Impact of EIC early science eP runs on unpolarized PDFs

EIC early science workshop – CFNS – Stony Brook

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with A. Accardi, M. Cerutti, S. Li, J. Owens and S. Park

Disclaimer

Scenarios and assumptions are based on:

	Species	Energy (GeV)	Luminosity/year (fb-1)	Electron polarization	p/A polarization
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG

Note: the eA luminosity is per nucleon

nuclear PDF perspective on saturation and the need for *eP* baselines

1. have *eA* data e.g.: $(e + Au)$ at 10x100 GeV
2. do same kinematics $(e + P)$ run (and $(e + D)$ run)

small-x region

Benefits:

+ better control of different effects at the same kinematics
  → crucial for "finding" saturation
+ extra: additional $(e + P)$ data set → extraction of F_L

First results from impact study on CJ global fit

large-x region

Scenario A $(e + D)$ at 10x130 GeV

Scenario B $(e + D)$ at 10x130 GeV + $(e + P)$ at 10x130 GeV

Scenario C $(e + D)$ at 10x130 GeV + $(e + P)$ at 10x130 GeV + $(e + P)$ at 10x250 GeV

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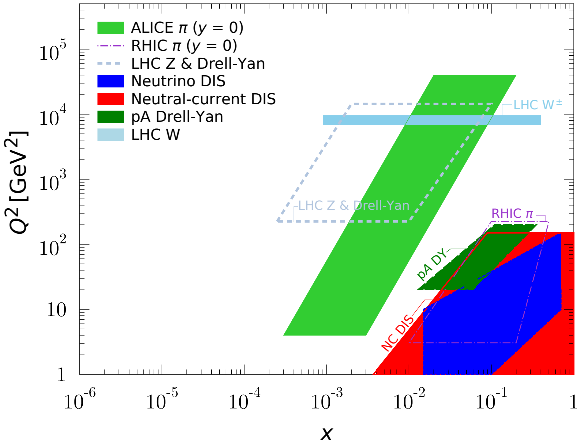
small-x region

Experimental data for global nuclear PDF fit

- good coverage for intermediate- to high-x
- good coverage for low-x at high energies
  - but: only $(P + Pb)$ data
- missing coverage for low-x at low energies

$\Rightarrow$ **"saturation discovery region" for global fits!**



[2311.00450]

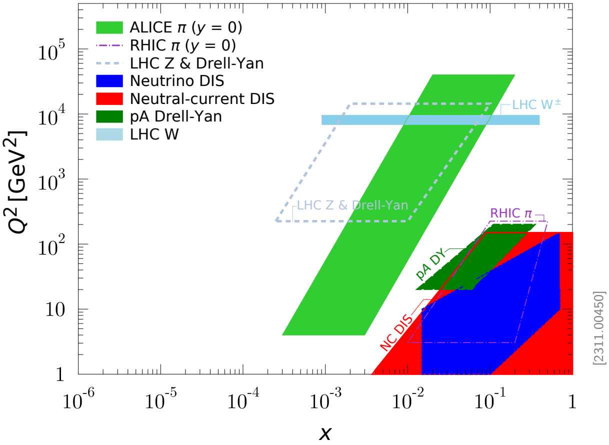
Fitting without baseline at low energies

nPDF "saturation discovery region"

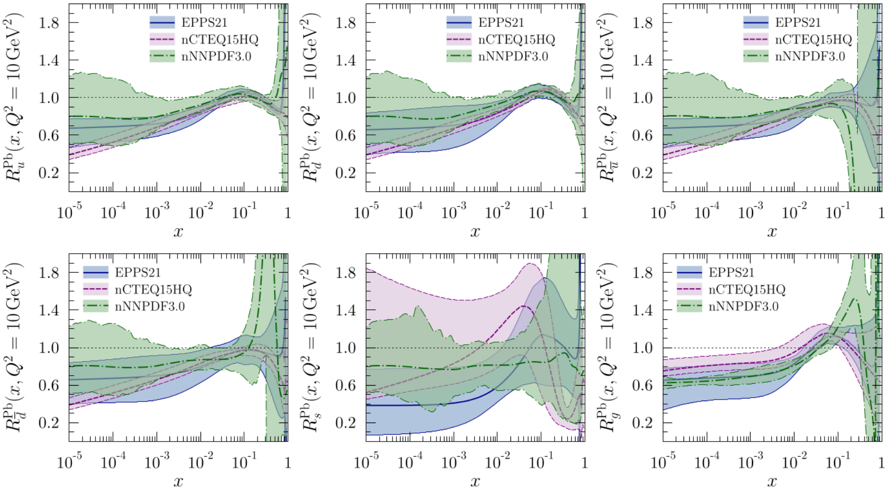
1. assume high energy data with or without saturation
2. use theoretical prediction without saturation effects
   - currently no problem, since PDFs at low-Q^2 can go as low as they want
3. new data at low-Q^2
   - tension between high-Q^2 and low-Q^2 data at small-x

