SLAC-PUB-1364 LBL-2474 (E) December 1973

A SEARCH FOR B AND ρ' (1250) PRODUCTION

IN-THE REACTION $\gamma p \rightarrow p \pi^+ \pi^- + NEUTRALS AT 2.8, 4.7 AND 9.3 GeV^+$

J. Ballam, G. B. Chadwick, Y. Eisenberg,[†]
E. Kogan, [†] K.C. Moffeit, I.O. Skillicorn,^{††}
H. Spitzer,[‡] and G. Wolf[‡][‡]

Stanford Linear Accelerator Center Stanford University, Stanford, California 94305

and

H.H. Bingham, W.B. Fretter, W.J. Podolsky,**
M.S. Rabin,***A.H. Rosenfeld,
G. Smadja,**** and G.P. Yost

University of California and Lawrence Berkeley Laboratory Berkeley, California 94720

and

P. Seyboth

Max-Planck-Institut für Physik und Astrophysik München, Germany

(Submitted to Nucl. Phys. B)

†Present address: Weizmann Institute, Rehovoth, Israel.

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

^{††}Present address: University of Glasgow, Physics Department, Glasgow, Scotland.

[‡] Present address: University of Hamburg, Physics Department, Hamburg, Germany.

[‡] [‡]Present address: DESY, Hamburg, Germany.

^{**} Present address: University of Washington, Seattle, Washington.

^{***} Present address: University of Massachusetts, Amherst, Massachusetts.

^{****}Fellow of the Miller Institute of Basic Research in Science; Present address: DPHPE, CEN, Saclay, France.

ABSTRACT

We have studied the reaction $\gamma p \rightarrow p\pi^{+}\pi^{-}$ + neutrals in the LBL-SLAC 82" hydrogen bubble chamber exposed to a linearly polarized photon beam at 2.8, 4.7 and 9.3 GeV. We observe an enhancement at 1.24 GeV in the mesonic mass recoiling against the proton. The enhancement is produced peripherally with slopes of 5-7 GeV⁻² and cross sections of 1-3 µb. We show that $\omega \pi^{0}$ is likely to be the major decay mode and give upper limits for other decay modes. The enhancement can be either the $J^{P} = 1^{+}$ B meson, a yet unestablished $J^{P} = 1^{-}$ meson decaying via $\omega \pi^{0}$, or a diffractively produced Deck-type background. The observed decay correlations are compatible with an s-channel helicity conserving production process. Our data at higher masses are consistent with a $\rho \epsilon$ decay of the $\rho'(1600)$ and we obtain an upper limit of $4 \pm 1 \mu b$ for $\rho'(1600)$ production in the final state $p\pi^{+}\pi^{-}$ + neutrals at 9.3 GeV.

CONTENTS

. *v*

-

ţ

.

		Page
I.	Introduction	4
п.	Event Selection and Channel Cross Section	5
ш.	General Characteristics of the Reaction $\gamma p \rightarrow p \pi^+ \pi^-$	
	+ Neutrals	6
IV.	Study of the $M_{\pi^+\pi^-MM}$ Enhancement near 1.25 GeV	8
	A. Mass and Width	8
	B. Decay Modes	8
	C. Decay Distributions	11
	D. Cross Sections	13
	E. Comparison with other Experiments	17
	F. t Distributions	18
	G. Discussion and Conclusions	18
v.	Search for the $\pi^+\pi^-$ + Neutrals Decay Modes of the ρ' (1600)	21
	A. $\rho'(1600) \rightarrow \rho^{O} \epsilon \rightarrow \pi^{+} \pi^{-} \pi^{O} \pi^{O}$	21
	B. $\rho'(1600) \rightarrow \pi^+ \pi^- + \text{Neutrals}$	22
	C. Conclusions	23

-3-

i

I. INTRODUCTION

One of the most interesting aspects of γp interactions has been the diffractive production of vector mesons. Measurements of ρ , ω and ϕ photoproduction have revealed a dominant, roughly energy independent, part of the cross section which proceeds via natural parity exchange and conserves s-channel helicity¹. Recently a new vector meson state, the $\rho'(1600)$, has been found in the reaction $\gamma p \rightarrow p \rho' \rightarrow p \rho^0 \pi^+ \pi^-$ with production properties similar to those of ρ , ω and ϕ production².

All previous track chamber studies of vector meson photoproduction have been confined to final states with zero or one (undetected) neutral particle in the final state. In this paper we study the reaction $\gamma p \rightarrow p \pi^+ \pi^- + two$ or more neutrals and search for yet undetected meson states. In particular we try to isolate the channel $\gamma p \rightarrow p \omega \pi^0 \rightarrow p \pi^+ \pi^- \pi^0 \pi^0$. This channel is of interest because the quantum numbers I^{GC} of an $\omega \pi^0$ -system are uniquely 1^{+-} . Hence the $\omega \pi^0$ -system has the same C parity as the photon and can be photoproduced diffractively.

The data presented below originate from a systematic study of γp reactions at 2.8, 4.7 and 9.3 GeV, using the LBL-SLAC 82-in. HBC exposed to the SLAC monochromatic backscattered laser beam. We have obtained 92, 150 and 275 events /µb at the three energies. The photon beam had a linear polarization P_{γ} of 94, 92 and 77% at 2.8, 4.7 and 9.3 GeV, respectively, and a momentum spread of $\Delta p/p \approx \pm 3\%$. Here we study the mesonic system recoiling against the outgoing proton. We find a peripherally produced enhancement near $M_{\pi}+\pi^{-}_{MM} = 1240$ MeV, which decays predominantly into $\omega\pi$. Its

-4-

production cross section is roughly energy independent. The enhancement can be identified with the $J^P = 1^+$ B meson, but our studies of the decay correlations show that an $J^P = 1^-$ assignment is equally possible. In addition, the enhancement could be due to a nonresonant Deck-type process. Finally, we study the $\pi^+\pi^-$ + neutrals decay of the $\rho'(1600)$.

II. EVENT SELECTION AND CHANNEL CROSS SECTION

The experimental setup and event analysis have been described in Refs. 1,3,4 and 5. Preliminary results at 2.8 and 4.7 GeV have been reported in Ref. 5. From our 3-prong events we selected a sample that had track ionizations consistent with the hypothesis

$$\gamma p \rightarrow p \pi^+ \pi^- + neutral(s)$$
 (1)

and which did not fit the 3-constraint reactions $\gamma p \rightarrow p\pi^+\pi^-$, $\gamma p \rightarrow pK^+K^-$ or $\gamma p \rightarrow pp\bar{p}$. The mass squared, MM^2 , of the neutral system was calculated assuming E_{γ} to be the mean beam energy of the particular exposure. The distribution of MM^2 (see Fig. 16 of Ref. 1) shows a clear peak at $MM^2 = M_{\pi^0}^2$ due to reaction

$$\gamma p \rightarrow p \pi^{\dagger} \pi^{-} \pi^{0}$$
 (2)

In order to select events from reaction

$$\gamma p \rightarrow p \pi^{\dagger} \pi^{-} + neutrals$$
 (3)

we eliminate events from reaction (2) by requiring $MM^2 > 0.1 \text{ GeV}^2$. By this cut

about 93% of the events from reaction (3) are retained, as determined from Monte Carlo calculations. The contamination of the sample by events from reaction (2) is about 1 μ b at 2.8 and 4.7 GeV and 1.5 μ b at 9.3 GeV. In addition, the part of the sample having proton momenta above 1.4 GeV/c is contaminated by events from the reaction

$$\gamma p \rightarrow n \pi^+ \pi^+ \pi^- (+ neutrals)$$
 . (4)

The channel cross section for reaction (3) is $14.0 \pm 2.0 \,\mu$ b and $20.8 \pm 3.9 \,\mu$ b at 2.8 and 4.7 GeV, respectively³. At 9.3 GeV the contamination by reaction (4) precludes a determination of the total channel cross section. In our subsequent studies we concentrate on the unique part of the sample with low proton momenta, i.e., $|t| < 1 \,\text{GeV}^2$, which is free of any contamination by reaction (4) ($t \equiv t_{p/p}$ is the four momentum transfer squared from the target to the outgoing proton). The cross section for channel (3) with $|t| < 1 \,\text{GeV}^2$ is 13 μ b at 9.3 GeV.

