NuTeV Structure Function Measurement

M. Tzanov for the NuTeV Collaboration

University of Pittsburgh, Pittsburgh, PA 15260

Abstract. The NuTeV experiment obtained high statistics samples of neutrino and antineutrino charged current events during the 1996-1997 Fermilab fixed target run. The experiment combines sign-selected neutrino and antineutrino beams and the upgraded CCFR iron-scintillator neutrino detector. A precision continuous calibration beam was used to determine the muon and hadron energy scales to a precision of 0.7% and 0.43% respectively. The structure functions $F_2(x,Q^2)$ and $xF_3(x,Q^2)$ obtained by fitting the y-dependence of the sum and the difference of the ν and $\overline{\nu}$ differential cross sections are presented.

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Neutrino deep inelastic scattering (DIS) provides a unique information for the structure of the proton and QCD, allowing the measurement of two structure functions (SF): $F_2(x,Q^2)$, and the parity-violating $xF_3(x,Q^2)$,which is accessible only by neutrino DIS [1]. The NuTeV experiment is a high-energy fixed target $\nu - Fe$ scattering experiment, which combines two new features: Separate high-purity neutrino and antineutrino beams, used to tag the primary lepton in charged-current interactions, and a continuous precision calibration beam, which improves the experiment's knowledge of the absolute energy scale for hadrons and muon, produced in neutrino interactions, to a precision of 0.43% and 0.7% respectively [2]. NuTeV took data during 1996-97 and collected 8.6×10^5 ν and 2.4×10^5 $\overline{\nu}$ charged-current (CC) interactions that passed analysis cuts.

ν-FE CHARGE CURRENT DIFFERENTIAL CROSS SECTION

The differential cross section is determined from

$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{1}{\Phi(E)}\frac{d^2N^{\nu(\overline{\nu})}(E)}{dxdy}, \tag{1}$$

where $\Phi(E)$ is the $\nu(\overline{\nu})$ flux in energy bins. The cross section event sample is required to pass fiducial volume cuts, μ track reconstruction quality cuts, a minimum muon energy threshold $E_\mu > 15$ GeV, a minimum hadronic energy threshold $E_{HAD} > 10$ GeV, and a minimum neutrino energy threshold $E_\nu > 30$ GeV. Selected events are binned in x, y, and E_ν bins, and corrected for acceptance and smearing using a fast detector simulation. $Q^2 > 1$ GeV^2 is required to minimize the non-perturbative contribution to the cross section. NuTeV data ranges from 10^{-3} to 0.95 in x, 0.05 to 0.95 in y, and from 30 GeV to 360 GeV in E_ν.

The flux is determined from data with $E_{HAD} < 20$ GeV using the "fixed ν_0" relative flux extraction method [1]. The integrated number of events in this sample is propor-

tional to the flux as $y = \frac{E_{HAD}}{E_\nu} \to 0$. Corrections up to order y^2, determined from the data sample, are applied to determine the relative flux to about the 1% level. Flux is normalized using the world average ν-Fe cross section $\frac{\sigma^\nu}{E_\nu} = 0.677 \times 10^{-38} cm^2/GeV$ [3].

The fast detector simulation, which takes into account acceptance and resolution effects, uses an empirically determined set of PDFs extracted by fitting the differential cross section [4]. The procedure is then iterated until convergence is achieved (within 3 iterations). Detector response functions are parameterized from the NuTeV calibration beam data samples [2].

STRUCTURE FUNCTIONS

The structure function $F_2(x,Q^2)$ is determined from a fit to the y-dependence of the sum of the $\nu, \overline{\nu}$ differential cross sections:

$$\left(\frac{d^2\sigma}{dxdy}^{\nu} + \frac{d^2\sigma}{dxdy}^{\overline{\nu}}\right) = \frac{G_F^2 ME}{\pi}\left[2\left(1-y-\frac{Mxy}{2E}+\frac{y^2}{2}\frac{1+4M^2x^2/Q^2}{1+R_L}\right)F_2 + y\left(1-\frac{y}{2}\right)\Delta xF_3\right], \tag{2}$$

