SLAC-PUB-852
January 1971

PHOTOPRODUCTION OF ω-MESONS FROM 1.2 to 8.2 GeV*

Y. Eisenberg, B. Haber, E. E. Ronat, Y. Stahl and G. Yekutieli
Weizmann Institute of Science
Rehovoth, Israel

J. Ballam, G. B. Chadwick, M. M. Menke,
P. Seyboth,** and A. Shapira***
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

and

J. Gandsman, J. Grunhaus, and A. Levy
Department of Physics and Astronomy
Tel-Aviv University, Tel-Aviv, Israel

ABSTRACT

The reaction $\gamma p \rightarrow \omega p$ was studied between 1.2 and 8.2 GeV using positron annihilation radiation. Assuming $\sigma \propto C_{OPE} \cdot E_{\gamma}^{-2} + C_{DIFF}$ we obtain for the Pomeron exchange cross section $(1.5 \pm .3)$ μb.

(Submitted to Physics Letters B)

---

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

** On leave from Max Planck Institute, Munich, Germany.

*** Present address, Weizmann Institute, Rehovoth, Israel.

γ

ob

Earlier experiments[1,2] on the photoproduction of ω mesons by photons with energies of 1.2 - 5.8 GeV have indicated that the cross section for the reaction:

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

decreases significantly as the photon energy is increased. The decrease in the ω cross section is presumably due to the fact that the photoproduction of ω has substantial contributions from particle exchange diagrams, which decrease with energy, and a nearly constant contribution from a diffraction process. In the present work we have extended the upper limit of the previous energy range and present data for reaction (1) in the interval $1.2 \leq E_\gamma \leq 8.2$ GeV.

The data was obtained in three photoproduction experiments using the SLAC 40" hydrogen bubble chamber exposed to the positron annihilation beam[3] which provided a monochromatic peak, centered at 4.3,[4] 5.25,[5] and 7.5 GeV respectively, plus a bremsstrahlung background. For this study all events not fitting the reaction $\gamma p \rightarrow p\pi^+\pi^-$ and consistent by observed track ionization with the reaction

$$\gamma p \rightarrow p\pi^+\pi^-\pi^o \tag{2}$$

with $E_\gamma > 1.2$ GeV were used. All such events were subjected to both a zero constraint and a one constraint (i.e., expected annihilation photon energy) kinematic fit. The 1C events were further required to have a missing mass in the range $-0.18 < MM^2 < 0.10$ GeV^2 and a confidence level > 0.005, removing most of the events with several neutral particles. For bremsstrahlung induced events no such missing mass selection was possible and hence we are only able to determine the total channel cross section for annihilation events.

The invariant-mass plots of the $\pi^+\pi^-\pi^o$ produced in reaction (2) for $E_\gamma \geq 3.0$ GeV are shown in Fig. 1. A clear ω signal is visible at all photon energies. The dashed curves in Fig. 1 represent the background assumed in the derivation of the ω cross sections. The "background level" has been estimated either by a fit of the $\pi^+\pi^-\pi^0$ mass distribution to phase space plus a gaussian shaped ω (for $E_\gamma < 3.7$ GeV) or by a hand drawn curve (for $E_\gamma > 3.7$ GeV). Table I shows the number of events in the sample for each energy interval, raw and corrected numbers of ω's and resulting cross sections. The corrections considered were: (a) loss of events with a short (invisible) proton; (b) contamination of the data by events not belonging to reaction (2), mainly events in which more than one π^0 was produced and which nevertheless gave a good 1C fit; (c) contamination of the data by reaction (2) events produced by photons outside each selected energy band, which gave acceptable 1C fit with E_γ inside the selected E_γ band; (d) ω events in which the 3π mass was reconstructed outside the interval $0.68 \leq M(\pi^+\pi^-\pi^0) \leq 0.88$ GeV, used to define an ω event, or removed by the other cuts. Since correction (a) is essentially a scanning loss, it can be best estimated by using our more abundant reaction, $\gamma p \rightarrow \rho^0 p$. It turned out to be negligible for $E_\gamma \lesssim 3$ GeV, and about (10 - 13.5)% at the energies 3.0 - 7.5 GeV. For the study of corrections (b) - (d) we have used the track and event simulation program PHONY. Both $p\omega$ and phase-space events were generated and subjected to the same geometry-kinematics fitting and cuts as the real events. Study of the fake events has indicated that by imposing the missing-mass cut ($-.18 < MM^2 < .10$ GeV^2) on the data the real ω events are not affected at all whereas contamination (b) above is removed almost entirely. Corrections (c) and (d) amounted to no more than 10% and thus even approximate knowledge of them should give us a good final cross section. The overall corrections for (a) - (d) are specified in Table I and for all energy intervals they are smaller than the statistical accuracy of the data. A further correction of 10% was applied to account for the neutral ω decay modes[6] which are not visible in the bubble chamber.

