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ABSTRACT

Using high energy antineutrino-neon interactions we have developed a method to separate $\bar{\nu}n$ and $\bar{\nu}p$ interactions on the basis of final state electric charge. We find the ratio of $\bar{\nu}n$ to $\bar{\nu}p$ cross sections to be 0.45 ± 0.08. In addition we present the scaling distributions for neutrons and protons separately. Our results are consistent with the predictions of the simple quark-parton model.

Previous experimental comparisons of neutrino-proton and neutrino-neutron scattering have been made at relatively low energies. There have been two measurements of the ratio of these cross sections from the study of neutrino-deuterium interactions[1,2] and one measurement[3] from the study of interactions in a heavy nucleus. In this paper we present results on $\bar{\nu}n$ and $\bar{\nu}p$ interactions in a heavy nucleus at high energies.

The data are based upon an exposure of 52,000 pictures from the Fermilab 15' bubble chamber filled with a hydrogen-neon mixture containing 21.0% atomic neon. The chamber was exposed to a wide band, double-horn focused antineutrino beam. The proton energy was 300 GeV and the mean proton intensity was 8.5×10^{12} protons per pulse. The external muon identifier (EMI) was used in this experiment. The details of the scanning and measuring procedures and of the muon identification by the EMI have been described previously.[4] Events with an identified positive muon with a momentum (p_μ) greater than 4 GeV/c, with a total antineutrino energy ($E_{\bar{\nu}}$) greater than 10 GeV, and with a total hadron energy (ν) greater than 2 GeV were selected for analysis. The antineutrino energy was estimated by applying an average correction to the visible energy for neutral-particle energy loss which was characteristic of the total event sample.[5]

The separaton of $\bar{\nu}n$ and $\bar{\nu}p$ events is based upon the expected difference in final state electric charge. Figure 1 shows the visible charge (vc) distribution for events in the selected sample. Events with one or more tracks of undetermined charge have been removed from the sample leaving a total of 564 charged-current (cc) events. "Stub" tracks which were less than one centimeter long were ignored. Interactions on free neutrons have vc = 0 while interactions on free protons have vc = +1. However, for interactions in nuclei secondary intranuclear interactions (re-scattering) and nuclear breakup lead to a visible charge often different from this expectation. As seen in Fig. 1, 26% of the events have vc > +1 while only 1% have vc < 0.

We now examine the dependence of vc on the kinematical variables $E_{\bar{\nu}}$, x, y, and the number of negative tracks. The kinematic variables used are defined as follows: $\nu = E_{\bar{\nu}} - E_{\mu}$, $x = Q^2/2m\nu$, $y = \nu/E_{\bar{\nu}}$ where E_{μ} is the muon energy, m is the proton mass, $Q^2 = 4E_{\mu}E_{\bar{\nu}} \sin^2\theta/2$, and θ is the angle between the $\bar{\nu}$ and μ^+ directions. In Fig. 2 we show distributions of the mean visible charge $< vc >$ and the dispersion D, where $D^2 = < vc^2 > - < vc >^2$, versus $E_{\bar{\nu}}$, the number of negative tracks, x, and y. We see from Fig. 2 that the nuclear effects, which are reflected in the vc distribution and hence $< vc >$ and D, are not strongly dependent on the kinematic variables of the neutrino interaction.[6]

