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DETERMINATION OF THE LONGITUDINAL AND THE TRANSVERSE PART IN π^+ ELECTROPRODUCTION

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We report on an experiment where the different contributions from the transverse and longitudinal polarization of the virtual photon are measured separately for the reaction $e^- p \to e^- \pi^+ n$. The data taken above the resonance region at small $|t|$ values in the q^2 range of $|q^2| < 0.5$ GeV^2 show a clear dominance of the longitudinal part of the cross section and are well described by a generalized Born-term model. Using this model the electromagnetic form factor of the pion is determined. At $q^2 = -0.35$ GeV^2 one gets $F_\pi = 0.598 \pm 0.021$.

The detailed knowledge of the transverse and longitudinal cross sections for the reaction $ep \to e\pi^+ n$ offers a new opportunity to probe the nature of inelastic electron-proton scattering. The results which are presented here extend the available data on the transverse-longitudinal separation of the cross section for the above reaction [1,2] to $|q^2|$ values below 0.5 GeV^2 at $W = 2.1$ GeV. In the one-photon exchange approximation the electroproduction is treated as photoproduction by spacelike virtual photons whose flux Γ is determined by the energy, the energy loss and the scattering angle of the electron. The cross section for $\gamma_V p \to \pi^+ n$ is then given by

$$2\pi \frac{d^2\sigma}{dt\, d\phi} = \frac{d\sigma_u}{dt} + \epsilon \frac{d\sigma_L}{dt} + \epsilon \cos 2\phi \frac{d\sigma_P}{dt} + \sqrt{2\epsilon(1+\epsilon)} \cos\phi \frac{d\sigma_I}{dt}, \tag{1}$$

where ϵ is the degree of transverse polarization of the virtual photon and ϕ is the angle between the electron-scattering plane and the pion-production plane. The subscripted terms describe the contributions to the cross section from the unpolarized transverse photons, the longitudinal polarization, the transverse polarization and the

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transverse-longitudinal interference, respectively. Generally, they depend on W, the c.m. energy of the virtual photon and target proton, on q^2, the square of the virtual photon mass, and on t, the square of the four-momentum transfer from the virtual photon to the pion. For a detailed description of the notation see ref. [3].

It is clear from eq. (1) that the four components of the cross section can be separated only if there is sufficient acceptance in ϕ and large variation in ϵ. To determine the cross section for different values of ϵ at a fixed point in the W-q^2 plane, one has to measure at different scattering angles θ of the electron and vary the primary energy E_0 according to the following relations:

$$\epsilon = \left\{1 + \left(2 + \frac{(W^2 - q^2 - M^2)^2}{4M^2|q^2|}\right) \mathrm{tg}^2\, \tfrac{1}{2}\theta\right\}^{-1} ,$$

$$q^2 = -4\, E_0 \left(E_0 - \frac{W^2 - q^2 - M^2}{2M}\right) \sin^2 \tfrac{1}{2}\theta$$

(M = proton mass).

For this purpose we carried out an experiment with the following parameters:

ϵ	E_0	θ	ϕ
~0.35 ,	2.5 GeV ,	20° to 40° ,	–60° to +60° ,
~0.35 ,	2.9 GeV ,	20° to 40° ,	–60° to +60° ,
~0.8 ,	4.0 GeV ,	8° to 14° ,	–0° to +360° .

