SEPARATION OF σ_L AND σ_U IN π^+-ELECTROPRODUCTION ABOVE THE RESONANCE REGION

P. BRAUEL, T. CANZLER, D. CORDS, R. FELST, G. GRINDHAMMER, M. HELM, W.-D. KOLLMANN*, H. KREHBIEL and M. SCHÄDLICH**

Deutsches Elektronen-Synchrotron DESY, Hamburg
and II. Institut für Experimentalphysik der Universität Hamburg, Germany

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The four cross section components σ_U, σ_L, σ_P and σ_I were separated in the reaction $\gamma_V + p \to \pi^+ + n$ at an electron four momentum transfer of $Q^2 = 0.70\ \mathrm{GeV}^2$ and an invariant hadronic mass of 2.19 GeV in the range of t between t_{min} and $-0.28\ \mathrm{GeV}^2$. The longitudinal cross section σ_L dominates at small $|t|$ and decreases rapidly with increasing $|t|$. The data are in rough agreement with the prediction of a generalized Born term model. The resulting value for the pion electromagnetic form factor is $F_\pi = 0.42 \pm 0.015$.

Single pion electroproduction

$$e + p \to e' + n + \pi^+ \tag{1}$$

offers the possibility to disentangle the contributions of different spin states of the virtual photon. A separation of the cross section for longitudinally polarized photons σ_L, which at small $|t|$ is dominated by one pion exchange, determines the pion electromagnetic form factor F_π in the space-like region.

Former electroproduction experiments to determine F_π [1] could not separate the longitudinal and transverse cross section components, and therefore required a model dependent calculation of the transverse cross section σ_U. The measurement of σ_U reported in ref. [2] showed that these calculations underestimate σ_U and thus overestimate F_π. In addition the separation of the various cross section components of reaction (1) yields interesting information about the slow decrease of $d\sigma/dt$ with Q^2 as has been observed recently [3,4] for $|t| > 0.2\ \mathrm{GeV}^2$. This behaviour of $d\sigma/dt$ indicated that the weak Q^2-dependence of $\sigma_{tot}(\gamma_V p)$ manifests itself already in the exclusive channel (1).

The cross section of reaction (1), assuming one photon exchange, is given by

$$\frac{d^4\sigma}{dQ^2 dW^2 dt d\phi} = \Gamma\left(\frac{d\sigma_U}{dt} + \epsilon\frac{d\sigma_L}{dt} + \epsilon\frac{d\sigma_P}{dt}\cos 2\phi + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_I}{dt}\cos\phi\right). \tag{2}$$

$\sigma_U = \frac{1}{2}(\sigma_\parallel + \sigma_\perp)$ is the contribution from transversely unpolarized photons, $\sigma_P = \frac{1}{2}(\sigma_\parallel - \sigma_\perp)$ from interference of the transversely polarized photon components, σ_L from longitudinal photons, and σ_I from interference of the transverse and longitudinal photon components. $\sigma_\parallel$ and $\sigma_\perp$ are the cross sections for photons having the electric vector parallel and perpendicular to the hadron production plane, respectively. The cross sections $\sigma_\perp$, $\sigma_\parallel$, σ_L and σ_I are at high W characterized by a unique naturality of the t-channel exchange [5]. Natural parity exchange contributes only to $\sigma_\perp$ and unnatural parity exchange only to $\sigma_\parallel$, σ_L and σ_I.

We present results of an experiment in which all four terms were separated simultaneously. The separation was performed at a (π^+n)-invariant mass of $W = 2.19$ GeV and electron four momentum transfer of $Q^2 = 0.70\ \mathrm{GeV}^2$ in the range of $t = (\gamma_V - \pi)^2$ between t_{min} and $-0.28\ \mathrm{GeV}^2$. The four cross section components are separated through their different ϕ- and ϵ-dependence. The angle ϕ and the virtual photon flux parameter Γ have been defined in ref. [3]. The polarisation parameter ϵ is given by $\epsilon^{-1} = 1 + 2(1 + (E - E')^2/Q^2)\cdot \mathrm{tg}^2\,\frac{1}{2}\theta_e$, where E' is the energy of

* Present address: Harvard University, Cambridge, Mass., USA.
** Present adress: Alfried Krupp v. Bohlen und Halbach Stiftung, Essen, Germany

the scattered electron and θ_e its angle with respect to the incident beam. In the present experiment the ϕ-dependence was measured at two different values of ϵ. The ϕ-range covered and the kinematical parameters defining the virtual photon are listed in table 1.

