## 0.1 Inclusive scattering at $x > 1$.

### 0.1.1 Introduction

Inclusive scattering from nuclei at $x > 1$ has provided a great deal of information about the high momentum components of the nuclear wave function. High momentum components are sensitive to short range correlations (SRCs) in the nucleus. These correlated nucleons are an important part of nuclear structure, and represent local high-density nuclear configurations. Comparisons of inclusive scattering from heavy nuclei and deuterium provided one of the first experimental signatures of short range correlations in nuclei [1, 2]. Above $x \approx 1.5$, the cross section behavior was identical for all nuclei measured, yielding a plateau in the $A/D$ ratio and indicating that the same two-nucleon correlations that generate the high-momentum nucleons in the deuteron are also the dominant source of high-momentum nucleons in heavy nuclei. Subsequently, short range correlations in nuclei have been probed in a variety of reactions: A(p,2p), A(e,e'p), A(e,e'NN).

Completed and planned measurements [3] at Jefferson Lab up to 6 GeV will map out the strength of two-nucleon short range correlations in nuclei. These measurements will also provide a first look at high-$Q^2$ cross sections for $2.5 \leq x < 3$, where the cross section is most sensitive to the presence of multi-nucleon correlations. Higher beam energies will dramatically increase both the $x$ and $Q^2$ range of the data. With the increased $x$ coverage possible with an 11 GeV beam at Jefferson Lab, we can map out the strength of correlations (both two-nucleon and multi-nucleon) as a function of nucleus, probing details of nuclear structure that go beyond mean-field or shell model calculations. In addition, by probing at the highest $Q^2$ values possible, we can isolate and probe the quark structure of correlated nucleons. This will allow us to look for new physics at high matter density (3-4 times nuclear matter densities in the region where two nucleons overlap). At high enough densities, as at high temperatures, hadrons should be deconfined and hadronic matter is replaced by a quark-gluon plasma. The observations of the EMC effect as well as more recent measurements that indicate the form factors of a nucleon are modified [4] when in a bound nucleus, already hint that confinement may be weakened at densities found inside of a nucleus. By probing the quark structure of correlated nucleons, we can look directly for modification to hadron structure at high density.

### 0.1.2 New Physics with 11 GeV Beam

An increase in beam energy will allow us to extend these measurements of the cross section to higher $x$ values while maintaining a fairly large momentum transfer ($Q^2 \approx 5$ (GeV/c)$^2$). This will increase our ability to probe the distributions of the highest momentum nucleons, dramatically increasing our sensitivity to multi-nucleon correlations.

Figure 1 shows a calculation of the $F_2$ structure function for Iron at the top of the quasielastic peak ($x = 1$), as well as in the tail of the nucleon momentum distribution ($x \approx 1.5$). The curves are calculations including two-nucleon [2] and multi-nucleon [5] correlations. The present data is consistent with two-nucleon SRCs being the dominant source of high momentum nucleons, and shows no indication of significant multi-nucleon correlations. At 11 GeV, the $Q^2$ coverage at $x = 1.5$ is significantly increased. This data, as well as similar data at even higher values of $x$ will provide much greater sensitivity to multi-nucleon correlations.