III. GENERAL CHARACTERISTICS OF THE REACTION $\gamma p \rightarrow p \pi^+ \pi^- + \text{NEUTRALS}$

Figures 1-6 show the $p\pi^+$, $p\pi^-$, pMM, $\pi^+\pi^-$, π^+MM and π^-MM mass distributions of reaction (3) at 2.8, 4.7 and 9.3 GeV. All distributions have $|t_{p/p}| < 1 \text{ GeV}^2$. From Figs. 1, 2 and 4 one observes $\Delta^{++}(1236)$ and ρ^0 production and weak indications of $\Delta^0(1236)$ production. The cross section for Δ^{++} production (all cross sections are for $|t_{p/p}| < 1 \text{ GeV}^2$) is about 3 µb at 2.8 and 4.7 GeV and 2 µb at 9.3 GeV. The shaded part of Fig. 1 has an additional cut

-6-

 $|t_{p/\Delta}^{++}| < 1 \text{ GeV}^2$. The cross sections for Δ^0 production are about 1/3 of those for Δ^{++} production. The ρ^0 production cross section at 4.7 and 9.3 GeV is about 1 µb for $|t| < 1 \text{ GeV}^2$.

The shaded part of Fig. 3 has additional cuts $0.6 < M_{\pi^+\pi^-} < 0.9$ GeV and $|t_{\gamma/\pi^+\pi^-}| < 0.5$ GeV², i.e., we have selected on peripherally produced ρ^{0} 's. From the shaded distribution at 9.3 GeV we infer an upper limit of 1 µb for the cross section of all inelastic diffractive processes of the type $\gamma p \rightarrow \rho^{0} + p +$ neutrals for $|t_{\gamma/\pi^+\pi^-}| < 0.5$ GeV².

Figure 6 shows an enhancement at 1300 MeV for $E_{\gamma} = 9.3$ GeV. The signal to background ratio is improved by a Δ^{++} cut $M_{p \pi^{+}} < 1.4$ GeV (shaded part). We ascribe this enhancement to the reaction $\gamma p \rightarrow \Delta^{++} A_2^-$ ($A_2^- \rightarrow \rho^- \pi^0 \rightarrow \pi^- \pi^0 \pi^0$ or $A_2^- \rightarrow \pi^- \eta^0 \rightarrow \pi^- +$ neutrals). The double resonance character is more clearly visible on a scatter plot $M_{p\pi^+}$ vs M_{π^-MM} (not shown); from this we determine a cross section of $0.3 \pm 0.08 \,\mu$ b. A comparable signal ($0.28 \pm 0.08 \,\mu$ b) due to the mode $A_2^- \rightarrow \rho^0 \pi^- \rightarrow \pi^+ \pi^- \pi^-$ is observed² in the reaction $\gamma p \rightarrow \Delta^{++} \pi^+ \pi^- \pi^-$. After adding the signals and correcting by a factor 1/0.841 for the undetected A_2 decay modes we obtain $\sigma(\gamma p \rightarrow \Delta^{++} A_2^-) = 0.7 \pm 0.15 \,\mu$ b at 9.3 GeV.

Figure 7(a)-(c) shows the distribution of the mesonic mass $M_{\pi}^{+}\pi^{-}MM$ recoiling against the proton in reaction (3) for three intervals of |t|. The mesonic system is produced peripherally with a t distribution having slopes of 5-6 GeV⁻² (not shown). Phase space weighted by e^{5t} peaks near the high mass edge of the $M_{\pi^{+}\pi^{-}MM}$ distribution. The reflection of Δ^{++} production also peaks at high masses. In contrast the mass spectra of Fig. 7(a) are enhanced at ~ 1.25 GeV. The enhancement is not present for $|t| > 0.5 \text{ GeV}^2$ (Fig. 7(b), (c)). Our mass resolution near 1.25 GeV is ±20 MeV, ±25 MeV and ±30 MeV at

-7-

the three energies. In the following we discuss the properties of the enhancement near.1.25 GeV in more detail.

IV. STUDY OF THE $M_{\pi^+\pi^-MM}$ ENHANCEMENT NEAR 1.25 GeV

A. Mass and Width

The shaded parts of Fig. 7(a) show events with $0.32 < M_{\pi^+\pi}^- < 0.6$ GeV. The signal near 1.25 GeV is almost unchanged, whereas the higher mass background is reduced. The peak is centered at 1220-1260 MeV and has a width of 130-300 MeV at 4.7 and 9.3 GeV (resolution unfolded). The determination of the width depends on the shape and size of the background chosen (see Section D below). (The width of the enhancement in the 2.8 GeV data is less well defined, because of the limited statistics and phase space limits cutting into the high mass tail of the enhancement.)

B. Decay Modes

Presently there are four established nonstrange meson resonances with masses between 1.2 and 1.3 GeV, the f, B, D and A_2 mesons. We easily can exclude f⁰ production because the dominant decay mode f⁰ $\rightarrow \pi^+\pi^-$ is not observed in reaction $\gamma p \rightarrow p\pi^+\pi^-$ (Figs. 2-4 of Ref. 1). The D meson is too narrow to be compatible with the enhancement in Fig. 7(a). The A_2 could be present in reaction (3) in its $A_2 \rightarrow \eta \pi^0$ decay mode. However, if the enhancement of Fig. 7(a) were due to $A_2 \rightarrow \eta \pi^0$, one would expect a 15 µb signal of $A_2 \rightarrow \pi^+\pi^-\pi^0$ in reaction $\gamma p \rightarrow p\pi^+\pi^-\pi^0$, which is not found (see Fig. 16 of Ref. 1). The B meson decays predominantly into $\omega \pi$. We have selected on ω 's produced in reaction (3) by the cut $0.32 < M_{\pi^+\pi^-} < 0.6$ GeV, which contains 93% of all $\omega \rightarrow \pi^+\pi^-\pi^0$ decays. The shaded portion of Fig. 7(a) demonstrates that the enhancement near 1.25 GeV is compatible with being completely due to a $\omega + m\pi^0$ (m \geq 1) decay mode. Hence it is compatible with being the B. For easier notation we refer to the enhancement by "B".

For the moment we leave the final identification open and discuss the following alternative decay modes of the "B".

(a) "B" $\rightarrow \rho^{0} + m\pi^{0} (m \ge 2)$

(b) "B"
$$\rightarrow \eta + m\pi^{0} \ (m \ge 1)$$

- (c) "B" $\rightarrow \pi^+\pi^- + m\pi^0 \ (m \ge 2)$ (decay into nonresonant π 's)
- (d) "B" $\rightarrow \rho^{\pm} \pi^{\mp} + m \pi^{0} \ (m \ge 1)$
- (e) "B" $\rightarrow \rho^+ \rho^-$, and "B" $\rightarrow \rho^\pm \pi^- \pi^0$.

