SLAC-PUB-1093
(TH) and (EXP)
August 1972

AMPLITUDE STRUCTURE IN PREDOMINANTLY POMERON EXCHANGE REACTIONS AND s-CHANNEL HELICITY NONCONSERVATION*

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ABSTRACT

The Pomeron exchange amplitudes in the reactions $\gamma p \to \rho^{o} p$ and $\gamma p \to \gamma p$ are separated and found to shrink with s like those of πN scattering. The s-channel helicity nonconserving amplitudes in ρ^{o} photoproduction at the γ-dipion vertex are also found to be similar to the corresponding ones in πN scattering.

(Submitted to the XVI International Conference on High Energy Physics, Batavia, Illinois, September 6-13, 1972, and to Phys. Rev. Letters.)

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*Work supported by the U. S. Atomic Energy Commission.

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We wish to report the results of an amplitude analysis performed on the following reactions:

$$\gamma + p \rightarrow \rho^{o} + p \tag{1a}$$

$$\gamma + p \rightarrow \gamma + p \tag{1b}$$

in the energy range 3-18 GeV and a comparison of the results with a similar analysis done for πN scattering. Clearly Compton scattering (1b) and πN elastic scattering at high energies are diffractive processes. However, also the ρ^{o} photoproduction reaction (1a) is generally considered[1] to be diffractive, possessing the typical Pomeron exchange gross features of elastic scattering, namely having a weak E_{γ} dependent cross section and a forward peaked $d\sigma/dt$. The experimental observation[2] that this reaction is predominantly s-channel helicity conserving (SHC) at the γ-ρ^{o} vertex has led to a postulate[3] that Pomeron exchange in general possesses SHC as one of its characteristics. In an extension of the earlier[2] experiments to higher energy[4] (9.3 GeV) and with increased statistics the existence of a small but significant s-channel helicity nonconserving amplitude in reaction (1a) has been suggested. Thus we shall compare separately the SHC and non-SHC amplitudes with the corresponding πN amplitudes and show that there is great similarity between the two processes in both the s and t dependence of the two types of amplitudes.

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^{o} photoproduction in the reaction $\gamma p \rightarrow \rho^{o} p$ should be related to Compton scattering. A recent compilation of Hesse[5a] gave the following results:

$$\mathrm{Im}\, a(\gamma p \rightarrow \gamma p)_{t=0} \propto \sigma_T(\gamma p) = C_P + C_{P'}\, s^{-1/2} + C_{A_2}\, s^{-1/2} \tag{2a}$$

and

$$C_p = (97.4 \pm 1.9)\ \mu b\ , \qquad C_{p'} = (78 \pm 7)\ \mu b \cdot GeV\ , \qquad C_{A_2} = (17 \pm 3.3)\ \mu b \cdot GeV \tag{2b}$$

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

Following the ideas of the dual absorptive model[6] (DAM) and a recent analysis[7] of πN scattering utilizing DAM, we write the SHC imaginary part of f exchange and the Pomeron exchange amplitudes respectively as:

$$\begin{aligned} \mathrm{Im}\ f(t) &= \frac{A_f}{\sqrt{s}}\ e^{B_f t}\ J_0(R\sqrt{-t}) \qquad (s \text{ in GeV}^2) \\ P(t) &= iA_p\ e^{B_p t} \end{aligned} \tag{3}$$

with a typical radius[6,7] for f exchange of $\approx$ 1 fermi (5 GeV^{-1}). This is the same form as was used for the I=0 part in the πN scattering analysis. Since the A_2 exchange contribution to reaction (1a) is small, we may write the cross section as:

$$\frac{d\sigma}{dt}(\gamma p \rightarrow \rho^o p) \cong |P(t) + f(t)|^2 \approx |P(t)|^2 + 2|P(t)|\ \mathrm{Im}\ f(t) \tag{4}$$

neglecting the $|f(t)|^2$ terms which, from (2) above, even at 5 GeV contribute only $\sim$ 4 percent in the forward direction. Note that so far we neglected completely the s-channel helicity nonconserving terms, which shall be discussed later.