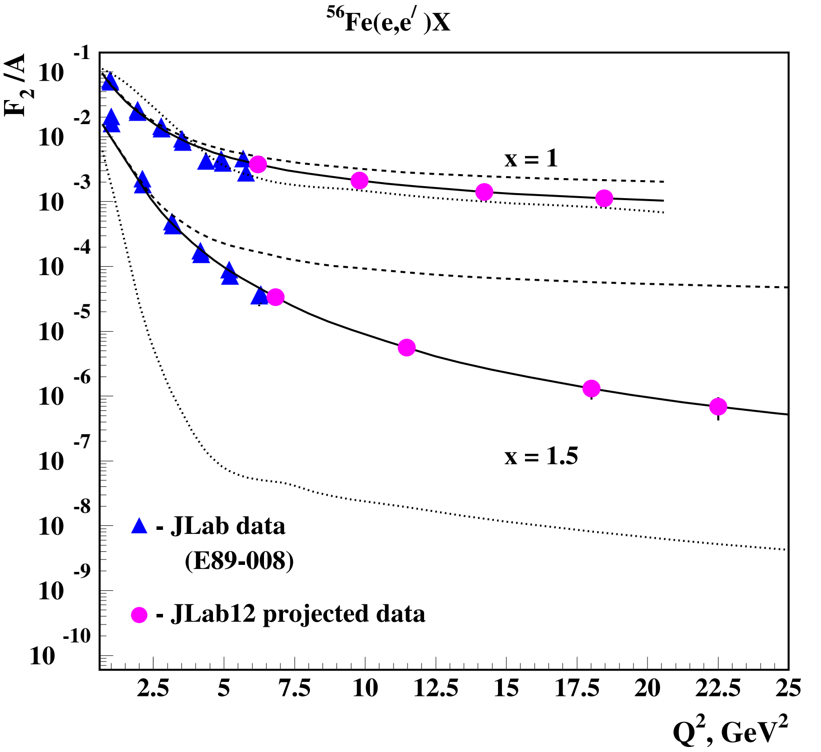


Figure 1: Structure function (per nucleon) for iron [3] from JLab E89008 (blue diamonds) and the proposed data using a 12 GeV CEBAF (red circles). The solid curve is the calculation including two-nucleon correlations, while the dashed curve includes a model of the multi-nucleon correlations.

Higher energies will also provide additional ways to attempt to separate two-nucleon correlations from multi-nucleon contributions. The target dependence of the inclusive cross sections may be the best way to identify the presence of multi-nucleon correlations, which can then be studied in detail using more exclusive reactions. Just as the plateau in the ratio of $\sigma_A/\sigma_D$ in the region of high-momentum nucleons ($1.5 < x < 2$) indicated the dominance of two-nucleon correlations, a plateau in the ratio of heavy nuclei to $^3$He for $x > 2.5$ would provide evidence for multi-nucleon correlations. Alternately, one can look for strength beyond $x = 2$ in heavy nuclei by examining the $Q^2$-dependence of $\sigma_A/\sigma_D$. If heavy nuclei do not have significant strength above $x = 2$, then the $Q^2$ evolution should be nearly identical for deuterium and heavy nuclei at large $x$. If there are significant multi-nucleon correlations, then the strength at $x > 2$ (absent for the deuteron), will significantly modify the $Q^2$-evolution, causing $\sigma_A/\sigma_D$ to increase with $Q^2$ as more strength from high-$x$ enters into the region of $x < 2$. Figure 2 shows the $Q^2$-dependence of the structure function ratio (Fe/D) assuming two-nucleon correlations only (bottom), and including multi-nucleon correlations (top). The curves come from the same calculations shown in Figure 1 [2, 5].

