# PARTIAL PHOTOPRODUCTION CROSS SECTIONS UP TO 12 GeV †

by

J. Ballam, G. B. Chadwick, Z. G. T. Guiragossian, P. Klein,
A. Levy,* M. Menke, E. Pickup, T. H. Tan, P. Seyboth,** and G. Wolf***
Stanford Linear Accelerator Center
Stanford University, Stanford, California

## ABSTRACT

The SLAC 40-inch HBC has been exposed to positron-electron annihilation radiation at 5 and 7.5 GeV, which was superimposed upon a background of Bremsstrahlung radiation with 12 GeV maximum energy. Reaction cross sections for events with no neutral particles are presented for all energies up to 12 GeV, for one neutral at 5 and 7.5 GeV, and for multineutral production at 7.5 GeV.

We report here the results obtained from a study of $\gamma p$ interactions produced by the SLAC annihilation beam in the SLAC 40" HBC. The special feature of this experiment is that the use of positron annihilation radiation allows a clean separation of events with a single neutral particle from multineutral events.

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The experimental arrangement, and details of the analysis, have been given in another paper.[1] So far $10^6$ pictures have been taken with this beam setup under various conditions and 180,000 have been analyzed to date:

I 60,000 pictures with 10 GeV $e^+$, 5.2 GeV annihilation energy

II 60,000 pictures with 12 GeV $e^+$, 7.5 GeV annihilation energy

III 60,000 pictures with 12 GeV $e^-$, Bremsstrahlung

We present combined results from these three different exposures on the following reactions which can be completely analyzed:

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

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

$$\rightarrow n\, 2\pi^+\pi^- \quad (3)$$

$$\rightarrow p\, 2\pi^+\, 2\pi^- \quad (4)$$

$$\rightarrow p\, 2\pi^+\, 2\pi^-\, \pi^0 \quad (5)$$

$$\rightarrow n\, 3\pi^+\, 2\pi^- \quad (6)$$

The separation of reactions with a single neutral particle from those with more than one is made possible at 5 and 7.5 GeV by the small energy uncertainty of the annihilation peak in the photon beam energy spectrum. For reactions with no missing neutrals, we are further able to obtain cross sections up to 12 GeV.

Annihilation Spectrum

The photon spectrum produced by high energy positrons on hydrogen at a given production angle consists of an annihilation peak superimposed upon a Bremsstrahlung spectrum. The relation between annihilation photon energy $E_\gamma$, production angle $\theta$, and positron energy $E_+$ is

$$E_\gamma = \frac{E_+}{1 + \frac{E_+}{2m}\theta^2} \quad (7)$$

where m is the electron mass and $E_+ \gg m$.

Owing to the finite acceptance $\Delta\theta$ in photon production angle, the annihilation photons have an energy spread about the nominal value. However, by measuring the position of the interaction point in the chamber, the photon production angle could be determined with a precision independent of the angular acceptance, using formula (7). The parameters were $E_+ = 10.0 \pm 0.05$ GeV, $\theta = 9.4$ mrad, $\Delta\theta = \pm 0.65$ mrad, $E_\gamma = 5.2 \pm 0.3$ GeV for Exposure I, and $E_+ = 12.0 \pm 0.06$ GeV, $\theta = 7.15$ mrad, $\Delta\theta = \pm 0.45$ mrad, for Exposures II and III ($E_\gamma = 7.5 \pm 0.4$ GeV). The uncertainty in the calculated energy arising from finite positron spot size, positron beam divergence, and multiple scattering in the hydrogen radiator, is $\pm$ 1.6%.

In Exposure I, one prong events were not recorded. Otherwise, the scanning and measuring procedures for pairs and events were the same for all three exposures and have been described in another paper.[1] Geometrical reconstruction and kinematic analysis were performed using the TVGP-SQUAW system, and fits inconsistent with ionization were rejected by visual inspection. The number and energy distribution of photons traversing the chamber was determined by counting and measuring a sample of the $e^+e^-$ pairs produced within the event volume, and using the known pair production cross sections. The pair spectrum found for Exposures II and III were presented in reference 1.

The number of events with 3 and 5 prong topologies (without strange particle decays) in the various exposures were

| | | | |
|---|---|---|---|
| 3 prong | 1413 (5.2 GeV $e^+$) | 1690 (7.5 GeV $e^+$) | 1290 (7.5 GeV $e^-$) |
| 5 prong | 183 | 266 | 82 |

Of these, 93.4% gave a successful geometrical reconstruction. Kinematic fits were made to the appropriate reactions (1) - (6).

