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and $|V_{cs}|$ in the CCFR Experiment**

U.K. Yang et. al

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

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MEASUREMENTS OF THE LONGITUDINAL STRUCTURE FUNCTION
 AND $|V_{cs}|$ IN THE CCFR EXPERIMENT *

U. K. Yang^f, C. McNulty^b, C. G. Arroyo^b, L. de Barbaro^e, P. de Barbaro^f, A. O. Bazarko^b,
 R. H. Bernstein^c, A. Bodek^f, T. Bolton^d, H. Budd^f, J. Conrad^b, D. A. Harris^f, R. A. Johnson^a,
 J. H. Kim^b, B. J. King^b, T. Kinnel^g, M. J. Lamm^c, W. C. Lefmann^b, W. Marsh^c, K. S. McFarland^c,
 S. R. Mishra^b, D. Naples^d, P. Z. Quintas^b, A. Romosan^b, W. K. Sakumoto^f, H. Schellman^e,
 F. J. Sciulli^b, W. G. Seligman^b, M. H. Shaevitz^b, W. H. Smith^g, P. Spentzouris^b, E. G. Stern^b,

M. Vakili^a, J. Yu^c

^a University of Cincinnati, ^b Columbia University,

^c Fermi National Accelerator Laboratory, ^d Kansas State University,

^e Northwestern University, ^f University of Rochester,

^g University of Wisconsin

Measurements of charged current neutrino and anti-neutrino nucleon interactions in the CCFR detector are used to extract the structure functions, F_2 , xF_3^ν , $xF_3^{\bar{\nu}}$ and R (longitudinal) in the kinematic region $0.01 < x < 0.6$ and $1 < Q^2 < 300 \text{ GeV}^2$. The new measurements of R in the $x < 0.1$ region provide a constraint on the level of the gluon distribution. The x and Q^2 dependence of R is compared with a QCD based fit to previous data. The CKM matrix element $|V_{cs}|$ is extracted from a combined analysis of xF_3 and dimuon data.

1 Introduction

Neutrino-nucleon scattering data is unique in probing the valence quark, sea quark, and gluon content of the nucleon through measurements of four different structure functions (F_2 , xF_3^ν , $xF_3^{\bar{\nu}}$ and R). In charged current ν -nucleon interaction, the differential cross section can be written as follows:

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{Edxdy} \propto \left[F_2^{\nu(\bar{\nu})}(x, Q^2) \left(1 - y + \frac{y^2}{2(1+R)} \right) \pm xF_3^{\nu(\bar{\nu})}(x, Q^2) \left(y - \frac{y^2}{2} \right) \right]$$

where x is the Bjorken scaling variable, Q^2 is the square of the four momentum transfer, and y is the fractional lepton energy loss. Within the quark-parton model (in leading order), $F_2^{\nu,\bar{\nu}} = x \sum(q + \bar{q})$ and $xF_3^{\nu,\bar{\nu}} = x \sum(q - \bar{q})_{-2x(s-c)}^{+2x(s-c)}$. Thus, the measurements of F_2 and xF_3 provide information on the valence and sea quarks. The size of the strange sea at low x can be obtained from the difference in xF_3^ν and $xF_3^{\bar{\nu}}$. The ratio R of the longitudinal and transverse structure functions provides information about the transverse momentum of the nucleon constituents. In leading order, $R = 0$, since the quarks have no transverse momentum. In the next to leading order formalism (NLO), R is non-zero because of transverse momentum associated with gluon emission¹. The NLO QCD prediction is given by an integral over the

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quark and gluon distribution and is proportional to α_s . Thus, a measurement of R provides a test of perturbative QCD at large x , and probes the gluon density at small x where the quark contribution is small. However, previous measurements of R have not been performed over wide kinematic regions except in the high x and low Q^2 regions where non-perturbative contributions are significant. A good measurement of R requires high statistics data at different beam energies (or y) for each x and Q^2 bin. Poor knowledge of R , especially at small x , leads to uncertainties in the extracted values of the structure function, F_2 . Therefore, measurements of R both at large Q^2 and at small x are needed. The CCFR experiment has a unique capability to measure R in these kinematic regions by using a high-intensity high energy wide-band neutrino beam and the massive CCFR neutrino detector.