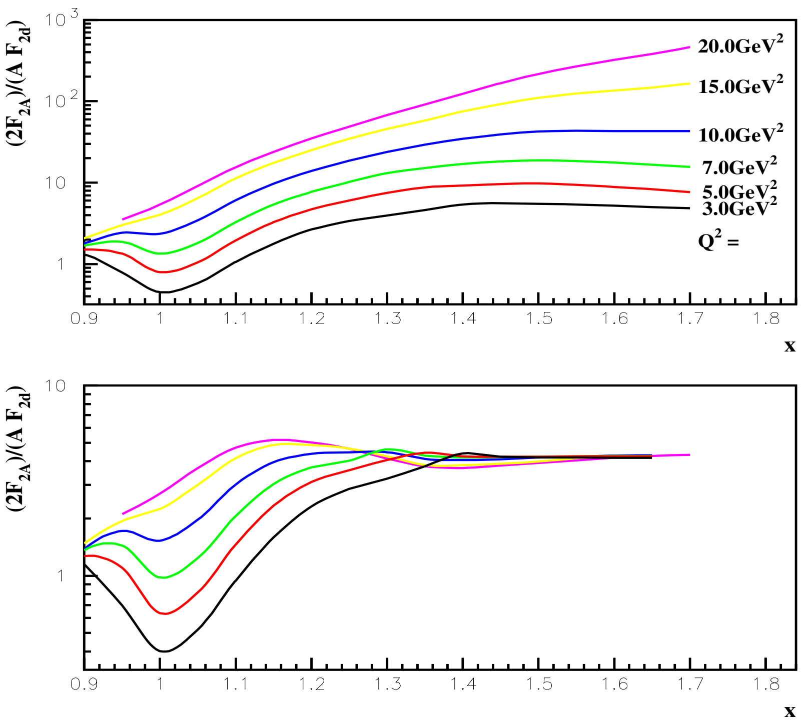


Figure 2: Iron to Deuteron ratio of structure function per nucleon ($F_2^A/A$) as a function of $x$ for several $Q^2$ values. The bottom plot is the calculation including only two-nucleon correlations, while the top plot includes a model of the multi-nucleon correlations.

In addition to improving the sensitivity to multi-nucleon correlations, higher energies will also provide a new way to study two-nucleon correlations through the behavior of quark distributions at large $x$ values. A measurement in the DIS scaling regime at $x > 1$ would allow us to measure for the first time the distributions of superfast quarks in nuclei, where the struck quark carries more momentum than an entire nucleon. These quark distributions are intrinsically related to the quark structure of the two-nucleon correlations which should dominate for $1 \le x \le 1.3$. The EMC effect demonstrates that the quark structure of a nucleus is more than just a convolution of the quark structure of its nucleons. If this comes from density-dependent modifications to nucleon structure, then a similar (but potentially larger) effect should be seen when one examines the quark distributions at large $x$, where the strength comes almost entirely from nucleon pairs that are nearly overlapping. The $x$-dependence from a convolution of the nucleon momentum distribution with the nucleon parton distribution functions will be very different from the quark distribution evident if there were exotic components to hadronic structure at high density (*e.g.* nucleon swelling or 6-quark bags). Such a measurement will give a clear indication of deviations from a purely hadronic picture of nuclear structure.

There is little data available for structure functions of nuclei at $x > 1$. Measurements of muon scattering from iron [6] have only upper limits above $x = 1.1$, and show a rapid falloff in the structure function near $x = 1$ ($F_2(x) \propto e^{-16.5x}$). Measurements of neutrino scattering from carbon [7] also have a limited $x$ range ($x < 1.2$), but indicate significantly more strength at large $x$ ($F_2(x) \propto e^{-8.3x}$). With the increase in $Q^2$ possible with the JLab energy upgrade, high precision measurements of the structure function can be made over a wide range in $x$, allowing us to cleanly map out the distribution of superfast quarks. Figure 3 shows the QE and inelastic contributions to the cross section for four different $Q^2$ values. At the larger values of $Q^2$, the inelastic contributions dominate the cross section well above $x = 1$.

