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γp INTERACTIONS AT 5.25 GeV*

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ABSTRACT

Photoproduction of resonances has been studied using positron annihilation radiation at 5.25 GeV in the SLAC 40-inch hydrogen bubble chamber. Results are presented on the nonstrange particle events and related to the Vector Dominance Model.

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The present study represents a search for resonance production in photon-nucleon hadronic interactions using the SLAC monochromatic annihilation radiation beam[1] in the SLAC 40-inch HBC at 5.25 GeV. Preliminary results have already been reported[2, 3] at this energy and at 7.5 GeV. A similar study using the beam at 4.3 GeV has also been presented.[4] Where comparison is possible, these results are in substantial agreement with experiments done in Bremsstrahlung beams with the CEA[5] and DESY[6] bubble chambers and the SLAC streamer chamber[7].

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The results are based on about 260,000 pictures with an average flux of 60 photons above 4 GeV per picture. The film was double scanned at an overall scanning efficiency greater than 96%, and 10,000 events measured, of which 30% are due to annihilation photons. Details of the analysis method are given elsewhere.[2,3] We stress that since the annihilation photon energy is known to ± 1.5%, we have obtained at high energy a clean sample of events for the following reactions:

$\gamma p \to p\pi^+\pi^-$	(1)	$\gamma p \to p\pi^+\pi^+\pi^-\pi^-$	(4)
$\to p\pi^+\pi^-\pi^0$	(2)	$\to p\pi^+\pi^+\pi^-\pi^-\pi^0$	(5)
$\to n\pi^+\pi^+\pi^-$	(3)	$\to n\pi^+\pi^+\pi^+\pi^-\pi^-$	(6)

Cross sections for these reactions were determined by counting and measuring a sample of 17,000 positron-electron pairs within the event fiducial volume, and using a pair production cross section of 19.8 mb.[6] Where resonance production was detected, fits to phase space plus resonances and their reflections in other particle combinations were made using a least squares method. The resulting cross sections are summarized in Table I.

(1) Reaction $\gamma p \to p\pi^+\pi^-$

The $\pi^+\pi^-$ mass spectrum for this reaction is shown in Fig. 1(a), where the solid curve is a fit to the Ross-Stodolsky[8] form of the ρ^0 resonance, along with phase space and $\Delta^{++}(1236)$ resonance reflection as described below. A fit using the Söding[9] form for the spectrum is indistinguishable in spectral shape and gives the same $\rho^0 p$ cross section to within 5% (see Table I). Both fits give nearly the same mean resonance mass of 764 ± 3 MeV and width of 136 ± 8 MeV.

Figure 1(b) displays the squared momentum transfer (t) distribution to the proton for the events in the ρ band, normalized to σ(ρp). The decrease near t = 0 has been seen in previous HBC work,[4,5,6] but not in counter experiments[10]. We have observed that it is a function of photon flux and believe the effect is mainly due to a bias against seeing low energy recoil protons. Therefore we assume a purely exponential form and find

$$\frac{d\sigma}{dt}\,(\gamma p \rightarrow p\rho^{o}) = (136 \pm 14\ \mu b\ GeV^{-2})\ \exp\ (7.14 \pm 0.4\ GeV^{-2})\ t$$

Figure 1(c) shows evidence for the process $\gamma p \rightarrow \pi^{-}\Delta^{++}$ with the cross section given in Table I. This value and the t distribution are in excellent agreement with those of Boyarski et al[11] who used a single arm spectrometer and a missing mass technique.

The presence of f and g^{o} are not required to make an acceptable fit to the spectrum of Fig. 1(a), although up to 3% f(1260) is allowed. The upper limit for g^{o} (1650) production is 1%. When previously published HBC data[4,5,6] between E_{γ} = 3.5 and 5.8 GeV are combined with those of Fig. 1(a), the upper limit for g^{o} production remains about 1%. If the g-meson is a Regge recurrence of the ρ it might be expected to be produced by a diffractive ρ meson scattering process in a manner analogous to the reaction $pp \rightarrow p\ N^{*}$ (1688) which occurs with about 3% of the intensity of the elastic scattering[12], and the same fraction of g^{o} to ρ^{o} would result.

