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Measurement of the Xenon/Deuterium Inelastic Cross Section Ratio Using 490 GeV/c Muons *

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MEASUREMENT OF THE XENON/DEUTERIUM INELASTIC CROSS SECTION RATIO USING 490 GeV/c MUONS

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ABSTRACT

Inelastic scattering of 490 GeV μ^+ from deuterium and xenon nuclei has been studied at energy transfers (ν) up to 370 GeV and four-momentum transferred squared (Q^2) down to 0.1 GeV^2. A depletion in the inelastic μ^+ cross section has been observed from xenon compared to deuterium in the kinematic range $0.001 < x_{Bj} < 0.08$. The ratio of the xenon/deuterium cross section decreases with increasing ν but does not depend on Q^2. The data extend the ν and Q^2 ranges studied previously in charged lepton and photoproduction experiments. The data agree qualitatively with models that invoke parton fusion in nuclei and models based on generalized vector dominance.

INTRODUCTION

Recent measurements [1,2,3] have confirmed that the yield of inelastically scattered muons per nucleon from heavy nuclei is suppressed in the low x_{Bj} region; $x_{Bj} = Q^2/2M\nu$ where Q^2 and ν are the four-momentum squared and energy transferred from the muon to the target and M is the target mass. This suppression, termed "shadowing", has been measured using virtual photons; it is reminiscent of earlier results obtained in photoproduction experiments [4]. New results from Fermilab experiment E665 augment these data by extending the kinematical range; this was made possible with the use of the highest energy muon beam available and a novel trigger. In addition, E665 has used the heaviest nuclei (xenon) to date[5].

APPARATUS

E665's apparatus has been described in detail elsewhere[6]. In this paper we will emphasize the elements that are relevant to the study of low Q^2, high ν scattering, that is, the detection and measurement of muons scattered through small angles (θ).

The momentum of the incident muons was measured using a beam spectrometer consisting of multiwire proportional chambers and small scintillation hodoscopes placed upstream and downstream of a dipole magnet. The resolution of the wire chambers enabled a reconstructed momentum resolution of 0.5% at 490 GeV/c. The hodoscopes defined the incident beam for the small angle trigger (SAT) described below. The scattered muon was identified by its presence downstream of a 3 *m* thick iron hadron absorber. Its momentum was measured by a forward spectrometer consisting of a large-aperture superconducting dipole magnet instrumented with proportional wire chambers and drift chambers. The momentum resolution of this spectrometer was 2.5% for a 490 GeV/c muon; this corresponds to the following range of resolutions:

	Maximum	Minimum
ν	0.8% at 375 GeV	30% at 40 GeV
Q^2	2% at 10 GeV^2	16% at 0.1 GeV^2
x_{Bj}	16% at 10^{-3}	16% at 10^{-1}

Inelastic muon scattering at low Q^2 typically results in muons that remain within the geometrical phase space of the unscattered beam. An interacting muon was detected by the SAT as follows: the incident muon's trajectory was extrapolated through the forward spectrometer to a hodoscope (placed downstream of the hadron absorber) and this position was compared to the counter that had fired. The event was recorded if the difference in the two positions was at least 2 counter widths. The SAT had significant acceptance above $Q^2 = 0.1$ GeV^2 which corresponds to a scattering angle of approximately 0.5 mr.

There was increased acceptance at high ν values and small θ. This kinematical region is dominated by events in which an incident μ loses a significant fraction of its momentum but continues travelling in its original direction. This frequently happens when the μ undergoes bremsstrahlung in the target or when small angle μ-e scattering occurs. These two processes were the dominant backgrounds to inelastic μ scattering in the high ν, low Q^2 region. Large angle μ scattering in the hadron absorber was also a source of fake triggers. These events were rejected from the final event sample during the analysis stage by determining that no interaction had occurred in the target.

An essential role in this study was played by a large aperture electromagnetic calorimeter with fine longitudinal and transverse segmentation[6]. This detector allowed an event-by-event detection of radiative photons which greatly reduced the uncertainty in the final corrections applied to the data sample.

DATA

Data from two targets (xenon, A=131, 8.5 gm/cm^2 and deuterium, 16 gm/cm^2) are reported here. In addition to these, a hydrogen and an empty target vessel were used.

