Summary of work done from the ATHENA proposal

EIC Detector-1 Inclusive Group
Kick-off meeting
9 May 2022

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with
Barak Schmookler (UC Riverside), Qinghua Xu (Shandong)

General Framework / Strategy

- Meetings every 2 weeks in steady-state

- Attendees were conveners + a couple of students + conveners from other physics / simulation groups + management representation + occasional visitors (typically <10 people)

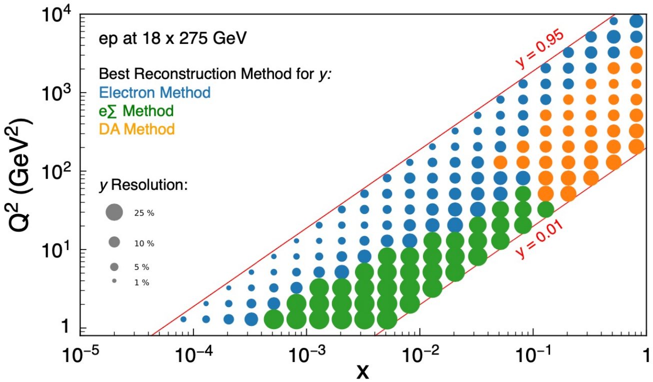
- Work for proposal was done by a small number of ATHENA colleagues + strong external collaborators (for PDF fitting)

Tasks:

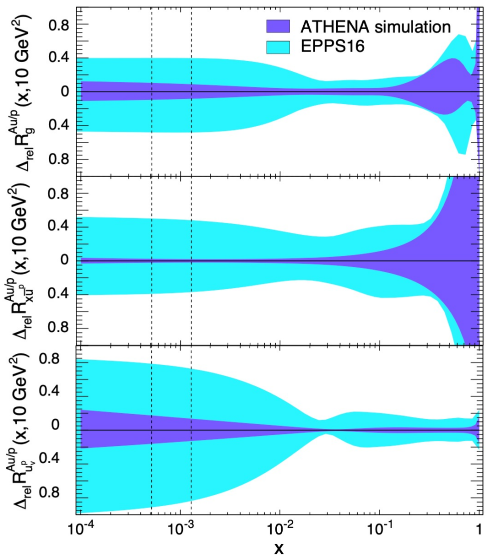
- Evaluating technical performance of ATHENA
- Testing simulation / software updates
- Further evaluating physics performance / motivation

- Work continued after proposal completion, based on 3 abstracts submitted to DIS'22

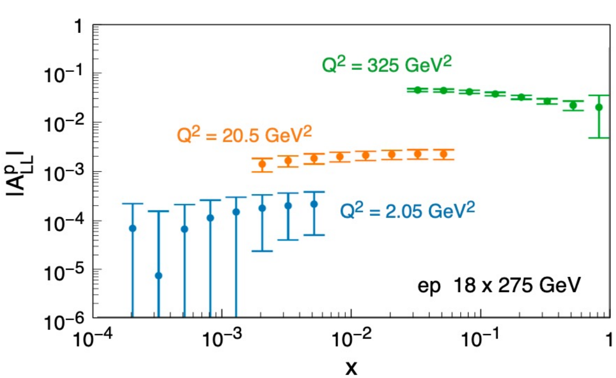
DIS'22 Abstracts



1) Kinematic Reconstruction for inclusive scattering at EIC-ATHENA
[ATHENA standalone]



2) Proton and Nuclear Collinear Parton Densities at the Electron Ion Collider using Simulated ATHENA Data
[with external colleagues from fitting groups]

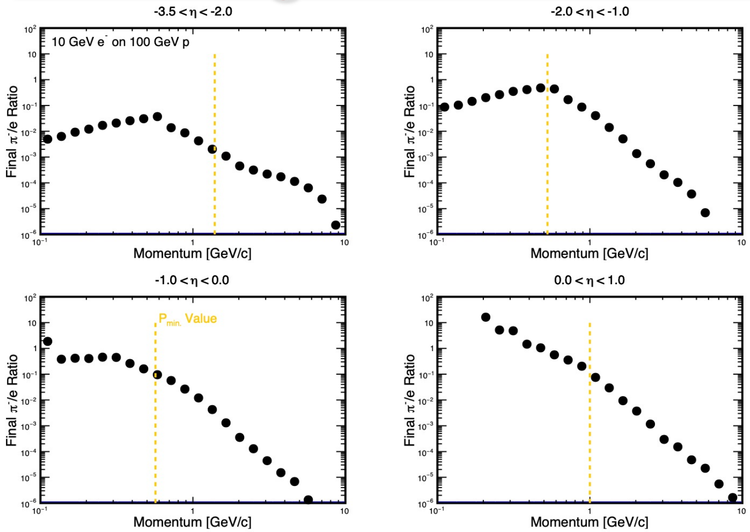


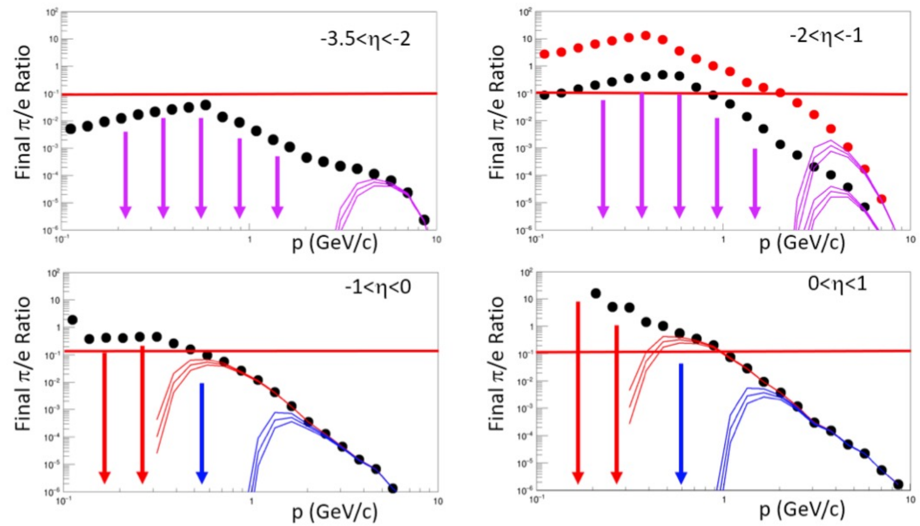
3) Probing Nucleon Spin Structure with Inclusive DIS at EIC-ATHENA
[with external colleagues from fitting groups]

