Proceedings of the DIS'2004, Štrbské Pleso, Slovakia

STRANGE SEA ASYMMETRY RESULTS FROM NUTEV

PANAGIOTIS SPENTZOURIS FOR THE NUTEV COLLABORATION
Fermilab, PO Box 500, Batavia, IL 60510, USA
E-mail: spentz@fnal.gov

We present results from the next to leading order (NLO) analysis of the dimuon data from NuTeV, a neutrino nucleon scattering experiment at FNAL. Charged current neutrino events with two oppositely charged muons in the final state provide a unique means of studying charm production and measuring the strange sea. NuTeV's sign-selected secondary beam allows the independent extraction of strange and anti-strange seas. In this discussion, we focus on the measurement of their momentum distribution asymmetry. Such an asymmetry could have significant impact in the interpretation of recent NuTeV electroweak results. We employee a fully consistent NLO analysis [1], and we measure a slightly negative asymmetry, consistent with zero.

Events containing two oppositely signed muons (dimuons) from muon neutrino deep inelastic scattering occur predominantly when a charmed particle is produced in a charged current (CC) interaction with a strange or down quark. Approximately 10% of the time the charmed hadrons decay semi-muonically, yielding a final state with two oppositely charged muons, one from the weak vertex and one from the charm decay. Charm production from down quarks is Cabibbo suppressed, making dimuons most sensitive to the strange sea. Dimuons are clearly distinguishable in a large neutrino detector such as that employed by NuTeV.

The NuTeV experiment took data during FNAL's 96-97 fixed target run and recorded 5102 dimuon events from CC ν_μ, and 1458 from CC $\overline{\nu}_\mu$ scattering in its iron target. The detector was calibrated throughout the run by muon, electron, and hadron beams so its response is well understood. NuTeV's beamline enabled separate high purity ν_μ and $\overline{\nu}_\mu$ beam running. This allowed independent extraction of the strange and antistrange seas.

The measurement of the difference between the strange and antistrange sea distributions is of particular interest, since it could be the explanation[2,3] for the almost 3σ difference between NuTeV's $\sin^2\theta_W$ result[4] from the standard model prediction. To eliminate this discrepancy a positive strange-antistrange momentum asymmetry, $S^- \equiv \int x[s(x) - \overline{s}(x)]dx$, as large as $+0.007$ is required[5]. NuTeV's dimuon data sample offers the opportunity to address this question directly

1 Fitting the Dimuon Cross Section

NuTeV has made its dimuon data available in the form of a dimuon cross section table[9], for dimuons with charm decay muon of energy greater than 5 GeV, in bins of Bjorken x, inelasticity y, and neutrino energy E_ν.

A fit to the dimuon cross section table requires the following components:

$$\frac{d\sigma_{2\mu}}{dxdy} = \frac{d\sigma_{charm}}{dxdy} \cdot EMC \cdot B_c \cdot \mathcal{A}\frac{d\sigma_{charm}}{dxdy} \cdot EMC \cdot B_c \cdot \mathcal{A} = \boxed{\text{fit}} \Rightarrow \frac{d\sigma_{2\mu}}{dxdy}, \quad (1)$$

$\frac{d\sigma_{2\mu}}{dxdy}$ is the measured dimuon cross section to which the LHS of the expression above is compared. $\frac{d\sigma_{charm}}{dxdy}$ is the charm cross section prediction, dependent on the strange sea and charm mass, which would be varied in a fit. EMC is an x dependent correction for the EMC effect and nuclear shadowing (here using a fit to charged lepton experiment data[11]). B_c is the semileptonic charm branching ratio (here 0.093[12]), and $\mathcal{A}$ is a kinematic acceptance correction to account for the 5 GeV cut on the energy of the muon from the semileptonic charm decay. It depends on E_ν, x, y as well as fragmentation and charm mass.

Since the gluon contribution is large, it is desirable that fits are performed at least at NLO, to have meaning beyond the context of neutrino-nucleon scattering[6]. When fitting a charm cross section model to this cross section, one must be able to simulate the effects of fragmentation and the subsequent semileptonic decay to calculate $\mathcal{A}$. This requires a cross section model dependent on the fragmentation momentum ratio z. At NLO, the charmed quark has transverse momentum due to the interaction with the gluon which must also be simulated. A relatively new calculation of the charm differential cross section in x, y, z, and charm rapidity η_c, implemented into the code DISCO[10], was employed into a Monte Carlo simulation. The simulation modeled the muons from the semileptonic decay, and $\mathcal{A}$ was calculated by dividing the number of events that pass a 5 GeV cut on the decay muon energy by the total number of events in each bin. Detector smearing effects need not be modeled, as they have been corrected out of the table.

