MASS CORRECTIONS AND NEUTRINO DIS* **

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Including the effects of the $\mathcal{O}(\gtrsim 1\text{ GeV})$ masses of the charm quark, τ lepton and target nucleon in DIS phenomenology is discussed with applications to CC neutrino DIS: Neutrino data for F_2 are revisited within the global analysis framework. A fully differential calculation refines the CC charm production process as a gate to extract $\{s(x), \bar{s}(x)\}$. New results are presented for a "heavy quark" version of the CTEQ6 set of PDFs and for ($\nu_\mu \to \nu_\tau$ oscillation-signal) τ neutrino cross sections.

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1. Introduction

This contribution to the proceedings gives an overview of some recent results for deep inelastic scattering mainly with neutrino beams interacting through charged currents. Neutrino data are an important component of PDF analyses because the weak currents single out quark flavour combinations different from those probed by the electromagnetic current; *e.g.* a charmed particle detected in the final state singles out the strange sea. Even more, armed with a well-tested QCD calculation of neutrino cross-sections, event rates can be related to neutrino fluxes (or absence of events to upper limits) in cases where the neutrino flux is unknown or its flavour composition is expected to oscillate, *e.g.* between ν_μ and ν_τ.

2. Probing QCD using neutrino experiments

2.1. Charm mass effects and neutrino data in global parton analyses

A satisfying conciliation of neutrino and charged lepton structure functions at modestly low-$x \sim 10^{-2}$ — addressed before in terms of the naive

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parton model as a violation of the approximate "5/18-rule" — has been a problem for a while. Charm production effects and charm mass dependence in the neutrino data have proven important and a "physics model independent" analysis [1] has improved the situation over previous comparisons which corrected for charm in a physics model dependent way. But comparing data sets for different hard processes for mutual compatibility necessarily requires the data to be compared to a common underlying theoretical model. A global pQCD analysis of hard scattering data provides the most appropriate framework for this comparison. Fig. 1 shows preliminary

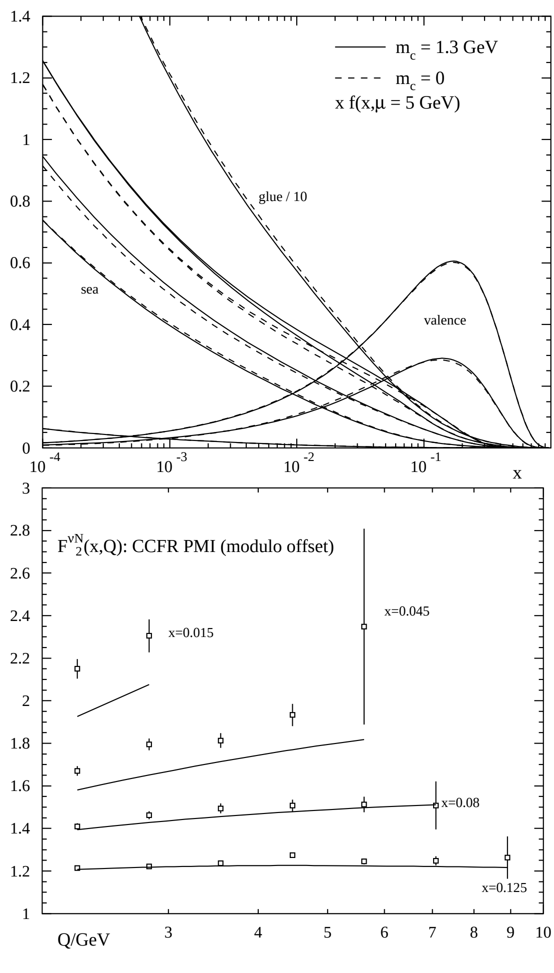

Fig. 1. Top: The relative effect of including DIS charm threshold effects in a 4-flavour ACOT(χ) global PDF analysis. Bottom: CTEQ6HQ PDF results compared with CCFR *physics model independent* low-x structure functions.

