Eur. Phys. J. A **18**, 449–451 (2003)
DOI 10.1140/epja/i2002-10257-7

THE EUROPEAN PHYSICAL JOURNAL A

Parton symmetries and the NuTeV anomaly

A.I. Signal[a] and F.G. Cao

Institute of Fundamental Sciences, Massey University, Palmerston North, New Zealand

Received: 30 September 2002 /
Published online: 22 October 2003 –

Abstract. Recently the NuTeV Collaboration (Phys. Rev. Lett. **88**, 091802 (2002)) announced a new measurement of $\sin^2\theta_{\mathrm{W}}$ which was approximately three standard deviations above the currently accepted standard model value. The NuTeV analysis depends on the assumption that various quark-parton model symmetries are not broken. In particular the analysis takes $\bar{s}(x) = s(x)$ and $d^n_{\mathrm{V}}(x) = u^p_{\mathrm{V}}(x)$. However models which break these symmetries are known. We examine the predictions of these models and their effect on the NuTeV result. In most instances the effect is to decrease the discrepancy between the NuTeV result and the accepted value.

PACS. 13.15.+g Neutrino interactions – 11.30.Hv Flavor symmetries

1 Introduction

The NuTeV Collaboration has measured NC to CC ratios in deep-inelastic $\nu(\bar{\nu})$-nucleon scattering. This enables them to determine the effective couplings to left- and right-handed quarks (g_{L} and g_{R}) and, via the Paschos-Wolfenstein (PW) ratio

$$R_{\mathrm{PW}} = \frac{\sigma^{\nu}_{\mathrm{NC}} - \sigma^{\bar{\nu}}_{\mathrm{NC}}}{\sigma^{\nu}_{\mathrm{CC}} - \sigma^{\bar{\nu}}_{\mathrm{CC}}} = g^2_{\mathrm{L}} - g^2_{\mathrm{R}} = \frac{1}{2} - \sin^2\theta_{\mathrm{W}}, \tag{1}$$

the value of the weak mixing angle

$$\sin^2\theta_{\mathrm{W}} = 0.2277 \pm 0.0013(\mathrm{stat}) \pm 0.0009(\mathrm{syst}). \tag{2}$$

Compared with the accepted value [1] of 0.2227 ± 0.0037 there is a 3σ discrepancy.

While this discrepancy may point to new physics, there are possible explanations in the standard model. As discussed by Davidson and collaborators [2], the PW ratio receives both electro-weak corrections and higher-order QCD corrections. However these appear to be too small to explain the discrepancy. Another possibility [3] is corrections arising from nuclear shadowing, which would be a higher twist effect. The possibility we will explore here is that the breaking of symmetries by the parton distributions can cause the observed discrepancy.

2 Parton symmetry breaking

There are two possible symmetry-breaking contributions to the PW ratio at leading order: quark-anti-quark asymmetries in the sea distributions and charge symmetry breaking in the valence distributions. Including both these effects the PW ratio becomes (to leading order in α_S)

$$R_{\mathrm{PW}} = \frac{1}{2} - \sin^2\theta_{\mathrm{W}} + \frac{3b_1 + b_2}{\langle x(u_{\mathrm{V}} + d_{\mathrm{V}})\rangle/2}\Big[\langle x(c-\bar{c})\rangle - \langle x(s-\bar{s})\rangle + \frac{1}{2}\big(\langle x\delta u_{\mathrm{V}}\rangle - \langle x\delta d_{\mathrm{V}}\rangle\big)\Big], \tag{3}$$

where

$$\delta u_{\mathrm{V}} = u^p_{\mathrm{V}} - d^n_{\mathrm{V}}; \qquad \delta d_{\mathrm{V}} = d^p_{\mathrm{V}} - u^n_{\mathrm{V}} \tag{4}$$

are the charge symmetry-breaking valence distributions and

$$b_1 = \Delta^2_u = g^2_{\mathrm{L}_u} - g^2_{\mathrm{R}_u}; \qquad b_2 = \Delta^2_d = g^2_{\mathrm{L}_d} - g^2_{\mathrm{R}_d}. \tag{5}$$

At the NuTeV scale ($Q^2 = 16\,\mathrm{GeV}^2$) the coefficient in front of the square brackets of eq. (3) is about 1.3, so a symmetry-breaking term inside the square brackets of -0.0038 would explain the discrepancy between the NuTeV value and the accepted value of $\sin^2\theta_{\mathrm{W}}$.

