SLAC-PUB-1092
LBL-1055
(TH) and (EXP)
August 1972

OBSERVATION OF SMALL s-CHANNEL HELICITY FLIP AMPLITUDES IN VECTOR MESON PHOTOPRODUCTION*

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ABSTRACT

Evidence is presented that although s-channel helicity conservation is dominant in ρ^o photoproduction, a small amount of helicity flip which is not strongly dependent on photon energy occurs for dipions near the ρ^o mass. The ratio of helicity single-flip to nonflip amplitudes at the γ-ρ vertex is comparable in magnitude to that found in πp scattering.

*Work supported by the U. S. Atomic Energy Commission and the National Science Foundation.

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

Photoproduction of ρ^0 mesons in the reaction $\gamma p \rightarrow \rho^0 p$ is generally considered to be diffractive, i.e., dominated by Pomeron exchange.[1,2,3] It has previously been shown[2,3] that at low $|t|$ the s-channel helicity of the photon is almost completely conserved by the ρ^0. This led Gilman et al.[4] to speculate that s-channel helicity conservation (SHC) was a property of Pomeron exchange. Analysis of πp elastic scattering[5] and of polarization correlations[6] at 6 GeV/c indicates that SHC is approximately valid for the proton vertex as well, the I=0 exchange helicity flip amplitudes being $\sim 10\%$ of the nonflip amplitudes at that energy. In this letter we investigate the contribution of helicity flip at the γ-ρ vertex using new photoproduction data at 9.3 GeV. Because of background interference problems[3,7] we shall first present the experimental data on the dipion angular distributions and discuss the underlying ρ^0 amplitude structure later.

The data presented here are from a 1.2 million picture exposure of the SLAC-LBL 82" hydrogen bubble chamber to a 9.3 GeV linearly polarized photon beam. This beam is produced by backscattering laser photons from the SLAC 19 GeV electron beam. For comparison we use data from exposures at 2.8 and 4.7 GeV;[2,3] a comprehensive description of experimental details can be found in Ref. 2, 3, and 8. In this letter we consider in detail only the angular distributions of ρ^0 decay in $\gamma p \rightarrow \rho^0 p$, although we have made a parallel analysis of the reaction $\gamma p \rightarrow \omega p$ and shall include some relevant parameters of this reaction for comparison with the ρ^0.

In Fig. 1 we show the density matrix elements for dipion pairs in the ρ^0 region in the helicity system from a maximum-likelihood fit to the data in t intervals as described in Appendix A of Ref. 3. This fitting procedure removes incoherent Δ^{++} and phase-space backgrounds but assumes no coherent background.[9,10] If the dipions are produced by a completely SHC mechanism, one expects $\rho^0_{11} = \rho^1_{1-1} = -\text{Im}\,\rho^2_{1-1} = \frac{1}{2}$ and all other $\rho^\alpha_{ik} = 0$.

As can be seen, ρ^0_{00} is consistent with being zero at all t, but Re ρ^0_{10} and to a lesser extent, ρ^0_{1-1} are significantly nonzero for the larger |t| intervals.[11] To test for an instrumental source of the small deviations from zero in the density matrix elements we evaluated the ρ^α_{ik} separately for photon polarization parallel and normal to the bubble chamber magnetic field. Since the ρ^0 decays preferentially in the polarization plane, this effectively rotates the asymmetry of the angular distribution by 90° in the chamber. Both samples gave the same result.

Relevant quantities for a study of helicity-flip are:

$$\rho^0_{00}\frac{d\sigma}{dt} = \frac{1}{2}\sum |T_{0\lambda_{N'},1\lambda_N}|^2 \tag{1a}$$

$$\left(\rho^1_{1-1} + \text{Im}\,\rho^2_{1-1}\right)\frac{d\sigma}{dt} = \frac{1}{2}\sum T_{1\lambda_{N'},-1\lambda_N} T^*_{-1\lambda_{N'},1\lambda_N} \tag{1b}$$

