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Inclusive Electron Scattering at High Q^2 in the Region $1 < x < 3$

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Abstract

New inclusive electron scattering data at high Q^2 from nuclei taken in the x range unavailable to the free nucleon are presented. The ratios of cross section per nucleon, $(4/56)d\sigma^{Fe}/d\sigma^{He}$, show a plateau for $1.3 < x < 2.0$ which has been suggested as a signature of quark clusters in nuclei. The subtraction of the quasielastic cross section from the inclusive spectra reveals that the data scale in x at low momentum transfer. A proposal for a new experiment is discussed.

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It is is useful to conceptualize the inclusive electron scattering cross section from nuclei at high momentum transfer ($Q^2 \geq 1$ $(GeV/c)^2$) as dominated by two dissimilar processes. The first (See Figure 1a) is the absorption of a virtual photon by an offshell nucleon in the nucleus (quasielastic scattering); with the transfer of momentum q and energy υ the nucleon is ejected from the nucleus with the constraint that $P_\mu^2 = M_n^2$, i.e. the final knocked out nucleon is on it's mass shell. This mechanism is responsible for the broad quasielastic peak seen (at lower momentum transfers) in the spectrum of final electron energies and is a source of information about the momentum and energy distributions of the bound nucleons[1]. This process is characterized by the momentum dependence of the elastic nucleon form factor - the cross section falls like $1/Q^8$.

The second process (Fig. 1b) is inelastic scattering from the bound offshell nucleons in the nucleus with an indeterminate final state. This process includes resonance production and non-resonant pion production from nucleons; it is dominated by the deep inelastic scattering from the nucleon constituents (quarks). At large Q^2 and υ data exhibit Bjorken scaling with only a QCD logarthimic dependence on Q^2 and can be expressed in terms of the distribution function of the quarks inside the nucleus directly. Experimentally one can control the relative dominance of the two processes by measuring the inclusive spectra at different momentum transfers. In this talk, I will present inclusive data from nuclei measured over a wide range of momentum transfer that allow us to observe the transition from the quasielastic case (1a) to the inelastic case (1b). Of special interest is that these data are measured in a region that may

provide a testing ground for various models generated to explain the EMC effect; a number of models give similar predictions for $x < 1$, but differ for $x > 1$.

The experiment, done at SLAC, was designed to allow information about both the processes described above to be extracted. At moderate Q^2, the cross section should be sensitve to momentum distribution of the nucleons and provide a test of ground state nuclear wave functions. In 1975 G. West[2] showed that, in the impulse approximation, at high momentum transfer the quasielastic cross section should scale, i.e. the cross section should be a function of single variable $y = y(q,\nu)$; $y(q,\nu)$ is the longitudinal momentum of the knocked out nucleon before scattering calculated according to Ref. 3. The cross section, if this y-scaling is valid, can be expressed in terms of a longitudinal momentum distribution

$$F(y) = d\sigma/d\nu d\Omega (Z*d\sigma_{ep}(q) + N*d\sigma_{en}(q))^{-1} dy/d\nu,$$

where $d\sigma_{ep}$ and $d\sigma_{en}$ are the electron-proton and electron-neutron elementary cross sections respectively. The y-scaling hypothesis had been successfully applied[3] to ^{3}He. The present experiment was motivated by the possiblity of improving our understanding of y-scaling hypothesis by its extension to nuclei from $A = 4 \sim 197$. By making measurements over a range of momentum transfers, the convergence of the scaling function could be studied. This scaling law rests on the identification of the nuclear constituents as nucleons, the scaling function depends directly on the properties of the nucleon in the nuclear medium, e.g. the elastic form factor. The scaling function, F(y), has been used[4] to set a limit on the modification of the nucleon properties inside

the nucleus. This fact makes the data presented here of relevance to the work done at higher Q^2 in the $x < 1$ region where medium modification of quark properties has been suggested as an explanation for the EMC effect. Modified nucleon properties can explain the missing strength in the Coulomb sum rule in the low Q^2 quasielastic region. A partial analysis of these new data in terms of y-scaling has been published[5].