$\Rightarrow$ **indicates saturation**

nuclear PDFs need to become precise a small-x



Nuclear ratio of EPPS21 vs. nNNPDF3.0 vs. nCTEQ15HQ

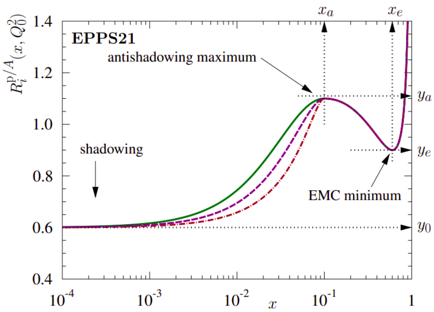


[2311.00450]

The Proton baseline is a key ingredient for nPDFs

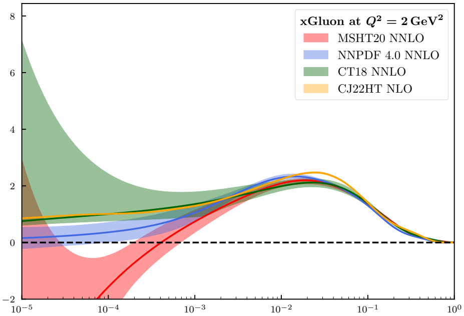
Example EPPS21: Bound Proton

$$f_i^{p/A}(x, Q_0^2) = R_i^{p/A}(x, Q_0^2) f_i^p(x, Q_0^2)$$

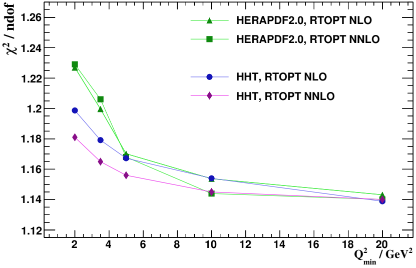


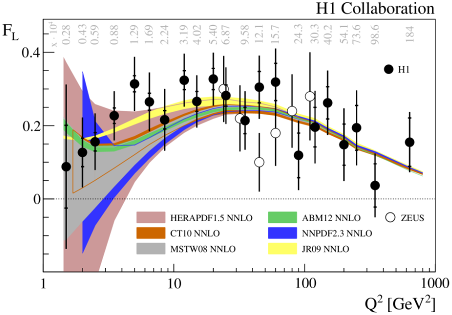
[EPJC 82, 413]

Current status of free Proton PDFs at low Q^2



Extra: F_L at small-x





- strong dependence on $Q^2_{\min}$ cut
- large uncertainty on theoretical predictions

see also:

Prospects for measurements of the longitudinal proton structure function F_L at the Electron Ion Collider

Javier Jiménez-López [*1], Paul R. Newman [†2], and Katarzyna Wichmann [‡3]

First results from impact study on CJ global fit

large-x region

Scenario A $(e + D)$ at 10x130 GeV

Scenario B $(e + D)$ at 10x130 GeV $+$ $(e + P)$ at 10x130 GeV

Scenario C $(e + D)$ at 10x130 GeV $+$ $(e + P)$ at 10x130 GeV $+$ $(e + P)$ at 10x250 GeV

