ELECTROPRODUCTION OF NEUTRAL PIONS AND TEST OF THE QUARK-PARTON MODEL

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We present the first data on the inclusive structure function for π^0-electroproduction. The data are compared to charged pion electroproduction and charged pion production from electron-positron annihilation taking the quark-parton model as a guide.

The cross section for inclusive electroproduction reactions like $e + p \to e + \pi + X$ is usually given in terms of the invariant cross section

$$E\,\mathrm{d}^3\sigma/\mathrm{d}p^3(\nu, q^2, p_\parallel, p_\perp)$$

for the reaction $\gamma_v + p \to \pi + X$ where the symbols used have the usual meaning explained for example in ref. [1]. By integrating over $p_\perp$ and dividing by $\sigma_{tot}^{\gamma_v p}(q^2, \nu)$ a structure function f is defined i.e.

$$f(\nu, q^2, x_F) = \frac{1}{\pi\sigma_{tot}} \int_0^{p^2_{\perp\max}} \frac{E^*}{p^*_{\max}} \frac{\mathrm{d}^2\sigma}{\mathrm{d}x_F\,\mathrm{d}p_\perp^2} \approx \frac{1}{\pi\sigma_{tot}} x_F \frac{\mathrm{d}\sigma}{\mathrm{d}x_F} \tag{1}$$

where $x_F = p^*_\parallel/p^*_{\max}$.

In order to make the comparison with the quark-parton model easier we present our final results in terms of the structure function

$$f(\nu, q^2, z) = (1/\pi\sigma_{tot}) z\,\mathrm{d}\sigma/\mathrm{d}z \tag{2}$$

where $z = E_\pi/\nu$ with E_π the pion energy and ν the energy loss of the electron in the laboratory system. At large values of q^2 and ν both functions are identical. For our data the difference between the structure functions defined in eq. (1) and eq. (2) does not exceed 10%.

In the quark-parton model $f(\nu, q^2, z)$ is expressed by a set of simple functions $q(x)$ and $D_q^h(z)$. Here $q(x)$ is the number of quarks of the type q in the proton (for example $u(x)$, $d(x)$ for up quarks and down quarks, respectively) with the relative momentum $x = p_{quark}/p_{proton} = |q^2|/(2M\nu)$. $D_q^h(z)$ is the number of hadrons of the type h in which the quark q is fragmenting, with $z = p_{hadron}/p_{quark}$.

For electroproduction of pions one usually only includes u, $\bar{u}$, d, $\bar{d}$ and neglects strange and charmed quarks. It is easy to show that

$$f_{ep\to e\pi^\pm X}(x, z) = \frac{z}{\pi} \frac{(\frac{4}{9}u(x) + \frac{1}{9}\bar{d}(x))D_u^{\pi^\pm}(z) + (\frac{1}{9}d(x) + \frac{4}{9}\bar{u}(x))D_u^{\pi^\mp}(z)}{\frac{4}{9}(u(x) + \bar{u}(x)) + \frac{1}{9}(d(x) + \bar{d}(x))} \tag{3}$$

The number of independent fragmentation functions has been reduced to $D_u^{\pi^+}(z)$ and $D_u^{\pi^-}(z)$ using charge symmetry and isospin arguments.

The measured charge ratio in electroproduction experiments can thus be used to extract information on the ratio of the fragmentation functions $D_u^{\pi^+}/D_u^{\pi^-}$. According to the model this ratio is independent of x in nice agreement with experiments [2].

Our special interest concerns π^0 electroproduction. The model predicts

$$D_q^{\pi^0} = \tfrac{1}{2}(D_q^{\pi^+} + D_q^{\pi^-}). \tag{4}$$

This leads immediately to

$$\tfrac{1}{2}(f_{\mathrm{ep}\to\mathrm{e}\pi^+\mathrm{X}}(x,z)+f_{\mathrm{ep}\to\mathrm{e}\pi^-\mathrm{X}}(x,z))$$
$$=\frac{1}{2}\frac{z}{\pi}(D_\mathrm{u}^{\pi^+}(z)+D_\mathrm{u}^{\pi^-}(z))=f_{\mathrm{ep}\to\mathrm{e}\pi^0\mathrm{X}}(z)\,. \tag{5}$$