As Q^2 increases ($Q^2 > 1$ $(GeV/c)^2$) inclusive data from nuclei should reflect non-nucleonic degrees of freedom., i.e data should no longer be reliably described only in terms of nucleons and mesons, but a description must include sub-nucleonic degrees of freedom. Exact Faddeev calculations compared to inclusive data[6] from ^3He measured at SLAC emphasized the inability of conventional nuclear physics to describe electron scattering data at moderate Q^2. The ^3He data was subsequently described in a quark-cluster model[7] that included the contributions from 3-,6-,9- quarks clusters to the inclusive cross sections. This quark cluster model was later successful in describing most of the EMC effect[8]. This model makes specific predictions for the ratio of nuclear structure functions for values of $x > 1$ characterized by a step like behavior at integral values of x due to the dominance of 3-,6-,9- quark clusters at different values of ν.[9]

This experiment complements the inclusive data at high Q^2 (EMC-SLAC) and the nucleon-meson region characterized by low Q^2 and ν. Figure 2 show the kinematic extent of these new data on the Q^2-$2m\nu$ plane; the diagonal line corresponds to $x = 1$ and line parallel to larger values of x (=2,3,...16). We measured the inclusive spectrum from a range of nuclei over a Q^2 range of 0.25 - 3.0

$(GeV/c)^2$. These data provide a testing ground for modern models of the nucleus and a kinematic extension to the regions where EMC models might be tested.

The rest of this paper is organized in the following way. First I will describe very briefly the experiment. Then I will present some of the data in the form of ratios of cross section per nucleon, along with predictions based on the quark cluster model and few nucleon correlations. Finally I will describe a new experimental proposal and summarize.

Experiment

These data are from the first experiment done at SLAC as part of the Nuclear Physics program utilizing a new high intensity injector situated at sector 26 of the 30 sector linac. The momentum analyzed electrons delivered to End Station A scattered from solid targets (C, Al, Fe, Au) of natural isotopic abundance and cooled (21°K) He^4 (gaseous) and H^2 (liquid) extended targets. The scattered electrons were detected in the 8 GeV spectrometer in End Station A using the 'standard' particle identification and tracking detectors. Data were taken at 2.02 GeV at 15° and 20° and at 3.595 GeV at 16°, 20°, 25°, and 30°. The cross sections were measured from the threshold for nucleon knockout to the first resonance region. The cross sections were calculated offline and corrected for radiative effects using the formulae of Stein et al.[10]

The data set for Fe is shown in Fig. 3. The cross section $d^2\sigma/d\Omega d\nu$, plotted versus ν, varies by almost 6 orders of magnitude over the range of Q^2 and ν indicated. The quasielastic peak is seen clearly at low Q^2. At higher Q^2 the quasielastic peak is obscured by inelastic processes that include Δ production,

non-resonant π production, excitation of higher nucleon resonances, and deep inelastic electron-nucleon scattering. At the highest Q^2 the cross section is a monotonically increasing function of ν. For nuclei heavier than C, the quasielastic peak is less well defined because the larger Fermi motion smear the inelastic processes into the quasielastic region. For ^{4}He, the quasielastic peak is distinct until Q^2 becomes greater than 1 $(GeV/c)^2$. The kinematic extent of the data sets of ^{4}He, Al, and Au are less extensive than the one shown in Fig. 3.

x-Scaling

In Figure 4 we show the ratio, per nucleon, of the cross section from Fe to He^4 against the Bjorken x ($x = Q^2/2m\nu$) at six different Q^2. At every momentum transfer the ratio of iron to helium at x = 1 is less than 1, which can be understood from the heights of iron and helium quasielastic peaks which are the dominant feature of the inclusive spectra at these momentum transfer. The quasielastic peak of iron is broader than that of helium, which has a smaller k_F. The dissimilar momentum distributions of the two nuclei are also responsible for the increase in the ratio as x increases. An interesting feature of these data is the appearance of a plateau in the ratio as the Q^2 increases. It is difficult to explain this feature as the ratio of two different momentum distributions; the ratio of exponentials with different slopes yield another exponential.

Figure 5 is the ratio of iron to helium at a $Q^2 \simeq 1.3\ (GeV/c)^2$ along with the results of a calculation by J. Vary[11] based on the quark cluster model. The calculation of the inelastic structure function includes a quasielastic piece based on the spectral function for ^3He extended to heavier nuclei through a parametrization of the low-k and high-k pieces. The contributions from deep inelastic scattering from quarks in 3-,6-,9-,12- quark clusters are calculated as a product of the probability for the overlap of the quark clusters and the convolution of the momentum distribution with the quark structure functions. The momentum distribution of the clusters is the same as that used for the quasielastic piece and the quark distributions come from naive quark counting rules. The results seen in Figure 5 are remarkable in that it reproduces the plateau in the data. Unfortunately the relative contribution of the quasielastic piece to that quark cluster contribution in the region $1.2 < x < 2.0$ is not shown.

Figure 5 includes (the dashed line) a prediction by Frankfurt and Strikman[12] for $1.5 < x < 2$ based on a QCD few nucleon correlations model. The flat region in the ratio is a consequence that different nuclei should have high momentum tails from correlations that are proportional to the nuclear density.

