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Abstract

Results of an experiment on hadron production in deep-inelastic electron scattering are presented. Good agreement with the predictions of the quark-parton model is found. The fragmentation functions for u and d quarks into pions are determined, and comparison is made with other deep-inelastic processes and with recent jet model calculations.

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In this letter we present results from a high-statistics experiment on the charged hadrons produced in deep inelastic electron-proton scattering in a kinematic region dominated by valence quarks. We use the data to test the quark-parton model, to determine quark fragmentation functions, and to compare with recent jet model calculations.

In the quark-parton model, at sufficiently high Q^2 and W, the cross section for producing hadrons of type h can be expressed as a summation over all quarks by

$$\frac{1}{\sigma(x)} \frac{d\sigma^h}{dz}(x,z) = \frac{\Sigma e_i^2 \, q_i(x) \, D_i^h(z)}{\Sigma e_i^2 \, q_i(x)} \qquad (1)$$

where $q_i(x)$ is the density of quarks of flavor i and charge e_i in the target proton[1,2]. The quark framentation function $D_i^h(z)$ is the number of hadrons of type h and momentum fraction $z = p^{lab}/\nu$ per dz, arising from the fragmentation of quark i. As usual we define $-Q^2$ and ν as the invariant mass squared and laboratory energy of the virtual photon; W is the invariant mass of the final state hadrons, and $x = Q^2/2M\nu$.

The experiment was performed in an 11.5 GeV electron beam at the Wilson Synchrotron Laboratory. The apparatus, consisting of a streamer chamber with nearly 4π acceptance triggered by a scattered electron, is described elsewhere[3]. Since it was not possible to distinguish among hadrons in this experiment, pion production cross sections were obtained by subtracting kaons and protons on a statistical basis. The contribution of charged kaons was determined from our measured kaon fragmentation functions[3] together with the assumptions $D_u^{K-}/D_u^{K+} = D_u^{\pi-}/D_u^{\pi+}$, $D_s^{K+} \ll D_s^{K-}$. This contribution (10 ± 3)% is nearly independent of z.

The proton subtraction was made using a parametrization of the structure function for proton electroproduction. This parametrization, which is a function of $p_\perp$, $p^*_{||}/p^*_{max}$, and W, describes available data[4] to within 20%. The $p_\perp$ dependence was obtained from experiments in a lower W range than our experiment, and the W and $p^*_{||}/p^*_{max}$ dependences came from measurements at $p_\perp < .14$ GeV/c. With the restriction of $W^2 > 12$ GeV^2 for positive hadrons, the proton contribution (before subtraction) is only (20 ± 6)% of all charged hadrons at z = 0.3, and it decreases as z approaches 1.

Elastic ρ^0 and ω production events were identified by kinematic reconstruction and excluded from the data sample. This resulted in a z-dependent correction of up to 20%.

Additional corrections of 8% were made for inefficiences due to overlapping tracks and a small insensitive region in the streamer chamber, as well as for hadrons misidentified as bremsstrahlung or Møller scattered electrons. Radiation corrections[5] adjusted z upwards by lowering the value of ν by 6% on the average.

To test the quark-parton model we restrict the x range to x > 0.1 where valence quarks dominate. Using charge conjugation and isospin invariance and neglecting strange quarks from the nucleon's sea, eq. (1) for the sum of π^+ and π^- becomes independent of x:

$$\frac{1}{\sigma(x)}\left[\frac{d\sigma^{\pi^+}}{dz}(x,z) + \frac{d\sigma^{\pi^-}}{dz}(x,z)\right] \cong D_u^{\pi^+}(z) + D_u^{\pi^-}(z) \quad . \qquad (2)$$

In Fig. 1 we present the left-hand side of eq. (2) for 3 regions of x, divided by the average of (2) over the full x range at each fixed z value. We conclude that the predicted x-independence holds within reasonable accuracy. The limitation of this test is the systematic error associated with the kaon and proton subtractions. Similar previous tests have suffered from either kaon and proton contamination, significant sea quark contributions, limited x range, or limited $p_\perp$ range[6].

