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CHARGE RETENTION IN DEEP INELASTIC ELECTROPRODUCTION

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Abstract

We have measured the net charge of the forward hadrons electroproduced from a proton target and have observed a rise with increasing x (= $Q^2/2M\nu$). This effect is expected in the quark-parton model as the electroproduction of hadrons becomes dominated by the fragmentation of u quarks. The data are also consistent with jet models in which a high momentum leading hadron is more likely to be carrying the parent quark than is a slower hadron.

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The identification of final state hadrons as the fragmentation products of fractionally charged quarks is an important but experimentally elusive feature of the quark-parton model. As a direct test of this feature, Feynman conjectured that the hadrons arising from quark fragmentation would retain the charge of the parent quark when averaged over many events.[1] This test would be straightforward if the quark and target fragmentation regions were separated by a plateau in the hadron rapidity distribution, but this would require an energy much higher than that currently available. At present energies, the quark and target fragmentation regions overlap by an amount that depends on the hadronic center-of-mass energy W. On the other hand, the relative proportions of different flavors, and hence the average charge, of the scattered quarks is a function of $x = Q^2/2M\nu$ (where $-Q^2$ and ν are the mass-squared and energy of the virtual photon). Thus, if the overlap is fixed by holding W constant, then any x dependence observed in the charge of the forward-going hadrons would be indicative of the charge retention effect. In this letter we report an observation of such x dependence in a deep inelastic electroproduction experiment. Our data can also be used to check the idea that a parent quark flavor can be identified using the charge of the leading hadron[2].

The experiment was performed at the Wilson Synchrotron Laboratory of Cornell University with an 11.5 GeV electron beam incident on a liquid hydrogen target. The charged final state hadrons were observed in a streamer chamber triggered by a scattered electron as discussed in reference 3. The analysis described here is based on events in the region $1. < Q^2 < 6.$ GeV^2 ($\langle Q^2 \rangle = 2.4$ GeV^2) and $2.5 < W < 4.2$ GeV ($\langle W \rangle = 3.2$ GeV). Results consistent with those presented here were also obtained with more restricted W ranges and with more stringent electron identification criteria. Since the streamer chamber had nearly 4π acceptance, all charged final state particles were detected throughout a large kinematic region, minimizing systematic uncertainties.

In the quark-parton model, the mean net charge <c> in the quark fragmentation region is given by the sum of the charges of the parent quarks, each weighted by its contribution to the inelastic cross section but shifted by a universal constant η. This constant is the average charge of the antiquarks formed in the fragmentation process and must be added to the charge of the parent quark (or subtracted if the parent is an antiquark), because hadrons, and not individual quarks, are observed in an experiment[4]. Thus,

$$<c> = \frac{\Sigma\, e_j^2\, (e_j \pm \eta)\, q_j(x)}{\Sigma\, e_j^2\, q_j(x)} \qquad (1)$$

where $q_j(x)$ is the number density distribution of quark flavor j with charge e_j.

Limiting values of η would be zero if $u\bar{u}$, $d\bar{d}$, and $s\bar{s}$ pairs were equally probable, or -1/6 if strange quarks were completely suppressed. In an earlier publication[3], we reported a measurement of the relative probability of electroproducing strange or nonstrange hadrons. Using this result and assuming the ratio of vector to pseudoscalar meson production[5] to be between 1 and 3, we have calculated that η falls between -0.12 and -0.09.

We have measured <c> by including all hadrons (including protons) with x_F ($= p_{\parallel}^*/p_{MAX}^*$) greater than some suitably chosen value, where $p_{\parallel}^*$ is the component of the hadron's momentum in the direction of the virtual photon, and the asterisk indicates the hadronic center-of-mass frame. Since this experiment had no provision for distinguishing among hadrons, mass assignments necessary for the Lorentz transformation were made on a statistical basis using parametrizations of hadron structure functions measured in inclusive experiments[6]. The dominant source of uncertainty in this procedure is the extrapolation of the available proton data from the energy region $2.0 < W < 3.1$ GeV to our energy range[7]. As a check of these parametrizations, we compared the laboratory momentum distributions expected for the sum of positive pions, kaons, and protons to our measured positive track distributions and found excellent agreement in both the shape and normalization. The mass assignment procedure introduces x-independent uncertainties in $\langle c \rangle$ of ±4% due to the kaons and ±6% due to the protons. The loss of forward hadrons due to experimental inefficiences has a net effect on $\langle c \rangle$ of less than 5 percent.

