Large-Angle High-Energy Photoproduction of Single π^+ Mesons from Liquid Hydrogen

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We have measured angular distributions for single photoproduced π^+ mesons at 4.0-, 5.0-, and 7.5-GeV incident photon energies and at lab angles from 11° to 66° with the Stanford Linear Accelerator Center 8-GeV spectrometer. Combined with previous Stanford Linear Accelerator Center results, this gives complete angular coverages for this range of energies. The data show the usual "t" and "u" diffraction peaks and a "central plateau" region dropping as $S^{-7.3}$.

Previous experiments on the photoproduction of single-charged-pion production from hydrogen via $\gamma+p\rightarrow\pi^++n$ have been made over the range of $|t|$ values from 0 to 3.0 $(\mathrm{GeV}/c)^2$ and $|u|$ values from 0 to 1.7 $(\mathrm{GeV}/c)^2$.[1,2] The cross sections in $d\sigma/dt$ can be approximated by the formulas $d\sigma/dt \propto S^{-2}e^{-3.3|t|}$ for $1<|t|<3$ $(\mathrm{GeV}/c)^2$ and $d\sigma/dt\propto S^{-3}\times e^{-|u|}$ for $0.5<|u|<1.5$ $(\mathrm{GeV}/c)^2$. It seemed of interest to obtain complete angular distributions over several energies, which could be compared with the elastic πp scattering distributions.[3]

The experiment was a standard single-arm "missing-mass" identification of the process using an analysis of the kinematic step to provide cross-section measurements.[1,2] The Stanford Linear Accelerator Center (SLAC) 8-GeV spectrometer[4] was used to analyze pions (and protons) produced by the SLAC bremsstrahlung beam passing through a liquid-hydrogen target. The beam layout is shown in Fig. 1. The bremsstrahlung beam could be prepared either with a radiator 52 m upstream from the liquid-hydrogen target (distant targeting), which was then followed by a sweep magnet to remove the main electron beam, or, in order to obtain maximum photon-beam intensities, could be prepared by placing a radiator 2 m in front of the hydrogen target and allowing both the photons and electrons to proceed through the target. The pure photon beam obtained with the distant targeting could be monitored with a secondary-emission quantameter. The close-up targeting was monitored with the standard SLAC toroids to give the number of electrons in the beam, and effective photon fluxes were calculated

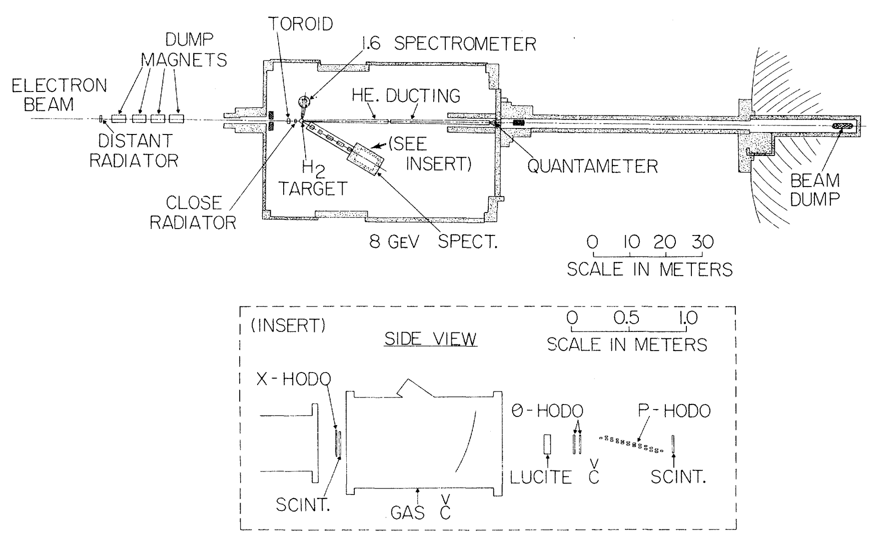

FIG. 1. Experimental layout. The counters of the 8-GeV spectrometer are shown in the inset.

from the amount of radiator in the beam line. These calculations were cross checked by changing the amount of radiator in the beam line, and by comparing the observed rates with the standard bremsstrahlung beam. The rates used for these cross comparisons were measured with the 1.6-GeV spectrometer set to detect low-energy π^+ mesons (500 MeV/c) produced at 90° in the lab. The two methods of comparison gave agreement to a few percent.

