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A SEARCH FOR B AND $\rho'(1250)$ PRODUCTION IN THE REACTION $\gamma p \to p\pi^+\pi^-$ + NEUTRALS AT 2.8, 4.7 AND 9.3 GeV *

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Abstract We have studied the reaction $\gamma p \to p\pi^+\pi^-$ + 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 ± 1 μb for $\rho'(1600)$ production in the final state $p\pi^+\pi^-$ + neutrals at 9 3 GeV

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1. 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 helicity [1]. Recently a new vector meson state, the $\rho'(1600)$, has been found in the reaction $\gamma p \to p\rho' \to p\rho^0\pi^+\pi^-$ with production properties similar to those of ρ, ω and ϕ production [2]

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 $\gamma p \to p\pi^+\pi^-$ + two or more neutrals and search for yet undetected meson states. In particular we try to isolate the channel $\gamma p \to p\omega\pi^0 \to p\pi^+\pi^-\pi^0\pi^0$. 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 82in 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 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 a $J^P = 1^-$ assignment is equally possible. In addition, the enhancement could be due to a non-resonant Deck-type process. Finally, we study the $\pi^+\pi^-$ + neutrals decay of the $\rho'(1600)$.

The organization of the paper is as follows. Sect. 2 covers the event selection and channel cross section. Sect 3 deals with general characteristics of the reaction $\gamma p \to p\pi^+\pi^-$ + neutrals. Sect 4 contains a study of the $M_{\pi^+\pi^-MM}$ enhancement near 1.25 GeV. Sect. 5 discusses the $\pi^+\pi^-$ + neutrals decay modes of the $\rho'(1600)$

2. Event selection and channel cross section

The experimental set up and event analysis have been described in refs [1, 3–5]. Preliminary results at 2.8 and 4.7 GeV have been reported in ref [5] From our three prong events we selected a sample that had track ionizations consistent with the hypothesis

$$\gamma p \to p\pi^+\pi^- + \text{neutral(s)}\,, \tag{1}$$

and which did not fit the three-constraint reactions $\gamma p \to p\pi^+\pi^-$, $\gamma p \to pK^+K^-$ or $\gamma p \to pp\bar{p}$. 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 $MM^2 = M^2_{\pi^0}$ due to the reaction

$$\gamma p \to p\pi^+\pi^-\pi^0 \tag{2}$$

In order to select events from reaction

$$\gamma p \to p\pi^+\pi^- + \text{neutrals} \ , \tag{3}$$

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 μb at 2.8 and 4.7 GeV and 1.5 μb 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

$$\gamma p \to n\pi^+\pi^+\pi^- \ (+ \text{neutrals}) \ . \tag{4}$$

The channel cross section for reaction (3) is 14.0 ± 2.0 μb and 20.8 ± 3.9 μb at 2.8 and 4.7 GeV, respectively [3]. 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 μb at 9.3 GeV

3. General characteristics of the reaction $\gamma p \to p\pi^+\pi^-$ + neutrals

Figs 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 $|t_{p/\Delta^{++}}| < 1\ \text{GeV}^2$. The cross sections for Δ^0 production are about $\frac{1}{3}$ 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 $|t_{\gamma/\pi^+\pi^-}| < 0.5\ \text{GeV}^2$, i.e., we have selected on peripherally produced ρ^0. 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 $\gamma p \to \rho^0 + p$ + neutrals for $|t_{\gamma/\pi^+\pi^-}| < 0.5\ \text{GeV}^2$

Fig. 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 $\gamma p \to \Delta^{++} A_2^-$ ($A_2^- \to \rho^-\pi^0 \to \pi^-\pi^0\pi^0$ or $A_2^- \to \pi^-\eta^0 \to \pi^-$ + neutrals). The double resonance character is more clearly visible

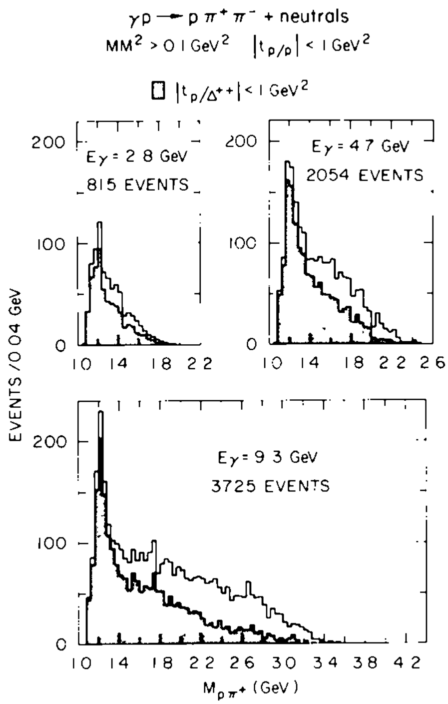

Fig 1. Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 2 8, 4.7 and 9 3 GeV $p\pi^+$ mass distribution for $|t_{p/p}| < 1$ GeV^2 Events with $|t_{p/\Delta^{++}}| < 1$ GeV^2 are shaded

on a scatter plot $M_{p\pi^+}$ *versus* M_{π^-MM} (not shown), from this we determine a cross section of 0 3 ± 0.08 μb. A comparable signal (0 28±0.08 μb) due to the mode $A_2^- \to \rho^0\pi^- \to \pi^+\pi^-\pi^-$ is observed [2] in the reaction $\gamma p \to \Delta^{++}\pi^+\pi^-\pi^-$. After adding the signals and correcting by a factor 1/0.841 for the undetected A_2 decay modes we obtain $\sigma(\gamma p \to \Delta^{++}A_2^-) = 0.7 \pm 0.15$ μb at 9.3 GeV.