$$2\text{Re}\,\rho^0_{10}\frac{d\sigma}{dt} = \frac{1}{2}\text{Re}\sum\left(T_{1\lambda_{N'},1\lambda_N} - T_{-1\lambda_{N'},1\lambda_N}\right)T^*_{0\lambda_{N'},1\lambda_N} \tag{1c}$$

$$\rho^0_{1-1}\frac{d\sigma}{dt} = \frac{1}{2}\text{Re}\sum T_{1\lambda_{N'},1\lambda_N} T^*_{-1\lambda_{N'},1\lambda_N} \tag{1d}$$

with the normalization:

$$\frac{d\sigma}{dt} = \frac{1}{4}\sum_{\lambda\text{'s}} |T_{\lambda_\rho\lambda_{N'},\lambda_\gamma\lambda_N}|^2 \tag{1e}$$

where $T_{\lambda_\rho\lambda_{N'},\lambda_\gamma\lambda_N}$ is the amplitude for producing a ρ^0 and nucleon with helicities λ_ρ and $\lambda_{N'}$ from an initial γ and nucleon with helicities λ_γ and λ_N. The sum in (1a) - (1d) is over the nucleon helicities. The observation that the LHS of (1a) and (1b) are zero (Fig. 1) indicates that SHC amplitudes dominate strongly at the

γ-ρ vertex. The terms Re ρ^0_{10} and ρ^0_{1-1} are nonzero[12] at large $|t|$, implying that an interference between helicity nonflip and flip amplitudes exists, and of course interference terms are much more sensitive to small flip amplitudes than the intensity terms (1a) and (1b).

Amplitude ratios can be deduced from the ρ^α_{ik} under the following assumptions: (1) Natural parity exchange[13] dominates ($P_\sigma \approx 1$); (2) Amplitudes with helicity flip at the γ-ρ vertex are small; (3) Amplitudes with helicity flip at the nucleon vertex are small; (4) The nonflip amplitude $T_{1\frac{1}{2}1\frac{1}{2}}$ is imaginary (an amplitude analysis of the reaction $\gamma p \rightarrow \rho^o p$ is given by G. Chadwick et al.[6]).

In Table I we summarize our estimates of the helicity flip contributions at the γ-dipion vertex. We chose the $|t|$ interval $0.18 \leq |t| \leq 0.80$ GeV^2 because the flip amplitudes have kinematic zeroes at $t = t_{min}$. Also included are results from our 2.8 and 4.7 GeV exposures. From Re ρ^0_{10} we deduce that Im $T_{01}/|T_{11}|$ is about 15% and occurs dominantly as a result of natural parity exchange. The interpretation of the double-flip term, ρ^0_{1-1}, is less clear.[11]

It is interesting to study the amplitude T_{01}. From the relations summarized in Table I we note that to a good approximation the SHC-violating single-flip amplitude is given by

$$\text{Im } T^N_{0\frac{1}{2}1\frac{1}{2}} \simeq 2\sqrt{\frac{d\sigma}{dt}} \text{ Re } \rho^N_{10} \quad . \tag{2}$$

In Fig. 2 this quantity is plotted for all three photon energies. There is no strong energy dependence in the data. We note that the ratio of helicity-flip to nonflip amplitudes in πN scattering[6] is of similar magnitude to that of ρ^o photoproduction (see Table I) and is also weakly energy dependent.

Discussion

At 9.3 GeV the photoproduced ρ^o appears to be almost entirely free of background, i.e., above $M_{\pi\pi} \sim 1$ GeV a plateau of $\sim 2\%$ of the peak intensity is seen. However, as was shown at the lower energies,[3,7] the skewed Breit-Wigner form of the $M_{\pi\pi}$ distribution, which persists at 9.3 GeV,[8] may be explained by the presence of a coherent p-wave background which is well described by the Drell effect[9] in the Söding model.[10] Therefore, in looking for small effects of SHC violation ($\sim 2\%$ in the intensity) we must examine the possibility that they are actually due to a background. For this we examine the dependence of ρ_{ik} on the dipion mass. Figures (3a) and (3b) show the unnormalized moments summed over the angular distribution data (θ and ϕ are the polar and azimuthal angles of the dipion decay in the helicity system):