As the charm component of the sea is generated perturbatively, we expect $c(x) = \bar{c}(x)$, however processes such as $N \to \Lambda K$ can generate a non-perturbative component to the strange sea [4] and different shapes for $s(x)$ and $\bar{s}(x)$. The meson cloud model (MCM) [5] is a useful model for calculating the contributions to the strange sea from processes involving the meson cloud. We have used two approaches for the parton distributions of the baryons (Λ, Σ) and the kaon:

1. Take the baryon distributions to be $SU(3)$ symmetric *i.e.* $s^{\Lambda}(x) = s^{\Sigma}(x) = u^p(x)/2$, and for the kaon distribution use the Dortmund group parametrization [6].

[a] e-mail: a.i.signal@massey.ac.nz

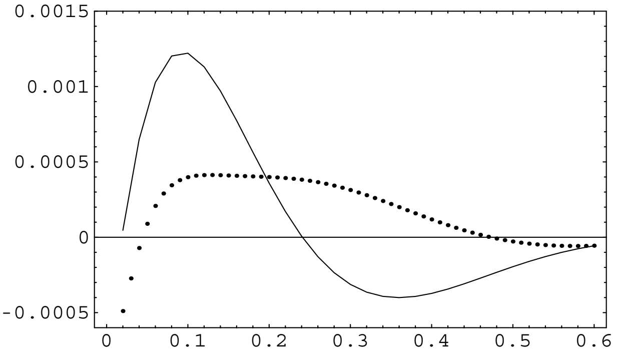

Fig. 1. The strange sea asymmetry calculated in the meson cloud model with $SU(3)$ symmetric baryon distributions (solid line) and the bag model baryon and kaon distributions (dotted line).

2. Calculate the distributions using the bag model [7], which breaks $SU(3)$.

While these two methods give different shapes for $x(s-\bar{s})$ (see fig. 1) they give similar results for the sign and magnitude of the integral of this distribution. For the MCM cut-off parameter $\Lambda = 1.08\,\mathrm{GeV}$ we find

$$\langle x(s-\bar{s})\rangle \approx 0.0001, \tag{6}$$

and varying the value of Λ does not significantly change the order of magnitude of this result. Thus it appears that any strange sea asymmetry is probably an order of magnitude too small to affect the NuTeV result.

It is interesting to note that one PDF fit [8] does allow $s(x) \neq \bar{s}(x)$, finding $\langle x(s-\bar{s})\rangle = 0.002 \pm 0.0028$ at $Q^2 = 20\,\mathrm{GeV}^2$, however the difference is mostly at large x rather than small x as in the MCM. NuTeV have also looked for a strange asymmetry [9], and find a small negative value for $\langle x(s-\bar{s})\rangle$, with a large (100%) uncertainty. Also the fit they used did not satisfy $\langle s-\bar{s}\rangle = 0$.

Charge symmetry is usually a good symmetry in quark phenomenology. The scale of any violation of CS is set by $(M_n - M_p)/M_p \approx 0.1\%$, however this may be enough to affect the significance of the NuTeV result. In the MCM charge symmetry breaking (CSB) can arise from mass differences in isospin multiplets. Cao and Signal [10] found a small effect in valence distributions: $\langle x\delta u_{\mathrm{V}}\rangle = -0.00018$ and $\langle x\delta d_{\mathrm{V}}\rangle = -0.00015$ with the MCM cut-off parameter $\Lambda = 1.08\,\mathrm{GeV}$. However CSB can also occur in the "bare" valence distributions, and this is much harder to estimate. There can be contributions from the mass difference between the proton and neutron, from the shift in mass of the intermediate state (Bickerstaff and Thomas [11] estimate $(m_{dd} - m_{uu}) = 4\,\mathrm{MeV}$), and from any change in the quark wave function due to changes in quark mass and changes in the boundary conditions. Using the bag model Sather [12] found $\langle x\delta u_{\mathrm{V}}\rangle - \langle x\delta d_{\mathrm{V}}\rangle = -0.0047$. A more extensive calculation by Rodionov, Thomas and Londergan [13] found that the valence distributions could be changed by as much as 5%, especially in the large x region. They concluded that shifts in the intermediate state mass give the most important CSB effect. The changes in the nucleon mass and the quark wavefunction both give 1% effects.

We have investigated the effect of varying the intermediate state mass M_n and the initial mass M using the formalism of the Adelaide group [14]. The parton distribution can be written

$$q(x) = M \sum_n \int_{p_m}^{\infty} p_n\,\mathrm{d}p_n G(pn),$$
$$p_m = \left|\frac{M^2(1-x)^2 - M_n^2}{2M(1-x)}\right|, \tag{7}$$

and we restrict our discussion to diquark intermediate states. A change in M or M_n then causes a change in the parton distribution

$$\mathrm{d}q(x) = \frac{\partial q(x)}{\partial M_n}\mathrm{d}M_n + \left(\frac{\partial q(x)}{\partial M} + \frac{\partial q(x)}{\partial x}\frac{\mathrm{d}x}{\mathrm{d}M}\right)\mathrm{d}M, \tag{8}$$