We report here on new extractions of R and the magnitude of strange sea using a sample of neutrino and antineutrino interactions in the CCFR detector. An extraction of the CKM matrix element $|V_{cs}|$ is achieved by combining the strange sea measurement with our previous dimuon results².

2 A Preliminary CCFR measurement of R and $|V_{cs}|$

The event sample combines data from two runs (E744 and E770) collected using the Fermilab Tevatron Quad-Triplet neutrino beam. The wide-band beam is composed of ν_μ and $\bar{\nu}_\mu$ with energies up to 600 GeV. The CCFR neutrino detector³ consists of non-magnetic steel-scintillator target calorimeter instrumented with drift chambers. The hadron energy resolution is $\Delta E/E = 0.85/\sqrt{E}(\text{GeV})$. The target is followed by a solid iron toroid muon spectrometer which measures muon momenta with a resolution $\Delta p/p = 0.11$. The three independent kinematic variables x , Q^2 , and y are reconstructed from measurements of the hadronic energy (E_h), muon momentum (P_μ), and muon angle (θ_μ). The relative flux⁴ at different energies is obtained from the events with low hadron energy, $E_h < 20$ GeV, and is normalized to the average value of the world's neutrino total cross section measurements, $\sigma^{\nu N}/E = (0.677 \pm 0.014) \times 10^{-38}$ cm²/GeV, and $\sigma^{\bar{\nu} N}/\sigma^{\nu N} = 0.499 \pm 0.005$ ⁴. The total data sample used in structure function extraction consists of 1,280,000 ν_μ and 270,000 $\bar{\nu}_\mu$ events (after fiducial and kinematic cuts $P_\mu > 15$ GeV, $\theta_\mu < .150$, $E_h > 10$ GeV, $Q^2 > 1$ GeV², and $30 < E_\nu < 360$ GeV). Dimuon events are removed and used in an separate analysis leading to another determination of the strange sea².

The structure functions (SF's) are extracted by minimizing a χ^2 in the comparison of the y distribution for data and Monte Carlo (MC) events. In order to extract the SF's as a function of x and Q^2 , a χ^2 analysis is formed in each (x, Q^2) bin:

$$\chi^2(x, Q^2) = \sum_{20 \text{ } y\text{-bins}}^{\nu} \frac{[N_{data}^{\nu} - N_{MC}^{\nu}(SF)]^2}{\sigma_{data}^2 + \sigma_{MC}^2} + \sum_{20 \text{ } y\text{-bins}}^{\bar{\nu}} \frac{[N_{data}^{\bar{\nu}} - N_{MC}^{\bar{\nu}}(SF)]^2}{\sigma_{data}^2 + \sigma_{MC}^2}$$

The effects of detector acceptance and resolution smearing are implemented in the generation of the MC events (N_{MC}). The analysis incorporates bin centering, normalization, and various corrections (e.g. QED and electroweak radiative corrections, the W boson propagator, the non-isoscalar nature of the iron target, and the effects of the charm quark mass using the slow rescaling formalism).

We obtain the values of R and ΔxF_3 ($= xF_3^{\nu} - xF_3^{\bar{\nu}}$) as well as F_2 and xF_3^{avg} ($= (xF_3^{\nu} + xF_3^{\bar{\nu}})/2$) using the above global fits (after few iterations, because a priori knowledge of the SF values is required to generate the MC events). The sensitivity to the R and ΔxF_3 at each (x, Q^2) bin comes from the y dependence, especially at high y . The values of F_2 and xF_3^{avg} at

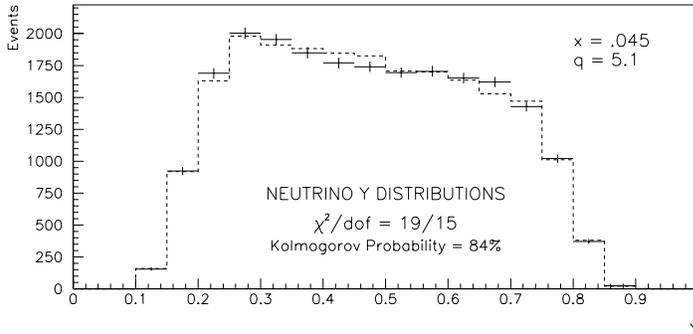


Figure 1: The y -distribution for the $x = .045$, $Q^2 = 5.1$ GeV² bin. The histogram is the data and the points are the MC predictions using the best fit structure functions from the 3-parameter fit in that (x, Q^2) bin.

