22,232

CONF-720923--14

MEASUREMENT OF PHOTOPRODUCTION OF ω^0 AND ρ^0 MESONS IN HYDROGEN*

Gary E. Gladding,[†] John J. Russell,[‡]
Michael J. Tannenbaum,[§] Jeffrey M. Weiss,^{||}
and
Gordon B. Thomson[¶]

Harvard University, Cambridge, Massachusetts

Submitted to the XVI International
Conference on High Energy Physics

Chicago - September 6-13, 1972

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

* Work supported by the U.S. Atomic Energy Commission, Contract AT(30-1)-2752

† Present Address: University of Illinois, Champaign-Urbana, Ill. 61801

‡ Present Address: Southeastern Mass. Univ., No. Dartmouth, Mass. 02747

§ Present Address: The Rockefeller Univ., New York, N.Y. 10021
Alfred P. Sloan Foundation Fellow

|| Present Address: CERN, 1211 Geneva 23, Switzerland

¶ Present Address: Case Western Reserve Univ., Cleveland, Ohio 44106

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

The t distribution for photoproduction of ρ^0 and ω^0 mesons from hydrogen has been measured for incident energies between 2.0 and 4.7 GeV. A Söding interference model fits the ρ^0 data and gives t distributions in agreement with $\pi^\pm p$ elastic scattering and most previous ρ^0 experiments; but disagrees with that of the SLAC, LBL laser beam bubble chamber. The ρ^0 decay density matrix shows non-conservation of s-channel helicity for $t \geq 0.5 \text{ GeV}^2$.

In the course of a photoproduction missing mass experiment¹ we have studied the reactions $\gamma + p \rightarrow p + \rho^0$ and $\gamma + p \rightarrow p + \omega^0$ for incident photon energies from 2.0 to 4.7 GeV. In this energy range, the t dependence of both reactions has been measured only in limited statistics bubble chamber experiments.^{2,3} For the photon energy range 6 to 18 GeV, there exist measurements of t distributions in the ρ^0 region by a recoil proton detection method⁴ similar to ours. However, that experiment gave insufficient mass resolution to separate the ρ^0 and ω^0 contributions. Since the ω^0 contribution is small in that energy range, the experiment gives a measurement of the ρ^0 cross section. Several counter experiments⁵ have measured the mass spectrum of $\pi^+\pi^-$ pairs photoproduced in hydrogen at low t ; and a recent Cornell experiment⁶ has measured the t distribution of elastic ρ^0 production at 8.3 GeV.

Our experiment was done using a tagged photon beam ($\pm 1\frac{1}{2}\%$ accuracy of photon energy), a wire spark chamber magnetic spectrometer to detect recoil protons and a set of wire spark chambers around the photon beam to detect forward-going charged decay products from the produced boson states. (Figure 1) The tagged photon beam gave mass resolution good enough to separate the ω^0 and ρ^0 signals; and the decay chambers enabled us to measure the ρ^0 shape and the mass resolution at the ω^0 peak. In Fig. 2 (a-d) are shown data obtained using only the recoil proton information. Even at high t the ρ - ω peak is clearly defined; the number of events is about 10 times that in the corresponding bubble chamber experiments. The acceptance of the recoil spectrometer has been calculated analytically since a Monte Carlo acceptance of sufficient accuracy would require excessive computer time.

In order to separate ω^0 and ρ^0 production, we make use of the decay product information. In Fig. 3 are shown missing mass distributions of the events which had two decay tracks observed to come from the γp vertex. Fig. 3a contains those events which could be fit to the hypothesis $\gamma + p \rightarrow p + \pi^+ + \pi^-$. Fig. 3b shows the events satisfying neither this hypothesis nor $\gamma + p \rightarrow p + K^+ + K^-$, which means that they are ≥ 3 body decays. The peak due to

is evident; it provides the ω^0 effective width (55 MeV FWHM including resolution) used in our subsequent analysis. This observed width agrees well with our estimate for the missing mass resolution of our apparatus.