We have used a simple model to separate interactions with neutron and proton targets by using the observed vc distribution. Let N_0, N_1 and N_{H_2} denote the true number of antineutrino events occurring on neutron targets in neon, proton targets in neon, and hydrogen nuclei respectively. We define W_i to be the probability that nuclear effects (or other mechanisms) will shift the visible charge of the interactions by i units of charge. We assume that W_i is the same for interactions off neutron or proton targets in the neon and that the $\bar{\nu}p$ cross section is the same for free protons and protons bound in the neon. With these assumptions we can write the following set of equations for the number of observed events with charge i, N_i^*:

$$N_1^* = N_o W_1 + N_1 W_o + N_{H_2}, \quad (1)$$

$$N_i^* = N_o W_i + N_1 W_{i-1} \text{ for } -2 < \underset{i \neq 1}{i} < 7,$$

$$\Sigma_i W_i = 1,$$

Using the known nuclear composition of the neon-hydrogen mixture we solve the equations for W_i, N_o, N_1 giving the ratio η of the $\bar{\nu}n$ to $\bar{\nu}$ p cross section, $\eta = N_o/N_1$. We find $\eta = 0.45 \pm 0.08$ for $E_{\bar{\nu}} \geq 10$ GeV. The value of η is not strongly dependent on $E_{\bar{\nu}}$. For $10 \leq E_{\bar{\nu}} < 25$ GeV we obtain $\eta = 0.40 \pm 0.11$ while for $E_{\bar{\nu}} > 25$ GeV we obtain $\eta = 0.51 \pm 0.13$. Considering only interactions with valence quarks predicts $\eta = 0.5$. Specific quark parton models[7,8] give predictions ranging from $\eta = 0.62$ to $\eta = 0.42$.

By solving Eq. (1) in various x and y regions we obtain η as a function of x and y and also the corresponding x and y distributions for $\bar{\nu}n$ interactions (dN_o/dx, dN_o/dy) and $\bar{\nu}p$ interactions (dN_1/dx, dN_1/dy). The results are shown by the solid data points in Fig. 3. The strong enhancement in the small x ($x < 0.1$) region of Fig. 3(a) indicates a larger role for sea quarks in neutron interactions than in proton interactions. The solid curves in Fig. 3 are obtained using the quark distributions of Field and Feynman[9] and are in qualitative agreement with the data. Our experimental errors are too large to allow us to distinguish between various other quark models. The striking difference between the neutron and proton x-distributions is evident. We find that $< x > = 0.18 \pm 0.02$ for the neutron data compared with $< x > = 0.29 \pm 0.01$ for the proton data; $< y >$ for the neutron and proton data are comparable, being $0.37 \pm .02$ and 0.35 ± 0.01 respectively.

In figures 3(g) and 3(h) we have compared the proton x and y distributions obtained from our analysis (solid data points) with the distributions obtained from $\bar{\nu}p$ interactions in hydrogen[10] (open triangular data points). The two distributions are in excellent agreement.

The neutron and proton distributions in Fig. 3, represented by the solid data points, were obtained by solving Eq. (1). It is also possible to define neutron and proton data samples from the visible charge of the events. One may define a neutron sample by taking events with $vc \leq 0$ and a proton sample by taking events with $vc \geq +1$. Using this method to separate neutron and proton interactions, we estimate the proton contamination of the neutron sample to be 13%, $(N_1 \sum_{i=1}^{3} W_{-i})$ and the neutron contamination of the proton sample to be 10%, $(N_o \sum_{i=1}^{7} W_i)$. The vc selection has the advantage that one need not fit Eq. (1) to obtain neutron and proton distributions, instead one obtains directly "neutron" $(vc \leq 0)$ events and "proton" $(vc \geq +1)$ events. The average negative hadron multiplicity $< h^- >$ for the "neutron" and "proton" samples, for example, can then be obtained by a simple track counting and yields $\langle h^- \rangle = 2.0 \pm 0.3$ from neutron interactions and $\langle h^- \rangle = 1.71 \pm 0.1$ for proton interactions. The dashed histograms in figures 3(c)-3(f) show the x and y distributions for the vc selected "neutron" and "proton" samples. The agreement between the two separation methods and with the $\bar{\nu}p$ results from the hydrogen experiment leads us to believe that our results are relatively unbiased at the present level of statistics.