In Figure 1 the yield from deuterium is shown as a function of x_{Bj} with the requirement that $y = \nu/E_{inc} <$

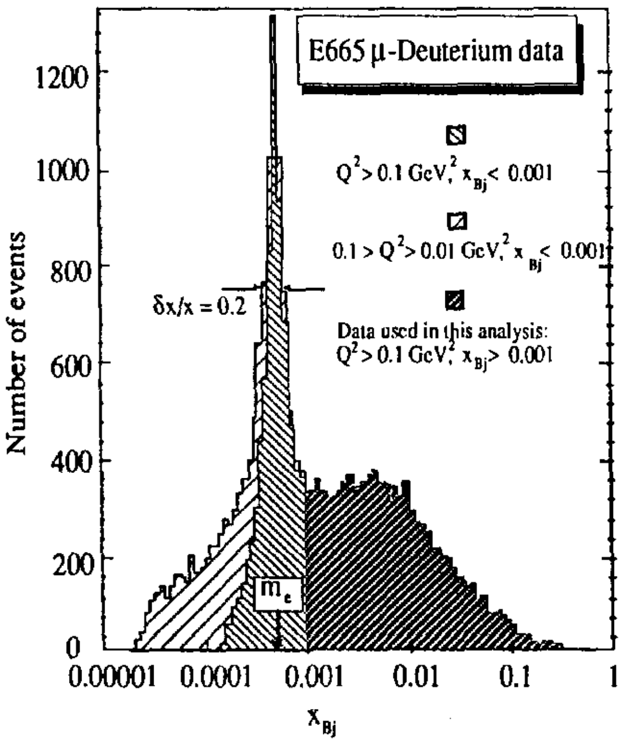

Figure 1. Yield of scattered μ from deuterium. The data in the region 10^{-4} are dominated by events with $0.01 < Q^2 < 0.1$ GeV^2. These data, and those corresponding to μ-e elastic scattering, were eliminated by the cut $x_{Bj} > 10^{-3}$.

0.75; this requirement eliminates the majority of bremsstrahlung events. A significant fraction of μ-e elastic scattering events survive; these events are peaked at $x_{Bj} = m_e/m_p = 1/1836$. The width of the peak is a measure of the x_{Bj} resolution (20% at x_{Bj} = 0.0005) and agrees with the estimated resolution obtained from chamber resolutions. The μ-e peak restricts the kinematical region which can be used to analyze deep inelastic scattering using the μ alone to $x_{Bj} > 0.001$. A final event sample comprising 10276 xenon and 9914 deuterium inelastic μ scattering events was obtained by applying the following kinematical cuts: $E_{inc} > 400$ GeV, $\nu > 40$ GeV, $y < 0.75$, $Q^2 > 0.1$ GeV^2, and $x_{Bj} > 0.001$.

CORRECTIONS

Data from deuterium and xenon were obtained in two different time periods and therefore the yields were potentially sensitive to time dependent effects in the apparatus' performance. The following is a list of the major corrections (including time dependent ones) applied to the data:

Empty target subtraction: A small fraction of events originated from material other than the xenon or deuterium targets. A correction for this was made by obtaining data from an empty target vessel with a yield of typically 4% of the full target. The correction was dependent on x_{Bj} attaining a maximum value of 15% at $x_{Bj} = 0.001$. The estimated uncertainty on the *ratio* of the xenon/deuterium cross section was 1%.

Normalization: Two independent methods were used to determine the beam flux. A difference of 0.7% remained after studies.

Scattered μ reconstruction: The efficiencies of the wire chambers in the forward spectrometer were time dependent which led to an uncertainty of 4% on the ratio of the cross sections.

Target density: The uncertainty in the densities of the two targets led to a potential error of 0.4% in the cross section ratio.

Radiative corrections: These corrections are especially important in the high y (low x_{Bj}) kinematical region. Up to 70% of the scattered μ yield from a μ-xenon interaction originates from radiative processes whch corresponds to a 25% correction on the cross section ratio.

The corrections were performed using a two-stage process. First, the kinematical cuts mentioned in the previous section were applied; these minimized the number of bremsstrahlung and μ-e events. Second, to the remaining sample, two independent methods were used to estimate the necessary corrections : (a) events were discarded if the electromagnetic calorimeter had detected more than 80% of the virtual photon's energy (ν) and a requirement on the maximum number of energy clusters detected in the calorimeter was satisfied (b) event yields were corrected using a calculation based on a computer program[7].

There was consistency between the two approaches (even at high y values where the correction is large). It is estimated that a maximum systematic uncertainty of 7% remains in the radiative correction. The results presented in the following section were all produced by applying *calculated* radiative corrections rather than by eliminating events using data from the calorimeter. Combining all the potential uncertainties results in a maximum systematic error on the ratio of xenon/deuterium yields of ~8%.

