A Unified Approach to $e/\nu - N$ Deep Inelastic Scattering Cross Sections at all Q^2

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We present the results of a new scaling variable, ξ_w in modelling neutrino- and electron-nucleon scattering cross sections using effective leading order PDFs. Our model desribes all deep inelastic scattering charged lepton-nucleon scattering data including resonance data (HERA/NMC/BCDMS/SLAC/JLab) from very high Q^2 to very low Q^2 (down to photo-productin region), as well as CCFR neutrino data. Non-perturbative QCD effects at low Q^2 region turn out to be well described by this new scaling variable. Our model is currently used for neutrino oscillation experiments at few GeV region.

The field of neutrino oscillation physics has progressed from the discovery of neutrino oscillation [2] to the era of precision measurements of mass splitting and mixing angles. Currently, cross sections for neutrino interactions in the few GeV region have not been measured well. This results in large systematic uncertainties in the extraction of mass splitting and mixing parameters (e.g. by the MINOS, NOνA , K2K and T2K experiments). Therefore, reliable modeling of neutrino cross sections at low energies is essential for precise neutrino oscillations experiments. In the few GeV region, there are three types of neutrino interactions: quasi-elastic, resonance, and inelastic scattering. It is very challenging to disentangle each contribution separately, especially, resonance production versus deep inelastic scattering (DIS) contributions. There are large non-perturbative QCD corrections to the DIS contributions in this region.

Our approach is to relate neutrino interaction processes using a quark-parton model to precise charged-lepton scattering data. In a previous communication [3], we showed that our effective leading order model using an improved scaling variable ξ_w describes all deep inelastic scattering charged lepton-nucleon scattering data including resonance data (SLAC/BCDMS/NMC/HERA/Jlab) [4, 5] from very high Q^2 to very low Q^2 (down to photo-production region), as well as high energy CCFR neutrino data [6].

The proposed scaling variable, ξ_w is derived using energy momentum conservation, assuming massless initial state quarks bound in a proton of mass M.

$$\xi_w = \frac{2x(Q^2 + {M_f}^2 + B)}{Q^2[1 + \sqrt{1 + (2Mx)^2/Q^2}] + 2Ax}, \tag{1}$$

here, M_f is the final quark mass (zero except for charm-production in neutrino processes). The parameter A accounts for the higher order (dynamic higher twist) QCD terms in the form of an enhanced target mass term (the effects of the proton target mass are already taken into account using the exact form in the denominator of ξ_w). The parameter B accounts for the initial state quark transverse momentum and final state quark effective $\Delta {M_f}^2$ (originating from multi-gluon emission by quarks). This parameter also allows us to describe the data also in the photoproduction limit (all the way down to $Q^2 = 0$).

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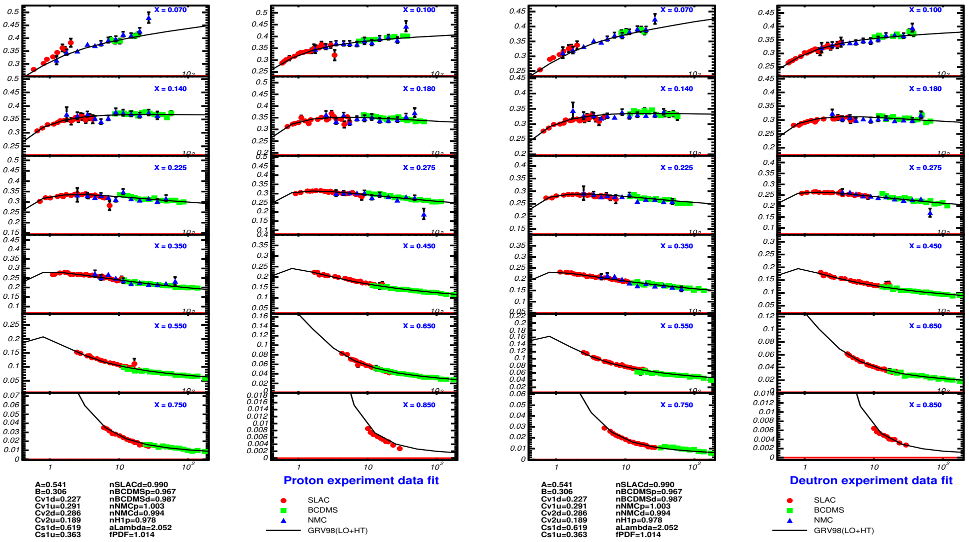