where the second term is a total derivative as x and M are not independent. We then obtain

$$\mathrm{d}q(x) = \frac{\partial q(x)}{\partial x} g(x)\mathrm{d}M_n + \frac{1}{M}\frac{\partial}{\partial x}(xq(x))\mathrm{d}M, \tag{9}$$

where

$$g(x) = \frac{2M_n(1-x)}{M^2(1-x)^2 + M_n^2}\,. \tag{10}$$

Comparing this expression with that of Sather, we see that the second term agrees, and the first term is the same if p_m is kept constant. Taking moments then gives

$$\langle x^j\,\mathrm{d}q(x)\rangle = -\left[j\langle x^{j-1}q(x)g(x)\rangle + \left\langle x^j q(x)\frac{\partial g(x)}{\partial x}\right\rangle\right]\mathrm{d}M_n - \frac{j}{M}\langle x^j q(x)\rangle\mathrm{d}M. \tag{11}$$

The second term can be evaluated using the full parton distribution $q(x)$, but the first should be evaluated using just the diquark intermediate states. We can do this using the bag model calculation of Boros and Thomas [7] and evolving at NLO up to $16\,\mathrm{GeV}^2$. We obtain the CSB in the valence distributions (giving the contribution of each term in eq. (11)):

$$\langle x\delta d_{\mathrm{V}}(x)\rangle = 0.0011 + 0.00017, \tag{12}$$
$$\langle x\delta u_{\mathrm{V}}(x)\rangle = 0 + 0.00033. \tag{13}$$

As the u_{V} distribution always arises from (ud) diquark intermediate states, these is no effect on this distribution from the 4 MeV splitting between dd and ud intermediate states. We also see that the shift in the intermediate state mass gives the dominant CSB contribution to the d_{V} distribution, in agreement with the results of ref. [13]. We find a total CSB contribution to the PW ratio of

$$\frac{1}{2}\langle x\delta u_{\mathrm{V}}(x)\rangle - \frac{1}{2}\langle x\delta d_{\mathrm{V}}(x)\rangle \approx -0.0006, \tag{14}$$

which is not large enough in magnitude to bring the NuTeV result into agreement with the accepted value of $\sin^2\theta_{\mathrm{W}}$, but does decrease the discrepancy a little.

3 Summary

We have investigated the possible role of symmetry breaking among parton distributions as an explanation of the anomalous NuTeV result for $\sin^2\theta_W$. The most important symmetry-breaking contributions are an asymmetry in the strange sea and charge symmetry breaking in the valence distributions. However detailed calculation shows that both these contributions are too small in magnitude to explain the anomaly, but the tendency is for them to reduce the size of the difference between the NuTeV value and the accepted value, so that the discrepancy is now at the 2σ level. We note that there is very little experimental information on these symmetry-breaking contributions.

This work is supported by the Marsden Fund of the Royal Society of New Zealand, and by the Science and Technology Postdoctoral Fellowship of the Foundation for Research Science and Technology.

References

1. LEPEWWG, Report CERN-EP/2001-098, hep-ex/0112021.
2. S. Davidson *et al.*, JHEP **02**, 037 (2002).
3. G.A. Miller, A.W. Thomas, hep-ex/0204007.
4. A.I. Signal, A.W. Thomas, Phys. Lett. B **191**, 205 (1987).
5. H. Holtmann, A. Szczurek, J. Speth, Nucl. Phys. A **596**, 631 (1996); J. Speth, A.W. Thomas, Adv. Nucl. Phys. **24**, 83 (1997).
6. M. Glück, E. Reya, M. Stratmann, Eur. Phys. J. C **2**, 159 (1998).
7. C. Boros, A.W. Thomas, Phys. Rev. D **60**, 074017 (1999).
8. V. Barone, C. Pascaud, F. Zomer, Eur. Phys. J. C **12**, 2 (2000).
9. NuTeV Collaboration (M. Goncharov *et al.*), Phys. Rev. D **64**, 112006 (2001).
10. F.G. Cao, A.I. Signal, Phys. Rev. C **62**, 015203 (2000).
11. R.P. Bickerstaff, A.W. Thomas, Phys. Rev. D **35**, 108 (1987).
12. E. Sather, Phys. Lett. B **191**, 205 (1992).
13. E.N. Rodionov, A.W. Thomas, J.T. Londergan, Mod. Phys. Lett. A **9**, 1799 (1994).
14. A.I. Signal, A.W. Thomas, Phys. Rev. D **40**, 2832 (1989); A.W. Schreiber, A.I. Signal, A.W. Thomas, Phys. Rev. D **44**, 2653 (1991).