PDF and strong coupling studies for ultimate DIS: HERA + EIC + LHeC + FCC

P. Newman, K. Wichmann

Data samples

- HERA: combined NC & CC, e+p & e-p, unpolarised
- EIC: NC for 5 center-of-mass energies e-p, CC for highest cms, following arXiv:2307.01183 (note: alphas = 0.116)
- LheC NC + CC: arXiv:2007.14491

Parameter	Unit	Data set								
		D1	D2	D3	D4	D5	D6	D7	D8	D9
Proton beam energy	TeV	7	7	7	7	1	7	7	7	7
Lepton charge		−1	−1	−1	−1	−1	+1	+1	−1	−1
Longitudinal lepton polarisation		−0.8	−0.8	0	−0.8	0	0	0	+0.8	+0.8
Integrated luminosity	fb^{-1}	5	50	50	1000	1	1	10	10	50

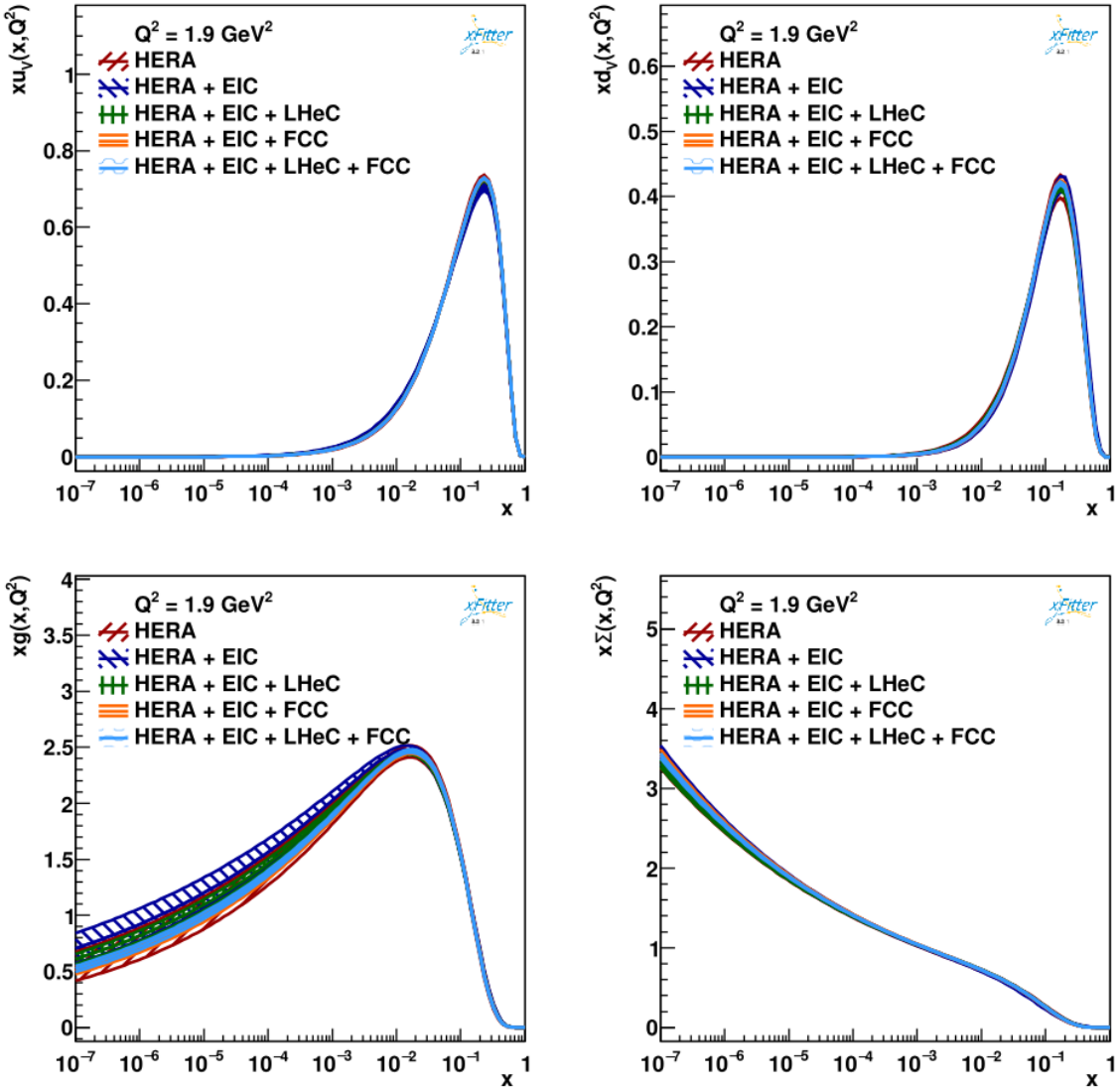
- FCC NC + CC: arXiv:2007.14491

Set	E_e/GeV	E_p/TeV	$P(e)$	Charge(e)	Luminosity/ab^{-1}
A: e^-	60	50	−0.8	−1	1
B: e^-	60	50	+0.8	−1	0.3
C: e^+	60	50	0	+1	0.1
D: low E	20	7	0	−1	0.1
E: eA	60	20	−0.8	−1	0.01

Pseudo-data simulation

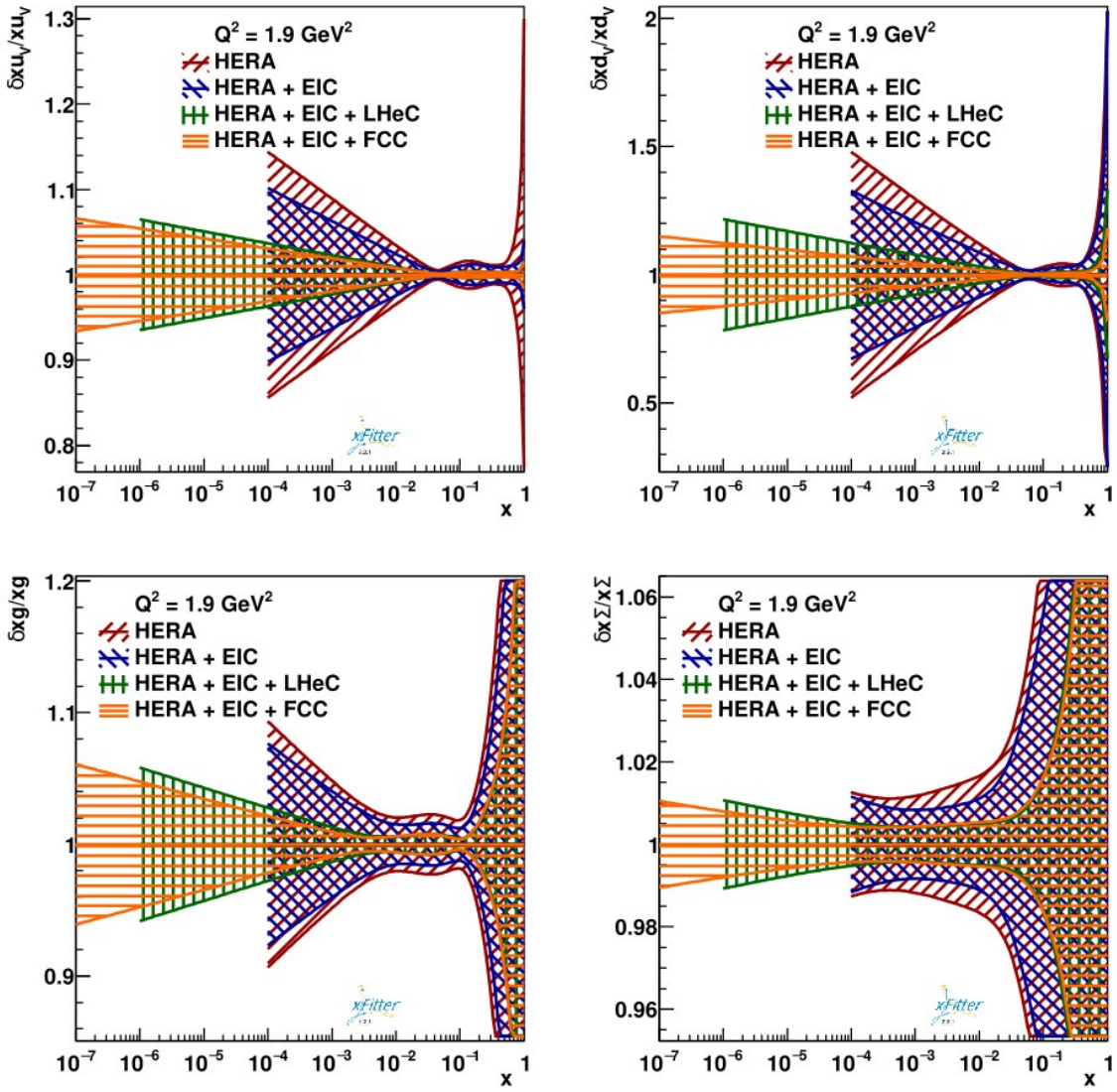
- Cross sections generated with HERAPDF2 NNLO style
  - without negative gluon term (characteristic for HERAPDF) – both LHeC and FCC go to very low-x
  - Available LHAPDF sets go only to x = 10-6, not sufficient for FCC
  - alphas = 0.116 (following previous EIC studies, has no influence on conclusions)
- Smearing according to estimated statistical and systematic uncertainties (both correlated and uncorrelated) + 1% for lumi + 1% for polarisation (where applicable)
- Studies of possibly not-compatible samples
  - done with EIC simulated with negative gluon term (EIC x range fine for that)
- Predictions and fits done using xFitter