Thus the quark-parton model makes two very stringent predictions:

a) The structure function in π^0-electroproduction must only depend on z.

b) The value of $f_{\mathrm{ep}\to\mathrm{e}\pi^0\mathrm{X}}$ is given by the average of the π^+- and π^--structure functions evaluated at the same value of z. Because of

$$\frac{\mathrm{d}N_\pi}{\mathrm{d}z}=\frac{1}{\sigma_\mathrm{tot}}\frac{\mathrm{d}\sigma}{\mathrm{d}z}=\frac{\pi}{z}f_{\mathrm{ep}\to\mathrm{e}\pi\mathrm{X}}$$

one can simply say that the differential π^0-multiplicity $\mathrm{d}N_{\pi^0}/\mathrm{d}z$ in electroproduction must be given by the average of the π^+- and π^--multiplicity. If this is not borne out by experiment the quark-parton explanation of the π^+/π^--ratio is seriously damaged [3].

A further test of the model can be done by comparing the π^0-results with the data of $\mathrm{e^+e^-}$-annihilation into charged pions. Ignoring a small possible difference due to the fragmentation of strange quarks into pions the model predicts

$$\frac{z}{\pi\sigma_\mathrm{tot}}\frac{\mathrm{d}\sigma}{\mathrm{d}z}\bigg|_{\mathrm{e^+e^-}\to\pi\mathrm{chX}}=\frac{2z}{\pi}(D_\mathrm{u}^{\pi^+}+D_\mathrm{u}^{\pi^-})=4f_{\mathrm{ep}\to\mathrm{e}\pi^0\mathrm{X}}. \tag{6}$$

Herein $\mathrm{d}\sigma/\mathrm{d}z|_{\mathrm{e^+e^-}\to\pi\mathrm{chX}}$ is the inclusive cross section for production of a charged pion in $\mathrm{e^+e^-}$-annihilation at $z=E_\pi/E_\mathrm{beam}$.

To study these questions we have carried out a π^0-electroproduction experiment at the 7.5 GeV synchrotron DESY at Hamburg. The apparatus used has been described in ref. [4]. Data have been taken at incoming electron energies of 4, 5, 6 and 7 GeV. The range in q^2 and ν covered by our experiment is roughly given by

$$-0.2>q^2>-1.3\ \mathrm{GeV}^2$$
$$3.1<\nu<6.1\ \mathrm{GeV}.$$

Because the virtual photons are transversely and longitudinally polarized the invariant cross section $E\mathrm{d}^3\sigma/\mathrm{d}p^3$ is given by the well known expression

$$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3}=\frac{1}{\pi}\frac{E^*}{p^*_\mathrm{max}}\left[\frac{\mathrm{d}^2\sigma_\mathrm{u}}{\mathrm{d}x_\mathrm{F}\,\mathrm{d}p_\perp^2}+\epsilon\frac{\mathrm{d}^2\sigma_\mathrm{L}}{\mathrm{d}x_\mathrm{F}\,\mathrm{d}p_\perp^2}+\epsilon\cos 2\phi\frac{\mathrm{d}^2\sigma_\mathrm{p}}{\mathrm{d}x_\mathrm{F}\,\mathrm{d}p_\perp^2}+\sqrt{2\epsilon(\epsilon+1)}\cos\phi\frac{\mathrm{d}^2\sigma_\mathrm{I}}{\mathrm{d}x_\mathrm{F}\,\mathrm{d}p_\perp^2}\right].$$

For the evaluation of the structure function we have to separate $\mathrm{d}^2\sigma_\mathrm{u}/(\mathrm{d}x_\mathrm{F}\,\mathrm{d}p_\perp^2)$; This is done by analyzing the ϕ-dependence of the measured cross sections. In fig. 1 $E\mathrm{d}^3\sigma/\mathrm{d}p^3$ is plotted versus $\phi_{\pi\gamma}$ for some typical values of the kinematical variables. The data are very well consistent with

$$\mathrm{d}^2\sigma_\mathrm{p}/\mathrm{d}x_\mathrm{F}\,\mathrm{d}p_\perp^2=0 \quad \text{and} \quad \mathrm{d}^2\sigma_\mathrm{I}/\mathrm{d}x_\mathrm{F}\,\mathrm{d}p_\perp^2=0.$$

