# HIGHER TWISTS EFFECTS IN DIS ON NUCLEI

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## 1. INTRODUCTION

The study of the hadron structure at high energies is one of the main goals of the high energy colliders (KHALEK et al., 2022). From the analyses performed in the $ep$ collider at HERA, we know that the proton structure function increases with the decreasing of the Bjorken-$x$ variable, that a large fraction of the observed events ($\approx 10\%$) are diffractive and that the total cross sections present the property of geometric scaling. All these results can be quite well described by models based on Color Glass Condensate (CGC) formalism, which takes into account non - linear effects that are inherent to the QCD dynamics at high energies when the hadron becomes a dense system.

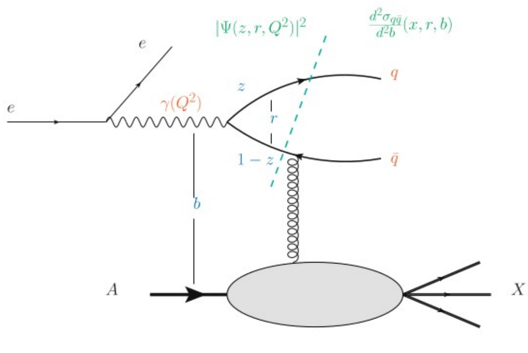
The transition line between the linear and non-linear regimes of the QCD dynamics is described by the saturation scale $Q_s$ , which is predicted to depend on $x$ and the mass number of a nucleus $A$:

$$Q_{s,A}^2 = A^{1/3} Q_{s,p}^2 = A^{1/3} Q_0^2 \left(\frac{x_0}{x}\right)^{\lambda} \tag{1}$$

Then, as $Q_s$ increases at smaller values of $x$ and larger values of $A$ , future electron-nucleus colliders (KHALEK et al., 2022) are expected to provide the ideal scenario to determine whether parton distributions saturate or not and allow us to disentangle non - linear from linear physics. One important characteristic of the non - linear approaches is that they resum higher twist contributions (BARTELS et al., 2000), i.e. they contain information of all orders in $1/Q^2$ in the perturbative expansion. In the Operator Product (OPE), the scattering amplitudes are expanded into a series of contributions $\sigma = \sum_{\tau} \sigma_{\tau}(Q^2)$, with $Q^2$ being the characteristic hard scale, $\sigma_{\tau} \propto 1/Q^{\tau}$ and $\tau = 2, 4, \ldots$ being the twist.

Moreover, a more recent analysis (MOTYKA et al., 2018) shown the strength of the effects of the higher twist corrections in the small - $x$ and moderate/low $Q^2$ region using the HERA data. Therefore, with the Electron-Ion collider (EIC) being proposed, we were motivated to study the higher twists effects in DIS on nuclei which we will show in what follows.

**Figure 1** - Representation of the deep inelastic scattering on nuclei in the dipole formalism.



## 2. METHODOLOGY

In the deep inelastic scattering and at the dipole frame, the $eA$ scattering can be viewed in terms of the photon emission by the electron, the splitting of the photon in a color dipole and the propagation of the dipole in the gluonic field of the nucleus, as shown on Figure 1. At high QCD field strengths, the multiple scatterings of the dipole with the nucleus become relevant and must be taken into account. In this frame, the nuclear structure functions can be factorized as follows

$$F_{L,T}(x,Q^2)=\frac{Q^2}{4\pi^2\alpha_{em}}\int dz\int d^2\boldsymbol{r}\int d^2\boldsymbol{b}|\Psi_{L,T}(z,\boldsymbol{r},Q^2)|^2\frac{d^2\sigma}{d^2\boldsymbol{b}}(x,\boldsymbol{r},\boldsymbol{b}), \quad (2)$$

where $\boldsymbol{r}$ denotes the transverse size of the dipole, $z$ is the longitudinal momentum fraction carried by the quark, $\boldsymbol{b}$ is the transverse distance from the center of the nucleus to the center of mass of the $q\bar{q}$ dipole and $\Psi_{T,L}$ are the wave functions of the photon corresponding to their transverse or longitudinal polarizations. Moreover, we assume:

$$\frac{d^2\sigma}{d^2\boldsymbol{b}}(x,\boldsymbol{r},\boldsymbol{b})=2\left(1-e^{-r^2Q^2_{s,A}(x)/4}\right)S(\boldsymbol{b}), \quad (3)$$