Figure 1: Comparisons of the predictions of our model to DIS F_2 proton data [left], deuteron data [right].

A brief summary of our effective leading order (LO) model is given as follows;

- The GRV98 LO PDFs [7] are used to describe the F_2 data at high Q^2 region.
- The scaling variable x is replaced with the improved scaling variable ξ_w (Eq. 1).
- All PDFs are modified by K factors to describe low Q^2 data in the photoproduction limit.

$$K_{sea}(Q^2) = \frac{Q^2}{Q^2 + C_s}, \qquad K_{valence}(Q^2) = [1 - G_D^2(Q^2)] \left(\frac{Q^2 + C_{v2}}{Q^2 + C_{v1}} \right), \tag{2}$$

  where $G_D = 1/(1+Q^2/0.71)^2$ is the proton elastic form factor. At low Q^2, $[1-G_D^2(Q^2)]$ is approximately $Q^2/(Q^2+0.178)$. Different values of the K factor are obtained for u and d quarks

- The evolution of the GRV98 PDFs is frozen at a value of $Q^2 = 0.80$. Thus, $F_2(x, Q^2 < 0.8) = K(Q^2) \times F_2(\xi, Q^2 = 0.8)$.
- Finally, we fit to all inelastic charged lepton scattering data (SLAC/BCDMS/NMC/H1) and photoproduction data on hydrogen and deuterium. We obtain excellent fits with; A=0.538, B=0.305, C^d_{v1}=0.202, C^u_{v1}=0.291, C^d_{v2}=0.255, C^u_{v2}=0.189, C^d_{s1}=0.621, C^u_{s1}=0.363, and χ^2/DOF =1874/1574. Because of the K factors to the PDFs, we find that the GRV98 PDFs need to be multiplied by a factor of 1.015.

The measured structure functions data are corrected for the relative normalizations and for nuclear binding effects [8] in the deuterium data. A separate charm pair production contribution using the photon-gluon fusion model is added to describe the HERA F_2 and photoproduction data. Our effective LO model describes various DIS and photo-production

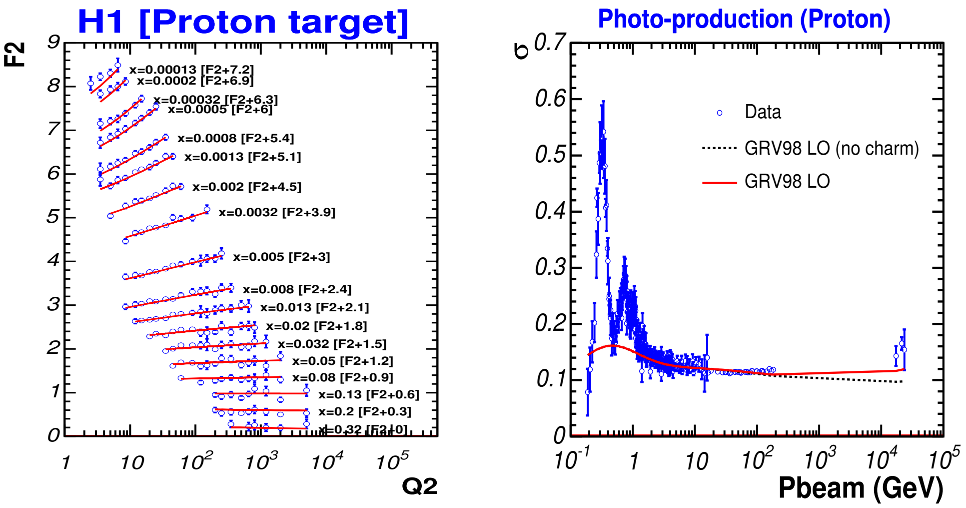

Figure 2: Comparisons of the predictions of our model to F_2 HERA [left], and photo-production data [right].