Fits were performed using acceptance corrections calculated with a constant Collins-Spiller[13] epsilon of 0.75. When fitting at NLO it becomes difficult to fit both the charm mass and epsilon at the same time. It was found that strange asymmetry results were insensitive to the choice of epsilon, so a value found to match NLO Monte Carlo to data well was chosen, and varied over a conservative range (0.25) for error estimates. Charm mass was then allowed to vary in the fit.

2 Strange Asymmetry Results

Several fits to the dimuon cross section tables have been performed both in LO and NLO QCD and with different methods of parameterizing the strange sea. The first class of fits treats the strange and antistrange seas completely independently, using a more or less traditional parameterization, with $s(x,Q) = \kappa(1-x)^{\alpha}\left[\frac{\overline{u}(x,Q)+\overline{d}(x,Q)}{2}\right]$ and $\overline{s}(x,Q) = \overline{\kappa}(1-x)^{\overline{\alpha}}\left[\frac{\overline{u}(x,Q)+\overline{d}(x,Q)}{2}\right]$. QCD evolution with this scheme is through already evolved $\overline{u}$ and $\overline{d}$ distributions. κ, α, $\overline{\kappa}$, $\overline{\alpha}$ are varied to modify the shape and sizes of the strange and antistrange seas. The asymmetry $S^- = \int xs^- dx = \int x[s(x)-\overline{s}(x)]dx$ from a LO fit with the CTEQ5L pdf set was found to be -0.0003 ± 0.0011; tending slightly negative, but consistent with zero. This is different from the published LO result of -0.0027 ± 0.0013 which was obtained by a LO fit to combined NuTeV and CCFR data with a different set of PDF's. In this work we only fit the NuTeV tables.

Using the same parameterization scheme as above, a NLO cross section[7,8] fit using CTEQ6M nonstrange pdf's was then performed and S^- was -0.0011 ± 0.0014, again consistent with zero but tending negative at low x. Modifying pre-evolved pdf's by a function of x as this scheme does however, technically violates the Alterelli Parisi equations. Another fit was performed with the same functional form for the strange and antistrange seas, this time $s(x)$ and $\overline{s}(x)$ at a Q_0 of 1.3 GeV. The pdf's were then properly evolved in Q^2 with a version of the EVLCTEQ evolution code which allowed strange and antistrange seas to be different[14]. The results were very similar, with an asymmetry of -0.0013 ± 0.0013.

Evolving the strange and antistrange seas properly brings the analysis closer to full QCD compliance, however this scheme violates both the flavor sum rule by not requiring $\int s^-$ to be zero, and the momentum sum rule by not normalizing the strange sea relative to the nonstrange pdfs. Following the example of Olness et al.[15] a fit was also performed using the following parameterization: $s^+(x, Q_0) = \kappa^+(1-x)^{\alpha^+} x^{\gamma^+} \left[\overline{u}(x, Q_0) + \overline{d}(x, Q_0)\right]$, and $s^-(x, Q_0) = s^+(x) \tanh\left[\kappa^-(1-x)^{\alpha^-} x^{\gamma^-} \left(1 - \frac{x}{x_0}\right)\right]$, so that $s = \frac{s^+ + s^-}{2}$, and $\overline{s} = \frac{s^+ - s^-}{2}$. In this scheme, the flavor sum rule is enforced by choosing an x_0 such that $\int s^-$ is zero. In our implementation, the momentum sum rule constraint was not enforced, since it was found that it does not affect the asymmetry but removes an important degree of freedom in the fit. Results from fitting with this parameterization are shown in Fig. 1 for a Q^2 of 10 GeV^2. The data prefers satisfying the flavor sum rule by forcing s^- to spike positive at a very low x_0 of 0.009, lower in x any of the data table points. The χ^2 is 37/37 NDF. The asymmetry follows the same trend as the previous parameterization with a value of -0.0009 ± 0.0014.