We used in our analysis both the parameterization ρ^o cross sections of Ref. 4 (E_γ = 2.8 - 9.3 GeV) and also the data of Anderson <u>et al</u>.[8a] (6.5 - 17.8 GeV), which agree well in the region of overlap, in order to cover the largest possible s and t regions. The data is not sufficiently accurate to warrant a simultaneous determination of all the parameters of (3) and (4). Thus, we first determine the parameters A_f and A_p in (4) from a fit of $d\sigma/dt$ of the data between 4.7 - 17.8 GeV, utilizing parameterized B_p and B_f slopes of the form $B = b_1 + b_2 \ln s$ (six parameter fit). The results are given in Table I. We use these A_p and A_f in a second fit, done at each energy separately, in order to obtain directly and more accurately B_p and B_f as functions of s. The fits are very good and several fitted curves are shown in Fig. 1a. Figure 1b shows the fitted values of B_p and B_f. In Table I we also show the values of A_p and A_f calculated by Davier[7] for πN scattering and our results for the ρ^o photoproduction reaction (1a), scaled by the factor $\gamma_\rho/\sqrt{\alpha\pi}$. By VDM these should represent the amplitudes $\rho^o p \rightarrow \rho^o p$ (the value of $\gamma_\rho^2/4\pi$ was taken to be 0.6 as obtained in the e^+e^- colliding beam experiment[5b]). We note good agreement between πN and ρN in both the magnitude and relative importance of the Pomeron and f^o-exchange forward amplitudes. In Fig. 1b we have also plotted the slope parameters resulting from a fit of Compton scattering data[8b] to relation (4), assuming the imaginary part of A_2 exchange to have a similar peripheral structure to f exchange[6] and using the parameterization (2). Good agreement is evident between the Pomeron slopes determined from Compton scattering, ρ^o photoproduction and πp scattering.

Our results depend upon the specific DAM amplitudes assumed in Eq. (3) above. Within this model, however, the data of Fig. 1 indicates clearly the following features: (a) the Pomeron amplitude shrinks with increasing E_γ and has a t-slope of $\sim 1.6\ \text{GeV}^{-2}$ at 3 GeV and $\sim 3\ \text{GeV}^{-2}$ at 18 GeV. Note that to the extent that Φ photoproduction is due entirely to P-exchange, its slope parameter for small $|t|$'s should be given by B_p. The observed[1,4] Φ slopes are also plotted in Fig. 1b and indeed agree with our derived P-exchange slopes.

(b) The f-exchange slope is consistent with a linear increase in ln s. Again we note that in all details the results of Fig. 1 are very similar to those of πN and Kp scattering.[6,7] It is interesting to note how an increasing Pomeron slope plus an f-exchange term that has a steeper t-distribution (at low $|t|$) but decreases with s yield an observed slope of $d\sigma/dt$, which remains almost constant at all photon energies.

We now turn to the question of s-channel helicity nonconservation. In the linearly polarized photon experiment,[4] reaction (1a) was studied in detail. In the natural parity t-channel exchange a significant interference term between the nonflip and single helicity flip at the γ-ρ^o vertex near $M_{\pi\pi} \approx M_\rho$ was seen. In terms of the helicity amplitudes in the s-channel,[2] this term is:

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

where the sum is over the nucleon indices (not written explicitly). It is quite possible that this term is associated with the ρ^o production mechanism. Since for small $|t|$ and at high energies the cross section for reaction (1a) is essentially $|T^N_{11}|^2$, we can assume T^N_{11} to be purely imaginary to set the relative phase and write:

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

$$\mathrm{Im}\,T^N_{01} \simeq 2\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\,\rho^N_{10} \quad . \qquad (7)$$