We neglect "B" $\rightarrow \rho^+ \rho^-$ + neutrals because of limited phase space. By selecting events with 0.6 < $M_{\pi^+\pi^-} < 0.9$ GeV the "B" signal disappears almost completely. Hence we can exclude significant contributions of mode (a) "B" $\rightarrow \rho^0 + m\pi^0$ (m ≥ 2). By selecting on 0.41 < $M_{\pi^+\pi^-} < 0.6$ GeV, we find little reduction in "B" signal. This excludes dominant contributions from mode (b) "B" $\rightarrow \eta + m\pi^0$ (m ≥ 1), which would yield $\pi^+\pi^-$ pairs with $M_{\pi^+\pi^-} < 0.41$ GeV. If modes (c) or (d) were dominant one would expect a "B" signal in the related modes

(f) $"B" \rightarrow \pi^{+}\pi^{-}\pi^{+}\pi^{-} + m\pi^{0} \ (m \ge 0)$ (g) $"B" \rightarrow \rho^{0}\pi^{+}\pi^{-} \text{ and } "B" \rightarrow \rho^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$.

Figures 8(b) and (c) show the 4π and 5π mass distributions of reaction $\gamma p \rightarrow p 2\pi^+ 2\pi^-$ and $\gamma p \rightarrow p 2\pi^+ 2\pi^- \pi^0$, respectively, together with the $M_{\pi^+\pi^-MM}$

-9-

distribution of reaction (3) (Fig. 8(a)). There are few events at masses < 1.24 GeV in Fig. 8(b), (c). The relatively fast rise near $M_{\pi^+\pi^+\pi^-\pi^-} \approx 1.3$ GeV is due to $\rho'(1600)$ production². Also the $\geq 6\pi$ mass distribution (i.e., $M_{2\pi^+2\pi^-m\pi^0}$) of reaction $\gamma p \rightarrow p2\pi^+2\pi^- + m\pi^0$ (m ≥ 2) (not shown) has no signal in the "B" region. Hence there is no indication of the "B" decay modes (f) and (g). By isospin arguments we then do not expect major contributions from decay modes (c) and (d).* The same arguments do not apply for an isospin-1 "B" $\rightarrow \rho^+ \rho^-$ decay, because an isospin-1 "B" cannot decay via $\rho^0 \rho^0$. However a $\rho^+ \rho^-$ decay is unlikely on the grounds of the observed $M_{\pi^+\pi^-}$ dependence of the "B" peak.**

*If the enhancement has I=0 and conserves isospin in its decay, then the $2\pi^+2\pi^-$ decay mode must be at least half as large as the $\pi^+\pi^-2\pi^0$ mode⁵ and the $2\pi^+2\pi^-\pi^0$ mode must be at least twice as large as the $\pi^+\pi^-3\pi^0$ mode. If I=1, such general limits cannot be set, but we can consider specific decay modes: If "B" \rightarrow xy, where x is any I=1 dipion state and y is an I=0 (I=2) dipion state, we expect twice for I=0 (2/13, for I=2) as many decays into $2\pi^+2\pi^-$ as into $\pi^+\pi^-2\pi^0$. Also, "B" $\rightarrow A_1^+\pi^+$ gives equal rates for $2\pi^+2\pi^-$ and $\pi^+\pi^-2\pi^0$. Since we see no indication of "B" decay modes (f) and (g), these arguments suggest that there are no major contributions from modes (c) and (d).

**The fraction of "B" $\rightarrow \rho^+ \rho^-$ events having $M_{\pi^+\pi^-} > 0.6$ GeV has been estimated by Monte Carlo calculations to be 20-30%; this estimate depends on the assumed J^P (we considered 1⁺ and 1⁻). In contrast only 5% of the $\pi^+\pi^-$ pairs from a $B \rightarrow \omega \pi^0$ decay have $M_{\pi^+\pi^-} > 0.6$ GeV. In order to experimentally determine the $\rho^+\rho^-$ decay mode of the "B" we consider all events with $M_{\pi^+\pi^-} < 1.24$ GeV, since in this region nondiffractive backgrounds are expected to be small at 9.3 GeV (see Section D below). We have 23 events with $M_{\pi^+\pi^-} > 0.6$ GeV from a total of 266 events (i.e., $8.6 \pm 2\%$). Hence the data are consistent with predominant $\omega \pi$ decay. However we cannot exclude 55% $\omega \pi$ and 45% $\rho^+\rho^-$ (90% C.L.).

- 10 -

Finally, the upper limit for "B" $\rightarrow \omega \pi^+ \pi^-$ is 0.05 µb at 9.3 GeV. From isospin arguments "B" $\rightarrow \omega \pi^0 \pi^0$ is then expected to be small compared to the peak in Fig. 7(a). Neglecting "B" $\rightarrow \omega m \pi^0$ (m \geq 3) leaves us with "B" $\rightarrow \omega \pi^0$ as the only major decay mode.

We have established upper limits (at 90% confidence level) for various decay modes normalized to the observed decay rate via "B" $\rightarrow \pi^+\pi^-$ + neutrals, as determined in the following section. The estimates are given in Table I. The estimates for decay modes (c) and (d) depend on explicit models for the spin and isospin structure of the "B" system and the decay particles. Hence no numbers are given.

In conclusion, from the $M_{\pi^+\pi^-}$ dependence of the enhancement at $M_{\pi^+\pi^-MM} \sim 1.24 \text{ GeV}$ and from the study of other channels we find $\omega \pi^0$ to be the major decay mode.

C. Decay Distributions

Next we study the decay distributions of the "B" enhancement. Note that if the "B" has $J^P = 1^+$ or 1^- it may be produced by a helicity conserving diffractive process. The case of $J^P = 1^-$ is analogous to ρ or $\rho'(1600)$ production. A B meson with the quantum numbers $J^{PC} = 1^{+-}$ can be produced by exchanging the quantum numbers of the Pomeron plus one unit of angular momentum⁶.

A complete analysis of the "B" decay is impossible in our experiment because the two π^{0} 's were not detected. However, we can attempt to find a correlation between the initial polarization and direction of the photon and the final momentum vectors of the charged pions. We use the following three analyzers to calculate angles in the helicity frame*:

^{*} We analyze the "B" decay in the helicity frame, where the z axis is the direction of the "B" in the overall (γp) c.m.s. The y axis is the normal

- (a) the sum of the π^+ and π^- momenta in the "B" rest frame,
- (b) the direction of the π^+ in the $\pi^+\pi^-$ rest system,
 - (c) the normal $\pi^+ \times \pi^-$ of the π^+ and π^- directions as calculated in the "B" rest frame.

Figure 9(a) shows the distribution of $\cos \theta$ and ψ

for events in the "B" region using analyzer (a). If the "B" decays into $\omega \pi^{0}$ this analyzer gives the best estimate of the $\omega \pi^{0}$ decay angular distribution in the "B" rest frame. The presence of a forward-backward asymmetry in the cos θ distribution of Fig. 9(a) therefore indicates either that the $\omega \pi^{0}$ system is not in a pure spin state or that there is a significant contribution from background processes.

Figure 9(b) and (c) shows distributions of the angles θ and ψ for events in the "B" region at 4.7 and 9.3 GeV using the analyzers (b) and (c). We find

to the production plane, defined by the cross product $\hat{k} \times \hat{v}$ of the direction of the photon and the "B". The x axis is given by $\hat{x} = \hat{y} \times \hat{z}$. The angle between the polarization of the photon, $\hat{\epsilon}$, and the production plane in the overall c.m. system is defined by $\cos \phi = \hat{\epsilon} \cdot (\hat{y} \times \hat{k})$, $\sin \phi = \hat{y} \cdot \hat{\epsilon}$. The decay angles θ , ϕ are the polar and azimuthal angles of the appropriate analyzer \hat{n} :

- (a) \hat{n} is the sum of the π^+ and π^- momenta in the "B" rest frame.
- (b) \hat{n} is the direction of the π^+ in the $\pi^+\pi^-$ rest system.
- (c) $\hat{n} = \pi^+ \times \pi^-$, the normal to the plane of the π^+ and π^- directions as calculated in the "B" rest frame. Transformations to the "B" rest frame were performed using the nominal photon energy of each particular exposure. (The finite width of the photon spectrum has a negligible broadening effect on the angles, i.e., $\Delta(\cos \theta) = 0.025$ and $\Delta \psi = 3^0$ (fwhh).)