Comparison of PDFs



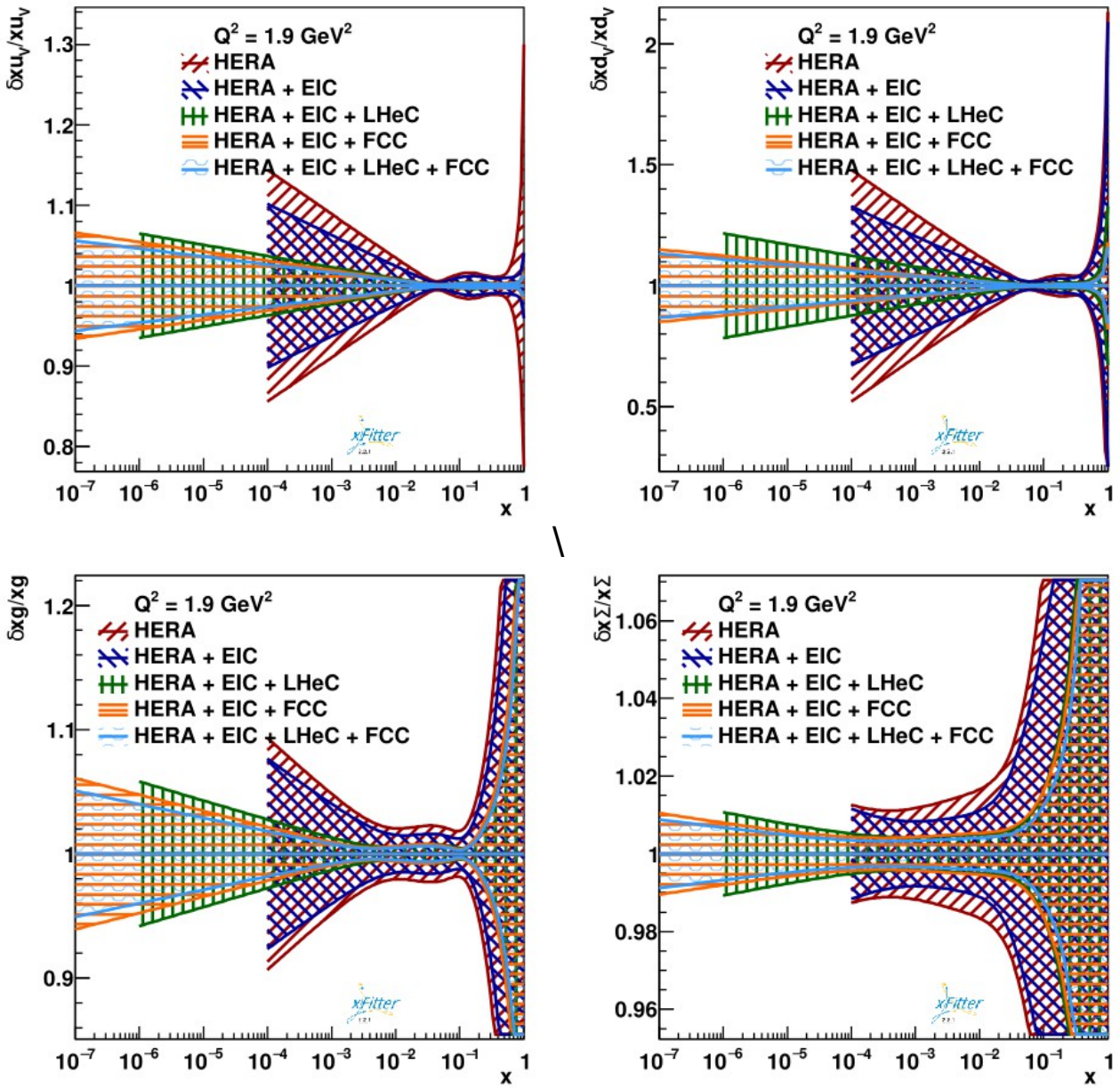
- Well compatible by construction
- Note low x!

Comparison of experimental uncertainties

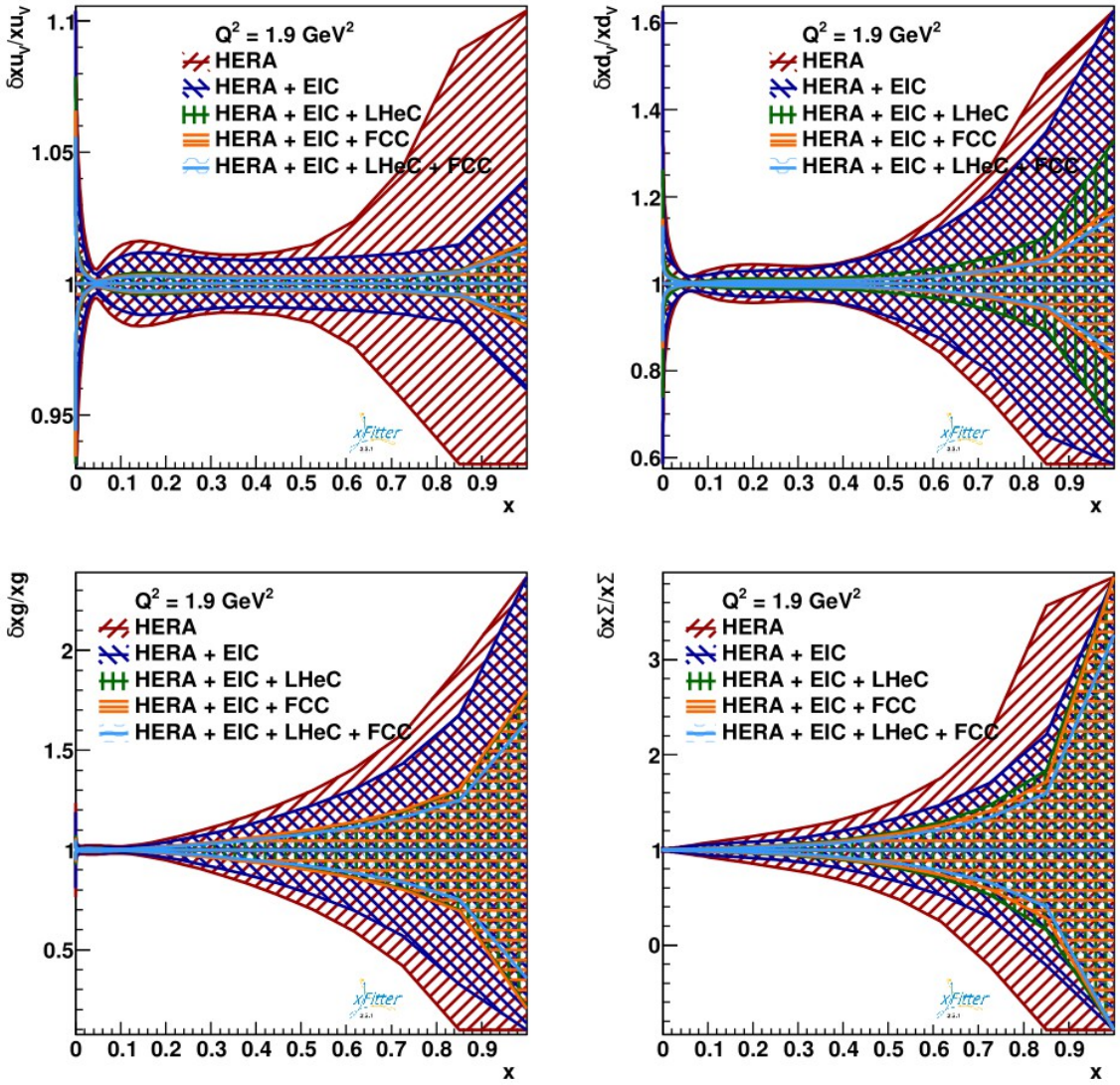


- Stunning improvements of uncertainties + extension of x range down to x^{-6} for LHeC and x^{-7} for FCC

Comparison of experimental uncertainties

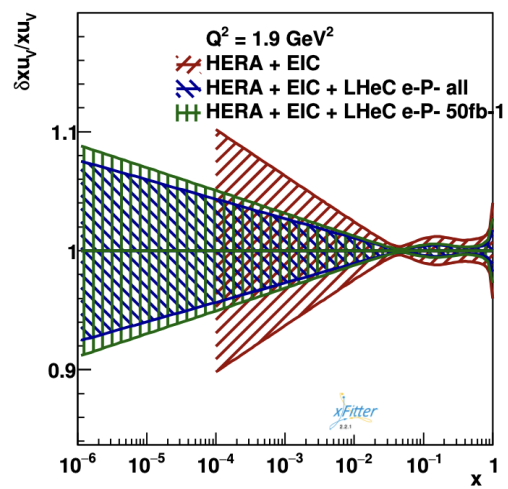


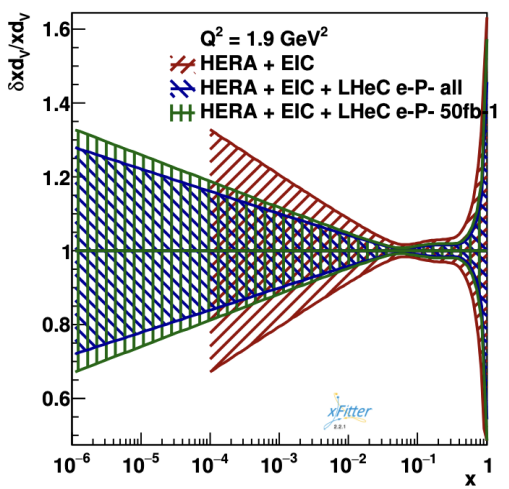
Comparison for large x

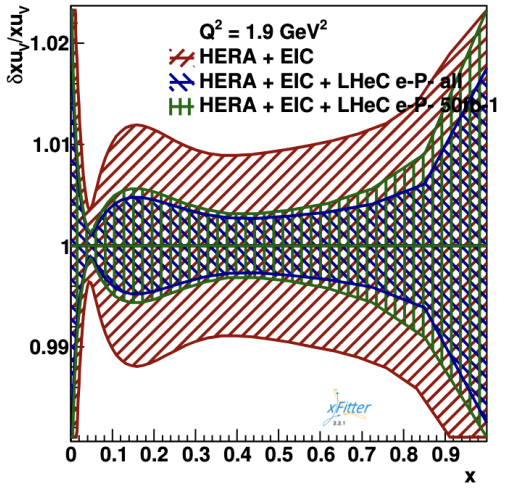


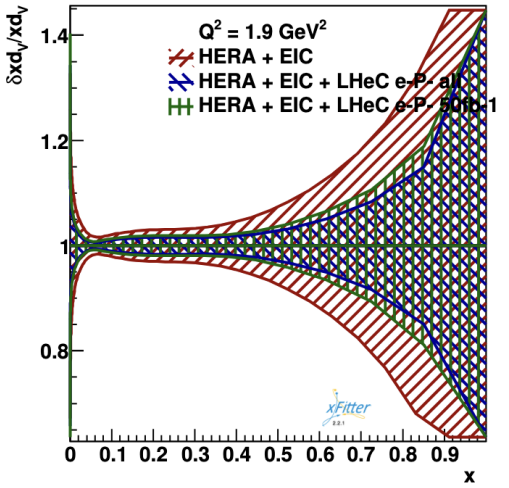
- Improvement also for large x, especially valence quarks and gluon