Each topic had a (separate) write-up
in the proposal supplementary material

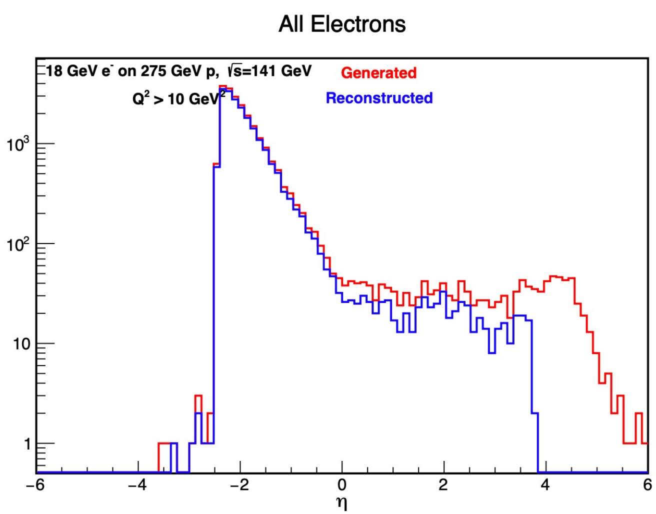
Performance with `Fully' Simulated Data

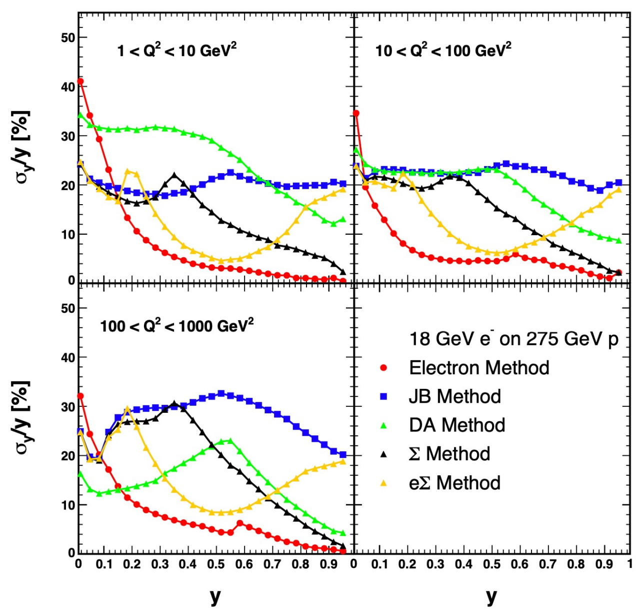
π/e Background Contamination





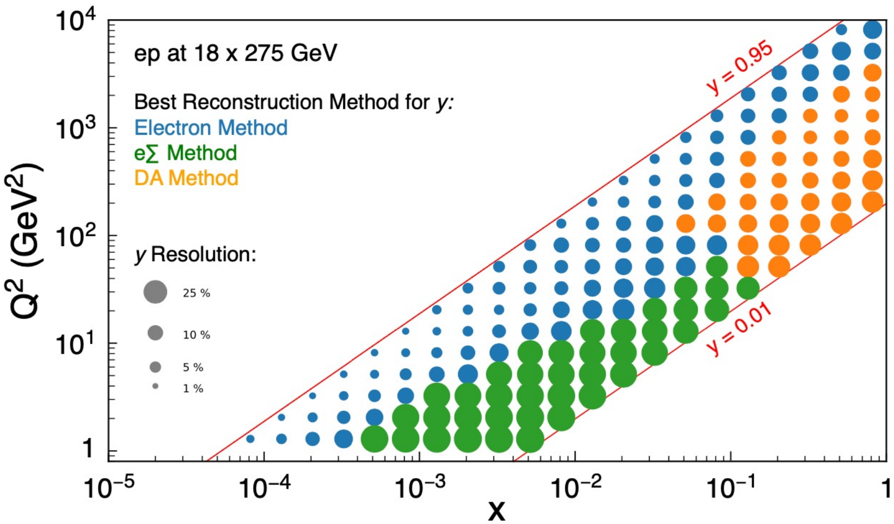
Acceptances

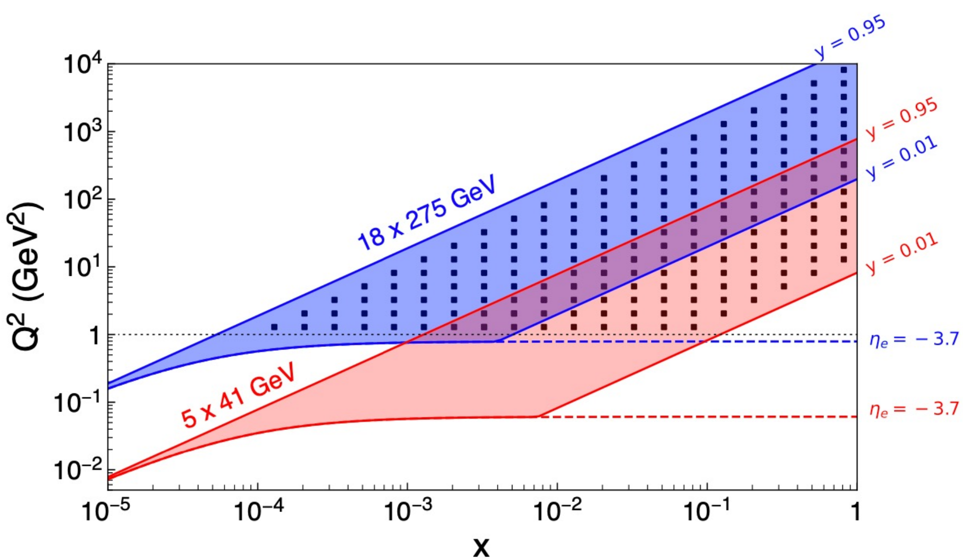




Resolutions With 1st approx'n to Particle Flow algorithm

Fit Input Data (ep)





- Detailed simulation work to optimise resolutions throughout phase-space
→ 5 bins per decade in x and Q^2

- Kinematic coverage: $Q^2 > 1$ GeV^2, $0.01 < y < 0.95$, $W > 3$ GeV

- Lower y accessible in principle, but easier to rely on overlaps between data at different $\sqrt{s}$

- Highest x bin centre at x=0.815

e-beam E	p-beam E	$\sqrt{s}$ (GeV)	inte. Lumi. (fb^{-1})
18	275	140	15.4
10	275	105	100.0
10	100	63	79.0
5	100	45	61.0
5	41	29	4.4

- CC data also included for highest $\sqrt{s}$

Fit Input Data (eA)

Similar approach for eA … Per-nucleon integrated luminosities:

5 x 41GeV:	**4.4 fb^{-1}**
10 x 110GeV:	**79 fb^{-1}**
18 x 110GeV:	**79 fb^{-1}**

Systematic Precision

- Dominant sources at HERA were
  - Electron energy scale (intermediate y)
  - Photoproduction background (high y)
  - Hadronic energy scale / noise (low y)

- EIC will improve in all areas (e.g. dedicated ATHENA particle ID detectors allow π/e contamination at 10^{-6} level at low momenta)

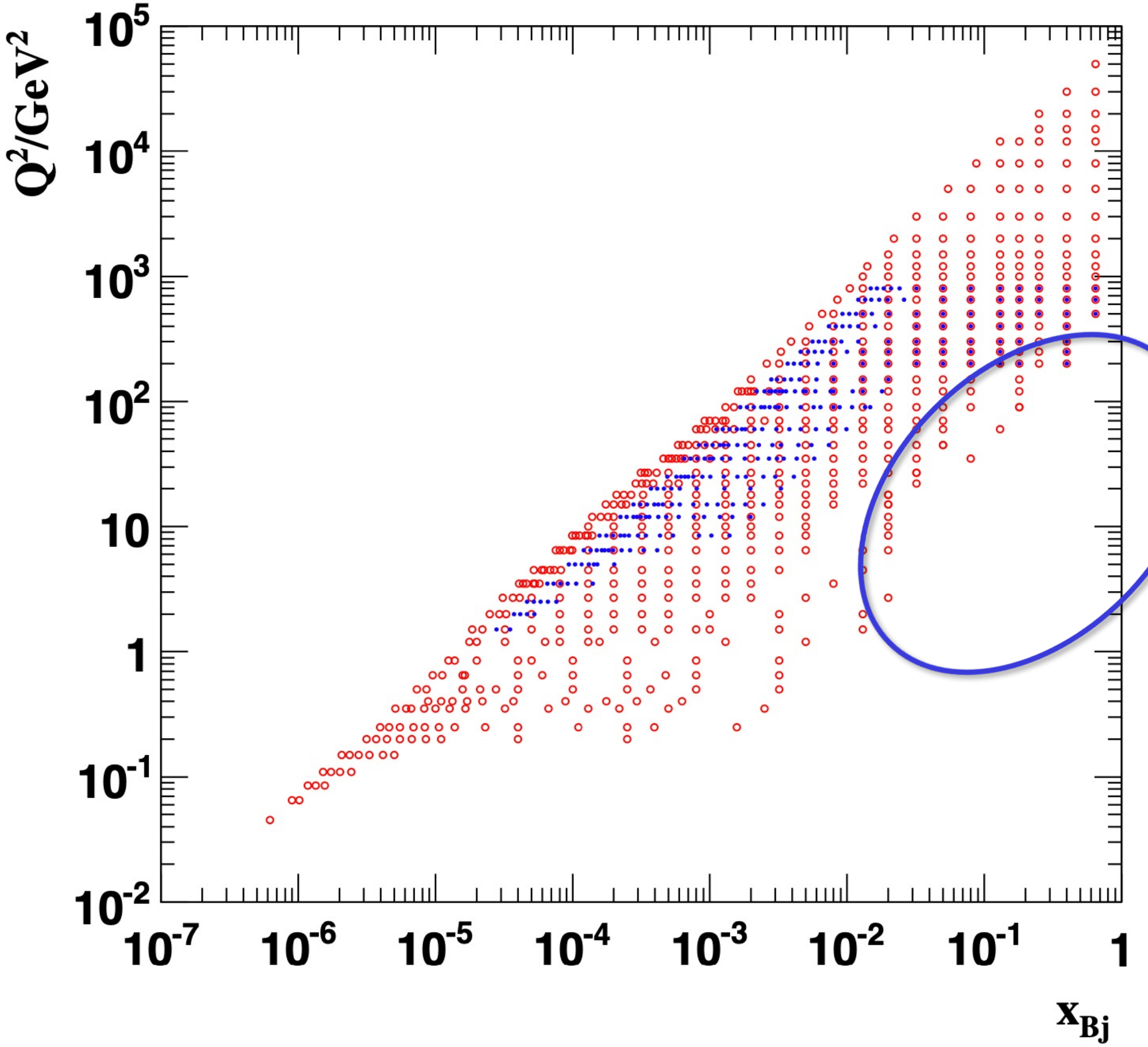
- ATHENA systematic precision compatible with assumptions in Yellow report:

→ **1.5-2.5% point-to-point uncorrelated**
→ **2.5% normalisation (uncorrelated between different $\sqrt{s}$)**

Impact on HERAPDF2.0 Proton PDFs

- `DIS-only’, HERA (or HERA+EIC/ATHENA) data

- Using xFitter framework



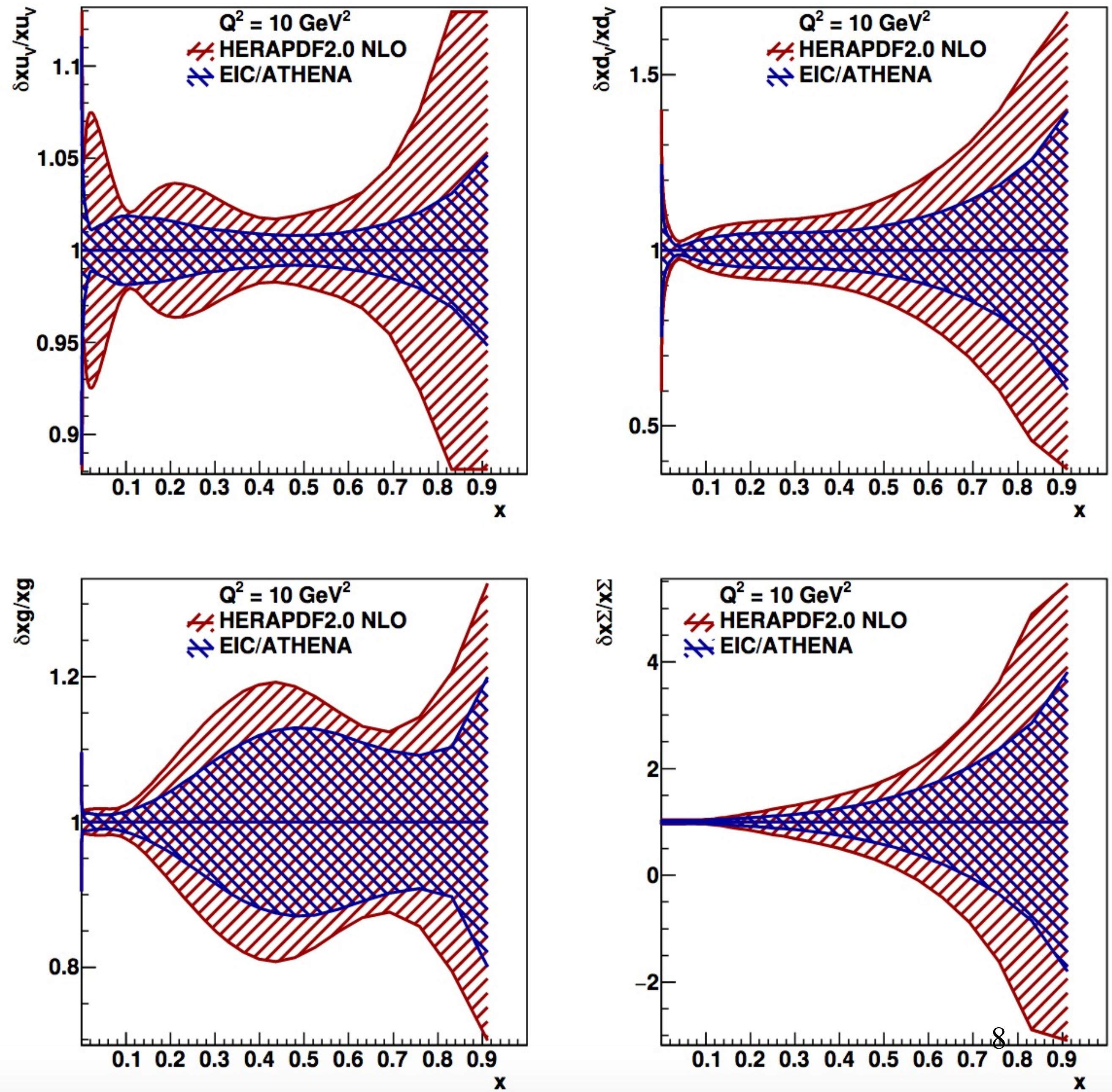
HERA data have limited high x sensitivity due to kinematic correlation between x and Q^2 and $1/Q^4$ factor in cross section

Impact of EIC/ATHENA on HERAPDF2.0

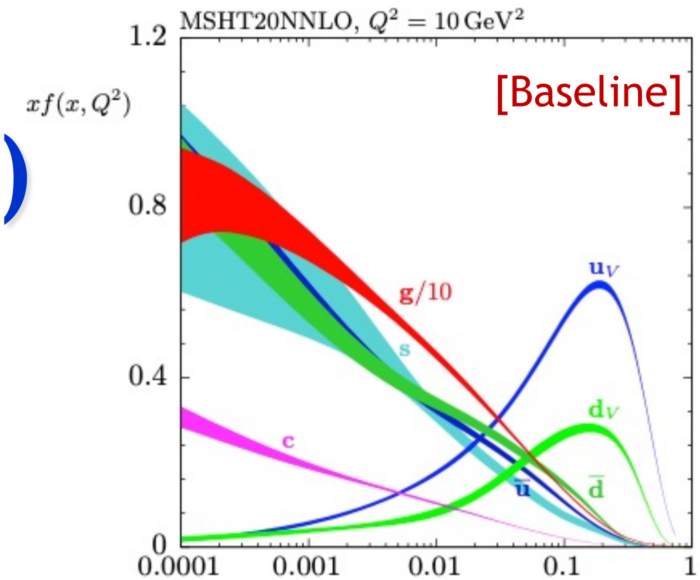
Fractional total uncertainties with / without EIC / ATHENA data included along with HERA

(linear x scale)

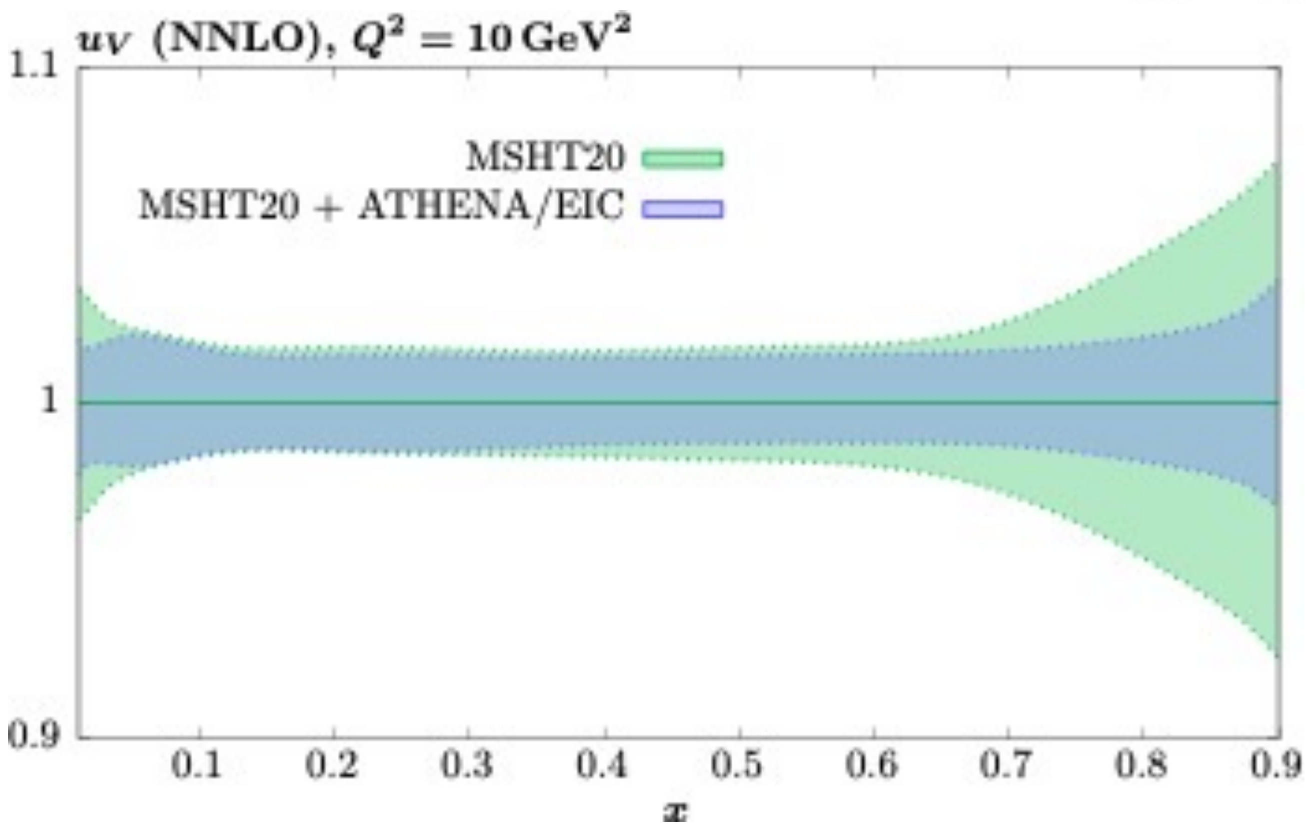
… EIC will bring significant reduction in uncertainties for all parton species at large x