The counting system is shown in Fig. 1. The trigger system contained a threshold gas Cherenkov counter employing Freon 12 with high efficiency for pions (~99%) above 1.75 GeV/c, a Lucite threshold Cherenkov counter which rejected protons with momenta less than 1.5 GeV/c, and two trigger scintillators. Pions above 1.8 GeV/c were recorded by a coincidence between the scintillator trigger counters, the threshold gas Cherenkov counter, and the Lucite counter. At momenta below 1.7 GeV/c a coincidence was made with only the trigger scintillator and the threshold Lucite counter. Protons and kaons were monitored by observing the trigger rates with the scintillators, the Cherenkov gas counter in anticoincidence, and the Lucite Cherenkov counter in coincidence for momenta above the threshold in the Lucite counter. The trigger pulses were used to strobe the momentum (p) and angle-defining (θ) hodoscopes, and the pulses were sorted into missing-mass bins. A cut was made with an "X" hodoscope to reject non-target-associated backgrounds. The "X" hodoscope was placed 2 m in front of the focal plane and consisted of 21 counters that divided the horizontal plane (or production angle) into 21 pieces. This information, when combined with the knowledge of the horizontal production angle obtained with the θ hodoscope, permitted a rough reconstruction of the horizontal point of origin of the particle at the target. A loose cut was made on this position (98% efficient as determined from electron scattering) that provided a rejection against non-target-associated room backgrounds of about 20 to 1. Singles rates were kept below a few per pulse at all times, and dead-time corrections typically ran at 10% or less.

For data-taking conditions the spectrometer was set to a fixed angle and the momentum was varied in order to obtain the curves for yield versus the "missing-mass squared" from which the kinematic step at the appropriate threshold could be obtained. The spectrometer was operated so that the acceptance was constant within a few percent over the fiducial region set by the p and θ hodoscopes. The azimuthal acceptance was determined by adjustable front slits. The solid angle and efficiency of the spectrometer could be obtained from the known geometrical and magnetic parameters of the system, or by calibration with the proton peak associated with elastic electron-proton scattering. The two methods agreed within a few percent. The main uncertainty in determining absolute cross sections came from the uncertainties in the knowledge of the absorption and knock-on electron corrections in the counter telescope. These corrections were of the order of 22% with an estimated systematic uncertainty of 5%. Our estimated systematic uncertainty in the absolute cross sections is 10%.

Figure 2 shows our final measured cross sections. The error bars contain statistical errors

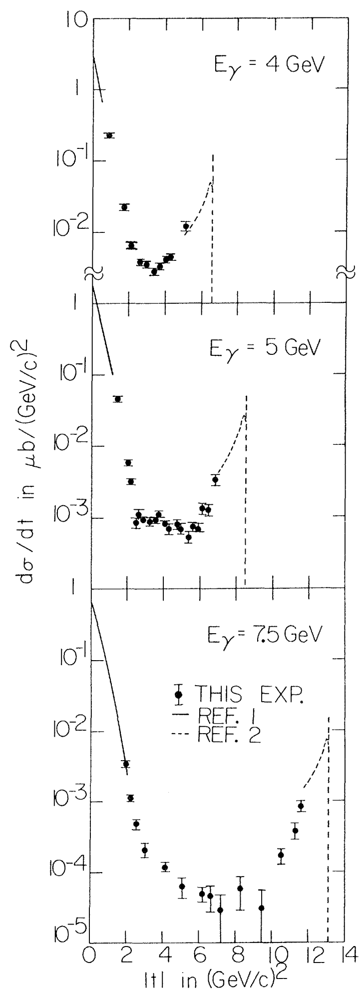

FIG. 2. Results of the experiment. Results for small $|t|$ and $|u|$ values are indicated (Refs. 1 and 2).

and systematic errors for the measured dead-time corrections and the extrapolated background subtractions underneath the kinematic step.