Using the Vector Dominance Model[13] (VDM) and neglecting ω and φ contributions, one can calculate the ρ^{o}- p elastic and total cross sections using the ρ^{o} photoproduction cross section at t = 0 and the γ-ρ coupling constant. If the coupling constant, $\gamma_{\rho}^{2}/4\pi$, is taken to be 0.5[14,15,16] our measured value of dσ/dt ($\gamma p \rightarrow \rho^{o}p$) implies that $\sigma_{el}(\rho^{o}p) = 5.3 \pm .5$ mb and $\sigma_{tot}(\rho^{o}p) = 27.5 \pm 1.7$ mb. These values are close to the mean of $\pi^{\pm}p$ scattering cross sections

(5.6 ± 1 mb and 28 ± 0.5 mb respectively) required by the simple quark model. Using $\gamma_\rho^2/4\pi = 1.1 \pm .1$[17,18] these values become $7.7 \pm .8$ and 40 ± 4 mb respectively.

(2) Reaction $\gamma p \rightarrow p\pi^+\pi^-\pi^0$

Figure 1(d) displays the $\pi^+\pi^-\pi^0$ invariant mass spectrum for this reaction and shows ωp production. The experimental width of the ω peak is $\pm$ 15 MeV, indicating the mass resolution of the experiment. In the t region 0.05 - 0.6 GeV^2, the momentum transfer distribution fits the form

$$\frac{d\sigma}{dt}\,(\gamma p \rightarrow p\omega) = (15 \pm 5 \quad \mu b\ GeV^{-2})\ \exp\,(8.2 \pm 1.4\ GeV^{-2})t.$$

The ratio of ρ^0 to ω forward cross sections is therefore 9 ± 3.5.

Other than ω, no evidence for resonances is apparent in the $\pi^+\pi^-\pi^0$ mass spectrum. Upper limits to A_1^0 and A_2^0 production are shown in Table I. Their absence is not unexpected as neither resonance can be produced under VDM by π^0 exchange because of isospin, and neither may be diffractively produced because of spin and C parity.

Evidence of ρ and of Δ production, as indicated in Table I, are found in this channel. The upper limit for $\rho^-\Delta^{++}$ associated production is 0.5 μb, in agreement with Ref. (6) but not with Ref. (4). Assuming that this reaction proceeds via the one pion exchange mechanism (OPE), with form factors determined in πp interactions[19], we find $\Gamma(\rho \rightarrow \pi\gamma) < 0.2$ MeV.

(3) Reaction $\gamma p \rightarrow n\pi^+\pi^+\pi^-$

This channel is interesting in that production of A_1^+ and A_2^+ may proceed by OPE under the VDM assumption, for which photoproduction cross sections of up to several microbarns have been predicted.[20] No such relatively strong signal is seen, as is demonstrated by Fig. 2(a), although the presence of some A_2^+ production is compatible with the data (see Table I). We have calculated the cross section expected for the process $\rho^o p \to A_2^+$ using the OPE model calculations of Wolf[19]. The ρ^o is taken to have zero mass and the VDM relation

$$\sigma(\gamma p \to nA_2^+) = \frac{\alpha\pi}{\gamma_\rho^2} 2\rho_{11}\ \sigma(\rho^o p \to nA_2^+)$$

is used, where ρ_{11} is the usual spin density matrix element for the ρ^o from A^+ decay, α is the fine structure constant and $\gamma_\rho^2/4\pi = 0.5$. The on-mass-shell $\rho^o - \pi^-$ scattering cross section entering into the OPE formula was put equal to

$$\sigma(\rho^o\pi^+ \to A \to \rho^o\pi^+) = 2.5\ \pi \lambda\!\!\!^{-2} \frac{m_A^2\ \Gamma_A^2}{(m^2 - m_A^2)^2 + m_A^2\ \Gamma_A^2}$$

with $m_A = 1.32$ GeV and $\Gamma_A = 0.03$ GeV, assuming A_{2H} production. The off-mass-shell corrections used the same r.m.s. radius as found for the f-meson[19]. The value of ρ_{11} was taken to be 0.5, its maximum value, as expected for a 2^+ particle decaying into $\rho\pi$. The resulting cross section is calculated to be 0.3 μb, consistent with the data.