Other workers[13,14] have begun to make predictions for the $x > 1$ region. Reference 13 gives a classification of the different contributions to the nuclear structure functions:

$$F_{2A} = F^{I}_{2A} + F^{Q}_{2A} + \Sigma F^{B}_{2A}$$

where I, Q, B mean inelastic, nucleon quasielastic and correlated multi-nucleon (fragments B) quasielastic. These contribute in the respective

kinematic regions $x < 1$, $x \sim 1$, $x > 1$. Using a relativistic description of the nucleus, they predict the behavior of F_{2A} of different nuclei as a function of x. Reference 14 descibes these data in terms of conventional nucleon degrees of freedom and finds that short-range few-nucleon correlations are important.

Of great interest since the results of the EMC is a measurement of the nuclear deep inelastic stucture functions at $x > 0.8$ where data from the free nucleon are unavailable. It appears now that the EMC effect can be explained by convolution of the nucleon structure functions, evaluated ater taking into account the binding energies, with the nucleon momentum distributions. A discrepancy between a measurement of the structure functions and a convolution model at large x can either be due to a problem with the momentum distribution used as the smearing function or due to the modifications of the free nucleon properties inside the nucleus or the availability of additional degrees of freedom inside the nucleus, e.g. quark clusters. It should be possible to separate these two effects in principle. The stucture function at large x ($x \simeq 1.5$) is sensitive to the tail of the momentum distribution while at $x \simeq 1$ the structure function is relatively insensitive to the tail.[15]

We have made some first attempts to study the inelastic piece of these data. We have subtracted the single nucleon knockout piece using a model based on y-scaling, assigning a 10% error to the subtraction procedure. In Figure 6 are shown the inelastic structure function, νW_2, of Fe for $Q^2 = 0.9$, 1.8, and 2.7 $(GeV/c)^2$ with different symbols indicating the different data sets. (In calculating νW_2 we have taken $R = 0.18$.) The data appears to scale in x over this limited range in momentum transfer and these data indicate that it will be

possible push these measurements to larger values of x. In addition Figure 6 includes a model calculation at $Q^2 \sim 2.7$ $(GeV/c)^2$ for νW_2 following Bodek and Ritchie[16] with the inclusion of a binding energy term.

Our collaboration has proposed a new experiment to be done at SLAC (designated NE14) titled "Deep Inelastic Scattering at X > 1. Based on count rate calculations (constrained by an upper limit of 6 GeV incident beam energy) we have estimated that the deep inelastic structure function from Fe can be measured to x = 1.2, 1.3, 1.13, 1.01 at Q^2 of 4., 6., 8. $(GeV/c)^2$ respectivelly, with 30% error on the measurement. The resolution in $\Delta x/x$ will be 0.025. This experiment has not been scheduled into the NPAS program. At this time it appears the earliest avaliable running period will be summner 1989.

Summary

We have measured inclusive electron scattering from a range of nuclei in the Q^2 range of 0.25 to 3.0 $(GeV/c)^2$. The ratios of $d\sigma^{Fe}/d\sigma^{He}$ per nucleon show at low Q^2 a rapid increase when plotted versus x. At a $Q^2 \sim 1$, the ratios exhibit a plateau which is suggested by a quark cluster model. After subtracting the quasielastic contribution from the inclusive data, the inelastic structure function scales in x at a relatively low momentum transfer. These data, at x > 1, form a solid basis with which to test the dissimilar models used to explain the EMC-SLAC data. We have a unique set of data with which to extend our understanding of quarks and nuclear degrees of freedom in nuclei In addition, we have proposed a new experiment to extend these data to large Q^2.

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Figure Captions:

Figure 1. Diagrams for the quasielastic(a) and inelastic(b) contributions of inclusive scattering.

Figure 2. Q^2-$2m\nu$ plane for these data.

Figure 3. $d\sigma/d\Omega d\nu$ for Fe versus energy loss. The Q^2 range (Q^2 decreases with increasing energy loss) is shown for each line. Arrows indicate x = 1,2.

Figure 4. Ratios at 6 different energies and angles versus x for iron to helium.

Figure 5. Ratio at 3.595, 20. with quark cluster calculation by J. Vary[11] and (dashed line) prediction by Frankfurt and Strikman[12].

Figure 6. The inelastic structure function for Fe at $1 < Q^2 < 2.5$ $(GeV/c)^2$. The quasielastic component to the cross section has been subtracted. The dashed line is calculation based on the work of Ref 16.