The charge $\langle c \rangle$ for $X_F > 0$ is plotted in figure 1 as a function of x, along with points from photoproduction and muoproduction experiments. The photoproduction point was obtained from fits to the π^+/π^- ratio[8,9], the π^- production cross section[10], and the proton production cross section[8] measured at energies close to ours. There is a systematic uncertainty in this point due to the lack of π^+/π^- and proton data for $p_\perp < 0.2$ GeV/c. The muoproduction points were calculated from the charged hadron data of Loomis et al.[11] ($Q^2 > 2.$ GeV^2, $W > 4.47$ GeV). These data were fit with exponentials down to $X_F = 0.08$ and extrapolated to $X_F = 0$. The muoproduction points were collected at a higher W than the others, resulting in a smaller overlap of the quark and target fragmentation regions. Nevertheless, these measurements of $\langle c \rangle$ agree with ours in the x range they share and follow the trend of the other experiments, indicating that even a moderate change in W does not significantly alter our results.

The curves in figure 1 show the x dependence of equation (1) using the quark distribution functions of Field and Feynman[12]. $\langle c \rangle$ is expected to rise with increasing x as the interactions become dominated by valence u quarks. The data are in agreement with this prediction.

The x dependent trend of the data remains unchanged as the X_F cut is raised (figure 2), confirming that the observed effect is not simply a consequence of the experimental definition of the quark fragmentation region. Raising this cut reduces the probability that the parent quark is included in the forward region, but does not affect the predicted x dependence. The overall value of $\langle c \rangle$ falls because the average then includes events with no charged or neutral hadrons forward of the cut. A higher X_F cut reduces the systematic uncertainties in the photoproduction and muoproduction points because extrapolations outside the X_F range of the available data are not required.

To further examine the effect of various X_F cuts, we have plotted the average total charge $\Gamma(X_F)$ forward of these cuts in figure 3 for events with $x > 0.2$. We have included at each point only those events having at least one charged hadron forward of the corresponding cut. $\Gamma(X_F)$ is seen to be independent of X_F for $0. < X_F < 0.6$, showing that the overall drop seen when the cut is raised in figure 2 is due to an increase in the fraction of events with no forward charged hadrons, and not to a relative increase in the number of negative hadrons.

Figure 3 can also be used to test whether the charge of the leading particle is a clue to the identity of the parent quark, an idea that arises naturally from jet models[2]. This can be checked for X_F cuts greater than 0.5, because there can be at most one hadron with $X_F > 0.5$ in any event. For example, the value 0.45 ± 0.03 measured at $X_F > 0.5$ indicates that 72% of the charged hadrons past this cut are positive. For $x > 0.2$ ($\langle x \rangle = 0.28$), approximately 87% of the total cross section is due to u quarks and 11% is due to d quarks. Neglecting sea quark contributions, we then conclude that for jets initiated by u quarks, 80% of the charged hadrons with $X_F > 0.5$ will be positive.

As the X_F cut is increased further, the average charge of the leading particle rises. The curve in figure 3 is the result of a Monte Carlo jet simulation similar to the recursive scheme suggested by Field and Feynman[2], but modified to match our strange particle distributions[3] and energy range. For X_F cuts less than 0.5, the Monte Carlo is sensitive to uncertainties in the latter modification, and non-leading hadrons contribute to our measurement of $\Gamma(X_F)$.

In conclusion, our data indicate that electroproduced hadrons in the quark fragmentation region retain the charge of the parent quarks. The agreement between our data and a simple quark-parton model is striking. We also find that the mean charge of high momentum leading hadrons is consistent with the prediction of a quark jet model.

