RATIO OF π^- TO π^+ PHOTOPRODUCTION FROM DEUTERIUM AT 8 AND 16 GeV*

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We have studied the ratio $R=[d\sigma(\gamma d\rightarrow\pi^-pp)/dt][d\sigma(\gamma d\rightarrow\pi^+nn)/dt]^{-1}$ at 8 and 16 GeV for momentum transfers $|t|$ from about 0.001 to 1.3 GeV^2. R is close to unity for $|t|<m_\pi^2$, but falls very rapidly with increasing $|t|$, passing through $\frac{1}{2}$ near $|t|=0.1$ GeV^2 and having a minimum value of about $\frac{1}{3}$ near $|t|=0.4$ GeV^2; it slowly increases at larger momentum transfers. These results are similar to those obtained in other laboratories at 3.4 and 5 GeV. This implies considerable interference between the isoscalar and isovector photon amplitudes.

If the photon possessed definite isospin, the two reactions

$$\gamma n\rightarrow\pi^-p, \tag{1}$$

$$\gamma p\rightarrow\pi^+n \tag{2}$$

would be related to one another by a simple isospin rotation and the cross sections would be equal. However, interference terms between the isoscalar and isovector photon amplitudes have opposite signs for processes (1) and (2), and these interference terms can lead to a difference in the two cross sections. G-parity conservation restricts the t-channel exchanges to $G=+1$ and -1 for the isoscalar and isovector photon amplitudes, respectively. In terms of t-channel exchanges, a difference in the cross sections for Reactions (1) and (2) thus requires a minimum of two exchanges, one of each G parity.

The method used to study the $\pi^\pm$ fluxes was basically the same as that used previously in the study of $\gamma p\rightarrow\pi^+n$.[1] A high-power bremsstrahlung beam was used to photoproduce the pions in a liquid-deuterium target and these pions were momentum analyzed by the Stanford Linear Accelerator Center 20-GeV/c spectrometer, separated from electron and muon contamination by their interaction properties and from K's and protons with a threshold Čerenkov counter. The pion momentum distributions resulting from photons near the bremsstrahlung tip were fit with a step (suitably smeared) for single-pion production. The spectator nucleon carries off some momentum from the process, degrading the sharpness of the step; this deuterium smearing of the step is negligible at small t, but makes it impractical to use a bremsstrahlung beam to study pion production from deuterium for $|t|\gtrsim 2$ GeV^2 unless the other final-state particles are also detected.[2]

The cross sections for charged-pion production from deuterium can differ from that of free nucleons because of three effects: (1) the Pauli exclusion principle, (2) Glauber corrections for interactions of the pion with the spectator nucleon, and (3) final-state interactions of the two nucleons. Since the momentum transfer is very small (~1 MeV/c) at 0°, final states with the two (identical) nucleons in the same spin state will be suppressed by the exclusion principle. Angular-momentum conservation allows only spin-flip amplitudes for 0° pion photoproduction, and the two nucleons in the initial state must have parallel spins if the final-state nucleons are to be in different spin states. This is the case for the $J_z=\pm1$ states of the deuteron, but not for $J_z=0$, and for an unpolarized target the cross section should be reduced by $\frac{1}{3}$ at 0°. The general form of this suppression has been obtained under the impulse and closure approximations[3] as

$$d\sigma(d)/dt=[1-\tfrac{1}{3}H(q)]d\sigma(p)/dt, \quad \text{pure spin flip,} \tag{3}$$

$$d\sigma(d)/dt=[1-H(q)]d\sigma(p)/dt, \quad \text{pure spin-nonflip,} \tag{4}$$

where H is simply the deuteron form factor. Hence the exclusion-principle suppression dies away very rapidly with increasing momentum transfer.

In Fig. 1, we show our deuterium/hydrogen π^+ ratio[4] together with those obtained from other experiments above 3 GeV.[5] Also shown is the exclusion-principle factor $1-\frac{1}{3}H(q)$ for pure spin flip, calculated using the Hulthén wave function. The data do indeed show a suppression in the forward direction. Recent calculations[6] have been made which incorporate not only the exclusion effects, but also the Glauber correction. Although the latter correction cannot be calculated unambiguously, it appears to be about 5 or 10%.