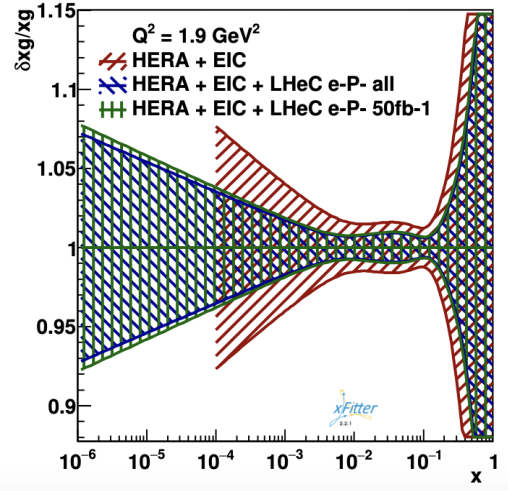
"Only" 50 fb^{-1} lumi for LHeC

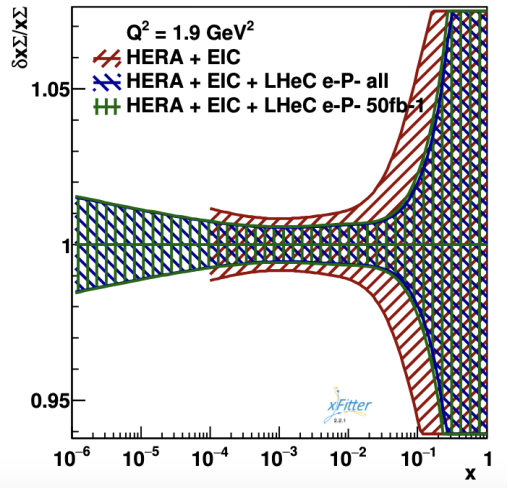


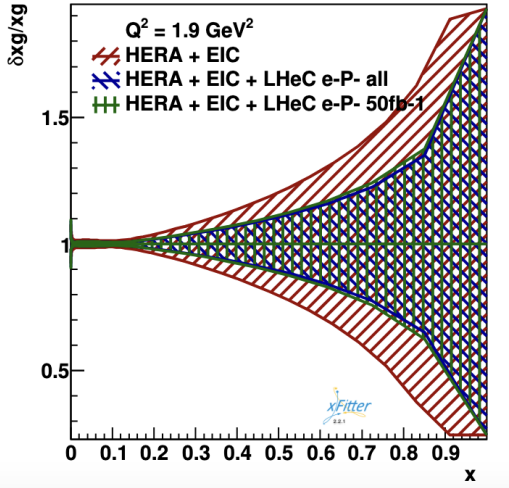


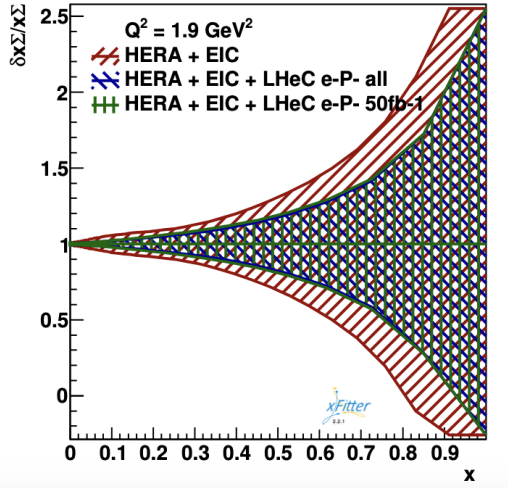






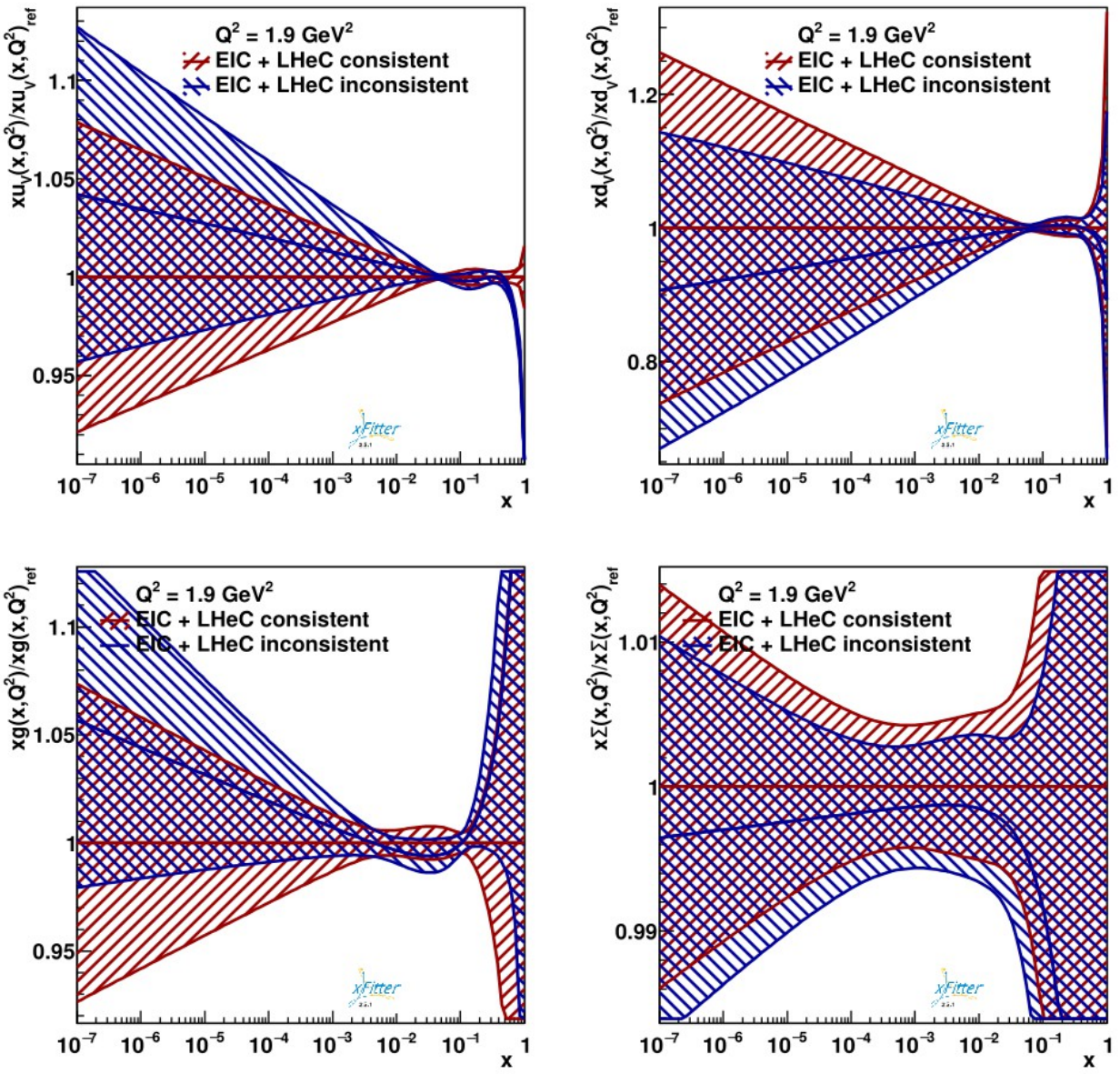






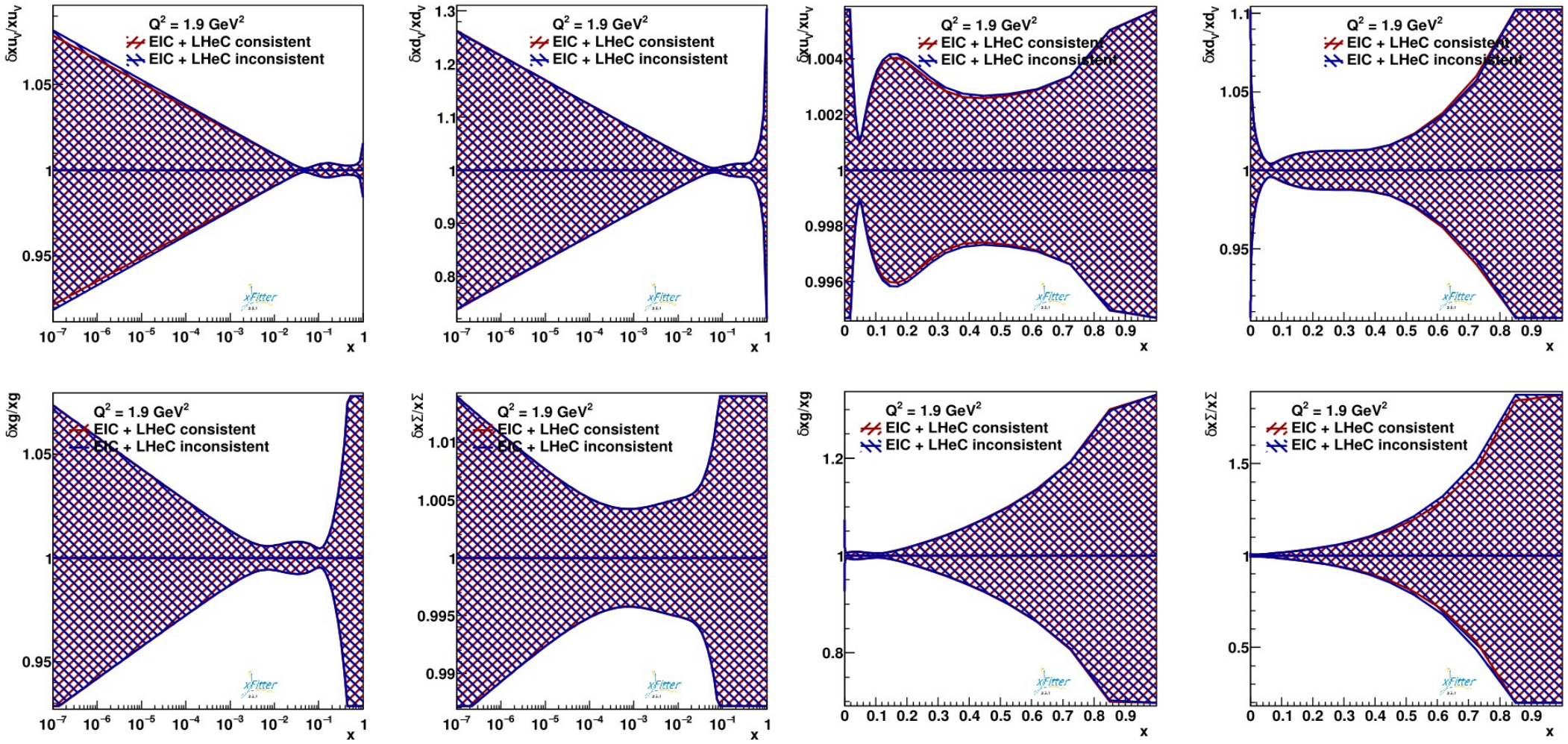
- Only 50 fb^{-1} instead of 1000 fb^{-1} for LHeC enough for vastly improving uncertainties (especially at large x almost no difference)

