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Scalar-Transverse Separation for Single π^+ Electroproduction*

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We report measurements of the exclusive electroproduction reaction $e+p\rightarrow e+\pi^++n$ for pions produced near 0° in the virtual-photon–proton center-of-mass system with values of ϵ in the range $0.35<\epsilon<0.45$. Combination with data taken at ϵ near 1 allows us to separate the contributions from transversely polarized and scalar photons in the range $1.2\ \mathrm{GeV}^2<Q^2<3.3\ \mathrm{GeV}^2$.

The inclusive electroproduction reaction,

$$e+p\rightarrow e+\pi^++n, \tag{1}$$

has been studied extensively[1-6] and has been used in conjunction with the generalized electric Born-term dispersion-theory model to determine the pion form factor.[7-9] This model assumes that the pion form factor enters via the one-pion-exchange diagram and that, for pions produced along the direction of the virtual photon, the cross section is dominated by the amplitude for scalar photons. It has been known for some time that the dispersion theory does not correctly reproduce the measured scalar-transverse interference term.[1] Experimentally it is much larger than the theoretical prediction and at large angles it has the opposite sign. Gutbrod and Kramer[10] were able to reproduce this behavior by allowing the proton form factor to vary from its on-shell value. They showed that this resulted in the transverse component varying with Q^2 in a manner similar to that observed for the virtual-photon–proton total cross section.

This paper reports new measurements of single-pion electroproduction carried out at the Wilson Synchrotron Laboratory at Cornell University and the first separation of the cross section into scalar and transverse components. This gives an important new test of the dispersion theory model for Reaction (1).

Reaction (1) is conventionally analyzed in terms of the virtual photoproduction reaction,

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

where square-Q^2 of the mass, energy ν, direction, and polarization parameter ϵ of the virtual photon are tagged by the scattered electron. The cross sections for Reactions (1) and (2) are related by[11]

$$d\sigma(1)/d\Omega_e dE' d\Omega_\pi=\Gamma d\sigma(2)/d\Omega_\pi,$$

where Γ is the "flux" of virtual photons. The cross section for Reaction (2) may be written in the general form[12]

$$d\sigma/d\Omega_\pi=A+\epsilon B\cos2\varphi+\epsilon C+\left[\tfrac{1}{2}\epsilon(\epsilon+1)\right]^{1/2}D\cos\varphi, \tag{3}$$

where A, B, C, and D are functions of W (the total energy of the virtual-photon–proton system), Q^2, and θ (the center-of-mass angle between the pion and virtual photon). φ is the azimuthal angle between the electron scattering plane and the plane defined by the pion and the virtual photon. A is due to transverse photons and C is due to scalar photons. B and D arise from the interference between the two transverse polarizations and the scalar and transverse polarizations, respectively. The values for A and C were calculated by first averaging over φ so as to obtain $A+\epsilon C$ and using the measurements at different ϵ to separate A and C. All previous measurements of Reaction (1) have been made for values of ϵ in the range $0.80<\epsilon<0.95$ and thus could not be used to determine the individual contributions due to A and C.

A two-arm spectrometer system was used to take data at the (W, Q^2) points (2.15 GeV, 1.2 GeV^2), (2.65 GeV, 2.0 GeV^2), and (2.65 GeV, 3.3 GeV^2) for values of ϵ in the range $0.35<\epsilon<0.45$. The apparatus was identical to that described by Browman *et al.*[13] except that the roles of the two arms were reversed. A lead-Lucite shower counter and a threshold Freon Cherenkov counter served to identify the electrons. Pions were identified by a threshold Freon Cherenkov counter when their momenta were greater than 1.8 GeV/c and by time of flight at smaller momenta. The data have been corrected for random coincidences (~1%), electronics dead time (~5%), target-wall background (~1%), absorption in counters (~5%), pion decay losses (~3%), and electron misidentification (~1%). In addition a radiative correction varying from 30 to 40% has been made for events which are not identified as Reaction (1) because of radiation of photons.[14]

The overall systematic error in this experiment is estimated to be at the most ±7%. Both spectrometers were checked with elastic electron scattering and the mean ratios of the measured elastic-scattering cross sections to the average of the world data for the electron and hadron arms were 0.972 ± 0.010 and 0.993 ± 0.004, respectively. The estimated systematic error in the high-ϵ data[2,3] with which these data are combined to separate the scalar and transverse terms is ±7%. The spectrometers used in the earlier experiments were also checked with elastic electron-scattering measurements. The mean ratios of the measured elastic-scattering cross sections to the average of the world data for the electron and hadron arms were 0.994 ± 0.007 and 0.998 ± 0.009, respectively. The same Faraday cup was used in both experiments. The radiative corrections in the two experiments were nearly the same and the error in this correction is estimated to be less than 2%. Since the two spectrometer systems were quite similar and the procedures for the data analysis were almost identical, the systematic errors are correlated. In presenting the measured A and C components of the cross section, we have included only the statistical errors. It is estimated that the overall systematic uncertainty in A and C is ±7% and that the additional error in the ratio due to the uncorrelated portion of the systematic error is ±3%.