The energy dependence of the $\gamma p \to \omega p$ cross section is shown in Fig. 2(a). In this figure we present our results together with the recent data at 2.8 and 4.7 GeV from the polarized-photon (laser) experiment at SLAC.[7] A more comprehensive compilation of cross sections[1,2,7,8] for reaction (1) is given in Fig. 2(b). As already mentioned the ω total cross section decreases with the photon energy. We have attempted to fit the data of Fig. 2(a) (for $E_\gamma \geq 2.0$ GeV) to a curve of the type

$$\sigma(\gamma p \to \omega p) = C_{OPE} \cdot E_\gamma^{-\alpha_1} + C_{DIFF} \cdot E_\gamma^{-\alpha_2} \tag{3}$$

where E_γ is the photon laboratory energy in GeV. We assume that the energy dependence of the one pion exchange (OPE) and diffractive contributions could be approximated by a power law. The possible A_2 exchange contributions have been neglected. Our present data is too meager for a more detailed analysis. α_1 is expected[9] to be between 1.6 - 2.5, and α_2 should be small since the diffraction cross section does not depend strongly on E_γ. The cross sections were fitted to Eq. (3) using two sets of fixed values for α_1 and α_2. For $\alpha_1 = 2.0$ and $\alpha_2 = 0$ we obtain $C_{OPE} = 31 \pm 5$ and $C_{DIFF} = 1.5 \pm 0.3$. (For $\alpha_1 = 1.6$ and $\alpha_2 = 0.08$, the values used in Ref. 2, we get $C_{OPE} = 22 \pm 4$ and $C_{DIFF} = 1.2 \pm 0.45$.)

The calculated OPE contribution to the $\gamma p \to \omega p$ total cross section determined with the above parameters is shown in Fig. 2(a) as a function of the photon energy (dashed line). For a comparison we have plotted the unnatural exchange cross section for reaction (1) at 2.8 and 4.7 GeV as determined recently in the polarized photon experiment.[7] The agreement between the calculated and observed cross sections is good.[10]

The parameterization (3) determines independently the diffractive and OPE contributions to the ω cross sections at all energies. Thus, with some plausible assumptions about the two processes, the differential cross sections and the density matrix elements for reaction (1) can be calculated and compared with experiment. The observed differential cross section $d\sigma/dt$ for photon energies above 2.0 GeV is shown in Fig. 3(a) - 3(f). Since the diffractive part of the amplitude in the forward direction is pure imaginary and the OPE part is real we can write:

$$\frac{d\sigma}{dt} = \frac{d\sigma(\mathrm{OPE})}{dt} + \frac{d\sigma(\mathrm{DIFF})}{dt} \quad . \tag{4}$$

For the diffractive part of the cross section we write

$$\frac{d\sigma(\mathrm{DIFF})}{dt} = A\, e^{-B|t|}; \qquad \sigma(\mathrm{DIFF}) = \frac{A}{B} \tag{5}$$

If we take $B \simeq 7\ \mathrm{GeV}^{-2}$, which is our average value[4,5] for the ρ^o slope in $\gamma p \to \rho^o p$, and (DIFF) = C_{DIFF} = 1.5 ± 0.3 μb we get A = 10.5 ± 2.1 μb where the error does not include the experimental and theoretical uncertainty in B. This value is in close agreement with the value of A derived by Behrend et al.[11] from a study of ω production on complex nuclei. The OPE part of the cross section was calculated with final state absorption corrections.[12] We used a sharp cutoff model[13] with a radius of R = .8 fermi and $\Gamma(\omega\ \pi^o\gamma) = 1.2$ MeV.[6] The calculated curves are shown in Fig. 3 and are in good agreement with the observed cross sections.

