Summary of Working Group 3

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Abstract. The parallel sessions of the working group 3 were devoted to the discussions of short-baseline neutrino physics program at neutrino factories. First, possible studies of parton distribution functions (PDFs), in particular nuclear and polarized PDFs, are discussed in this summary. Second, the extractions of α_s from sum rules and structure functions of deep-inelastic neutrino-nucleon scattering, higher-order perturbative QCD corrections and estimates of high-twist effects are summarized. Third, the situation of the observed NuTeV $\sin^2\theta_W$ anomaly is discussed.

1. Introduction

Neutrino reactions played an important role in investigations of hadron structure and determinations of basic QCD and electroweak (EW) parameters. Recently, the feasibility of constructing future neutrino factories with intense neutrino beams was investigated in Europe, Japan and US. In particular, proton and deuteron targets will become available at these factories, so that the actual nucleon structure can be investigated together with the detailed studies of nuclear corrections.

In analyzing the neutrino-reaction processes, it is essential to use accurate parton distribution functions (PDFs) in the nucleon. The current status of art was summarized by Stirling [1] in his plenary talk at this workshop. It was explained that different PDF sets are constructed from available experimental data including the data for structure functions in unpolarized and polarized deep-inelastic scattering (DIS). Due to the existence of various experimental data in the wide region of x, the unpolarized PDFs are now well determined from very small x to relatively large x. However, the situation of the polarized PDFs and nuclear PDFs is, in particular, worse than the one of the unpolarized PDFs. It should be stressed that these studies are really important not only for fundamental understanding of hadron structure but also for applications to the reactions with heavy-ions and neutrinos. In the first part of working group 3 (WG3) parallel sessions, we try to understand the present situation of the nuclear and polarized PDFs, and then possible studies at the neutrino factories are discussed.

The physics of various neutrino-induced unpolarized processes was also discussed at this workshop. Because of planned huge statistics of unpolarized νN data with relatively low Q^2 at the neutrino factories, it is becoming more realistic to investigate non-perturbative $1/Q^2$ corrections to Bjorken unpolarized and Gross-Llewellyn Smith sum rules, and their comparison with available theoretical estimates. These phenomenological investigations are closely related to the problem of correlations between high-twist effects and the values of QCD coupling constant α_s, which is extracted from experimental data in different orders of perturbation theory. The related experiments at the neutrino factories can put investigations of the role of twist-4 corrections and determinations of α_s-values from νN DIS characteristics on more solid ground.

More detailed studies of neutrino-induced processes can be also important for checking the predictions of the standard EW model and independent extractions of its parameters. A typical example is the recent NuTeV work of Ref. [2], which reported that the extracted $\sin^2\theta_W$ value from the ratios of neutral current to charged current DIS cross-sections is in over 3σ deviation from the result of LEP EW Working Group (LEPEWWG). Clearly, this intriguing situation is waiting its explanation.

We summarize the presentations during the first two days of the WG3 parallel sessions. The discussions of nuclear and polarized PDFs are reported in Sec. 2. The DIS sum rules, higher-twists, extractions of α_s, modified GRV98 leading-order unpolarized PDFs and the status of NuTeV anomaly are discussed in Sec. 3. Low-energy neutrino physics was discussed at the joined sessions with the working group 2 on the third day, and this part is included in the summary of the working group 2 [3].

2. Parton distribution functions

The first day of the WG3 parallel sessions was focused on discussions of the nuclear and polarized PDFs. Note that there are extensive reports on structure functions and PDFs at future neutrino factories by M. L. Mangano *et. al.* [4, 5] and C. Albright *et. al.* [6] , so that the reader may look at these reports for introduction.

2.1. Nuclear PDFs

There were three talks on the nuclear PDFs by J. G. Morfin, C. A. Salgado, and S. Kumano. It is known that nuclear effects modify the PDFs in the nucleon. This topic has been investigated since the discovery of the EMC effect for the structure functions F_2 in muon scattering. However, due to the lack of accurate deuteron data, nuclear effects are not seriously investigated in neutrino-nucleus scattering. If a neutrino factory is built, as discussed in this workshop, it could play an important role in determining accurate nuclear PDFs. The studies are valuable for high-energy nuclear structure physics, application to heavy-ion phenomena, and also neutrino oscillation physics.

