Fermi National Accelerator Laboratory

FERMILAB Conf-94/220-E
E665

Structure Functions and Structure Function Ratio F_2^n/F_2^p at Small x_{Bj} and Q^2 in Muon-Nucleon Scattering

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July 1994

Presented at the *Vth International Conference on the Intersections of Nuclear & Particle Physics,*
St. Petersburg, Florida

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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Abstract

Preliminary results on the measurement of the structure functions $F_2^p(x_{Bj}, Q^2)$ and $F_2^d(x_{Bj}, Q^2)$ and of the ratio F_2^n/F_2^p from experiment E665 are presented. The data were obtained using 465 GeV/c muons scattering off liquid hydrogen and deuterium targets. The dependence of the structure functions on x_{Bj} and Q^2 is examined in the kinematic range $x_{Bj} > 8 \times 10^{-4}$ and $Q^2 > 0.2\ GeV^2/c^2$. The structure function ratio is presented as a function of x_{Bj}, for $x_{Bj} > 10^{-6}$.

Introduction

In the single-photon exchange approximation the differential cross-section for lepton-nucleon scattering can be written as :

$$\frac{d^2\sigma_{1\gamma}(x_{Bj}, Q^2)}{dQ^2 dx_{Bj}} = \frac{4\pi\alpha^2}{Q^4}\frac{F_2(x_{Bj}, Q^2)}{x_{Bj}}\left[1 - y - \frac{Mx_{Bj}y}{2E} + \frac{y^2(1 + 4M^2x_{Bj}^2/Q^2)}{2(1 + R(x_{Bj}, Q^2))}\right] \quad (1)$$

where E is the incoming lepton energy and $-Q^2$ is the square of the four-momentum transfer. In the laboratory frame $x_{Bj} = Q^2/2M\nu$, ν is the energy transferred from the incoming lepton to the target and $y = \nu/E$. $F_2(x_{Bj}, Q^2)$ is the structure function of the target nucleus and $R(x_{Bj}, Q^2)$ is the ratio of the longitudinal to the transverse virtual photon cross-sections.

In order to extract the single-photon exchange cross-section from the measured event rates, radiative corrections must be applied for the higher order electromagnetic processes. For the analysis presented here these corrections are made according to the Mo and Tsai formalism [1]. The input F_2 for this procedure is constructed using fits to existing data from deep inelastic lepton-nucleon scattering and resonance production. The parameterization of Donnachie and Landshoff [2] is used to extrapolate to low Q^2 at high W^2. Furthermore, to extract the F_2 from these corrected event rates the functional form of R must be known. In the structure function analysis R is taken as R_{SLAC} [3]. For the ratio analysis the assumption is that $R^p = R^n$, in which case the ratio of the single-photon exchange cross-section is equal to the structure function ratio (R is measured to be the same for protons and neutrons [3] in a subset of the kinematic range covered by our measurement).

The data used are from the 1991 data run of experiment E665 at Fermilab. A muon beam with average energy 465 GeV impinged on cryogenic liquid H_2 and D_2 targets and on an evacuated vessel. The targets were cycled into the beam with a frequency of approximately once/minute. Target cycling greatly reduces the time-dependent systematic errors in the ratio measurement. The empty target data are used to subtract on a statistical basis the contribution of the out-of-target scatters.

Events were triggered when an outgoing muon scattered at greater than 1 mrad with respect to the beam muon (the small-angle trigger – SAT). In the ratio analysis a second trigger is also used. It uses the hadronic final state event properties and it is based on the energy deposited in the calorimeter (calorimeter trigger – CAL).

A detailed description of the experimental apparatus can be found in reference [4].

F_2^p and F_2^d

The behaviour of the structure function F_2 is expected to be very different in the extreme limits of the kinematic variables. For $Q^2 \to \infty$ (Deep Inelastic Scattering – DIS limit) F_2 almost scales with x_{Bj}, and has only a logarithmic Q^2 dependence from the Quantum Chromodynamics (QCD) radiative effects. In the $Q^2 \to 0$ limit (real photoproduction) F_2 should vanish (electromagnetic current conservation), and be proportional to Q^2 in order to match the real photoproduction hadronic cross-section: $\lim_{Q^2 \to 0} F_2 = \sigma^{\gamma N} \frac{Q^2}{4\pi^2 \alpha}$. The E665 data cover the very interesting transition region between these two limits.