Finally, the ω decay density matrix elements ρ^H_{00}, Re ρ^H_{10} and ρ^H_{1-1}, in the helicity frame, were calculated using the relation

$$\rho_{ij}(t) = \frac{\frac{d\sigma\,(\mathrm{OPE})}{dt}\,\rho^{\mathrm{OPE}}_{ij}(t) + \frac{d\sigma\,(\mathrm{DIFF})}{dt}\,\rho^{\mathrm{DIFF}}_{ij}(t)}{d\sigma/dt} \tag{6}$$

We assumed the diffractive part of the cross section to be helicity conserving[7] and thus giving $\rho^H_{00} = \mathrm{Re}\ \rho^H_{10} = \rho^H_{1-1} = 0$ in the helicity frame. The OPE density matrix was calculated with the sharp-cutoff model mentioned above. The final results of the calculations as well as our experimental results are shown in Fig. 4. Again we note fair agreement between theory and experiment.

In conclusion, the energy dependence of $\sigma(\gamma p \rightarrow \omega p)$ can be parameterized[12] by Eq. (3). This parameterization reproduces well the experimental total and differential cross sections and density matrix elements. The forward diffractive differential cross section derived with $\alpha_1 = 2$ and $\alpha_2 = 0$ is in good agreement with other recent results.[11] The total diffractive cross section is found to be $1.5 \pm 0.3\ \mu b$.

We wish to thank the SLAC bubble chamber operations crew and the Experimental Facilities Division personnel for help in obtaining the exposures, and the scanning teams of the three institutions for their excellent work. We thank Dr. Z.G.T. Guiragossián for much initial help.

REFERENCES

1. Cambridge Bubble Chamber Group, Phys. Rev. 155, 1468 (1967).
2. Aachen-Berlin-Bonn-Hamburg-Heidelberg-München Collaboration, Phys. Rev. 175, 1669 (1968).
3. J. Ballam *et al.*, Nucl. Instr. and Methods 73, 53 (1969).
4. Y. Eisenberg *et al.*, Phys. Rev. Letters 22, 669 (1969).
5. J. Ballam *et al.*, Phys. Letters 30B, 421 (1969).
6. Particle Data Group, Phys. Letters 33B, 1 (1970).
7. J. Ballam *et al.*, Report No. SLAC-PUB-729 and Phys. Rev. Letters 24, 1364 (1970).
8. M. Davier *et al.*, Phys. Letters 28B, 619 (1969).
9. D.R.O. Morrison, Phys. Letters 22, 528 (1966); A. Shapira *et al.*, Nucl. Phys. B23, 583 (1970).
10. The unnatural exchange cross section $\sigma^u = 2.7 \pm .4\ \mu b$ at 2.8 GeV plotted in Fig. 2(a) corresponds to events with $|t| < 1.0\ GeV^2$. As the cross section for events with $|t| > 1.0\ GeV^2$ at 2.8 GeV is $0.6\ \mu b$, σ^u should be increased and will move closer to the calculated curve.
11. H.-J. Behrend *et al.*, Phys. Rev. Letters 24, 1246 (1970).
12. For explicit OPE expressions see K. Schilling and F. Storim, Nucl. Phys. B7, 559 (1968).
13. B. Haber and G. Yekutieli, Phys. Rev. 160, 1410 (1967).

TABLE I

Number of observed events, corrected ω events, ω total cross sections and monochromatic total channel cross sections as a function of the incoming photon energy (E_γ).