The ratio (6) is shown in Fig. 2a and the amplitudes (7) for ρ^o photoproduction are given in Ref. 4. Both are weakly dependent on E_γ. However, considering the present statistical accuracies and uncertainties of the above assumptions, the structure in t of the flip term cannot lead to any definite conclusions (the typical $\simeq J_1(R\sqrt{-t})$ which might be expected for Regge exchange[6] is less likely than a flat structure expected[9] from Pomeron central distribution). In the forward direction the flip amplitude is expected to vanish like $\sqrt{-t}$ and indeed it seems to be consistent with zero for $|t| < .2\ \mathrm{GeV}^2$. At larger t's it approaches 10 - 20 percent of the nonflip term (Fig. 2a).

Finally, we compare the photoproduction non-SHC data with the corresponding πN data. In a recent analysis[10] of πN polarization the following combination which isolates the I=0 t-channel exchange was used:

$$P_0(t) \equiv \frac{1}{2}\left[P^- \frac{d\sigma^-}{dt} + P^+ \frac{d\sigma^+}{dt} - P^o \frac{d\sigma^o}{dt}\right] \Big/ \left[\frac{d\sigma^-}{dt} + \frac{d\sigma^+}{dt} - \frac{d\sigma^o}{dt}\right] \simeq \frac{|F^o_{+-}|}{|F^o_{++}|} \sin\left(\Phi^o_{++} - \Phi^o_{+-}\right) \tag{8}$$

$P^{+,-,o}$ and $d\sigma^{+,-,o}$ are respectively the polarizations and cross sections for π^+ and π^- elastic scatterings and π^- charge-exchange. Φ^o_{++}, Φ^o_{+-} and $|F^o_{++}|$, $|F^o_{+-}|$ are respectively the phases and absolute values of the I=0 exchange, s-channel helicity conserving and helicity flip nucleon amplitudes. From recent πp polarization and elastic scattering measurements[11] in the energy range 6-14 GeV/c we obtain the quantity $P_0(t)$ and show it in Fig. 2b. We indeed notice that it seems to decrease with energy.[10] However, we disagree with the conclusions of Ref. 10 that this is a proof that SHC is approached rapidly (like P^{-2}_{lab}) in the I=0 exchange part of πN elastic scattering. In fact we note that (8) is <u>entirely different</u> from Re ρ^N_{10}, Eq. (6); in (6) we determine the <u>large</u> component of the helicity flip terms (Im $T^N_{01}/|T^N_{11}|$) while (8) measures essentially Re $F^o_{+-}/|F^o_{++}|$ (the phase is relative to that of F^o_{++}, assumed purely imaginary as before). From the <u>polarization correlation</u> measurements one can determine directly all amplitudes. At 6 GeV Refs. 12 and 13 find that indeed Im F^o_{+-} is much larger than Re F^o_{+-} and that Im $F^o_{+-}/|F^o_{++}|$ is about 10-20 percent for $|t| = .2 - .8\ GeV^2$, in agreement with the photoproduction results. The most recent values[13] for $|F^o_{+-}|/|F^o_{++}|$ are also shown in Fig. 2a and seem to agree with the ρ^o-photoproduction data. At 9-10 GeV we show 2 Re ρ^N_{10} from the photoproduction experiment[4] and $|F^o_{+-}|/|F^o_{++}|$ from the πN polarization[11] utilizing Eq. (8) and the calculated phases[10] ($|t| < .6\ GeV^2$). We also show in the same figure the amplitude ratios as obtain from the polarization correlation experiment at 16 GeV/c.[13] Again rough agreement is evident. Finally we show in Fig. 2c the flip amplitudes $|F^o_{+-}|$ as determined by Ref. 13 and the photoproduction amplitude Im T^N_{10} multiplied by the VDM constant $\gamma_\rho/\sqrt{\alpha\pi}$. Again good agreement is observed. We conclude that all available data and analysis indicate presence of small non-SHC terms in diffractive processes, which do not vary rapidly with energy. More precise experiments at higher $|t|$ and s are clearly desirable; however, already the present data does not indicate a zero at $-t \simeq .6\ GeV^2$, which is expected[6,9] if most of the s-helicity flip is due to f exchange. We emphasize that in the photoproduction experiments single helicity flip at the γ-ρ^o is measured while the πN experiments measure the nucleon flip. Our comparison shows that both flip terms are similar to each other. It is also interesting to note that in absolute magnitude, the I=0 exchange SHC-violating amplitude in πN scattering, $|F^o_{+-}|$, is very close to the corresponding $\gamma p \to \rho^o p$ amplitude when multiplied by the VDM factor $\gamma_\rho/\sqrt{\alpha\pi}$ $(\gamma^2_\rho/4\pi = .6)$.