A test of the quark-parton model which is independent of hadron identification uncertainties can be made using only negative hadrons. Restricting the data to x > .2, one can neglect quarks in the nucleon sea and obtain

$$\frac{1}{\sigma(x)} \frac{d\sigma^{h^-}(x,z)}{dz} = \frac{4q_u(x)[D_u^{\pi^-}(z) + D_u^{K^-}(z)] + q_d(x)[D_d^{\pi^-}(z) + D_d^{K^-}(z)]}{4q_u(x) + q_d(x)} \quad (3)$$

Since u quarks account for $\sim$ 8/9 of the cross section nearly independently of x, the variation of eq. (3) with x is small as long as $D_d^{h^-}/D_u^{h^-} \leq 4$. Assuming this bound, which is consistent with our data (see below), the net variation of eq. (3) is less than 10% for .2 < x < .6. Figure 2 shows this prediction to be well supported by the data.

In Fig. 3 we present our charged pion data in comparison with corresponding data for π^0 electroproduction[7] and for $\pi^\pm$ production by e^+e^- annihilation[8] (where $z = E_h^{lab}/E_{beam}$) below the charm threshold, multiplied by 2 and 0.5 respectively. In the quark-parton model these pion distributions are expected to be equal, apart from a difference of at most 10% between the ep and the e^+e^- data due to different contributions from strange quarks. The agreement between the two electroproduction experiments is excellent. The e^+e^- data agree with the ep data within $\sim$30% but a somewhat different z dependence is suggested. Comparison of our data with the parametrizations by Sehgal[2], Andersson et al.[9] and the "standard jet model" of Field and Feynman[10] for fragmenting u or d quarks is also shown in Fig. 3.

To determine the fragmentation functions $D_u^{\pi^\pm}(z)$, we have fitted eq. (1) to our $\pi^\pm$ data in bins of x and z. The kinematic region was $2 < Q^2 < 6$ GeV^2 ($\langle Q^2\rangle = 2.8$ GeV^2), $0.1 < x < 0.45$ ($\langle x\rangle = 0.2$), $12 < W^2 < 16$ GeV^2 for π^+, and $9 < W^2 < 16$ GeV^2 for π^-. The quark density functions $q_i(x)$ were taken from Field and Feynman[11]; the sea quark parametrization is not critical in our x range. The fit gives $\chi^2 = 108$ for 90 degrees of freedom, confirming that eq. (1) of the quark-parton model is consistent with our data.

The fitted fragmentation functions are shown in Fig. 4. They are in agreement with those proposed by Field and Feynman[10]. In particular, their predicted limiting behavior at $z \to 1$ is consistent with our results. For comparison, results from the reactions $\bar{\nu}p \to \mu^+h^-X$ and $\nu p \to \mu^-h^-X$ are also shown[12,13]. These reactions are expected to be dominated by $D_u^{\pi^+}$ and $D_u^{\pi^-}$ respectively, but due to sea quark contributions and K^- production, the agreement with our data is not expected to be perfect.

After having determined $D_u^{\pi^\pm}(z)$, $D_u^{\pi^0}(z)$ can be calculated. The momentum sum rule for forward going pions gives

$$\sum_{\pi^+,\pi^-,\pi^0} \int_{0.3}^{1.} zD_u^{\pi}(z)dz = 0.25 \pm 0.01 \tag{4}$$

Using our fragmentation functions for kaons[3], we obtain

$$\sum_{K^+,K^-,K^0,\bar{K}^0} \int_{0.3}^{1.} zD_u^{K}(z)dz = 0.028 \pm 0.006 \tag{5}$$

Adding (4) and (5) shows that pions and kaons with $z > 0.3$ carry about 30% of the total momentum of the parent quark.

In Fig. 5, the z distributions of the fastest and second fastest charged hadrons (including K's but not protons) are shown. Comparison with the prediction for "standard jets" by Field and Feynman[10] again shows rather good agreement. In the region $z > 0.3$, the fastest and second fastest charged hadrons carry (21 ± 1)% and (1.7 ± 0.2)% of the total momentum.

In summary, our investigation of electroproduced final states has shown good agreement with the quark-parton model. Comparison with other deep-inelastic processes suggests a common mechanism for hadron production. In addition, we find our data in agreement with the "standard jet" model of Field and Feynman.

