ABSTRACT

Improved measurements of the hadronic structure function, F(x'), and charge ratio are presented for the inelastic scattering of muons by protons and neutrons. Correlation data between the leading and successive hadrons is also presented.

Paper to be presented by A. L. Sessoms

XVIII INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

TBLISI USSR JULY 15-21, '76

NEW RESULTS IN MUON-PRODUCTION OF HADRONS AT HIGH ENERGIES*

H.L. Anderson, V.K. Bharadwaj, N.E. Booth, R.M. Fine, W.R. Francis,

B.A. Gordon, R.H. Heisterberg, R.G. Hicks, T.B.W. Kirk, G.I. Kirkbride,

W.A. Loomis, H.S. Matis, L.W. Mo, L.C. Myrianthopoulos, F.M. Pipkin,

S.H. Pordes, T.W. Quirk, W.D. Shambroom, A. Skuja, L.J. Verhey,

W.S.C. Williams, Richard Wilson, S.C. Wright

Enrico Fermi Institute, The University of Chicago, Chicago, Ill. 60637

High Energy Physics Laboratory & The Department of Physics, Harvard University, Cambridge, Massachusetts 02138

The Department of Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801

Oxford University, Nuclear Physics Laboratory, Keble Road, Oxford, OX1 3RH, England

*Supported by ERDA contracts No. E(11-1)3064 and 1195, NSF Contract No. MPS 71-03-186, and the Science Research Council (U.K.).

In recent papers[1,2] we have reported measurements of the hadron spectra produced by the inelastic scattering of muons from protons and neutrons. We have since doubled the amount of data for muon proton scattering at 150 GeV/c and present improved results for the structure function, F(x'), and the charge ratio N^+/N^-. The new results are based on 8600 and 7200 muon scatters in hydrogen and deuterium respectively, these scatters having $q^2 \geq 0.5$ $(GeV/c^2)^2$. The respective luminosities are 4.0×10^{10} muons incident on 8.4 gm/cm^2 of hydrogen and 1.84×10^{10} muons incident on 20.0 gm/cm^2 of deuterium.

We briefly review the kinematics of muon scattering and hadron production. In the one photon approximation, when the muon scatters it exchanges a virtual photon of mass $-q^2$ and energy ν with the hadronic system. These Lorentz invariant quantities completely define the muon kinematics. For the hadrons it is most convenient to work in the center of mass system between virtual photon and nucleon. The center of mass energy is s: $s = 2M\nu - q^2 + M^2$ where M is the nucleon mass. The hadron kinematics are defined by E^*, $p_{\parallel}^*$, p_{max}^* and p_T, respectively the hadron's energy, longitudinal momentum, maximum momentum and transverse momentum in the center of mass system.

The hadronic structure function F(x'), is defined as

$$F(x') = \int_0^\infty dp_T^2 \frac{1}{\pi} \frac{1}{\sigma} \frac{E^*}{\left(p_{max}^{*\,2} - p_T^2\right)^{1/2}} \cdot \frac{d^2\sigma}{dx'dp_T^2} \qquad (1)$$

where

$$x' = \frac{P_{\parallel}}{\left(p_{max}^{*\,2} - p_T^2\right)^{1/2}}$$

and σ is the total muon scattering cross section. The hadronic charge ratio N^+/N^- is the ratio of the number of positive hadrons in a given x' interval to the number of negative hadrons. We discuss both of these quantities as functions of s and q^2.

We have used the same analysis described in the earlier papers with the following improvement. We have removed from the data the elastic production of particle pairs by virtual photons. The large majority of these events are ρ°-mesons or converted bremsstrahlung photons. Elastic pairs are those events in which the pair of particles produced have 96% or more of the energy lost by the muon.

Figures 1 and 2 are the hadronic structure functions for the neutron and proton displayed as functions of q^2 and s. The straight line is a good representation of lower energy data.[3] We observe that at very low x', F(x') for positive and negative hadrons "scales", e. g., it does not change with q^2 or s. For higher x' there appears to be a difference between the positive and negative hadron functions. At highest q^2 and lowest s there is a suggestion that the x' slope of the structure function is becoming more negative.