For the events satisfying the $\gamma p \rightarrow p \pi^+ \pi^-$ hypothesis, we had to add Monte Carlo techniques to our analytical calculation of the acceptance. We did this assuming all $\pi^+ \pi^-$ pairs are decay products of a vector meson described by the usual decay density matrix in the helicity system, i.e., θ^* is the angle between the decay direction and the recoil proton in the meson rest system: ⁷

$$W(\cos \theta^*) d\Omega^* = \frac{3}{2\pi} \left[\left(\frac{1-\rho_{00}}{2} \right) \sin^2 \theta^* + \rho_{00} \cos^2 \theta^* \right] d\Omega^*$$

Since the beam was unpolarized and our apparatus was roughly symmetric in azimuthal acceptance, we simply averaged over the decay particle azimuth. The cuts on θ^* ($0.0 \leq \cos \theta^* \leq 0.7$) were chosen so that the minimum acceptance was no less than 1/3 of the maximum. For a given θ^* , the acceptance did not vary by more than 20% for all t . (Figure 4)

We could then make a simultaneous fit to the recoil proton spectrum for all events, and for that subset satisfying the $p \pi^+ \pi^-$ hypothesis. This enables a clean separation of ρ and ω signals by strongly constraining the ρ shape. We have done

this assuming two different descriptions of the ρ mass distribution: 1) the once-fashionable Ross-Stodolsky modified Breit-Wigner,⁸ with the power of $(m_\rho/m)^n$ allowed to vary with t

$$\frac{d^2\sigma_{\pi\pi}}{dt dm} = 2m \frac{d\sigma_\rho}{dt} N(\Gamma, n) \frac{m_\rho \Gamma(m) \left\{ \frac{m_\rho}{m} \right\}^{n(t)}}{(m_\rho^2 - m^2)^2 + m_\rho^2 \Gamma^2(m)}$$

where N is a factor to normalize the modified resonance factor and

$$\Gamma(m) \equiv \Gamma_\rho \frac{m_\rho}{m} \left[\frac{(m/2)^2 - m_\pi^2}{(m_\rho/2)^2 - m_\pi^2} \right]^{3/2}$$

and 2) a Soding interference model⁹ allowing the coefficients of both interference and "Drell" terms as free parameters in each t bin:

$$\frac{d^2\sigma_{\pi\pi}}{dt dm} = \frac{2m \cdot \left\{ \frac{1}{\pi} \frac{d\sigma_\rho}{dt} m_\rho \Gamma(m) + C_2(t) (m_\rho^2 - m^2)^2 + C_1(t) \sqrt{\frac{1}{\pi} \frac{d\sigma_\rho}{dt} m_\rho \Gamma(m) (m_\rho^2 - m^2)} \right\}}{(m_\rho^2 - m^2)^2 + m_\rho^2 \Gamma^2(m)}$$

Finally, a smooth polynomial background was added.¹⁰

Fig. 5 shows the results of such simultaneous fits with the Soding model. They fit the data quite well. At low t the resonance parameters obtained are $m_\rho = 775 \pm 5$, $\Gamma_\rho = 147 \pm 11$, and

$m_\omega = 780 \pm 3$ MeV. In the Ross-Stodolsky fit we find the previously observed effect² that $n(t)$ drops from 5 at $t \sim 0.2$ to 1 at $t = 0.6$ and $t = 0.85$. (Figure 6) It is important to note that the cross sections obtained from the two models agree well within errors as seen in Table I. In addition, the m_ρ and Γ_ρ values obtained agree well with those obtained from colliding beam experiments¹¹ as well as with those from other production experiments.^{2,5,12} (Table II)

Also shown in Table I are the results for the helicity frame density matrix element ρ_{00} , found by studying the $p\pi\pi$ decay polar angular distributions. (Figure 7) The results for ρ_{00} are plotted in Fig. 8. They indicate clearly deviation from $\rho_{00} = 0.0$ for $t > 0.5$ GeV², i.e., failure of s-channel helicity conservation.²