For $|t|$ values up to about 3 $(\mathrm{GeV}/c)^2$ the data show the typical exponential $(e^{-3.3|t|})$ falloff of the cross section observed by Boyarski *et al.*[1] The data for the u channel show a slower falloff with $|u|$ $(\sim e^{-1.3|u|})$ which is in reasonable agreement with the results of Anderson *et al.*[2] The central plateau region is distinct from either of these regions and has only a small dependence on the $|t|$ or $|u|$ values, but a very strong S dependence. The S dependence of $d\sigma/dt$ measured at 90° c.m. goes as $S^{-7.3\pm0.4}$. If the 90° c.m. data are extrapolated into the low-energy region, the cross sections agree with those observed for low-energy "resonance-averaged" photoproduction of single pions in the 1–3-GeV region.[5]

Figure 3 shows a comparison of the 5-GeV data of the present experiment multiplied by a scale factor, and the corresponding π^+ and π^- elastic scattering data and π^-p charge exchange.[3] The πp data show the same qualitative features of forward and backward peaks and a central plateau region dropping with a high S dependence. As can be seen from Fig. 3 the backward peak and plateau region can be approximately represented by the form

$$\frac{d\sigma}{dt}(\gamma p \to \pi^+ n)$$
$$\simeq \frac{1}{2}\left[\frac{d\sigma}{dt}(\pi^+p\to\pi^+p)+\frac{d\sigma}{dt}(\pi^-p\to\pi^-p)\right]\frac{1}{217}.$$

The $\frac{1}{217}$ scale factor is the ratio of the γp total cross section to the average of the π^+p and π^-p total cross sections. This factor scales the $\gamma p \to \pi^+ n$ and πp elastic differential cross sections very well, thus showing the close correspondence between large-angle photoproduction and hadronic processes. The marked dip of the pion data at the junction of the central plateau with the forward and backward peaks seems to be absent in our data. The S dependence observed for the 90° c.m. pion data is also very close to that observed in this experiment. In view of the fact that the 90° c.m. cross section extrapolates to the observed 1.5-GeV low-energy resonance cross sections, it would seem plausible to regard the cross sections observed by us at high energies to be the residue of the resonance or S-channel cross sections.

An interesting interpretation of the pion results has been obtained in a quark or parton interchange

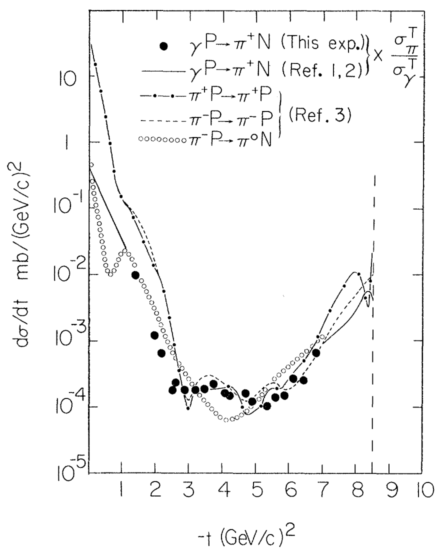

FIG. 3. Comparison of our 5-GeV data with the 5-GeV π^+ and π^- elastic scattering, and π^-p charge exchange.

model by Gunion, Brodsky, and Blankenbeckler.[6] This model assumes that the incoming and central target particles scatter by interchanging constituents and involves a hadronic form factor for both vertices. This model leads to a central plateau region dropping as $\sim S^{-13/2}$ when applied to photoproduction.

In summary there is a "central plateau" in the angular distribution of single photoproduced pions falling as $S^{-7.3}$. Our photoproduction results clearly parallel those observed for hadronic scattering and demand a common explanation.

