Ref.TH.1465-CERN

HELICITY CONSERVATION IN ω PHOTOPRODUCTION

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ABSTRACT

We use a Regge pole model to describe the ω photoproduction data. The unnatural parity exchange contributions are found to be t channel helicity conserving, and we argue that π exchange is unimportant in this reaction. The existing data indicate that natural parity exchanges do not conserve s channel helicity.

Ref.TH.1465-CERN
6 March 1972

The discovery [1] of s channel helicity conservation (shc) in rho photoproduction has led to the suggestion [2] that perhaps shc is a universal feature of Pomeron exchange. Therefore it is of interest to examine the omega photoproduction data. A description of the reaction

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

is not as simple as one of ρ^0 photoproduction, since, in reaction (1), the contributions from isospin one exchanges (and, therefore, from unnatural parity exchanges) are expected to be important at intermediate energies, whereas, in $\gamma p \rightarrow \rho^0 p$, these exchanges are suppressed [*].

The differential cross-section (dcs) for reaction (1) has been measured [5)-7)] at energies from 1.6 to 7.5 GeV, and there are preliminary measurements at 9.3 GeV by a group at SLAC [8]. The dcs at these energies is still falling fairly rapidly with energy, and the data of Eisenberg et al. [5] at 3.35, 4.2 and 5.25 GeV/c seem to indicate a very narrow forward dip at $|t|$ values of less than 0.02 $(\mathrm{GeV}/c)^2$. Unfortunately, none of the other measurements extend to this small $|t|$ region.

The most enlightening data are the density matrix elements measured at SLAC at energies of 2.8, 4.7 [6] and 9.3 [8] GeV in experiments with linearly polarized photon beams. From these data, one can extract separately the contributions from natural and unnatural parity exchanges by using the result [9] that

$$\rho^{0\,(\pm)}_{mm'} = \frac{1}{2}\left(\rho^{0}_{mm'} \mp (-1)^m \rho^{1}_{-mm'} \right) \tag{2}$$

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*) This statement follows directly from vector meson dominance (vmd) [3]. In particular,

$$\frac{M_1(\gamma p \rightarrow \rho^0 p)}{M_0(\gamma p \rightarrow \rho^0 p)} \Big/ \frac{M_1(\gamma p \rightarrow \omega p)}{M_0(\gamma p \rightarrow \omega p)} = \frac{\gamma_\omega^2}{\gamma_\rho^2} \sim \frac{1}{9}$$

where $M_I(\gamma p \rightarrow V^0 p)$ represents the contribution of isospin I exchange to the $\gamma p \rightarrow V^0 p$ amplitudes ; the vmd relation has been written as

$$|\gamma\rangle = \sqrt{\frac{\pi\alpha}{\gamma_\rho^2}}\,|\rho^0\rangle + \sqrt{\frac{\pi\alpha}{\gamma_\omega^2}}\,|\omega\rangle + \sqrt{\frac{\pi\alpha}{\gamma_\varphi^2}}\,|\varphi\rangle$$

and the numerical value of $\gamma_\omega^2/\gamma_\rho^2$ is the standard [4] SU(3) prediction.

where the upper (lower) sign refers to the contribution from natural (unnatural) parity exchanges and we have adopted the formalism of Ref. 9). The results of this separation are shown in Fig. 1 for the natural parity exchange in the helicity frame *) and in Fig. 2 for the unnatural parity exchanges in the Gottfried-Jackson frame. We observe that the natural parity contributions to the $\gamma p \to \omega p$ density matrices in the helicity frame **) do not exhibit the simple empirical regularity found in the ρ^{o} photoproduction density matrices [1]. On the other hand, the data on the unnatural parity density matrix elements show a simple regularity in the Gottfried-Jackson frame, namely, $\rho^{o(-)}_{oo} = \mathrm{Re}\,\rho^{o(-)}_{1o} = \rho^{o(-)}_{1-1} \simeq 0$ with $\rho^{o\,(-)}_{11}$ non-zero and approximately constant in t. This result implies that the unnatural parity exchanges in reaction (1) conserve t channel helicity, i.e., are thc, at the $\gamma\omega$ vertex.

Furthermore, we argue that the $\tau p = -1$ contributions must be due to A_1, rather than π exchange for the following reasons :

1) in order to satisfy the threshold relations at t = 0, be consistent with factorization, and produce forward peaks in reactions such as pn → np, $\gamma N \to \pi N$, and $\pi N \to \rho N$, π exchange must be absorbed ; absorption necessarily destroys the thc properties of π exchange ; this is apparent in $\pi N \to \rho N$ where the measured [10] $\tau P = -1$ density matrix elements are not thc ;

2) we naively expect the π contribution to the dcs to decrease rapidly with t ($\sim e^{t/m_\pi^2}$), whereas the $\tau P = -1$ contributions to the $\gamma p \to \omega p$ dcs have approximately the same t dependence as the $\tau P = +1$ contributions.

In terms of the t channel helicity amplitudes, $M^t_{\lambda_N' \lambda_N ; \lambda_\omega \lambda_\gamma}$, the t channel parity conserving helicity amplitudes (t-pcha), $M^{\pm}_{\mu\lambda}$, can be written as

$$M^{\pm}_{\mu\lambda} = M^t_{\lambda_N' \lambda_N ; \lambda_\omega \lambda_\gamma} \mp (-1)^{\lambda_N - \lambda_N'} M^t_{-\lambda_N' -\lambda_N ; \lambda_\omega \lambda_\gamma}$$

where

$$\lambda = |\lambda_\gamma - \lambda_\omega| \ , \quad \mu = |\lambda_N' - \lambda_N|$$

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*) For the definitions of the various reference frames, see, e.g., Ref. 1).