Our results for ω^0 production are plotted in Fig. 9ab. In contrast with ρ^0 production, they are strongly energy dependent. (Figure 10) Previous results for ω^0 production in hydrogen have been obtained only in bubble chambers.^{2,3} These experiments have calculated and beautifully demonstrated with the polarized photon beam² that the characteristics of ω^0 production for $t < 0.4$ could be explained by a model mixing approximately equally OPE and diffractive production. Our results are consistent with this conclusion for $0.15 \leq t \leq 1.0$.

The history of ρ^0 photoproduction in hydrogen has been confused by the complicated function required to describe the

ρ^0 shape. (e.g. Fig. 5) An erroneous result from the Orsay storage ring¹³ certainly added to the confusion; but even apart from that, a single experiment, the SLAC/Berkeley-Tufts Laser Beam Bubble Chamber², produced inconsistent results from the two different methods of extracting the ρ^0 cross section from the raw data. Our method of fitting all the parameters individually for each t bin, as explained in footnote 10, has apparently paid off since we have arrived at a completely consistent set of values for m_ρ , Γ_ρ and $d\sigma_\rho/dt$. Our results for the rho differential cross section are shown in Figure 11, calculated from the Söding model. As pointed out previously, our results from the Ross-Stodolsky model are essentially identical. Figure 12a shows our results along with some previous results^{3,4,5,6}, not including SBT². Figure 12b shows our results in comparison to the SBT² Ross-Stodolsky parametrization fit. All these results look reasonably consistent. However, if we compare these same results to the SBT² Söding fit (Figure 13), they seem much less consistent. To put these comparisons of data on a more quantitative level, it is convenient to fit the data of individual experiments to a simple function and compare the results of the fits.

Anderson, et al,⁴ have shown that for energies from 6 to 18 GeV, the s and t dependence of ρ^0 photoproduction is strikingly similar to $\pi^\pm p$ elastic scattering. Using the quark model and vector dominance they could fit all the ρ^0 data by adjusting only one free parameter $\gamma_\rho^2/4\pi = 0.61$ ¹⁴.

$$\frac{d\sigma(s)}{dt} \gamma p \rightarrow \rho p = \frac{\alpha/4}{\gamma_\rho^2/4\pi} \left(\frac{1}{2} \sqrt{\frac{d\sigma(s)}{dt}(\pi^+ p)} + \frac{1}{2} \sqrt{\frac{d\sigma(s)}{dt}(\pi^- p)} \right)^2$$

Our data support this procedure at lower energies. The fits shown in Fig. 11 are for $\gamma_\rho^2/4\pi = 0.82 \pm 0.06$ at 2.9 - 3.7 GeV and $\gamma_\rho^2/4\pi = 0.78 \pm 0.06$ at 3.7 - 4.7 GeV corresponding to $d\sigma_\rho/dt|_{t=0} = 130 \pm 7 \text{ } \mu\text{b/GeV}^2$ at the lower energy and $110 \pm 6 \text{ } \mu\text{b/GeV}^2$ at the higher.

The same t variation is often characterized by fitting to an exponential. The data of Anderson, et al,⁴ clearly show that in the range $0.2 \leq t \leq 1.0$ the t dependence can not be fit by a simple exponential. A quadratic concave term is required. This is supported by Berger, et al,⁶ who find at 8.3 GeV that $d\sigma_\rho/dt = (112 \pm 6) \mu\text{b/GeV}^2 \exp [(-9.6 \pm 0.7)t + (4.0 \pm 1.5) t^2]$ for $0.08 \leq t \leq 0.51$. We find at 3.7 to 4.7 GeV that our data is fit by $d\sigma_\rho/dt = (149 \pm 51) \mu\text{b/GeV}^2 \exp [(-10.0 \pm 0.8) t + (3.5 \pm 0.6) t^2]$ for the range $0.15 \leq t \leq 1.0 \text{ GeV}^2$. Both these results are quite similar to the behavior of $\pi^\pm p$ elastic scattering in this energy range¹⁵ $d\sigma_{\pi p}/dt \sim \exp(-9.0 t + 2.5 t^2)$.