The nuclear PDFs have been investigated in the leading order by many people; however, the first serious parameterization was reported by Eskola, Kolhinen, Ruuskanen, and Salgado (EKRS) [7]. In the EKRS set, the x region is divided into three parts. In the large x region, the F_2 data fix valence-quark behavior but sea-quark and gluon distributions are not determined. In the medium x region, the F_2 and Drell-Yan data constrain both the valence and sea distributions. At small x, they can determine the sea-quark distributions form the F_2 data, and the valence distributions are constrained by the baryon number. Certain x dependent functional forms are assumed in these three regions, and they are determined so as to agree with the F_2 and Drell-Yan (DY) data.

The PDFs in the nucleon have been obtained by χ^2 analyses of various high-energy reaction data. Unfortunately, such a technique was not developed for the nuclear PDFs until recently. The studies of Ref. [8] are intended to create a simple χ^2 method. Used data set was limited to F_2^A/F_2^D, so that the obtained distributions are rather different from those of the EKRS analysis. In particular, the small-x valence-quark and medium-x antiquark distributions are very different because the DY data are not included. After the publication, the analysis has been extended by including the DY data, and the preliminary results show a similar x dependent form to the EKRS except for the gluon distribution at medium x. At this stage, it is not possible to fix the gluon distribution in such an x region in any case.

These nuclear PDF analyses will not be developed significantly without new experimental data. As a new neutrino facility, the Fermilab-NuMI project was explained by J. G. Morfin [9]. The unpolarized cross section for neutrino scattering is expressed in term of three structure functions F_1, F_2, and F_3:

$$\frac{d^2\sigma}{dxdy} = \frac{G_F^2 s}{2\pi(1+Q^2/M_W^2)^2}\left[(1-y)F_2 + y^2 xF_1 \pm y(1-y/2)xF_3\right], \qquad (1)$$

where $+$ and $-$ of $\pm$ indicate neutrino and antineutrino reactions, respectively. The facility provides an extremely intense neutrino beam, and it is ideal for high statistics neutrino-nucleon/nucleus experiments. Among many physics topics at the NuMI facility, it is a unique opportunity for investigating the nuclear PDFs, particularly, the nuclear modification of the valence-quark distributions through the structure function F_3:

$$\frac{1}{4}\,[\,F_3^{\nu(p+n)} + F_3^{\bar{\nu}(p+n)}\,] = u_v + d_v + (s-\bar{s}) + (c-\bar{c}) \approx u_v + d_v \ . \qquad (2)$$

It is predicted by the parameterizations and some model studies, for example, by S. A. Kulagin [10] that the valence shadowing is in general different from the antiquark one. In the first stage of NuMI, carbon, iron, and lead targets are installed, then the ratios Fe/C and Pb/C are obtained typically within a few percent statistical errors by the three-year MINOS run. In the subsequent stage, LH_2 and LD_2 targets are prepared to measure proton and deuteron structure functions. Then, the ratios to the deuteron (A/D) will be obtained to find the nuclear effects. This topic will be also investigated eventually at the neutrino factories. There are other interesting aims of the NuMI project, namely studies of quasi-elastics scattering, $\sin^2\theta_W$ issue, polarized strange-quark and charm quark distributions [9].

2.2. Polarized PDFs

The details of the polarized PDFs are not known to the same extent that they are understood in the unpolarized PDFs. The reason is that a variety of data are not yet available. The data come from inclusive and semi-inclusive electron or muon scattering from the polarized proton, deuteron, and ^{3}He. However, they are not enough to determine the details of unpolarized PDFs, such as the polarized gluon distribution and x-dependent shape of antiquark distributions. Nevertheless, in the case of polarized PDFs, the situation is better than the one for the nuclear PDF studies. Indeed, there are on-going polarized experiments such as RHIC and COMPASS. Moreover, several active groups for the global χ^2 analysis are working in this area.