The exclusion effects, Glauber corrections, etc., are expected to be the same for π^+ and π^- production so that the cross-section ratio from

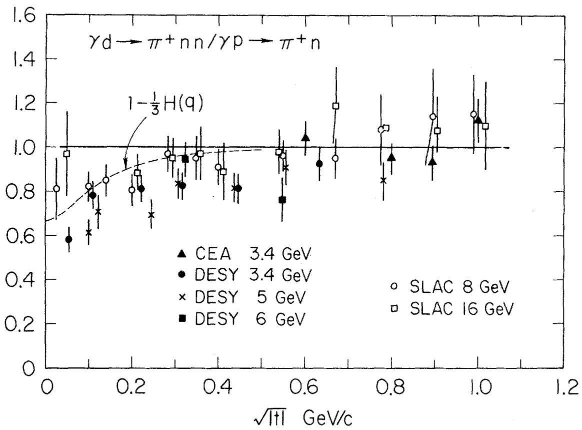

FIG. 1. The ratio of π^+ production from deuterium and hydrogen. Lower energy data from Cambridge Electron Accelerator and DESY (Ref. 5) are also shown. The curve $1-\frac{1}{3}H(q)$ represents the exclusion-principle effects expected for the spin-flip amplitudes. The data are plotted versus $\sqrt{|t|}$ to display the points at small t better.

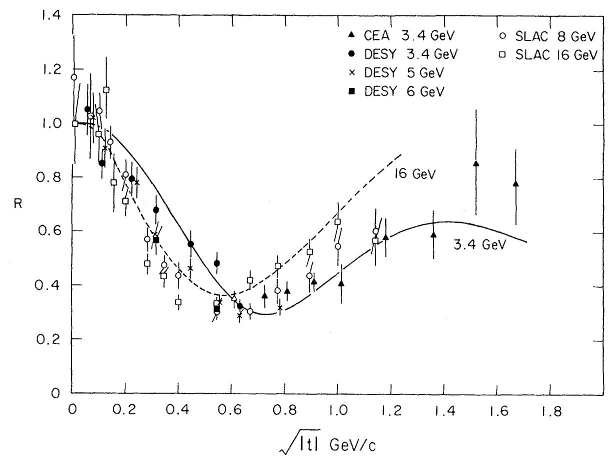

FIG. 2. The ratio π^-/π^+ from deuterium. Lower energy data from Cambridge Electron Accelerator and DESY (Ref. 5) are also shown. The data are plotted versus $\sqrt{|t|}$ to better display the points at small t. The curves were calculated from the model of Frøyland and Gordon, to be published.

free nucleons should be given to a good approximation by

$$\frac{\gamma n \to \pi^- p}{\gamma p \to \pi^+ n} = \frac{\gamma d \to \pi^- pp}{\gamma d \to \pi^+ nn} \equiv R. \tag{5}$$

At 16 GeV the pion-momentum spectrum was measured down into the multipion region to where the background was comparable with the single-pion contribution. Although the fits were made only to data cut off well before this point, it is interesting to note that the ratio of π^-/π^+ observed from multipion processes is roughly the same as the ratio of π^-/π^+ from single-pion production; this reduces any possible distortion of the single-pion ratio by background. Only data with missing-mass squared (calculated with $k=E_0$, the end-point energy) ≤ 1.18 GeV^2 were used and we estimate the systematic error in the ratio due to multipion processes to be $\lesssim 2\%$. Other systematic errors in the experiment should also largely cancel when taking the ratio of π^+ and π^- yields.

The data are shown in Fig. 2 together with the data from the 3.4 and 5-GeV experiments. The π^-/π^+ ratio is close to unity in the forward direction, but drops precipitously as $|t|$ increases, becoming $\frac{1}{2}$ at $|t|=0.1$ GeV^2 and $\frac{1}{3}$ in the region $|t| = 0.4$ GeV^2. In contrast to those theories which predict one dominant term at high energies, the ratio indicates an interference of terms which is relatively independent of energy. Some small energy trend can be seen. The low-energy ratio seems systematically higher than the high-energy ratio around $|t|=0.1$ GeV^2; this trend is reversed at larger momentum transfers.