The SBT Ross-Stodolsky parametrization fit at 4.8 GeV is also in agreement with all these experiments. For the range $0.02 \leq t \leq 0.4 \text{ GeV}^2$ the data is fit by

$$d\sigma/dt = (128 \pm 12) \mu\text{b/GeV}^2 \exp[(-8.9 \pm 1.2) t + (4.4 \pm 2.9) t^2]$$

The Söding fit of SBT to the same data, however, gives a result which is in quantitative and qualitative disagreement with all of the above results. The linear term is quite different in magnitude and the quadratic term is convex:

$$d\sigma/dt = (91 \pm 10) \mu\text{b}/\text{GeV}^2 \exp[(-5.5 \pm 1.3) t + (-1.2 \pm 3.3) t^2].$$

This situation is distinctly different from our fits in which the Söding and Ross-Stodolsky parametrizations give essentially the same result. (Table I)

In conclusion, we find at 2.9 - 4.7 GeV, good agreement with a quark model fit to the energy and t dependence of ρ photoproduction, yielding in the vector dominance approximation $\gamma_\rho^2/4\pi = 0.80 \pm 0.04$, independent of energy. Our analysis of cross sections in the Söding model disagrees with that of the SBT bubble chamber but agrees well with that of the Cornell group at a higher energy. We find at $t > 0.5$ significant failure of s -channel helicity conservation in ρ photoproduction.

REFERENCES

1. G. Gladding, J. J. Russell, M. J. Tannenbaum, J. M. Weiss, G. B. Thomson submitted to this Conference.
2. S.L.A.C., Berkeley, Tufts Collaboration, Ballam et al, Phys. Rev. Letters 24, 955 (1970); 24, 960 (1970); 24, 1364 (1970); Phys. Rev. D5, 545 (1972).
3. ABBHBM German Bubble Chamber Collaboration, Phys. Rev. 175, 1669 (1968); 188, 2060 (1969); SLAC-WEITZMAN-Tel Aviv Collaboration reported in Proceedings of 1971 International Symposium on Electron and Photon Interactions at High Energies, Ithaca, N. Y. 1972.
4. R. Anderson, et al, Phys. Rev. D1, 27 (1970).
5. H. Alvensleben, et al, Phys. Rev. Letters 23, 1058 (1969); G. McClellan, et al, Phys. Rev. D4, 2683 (1971).
6. C. Berger, et al, Phys. Letters 39B, 659 (1972).
7. Note that we do not distinguish the charge of the pions so that the distribution is folded and θ^* covers the range from 0 to $\pi/2$.
8. M. Ross and L. Stodolsky, Phys. Rev. 149, 1172 (1966); J. D. Jackson, Nuovo Cimento 34, 1644 (1964).
9. P. Söding, Phys. Letters 19, 702 (1965); T. Bauer, Phys. Rev. Letters 25, 485 (1970); J. Pumplin, SLAC-Pub 730 (1970).

10. Note that we broke up our data into four t intervals for each of two energy intervals yielding 8 missing mass and 8 $p\pi\pi$ spectra. Each dual mass spectrum had 40 to 45 data points. We then fit 15 or 14 parameters independently to each of the 8 dual mass spectra. Thus, in a particular t, k interval the parameters determined were

$\frac{d\sigma_\rho}{dt}, \frac{d\sigma_\omega}{dt}, m_\rho, \Gamma_\rho, m_\omega, \Gamma_\omega, C_1, C_2$ (or n), decay chamber normalization, 3 recoil proton background parameters, 3 $p\pi\pi$ background parameters, and a partridge in a pear tree.