Figs 7(a)-(c) show 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 $|t| > 0.5$ GeV^2 (fig. 7(b), (c)). Our mass resolution near 1.25 GeV is ±20 MeV, ±25 MeV and ±30 MeV at the three energies In the following we discuss the properties of the enhancement near 1 25 GeV in more detail

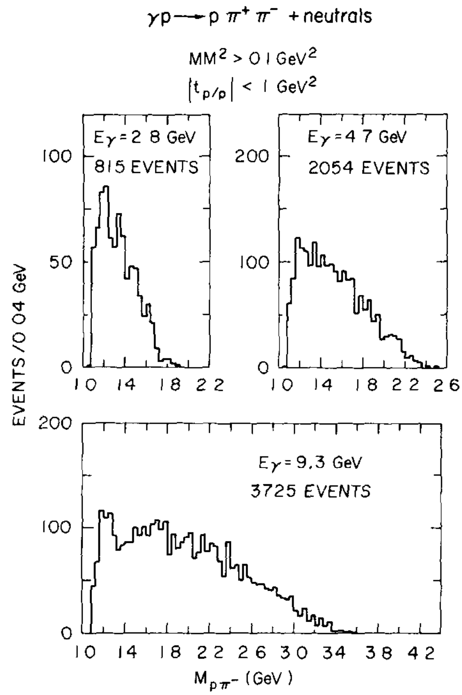

Fig 2 Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 2 8, 4.7 and 9 3 GeV $p\pi^-$ mass distribution for $|t_{p/p}| < 1$ GeV^2

4. Study of the $M_{\pi^+\pi^-MM}$ enhancement near 1.25 GeV

4.1 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 subsect. 4.4 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)

4.2. Decay modes

Presently there are four established non-strange meson resonances with masses between 1.2 and 1.3 GeV, the f, B, D and A_2 mesons We easily can exclude f^0 production because the dominant decay mode $f^0 \to \pi^+\pi^-$ is not observed in reaction $\gamma p \to p\pi^+\pi^-$ (figs 2–4 of ref. [1]). The D meson is too narrow to be compatible

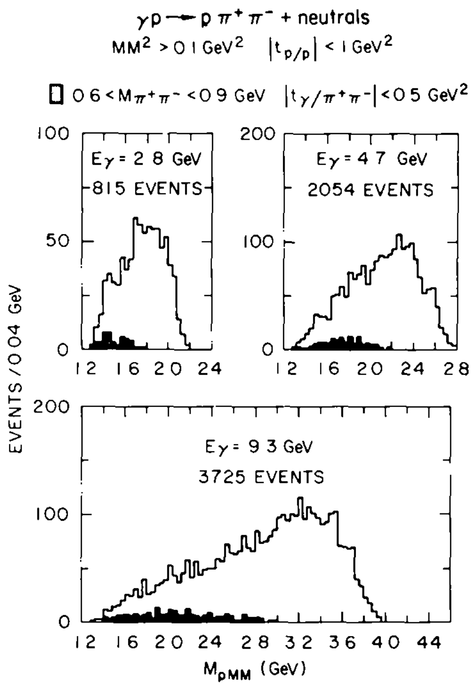

Fig. 3 Reaction $\gamma p \rightarrow p\pi^+\pi^-$ + neutrals at 2 8, 4 7 and 9 3 GeV pMM mass distribution for $|t_{p/p}| < 1$ GeV^2. Events with $0.6 < M_{\pi^+\pi^-} < 0\ 9$ GeV and $|t_{\gamma/\pi^+\pi^-}| < 0\ 5$ GeV^2 are shaded.

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 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 $\omega + m\pi^0$ ($m \geqslant 1$) 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" $\rightarrow \rho^0 + m\pi^0$ ($m \geqslant 2$) ,

(b) "B" $\rightarrow \eta + m\pi^0$ ($m \geqslant 1$) ,

(c) "B" $\rightarrow \pi^+\pi^- + m\pi^0$ ($m \geqslant 2$) (decay into non-resonant π's) ,

(d) "B" $\rightarrow \rho^\pm\pi^\mp + m\pi^0$ ($m \geqslant 1$) ,

(e) "B" $\rightarrow \rho^+\rho^-$, and "B" $\rightarrow \rho^\pm\underbrace{\pi^\mp\pi^0}_{I=1}$.

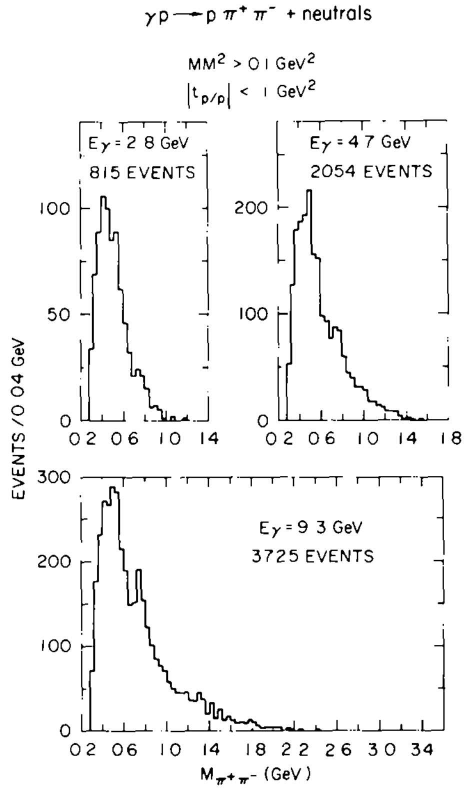

Fig 4 Reaction $\gamma p \rightarrow p\pi^+\pi^-$ + neutrals at 2.8, 4.7 and 9.3 GeV $\pi^+\pi^-$ mass distribution for $|t_{p/p}| < 1$ GeV^2.