data down to the $Q^2 = 0$ limit, as shown in Fig. 1 and Fig. 2. We also find a good agreement with the most recent F_L data and F_2 data in the resonance region from the E94-110, and the JUPITER experiments [9] at Jlab, as shown in Fig. 3. Our predictions for F_L are obtained using our F_2 model and R_{1998} [10].

In neutrino scattering, there is an additional axial vector contribution, which is not zero at the $Q^2 = 0$ limit. At high Q^2, both axial and vector contributions are expected to be same. Thus, it is important to understand the axial-vector contribution at low Q^2 by comparing to future low energy neutrino data (e.g. MINERνA [11]). As a preliminary step, we compare the CCFR and CDHSW [12] high energy neutrino data with our model, assuming that the vector contribution is the same as the axial vector contribution. We find that the CCFR/CDHSW neutrino data are well described by our model.

We are currently working on constraining the low Q^2 axial vector contribution using low energy CDHSW and CHORUS [13] data. The form of the fits we plan to use is motivated by the Adler sum rule [14] for the axial vector contribution as follows:

$$K_{sea-ax}(Q^2) = \frac{Q^2 + C_{2s-ax}}{Q^2 + C_{1s-ax}}, \qquad K_{valence}(Q^2) = [1 - F_A^2(Q^2)] \left(\frac{Q^2 + C_{2v-ax}}{Q^2 + C_{1v-ax}} \right), \tag{3}$$

where $F_A(Q^2) = -1.267/(1 + Q^2/1.00)^2$. Nuclear effects for heavy target are also important and may be different for the vector and axial vector structure functions. Future measurements on the axial vector contribution from the MINERνA experiment will be important in constraining this model.

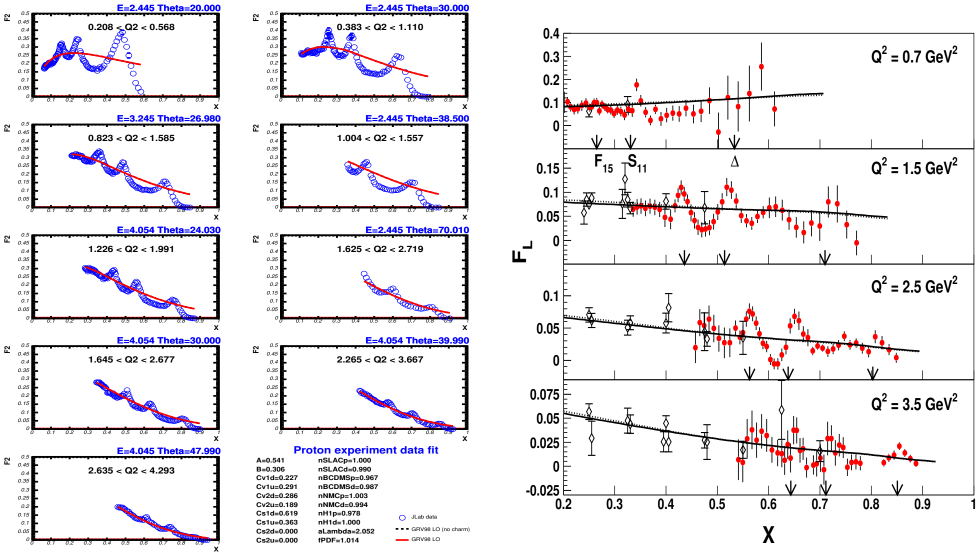

Figure 3: Comparisons of the predictions of our model to F_2 proton resonance data [left], and F_L proton data [right].

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