results of such a study [2] which is an extension of [3]. The PDFs in [3] were obtained setting $m_c = 0$ in the hard cross sections at collider energies. Here, the DIS charm threshold was taken into account and $m_c = 1.3$ GeV was employed with the cross sections in [4]. The results in Fig. 1 are derived from a (simplified-) ACOT (χ) prescription which — as explained in the second Ref. of [4] — uses a slow rescaling variable χ to obey the threshold condition $W > 2m_c$; results for a PDF set in the *fixed flavour scheme* are also underway [2]. The top plot of Fig. 1 quantifies the amount of change in the PDFs that compensates for introducing the charm threshold in the DIS hard scattering cross-sections. This systematic shift can be larger than the statistical uncertainties in the PDFs [3]. In the bottom plot of Fig. 1 one observes that the agreement with the "physics model independent" neutrino structure functions is not fully satisfactory at low-x. Compare, however, with Robert Bernstein's presentation at this conference of preliminary NuTeV structure functions [5]. The tendency seems to be that these preliminary results compare more favourably with the NLO PDF predictions at low-x. Apart from m_c, there is no room here to discuss further theoretical factors in the evaluation of neutrino structure functions and the reader is referred to [6] and to the literature quoted therein. As it stands now, the published F_2^ν in Fig. 1 and $\Delta x F_3^\nu$ as analyzed in [6] cannot be described fully satisfyingly within perturbative QCD.

2.2. Differential distributions for charm in neutrino-production

The strange sea density $s(x, \mu^2)$ is the least well determined of the quark PDFs [6]. Interest in $s(x, \mu^2)$ was revived recently also from the fact that the anomaly in the NuTeV measurement of the Weinberg angle may depend on intrinsic $|uuds\bar{s}\rangle$ fluctuations generating $(s - \bar{s})(x, \mu^2) \neq 0$ [7]. Global QCD fits have previously employed the integrated strangeness suppression factor $\kappa = \int dxx(s + \bar{s}) / \int dxx(\bar{u} + \bar{d})$ to constrain $s(x, \mu^2)$. More detailed information can be expected from analyzing CC neutrino-production of charm ($W^+ s \to c$) at full differential level including all NLO diagrams. As in the NC case, theory needs to provide differential information because of detector non-isotropy and experimental cuts.

Fig. 2 shows a recent calculation [8] for typical fixed target kinematics. A `FORTRAN` code `DISCO` has been made available and was interfaced with the NuTeV detector Monte Carlo. It should soon be possible to fix the size of $s(x, \mu^2)$ at NLO and settle the question whether $(s - \bar{s})(x, \mu^2)$ is of relevant size.

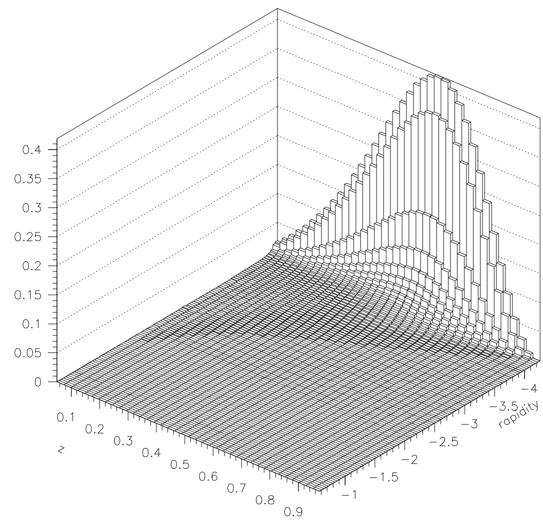

Fig. 2. Binned differential distribution for CC neutrino-production of charm on an isoscalar target: $E_\nu = 80$ GeV, $x = 0.1$, $Q^2 = 10$ GeV^2.

3. Probing neutrino oscillations using QCD

Results from the SuperKamiokande underground experiment measuring the atmospheric neutrino flux suggest that μ neutrinos oscillate into τ neutrinos with nearly maximal mixing [9]. A test of the oscillation hypothesis is ν_τ production of τ through charged current interactions, a process which will be studied in underground neutrino telescopes as well as long-baseline experiments measuring neutrino fluxes from accelerator sources. In the following the deep-inelastic contribution to $\nu_\tau N \to \tau X$ is presented incorporating NLO QCD corrections, target mass, τ mass and charmed quark mass corrections. Future work will combine DIS with elastic and resonant neutrino-production channels. The charged current ν_τ (anti-)neutrino differential cross section is represented by a standard set of 5 structure functions [10]:

$$\begin{aligned}\frac{d^2\sigma^{\nu(\bar\nu)}}{dx\,dy} = \frac{G_F^2 M_N E_\nu}{\pi(1+Q^2/M_W^2)^2} & \left\{ (y^2 x + \frac{m_\tau^2 y}{2E_\nu M_N}) F_1^{W^\pm} \right.\\ & + \left[(1 - \frac{m_\tau^2}{4E_\nu^2}) - (1 + \frac{M_N x}{2E_\nu}) y \right] F_2^{W^\pm} \\ & \pm \left[xy(1-\frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M_N} \right] F_3^{W^\pm} \\ & \left. + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M_N^2 x} F_4^{W^\pm} - \frac{m_\tau^2}{E_\nu M_N} F_5^{W^\pm} \right\} . \qquad (1)\end{aligned}$$