**) We have also looked at the $\rho^{o(+)}_{mm'}$ in the Gottfried-Jackson and Adair frames, and found that they are not simple in any frame.

and we have used the phase convention of Cohen-Tannoudji, Morel and Navelet [11] rather than that of Jacob and Wick [12]. The results of Ader, Capdeville and Navelet [13] then enable us to write down the t channel kinematic singularity-free parity conserving helicity amplitudes (t-ksfpcha), $F^{\pm}_{\mu\lambda}$, i.e.,

$$F^{\pm}_{\mu\lambda} = \left(K^{\pm}_{\mu\lambda}\right)^{-1} M^{\pm}_{\mu\lambda}$$

where the $K^{\pm}_{\mu\lambda}$'s are taken from Ref. 13). The $F^{\pm}_{\mu\lambda}$'s can then be Reggeized according to the prescription 14)

$$F^{\pm}_{\mu\lambda} = \frac{\beta^{\pm}_{\mu\lambda}(t)}{\Gamma(\alpha(t)+1-\lambda_m)} \cdot \frac{1+\tau e^{-i\pi\alpha(t)}}{\sin \pi\alpha(t)} \; \nu^{\alpha(t)-\lambda_m}$$

where

$$\lambda_m \equiv \max(\lambda,\mu) \; , \qquad \nu \equiv \frac{s-u}{4M} \; , \qquad \tau$$

is the signature of the exchanged Regge pole with trajectory $\alpha(t) = \alpha_0 + \alpha' t$ and residue function $\beta^{\pm}_{\mu\lambda}$ (t). Once the kinematic constraints [13] at t channel thresholds and pseudothresholds $(t = 0, m^2_\omega , 4M^2)$ have been imposed, the Reggeization procedure is complete.

For detailed analysis, we have parametrized the Pomeron contribution to each t-pcha in $\gamma p \to \omega p$ as a constant parameter times the corresponding shc amplitude, i.e.,

$$M^{\mathbb{P}}_{\mu\lambda} = r_{\mu\lambda} M^{\mathbb{P}}_{\mu\lambda}(shc)$$

with $r_{oo} \equiv 1$ *). The deviations of the $r_{\mu\lambda}$ from 1 then directly represent the extent of shc violation in $\gamma p \to \omega p$. We have assumed exchange degenerate P' and A_2 trajectories, but have made no assumptions as to their couplings to different helicity amplitudes. For the reasons discussed above, we have assumed the $\tau P = -1$ contributions to be thc at the $\gamma\omega$ vertex and to be due to A_1 exchange. The trajectories used in our fit are listed in Table I.

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*) Attempts to fit the data with an shc Pomeron, thc A_1 and arbitrary helicity couplings for P' - A_2 were unsuccessful.

We have used this Regge model to fit the dcs data above 3 GeV and the density matrix elements at 2.8 and 4.7 GeV. Our fits are shown in Figs. 3 and 4, and the values obtained for $r_{\mu\lambda}$ are presented in Table II. We note that the fits extrapolate very well to the dcs data from 1.6 to 3.0 GeV, in agreement with duality expectations [15]. The most violent disagreement between our fits and the data occurs in the small $|t|$ region for ρ^1_{1-1} and $\mathrm{Im}\,\rho^2_{1-1}$ at 2.8 and 4.7 GeV where the data are zero, whereas, in the forward direction, angular momentum and parity conservation require that $\rho^1_{1-1} = -\mathrm{Im}\,\rho^2_{1-1} = \frac{1}{2}$. From a strong $|t|$ dependence of our A_1 contribution, i.e., $|t|\,\alpha(t)\,\sin\theta$, at small $|t|$, we have succeeded in reproducing the forward dip.

We conclude that a Regge pole model can describe the ω photoproduction data, but that the Pomeron is <u>not</u> shc at the $\gamma\omega$ vertex. Furthermore, the unnatural parity contribution must be due to A_1 exchange rather than π exchange.

ACKNOWLEDGEMENTS

I wish to thank Professor V. Barger for suggesting this problem and for many helpful discussions ; W. Massman and J. Luthe for computational assistance, and the National Research Council of Canada for financial support.

TABLE I : REGGE TRAJECTORIES

$$\alpha_P = 1 + 0.5\ t$$

$$\alpha_{P'} = \alpha_{A_2} = 0.5 + t$$

$$\alpha_{A_1} = -0.02 + t$$

TABLE II : VIOLATION OF SHC FOR THE POMERON

$$r_{10} = 0$$

$$r_{01} = 0.839$$

$$r_{11} = 6.97$$

$$r_{02} = 1.67$$

$$r_{12} = 2.51$$

REFERENCES

1) J. Ballam et al. - Phys.Rev.Letters 24, 960 (1970).

2) F.J. Gilman, J. Pumplin, A. Schwimmer and L. Stodolsky - Phys.Letters 31B, 387 (1970).

3) J.J. Sakurai - "Proceedings of the 4th International Symposium on Electron and Photon Interactions at High Energies", edited by D.W. Bracken (Daresbury, 1969).

4) H. Harari - Phys.Rev. 155, 1565 (1967).

5) Y. Eisenberg et al. - Phys.Rev.Letters 22, 669 (1969) ; Phys.Letters 34B, 439 (1971).

6) J. Ballam et al. - Phys.Rev.Letters 24, 1364 (1970).

7) Aachen-Berlin-Bonn-Hamburg-Heidelberg-München collaboration - Phys.Rev. 175, 1669 (1969).