EIC "inconsistent": LHeC



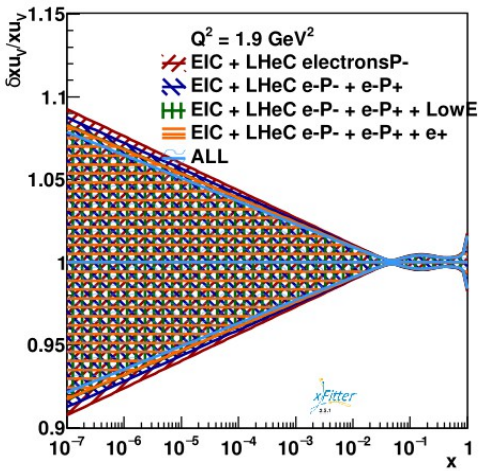
- PDF shapes consistent within uncertainties

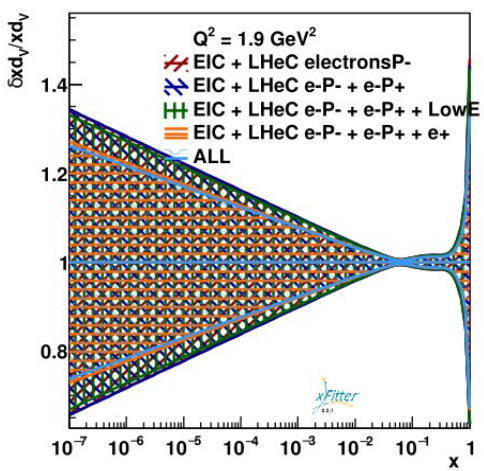
EIC "inconsistent": LHeC

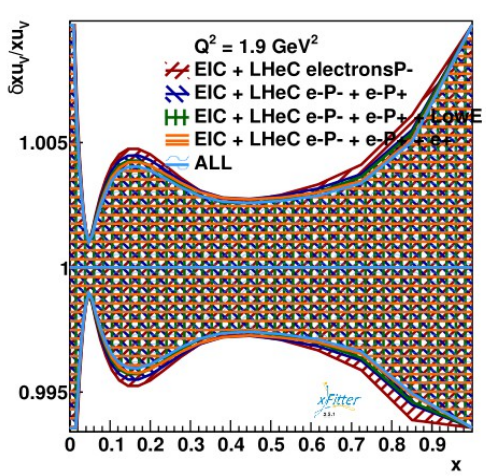


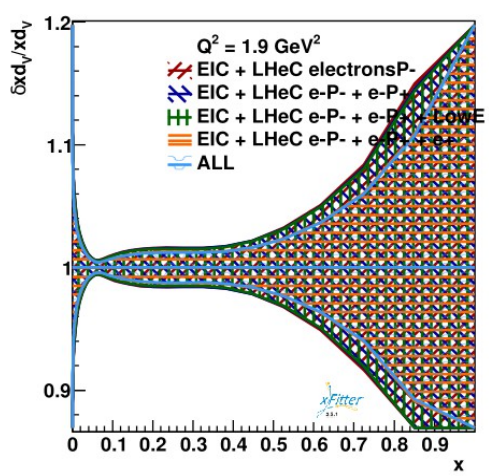
- Almost no difference in uncertainties
- The same conclusion for FCC and LHeC and FCC (back-up slides)

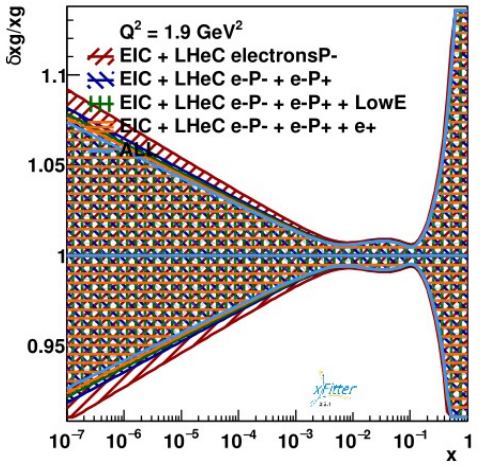
LHeC stacked: which samples matter most?