The results of recent global analyses of polarized data were reported at this workshop by J. Blümlein, E. Leader, and M. Hirai. The techniques of their analysis are almost the same. Blümlein and Böttcher (BB) [11], Leader, Sidorov, and Stamenov

(LSS) [12], and Asymmetry Analysis Collaboration (AAC) [13] have slightly different initial distributions:

$$
\begin{aligned}
x\Delta f_i(x,Q_0^2) &= \eta_i\, A_i\, x^{a_i}\, (1-x)^{b_i}\, (1+\gamma_i\, x+\rho_i\sqrt{x}) && \text{in BB,}\\
\Delta f_i(x,Q_0^2) &= \eta_i\, A_i\, x^{a_i}\, f_i(x,Q_0^2) && \text{in LSS,}\\
\Delta f_i(x,Q_0^2) &= A_i\, x^{\alpha_i}\, (1+\gamma_i\, x^{\lambda_i})\, f_i(x,Q_0^2) && \text{in AAC.}
\end{aligned}
\tag{3}
$$

Here, f_i is the corresponding unpolarized distribution in the nucleon. There are also other recent studies on the polarized PDFs [14]. These distributions are evolved to the experimental Q^2 points of the spin asymmetry A_1 or g_1. Then, the parameters in Eq. (3) are determined so as to minimize the χ^2 value. In the updated analysis of the LSS, the SLAC-E155 data are included by taking care of the positivity constraint and using updated values for the axial charges a_3 and a_8. It is important that the BB analysis demonstrated error bands for the polarized PDFs, so that the uncertainties of the present distributions become clear. In particular, the error band is very large for the polarized gluon distribution, which should be determined more precisely by future measurements. An error analysis was also made by AAC. The AAC error bands show similar tendency; however, the details are different due to the different choice of the functional form. For example, the gluon error is larger for AAC than the one for BB.

Possibilities of determining the polarized strange-quark distribution in neutrino reactions were discussed by K. Sudoh, and charmed meson detectors were discussed by P. J. M. Soler. Semi-inclusive D and $\bar{D}$ production cross sections were investigated in polarized neutrino-proton reactions [15]. Four different parameterizations, AAC, BB, GRSV, and LSS, are used for calculating the polarization asymmetry. Because a charm quark is produced partially from a strange quark in the nucleon, the studies indicate that the polarized strange-quark distribution could be measured by these reactions. Experimentally, silicon detectors have been developed by the NOMAD-STAR group [16] for the charm identification in neutrino reactions, and it was installed inside the NOMAD experiment. From about 11,500 ν_μ charged-current events, 45 charmed mesons were obtained. The studies indicate that the silicon detectors could be used at the future neutrino factories for identifying the charmed mesons, so that they could contribute significantly to the PDF studies.

The situation of the HERMES experiment and possible neutrino experiments were presented by T.-A. Shibata. Near-future polarized experiments were discussed by N. Saito. The HERMES experiments measured semi-inclusive hadron production cross sections in polarized electron-nucleon scattering, and the data enabled them to investigate flavor decomposition of the polarized PDFs [17]. Furthermore, the single spin azimuthal asymmetry measurements indicated chiral-odd distributions. From his experience of these experiments, he suggested that a future neutrino factory should have detectors with good particle identification in the final state for precise determination of the polarized PDFs. Next, N. Saito explained the present and near-future experiments to study the polarized PDFs [18]. The present data are mainly taken for the inclusive structure function g_1 and some semi-inclusive reactions, so that they provide us a limited information for the gluon polarization. However, since RHIC, HERMES, COMPASS, and TESLA-N projects intend to measure $\Delta g(x)/g(x)$ accurately, the situation should become clear in the near future. In particular, he demonstrated that the RHIC Δg measurements provide a strong constraint for the gluon polarization. Indeed, after including virtual RHIC data in the global fit, the Δg error becomes significantly smaller. In addition, the W production measurements should provide a constraint for the polarized antiquark distributions.

As for the polarized PDFs and structure functions at the neutrino factories, there were discussions by E. Leader and G. Ridolfi. There are extensive studies of polarized structure functions and polarized PDFs, which could be obtained from the possible European neutrino factory [4, 5]. In addition to the polarized structure functions g_1 and g_2 in electron or muon scattering, there are new ones, namely g_3, g_4, and g_5, in polarized neutrino scattering. In should be noted, however, that there are different definitions for these functions among researchers, and they are summarized in Ref. [19]. In the convention of Refs. [4, 5, 19], g_4 and g_5 are related by $g_4 = 2xg_5$ in the leading order. Neglecting the g_2 and g_3 terms by taking the high-energy limit, we have [4, 5]

$$\frac{d^2\Delta\sigma^{\lambda_\ell}}{dx\,dy} = \frac{G_F^2}{\pi(1+Q^2/m_W^2)^2}\frac{Q^2}{xy}[-\lambda_\ell\, y(2-y)xg_1 - (1-y)g_4 - y^2 x g_5], \tag{4}$$

where λ_ℓ is the lepton helicity, and $\Delta\sigma$ is the difference between the polarized cross sections: $\Delta\sigma = \sigma_{\lambda_p=-1} - \sigma_{\lambda_p=+1}$ with the proton helicity λ_p.

