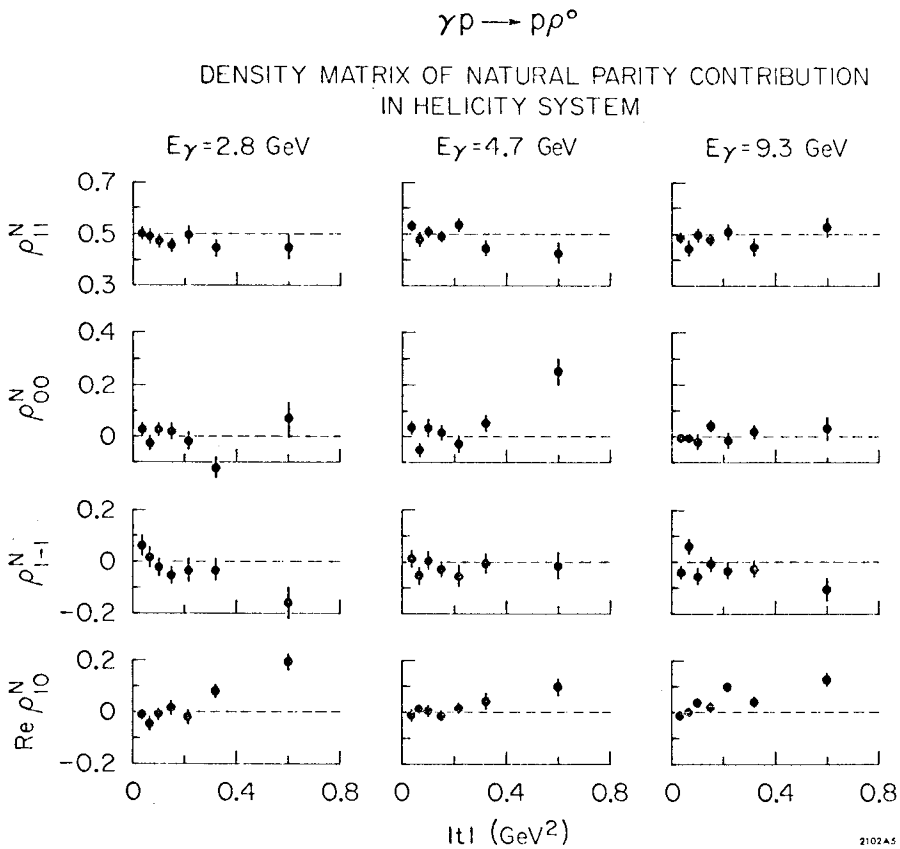

Fig. 3. Natural parity exchange density matrix elements in ρ^0 photoproduction.

experiments[3] at lower energies, deviations of the density matrix element Re ρ^N_{10} from zero, are clearly visible (see Fig. 3). It is reasonable[1] to take the effect as being associated with ρ^0 photoproduction, reaction (1), and thus it shows deviations from SHC which are either independent or weakly depend on E_γ. (The effect is clearly visible only at high $|t|$ since in general single flip terms are expected to vanish near t=0 like $\sqrt{-t}$.)

In terms of the s-channel helicity amplitudes T_{ik} at the γ-ρ^0 vertex the term Re ρ^N_{10} can be written[2] as:

$$\mathrm{Re}\,\rho^N_{10} \approx \mathrm{Re}\sum\left(T^N_{11}\,T^{N*}_{01}\right)/4\,\frac{d\sigma}{dt} \tag{5}$$

where the sum is over the (suppressed) nucleon indices. By the results presented above and since the squares of all amplitudes are small compared with $|T^N_{11}|^2$ we may assume T^N_{11} to be pure imaginary and $d\sigma/dt \simeq |T^N_{11}|^2$. Thus

$$\frac{\mathrm{Im}\, T^N_{01}}{|T^N_{11}|} \simeq 2\,\mathrm{Re}\,\rho^N_{10} \tag{6}$$

$$\mathrm{Im}\, T^N_{01} \simeq 2\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\,\rho^N_{10} \tag{7}$$

From Fig. 3 we see that the ratio (6) of flip to nonflip amplitudes seems to be about constant with energy and thus it is likely that the composition of the non-SHC terms is similar to that of the helicity conserving terms derived above. In Fig. 4 we show the results at an average E_γ of 7 GeV and we see

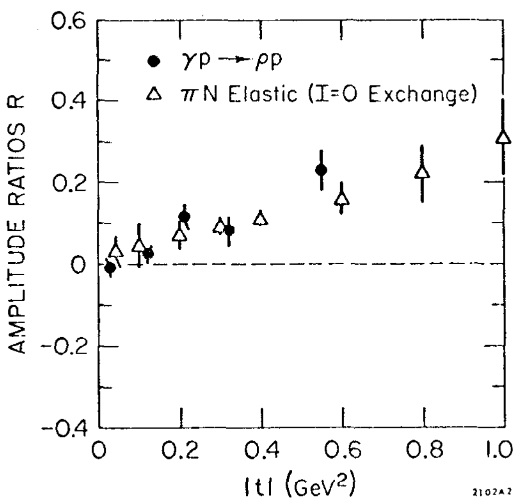

Fig. 4. Ratio of single flip to nonflip amplitude in πN scattering (6 GeV) and $\mathrm{Im}\, T^N_{10}/|T^N_{11}| \simeq 2\,\mathrm{Re}\,\rho^N_{10}$ in photoproduction (average $E_\gamma = 7$ GeV).

