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Electroproduction of Neutral Pions and Test of the Quark-Parton Model

by

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Abstract

We present the first data on the inclusive structure function for π^o-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 $\gamma_v + p \rightarrow \pi + X$ where the symbols used have the usual meaning explained for example in reference 1. By integrating over $p_{\perp}$ and dividing by $\sigma_{tot}^{\gamma_v p}(q^2, \nu)$ a structure function f is defined i.e.

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

where

$$x_F = \frac{p^*_{||}}{p^*_{max}} .$$

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

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

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 $x = p_{quark}/p_{proton} = |q^2|/(2\,M\nu)$. $D_q^h(z)$ 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

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

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^o electroproduction. The model predicts

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

This leads immediately to

$$\frac{1}{2}(f_{ep\to e\pi^+X}(x,z) + f_{ep\to e\pi^-X}(x,z)) = \frac{1}{2}\frac{z}{\pi}(D_u^{\pi^+}(z) + D_u^{\pi^-}(z)) = f_{ep\to e\pi^oX}(z) \,. \quad (5)$$

Thus the quark parton model makes two very stringent predictions:

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

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

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

one can simply say that the differential π^o-multiplicity $\frac{dN_{\pi^o}}{dz}$ 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^o-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

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

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

To study these questions we have carried out a π^o-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

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

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

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

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\pi}\frac{E^*}{p^*_{max}}\left[\frac{d^2\sigma_u}{dx_F\,dp_\perp^2} + \varepsilon\frac{d^2\sigma_L}{dx_F\,dp_\perp^2} + \varepsilon\cos 2\phi\,\frac{d^2\sigma_p}{dx_F\,dp_\perp^2} + \sqrt{2\varepsilon(\varepsilon+1)}\cos\phi\,\frac{d^2\sigma_I}{dx_F\,dp_\perp^2}\right]$$

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 $\frac{1}{\pi}\frac{E^*}{p^*_{max}}\frac{d^2\sigma_u}{dx_F\,dp_\perp^2}$ 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 $B = 4.37 \pm .21\ \text{GeV}^{-2}$. 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 $f(\nu,q^2,z)$ for four combinations of ν and q^2, namely

$q^2 = -0.45\ \text{GeV}^2$ $\quad \nu = 3.42$ GeV
$\nu = 4.53$ GeV
$\nu = 5.56$ GeV

$q^2 = -0.90\ \text{GeV}^2$ $\quad \nu = 4.90$ 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 plot in fig. 4 we have chosen the $q^2 = -1.45$ GeV^2 data for the charged pions and the $q^2 = -.9$ GeV^2 data for the π^o-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^o-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 emphazise 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^o 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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2. J.F. Martin and L.S. Osborne, PRL 38 (1977) 1193.

3. F. Gilman, SLAC PUB 1396 (1974).

4. Ch. Berger et al., DESY 77/42 (1977).

5. J.F. Martin et al., paper prepared for publication. We used the data as given to us by J.F. Martin.

6. A cut on the elastically produced ρ^o makes the $|q^2| < 1$ GeV^2 data consistent with the $|q^2| = 1.45$ GeV^2 data. J. F. Martin private communication.