RESULTS

The kinematics of inelastic μ scattering are described by two independent variables, the choice of which is often influenced by the physics being studied. The data in this section are presented as a function of Q^2, ν and x_{Bj}.

The Q^2 variation of the xenon/deuterium cross section ratio per nucleon is presented in Figure 2 for an interval of x_{Bj}; data from NA28[1,2] for a similar x_{Bj} range are also shown . In addition, a point from photoproduction[4] is included. E665's data increase the kinematical range previously studied and one can see that there is no evidence of a Q^2 dependence of the cross section ratio.

The ν dependence of the xenon/deuterium cross section ratio is shown in Figure 3. The E665 data span a range $0.1 < Q^2 < 0.5$ GeV^2 and are compared with NA28[8] and photoproduction data[4]. The E665 data are consistent with shadowing increasing with photon (real or virtual) energy; the amount of shadowing from virtual photons appears to be less than that from real photons.

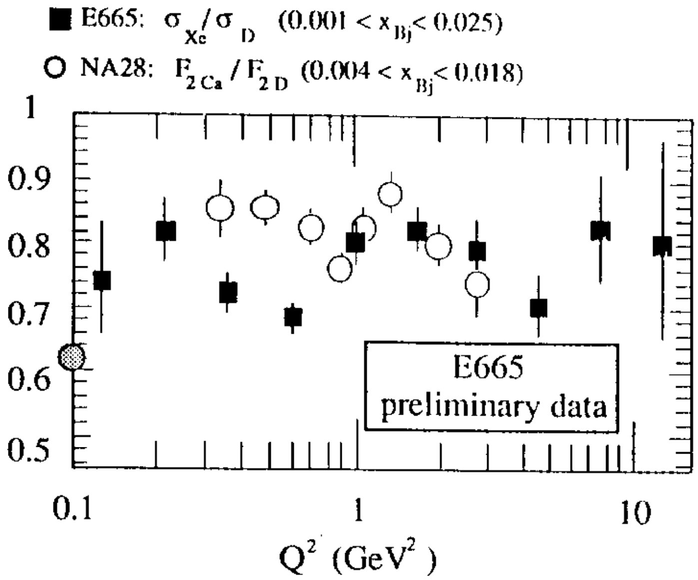

Figure 2. Q^2 dependence of the E665 σ_{Xe}/σ_D cross section ratio. (solid squares) compared to NA28's[1,2] calcium/deuterium data (open circles). The photoproduction point (shown as a shaded circle on the vertical axis) was obtained by extrapolating A_{eff}/A for Cu data[4] to Xe. Only statistical errors are shown for the E665 data.

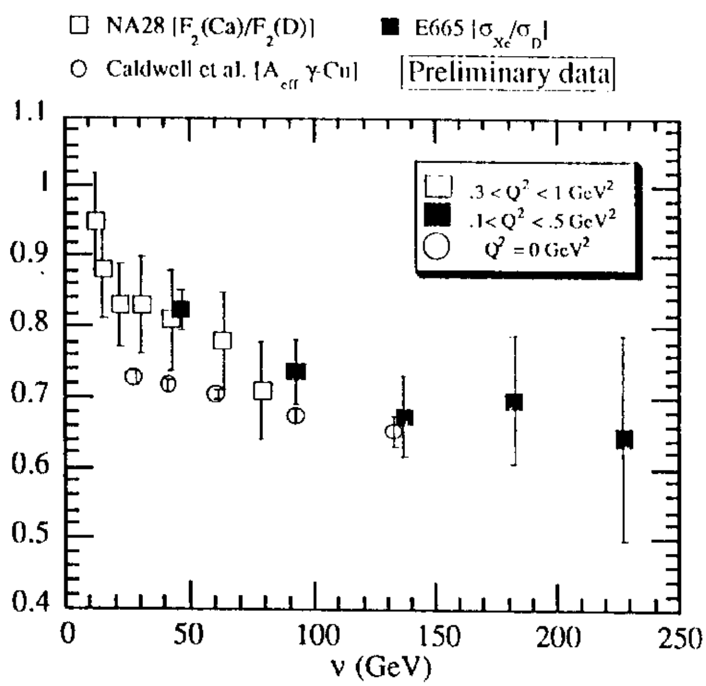

Figure 3. Energy dependence of shadowing. E665 data are shown as solid squares and are compared to NA28 data [8] (open squares) and A_{eff}/A for Cu data from photoproduction[4] (open circles). Only statistical errors are shown for the E665 data.