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REFERENCES

1. R.P. Feynman, Photon-Hadron Interactions (W.A. Benjamin, Reading, Mass., 1972).

2. L.M. Sehgal, Proceedings 1977 Int. Symposium on Lepton and Photon Interactions at High Energies, ed. F. Gutbrod (Deutsches Elektronen Synchrotron, Hamburg, Germany, 1977).

3. I. Cohen, et al., Phys. Rev. Lett. 40, 1614 (1978).

4. H. Ackermann et al., Nucl. Phys. B120, 365 (1977);
   J.C. Alder et al., Nucl. Phys. B46, 415 (1972);
   C.J. Bebek et al., Phys. Rev. Lett. 32, 27 (1974);
   C.J. Bebek et al., Phys. Rev. D15, 3077 (1977);
   A. Browman et al., Phys. Rev. Lett. 37, 651 (1976).

5. L. Mo and P. Tsai, Rev. Mod. Phys. 41, 205 (1969).

6. C. del Papa et al., Phys. Rev. D15, 2425 (1977);
   C.J. Bebek et al., Phys. Rev. D16, 1986 (1977);
   W.A. Loomis et al., "Hadron Production in Muon-Proton and Muon-Deuterium Collisions", to be published.
   J.F. Martin et al., Phys. Rev. Lett. 38, 1193 (1977);
   J.M. Scarr et al., DESY 77/77 (1977).

7. C. Berger et al., Phys. Lett. 70B, 47 (1977), and private communication.

8. R. Brandelik et al., Phys. Lett. 67B, 358 (1977), and private communication.

9. B. Andersson, G. Gustafson, and C. Peterson, Nucl. Phys. B135, 273 (1978).

10. R.D. Field and R.P. Feynman, preprint CALT-68-618 (1977), to be published.

11. R.D. Field and R.P. Feynman, Phys. Rev. D15, 2590 (1977).

12. M. Derrick et al., preprint ANL-HEP-PR-77-39 (1977), to be published.

13. J.C. Vander Velde, Proceedings of the Flaine Conference (1977), p. 365.

FIGURE CAPTIONS

1. Sum of the π^+ and π^- distributions for different regions of x, testing dependence on x. The z dependence has been divided out.

2. The negative hadron distribution for different regions of x.

3. Sum of the π^+ and π^- distributions for this experiment, compared with measurements from other deep-inelastic processes (Refs. 7 and 8) and with various quark parton model parametrizations (Refs. 2, 9, and 10). The kinematic range of this experiment is $2 < Q^2 < 6$ GeV^2, $12 < W^2 < 16$ GeV^2 for π^+, $9 < W^2 < 16$ GeV^2 for π^-, and $0.1 < x < 0.45$.

4. Fragmentation functions of u quarks into π^+ and π^- compared with results from νp and $\bar{\nu} p$ experiments (refs. 12 and 13), and with the parametrizations by Sehgal, Andersson et al., and Field and Feynman (refs. 2, 9, and 10).

5. z distribution of the fastest and second fastest hadrons for the kinematic region $2 < Q^2 < 6$ GeV^2, $12 < W^2 < 16$ GeV^2, and $0.1 < x < 0.45$ where u quarks are expected to dominate; compared with the prediction by Field and Feynman (ref. 10) for u quark jets of 10 GeV total momentum.

