NuTeV Structure Function Measurement


The NuTeV Collaboration

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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 $\nu$ and $\bar{\nu}$ differential cross sections are presented.

Keywords: nuetev; structure function.

Neutrino-nucleon deep inelastic scattering (DIS) probes the structure of the nucleon and QCD. 1 The NuTeV experiment is a high-energy fixed target $\nu N$ 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 muons produced in neutrino interactions. 2 $8.6 \times 10^5 \nu$ and $2.3 \times 10^5 \bar{\nu}$ charged-current (CC) interactions passing analysis cuts were collected during NuTeV's data taking run.

1. $\nu$-Fe CC Differential Cross Section

The differential cross section is determined from

$$\frac{d^2\sigma^{\nu}(E)}{d\Omega d\phi} = \frac{1}{\Phi(E)} \frac{d^2N^{\nu}(E)}{d\phi d\theta}.$$  

(1)
where $\Phi(E)$ is the $\nu(\bar{\nu})$ flux in energy bins. The cross section event sample is required to pass fiducial volume cuts, $\mu$ track reconstruction quality cuts, and minimum energy thresholds of $E_{\mu} > 15$ GeV, hadronic energy, $E_{HAD} > 10$ GeV, and neutrino energy, $E_\nu > 30$ GeV. Selected events are binned in $x$, $y$, and $E_\nu$ 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 300 GeV in $E_\nu$.

The flux is determined from data with $E_{HAD} < 20$ GeV using the "fixed $\nu_\mu$" relative flux extraction method. $^1$ The integrated number of events in this sample as $y = \frac{E_{HAD}}{E_\nu} \rightarrow 0$ is proportional to the flux. Corrections, determined from the data sample, up to order $y^2$ are applied to determine the relative flux to about the 1% level. Flux is normalized using the world average $\nu$-Fe cross section $\sigma_{\nu Fe} = 0.677 \times 10^{-38}$ 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. $^2$

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 $\nu, \bar{\nu}$ differential cross sections:

$$\left( \frac{d^2\sigma}{dx dy} + \frac{d^2\sigma}{dx dy} \right) = \frac{G^2_{\nu e} \frac{M E}{\pi}}{x} \left[ 2 \left( 1 - y - \frac{M x y}{E} \right) + \frac{y^2 + 4M^2 x^2/Q^2}{1 + R_L} \right] F_2 + \frac{y}{2} \Delta x F_3, \tag{2}$$

where $F_2 = \frac{x F_2^\nu + x F_2^\bar{\nu}}{2}$, $R_L(x, Q^2)$ is the ratio of the cross section for scattering from longitudinally to transversely polarized W-bosons where, $2x F_1 = F_2^\nu (1 + R_L(x, Q^2))$.

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 $\Delta x F_3$ 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 $\nu$-Fe scattering measurements (CDHSW, $^8$ CCFR). $^9$ NuTeV $F_2$ is in agreement with CDHSW and CCFR for medium $x \,(0.03 < x < 0.4)$. At high $x$ NuTeV result agrees in level with CDHSW, but not in shape. NuTeV $F_2$ is systematically above CCFR for $x > 0.4$: 5% at $x = 0.45$, 10% at $x = 0.55$, 20% 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 $\nu, \bar{\nu}$ differential cross sections:

$$\left[ \frac{d^2\sigma}{dx dy} - \frac{d^2\sigma}{dx dy} \right] = \frac{2G^2_{\nu e} \frac{M E}{\pi}}{x} \left( y - \frac{y^2}{2} \right) x F_3^{AV}(x, Q^2) \tag{3}$$
Fig. 1. Preliminary NuTeV $F_2$ (left) and $xF_3$ (right) in comparison with previous $\nu$-Fe scattering experiments

where $xF_3^{AVG} = \frac{1}{2}(xF_3^p + xF_3^n)$. $F_2^n(x, Q^2) \approx F_2^p(x, Q^2)$ 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 $xF_3(x, Q^2)$ from fits to the cross section difference. NuTeV $xF_3$ agrees with CCFR and CDHSW for $0.03 < x < 0.4$. For $x > 0.4$ NuTeV result agrees in level, but not in shape with CDHSW, and is systematically higher than CCFR(97). \(^6\)

3. Conclusions

In conclusion, we have measured $F_2$ and $xF_3$ structure functions. NuTeV result is in good agreement with previous $\nu$-Fe results over the intermediate $x$ range ($0.03 < x < 0.4$). At high-$x$ ($x > 0.4$) NuTeV result is systematically higher than CCFR result, it agrees in level with CDHSW, but not in shape.

References