E_γ(GeV)	Events[(a)] Observed	No. of ω^0 Events		$\sigma_T(\omega)$[(c)] (μb)	Total Channel Cross Sections (μb)
		Observed	Corrected		
1.2 - 1.5	742	220	235	6.9 ± 1.4	---
1.5 - 2.0	1239	180	194	6.7 ± 1.2	---
2.0 - 2.5	978	141	150	6.9 ± 1.5	---
2.5 - 3.0	512	66	75	6.2 ± 0.9	---
3.0 - 3.7	603	34	36[(b)]	2.8 ± 0.7	---
3.7 - 4.7	631	81	95[(b)]	2.9 ± 0.4	18.2 ± 2.0
4.7 - 5.8	430	52	57[(b)]	2.3 ± 0.4	13.5 ± 1.5
6.8 - 8.2	464	68	73[(b)]	2.0 ± 0.3	11.8 ± 1.2

(a) Unique 0C events for the bremsstrahlung data (1.2 - 3.7 GeV) and events surviving the missing mass ($-.18 < MM^2 < .10$ GeV^2) and probability ($P(\chi^2) \geq .005$) cuts for the 1C data (3.7 - 8.2 GeV).

(b) Including 10 - 13% forward scanning loss correction.

(c) Including ω neutral[6] decay modes (10% correction).

FIGURE CAPTIONS

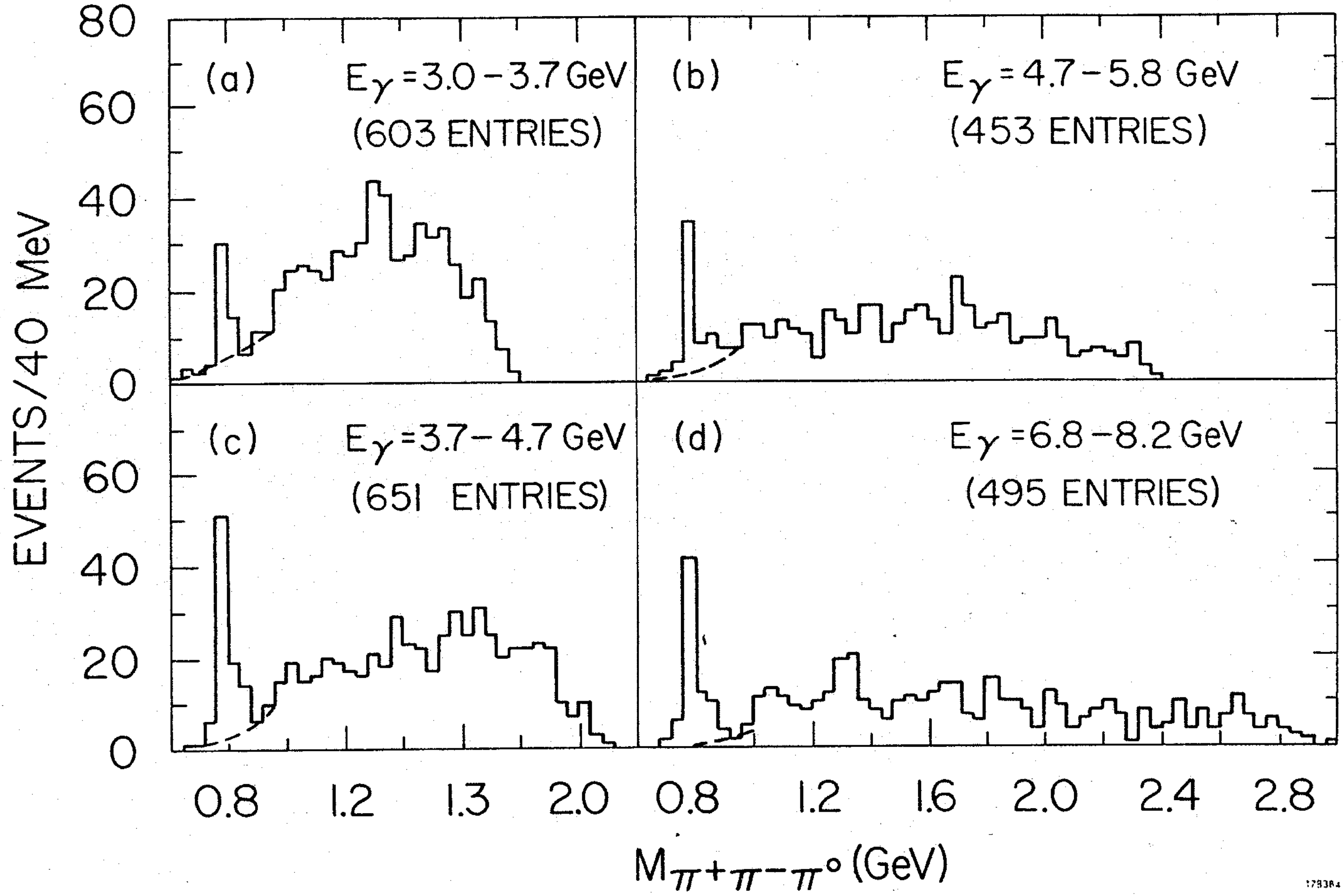
1. $\pi^+\pi^-\pi^o$ invariant-mass distributions for $\gamma p \rightarrow p\pi^+\pi^-\pi^o$ with photon energies in the range of 3.0 - 8.2 GeV. Dashed lines indicate the phase space background assumed.