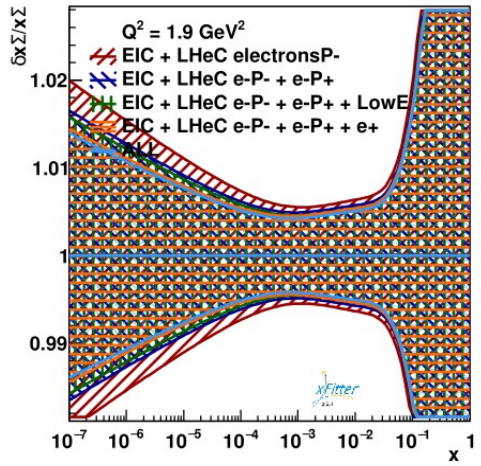


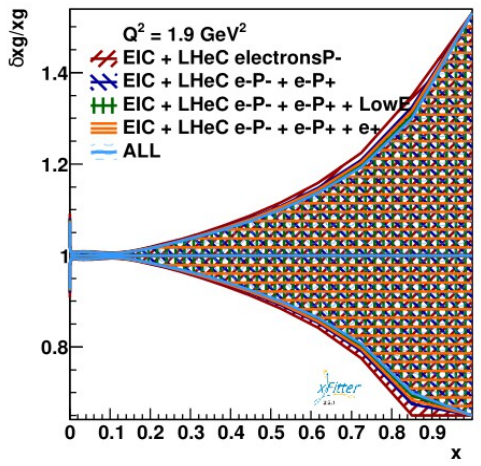


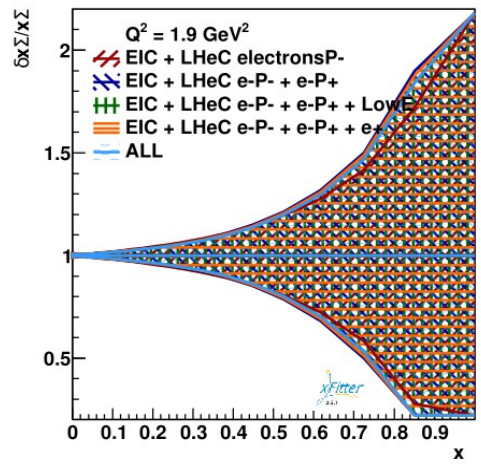






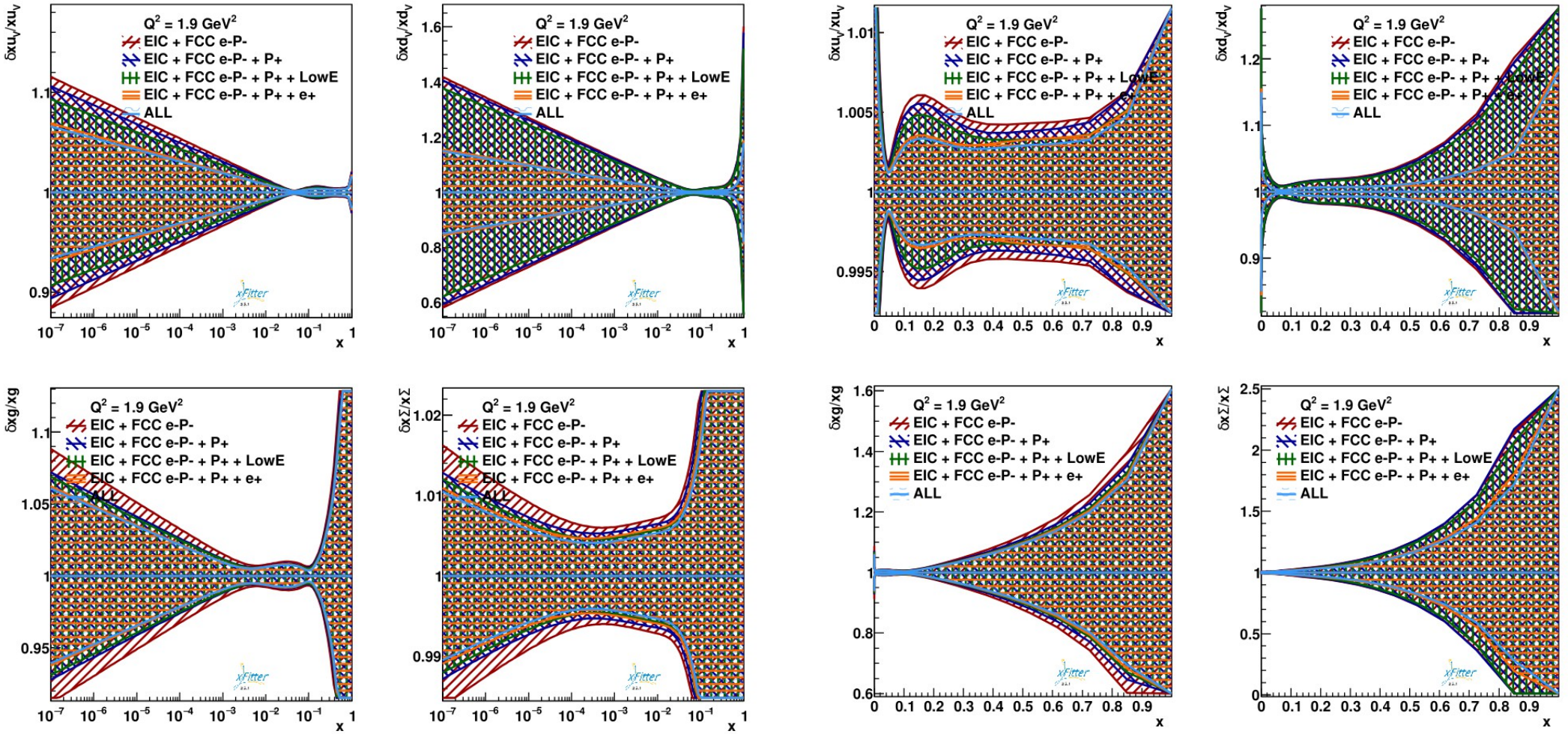






- Essentially all precision brought already by the main e-P- sample

FCC stacked: which samples matter most?



- More complicated picture here: e-P- most important …
- … but positrons seem to play a role as well (maybe others as well)

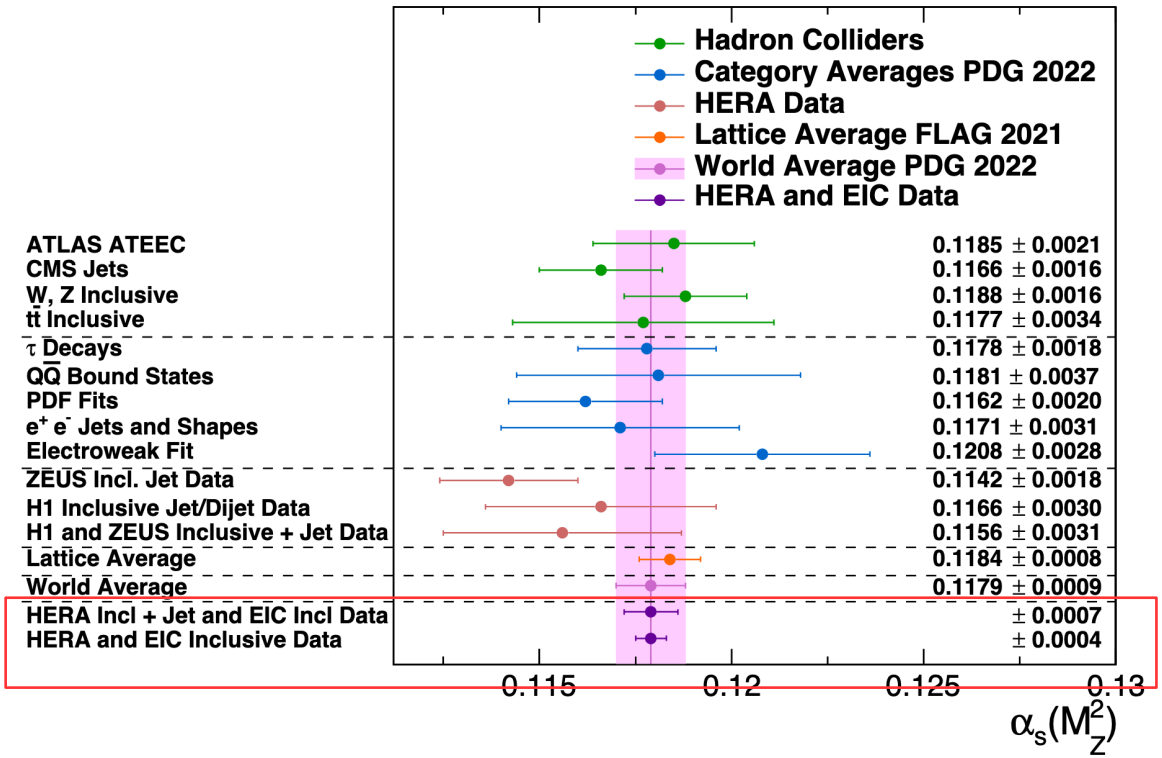
Strong coupling determination with DIS only

- Previous studies of alphas estimation with HERA+EIC DIS data only arXiv:2307.01183

- Mainly due to EIC large-x region strong coupling can be estimated from DIS data only (no jets/etc needed), with very good precision, competitive to all present measurements and lattice calculations (no large scale variation uncertainties
- Can this be extended further with LHeC and FCC?

Extraction of the strong coupling with HERA and EIC inclusive data

Salim Cerci[1], Zuhal Seyma Demiroglu[2,3], Abhay Deshpande[2,3,4], Paul R. Newman[5], Barak Schmookler[6], Deniz Sunar Cerci[1], Katarzyna Wichmann[7]



- Above studies repeated with addition of LHeC and FCC pseudo-data

Improvements in alphas estimation

Nominal result: no negative gluon term

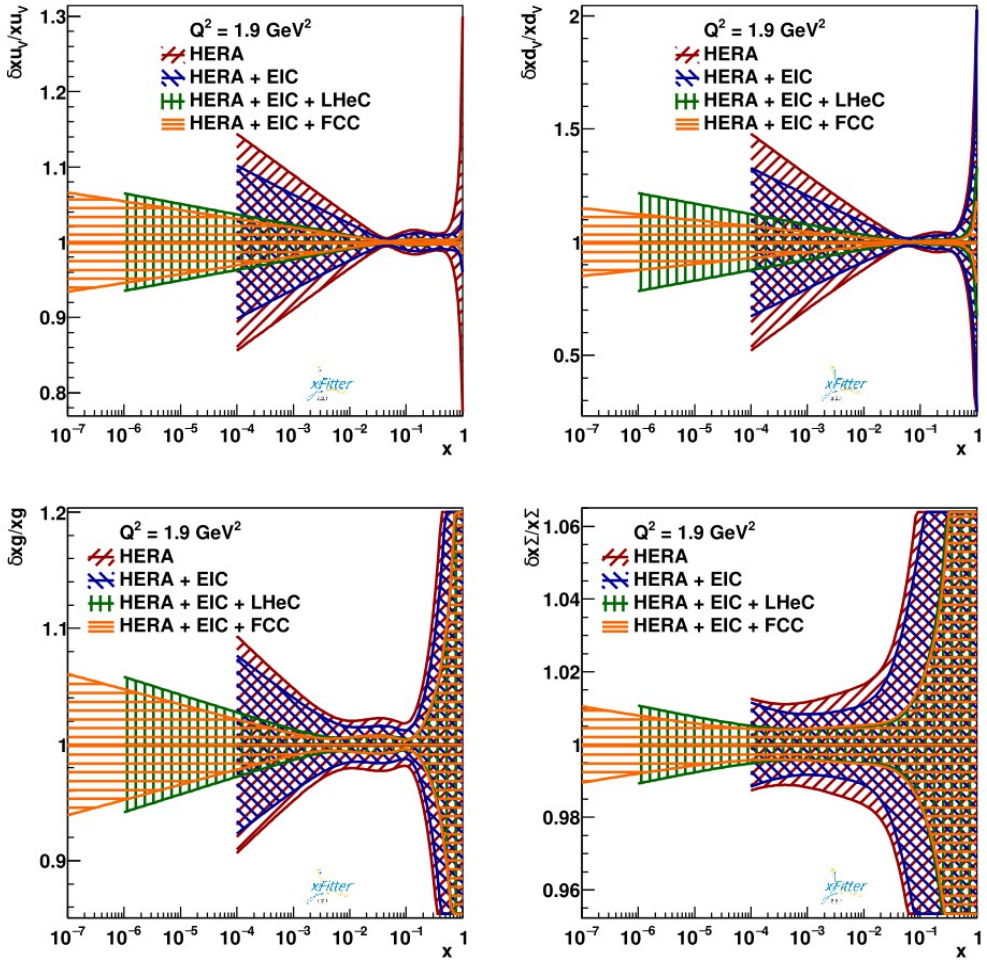
- EIC: as = 0.11561 +- 0.00047
- EIC + LHeC: as = 0.11573 +- 0.00030
- EIC + FCC: as = 0.11587 +- 0.00025
- EIC + LheC +FCC: as = 0.11589 +- 0.00022