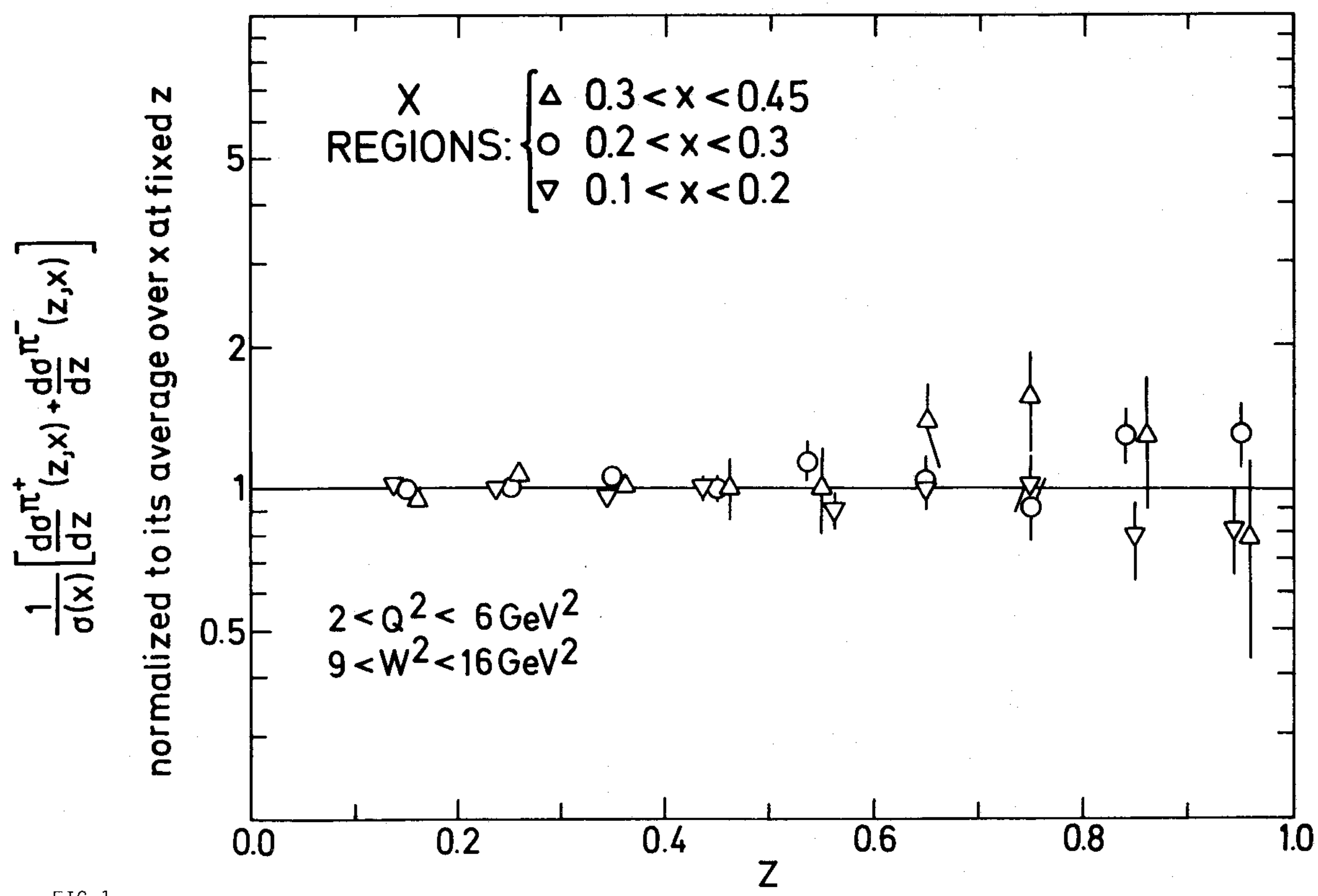