Following a similar procedure for the A_1 meson ($\Gamma_A = 0.08$ GeV, $M_A = 1.07$ GeV), and assuming s wave $\rho\pi$ resonant scattering, we find $\sigma_{A1} = 1.1\ \mu$b for $\rho_{11} = 0.5$. However, for the decay of a 1^+ state into $\rho\pi$, ρ_{11} may be much smaller owing to a predominantly longitudinal ρ^o polarization[21]. Hence the non-observation of A_1^+ production may not necessarily be taken as evidence against the resonance interpretation of the effect, contrary to the suggestion of Poe et al[20].

(4) Reaction $\gamma p \to p\pi^+\pi^+\pi^-\pi^-$

This channel indicates ρ^o production, as shown in Fig. 2(b) where the shaded events are in association with the strong Δ^{++} signal in the $p\pi^+$ system.

In addition, Fig. 21(c) presents the $\pi^+\pi^-\pi^-$ spectrum for all combinations (unshaded) and for those combinations where the other π^+ is in the Δ^{++} region when associated with the proton. A three standard deviation enhancement at mass 1.32 GeV is apparent, and is mainly associated with Δ^{++}. The momentum transfer distribution to the Δ^{++} for events in the enhancement region is peripheral, about 80% of events having $t < 0.5$. The solid curves in Fig. 2(c) show a fit to phase space plus resonance with $M = 1.32$ GeV and $\Gamma = 0.03$ GeV, the parameters for "A_{2H}."

The A_{2H} may be produced under VDM by OPE, in a manner similar to that discussed under reaction (3). A calculation of the OPE cross section leads to $\sigma\ (\gamma p \to \Delta^{++}\ A_{2H}^-) \sim 0.4\ \mu b$, somewhat lower than but consistent with that observed. A calculation of the cross section for a 1^- spin parity leads to nearly the same predicted value. Although A_{2L} production is not actually excluded statistically, it is interesting to speculate that the suppression of A_{2L} might be attributed again to a longitudinal ρ meson coupling. In such a case a $J^P = 2^+$ or other normal parity assignment to A_{2L} would not be favored.

Independent of this enhancement, we find a contribution from the reaction

$$\gamma p \to \Delta^{++}\rho^0\pi^-$$

which accounts for 30% of reaction (4). However, no structure is found in the $\Delta^{++}\pi^-$ or $\Delta^{++}\rho^0$ spectra for these events.

(5) Reaction $\gamma p \to p\pi^+\pi^+\pi^-\pi^-\pi^0$

A strong Δ^{++} signal, similar to that found in reaction (4) is seen in the $p\pi^+$ system, as well as ω^0 production in the $\pi^+\pi^-\pi^0$ mass spectrum shown in Fig. 2(d). Most of the ω^0 production is in association with the Δ^{++}. No evidence for B or g meson production is found in the $\omega^0\pi^\pm$ combinations.