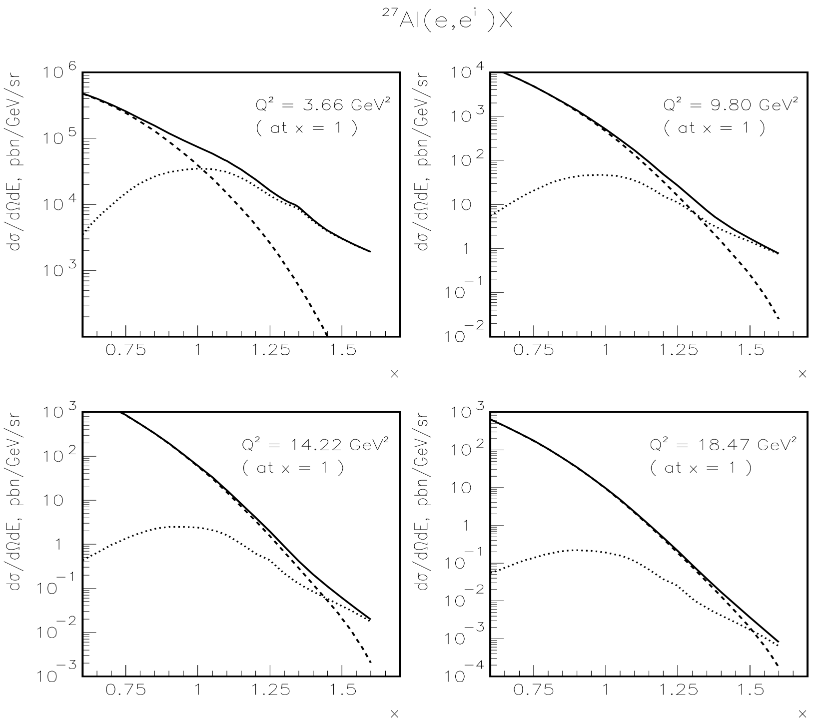


Figure 3: Calculation of the quasielastic (dotted line), inelastic (dashed), and total (solid) cross section for inclusive scattering.

### 0.1.3 Cross section and rates

The following figures can be used to determine the kinematics and estimate the rates that one might expect with the 12 GeV upgrade. Figure 4 shows the expected kinematic range in $x$ and $Q^2$. Several assumptions were made in calculating the kinematic range while assuring adequate rate. A 6% radiation length Fe target with 60 microAmps of current was assumed, and a maximum of 10 hours runtime per x bin to give max 8% error per bin. The $Q^2$ range can be increased by increasing the maximum scattering angle, but pion and positron-electron pair production background become quite large (and grow rapidly) as the scattering angle is increased.

Figures 5 and 6 give the rates at $x = 1$ (or $y \approx 0$) and $y = -0.5$ respectively. The dashed blue line is the ratio of quasielastic to the total cross section and is read against the left-most axis and is given as a function of three momentum $\mathbf{q}$ which is read on the top axis. The solid red lines provide the kinematics and make the connection between the energy and the scattering angle. The numbers at the far left of each line gives the three and four momentum transfers. From the dashed green lines, labeled with the three momentum transfer, one can read the cross section (right axis) as a function of the scattering angle.

Parameterizations of previous pion photo- and electro-production indicate that $\pi/e$ ratios may reach $\sim 200$, but a threshold Cerenkov detector and electromagnetic shower counter can provide sufficient particle ID to reduce the uncertainties due to pion subtraction to $< 0.4\%$.

The presence of background electrons from charge symmetric processes (e.g. Dalitz pairs and $\gamma$ conversion) can be checked by reversing the spectrometer momentum and measuring the yield of $e^+$. Estimates of this background indicate that the subtraction may be as much as 50% at the lowest $x$ and largest angle resulting in an uncertainty of $< 5\%$ in the cross section (the charge symmetry of these processes on nuclei has been checked at the level of a few %).