that they are similar[12-14] to the corresponding ones in πp scattering at 6 GeV/c. The t-dependence of the amplitudes, (7) above, is shown in Fig. 5. Neither πp nor ρp shows the characteristic $J_1(R\sqrt{-t})$ structure which might be expected for Regge exchange[7,9] (see Fig. 5).

Finally, I would like to compare the SHC violating terms in photoproduction with the corresponding ones in π-nucleon scattering. In a recent[12] analysis of πN polarization data the following combination which isolates the I=0 t-channel exchange was used:

$$\frac{1}{2}\left[p^- \frac{d\sigma^-}{dt} + p^+ \frac{d\sigma^+}{dt} - p^0 \frac{d\sigma^0}{dt}\right] \Big/ \left[\frac{d\sigma^-}{dt} + \frac{d\sigma^+}{dt} - \frac{d\sigma^0}{dt}\right] \simeq \frac{|F^0_{+-}|}{|F^0_{++}|} \sin\left(\Phi^0_{++} - \Phi^0_{+-}\right) \tag{8}$$

where $P^{+,-,0}$ and $d\sigma^{+,-,0}$ are respectively the polarizations and cross sections for π^+ and π^- elastic scatterings and π^- charge-exchange ($\pi^- p \to \pi^0 n$). Φ^0_{++}, Φ^0_{+-} and $|F^0_{++}|$, $|F^0_{+-}|$ are respectively the phases and absolute values of the I=0 exchange, s-channel helicity conserving and nucleon helicity flip amplitudes. It was argued in Ref. 12 that relation (8) seems experimentally to decrease like P_{lab}^{-2} and that this is a proof that SHC is approached rapidly in the I=0 exchange part of πN scattering. We disagree with this conclusion and note that (8) reduces to Re $F_{+-}^{o}/|F_{++}^{o}|$ for the (reasonable) assumption that F_{++}^{o} is imaginary, while the large (Ref. 13) component of the flip term is Im F_{+-}^{o} and not Re F_{+-}^{o}. Thus, in computing the analogue of (6) for πN scattering the value of Im $F_{+-}^{o}/|F_{++}^{o}|$ or $|F_{+-}^{o}|/|F_{++}^{o}|$ should be used and this is obtainable[13] from the very difficult spin correlation measurements. However, this is the only way to test SHC in πN scattering. In Fig. 4 we show that at 6 GeV c there is complete agreement between 2 Re ρ_{10}^{N} for reaction (1) and $|F_{+-}^{o}|/|F_{++}^{o}|$ of πN scattering.[13, 14]

Finally, in Fig. 5 we show together with the $\gamma p \to \rho^{o} p$ non-SHC amplitude (7) the corresponding[1] ones for the natural parity exchange in ω^{o} photoproduction ($\gamma p \to \omega p$) and the πN amplitudes, scaled again by the VDM factor $\gamma_{\rho}/\sqrt{\alpha\pi}$. We note (a) the ω^{o} amplitudes are smaller than (or equal to) the ρ^{o} ones and therefore the non-SHC terms could not be due to A_2 exchange, which is expected, by SU(3), to be three times bigger for ω^{o} as compared with ρ^{o} (the opposite is true for P or f^{o} exchange).
(b) Again there is agreement in magnitude between the s-channel helicity single flip terms of ρ^{o} photoproduction and πN scattering when scaled by VDM, in exactly the same way as in the SHC amplitudes discussed above.

