A MEASUREMENT OF THE RATIO OF LONGITUDINAL AND TRANSVERSE
STRUCTURE FUNCTIONS IN NEUTRINO INTERACTIONS BETWEEN 30 AND 200 GeV

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ABSTRACT

A new measurement of the ratio $R = \sigma_L / \sigma_T$ of longitudinal and transverse structure functions in neutrino interactions on iron between 30 and 190 GeV neutrino energy is reported. The result is given as a function of the scale parameter x and the inelasticity ν of the interaction. The average value is $R = 0.10 \pm 0.07$ around $\nu \approx 50$ GeV and is in accordance with a prediction from the QCD theory.

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In the last few years inclusive lepton scattering data have provided important tests of quark interaction theories through the analysis of scaling violations observed in deep inelastic structure functions [1-3]. The Quantum Chromodynamics (QCD) theory [4] of the strong interaction between coloured quarks and gluons can account for the observed deviations from scaling in a wide range of the four-momentum transfer Q^2 to the hadronic final state, as for example, in the reaction considered here

$$\nu + \text{nucleon} \rightarrow \mu + \text{hadrons} . \quad (1)$$

The inclusive cross-section for this reaction can be parametrized in terms of three structure functions [5], F_1 , F_2 , and F_3 . The structure function $F_2(x, Q^2)$ is most precisely determined experimentally. A comparison of F_2 with QCD, however, relies on the variation of F_2 with Q^2 , which is not as well determined as F_2 itself. In the simple quark-parton model the transverse momentum of the quarks is assumed to be small [6] and the contribution to F_2 due to the cross-section of longitudinally polarized intermediate vector bosons is expected to be negligible [7]. In QCD a transverse motion of the quarks is induced by gluon emission and quark-antiquark pair generation. The resultant transverse quark momentum is proportional to the value of the strong coupling constant $\alpha_s(Q^2)$ in the lowest order QCD [8,9]. Correspondingly, a non-zero value of the longitudinal structure function $F_L = F_2(1 + Q^2/\nu^2) - 2xF_1$ is expected. A measurement of F_L or the ratio $R = \sigma_L/\sigma_T$ of the longitudinal and transverse cross-sections allows, therefore, an independent test of QCD.

In this letter we report a new determination of $R = \sigma_L/\sigma_T = F_L/2xF_1$ in charged-current neutrino interactions on an iron target. Comparable results for R on the basis of charged-lepton interactions on hydrogen at moderate values of Q^2 have been published [2,10]. Previous results from neutrino interactions were obtained invoking either Bjorken scaling [11-13] or a definite prescription of scaling violations [1,3] which was not tested independently [14]. The present analysis is free from the uncertainties implied, in particular, by the assumptions about deviations from scaling.

The study is based on new 200 GeV narrow-band neutrino beam data obtained during 1978 and 1979 at the CERN Super Proton Synchrotron (SPS). Beam and detector correspond, in principle, to the apparatus described previously [15], with minor modifications. The new data comprise 65,000 ν and 23,000 $\bar{\nu}$ events in the fiducial region (600 t) of the detector. The data selection follows closely the method employed in previous charged-current work [3]. We note, in particular, the cuts in muon momentum ($p_\mu > 7$ GeV) and total visible energy ($30 \text{ GeV} < E_\nu < 190 \text{ GeV}$) applied to obtain a good reconstruction efficiency for the muon track, and a well-defined neutrino energy spectrum. The event sample is characterized by the following average kinematic quantities:

$$\langle Q^2 \rangle \approx 20 \text{ GeV}^2/c^2, \quad \langle \nu \rangle \approx 50 \text{ GeV}, \quad \langle x \rangle \approx 0.20.$$

The differential cross-section for inclusive neutrino interactions can be expressed as [5]

$$\frac{d\sigma^{\nu, \bar{\nu}}}{dx dy} = \frac{G^2 M E_\nu}{2\pi} \left\{ F_2^{\nu, \bar{\nu}} [1 + (1 - y)^2 - R' y^2] \pm (2y - y^2) x F_3^{\nu, \bar{\nu}} \right\}, \quad (2)$$

where the upper and lower signs refer to the cross-section of neutrinos and antineutrinos, respectively. Here $x = Q^2/2M\nu$ and $y = \nu/E_\nu$ are the usual scaling variables, and $R' = 1 - 2xF_1/F_2 + 1/2 Q^2/\nu^2$. The parameter R' is related to R , as defined above by $R \approx R'/(1 - R') + 1/2 Q^2/\nu^2$. On isoscalar targets and in the quark-parton model, $2xF_1^{\nu, \bar{\nu}} = q + \bar{q}$ and $xF_3^{\nu, \bar{\nu}} = (q - \bar{q}) \pm 2(s - c)$ can be expressed in terms of the quark and antiquark densities $q(x, Q^2)$ and $\bar{q}(x, Q^2)$ and the difference $s(x, Q^2) - c(x, Q^2)$ between the strange and the charmed quark content of the nucleon. The dominant contribution $q - \bar{q}$ to the xF_3 term in eq. (2) is removed by summing neutrino and antineutrino cross-sections, and dropping the ν and $\bar{\nu}$ superscripts for the average structure functions. Including a correction for non-isoscalar targets ($\delta = 0.023$ for iron) we then obtain

$$\frac{d\sigma^\nu}{dx dy} + \frac{d\sigma^{\bar{\nu}}}{dx dy} = \frac{G^2 M E_\nu}{\pi} \left\{ F_2 [1 + (1 - y)^2 - R' y^2] + [\delta(q - \bar{q}) + 2(s - c)] (2y - y^2) \right\}. \quad (3)$$