Separation of reactions:

For reactions (1) and (4) where there is no missing neutral particle, the photon energy can be determined uniquely through a 3 constraint fit (3C). Any event fitting to reaction (1) or (4), and satisfying the ionization criterion, was accepted as a genuine 3C event. Fake calculations[2] have shown that (a) no 3 or 5 prong events involving neutrons will fit the 3C hypothesis, (b) the contamination of reaction (1) by single and multiple $\pi^0$ events is less than 5%, and (c) the contamination of reaction (4) is negligible.

In separating single $\pi^0$ events produced by annihilation photons, one is faced with two problems. The first is the same as encountered in charged particle beam experiments, namely contamination from multineutral particle production by the annihilation photons owing to finite measuring accuracy. The second is the elimination of false fits coming from events due to Bremsstrahlung photons. The procedure used to effect the separation was to compare the hypothesis with one constraint (1C) and zero constraints (0C).

The 1C fit assumes production by an annihilation photon, while the OC fit allows any photon energy. For genuine events, the photon energies from 1C and OC fits must agree. Fig. 1 shows the distribution of the differences between 1C and OC determinations of photon energy for the reactions (2), (3), (5) and (6) from the 5 and 7.5 GeV exposures. As can be seen, the distributions peak sharply at zero, indicating a clean separation of single neutral production. The arrows indicate cut-offs used for determining the corresponding cross sections. After use of the ionization criterion, less than 15% of these events were ambiguous between single neutron and $\pi^0$ production. These were divided on the basis of $\chi^2$.

Cross sections for reactions

(a) $\gamma p \rightarrow p\pi^+\pi^-$

Fig. 2a shows the cross section for this reaction as a function of photon energy. From 4 to 12 GeV the cross section remains rather constant. Below 5.8 GeV the cross section values are in agreement with those found in the CEA[3] and DESY[4] experiments, and are consistent over our range with the more recent SLAC streamer chamber results.[5]

Fig.2b shows the $\pi^+\pi^-$ mass distribution for photon energies between 5 and 8 GeV, in which $\rho^0$ production clearly predominates. Averaged over the annihilation peak regions the $\rho^0$ production cross section are 16 ± 2.5 μb at 5.2 GeV and 14 ± 2.5 μb at 7.5 GeV.

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

Fig. 2c shows the cross section for this reaction as a function of photon energy. It reaches a roughly constant value ~ 5 μb above 3 GeV. Also shown in Fig. 2c are cross-section values as predicted by Satz who relates this reaction to the analogous πp and pp reactions using the vector-dominance model and a quark model.[6] The theoretical cross sections agree with the measured values.

(c) Single neutral production

For these reactions we can report cross sections only at the annihilation peaks. These are presented in Table I. The ratio between $\pi^0$ and neutron associated events is about 2, reminiscent of πp interactions. The cross section for reactions (2) and (3) decrease substantially between 5 and 7.5 GeV, in contrast to those of reactions (5) and (6).

(d) Multineutral production

At 7.5 GeV, the cross section for multineutral events may be deduced by counting the numbers of 3 and 5 prong events not assigned a 1C or 3C interpretation, and subtracting those of the $e^-$ exposure from those of the $e^+$ exposure. The technique, and corrections applied, are as described in another paper,[1] except that the events have been divided as far as possible into proton and neutron associated events on the basis of track ionization (ambiguous events were divided equally). The resulting cross sections are shown in Table I.

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TABLE I

Partial cross sections

| | $E_\gamma$ = 5.2 GeV | $E_\gamma$ = 7.5 GeV |
|---|---|---|
| $\gamma p \to p\pi^+\pi^-$ | 19.8 ± 2.8 | 16.0 ± 2.0 |
| $\to p\pi^+\pi^-\pi^0$ | 20.8 ± 3.6 | 10.9 ± 2.3 |
| $\to n2\pi^+\pi^-$ | 11.2 ± 2.4 | 7.3 ± 1.7 |
| $\to p\pi^+\pi^-\pi^0\pi^0 \ldots$* | | 30 ± 7 |
| $\to n2\pi^+\pi^-\pi^0 \ldots$* | | 14 ± 6 |
| $\to p2\pi^+2\pi^-$ | 5.5 ± 1.5 | 4.2 ± 1.1 |
| $\to p2\pi^+2\pi^-\pi^0$ | 8.6 ± 2.6 | 13.2 ± 3.8 |
| $\to n3\pi^+2\pi^-$ | 3.3 ± 1.2 | 3.4 ± 1.3 |
| $\to \begin{pmatrix} p2\pi^+2\pi^-2\pi^0 \ldots \\ n3\pi^+2\pi^-\pi^0 \ldots \end{pmatrix}^*$ | | 18.2 ± 3.1 |
| $\gamma p \to p\rho^0$ | 16.0 ± 2.5 | 14.4 ± 2.5 |

*More than one neutral particle

## Figure Captions

Figure 1 Difference between photon energy found in 1C and OC fits to reactions with missing neutral particles at 5.2 and 7.5 GeV. The arrows indicate the cut-offs used in calculation of cross sections. Events with |difference| > 1.4 GeV are not shown. They were rejected as 1C events.