The experimental layout is shown in fig. 1. The primary electron was incident on a 4.5 cm long hydrogen target. The scattered electron and the produced hadron were detected in coincidence. The momenta of the particles were determined by measuring the angle of deflection in a magnetic field using optical spark chambers. The identification of the scattered electron was effected by means of a Čerenkov and a shower counter. The produced pion was separated from protons and kaons with the aid of another Čerenkov counter and by time-of-flight measurement. Further details are given in refs. [3,4], where basically the same experimental set-up was used. The smaller bending magnet in fig. 1 was switched on when the data were taken at larger values of θ. Except for this magnet the experimental conditions were identical for all energies. Therefore the relative systematic error in combining the data samples at different values of ϵ was kept to a minimum. The resolution in W, q^2 and t for all primary energies was

$$\Delta W = 0.006 \text{ GeV} , \qquad \Delta q^2 = 0.006 \text{ GeV}^2 , \qquad \Delta t = 0.003 \text{ GeV}^2 .$$

A comparison of the present measurements at E_0 = 4.0 GeV with the corresponding part of the data described in ref. [3] shows that the old values of the cross sections are too high. Careful checks have proved that this was a normalization error in the previous data which was due to the wrong recording of the random triggers for that particular run at E = 4.0 GeV.

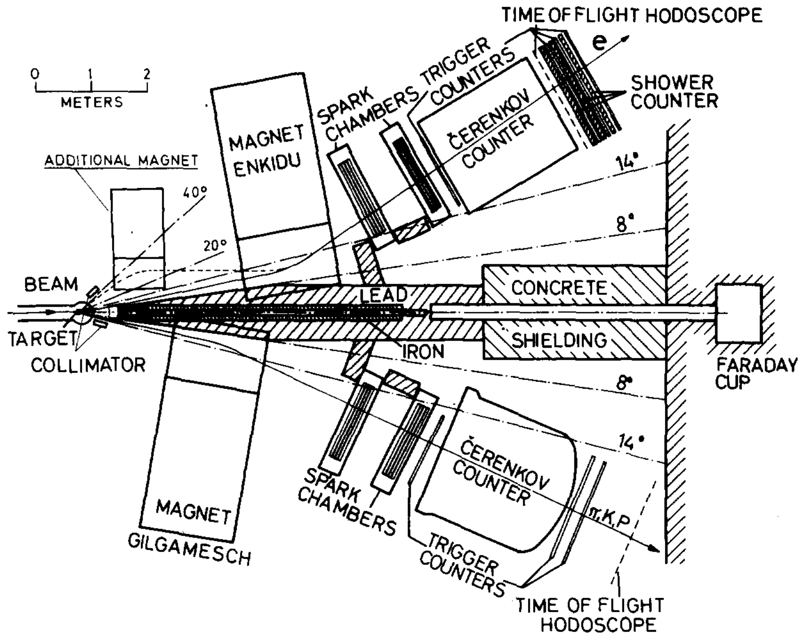

Fig. 1. Experimental layout.

Single π^+ production was separated from other channels by applying cuts in the invariant mass of the unobserved particles. The missing-mass spectra for the three incident energies are shown in fig. 2.

The cross sections were corrected for the efficiency loss of the trigger, shower and Čerenkov counters, strong interaction of the π^+, target walls and the missing-mass cuts. The overall corrections varied between 3% and 6%, depending on the incoming electron energy. The momentum-dependent corrections for the decay of pions ranged from 1.5% to 4.5%. The radiative corrections were calculated using the method proposed by De Calan and Fuchs [5]. They were about 15% and showed no strong dependence on ϵ. The systematic error introduced by the uncertainties in the above corrections including that in the intensity of the primary beam is estimated to be less than 5%, which is not included in the errors given in this paper.

The four components of the cross section described in relation (1) were determined through a maximum-likelihood fit to the data. Fig. 3 shows their dependence on t for a c.m. energy of $W = 2.1$ GeV and $q^2 = -0.35$ GeV^2. In the forward direction ($|t_{\min}| < |t| < 0.05$ GeV^2) the longitudinal component is dominant. Its behaviour is compatible with e^{14t}, in agreement with the dependence observed in ref. [2] in a neighbouring t region at a slightly different q^2 of -0.7 GeV^2. We have also analysed our data in the above t region ($|t_{\min}| < |t| < 0.2$ GeV^2), where the cross section was averaged over ϕ in the range $-60° < \phi < 60°$. Assuming that in