Then

$$\cos \theta = \hat{\mathbf{n}} \cdot \hat{\mathbf{z}}, \quad \cos \phi = \hat{\mathbf{y}} \cdot (\hat{\mathbf{z}} \times \hat{\mathbf{n}}) / |\hat{\mathbf{z}} \times \hat{\mathbf{n}}|,$$

$$\sin \phi = -\hat{\mathbf{x}} \cdot (\hat{\mathbf{z}} \times \hat{\mathbf{n}}) / |\hat{\mathbf{z}} \times \hat{\mathbf{n}}|, \text{ and } \psi = \phi - \boldsymbol{\phi}.$$

no structure in the $\cos \theta$ distribution. The ψ distributions of Fig. 9(b) at 4.7 and 9.3 GeV show weak indications of a $\cos^2 \psi$ signal. Note that background has not been subtracted. Figure 9(b) and (c) also gives the amount of the $\sin^2 \theta \cos^2 \psi$ component in the angular distribution as determined from

$$\Pi = \frac{1}{P_{\gamma}} \sqrt{\frac{40\pi}{3}} \sum_{Re} Y_2^2(\theta, \psi)$$

If measures the number of s-channel helicity conserving $\omega \pi$ events if the analyzer is perfect. One observes a signal of about 80 ± 25 events in the "B" region at each energy using analyzers (b) or (c).

For comparison we have generated by a Monte Carlo method helicity conserving "B" events with $J^{P} = 1^{\pm}$ and a decay via $\omega \pi^{0}$ or $\rho^{+}\rho^{-}$. Table II gives the calculated efficiencies for detecting signals in the distributions of θ , ψ and II if the analyzers (b) and (c) are used. The predicted efficiency of II for an $\omega \pi$ decay is 0.3 for $J^{P} = 1^{-}$ and 0.5 for $J^{P} = 1^{+}$ using analyzer (b). After correcting for these efficiencies the number of helicity conserving "B" events is 270 \pm 90 for 1⁻ and 160 \pm 50 for 1⁺ at each energy. Within errors these numbers are compatible with the number of "B" events determined below (Section D, method (a)).

A further examination of Figure 9(b) and (c) and Table II shows that the decay correlations observed in the present experiment are not sufficient to distinguish between a $J^P = 1^+$ or 1^- assignment for the "B".

D. Cross Sections

In order to determine the "B" production cross section the background must be known. As mentioned above, peripheral phase space and the reflection

-13-

from $\gamma p \rightarrow \Delta^{++} \pi^- \pi^0 \pi^0$ peak at high masses; also a contribution from $\gamma p \rightarrow p \rho'(1600) \rightarrow p \pi^+ \pi^- \pi^0 \pi^0$ would not yield any substantial contribution below $M_{\pi^+\pi^-MM} = 1.3 \text{ GeV}$. There are, however, two sources of background which could be present at low $M_{\pi^+\pi^-MM}$. (1) Nondiffractive $\gamma p \rightarrow p \omega \pi^0$. The reaction $\gamma n \rightarrow p \omega \pi^-$ has been observed at 4.3 GeV with a cross section of $1.4 \pm 0.5 \,\mu$ b and a rather flat $\omega \pi^-$ mass distribution^{7,8}. A similar contribution is expected in the nondiffractive part of reaction $\gamma p \rightarrow p \omega \pi^0$ but is likely to die out with increasing energy. (2) Diffractive $\gamma p \rightarrow p \omega \pi^0$. Here backgrounds can contribute to $\gamma p \rightarrow p \omega \pi^0$ according to the diagrams shown in Fig. 10.

The Drell-Deck disgrams (a) and (b) of Fig. 10 result in a predominantly $J^{P} = 1^{+} \omega \pi$ state, whereas diagram (c) would be expected to give a $J^{P} = 1^{-} \omega \pi$ state, if the $\omega \pi$ -system results from the tail of the ρ^{0} . We have calculated the contribution of diagram (a) from the OPE model of G. Wolf⁹. The predicted cross section decreases from 3 to $2 \mu b$, when going from 2 to 9.3 GeV. The predicted $\omega \pi^{0}$ mass distribution has a maximum at ~ 1.2 GeV and then falls off rather slowly up to the phase space limit. In contrast a Reggeized Deck calculation¹⁰ of diagram (a) would yield a much narrower mass distribution peaking at 1.2 GeV and having a full width at half height of 350 MeV at 9.3 GeV. The cross section is about the same as that from the un-Reggeized OPE calculation. The background from diagram (c) is probably small in the B region¹¹. So the backgrounds from diagrams (a) and (b) are used in the following. The cross sections were determined using two methods, firstly keeping the "B" width fixed at 150 MeV (method (a)), and secondly leaving it variable (method (b)).

In method (a) our object is to test if the enhancement is compatible with being the B(1235). The cross sections were determined from the shaded part of Fig. 7(a) by superimposing an s-wave Breit-Wigner distribution, with

-14-

resolution folded in, upon a hand drawn background curve. We used a fixed natural width of 150 MeV. (The use of a width of 100 MeV reduces the resulting cross sections only by 5-10%.) The background curves were chosen to resemble the mesonic mass distributions of the following reactions:

(a) peripheralized $\gamma p \rightarrow p \pi^+ \pi^- \pi^0 \pi^0$, generated with e^{6t} by a Monte Carlo program; (b) a mixture of the experimental distributions of reactions $\gamma p \rightarrow p 2 \pi^+ 2 \pi^-$ and $\gamma p \rightarrow p 2 \pi^+ 2 \pi^- \pi^0$ (Fig. 8(b), (c)); (c) contributions which extend to low masses like

$$\gamma p \rightarrow p \omega \pi^0$$

according to the OPE calculation by Wolf. The curves chosen are shown in Fig. 7(a) and fit the data well. The event numbers obtained were corrected for events with $MM^2 < 0.1 \text{ GeV}^2$ (correction factor 1.07), events with $M_{\pi^+\pi^-} < 0.32$ or $M_{\pi^+\pi^-} > 0.6 \text{ GeV}$ (factor 1.08), and for the unobserved decay modes of the ω (factor 1.11). The resulting cross sections are given in Table III. The errors quoted include a conservative estimate of the uncertainties in the background curves. It should be noted that we have assumed that the "B" does not interfere with the background; note also that the shape of the $p\omega\pi^0$ background was chosen according to the OPE calculation. The use of a $p\omega\pi^0$ background from a Reggeized Deck model might result in lower cross sections.

