High twists and the NNLO QCD corrections in DIS

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Abstract

We discuss interplay between the high-twist (HT) terms in the operator-product expansion and the next-to-next-to-leading-order (NNLO) QCD corrections to the deep-inelastic-scattering structure functions in analysis of the high-precision data for charged leptons. Under account of the NNLO corrections the observed HT terms change within their experimental errors only and do not vanish in the NNLO.

The high-twist (HT) contribution to the deep-inelastic-scattering (DIS) structure functions arising in the operator-product expansion (OPE) obey the power-like dependence on the momentum transferred Q. This Q-dependence of the HT terms differs from the logarithmic-like Q-dependence typical for the leading-twist (LT) terms. Nevertheless the problem of separation of the HT and LT terms is discussed for many years. This problem was recognized in Ref.[1] and was confirmed with the observation that the HT terms decrease under account of the NLO QCD corrections to the leading-twist (LT) terms in the analysis of DIS data. Later the decrease of the HT terms under account of the NNLO corrections was observed in the analysis [2] of νN DIS data [3]. This interplay between the higher-order (HO) corrections and the HT terms is ascribed to both the HO corrections and the HT terms are largest at small Q at that the Q-dependence of HO corrections is similar to the Q-dependence of HT terms ($\alpha_s^n(Q) \sim 1/Q^m$). Meanwhile interplay of the HO corrections and the HT terms is possible only if statistical accuracy of the analyzed data is insufficient to disentangle the log-type and power-like contributions to the structure functions (evidently this is the case for the data of Ref. [3]). In order to study this interplay more accurately and clarify the magnitude of HT terms we performed the analysis of data on DIS of charged leptons, which are by order of magnitude more precise than the neutrino data.

We use in the analysis 2274 data points on the cross sections of DIS scattering of the charged leptons off the proton and deuterium targets [4] with $Q^2 = 2.5 \div 300$ GeV^2 and $x = 4 \cdot 10^{-5} \div 0.75$ in order to suppress the

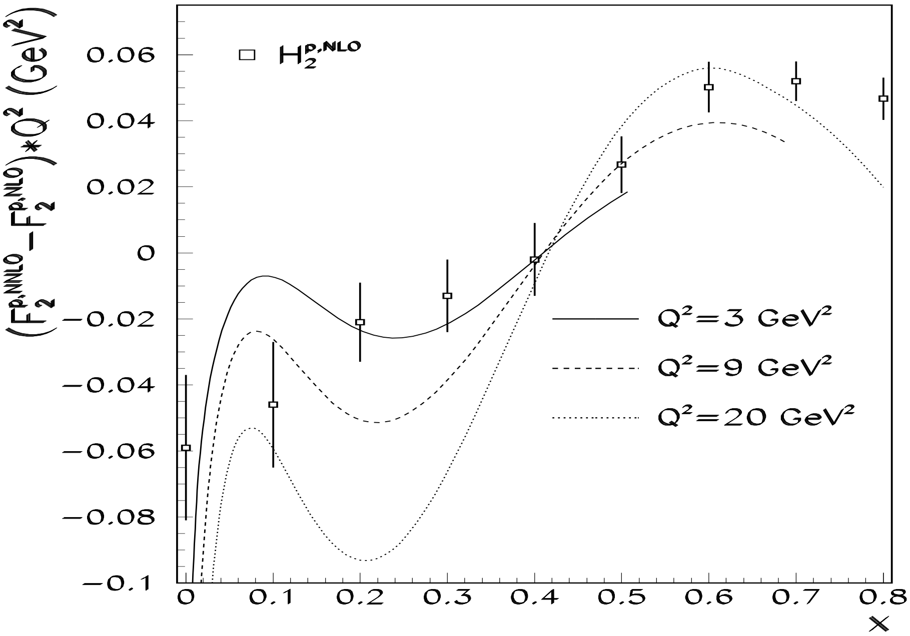

Figure 1: Shown is comparison of the NNLO corrections and the HT contribution to F_2^p obtained in the NLO fit.

theoretical uncertainties which rapidly rise at small Q and large x. The data were described using OPE expansion of the structure functions $F_{2,\mathrm{L}}$

$$F_{2,\mathrm{L}}(x,Q) = F_{2,\mathrm{L}}^{\mathrm{LT,TMC}}(x,Q) + \frac{H_{2,\mathrm{L}}(x)}{Q^2}$$

with account of the twist-4 contributions, where the functions $H(x)$ are parameterized in the piece-linear form and $F_{2,\mathrm{L}}^{\mathrm{LT,TMC}}$ are the LT terms with account of the target-mass corrections. To provide self-consistency of the analysis the LT terms were calculated using the parton distributions fitted simultaneously with the HT terms and the value of strong coupling constant α_{s}. The QCD evolution of parton distributions was performed in the $\overline{MS}$ scheme with the fixed number of flavors equal to 3. The QCD evolution equations with the NNLO corrections taken into account using the parameterizations of Ref.[5] were integrated numerically in the x-space. The code used for the integration was checked against Les Houches benchmark [6] and