In the vector-dominance model the contributions of the isovector-photon terms to the cross section are expected to dominate the isoscalar contributions. The interference terms are important, however, as evidenced by the large difference in the π^+ and π^- cross sections. Taking the sum of these cross sections causes the interference terms to drop out, and ignoring the few percent isoscalar contributions, the model predicts[7,8]

$$\frac{1+R}{2}\left(\frac{d\sigma}{dt}\right)_{\gamma p \to \pi^+ n} = g_{\rho\gamma}^{\ 2}\left(\rho_{11}^{\ \text{hel}}\frac{d\sigma}{dt}\right)_{\pi^- p \to \rho^0 n} \tag{6}$$

Generally good agreement is obtained, as shown in Fig. 3. It should be noted that the agreement may be fortuitous considering the recent discrepancy between the polarized-photon cross sections for Reactions (1) and (2) and the vector-dominance prediction.[9] The data on ω production by pions are rather sketchy, but there may be some difficulty in explaining the large difference between π^+ and π^- photoproduction cross sections.[10]

Several theoretical models have been used to fit the $\gamma p \to \pi^+ n$ data, many of the models concentrating on the sharp-forward-peak region. With the rapid falloff of R in the forward direction, any model purporting to fit the data beyond $|t| = m_\pi^{\ 2}$ must include isoscalar-photon amplitudes

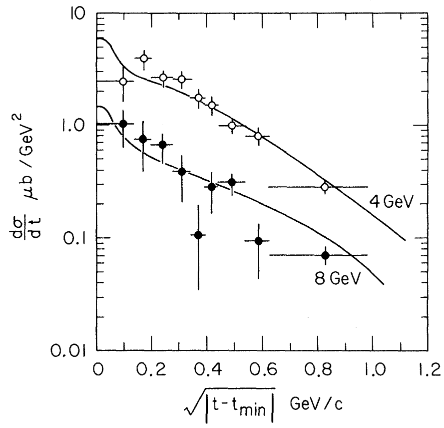

FIG. 3. Vector-dominance comparison of the reaction $\pi^- p \to \rho^0 n$ with $\frac{1}{2}(1+R)d\sigma(\gamma p \to \pi^+ n)/dt$. The points are the values obtained in Ref. 8 for $g_{\rho\gamma}{}^2[\rho_{11}{}^{\text{hel}}(d\sigma/dt)]_{\pi^- p \to \rho^0 n}$ with $g_{\rho\gamma}{}^2 = 4\times 10^{-3}$. The curves show the experimental results for $\frac{1}{2}(1+R)d\sigma(\gamma p \to \pi^+ n)/dt$. The 5-GeV photoproduction cross sections were extrapolated from 5 to 4 GeV assuming a k^{-2} dependence.

in order to reproduce the experimental value of R. Models giving good fits to the π^+ data at $|t| > m_\pi{}^2$ without such terms cannot possibly fit the π^- data.

Amati et al.[11] fit the π^+ differential cross section over a wide range of t and s with a model which included a "background" term to account for the nonzero forward cross section. Unfortunately, this model predicts $R > 1$ (B exchange interfering with π exchange and the background term) instead of less than one as observed.[12] Brower and Dash[13] have made the most extensive attempt to fit the pion-photoproduction data using only evasive and conspiring Regge trajectories $-\pi, \pi_c, \rho, A_2, B$. While this model fits the π^+ data well, it gives a π^-/π^+ ratio considerably larger than experiment in the region around $|t| = 0.5$ GeV^2 where the predicted ratio goes through 1.

Frøyland and Gordon[14] use evading π and ρ trajectories plus an evading ρP cut and a conspiring πP cut to fit the π^+ differential cross section from 2 to 16 GeV (Ref. 1 and Buschhorn et al.[15]) and the π^-/π^+ ratio at 3.4 and 5 GeV (Ref. 5). Their fit reproduced the data quite well and correctly predicted the asymmetry of π^+ produced by linearly polarized photons.[16] As shown in Fig. 2, their prediction for the π^-/π^+ ratio at high energies is also qualitatively correct. However, the model predicts, according to our calculations, a large asymmetry of π^- produced by linearly polarized photons which is contradicted by experiment.[17]

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[2]We effectively measure the four-momentum of both the photon and pion and thus $t = (k_\mu - p_\mu)^2$ is determined directly and is not smeared by the Fermi motion. The center-of-mass energy is smeared, however, the effect corresponding to a ±4% spread in photon energy.