The experimental arrangement is shown in fig. 1. The external beam from DESY was focused onto a 10 cm long liquid hydrogen target. Electrons and pions were detected in coincidence using two nearly identical magnetic spectrometers as described in ref. [6]. Details on the event reconstruction and particle identification procedures are given in ref. [3], where the high ϵ measurements have been reported. For the low ϵ measurement, however, the former hadron spectrometer had to be used to measure electrons at large angles, and the former electron spectrometer, which could not be moved to large angles, was now used to detect hadrons. The new situation is indicated in fig. 1. Pions and kaons could no longer be separated by the Č-counter, since the vessel was not constructed for high pressure. However, kaons misidentified as pions have a missing mass $M_X \geqslant 1.18$ GeV, and can therefore be clearly separated from the recoiling neutron, as shown in fig. 2. Protons were eliminated by time of flight.

Events with 0.85 GeV $\leqslant M_X \leqslant$ 1.02 GeV were grouped into several (ϕ, t)-bins and weighted with the appropriate acceptance function, as calculated by Monte Carlo techniques. The various corrections applied are discussed and listed in ref. [3]. The overall uncertainty of the normalization was estimated to be $\lesssim 5\%$. The normalization uncertainties are to a large

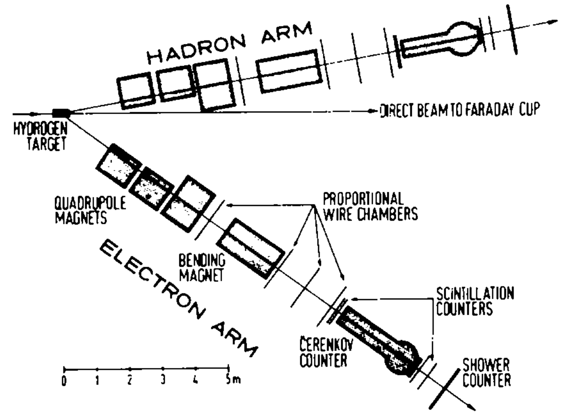

Fig. 1. Top view of the two spectrometers. Charged particles are bent vertically.

Table 1

ϵ	0.86	0.33
θ_e [deg]	10	36
E [GeV]	6.0	3.0
E' [GeV]	3.4	0.6
W [GeV]	2.19	2.19
Q^2 [GeV^2]	0.70	0.70
ϕ [deg]	0 – 360	90 – 270

extent correlated between the low- and high-ϵ-measurements, since the same apparatus and data analysis programs were used, and contribute therefore only to the overall normalization error. Eq. (2) was used to fit the corrected data for each t-bin separately taking σ_U, σ_L, σ_P and σ_I as free parameters. Only statistical errors were taken into account in this fit. The results, however, are shifted within the error bars only, if we make the pessimistic assumption that the normalization of one data set is different by 5%.

The cross section components are plotted versus $|t|$ in fig. 3a. The longitudinal contribution σ_L dominates at small $|t|$ but decreases rapidly with increasing $|t|$. Fitting this decrease with an exponential $e^{-b|t|}$, we obtain b = (14 ± 2 GeV^{-2}. Assuming that the pion pole

