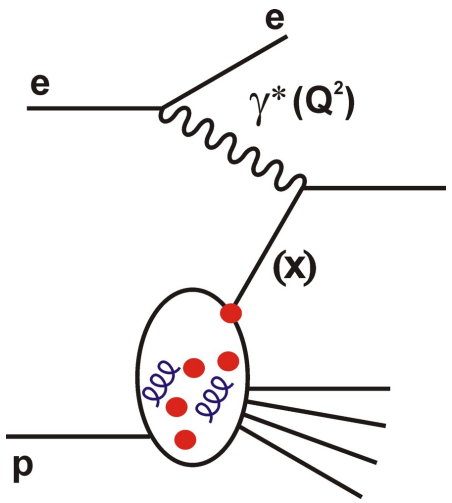
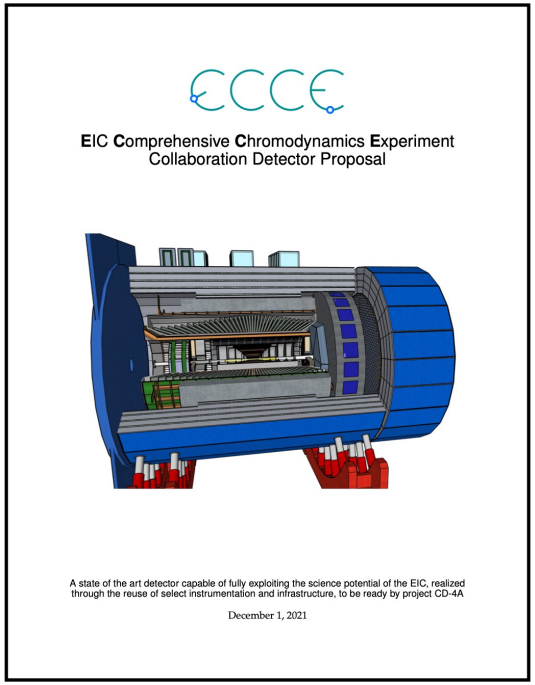
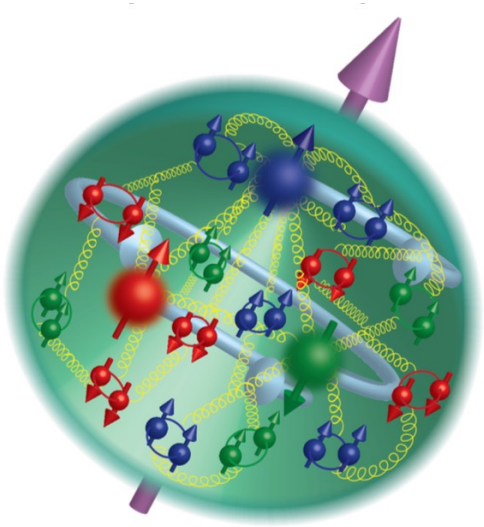
Inclusive Physics @ EIC: Status and UK Contributions in the Detector Proposal Phase



EIC-UK Discussion Meeting
30 June 2022

Paul Newman (Birmingham)





UK Leadership and Contributions

ATHENA

Paul Newman - Convener
- Assessment of impact on proton and nuclear PDFs

Stephen Maple – Performance studies (kinematic reconstruction etc)

Tom Cridge, Lucian Harland-Lang, Robert Thorne
- Assessment of impact on proton PDFs

ECCE

Claire Gwenlan - Convener
- Assessment of impact on proton PDFs

DETECTOR-I

Glaire Gwenlan and Paul Newman
- Conveners

Stephen Maple - Kinematic fitting studies

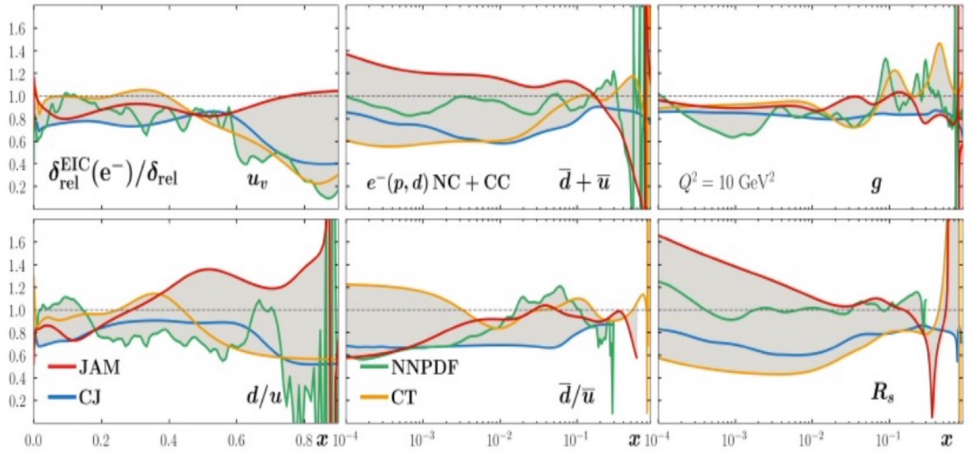
More emerging …

Some examples of work done follow (with apologies for ATHENA bias)

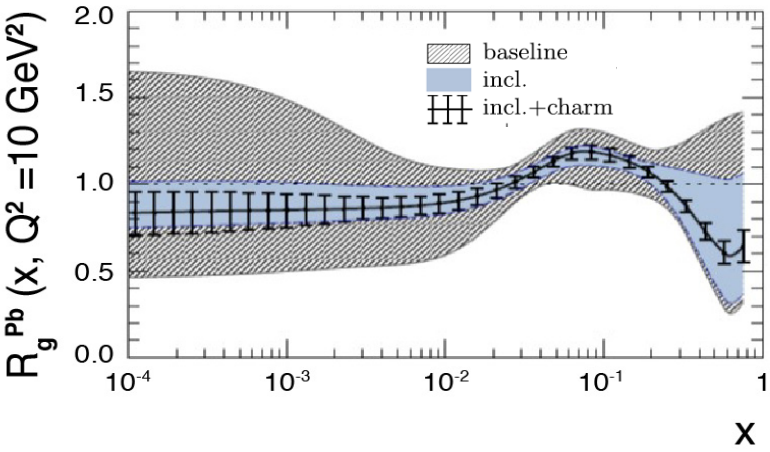
Unpolarised Collinear PDFs: Previous Work

- Several groups previously investigated EIC sensitivity to collinear PDFs, most recently in the context of the 2020/21 Yellow Report

Proton PDFs [arXiv:2103.05419]



