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Higher Twist Contributions to Deep-Inelastic Structure Functions

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We report on a recent extraction of the higher twist contributions to the deep inelastic structure functions $F_2^{ep,ed}(x,Q^2)$ in the large x region. It is shown that the size of the extracted higher twist contributions is strongly correlated with the higher order corrections applied to the leading twist part. A gradual lowering of the higher twist contributions going from NLO to N^{4}LO is observed, where in the latter case only the leading large x terms were considered.

In wide kinematic regions the deeply inelastic structure functions can be described by their leading twist contributions within Quantum Chromodynamics (QCD). Higher twist corrections [1] emerge both in the region of large [2,3] and small values [4,5] of the Bjorken variable x. The leading twist sector, both for unpolarized and polarized deeply inelastic scattering, is well explored within perturbative QCD up to the level of 3–loop, resp. 2–loop, corrections [6, 7], including the heavy flavor contributions [8]. On the other hand, very little is known on the scaling violations of dynamical next-to-leading twist correlation functions and the associated Wilson coefficients [1], even on the leading order level. In many experimental and phenomenological analyzes, cf. [2, 3], higher twist contributions are parameterized by an 'Ansatz' [2], which is fitted accordingly. Within QCD this ad-hoc treatment cannot be justified, performing at the same time a higher order analysis for the leading twist terms. Since neither the corresponding higher twist anomalous dimensions nor Wilson coefficients were calculated, the data analysis has to be limited in the first place to the kinematic domain in which higher twist terms can be safely disregarded.

In the following we report on the determination of the higher twist contributions in the deeply-inelastic structure functions $F_2^{ep,ed}(x,Q^2)$, see Ref. [9] for details. Higher twist contributions were also studied in deep-inelastic neutrino scattering, cf. [10]. Also in the case of polarized deeply inelastic scattering higher twist corrections are present in general. Since the polarized structure functions are measured through an asymmetry, the effect of higher twist contributions in the denominator function has to be known in detail. In [11] no significant higher twist contributions were found. Other authors claim contributions in the low x region [12], which is also the region of very low values of Q^2. These effects need further study.

In the case of the structure functions $F_2^{ep,ed}(x,Q^2)$ we investigate the flavor non-singlet contributions in the large x region for $Q^2 \geq 4\,\mathrm{GeV}^2, W^2 \geq 12.5\,\mathrm{GeV}^2$, cf. [13]. [a] One generally may consider flavor non-singlet combinations and perform a three-loop QCD analysis, which requires the $O(\alpha_s^2)$ Wilson coefficients [15] and the 3–loop anomalous dimensions [6].

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[a] For power correction analyzes in the resonance region see [14]. Here the concept of the twist-expansion is not applicable, except assuming duality.

The analysis can even be extended effectively to 4–loop order, since the dominant contribution there is implied by the 3–loop Wilson coefficient [7], parameterizing the yet unknown 4–loop anomalous dimension with a ± 100 % error added to an estimate of this quantity formed as Padé-approximation out of the lower order terms. A comparison with the 2nd moment of the 4–loop anomalous dimension calculated in [16] showed [13] that the agreement is better than 20 %, which underlines that the above approximation may be possible. We limit the QCD–analysis of the twist–2 contributions to this representation since neither $\alpha_s(\mu^2)$ nor the splitting and coefficient functions are known beyond this level. Furthermore, heavy quark and target mass corrections are applied.

The evolution equations are solved in Mellin-N space, cf. [17]. The non–singlet structure function at the starting scale of the evolution, Q_0^2, is given by

$$F_2^{p,d;\rm NS}(N,Q^2) = \sum_{k=0}^{\infty} a_s^{k-1}(Q^2) C_{k-1}^{\rm NS}(N) f_2^{p,d;\rm NS}(N,Q^2) \; , \tag{1}$$

with $C_k^{\rm NS}(N)$ the expansion terms of the non–singlet Wilson coefficient with $C_0(N) = 1$, $a_s(Q^2) = \alpha_s(Q^2)/(4\pi)$ and $f_2^{p,d;NS}(N,Q^2)$ the corresponding combination of quark distributions, cf. [13]. Here we identify both the renormalization and factorization scale with Q^2. Beyond $O(a_s^3)$ dominant large x contributions to the Wilson coefficient were calculated in [18].

We then extrapolate the results to the region $4\,{\rm GeV}^2 \leq W^2 \leq 12.5\,{\rm GeV}^2$ and determine effective higher twist coefficients $C_{\rm HT}(x,Q^2)$ given by

$$F_2^{\rm exp}(x,Q^2) = F_2^{\rm tw2}(x,Q^2) \cdot \left[\frac{O_{\rm TMC}\left[F_2^{\rm tw2}(x,Q^2)\right]}{F_2^{\rm tw2}(x,Q^2)} + \frac{C_{\rm HT}(x,Q^2)}{Q^2[1\,{\rm GeV}^2]} \right] \; . \tag{2}$$

Here $O_{\rm TMC}[\;\;]$ denotes the operator of target mass corrections.