7. C. de Papa et al., PR D15 (1977) 2425.

8. The DASP Collaboration, R. Brandelik et al., PL 67B (1977) 358.

Figure Captions

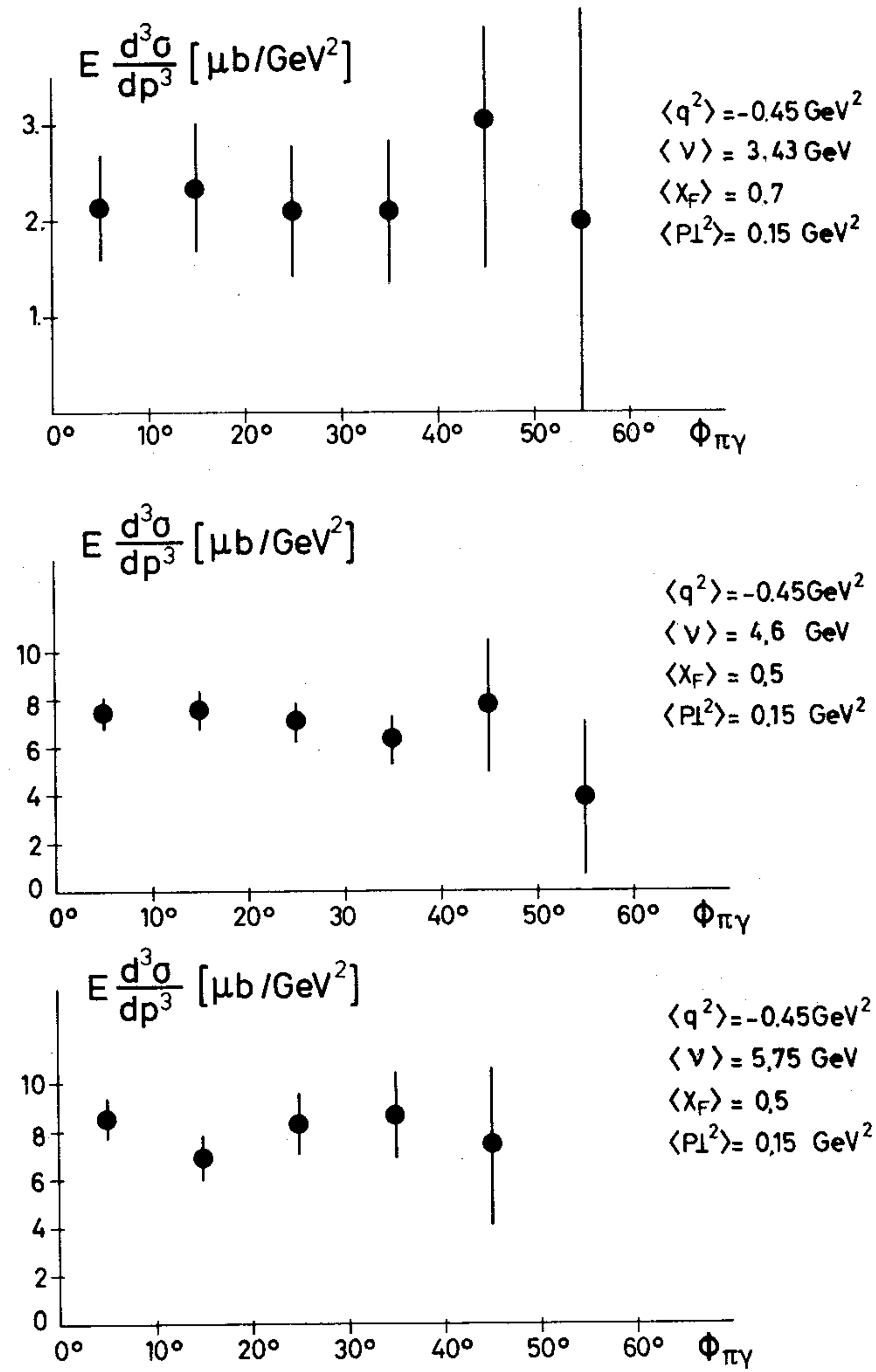
Fig. 1 Invariant cross section $E \frac{d^3\sigma}{dp^3}$ versus $\phi_{\pi\gamma}$.

Fig. 2 Invariant cross section $E \frac{d^3\sigma}{dp^3}$ versus $p_\perp^2$.