F_4 and F_5 are ignored in μ neutrino interactions because of a suppression factor depending on the square of the charged lepton mass (m_ℓ) divided by the nucleon mass times neutrino energy, $m_\ell^2/(M_N E_\nu)$. At LO, in the limit of massless quarks and target hadrons, F_4 and F_5 are

$$F_4 = 0\,, \tag{2}$$
$$2xF_5 = F_2\,, \tag{3}$$

where x is the Bjorken-x variable. These generalizations of the Callan–Gross relation $F_2 = 2xF_1$ are called the Albright–Jarlskog relations. As with the Callan–Gross relations, the Albright–Jarlskog relations are violated by NLO[1] QCD and kinematic mass corrections. Fig. 3 quantifies the violation of Eq. (2) and compares ν_μ and ν_τ DIS interactions with and without

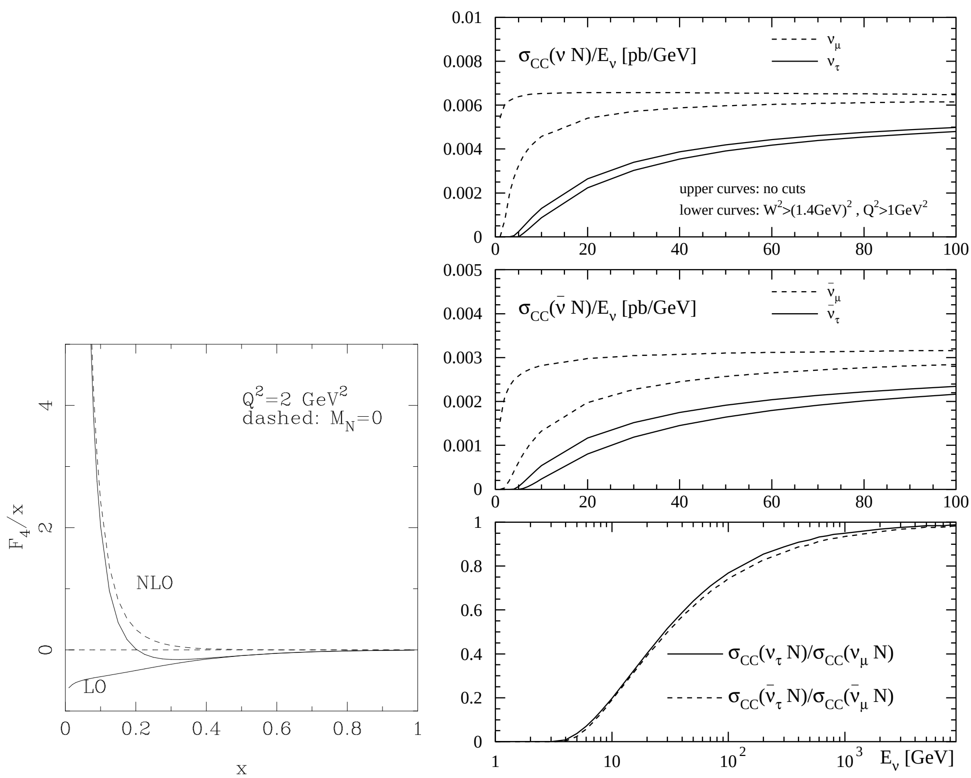

Fig. 3. Left: Violation of Eq. (2) from mass and NLO corrections. Right: Cross sections for inclusive neutrino- [$\sigma_{\rm CC}(\nu N)$] and anti-neutrino [$\sigma_{\rm CC}(\bar\nu N)$] production on an isoscalar target.

[1] Ref. [11] finds that Eq. (3) is *not* violated at NLO in *massless* QCD.

DIS cuts. The effect of these imposed cuts is much less pronounced for ν_τ DIS where m_τ acts as a physical cut-off of non-DIS interaction. It may surprise how slowly $\sigma_{\rm CC}(\nu_\tau N)$ approaches $\sigma_{\rm CC}(\nu_\mu N)$ from below at very high neutrino energies indicating a persistent τ threshold effect. About half of the reduction at high energies is actually of dynamic origin, to be attributed to a negative F_5 contribution to (1), where around *e.g.* 1 TeV the $m_\tau^2/E_\nu M_N$ suppression is neutralized to some extent by a low-x enhancement; note that F_5 is the only structure function the contribution of which to $d\sigma$ rises like $q(x)$ and not $xq(x)$. The net effect is that the remaining threshold suppression is seemingly doubled.

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