HAL
open science

Recent tests for the statistical parton distributions

Claude Bourrely, Franco Buccella, Jacques Soffer

▶ **To cite this version:**

Claude Bourrely, Franco Buccella, Jacques Soffer. Recent tests for the statistical parton distributions. Modern Physics Letters A, 2003, 18, pp.771-778. hal-00127010

HAL Id: hal-00127010

https://hal.science/hal-00127010v1

Submitted on 27 Jan 2007

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Recent tests for the statistical parton distributions

Claude Bourrely [a], Franco Buccella [b] and Jacques Soffer [a]

[a] Centre de Physique Théorique[1], CNRS-Luminy,
Case 907, F-13288 Marseille Cedex 9 - France

[b] Dipartimento di Scienze Fisiche, Università di Napoli,
Via Cintia, I-80126, Napoli and INFN, Sezione di Napoli, Italy

Abstract

We compare some recent experimental results obtained at DESY, SLAC and Jefferson Lab., with the predictions of the statistical model, we have previously proposed. The result of this comparison is very satisfactory.

CPT-2002/P.4451
UNIV. NAPLES DSF-24/2002

[1] Unité propre de Recherche 7061

Deep inelastic phenomena have played a crucial role in the discovery of QCD, as the theory of strong interactions, to establish its property of being asymptotically free [1] and to provide the logarithmic scaling violations found experimentally. However, concerning our present knowledge of the parton distributions at a given Q^2, the situation is far from being settled. Indeed, the very precise measurements in unpolarized deep inelastic scattering (DIS) for electron-nucleon and charged current neutrino induced reactions, yield the structure functions $F_2^{p,n}(x,Q^2)$ and $xF_3^{\nu N}(x,Q^2)$, which involve the combinations of parton distributions $q_i(x,Q^2) \pm \bar{q}_i(x,Q^2)$, summed over the flavors $i = u, d, s, ...$ Therefore, due to data statistical limitations, there is some ambiguity in deriving from these structure functions, the quark and antiquark distributions for each flavor. In fact a flavor symmetric sea, namely $\bar{d}(x) = \bar{u}(x)$, assumed in the Gottfried sum rule [2], was disproved by the NMC Collaboration [3] and one gets instead, at $Q^2 = 4\mathrm{GeV}^2$,

$$\bar{d} - \bar{u} = \int_0^1 (\bar{d}(x) - \bar{u}(x))dx = 0.153 \pm 0.015\,. \tag{1}$$

From a global QCD analysis of DIS, we recall that there is also some evidence for an asymmetry between $s(x)$ and $\bar{s}(x)$ in the nucleon sea [4].

Polarized DIS yield the measurements of the spin-dependent structure functions $g_1^{p,n,d}(x,Q^2)$, which are combinations of $\Delta q_i(x,Q^2) + \Delta\bar{q}_i(x,Q^2)$ and do not allow to disentangle the Δq_i and $\Delta\bar{q}_i$ contributions. The original Ellis-Jaffe sum rule [5], which was obtained with the assumption that only u and d quarks contribute to it, reads for the proton case

$$\Gamma_1^p = \int_0^1 g_1^p(x)dx = \frac{F}{2} - \frac{D}{18} = 0.185\,. \tag{2}$$

The EMC Collaboration discovered, nearly 15 years ago, that this sum rule has also a substantial defect, since they found, at $< Q^2 >= 10.7\mathrm{GeV}^2$, $\Gamma_1^p = 0.126 \pm 0.010(stat) \pm 0.015(syst)$ [6]. According to an interpretation of this result which was proposed earlier, the strange quarks had a large negative contribution [7]. However the EMC result has been confirmed to a higher level of accuracy, for example, at $Q^2 = 3\mathrm{GeV}^2$, one finds $\Gamma_1^p = 0.132 \pm 0.003(stat) \pm 0.009(syst)$ [8].