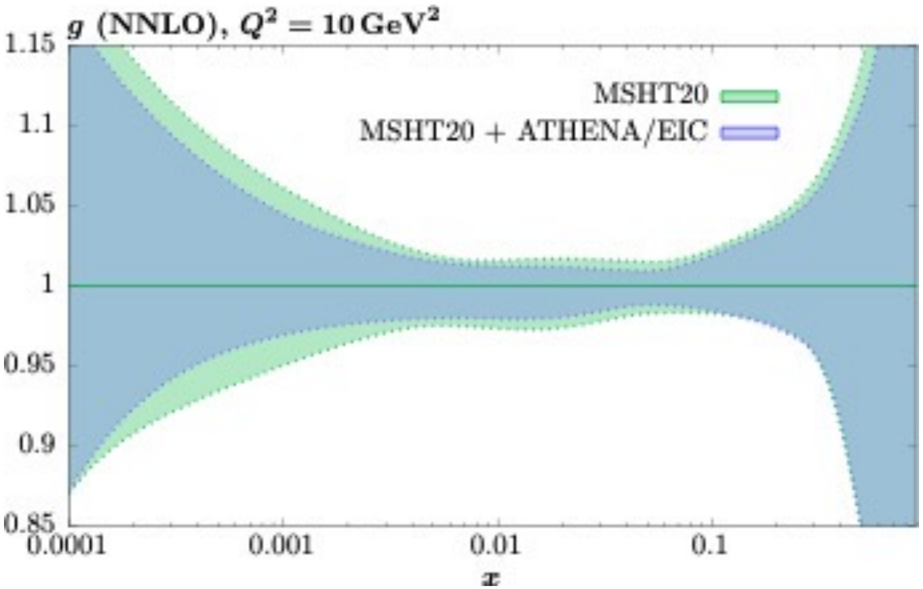
Impact relative to Global Fit: MSHT20 (NNLO)

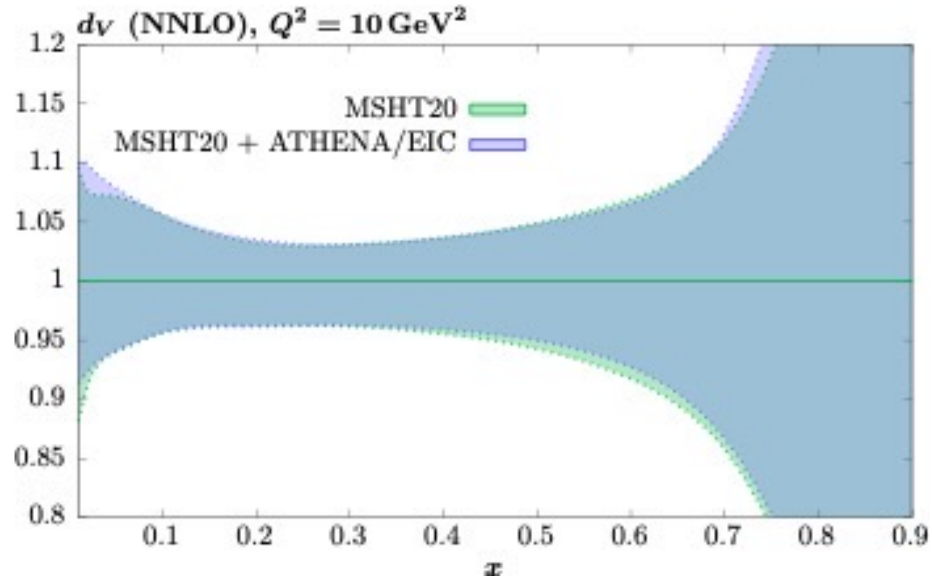


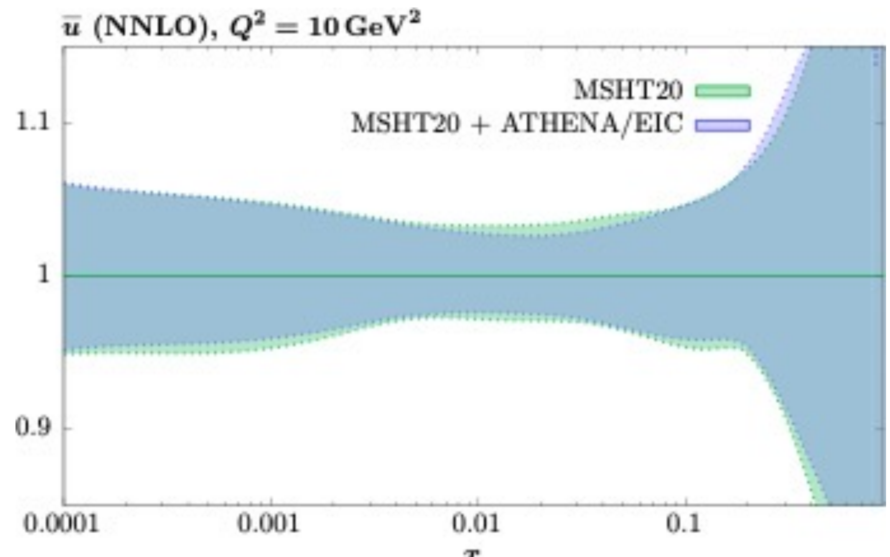
Significant impact of EIC/ATHENA data in up quark precision as x→1 (charge-squared weighting)



