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.

We gratefully acknowledge the assistance of the following people in preparing this experiment: J. Pine, H. deStaebler, R. Miller, and G. Loew for work on the positron beam, R. R. Larsen, A. Kilert, and the Research Area Department for work on the annihilation beam, W. B. Johnson and D. W. G. S. Leith for help with beam testing, R. Watt and the bubble-chamber design and operating groups, and our scanners and supervisors for their excellent and enthusiastic work. In addition we thank Y. Eisenberg for many discussions.

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γ-p TOTAL HADRONIC CROSS SECTIONS AT 7.5 GeV*

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The total hadronic γp cross section has been measured using 7.5-GeV positron-electron annihilation radiation in a hydrogen bubble chamber. A value of 126 ± 17 μb is found, excluding reactions with only one charged particle (~3 μb).

We report a measurement of the total hadronic γp cross section $\sigma_{\gamma p}{}^{\text{tot}}$ at 7.5 GeV. The method used was to expose the Stanford Linear Accelerator Center 40-in. hydrogen bubble chamber to high energy positron-electron annihilation radiation (plus a background of wide-angle bremsstrahlung) and to subtract out the bremsstrahlung contribution by making an identical exposure using electron-induced radiation instead of that from positrons. We find $\sigma_{\gamma p}{}^{\text{tot}} = 126 \pm 17$ μb if we neglect reactions with one charged particle.

Beam. – The layout of the beam is shown in Fig. 1. A positron or electron beam of 12 GeV/c momentum with a spread of ±0.5% traverses a 15-cm liquid-hydrogen target and is dumped into a shielding mass. At the target cell the spot was about 3 mm in diameter. The e^+ or e^- beam position and direction were kept to $<10^{-4}$ rad by checking the toroid position monitors $P36$ and $2P1$. Photons produced at an angle of 7.15 mrad pass through the collimators $C0$, $C1$, and $C2$ (altogether 140 radiation lengths) and enter the 40-in. hydrogen bubble chamber. Charged particles are removed by three sweeping magnets, and the low-energy photon component is suppressed by 1 radiation length of lithium hydride placed in a magnetic field. The beam cross section at the bubble chamber was 42×6.5 cm^2.

Bubble Chamber. – The Stanford Linear Accelerator Center 40-in. hydrogen bubble chamber has a visible volume 1 m in diameter and 0.5 m in depth, and a magnetic field of 26 kG. A Scotchlite-lined piston provides bright field illumination. A study of a zero-field exposure to charged

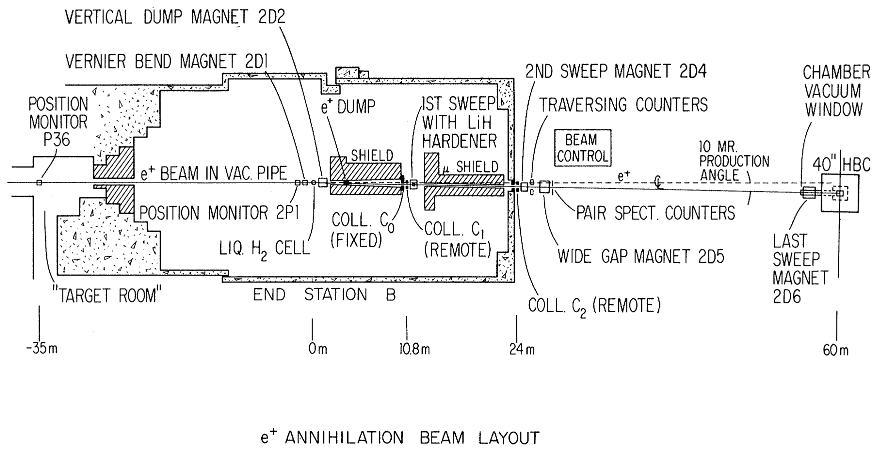

FIG. 1. Layout of the positron annihilation beam used in the experiment.

particles showed that the maximum detectable momentum is >400 GeV/c. The chamber was operated between 1 and 1.5 cps.

Scanning and Measuring.—A total of 90 000 photographs were taken in the positron run, and 60 000 in the electron run. The results reported are based on analyses of 60 000 pictures of each kind. Two independent scans were made for all pictures and discrepancies were resolved before measuring. In order to insure the same efficiency for each type of film, a similar density of pairs per picture was used, and the e^+ and e^- rolls were scanned alternately. The photon flux and spectrum were determined by counting and measuring e^+e^- pairs of energy above 100 MeV within the event fiducial volume. In the e^+ pictures the number of pairs per picture was 14.6; in the e^-, 12.4. The difference here is mainly due to annihilation pairs which produce very little additional obscuration of the photographs.

All event topologies, including one- and two-prong types (the latter may represent a three-prong with a very low-energy proton), were recorded. One-prong events were analyzed on only 30 000 pictures of each exposure. The events were measured, the geometrical and kinematic analysis performed by the TVGP-SQUAW system, and results checked by physicists at the scanning table. In this way events produced outside the beam dimension could be rejected, Dalitz pairs detected, and scattered particles distinguished from true events. Using the reaction $\gamma p \rightarrow p\pi^+\pi^-$ the measurements also allowed an independent check of pair scan, event scan, and analysis over the part of the photon energy range for which the reaction cross sections have already been reported.[1,2]

Results.—The energy spectra determined from 6675 pairs measured in the e^+ exposures and from 6057 pairs in the e^- exposure are shown in Fig. 2. The bremsstrahlung and annihilation components in the e^+-induced spectrum are evident. We note here that the annihilation photons have an energy of 7.5 ± 0.4 GeV, but the energy for each individual event can be determined to ± 0.12 GeV from its position in the chamber as described in another paper.[3] In Fig. 2 the e^- pairs are weighted by a factor 0.992 to give same number of pairs between 0.4 and 5.0 GeV that were found in the e^+ spectrum. It can be seen that the bremsstrahlung contributions in both cases agree well in spectral shape, so that the subtraction of bremsstrahlung events from the e^+ exposure can be made in an unambiguous way.