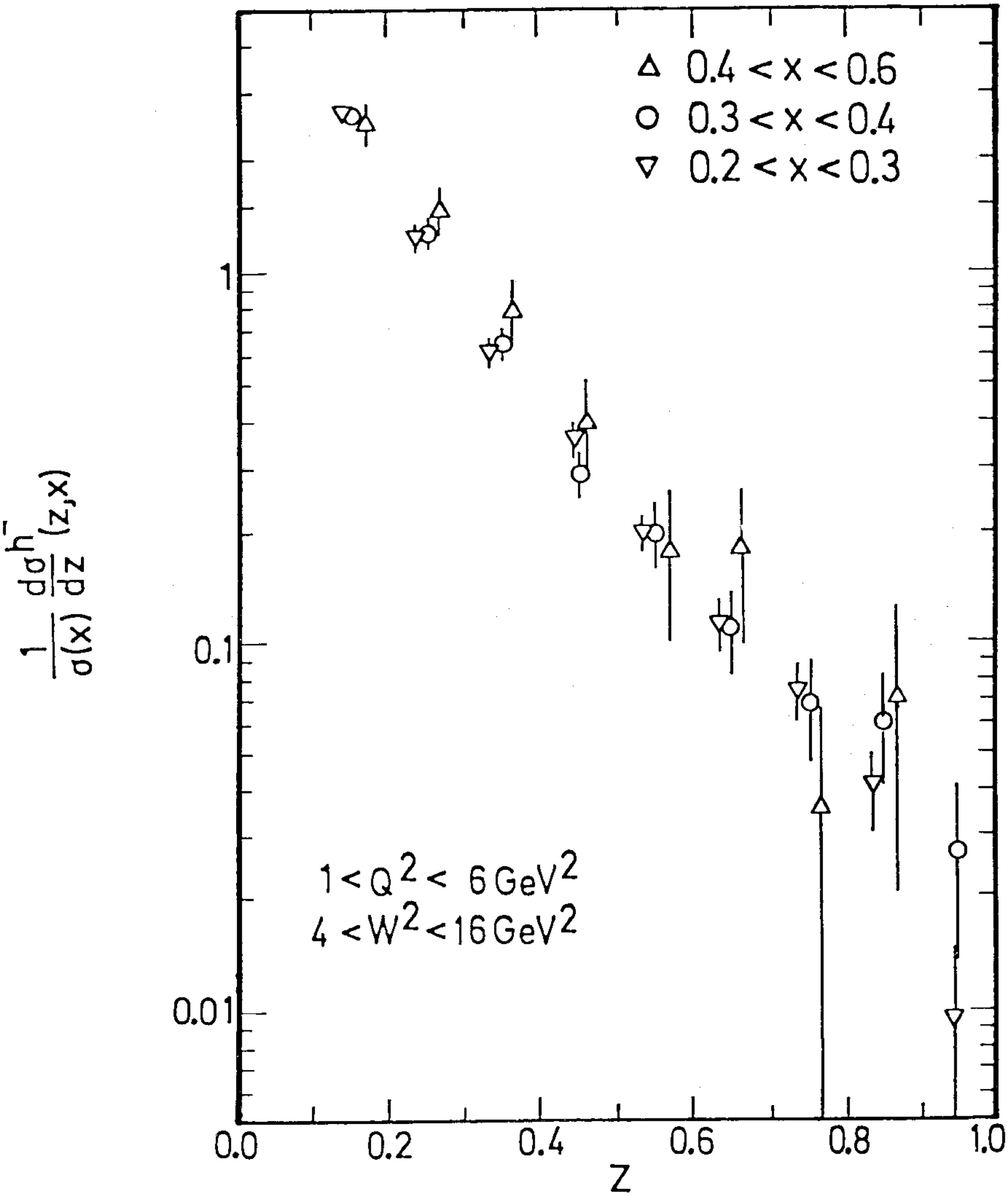