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TABLE I

REACTION AND RESONANCE PRODUCTION CROSS SECTIONS AT 5.25 GeV

Reaction	$\sigma(\mu b)$	Resonances	$\sigma(\mu b)$[a]	Reaction	$\sigma(\mu b)$	Resonances	$\sigma(\mu b)$
$\gamma p \to p\pi^+\pi^-$	22.4±1.0[b]	ρ^0	18.5 ±0.6[b]	$\gamma p \to n\pi^+\pi^+\pi^-$	10.2±0.6	Δ^-	<1.0
		Δ^{++}	1.7 ±0.4			ρ^0	0.8 ± 0.4
		$f^0 \to 2\pi$	< 0.5			A_1^+	<0.1
		$g^0 \to 2\pi$	< 0.1			A_2^+	$0.4 \pm .2$
$\gamma p \to p\pi^+\pi^-\pi^0$	18.4±1.0	ω^0	2.0 ±0.5[b][c]	$\gamma p \to p\pi^+\pi^+\pi^-\pi^-$	6.4±0.5	Δ^{++}	3.3±0.8
		Δ^{++}	2.5 ±0.8			ρ^0	2.7±0.8
		ρ^-	2.3 ±0.7			A_2^-	1.2±0.4
		Δ^+	1.7 ±0.5			A_1^-	<1.4
		ρ^0	0.7 ±0.6			$\Delta^{++}A_2^-$	0.7±0.3
						$\Delta^{++}\rho^0$	1.3±0.6
		Δ^0	0.3 ±0.3			$g^0 \to 4\pi$	<1.0
		ρ^+	2.8 ±1.0	$\gamma p \to p\pi^+\pi^+\pi^-\pi^-\pi^0$	10.3±0.6	Δ^{++}	3.9±1.5
		$\Delta^{++}\rho^-$	< 0.5			ω^0	1.5±0.4
		$\Delta^+\rho^0$	0.4 ±0.4			ρ^0	~2.8
		$\Delta^0\rho^+$	0.0 ±0.5			A_1^0	$\lesssim 2.5^{+.8}_{-2.5}$
		A_1^0	< 0.4			$\Delta^{++}\omega^0$	0.5±0.2
