EIC Letter of Interest: Higher twist effects in inclusive and diffractive nuclear structure functions

K. Golec-Biernat[a,1], L. Motyka[b,2], M. Sadzikowski[b,3] and W. Słomiński[b,4]

[a] *Institute of Nuclear Physics PAN, Radzikowskiego 152, 31-342 Kraków, Poland*
[b] *Institute of Theoretical Physics, Jagiellonian University, S.Łojasiewicza 11, 30-348 Kraków, Poland*

August 29, 2020

Physics goal:

We aim to provide estimates of higher twist corrections to inclusive and diffractive nuclear structure functions F_2 and F_L at the Electron Ion Collider (EIC) on the basis of analyses performed for DIS at HERA [1, 2] and to improve the theoretical understanding of higher twist corrections at small x.

Tools:

1) Extraction of higher twist corrections from phenomenological models (mostly from the saturation models by Golec-Biernat and Wüsthoff (GBW) [3, 4], and by Bartels, Golec-Biernat and Kowalski (BGBK) [5] saturation models), and from QCD evolution equations by: Balitsky, Fadin, Kuraev and Lipatov (BFKL) [6], Balitsky and Kovchegov (BK) [7] and Bukhvostov, Frolov, Kuraev and Lipatov (BFKL') [8].

2) Extrapolation to the EIC conditions of the fits to HERA data based on combined DGLAP + higher twist scheme.

Motivation:

The successful DGLAP description of DIS and DDIS scattering on the nucleon and nuclei is based on the leading twist 2 approximation in the Wilson operator product expansion. Besides the twist 2 contributions that are leading at large Q^2, however, the total cross sections contain also higher twist terms suppressed by powers of $1/Q^2$. They are interesting for two main reasons. Firstly, they correspond to multiple parton distributions in the nucleus or nuclei, thus probing their structure in a novel way. Then the higher twist corrections affect actual measurements and are expected to spoil the quality of pure DGLAP fits and their extrapolations. They also affect the determination of parton density functions. Thus it is important both to have a good theoretical control of higher twist terms, and also to measure their effects in experiment.

In the small x region and for moderate Q^2 corrections to the DGLAP description coming from the higher twist terms are enhanced due to rapid small x growth of the higher twist gluonic operators. The most important corrections to F_2 and F_L (inclusive and diffractive) enter at twist 4. The leading contribution to twist 4 correction is driven by evolution of four-gluon quasipartonic operator, which in the large N_c limit is proportional to the square of gluon density function. The relative importance of the leading twist 4 corrections to the leading twist 2 contribution to the structure functions may be reasonably well approximated by

$$\frac{\Delta F_{2,L}^{\text{twist }4}}{F_{2,L}^{\text{twist }2}} \propto \frac{xg(x,Q^2)}{Q^2}$$

where the leading x and Q^2 dependence of the ratio is kept track of, and $g(x,Q^2)$ is the gluon density. This functional form of the correction is deeply rooted in QCD — it generically follows from QCD evolution equations up to logarithmic corrections. On top of that, when the target is a nucleus with a mass number A, the relative higher twist effects are predicted to scale up as $A^{1/3}$. The proportionality

---

[1] `golec@ifj.edu.pl`

[2] `leszek.motyka@uj.edu.pl`

[3] `mariusz.sadzikowski@uj.edu.pl`

[4] `wojtek.slominski@uj.edu.pl`

factor, related to coupling of four gluon quasipartonic state to the projectile and target, however is not well constrained by theory, and only weakly by measurements.