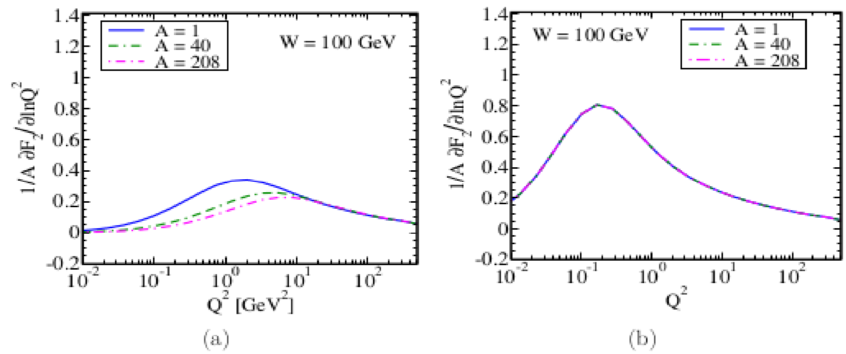
where $r\equiv|\boldsymbol{r}||$ , $Q_{s,A}(x)$ is the saturation scale for the nucleus and $S(\boldsymbol{b})$ is the profile function in impact parameter space, which is usually described by a R Wood - Saxon distribution. Theoretically, we expect that $Q^2_{s,A}=A^{\alpha}\times Q^2_{s,p}$ , with $\alpha\approx 1/3$ , and that $\int d^2\boldsymbol{b}S(\boldsymbol{b})\propto A^2/3$ . Following (BARTELS et al., 2000), we can employ a Mellin transform of Eq. (2) and perform an expansion in powers of $\xi\equiv Q^2_{s,A}/Q^2_{s,p}$ . Such procedure implies:

$$F_T(x,Q^2)=F_T^{\tau=2}(x,Q^2)+F_T^{\tau=4}(x,Q^2)+F_T^{\tau=6}(x,Q^2)+F_T^{\tau=8}(x,Q^2),$$
$$F_L(x,Q^2)=F_L^{\tau=2}(x,Q^2)+F_L^{\tau=4}(x,Q^2)+F_L^{\tau=6}(x,Q^2)+F_L^{\tau=8}(x,Q^2). \quad (4)$$

The analytic expressions for each term of these sums are presented in (BANDEIRA; GONÇALVES, 2023).

The same procedure can be performed for the logarithmic $Q^2$ slope which is sensitive to the saturation effects and can be used to discriminate between the linear and non-linear descriptions of the QCD dynamics (GONÇALVES, 2000). Then, we calculate the $Q^2$ and $x$ dependencies of $\partial F_2^A/\partial \ln Q^2$ for a fixed value of the photon - nucleus center - of - mass energy $W$ , which is possible using that $x=Q^2/W^2$. which is shown on Figure 2. We predict the presence of a maximum in the slope, with the position being dependent on A , when non - linear effects are present, in agreement with the results derived in (GONÇALVES, 2000).

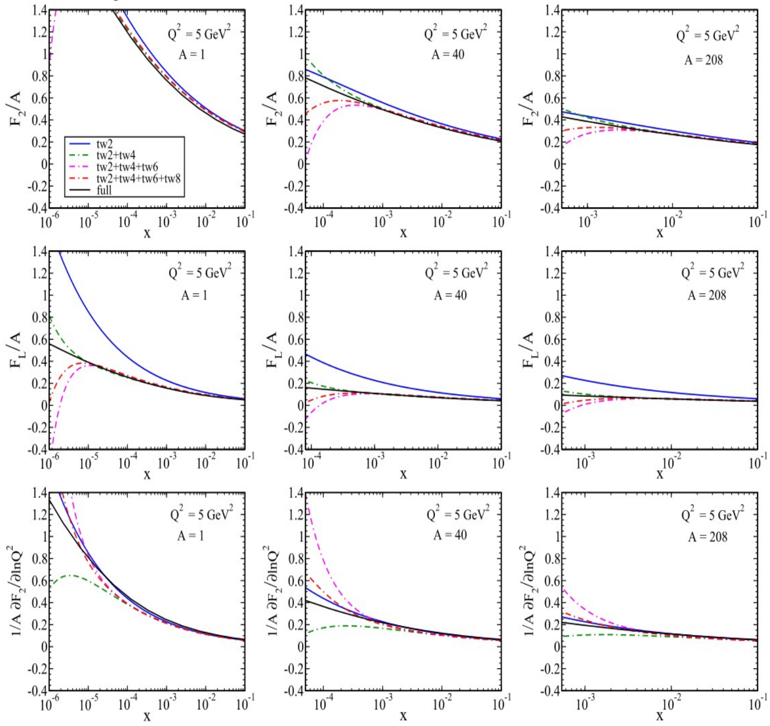
**Figure 2 -** Predictions for $\partial F_2^A/\partial \ln Q^2$ , normalized by $A$, considering different nuclei with $W=100$ GeV are presented in panel (a). In panel (b) are showed the predictions derived disregarding the non - linear effects.