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

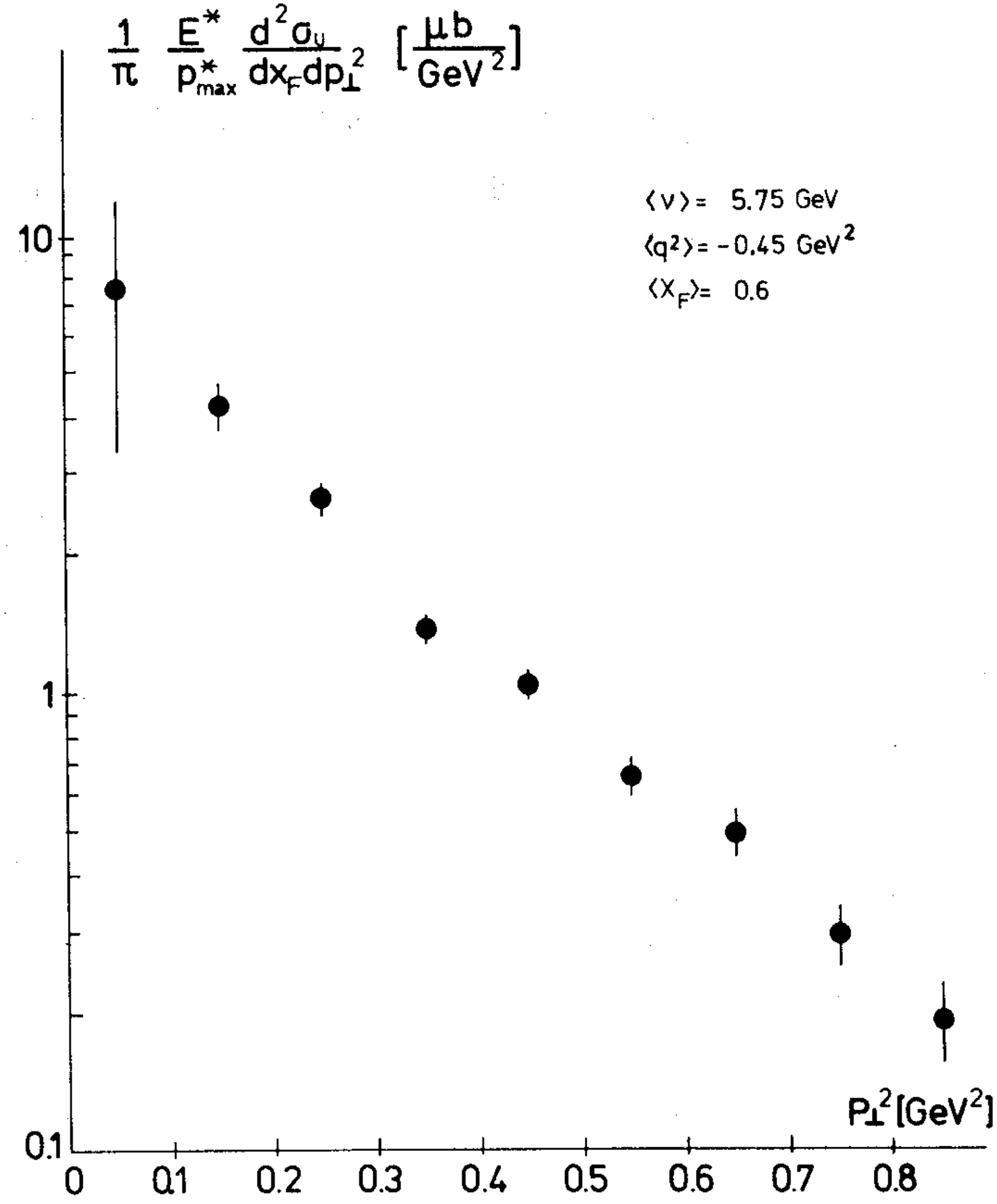
Fig. 4 Comparison of the π^o-structure function with charged pion and charged hadron electroproduction.