We neglect "B" $\rightarrow \rho^+\rho^-$ + neutral(s) 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" $\rightarrow \rho^0 + m\pi^0$ $(m \geqslant 2)$. 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" $\rightarrow \eta + m\pi^0\,(m \geqslant 1)$, 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" $\rightarrow \pi^+\pi^-\pi^+\pi^- + m\pi^0\,(m \geqslant 0)$,

(g) "B" $\rightarrow \rho^0\pi^+\pi^-$, and "B" $\rightarrow \rho^\pm\pi^\mp\pi^+\pi^-$

Figs 8(b) and (c) show the 4π and 5π mass distributions of reaction $\gamma p \rightarrow p2\pi^+2\pi$ and $\gamma p \rightarrow p2\pi^+2\pi^-\pi^0$, respectively, together with the $M_{\pi^+\pi^-\text{MM}}$ distribution of reaction (3) (fig. 8(a)). There are few events at masses < 1.24 GeV in figs. 8(b), (c). The relatively fast rise near $M_{\pi^+\pi^+\pi^-\pi^-} \approx 1.3$ GeV is due to $\rho'(1600)$ production [2]. Also the $\geqslant 6\pi$ mass distribution (i.e , $M_{2\pi^+2\pi^-m\pi^0}$) of reaction $\gamma p \rightarrow p2\pi^+2\pi^- + m\pi^0$

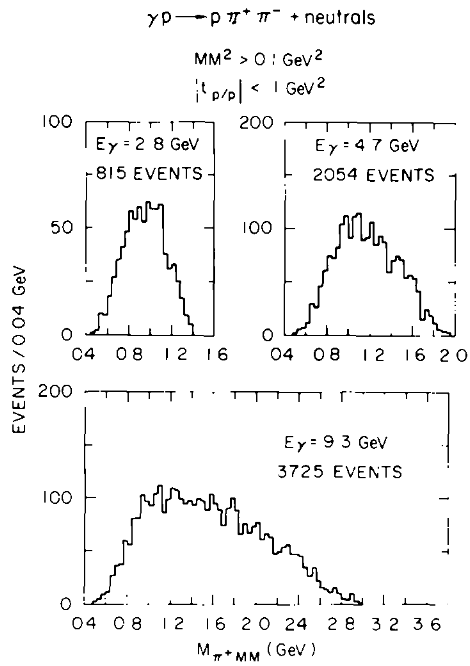

Fig. 5 Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 2 8, 4.7 and 9 3 GeV π^+MM mass distribution for $|t_{p/p}| < 1$ GeV^2.

($m \geqslant 2$) (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" $\to \rho^+\rho^-$ 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 $\pi^+\pi^-2\pi^0$ mode [5] 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" $\to xy$, where x is any $I = 1$ dipion state and y is an $I = 0$ ($I = 2$) dipion state, we expect twice for $I = 0$ ($\frac{2}{13}$ for $I = 2$) as many decays into $2\pi^+2\pi^-$ as into $\pi^+\pi^-2\pi^0$ Also, "B" $\to A_1^{\pm}\pi^{\mp}$ 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 events from a "B" decay into $\rho^+\rho^-$ 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 $\to \omega\pi^0$ 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 $M_{\pi^+\pi^-\mathrm{MM}} < 1$ 24 GeV, since in this region non-diffractive backgrounds are expected to be small at 9 3 GeV (see subsect 4 4 below) We have 23 events with $M_{\pi^+\pi^-} > 0$ 6 GeV from a total of 266 events (i e , 8 6 ± 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.).

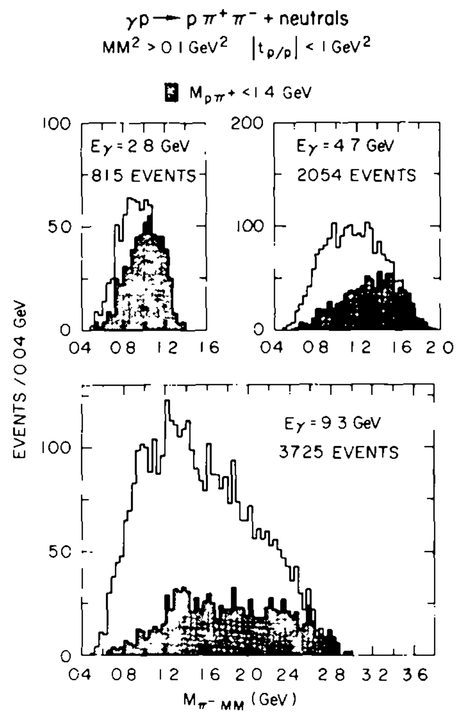

Fig 6 Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 2 8, 4.7 and 9 3 GeV. π^-MM mass distribution for $|t_{p/p}| < 1$ GeV^2. Events with $M_{p\pi^+} < 1.4$ GeV are shaded

Finally, the upper limit for "B" $\to \omega\pi^+\pi^-$ is 0.05 μb at 9 3 GeV. From isospin arguments "B" $\to \omega\pi^0\pi^0$ is then expected to be small compared to the peak in fig. 7(a). Neglecting "B" $\to \omega m\pi^0$ ($m \geqslant 3$) leaves us with "B" $\to \omega\pi^0$ 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" $\to \pi^+\pi^-$ + neutrals, as determined in subsect. 4.4 (method (a)). The estimates are given in table 1. 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 $M_{\pi^+\pi^-\text{MM}} \sim 1.24$ GeV and from the study of other channels we find $\omega\pi^0$ to be the major decay mode

4.3. 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 pro-

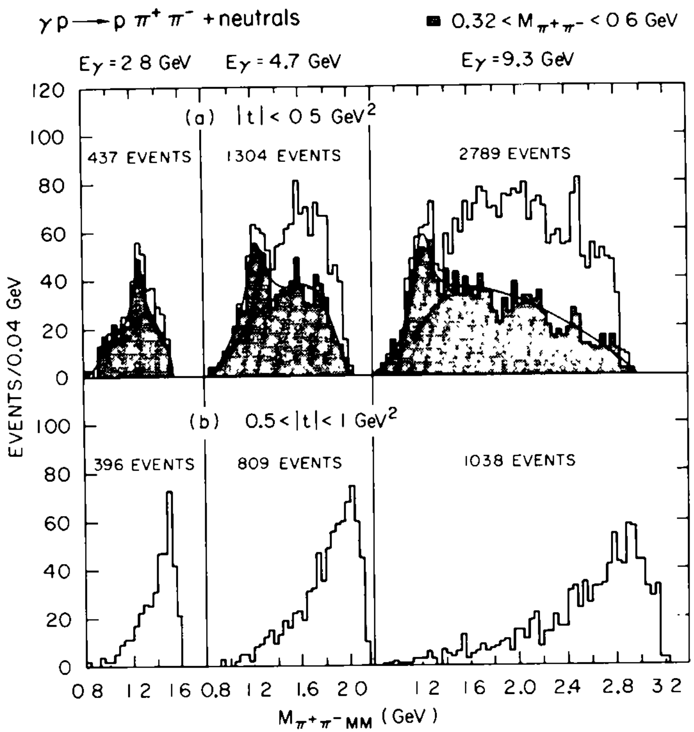

Fig. 7 (a) and (b)