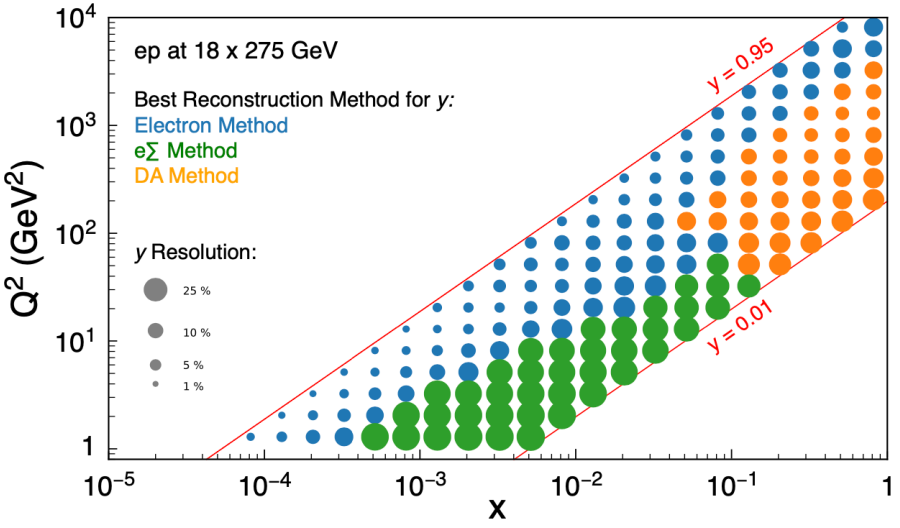
Nuclear PDFs
[PRD 96 (2017) 114005]

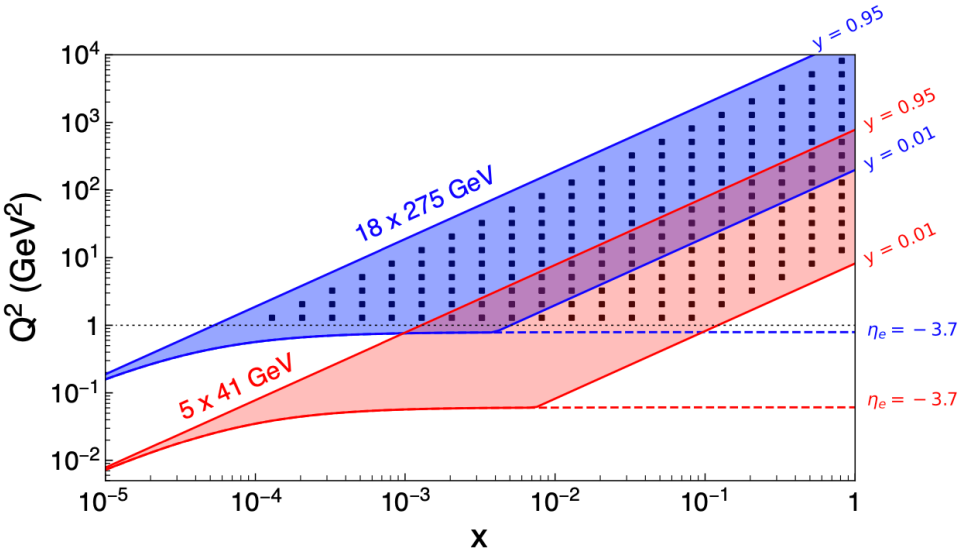


- ECCE and ATHENA studies were more up-to-date on planned datasets at different $\sqrt{s}$ and backed up by more detailed detector simulations

- They also introduced new global and non-global PDF fitting techniques.

Simulated ep Data (ATHENA)





- 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 $\sqrt{s}$

EIC Impact on HERAPDF2.0 Proton PDFs

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

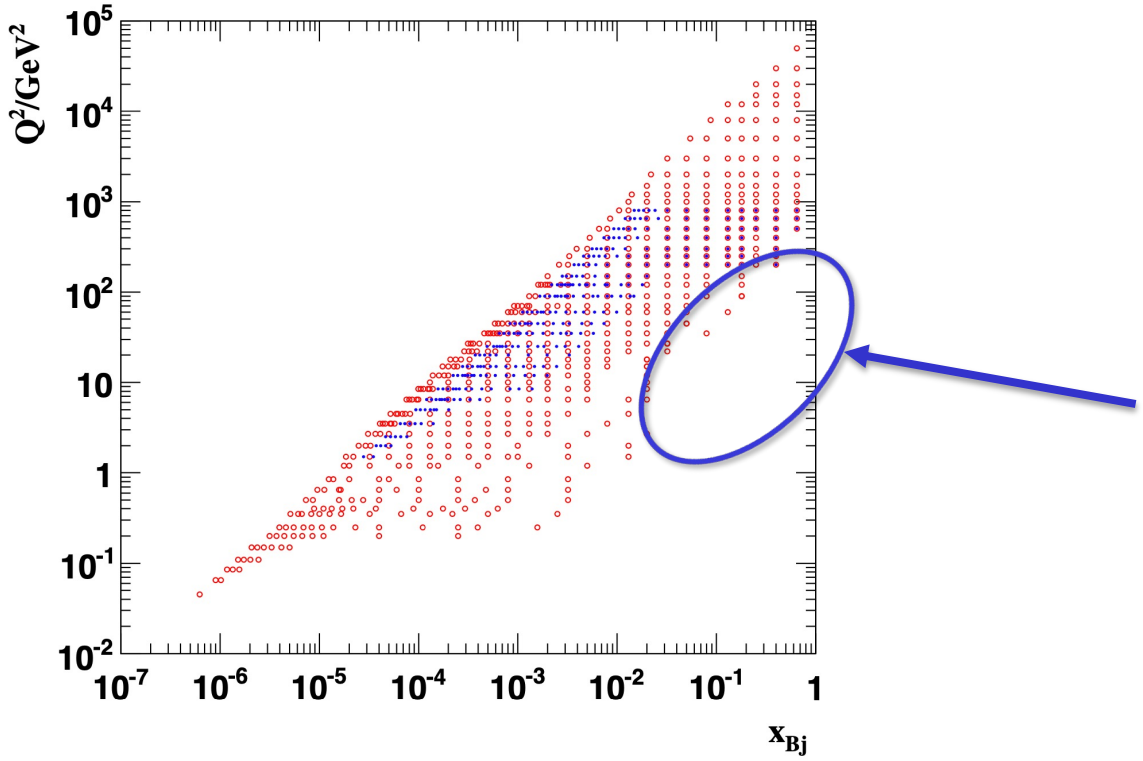
- Using xFitter framework [EPJ C75 (2015) 304]