Impact relative to MSHT20



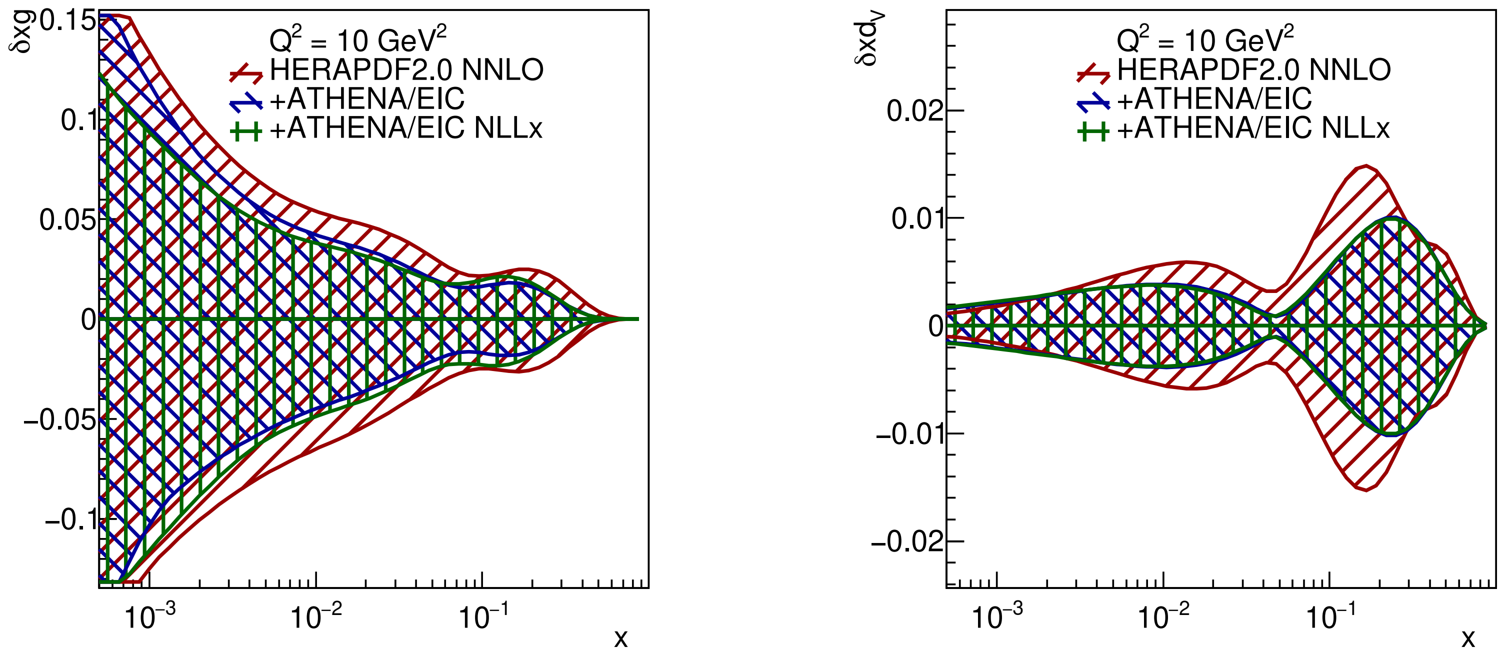




Small, but valuable improvements in all parton species at all x, Q^2, notably the gluon

Sensitivity to Low x Effects in ep?

- HERAPDF fits repeated with inclusion of log(1/x) resummation in simulated data and for fitting (NLLx via HELLx+APFEL, starting from $Q^2 = 2.5\ GeV^2$)

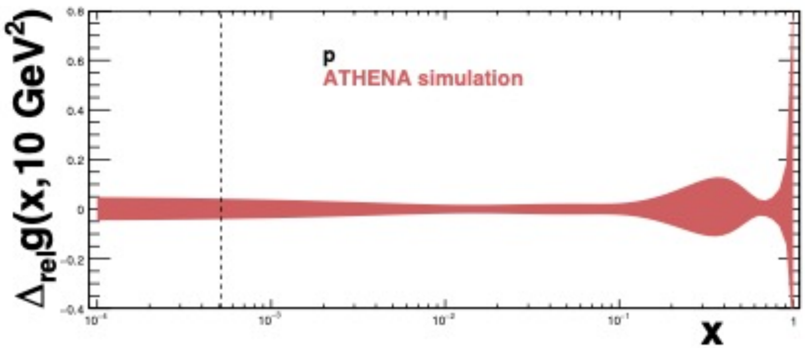


- EIC/ATHENA gives mild effect on gluon uncertainty at low x. Other PDFs unaffected. $\Delta\chi^2$ studies would be the obvious next step.

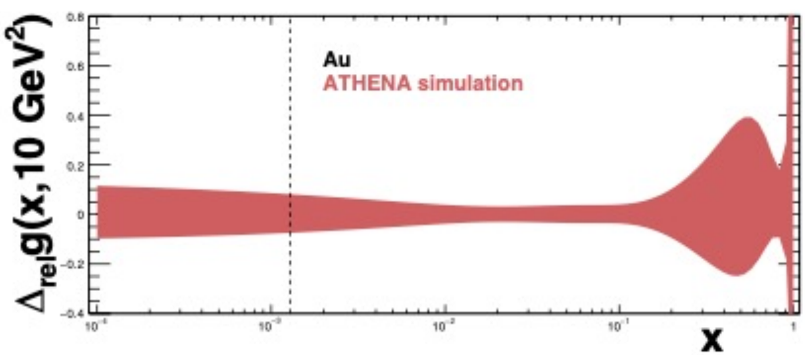
- Probably little or no sensitivity in ep data, due to restricted low x kinematic range compared with HERA

- Similar studies with nuclear targets will be interesting …

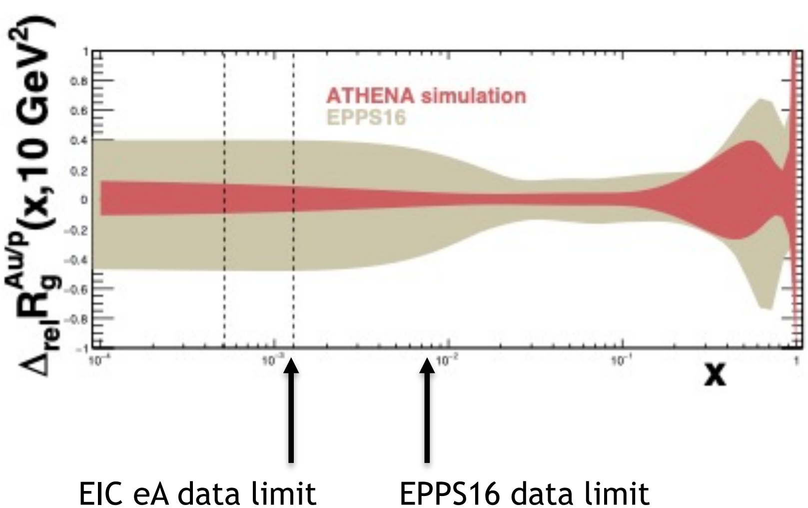
Impact on Nuclear PDFs: Gluon



Projected uncertainty
on gluon density of proton
from ATHENA-only fit



Projected uncertainty
on gluon density of (gold) nucleus
from ATHENA-only fit → ~10%