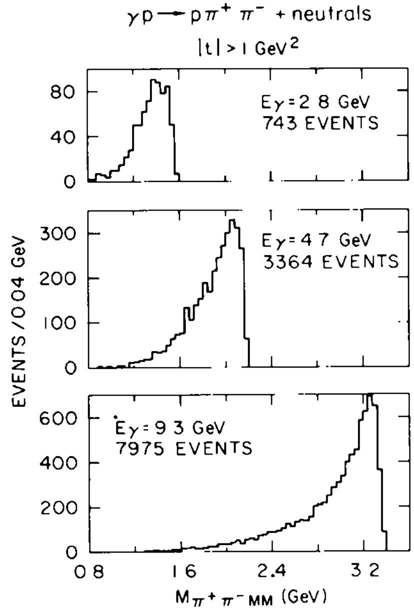

Fig 7 (c)

Fig. 7. Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 2 8, 4.7 and 9 3 GeV $\pi^+\pi^-$MM mass distribution for (a) $|t| < 0.5$ GeV^2, (b) $0.5 < |t| < 1$ GeV^2, (c) $|t| > 1$ GeV^2. In (a) events with $0.32 < M_{\pi^+\pi^-} < 0.6$ 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 subsect 4 4) The full curves include the fitted contribution of the "B"

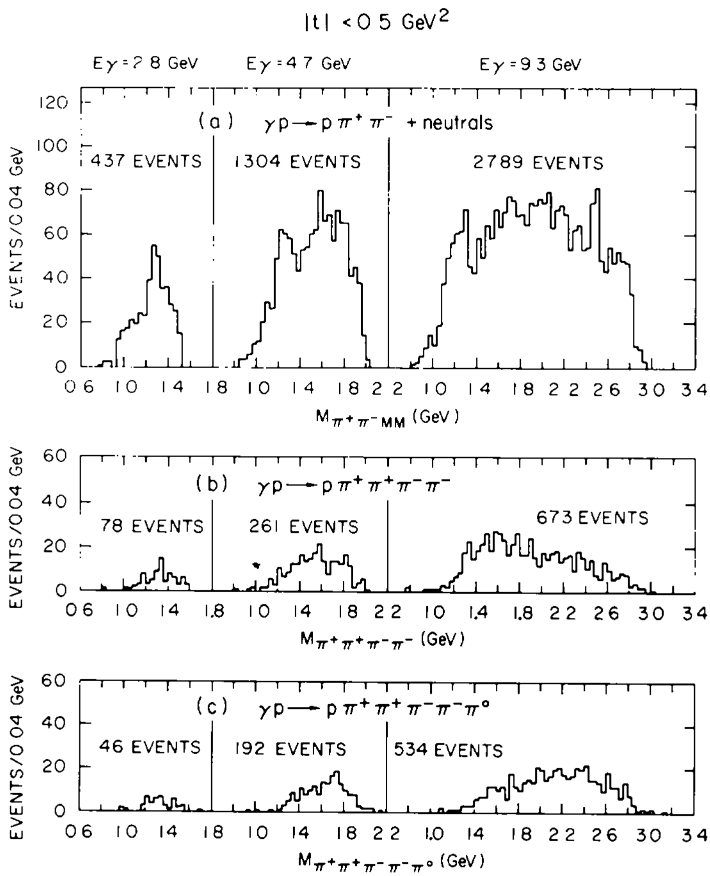

Fig. 8. Distribution of the mesonic mass recoiling against the proton for $|t| < 0.5\ \mathrm{GeV}^2$, (a) $M_{\pi^+\pi^-\mathrm{MM}}$ from reaction $\gamma p \to p\pi^+\pi^-$ + neutrals, (b) $M_{\pi^+\pi^+\pi^-\pi^-}$ from reaction $\gamma p \to p\pi^+\pi^+\pi^-\pi^-$, (c) $M_{\pi^+\pi^+\pi^-\pi^-\pi^0}$ from reaction $\gamma p \to p\pi^+\pi^+\pi^-\pi^-\pi^0$.

cess. 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 momentum [6].

A complete analysis of the "B" decay is impossible in our experiment because the two π^0 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 *

* Footnote see next page.

Table 1
Upper limits (90% C L) for "B" decay normalized to "B" → $\pi^+\pi^-$ + neutrals

"B" → $\pi^+\pi^-$	< 30%
→ K^+K^-	< 10%
→ $\pi^+\pi^-\pi^0$	< 50%
→ $\eta\pi^0$ ↳ $\pi^+\pi^-\pi^0$	< 30%
→ ρ^0 + neutrals	< 15%
→ $2\pi^+2\pi^-$ including $\rho^0\pi^+\pi^-$	< 25%
→ $2\pi^+2\pi^-\pi^0$ including $\rho^\pm\pi^\mp\pi^+\pi^-$ and $\omega\pi^+\pi^-$	< 7%
→ $\omega\pi^+\pi^-$	< 5%
→ $\omega\pi^0\pi^0$	< 10%
→ $\eta\pi^+\pi^-$	< 5%
→ $\eta\pi^0\pi^0$	< 10%
→ $\rho^+\rho^-$	< 45%
→ $\pi^+\pi^-$ + $m\pi^0$ ($m \geq 2$) → $\rho^\pm\pi^\mp$ + $m\pi^0$ ($m \geq 1$)	no positive evidence, upper limits model dependent

The upper limits were determined at 9 3 GeV for $|t| < 0$ 5 GeV^2. The rate of "B" → $\pi^+\pi^-$ + neutrals was taken from method (a), subsect 4.4. Similar limits were obtained at 4 7 GeV [5]

(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 $\boldsymbol{\pi}^+ \times \boldsymbol{\pi}^-$ of the π^+ and π^- directions as calculated in the "B" rest frame.

