Nuclear PDFs and Small-x QCD at the Electron Ion Collider

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Motivation

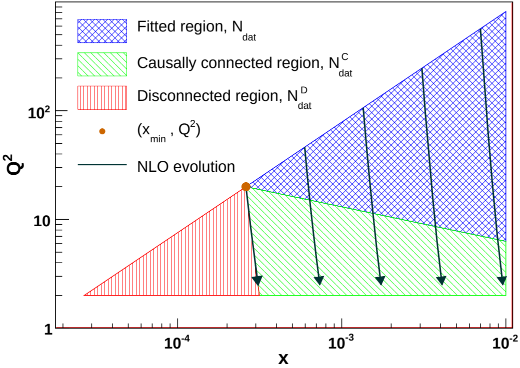
- **Electron–nucleon** and **Electron–nucleus** collisions offer clean tools to probe QCD matter
- At small-x and Q^2 we expect the onset of new QCD regimes: linear resummations, non–linear effects (enhanced in nucleus)
- An Electron Ion Collider (EIC) offers unprecendent capabilities for probing nuclear PDFs and non–linear QCD
- In this talk we will first present a method used to identify deviations from DGLAP in HERA data – and then apply it to e–Pb scattering at the EIC

Outline

DEVIATIONS FROM NLO DGLAP IN INCLUSIVE HERA DATA

Caola, Forte, J.R., Nucl.Phys.A854:32-44,2011, arXiv:1007.5405
Caola, Forte, J.R., Phys.Lett.B686:127-135,2010, arXiv:0910.3143

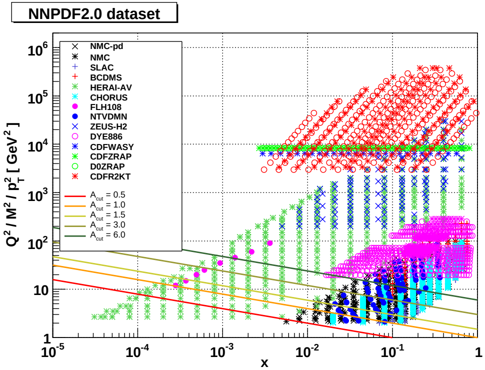
Search for deviations from NLO DGLAP



General Strategy:

- Cut out data in the "unsafe" (small–x and Q^2) region
- Determine PDFs in the "safe" (large-x and Q^2) region
- Evolve backwards and compare to data in causally connected region
- Tension between data and back-evolution: deviations from NLO DGLAP

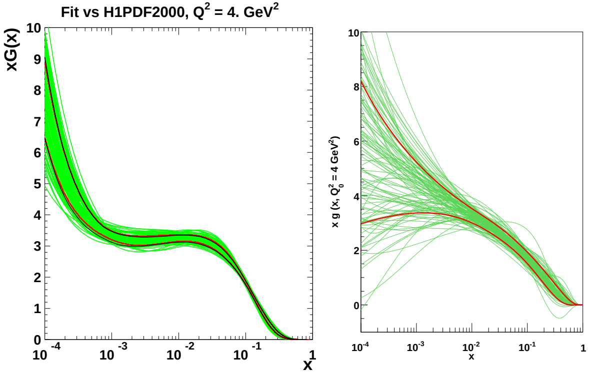
Search for deviations from NLO DGLAP



General Strategy:

- Cut out data in the "unsafe" (small–x and Q^2) region
- Determine PDFs in the "safe" (large-x and Q^2) region
- Evolve backwards and compare to data in causally connected region
- Adopt *Saturation–inspired* cut $Q^2 \geq A_{\rm cut} x^{-1/3}$, $A_{\rm cut} = 0.5 - 1.5$

Simple functional froms vs. NeuralNets



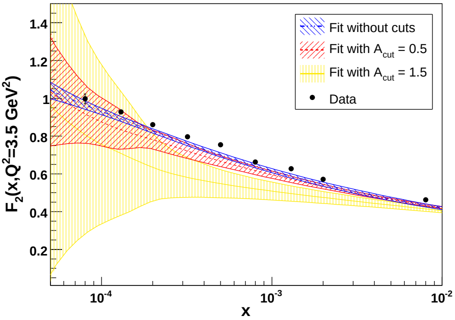
Flexible input PDF parametrization crucial to not bias the results for extrapolation in the DGLAP causally connected region

- Simple functional forms $q(x) = Ax^b(1-x)^c P(x)$ (CT, MSTW, ABKM, HERAPDF)
  $\rightarrow$ systematic underestimation of uncertainties
- Artificial Neural Networks as universal interpolants (NNPDF)
  $\rightarrow$ avoid theoretical bias from choice of PDF functional form
- Compare $\mathcal{O}$(300) parms in NNPDF with $\mathcal{O}$(10-25) parms in standard PDF sets

also PDFs from Chebichev polynomials, Glazov, Moch, Radescu, arXiv:1009.6170 and Pumplin, arXiv:0909.5176