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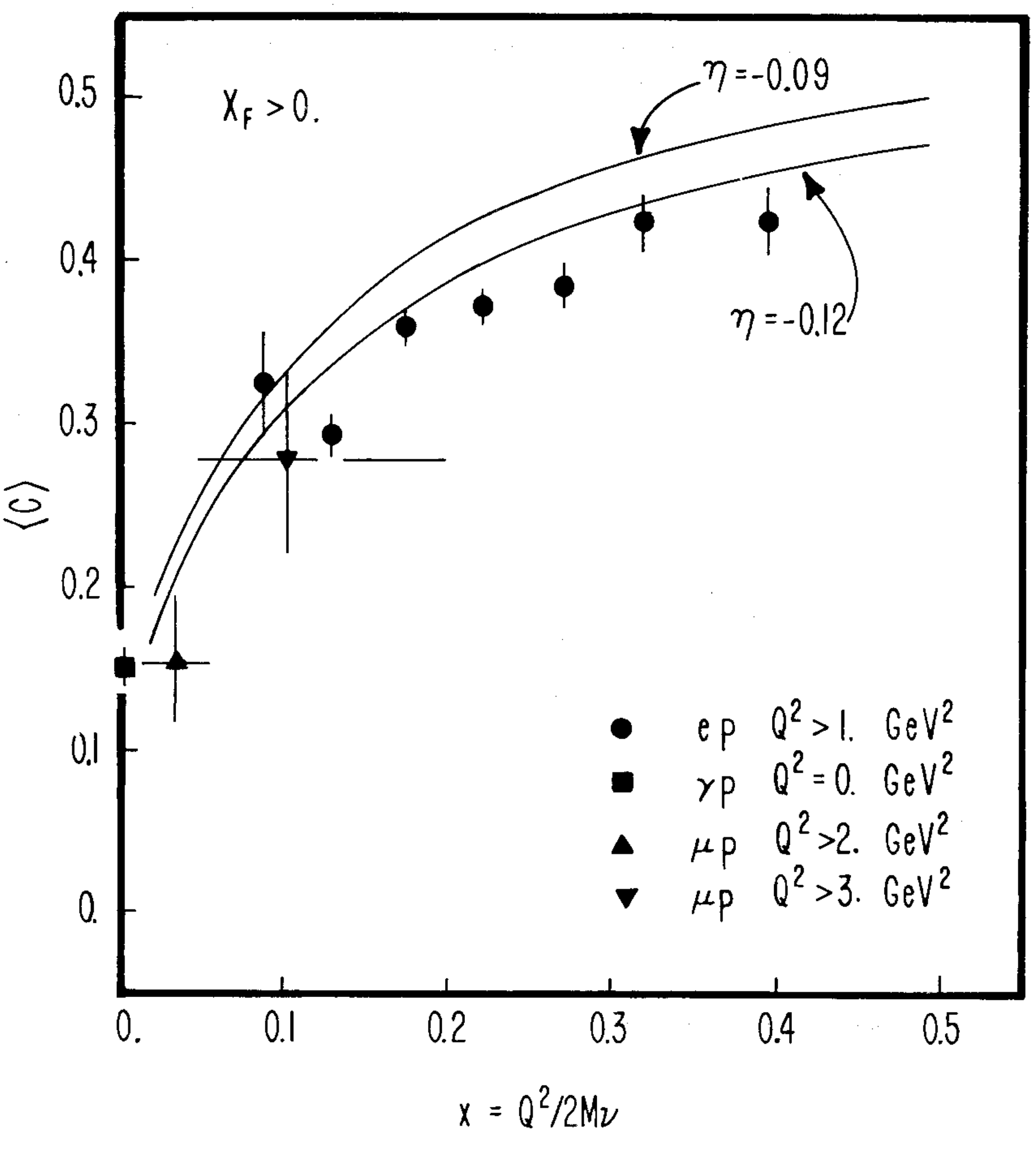
FIGURE CAPTIONS