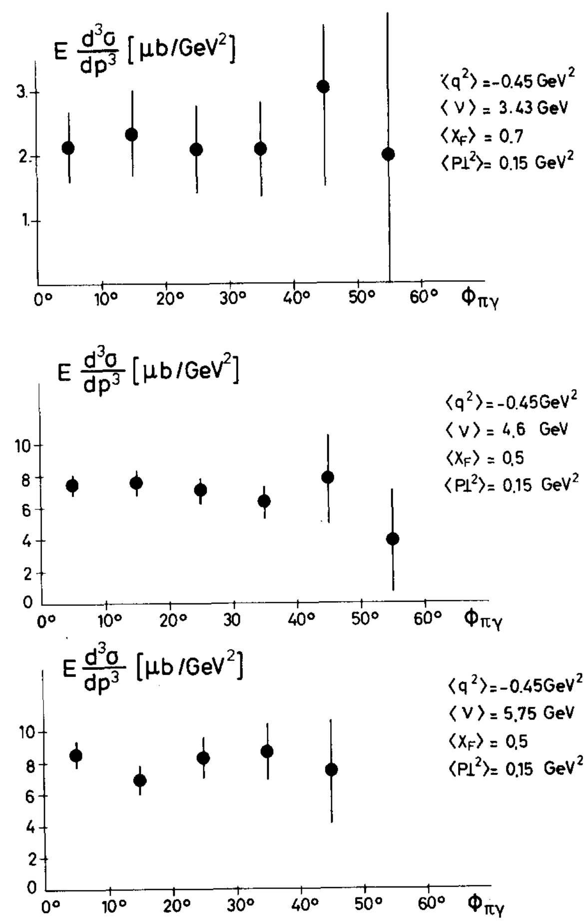

Fig. 1. Invariant cross section $E\mathrm{d}^3\sigma/\mathrm{d}p^3$ versus $\phi_{\pi\gamma}$.

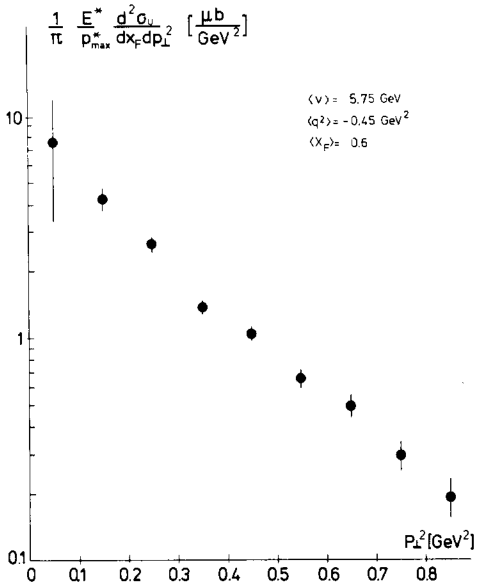

Fig. 2. Invariant cross section $E\,d^3\sigma/dp^3$ versus $p_\perp^2$.

Throughout the following we will assume $d^2\sigma_L/(dx_F \times dp_\perp^2)$ to be zero in accordance with the quark model, although we have not proven it experimentally.

In fig. 2 a typical plot of $\pi^{-1}(E^*/p^*_{max})\,d^2\sigma_u/dx_F dp_\perp^2$ versus $p_\perp^2$ is shown.

The data can be very well represented by an exponential $A \exp(-Bp_\perp^2)$ with a slope parameter of $B = 4.37 \pm 0.21\ \mathrm{GeV}^{-2}$. Similar slope parameters are found in other regions of the kinematical area and more detailed information will be given in an incoming paper.

From the measured $p_\perp$-distributions we have determined the structure function $f(\nu, q^2, z)$ for four combinations of ν and q^2, namely

$q^2 = -0.45\ \mathrm{GeV}^2$ $\nu = 3.42$ GeV

$\nu = 4.53$ GeV

$\nu = 5.56$ GeV

$q^2 = -0.90\ \mathrm{GeV}^2$ $\nu = 4.90$ GeV .

The data (fig. 3) exhibit a very nice scaling behaviour within the error bars, i.e. the structure function depends only on z.