To summarize, by using the visible charge (vc) distribution from $\bar{\nu}$ interactions in a Neon-H_2 mixture we have developed a procedure which allows us to obtain separately $\bar{\nu}$-neutron and $\bar{\nu}$-proton distributions. In addition, a simple selection on vc allows a separation into "neutron" and "proton" event samples. Using the above selection methods we find that:

1) The ratio of the $\bar{\nu}n$ and $\bar{\nu}p$ cross sections is not strongly dependent on antineutrino energy in the 10-100 GeV region and is equal to 0.45 ± 0.08 in agreement with quark-parton model predictions.

2) The x and y distributions for our proton events are in excellent agreement with the same distributions obtained from $\bar{\nu}p$ interactions in hydrogen.

3) The x-distributions show that the relative contribution of antiquark interactions in $\bar{\nu}n$ events is significantly larger than for $\bar{\nu}p$ events as expected in the quark model.

4) The x and y distributions for the neutron and proton events are in qualitive agreement with the predictions of Field and Feynman.

REFERENCES

[1]M. Derrick, Proc. Inter. Neutrino Conf., Aachen.

[2]Cazzoli et al., Proc. Inter. Symposium on la Physique du Neutrino a'haute Energie, Parie 1975, p. 317.

[3]Gargamelle Neutrino Propane Collaboration ibid p. 327.

[4]J. P. Berge et al., Phys. Rev. Lett. 33, 266 (1977).

[5]Fermilab-IHEP-ITEP-Michigan Neutrino Group, Phys. Rev. Lett. 33, 382 (1977).

[6]From Fig. 2(c) it is seen that < vc > for events without negative tracks is greater than for events with negative tracks. This effect is connected with the lower observation efficiency for 1-prong events. We estimate an efficiency for 1-prong events (with cuts: $E_{\bar{\nu}} > 10$ GeV, $p_{\mu} > 4$ GeV/c, $\nu > 2$ GeV/c) of ~35% in our mixture while the average scan efficiency for the total cc sample is ~95%. We corrected the number of events with +1 charge for the 1-prong observation efficiency (open entry on Fig. 2(c)).

[7]A. De Rujula et al., Rev. Mod. Phys. 46, 391 (1977).

[8]V. Barger and R. Phillips, Nucl. Phys. B73, 269 (1974).

[9]R. D. Field and R. P. Feynman, Phys. Rev. D15, 2590 (1977). The experimental cuts $E_{\bar{\nu}} > 10$ GeV, $P_{\mu} > 4$ GeV/c and $\nu > 2$ GeV have been included in the model calculations.

[10]M. Derrick et al., Phys. Rev. D17, 1 (1978).