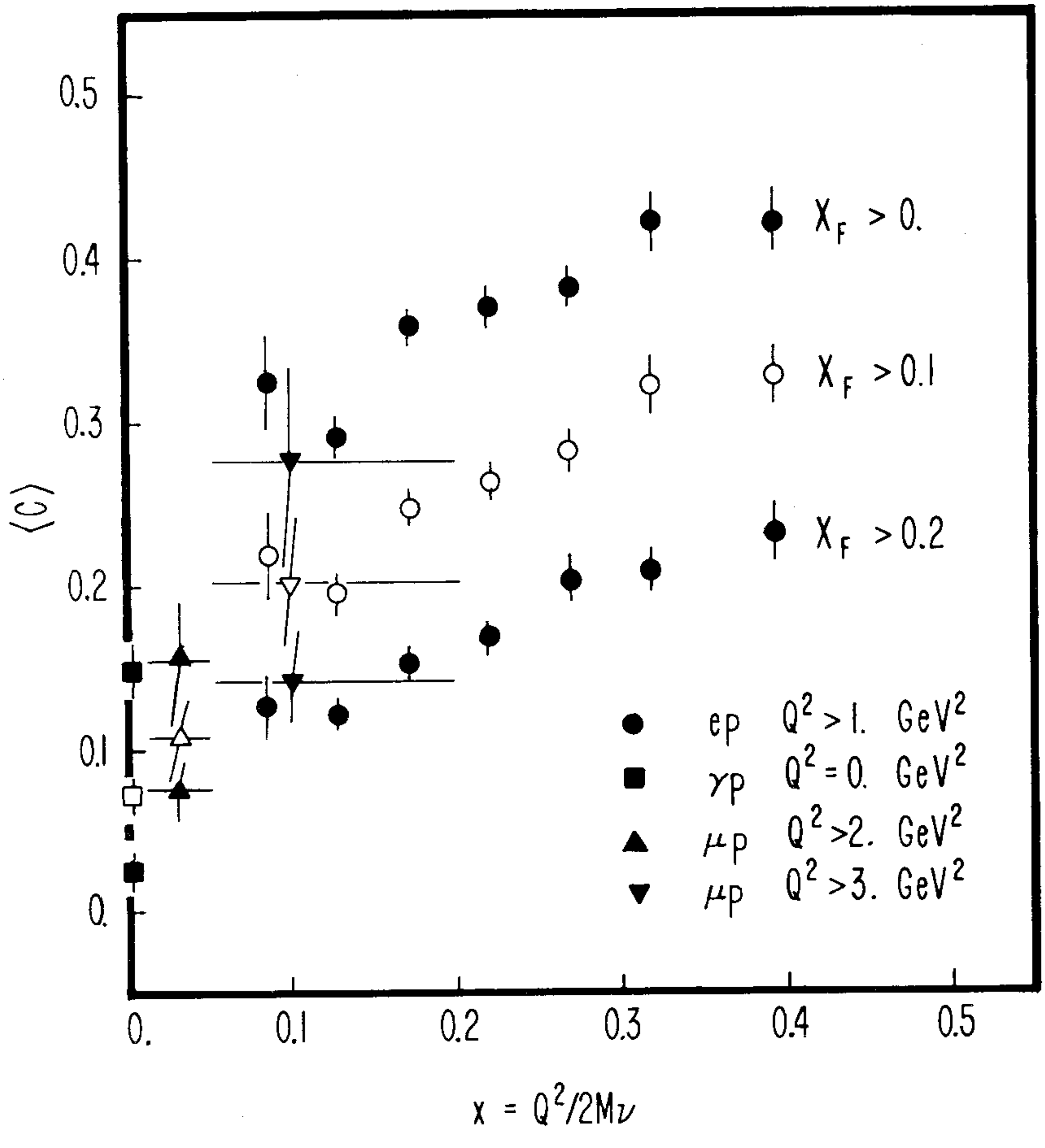
1. The x dependence of the mean charge of hadrons with $X_F > 0.$ is compared to a quark-parton model calculation. The photoproduction point is based on fits to the data of references 8, 9, and 10, and the muoproduction points are based on data from reference 11. The error bars show statistical uncertainties only. The curves are given by equation (1).

2. The insensitivity of the x dependence of the mean forward charge to the particular X_F cut is checked for various cuts.

3. The net charge forward of various X_F cuts is plotted for events with $x > 0.2$. Each data point contains only events having at least one charged hadron forward of the corresponding X_F value. The curve is the result of a Monte Carlo jet model calculation.



0.5
0.4
0.3
0.2
0.1
0.
⟨C⟩
$X_F > 0.$
$\eta = -0.09$
$\eta = -0.12$
ep $Q^2 > 1.$ GeV^2
γp $Q^2 = 0.$ GeV^2
μp $Q^2 > 2.$ GeV^2
μp $Q^2 > 3.$ GeV^2
0. 0.1 0.2 0.3 0.4 0.5
$x = Q^2/2M\nu$