The charged-current structure functions g_1 and g_5 are expressed in term of the polarized PDFs in the leading order:

$$\begin{aligned} g_1^{W^+} &= \Delta\bar{u} + \Delta d + \Delta s + \Delta\bar{c}, \quad & g_1^{W^-} &= \Delta u + \Delta\bar{d} + \Delta\bar{s} + \Delta c, \\ g_5^{W^+} &= \Delta\bar{u} - \Delta d - \Delta s + \Delta\bar{c}, \quad & g_5^{W^-} &= -\Delta u + \Delta\bar{d} + \Delta\bar{s} - \Delta c. \end{aligned} \tag{5}$$

A combination of the g_1 structure functions becomes the flavor singlet distribution:

$$\begin{aligned} \Delta\Sigma(x) &= (g_1^{W^+ + W^-})_p = (g_1^{W^+ + W^-})_n \\ &= \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s} + \Delta c + \Delta\bar{c}, \end{aligned} \tag{6}$$

where isospin symmetry is used for the distributions in the neutron. It is especially important that the spin content $\Delta\Sigma = \int dx \Delta\Sigma(x)$ is found directly. In the present situation, the spin content is determined by the χ^2 analysis of electron and muon scattering data together with the first moments $\int dx \Delta u_v$ and $\int dx \Delta d_v$, which are fixed by semi-leptonic decay data. According to Eq. (6), we do not have to rely on such low-energy data. As noticed in Ref. [13], the accurate determination of $\Delta\Sigma$ is not possible at this stage because the polarized antiquark distribution $\Delta\bar{q}(x)$ cannot be determined at small x from the present data. The neutrino reactions should provide valuable information on the spin content. Combining these structure functions, we obtain, for example,

$$\begin{aligned} &(g_5^{W^+ + W^-})_p = (g_5^{W^+ + W^-})_n = -\Delta u + \Delta\bar{u} - \Delta d + \Delta\bar{d} - \Delta s + \Delta\bar{s} - \Delta c + \Delta\bar{c}, \\ &(g_5^{W^+ - W^-})_p + (g_5^{W^+ - W^-})_n = -2\,(\Delta s + \Delta\bar{s}) + 2\,(\Delta c + \Delta\bar{c}), \\ &(g_1^{W^+ - W^-})_p + (g_1^{W^+ - W^-})_n = 2\,(\Delta s - \Delta\bar{s}) - 2\,(\Delta c - \Delta\bar{c}). \end{aligned} \tag{7}$$

Therefore, the first g_5 combination is especially useful for determining the polarized valence-quark distributions. Furthermore, the second g_5 combination indicates the polarized strange- and charm-quark distributions. If the g_1 data are accurate enough, it could be possible to find the difference between Δs and $\Delta\bar{s}$. The feasibility of measuring these structure functions g_1 and g_5 was investigated for the European neutrino factory in Ref. [5], and possible errors are estimated in the region $x > 0.1$. In particular, G. Ridolfi showed in his talk that the first moments of C-even distributions $(\Delta q + \Delta\bar{q})$ could be improved by an order of magnitude in comparison with the present uncertainties, whereas those of C-odd distributions $(\Delta u - \Delta\bar{u},\, \Delta d - \Delta\bar{d})$ are determined at the level of a few percent. In this way, measurements of g_1 and g_5 should provide important information for the polarized PDFs.

