

Nuclear parton distributions and deviations from DGLAP at an Electron Ion Collider

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Abstract. We explore the potential of an Electron Ion Collider to determine nuclear modifications of PDFs. We find that gluon shadowing can be accurately measured down to $x = 10^{-3}$, and discuss the possibility of detecting non-linear QCD effects with inclusive measurements.

Keywords: QCD in nuclei, PDFs, electron ion collider

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One of the main physics goals of a future Electron Ion Collider (EIC) will be to accurately measure nuclear modifications of gluons and quarks as well as the possible onset of non-linear QCD dynamics in heavy nuclei. In this contribution we present a preliminary analysis which aims at determining the potential of the EIC to measure gluon shadowing and anti-shadowing and its sensitivity to saturation dynamics.

The input for this analysis is the EIC pseudo data for the inclusive DIS cross section in two scenarios, a medium energy EIC ($\sqrt{s} = 12, 17, 24, 32, 44$ GeV, denoted by stage I) and a full energy EIC ($\sqrt{s} = 63, 88, 124$ GeV, stage II). The kinematic coverage is summarized in Fig. 1. The pseudo-data was generated starting from $e + p$ and $e + n$ cross sections computed using the NNPDF2.0 set [1]. An integrated luminosity of 4 fb^{-1} was assumed for all energies, and the pseudo-data has been corrected for the expected statistical fluctuations. For most of the x range the resulting statistical errors are negligible compared to the assumed 2% systematic error. Nuclear effects have been included in the approximation where the longitudinal and transverse cross sections in Lead (^{208}Pb) can be expressed in terms of the proton cross sections as

$$\sigma_{T,L}^{\text{Pb}}(x, Q^2, y) = K_{T,L}^{\lambda}(x, Q^2, y) \sigma_{T,L}^{\text{p}}(x, Q^2, y), \quad (1)$$

where the factors K describe nuclear effects; the label λ sets the intensity of the assumed saturation effects, and $\lambda = 1$ corresponds to the nominal saturation in the IP Non-sat model [2], *i.e.*, we assume no saturation for the interaction with the nucleons. In particular, the K -factors in Eq. (1) are given by the following piece-wise expression. For small $x \leq 0.01$, $K_{T,L}^{\lambda}$ is given in terms of the dipole cross section of the IP Non-sat model. In the $0.01 \leq x \leq 0.1$ interval, we assume that $K_{T,L}^{\lambda}$ increases linearly from the value given by the IP Non-sat model at $x = 0.01$ up to $K_{T,L}^{\lambda} = 1$ at $x = 0.1$. Finally, for $x > 0.1$, we assumed that $K_{T,L}^{\lambda}$ is equal to the ratio of the nuclear to free nucleon structure functions, $F_{2A}(x, Q^2)/[AF_{2N}(x, Q^2)]$ taken from Ref. [3]. This simple model is intended

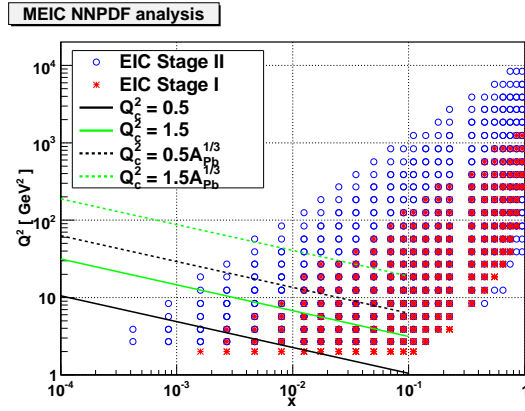


FIGURE 1. Kinematical coverage of the pseudo-data included in the NNPDF analysis of the EIC Pb cross sections, both for stage I and for stage II. Kinematical cuts relevant to study the onset of non-linear phenomena are also shown.

