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A Measurement of $R = \sigma_L/\sigma_T$ in Deep Inelastic Neutrino-Nucleon Scattering at the Tevatron

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Abstract. Measurements of neutrino-nucleon and antineutrino-nucleon differential cross sections using the CCFR neutrino detector at Fermilab have been used to extract preliminary values of $R = \sigma_L/\sigma_T$ in the kinematic region $0.01 < x < 0.6$, and $4 < Q^2 < 300$ GeV^2. The new data provide the first measurements of R in the $x < 0.1$ region. The x and Q^2 dependence of R is compared with a QCD based fit to previous data. The QCD fit, which provides an estimate of R in small x region where R has not been previously measured, is in good agreement with the new CCFR data. *(To be published in Jou. Phys. G)*

1. Introduction

The ratio $R = \sigma_L/\sigma_T$ of the longitudinal and transverse absorption cross sections in deep inelastic lepton-nucleon scattering provides information about the transverse momentum and spin of the nucleon constituents. Within the theory of quantum chromodynamics (QCD), the nucleon constituents are spin 1/2 quarks and spin 1 gluons. In leading order QCD, $R = 0$, since the quarks have no transverse momentum. In the next to leading order formalism (NLO), to first order in α_s, R is non-zero because of transverse momentum associated with gluon emission [1]. The NLO QCD prediction is given by an integral over the quark and gluon distribution and is proportional to α_s. A measurement of R is a test of perturbative QCD at large x, and a clean probe of the gluon density at small x where the quark contribution is small.

Poor knowledge of R , especially at small x, results in uncertainties in the structure functions extracted from deep inelastic scattering cross sections. The most precise previous measurements of R are from SLAC electron scattering experiments [2], and are at high x and low Q^2, where non-perturbative contributions (e.g. target mass and higher twist effect) are important. Therefore, extraction of structure functions at large Q^2 or small x must rely on good measurements of R, or on reasonable estimates of R in the kinematic region where R has not been measured.

We report here on a new extraction of R from measurements of neutrino and antineutrino differential cross sections in the CCFR neutrino detector. We compare the data (particularly at small x) to the prediction of a QCD based fit to R by Bodek, Rock and Yang [3]. Extrapolation of such a QCD based fit to smaller values of x can be also used to obtain estimates of R in the HERA region where R has not been measured.

2. R calculation within QCD

In this section we provide a brief description of the QCD based model of Bodek, Rock and Yang (BRY). They have used a calculation [4] of the QCD contribution to R to order α_s^2 (NNLO). The contribution of massive heavy quark (charm) effects to R has been included within the photon gluon fusion process [5]. These higher order QCD corrections and heavy charm quark effects are important at small x. In addition, the SLAC data on R indicate that there are additional non-perturbative $1/Q^2$ and $1/Q^4$ contributions at low Q^2 [2, 3]. One of these contributions, target mass effects, dominates at low Q^2 and large x. A comparison of the calculation (including both the heavy charm contribution to order α_s^2 and the Georgi-Politzer target mass corrections [6]) to the SLAC data indicates that additional small higher twist contribution at low Q^2 are required [3]. A parameterization of the higher twist effects at low Q^2 should be constrained such that R approaches zero at the photoproduction limit ($Q^2 = 0$). BRY find that a simple empirical parameterization of the higher twist contribution to R (of the form $A[(Q^2 - B)/(Q^4 + C)]$) fits the SLAC data very well. The best BRY fit to the all previous data [2, 7] (for $Q^2 > 0.4$ GeV^2), using the GRV94 [8] parton distribution for the QCD contribution, yields $A = 0.37$, $B = 0.82$, and $C = 0.54$ (χ^2/dof is 21.7/19).

Figure 1 shows some of the previous data and the model predictions calculated using various parton distributions. All curves include QCD to order α_s^2, the Georgi-Politzer target mass correction and the empirical small higher twist contribution. The curves labeled with (h) also include the effects of the charm quark mass. Also shown for comparison are the extrapolation of a previous empirical fit (Rworld) for R used by the SLAC, CCFR, and NMC collaborations. The QCD model predictions with various parton distributions [8, 9] all yield similar results for R at large x (> 0.1). At small x, the predictions of the model using either the MRSD$'_-$ and the MRSA distributions are very different because of the different gluon distributions. Note that target mass effects at small x are negligible, and the small empirical higher twist contribution is assumed to be independent of x. The model calculated with the GRV94 parton distributions (solid curve, figure 1) is probably the best available estimate for extracting F_2 in regions where R has not been measured. We proceed to test the models shown in figure 1 against the new CCFR data in the section below.