Over the last few years several empirical parametrizations have been proposed with $\Delta p(x) = P_p(x)p(x)$, without a physical interpretation of the parameters which appear in the unpolarized part $p(x)$ and in the polynomial $P_p(x)$. By observing that $u^+(x)$ is the parton dominating at high x, a first

attempt to relate unpolarized to polarized quark distributions has been given in [9], suggesting for $x \geq 0.2$, where the valence quarks dominate,

$$\Delta u(x) = u(x) - d(x)\,. \tag{3}$$

It leads to the following relation between the unpolarized and polarized structure functions

$$x g_1^p(x) = \frac{2}{3}[F_2^p(x) - F_2^n(x)]\,, \tag{4}$$

if one neglects the contribution of $\Delta d(x)$, which is expected to be smaller than $\Delta u(x)$ and whose contribution is reduced by the factor $e_d^2/e_u^2 = 1/4$. In fact, by using the available data [3] for the r.h.s. of Eq. (4), one predicts $\Gamma_1^p = 0.156$ at $Q^2 = 4\mathrm{GeV}^2$, which is in reasonable agreement with the data.

The existence of the correlation, broader shape higher first moment, suggested by the Pauli principle, has inspired the introduction of Fermi-Dirac (Bose-Einstein) functions for the quark (gluon) distributions [10]. After many years of research, we recently proposed [11], at the input scale $Q_0^2 = 4\mathrm{GeV}^2$

$$xu^+(x,Q_0^2) = \frac{AX_{0u}^+ x^b}{\exp[(x - X_{0u}^+)/\bar{x}] + 1} + \frac{\tilde{A}x^{\tilde{b}}}{\exp(x/\bar{x}) + 1}\,, \tag{5}$$

$$x\bar{u}^-(x,Q_0^2) = \frac{\bar{A}(X_{0u}^+)^{-1}x^{2b}}{\exp[(x + X_{0u}^+)/\bar{x}] + 1} + \frac{\tilde{A}x^{\tilde{b}}}{\exp(x/\bar{x}) + 1}\,, \tag{6}$$

$$xG(x,Q_0^2) = \frac{A_G x^{\tilde{b}+1}}{\exp(x/\bar{x}) - 1}\,, \tag{7}$$

and similar expressions for the other light quarks (u^-, d^+ and d^-) and their antiparticles. We assumed $\Delta G(x,Q_0^2) = 0$ and the strange parton distributions $s(x,Q_0^2)$ and $\Delta s(x,Q_0^2)$ are simply related [11] to $\bar{q}(x,Q_0^2)$ and $\Delta\bar{q}(x,Q_0^2)$, for $q = u, d$. A peculiar aspect of this approach, is that it solves the problem of desentangling the q and $\bar{q}$ contribution through the relationship [12]

$$X_{0u}^+ + X_{0\bar{u}}^- = 0\,, \tag{8}$$

and the corresponding one for the other light quarks and their antiparticles. It allows to get the $\bar{q}(x)$ and $\Delta\bar{q}(x)$ distributions from the ones for $q(x)$ and $\Delta q(x)$.

By performing a next-to-leading order QCD evolution of these parton distributions, we were able to obtain a good description of a large set of very

precise data on $F_2^p(x,Q^2), F_2^n(x,Q^2), xF_3^{\nu N}(x,Q^2)$ and $g_1^{p,d,n}(x,Q^2)$ data, in correspondance with the *eight* free parameters :

$$X_{0u}^+ = 0.46128,\ X_{0u}^- = 0.29766,\ X_{0d}^- = 0.30174,\ X_{0d}^+ = 0.22775\,, \tag{9}$$

$$\bar{x} = 0.09907,\ b = 0.40962,\ \tilde{b} = -0.25347,\ \tilde{A} = 0.08318\,, \tag{10}$$

and three additional parameters, which are fixed by normalization conditions

$$A = 1.74938,\ \bar{A} = 1.90801,\ A_G = 14.27535\,. \tag{11}$$

Therefore crucial tests will be provided by measuring flavor and spin asymmetries for antiquarks, for which we expect [11, 12]

$$\Delta\bar{u}(x) > 0 > \Delta\bar{d}(x)\,, \tag{12}$$

$$\Delta\bar{u}(x) - \Delta\bar{d}(x) \simeq \bar{d}(x) - \bar{u}(x) > 0\,. \tag{13}$$

The inequality $\bar{d}(x) - \bar{u}(x) > 0$ has the right sign to agree with the defect in the Gottfried sum rule [2], but not with the trend shown at high x by the E886 experiment [13]. An important test will be provided by studying $W^\pm$ production at RHIC-BNL at $\sqrt{s} = 200$GeV [11].