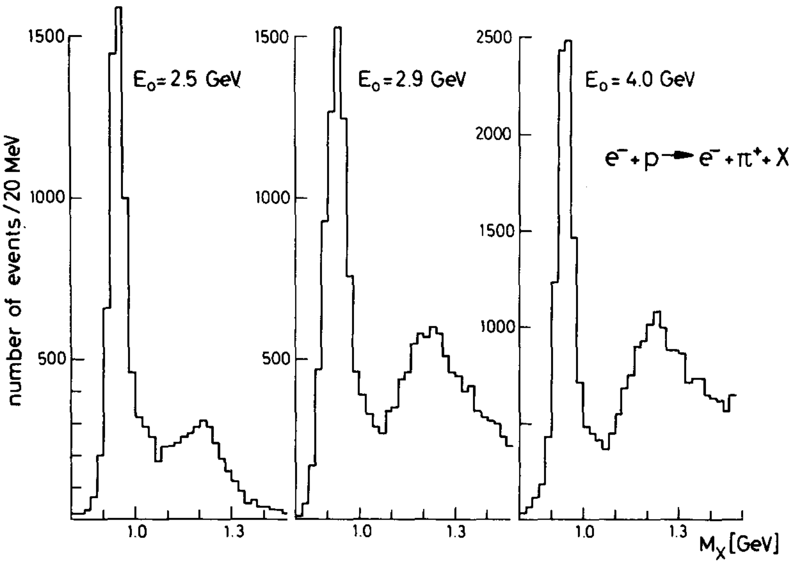

Fig. 2. Spectra of missing mass $m_X = \sqrt{(e + p - e' - \pi^+)^2}$ for the reaction e p → e π^+ + (anything) obtained with the primary electron energies 2.5, 2.9 and 4.0 GeV, respectively.

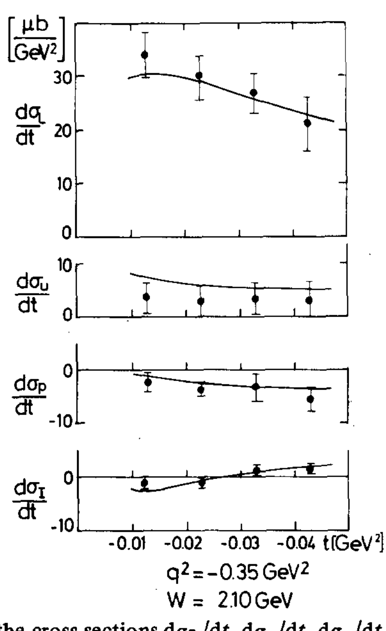

Fig. 3. The t dependence of the cross sections $d\sigma_L/dt$, $d\sigma_u/dt$, $d\sigma_p/dt$, $d\sigma_I/dt$: The lines are the results of a generalized Born-term model [7].

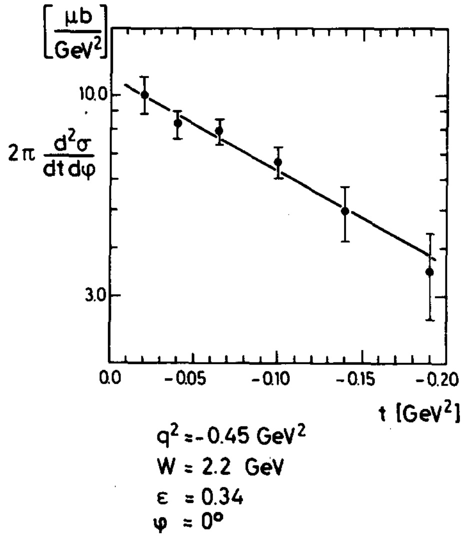

Fig. 4. The t dependence of the cross section averaged over the ϕ range $-60° < \phi < +60°$. The line corresponds to $e^{5.6t}$.

this t range $d\sigma_p/dt$ and $d\sigma_I/dt$ do not deviate drastically from their measured values at small t, their contribution to the integrated cross section is small. Therefore the resulting t dependence shown in fig. 4 is mainly due to $d\sigma_u/dt + \epsilon\, d\sigma_L/dt$. The exponential fall has a slope of 5.6 ± 1.0, which is well below the one observed for $d\sigma_L/dt$. This suggests that $d\sigma_u/dt$ becomes increasingly more important at higher $|t|$, which was also observed in ref. [2].