In method (b) we used Monte Carlo generated rather than hand drawn background curves and performed χ^2 fits to the $M_{\pi^+\pi^-MM}$ distribution leaving the mass and width of the "B" as adjustable parameters. In this fit we want to determine the maximum amount of diffractive production in the "B" region by fitting an s-wave Breit-Wigner distribution of variable width. In order to keep the number of different background contributions manageable we made an

additional missing mass cut MM < 0.9 GeV. This cut eliminates most of the events with three or more π^{0} 's, while keeping most of those with two π^{0} 's and $M_{\pi^{+}\pi^{-}\pi^{0}\pi^{0}} < 1.5$ GeV. Figure 11(a) shows the $M_{\pi^{+}\pi^{-}MM}$ distribution for |t| < 1 GeV² after applying the missing mass cut MM < 0.9 GeV. Figure 11(b) has an additional cut $M_{\pi^{+}\pi^{-}} < 0.6$ GeV. Background curves were generated according to the following reactions

- (1) peripheralized phase space $\gamma p \rightarrow p \pi^+ \pi^- \pi^0 \pi^0$ with exp (6t_{p/p});
- (2) reflection from peripheralized Δ^{++} production via $\gamma p \rightarrow \Delta^{++} \pi^{-} \pi^{0} \pi^{0}$ with exp (5.5t_{p/ Δ});
- (3) at 9.3 GeV only: contribution from $\rho'(1600)$ production using an s-wave Breit-Wigner distribution of fixed mass and width (M = 1650 MeV, $\Gamma = 500$ MeV).

No additional $p\omega \pi^0$ background was fitted. We performed several fits with backgrounds (1) - (3). The fitted "B" mass always came out between 1220 and 1260 MeV. The fitted width (resolution unfolded) varied between 230 and 310 MeV. The curves in Fig. 11 show results of the fits. The dotted curves give the sum of all background contributions. The dashed curves give the fitted Breit-Wigner distribution.

The event numbers obtained were corrected for the cut $MM^2 > 0.1 \text{ GeV}^2$ (as above) and for the cuts MM < 0.9 GeV and $M_{\pi^+\pi^-} < 0.6 \text{ GeV}$ (combined factor 1.19). Also all numbers were corrected for the unobserved decays of the ω (factor 1.11).

The resulting cross sections are given in Table III. As mentioned above the cross sections depend on the width used to describe the "B" peak. For a width of 150 MeV (which is consistent with the width of the "real" B-meson) the cross sections are about $1.5 \ \mu b$ at $2.8 \ \text{GeV}$ and drop to about $1 \ \mu b$ at $9.3 \ \text{GeV}$.

-16-

For a width of 250 MeV the cross sections are bigger by about a factor of two. Hence the cross section determination is linked to the identification of the "B". We defer further conclusions to a final discussion.

E. Comparison with Other Experiments

The first evidence for an enhancement at 1.24 GeV in the missing mass recoiling against the proton in reaction $\gamma p \rightarrow p$ + anything was reported by Anderson <u>et. al.</u>¹². The cross sections were measured at photon energies of 13-17 GeV and were reported to be similar to those of the ϕ meson. Numbers for 0.3 < |t| < 0.7 GeV² are given in the thesis of Kreinick¹³. The results of Kreinick have been confirmed by the same group in a recent measurement at |t| = 0.6 GeV² and E_{γ} = 8-15 GeV using a similar apparatus¹⁴.

Since we do not observe a "B" bump with comparable cross section in any other final state except reaction (3), we can identify the enhancement of Refs. 12 and 13 with our "B". We have extrapolated the differential cross sections of Ref. 13 using an exponential slope of $6 \pm 2 \text{ GeV}^{-2}$ (as derived from our t distribution, see below). The resulting cross section estimate is $0.7 \pm 0.3 \,\mu\text{b}$ at $E_{\gamma} = 13-14.5$ GeV. Note that the cross sections of Ref. 13 were obtained using a "B" width of 100 MeV. In the procedure of Ref. 13 the cross section is essentially directly proportional to the width used. For the purpose of comparing to our results from method (a), the cross sections of Ref. 13 have to be scaled by approximately a factor 1.5, resulting in a total cross section estimate of $1.05 \pm 0.45 \,\mu\text{b}$.

Figure 12 shows our cross sections from method (a) and the points derived from the data of Ref. 13. The "B" production cross section seems to fall slightly with increasing energy. However an energy "independent" behavior

-17-

like in $\gamma p \rightarrow p \rho^{0}$ cannot be ruled out. Our cross sections at 2.8 and 4.7 GeV also agree with preliminary results obtained in the DESY streamer chamber exposed to a tagged photon beam¹⁵.

F. t Distributions

Figure 13 shows the t distribution in the "B" region at 9.3 GeV. The t distributions of events in the ω selection band $0.32 < M_{\pi^+\pi^-} < 0.6$ GeV can be well described by an exponential of the form exp (At). The slopes A were fitted in the interval from $|t_0|$ to 0.4 GeV^2 , where $|t_0|$ is the larger of $|t|_{\min}$ and 0.02 GeV^2 . The results are shown in Fig. 14 as a function of $M_{\pi^+\pi^-MM}$. The slopes at the B peak rise from 5 to 7 GeV⁻² with increasing photon energy and show little dependence on $M_{\pi^+\pi^-MM}$. Hence the background and the "B" peak seem to have a similar t dependence and the slopes determined for $1.15 < M_{\pi^+\pi^-MM} < 1.35$ GeV can be considered as the slopes of the "B". From

the total cross section of method (a) and a slope of 7 GeV⁻² we derive a forward cross section (t=0) of $8 \mu b/\text{GeV}^2$ at 9.3 GeV.

G. Discussion and Conclusions

(i) We observe an enhancement at $M_{\pi^+\pi^-MM} = 1240 \pm 20 \text{ MeV}$ compatible with an $\omega \pi^0$ decay mode. The quantum numbers of an $\omega \pi^0$ system must be $I^G = 1^+$, C = -1. A sizeable $\rho^+\rho^-$ decay with $I^{GC} = 1^{+-}$ cannot be ruled out*. There is no evidence for the "B" in any final state other than $\pi^+\pi^-$ + neutrals.

(ii) We next discuss the production mechanism. Since the "B" cross section does not vary strongly with energy, it may be diffractively produced.Moreover, although we cannot rule out the possibility of production via

^{*}Generally a $\rho^+ \rho^-$ system can have $I^G = 0^+$, 1^+ , 2^+ . We exclude I = 2, which would be an exotic state. If I = 0 the decay into $\rho^0 \rho^0$ would be allowed. However the data of Ref. 2 show that this mode is small or nonexistent. This leaves $I^G = 1^+$ and C = -1.

f-exchange, the case against I = 1 exchange is quite strong:

(a) Since the C parities of the photon and the $\omega\pi$ -system are both -1, the C parity of the exchanged object has to be C = +1. This allows for π , A₁ and A₂ exchange. Then from G parity conservation only the I = 0 part (i.e., the ω part) of the photon can contribute. This suppresses nondiffractive contributions by the ratio of the $\gamma\omega$ and $\gamma\rho$ coupling constants which is about 1/9. In particular, an OPE calculation¹⁶ of $J^P = 1^+$ B production yields σ^{OPE} ($\gamma p \rightarrow pB(1235)$) $\approx \frac{1}{10} \sigma^{OPE}$ ($\gamma p \rightarrow p\omega$), which amounts to 0.3, 0.1 and 0.01 μ b at 2.8, 4.7 and 9.3 GeV, respectively, if the experimental unnatural parity exchange part of the ω -photoproduction cross section is used¹.

(b) No evidence has been found^{7,8} for nondiffractive B-photoproduction via $\gamma n \rightarrow pB^-$. The upper limit of the cross section was measured to be $\sigma(\gamma n \rightarrow pB^- \rightarrow p\omega\pi^-) < 0.3 \ \mu b (90\%$ confidence level)⁸ in the photon energy interval 2.5 < E_{γ} < 5.3 GeV. Hence only minor nondiffractive contributions are expected in $\gamma p \rightarrow pB^{0}$ (for a pure I = 1 exchange, Clebsch-Gordan-coefficients suppress the reaction off the proton by a factor of two).