In order to test eq. (5) we compare our results with the data of a recent experiment at SLAC [5]. For the

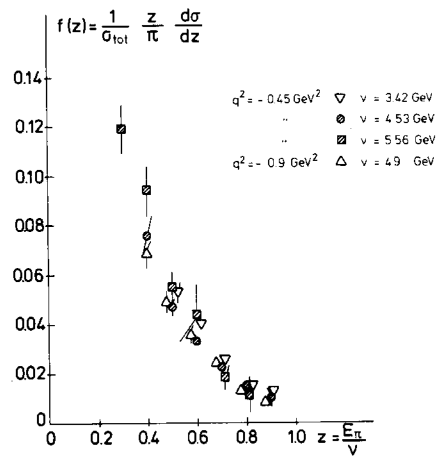

Fig. 3. Inclusive π^0-structure function versus z for various values of ν and q^2.

plot in fig. 4 we have chosen the $q^2 = -1.45\ \mathrm{GeV}^2$ data for the charged pions and the $q^2 = -0.9\ \mathrm{GeV}^2$ data for the π^0mesons. The reason for that choice is that at smaller values of $|q^2|$ one still has appreciable contributions from the decay of diffractively produced ρ^0-mesons in the charged pion sample ‡. As seen in

‡ A cut on the elastically produced ρ^0 makes the $|q^2| < 1\ \mathrm{GeV}^2$ data consistent with the $|q^2| = 1.45\ \mathrm{GeV}^2$ data [6].

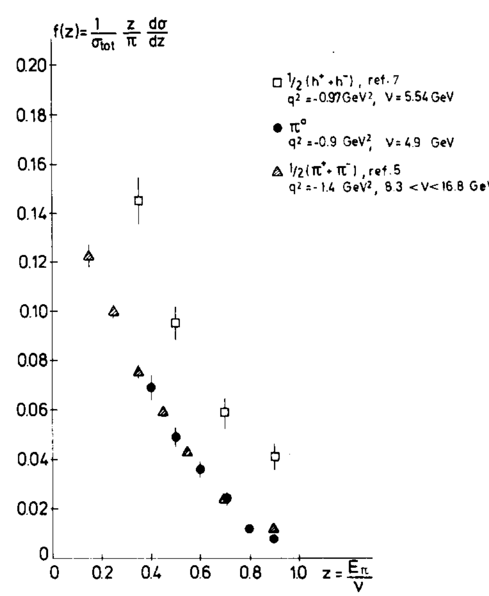

Fig. 4. Comparison of the π^0-structure function with charged pion and charged hadron electroproduction.

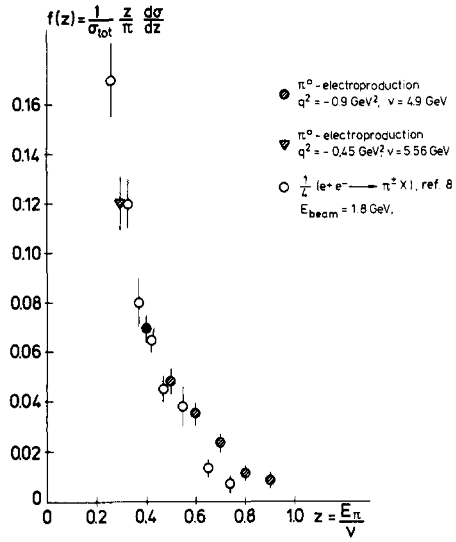

Fig. 5. Comparison of π^0-electroproduction with e^+e^--annihilation into charged pions.

the figure the data follow very well the quark-parton model prediction of eq. (5).

We emphasize that it is important for this sort of analysis to only take electroproduction data where the pions have been identified. In fig. 4 we have added the data of the SLAC-Santa Cruz streamer chamber experiment [7] where the structure functions $f_{ep\to eh^\pm X}$ have been measured. There is obviously a large difference between hadron and pion spectra. The authors of ref. [7] estimate the contribution of diffractively produced ρ^0 to the hadron spectra to be in the order of 40% at $z = 1$ and ~5% at $z = 0.5$.

To check relation (6) we compared our data with the results of a storage ring experiment. The DASP group at DESY has measured the annihilation cross section into charged pions [8]. Fig. 5 shows the comparison of the two experiments. The agreement below $z = 0.6$ is very nice. For higher z-values there is a discrepancy which might indicate some trouble.

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