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

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FIGURE CAPTIONS

1. (a) Fits of $d\sigma/dt$ of ρ^o photoproduction to sum of P and f exchange, utilizing DAM.

   (b) P and f exchange amplitude slopes as obtained from fits of $d\sigma/dt$. The errors in $\gamma p \rightarrow \rho^o p$ are statistical only. The systematic uncertainties are estimated to be ±10%.

2. (a) $2\,\mathrm{Re}\,\rho^N_{10}$ for the reaction $\gamma p \rightarrow \rho^o p$ and $|F^o_{+-}|/|F^o_{++}|$ for πN scattering.

   (b) $P_0(t) = (|F^o_{+-}|/|F^o_{++}|)\sin(\Phi^o_{++} - \Phi^o_{+-})$ for πN scattering as calculated from Ref. 11 (see text).

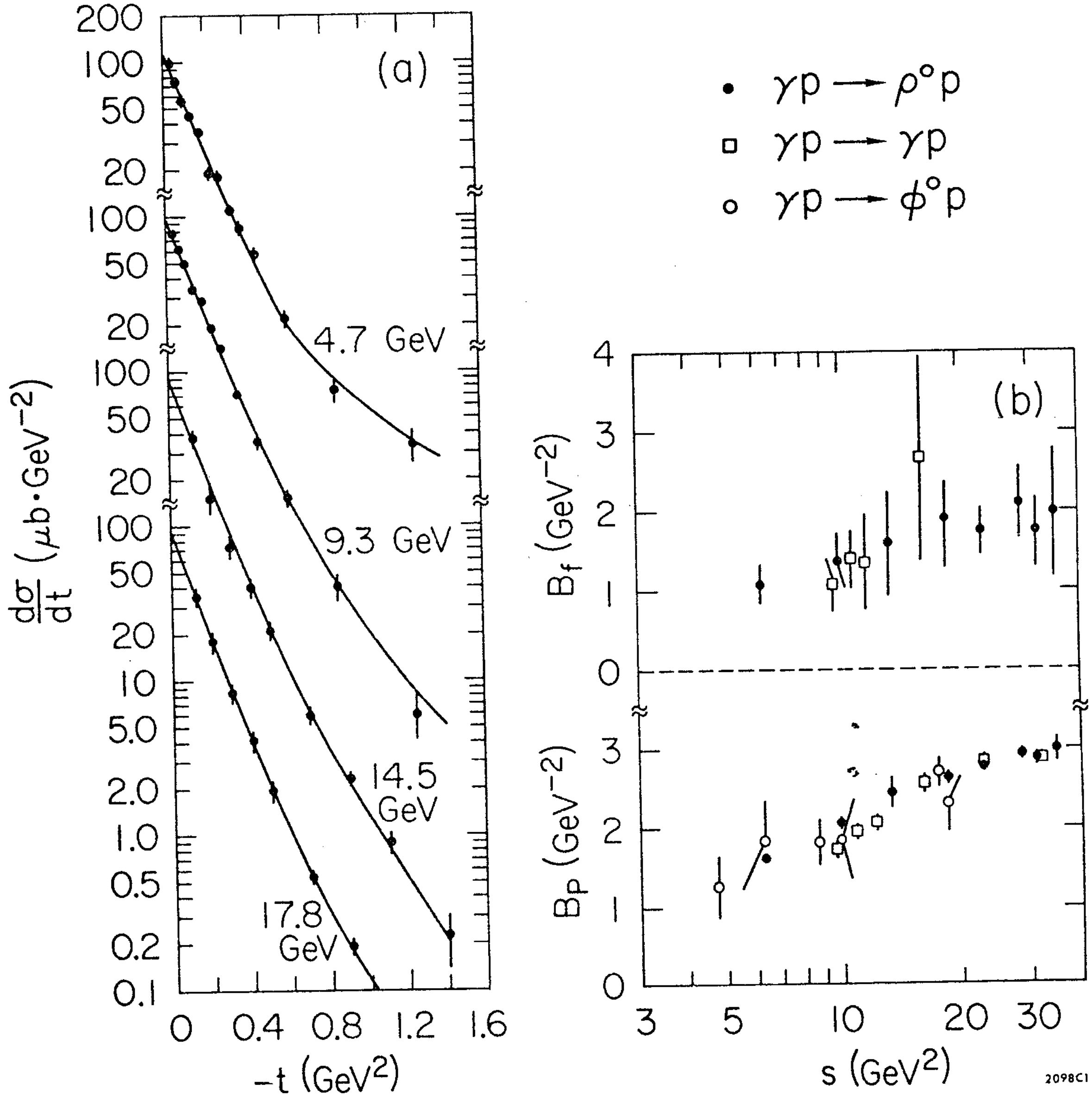
   (c) Calculated $|F^o_{+-}|$ for πN scattering from Ref. 13 and $\mathrm{Im}\,T^N_{10}$ for ρ^o photoproduction normalized by the VDM constant with $\gamma^2_\rho/4\pi = .6$ (see text). For clarity purposes some error bars have been eliminated.