### 0.1.4 Hardware Requirements

The physics program described above involves extending current inclusive scattering measurements to the highest possible values of $Q^2$ for $x > 1$, as well the highest $x$ possible for moderate $Q^2$ values ($\approx 5$ (GeV/c)$^2$). To extend the $x$ range, we need to detect extremely high momentum electrons (up to 10-11 GeV/c), with coverage of forward angles ($\theta < 30°$). To extend the $Q^2$ range, we need a high momentum spectrometer (6 GeV/c or more) covering a wide angular range (roughly $20° < \theta < 60°$). In both cases, the measurements will require high luminosities and moderate ($\sim 10^{-3}$) or better momentum resolution. The data at highest $x$ could be taken in the planned SHMS spectrometer in Hall C. The highest $Q^2$ data could be taken using the existing HMS spectrometer in Hall C. Much of this data could also be taken with the proposed MAD spectrometer, although the 6 GeV/c momentum would limit the data at 11 GeV to $\theta > 27°$, which gives $x < 1.6$. This would be sufficient for measuring the structure functions near $x = 1$, but not for the $A/^3He$ measurements at $x > 2$ or the $Q^2$-dependence of the $A/D$ ratio, both of which are sensitive to the presence of multi-nucleon correlations.

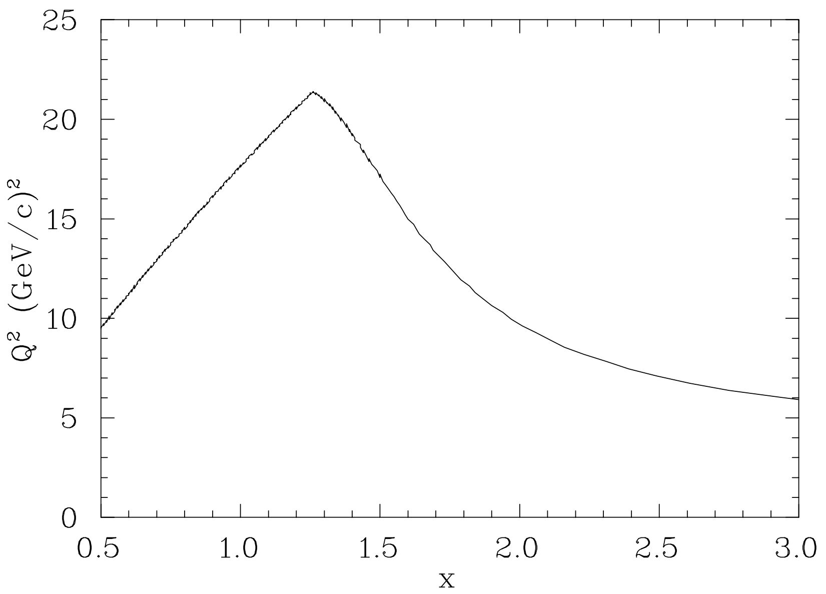


Figure 4: Expected kinematic range in $x$ and $Q^2$ using an 11 GeV beam at Jefferson Lab.

### 0.1.5 Summary

Using an 11 GeV beam at Jefferson Lab together with the existing HMS and the planned SHMS, the kinematic range of measured inclusive cross section data can be dramatically increased in both $x$ and $Q^2$. The increased $x$ coverage allows one to map out the strength of both two-nucleon and multi-nucleon correlations as a function of nucleus. By probing the highest $Q^2$, we can study the quark structure of correlated nucleons and look for new physics at high matter density.