2. (a) $\gamma p \rightarrow \omega p$ total cross sections (σ^T) for this experiment and for Ref. 7. The inverted triangles represent the unnatural parity exchange cross sections (σ^u) for events with $|t| < 1.$ GeV^2 at 2.8 and 4.7 GeV (Ref. 7). The solid curve is for σ^T and the dashed curve for σ^u calculated from Eq. (3) with $C_{OPE} = 31.0$, $C_{DIFF} = 1.5$.

   (b) A compilation of $\gamma p \rightarrow \omega p$ cross sections (Refs. 1, 2, 7, 8 and this experiment).

3. Differential cross section $d\sigma/dt$ for the reaction $\gamma p \rightarrow \omega p$ with photon energies above 2.0 GeV. The curves are the calculated cross sections (see text).

4. The spin density matrix elements $\rho^H_{0,0}$, Re $\rho^H_{1,0}$ and $\rho^H_{1,-1}$ in the helicity system for the reaction $\gamma p \rightarrow \omega p$. The curves are the calculated matrix elements (see text).



80
60
40
20
0
60
40
20
0
EVENTS/40 MeV
(a)
E_γ=3.0−3.7 GeV
(603 ENTRIES)
(b)
E_γ=4.7−5.8 GeV
(453 ENTRIES)
(c)
E_γ=3.7−4.7 GeV
(651 ENTRIES)
(d)
E_γ=6.8−8.2 GeV
(495 ENTRIES)
0.8
1.2
1.3
2.0
0.8
1.2
1.6
2.0
2.4
2.8
$M_{\pi^+\pi^-\pi^0}$ (GeV)