The difference between positive and negative distributions is best displayed by the charge ratios in Figure 3, plotted as functions of $\omega = \frac{2M\nu}{q^2}$. The ω is the value obtained by averaging over the q^2 - s regions of Figures 1 and 2. We have shown other data[4] and the fit of Dakin and Feldman[5] to these data using their simple quark model. Our data and the

data of Bebek et al.[4] follow the trend of the fit for the proton but are systematically below it. Dakin et al.[3] could not remove protons from their charge ratio.[6] Bebek et al.'s data is for pions only; our data is at sufficiently high energy that the proton contribution is negligible. What is striking is that over the wide range of energies of the various experiments the data is consistent with a charge ratio dependent only on ω. These data support the naive quark model and its description of the hadronic structure functions over a wide range of q^2 and s.

Many people[7] have proposed the idea that the hadronic distributions observed in lepton scattering and in large transverse momentum hadron-hadron interactions are essentially the same phenomena. To provide more tests of this idea we have analyzed hadronic correlations in the following manner. For events with $s > 100\ GeV^2$ we have plotted the quantity $P(z_2)$

$$P(z_2) = \frac{\int_{1/2}^{1} \frac{1}{\sigma} \frac{d\sigma}{dz dz_2} dz}{\int_{1/2}^{1} \frac{1}{\sigma} \frac{d\sigma}{dz} dz} \qquad (2)$$

where $z = E_h/\nu$ is the fraction of the photon's lab energy carried by a hadron (z is also a Lorentz invariant). z_2 is the fraction of the remaining energy carried by a remaining hadron:

$$z_2 = \frac{E_{h2}}{\nu - E_{h1}} = \frac{z'}{1 - z}, \quad z' = \frac{E_{h2}}{\nu}$$

For this analysis we have combined the neutron and proton data. Figure 4 shows $P(z_2)$ for various sign combinations. There is clear symmetry between the opposite signed pairs and between the like signed pairs. Opposite signed second particles have higher z_2 on average. We have removed "elastic" events (ρ° production and bremsstrahlung conversion) by demanding that the total z of the two particles be less than 0.96 and that the mass of pairs (assuming both are pions) is greater than .35 GeV. These events would appear as a peak at $z_2 = 1$ in the $P(z_2)$ distributions.

To compare these data with some expectations we have plotted the following curves:

(a) The inclusive distribution for negative particles (the positive distribution is identical). This is the full line in Figure 4.

(b) The uncorrelated probability for z_2 using the inclusive z distribution. In effect given we have a particle with $z_1 \geq 1/2$ we recast the inclusive z distribution in terms of $z_2 = \frac{z}{1 - z_1}$ and plot it for values of $z < 1 - z_1$. This is the dashed line.

The opposite signed pairs follow the trend but are lower than the uncorrelated distribution for z_2. The like signed pairs follow the trend of the single inclusive distribution. In approximate terms the like signed second particle appears to share the remaining energy much as all particles share the initial energy. Figure 5 shows the mass distributions and relative azimuthal angles of the hadron pairs. The unlike pairs show enhancement at the ρ° mass but this is not a large part of the spectrum.

In both cases the azimuthal angle distriubtion is flat. These results are very similar to correlation data from high transverse momentum hadron-hadron collisions[8] and lends weight to the idea that these hadrons have similar origins.

We thank the staffs of Fermilab, our home institutions and the Rutherford Lab whose help made this work possible.

REFERENCES

1. W. A. Loomis et al., Phys. Rev. Lett. 35, 1483 (1975).

2. H. L. Anderson et al. (to be published).

3. J. T. Dakin et al., Phys. Rev. 10D, 1401 (1974).

4. C. J. Bebek et al., Phys. Rev. Lett. 34, 759 (1975).

5. J. T. Dakin and G. J. Feldman, Phys. Rev. 8D, 2862 (1973).

6. For a discussion of proton effects on charge ratios see G. Wolf. Proceedings of the 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford University (1975).