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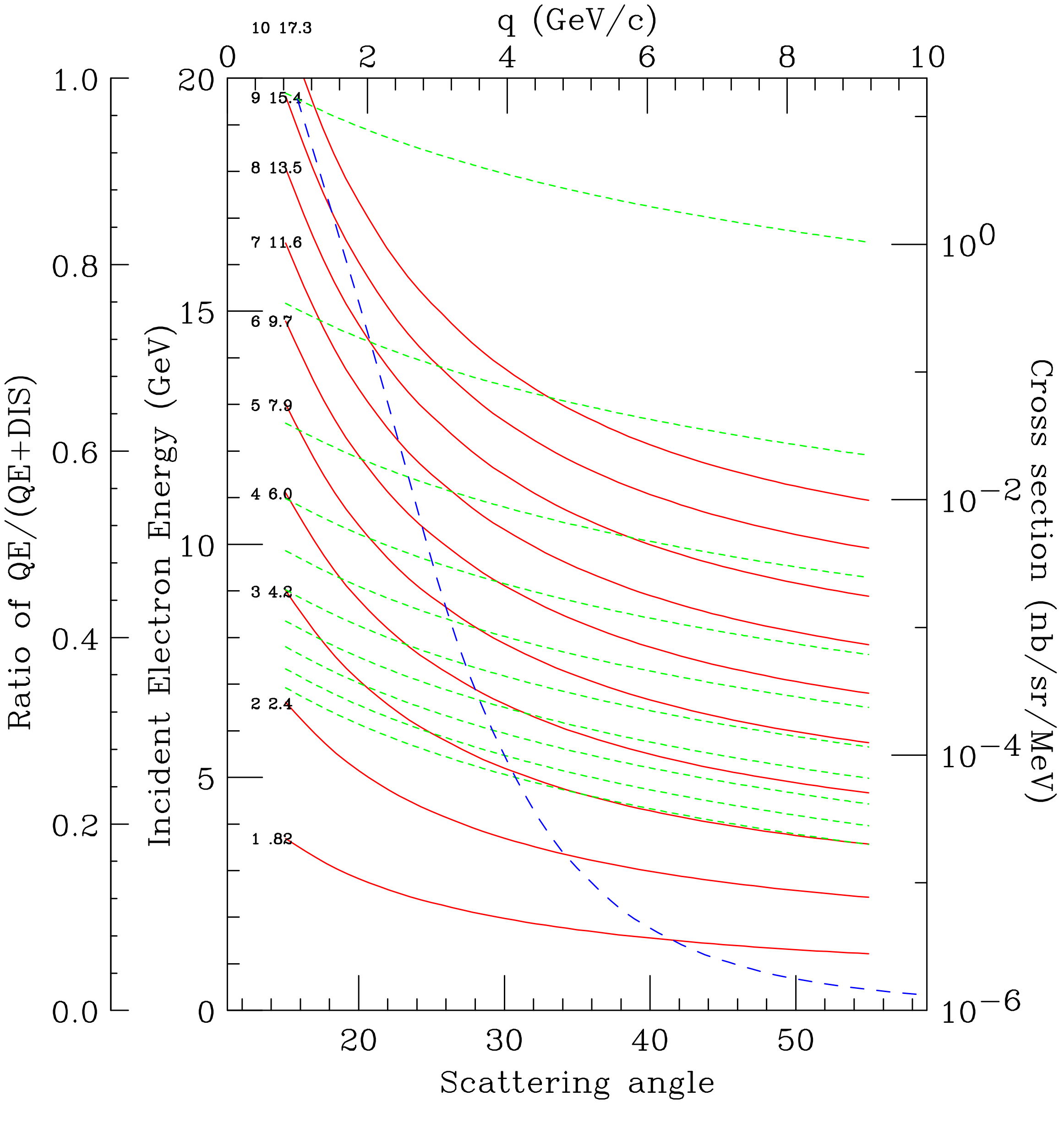


Figure 5: Cross section, kinematics and ratio of QES to (QES + DIS) at $x = 1$. The event rate is $\frac{d\sigma^2}{d\Omega dE'} \cdot \mathcal{L} \cdot \Delta E \cdot \Omega$. With $\mathcal{L} = 10^{37}, \Delta E = 50$ MeV and $\Delta\Omega = 5(3)$ msr, 1 nb/(sr-MeV) yields about 9(6) events/hour.