The HERMES Collaboration has provided [14] a measurement of $\Delta\bar{u}(x) - \Delta\bar{d}(x)$ displayed in Fig. 1, which shows, within the large errors, consistency both with the vanishing value implied by a flavor symmetric polarization of the sea and with our predicted positive value, but disfavors the large positive values predicted by the chiral QSM [15].

The other polarized structure function $g_2(x,Q^2)$, if one neglects twist-three contributions, is given in terms of $g_1(x)$ by the Wandzura-Wilczek formula [16]

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{g_1(y,Q^2)}{y} dy\,. \tag{14}$$

We compare our prediction for $g_2^{p,WW}(x,Q^2)$ with the preliminary data from SLAC [17] in Fig. 2 and we conclude that the theoretical curve is in good agreement with the experimental data. In Fig. 3 we compare our prediction for $g_2^{n,WW}(x,Q^2)$ with the available measurements [18]$^-$[20] and, once again, there is no disagreement with the data, since about the same number of the central values of the experimental points, which are affected by large experimental errors, fall above and beneath the theoretical curve. The functions

$g_1(x,Q^2)$ and $g_2(x,Q^2)$ enter in the expression of the asymmetry $A_1(x,Q^2)$ measured in polarized DIS, as follows

$$A_1(x,Q^2) = \frac{[g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)]\, 2x[1+R(x,Q^2]}{(1+\gamma^2)F_2(x,Q^2)}\,, \tag{15}$$

where $\gamma^2 = 2M_p x/Q^2$ and R is the ratio of longitudinal and transverse virtual photo-absorption cross sections. We plot in Figs. 4, 5, our predictions for A_1^p and A_1^n respectively, and compare them with the available experimental results [18]$^-$[26], including three recent points for A_1^n at high x measured at Jefferson Lab. [27], which are in fair agreement with our predictions. In particular the positive values found at high x for A_1^n agree with the dominance of the parton $d^+(u^+)$ at higher x in the neutron (proton), which is a typical consequence of our parton statistical approach. In Fig. 5, the dashed curve corresponds to $A_1^n = g_1^n/F_1^n$, which is obtained by making the approximation $g_2^n = -g_1^n$. We see that the use of the exact Wandzura-Wilczek expression for g_2^n Eq. (14) leads to a larger A_1^n at high x, as shown by the solid curve. The same effect exists also for the proton case.

Finally we show in Fig. 6 our predictions in very good agreement with the behavior at high Q^2 and large x of the neutral current structure function $xF_3^{NC}(x,Q^2)$, measured by ZEUS [28] and H1 [29], at HERA in $e^{\pm}p \to e^{\pm}X$.

To conclude, the above comparison between recent experimental results and the predictions of the statistical parton distributions, shows that this simple and physical approach remains reliable. We look forward to more severe tests provided by the flavor and spin asymmetries of $\bar{q}$ distributions.

Acknowledgments

We thank J.P. Chen, Z.E. Meziani, C. Vallèe and X. Zheng for usefull discussions on recent data of their collaborations.

References

[1] H.D. Politzer, Phys. Rev. Lett. 30 (1973) 1346; D.J. Gross, F. Wilson, Phys. Rev. Lett. 30 (1973) 1342.

[2] K. Gottfried, Phys. Rev. Lett. 18 (1967) 1154.

[3] NMC Collaboration, M. Arneodo *et al.*, Phys. Rev. D 50 (1994) R1.

[4] F. Zomer, Nucl. Phys. B (Proc. Suppl.) 79 (1999) 115.

[5] J. Ellis, R. Jaffe, Phys. Rev. D 9 (1974) 1444.

[6] EMC Collaboration, J. Ashman *et al.*, Phys. Lett. B 206 (1988) 364; Nucl. Phys. B328 (1989) 1.

[7] M. Glück, E. Reya, Z. Phys. C 39 (1988) 569.