3. Unpolarized deep-inelastic scattering

The second part of the WG3 sessions was devoted to the discussions of the physical information, which can be obtained from theoretical and experimental considerations of characteristics of unpolarized DIS. These characteristics are related to the differential cross-sections in Eq. (1) where $0 \le x \le 1$, $y = E_{had}/E_\nu$, and $0 \le y \le 1/(1 + \frac{xM_W}{2E_\nu})$. Because of the large variation of y at the neutrino factories [4], it is possible to extract not only the standard structure functions (SFs) $F_2^{\nu N}$ and $xF_3^{\nu N}$ but also $F_1^{\nu N}$ from the cross-sections of Eq. (1). This procedure might allow us to push ahead new QCD studies, which aim at a direct analysis of scaling violation in $F_1^{\nu N}$ SF data. Moreover, in addition to two well-known sum rules of νN DIS, namely to the Adler sum rule

$$I_{F_2} = \int_0^1 \frac{dx}{x}\left[F_2^{\nu n}(x,Q^2) - F_2^{\nu p}(x,Q^2)\right] = 2 \tag{8}$$

and the Gross–Llewellyn Smith sum rule

$$I_{F_3} = \frac{1}{2}\int_0^1 \left[F_3^{\nu n}(x,Q^2) + F_3^{\nu p}(x,Q^2)\right] = 1 - \frac{\alpha_s}{\pi} - ... + O\left(\frac{1}{Q^2}\right) , \tag{9}$$

it will also be possible to verify the Bjorken unpolarized sum rule

$$I_{F_1} = \int_0^1 dx\left[F_1^{\nu n}(x,Q^2) - F_1^{\nu p}(x,Q^2)\right] = 1 - \frac{2}{3}\frac{\alpha_s}{\pi} - .... + O\left(\frac{1}{Q^2}\right) . \tag{10}$$

Note that, contrary to the exact theoretical expression for Eq. (8), the integrals I_{F_3} and I_{F_1} contain perturbative QCD corrections, calculated explicitly in the $\overline{MS}$-scheme up to order α_s^3 in Refs.[20] and [21] respectively and estimated by different ways at the α_s^4 level (see Refs.[22, 23, 24]). Therefore, experimental measurements of these DIS sum rules can provide useful information on the value of the QCD coupling constant α_s. Moreover, while the existing sets of data for the xF_3 SF, including the most precise published one provided by the CCFR collaboration [25], were already used for the extraction of I_{F_3} at different Q^2 bins [26] (see Ref. [27] for the discussion of the Q^2 behavior of I_{F_3}, extracted from previous CCFR data), new experiments at the neutrino factories can give the possibility of the first measurement of the I_{F_1} sum rule. It is interesting from the point of view of an independent determination of α_s (see Ref. [4]). This problem was discussed at this workshop in the talk of Ref. [28].

It should be stressed that theoretical α_s ambiguities, which result from the comparison of the QCD predictions with DIS experimental data, and with the sum rules I_{F_3} and I_{F_1} in particular, are related to the uncertainties in the non-perturbative twist-4 corrections. They manifest themselves as the $O(1/Q^2)$-contributions to the corresponding theoretical predictions. In the case of the mentioned sum rules, the twist-4 model-independent matrix elements are known [29]. The problem of getting concrete numbers for these matrix elements was discussed in detail in the talk of Weiss [30]. He presented the preliminary calculations of twist-4 contributions to I_{F_3} and I_{F_1} within the framework of the instanton-vacuum model, developed in Ref. [31]. In the case of I_{F_3}, the reported estimates turned out to be in good agreement with the ones obtained in Ref.[32] with the help of three-point function QCD sum rules. Within existing theoretical uncertainties, this result of Ref. [32] is supported by the independent three-point function QCD sum rule analysis of Ref. [33]. In the case of another twist-4 operator, which contributes to I_{F_1}, the estimate reported by Weiss also confirmed the results of Ref. [32] obtained with the help of three-point function

QCD sum rules. As demonstrated in Ref. [28], the errors of the twist-4 contribution to I_{F_1} are playing the dominant role in the uncertainties of $\alpha_s(M_Z)$, extracted from the Q^2-behavior of this sum rule with the next-to-leading order (NLO) PDF set of Ref. [34]. Indeed, in the process of normalizing the theoretical expression for I_{F_1} to $Q^2 = 4$ GeV^2 and $Q^2 = 10$ GeV^2, the authors of Ref. [28] obtained $\Delta^{HT}\alpha_s(M_Z) = 0.012$ and $\Delta^{HT}\alpha_s(M_Z) = 0.007$. It is now important to fix in more detail the theoretical errors in the calculations of the twist-4 contributions to I_{F_1}, performed by different methods in Refs. [32] and [30].