Fig. 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

* 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 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 $\boldsymbol{n}$
(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) $\hat{n} = \boldsymbol{\pi}^+ \times \boldsymbol{\pi}^-$, 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 $\Delta\psi = 3°$ (fwhh))
Then

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

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

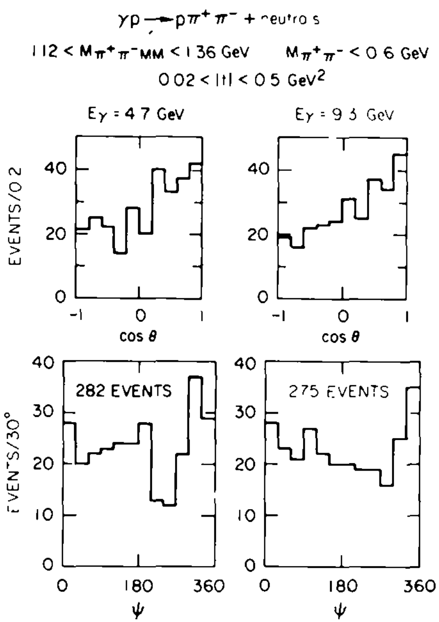

Fig. 9(a).

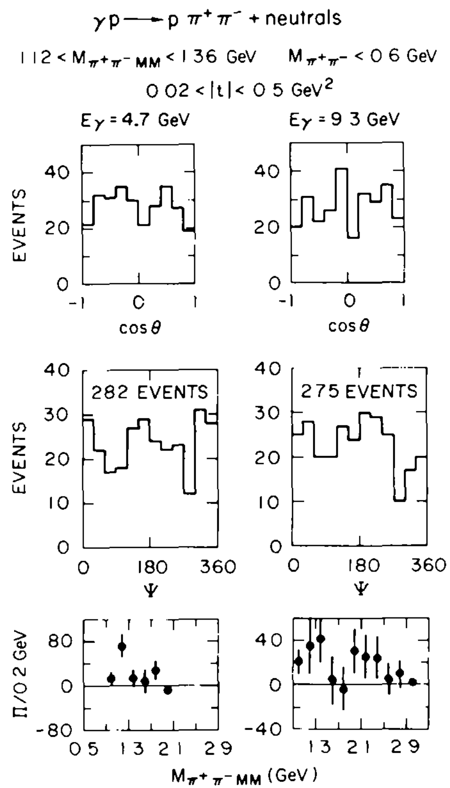

Fig. 9(b).

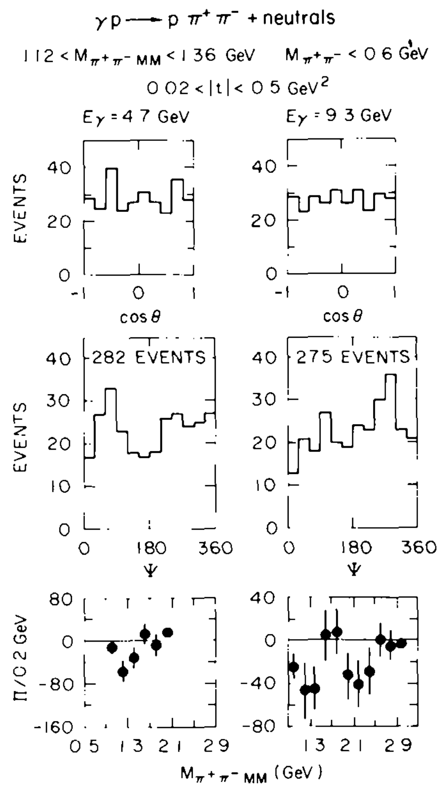

Fig. 9(c)

Fig. 9. Reaction $\gamma p \to p\pi^+\pi^-$ + 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 $M_{\pi^+\pi^-} < 0.6$ GeV, $1.12 < M_{\pi^+\pi^-MM} < 1.36$ GeV, $0.02 < t < 0.5$ GeV^2. The angles were calculated using the analyzers (a) (fig. 9(a)), (b) (fig. 9(b)) and (c) (fig. 9(c)) defined in the text (subsect. 4.3).

Table 2
Predicted signals in the decay distribution of "B" → $\omega\pi^0$ and "B" → $\rho^+\rho^-$ 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 [a]. (The symbols π, γ, ω, ρ denote the momenta of the respective particles, ϵ is the polarization vector of the photon. The subscripts indicate the frame in which the momenta are measured. The $(\omega-\pi^0)$ and $(\rho^+-\rho^-)$ terms are taken in the "B" rest system.)

	Decay mode	State J^P	Matrix element	Analyzer $\hat{\pi}^+(\pi^+\pi^-$ RS)		Analyzer $\pi^+ \times \pi^-$ ("B" RS)	
				Signal	Π efficiency	Signal	Π efficiency
(a)	$\omega\pi^0$ 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
(a)	$\omega\pi^0$ 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^-	$\epsilon \cdot (\pi_\rho^+ \times \pi_\rho^-) \times (\rho^+-\rho^-)$ [b]	$1 + 0.2 \sin^2\theta$ 1	+0.1	$1 + 0.5 \cos^2\theta$ $1 + \sin^2\psi$	0.4
(b)	$\rho^+\rho^-$ relative s wave	1^+	$(\epsilon \times \gamma)\ (\pi_\rho^+ \times \pi_\rho^-)$	$1 + 0.2 \cos^2\theta$ $1 + \cos^2\psi$	+0.3	$1 + 2.5 \sin^2\theta$ $1 + 4.5 \sin^2\psi$	−0.8

[a] 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 ($\Gamma_d \leqslant \frac{1}{2}\Gamma_s$). 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 figs. 9(b) and (c).

[b] The form of the matrix element used here is not unique since three angular momenta are being coupled.

$\omega\pi^0$ decay angular distribution in the "B" rest frame. The presence of a forward-backward asymmetry in the $\cos\theta$ 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

Figs. 9(b) and (c) show 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 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. Figs. 9(b) and (c) also give the amount of the $\sin^2\theta \cos^2\psi$ component in the angular distribution as determined from

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

Π 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 2 gives the calculated efficiencies for detecting signals in the distributions of θ, ψ and Π if the analyzers (b) and (c) are used. The predicted efficiency of Π 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 ± 90 for 1^- and 160 ± 50 for 1^+ at each energy. Within errors these numbers are compatible with the number of "B" events determined below (subsect. 4.4, method (a)).