[3]See, for example, Wonyong Lee, thesis, University of California Radiation Laboratory Report No. UCRL-9691, 1961 (unpublished).

[4]The systematic error on our determination of the deuterium/hydrogen π^+ ratio resulting from the uncertainty in the density of the liquid deuterium in our target is ±3%; this uncertainty is not included in the error bars of Fig. 1.

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[12]Simply reversing the sign of the B amplitude and refitting did not lead to a good fit, even when we allowed the variation of several of the parameters which were originally considered to be fixed. This does not imply that the idea of "background" as opposed to a conspiring π is necessarily at fault, but rather that a more complicated form is needed to parametrize the residue functions, etc.

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[17]Z. Bar-Yam et al., in the Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, August, 1968 (to be published); Geweniger et al., Ref. 9.

DIFFRACTION DISSOCIATION AND THE REGGEIZED ABSORPTION MODEL*

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A simplified but self-consistent model calculation is made to include the effects of diffraction dissociation in the Reggeized absorption model of Henyey et al. The calculation provides a method for estimating their parameter λ, which describes the extra effect of diffractive dissociation. An estimate based on present experimental information is not as large as the value they need to fit the data.

In a model which describes high-energy inelastic scattering in terms of the absorption model with Reggeon exchange, Henyey et al.[1] have introduced an additional parameter λ having the effect of increasing the absorption in both entrance and exit channels. They ascribe this increase to diffractive dissociation. The value $\lambda=1$ corresponds to no increased absorption, and in order to fit experimental inelastic cross sections these authors need to use values $\lambda\sim 2$. The purpose of this note is to present a very simple calculation which includes diffraction dissociation in a proper unitary manner, and which makes it possible to estimate λ from experimental data on diffractive dissociation. The estimate we make is $\lambda \simeq 1.2$.

The process, exemplified by $\pi^-+p\to\pi^0+n$, is described by the diagram in Fig. 1. In the initial channel, the π^-+p system suffers absorption, which depletes the low partial waves. Exchange of the ρ Reggeon produces the final state π^0+n, which goes through the corresponding absorptive process in the final channel. In the notation of Ref. 1, the final inelastic amplitude $T^{\rm Abs}$ is given by

$$T^{\rm Abs}=\sum(2l+1)S_l^{\rm el}T_l^{\rm ex}P_l,$$

where $T_l^{\rm ex}$ represents pure Regge exchange, and $S_l^{\rm el}$, the elastic S-matrix element, here represents the modification due to absorption. It is in $S_l^{\rm el}$ that the additional parameter λ is introduced: $S_l^{\rm el}\to 1+\lambda(S^{\rm el}-1)$. This modification is made to represent the extra contribution to $T^{\rm Abs}$ of intermediate states produced diffractively in either the initial or the final elastic scatterings, as is also indicated in Fig. 1. With the simple parametrization used by Gottfried and Jackson, for example,[2] $S_l^{\rm el}=1-ce^{-l^2/l_0^2}$, this means using an effective absorption $S_l^{\rm el}=1-\lambda ce^{-l^2/l_0^2}$. Since usually c is close to 1, $\lambda\sim 2$ means that $\exp(2i\delta_l)<0$ for the low partial waves. One suspects that this may violate unitarity.

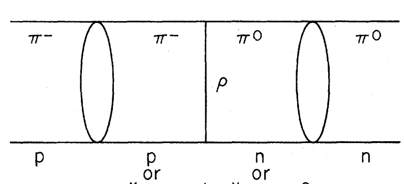

FIG. 1. Schematic diagram of Reggeon exchange with absorption in the entrance and exit channels.

To make a calculation which is simple and which preserves unitarity so far as diffractive dissociation is concerned, we first consider the process as involving two coupled channels, the elastic channel and the channel connected to it by diffractive dissociation. The initial channels, denoted by $|1\rangle$ and $|2\rangle$, respectively, are connected to the final channels $|1'\rangle$ and $|2'\rangle$ by Reggeon exchange. For simplicity, the pairs of channels are assumed to be degenerate in energy, and the coupling due to diffractive dissociation is described by potential scattering. In terms of the imaginary potential $V(r)$ which describes the absorption, the coupling is assumed to be indepen-