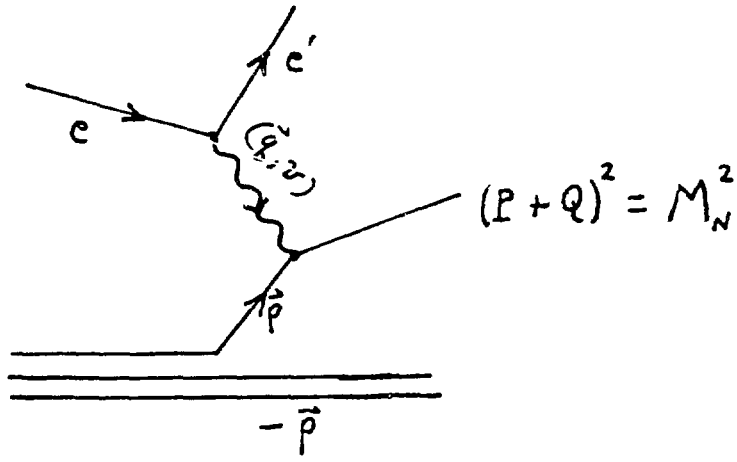


Figure 1a

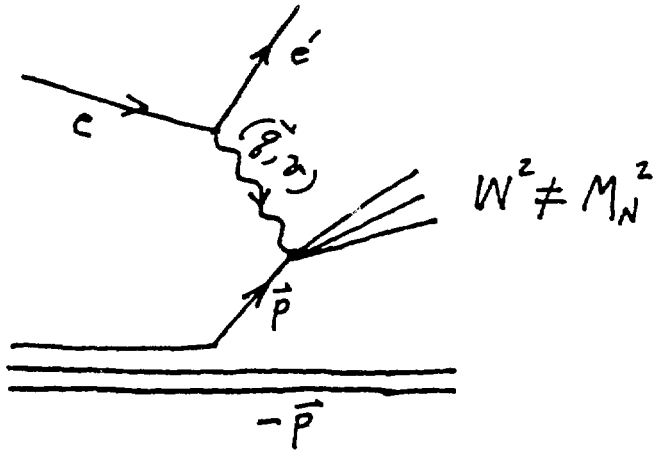
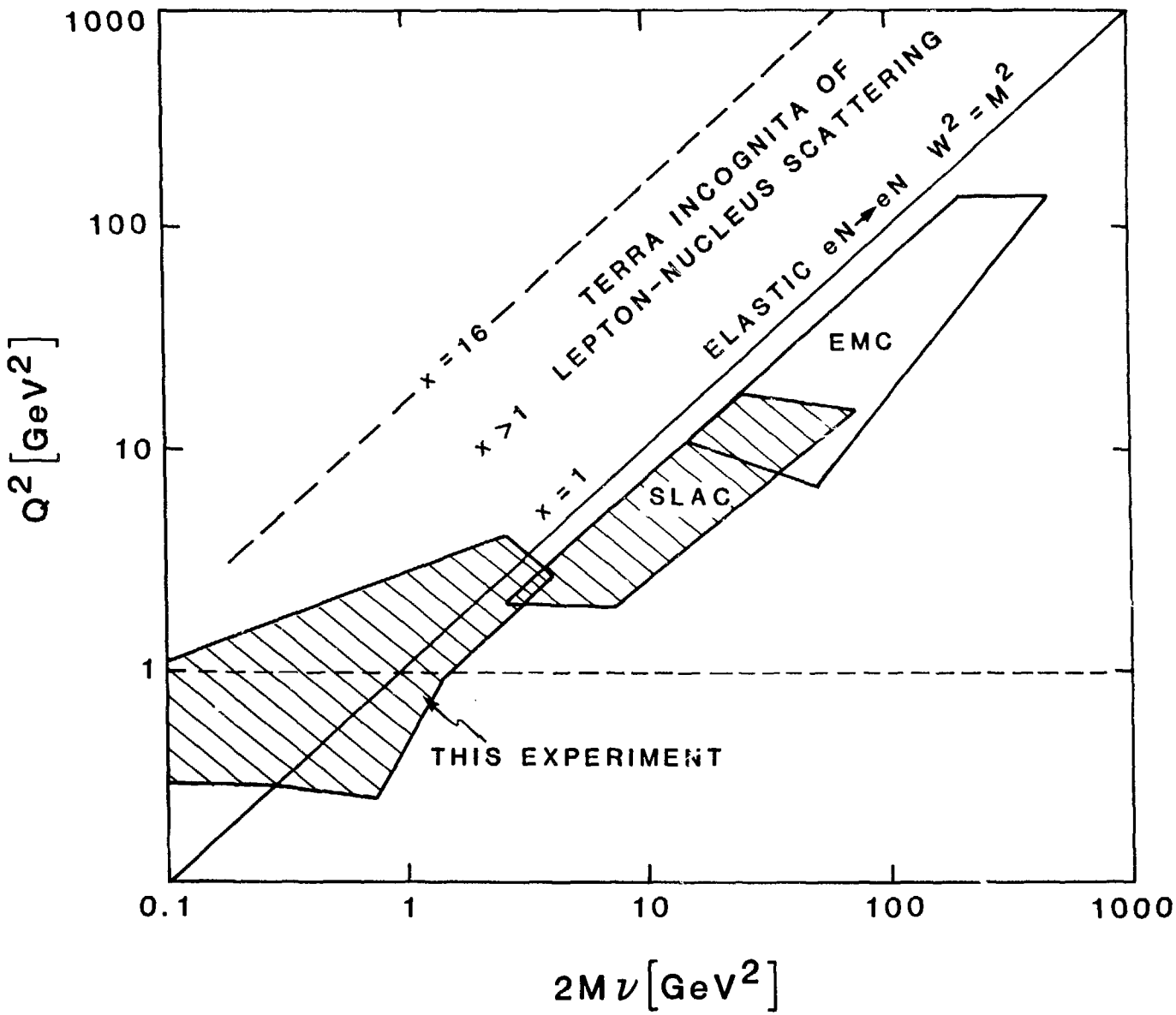