7. J. D. Bjorken, Lectures at the SLAC Summer Institute in Particle Physics, July 21-31, 1975 (unpublished).

8. L. DiLella, Proceedings of the 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford University (1975).

FIGURE CAPTIONS

1. Structure functions for the proton for various q^2-s ranges. The dashed line is $0.35 \exp(-3.25x')$.

2. Structure functions for the neutron for various q^2-s ranges.

3. Charge ratios for proton and neutron.

4. $P(z_2)$ for various sign combinations. The solid line is $\frac{1}{\sigma}\frac{d\sigma}{dz}$ for negative hadrons. The dashed line is the uncorrelated z_2 distribution derived from $\frac{1}{\sigma}\frac{d\sigma}{dz}$.

5. a) Mass distributions for particle pairs. b) Relative azimuthal angle distribution for particle pairs.

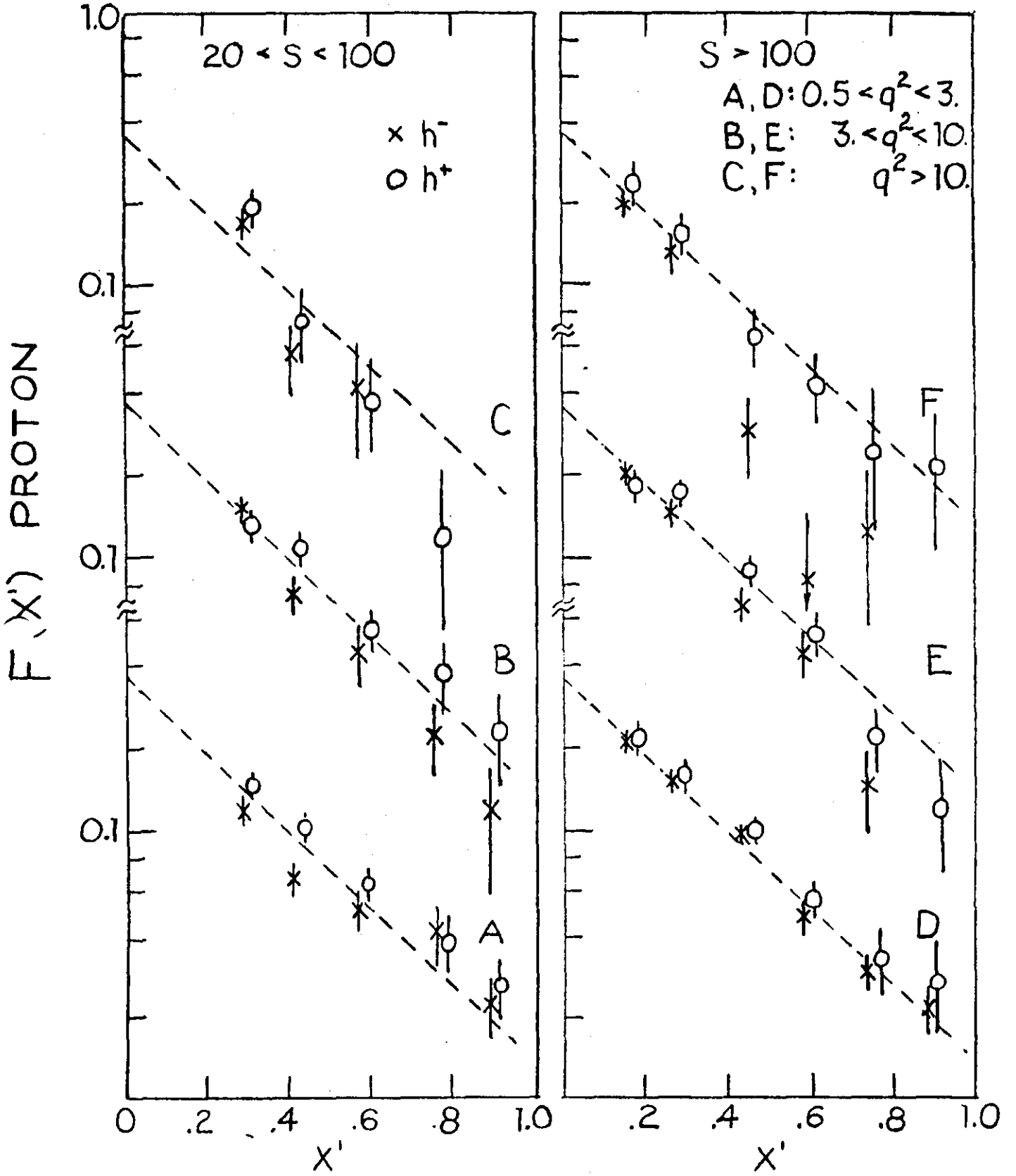

20 < S < 100
× h⁻
○ h⁺
S > 100
A, D: 0.5 < q² < 3.
B, E: 3. < q² < 10.
C, F: q² > 10.
A
B
C
D
E
F
1.0
0.1
0.1
0.1
0
.2
.4
.6
.8
1.0
X'
F(X') PROTON