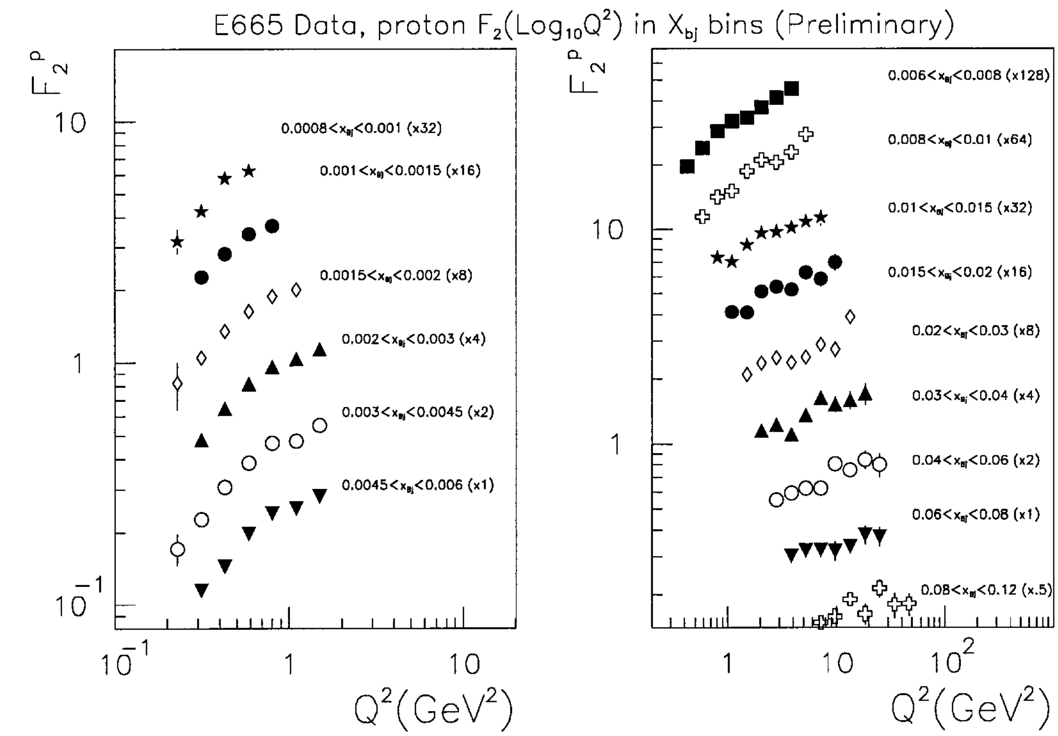

Fig. 1 F_2^p as a function of Q^2 in x_{Bj} bins. The errors shown are statistical.

In order to measure the absolute structure functions the raw event yields are corrected for the effects of reconstruction efficiency and apparatus acceptance, as well as the higher order electromagnetic effects. These effects are taken into account using an event-by-event weighting procedure. The kinematics of the event are determined from the 4–momenta of the incident and outgoing muon at the reconstructed vertex. The beam energy must be between 350 and 600 GeV, $\nu > 25$ GeV and the energy of the scattered muon must be greater than 80 GeV. The data sample consists of 664 nb^{-1} of $\mu - p$ data and 749 nb^{-1} of $\mu - d$ data, which corresponds to $\sim$ 200000 events per target.

The F$_2$ results are shown in figure 1 for the proton target, as a function of Q^2 in different x_{Bj} bins. The errors shown are statistical only. The results for the deuteron F$_2$ are similar. The size of the systematic error is of the order of $\sim 10 - 20\%$. This error is dominated by the level of knowledge of the reconstruction efficiency of the scattered muon.

The measurement covers the x_{Bj} range of $8 \times 10^{-4} < x_{Bj} < 1.2 \times 10^{-1}$ and $Q^2 > 0.2$ GeV^2/c^2. The lower x_{Bj} limit is set by the presence of the large muon-electron ($\mu - e$) elastic scattering peak centered at $x_{Bj} = m_e/m_p = 0.000545$. This background is caused by the scattering of incident muons off the atomic electrons of the targets.

The x_{Bj} values obtained are comparable with those of the HERA experiments ZEUS and H1 and extend to smaller values than previous fixed-target experiments. In Q^2 the measurement covers the scaling (Parton Model) region at higher Q^2 and approaches the non–scaling (real photoproduction) limit for the smaller Q^2 values, where the Q^2 dependence is much stronger. The results are still preliminary and the systematic errors will be reduced as the analysis progresses.

F_2^n/F_2^p

In the extraction of the ratio the assumption is that the deuteron cross-section is the exact sum of the proton and the neutron cross-sections. The following kinematic and resolution cuts are applied : $0.1 < y < 0.8$, $\nu > 40$ GeV/c, $\delta\nu/\nu < 0.3$, $Q^2 > 0.1$ GeV$^2/c^2$ (0.001 GeV$^2/c^2$ for CAL trigger). The beam energy must be between 350 and 600 GeV.