The determination of R proceeds as follows. The data are binned in x , y , and ν . The relative normalization of neutrino and antineutrino data is obtained assuming charge symmetry $F_2^\nu = F_2^{\bar{\nu}}$. To this end the neutrino and antineutrino cross-sections $d\sigma/dy$ are adjusted to the same value at $y = 0$ by a single parameter for the relative scale. A Monte Carlo simulation of the detector response is used to calculate the effects due to acceptance and resolution on constant, linear, and quadratic terms in the y -dependence of the cross-section according to eq. (3). It is then, in principle, possible to obtain a value of R in every (x, ν) bin from a fit to the observed y -distribution. The present statistics, however, are not sufficient to give a meaningful result in a large number of bins. As a first step we determine, therefore, the ν -dependence of R after summing the data in x . For illustration, the summed y -distributions $d\sigma^\nu/dy + d\sigma^{\bar{\nu}}/dy$ in different ν bins are shown in fig. 1, together with the best fits of R' in each bin. The resulting R values are displayed in fig. 2. At small and large ν , the y -distributions are limited by kinematics, leading to large statistical and systematic errors. Therefore, only the results in the region $10 \text{ GeV} < \nu < 170 \text{ GeV}$ are retained.

As a second step we determine the x -dependence of R , performing fits to the y -distributions in (x, ν) bins assuming a Q^2 independent value of R' for every x bin. Note that here the average value of Q^2 changes with x . The result of these fits is displayed in fig. 3. As R does not seem to depend strongly on either x or Q^2 , an average value of $\langle R \rangle = \int F_L(x) dx / \int 2xF_1(x) dx$ around $\langle \nu \rangle \approx 50 \text{ GeV}$ can be obtained by averaging the results in ν bins, giving $\langle R \rangle = 0.10 \pm 0.025 \pm 0.06$ where statistical and systematic errors are given separately. Excluding the domain where systematic errors dominate, we obtain $\langle R \rangle = 0.13 \pm 0.035 \pm 0.04$ in the range $45 \text{ GeV} < \nu < 80 \text{ GeV}$.

A careful analysis of systematic errors has been made. The present result is sensitive to radiative corrections and to the amount of strange sea in the nucleon. The electromagnetic radiative corrections [16] have been applied using the method of de Rújula et al. The effect on R is an increase of 0.03 on an

average. For the strange sea we assume $(s - c) = 0.12 \bar{q}(x)$, consistent with the cross-section for charm production observed in opposite-sign dimuon events [17]. A change to $(s - c) = 0.20 \bar{q}(x)$, corresponding to half SU(3) symmetric sea, would increase R by 0.02. The present uncertainty in the amount of strange sea is not included in the systematic error of R. Other systematic errors have been evaluated by a change of individual parameters entering into the analysis, and adding in quadrature the effects due to different sources of systematic errors. Among these the most important are the uncertainties due to beam composition, i.e. the relative amount of pions and kaons in the positive and negative beams, the error in the muon and hadron energy calibrations and the non-linearity of the hadron energy measurement.

These results can be compared with measurements of R using inelastic charged-lepton scattering at smaller values of Q^2 : $R = 0.21 \pm 0.10$ at $Q^2 \approx 10 \text{ GeV}^2/c^2$ as measured at SLAC in ep scattering [10] and $R = 0.52 \pm 0.35$ at $Q^2 \approx 2 \text{ GeV}^2/c^2$ as measured in μp scattering at FNAL [2]. A QCD prediction following Altarelli and Martinelli [9] with the inclusion of target mass effects [18] is shown in figs. 2 and 3. This particular calculation is based on the observed shape of $F_2(x, Q^2)$ and $\Lambda = 0.5 \text{ GeV}$ and a gluon x-distribution proportional to $(1 - x)^5$ at $Q^2 = 20 \text{ GeV}^2/c^2$ consistent with previous QCD fits to neutrino data in the same kinematic region [3]. The agreement with the data is reasonable, although perhaps not overwhelming. It has been suggested that certain non-perturbative effects (higher twist) might contribute substantially to R [19]. Considering the sizes of the statistical and systematic uncertainties, we feel that a more quantitative comparison is not justified at the moment.

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Figure captions

- Fig. 1 : The summed cross-section $d\sigma^V/dy + d\sigma^{\bar{V}}/dy$ (in units of $G^2 M E_V/\pi$) for different values of ν . The continuous lines correspond to the best fit according to eq. (3), the dashed lines to $R' = 0$.
- Fig. 2 : The value of R averaged over x as a function of energy transfer ν . The error bars on the data points include statistical and systematic errors, the inner error bars giving the contribution due to statistics. A QCD prediction for $\Lambda = 0.5$ GeV is indicated by the line.
- Fig. 3 : The value of R averaged over ν as a function of the scale variable x . The curve shows a QCD prediction for a gluon distribution $\sim (1-x)^5$ and $\Lambda = 0.5$ GeV.

Fig. 1

Fig. 2

Fig. 3