The x_{Bj} variation of the data is shown in Figure 4; a strong suppression occurs as x_{Bj} decreases. E665's data are compared to structure function measurements from NA28. Increasing amounts of shadowing with

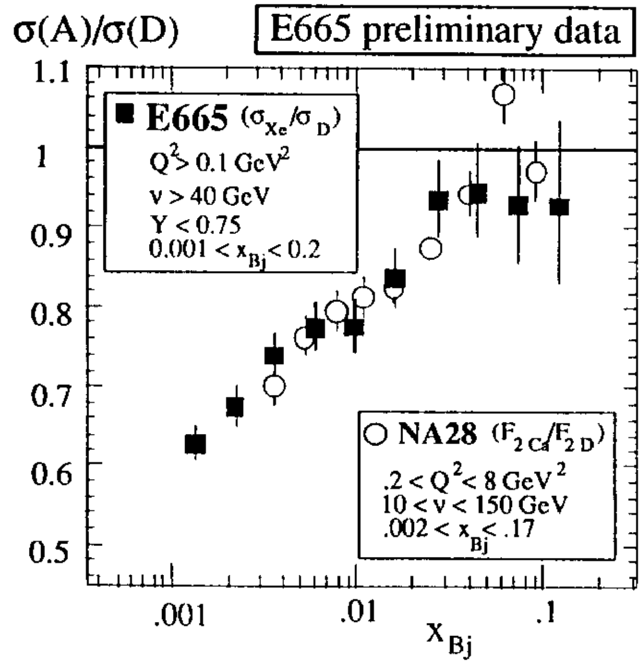

Figure 4. The x_{Bj} dependence of the xenon/deuterium cross section ratio. (E665 data, solid squares) and the Calcium/ deuterium structure functions (NA28 data, open circles). The estimated systematic errors are 8%. (E665) and 6% (NA28). Only statistical errors are shown for the E665 data.

atomic number, A, have been previously measured in photoproduction and μ scattering. E665's data are expected to lie somewhat below NA28's because of E665's heavier xenon target . This is not ruled out as the quoted systematic errors from the two experiments are 6% for NA28 and 8% for E665. Recent preliminary results from the high statistics NMC experiment [3] using calcium and deuterium targets report ratios higher than those reported by NA28. Comparing E665's data with NMC's would lead to the conclusion that shadowing continues to increase with A even for heavy nuclei such as xenon.

The E665 data in the vicinity of $x_{Bj} = 0.002$ suggest that shadowing continues to increase with decreasing x_{Bj}; there is no evidence for "saturation".

COMPARISON WITH THEORETICAL MODELS

E665's data are consistent with an increase in shadowing with ν; such a dependence is not predicted by vector meson dominance (VMD) or generalized VMD models [9]. Shadowing is predicted to increase until the lifetime of the vector meson fluctuation ($\tau = 2\nu/[Q^2 + m_v{}^2]$, where m_v is the mass of the vector meson) is comparable to the nuclear radius[10]. This should occur approximately at ν = 5 GeV, after which no substantial increase should take place.

There is no evidence for a Q^2 dependence of shadowing at constant x_{Bj}. This may be consistent with generalized VMD models [11,12,13]. Several parton models based on the concept of parton recombination have been proposed[14,15,16]. Although within QCD it is expected that shadowing will decrease as Q^2 increases, this effect is expected to be offset by the increase in the density of low-x_{Bj} partons. A slow decrease in shadowing is expected as Q^2 increases[14]. E665's data supports a weaker Q^2 dependence than predicted by most parton-based models.

Many models predict shadowing for $x_{Bj} < 0.1$. However, most of them anticipate a smaller amount than is seen by the data; several also expect shadowing to saturate because of the finite thickness of nuclei. The disagreement between parton-based predictions and experimental data may be due to the theoretical calculations being performed at a fixed value of Q^2, typically ~4 GeV^2. In contrast to this the data have been averaged over a Q^2 range for each x_{Bj} value which leads to a correlation between x_{Bj} and Q^2 (for example at $x_{Bj} = 0.0013$, $\langle Q^2 \rangle = 0.4$ GeV^2 whereas at $x_{Bj} = 0.13$, $\langle Q^2 \rangle = 20$ GeV^2).

CONCLUSIONS

New data have been presented for muons scattering inelastically from xenon and deuterium targets. The data increase the kinematical region previously studied and confirm that shadowing increases with decreasing x_{Bj}. The data support no Q^2 dependence for fixed x_{Bj} and a weak ν dependence of shadowing is apparent for low Q^2, high ν photons.

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