[8] E143 Collaboration, K. Abe *et al.*, Phys. Rev. D 58 (1998) 112003.

[9] F. Buccella, J. Soffer, Mod. Phys. Lett. A 8 (1993) 225.

[10] C. Bourrely, F. Buccella, G. Miele, G. Migliore, J. Soffer, V. Tibullo, Z. Phys. C 62 (1994) 431.

[11] C. Bourrely, F. Buccella, J. Soffer, Eur. Phys. J., C 23 (2002) 487.

[12] R.S. Bhalerao, Phys. Rev. C 63 (2001) 025208.

[13] NuSea Collaboration, R.S. Towell *et al.*, Phys. Rev. D 64 (2001) 0522002.

[14] HERMES Collaboration, H.E. Jakson, Int. J. Mod. Phys. A 17 (2002) 3551.

[15] B. Dressler *et al.*, Eur. Phys. J. C 14 (2000) 147.

[16] S. Wandzura, F. Wilczek, Phys. Lett. B 72 (1977) 195.

[17] SLAC E155 Collaboration, P.L. Anthony *et al.*, SLAC-PUB-8813, hep-ex/0204028.

[18] E142 Collaboration, P.L. Anthony *et al.*, Phys. Rev. D 54 (1996) 6620.

[19] E143 Collaboration, K. Abe *et al.*, Phys. Rev. D 58 (1998) 112003.

[20] E154 Collaboration, K. Abe *et al.* , Phys. Lett. B 404 (1997) 377.

[21] EMC Collaboration, Ashman *et al.*, Nuc. Phys. B 328 (1989) 1.

[22] E155 Collaboration, P.L. Anthony, Phys. Lett. B 493 (2000) 19.

[23] HERMES Collaboration, A. Airapetian *et al.*, Phys. Lett. B 442 (1998) 484.

[24] SMC Collaboration, Adeva *et al.*, Phys. Rev. D 60 (1999) 072004.

[25] SLAC E154 Collaboration, K. Abe *et al.*, Phys. Rev. Lett. 79 (1997) 26.

[26] HERMES Collaboration, K. Ackerstaff *et al.*, Phys. Lett. B 404 (1997) 383.

[27] Jlab E-99-117 Collaboration, X. Zheng *et al.*, Precision measurement of neutron spin asymmetry and spin-flavor decomposition, submitted to *Phys. Rev. Lett.*.

[28] ZEUS Collaboration, S. Chekanov *et al.*, DESY-02-133, hep-ex/0208040.

[29] H1 Collaboration, C. Adloff *et al.*, Eur. Phys. J. C 19 (2001) 269.