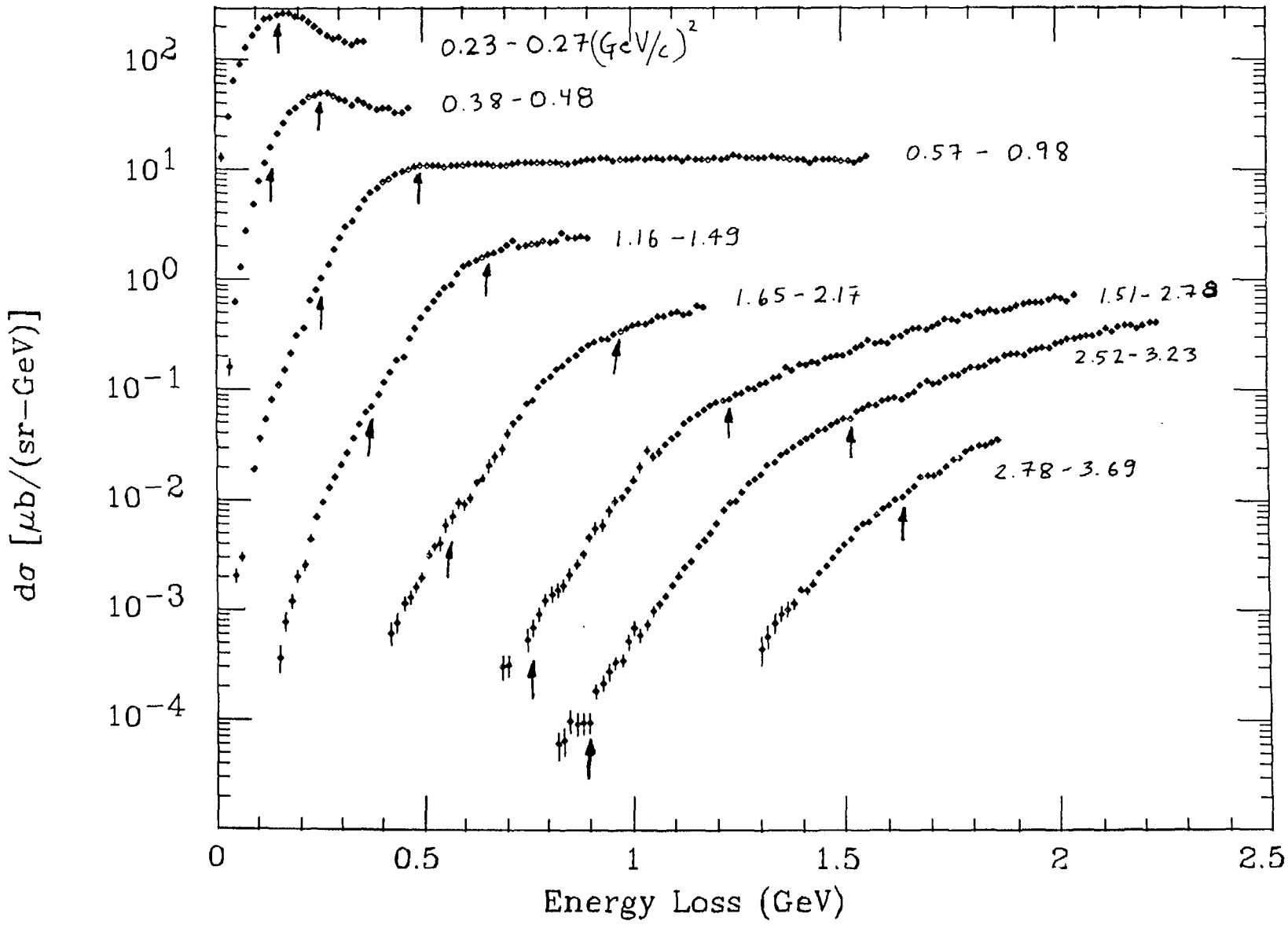