TABLE I

POMERON AND f-EXCHANGE AMPLITUDES

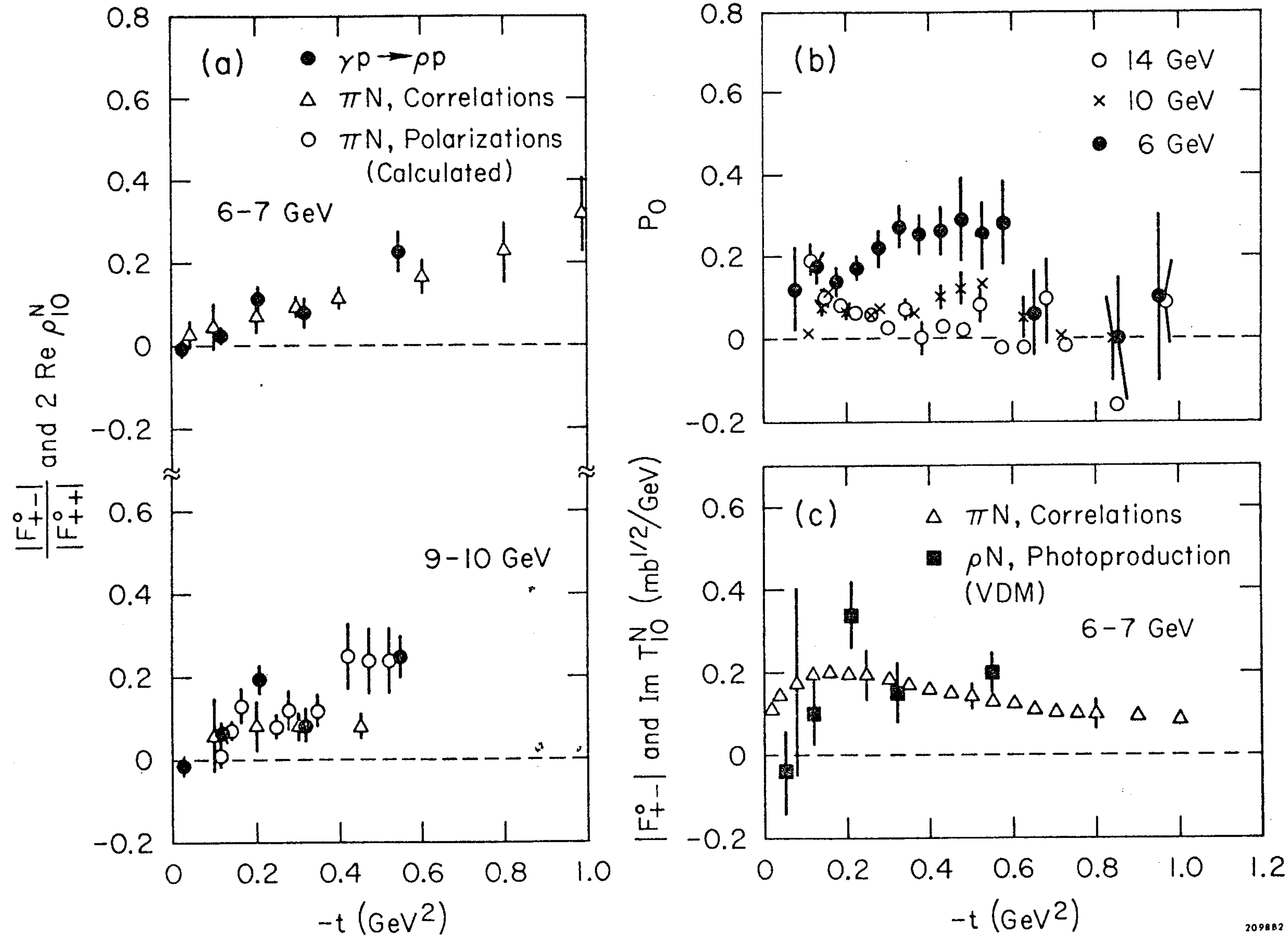
Parameter	This Analysis $\gamma p \rightarrow \rho p$	Scaled by VDM $\rho p \rightarrow \rho p$	Ref. 7 $\pi N \rightarrow \pi N$
A_p	$7.6 \pm .5\ \mu b^{1/2}\ GeV^{-1}$ *	$4.6 \pm .3\ mb^{1/2}\ GeV^{-1}$	$4.82 \pm .14\ mb^{1/2}\ GeV^{-1}$
A_f	$10.7 \pm .9\ \mu b^{1/2}$	$6.4 \pm .6\ mb^{1/2}$	$5.4 \pm .5\ mb^{1/2}$
B_p	$(.59 \pm .23) + (.69 \pm .07) \ln s$		
B_f	$(.35 \pm .27) + (.47 \pm .28) \ln s$		
χ^2/N_D	51/60		

*Systematic error due to uncertainty in extracting the ρ^0 cross sections[2] is included.



(a)
$\frac{d\sigma}{dt}$ (μb·GeV^{-2})
4.7 GeV
9.3 GeV
14.5 GeV
17.8 GeV
−t (GeV^2)
(b)
$\gamma p \to \rho^\circ p$
$\gamma p \to \gamma p$
$\gamma p \to \phi^\circ p$
B_f (GeV^{-2})
B_P (GeV^{-2})
s (GeV^2)
2098C1

Fig. 1



(a)
γp → ρp
πN, Correlations
πN, Polarizations
(Calculated)
6-7 GeV
9-10 GeV
|F°+−| / |F°++| and 2 Re ρ^N_10
−t (GeV²)
(b)
14 GeV
10 GeV
6 GeV
P0
(c)
πN, Correlations
ρN, Photoproduction
(VDM)
6-7 GeV
|F°+−| and Im T^N_10 (mb^1/2/GeV)
−t (GeV²)
209882

Fig. 2