						$B^- \to \omega\rho\pi^-$	<0.4
		A_2^0	< 0.4			$g^- \to 4\pi$	<2.0
				$\gamma p \to n3\pi^+2\pi^-$	4.7±0.4		

(a) Single resonance cross section included associated resonance production, < means 90% C.L.

(b) Corrected for forward loss in scanning (see text).

(c) Corrected for neutral decay modes.

FIGURE CAPTIONS

1. a) Invariant mass spectrum of dipions in reaction (1). The curve is the best fit to the Ross-Stodolsky resonance form for ρ^o production plus phase space and $\Delta^{++}(1236)$ reflection.

   b) Differential cross section versus four momentum transfer squared from photon to ρ^o for reaction (1), using the fit values in (a). The fitted curve is the exponential form described in the text.

   c) π^+p invariant mass spectrum for reaction (1) with the best fit curve $\Delta^{++}(1236)$, ρ^o reflection and phase space.

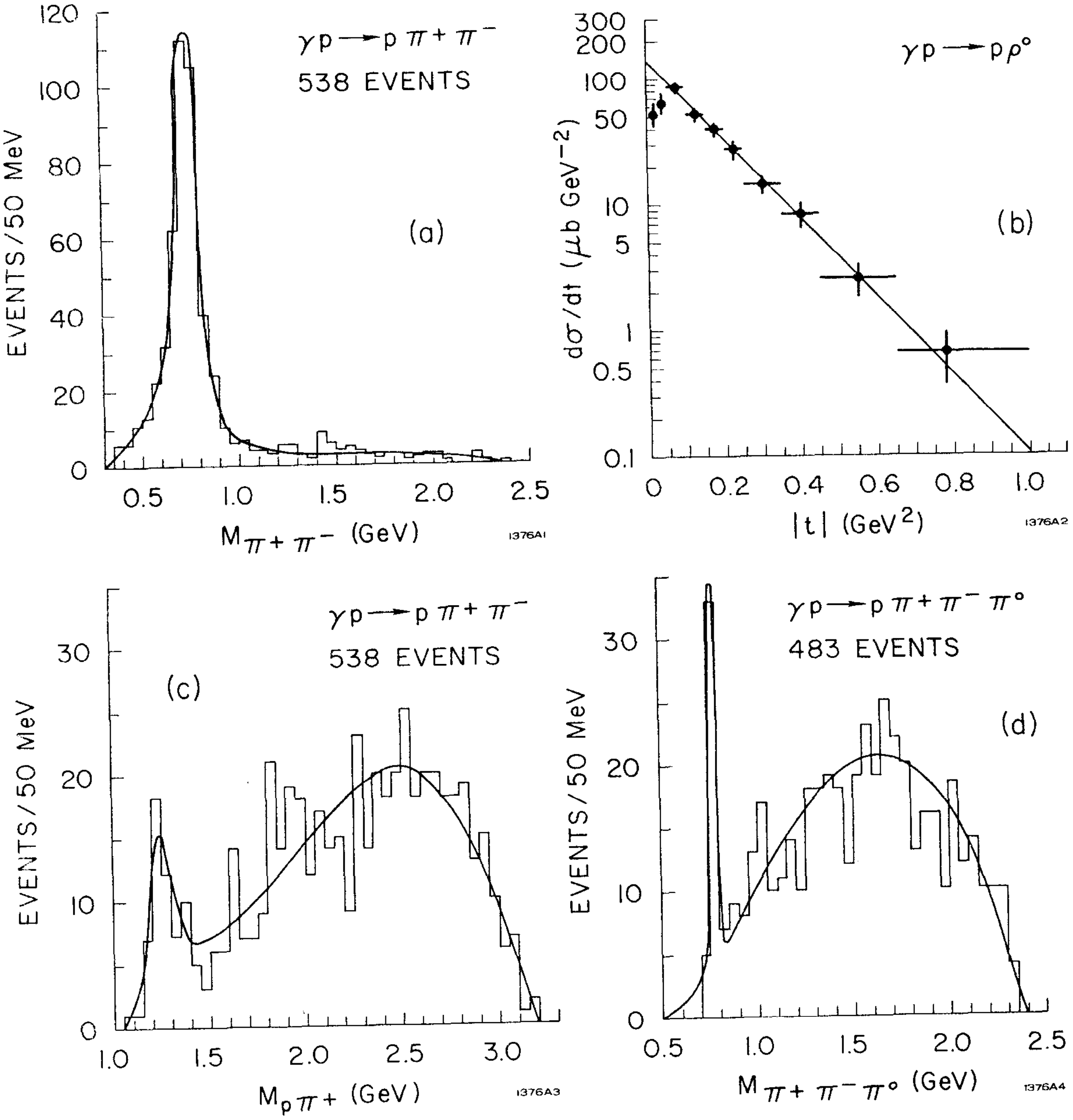
   d) $\pi^+\pi^-\pi^o$ mass spectrum for reaction (2) with the fit curve for ω^o production and phase space plus reflections of Δ and ρ in the amounts shown in Table I.