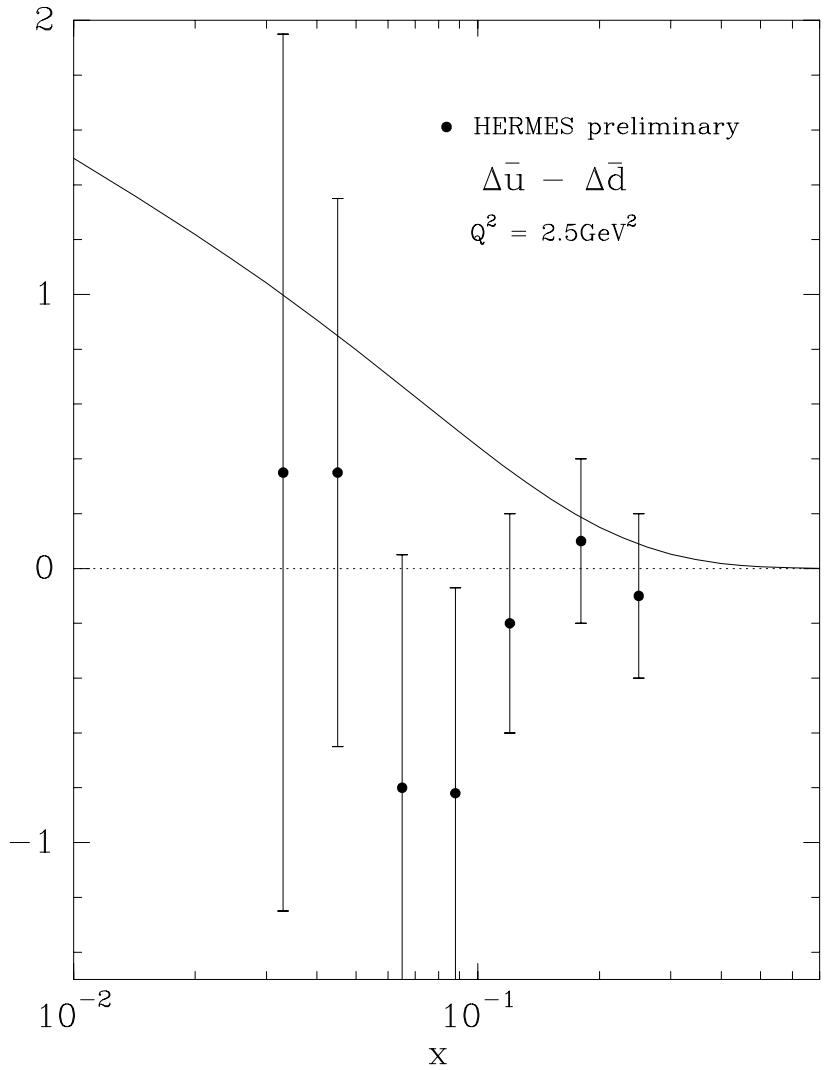

Figure 1: Flavor asymmetry $\Delta\bar{u} - \Delta\bar{d}$ of the light sea quark as a function of x, for $Q^2 = 2.5\mathrm{GeV}^2$. Preliminary data from HERMES Coll. [14].

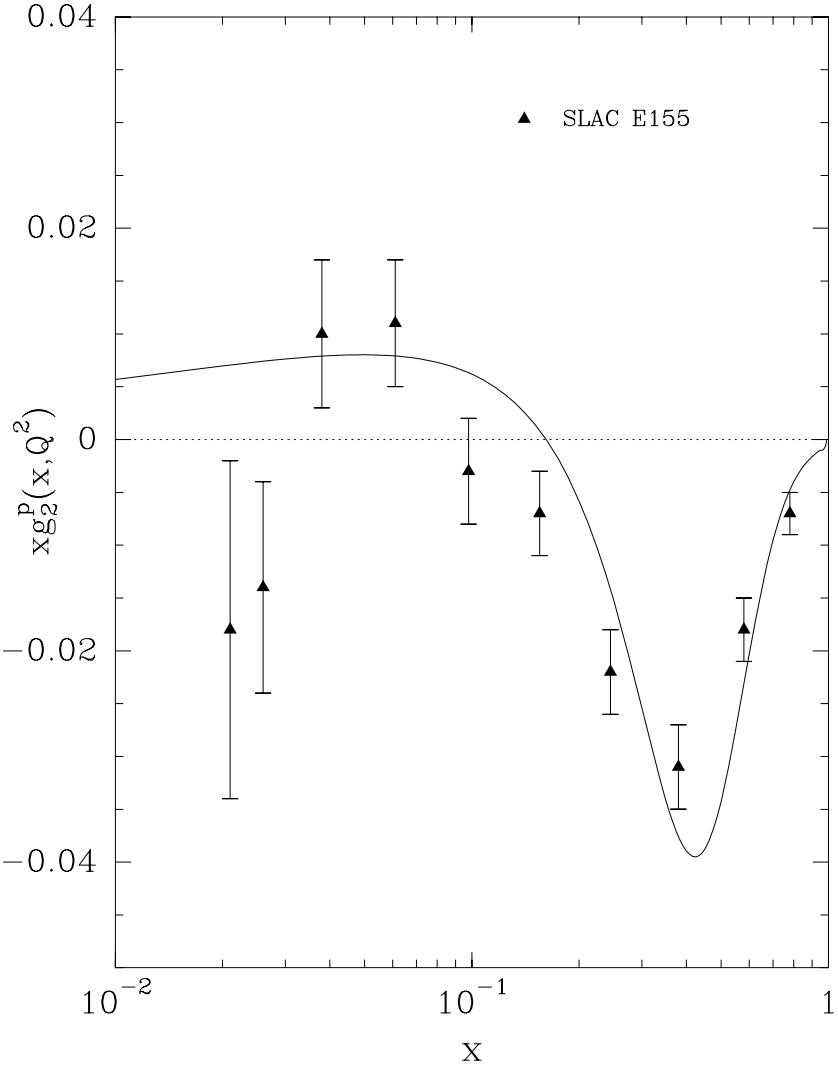

Figure 2: xg_2 for proton as a function of x, for $Q^2 = 4\text{GeV}^2$. Data from SLAC E155 [17].