- PDF parameterisations (14 parameters)

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2) \text{ ... for ...}$$

$$xg(x), xu_v(x), xd_v(x), x\bar{U}(x), x\bar{D}(x)$$

Variation	Standard Value
$Q^2_{\min}$ [GeV^2]	3.5
$Q^2_{\min}$ [GeV^2] HiQ2	10.0
M_c(NLO) [GeV]	1.47
M_c (NNLO) [GeV]	1.43
M_b [GeV]	4.5
f_s	0.4
$\alpha_s(M_Z^2)$	0.118
μ_{f_0} [GeV]	1.9



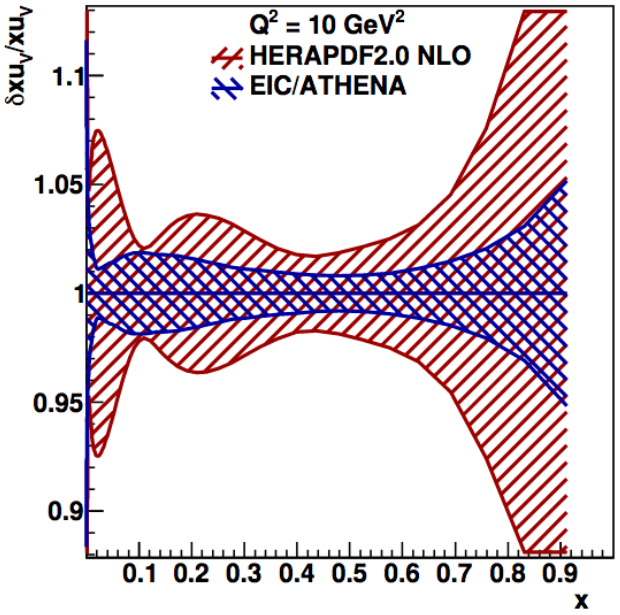
HERA data have limited high x sensitivity due to kinematic correlation between x and Q^2 and $1/Q^4$ factor in cross section

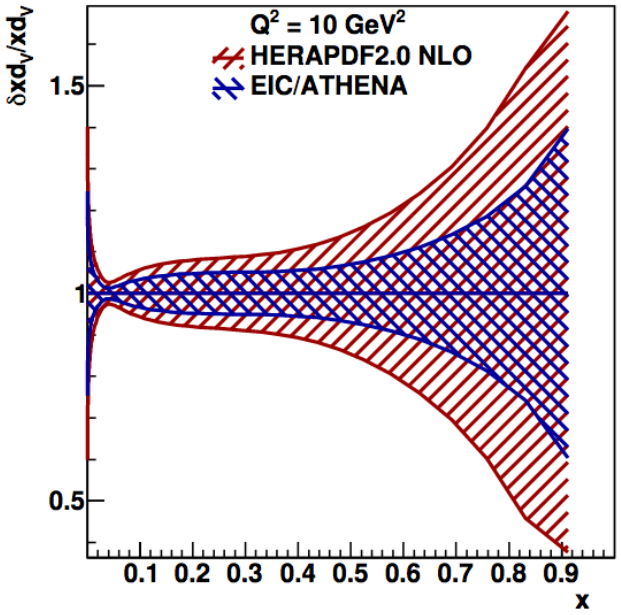
Impact of EIC/ATHENA on HERAPDF2.0

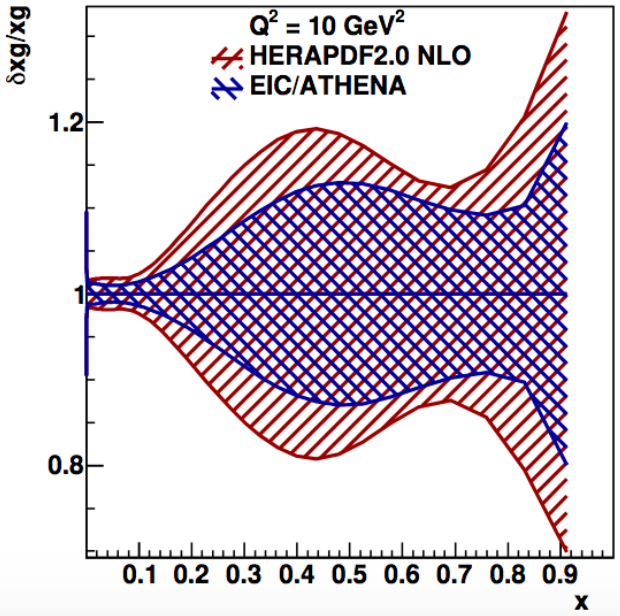
Fractional total uncertainties with / without EIC / ATHENA data included along with HERA

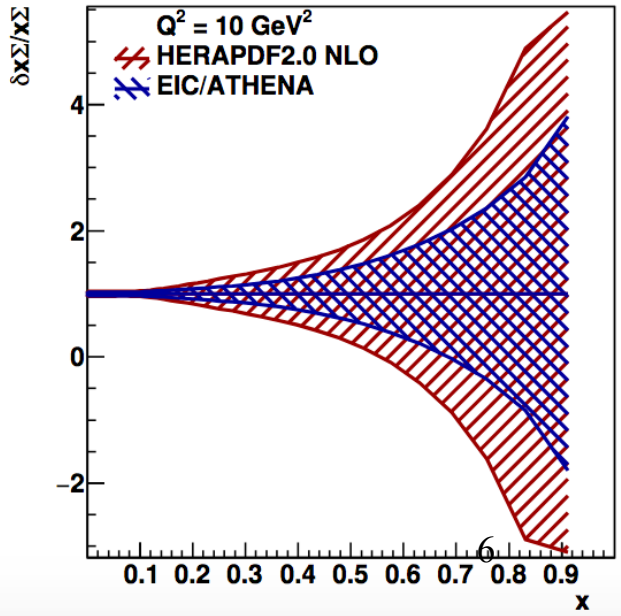
(linear x scale)

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









Impact relative to Global Fits

- Global fits connstrain high x region with fixed-target (eA) DIS + PDF-sensitive LHC data → improves precision, but adds theoretical complexity, requiring increased tolerances where there are tensions

MSHT20 [EPJ C81 (2021) 4]