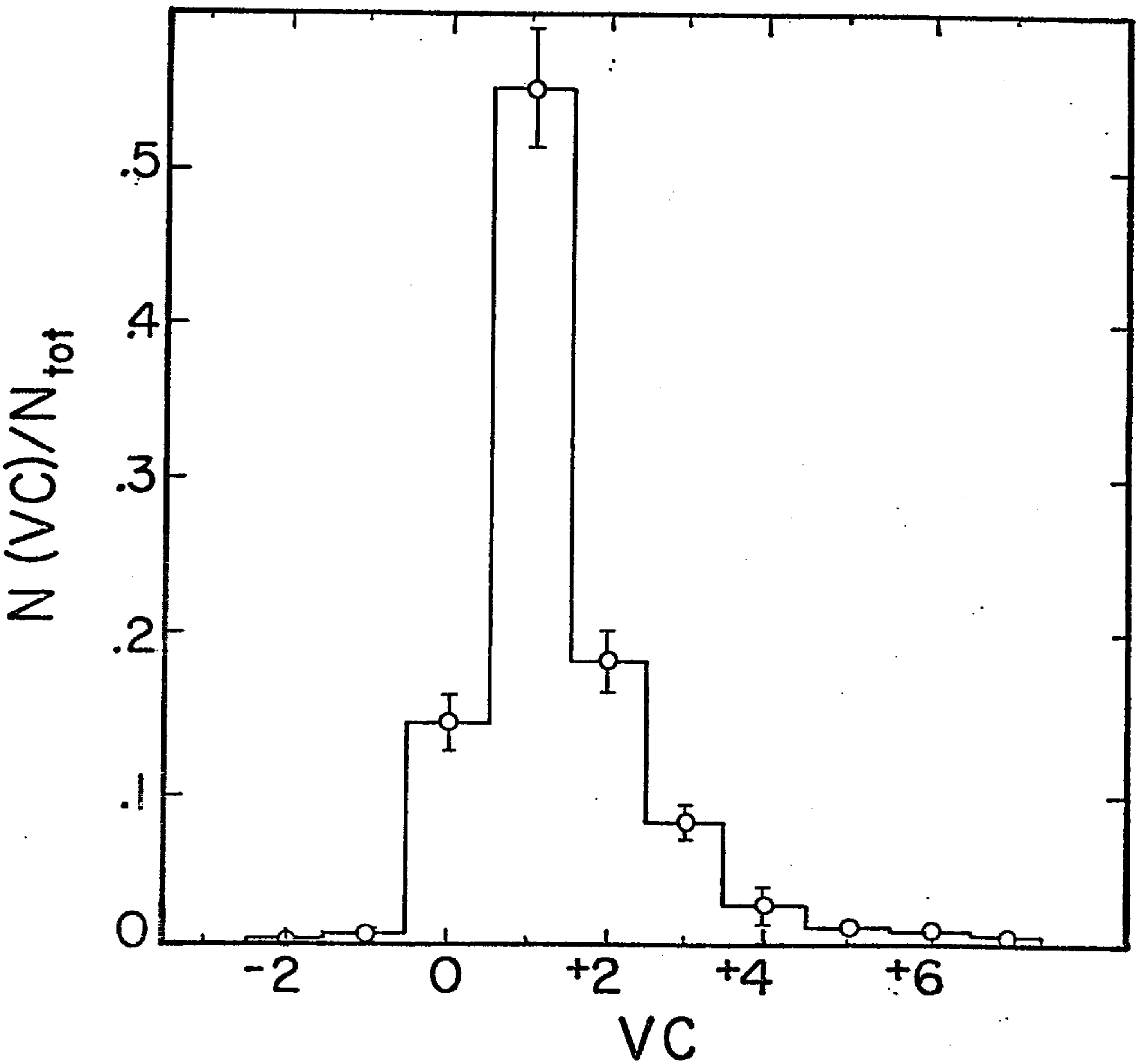

Fig. 1. The visible charge (vc) distribution normalized to unity.