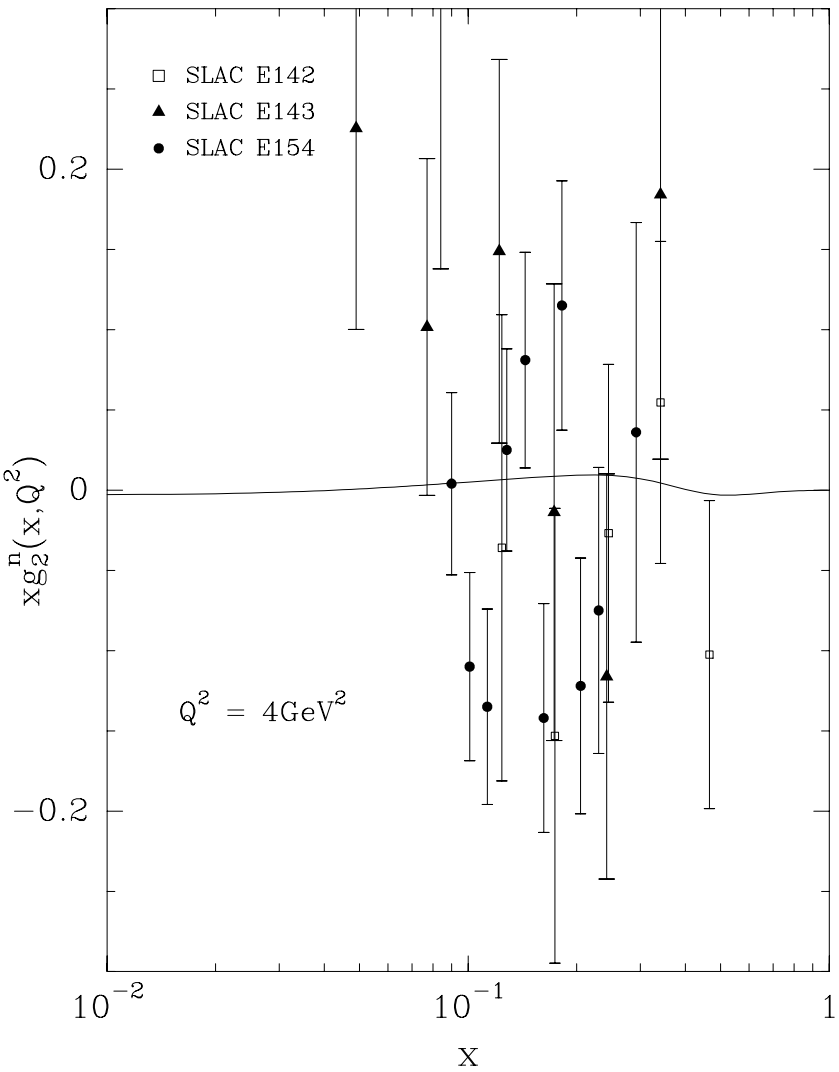

Figure 3: xg_2 for neutron as a function of x, for $Q^2 = 4\mathrm{GeV}^2$. Data from E142, E143, E154 [18]-[20].