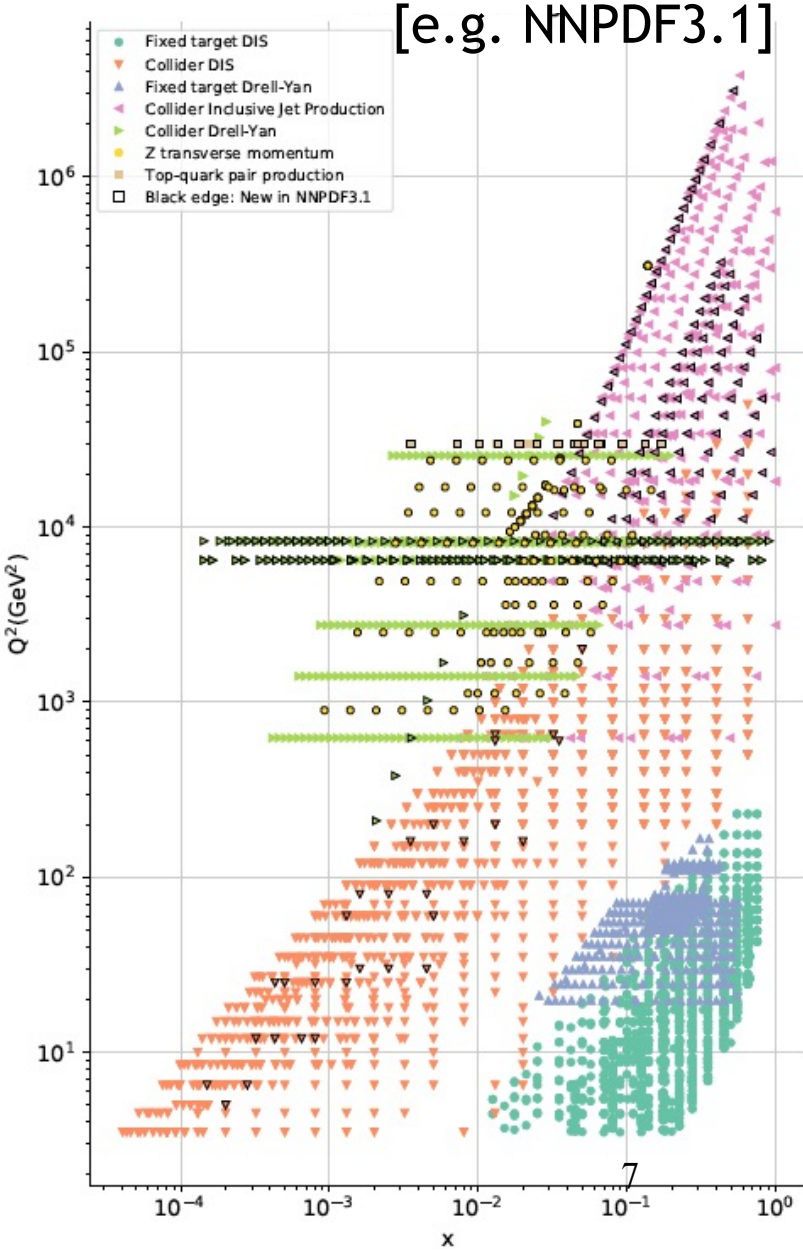
- Parameterisations using Chebyshev polynomials (52 parameters in total)

$$xf(x,Q_0^2) = A(1-x)^{\eta}x^{\delta}\left(1+\sum_{i=1}^{n}a_i T_i^{\mathrm{Ch}}(y(x))\right)$$

- Data with $Q^2 > 2$ GeV^2, $W^2 > 15$ GeV^2

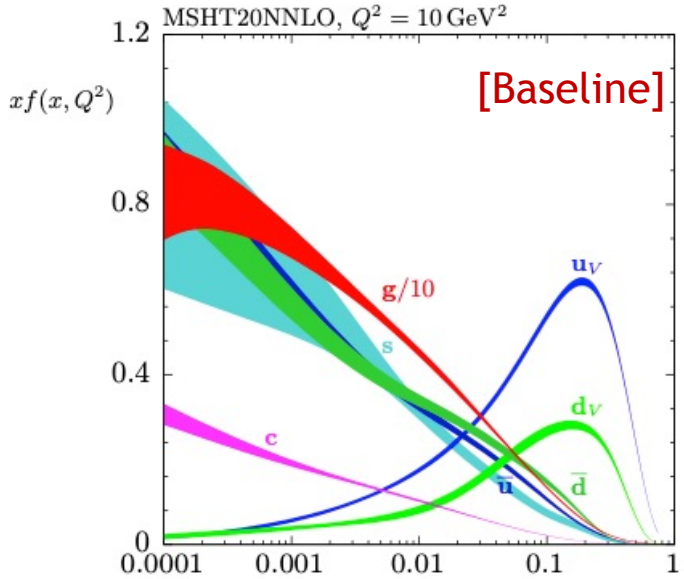
- $m_c = 1.40$ GeV, $m_b = 4.75$ GeV, $\alpha_s = 1.118$, starting scale $\mu_{f0} = 1.0$ GeV

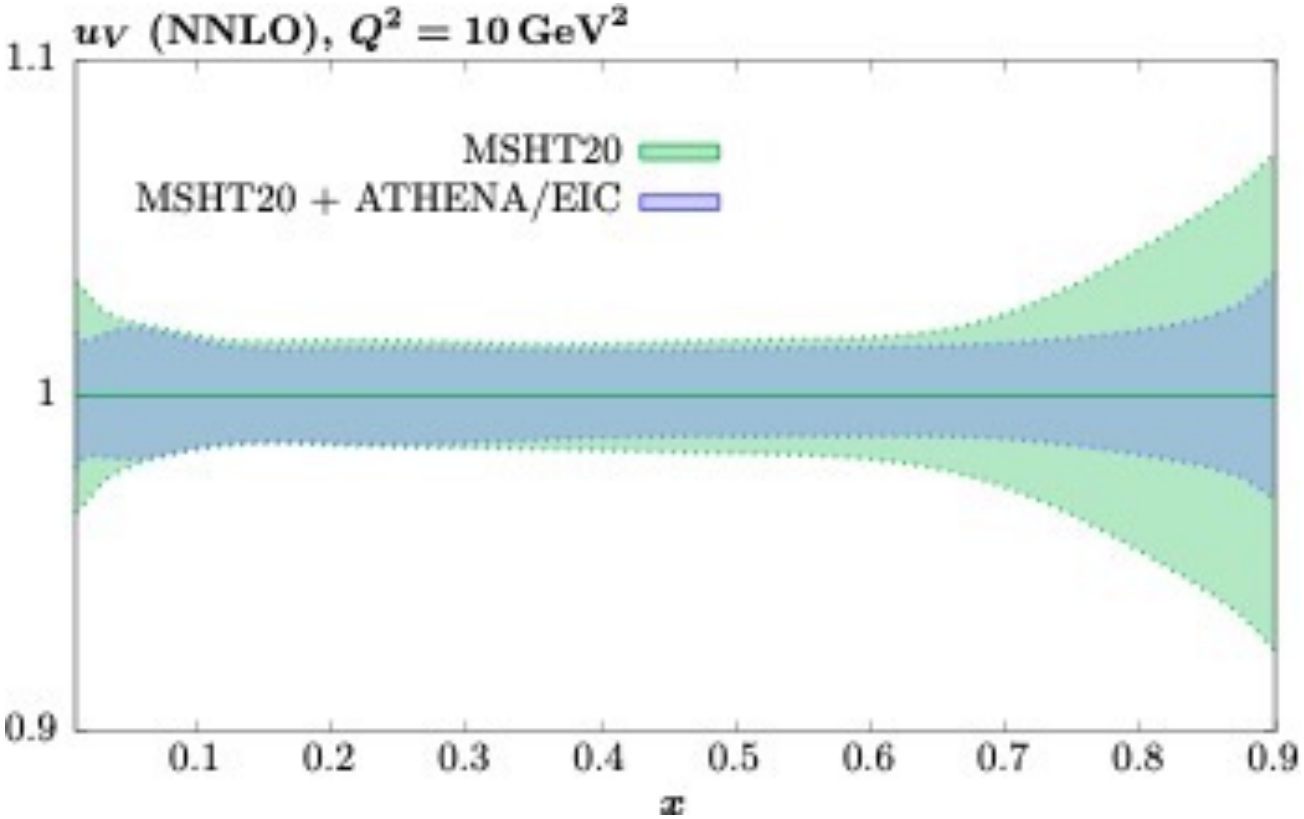
[e.g. NNPDF3.1]