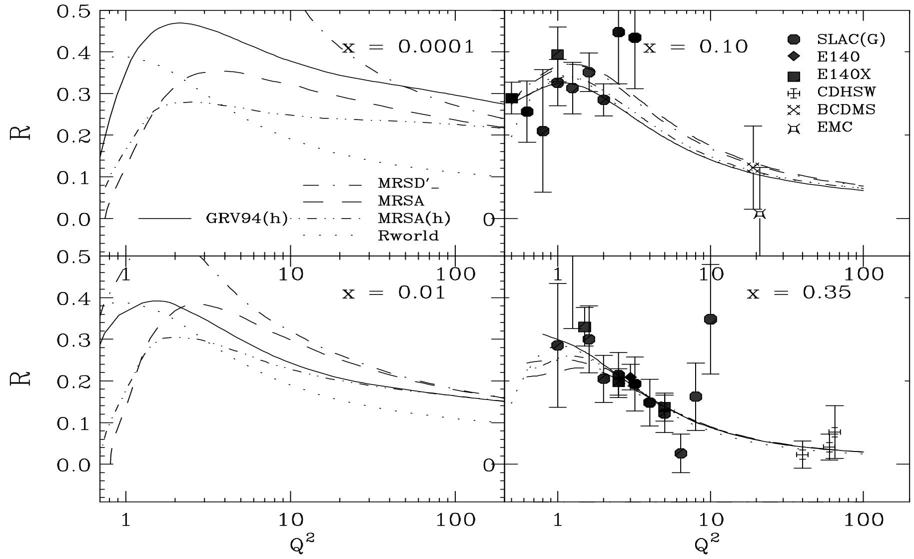

Figure 1. R at fixed x vs Q^2: A comparison of the BRY prediction of R calculated using various parton distributions (including target mass and empirical higher twist) to data. A massive heavy (charm) quark contribution is included in the MRSA(h) and GRV94(h) prediction. Also shown is Rworld, which is a previous empirical parameterization of R data in the SLAC region.

3. A Preliminary CCFR measurement of R

The data sample includes two CCFR data runs (E744 and E770) collected using the Fermilab Tevatron Quad-Triplet neutrino beam. The wide-band beam is composed of

ν_μ and $\overline{\nu}_\mu$ with energies up to 600 GeV. The CCFR neutrino detector [10] consists of an unmagnetized steel-scintillator target calorimeter instrumented with drift chambers. The hadron energy resolution is $\Delta E/E = 0.85/\sqrt{E}(\mathrm{GeV})$. The target is followed by a solid iron toroidal magnet muon spectrometer which measures muon momentum with a resolution $\Delta p/p = 0.11$. The relative flux at different energies is obtained from the events with low hadron energy, $\nu < 20$ GeV, and is normalized so that the neutrino total cross section equals the world average $\sigma^{\nu N}/E = (0.674 \pm 0.014) \times 10^{-38}$ cm^2/GeV, and $\sigma^{\overline{\nu}N}/\sigma^{\nu N} = 0.504 \pm 0.005$.