each x and Q^2 bin are extracted by averaging over all the y bins. In this analysis the extracted values of R are highly correlated with the values ΔxF_3 at low x . However, since the dimuon results² provides an independent determination of the size of the strange sea (s), it is used to constrain the ΔxF_3 in the overall fit. We use $\Delta xF_3 = x \int_x^1 C_3(\frac{x}{y}, Q^2) 4[s(y, Q^2) - c(y, Q^2)] dy$, where C_3 is the hard scattering coefficient. Here, the strange sea (s) from our dimuon data, and the charm sea (c) from the CTEQ2M⁵ parametrization (c is an order of magnitude smaller than s in our kinematic region). These estimated values of ΔxF_3 are used as input in the extraction of R , F_2 , and xF_3^{avg} (3-parameter fit). To obtain a measurement of the strange sea which is independent of the dimuon data, a 4-parameter fit is performed in which the relative size of strange sea, $\kappa (\equiv \frac{2s}{u_s+d_s})$ is allowed to vary. Systematic errors are determined for each of the fit parameters by repeating the fits and varying the experimental and model parameters within their respective uncertainties. The following systematic uncertainties are investigated: the muon and hadron energy scale uncertainty (1%), the uncertainties in the flux extraction, normalization (here only F_2 and xF_3^{avg} are affected), and physics model parameters (e.g. strange sea, and charm sea).

A typical 3-parameter fit to the y distribution in one of the (x, Q^2) bins is shown in Fig. 1. The extracted values of R at fixed x vs Q^2 (from 3-parameter fit) are shown on Fig. 2. The new data provide the first Q^2 dependent measurements at $x < 0.05$. The NMC data⁶ shown in Fig. 2 are integrated over Q^2 , and plotted on the nearest x bin. At higher x , our new measurements are in good agreement with the other existing data (SLAC⁷, EMC⁸, BCDMS⁹, NMC, and CDHSW¹⁰), and with predictions¹¹ of the Bodek, Rock and Yang calculated using various PDF's¹² (the predictions come from a QCD based model which includes NNLO terms, heavy quark effects, target mass corrections, and a phenomenologically determined higher twist contribution). The extracted values of F_2 and xF_3^{avg} from the 3-parameter fit are in good agreement with previous CCFR measurements⁴ using these data.

The extracted values of κ from the 4-parameter fit are shown in Fig. 3 as a function of x . The values of κ do not show any dependence on x . The overall average value of $\kappa = 0.453 \pm 0.106^{+0.028}_{-0.096}$ is in good agreement with the dimuon result ($\kappa = 0.477 \pm 0.055$), indicating that the QCD effects of strange sea in both inclusive and dimuon cross section are consistent, thus the 3-parameter fit provide a reliable extraction of R . This measurement of κ can be combined with our independent result² of $\frac{\kappa}{\kappa+2} |V_{cs}|^2 = 0.200 \pm .015$ derived from the dimuon analysis to obtain the CKM matrix element $|V_{cs}|$. The resulting value of $|V_{cs}|$ is $1.05 \pm 0.10^{+0.07}_{-0.11}$.