$$-\frac{5}{4\sqrt{2}} \sum \sin 2\theta_i \cos \phi_i \propto \mathrm{Re}\, \rho^0_{10} \frac{d\sigma}{dM_{\pi\pi}} \tag{3a}$$

and

$$-\frac{5}{4} \sum \sin^2 \theta_i \cos 2\phi_i \propto \rho^0_{1-1} \frac{d\sigma}{dM_{\pi\pi}} \tag{3b}$$

as a function of $M_{\pi\pi}$ for the region $0.2 \leq |t| \leq 0.8$ GeV^2, where the signal appears strongest. The moments show structure in the ρ^o region. The solid curve is calculated from an SHC Söding model[3] assuming that the ρ^o is produced with the elements $\mathrm{Re}\, \rho^0_{10} = \rho^0_{1-1} = 0$. A characteristic interference pattern is apparent for the calculated unnormalized moments. In the above calculation, the Drell diagram produces a complicated angular distribution in the dipion rest system, which has a relatively smooth $M_{\pi\pi}$ dependence. The interference of this term with the SHC $\rho^o \to \pi^+\pi^-$ decay term, which has a rapidly varying phase near $M_{\pi\pi} = M_\rho$, then produces the calculated pattern. A similar interference effect brings about the experimentally observed[3, 8] skewing of the ρ^0 mass distribution at small $|t|$. In Fig. 3c and 3d we replot Figs. 3a and 3b to show the difference between the moment sums of the experimental data and the Söding model calculations. The curves are p-wave Breit-Wigner shapes with the parameters of the ρ^0. We would expect an effect specific to $\gamma p \rightarrow \rho^0 p$ to show such a shape, while an effect from background would show a smooth $M_{\pi\pi}$ dependence (incoherent background) or an interference pattern (coherent background). Indeed, the effect is consistent with being specific to the ρ^0. We also note from the calculated curves in Figs. 3a and 3b that the Söding model predicts an interference curve which vanishes near $M_{\pi\pi} = M_\rho$ and is anti-symmetric around this point over a range of $\pm\Gamma_\rho$. This behavior results from the assumed mainly imaginary phase of the Drell term. Thus any symmetric and narrow ($\pm 1\ \Gamma_\rho$) band about M_ρ would contain a contribution from the interference terms which averages to zero for all density matrix elements at all t; it follows that within the framework of the Söding model that we used, the data of Fig. 1 are almost free of any background and represent the pure contribution of the ρ^0 itself. However, as we have emphasized,[3] considerable uncertainties exist in the calculation of the Drell background. For example, the phase of the Drell term is not known, and the shape of the dipion mass spectrum could be changed by the terms that are required to make the Drell background gauge invariant. Consequently, because we have no unique prescription for the coherent Drell background, we must conclude that the question of the existence of s-channel helicity flip ρ^0 photoproduction amplitudes suffers from a <u>theoretical uncertainty</u> that cannot be resolved by us at the present time.

As argued above, it is possible that the single helicity flip terms are related to ρ^0 photoproduction and thus it is interesting to look for similar effects in ω photoproduction. In Fig. 2 we show the RHS of Eq. (2) obtained from[8] analyzing the ω decay from $\gamma p \to \omega p$ and taking the natural parity exchange part only. For this reaction we found $\rho^N_{00} = \frac{1}{2}\left(\rho^0_{00} - \rho^1_{00}\right) = 0.09 \pm 0.10$ (at 9.3 GeV) for $0.06 < |t| < .60$ GeV^2, indicating that this is a dominantly SHC reaction also. No evidence for helicity flip is apparent in Re $\rho^N_{10}(\omega)$. We note that if A_2 exchange were responsible for the Im T^N_{01} amplitude in ρ^o production, it should be about three times stronger in ω production by SU(3), while P or P' exchange would make it 1/3 that of the ρ^o.

In conclusion, we observe evidence for small SHC violating terms, which are not strongly energy-dependent, in the reaction $\gamma p \to p\pi^+\pi^-$ near $M_{\pi\pi} = M_\rho$. It is interesting to note that the ratio of single-flip to nonflip amplitudes at the γ-dipion vertex is close to the corresponding ratio at the proton vertex in πN scattering.