Finally, to examine whether a positive asymmetry is compatible with the NuTeV dimuon data, we constrained s^- to be positive and allowed $s+$ to vary. The result is also shown in Fig.1 and corresponds to a positive asymmetry of $+.0016$, less than one quarter of the amount needed to resolve the NuTeV $\sin^2\theta_W$ discrepancy. The χ^2 of the fit holding s^- fixed to this shape never improved beyond 55/40 NDF.

3 Conclusions

We have presented new fit results for the strange asymmetry using the NuTeV forward dimuon cross section data. In general all the fits tended toward a small negative strange asymmetry at low x, always consistent with zero. When the asymmetry was constrained to be positive, the χ^2 increased significantly, making even a small positive asymmetry difficult to accommodate with our data. These results are still preliminary, and it should be noted that the CTEQ collaboration has extracted a positive asymmetry from their preliminary fits including the NuTeV tables. It is agreed however, that the NuTeV $\sin^2\theta_W$ discrepancy is unlikely to be due to an asymmetry in the strange and antistrange pdf's. NuTeV and CTEQ are continuing to collaborate to resolve any discrepancies in the theoretical assumptions used.

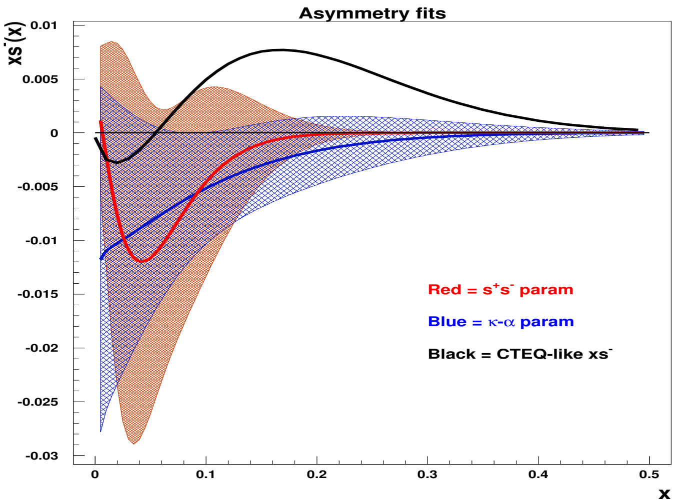

Figure 1. Momentum asymmetry distributions from fits with various assumptions: $\kappa - \alpha$ parameterization (blue), CTEQ s^+, s^- (red), and a constrained positive asymmetry case. The shaded area corresponds to the uncertainty in each case. The uncertainty from the positive asymmetry fit is not displayed, but is similar to the other two cases.

References

1. D. Mason, PhD Thesis, University of Oregon, in preparation.
2. S. Davidson, S. Forte, P. Gambino, N. Rius and A. Strumia, JHEP **0202**, 037 (2002)
3. S. Kretzer, F. Olness, J. Pumplin, D. Stump, W. K. Tung and M. H. Reno, arXiv:hep-ph/0312322.
4. G. P. Zeller *et al.* , Phys. Rev. Lett. **88**, 091802 (2002) [Erratum-ibid. **90**, 239902 (2003)]
5. K. S. McFarland and S. O. Moch, arXiv:hep-ph/0306052.
6. M. A. G. Aivazis, J. C. Collins, F. I. Olness and W. K. Tung, Phys. Rev. D **50**, 3102 (1994)
7. M. Gluck, S. Kretzer and E. Reya, Phys. Lett. B **380**, 171 (1996) [Erratum-ibid. B **405**, 391 (1997)]
8. S. Kretzer and I. Schienbein, Phys. Rev. D **58**, 094035 (1998)
9. M. Goncharov *et al.*, Phys. Rev. D **64**, 112006 (2001)
10. S. Kretzer, D. Mason and F. Olness, Phys. Rev. D **65**, 074010 (2002)
11. B. Seligman PHD thesis, Columbia University, page 250
12. T. Bolton, ArXiv:hep-ex/9708014.
13. P. D. B. Collins and T. P. Spiller, J. Phys. G **11**, 1289 (1985).
14. W.K. Tung, private communication
15. F. Olness *et al.*, arXiv:hep-ph/0312323.