11. D. Benaksas, et al, Phys. Letters 39B, 289 (1972).
12. Particle Data Group, Rev. Mod. Phys. Supplement (April 1971).
13. J. E. Augustin, et al, Nuovo Cimento 2, 214 (1969).
14. Anderson, et al, Phys. Rev. D7, 1937 (1972) have recently measured $\gamma_\rho^2/4\pi = 0.68 \pm 0.03$ (± 0.15 systematic) in a quark model independent way by comparing ρ^0 photoproduction from H_2 and D_2 .
15. ABBHLM Collaboration, Phys. Letters 10, 248 (1964) and Nuovo Cimento 31, 729 (1964); R. Eisner, et al, Phys. Rev. 164, 1699 (1967).

FIGURE CAPTIONS

Figure 1 - a) Diagram of CEA tagging system.

b) Apparatus for ρ^0 and ω^0 production. The recoil proton is measured in the magnetic spectrometer. The decay products are measured in the spark chambers downstream of the H_2 target.

Figure 2 - Missing mass spectra obtained from the recoil proton spectrometer. The quantity plotted is the integral of $d^2\sigma/dt dm$ over a 20 MeV bin in missing mass and a particular t interval for incident photon energies between 2.9 and 4.7 GeV. The t intervals are as follows:

- a) $.15 \leq t \leq .30 \text{ GeV}^2$
- b) $.30 \leq t \leq .50 \text{ GeV}^2$
- c) $.50 \leq t \leq .70 \text{ GeV}^2$
- d) $.70 \leq t \leq 1.0 \text{ GeV}^2$

Figure 3 - Raw mass spectra of events with two forward decay tracks emerging from the same vertex as the proton.

a) Events fitting the kinematic hypothesis

$$\gamma + p \rightarrow p + \pi + \pi.$$

b) Events not satisfying hypotheses

$$\gamma + p \rightarrow p + \pi + \pi \quad \text{or} \quad \gamma + p \rightarrow p + K + K.$$

Figure 4 - Acceptance for $\rho^0 \rightarrow \pi^+ + \pi^-$ decays versus angle of the decay in the helicity system.

Figure 5 - Söding fits to the dual mass spectra for the four t intervals. The recoil proton only mass spectra are on the left and the $p\pi\pi$ mass spectra are on the right. The t intervals are the same as Figure 2. The legend is given on Figure 5a.

Figure 6 - Fitted value of Ross-Stodolsky variable $n(t)$.

Figure 7 - Rho decay angular distributions versus θ^* for the four t intervals. The fitted curve is calculated with the values of ρ_{00} given in Table I.

Figure 8 - Plot of our measured values of ρ_{00} from Table I. They agree nicely with SLAC BC² results for $t \leq 0.5$ and clearly show a deviation from $\rho_{00}=0$ at higher t .

Figure 9 - Differential cross sections for ω^0 photoproduction.
a) Photon energy range 2.9 to 3.7 GeV. b) Photon energy range 3.7 to 4.7 GeV. SLAC bubble chamber data² is shown for comparison and is in excellent agreement.

Figure 10 - Ratio of ω^0 to ρ^0 differential cross sections $d\sigma/dt$. The ω is a much larger effect at lower energies.

Figure 11 - Results of this experiment for the differential cross section for ρ^0 photoproduction, $d\sigma/dt$. The solid line is a quark model fit as explained in the text,

Figure 12 - Comparison of our Rho photoproduction differential cross sections with those of other experiments. (12a) compares our Söding fits with other Söding fits^{3,4,5,6}. (12b) compares our Söding fit with the SLAC BC Ross-Stodolsky fit² and other data^{3,4}. The data are in reasonable agreement.

Figure 13 - Comparison of our Rho photoproduction differential cross section with the SLAC BC Söding fit². The data appear to be in qualitative disagreement. Our data exhibits a concave curvature while the SLAC data appears to favor a convex curve. This is born out by the fits to the data as discussed in the text.