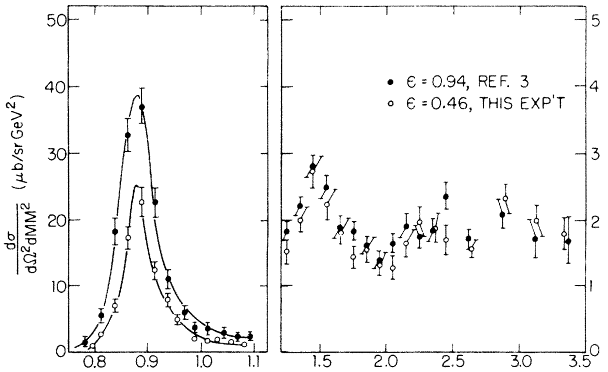

FIG. 1. Missing-mass spectrum for the reaction $\gamma_v+p\rightarrow\pi^++x$ for $W=2.15$ GeV, $Q^2=1.2$ GeV^2, $|t-t_{\min}|<0.02$ GeV^2 for $\epsilon=0.94$ and $\epsilon=0.46$.

Figure 1 shows the missing-mass spectrum for the reaction $\gamma_v+p\rightarrow\pi^++x$ for the low-ϵ and high-ϵ data[15] at $W=2.15$ GeV and $Q^2=1.2$ GeV^2 for $|t-t_{\min}|<0.02$ GeV^2. The cross section for the exclusive π^+n channel shows a strong dependence on ϵ while that for the $\pi^+\Delta^0$ exclusive channel and for inclu-

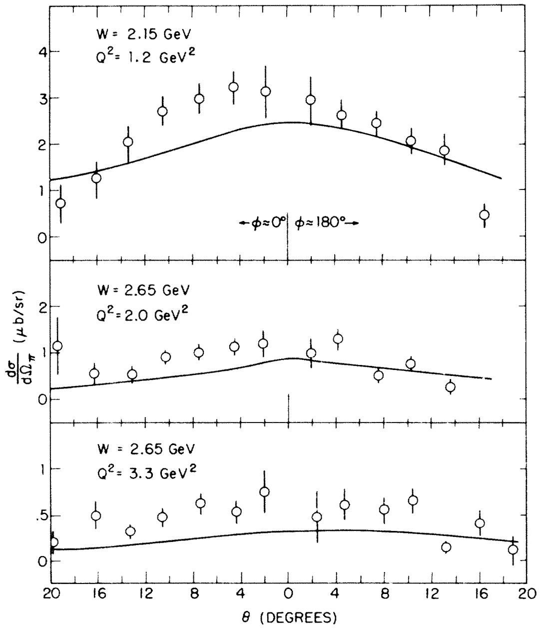

FIG. 2. The observed angular dependence of the reaction $\gamma_v+p\rightarrow\pi^++n$ for the three (W,Q^2) points. The solid lines are the dispersion-theory prediction calculated with the pion form factor given by $F_\pi=1/(1+Q^2/0.471)$.

sive pion production shows little if any dependence on ϵ. The smallness of the scalar contribution for the inclusive channel agrees with the Stanford Linear Accelerator Center–Massachusetts Institute of Technology measurements of the total electroproduction cross section which show that $\sigma_S/\sigma_T \simeq 0.14 \pm 0.07$.[16]

Figure 2 shows the angular distribution near 0° and 180° for single-pion production in the low-ϵ region for the three (W, Q^2) points. Similar data were obtained for φ near $-90°$ and $+90°$. The solid curves are the predictions of the dispersion theory,[7] assuming that the pion form factor as determined in the analysis reported earlier[3] is given by $F_\pi = (1 + Q^2/0.471)^{-1}$. The data show an increasing discrepancy with the theory as Q^2 increases.

Figure 3 shows the measured angular dependencies of A and C at the three (W, Q^2) points obtained by combination of the new data reported here and the earlier data. The solid curves are the prediction of the dispersion theory[7] assuming that the pion form factor is given by the earlier analysis.[3] The theory badly underestimates the contribution of the transverse photons to the cross section. The theory also does not reproduce satisfactorily the observed angular dependencies of A and C. Since the longitudinal component $\mathbf{C}$ depends on the unknown pion form factor, the discrepancy in C at 0° can always be removed by adjusting the pion form factor so that the theory fits the data. The transverse term, A, cannot be adjusted in this manner.

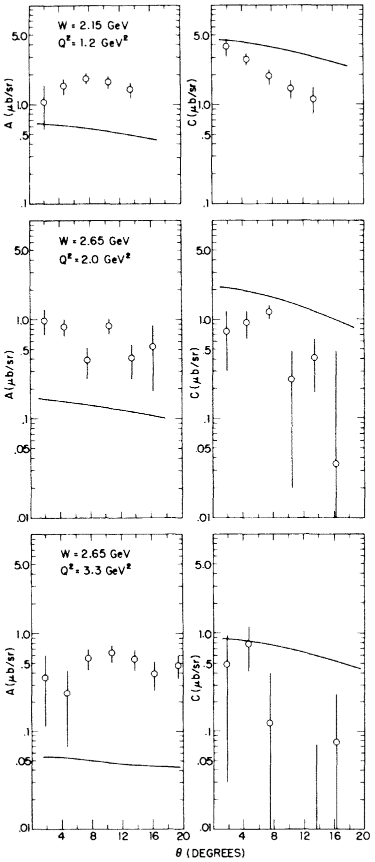

FIG. 3. The observed angular dependence of the transverse and scalar components A and C of the cross section for the reaction $\gamma_v + p \rightarrow \pi^+ + n$ for the three (W, Q^2) points. The solid curves are the dispersion-theory prediction using $F_\pi = 1/(1 + Q^2/0.471)$.