Acknowledgements

We wish to thank the SLAC Operations Crew, R. Watt and the 82" Bubble Chamber Operations Group for their assistance in performing this experiment. We thank R. Gearhart, J. J. Murray and C. K. Sinclair for their help during the early stages of the experiment. We acknowledge the diligence of our scanners and data reduction group, in particular D. Blohm, K. Eymann, W. Hendricks and A. Wang. We thank Y. Avni for helpful discussions.

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11. It is possible to separate[13] the ρ^{α}_{ik} into those originating from natural and unnatural parity exchange processes in the t-channel using appropriate combinations of ρ^{0}_{ik} and ρ^{1}_{ik}. We find no evidence for any substantial unnatural parity exchange (see P_{σ}, Fig. 1). However, while Re $\rho^{U}_{10} \approx 0$ and Re $\rho^{N}_{10} \approx$ Re ρ^{0}_{10}, the effect in ρ^{0}_{1-1} splits equally among ρ^{N}_{1-1} and ρ^{U}_{1-1} (see Ref. 8 for details). Thus the evidence for s-channel helicity double-flip in the natural parity exchange amplitudes is marginal.
12. The elements Re ρ^{1}_{10} and Im ρ^{2}_{10} have a similar meaning to Re ρ^{0}_{10} but have larger errors. They show (Fig. 1) a similar behavior. ρ^{1}_{11} has a

similar meaning to ρ^0_{1-1} and its smallness reduces[11] the effect of SHC-violation in ρ^N_{1-1}.

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FIGURE CAPTIONS

1. Helicity-system density matrix elements and parity asymmetry P_σ in the ρ region as a function of momentum transfer t_{pp}.
2. E_γ and t dependence of single helicity-flip amplitudes at the γ-V^0 vertex in vector meson photoproduction.
3. (a), (b) Unnormalized moments for $|t| = .2 - .8$ GeV^2 as function of $M_{\pi^+\pi^-}$ in the reaction $\gamma p \to p\pi^+\pi^-$. Curves are from Söding model calculations. N is the number of events in each mass bin. (c), (d) Deviations of measured moments from Söding model calculations. Curves are p-wave Breit-Wigner ρ^0 distributions normalized to area under the experimental points.

TABLE I

s-CHANNEL HELICITY-FLIP AMPLITUDE RATIOS IN THIS EXPERIMENT AND IN πN SCATTERING[6] FOR $.18 < |t| < .80$ GeV^2

Amplitude Ratios*	Experimental Values of Density Matrix Elements			
	2.8 GeV	4.7 GeV	9.3 GeV	Average
Photoproduction				
$\|T_{01}\|^2/\|T_{11}\|^2 \simeq \rho^0_{00}$	$-.01\pm.03$	$.07\pm.02$	$-.01\pm.02$	$.018\pm.012$
$\|T_{-11}\|^2/\|T_{11}\|^2 \simeq \rho^1_{1-1} + \text{Im}\,\rho^2_{1-1}$	$.04\pm.05$	$.11\pm.05$	$-.02\pm.05$	$.04\pm.03$
$\text{Im}\,T_{01}/\|T_{11}\| \simeq 2\,\text{Re}\,\rho^0_{10}$	$.16\pm.03$	$.12\pm.03$	$.14\pm.02$	$.14\pm.016$
$\text{Im}\,T_{-11}/\|T_{11}\| \simeq \rho^0_{1-1}$	$-.06\pm.03$	$-.05\pm.03$	$-.10\pm.02$	$-.08\pm.02$
πN Scattering				
$\|F^o_{+-}\|/\|F^o_{++}\|$ Isospin 0 Exchange		6 GeV/c		$.15\pm.02$

*The nucleon helicities in the photoproduction amplitudes listed are $\frac{1}{2}\frac{1}{2}$ (or $-\frac{1}{2}-\frac{1}{2}$).