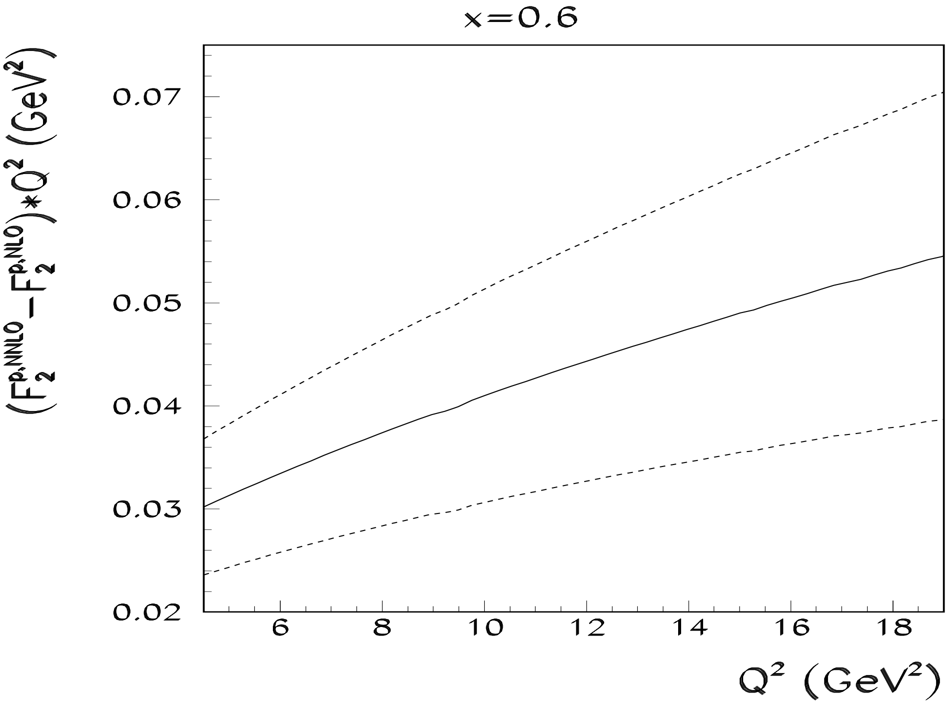

Figure 2: The Q-dependence of NNLO correction to F_2^p (full line) with the experimental errors bands for F_2^p (dashes).

demonstrated precision much better than accuracy of the data used in analysis.

The HT contribution to the proton structure function F_2^p obtained in the NLO approximation is compared to the NNLO correction to F_2^p in Fig.1. The magnitude of $H_2^{p,\mathrm{NLO}}$ clearly deviates off 0 within the experimental uncertainties, which are combinations of the statistical, point-to point correlated systematical, and normalization errors in data accounted in the analysis using the covariance matrix approach. Value of the NNLO correction is comparable to $H_2^{p,\mathrm{NLO}}$, but its Q-dependence does not fit to the $1/Q^2$ behavior (see Fig.2) and transfer of the NNLO correction to the shift in the HT term is possible only with changing the quality of fit. Alternatively, if effect of the NNLO correction is entirely compensated by the shift in other fitted parameters (e.g. in value of α_s), quality of the fit would remain the same at that possible shift in the HT term is at the level of the fluctuations in data. The

