Charm Production at NuTeV

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Neutrino deep-inelastic scattering provides a means to study both the strange and charm content of the nucleon. The NuTeV experiment (Fermilab E-815) takes full advantage of separated neutrino and anti-neutrino beams to probe the nucleon. The strange sea is studied with charged-current charm production resulting in an opposite-signed two muon final state. The charm content of the nucleon is probed via neutral-current charm production creating an event with a single wrong-signed muon. Preliminary results are presented for both analyses.

Charm production is a significant fraction of the total neutrino deep-inelastic scattering (DIS) cross-section. The semi-muonic decay of charm mesons creates unique final states to study exclusive charm production. For charged-current reactions, an opposite-signed two muon (dimuon) final state is available. Neutral-current production can create an event with a single muon with charge opposite that expected from a charged-current interaction (wrong-signed muon). Feynman diagrams for both reactions are shown in Fig. 1.

The NuTeV experiment studies ν and $\bar{\nu}$ DIS using the Sign-Selected Quadrupole Train (SSQT) beam and the Fermilab Lab E detector.[1] The SSQT allows separate running of neu-

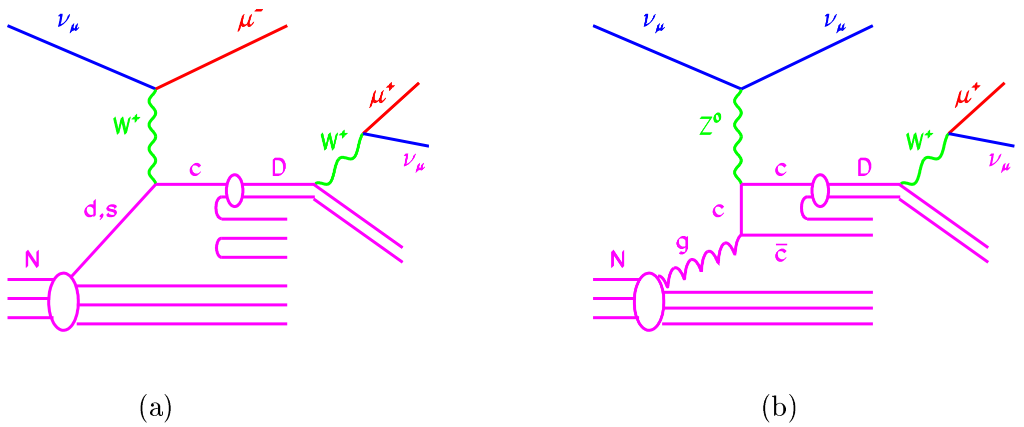


Figure 1: Feynman diagrams for (a) charged-current and (b) neutral-current charm production via neutrino DIS.

trino and anti-neutrino beams. The (anti-)neutrino beam is incident upon the Lab E target/calorimeter which has 42 segments each consisting of two liquid-scintillator counters and a drift chamber interspersed with 20 cm of iron. The calorimeter provides energy and position measurement for hadronic/electromagnetic showers and deeply-penetrating muon tracks. Immediately downstream is a toroid spectrometer which provides momentum measurement for muons. Analyses presented here use the full NuTeV data sample from the Fermilab 1996-97 fixed target run.

1 Charged-Current Charm Production

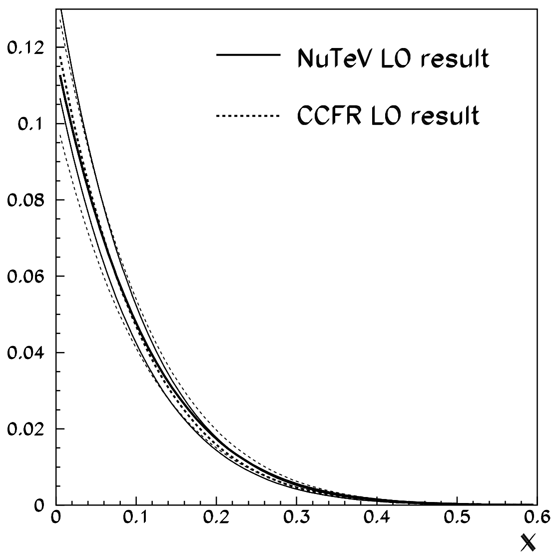
Neutrino charged-current DIS charm production results from scattering off d or s quarks in the nucleon. The Cabibbo suppression of scattering off d quarks greatly enhances the contribution of the s quarks. This allows the probing of the strange content of the nucleon.