$\gamma p \rightarrow p\rho^0$

$E_\gamma = 9.3$ GeV

DENSITY MATRIX IN HELICITY SYSTEM

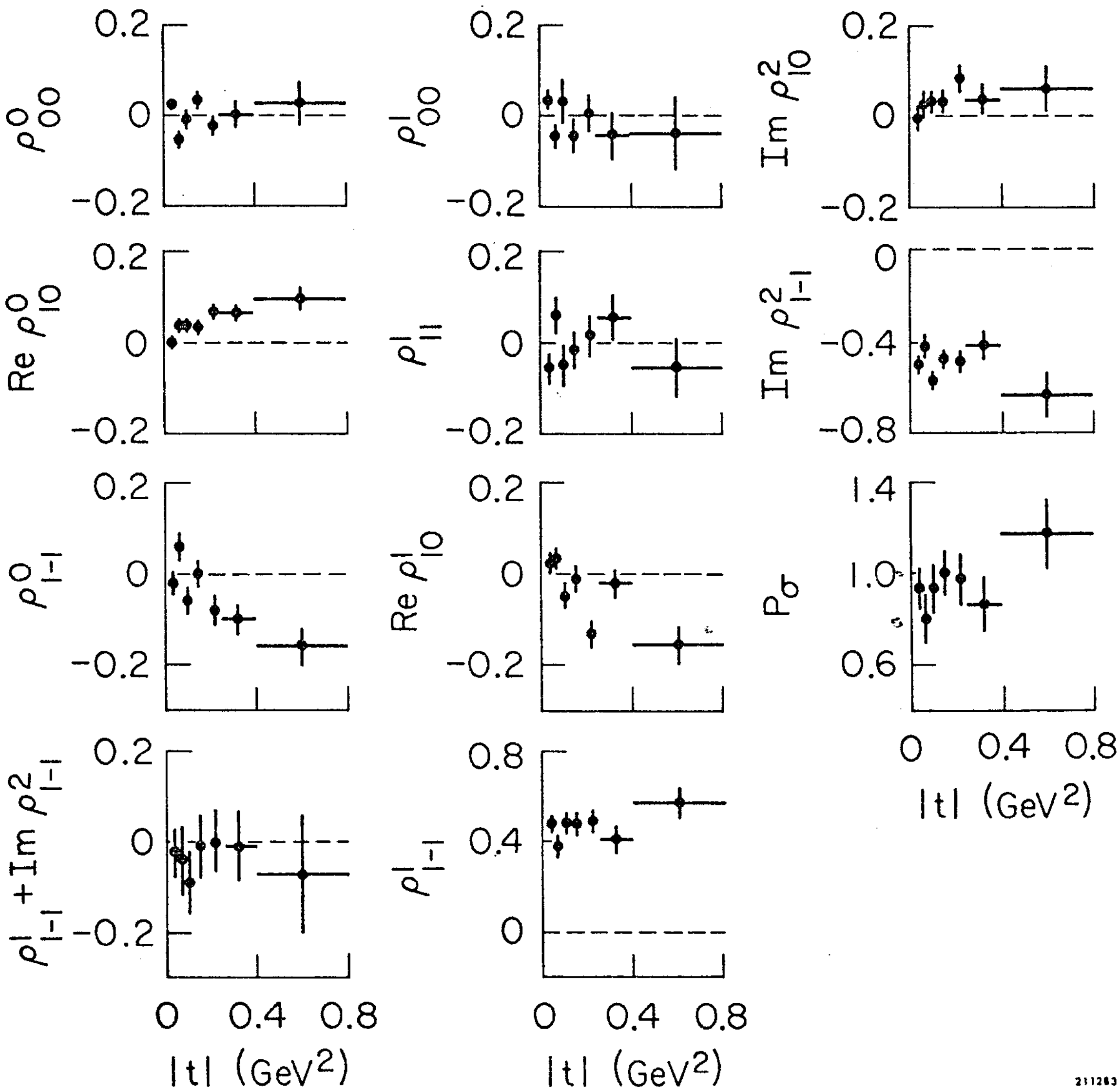
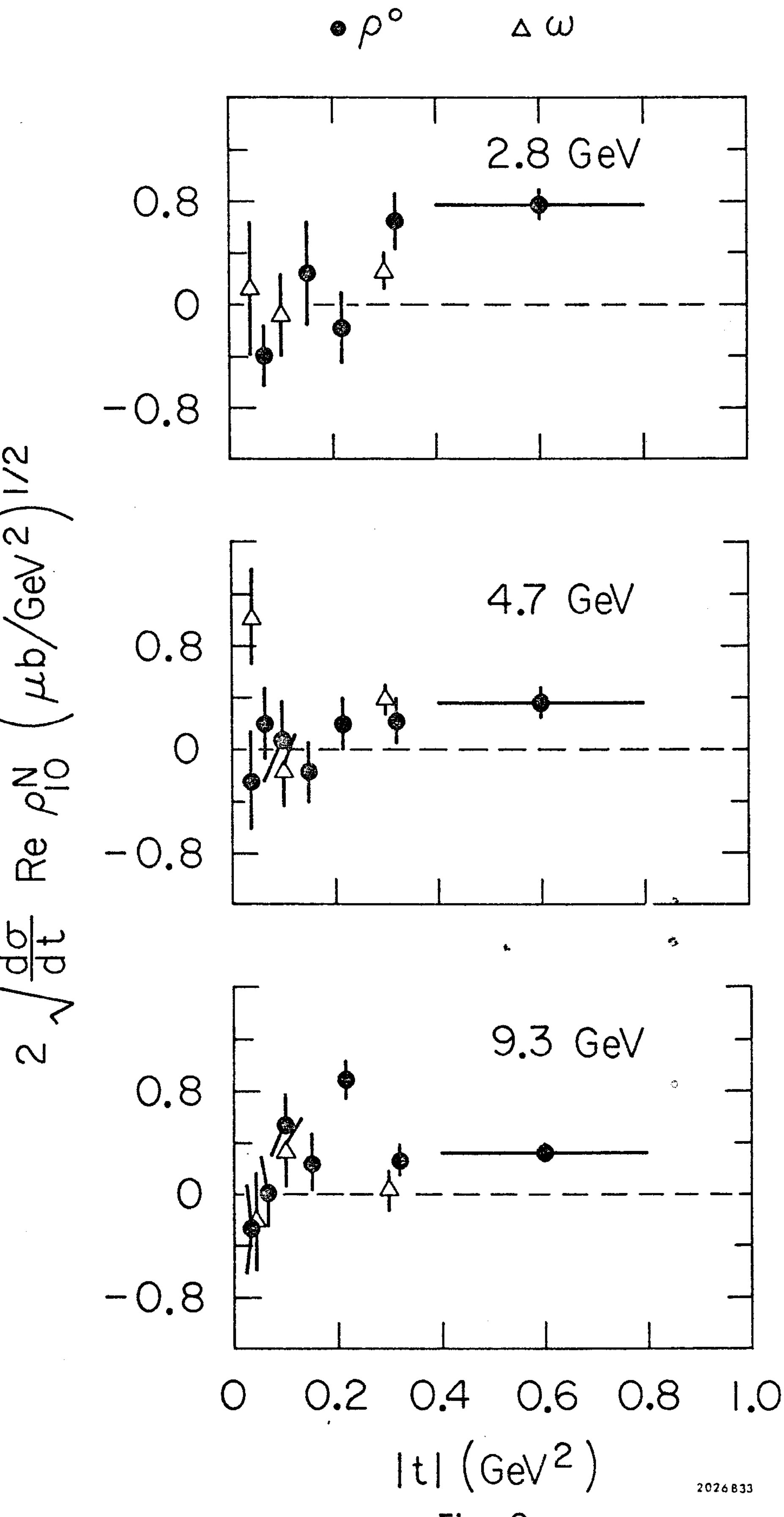