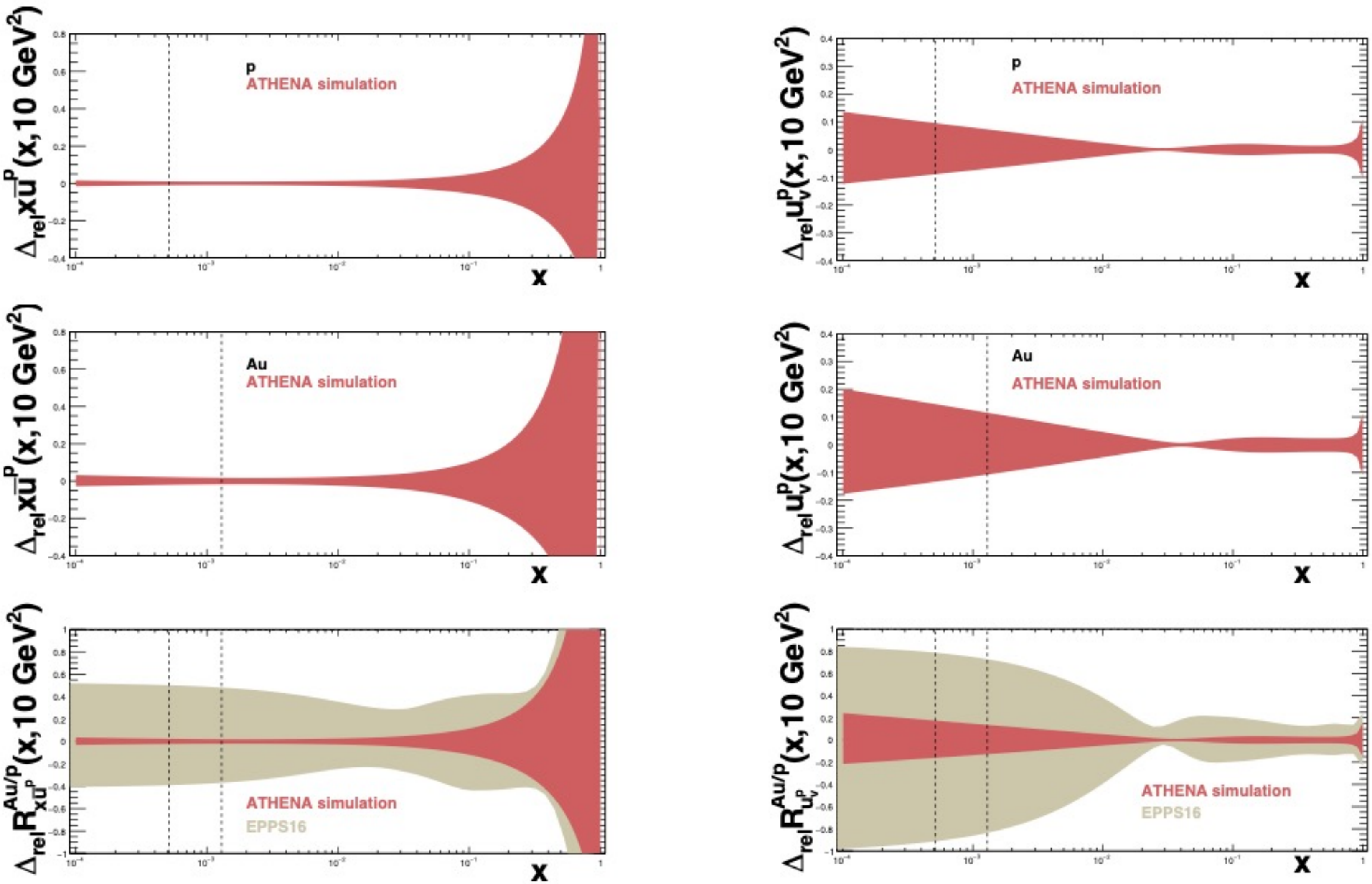


Projected uncertainty on nuclear modification factor, ATHENA-only compared with EPPS'16

→ Factor ~ 2 improvement at x~0.1 (tolerances)

→ Very substantial improvement in newly accessed low x region

Impact on Nuclear PDFs: ubar and u_v

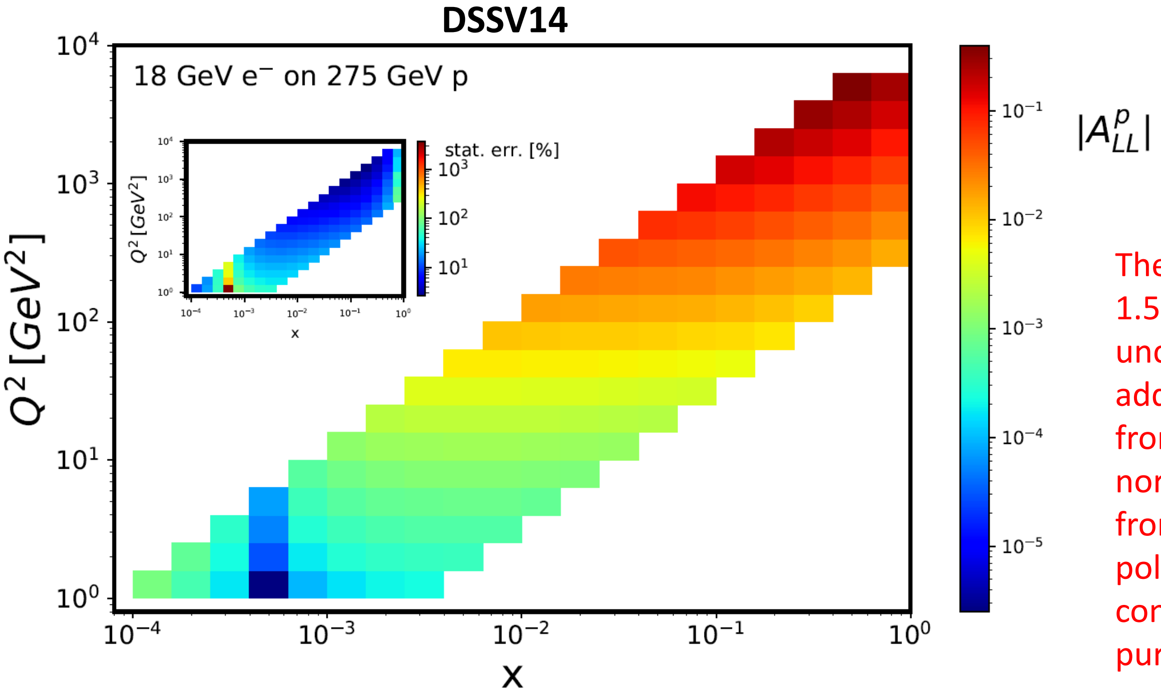


Similarly compelling improvements at low x for quark distributions

(Relative) Precision on A_{LL}

In most models, ALL becomes small in low x, low Q2 region
→ Challenge to keep systematics under control

Statistical and systematic uncertainties



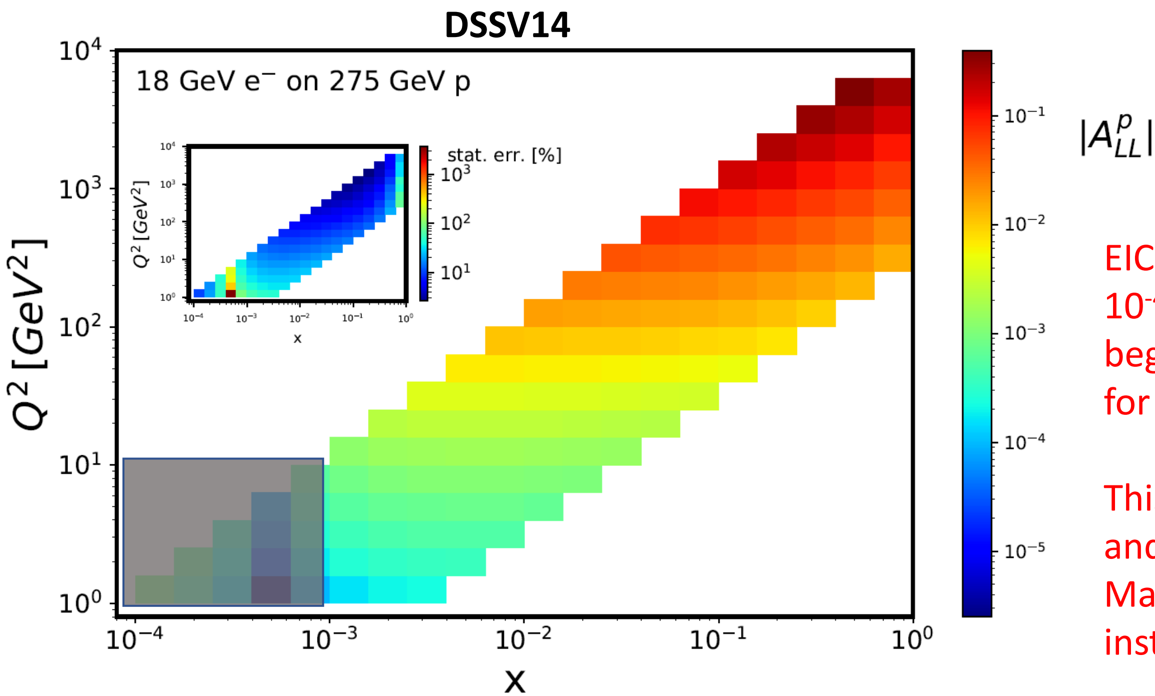
The systematic uncertainty estimation includes 1.5% point-by-point uncorrelated systematic uncertainty, 5% normalization uncertainty, and an additional systematic (shift) uncertainty of 10^{-4} from relative luminosity. The conservative 5% normalization uncertainty includes contributions from electron beam polarization (2%), proton polarization (2%), uncertainty related with pion contamination (3%, assuming 90% electron purity), and 1-2% on detector effects.

Statistical uncertainty on asymmetry measurement:

$$\sigma_{A_{LL}} = \frac{\sqrt{1 - A^2_{LL,meas}}}{P_e P_p \sqrt{N}} \approx \frac{1}{P_e P_p \sqrt{N}}$$

(Relative) Precision on A_{LL}

Statistical and systematic uncertainties



EIC kinematic coverage extends down to x of 10^{-4} for $Q^2 > 1$ GeV^2 …but statistical error begins to approach 100% of the asymmetry for $x < 10^{-3}$.

This assumes ~15 fb^{-1} integrated luminosity and 70-80% electron and proton polarization. Many years of running with high instantaneous luminosity can help.