The dimuon data set consists of events passing fiducial and kinematic selections and containing a hadronic shower ($>$ 10 GeV) with at least two muons. One muon must be toroid analyzed with more than 9 GeV in energy while the other muon must have more than 5 GeV in energy. The two sources of such events are charged-current charm production and a charged-current event with a π/K decaying within the shower.

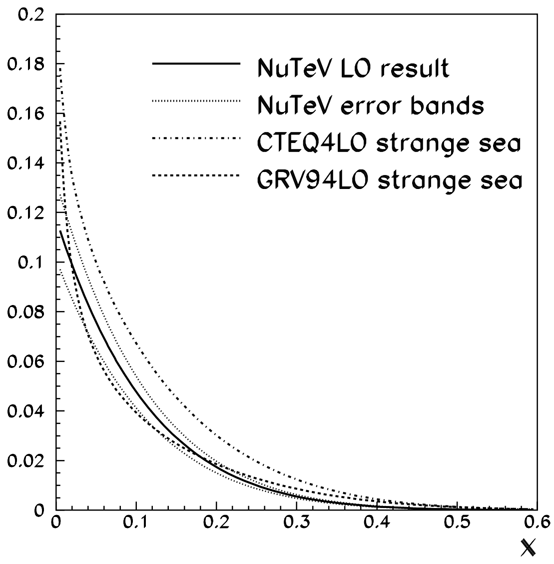
Data and Monte Carlo are binned in three variables: $x_{vis} = \frac{E_{vis}E_{\mu 1}\theta^2_{\mu 1}}{2m_p(E_{\mu 2}+E_{had})}$, $E_{vis} = E_{\mu 1} + E_{\mu 2} + E_{had}$, and $z_{vis} = \frac{E_{\mu 2}}{E_{\mu 2}+E_{had}}$ where the subscript vis ($visible$) refers to measured variables, $\mu 1$ is the primary muon and $\mu 2$ is the secondary muon. The Monte Carlo is weighted by the leading-order (LO) cross-section and normalized to agree with the two-muon data.

Four parameters are used to describe charged-current charm production. κ determines the size of the strange sea relative to the non-strange sea ($\sim \frac{2\bar{s}}{\bar{u}+\bar{d}}$). The shape of the strange sea is described by $(1-x)^\beta$. m_c is the mass of the charm quark and ϵ determines the Collins-Spiller fragmentation.[2] These parameters are varied to find the best agreement between data and Monte Carlo. The preliminary results of the fit are:

$$\begin{aligned}
\kappa &= 0.42 \pm 0.07 \pm 0.06 \\
\beta &= 8.5 \pm 0.56 \pm 0.39 \quad (Q^2 = 16\ GeV^2) \\
m_c &= 1.24 \pm 0.25 \pm 0.46\ \ GeV \\
\epsilon &= 0.93 \pm 0.11 \pm 0.15
\end{aligned}$$



(a)



(b)

Figure 2: Comparison of the NuTeV (with error bands) result to: CCFR result (a); theoretical predictions from CTEQ and GRV.

where the first error is statistical and the second error is systematic. The largest systematic error is from the flux which is expected to be reduced by further work. However, the errors for κ and α are already statistics limited so the improvement will be primarily for m_c and ϵ.

The results of this analysis for the strange sea compare favorably with previous measurements. CHARM II,[3] CCFR[4] and CDHS[5] have all measured the size of the strange sea to be $\sim 40\%$ of the non-strange sea. Figure 2(a) shows a comparison of the results of the CCFR and NuTeV strange sea measurements. There is excellent agreement between the two measurements. Figure 2(b) compares the NuTeV result to theoretical predictions from CTEQ and GRV. The NuTeV result is lower than the CTEQ prediction while in better agreement with GRV.