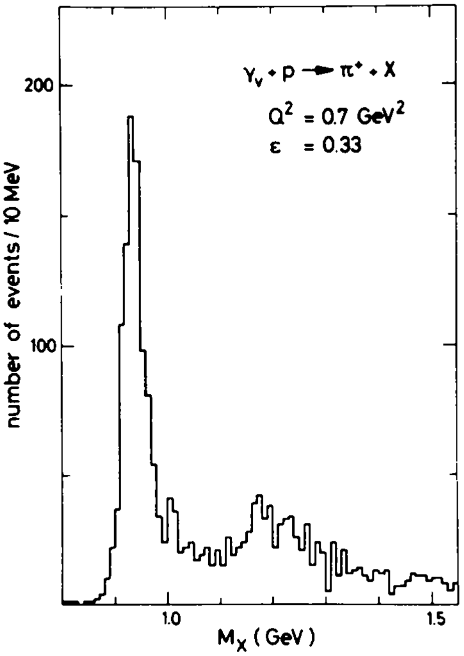

Fig. 2. The spectrum of the missing mass $M_X = \sqrt{(e+p-e'-\pi)^2}$

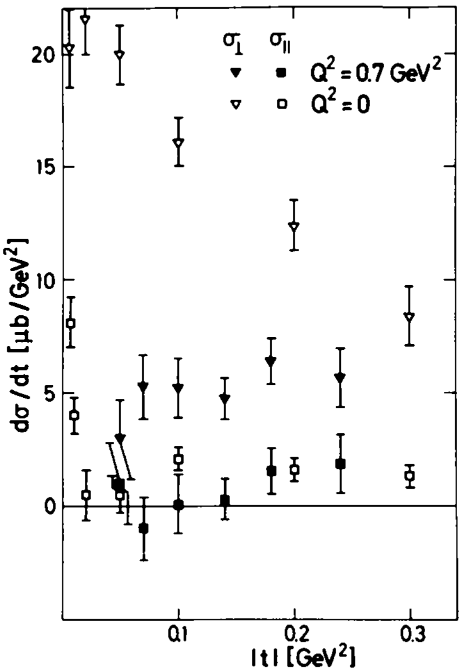

Fig. 3a

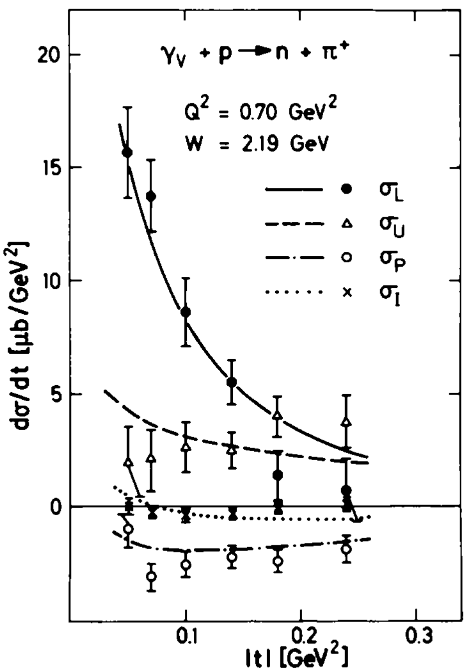

Fig. 3b

Fig. 3 (a) The cross sections σ_U, σ_L, σ_I and σ_P versus $|t|$ ($|t|_{min}$ = 0.024 GeV^2) as determined in this experiment. The curves shown are the predictions of the generalized Born term model of Gutbrod and Kramer. (b) Comparison of $\sigma_\perp$ and $\sigma_\parallel$ as calculated from σ_U and σ_P with photoproduction results of ref. [8]. The photoproduction cross sections were scaled from W = 2.69 GeV to W = 2.19 GeV according to $\sigma \sim (W^2 - M_p^2)^{-2}$.

contribution and the residual t-dependence $e^{-B|t|}$ factorize, one obtains $B = (5.6 \pm 2)$ GeV^{-2}. The transverse cross section σ_U shows no significant $|t|$-dependence within the errors. This behaviour suggests that the slow decrease of $d\sigma/dt$ with Q^2 observed recently [3,4] at large $|t|$ is due to σ_U as expected from the quark parton model and not due to a dominating σ_L contribution as conjectured in ref. [4].

We have used the generalized Born term model of Gutbrod and Kramer [7] to fit our data, and to extract the pion electromagnetic form factor F_π. This model uses as free parameters F_π and an off mass shell nucleon form factor F_1^V. The best fit yields $F_\pi = 0.42 \pm 0.015$ at $Q^2 = 0.7$ GeV^2, a value which lies between the VDM prediction $F_\pi^{VDM} = (1 + Q^2/m_\rho^2)^{-1} = 0.46$ and the mass shell value of $F_1^V = 0.41$. The best fit predictions of the various cross sections are plotted in fig. 3a. Constraining F_1^V to its mass shell value does not change σ_L and F_π significantly, but strongly changes σ_I and σ_P, and yields a σ_U about 50% lower than the best fit results. However, the discrepancy between the Born term model predictions of σ_U and the experimental data is not as striking as recently found by the Harvard-Cornell group [2] for $Q^2 \geqslant 1.2$ GeV^2.

The cross sections $\sigma_\parallel$ and $\sigma_\perp$, obtained from the σ_U and σ_P results of fig. 3a, are compared with photoproduction results in fig. 3b. The photoproduction cross sections [8] were scaled from W = 2.69 GeV to W = 2.19 GeV according to $\sigma \sim (W^2 - M_p^2)^{-2}$. The data indicate that the t-dependence of $\sigma_\perp$ changes with Q^2. The Q^2-dependence of $\sigma_\perp$ is compatible with $(1 + Q^2/m_\rho^2)^{-2}$ at $|t| \leqslant 0.1$ GeV^2 and seems to level off with increasing $|t|$. Within errors $\sigma_\parallel$ is zero except for $|t| > 0.15$ GeV^2, where it is compaitble with the photoproduction results.

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