The Evidence

Compare NNPDF2.0 without cuts and with cuts $A_{\rm cut} = 0.5$ and $A_{\rm cut} = 1.5$



- Backwards evolution for F_2 at low Q^2 undershoots HERA data
- Effect increases with cuts – but larger PDF errors from reduced dataset

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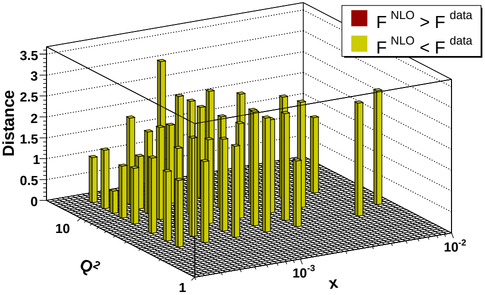

- Backwards evolution for F_2 at low Q^2 undershoots HERA data
- Statistically significant effect: account for data and PDF uncertainties

$$d_{\rm stat}(x, Q^2) \equiv \frac{F_{\rm data} - F_{\rm fit}}{\sqrt{\sigma^2_{\rm data} + \sigma^2_{\rm fit}}},$$

The Evidence

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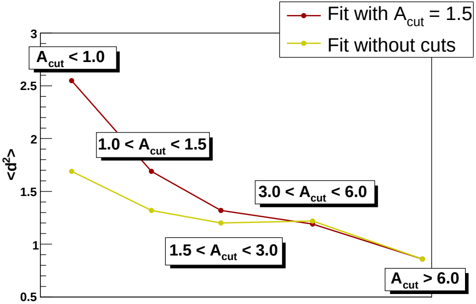
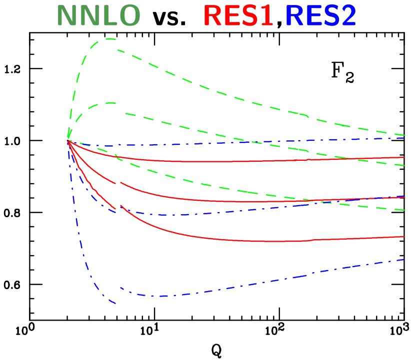


- Backwards evolution for F_2 at low Q^2 undershoots HERA data
- Statistically significant effect: accout for data and PDF uncertainties
- Systematic trend increases when going to small-x and Q^2

Deviations from NLO DGLAP in inclusive HERA data

Where do the deviations come from?

- NNLO? No – opposite trend
  Prediction → The χ^2 of NNLO fit to small-x and Q^2 HERA data worse than at NLO
  Confirmed by HERAPDF and NNPDF NNLO analysis
- Small-x resummation? Consistent with expected suppression



Altarelli, Ball, Forte 2008

- Non-linear effects? Expected to suppress F_2^p. But too small in HERA regime?

Work in progress to determine the source of the deviations

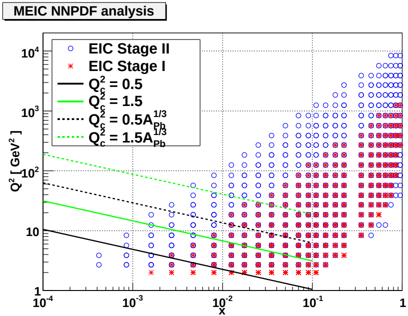
Linear and non linear effects can be disentangled at an Electron Ion Collider

Outline

Nuclear Parton Distributions and deviations from DGLAP evolution at an Electron Ion Collider

A. Accardi, V. Guzey and J. Rojo
To appear in the INT EIC workshop report

General Strategy at the EIC



Follow the HERA strategy:

- Generate pseudo-data for σ^{Pb} at EIC Stage-I and Stage-I+II
- Perform NNPDF analysis wo cuts $\rightarrow$ Determine accuracy in measurement of nuclear quarks and gluons
- Perform NNPDF analysis with cuts $\rightarrow$ Explore EIC sensitivity to non-linear effects

$$Q^2 \geq Q_c^2 x^{1/3}, \; Q_c^2 = A_{\mathrm{Pb}}^{1/3} A_{\mathrm{cut}}$$

- Similar cuts as with HERA data but boosted by nuclear factor $A_{\mathrm{Pb}}^{1/3}$
- The use of Pb pseudo-data only bypasses the problem of parametrizing the A dependence of nuclear PDFs