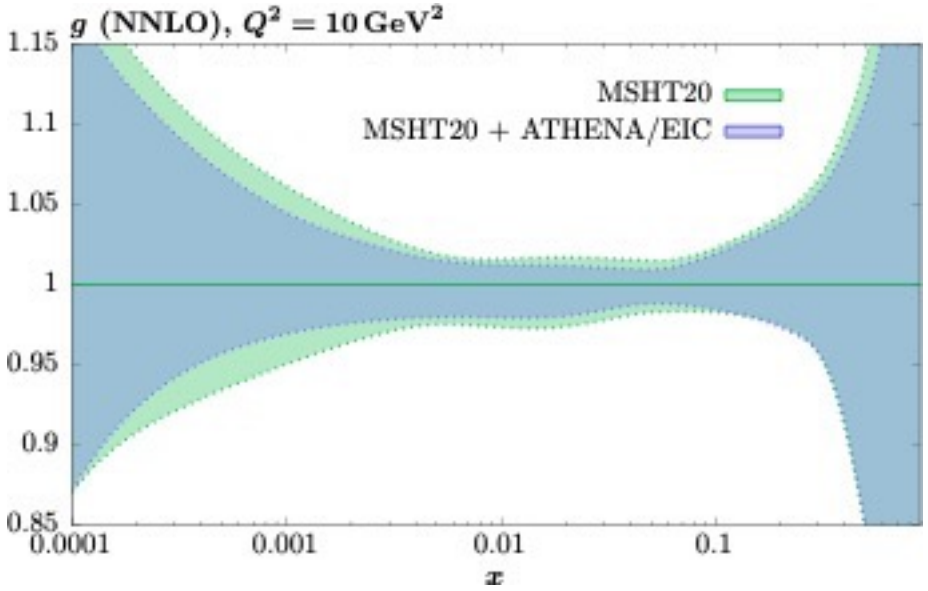
Impact relative to MSHT20 (NNLO)

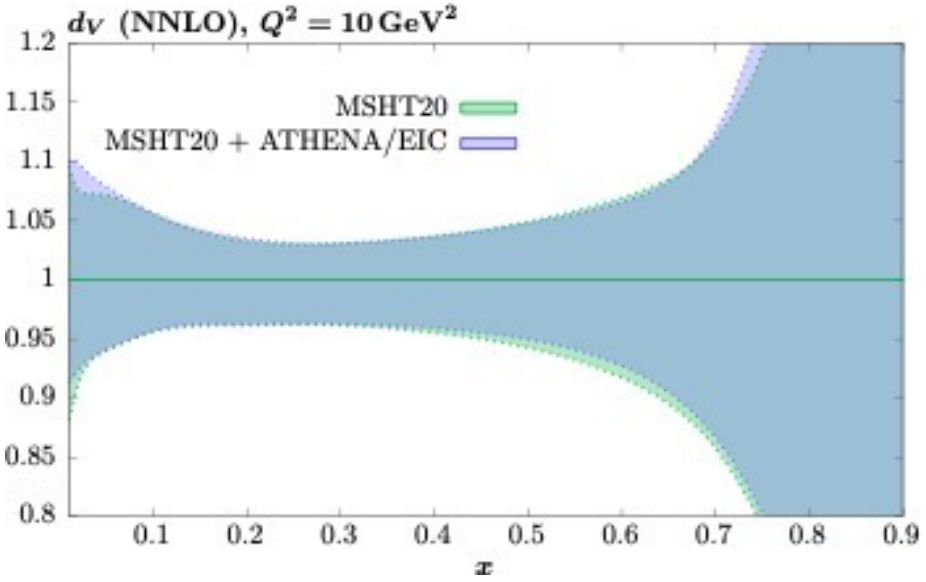
Significant impact of EIC/ATHENA data in up quark precision as x→1 (charge-squared weighting)