FIG. 1

6/3/76

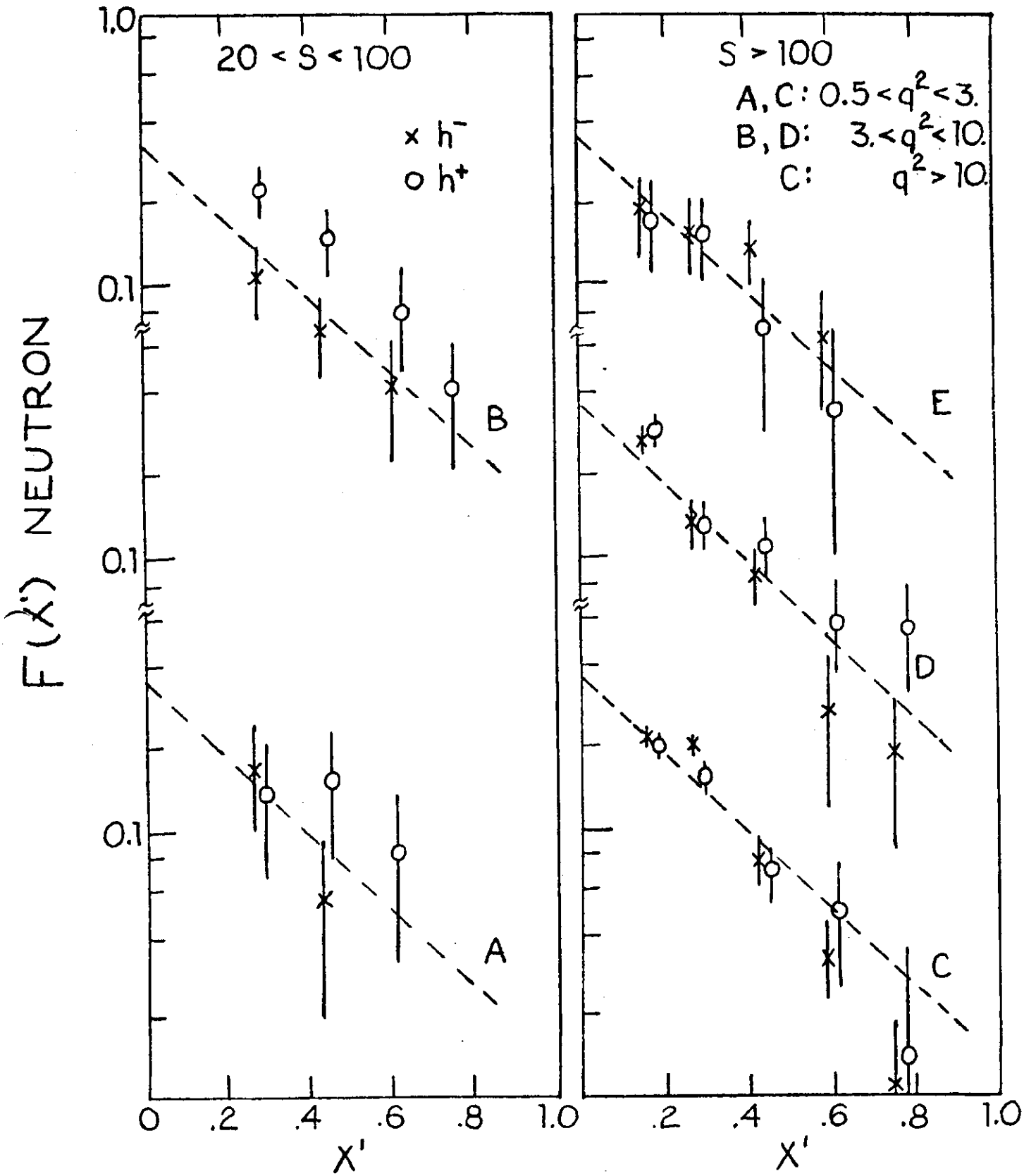