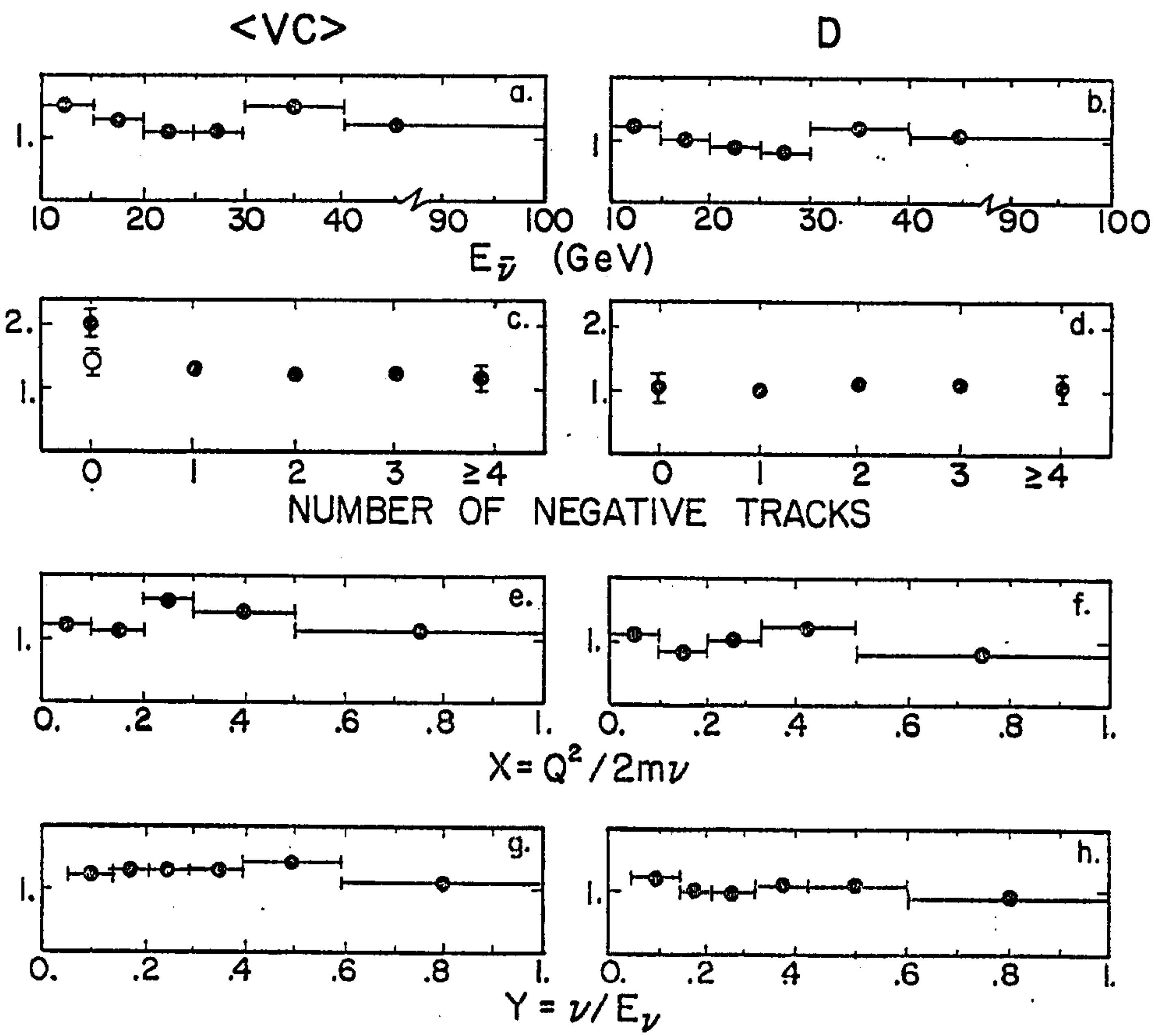

Fig. 2: Average visible charge < vc > and dispersion D versus: $E_{\bar{\nu}}$ (a) and (b); number of negative tracks (c) and (d); x (e) and (f); y (g) and (h). In (a) the open data point results from applying a 1-prong correction [see footnote 6].

Fig. 3: The solid data points show the values of as a function of x and y [(a) and (b)] and the normalized x and y distributions for the neutron sample [(c) and (d)] and proton sample [(e) and (f)] obtained from fits to Eq. 1 of the text. The dashed histograms in (c), (d), (e) and (f) show the corresponding normalized x and y distributions obtained using vc to define the neutron and proton samples as described in the text. The solid lines are the predictions of Field and Feynman. In (g) and (h) we compare our proton x and y distributions (solid data points) to those obtained from $\bar{\nu}p$ interactions (open triangles).