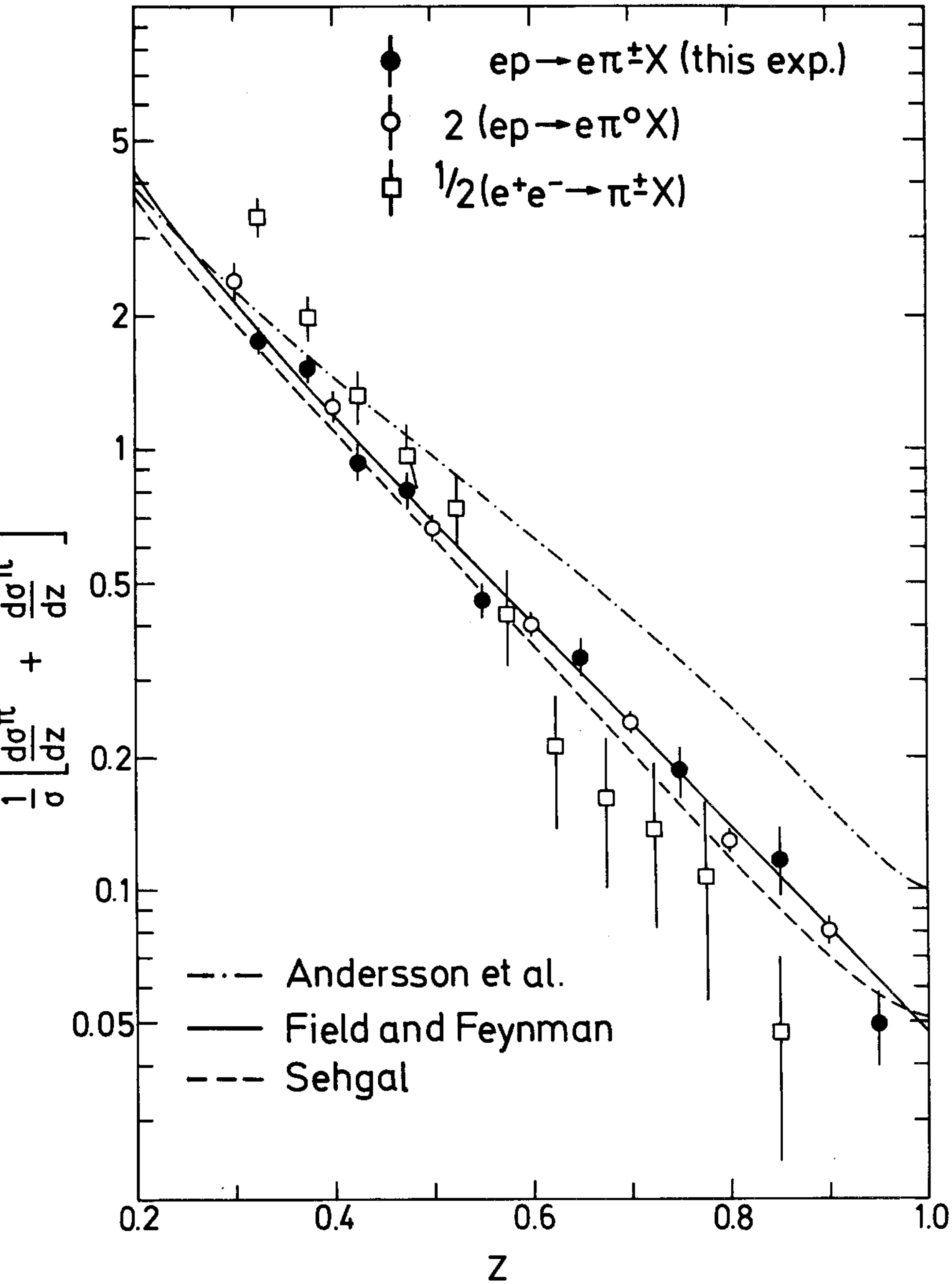