EIC "slightly" inconsistent: with negative gluon term

- EIC as = 0.11551 +- 0.00047
- EIC + LHeC as = 0.11548 +- 0.00031
- EIC + FCC as = 0.11563 +- 0.00026
- EIC + LHeC + FCC: as = 0.11560 +- 0.00022
- Additional uncertainty ? +- 0.00029
  - Total: +- 0.00036

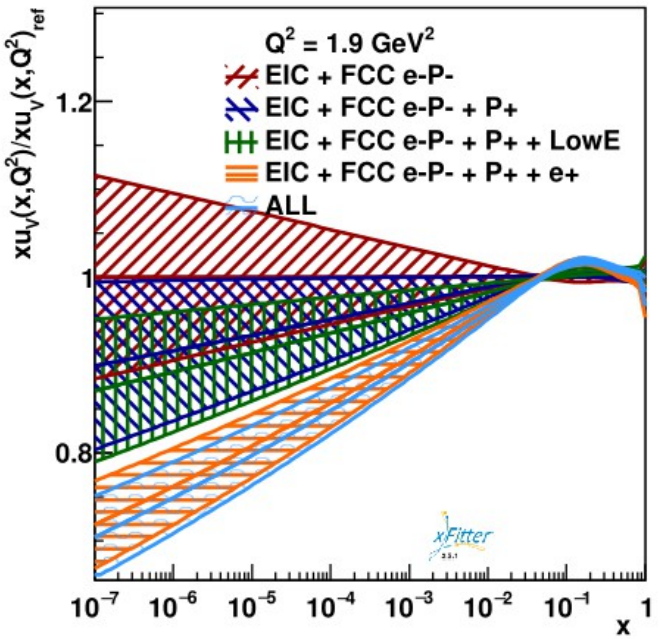
Summary

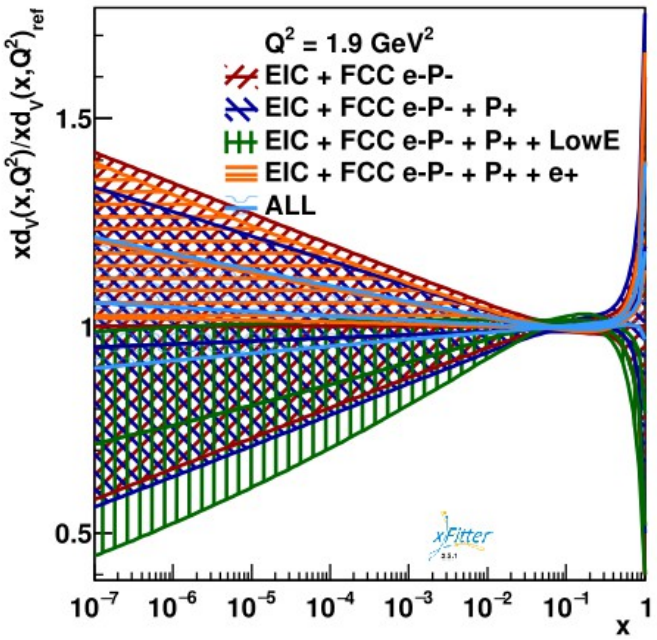
- Ultimate DIS sample HERA+EIC+LHeC+FCC will bring huge extension of low-x region in PDF estimation
  - Both for covering "unknown" regions and improving greatly uncertainties
  - FCC reaches to lower $x > 10^{-7}$
- Also for mid- and large-x PDF uncertainties will be hugely decreased
- Studies of strong coupling estimation show promise of more precise determination with DIS data only (reduced theoretical uncertainty!)

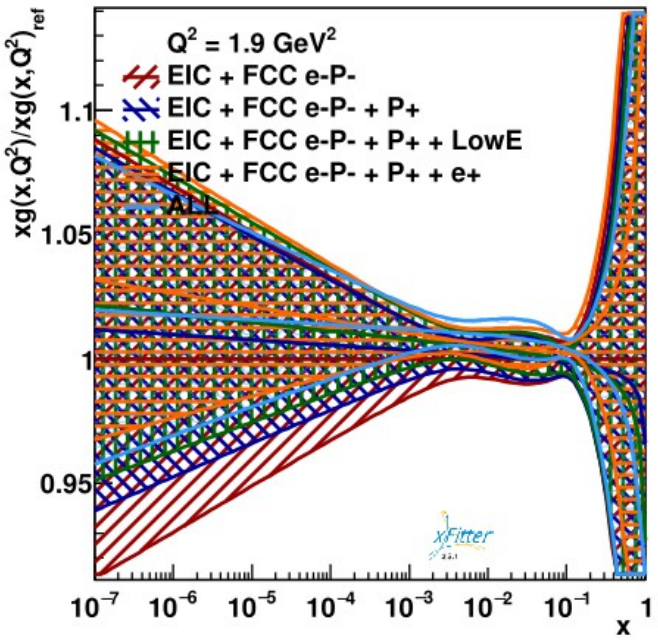


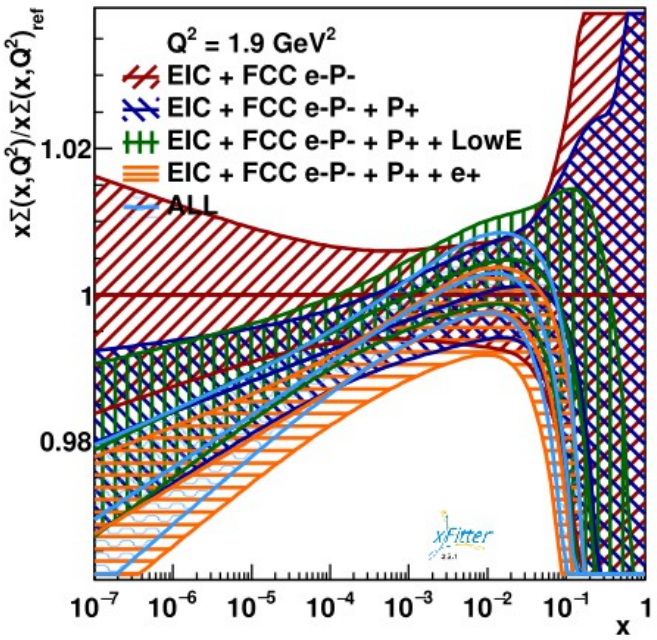
Additional slides

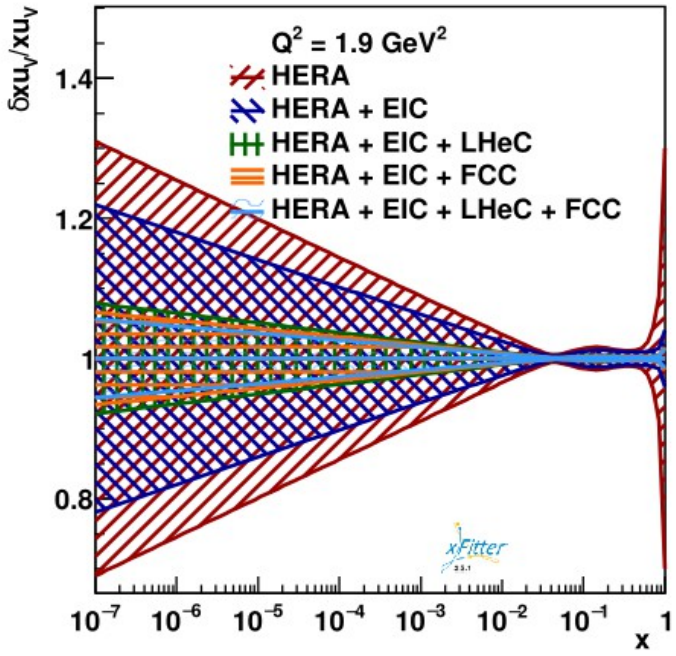
FCC stacked

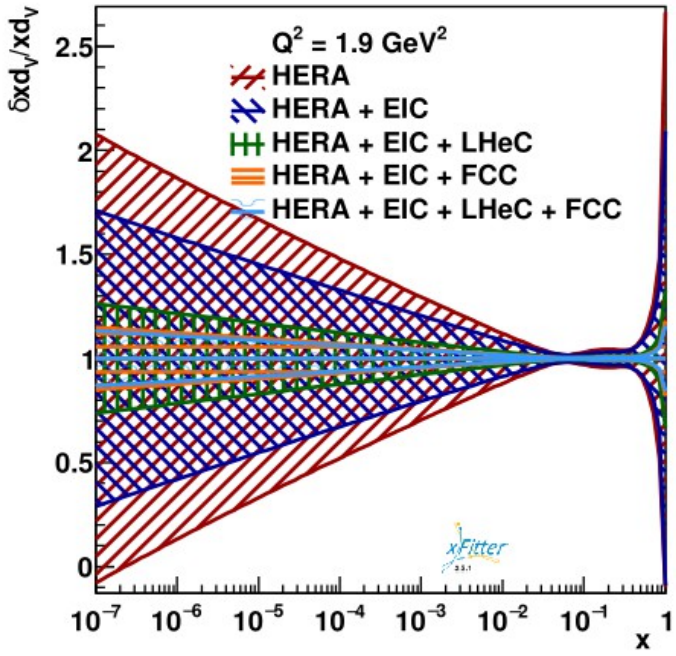

Q^2 = 1.9 GeV^2
EIC + FCC e-P-
EIC + FCC e-P- + P+
EIC + FCC e-P- + P+ + LowE
EIC + FCC e-P- + P+ + e+
ALL
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x
xFitter