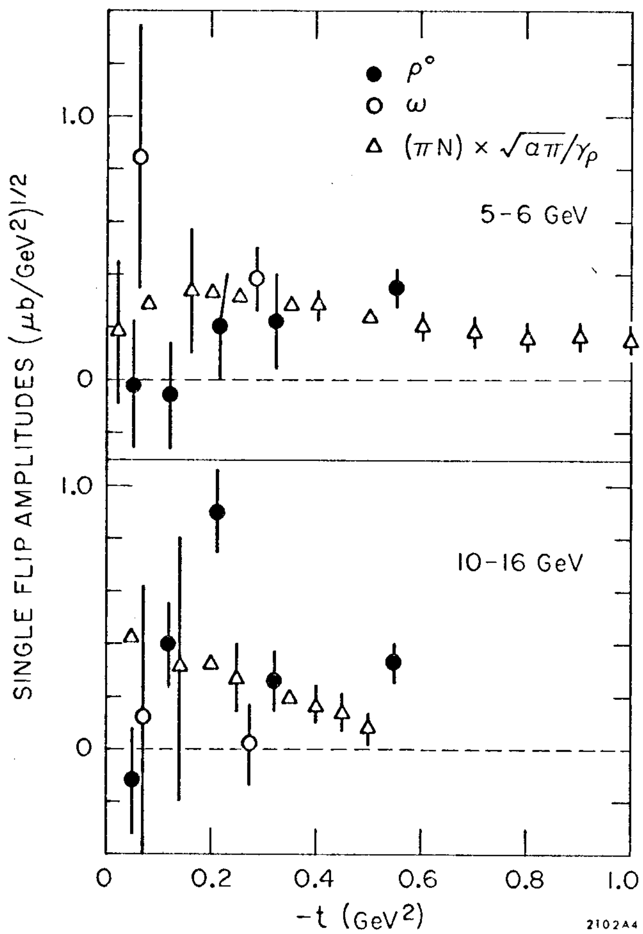

Fig. 5. Imaginary part of the single flip amplitudes (Im T_{10}^{N}) in ρ^{o} and ω photoproduction and $|F_{+-}^{o}|$ of πN scattering scaled by the VDM constant $\sqrt{\alpha\pi}/\gamma_{\rho}$. (New πN data, Ref. 14. For clarity purposes some error bars have been omitted.)

We therefore conclude that the present experimental evidence indicates existence of small non-SHC terms for $|t| \simeq .2 - .5$ GeV^2, in both πN scattering and ρ^{o} photoproduction. The s and t dependence of these amplitudes indicates that they are not predominantly due to f^{o} exchange.

Note added after talk was given: In two recent preprints (Ref. 14) the Saclay group has published the results of the spin correlation experiments in πp scattering at 6 and 16 GeV/c. The results are in good agreement with the photoproduction[1] results and support the conclusions that we summarized above. In particular, they obtain[14] for the $|t|$ range .2 - .5 GeV^2 $|F^0_{+-}|/|F^0_{++}|$ = .10 ± .015 at 6 GeV/c and .085 ± .02 at 16 GeV/c, indicating that within errors non-SHC amplitudes relative to SHC are energy independent (the new πp results[14] are shown in Figs. 4 and 5).

ACKNOWLEDGEMENTS

We are grateful to our colleagues of the SLAC-Berkeley collaboration and to Y. Avni, M. Davier, and F. Gilman for very fruitful discussions on various topics related to this work.

REFERENCES

1. J. Ballam, G. B. Chadwick, Y. Eisenberg, R. Gearhart, E. Kogan, K. C. Moffeit, J. J. Murray, P. Seyboth, C. K. Sinclair, I. O. Skillicorn, H. Spitzer, G. Wolf, H. H. Bingham, W. B. Fretter, W. J. Podolsky, M. S. Rabin, A. H. Rosenfeld, G. Smadja, and G. H. Yost, to be published (1972).
2. G. Chadwick, Y. Eisenberg, and E. Kogan, to be published (1972).
3. Cambridge Bubble Chamber Group, Phys. Rev. 146, 994 (1966); Aachen-Berlin-Bonn-Hamburg-Munchen Collaboration, Phys. Rev. 175, 1669 (1968); Y. Eisenberg et al., Phys. Rev. D5, 15 (1972). G. Wolf, Proc. of International Symposium on Electron and Photon Initiated Interactions (Cornell University, New York, 1971), p. 189.
4. J. Le Francois et al., Proc. of the 1971 Symposium on Electron and Photon Interactions (Cornell University, New York, 1971), p. 51.
5. J. Ballam et al., Phys. Rev. Letters 24, 960 (1971); Phys. Rev. D5, 545 (1972).
6. F. J. Gilman et al., Phys. Letters 31B, 387 (1970).
7. H. Harari, Ann. Phys. (N.Y.) 63, 432 (1971); M. Davier and H. Harari, Phys. Letters 35B, 239 (1971); H. Harari and A. Schwimmer, Report No. SLAC-PUB-952, to be published (1972).
8. M. Davier, Report No. SLAC-PUB-1027, to be published (1972).
9. Y. Avni, Report No. SLAC-PUB-1036 and SLAC-PUB-1048.
10. R. L. Anderson et al., Phys. Rev. D1, 27 (1970).
11. R. L. Anderson et al., Phys. Rev. Letters 25, 1218 (1970); A. M. Boyarski et al., Phys. Rev. Letters 26, 1600 (1971); G. Buschhorn et al., Phys. Letters 37B, 207 (1971).
12. V. Barger and F. Halzen, Phys. Rev. Letters 28, 194 (1972); preprint WISC-72-488 (1972).
13. F. Halzen and C. Michael, Phys. Letters 36B, 367 (1971).
14. A. de Lesquen et al., preprint 72-3 and G. Cozzika et al., preprint 72-4 (Saclay, 1972).