2. a) $\pi^+\pi^+\pi^-$ mass spectrum for reaction (3). The curve is a pure phase space distribution normalized to all events.

   b) $\pi^+\pi^-$ mass spectrum for reaction (4) for all events (four combinations per event) with the best fit for the ρ^o, phase space and the resonance reflection fractions of Table I. The shaded histogram shows $\pi^+\pi^-$ masses in association with $\Delta^{++}(1236)$ production (two combinations per event). The number of events with two $\Delta^{++}(1236)$ combinations is negligible.

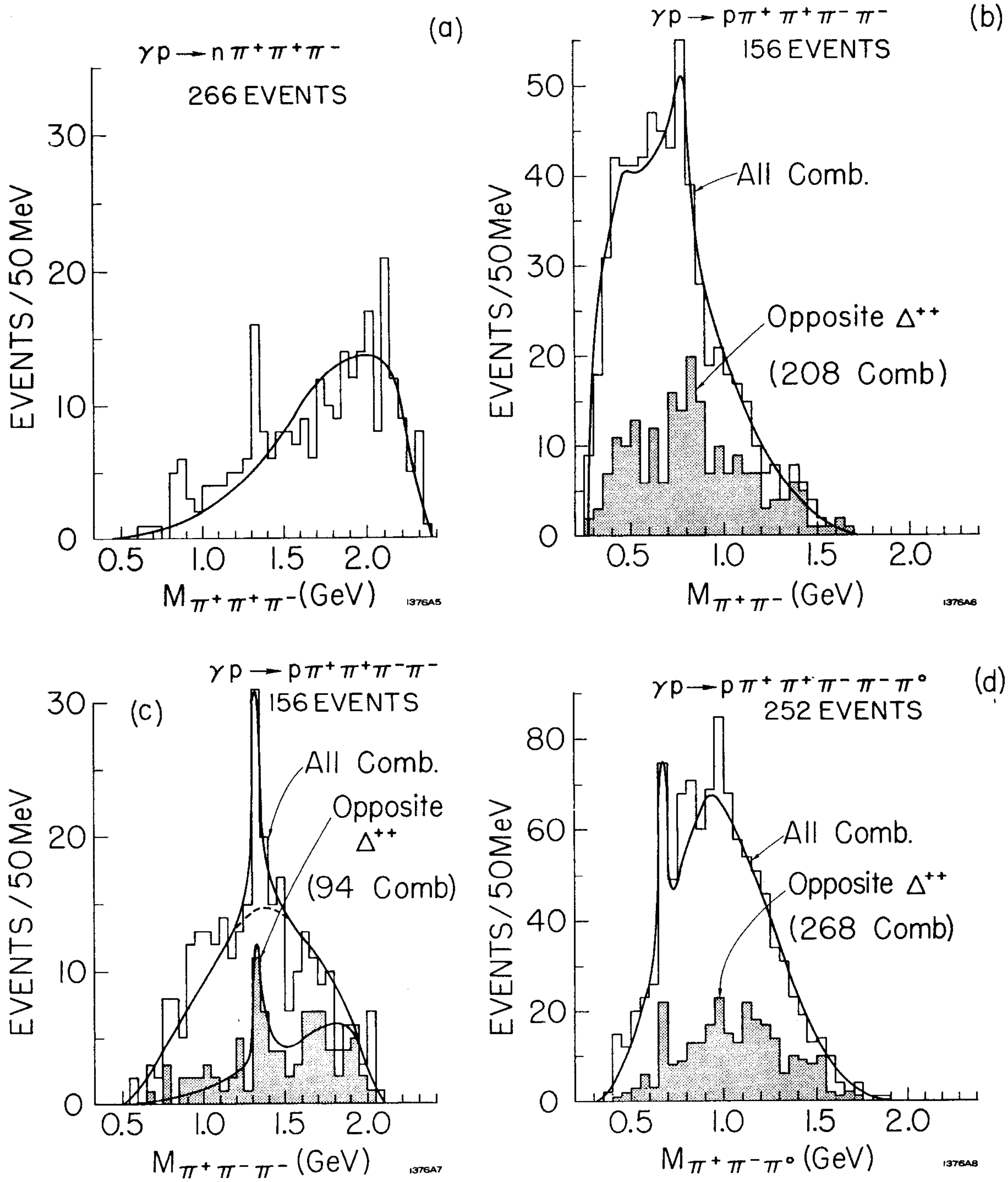
   c) $\pi^+\pi^-\pi^-$ masses for all events of reaction (4) shown unshaded, with those opposite $\Delta^{++}(1236)$ shaded. The curves are for the fits described in the text.

   d) $\pi^+\pi^-\pi^o$ mass distribution for reaction (5). All four possible combinations are shown unshaded, while those recoiling opposite a $p\pi^+$ pair in the $\Delta^{++}(1236)$ region are shown shaded. The curve again represents the fit with the resonance fractions shown in Table I.



γp → pπ+π−
538 EVENTS
(a)
EVENTS/50 MeV
Mπ+π− (GeV)
1376A1
γp → pρ°
(b)
dσ/dt (μb GeV−2)
|t| (GeV2)
1376A2
γp → pπ+π−
538 EVENTS
(c)
EVENTS/50 MeV
Mpπ+ (GeV)
1376A3
γp → pπ+π−π°
483 EVENTS
(d)
EVENTS/50 MeV
Mπ+π−π° (GeV)
1376A4

Fig. 1



γp → nπ⁺π⁺π⁻
266 EVENTS
(a)
EVENTS / 50 MeV
M π⁺π⁺π⁻ (GeV)
1376A5
γp → pπ⁺π⁺π⁻π⁻
156 EVENTS
(b)
All Comb.
Opposite Δ⁺⁺
(208 Comb)
M π⁺π⁻ (GeV)
1376A6
γp → pπ⁺π⁺π⁻π⁻
156 EVENTS
(c)
All Comb.
Opposite Δ⁺⁺
(94 Comb)
M π⁺π⁻π⁻ (GeV)
1376A7
γp → pπ⁺π⁺π⁻π⁻π°
252 EVENTS
(d)
All Comb.
Opposite Δ⁺⁺
(268 Comb)
M π⁺π⁻π° (GeV)
1376A8

Fig. 2