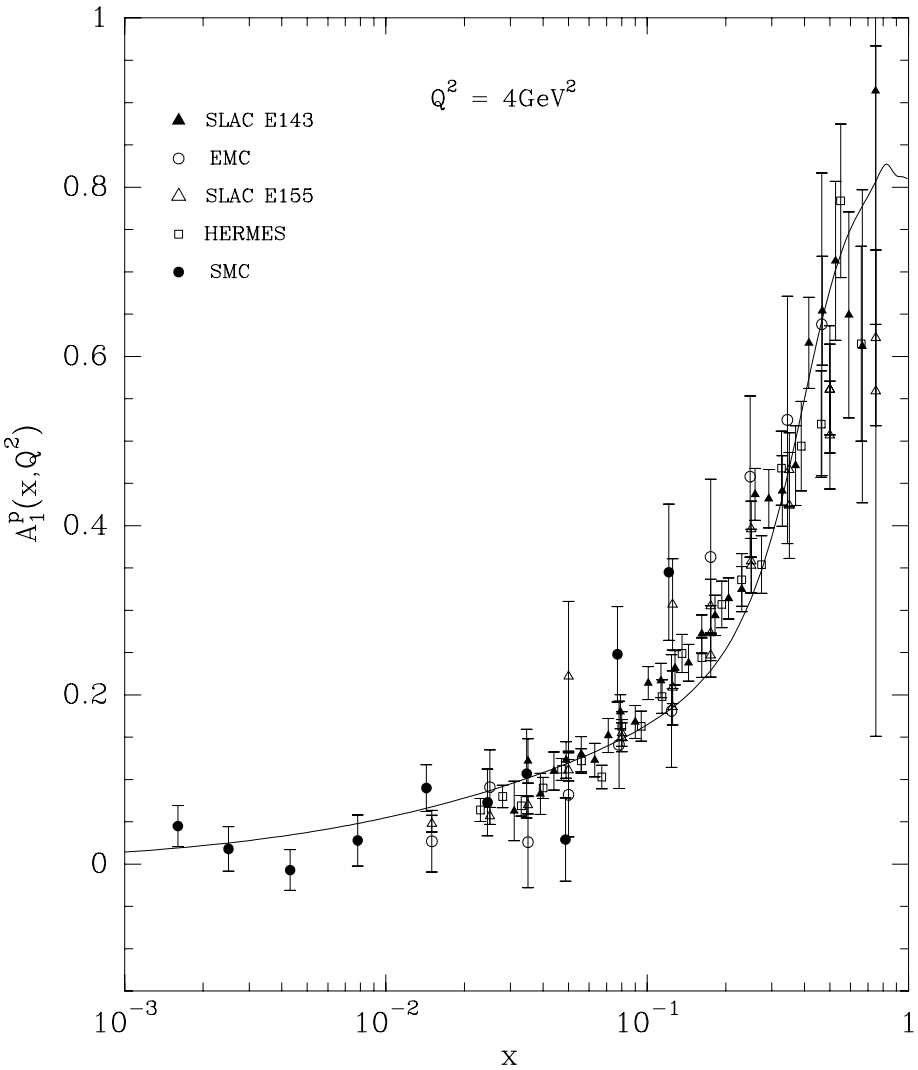

Figure 4: A_1^p as a function of x, for $Q^2 = 4\mathrm{GeV}^2$. Data from E143[19], EMC[21], E155[22], HERMES[23], SMC[24].