The above arguments lead us to conclude that the major part of the cross section is due to a diffractive process.

(iii) We now consider three possible interpretations of the 'B' enhancement.

(a) <u>The ρ tail.</u> The "B" enhancement could be interpreted as the onset of the $\omega \pi^0$ or $\rho^+ \rho^-$ decay of the ρ^0 (760). G. Kramer has calculated that the cross section for the process $\gamma p \rightarrow p \rho^0$ (760) $\rightarrow p \omega \pi^0$ peaks at $M_{\pi^+\pi^-MM}^{-1.1} = 1.1$ GeV and amounts to about 0.1 μ b in the mass interval 1.15 < $M_{\pi^+\pi^-MM}^{-1.35}$ GeV. ¹¹ These results are not able to explain the observed "B" enhancement.

(b) <u>A nonresonant Deck process</u>. The Deck process $\gamma p \rightarrow p \omega \pi^0$ discussed above yields a peak in the $M_{\pi^+\pi^-MM}$ distribution at ~1.2 GeV. The width of the mass distribution from the Deck effect is ≥ 350 MeV. If we assume that there is no other background in the B region, the fitted width of the "B" can be as large as ~300 MeV. The data peaks at a higher mass than the mass distribution predicted by the Reggeized Deck model and also does not show the sharp rise at the $\omega \pi$ threshold predicted by the model. However, in view of the theoretical uncertainties in the calculation of the Deck effect, we cannot exclude the possibility that the enhancement is completely due to a nonresonant Deck process. The cross section for this Deck process is that given in Table III using method (b).

(c) <u>Production of genuine resonances (non $-\rho$ tail)</u>. Among the established meson resonances only the B-meson has a dominant $\omega \pi$ decay mode compatible with our data. The B might be photoproduced diffractively via an orbital momentum $\ell = 1$ exchange (this process would violate the Morrison-Gribov rule). The analysis of the B in this channel could be complicated by the existence of a Deck-like background interfering with the direct B production. But if this interference is neglected, our best estimate of the B cross section is given in Table III using method (a). Equally our "B" could be the long sought $\rho'(1250)^*$, possibly produced along with a $J^P = 1^+$ Deck-like background. Our analysis of the decay distributions does not allow us to differentiate between a pure 1^+ or 1^- state or a mixture of these states.

^{*}Indications for $\rho'(1250) \rightarrow \omega \pi$ have been found previously in the reaction $\bar{p}p \rightarrow (\omega \pi) \pi^{17}$; the fitted mass and width were $M = 1256 \pm 10$ MeV and $\Gamma = 130 \pm 20$ MeV.

V. SEARCH FOR THE $\pi^+\pi^-$ + NEUTRALS DECAY MODES OF THE $\rho'(1600)$

The $\rho'(1600)$ has been observed in this experiment in the channel $\gamma p \rightarrow p \pi^+ \pi^+ \pi^- \pi^-$. The production cross section was measured² as $1.6 \pm 0.4 \,\mu b$ at 9.3 GeV. The observed enhancement is compatible with a pure $\rho^0 \epsilon$ decay, where ϵ is an I = 0 s-wave state. In this case a signal due to the decay mode $\rho' \rightarrow \rho \epsilon \rightarrow \pi^+ \pi^- \pi^0 \pi^0$ would be expected in channel (3) and decay modes such as $\rho' \rightarrow \omega \pi^0$ and $\rho^+ \rho^-$ could also be observed in this channel. In the following we study the compatibility of our data with the above decay modes.

A. $\rho'(1600) \rightarrow \rho^{0} \epsilon \rightarrow \pi^{+} \pi^{-} \pi^{0} \pi^{0}$

We try to isolate the $\rho^{0} \epsilon^{0}$ decay by applying a ρ cut 0.6 $< M_{\pi^{+}\pi^{-}} < 0.9$ GeV and a t cut $|t| < 0.5 \text{ GeV}^{2}$. Figure 15(a) shows the resulting $M_{\pi^{+}\pi^{-}MM}$ distribution. Peripheralized phase space with the same cuts would peak at 2.4 GeV. In contrast, Figure 15(a) shows a broad maximum between 1.6 and 2 GeV. The maximum peaks at higher masses than expected from the ρ' signal in the $p\pi^{+}\pi^{+}\pi^{-}\pi^{-}$ final state. Hence some presently unidentified background or resonance contributions must be present between masses of 1.8 and 2.1 GeV.

From the above cross section for $\gamma p \rightarrow p\rho' \rightarrow p\pi^+\pi^+\pi^-\pi^-$ one expects (after applying Clebsch-Gordan-coefficients and the relevant cuts) 165 ± 50 events $\rho' \rightarrow \rho^0 \epsilon \rightarrow \pi^+\pi^-\pi^0\pi^0$ in Figure 15(a). This is compatible with the observed enhancement. In addition the presence of the $\rho^0 \epsilon$ decay should lead to a ρ^0 signal in the $M_{\pi^+\pi^-}$ distribution. Figure 15(b) shows the $M_{\pi^+\pi^-}$ distribution in the ρ' region 1.4 < $M_{\pi^+\pi^-MM}$ < 2 GeV. Although the ρ signal is not prominent, it is

-21-

compatible with the predicted size.

Next we study the decay distribution using the analyzer (b) and the angles defined in Section IV.C. The polarization information of a ρ' which is produced in an s-channel helicity conserving process and which decays into $\rho^{0} \epsilon \rightarrow \pi^{+}\pi^{-}\pi^{0}\pi^{0}$ in a relative s-wave state, is contained in the ρ^{0} . Hence the π^{+} direction in the $\pi^{+}\pi^{-}$ rest system (i.e., analyzer (b)) is a perfect analyzer and would show a $\sin^{2} \theta \cos^{2} \psi$ signal for ρ' produced by a helicity conserving mechanism. Figure 15(c) shows the quantity II (which measures the amount of $\sin^{2} \theta \cos^{2} \psi$ component). From the II cross section in the reaction $\gamma p \rightarrow p\rho' \rightarrow p\pi^{+}\pi^{+}\pi^{-}\pi^{-}$ one expects (after applying Clebsch-Gordan-coefficients and the relevant cuts) 110 ± 42 events in the interval $1.2 < M_{\pi^{+}\pi^{-}MM} < 2.0$ GeV of Figure 15(c). Experimentally we find 65 \pm 32 events in the same interval. We also observe a II signal of 110 \pm 32 events for $M_{\pi^{+}\pi^{-}MM} > 2$ GeV which is presently not understood.

B. $\rho'(1600) \rightarrow \pi^+\pi^- + \text{Neutrals}$

In this section we give an upper limit for the ratio

 $R = \frac{(\rho' \rightarrow \pi^+ \pi^- + neutrals)}{(\rho' \rightarrow \pi^+ \pi^- \pi^+ \pi^-)} \quad . \text{ The ratio R has been taken to be the ratio of}$ the numbers of events at 1.5 GeV in the $\pi^+ \pi^+ \pi^- \pi^-$ and $\pi^+ \pi^- MM$ mass distributions for $|t| < 0.5 \text{ GeV}^2$. R was evaluated by summing over an 100 MeV wide interval centered at 1.5 GeV. This procedure makes use of our observation from the channel $\gamma p \rightarrow p \pi^+ \pi^+ \pi^- \pi^-$ that (a) the ρ' mass spectrum (as measured by II) peaks at 1.5 GeV and (b) there is no significant background at this 4π mass. These observations may not be strictly correct for the channel $\gamma p \rightarrow p \pi^+ \pi^- + neutrals$ since different decay modes may have different mass spectra; also a $J^P = 1^+ \pi \omega$ Deck background may exist in the ρ' mass region.