Statistical uncertainty on asymmetry measurement:

$$\sigma_{A_{LL}} = \frac{\sqrt{1 - A^2_{LL,meas}}}{P_e P_p \sqrt{N}} \approx \frac{1}{P_e P_p \sqrt{N}}$$

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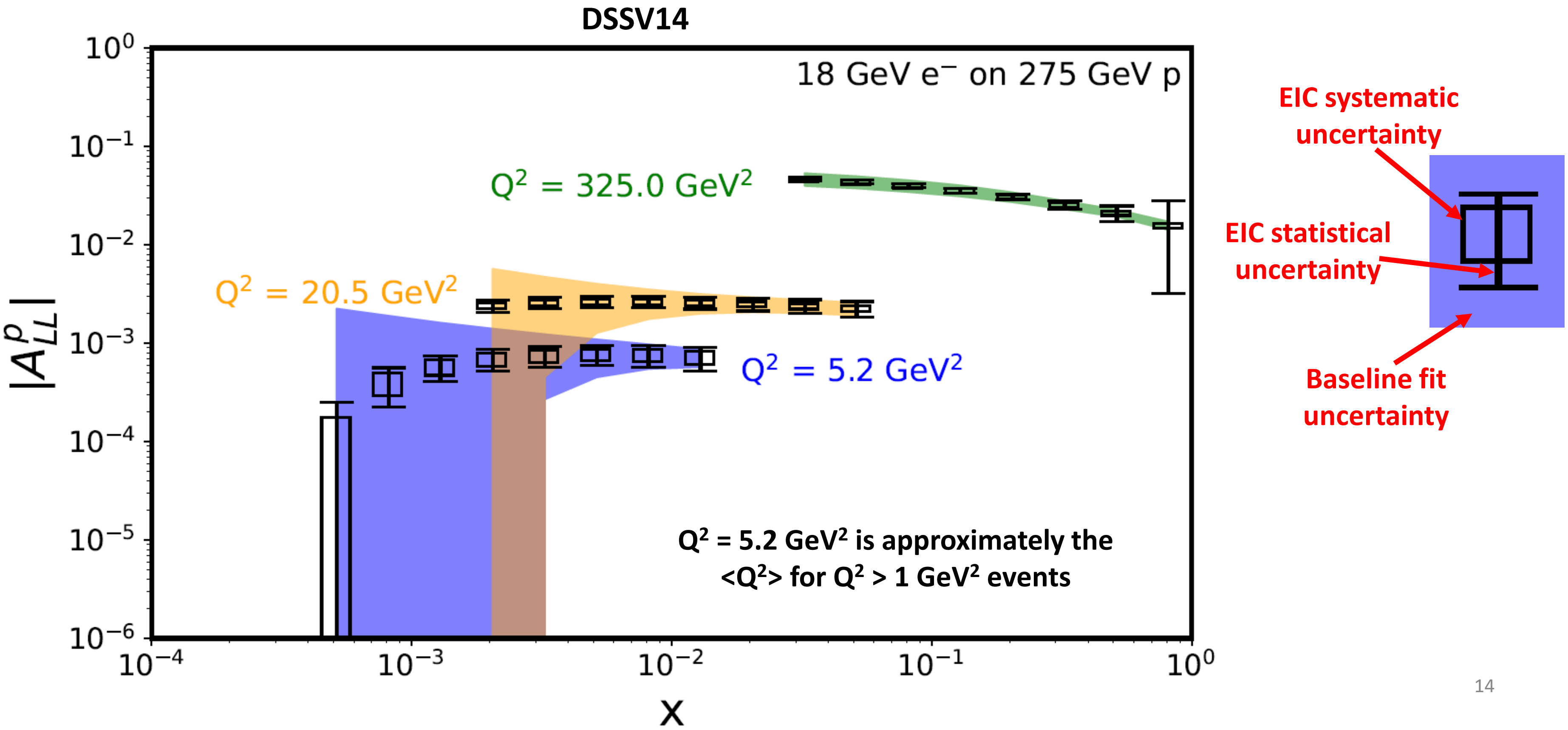
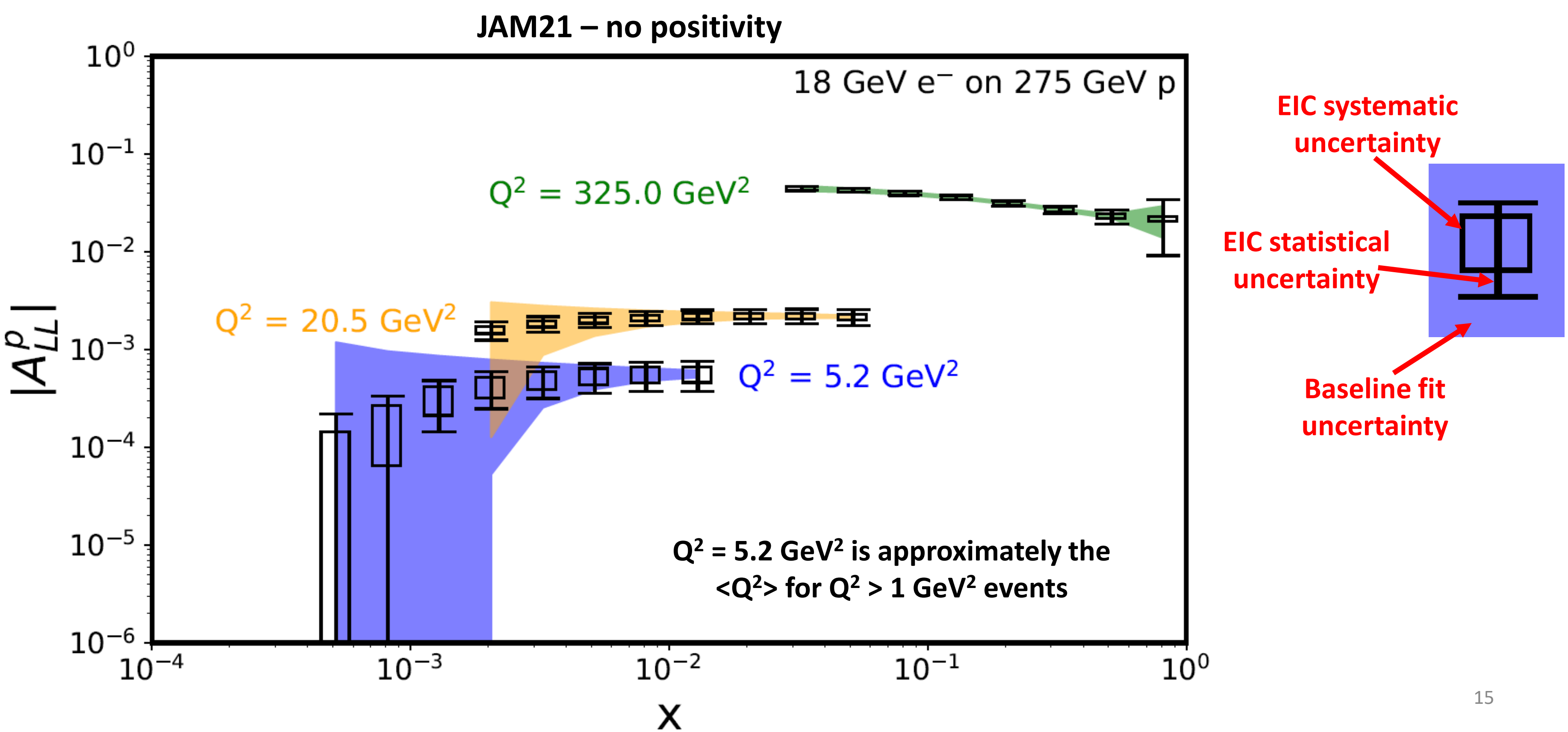
Impact on A_{LL}