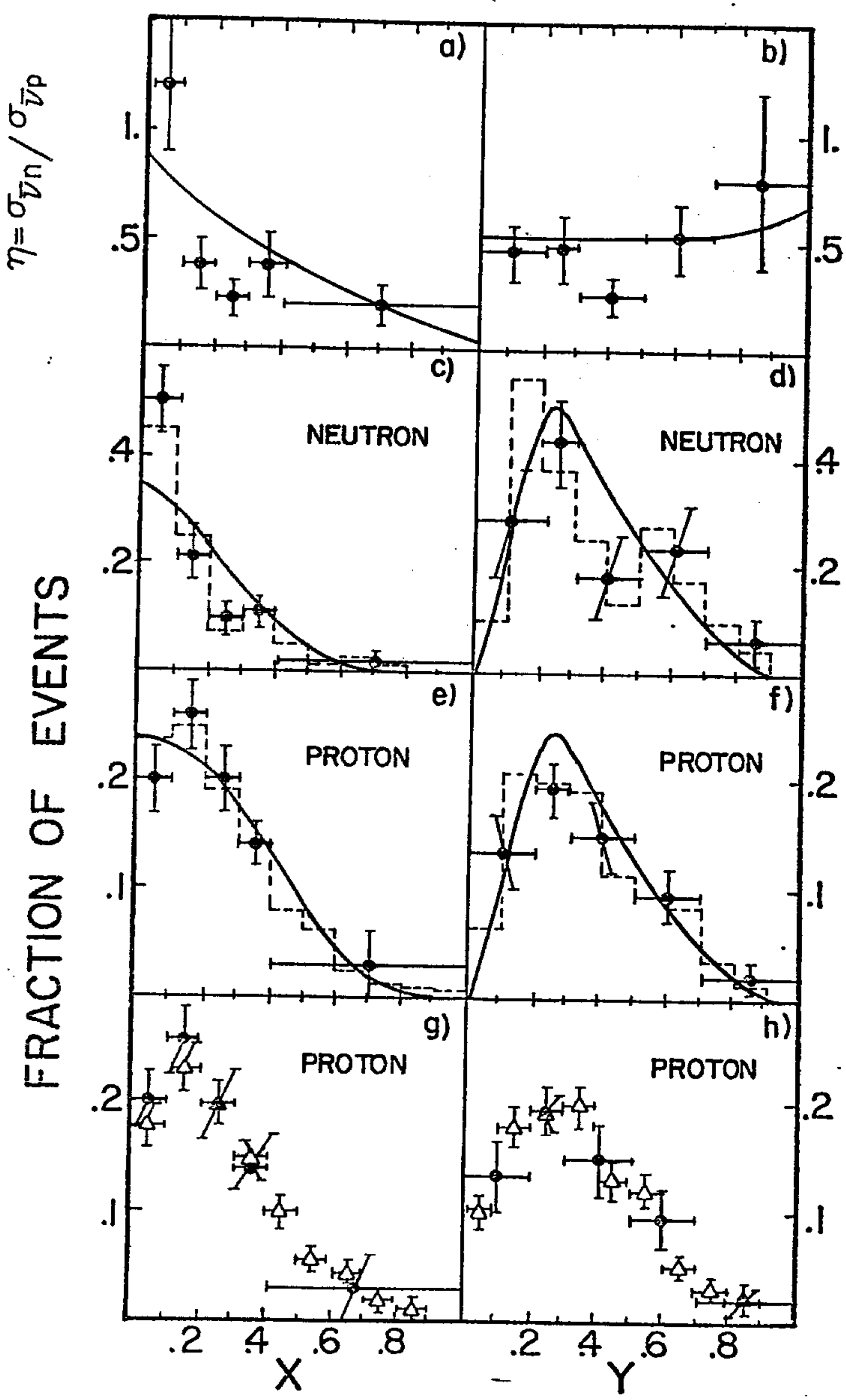
a)
b)
c)
d)
e)
f)
g)
h)
$\eta = \sigma_{\bar{\nu}n} / \sigma_{\bar{\nu}p}$
NEUTRON
NEUTRON
PROTON
PROTON
PROTON
PROTON
FRACTION OF EVENTS
X
Y

Figure 3

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