Fig. 1

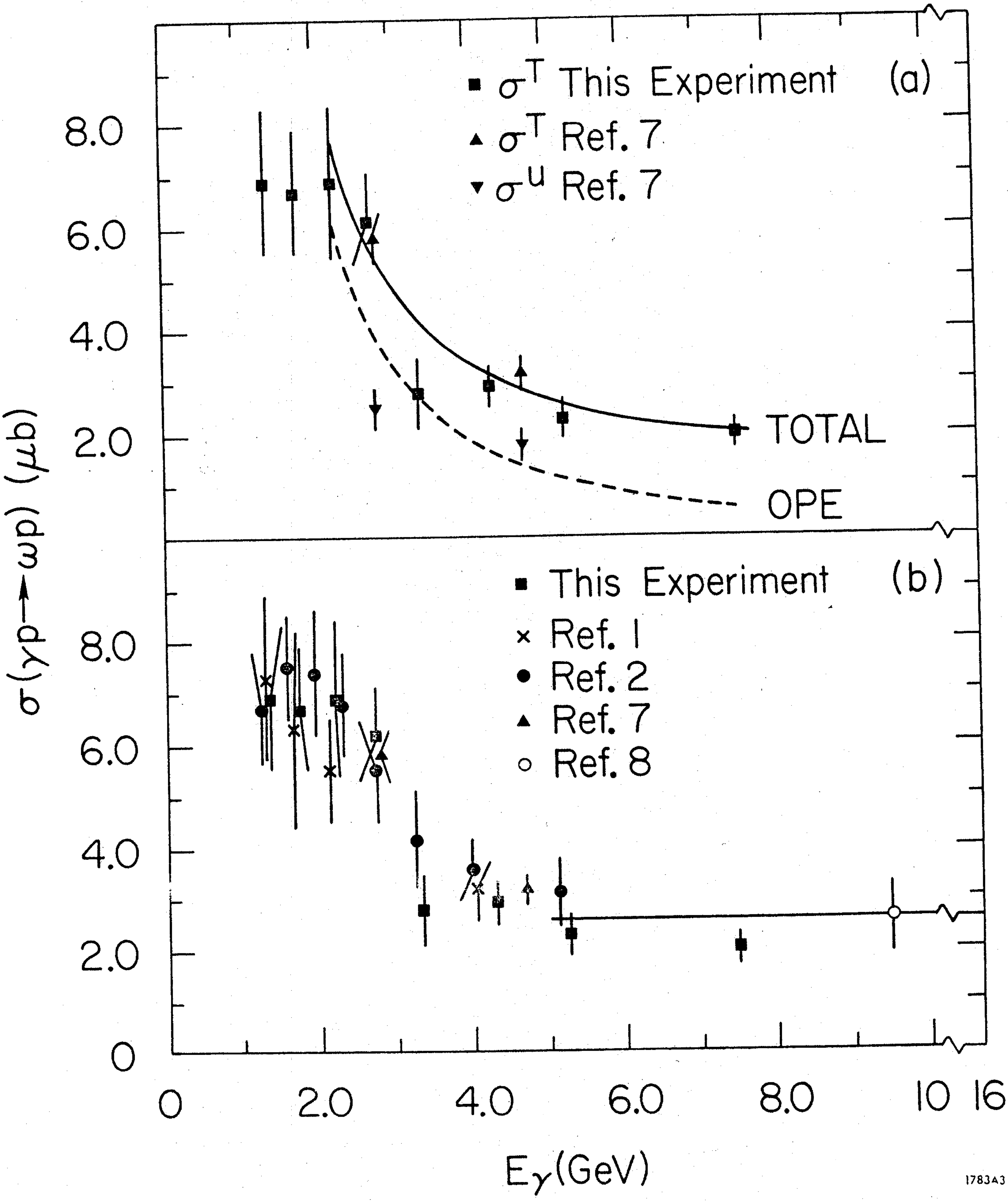
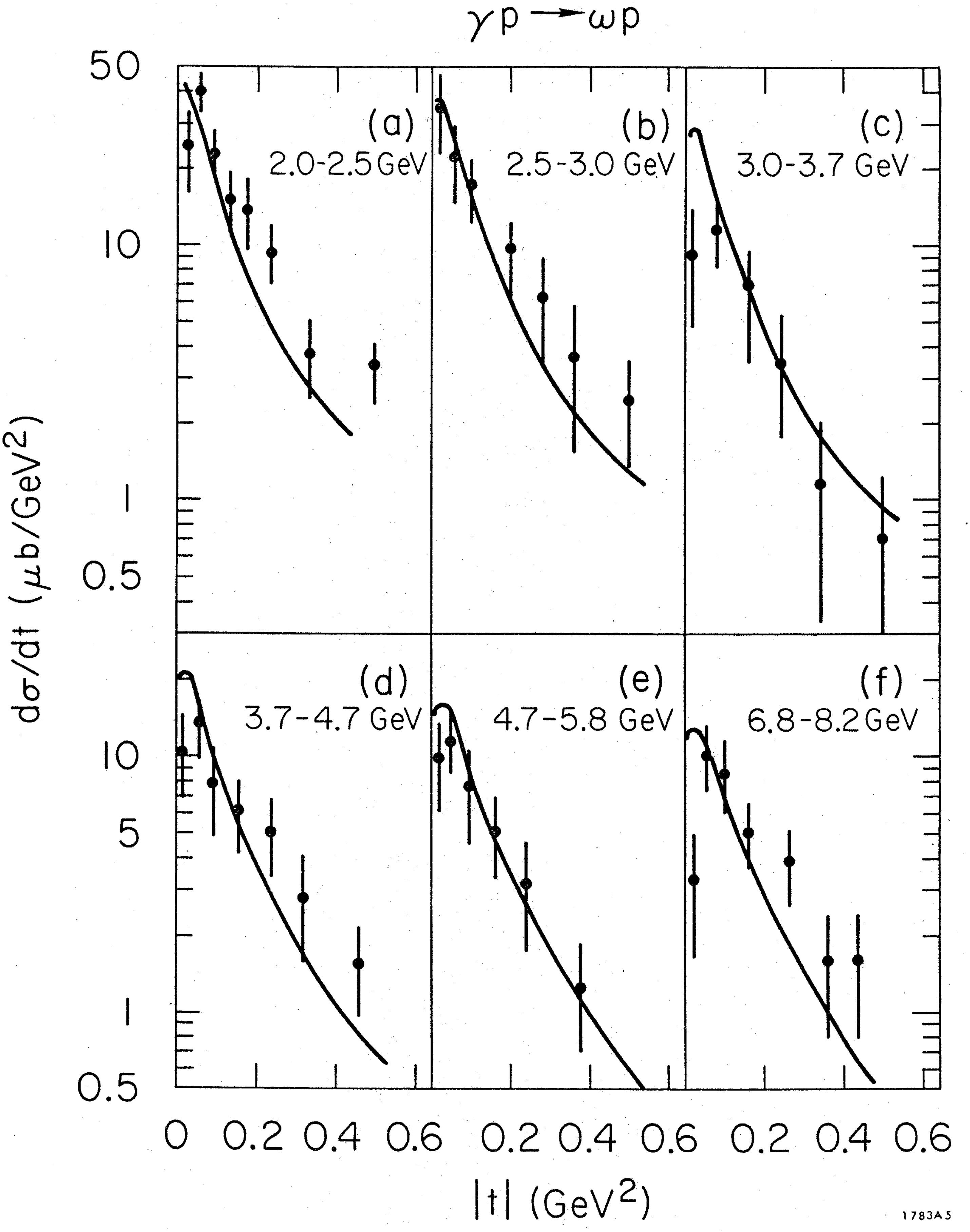
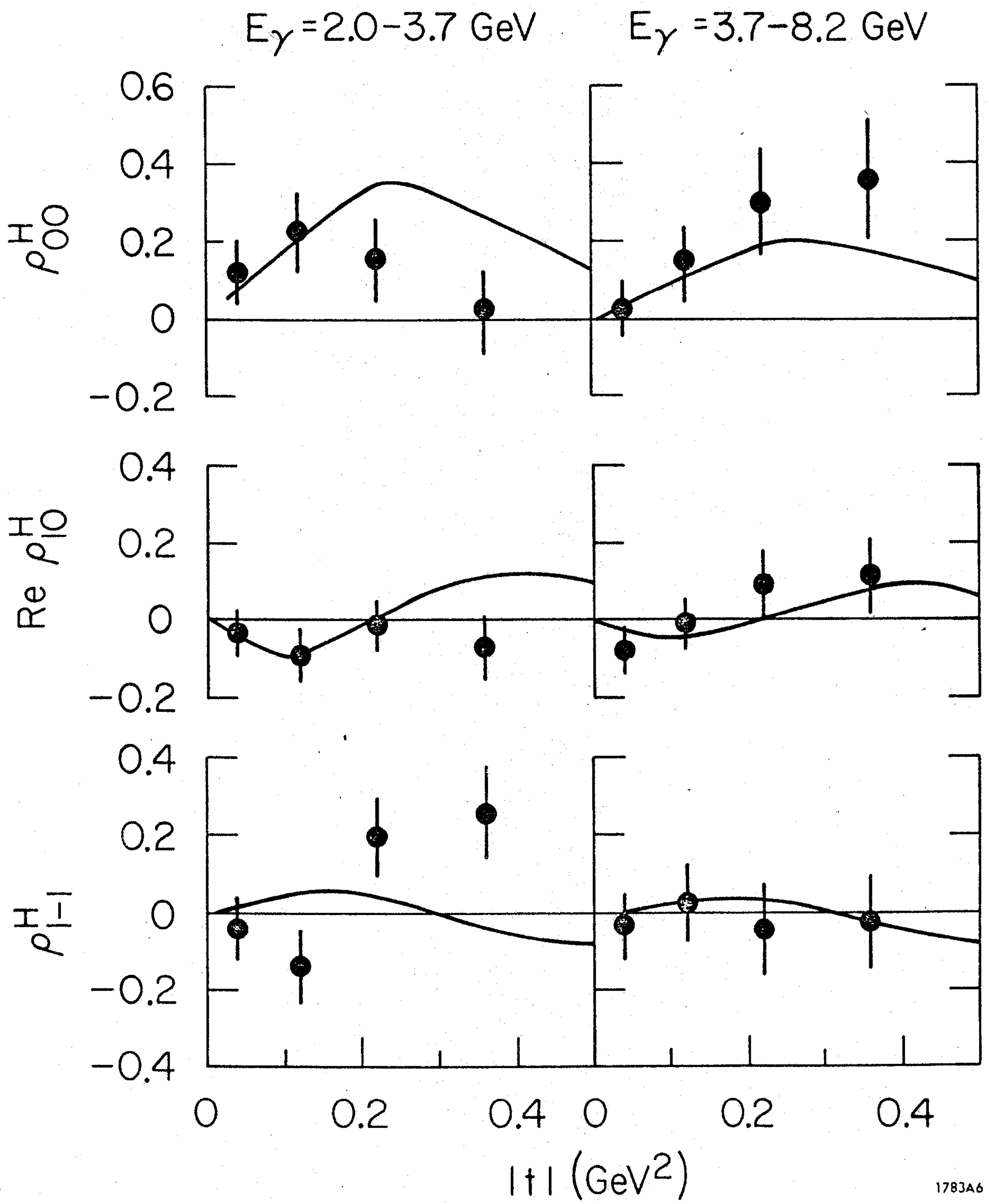

σ^T This Experiment
(a)
σ^T Ref. 7
σ^u Ref. 7
TOTAL
OPE
This Experiment
(b)
Ref. 1
Ref. 2
Ref. 7
Ref. 8
σ(γp→ωp) (μb)
8.0
6.0
4.0
2.0
0
0
2.0
4.0
6.0
8.0
10
16
Eγ(GeV)
1783A3

Fig. 2



$\gamma p \rightarrow \omega p$
50
10
1
0.5
5
$d\sigma/dt$ (μb/GeV^2)
(a)
2.0-2.5 GeV
(b)
2.5-3.0 GeV
(c)
3.0-3.7 GeV
(d)
3.7-4.7 GeV
(e)
4.7-5.8 GeV
(f)
6.8-8.2 GeV
0
0.2
0.4
0.6
$|t|$ (GeV^2)
1783A5

Fig. 3



Eγ = 2.0–3.7 GeV
Eγ = 3.7–8.2 GeV
ρ^H_{00}
Re ρ^H_{10}
ρ^H_{1-1}
0.6
0.4
0.2
0
−0.2
−0.4
0
0.2
0.4
|t| (GeV²)
1783A6

Fig. 4