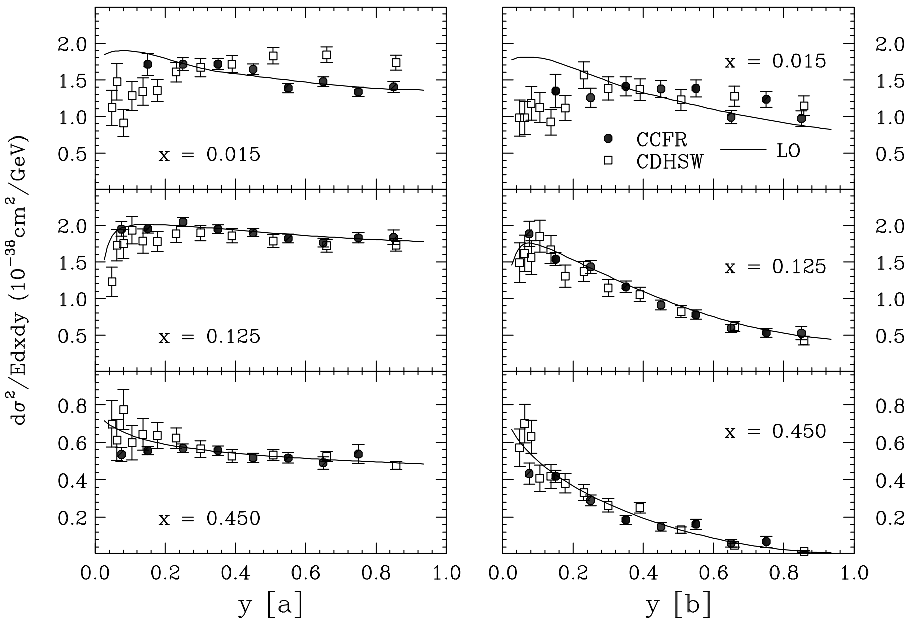

Figure 2. Preliminary differential cross section (statistical error only) for neutrino[a] and antineutrino[b] at $E_\nu = 150$ GeV: Preliminary CCFR data (solid circles) are compared to the QCD LO prediction and previous CDHSW data (open squares).

Preliminary values of R have been extracted from the differential cross sections in neutrino charged current scattering. The differential cross sections are written as

$$\frac{d^2\sigma}{Edxdy} = \frac{G_F^2 M}{\pi}\left[F_2(x,Q^2)\left(1-y+\frac{y^2}{2(1+R)}\right) \pm xF_3(x,Q^2)\left(y-\frac{y^2}{2}\right)\right] \quad (1)$$

where $y = \nu/E_\nu$ is the inelasticity, and $R = \sigma_L/\sigma_T = F_2(1+Q^2/\nu^2)/2xF_1 - 1$. In the quark-parton model, $2xF_1^{\nu,\overline{\nu}} = q + \overline{q}$ and $xF_3^{\nu,\overline{\nu}} = (q-\overline{q}) \pm 2(s-c)$ on an isoscalar target.

The data sample consists of 1,280,000 ν_μ and 270,000 $\overline{\nu}_\mu$ events after fiducial and kinematic cuts ($P_\mu > 15$ GeV, $\theta_\mu < .150$, $\nu > 10$ GeV, $Q^2 > 1$ GeV^2, and $E_\nu > 30$ GeV). Dimuon events are removed because of the ambiguous identification of the leading muon for high y events. The data are corrected by Monte Carlo for cuts, acceptance and resolution smearing. The differential cross sections are determined in bins of x,

y and E_ν ($0.01 < x < 0.60$, $0.05 < y < 0.95$, and $30 < E_\nu < 360$ GeV). Figure 2 shows the differential cross sections at $E_\nu = 150$ GeV. The differential cross sections agree with a LO QCD model which predicts a quadratic y dependence at small x for neutrino and anti-neutrino and a flat y distribution at high x for the neutrino cross section. A comparison of CCFR and CDHSW differential cross sections [7] indicates good agreement at high x, and poor agreement at small x, as shown in Figure 2.

The values of R are extracted from linear fits to F vs ϵ at fixed x and Q^2 bins through the following relation,

$$F(x, Q^2, \epsilon) = \frac{\pi(1-\epsilon)}{y^2 G_F^2 ME}\left[\frac{d^2\sigma^\nu}{dxdy} + \frac{d^2\sigma^{\overline{\nu}}}{dxdy}\right] = 2xF_1(x, Q^2)\left[1 + \epsilon R(x, Q^2)\right] \quad (2)$$

which assumes $xF_3^\nu = xF_3^{\overline{\nu}}$. Here $\epsilon \simeq 2(1-y)/(1+(1-y)^2)$ is the polarization of virtual W boson. Corrections for electroweak radiative effects (Bardin), the W boson propagator, and isoscaler target (the 6.85% excess of neutron over proton in iron) are applied. The correction for $\Delta xF_3 = xF_3^\nu - xF_3^{\overline{\nu}}$ (which is important at small x) requires a knowledge of the strange sea and charm production mass effects (e.g. slow rescaling). The strange sea distribution, extracted to NLO from CCFR dimuon data [11] has been used. The fits for R at each x and Q^2 have reasonable χ^2. Figure 3 shows one of the linear fits. The values of R with statistical errors at fixed x vs Q^2 are shown in Figure 4. The new data, which extends a decade lower in x, are in agreement with the QCD based model. The values of R are not sensitive to the normalization of the absolute flux. The dominant uncertainty at very small x and low Q^2 is from the non-zero value of ΔxF_3 because of uncertainties in the slow rescaling formalism and the level of the strange sea. Therefore, the values of R in the kinematic region $x < 0.1$ and $Q^2 < 4$ GeV^2 are not shown at present.