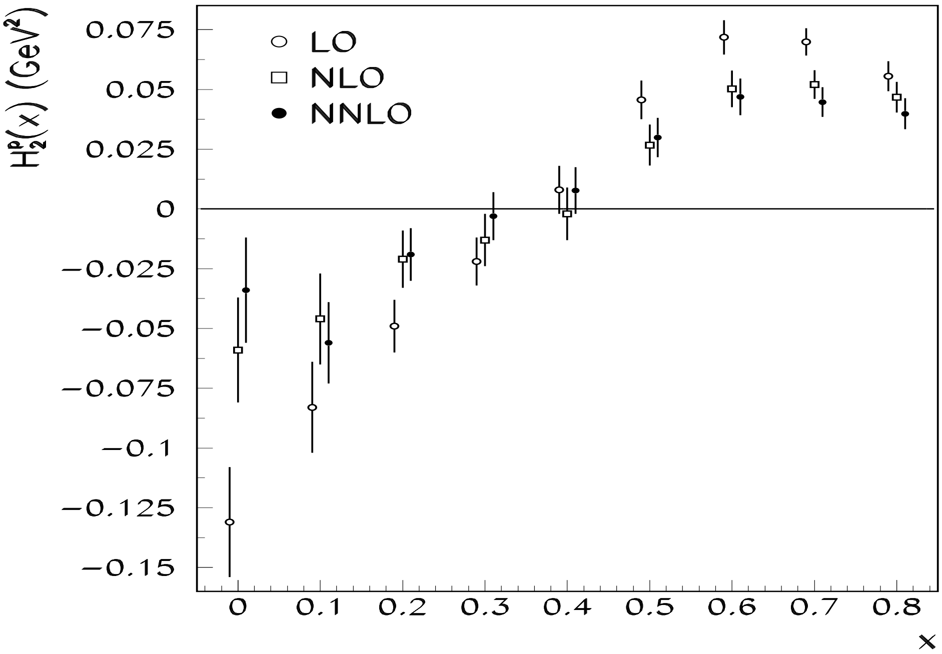

Figure 3: The values of HT terms in F_2^p obtained in the LO, NLO, and NNLO fits.

observed shift of H_2^p from the NLO to the NNLO is of the scale of the experimental errors (see Fig.3), i.e. is not statistically significant, while the value of $\chi^2/NDP = 1.11$ both for the NLO and the NNLO. At the same time quality of the fit worsens from the NLO to the LO ($\chi^2/NDP = 1.20$ in the LO) and this is accompanied by the statistically significant shift of H_2^p. Summarizing these observations we conclude that poor description of the data in the LO does lead to generation of a fake contribution to HT terms, but this contribution essentially decreases in the NLO (and even more in the NNLO) getting smaller than fluctuations in the existing data. Remaining deviation of H_2^p off zero can be considered as a genuine HT contribution to F_2^p. This contribution is maximal at $x \sim 0.6$. In this region of x the HT term is larger than the experimental error in F_2^p up to $Q^2 \sim 20$ GeV^2 (see Fig.4) rising for small hadronic invariant mass [7]. This is in disagreement with the results of Ref.[8], but the comparison with that analysis is difficult since it was based

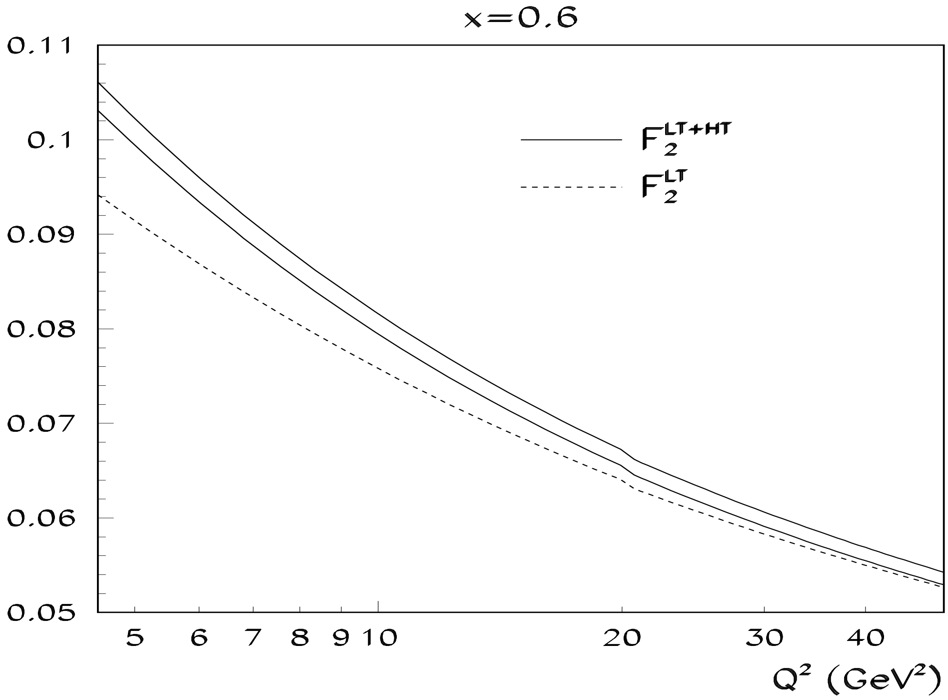

Figure 4: Relative magnitude of the HT and LT terms in F_2^p.

on the parameterization of HT terms within the infrared renormalon model.

The errors in HT contribution to the structure functions $xF_3^{\nu N}$ obtained in Ref.[2] are much larger than the errors in H_2^p obtained in our analysis (see Fig.5). Since the scales of HT terms would be similar in both cases, this means that the precision of existing neutrino data is quite insufficient for the quantitative estimation of the HT terms. In particular, to clarify the conclusion of Ref.[2] about vanishing the HT terms in the NNLO the experiments with luminosity typical for the proposed neutrino factories are required [9].