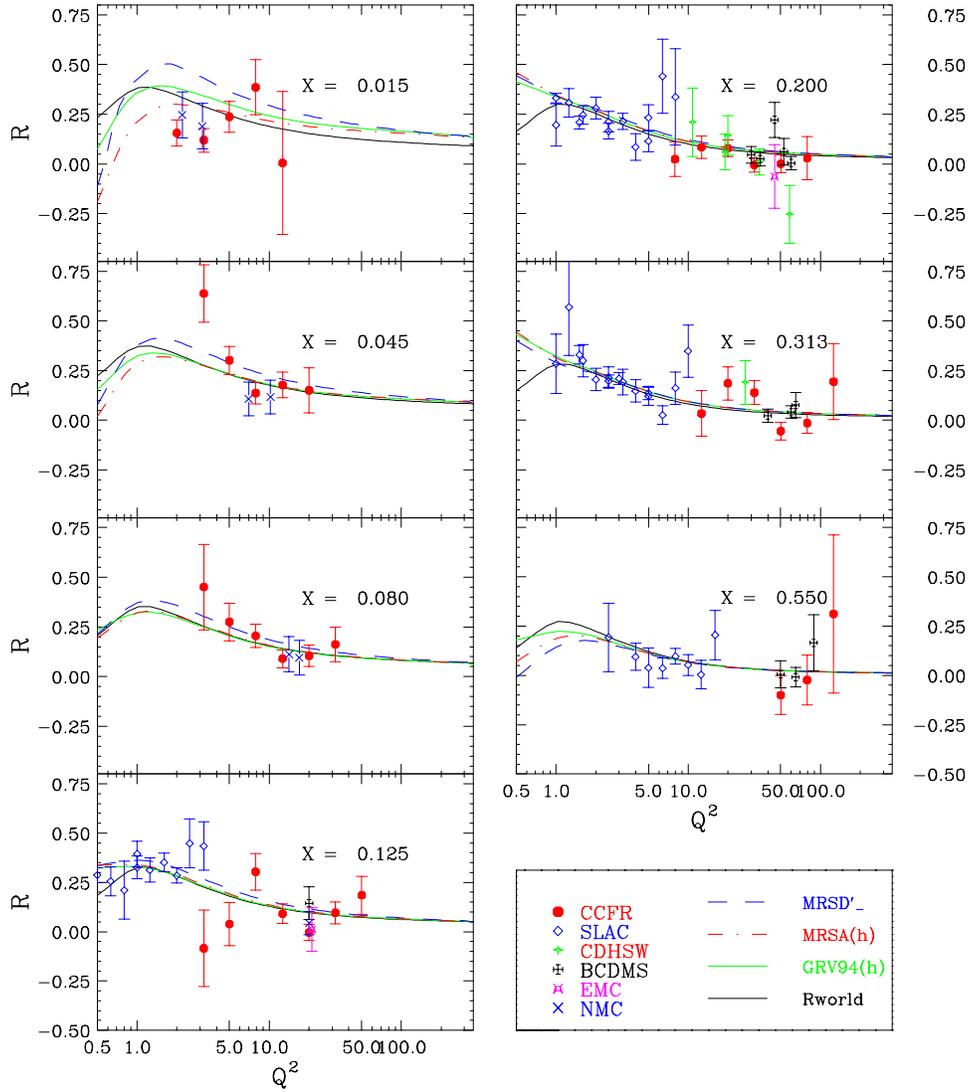


Figure 2: Measurements of R at fixed x vs Q^2 : The preliminary CCFR data are compared with other measurements and with a calculations from a QCD based model (Bodek, Rock and Yang) using various parton distribution functions. The empirical Whitlow parameterization (Rworld) is also shown as a solid curve.

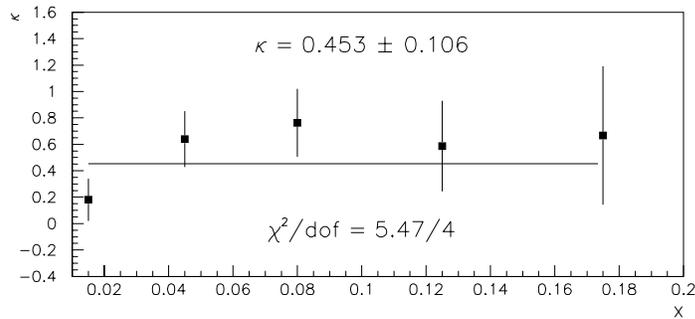


Figure 3: Values of κ extracted from 4 parameter fit. Here $\kappa(x)$ is assumed to be constant over the Q^2 range in each x bin. The solid line shows the average value of $\kappa = 0.453 \pm 0.106_{-0.096}^{+0.028}$.

This determination is relatively free of theoretical assumptions. There is good agreement with the value of $|V_{cs}|_D = 1.01 \pm 0.18$ ¹³ extracted from the D_{e3} decay rate (that value relies on theoretical assumptions about the D form factor at $Q^2 = 0$).

In summary, the new CCFR measurements of R extend to lower x and higher Q^2 than previous results. The extracted value of κ is in good agreement with the value previously measured using the dimuon data sample, and yields the most precise experimental determination of $|V_{cs}|$. New data from our recent NuTeV run (96-97), taken with a sign selected neutrino beam, are expected to yield more precise determination of R and k at low x .

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