NEUTRINO-PRODUCTION OF CHARM AND THE STRANGENESS ASYMMETRY OF THE NUCLEON

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Interest in the strange nucleon sea has been renewed when it was realized that the strangeness asymmetry $s^- = s - \bar{s}$ plays a prominent role in the interpretation of the NuTeV weak mixing angle anomaly. I overview the NLO QCD calculation of the neutrino-production of opposite-sign dimuons as the experimental signature of the strange quark parton density. Results from a recent CTEQ fit are presented and discussed with respect to their stability under NLO corrections and their impact on the NuTeV measurement.

1 Introduction: Sea Quarks

If the sea quarks of the nucleon could be considered as "resolved gluons", they were to inherit the gluon's flavour blindness and CP conjugation symmetry; i.e.

$$\bar{u}(x)|_{k_\perp^2>\mu^2} = \bar{d}(x)\big|_{k_\perp^2>\mu^2} = \bar{s}(x)|_{k_\perp^2>\mu^2} = s(x)|_{k_\perp^2>\mu^2} \quad , \tag{1}$$

where the restriction on $k_\perp$ phase space generically denotes some perturbative cut-off. For heavy quarks, it seems that the phenomenology of heavy quark production works reasonably well under the assumption that the heavy quark masses act as physical cut-offs in the perturbative regime ($m_Q > \mu$). This is certainly not true for light quarks, however, where there will necessarily be contributions from $k_\perp^2 < \mu^2$ that do not respect Eq. (1). It has been firmly established already that

$$\bar{u}(x) \neq \bar{d}(x) \neq \bar{s}(x) \tag{2}$$

and it remains to be settled by which amount the strange sea quark and anti-quark distributions differ:

$$s^-(x) \equiv (s - \bar{s})(x) \neq 0 \quad . \tag{3}$$

Here and throughout I am avoiding the notion sometimes found in the literature of (flavour or CP) symmetry "violation"; there is no symmetry breaking implied by Eqs. (2), (3) [e.g. CP conjugation turns $s(x)$ into $\bar{s}_{\bar{p}}(x)$ – the anti-strange sea of the anti-proton] and it would rather be a puzzle if these were exact equalities than inequalities to some degree. A broad literature on model calculations (see e.g. [1]) of the the sea quark boundary conditions (at μ) covers fascinating approaches to non-perturbative dynamics ranging from light-cone wave functions over meson cloud models to the chiral quark soliton model. Here I restrict myself to the observation that the inequality (3) seems unavoidable and will look at data on neutrino-production of charm

$$\nu_\mu\ s\ \to c\ \mu^- \quad \& \quad \bar{\nu}_\mu\ \bar{s}\ \to \bar{c}\ \mu^+ \tag{4}$$

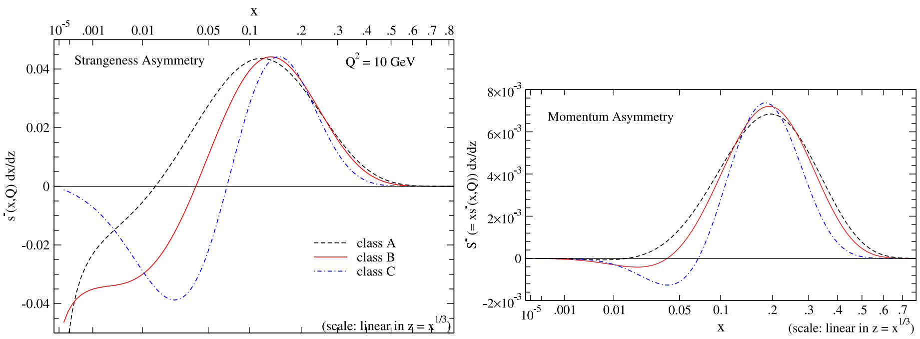

Figure 1. Representative results of the CTEQ strangeness asymmetry analysis.

to quantify if the amount can be significant. The experimental signature of the process (4) are opposite sign dimuons (the second muon stemming from the charm decay) in an active target [2]; I will next give an overview of the corresponding QCD calculations.

2 Neutrino-Production of Charm at NLO

Chromodynamic corrections to the inclusive charm production process in Eq. (4) were first calculated more than 20 years ago [3], a re-calculation e.g. in [4] fixes typos and provides modern $\overline{\mathrm{MS}}$ conventions which are also identical to the $m_s \to 0$ limit of the corresponding NLO corrections [5] in the ACOT scheme [6]. In order to meet the real world experimental requirements of applying acceptance corrections to data [2] taken with non-ideal detectors, differential NLO distributions were calculated in [7] and [8] that provide the charm hadron (D meson) kinematics in terms of the fragmentation z variable and rapidity η. The $d\sigma/dxdydzd\eta$ code DISCO [8] exists as an interface to the NuTeV MC event generator.