8) J. Ballam et al. - SLAC-PUB-980 (1971).

9) K. Schilling, P. Seyboth and G. Wolf - Nuclear Phys. B15, 397 (1970) ; B18, 332 (1970).

10) J.T. Carroll et al. - Phys.Rev.Letters 27, 1025 (1971).

11) G. Cohen-Tannoudji, A. Morel and H. Navelet - Ann.Phys.(N.Y.) 46, 239 (1968).

12) M. Jacob and G.C. Wick - Ann.Phys.(N.Y.) 7, 404 (1959).

13) J.P. Ader, M. Capdeville and H. Navelet - Nuovo Cimento 56A, 315 (1968).

14) P.R. Weiler, Jr. - University of Wisconsin Ph.D. Thesis (1971).

15) R. Dolen, D. Horn and C. Schmid - Phys.Rev. 166, 1768 (1968).

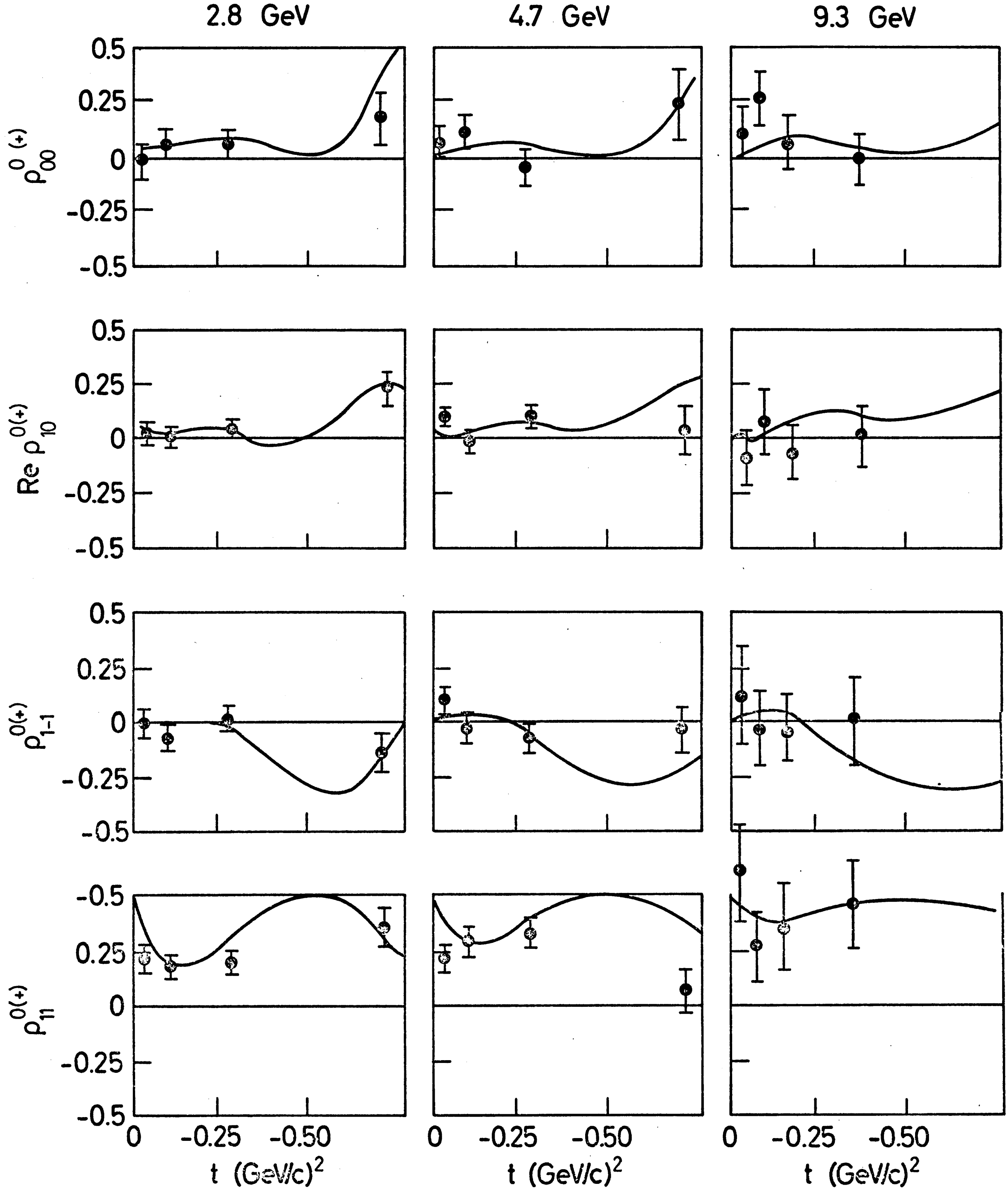
FIGURE CAPTIONS

Figure 1 Natural parity exchange ω density matrix elements in the helicity frame.

Figure 2 Unnatural parity exchange ω density matrix elements in the Gottfried-Jackson frame.

Figure 3 The $\gamma p \rightarrow \omega p$ differential cross-section.

Figure 4 The ω density matrices in the helicity frame.