-22-

However our fits to the B region lead us to expect that the latter effect is small (less than 20%). We find at 9.3 GeV a value for R of 2.6 \pm 0.4 which gives an upper limit for the cross section (including $\rho^{0} \epsilon$) for $\gamma p \rightarrow p \rho^{\dagger} \rightarrow p \pi^{+} \pi^{-}$ + neutrals of $4 \pm 1 \mu b$.

C. Conclusions

We have shown that there is a ρ° + neutrals signal in the channel $\gamma p \rightarrow p \pi^{+} \pi^{-}$ + neutrals which is compatible with the $\rho^{\circ} \in$ decay of the $\rho'(1600)$. We have derived an upper limit for the cross section for $\gamma p \rightarrow p \rho' \rightarrow p \pi^{+} \pi^{-}$ + neutrals of $4 \pm 1 \,\mu$ b at 9.3 GeV.

Acknowledgements

We wish to thank the SLAC Operations Crew, R. Watt and the 82-in. Bubble Chamber Operations Group for their assistance in performing this experiment. We thank R. Gearhart, R. Milburn, J.J. Murray, C.K. Sinclair and R. Windmolders 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 F. Gilman for helpful discussions.

REFERENCES

. .

÷.

. ·

-

· ·

I

1.	J. Ballam et.al., Phys. Rev. D7, 3150 (1973).			
2.	H.H. Bingham et.al., Phys. Letters <u>41B</u> , 635 (1972).			
3.	J. Ballam <u>et.al.</u> , Phys. Rev. D <u>5</u> , 545 (1972).			
4.	H.H. Bingham <u>et.al.</u> , Phys. Rev. D <u>8</u> , 1277 (1973).			
5.	W.J. Podolsky, LRL-Berkeley Report No. UCRL-20128 (1971) (Ph.D.			
	Thesis, unpublished).			
6.	F.J. Gilman et.al., Phys. Letters 31B, 387 (1970).			
7.	Y. Eisenberg et.al., Nucl. Phys. <u>B25</u> , 499 (1971).			
8.	Aachen-Bonn-Hamburg-Heidelberg-München-Collaboration, private			
	communication (1973).			
9.	G. Wolf, Phys. Rev. <u>182</u> , 1538 (1969).			
10.	G.W. Brandenburg et.al., Nucl. Phys. B16, 369 (1970).			
11.	G. Kramer, private communication (1972).			
12.	R. Anderson et.al., Phys. Rev. D1, 27 (1970).			
13.	D.L. Kreinick, Ph.D. Thesis, California Institute of Technology,			
	Pasadena (1970) (unpublished).			
14.	H. Halpern, private communication (1973).			
15.	E. Rabe, Internal Report No. DESY F1-71/2 (1971) (Diploma Thesis,			
	unpublished) and talk at the DPG Frühjahrstagung, Bonn (1972).			
16.	G.C. Fox and A.J.G. Hey, California Institute of Technology Report			
	No. CALT-68-373 (1973).			
17.	P. Frenkiel et.al., Nucl. Phys. <u>B47</u> , 61 (1972).			

-24-

TABLE I

Upper limits (90% C.L.) for "B" decay normalized to "B" $\rightarrow \pi^{+}\pi^{-}$ + neutrals. The upper limits were determined at 9.3 GeV for $|t| < 0.5 \text{ GeV}^{2}$. Similar limits were obtained at 4.7 GeV ⁵.

$"B" \rightarrow \pi^+\pi^-$	< 30%
$\rightarrow K^+K^-$	<10%
$\rightarrow \pi^+\pi^-\pi^0$	< 50%
$ \rightarrow \eta \pi^{O} $ $ \downarrow \pi^{+}\pi^{-}\pi^{O} $	< 30%
$\rightarrow \rho^{0}$ + neutrals	<15%
$\rightarrow 2\pi^+ 2\pi^-$ including $\rho^0 \pi^+ \pi^-$	·
$\rightarrow 2\pi^+ 2\pi^- \pi^0$ including $\rho^{\pm} \pi^{\mp} \pi^+ \pi^-$ and $\omega \pi^+ \pi^-$	- < 7%
$\rightarrow \omega \pi^+ \pi^-$	< 5%
$\rightarrow \omega \pi^{\mathbf{O}} \pi^{\mathbf{O}}$	< 10%
$\rightarrow \eta \pi^+ \pi^-$	< 5%
$\rightarrow \eta \pi^{\mathbf{O}} \pi^{\mathbf{O}}$	<10%
$\rightarrow \rho^+ \rho^-$	< 45%
$\rightarrow \pi^+\pi^- + m\pi^0 \ (m \ge 2)$	no positive evidence,
$\rightarrow \rho^{\pm}\pi^{\mp} + m\pi^{0} \ (m \ge 1)$	dependent

TABLE II

Predicted signals in the decay distribution of "B" $\rightarrow \omega \pi^0$ and "B" $\rightarrow \rho^+ \rho^-$ decays using the analyzers (b) and (c) (see text). The "B" events were generated by a Monte Carlo method assuming helicity conservation and $J^P = 1^{\pm}$ with the matrix elements given*. (The symbols π , γ , ω , ρ denote the momenta of the respective particles, ϵ is the polarization vector of the photon. The $\pi^+ \times \pi^-$ terms are evaluated in the ω rest frame; the $(\omega - \pi^{0})$ and $(\rho^{+} - \rho^{-})$ terms are taken in the "B" rest system.)

	Decay Mode	$_{\mathrm{J}^{\mathrm{P}}}^{\mathrm{State}}$	Matrix Element	Analyzer $\hat{\pi}^+$ ($\pi^+\pi^-$ RS) Signal II Efficiency		Analyzer $\pi^+ \times \pi^-$ ("B" RS) Signal IL Efficiency	
(a)	ωπ ⁰ relative p wave	1	$\epsilon \cdot (\pi^+ \times \pi^-)_{\omega} \times (\omega - \pi^0)$	$1 + 0.4 \sin^2 \theta$ $1 + 0.7 \cos^2 \psi$	+0.3	$1 + 0.4 \cos^2 \theta$ $1 + 0.7 \sin^2 \psi$	-0.3
	$\omega \pi^{0}$ relative s wave	1+	$(\epsilon \times \gamma) \cdot (\pi^+ \times \pi^-)_{\omega}$	$1 + \cos^2 \theta$ $1 + 1.5 \cos^2 \psi$	+0.5	$1 + \sin^2 \theta$ $1 + 1.4 \sin^2 \psi$	-0.5
(b)	$\rho^+ \rho^-$ relative p wave	1	$\epsilon \cdot (\pi^+ \times \pi^-)_{\omega} \times (\rho^+ - \rho^-)^{**}$	$1 + 0.2 \sin^2 \theta$	+0.1	$1 + 0.5 \cos^2 \theta$ $1 + \sin^2 \psi$	-0.4-
	$\rho^+ \rho^-$ relative s wave	1 ⁺	$(\epsilon \times \gamma) \cdot (\pi^+ \times \pi^-)_{\omega}$	$1 + 0.2 \cos^2 \theta$ $1 + \cos^2 \psi$	+0.3	$1+2.5 \sin^2 \theta$ $1+4.5 \sin^2 \psi$	-0.8

* Note that the predicted efficiencies for $J^P = 1^+$ were calculated for a pure s-wave decay. Data on B-production in πp interactions indicate the presence of some d-wave decay ($\Gamma_d \leq \frac{1}{2}\Gamma_s$). A pure d-wave decay would lead to approximately flat distributions with the above analyzers which decreases the detection efficiency and allows for more 1^+ in Fig. 9(b) and (c). ** The form of the matrix element used here is not unique since three angular momenta are being coupled.