Figure 2a. Cross section for reaction (1) as a function of photon energy. Data is compiled from Exposures I, II, and III.

b. Mass spectrum of $\pi^+\pi^-$ pairs from reaction (1) for photon energies 5-8 GeV. Data is combined from all exposures.

c. Cross section for reaction (4) as a function of photon energy, data combined from all exposures.

## References


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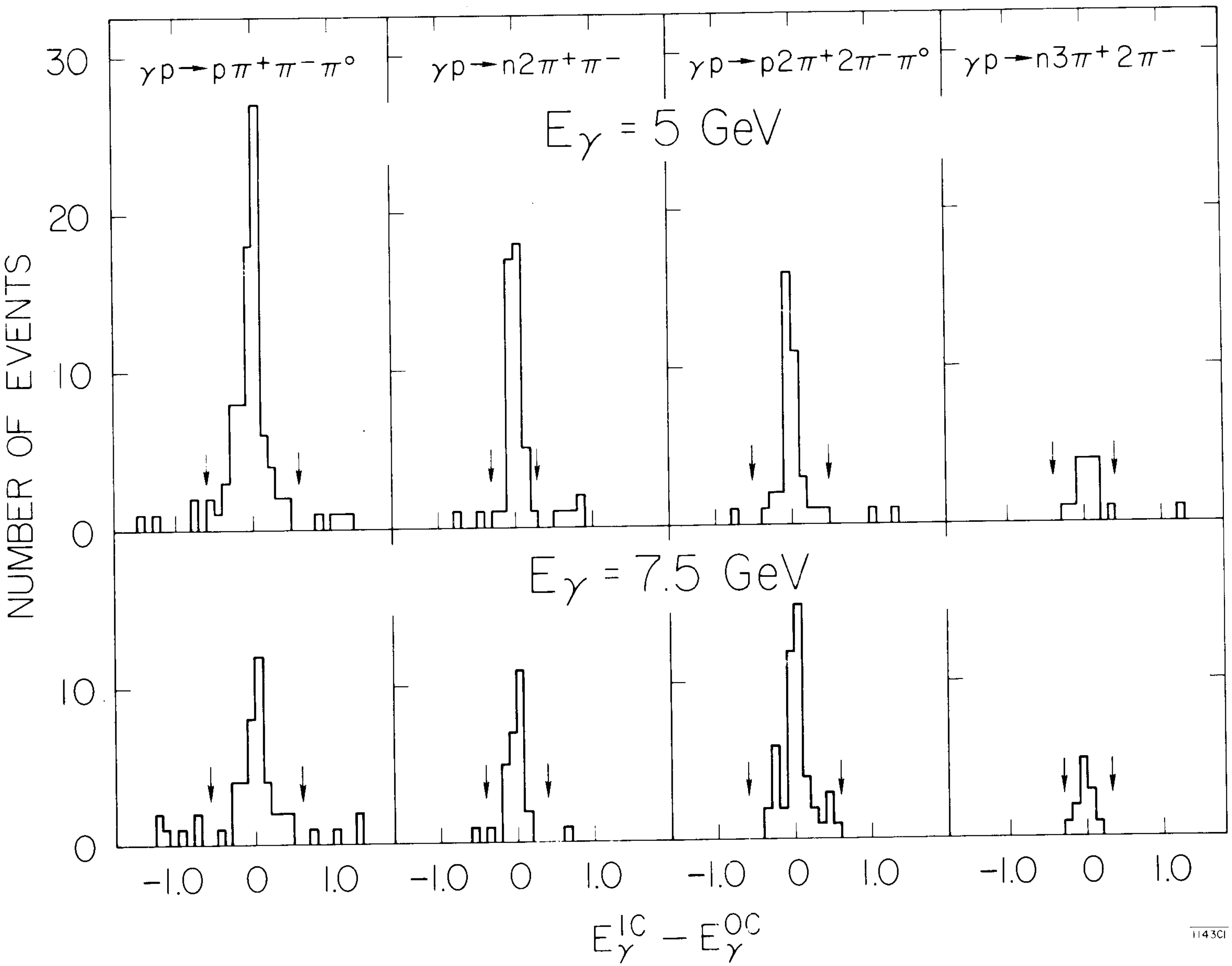