⟨C⟩
0.5
0.4
0.3
0.2
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0.1
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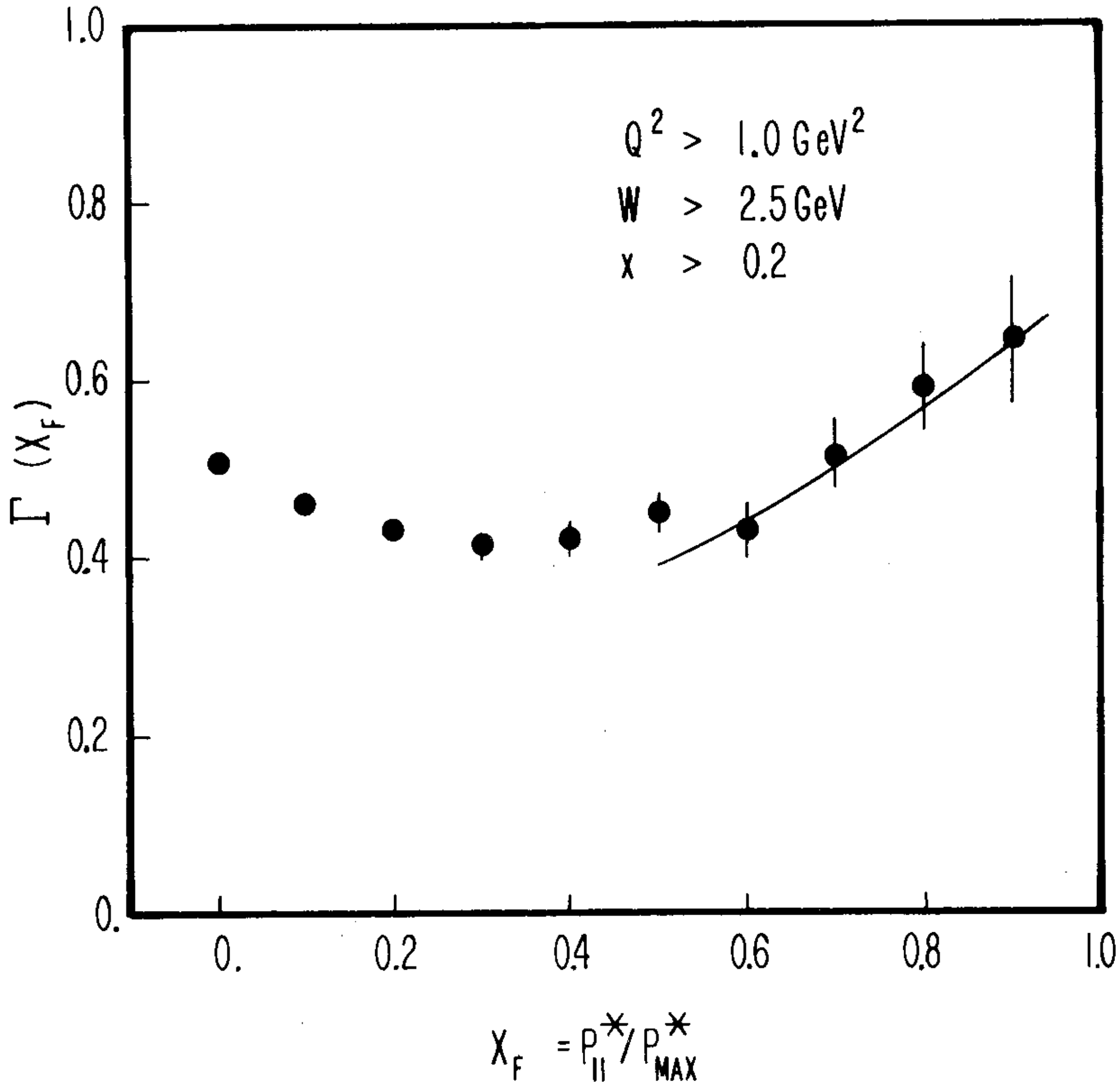
$X_F > 0.$
$X_F > 0.1$
$X_F > 0.2$
ep $Q^2 > 1.$ GeV^2
γp $Q^2 = 0.$ GeV^2
μp $Q^2 > 2.$ GeV^2
μp $Q^2 > 3.$ GeV^2
$x = Q^2/2M\nu$


1.0
0.8
0.6
0.4
0.2
0.
Γ (X_F)
Q² > 1.0 GeV²
W > 2.5 GeV
x > 0.2
0.
0.2
0.4
0.6
0.8
1.0
X_F = P*_II / P*_MAX