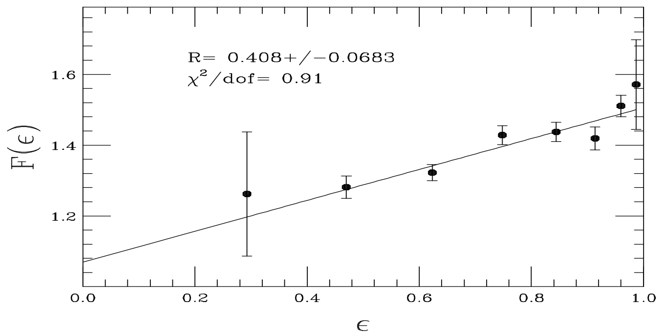

Figure 3. F(x,Q^2,ϵ) vs ϵ fit at $x = 0.045$ and $Q^2 = 5.01$ GeV^2: The errors on F are only statistical errors.

Better modelling of ΔxF_3 at low Q^2 and small x, and more precise data from the 1996-97 run of NuTeV (FNAL E815) experiment with sign selected neutrino beams are expected to yield better determinations of R at small x.

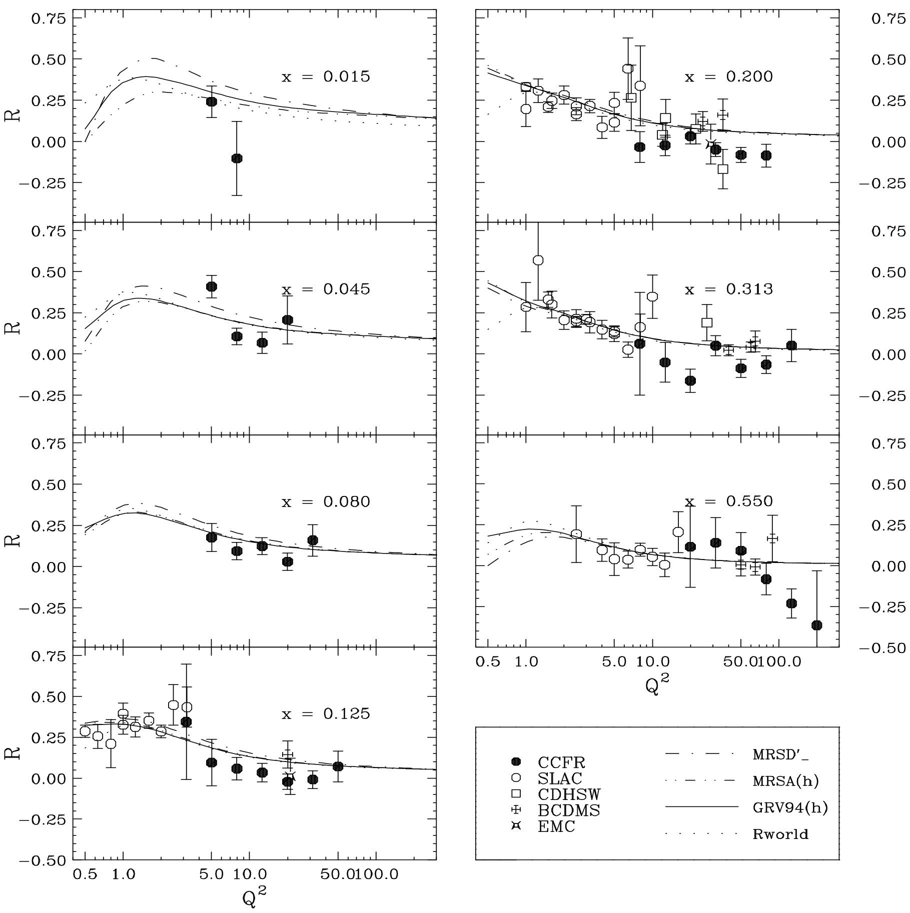

Figure 4. R at fixed x vs Q^2: Preliminary CCFR data are compared with other data and with the Bodek, Rock and Yang QCD based fit with various parton distributions.

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