X REGIONS:
△ 0.3 < x < 0.45
○ 0.2 < x < 0.3
▽ 0.1 < x < 0.2
2 < Q² < 6 GeV²
9 < W² < 16 GeV²
5
2
1
0.5
0.0
0.2
0.4
0.6
0.8
1.0
Z
1/σ(x) [dσ^π+/dz (z,x) + dσ^π−/dz (z,x)]
normalized to its average over x at fixed z

FIG.1



△ 0.4 < x < 0.6
○ 0.3 < x < 0.4
▽ 0.2 < x < 0.3
1 < Q² < 6 GeV²
4 < W² < 16 GeV²
1
0.1
0.01
0.0
0.2
0.4
0.6
0.8
1.0
Z

FIG.2



ep → eπ±X (this exp.)
2 (ep → eπ°X)
1/2(e+e- → π±X)
Andersson et al.
Field and Feynman
Sehgal
5
2
1
0.5
0.2
0.1
0.05
0.2
0.4
0.6
0.8
1.0
z
1/σ [dσ^π+/dz + dσ^π-/dz]

FIG.3

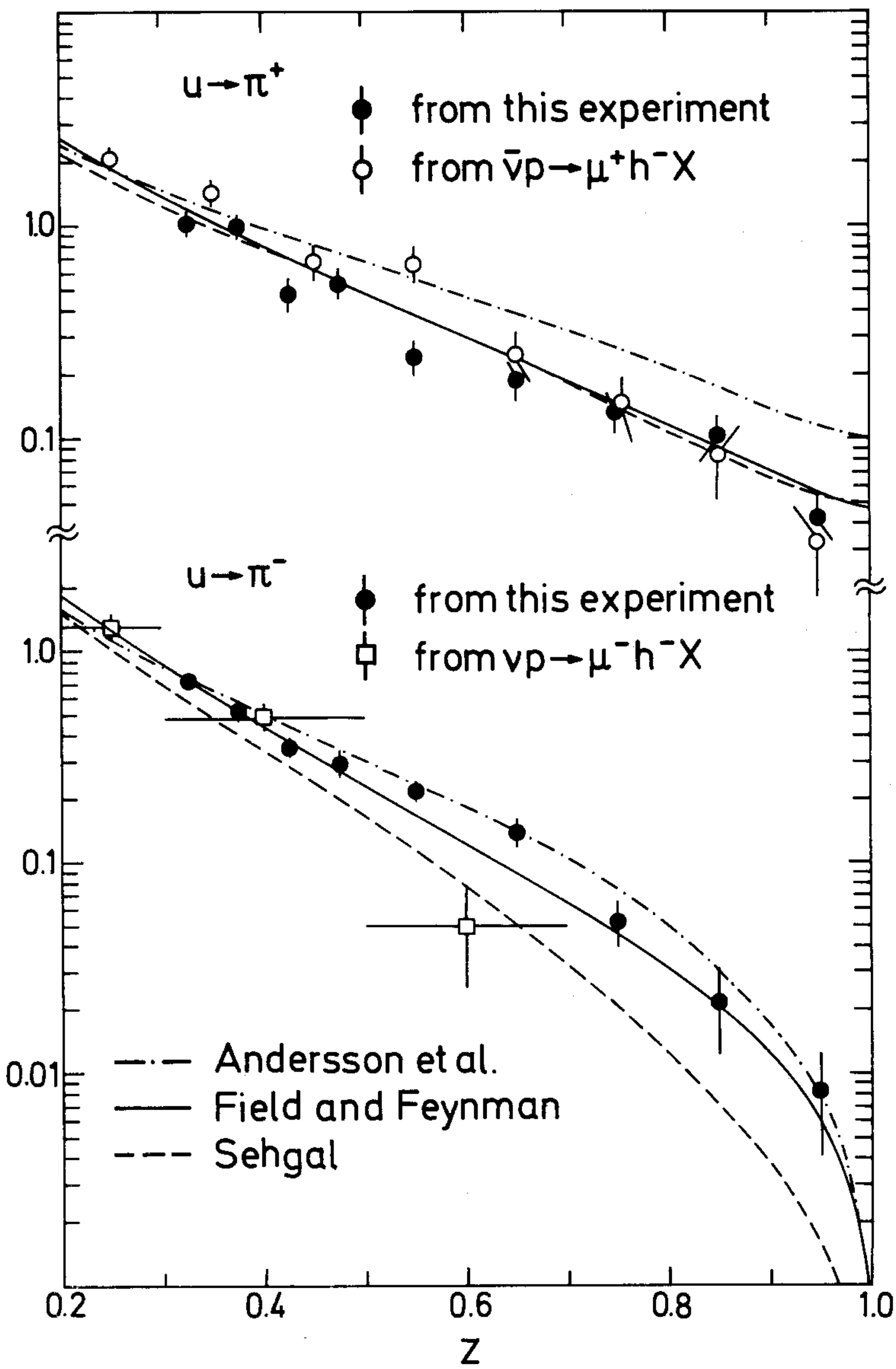

u → π⁺
from this experiment
from $\bar{\nu}p \rightarrow \mu^+ h^- X$
u → π⁻
from this experiment
from $\nu p \rightarrow \mu^- h^- X$
Andersson et al.
Field and Feynman
Sehgal
$D_u^{\pi^+}(z)$
$D_u^{\pi^-}(z)$
1.0
0.1
0.01
0.2
0.4
0.6
0.8
z