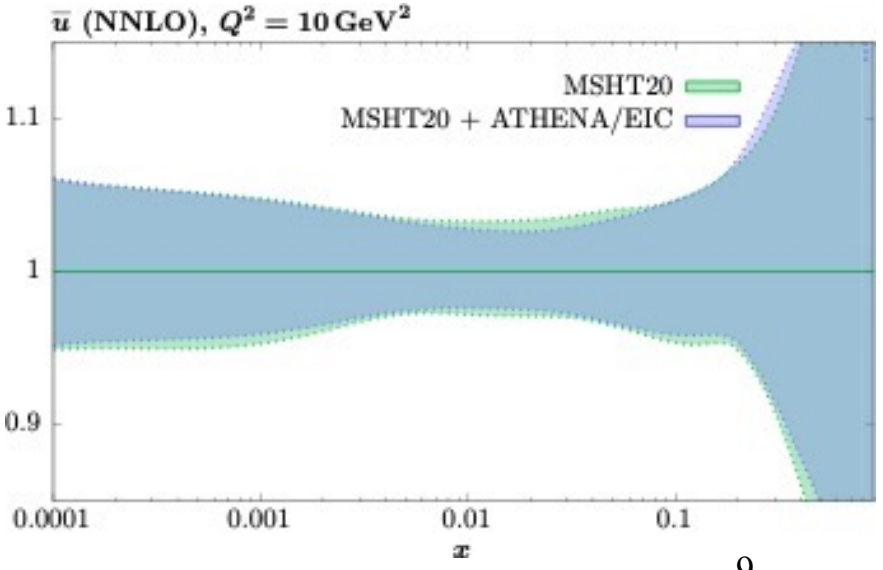




Impact relative to MSHT20

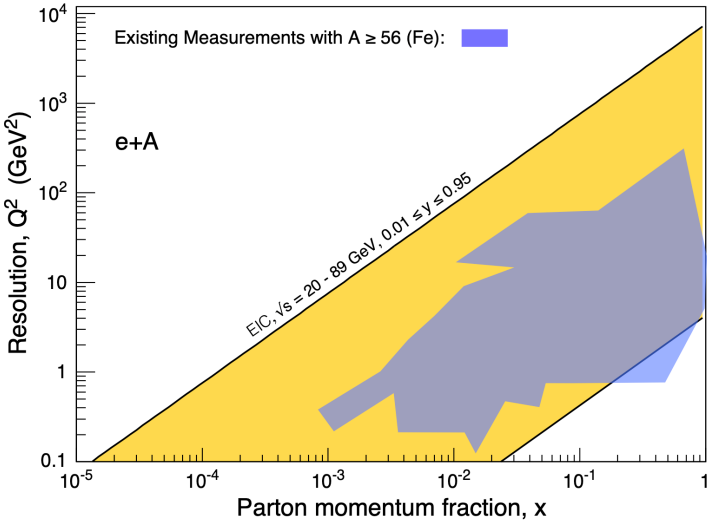






Small, but valuable improvements in all parton species at all x, Q^2, notably the gluon

EIC / ATHENA and nuclear PDFs



EIC will have revolutionary impact on eA phase space: → most promising environment to observe novel low x effects

Studies performed in xFitter framework to assess sensitivity of ATHENA relative to EPPS16

EPPS16 [EPJ C77 (2017) 163]

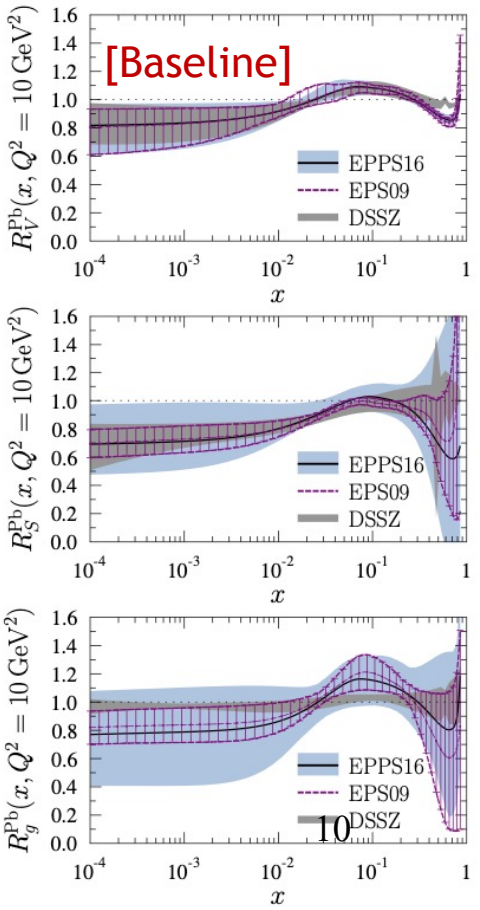
- Uses fixed target DIS and Drell-Yan data, hard processes from pA at the LHC and PHENIX π^0 data

$$f_i^{\mathrm{p}/A}(x,Q^2) = R_i^A(x,Q^2) f_i^{\mathrm{p}}(x,Q^2)$$

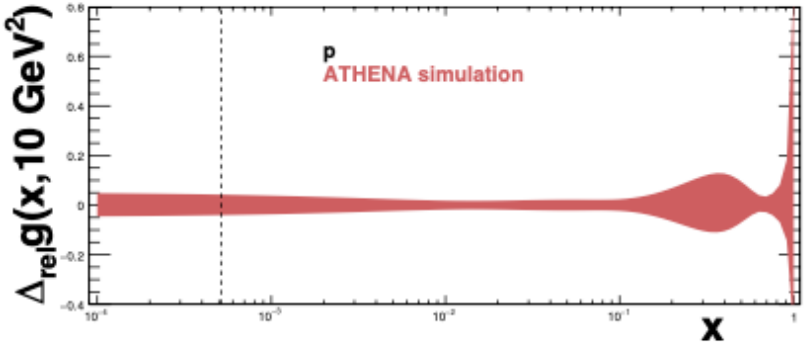
20 free params:

$$R_i^A(x,Q_0^2) = \begin{cases} a_0 + a_1(x-x_a)^2 & x \le x_a \\ b_0 + b_1 x^\alpha + b_2 x^{2\alpha} + b_3 x^{3\alpha} & x_a \le x \le x_e \\ c_0 + (c_1 - c_2 x)(1-x)^{-\beta} & x_e \le x \le 1, \end{cases}$$

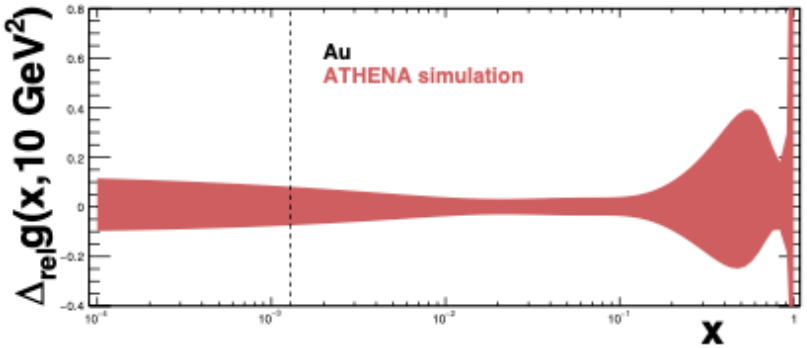
$\mu_{f0} = m_c = 1.3$ GeV, $m_b = 4.75$ GeV, $\alpha_s = 1.118$