For detailed NLO results I have to refer the reader to the original articles listed above. In this short write-up I have to restrict myself to an itemized summary:

(i) The NLO calculations all agree (some early discrepancies have been clarified).

(ii) For the fixed target kinematics under investigation, the NLO corrections to the LO process are modest, no bigger than $\mathcal{O}(\lesssim 20\%)$.

3 CTEQ Fit

Typical results of a recent CTEQ global data analysis [9] that includes the dimuon data in [2] are shown in Fig. 1. An essential constraint on these fits is the sum rule

$$\int [s(x) - \overline{s}(x)]\, dx = 0\,, \tag{5}$$

and a stable tendency of the fit is to realize the constraint through an oscillation from negative to positive with increasing x, resulting in a positive second moment integral

$$[S^-] \equiv \int x\,[s(x) - \bar{s}(x)]\,dx\ . \tag{6}$$

Eq. (6) is not overly sensitive to the low-x ambiguities visible in Fig. 1 – compare the number asymmetry on the left plot with the momentum asymmetry on the right. It is the second moment (which is not among the local quark operators probed in DIS) that the NuTeV anomaly is mostly sensitive to, through an approximately linear relation between $\sin^2\theta_W$ and $[S^-]$ that was first derived in [10].

Note that the results in Fig. 1 have been obtained by a fit that neglects the NLO corrections discussed in the previous section for consistency with the acceptance corrections that were applied to the data [2] based on a LO model. At worst, the CTEQ fit procedure constitutes a LO fit with spurious higher order terms from the evolution and correlation with the global data that are otherwise described to NLO accuracy. However, we do find the results to be very stable under NLO corrections and the uncertainty limit on $[S^-]$ below is considerably broader than the NLO effects. Final NLO results will have to await a certified update of the data [2] where acceptance effects are corrected based on the NLO theory [8].

At this conference, P. Spentzouris for the NuTeV collaboration has presented [11] results from a fit that is based on the calculations [4, 8] and uses the data [2] that are also included in the CTEQ analysis. While his results are within our limits (7) below, it is somewhat troublesome that he observes a qualitative preference for an oscillation from positive to negative and, accordingly, a negative $[S^-]$. The issue is currently investigated jointly by NuTeV and CTEQ.

4 Impact on the NuTeV Anomaly

By the Lagrangian multiplier method one finds a central value $[S^-] \simeq 0.002$ and conservative bounds

$$-0.001 < [S^-] < 0.004 \quad . \tag{7}$$

As described e.g. in [10, 12] this translates into a shift

$$-0.005 < \delta(\sin^2\theta_W) < +0.001 \tag{8}$$

in $\sin^2\theta_W$ as measured in neutrino scattering where there has been a $3\,\sigma$ discrepancy between the NuTeV result [13] and the world average of other measurements of $\sin^2\theta_{\rm W}$. The shift in $\sin^2\theta_W$ corresponding to the central fit bridges a substantial part ($\sim 1.5\sigma$) of the original $3\,\sigma$ discrepancy. For PDF sets with a shift toward the negative end, such as -0.004, the discrepancy is reduced to less than $1\,\sigma$. On the other hand, for PDF sets with a shift toward the positive end, such as $+0.001$, the discrepancy remains. For related discussions, see also the contributions [11, 14] to these proceedings.

5 Conclusions

Neutrino-production of charm is well understood in QCD and it provides a direct handle on the strange sea asymmetry. This last undetermined asymmetry in the unpolarized quark sea is bound to be non-zero but it is hard to quantify or even gauge for its significance in practice. A model independent global parton structure analysis can discriminate between models of non-perturbative strong interaction. Recently, the fascinating observation was made that these non-perturbative effects may have to be disentangled from perturbative physics at the 3-loop level [15]. Apart from these fascinating issues in QCD phenomenology, limits on the second moment $[S^-]$ provide an essential systematic uncertainty in the NuTeV measurement of the weak mixing angle, which shows a 3σ discrepancy with the standard model. The results of this study within their uncertainty limits suggest that the new dimuon data, the Weinberg angle measurement, and other global data sets used in QCD parton structure analysis can all be consistent within the standard model of particle physics.

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