QCD corrections beyond N^{3}LO are known in form of the dominant large-x contributions to the QCD–Wilson coefficients [18]. Since these corrections do quantitatively only apply in the range of large x we do not use them in the twist-2 QCD–fit, because here the data are mainly situated at lower values of x where beyond 4–loop order other contributions to the Wilson coefficients, which are not calculated yet, are as important. Furthermore, the 4–loop anomalous dimensions are yet unknown beyond the 2nd moment. The leading large x contributions are given in terms of harmonic sums of the type $S_{1,1,\ldots,1}(N)$ which obey a determinant representation [19] in single harmonic sums $S_l(N)$. The effective higher twist distribution functions $C_{\rm HT}^{p,d}(x)$ extracted are shown in Figures 1 from NLO to N^{4}LO. Here we averaged over the values in Q^2 within the x–bins. The leading twist terms are those given in [13], with the values of $\Lambda_{\rm QCD}^{(4)} = 265 \pm 27, 226 \pm 25, 234 \pm 26\,{\rm MeV}$, resp. in NLO, NNLO, and N^{3}LO. Both for the proton and deuteron data $C_{\rm HT}(x)$ grows towards large values of x, and takes values ~ 1 around $x = 0.6$. The inclusion of higher order corrections reduces $C_{\rm HT}(x)$ to lower values with a gradually smaller difference order by order. Yet for the highest bins, $x \geq 0.8$, the effect of the large x resummation terms is important. Earlier higher twist analyzes [3] limited to the next-to-leading order corrections are thus corrected by factors of 2 and larger at large x to lower values. Soft resummation beyond NLO was considered in [20]. In the present analysis we limited the investigation to the inclusion of the large x terms in N^{4}LO which are still in the vicinity of a nearly complete QCD analysis

as outlined above. The present description is likely to be final for values of $x \leq 0.8$. Beyond this range there are only few data. More data in this interesting region would be welcome and can be obtained at planned high-luminosity colliders such as EIC [21].

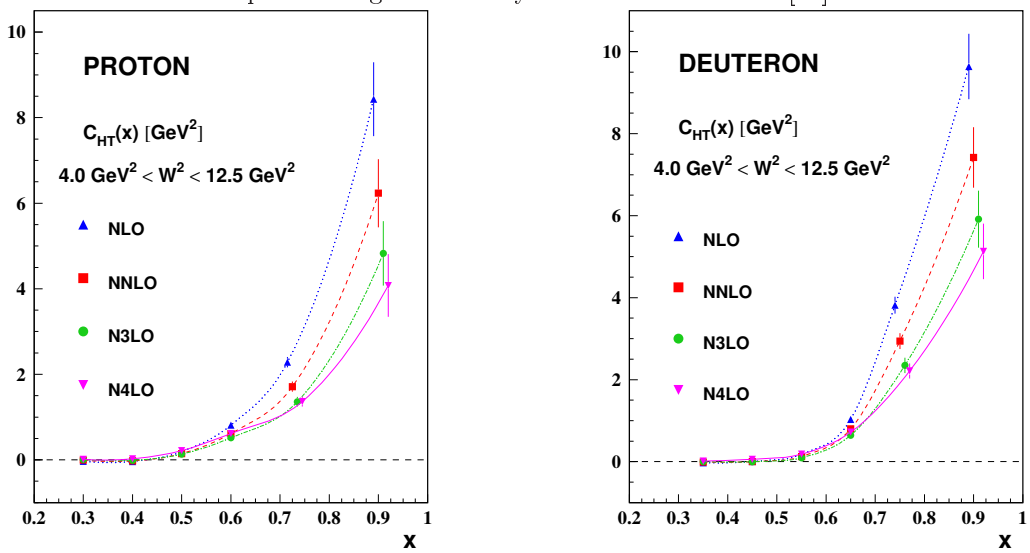

Figure 1 : The coefficient $C_{\rm HT}(x)$ for proton and deuteron data in the large The curves correspond to the cases of twist–2 corrections in NLO: dotted line, NNLO: dashed line, N^{3}LO dash-dotted line, and asymptotic N^{4}LO: full line, cf. [9].

In the present analysis we extracted the large x dynamical higher twist contributions to the structure functions in a model-independent way. It would be interesting to compare moments of the term $C_{\rm HT}(x)$ to lattice results, which allow to simulate the moments of the corresponding higher twist correlation functions, in the future.

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