In conclusion, we observe that in the analysis of lN DIS data the higher-twist terms in structure functions do not vanish even with account of the NNLO QCD corrections. The HT contribution to structure function F_2 extracted from the comparison to data is maximal at $x \sim 0.6$. Its relative error is $\sim 20\%$ in this region that allows for conclusive comparison with different theoretical models. Account of the HT terms in the analysis of ex-

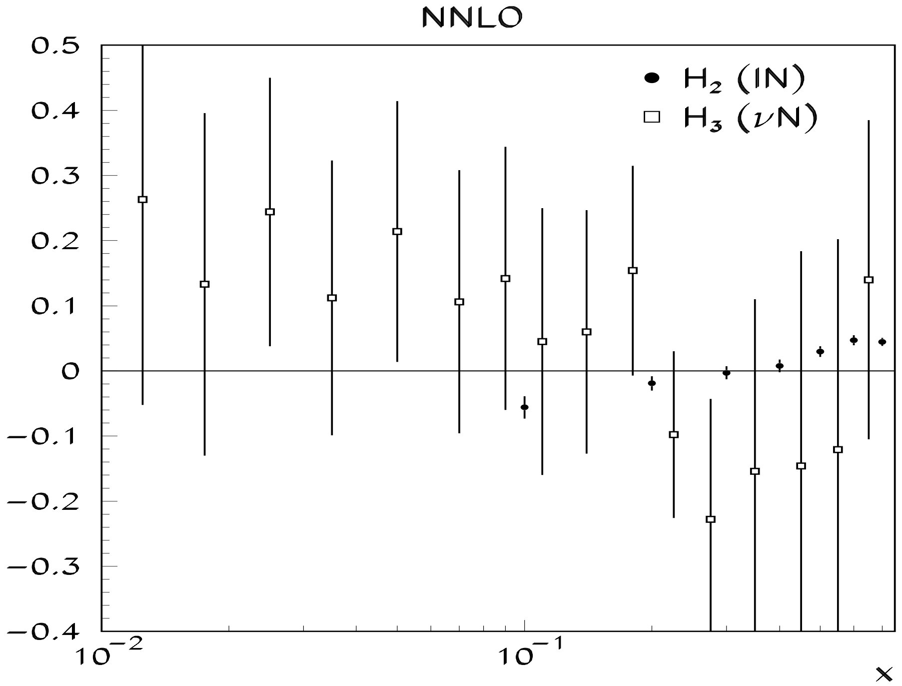

Figure 5: Comparison of the HT terms in the structure functions extracted from the lN (our fit) and νN DIS data [2].

isting DIS data is very important because they give non-negligible effect up to $Q^2 \sim 20$ GeV^2.

References

[1] L. F. Abbott and R. M. Barnett, Annals Phys. **125**, 276 (1980); L. F. Abbott, W. B. Atwood and R. M. Barnett, Phys. Rev. **D22**, 582 (1980).

[2] A. L. Kataev, G. Parente and A. V. Sidorov, Nucl. Phys. B **573** (2000) 405 [arXiv:hep-ph/9905310].

[3] W. G. Seligman *et al.*, Phys. Rev. Lett. **79** (1997) 1213.

[4] L. W. Whitlow, E. M. Riordan, S. Dasu, S. Rock and A. Bodek, Phys. Lett. **B282**, 475 (1992); A. C. Benvenuti *et al.* [BCDMS Collaboration], Phys. Lett. **B223** (1989) 485; A. C. Benvenuti *et al.* [BCDMS Collaboration], Phys. Lett. **B237** (1990) 592; M. Arneodo *et al.* [New Muon Collaboration], Nucl. Phys. **B483** (1997) 3 [hep-ph/9610231]; C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **21**, 33 (2001) [arXiv:hep-ex/0012053]; S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **21**, 443 (2001) [arXiv:hep-ex/0105090].

[5] W. L. van Neerven and A. Vogt, Phys. Lett. B **490**, 111 (2000) [arXiv:hep-ph/0007362].

[6] W. Giele *et al.*, arXiv:hep-ph/0204316.

[7] S. Liuti, R. Ent, C. E. Keppel and I. Niculescu, Phys. Rev. Lett. **89** (2002) 162001 [arXiv:hep-ph/0111063].

[8] U. K. Yang and A. Bodek, Eur. Phys. J. C **13** (2000) 241 [arXiv:hep-ex/9908058].

[9] M. L. Mangano *et al.*, arXiv:hep-ph/0105155.