A further examination of figs. 9(b) and (c) and of table 2 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".

4.4. 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 from $\gamma p \to \Delta^{++}\pi^-\pi^0\pi^0$ peak at high masses, also a contribution from $\gamma p \to p\rho'(1600) \to p\pi^+\pi^-\pi^0\pi^0$ would not yield any substantial contribution below $M_{\pi^+\pi^-\mathrm{MM}} = 1.3$ GeV There are, however, two sources of background which could be present at low $M_{\pi^+\pi^-\mathrm{MM}}$. (i) Non-diffractive $\gamma p \to p\omega\pi^0$. The reaction $\gamma n \to p\omega\pi^-$ has been observed at 4 3 GeV with a cross section of 1.4 ± 0 5 μb and a rather flat $\omega\pi^-$ mass distribution [7, 8]. A similar contribution is expected in the non-diffractive part of reaction $\gamma p \to p\omega\pi^0$ but is likely to die out with increasing energy (ii) Diffractive $\gamma p \to p\omega\pi^0$. Here backgrounds can contribute to $\gamma p \to p\omega\pi^0$ according to the diagrams shown in fig. 10.

The Drell-Deck diagrams (a) and (b) of fig 10 result in a predominantly $J^P = 1^+$

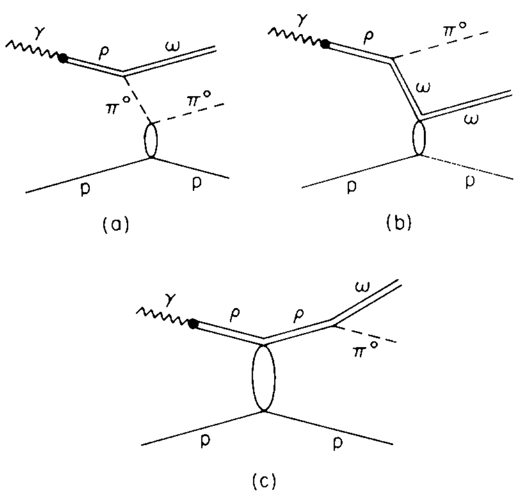

Fig. 10. Diagrams to describe diffractive $p\omega\pi^0$ backgrounds in the "B" region (a) and (b) are diagrams from a Deck-type mechanism, (c) $\pi\omega^0$ decay of the $\rho(760)$ tail.

$\omega\pi$ 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 Wolf [9] The predicted cross section decreases from 3 to 2 μb, 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 calculation [10] 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 unreggeized OPE calculation The background from diagram (c) is probably small in the B region [11]. 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 resolution folded in, upon a hand-drawn background curve. We use 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 $\gamma p \to p\pi^+\pi^-\pi^0\pi^0$, generated with e^{6t} by a Monte-Carlo program, (b) a mixture of the experimental distributions of reactions $\gamma p \to p2\pi^+2\pi^-$ and $\gamma p \to p2\pi^+2\pi^-\pi^0$ (fig 8(b), (c)), (c) contributions which extend to low masses like

Table 3
Production cross sections in the "B" region as determined from methods (a) and (b) (see subsect. 4.4). (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 subsect 4.4, including a correction for decays $\omega \to$ neutrals

	Method (a) $\lvert t \rvert < 0.5$ GeV^2 $\Gamma_B = 150$ MeV	Method (b) $\lvert t \rvert < 1$ GeV^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

$\gamma p \to p\omega\pi^0$,

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$^2 < 0.1$ GeV^2 (correction factor 1.07), events with $M_{\pi^+\pi^-} < 0.32$ or $M_{\pi^+\pi^-} >$ 0.6 GeV (factor 1.08), and for the unobserved decay modes of the ω (factor 1.11). The resulting cross sections are given in table 3. 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 $M_{\pi^+\pi^-\text{MM}}$ 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 Fig. 11(a) shows the $M_{\pi^+\pi^-\text{MM}}$ distribution for $\lvert t \rvert < 1$ GeV^2 after applying the missing mass cut MM < 0.9 GeV. Fig. 11(b) has an additional cut $M_{\pi^+\pi^-} < 0$ 6 GeV. Background curves were generated according to the following reactions

(i) peripheralized phase space $\gamma p \to p\pi^+\pi^-\pi^0\pi^0$ with $\exp(6t_{p/p})$,

(ii) reflection from peripheralized Δ^{++} production *via* $\gamma p \to \Delta^{++}\pi^-\pi^0\pi^0$ with $\exp(5.5t_{p/\Delta})$,

(iii) 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).

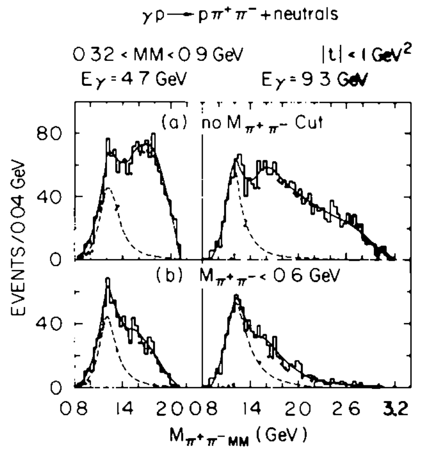

Fig. 11. Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 4.7 and 9.3 GeV. $\pi^+\pi^-$MM mass distribution for events with $0.32 < MM < 0.9$ GeV, $|t| < 1$ GeV^2 and (a) no $M_{\pi^+\pi^-}$ cut, (b) $M_{\pi^+\pi^-} < 0.6$ GeV. The curves are the results of fits according to method (b) (see subsect. 4.4). The dotted curve gives the sum of the contributions of $\rho'(1600)$ production, peripheralized phase space for $p\pi^+\pi^-\pi^0\pi^0$ and the process $\gamma p \to \Delta^{++}\pi^-\pi^0\pi^0$. 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.