-26-

TABLE III

Production cross sections in the "B" region as determined from methods (a) and (b) (see Section IV.D). (a) Cross sections obtained assuming a resonant enhancement of width 150 MeV. (b) Maximum cross section for diffractive production in the B region, as described by an s-wave Breit-Wigner distribution of variable width. The cross sections have been corrected by the factors mentioned in Section IV.D, including a correction for decays $\omega \rightarrow$ neutrals.

	Method (a) t < 0.5 GeV ² $\Gamma_B = 150$ MeV	Met t <	hod (b) 1 Ge V^2 ·	
E _γ (GeV)	Cross Section (µb)	Cross Section (µb)	Fitted Width (MeV)	Fitted Mass (MeV)
2.8	1.2 ± 0.7		- ·	-
4.7	1.5 ± 0.6	3.0 ± 0.7	230	1240
9.3	1.0 ± 0.3	2.5 ± 0.6	310	1250

FIGURE CAPTIONS

- 1. Reaction $\gamma p \rightarrow p\pi^+\pi^-$ + neutrals at 2.8, 4.7 and 9.3 GeV. $p\pi^+$ mass distribution for $|t_{p/p}| < 1 \text{ GeV}^2$. Events with $|t_{p/\Delta^{++}}| < 1 \text{ GeV}^2$ are shaded.
- 2. Reaction $\gamma p \rightarrow p\pi^{+}\pi^{-} + neutrals at 2.8, 4.7 and 9.3 GeV. <math>p\pi^{-}$ mass distribution for $|t_{p/p}| < 1 \text{ GeV}^{2}$.
- 3. Reaction $\gamma p \rightarrow p\pi^{+}\pi^{-} + neutrals at 2.8, 4.7 and 9.3 GeV. pMM mass distribution for <math>|t_{p/p}| < 1 \text{ GeV}^2$. Events with $0.6 < M_{\pi^{+}\pi^{-}} < 0.9 \text{ GeV}$ and $|t_{\gamma/\pi^{+}\pi^{-}}| < 0.5 \text{ GeV}^2$ are shaded.
- 4. Reaction $\gamma p \rightarrow p \pi^+ \pi^- + neutrals at 2.8, 4.7 and 9.3 GeV. <math>\pi^+ \pi^- mass$ distribution for $|t_{n/n}| < 1 \text{ GeV}^2$.
- 5. Reaction $\gamma p \rightarrow p \pi^+ \pi^- + neutrals at 2.8, 4.7 and 9.3 GeV. <math>\pi^+ MM$ mass distribution for $|t_{p/p}| < 1 \text{ GeV}^2$.
- 6. Reaction $\gamma p \rightarrow p\pi^+\pi^-$ + neutrals at 2.8, 4.7 and 9.3 GeV. π^-MM mass distribution for $|t_{p/p}| < 1$ GeV. Events with $M_{p\pi^+} < 1.4$ GeV are shaded.
- 7. Reaction γp → pπ⁺π⁻ + neutrals at 2.8, 4.7 and 9.3 GeV. π⁺π⁻MM mass distribution for (a) |t| < 0.5 GeV², (b) 0.5 < |t| < 1 GeV², (c) |t| > 1 GeV². In (a) events with 0.32 < M_π+_π- < 0.6 GeV are shaded. The dashed curve is a handdrawn background curve used for the determination of the "B" cross section according to method (a) (see Section IV.D). The full curves include the fitted contribution of the "B".</p>
- 8. Distribution of the mesonic mass recoiling against the proton for |t| < 0.5 GeV²; (a) M_{π⁺π⁻MM} from reaction γp → pπ⁺π⁻ + neutrals,
 (b) M_{π⁺π⁺π⁻π⁻} from reaction γp → pπ⁺π⁺π⁻π⁻, (c) M_{π⁺π⁺π⁻π⁻}π⁰ from reaction γp → pπ⁺π⁺π⁻π⁻π⁰.

- 9. Reaction γp → pπ⁺π⁻ + neutrals at 4.7 and 9.3 GeV. Distribution of the angles θ and ψ and of Π in the helicity system for events in the "B" region: M_π+_π- < 0.6 GeV, 1.12 < M_π+_π-MM < 1.36 GeV, 0.02 < t < 0.5 GeV². The angles were calculated using the analyzers (a) (Fig. 9(a)), (b) (Fig. 9(b)) and (c) (Fig. 9(c)) defined in the text (Section IV.C).
- 10. Diagrams to describe diffractive $p \omega \pi^0$ backgrounds in the "B" region: (a) and (b) are diagrams from a Deck-type mechanism, (c) $\pi \omega^0$ decay of the $\rho(760)$ tail.
- 11. Reaction γp → pπ⁺π⁻ + neutrals at 4.7 and 9.3 GeV. π⁺π⁻MM distribution for events with 0.32 < MM < 0.9 GeV, 't | < 1 GeV² and (a) no M_{π⁺π⁻} cut,
 (b) M_{π⁺π⁻} < 0.6 GeV. The curves are the results of fits according to method (b) (see Section IV.D). The dotted curve gives the sum of the contributions of ρ'(1600) production, peripheralized phase space for pπ⁺π⁻π⁰π⁰ and the process γp → Δ⁺⁺π⁻π⁰π⁰. The dashed curve is an s-wave Breit-Wigner distribution of variable width, which was fitted to determine the maximum amount of diffractive production in the "B" region. The full curve is the sum of the above contributions.
- 12. Cross section of reaction γp → p"B" as a function of the incident photon energy. The points labelled "This experiment" have been determined from method (a) (see Section IV. D) assuming a fitted "B" width of 150 MeV and an ωπ⁰ background according to the OPE calculation of G. Wolf. The cross sections have been corrected for decays ω→ neutrals. The point labelled "SLAC spectrometer Γ = 100 MeV" has been extrapolated from differential cross sections given in Ref. 13. The point labelled "Γ = 150 MeV" was obtained by scaling the above point by a factor 1.5.

-29-

- 13. Reaction $\gamma p \rightarrow p \pi^+ \pi^- + neutrals$ at 9.3 GeV. Differential cross section $d\sigma/dt$ for events in the "B" region $1.15 < M_{\pi^+ \pi^- MM} < 1.35$ GeV and $0.32 < M_{\pi^+ \pi^-} < 0.6$ GeV. No background has been subtracted.
- 14. Reaction $\gamma p \rightarrow p \pi^+ \pi^- + neutrals$ at 2.8, 4.7 and 9.3 GeV. Slopes A of the t distribution from a fit of exp (At) to events with $0.32 < M_{\pi^+\pi^-} < 0.6$ GeV in the interval 0.02 < |t| < 0.4 GeV².
- 15. Reaction $\gamma p \rightarrow p\pi^+\pi^- + neutrals$ at 9.3 GeV for $|t| < 0.5 \text{ GeV}^2$. (a) $\pi^+\pi^-\text{MM}$ mass distribution for 0.6 $< M_{\pi^+\pi^-} < 0.9 \text{ GeV}$. (b) $\pi^+\pi^-$ mass distribution in the ρ' region 1.4 $< M_{\pi^+\pi^-\text{MM}} < 2.0 \text{ GeV}$. (c) Distribution of II in the helicity system for 0.6 $< M_{\pi^+\pi^-} < 0.9 \text{ GeV}$.









antan di sebar Karanta







FIG. 7a and 7b





|t| < 0.5 GeV²

FIG. 8





ţ

FIG. 9b



ţ

FIG. 9c











FIG. 14