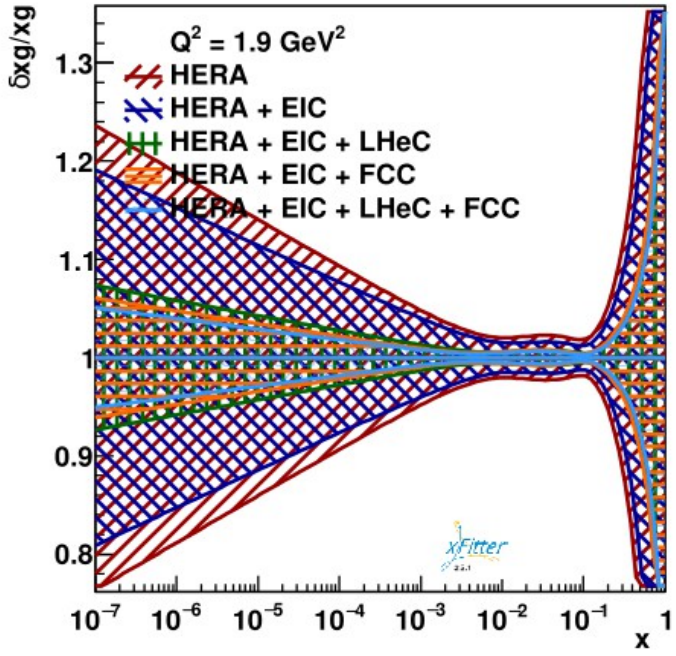

Q^2 = 1.9 GeV^2
EIC + FCC e-P-
EIC + FCC e-P- + P+
EIC + FCC e-P- + P+ + LowE
EIC + FCC e-P- + P+ + e+
ALL
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x
xFitter

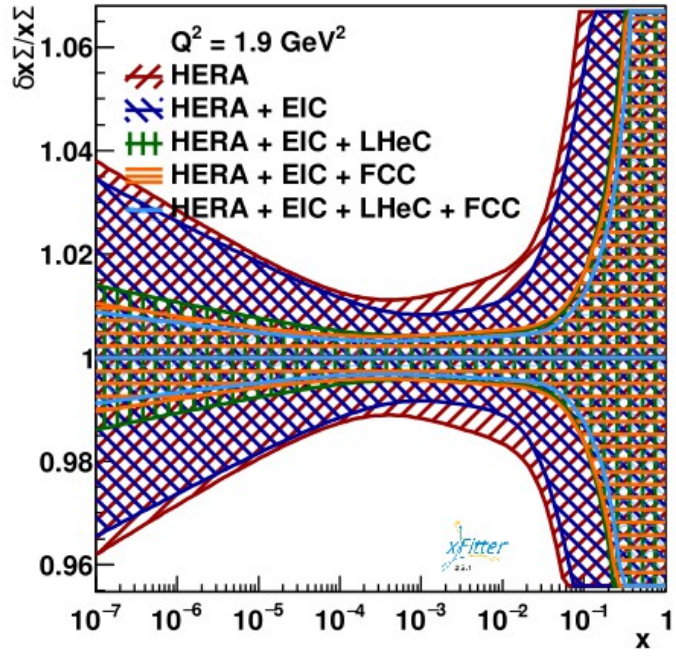

Q^2 = 1.9 GeV^2
EIC + FCC e-P-
EIC + FCC e-P- + P+
EIC + FCC e-P- + P+ + LowE
EIC + FCC e-P- + P+ + e+
ALL
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x
xFitter

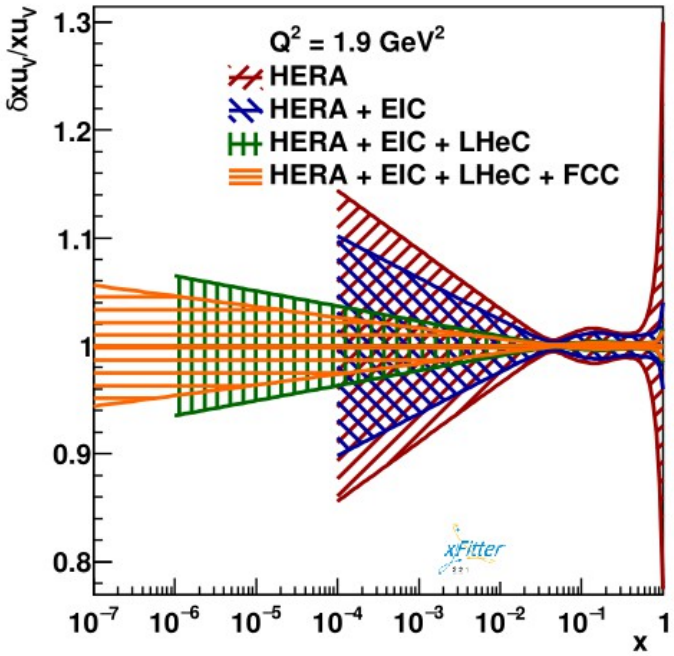

Q^2 = 1.9 GeV^2
EIC + FCC e-P-
EIC + FCC e-P- + P+
EIC + FCC e-P- + P+ + LowE
EIC + FCC e-P- + P+ + e+
ALL
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x
xFitter

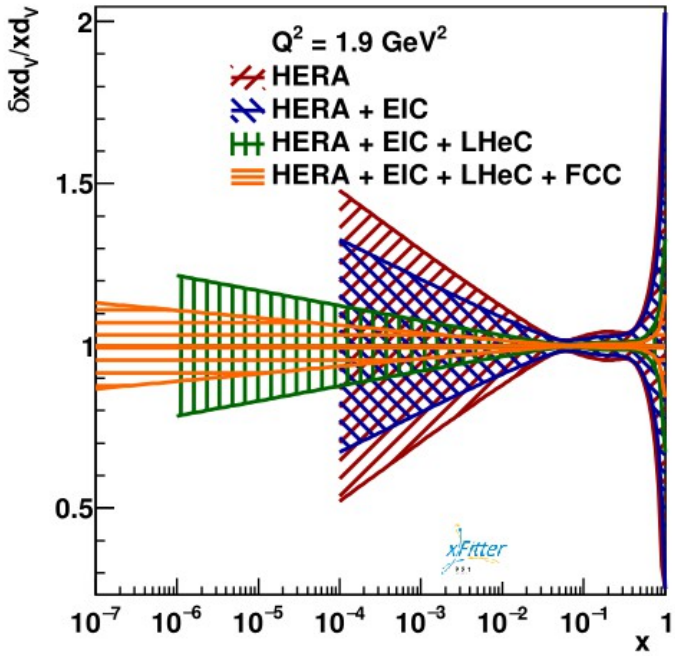

$\delta x u_v / x u_v$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + FCC
HERA + EIC + LHeC + FCC
x

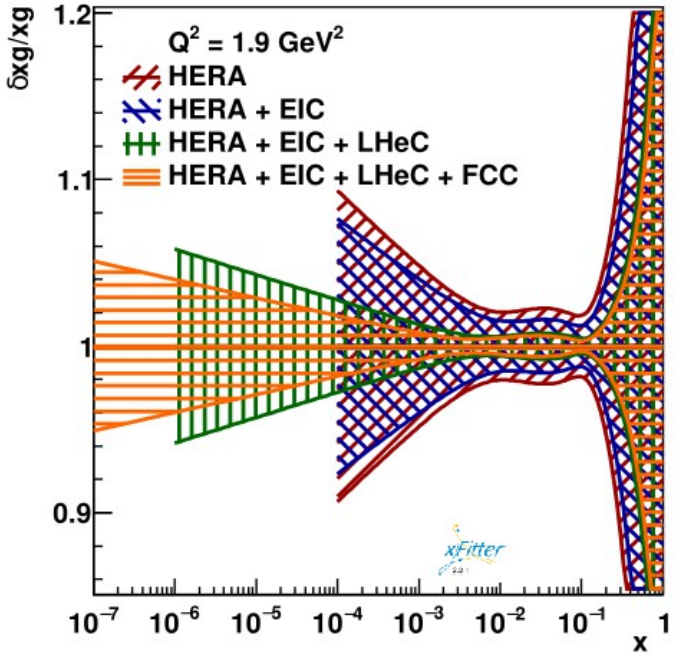

$\delta x d_v / x d_v$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + FCC
HERA + EIC + LHeC + FCC
x

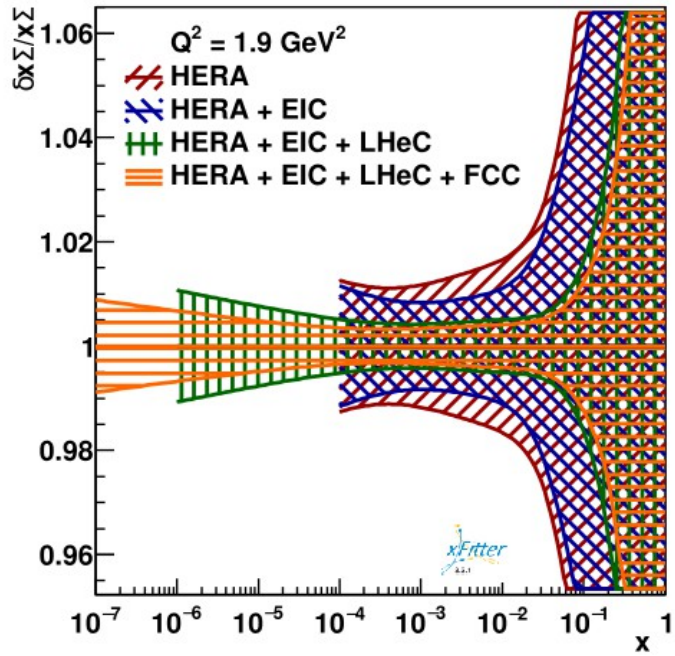

$\delta x g / x g$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + FCC
HERA + EIC + LHeC + FCC
x