However, the inclusion of higher-order perturbative QCD corrections into the $\alpha_s(M_Z)$ determination procedures can result in the appearance of a problem of correlations between perturbative and non-perturbative QCD contributions. This property was discovered in the process of the next-to-next-to-leading order (NNLO) fits to xF_3 data of the CCFR collaboration [35] with the NNLO corrections to anomalous dimensions of even non-singlet moments for F_2 SF calculated in Ref. [36]. (The summary of more detailed recent NNLO fits to xF_3 data [37] was reported to WG3 in the talk of Ref. [38]. The fits performed in Ref.[37] are based on the application of the NNLO corrections to anomalous dimensions of odd moments for xF_3 SF calculated in Ref. [39].) A similar pattern, discussed in the contribution of Ref.[40], was independently revealed in Ref. [41] in the process of the NNLO fits to SLAC, NMC and BCDMS data for the F_2 SF. As was argued further on [42] (see the talk by Cvetic [43]), the application of the Borel resummation technique, together with the incorporation of the the $1/Q^2$-term typical to the infrared renormalon approach (for a review, see Ref. [44]), leads to a minimization of the role of this power correction in the procedure of extracting $\alpha_s(M_Z)$ from the data for I_{F_3} at $Q^2 \leq 4$ GeV^2. The result in Ref. [43],

$$\alpha_s(M_Z) = 0.1167^{+0.0128}_{-0.0118}\ (\mathrm{exp}) \pm 0.0008\ (\mathrm{th})\ , \tag{11}$$

which follows from the resumed perturbative expression for I_{F_3}, turned out to be closer to the world average value of $\alpha_s(M_Z) = 0.1184 \pm 0.0031$ [45] than its analogue:

$$\alpha_s(M_Z) = 0.114^{+0.005}_{-0.006}\ (\mathrm{stat})^{+0.007}_{-0.009}\ (\mathrm{syst}) \pm 0.005\ (\mathrm{th}) \tag{12}$$

obtained in Ref. [26] by the CCFR/NuTeV collaboration from the truncated NNLO perturbative series for I_{F_3}, supplemented with the estimate of twist-4 power correction from Ref. [32]. Note that from our point of view, the theoretical uncertainties in Eq. (11) might be underestimated. Moreover, in view of different opinions on the role of non-perturbative effects in the extraction of α_s from the I_{F_3} sum rule and of the possible appearance of more precise data for xF_3 at the neutrino factories, it would be useful to clarify the role of twist-4 terms in the $\alpha_s(M_Z)$ determination from the I_{F_3} sum rule.

Let us return to the problem of parameterizing non-perturbative effects to DIS SFs. Contrary to the discussed sum rules, the complete form of dynamical twist-4 corrections in both xF_3 and F_2 is unknown. Therefore, various models for $1/Q^2$ contributions are generally used. The most popular one was constructed in Ref. [46] with the help of the infrared renormalon (IRR) approach. Within this approach, the $1/Q^2$ contributions to SFs are defined as $F_i^{HT}/Q^2 = (A_2^{'}/Q^2)\int_x^1 (dz/z) C_i(z) q(x/z, Q^2)$, where $q = u_v + d_v$ indicates the valence contributions, $C_i(z)$ is a part of the coefficient function which is calculated from the chain of quark, gluon and ghost loop insertions into the internal gluon line of the corresponding Born diagrams, and $A_2^{'}$ is the free parameter which should be extracted from the fits to experimental data.

Here we recall that in the era when experimental results for xF_3 were not precise enough, the concrete fits of Ref. [47] were not able to make an unambiguous choice between perturbative and non-perturbative sources of scaling violation. At present, thanks to the increase in precision of νN DIS experiments, it has become possible to separate the two mechanisms of scaling violation in the process of NLO fits. Indeed, the most recent NLO analysis of CCFR data for xF_3 SF [37] described in the talk of Ref. [38] allowed the extraction of both $\alpha_s(M_Z)$ of the $\overline{MS}$-scheme and the free parameter of the IRR model $A_2^{'}$ with reasonable error bars:

$$\alpha_s(M_Z) = 0.120 \pm 0.002 \text{ (stat)} \pm 0.005 \text{ (syst)} \qquad (13)$$
$$\pm\, 0.002 \text{ (thresh)}^{+0.010}_{-0.006} \text{ (scale)}$$
$$A_2^{'} = -\,0.125 \pm 0.053 \text{ GeV}^2 \ . \qquad (14)$$

The theoretical errors in $\alpha_s(M_Z)$ reflect the uncertainties in passing the threshold of production of b-quarks and the ambiguities in choosing renormalization and factorization scales. It is interesting that the NLO fits to F_2 data, performed in Ref. [41] with the help of the MRS(R2) PDF set [48] result in the value of $A_2^{'} = -0.104 \pm 0.005$ GeV^2, which is in agreement with the result of Eq. (14).