## 3. RESULTS AND DISCUSSION

In what follows, we present our results for the $x$ and atomic number dependencies of $F_2^A(x,Q^2)$ , $F_L^A(x,Q^2)$ and $\partial F_2^A/\partial \ln Q^2$ , normalized by $A$ , predicted by the phenomenological model used in our analysis assuming $Q^2=5\ \mathrm{GeV}^2$ and distinct values of $A$.

**Figure 3** - Predictions for the inclusive observables , normalized by $A$, considering different values of the atomic number and $Q^2=5\ \mathrm{GeV}^2$.




In Figure 3, the difference between the twist-2 and full predictions for $F_L^{A=1}$ becomes larger than $10\%$ for $x \le 10^{-3}$ and for larger values of $x$ when the atomic number is increased. For the slope, one has that higher - twist corrections become sizeable for $x \approx 10^{-3}$ , but similarly to what occurs in the $F_2$ case, the longitudinal and transverse contributions have opposite signal, which implies a small impact on the observable. However, it is important to emphasize that the difference between the twist - 2 and full predictions for $\partial F_2^A/\partial \ln Q^2$ is larger than that predicted for $F_2^A$ in the kinematical range considered.

Our results indicate that the behavior of longitudinal function structure is strongly modified by the higher twist corrections. A future experimental analysis of $F_L^A(x,Q^2)$ and will allow $\partial F_2^A/\partial \ln Q^2$us to probe the presence of the nonlinear effects in the QCD dynamics. In (BANDEIRA; GONÇALVES, 2023), we present a more detailed analysis where we include the fixed atomic number and different values of virtuality case and other comparisons.

## 4. CONCLUSION

One of the main goals of current and future colliders is the improvement of our understanding of the hadronic structure at high energies. In particular, the search for non-linear effects in the QCD dynamics is one of the major motivations for the construction of the EIC in the US. Which are expected to allow for the investigation of the hadronic structure with an unprecedented precision. Electron-nucleus collisions are considered ideal to probe the nonlinear regime, since the larger parton densities in the nuclear case, with respect to the proton case, enhance by a factor $\propto A^{1/3}$ the nuclear saturation scale, which determines the onset of non-linear effects in QCD dynamics.

Motivated by this aspect and by the fact that the non-linear approaches resums higher-twist contributions, in this work we have estimated the distinct twist terms and analyzed the impact of the different twists on $F_2^A(x,Q^2)$, $F_L^A(x,Q^2)$ and $\partial F_2^A/\partial \ln Q^2$ considering different values of the Bjorken -$x$ variable, photon virtuality $Q^2$ and atomic number A. We have estimated the logarithmic $Q^2$ slope for different values of the photon-nucleus center-of-mass energy. Our results indicate that the behaviour of $F_L^A(x,Q^2)$ is strongly modified by the higher twist corrections. Moreover, the results showed in here can be used as a motivator to investigate the impact of the higher twist corrections on the nuclear diffractive structure functions, since the diffractive observables are more sensible to nonlinear effects (BENDOVA et al., 2021) .

## 5. REFERENCES

BANDEIRA, Yan B.; GONÇALVES, Victor P. Higher twists effects in DIS on nuclei at the EIC and LHeC: a phenomenological analysis. **The European Physical Journal A**, v. 59, n. 2, p. 19, 2023.

BARTELS, Jochen; GOLEC-BIERNAT, K.; PETERS, Krisztian. An estimate of higher twist at small and low based upon a Saturation Model. **The European Physical Journal C-Particles and Fields**, v. 17, n. 1, p. 121-128, 2000.

BARTELS, Jochen; GOLEC-BIERNAT, Krzysztof; MOTYKA, Leszek. Twist expansion of the nucleon structure functions, F 2, and F L, in the DGLAP improved saturation model. **Physical Review D**, v. 81, n. 5, p. 054017, 2010.

BENDOVA, D. et al. Diffractive deeply inelastic scattering in future electron-ion colliders. **The European Physical Journal C**, v. 81, p. 1-11, 2021.

GONÇALVES, V. P. Searching saturation in eA processes. **Physics Letters B**, v. 495, n. 3-4, p. 303-308, 2000.

KHALEK, R. Abdul et al. Science requirements and detector concepts for the electron-ion collider: EIC yellow report. **Nuclear Physics A**, v. 1026, p. 122447, 2022.

MOTYKA, Leszek et al. Evidence of quasi-partonic higher-twist effects in deep inelastic scattering at HERA at moderate Q^ 2 Q 2. **The European Physical Journal C**, v. 78, p. 1-17, 2018.