FIGURE 1a TAGGING SYSTEM

FIGURE 1b 60° (APRIL) LAY-OUT

FIGURE 2 (c)

$$\iint \frac{d^2\sigma}{dt dm} dt dm$$

$$.50 < |t| < .70$$

$$2.9 < k < 4.7$$

1854 EVENTS

$$\Delta m = .020$$

σ
 μb

.03

.06

400

.500

.600

.700

.800

.900

1.000

1.100

1.200

MISSING MASS (GEV)

Raw mass spectra of events with two forward decay tracks successfully reconstructed to the same vertex with the proton (a) events satisfying the kinematic hypothesis $\gamma + p \rightarrow p + \pi^+ \pi^-$ (b) events not satisfying either the $\gamma + p \rightarrow p + \pi^+ \pi^-$ or $\gamma + p \rightarrow p + K^+ K^-$ hypotheses.

FIGURE 3

FIGURE 4 MU ACCEPTANCE for Decay events.
 $.66 < m < .84$

FIGURE 5a SÖDING MODEL

-----Rho	—•—Omega
Interference	—x—Poly. Background
—•—Drell	——Total

FIGURE 5b SÖDING MODEL

FIGURE 52 SÖÖING MODEL

FIGURE 5.1 SÖDING MODEL

FIGURE 6.

FIGURE 7 RHC DECAY ANGULAR DISTRIBUTIONS

FIGURE 8

FIGURE 9a

FIGURE 9b

ω/ρ^0 RATIO

$2.9 < k < 3.7$

$3.7 < k < 4.7$

FIGURE 10

FIGURE 11

FRANK RA

FIGURE 12b

TABLE I
SÖDING vs ROSS-STODOLSKY Fits $2.9 < k < 4.7$ GeV

		.15-.30		.30-.50		.50-.70		.70-1.0	
		ρ	ω	ρ	ω	ρ	ω	ρ	ω
<u>Soding Fit</u>									
$\frac{d\sigma}{dt}$	$\mu\text{b/GeV}^2$	20.0 ± 1.7	$4.07 \pm .40$	$5.45 \pm .75$	$1.47 \pm .28$	$1.33 \pm .30$	$.42 \pm .16$	$.69 \pm .18$	$.145 \pm .078$
<u>Ross-Stodolsky Fit</u>									
$\frac{d\sigma}{dt}$	$\mu\text{b/GeV}^2$	21.9 ± 2.7	$3.27 \pm .47$	$5.45 \pm .80$	$1.28 \pm .30$	$1.25 \pm .26$	$.40 \pm .15$	$.743 \pm .18$	$.067 \pm .057$
<u>Density Matrix Element</u>									
ρ_{00}		0.0 ± 0.12		0.12 ± 0.12		0.40 ± 0.18		0.72 ± 0.26	

TABLE II Summary of Rho Masses and Widths

		SÖDING		ROSS - STODOLSKY	
		m_ρ GeV	Γ_ρ GeV	m_ρ GeV	Γ_ρ GeV
THIS EXPERIMENT		$.775 \pm .005$	$.147 \pm .011$	$.777 \pm .004$	$.132 \pm .012$
ORSAY II ¹¹		$.775 \pm .007^*$	$.150 \pm .023^*$		
SLAC BC ²	2.7 GeV	$.778 \pm .003$	$.146 \pm .010$	$.766 \pm .003$	$.145 \pm .006$
	4.8 GeV	$.767 \pm .003$	$.146 \pm .010$	$.762 \pm .003$	$.141 \pm .005$
McCLELLAN, etal ⁵		$.770 \pm .001$	$.153 \pm .002$	$.768 \pm .001$	$.143 \pm .002$
$\pi N \rightarrow \pi\pi N$ ¹²		$.775 \pm .003$	$.145 \pm .009$		
(Physical Region)		$.768 \pm .002$	$.132 \pm .013$		

*Gounaris-Sakurai Formula