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



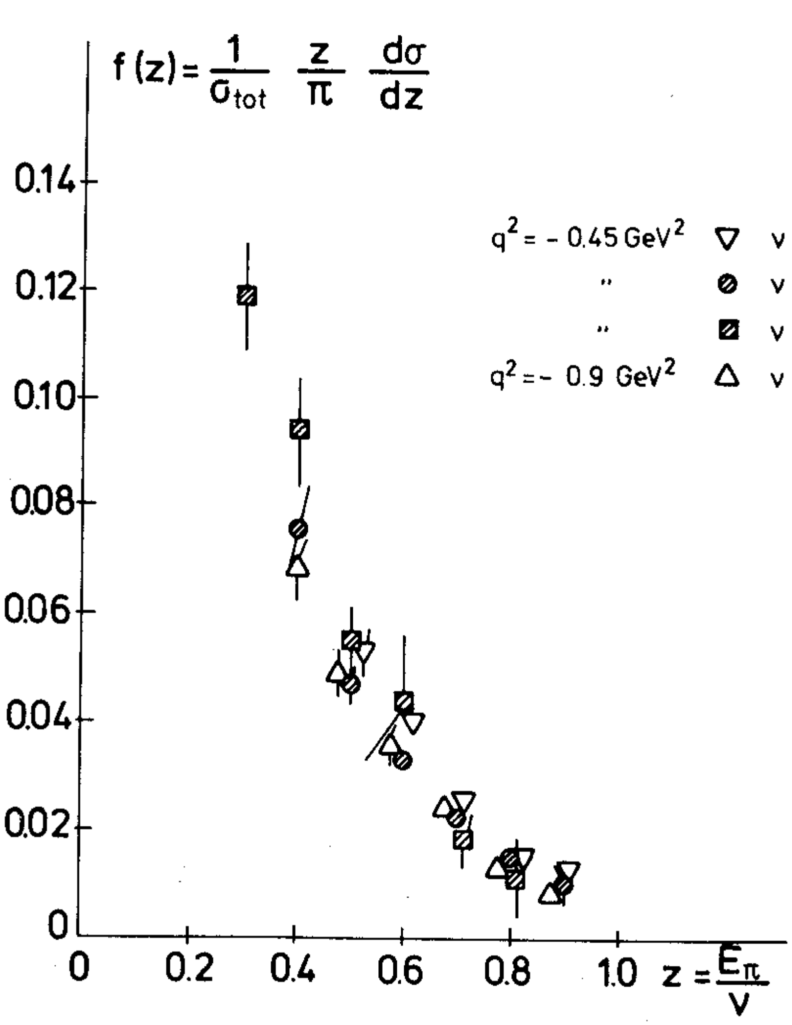
E d³σ/dp³ [μb/GeV²]
⟨q²⟩ = -0.45 GeV²
⟨ν⟩ = 3.43 GeV
⟨X_F⟩ = 0.7
⟨P⊥²⟩ = 0.15 GeV²
E d³σ/dp³ [μb/GeV²]
⟨q²⟩ = -0.45GeV²
⟨ν⟩ = 4,6 GeV
⟨X_F⟩ = 0,5
⟨P⊥²⟩ = 0,15 GeV²
E d³σ/dp³ [μb/GeV²]
⟨q²⟩ = -0.45GeV²
⟨ν⟩ = 5,75 GeV
⟨X_F⟩ = 0,5
⟨P⊥²⟩ = 0,15 GeV²
0° 10° 20° 30° 40° 50° 60° Φπγ