NUMBER OF EVENTS
$\gamma p \rightarrow p\pi^+\pi^-\pi^\circ$
$\gamma p \rightarrow n2\pi^+\pi^-$
$\gamma p \rightarrow p2\pi^+2\pi^-\pi^\circ$
$\gamma p \rightarrow n3\pi^+2\pi^-$
$E_\gamma = 5$ GeV
$E_\gamma = 7.5$ GeV
30
20
10
0
10
0
−1.0 0 1.0
−1.0 0 1.0
−1.0 0 1.0
−1.0 0 1.0
$E_\gamma^{IC} - E_\gamma^{OC}$
1143C1


Fig. 1

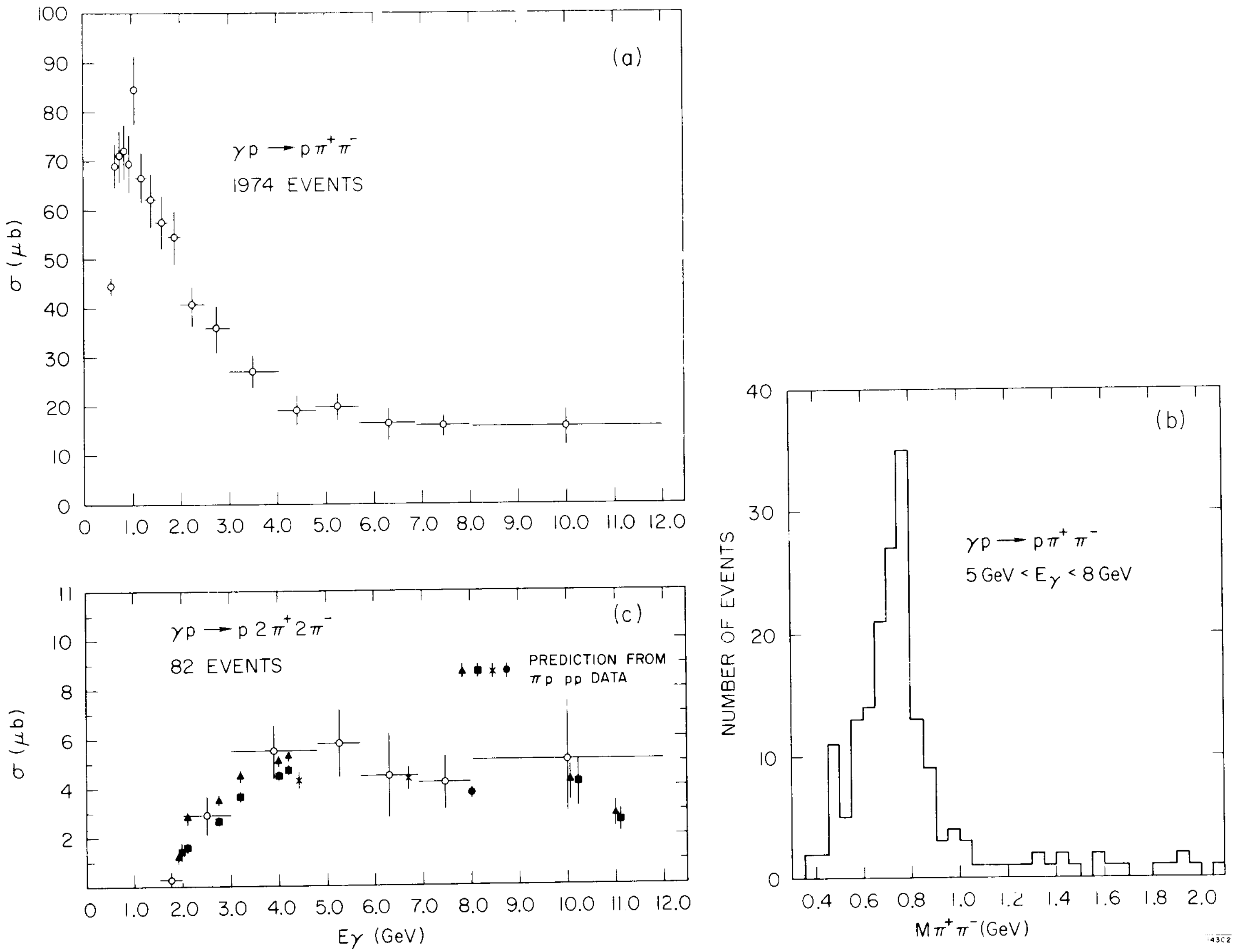
(a)
γp → pπ⁺π⁻
1974 EVENTS
σ (μb)
(c)
γp → p 2π⁺2π⁻
82 EVENTS
PREDICTION FROM
πp pp DATA
Eγ (GeV)
(b)
γp → pπ⁺π⁻
5 GeV < Eγ < 8 GeV
NUMBER OF EVENTS
Mπ⁺π⁻ (GeV)

Fig. 2