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 $MM^2 > 0.1$ GeV^2 (as above) and for the cuts $MM < 0.9$ GeV and $M_{\pi^+\pi^-} < 0.6$ 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 3. 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 μb at 2.8 GeV and drop to about 1 μb at 9.3 GeV. 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.

4.5. Comparison with other experiments

The first evidence for an enhancement at 1.24 GeV in the missing mass recoiling against the proton in reaction $\gamma p \to p$ + anything was reported by Anderson et al. [12].

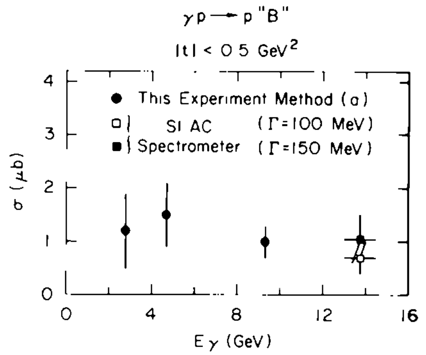

Fig. 12. Cross section of reaction $\gamma p \to p$"B" as a function of the incident photon energy The points labelled "This experiment" have been determined from method (a) (see subsect. 4.4) assuming a fitted "B" width of 150 MeV and an $\omega\pi^0$ background according to the OPE calculation of Wolf. The cross sections have been corrected for decays $\omega \to$ 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.

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 $0.3 < |t| < 0.7$ GeV^2 are given in the thesis of Kreinick [13]. The results of Kreinick have been confirmed by the same group in a recent measurement at $|t| = 0.6$ GeV^2 and E_γ = 8–15 GeV using a similar apparatus [14].

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, 13] with our "B". We have extrapolated the differential cross sections of ref. [13] using an exponential slope of 6 ± 2 GeV^{-2} (as derived from our t distribution, see below). The resulting cross section estimate is 0.7 ± 0.3 μb at E_γ = 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 ± 0 45 μb

Fig. 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" behaviour like in $\gamma p \to p\rho^0$ 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 beam [15].

4.6. *t distributions*

Fig. 13 shows the t distribution in the "B" region at 9.3 GeV. The t distributions

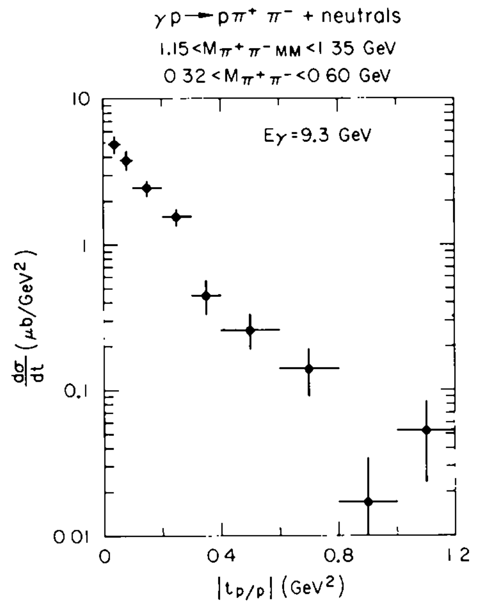

Fig. 13. Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 9 3 GeV Differential cross section $d\sigma/dt$ for events in the "B" region $1.15 < M_{\pi^+\pi^-MM} < 1\ 35$ GeV and $0.32 < M_{\pi^+\pi^-} < 0.6$ GeV. No background has been subtracted.

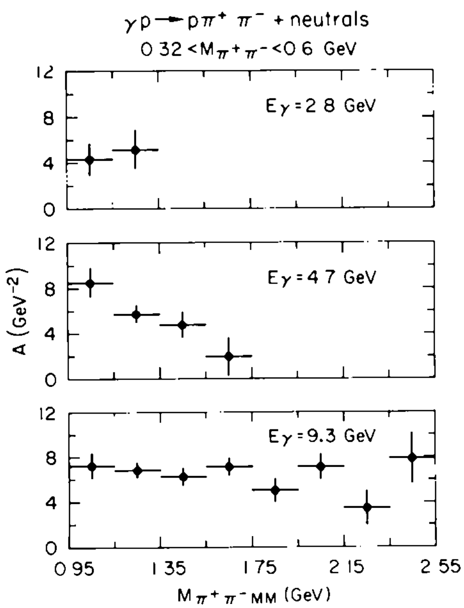

Fig. 14. Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 2.8, 4 7 and 9 3 GeV Slopes A of the t distribution from a fit of $\exp(At)$ to events with $0.32 < M_{\pi^+\pi^-} < 0.6$ GeV in the interval $0\ 02 < |t| < 0\ 4\ \text{GeV}^2$

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 μb/GeV^2 at 9.3 GeV

4.7 Discussion and conclusions

(i) We observe an enhancement at $M_{\pi^+\pi^-MM} = 1240 \pm 20$ 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* 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, A_1 and A_2 exchange. Then from G parity conservation only the $I = 0$ part (i.e., the ω part) of the photon can contribute This suppresses non-diffractive contributions by the ratio of the $\gamma\omega$ and $\gamma\rho$ coupling constants which is about $\frac{1}{9}$ In particular, an OPE calculation [16] of $J^P = 1^+$ B production yields $\sigma^{OPE}(\gamma p \to pB(1235)) \approx \frac{1}{10}\sigma^{OPE}(\gamma p \to p\omega)$, which amounts to 0.3, 0.1 and 0.01 μb at 2.8, 4.7 and 9.3 GeV, respectively, if the experimental unnatural parity exchange part of the ω-photoproduction cross section is used [1].