The ratio is extracted in three ways, with a different range of applicability (in x_{Bj}) of each of the methods. The first method uses the SAT data and applies radiative corrections to the ratio σ_n/σ_p for $x_{Bj} > 8 \times 10^{-4}$, in a way similar to the absolute F$_2$ measurement. This method cannot be applied in the x_{Bj} region where the $\mu - e$ elastic scattering contributes to the total measured event rate.

A second method has been developed for the SAT analysis. The electromagnetic (EM) calorimeter is used to identify events which are either $\mu - e$ elastic scatters or radiative background, and these events are then removed from the sample. The spread of the EM energy in the calorimeter, out of the scattering plane, and the energy of the largest calorimeter cluster are used in the definition of the cut.

The third method uses the CAL trigger to extend the measurement to $x_{Bj} \geq 10^{-6}$. This trigger has been designed to reject $\mu - e$ and hard target bremsstrahlung events.

The ratio σ_n/σ_p (which is equal to F_2^n/F_2^p, if $R^p = R^n$) is shown in Figure 2 for the 3 techniques, each one of them is shown where it has the smallest systematic error. The error bars shown are statistical only. In each x_{Bj} bin Q^2 is averaged. The average Q^2 values for three representative x_{Bj} bins (bin center 2×10^{-5}, 2×10^{-4} and 1.5×10^{-2}) are also shown. The ratio is compared with the results from the NMC data reanalysis (CERN-PPE/94-32). There is good agreement in the region of overlap. The

E665 measurement covers three more decades in the small x_{Bj} region compared to NMC. The total systematic error is less than 3.5%, with contributions from the relative normalization, the trigger acceptance differences and the effects of the various EM background rejection cuts. The investigation of the systematic uncertainties includes the use of monitoring triggers and Monte Carlo studies.

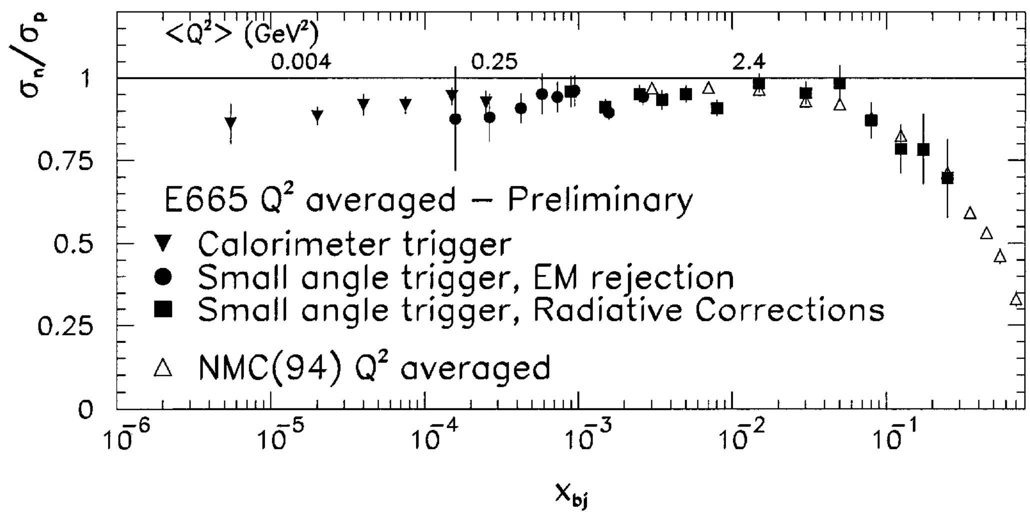

Fig. 2 σ_n/σ_p as a function of x_{Bj} . Also shown are results from the CERN NMC experiment (CERN-PPE/94-32).

The average value of the ratio is ~ 0.94 for $x_{Bj} < 0.05$. This may be indicative of the presence of shadowing in the deuteron [5] (assuming the Regge limit behaviour $F_2^n - F_2^p \rightarrow 0$, as $x_{Bj} \rightarrow 0$) Confirmation of shadowing in the deuteron is of great importance since the neutron contribution from all experiments that use deuteron targets has to take into account this effect. Taking shadowing into account can reduce the Gottfried sum rule value [6] by 10-15% [5]. An alternative interpretation, ignoring the possibility of shadowing, is that at low x_{Bj} there is a difference in the F_2 of protons as compared to neutrons. In this case, extrapolating to the Q^2 value of 4 GeV^2/c^2 where the Gottfried sum is evaluated [6], the sum will increase by ~ 0.05 per decade in x_{Bj}.

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