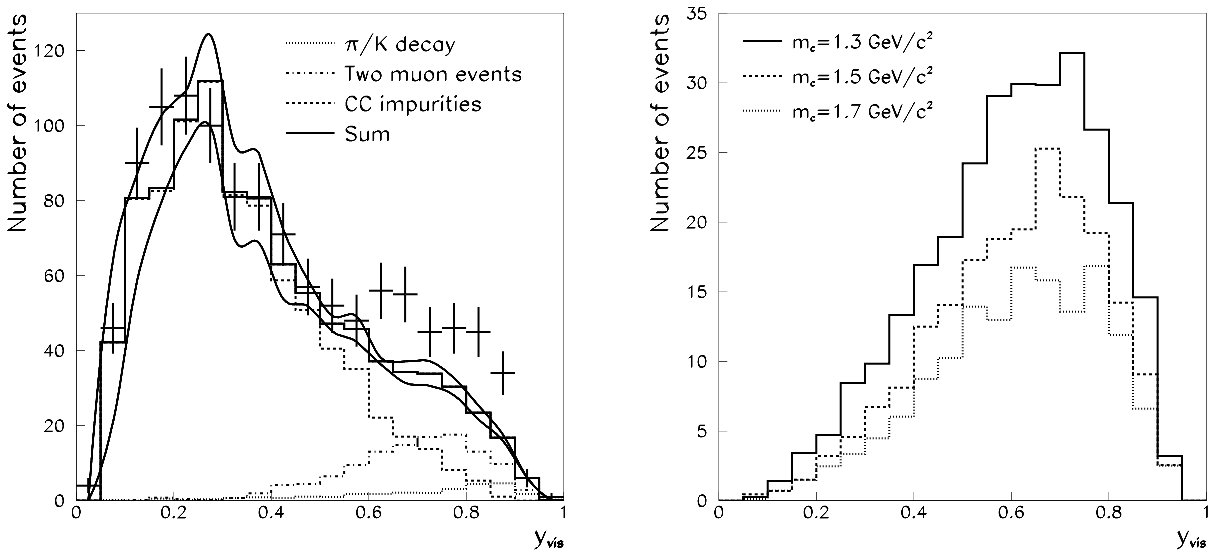
2 Neutral-Current Charm Production

Neutral-current (NC) charm production occurs via scattering off charm quarks in the nucleon (Fig. 1(b)). Analysis of this reaction probes the charm content of the nucleon. While some models allow for an intrinsic charm content of the nucleon, this analysis only considers gluon splitting as its source for charm.

This analysis considers events which have a single muon with the opposite charge from charged-current interactions of the selected beam type (wrong-sign events). This is possible because of NuTeV's ability to select between neutrino and anti-neutrino beams and the low contamination of wrong type neutrinos.

There are three sources of wrong-sign events other than NC charm production. The largest is charged-current impurities including events from anti-neutrinos in neutrino mode. This contamination is less than 2×10^{-3} of the beam intensity. Also included in this category are charged-current events where the sign of the muon is mis-identified (generally due to a large scatter in the toroid spectrometer). The second largest source comes from two-muon events (see Section 1) where the primary muon is not measured because it is of low energy or exits the detector. The third source comes from NC events where a π/K in the shower decays prior to interacting.

Figure 3(a) shows the wrong-signed muon data from NuTeV (points) for the variable $y_{vis} =$



(a) (b)

Figure 3: Neutral-current charm production (ν mode only). (a) NuTeV wrong-sign muon data (points) compared to the sum of the background sources (solid histogram) and systematic errors (curve). The individual background components are also shown as histograms.; (b) Predictions of neutral-current charm production for various values of m_c = 1.3,1.5,1.7.

$\frac{E_{HAD}}{E_{HAD}+E_\mu}$. The predictions for the individual background sources and their sum are also shown. A clear excess of events is seen at high y_{vis}. Figure 3(b) shows predictions for neutral-current charm production which peaks in the same region as the excess. [6]

3 Summary

The NuTeV sign-selected neutrino beams allows for improved studies of the strange and charm contributions to the nucleon sea. The strange sea is observed to be in agreement with previous measurements with a size which is $0.42 \pm 0.07 \pm 0.06$ the size of the average non-strange sea and a shape $(1-x)^{8.5\pm0.56\pm0.39}$ (at $Q^2 = 16$ GeV^2). The wrong-signed muon data shows a clear excess of events which is consistent with neutral-current charm production. Additional details of both analyses are available. [7]

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