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I. Physikalisches Institut der RWTH Aachen

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Deutsches Elektronen-Synchrotron DESY, Hamburg

F. Janata, D. Schmidt

Gesamthochschule Wuppertal

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Abstract

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 $e + p \rightarrow e + \pi + X$ is usually given in terms of the invariant cross section

$$E \frac{d^3\sigma}{dp^3}(\nu, q^2, p_{||}, p_{\perp})$$

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

$$f(\nu, q^2, x_F) = \frac{1}{\pi \sigma_{\text{tot}}} \int_0^{p_{||\text{max}}^2} \frac{E_{\pi}}{p_{\text{max}}^2} \frac{d^2\sigma}{dx_F dp_{\perp}^2} dp_{\perp}^2 = \frac{1}{\pi \sigma_{\text{tot}}} x_F \frac{d\sigma}{dx_F} \quad (1)$$

where

$$x_F = \frac{p_{||}}{p_{\text{max}}}.$$

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

$$f(\nu, q^2, z) = \frac{1}{\pi \sigma_{\text{tot}}} z \frac{d\sigma}{dz} \quad (2)$$

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 $x = p_{\text{quark}}/p_{\text{proton}} = |q^2|/(2 Mv)$. $D_q^h(z)$ is the number of hadrons of the type h in which the quark q is fragmenting, with $z = p_{\text{hadron}}/p_{\text{quark}}$.

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

$$f_{ep \rightarrow e\pi^+ X}(x, z) = \frac{z}{\pi} \frac{\left(\frac{4}{9} u(x) + \frac{1}{9} \bar{d}(x)\right) D_u^{\pi^+}(z) + \left(\frac{1}{9} d(x) + \frac{4}{9} \bar{u}(x)\right) D_u^{\pi^-}(z)}{\frac{4}{9} (u(x) + \bar{u}(x)) + \frac{1}{9} (d(x) + \bar{d}(x))}. \quad (3)$$

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

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

This leads immediately to

$$\begin{aligned} \frac{1}{2} (f_{ep \rightarrow e\pi^+ X}(x, z) + f_{ep \rightarrow e\pi^- X}(x, z)) &= \frac{1}{2} \frac{z}{\pi} (D_u^{\pi^+}(z) + D_u^{\pi^-}(z)) \\ &= f_{ep \rightarrow e\pi^0 X}(z). \end{aligned} \quad (5)$$

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

$$\frac{dN_{\pi}}{dz} = \frac{1}{\sigma_{\text{tot}}} \frac{d\sigma}{dz} = \frac{\pi}{z} f_{ep \rightarrow e\pi X}$$

one can simply say that the differential π^0 -multiplicity $\frac{dN_{\pi^0}}{dz}$ 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 e^+e^- -annihilation into charged pions. Ignoring a small possible difference due to the fragmentation of strange quarks into pions the model predicts

$$\frac{z}{\pi \sigma_{\text{tot}}} \left. \frac{d\sigma}{dz} \right|_{e^+e^- \rightarrow \pi^{\pm} X} = \frac{2z}{\pi} (D_u^{\pi^+} + D_u^{\pi^-}) = 4 f_{ep \rightarrow e\pi^0 X}. \quad (6)$$

Herein $\left. \frac{d\sigma}{dz} \right|_{e^+e^- \rightarrow \pi^{\pm} X}$ is the inclusive cross section for production of a charged pion in e^+e^- -annihilation at $z = E_{\pi}/E_{\text{beam}}$.

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 v covered by our experiment is roughly given by

$$-0.2 > q^2 > -1.3 \text{ GeV}^2$$

$$3.1 < v < 6.1 \text{ GeV}.$$

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

$$E \frac{d^3\sigma}{dp^3} = \frac{1}{\pi} \frac{E^2}{p_{\max}^2} \left[\frac{d^2\sigma_u}{dx_F dp_{\perp}^2} + \epsilon \frac{d^2\sigma_L}{dx_F dp_{\perp}^2} + \epsilon \cos 2\phi \frac{d^2\sigma_P}{dx_F dp_{\perp}^2} + \sqrt{2\epsilon(\epsilon+1)} \cos \phi \frac{d^2\sigma_I}{dx_F dp_{\perp}^2} \right]$$

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

$$\frac{d^2\sigma_P}{dx_F dp_{\perp}^2} = 0 \quad \text{and} \quad \frac{d^2\sigma_I}{dx_F dp_{\perp}^2} = 0.$$

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

In fig. 2 a typical plot of $\frac{1}{\pi} \frac{E^2}{p_{\max}^2} \frac{d^2\sigma_u}{dx_F dp_{\perp}^2}$ 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 $B = 4.37 \pm 2.1 \text{ GeV}^{-2}$. Similar slope parameters are found in other regions of the kinematical area and more detailed information will be given in an oncoming paper.

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

$$\begin{aligned} q^2 &= -0.45 \text{ GeV}^2 & v &= 3.42 \text{ GeV} \\ & & v &= 4.53 \text{ GeV} \\ & & v &= 5.56 \text{ GeV} \end{aligned}$$

$$q^2 = -0.90 \text{ GeV}^2 \quad v = 4.90 \text{ GeV}.$$

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 plot in fig. 4 we have chosen the $q^2 = -1.45 \text{ GeV}^2$ data for the charged pions and the $q^2 = -0.9 \text{ GeV}^2$ data for the π^0 -mesons. 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⁽⁶⁾. As seen in 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 $f_{ep \rightarrow eh^+X}$ 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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References and Footnotes

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Figure Captions

- Fig. 1 Invariant cross section $E \frac{d^3\sigma}{dp^3}$ versus $\phi_{\pi\gamma}$.
- Fig. 2 Invariant cross section $E \frac{d^3\sigma}{dp^3}$ versus $p_{\perp}^2$.
- Fig. 3 Inclusive π^0 -structure function versus z for various values of ν and q^2 .
- 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.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG.5