FIG. 1



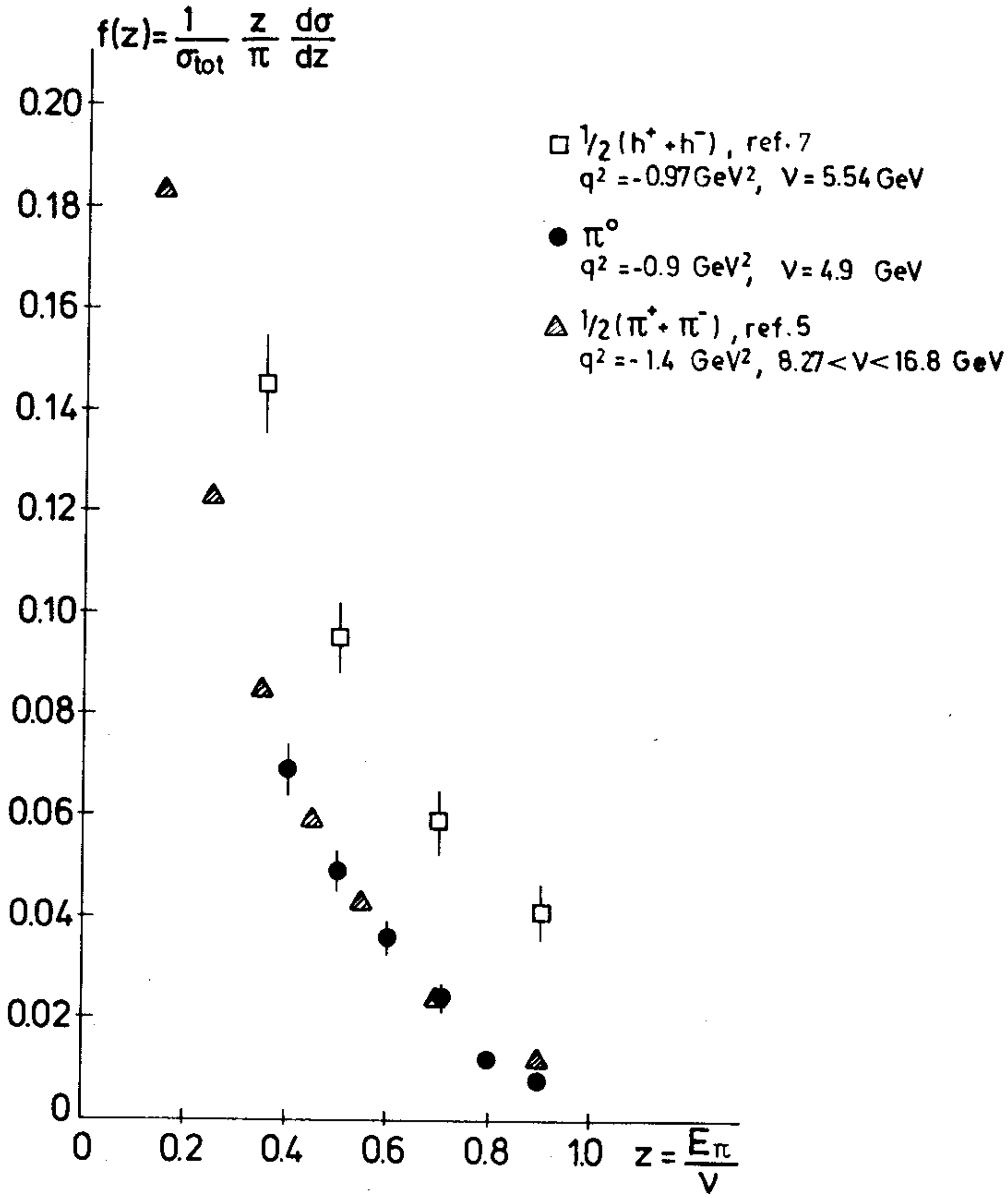
1/π E*/p*max d²σ_ν/dx_F dp⊥² [μb/GeV²]
⟨ν⟩ = 5.75 GeV
⟨q²⟩ = -0.45 GeV²
⟨X_F⟩ = 0.6
P⊥² [GeV²]