The numbers of events found for the various topologies are shown in Table I, as well as the corrections applied for scanning efficiency, for events out of beam, and for the difference in total bremsstrahlung flux in the e^+ and e^- exposures. The scanning efficiency as calculated in the standard way from two scans is better than 99% averaged over all topologies. No distinction between strange and nonstrange particles was made. The cross sections given in Table I for the various topologies have been calculated using the difference in numbers between e^+- and e^--induced pairs above 5.0 GeV and a cross section of 19.8 mb for pair production in hydrogen.[2]

The most abundant topology is that of the one-prongs, where about 80% of the events are due to single-pion production by photons below 0.5 GeV.[4] Because of this, the error on the one-

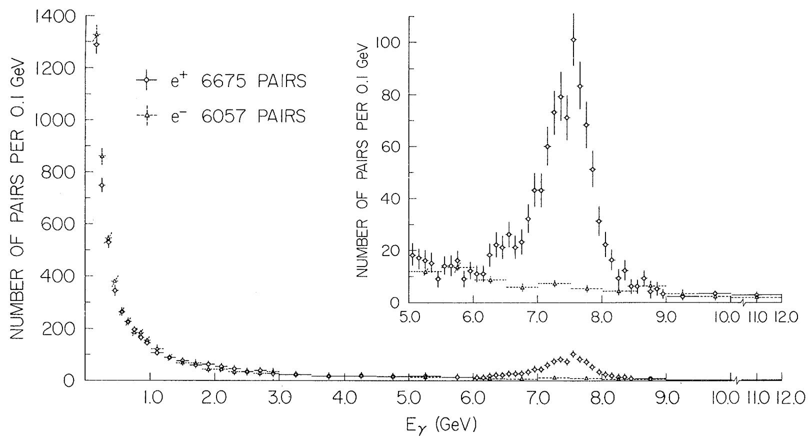

FIG. 2. Measured pair spectrum for e^+- and e^--induced radiation. The e^+-induced spectrum is that actually measured while the e^- has been normalized to have a bremsstrahlung component equal to that of the e^+ spectrum in the energy interval 0.4–5.0 GeV. The inset shows the annihilation enhancement at ~7.5 GeV.

prong cross section at 7.5 GeV is rather large. In addition, corrections had to be made for a background of events not produced by photons in the beam. These are made by neutrons produced in beam collimators, and by secondary bremsstrahlung photons. The number of background events produced within the beam region has been estimated from extrapolation of the number of events found outside the beam volume.

There is a slight excess of pairs found in the e^- exposure over that of the e^+ exposure in the energy range 0.15–0.4 GeV, amounting to 2 standard deviations. Since only single-pion production is present in this energy range, we can use the well-known cross section to correct for this effect. The various corrections and final results are given in Table I.

In the case of events with three or more prongs the situation is much more favorable because the threshold begins at higher photon energy, where the bremsstrahlung photon flux is less, and the 7.5-GeV production cross section is substantial, as can be seen in Table I. Here the errors shown include statistical uncertainty in the numbers of events and in the bremsstrahlung flux normalization and further include an estimate of the effect of a possible difference in spectral shape between e^+ and e^- exposures.

The total hadronic γp cross section is found to be 126 ± 17 μb averaged over the energy interval 7-8 GeV, neglecting events with one charged track. Recently a total γp hadronic-cross-section determination has been reported for energies up to 5.4 GeV, using a tagged photon beam

Table I. Observed and corrected numbers of events by topologies.

Topology[a]	Number of events uncorrected e^+	e^-	Estimated number of background events to be subtracted e^+	e^-	Number of events due to pair spectrum correction e^+	e^-	Corrected number of events[b] e^+	e^-	σ (μb)
(1) $\gamma p \to 1$ prong (only part of the film used)	2121	2363	60 ± 25	35 ± 25	0	162 ± 83	2082	2200	-57 ± 55
(2) $\to 3$ prongs	1752	1334					1764	1389	82.5 ± 16
(3) $\to 5$ prongs	280	87					281	90	41.6 ± 6
(4) $\to 7$ prongs	17	7					17	7	21.1 ± 1.5
$\gamma p \to$ all, without topology (1)	2049	1428					2062	1486	126 ± 17

[a]An n-prong event has n charged outgoing tracks, strange or nonstrange.
[b]Normalized to same bremsstrahlung flux and corrected for scan efficiency.

in a bubble chamber.[5] A value of $\sigma_{\gamma p}{}^{\text{tot}} = 116 \pm 17$ μb was found in the energy interval $3.5 < E_\gamma < 5.4$ GeV. Furthermore, that experiment showed that the one-prong cross section is decreasing with energy, being 30 ± 9 μb between 2.3 and 3.5 GeV and 12 ± 6 μb between 3.5 and 5.4 GeV.[6] Therefore, it is unlikely that neglecting the one-prong contribution will have any appreciable effect on the total cross section determined here.

Our value at 7.5 GeV, together with the measurements at lower energies, shows that within the errors the total cross section stays constant between 1.5 and 8 GeV. We may compare the measured $\sigma_{\gamma p}{}^{\text{tot}}$ values with the vector-dominance model which predicts for high energies $\sigma_{\gamma p}{}^{\text{tot}}$ to be approximately constant with a value of 110 ± 10 μb.[7]

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