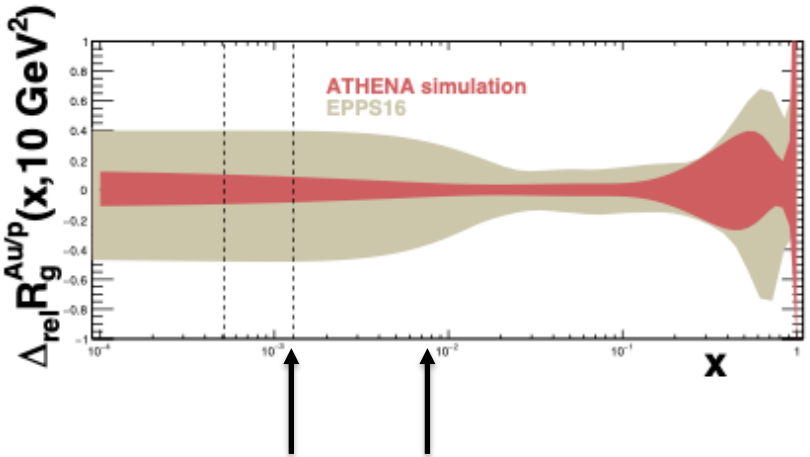
Impact on Nuclear PDFs: Gluon



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



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

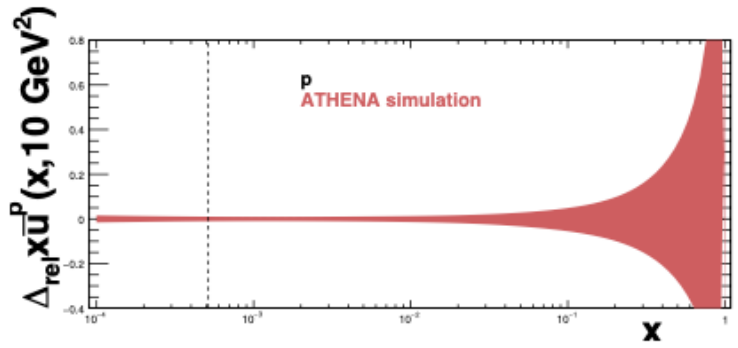


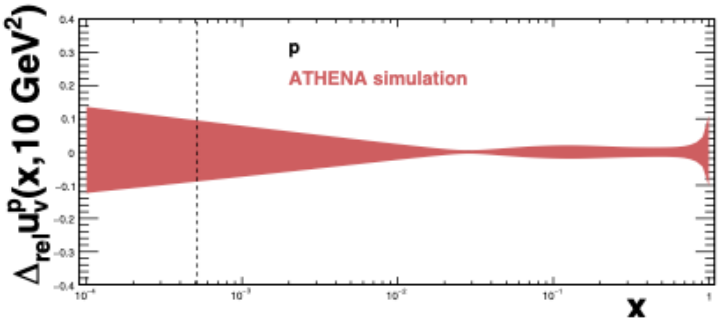
Projected uncertainty on nuclear modification factor, ATHENA-only compared with EPPS'16

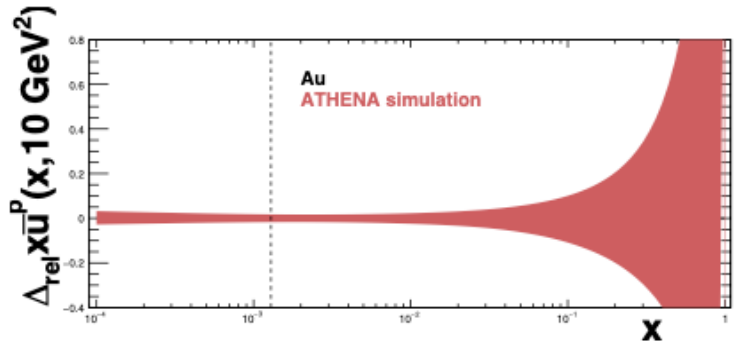
→ Factor ~ 2 improvement at x~0.1 (tolerances)

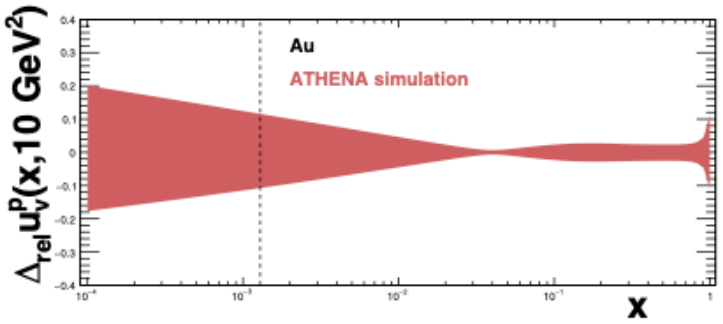
→ Very substantial improvement in newly accessed low x region