Fig. 1



● ρ°
△ ω
2.8 GeV
4.7 GeV
9.3 GeV
0.8
0
−0.8
0
0.2
0.4
0.6
0.8
1.0
|t| (GeV²)
2 √(dσ/dt) Re ρ^N_10 (μb/GeV²)^1/2
2026B33

Fig. 2

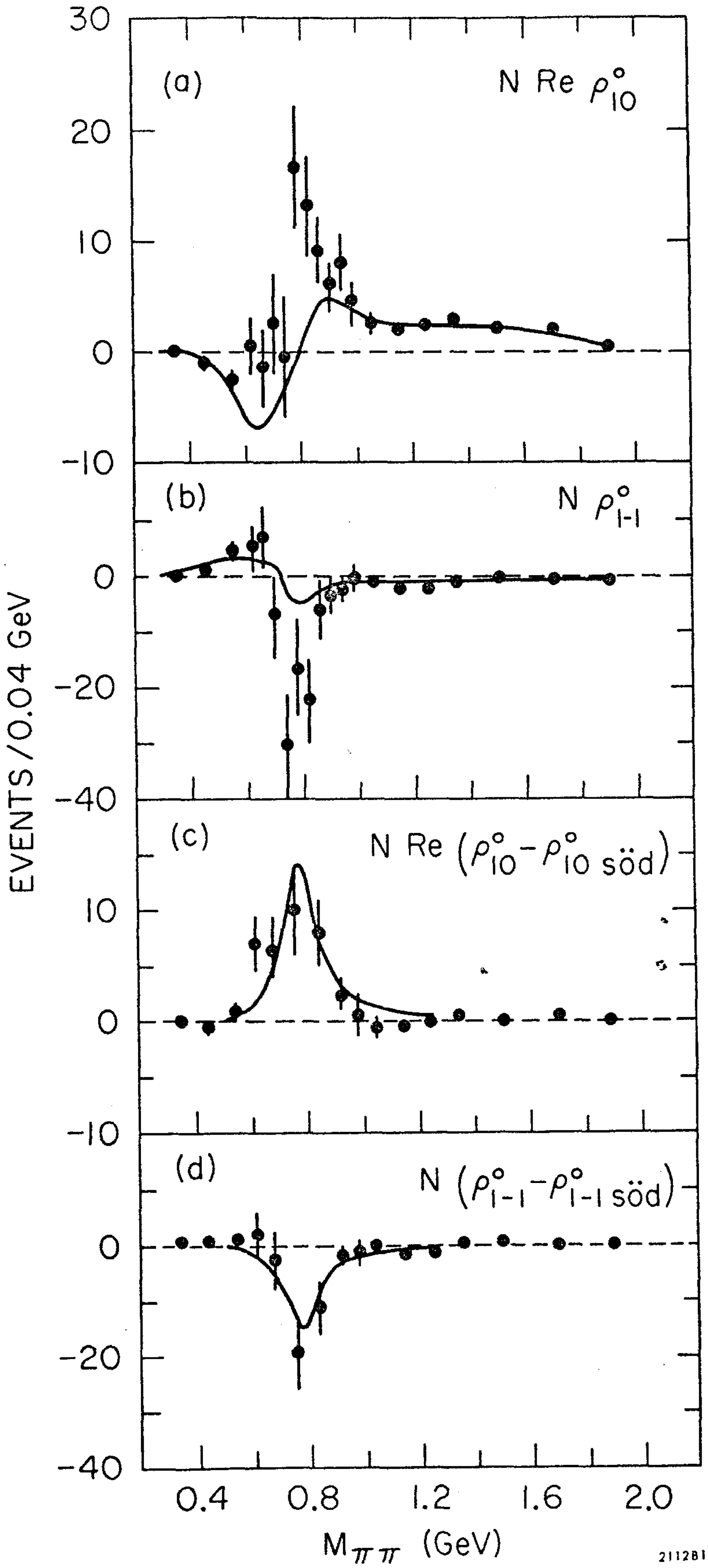

EVENTS/0.04 GeV
(a)
N Re ρ^0_{10}
(b)
N ρ^0_{1-1}
(c)
N Re $(\rho^0_{10} - \rho^0_{10}$ söd)
(d)
N $(\rho^0_{1-1} - \rho^0_{1-1}$ söd)
30
20
10
0
-10
-20
-40
0.4
0.8
1.2
1.6
2.0
$M_{\pi\pi}$ (GeV)
211281

Fig. 3