where $F_2 = \frac{F_2^\nu + F_2^{\overline{\nu}}}{2}$, $R_L(x,Q^2)$ is the ratio of the cross section for scattering from longitudinally to transversely polarized W-bosons,and $\Delta xF_3 = xF_3^\nu - xF_3^{\overline{\nu}}$. Cross sections are corrected for QED radiative effects and for 5.67% excess of neutrons over protons in our iron target before the sum is formed [5]. To extract $F_2(x,Q^2)$ we use ΔxF_3 from a NLO QCD model as input (TRVFS) [6]. The input value of $R_L(x,Q^2)$ comes from a fit to the world's measurements [7]. NuTeV $F_2(x,Q^2)$ for neutrino scattering on iron is shown on Fig. 1 (left) compared with previous ν-Fe scattering measurements (CDHSW [8], CCFR [9]). NuTeV F_2 is in reasonable agreement with CDHSW and CCFR for $x < 0.4$. At high-x NuTeV F_2 is systematically above CCFR: 4% at $x = 0.45$, 9% at $x = 0.55$, 18% at $x = 0.65$.

Similarly, the structure function $xF_3(x,Q^2)$ is determined from a fit to the y-dependence of the difference of the $\nu, \overline{\nu}$ differential cross sections:

$$\left[\frac{d^2\sigma^\nu}{dxdy} - \frac{d^2\sigma^{\overline{\nu}}}{dxdy}\right] = \frac{2G_F^2 ME}{\pi}\left(y - \frac{y^2}{2}\right)xF_3^{AVG}(x,Q^2), \tag{3}$$

where $xF_3^{AVG} = \frac{1}{2}(xF_3^\nu + xF_3^{\overline{\nu}})$. $F_2^\nu(x,Q^2) \approx F_2^{\overline{\nu}}(x,Q^2)$ are nearly identical so no additional model input is required. Cross sections are corrected for QED radiative effects and for 5.67% excess of neutrons over protons in our iron target before the difference is formed [5]. Fig. 1 (right) shows the NuTeV measurement of $xF_3(x,Q^2)$ compared to previous ν-Fe results (CDHSW [8], CCFR(97) [3]). NuTeV xF_3 agrees with CCFR(97) and CDHSW for $x < 0.4$. For $x > 0.4$ NuTeV result is systematically higher than CCFR(97) [3].

We have determined that the largest contribution to the discrepancy with CCFR at high-x is due to a mis-calibration of the magnetic field map of the muon spectrometer in CCFR. NuTeV and CCFR used the same muon spectrometer. Hence, the radial dependence of the magnetic field should be the same. NuTeV mapped the entire surface of the

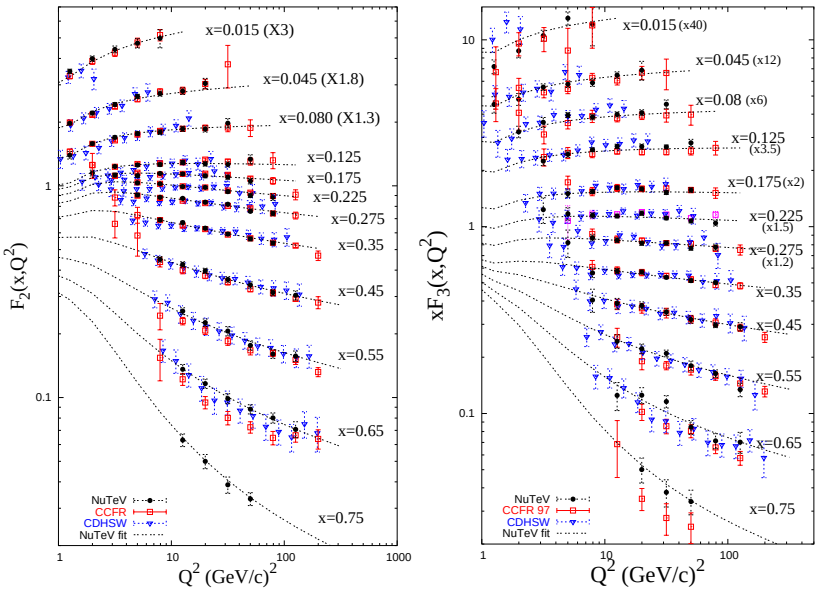

FIGURE 1. NuTeV F_2 (left) and xF_3 (right) in comparison with previous ν-Fe scattering experiments.

muon spectrometer with calibration beam of muons, which provided precise calibration of the magnetic field [2], while CCFR used a model for the magnetic field map and one high statistics calibration muon run, aimed at a single point of the spectrometer, to set the overall normalization [10]. The difference of the two magnetic field maps is an effective 0.8% shift of the muon energy scale, which accounts for a third of the discrepancy. Additional contributions to the discrepancy are the different cross section models used by NuTeV and CCFR (3% of the 18%), and the NuTeV's improved muon and hadron energy smearing models (2% of the 18%). All of the above differences account for two thirds of the discrepancy.