2.8 GeV
4.7 GeV
9.3 GeV
$\rho^{0(+)}_{00}$
Re $\rho^{0(+)}_{10}$
$\rho^{0(+)}_{1-1}$
$\rho^{0(+)}_{11}$
0.5
0.25
0
-0.25
-0.5
0
-0.25
-0.50
t (GeV/c)^2

FIG.1

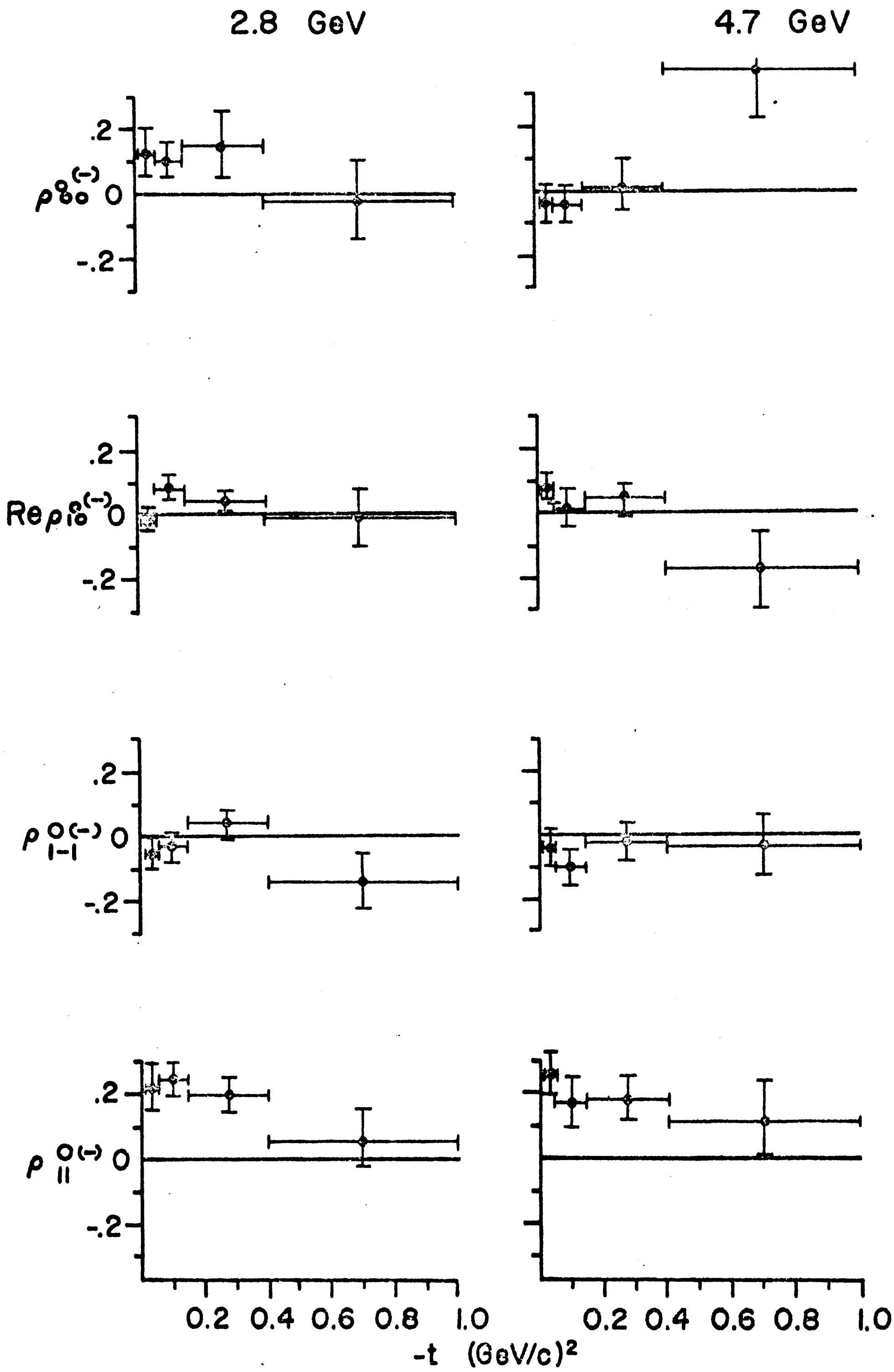


FIGURE 2

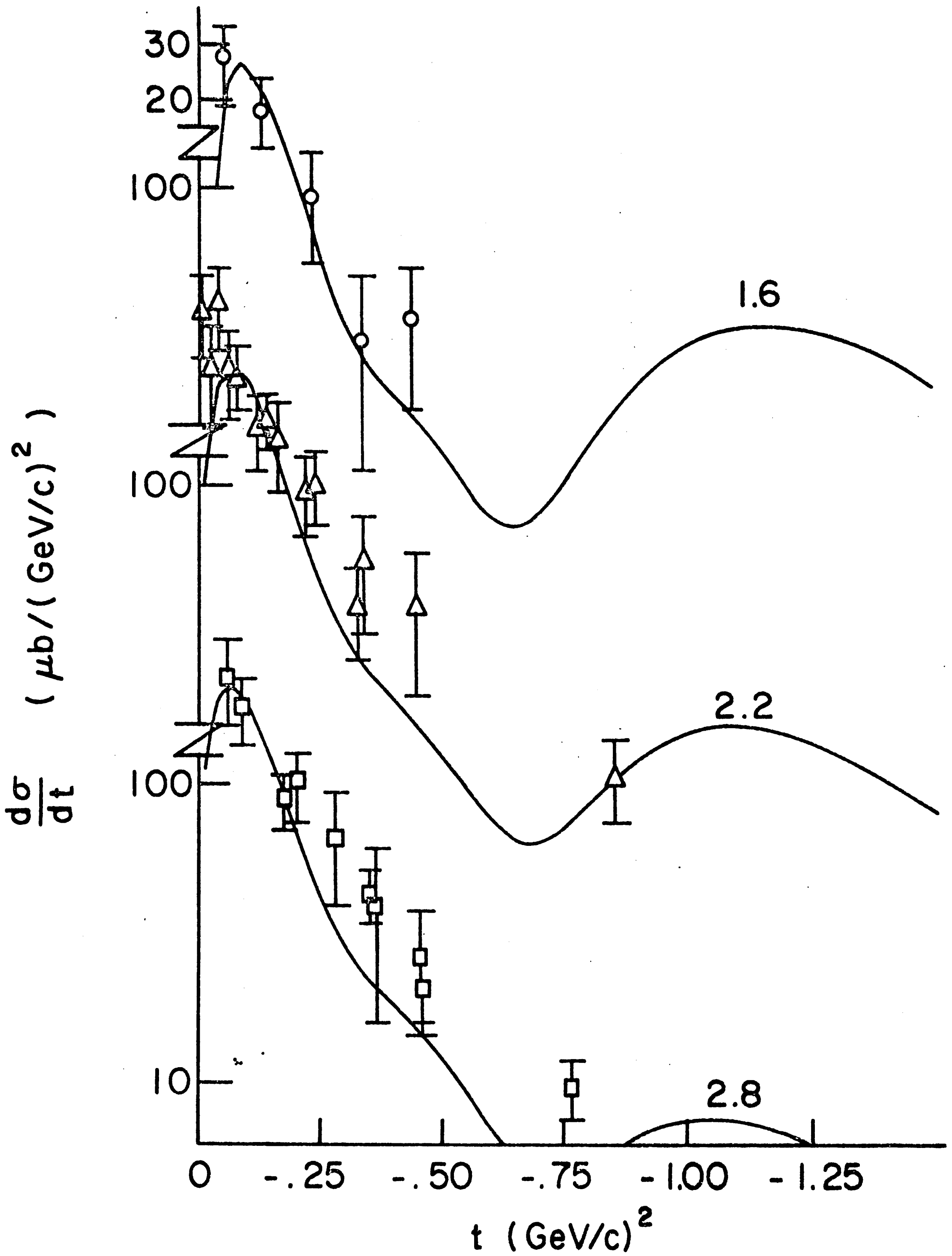
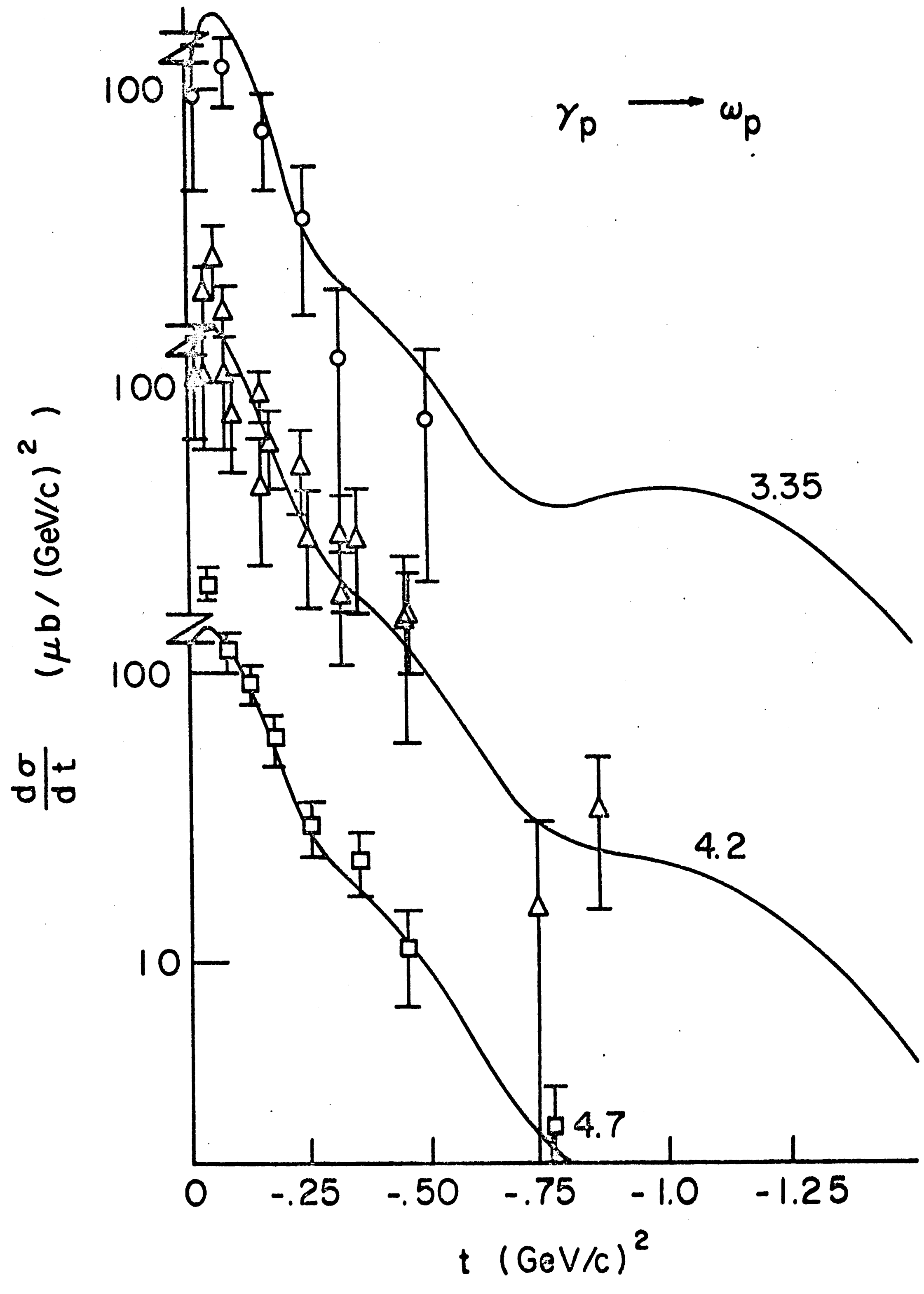