FIG.4

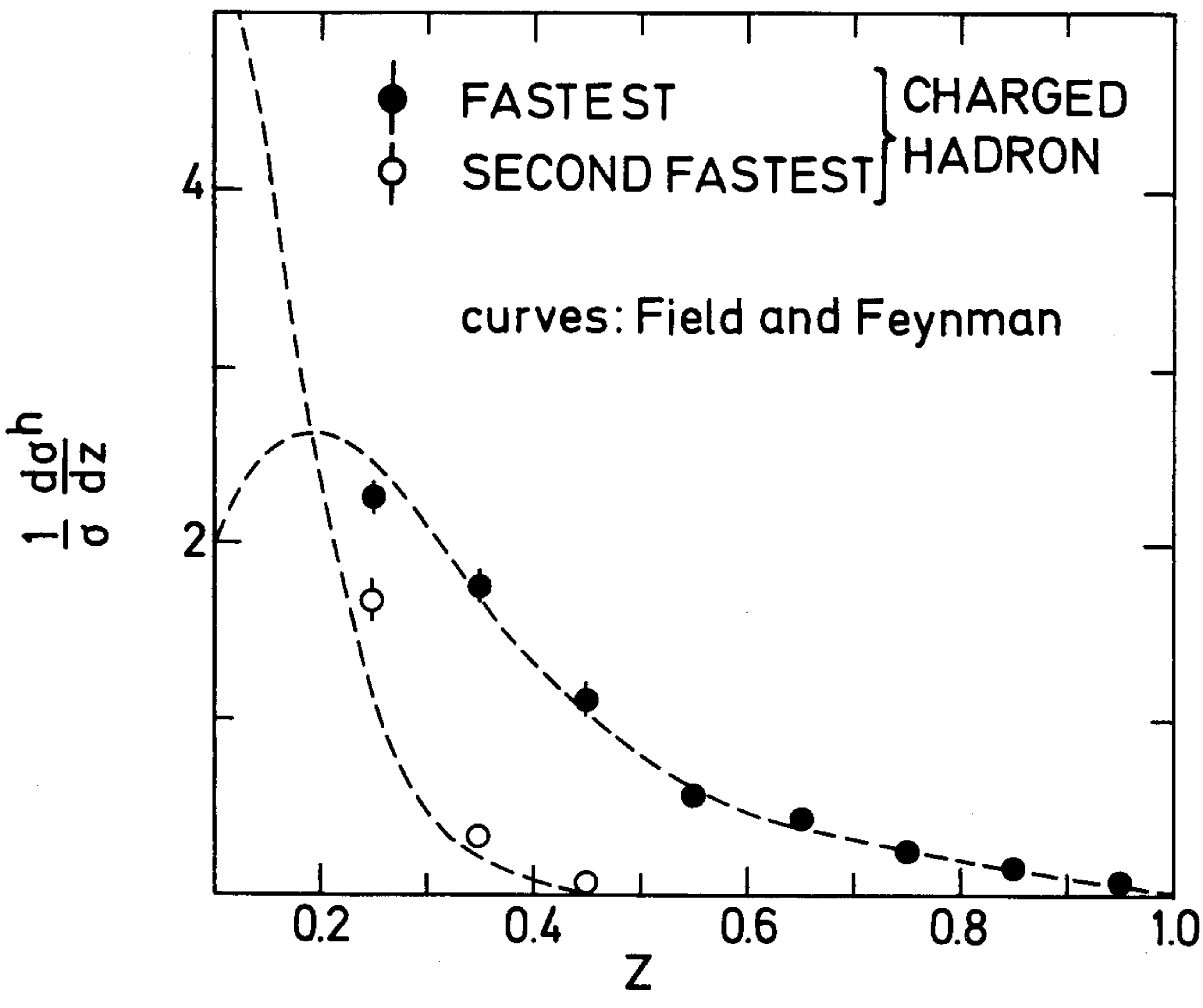

FASTEST
SECOND FASTEST
CHARGED HADRON
curves: Field and Feynman
4
2
$\frac{1}{\sigma}\frac{d\sigma^h}{dz}$
0.2
0.4
0.6
0.8
1.0
Z

FIG.5