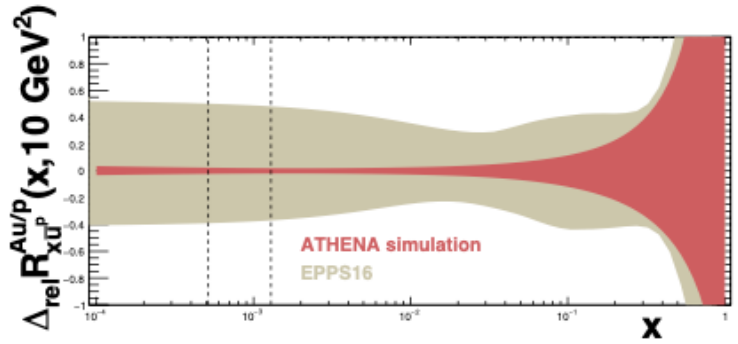
Impact on Nuclear PDFs: ubar and u_v

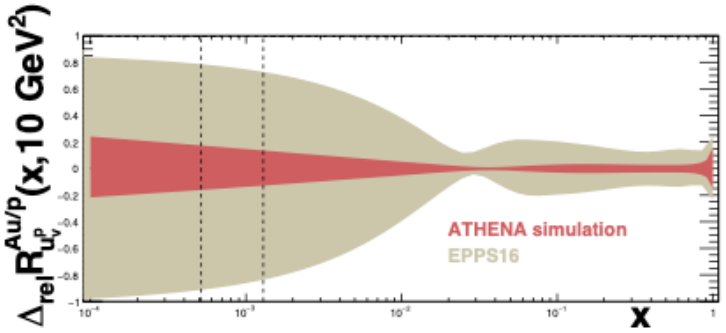












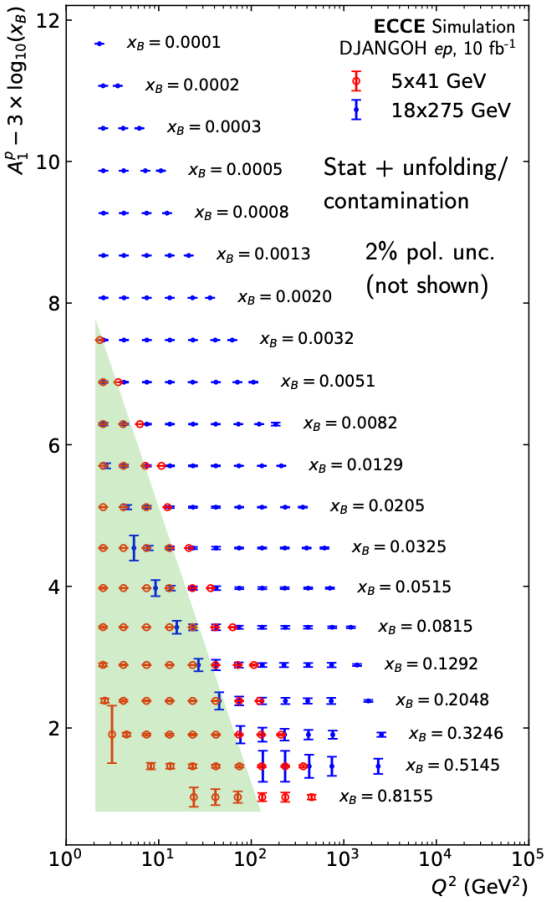
Similarly compelling improvements at low x for quark distributions

Nucleon Spin

$$A_{\parallel} = \frac{\sigma^{\leftrightarrows} - \sigma^{\rightrightarrows}}{\sigma^{\leftrightarrows} + \sigma^{\rightrightarrows}}$$

Double-spin asymmetry sensitive to $g_1(x,Q^2)$, which measures quark and gluon contributions to spin

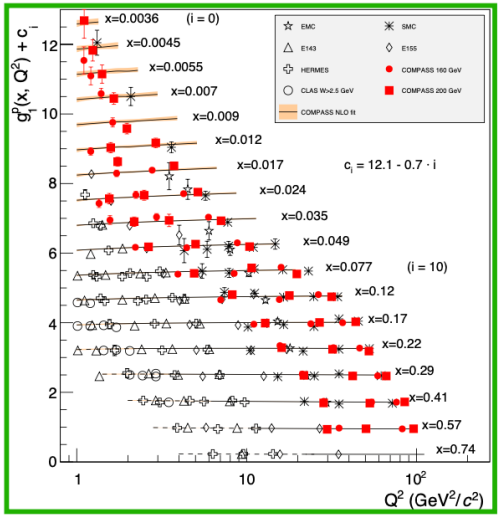
Previous (fixed target) data restricted to high x and modest Q2 → large uncertainties



EIC: Down to $x \approx 10^{-4}$, $Q^2 \approx 1\text{-}10^3$ GeV²!

Maximize constraints on gluon spin with multiple $\sqrt{s}$ settings

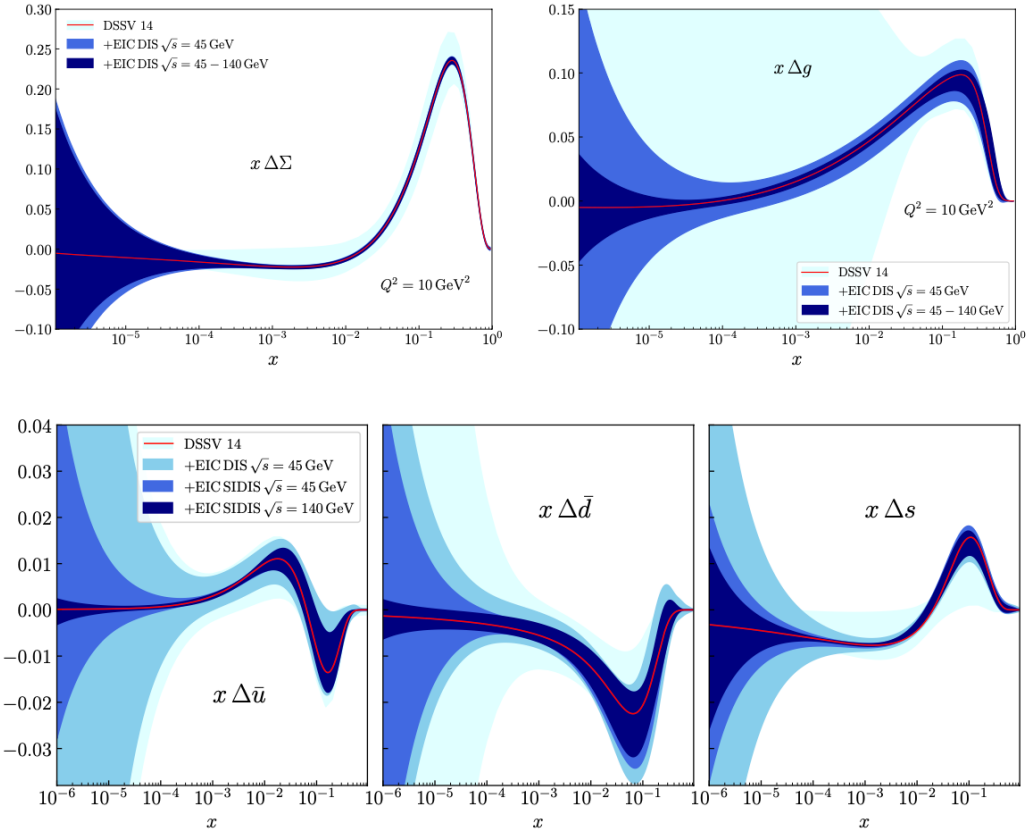
Current:
Down to $x \approx 0.005$,
$Q^2 \approx 1\text{-}100$ GeV².



Nucleon Spin

Impact of EIC measurements

- Dedicated impact plots for ECCE pseudodata in-progress
- ECCE meets detector requirements from Yellow Report
- Use YR plots to illustrate impact



Comments

- So far our community focused on things we know well (unpolarised collinear proton PDFs as studied extensively at HERA and LHC)
  - → Convinced a (sceptical) community of value for high x partons
  - → We are leading here - plenty of scope to continue

- EIC main physics goals are somewhat different …
  - → Proton spin
  - → Proton mass
  - → Behaviour of gluons at high densities

- EIC has very rich potential for observables that are not so familiar …
  - → Polarised (helicity) PDFs
  - → (Heavy) nuclear PDFs
  - → Deuterons, 3He targets
  - → Semi-inclusive channels

… lots still to be understood about EIC potential in these areas

… big opportunities as we learn new physics and diversify our effort into new areas