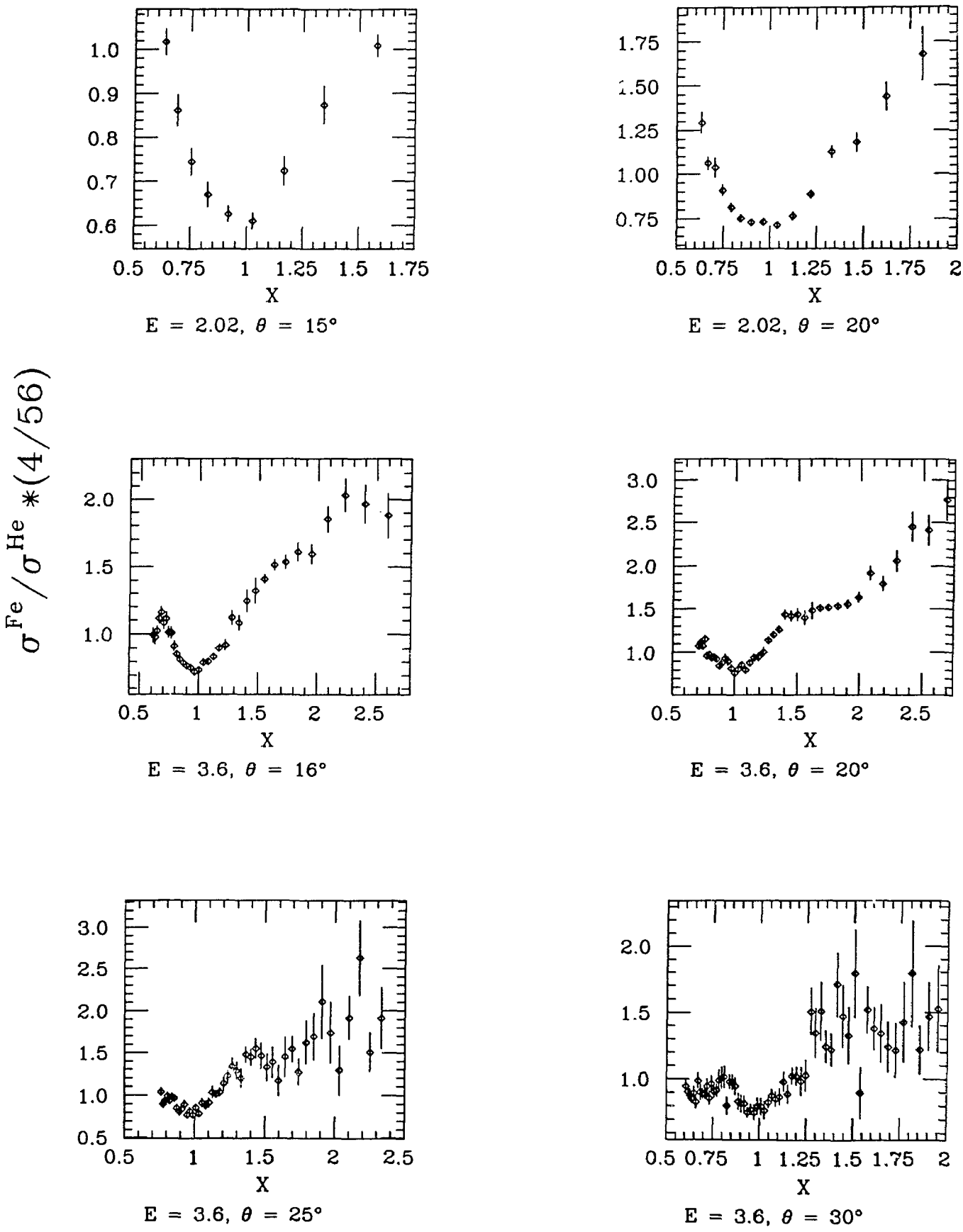
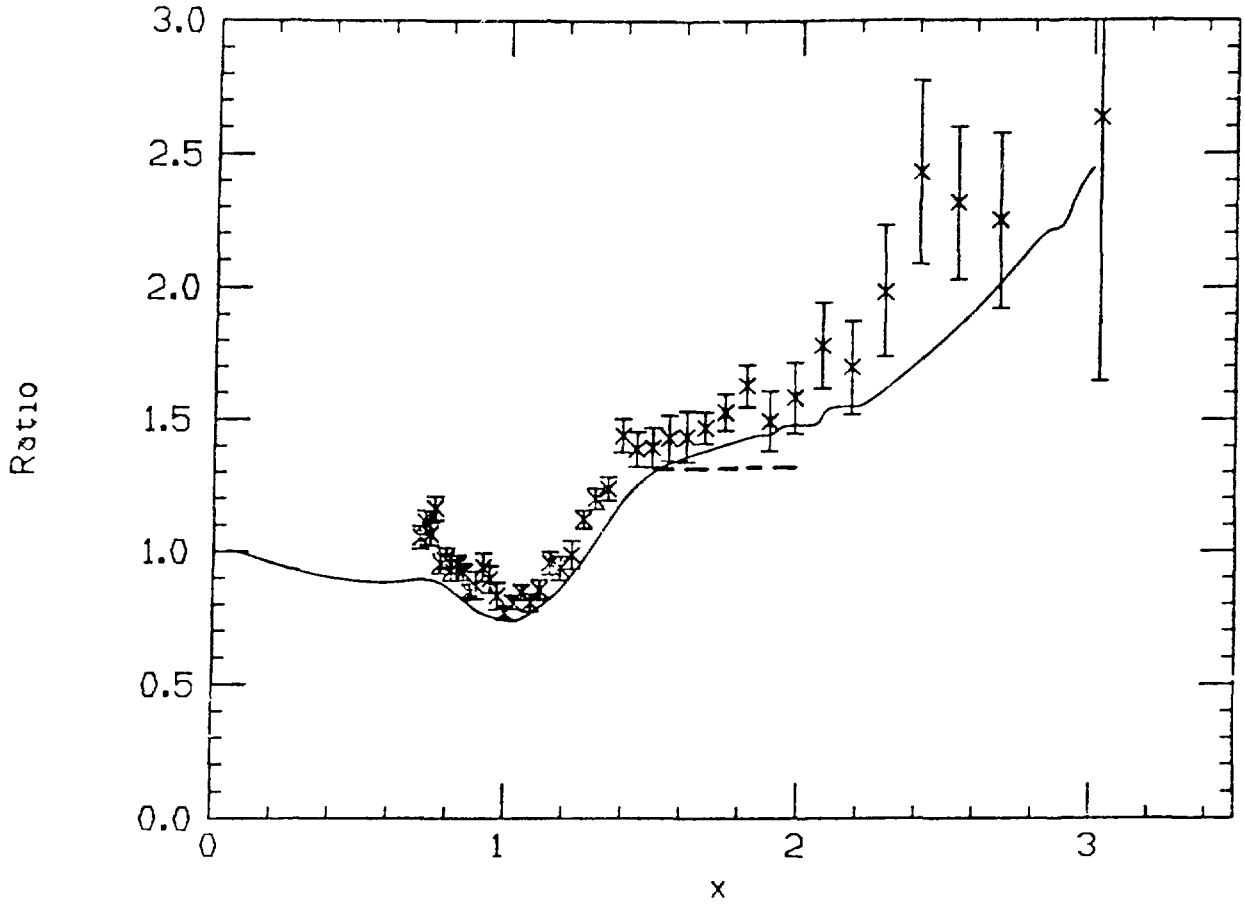