As shown in the talks of Refs. [38, 40], the incorporation of the NNLO corrections into the fits to xF_3 and F_2 data makes the detection of dynamical $1/Q^2$- contributions more problematic, provided that the NNLO values of $\alpha_s(M_Z)$ are lying not far from the world average result of $\alpha_s(M_Z) \approx 0.118$. Indeed, the IRR model parameter obtained from the NNLO fits to CCFR'97 xF_3 data is comparable with zero, within the statistical error bars: $A_2^{'} = -0.013 \pm 0.051$ GeV^2 (see e.g. Ref. [37]). A similar value, namely $A_2^{'} = -0.0065 \pm 0.0059$ GeV^2, was obtained from the NNLO fits to F_2 SF data [41] based on application of the recent estimates of the NNLO DGLAP splitting functions for the NNLO PDFs [49]. Moreover, as shown in Refs. [50, 37, 51], the effect of minimization of the $1/Q^2$ contributions to xF_3 SF extracted at the NNLO does not depend on the model chosen for their parameterization. Thus, we are returning to the situation of 1979 at a new level of understanding. Indeed, we can conclude that, in order to detect at the NNLO signals from dynamical $1/Q^2$-contributions to the DIS structure functions, we need more precise experimental data, which can be obtained in the future at the neutrino factories.

It is planned that the neutrino factories will cover the region with low Q^2. In the second part of the contribution of Ref.[40], based on the second talk of Bodek, the modification of GRV98 LO PDFs [52] was proposed. The main modifications are based on the application of the introduced new scaling variable ξ_w (see Ref.[40]). These modified GRV98 LO PDFs can be used to model electron, muon and neutrino inelastic scattering cross-sections at both very low and high energies.

Among the most recent problems discussed at the WG3 meeting, there was the NuTeV anomaly, described in the detailed talk of Bernstein [53]. In this talk, the extracted $\sin^2\theta_W$ from NuTeV data for the ratios of neutral current to charged current DIS cross-sections

$$R^{\nu} = \frac{\sigma(\nu N \to \nu X)}{\sigma(\nu N \to l^- X)} \ \text{ and } R^{\overline{\nu}} = \frac{\sigma(\overline{\nu} N \to \overline{\nu} X)}{\sigma(\overline{\nu} N \to l^+ X)} \qquad (15)$$

is reported. The NuTeV collaboration obtained the ratios $R^{\nu} = 0.3916 \pm 0.0007$ and $R^{\overline{\nu}} = 0.4050 \pm 0.0016$ from their data. Using a LO description for the cross-sections with the LO PDFs, they obtained the following value for $\sin^2\theta_W$ [2]:

$$\sin^2\theta_W^{on-shell} = 0.2277 \pm 0.0013\ (\text{stat}) \pm 0.009\ (\text{syst}) \\ - 0.00022\left(\frac{M_t^2 - (175\ \text{GeV})^2}{(50\ \text{GeV}^2)}\right) + 0.00032\ln\left(\frac{M_{Higgs}}{150\ \text{GeV}}\right)\,. \tag{16}$$

This value has a 3σ deviation from the one obtained from the fit to other electroweak measurements by LEPEWWG: $\sin^2\theta_W^{on-shell} = 0.2227 \pm 0.0037$. The origin of the new NuTeV deviation from the standard LEPEWWG one was tried to be understood in the talk of Davidson [54], which was based on the detailed work of Ref. [55]. Unfortunately no convincing enough arguments in favor of the explanation of the origin of the existing discrepancy (see, however, Ref. [56]) including the consideration of definite effects from physics beyond the standard model, were found. In this situation, it is worth while relying on publication of NuTeV data for cross-sections and SFs to allow the interested community to try to clarify the situation with the help of independent analyses of these new experimental data, which should include all types of QCD effects, including those related to NLO perturbative QCD corrections.

To conclude, the work of WG3 at the NuFact'02 workshop turned out to be valuable for various aspects of non-oscillation neutrino physics. We hope that the outcome of these works will be used for the continuation of the planning of new experiments at the neutrino factories.

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