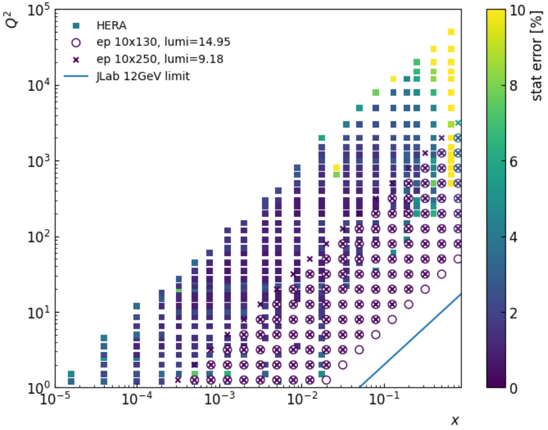
Baseline newest CJ release: CJ22ht

Systematic uncertainties from higher-twist corrections in DIS at large x

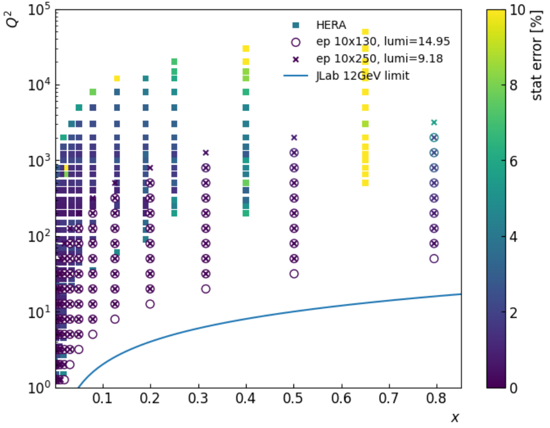
Matteo Cerutti,[1,2,*] Alberto Accardi,[1,2,†] I. P. Fernando,[3,‡] Shujie Li,[4,5,§] J.F. Owens,[6,¶] and Sanghwa Park[2,**]

[accepted by PRD, arXiv:2501.06849]

eP runs: kinematics & statistics



- improved precision at low-x



- improved precision at large-x

Comments

- scenarios provided by **Stephen Maple**
- the results are preliminary
- each data set corresponds to 1yr of measurement
- uncertainties: statistical + systematic
- central value fixed to baseline

Scenario A

Species:	$(e + D)$
Energy:	10x130 GeV
Luminosity:	11.4 fb^{-1}

Scenario B

Species:	$(e + D)$	$(e + P)$
Energy:	10x130 GeV	10x130 GeV
Luminosity:	11.4 fb^{-1}	5.33 fb^{-1}

Scenario C

Species:	$(e + D)$	$(e + P)$	$(e + P)$
Energy:	10x130 GeV	10x130 GeV	10x250 GeV
Luminosity:	11.4 fb^{-1}	5.33 fb^{-1}	9.18 fb^{-1}

Gluon PDF

only indirect sensitivity from DIS cross section

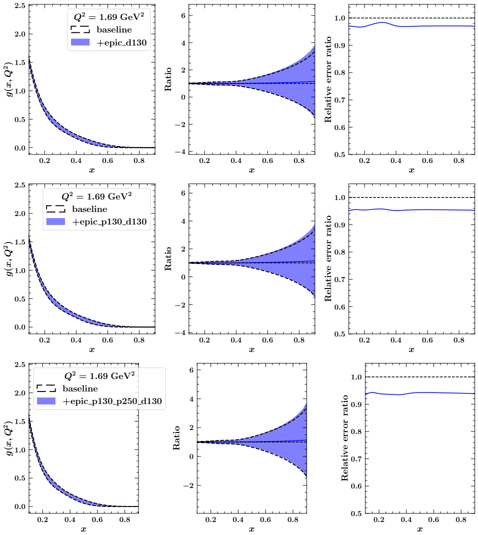
$\sim$ DGLAP evolution

$\sim$ $\boldsymbol{F_2}$: suppressed by α_S

$\sim$ $\boldsymbol{F_L}$: same order as quarks, but F_L is kinematically suppressed

Impact

- weak impact from $(e + D)$ (expected)
- main impact from $(e + P)$
- reduced uncertainty overall by $\sim$6%



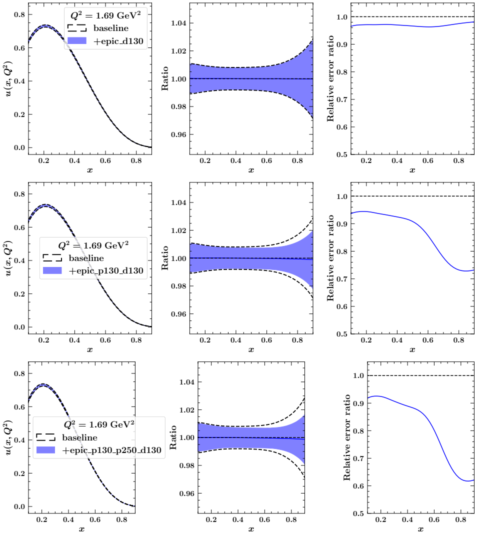
Up-quark PDF

leading order contribution to F_2

$$\left[F_2^{\gamma},\ F_2^{\gamma Z},\ F_2^{Z}\right] = x \sum_q \left[e_q^2,\ 2e_q g_V^q,\ {g_V^q}^2 + {g_A^q}^2\right]\ (q+\bar{q})$$

Impact

- weak impact from $(e+D)$ (expected)
- main impact from $(e+P)$
- reduced relative uncertainty by up to ∼40% at large-x



Offshell expansion of the Deuteron

within the "weak binding approximation":