Figure 4(a) shows a plot of A versus Q^2 for $W = 2.65$ GeV and $\theta < 3°$. The photoproduction point was taken from Ref. 17. The $Q^2 = 1.2$ GeV^2 point was obtained through a comparison of the data reported here with earlier data and a projection from $W = 2.15$ GeV using the W dependence of the dispersion theory. The curves show the prediction of the dispersion theory and the behavior found for the virtual-photon–proton total cross section. The Q^2 dependence of A is much weaker than that predicted by the dispersion theory and is compatible with being the same as that for the total cross section. Figure 4(b) shows a plot of

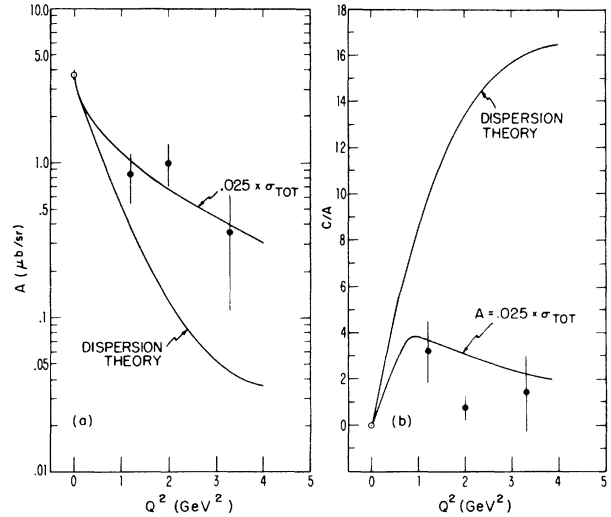

FIG. 4. (a) The Q^2 dependence of the transverse component A for $W = 2.65$ GeV and $\theta < 3°$. The solid curves are the dispersion-theory prediction and a dependence on Q^2 which is the same as that found experimentally for the virutal-photon–proton total cross section. (b) The ratio C/A as a function of Q^2. The solid curves were obtained using in one case the dispersion theory prediction for C and A and in the other the dispersion theory prediction for $\mathbf{C}$ together with the expression $(0.025\ \mathrm{sr}^{-1})\sigma_{\mathrm{tot}}$ for A.

the measured ratio C/A versus Q^2. The solid curves display the dispersion-theory prediction for C/A using $F_\pi = (1+Q^2/0.471)^{-1}$ and the value of C/A calculated using the dispersion-theory prediction for C together with the expression (0.025 $\text{sr}^{-1})\sigma_{\text{tot}}$ for A. The transverse component becomes increasingly important as Q^2 increases.

In conclusion, we have observed that the cross section for the reaction $\gamma_v + p \to \pi^+ + n$ has a strong dependence on ϵ indicating a substantial scalar component. The dispersion theory used to analyze the data in terms of the pion form factor[7] substantially underestimates the contribution of transverse photons at large values of Q^2. The transverse cross section has a much weaker Q^2 dependence than that predicted by the dispersion theory and it is compatible with being the same as that found for the virtual-photon–proton total cross section.

It is known from previous measurements[2,3] that the cross section for single-pion electroproduction has a significant isoscalar component which for fixed W increases with Q^2. The dispersion theory assumes that there is no isoscalar component. The isoscalar component could be contained entirely in the transverse component of the cross section and thus its neglect could partially account for the failure of the dispersion theory to reproduce the observed transverse component.

The data reported here imply that the previous determinations of the pion form factor using dispersion theory are overestimates. The redetermination of the pion form factor and the further analysis of the transverse component will be the subject of a later communication.

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Resonance Criteria and the $^1D_2$ Diproton*

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A relativistic three-body theory of the (2^+) $NN\pi$ system was applied to calculate elastic and inelastic $(^1D_2)$ pp scattering below 1 GeV. Although the amplitude satisfies all standard resonance criteria, it has no pole corresponding to a diproton resonance.

The spectrum of elementary "particles" provides the chief test of strong interaction dynamics. It is therefore critical that resonant phenomena be correctly analyzed and interpreted, i.e., that peaks in mass spectra be properly identified with poles of the S matrix. As noted by Trippe *et al.*,[1] presently acceptable criteria are almost uniquely linked to the behavior of the Argand plot (left-hand circle, "speed" maximizing near the resonance energy), although these criteria are not always applied objectively (e.g., the Z^* controversy[1]). Moreover, these criteria are primarily motivated by simple examples drawn from (multichannel) two-body scattering. Thus, a considerable majority of tabulated inelastic resonances have been analyzed on the basis of a