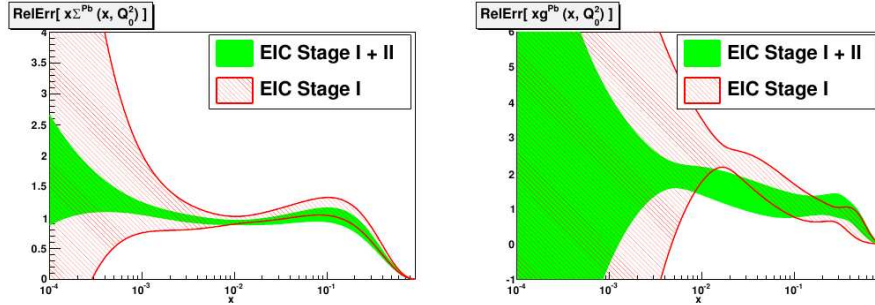


FIGURE 2. The quark singlet (left plot) and the gluon PDFs in ^{208}Pb (right plot) at the initial evolution scale $Q_0^2 = 2 \text{ GeV}^2$, for stage I and stage I+II.

for our initial studies summarized in this contribution; a more elaborate model will be considered in the future.

Nuclear parton distributions are then determined by a Next-to-Leading Order QCD fit of the pseudo-data within the NNPDF framework [1, 4, 5, 6], assuming collinear factorization for nuclear targets, and only using pseudo-data for ^{208}Pb . The kinematic cuts used to ensure the validity of DGLAP evolution are $Q^2 \geq 2 \text{ GeV}^2$ and $W^2 \geq 12.5 \text{ GeV}^2$. In Fig. 2, we show the singlet and the gluon Lead PDFs at the initial scale $Q^2 = 2 \text{ GeV}^2$ obtained using only stage I data, and then adding the stage II data. To illustrate the accuracy that the EIC can reach in the determination of nuclear gluon PDF we show in Fig. 3 their relative uncertainties alongside those of the proton's NNPDF2.0 [1] combined with those of the EPS09 nuclear modifications [8] for ^{208}Pb . The NNPDF2.0 and EPS09 relative uncertainties have been added linearly for a conservative estimate of the total uncertainty.

The measurement of the nuclear modifications of the gluon are one of the most important measurements at the EIC, since this quantity is essentially unknown from present data. From Fig. 2 we see that one can determine with a reasonable accuracy the

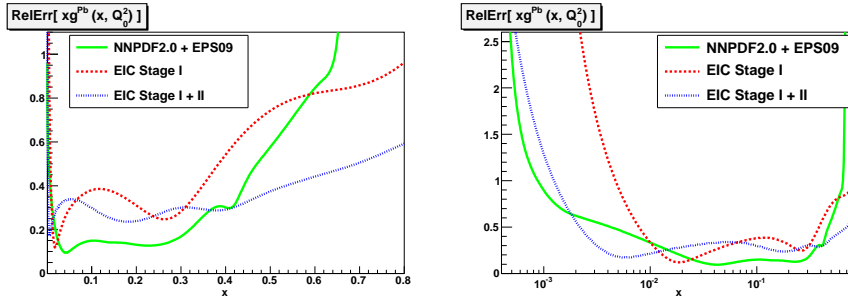


FIGURE 3. The relative uncertainty in the gluon PDF in ^{208}Pb at the initial evolution scale $Q_0^2 = 2 \text{ GeV}^2$, with stage I and stage I+II data. The analogous results for the PDFs in ^{208}Pb using NNPDF2.0+EPS09 parametrizations are also shown.

gluon shadowing down to $x \sim 10^{-3}$ in stage II and down to $x \sim 10^{-2}$ in stage I. The better capabilities of stage II stem both from its greater lever arm in Q^2 and its coverage of smaller values of x , see Fig. 1. In particular, the precision of the determination of the gluon distribution in ^{208}Pb in Stage II at small x is comparable to estimates from global proton fits. On top of this, at the EIC it will be possible to study gluon anti-shadowing, and EMC and Fermi motion effects in the gluon channel with much better accuracy than afforded by current global nuclear fits. We can also see that EIC will measure accurately the sea quark shadowing, and that nuclear modifications of light quarks at large x could be measured a precision similar or even better than for the proton case.