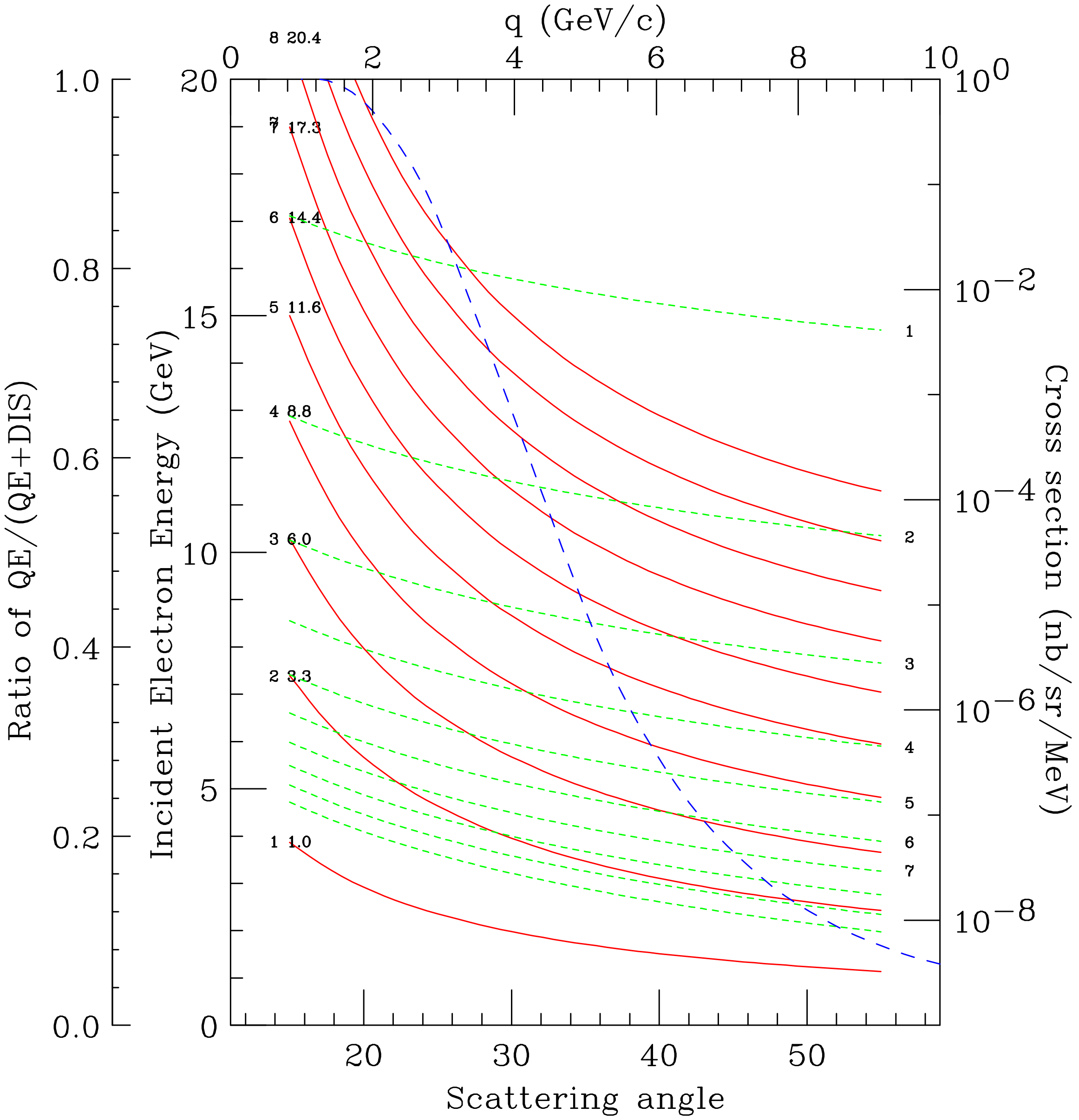


Figure 6: Cross section, kinematics and ratio of QES to (QES + DIS) at $y = -0.5$. The event rate is $\frac{d\sigma^2}{d\Omega dE'} \cdot \mathcal{L} \cdot \Delta E \cdot \Omega$. With $\mathcal{L} = 10^{37}, \Delta E = 50$ MeV and $\Delta\Omega = 5(3)$ msr, 1 nb/(sr-MeV) yields about 9(6) events/hour.