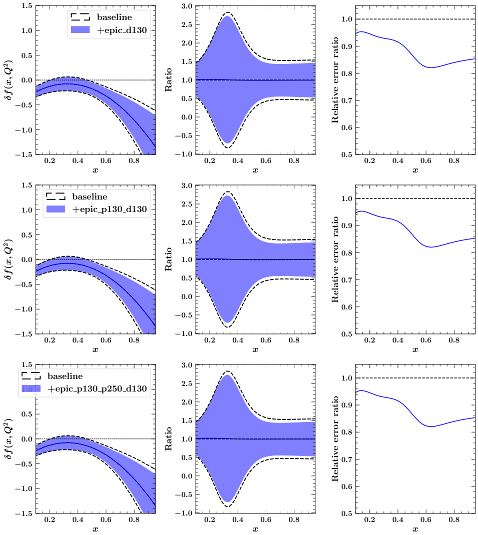
$$F_{2N}(x,Q^2,p^2) = F_{2N}^{\text{free}}(x,Q^2)\left[1 + \frac{p^2 - M^2}{M^2}\delta f(x)\right]$$

Free proton, neutron structure function

"offshell function"

Impact

- strong impact from $(e + D)$
- up to ∼20% reduced relative uncertainty
- weak impact from $(e + P)$ (expected)



Higher twist corrections (neutron)

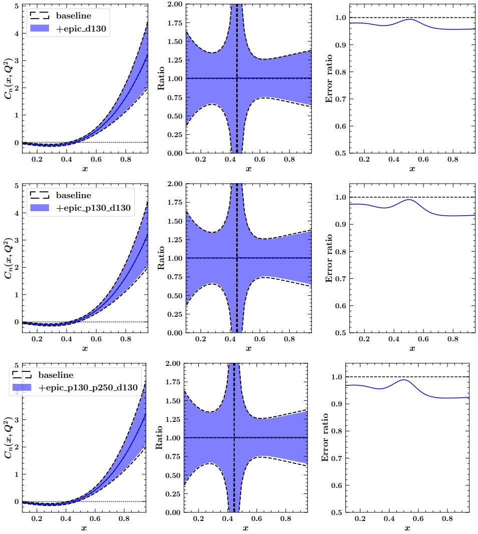
“catch-all” function for residual power corrections

$$F_{2N}^{\text{mult}}(x,Q^2) = F_{2N}^{\text{TMC}}(x,Q^2)\left(1+\frac{C(x)}{Q^2}\right)$$

important feature: suppressed by $1/Q^2$

Impact

- small impact from $(e+D)$
- small impact from $(e+P)$
- good result: disentanglement from other effects! important difference to JLab data
- C_p sees impact: reduced uncertainty by up to ∼15%



Conclusion

nuclear PDF perspective on saturation and the need for *eP* baselines

1. have *eA* data e.g.: $(e + Au)$ at 10x100 GeV
2. do same kinematics $(e + P)$ run (and $(e + D)$ run)

Benefits:

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small-x region

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Scenario A strong impact on off-shell PDF modification → even more with tagged DIS! possible disentanglement for higher twist corrections from other effects!

Scenario B as scenario A, plus sizeable impact on Gluon and Up-quark distribution

Scenario C similar to Scenario II but with more statistics additional $(e + P)$ data set → extraction of F_L

large-x region

Thank you!

backup

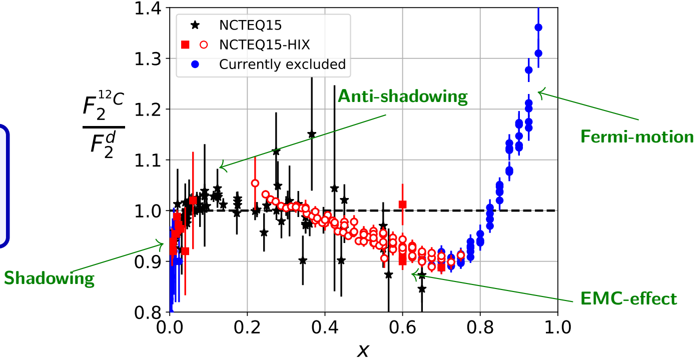
Structure of nuclei

- Nuclear binding energy $\sim 1\%$ of mass
- First approximation:
  nuclei consist of free protons & neutrons

$$F_2^A(x) \approx\neq Z F_2^{p,free}(x) + N F_2^{n,free}(x)$$

$\Rightarrow$ **does not work**

- Cross-sections in nuclear collisions are modified
- Can we translate these modifications into **universal** quantities?



$\Rightarrow$ **nuclear PDFs**

Nuclear modification: free proton vs bound proton