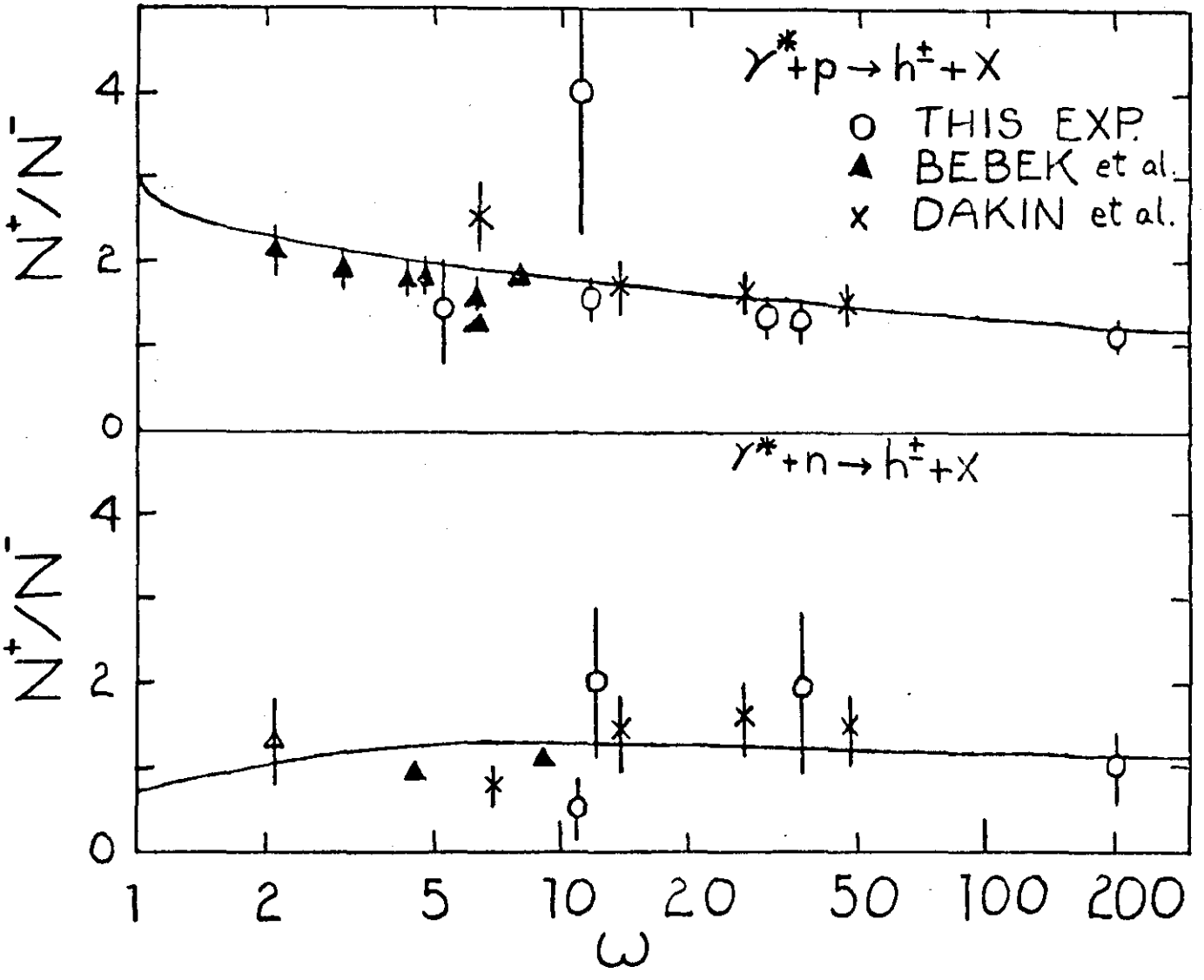