Figure 1b


1000
100
10
1
0.1
1
10
100
1000
Q^2 [GeV^2]
$2M\nu$ [GeV^2]
TERRA INCOGNITA OF
LEPTON-NUCLEUS SCATTERING
x = 16
x > 1
x = 1
ELASTIC eN→eN
$W^2 = M^2$
EMC
SLAC
THIS EXPERIMENT


0.23 - 0.27 (GeV/c)^2
0.38 - 0.48
0.57 - 0.98
1.16 - 1.49
1.65 - 2.17
1.51 - 2.78
2.52 - 3.23
2.78 - 3.69
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$d\sigma$ [μb/(sr-GeV)]
0
0.5
1
1.5
2
2.5
Energy Loss (GeV)


$\sigma^{Fe}/\sigma^{He} * (4/56)$
X
E = 2.02, θ = 15°
E = 2.02, θ = 20°
E = 3.6, θ = 16°
E = 3.6, θ = 20°
E = 3.6, θ = 25°
E = 3.6, θ = 30°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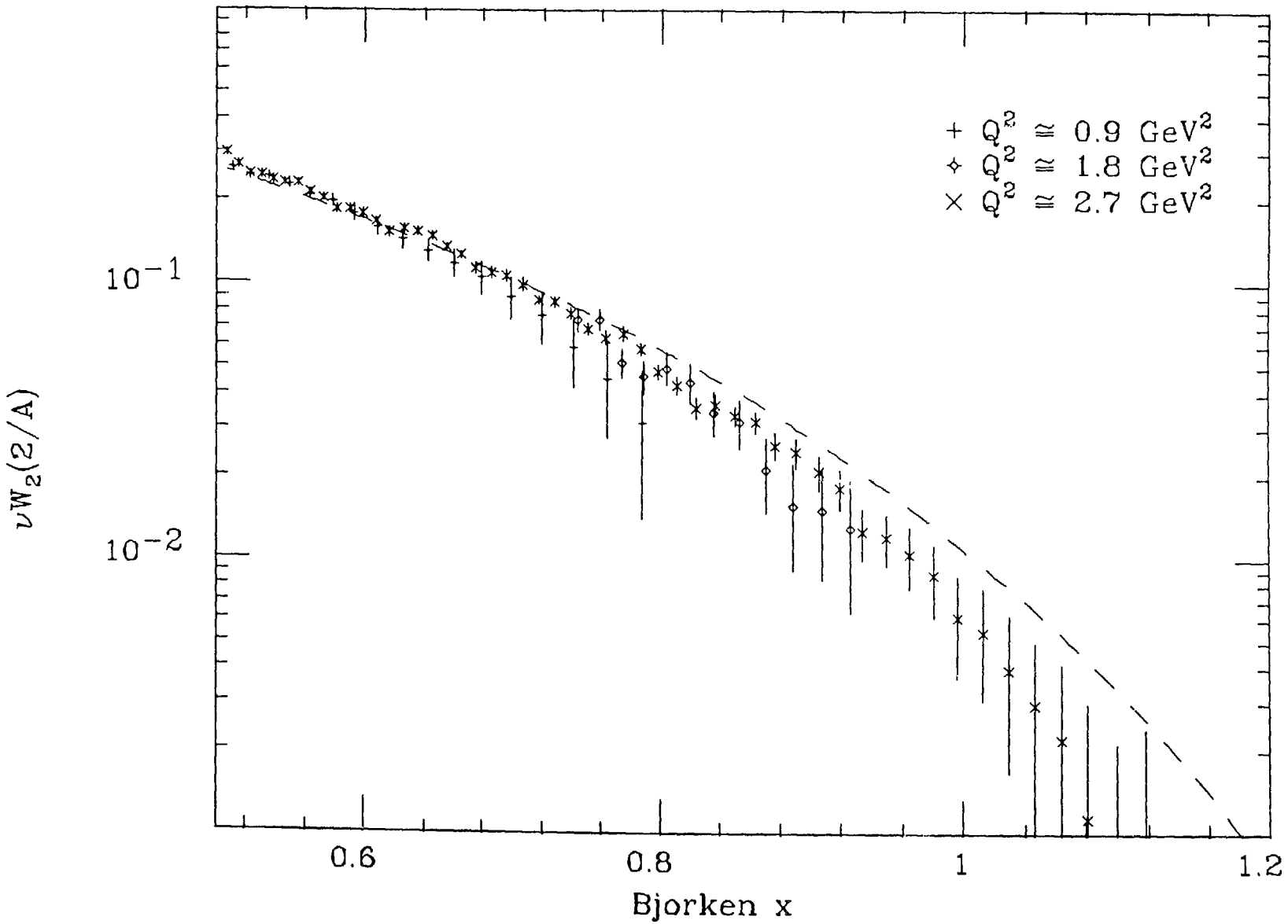
2.5
2.0
1.5
1.0
0.5
0.0
Ratio
0
1
2
3
x


+ $Q^2 \cong 0.9$ GeV^2
✧ $Q^2 \cong 1.8$ GeV^2
× $Q^2 \cong 2.7$ GeV^2
10^{-1}
10^{-2}
$\nu W_2(2/A)$
0.6
0.8
1
1.2
Bjorken x