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Nonrenormalization Theorem in the Chiral Symmetry Limit*

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We show that the form factors of the strangeness-changing current are renormalized in first order, rather than second order, in the symmetry-breaking parameters if the chiral symmetry is realized by Nambu-Goldstone bosons. The first-order renormalization is explicitly calculated for the meson and baryon form factors.

In this note we re-examine the celebrated nonrenormalization theorem of Ademollo and Gatto[1] and Behrends and Sirlin[2] in the light of recent observations on perturbation theory about a Nambu-Goldstone symmetry.[3] The nonrenormalization theorem asserts that the vector form factors of currents at zero momentum transfer, whose associated charges are the generators of a symmetry group, remain unrenormalized up to second order in the symmetry breaking. The implication of this theorem—that the renormalization effects are therefore small—is crucial to establishing contact between the Cabibbo theory of weak interactions and experiment.

This theorem is certainly true in the case that the symmetry limit is realized in the usual way in which the states are irreducible representations of the symmetry group. If, however, the symmetry limit is realized by ground-state Nambu-Goldstone bosons, we find that the form factors are renormalized to *first* order in the symmetry-breaking parameters.

We now illustrate this remark using the language of the $(\underline{3}^*, \underline{3}) \oplus (\underline{3}, \underline{3}^*)$ model, although the result is actually model independent. Consider the Hamiltonian density

$$H(x) = H_0(x) + \epsilon_0 u_0(x) + \epsilon_8 u_8(x),$$

where $H_0(x)$ is chiral SU(3) $\otimes$ SU(3) invariant and $u_{0,8}(x)$ transform like members of the $(\underline{3}^*, \underline{3}) \oplus (\underline{3}, \underline{3}^*)$ representation. We assume that as the symmetry-breaking parameters ϵ_0 and ϵ_8 vanish, the symmetry of H_0 is realized by an octet of massless ground-state pseudoscalar bosons. If $f_+(0)$ is the K_{l3} decay form factor of the strangeness-changing current between a π and K, then with $f_+(0) = 1 + \epsilon_8^2 F(\epsilon_0, \epsilon_8)$ we find $F(\epsilon_0, 0) \to r/\epsilon_0 + s/\epsilon_0^{1/2} + \cdots$ as $\epsilon_0 \to 0$, with r a known constant. Consequently $f_+(0) = 1 + O((\epsilon_8/\epsilon_0)\epsilon_8)$ and the renormalization occurs in first order.

It is apparent from these remarks that if we consider perturbation theory in ϵ_8 about SU(3) then the correction is of $O(\epsilon_8^2)$ in accord with the usual theorem. However, if we consider perturbation theory about SU(3) $\otimes$ SU(3), which may be as good a symmetry as SU(3) $(\epsilon_8/\epsilon_0 \simeq -\sqrt{2})$, then the correction is properly of order $(\epsilon_8/\epsilon_0)\epsilon_8 \sim O(\epsilon_8)$—first order.

We indicate below how this result is obtained. We also calculate the renormalization, to first order, in a model-independent way. For the $f_+(0)$ form factor one obtains, with $f_\pi \simeq 0.96\mu_\pi/\sqrt{2}$,

$$f_+(0) = 1 - \frac{5(\mu_K^2 - \mu_\pi^2)^2}{384\pi^2 f_\pi^2 (2\mu_K^2 + \mu_\pi^2)} = 0.98 \qquad (1)$$

which is numerically only a 2% renormalization. We have also examined the renormalization for the baryon form factors, where this first-order renormalization is at most 7%. Our results do not alter the beautiful agreement of the Cabibbo theory with experiment and support the usual assumption of ignoring renormalization effects.

We follow Fubini and Furlan.[4] If we consider the matrix element of $[F_+, F_-] = I_3 + \frac{3}{2}Y$, $F_\pm = F_4 \pm iF_5$ with F_a a generator of SU(3), between ground-state mesons states $|M\rangle$, then we obtain