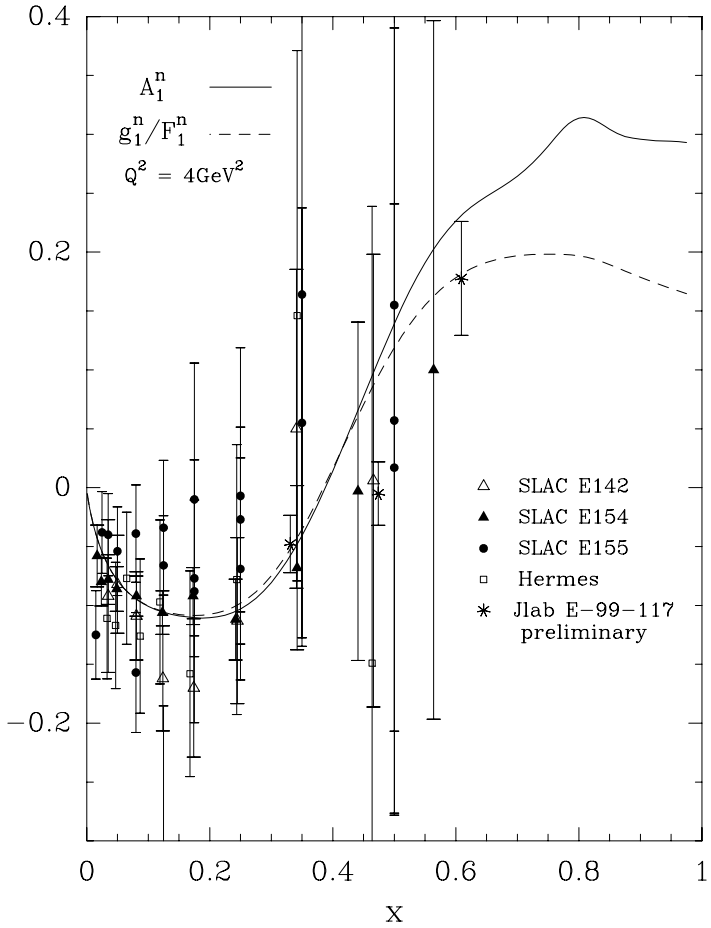

Figure 5: A_1^n as a function of x, for $Q^2 = 4\text{GeV}^2$ solid curve, g_1^n/F_1^n dashed curve. Data from E142[18], E155[22], E154[25], HERMES[26], Jlab E-99-117[27].

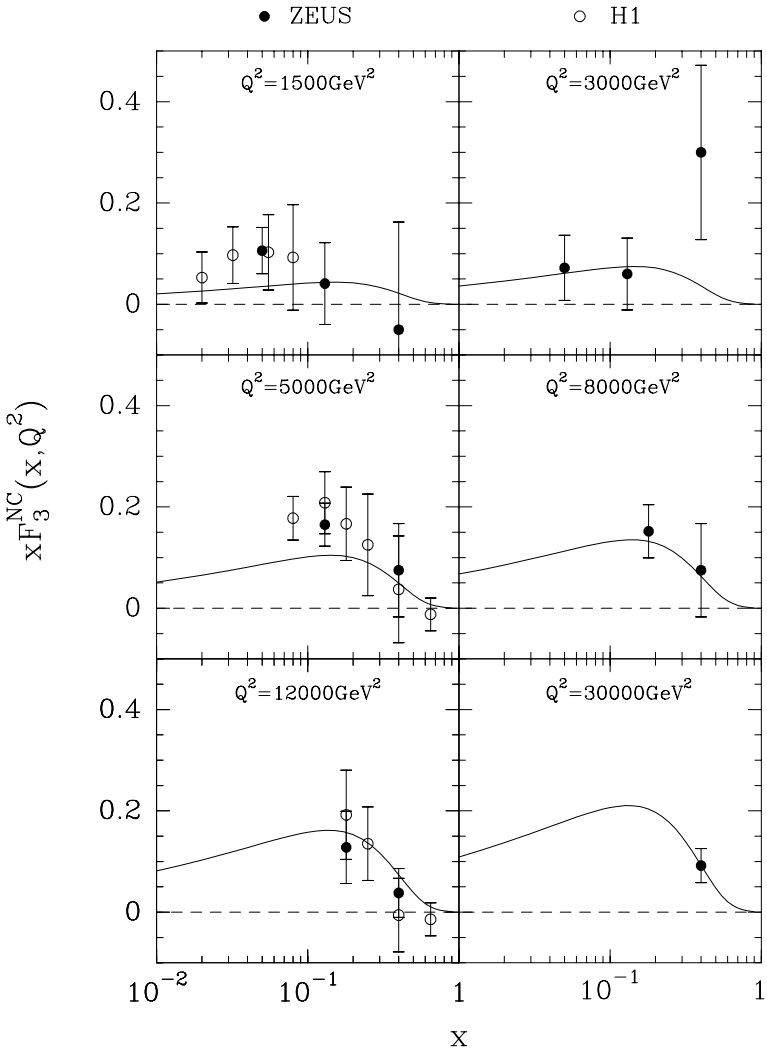

Figure 6: The structure function xF_3^{NC} as a function of x, for different Q^2. Data from ZEUS Coll. [28], H1 Coll. [29].