30
20
100
100
100
10
1.6
2.2
2.8
0
-.25
-.50
-.75
-1.00
-1.25
t (GeV/c)²
dσ/dt (μb/(GeV/c)²)

FIGURE 3a



γp → ωp
100
100
100
10
dσ/dt (μb/(GeV/c)²)
3.35
4.2
4.7
0
-.25
-.50
-.75
-1.0
-1.25
t (GeV/c)²

FIGURE 3b

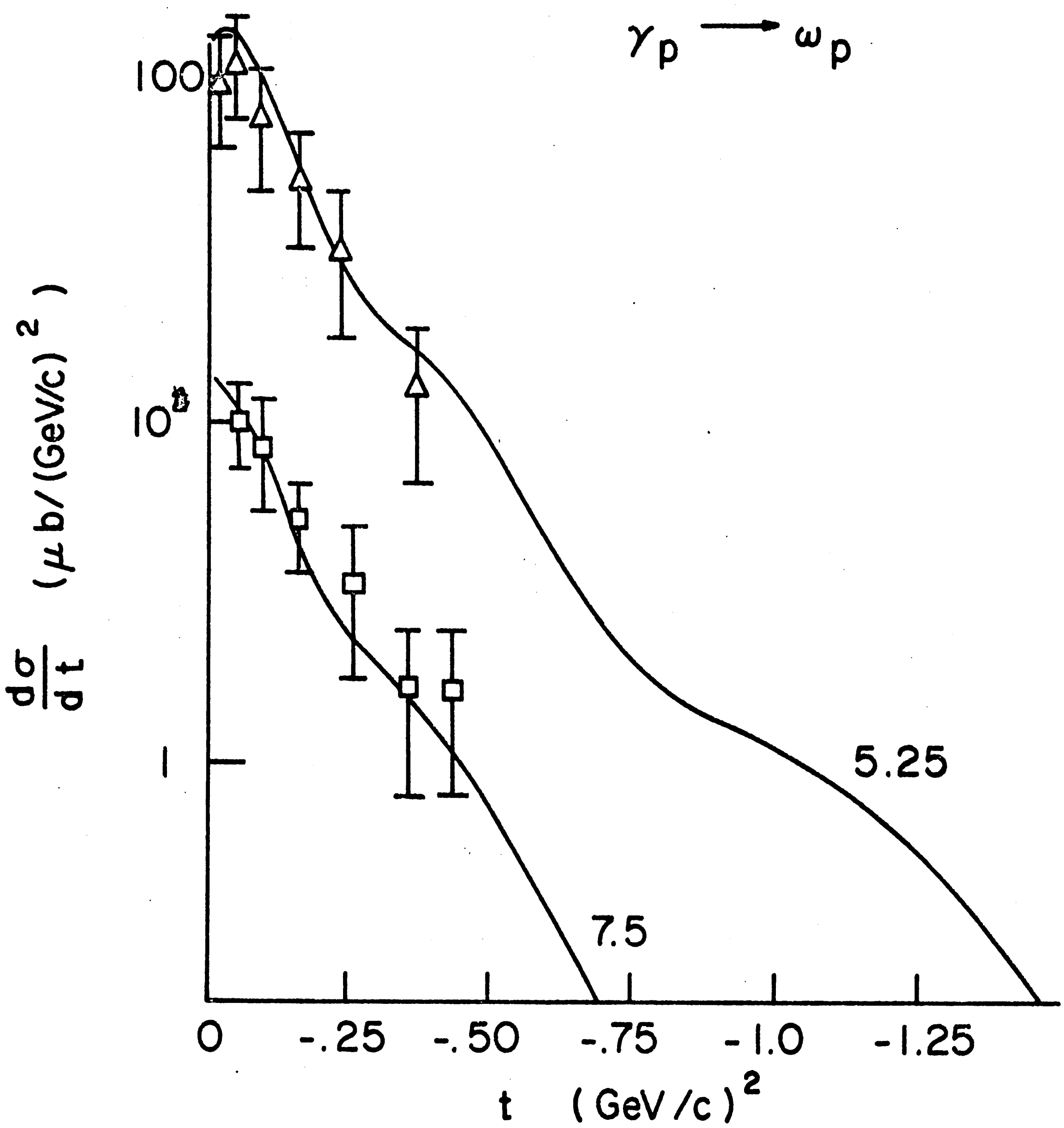


FIGURE 3c

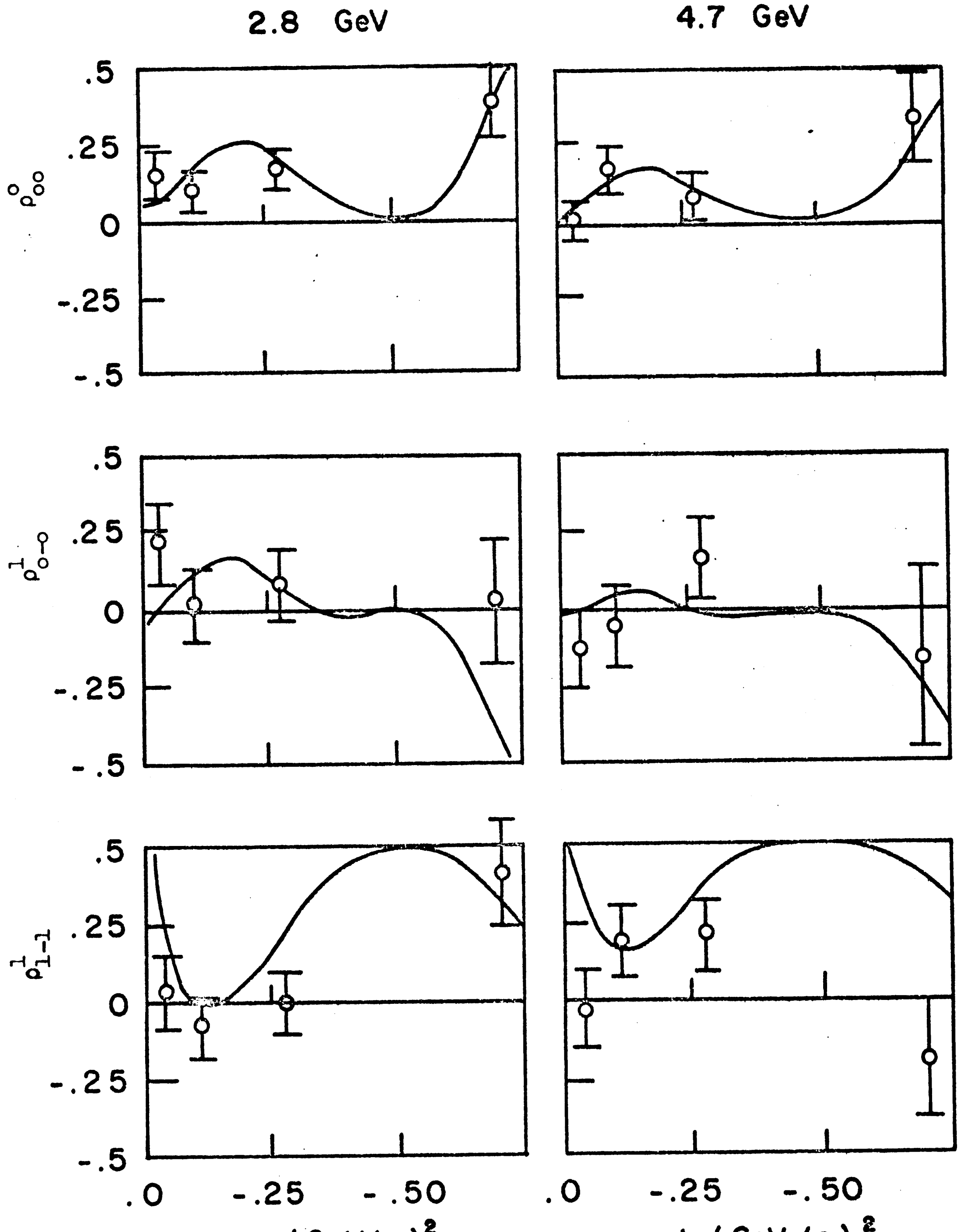
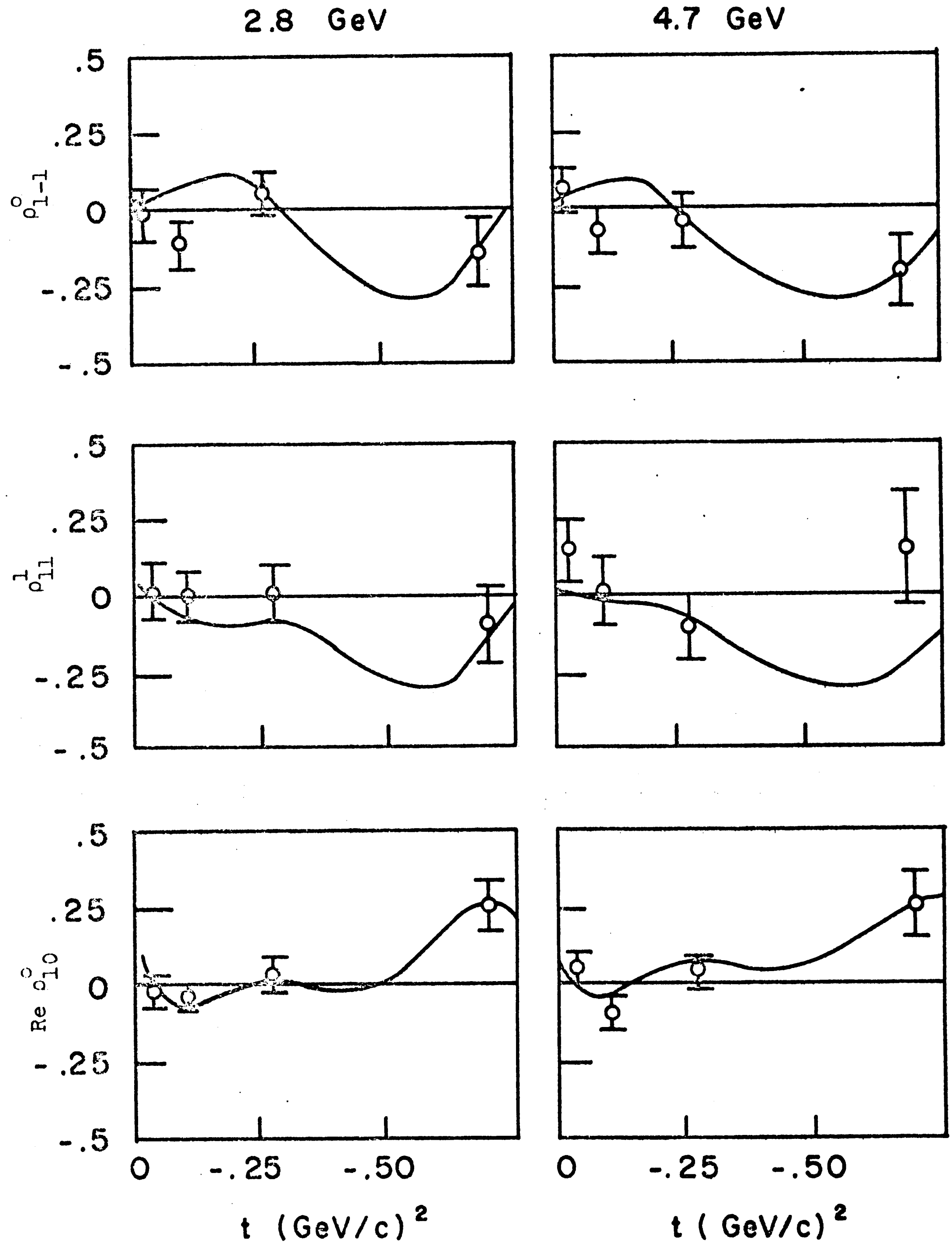