EIC pseudo-data generation

- Input for analysis: EIC pseudo data for the inclusive DIS
  1. Stage I: a medium energy EIC $\rightarrow \sqrt{s} = 12, 17, 24, 32, 44$ GeV
  2. Stage II: a full energy EIC $\rightarrow \sqrt{s} = 63, 88, 124$ GeV
- Integrated luminosity for all energies $\mathcal{L}$ =4 fb^{-1}
  Small compared to the assumed 2% systematic and 1% lumi uncertainties
- Nuclear effects included in K-factor approximation,

$$\sigma^{\mathrm{Pb}}_{T,L}\left(x, Q^2, y\right) = K^{\lambda}_{T,L}\left(x, Q^2, y\right)\sigma^{\mathrm{p}}_{T,L}\left(x, Q^2, y\right) \ ,$$

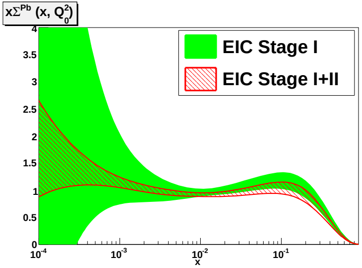
  $\sigma^{\mathrm{p}}_{T,L}\left(x, Q^2, y\right)$ from NNPDF2.0
  λ sets intensity of saturation ($\lambda = 1$ default of the IP Non-sat model)

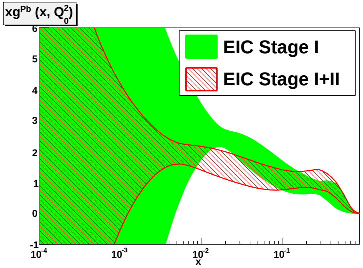
$$K^{\lambda}_{T,L} = \frac{2}{\langle \sigma_{q\bar{q}} \rangle_{T,L}} \int d^2b \left\langle \left(1 - e^{-\lambda \frac{1}{2} A \sigma_{q\bar{q}} T_A(b)}\right) \right\rangle_{T,L} ,$$

- For $x > 0.1$, $K^{\lambda}_{T,L}$ from EPS98 nuclear PDFs
- Pseudo data corrected for the expected statistical fluctuations

Nuclear PDFs at the EIC

- NLO DGLAP analysis of EIC Pb pseudo-data based on the NNPDF framework
  $\rightarrow$ Unbiased determination of nuclear quarks and gluons
- Gluon shadowing determined down to $x \sim 10^{-2}$ (Stage I) and $\sim 10^{-3}$ (Stage I+II)
  Important input for Heavy Ion Collisions
- Quark shadowing pinned down for smaller x
  Also good precision at large-x (anti-shadowing, Fermi motion)





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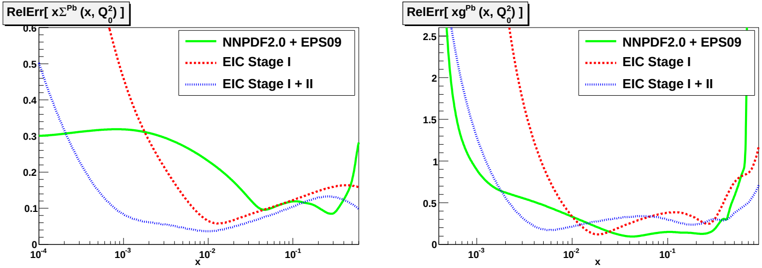
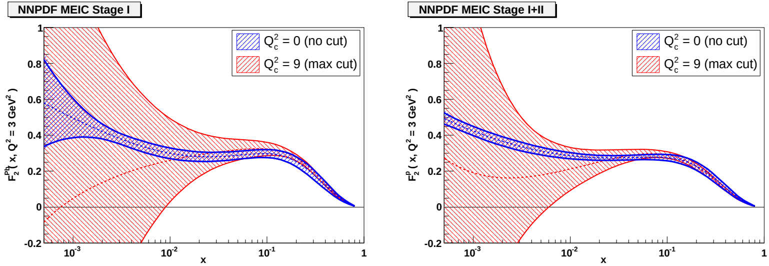


Pinning down non-linear QCD at the EIC

$$F_2^{\rm Pb}(x, Q^2 = 3\,{\rm GeV}^2)$$



Preliminary results:

- Compare results without cuts and with $Q^2 \geq Q_c^2 x^{-1/3}$ with $Q_c^2 \sim 9$ cut
- Compute in both cases $F_2^{\rm Pb}(x, Q^2)$ for Stage I and Stage I+II
- Systematic downward trend identified, but large PDF uncertainties from reduced dataset
- Work in progress to optimize cuts and determine statistical significance of effect

Outline

Summary

- Deviations from fixed order DGLAP indentifed in inclusive HERA data
  Consistent with small-x resummation and generic non-linear dynamics
- EIC will provide a accurate measurements of nuclear gluons and quarks
  Gluon shadowing down to $x \sim 10^{-3}$, anti-shadowing, Fermi motion, ...
  Important input for Heavy Ion Collision
- More work required to determine EIC sensitivity to non-linear effects in inclusive data

Thanks for your attention!

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