Expected EIC experimental precision



Impact on A_{LL}

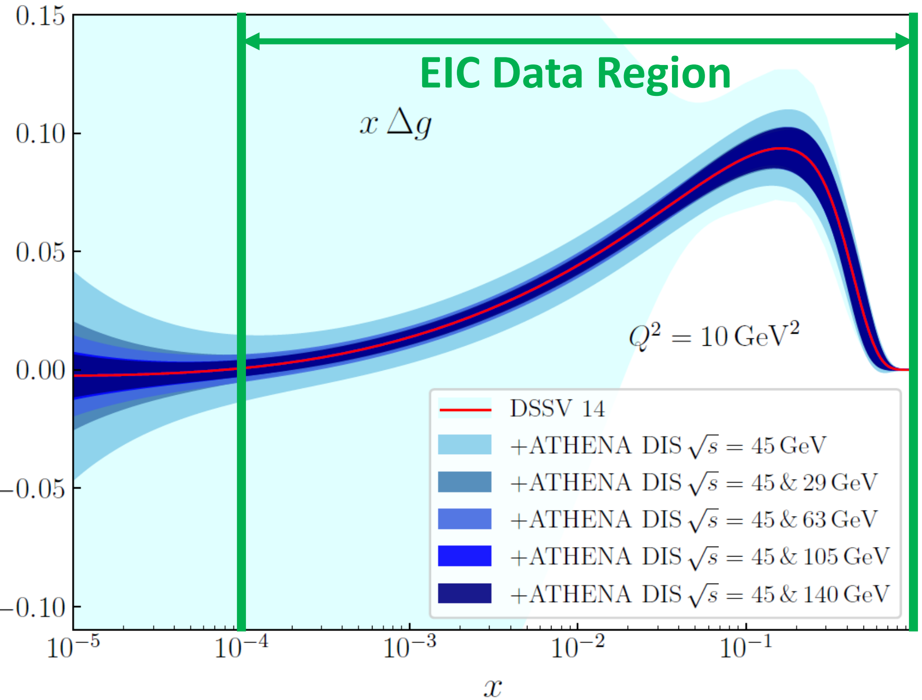
Expected EIC experimental precision

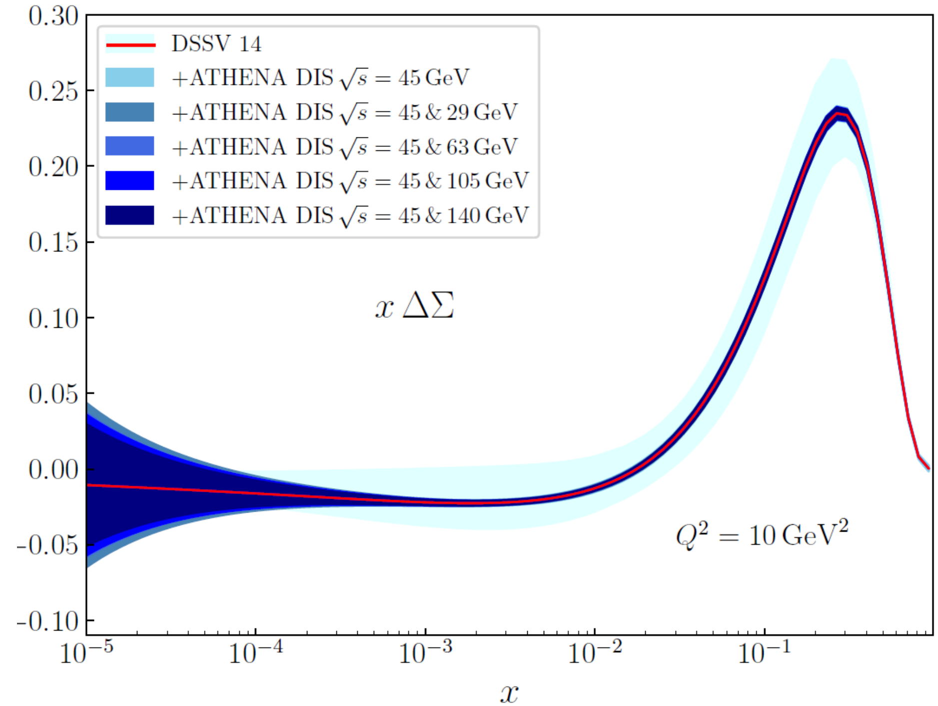


Impact on Helicity Distributions

[Re-evaluation of (pre)-Yellow Report studies, using ATHENA simulations]

Impact of the EIC on polarized PDFs: **DSSV**



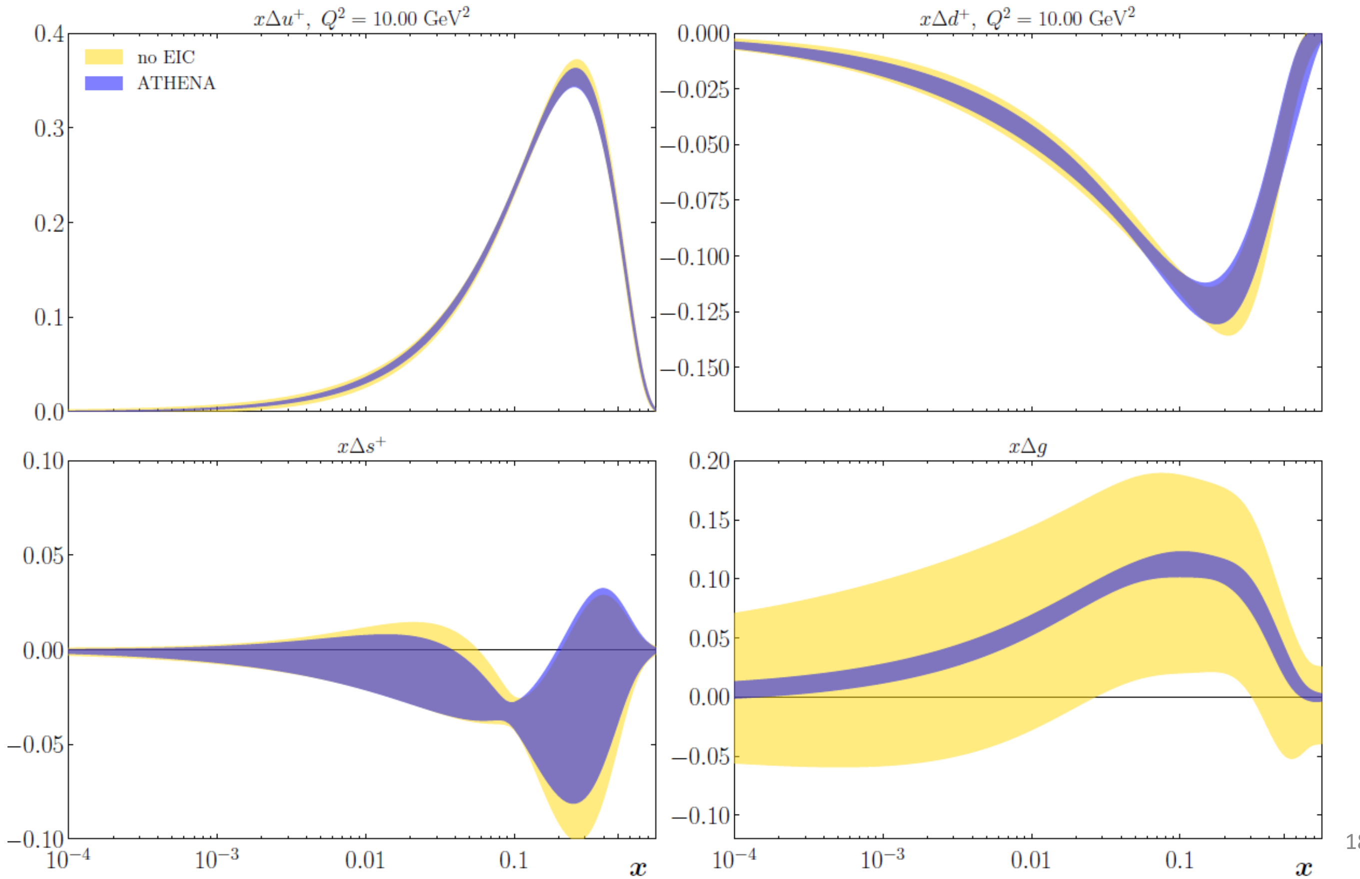


Very significant impact on polarized gluon and quark singlet PDFs using inclusive e-p only!

Impact on Helicity Distributions

Impact of the EIC on polarized PDFs: **JAM21 – no positivity**

Also shows very significant impact on polarized gluon PDF and moderate impact on flavor-separated PDFs using only inclusive e-p.



(Personal) Thoughts on next steps

At technical level …

- Keep updating results for new Detector-1 designs and new simulation / software releases

- Make a more realistic energy flow algorithm, particularly treatment of neutrals → overall hadronic final state reconstruction

- Investigate influence of QED radiation, especially ISR → New Monte Carlo generators (RAPGAP or DJANGO instead of PYTHIA8?)

- Look at kinematic fitting / machine-learning reconstruction algorithms

Physics observables …

- Merge ATHENA studies with ECCE and repeat for new detectors designs

- Make a more thorough evaluation of (some) systematic uncertainties

- Publish?