Figure 4a



2.8 GeV
4.7 GeV
.5
.25
0
-.25
-.5
ρ^0_{1-1}
ρ^1_{11}
Re ρ^0_{10}
0
-.25
-.50
t (GeV/c)^2
t (GeV/c)^2

Figure 4b

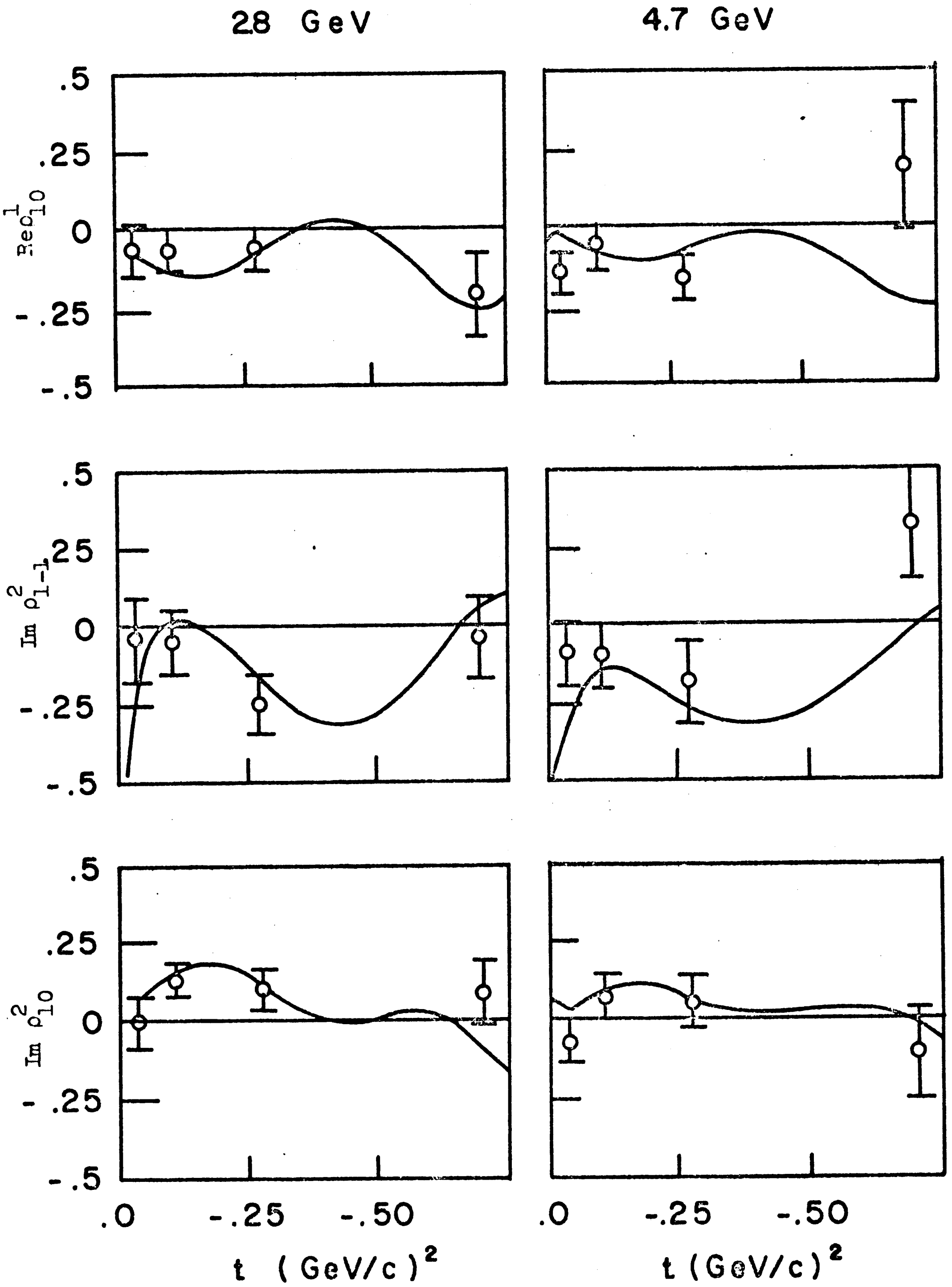

2.8 GeV
4.7 GeV
.5
.25
0
-.25
-.5
$Re\rho^1_{10}$
$Im\ \rho^2_{1-1}$
$Im\ \rho^2_{10}$
.0
-.25
-.50
t (GeV/c)^2

Figure 4c