1.0
20 < S < 100
× h⁻
○ h⁺
0.1
B
0.1
A
0.1
0
.2
.4
.6
.8
1.0
X'
F(X') NEUTRON
S > 100
A, C: 0.5 < q² < 3.
B, D: 3. < q² < 10.
C: q² > 10.
E
D
C
.2
.4
.6
.8
1.0
X'

FIG. 2

6/3/76


$\gamma^* + p \to h^\pm + X$
THIS EXP.
BEBEK et al.
DAKIN et al.
$\gamma^* + n \to h^\pm + X$
N^+/N^-
N^+/N^-
0
2
4
0
2
4
1
2
5
10
20
50
100
200
ω

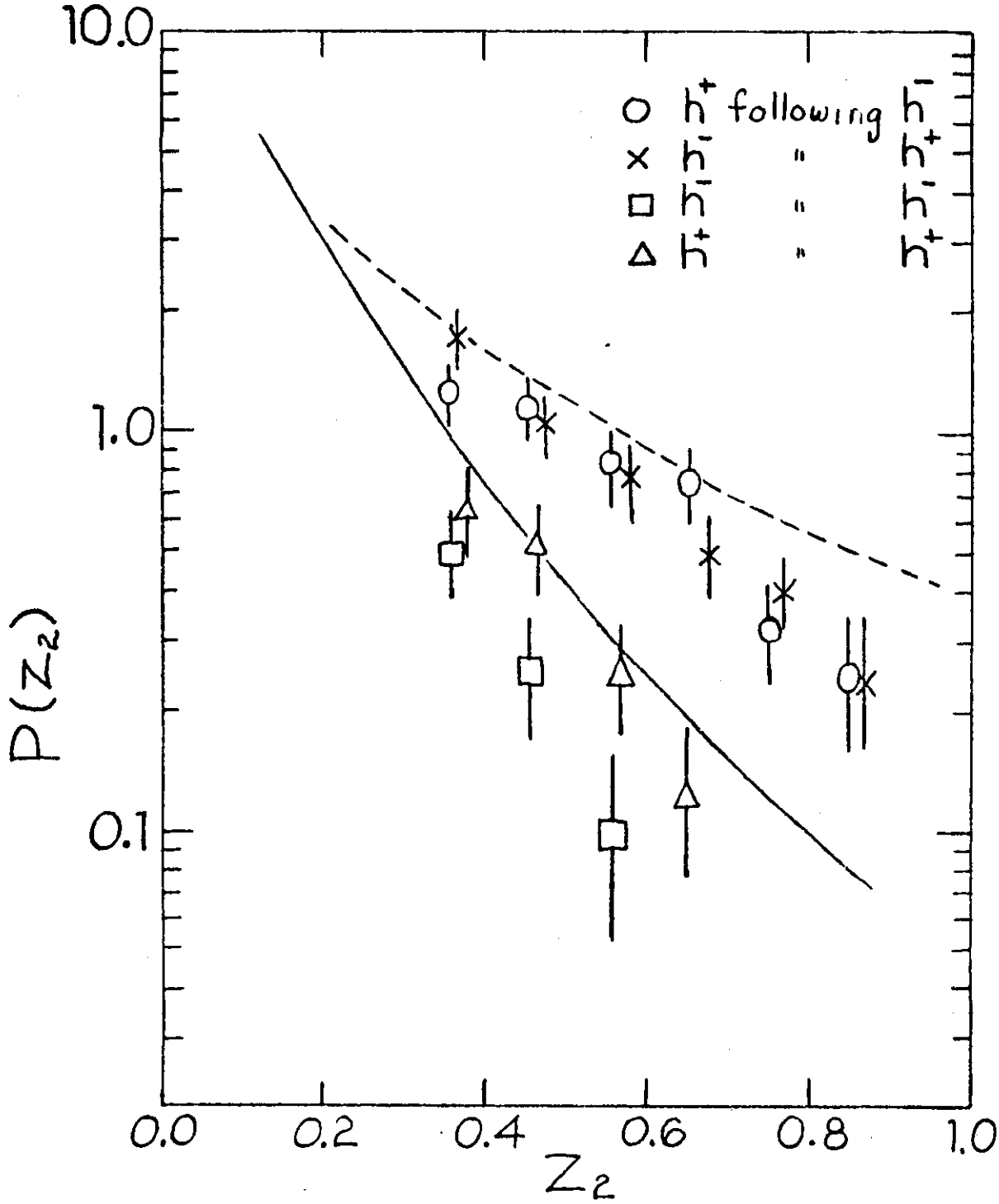


FIG. 4

6/3/16

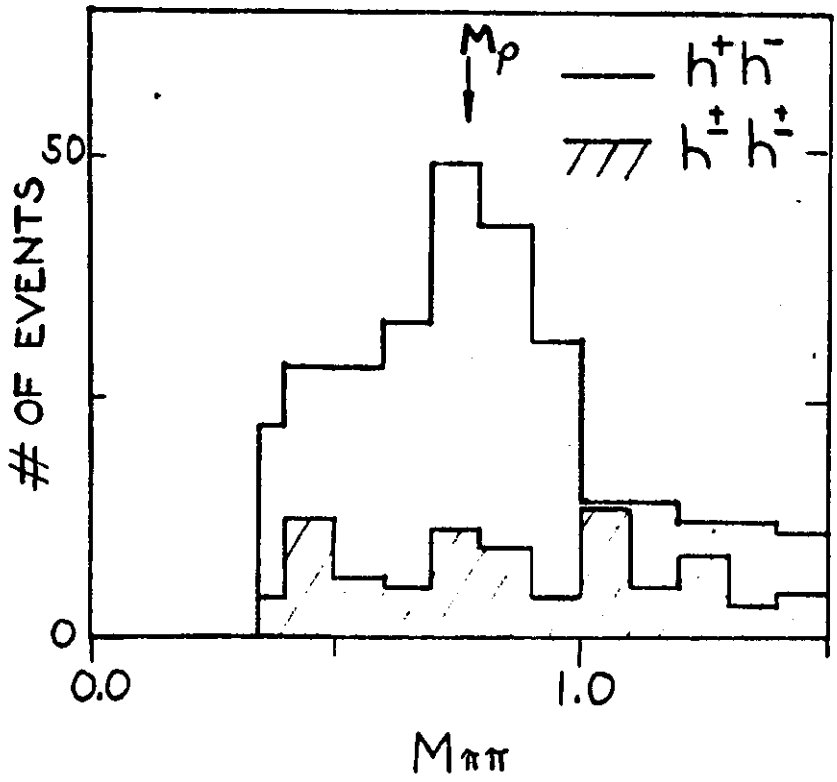


FIG 5a

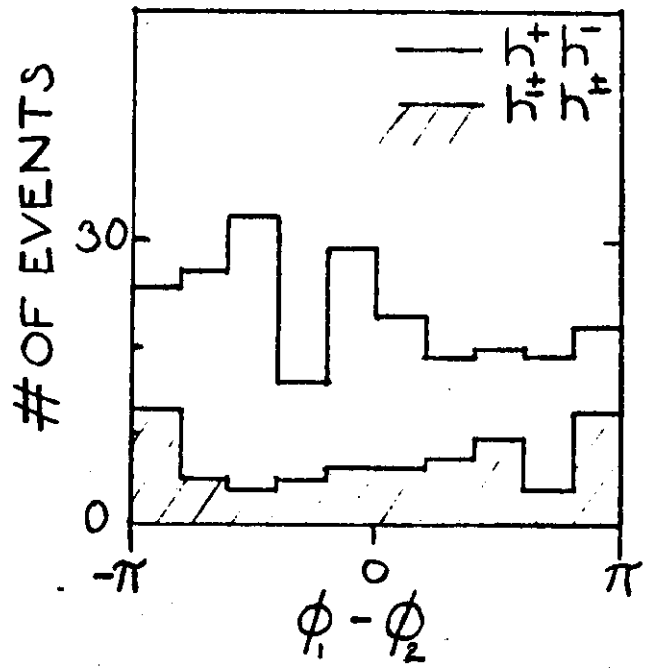


FIG 5b

6/3/76