A comparison with TRVFS(MRST2001E) [6, 11] and ACOT(CTEQ5) [12, 13] for F_2 and xF_3 is shown on Fig.2. Both theoretical curves are corrected for nuclear target [1, 3] and target mass effects [14]. NuTeV agrees with both theoretical calculations for $0.06 < x < 0.5$. For $x < 0.06$ both NuTeV and CCFR measure different Q^2-dependence than the theoretical predictions. At high-x both theoretical predictions are systematically higher than the NuTeV F_2 and xF_3.

The nuclear correction used to correct the theory curves is independent of Q^2 and based on a fit to charged-lepton data on nuclear targets. NuTeV perhaps indicates that neutrino scattering favors smaller nuclear effects at high-x than are found in charged-lepton scattering. At small x, new theoretical calculations show that in the shadowing region the nuclear correction has Q^2 dependence [15, 16]. The standard nuclear correction obtained from a fit to charged lepton data implies a suppression of 10% independent of Q^2 at $x = 0.015$, while for $x = 0.015$ reference [16] finds a suppression of 15% at $Q^2 = 1.25\text{GeV}^2$ and a suppression of 3.4% at $Q^2 = 7.94\text{GeV}^2$. This effect improves agreement with data at low-x.

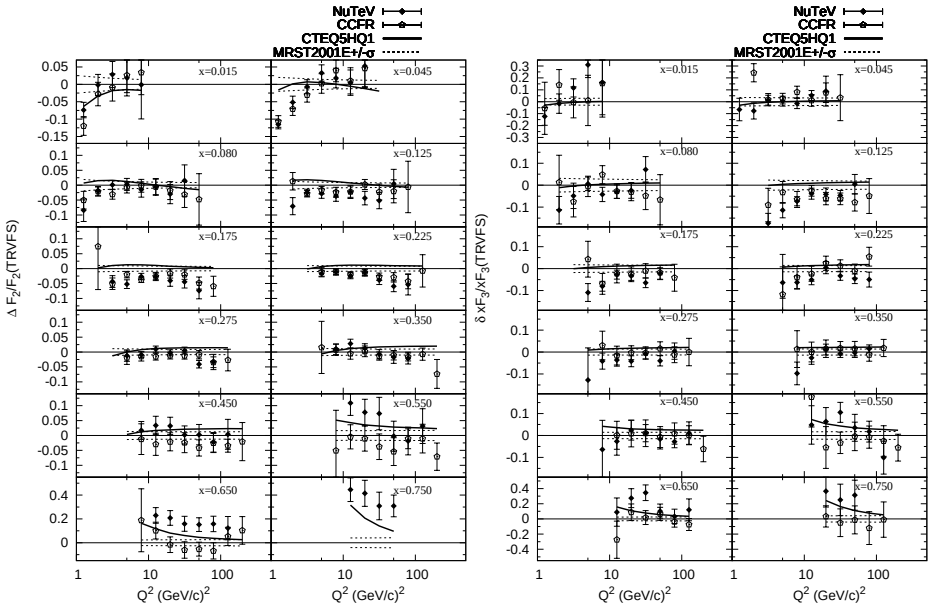

FIGURE 2. NuTeV and CCFR F_2(left) and xF_3(right) compared with TRVFS(MRST2001E) and ACOT(CTEQ5HQ1).

CONCLUSIONS

In conclusion, NuTeV has measured F_2 and xF_3 structure functions. This is the most precise measurement from neutrino scattering experiment to date. NuTeV result is in good agreement with previous ν-Fe results over the intermediate x region. At high-x NuTeV result is higher than the theoretical predictions. Perhaps, the nuclear correction is different for neutrino scattering.

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