FIG. 2



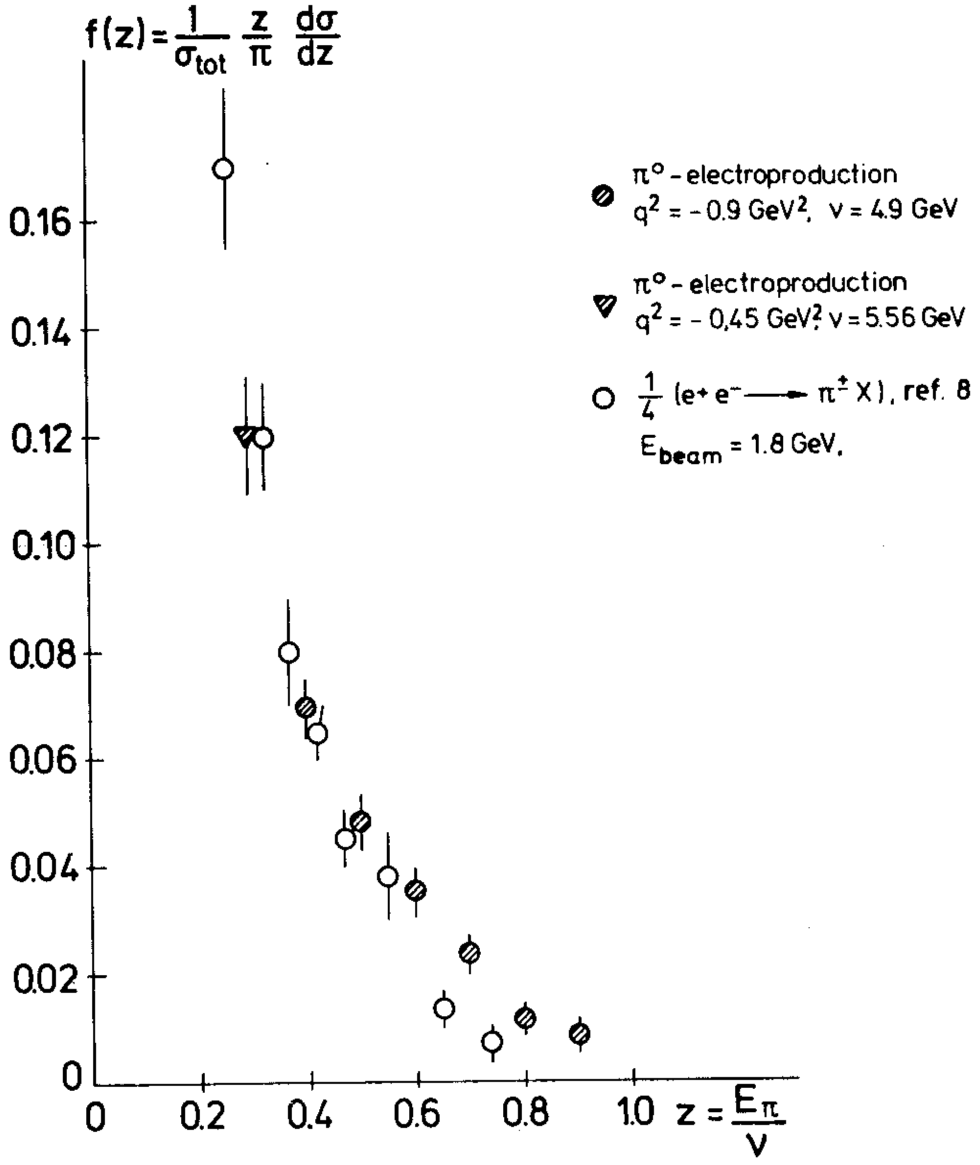
f (z) = 1/σtot z/π dσ/dz
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0.2
0.4
0.6
0.8
1.0
z = Eπ/ν
q² = - 0.45 GeV² ▽ ν = 3.42 GeV
" ν = 4.53 GeV
" ν = 5.56 GeV
q² = - 0.9 GeV² △ ν = 4.9 GeV

FIG. 3



f(z) = 1/σtot z/π dσ/dz
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0.2
0.4
0.6
0.8
1.0
z = Eπ/ν
□ 1/2 (h⁺ + h⁻) , ref. 7
q² = -0.97 GeV², ν = 5.54 GeV
● π°
q² = -0.9 GeV², ν = 4.9 GeV
△ 1/2 (π⁺ + π⁻) , ref. 5
q² = -1.4 GeV², 8.27 < ν < 16.8 GeV

FIG 4



$f(z) = \frac{1}{\sigma_{tot}} \frac{z}{\pi} \frac{d\sigma}{dz}$
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0
0.2
0.4
0.6
0.8
1.0
$z = \frac{E_\pi}{\nu}$
π^o - electroproduction
$q^2 = -0.9\ GeV^2,\ \nu = 4.9\ GeV$
π^o - electroproduction
$q^2 = -0{,}45\ GeV^2;\ \nu = 5.56\ GeV$
$\frac{1}{4}\ (e^+e^- \longrightarrow \pi^\pm X)$, ref. 8
$E_{beam} = 1.8\ GeV,$

FIG.5