Several recent analyses of DIS and diffractive DIS HERA data [2, 9, 10] revealed that the NLO and NNLO DGLAP fits break down when the region of the lowest $x < 10^{-4}$ and $Q^2 < Q_0^2$ is included, with the higher twist onset scale $Q_0^2 \simeq 5$ GeV^2. These deviations may be well explained by higher twist constributions, and, to some extent, by small x resummation effects [11]. When compared to HERA, the Electron Ion Collider is designed to provide somewhat lower energy per nucleon, $\sqrt{S}$, of the electron–nucleon scattering, but it may probe large nuclei. Assuming for a benchmark setup $A \simeq 200$ and $\sqrt{S} = 100$ GeV, one expects and increase of the higher twist onset scale by $A^{1/3} \simeq 6$. Then the reach in x is decreased by factor of about 10 w.r.t. HERA, lowering the higher twist onset scale Q_0^2 by a factor of about two or more at larger Q^2. Thus, the overall effects is an enhancement of the higher twist effects at the EIC, and in the benchmark setup one expects that the higher twist effects become visible in the region of $10^{-4} < x < 10^{-3}$ for $Q^2 > 10$ GeV^2. Hence the higher twist effects should appear well in perturbative domain, and also in a region where the experimental measurements should be precise. An additional advantage of combining the higher twist determination in scattering on large nuclei at the EIC with the analysis of HERA data is a different mix of the small x resummation effects and $A^{1/3}$ enhanced higher twist effects. Hence, one expects the small x effects to be much stronger in HERA data and the nuclear higher twist effects to be stronger at the EIC.

Research plan:

The basis of our approach was elaborated in several papers, that were focused on the electron–proton scattering at HERA [1, 2, 12, 13, 14].

So, the first main research goal is to extrapolate the obtained results [1, 2] to the EIC conditions and estimate the higher twist effects in F_2 and F_L in inclusive and diffractive DIS on different nuclei.

The second main research goal is to improve the theoretical understanding of the higher twist evolution and couplings in the small x regime. So far, in order to model and parameterize the higher twist effects we used eikonal models for multiple scattering, as they enter into the GBW and BGBK saturation model, and the multiple scattering in the BFKL approach. We intend to get more insight into the problem by analysis of multi-gluon and non-linear QCD evolution equations.

References

[1] L. Motyka, M. Sadzikowski and W. Słomiński, Phys. Rev. D **86** (2012) 111501.

[2] L. Motyka, M. Sadzikowski, W. Słomiński and K. Wichmann, Eur. Phys. J. C **78** (2018) no.1, 80

[3] K. J. Golec-Biernat and M. Wüsthoff, Phys. Rev. D **59** (1998) 014017; Phys. Rev. D **60** (1999) 114023.

[4] K. Golec-Biernat and S. Sapeta, JHEP **03** (2018), 102.

[5] J. Bartels, K. J. Golec-Biernat and H. Kowalski, Phys. Rev. D **66** (2002), 014001.

[6] E. A. Kuraev, L. N. Lipatov and V. S. Fadin, Sov. Phys. JETP **45** (1977) 199 [Zh. Eksp. Teor. Fiz. **72** (1977) 377]; I. I. Balitsky and L. N. Lipatov, Sov. J. Nucl. Phys. **28** (1978) 822 [Yad. Fiz. **28** (1978) 1597].

[7] I. Balitsky, Nucl. Phys. B **463** (1996) 99; Y. V. Kovchegov, Phys. Rev. D **60** (1999) 034008; Phys. Rev. D **61** (2000) 074018.

[8] A. P. Bukhvostov, G. V. Frolov, L. N. Lipatov and E. A. Kuraev, Nucl. Phys. B **258** (1985) 601.

[9] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, Eur. Phys. J. C **76** (2016) no.4, 186.

[10] I. Abt, A. M. Cooper-Sarkar, B. Foster, V. Myronenko, K. Wichmann and M. Wing, Phys. Rev. D **94** (2016) no.3, 034032.

[11] R. D. Ball, V. Bertone, M. Bonvini, S. Marzani, J. Rojo and L. Rottoli, Eur. Phys. J. C **78** (2018) no.4, 321.

[12] J. Bartels, K. J. Golec-Biernat and K. Peters, Eur. Phys. J. C **17** (2000) 121.

[13] J. Bartels, K. Golec-Biernat and L. Motyka, Phys. Rev. D **81** (2010) 054017.

[14] L. Motyka and M. Sadzikowski, Acta Phys. Polon. B **45** (2014) 11, 2079.