(b) No evidence has been found [7, 8] for non-diffractive B photoproduction *via* $\gamma n \to pB^-$. The upper limit of the cross section was measured to be $\sigma(\gamma n \to pB^- \to p\omega\pi^-) < 0.3$ μb (90% confidence level) [8] in the photon energy interval $2.5 < E_\gamma < 5.3$ GeV. Hence only minor non-diffractive contributions are expected in $\gamma p \to pB^0$ (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) The ρ tail. The "B" enhancement could be interpreted as the onset of the $\omega\pi^0$

* 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 non-existent This leaves $I^G = 1^+$ and $C = -1$.

or $\rho^+\rho^-$ decay of the $\rho^0(760)$. Kramer has calculated that the cross section for the process $\gamma p \to p\rho^0(760) \to p\omega\pi^0$ peaks at $M_{\pi^+\pi^-MM} = 1.1$ GeV and amounts to about 0.1 μb 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) A non-resonant Deck process. The Deck process $\gamma p \to p\omega\pi^0$ 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 non-resonant Deck process. The cross section for this Deck process is that given in table 3 using method (b).

(c) Production of genuine resonances (non-ρ tail). 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 $l = 1$ 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 3 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.

5. Search for the $\pi^+\pi^-$ + neutrals decay modes of the $\rho'(1600)$

The $\rho'(1600)$ has been observed in the channel $\gamma p \to p\pi^+\pi^+\pi^-\pi^-$ [2]. The production cross section was measured [2] as 1.6 ± 0.4 μb 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 $\rho' \to \rho\epsilon \to \pi^+\pi^-\pi^0\pi^0$ would be expected in channel (3) and decay modes such as $\rho' \to \omega\pi^0$ 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.

5.1. $\rho'(1600) \to \rho^0\epsilon \to \pi^+\pi^-\pi^0\pi^0$

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 $|t| < 0.5$ GeV^2. Fig. 15(a) shows the resulting $M_{\pi^+\pi^-MM}$ distribution. Pe-

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

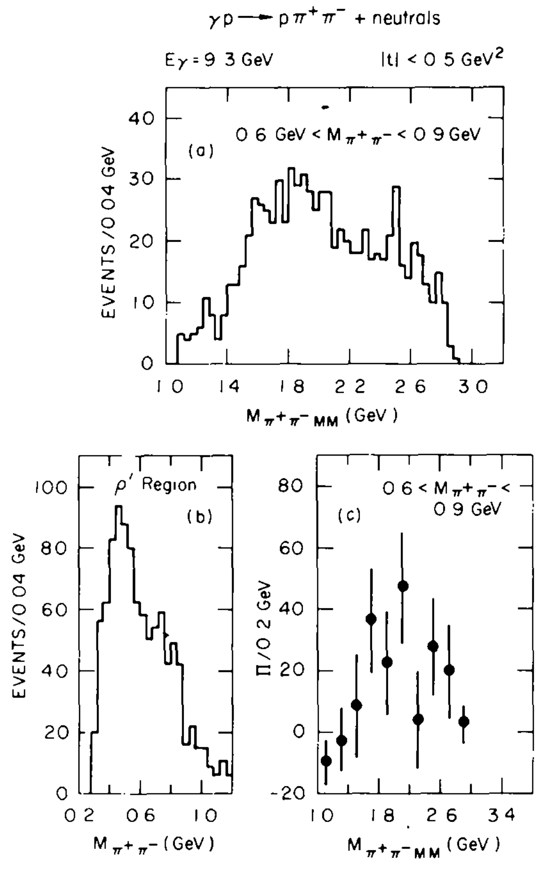

Fig. 15. Reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at 9.3 GeV for $|t| < 0.5$ GeV^2. (a) $\pi^+\pi^-$MM mass distribution for $0.6 < M_{\pi^+\pi^-} < 0.9$ GeV. (b) $\pi^+\pi^-$ mass distribution in the ρ' region $1.4 < M_{\pi^+\pi^-\mathrm{MM}} < 2.0$ GeV. (c) Distribution of Π in the helicity system for $0.6 < M_{\pi^+\pi^-} < 0.9$ GeV

ripheralized phase space with the same cuts would peak at 2.4 GeV. In contrast, fig. 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 $\gamma p \to p\rho' \to p\pi^+\pi^+\pi^-\pi^-$ one expects (after applying Clebsch-Gordan coefficients and the relevant cuts) 165 ± 50 events $\rho' \to \rho^0\epsilon \to \pi^+\pi^-\pi^0\pi^0$ in fig. 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. Fig. 15(b) shows the $M_{\pi^+\pi^-}$ distribution in the ρ' region $1.4 < M_{\pi^+\pi^-\mathrm{MM}} < 2$ GeV. Although the ρ signal is not prominent, it is compatible with the predicted size.

Next we study the decay distribution using the analyzer (b) and the angles defined in subsect. 4.3 The polarization information of a ρ' which is produced in an s-channel helicity conserving process and which decays into $\rho^0\epsilon \to \pi^+\pi^-\pi^0\pi^0$ 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. Fig. 15(c) shows the quantity Π (which measures the amount of $\sin^2\theta\ \cos^2\psi$ component). From the Π cross section in the reaction $\gamma p \to p\rho' \to p\pi^+\pi^+\pi^-\pi^-$ 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 fig. 15(c). Experimentally we find 65 ± 32 events in the same interval. We also observe a Π signal of 110 ± 32 events for $M_{\pi^+\pi^-MM} > 2$ GeV which is presently not understood

5.2. $\rho'(1600) \to \pi^+\pi^-$ + neutrals

In this section we give an upper limit for the ratio

$$R = \frac{(\rho' \to \pi^+\pi^- + \text{neutrals})}{(\rho' \to \pi^+\pi^-\pi^+\pi^-)} .$$

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 $|t| < 0.5$ 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 $\gamma p \to p\pi^+\pi^+\pi^-\pi^-$ that (a) the ρ' mass spectrum (as measured by Π) 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 $\gamma p \to p\pi^+\pi^-$ + 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. 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 ± 0.4 which gives an upper limit for the cross section (including $\rho^0\epsilon$) for $\gamma p \to p\rho' \to p\pi^+\pi^-$ + neutrals of 4 ± 1 μb

5.3. Conclusions

We have shown that there is a ρ^0 + neutrals signal in the channel $\gamma p \to p\pi^+\pi^-$ + neutrals which is compatible with the $\rho^0\epsilon$ decay of the $\rho'(1600)$. We have derived an upper limit for the cross section for $\gamma p \to p\rho' \to p\pi^+\pi^-$ + neutrals of 4 ± 1 μb at 9.3 GeV

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