The presented analysis was based on the validity of collinear factorization for nuclei, and the validity of linear DGLAP evolution in Q^2 . However, at small enough x and Q^2 , deviations from linear fixed-order DGLAP evolution are expected to appear, e.g., due to small- x resummation effects [9] or gluon saturation [10]. In Refs. [11, 12] a general strategy was presented to quantify potential deviations from NLO DGLAP evolution, which was then applied to proton HERA data. In particular, in a global PDF fit, deviations from DGLAP in the data can be hidden in a distortion of parton distributions; however, these can be singled out by determining undistorted PDF from data in regions where such effects are expected to be small, evolving them down in the Q^2 region where deviations are expected to arise and comparing calculations to data not used in the PDF determination.

This approach can be applied as well to the nuclear case. From simple theoretical arguments about the energy and atomic number A dependence of the saturation scale [10], we expect deviations from linear evolution to appear when $Q^2 \lesssim \bar{Q}^2 (A\bar{x}/x)^{1/3}$, where \bar{x} is a reference value (we use $\bar{x} = 10^{-3}$ in our analysis) and \bar{Q}^2 is the scale where DGLAP evolution at \bar{x} would be broken in the proton. While saturation models may give an indirect indication of the value of \bar{Q}^2 , we wish to determine this scale in a model independent way as the scale at which deviations from DGLAP evolution can be detected from EIC nuclear target (pseudo-)data. The kinematical cut above can also be written as $Q^2 \lesssim Q_c^2 x^{-1/3}$ with Q_c^2 some constant setting the strength of the deviations from DGLAP. In Refs. [11, 12] the range $Q_c^2 \in [0.5, 1.5] \text{ GeV}^2$ was considered for the proton case; in the nuclear case one expects that this range should be rescaled by a factor $A_{\text{pb}}^{1/3} \approx 6$.

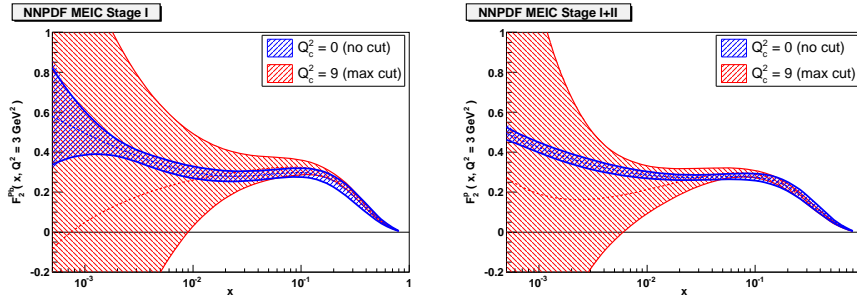


FIGURE 4. The Lead structure function $F_2^{\text{Pb}}(x, Q^2)$ at $Q^2 = 3 \text{ GeV}^2$ from the analysis of the EIC stage I (left plot) and stage I+II (right plot) simulated data with $\lambda = 1$, without kinematical cuts and with cuts using $Q_c^2 = 1.5A_{\text{Pb}}^{1/3} \sim 9$.

(Note that nuclear shadowing may reduce this impulse approximation estimate.) Typical values of these kinematical cuts for the nucleus of ^{208}Pb are shown in Fig. 1.

We show in Fig. 4 a representative result of the fits to the EIC pseudo-data after applying the cut with $\bar{Q}^2 = 1.5A_{\text{Pb}}^{1/3} \sim 9$, compared to the reference uncut fits to stages I and I+II pseudo-data with $\lambda = 1$. As expected when data is removed the uncertainties in the physical observables become much larger, but one can still see a systematic downwards shift in the central value, which is the signature of the departure from linear evolution [11, 12]. Note that this signal is already apparent with stage I data only, although its statistical significance might be marginal. Following this preliminary study, in the future we will present more detailed and quantitative studies of deviations from DGLAP in eA collisions at the EIC.

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