$d\sigma_p/dt$ and $d\sigma_u/dt$ can be expressed in terms of $d\sigma_\perp/dt$ and $d\sigma_\parallel/dt$ where $\perp$ and $\parallel$ refer to the virtual photon with the electric vector perpendicular and parallel to the hadron production plane:

$$\frac{d\sigma_u}{dt} = \frac{1}{2}\left(\frac{d\sigma_\parallel}{dt} + \frac{d\sigma_\perp}{dt}\right), \qquad \frac{d\sigma_p}{dt} = \frac{1}{2}\left(\frac{d\sigma_\parallel}{dt} - \frac{d\sigma_\perp}{dt}\right).$$

In a photoproduction experiment in our W range [6] it has been shown that for $|t| > 0.01$ GeV^2 $d\sigma_\parallel/dt$ is an order of magnitude smaller than $d\sigma_\perp/dt$. If this is also true for electroproduction then $d\sigma_u/dt \approx -d\sigma_p/dt$, which is supported by our data.

Assuming that at small $|t|$, $d\sigma_L/dt$ is dominated by π exchange, the data can be used to determine the electromagnetic form factor of the pion. For this purpose we have used the generalized Born-term model of Gutbrod and Kramer [7], who treat the pion and the off-mass-shell nucleon form factors as free parameters. As shown in fig. 3 the model describes our data well except that it slightly overestimates the contribution of $d\sigma_u/dt$. The fitted value of $F_\pi = 0.598 \pm 0.021$ at $q^2 = -0.35$ GeV^2 is slightly below the prediction of the vector meson dominance model of $(1 + |q^2|/m_\rho^2)^{-1} = 0.631$ and is compatible with the isovector Dirac nucleon form factor

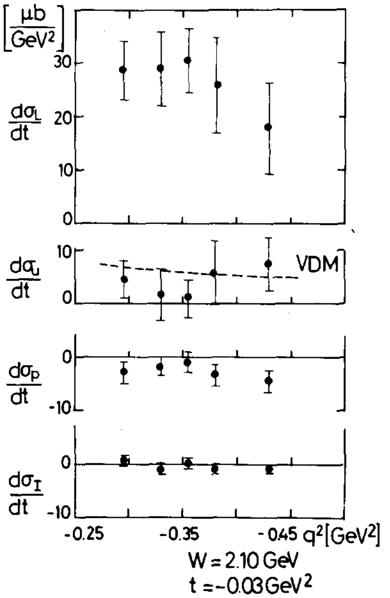

Fig. 5. The q^2 dependence of the cross sections $d\sigma_L/dt$, $d\sigma_u/dt$, $d\sigma_p/dt$, $d\sigma_I/dt$. The broken line was calculated using a simple vector meson dominance model ($\sim(q^2 - m_\rho^2)^{-2}$) normalized at $q^2 = 0$ to photoproduction values taken from ref. [9].

$F_1^V = 0.599$. This is in agreement with the findings of ref. [2] at $|q^2| = 0.7$ GeV^2, where the same model was used to extract F_π, and with the low-$|q^2|$ part of the results reported by another group [8], who have analysed their data using a different version of the Born-term model.

Fig. 5 shows the four components of the cross section as functions of q^2. In the covered range of q^2 no change in the dominance of $d\sigma_L/dt$ can be seen. The measured values of $d\sigma_u/dt$ are in agreement with the predictions of a simple vector meson dominance model (broken line) normalized to the photoproduction value taken from ref. [9].

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