$\delta x \Sigma / x \Sigma$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + FCC
HERA + EIC + LHeC + FCC
x

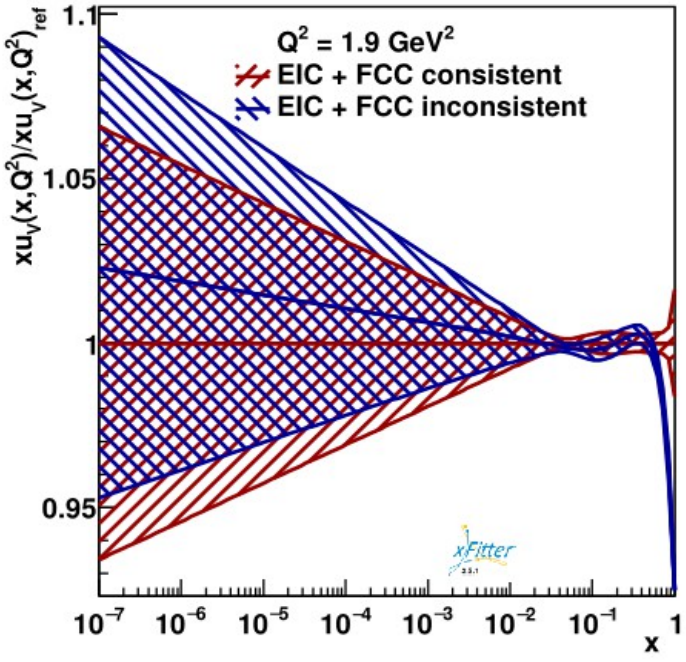

$\delta x u_v / x u_v$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + LHeC + FCC
xFitter
x

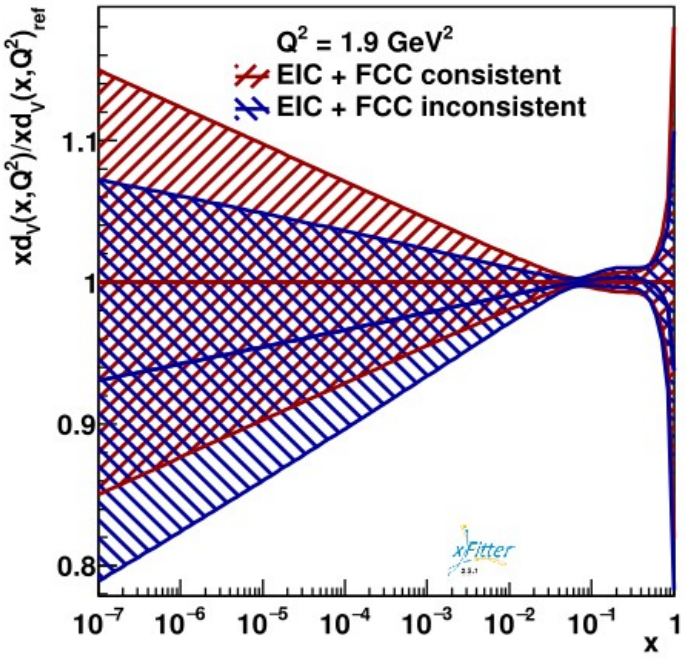

$\delta x d_v / x d_v$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + LHeC + FCC
xFitter
x

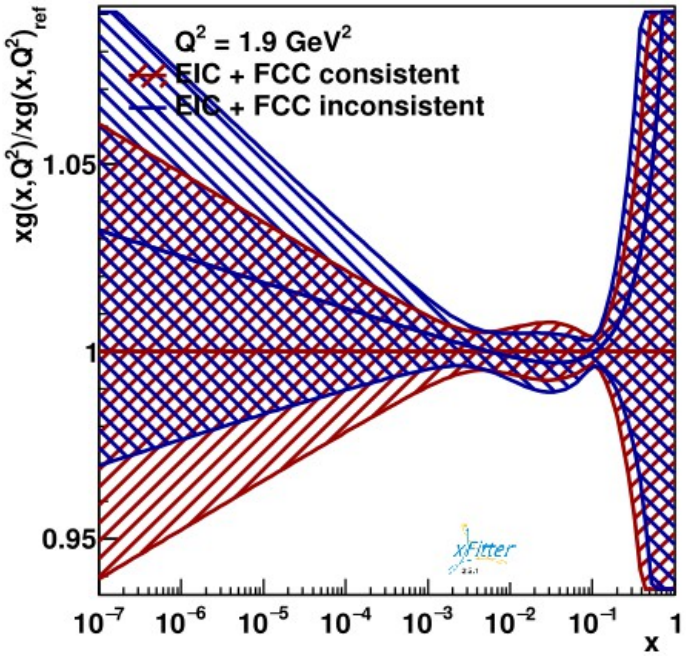

$\delta x g / x g$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + LHeC + FCC
xFitter
x

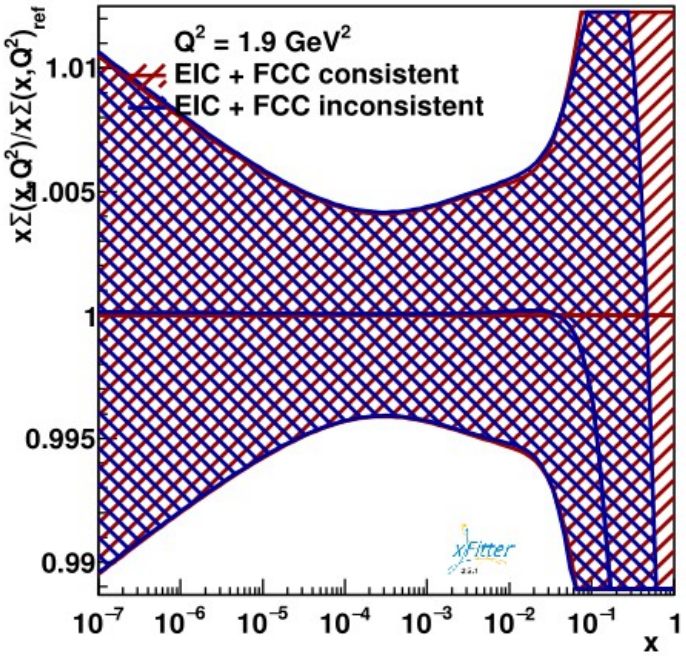

$\delta x \Sigma / x \Sigma$
Q^2 = 1.9 GeV^2
HERA
HERA + EIC
HERA + EIC + LHeC
HERA + EIC + LHeC + FCC
xFitter
x

EIC "inconsistent" with NG: FCC

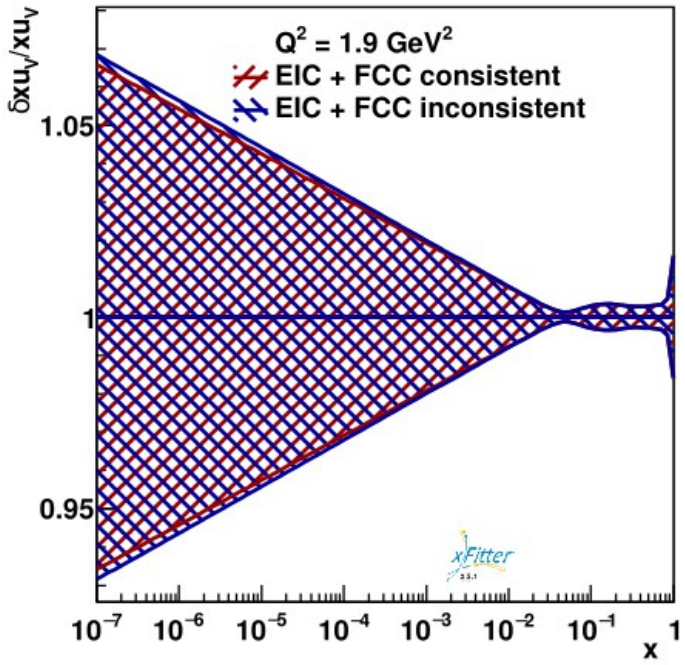


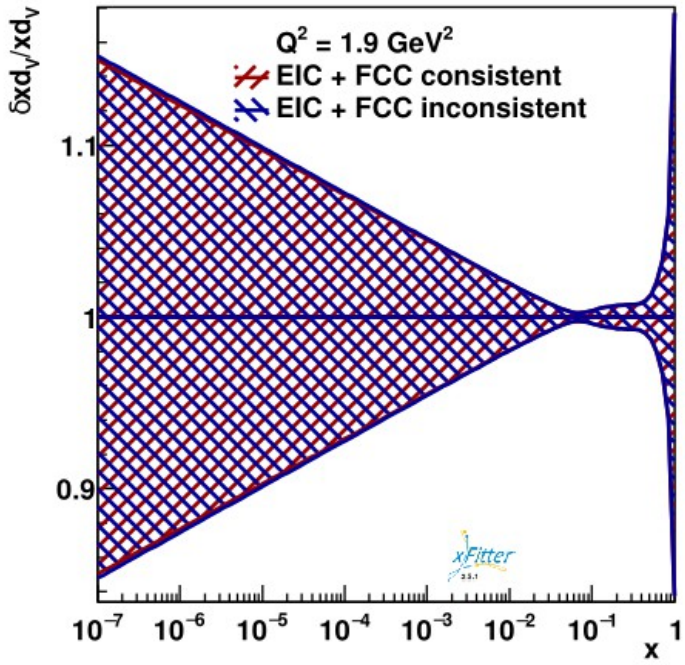


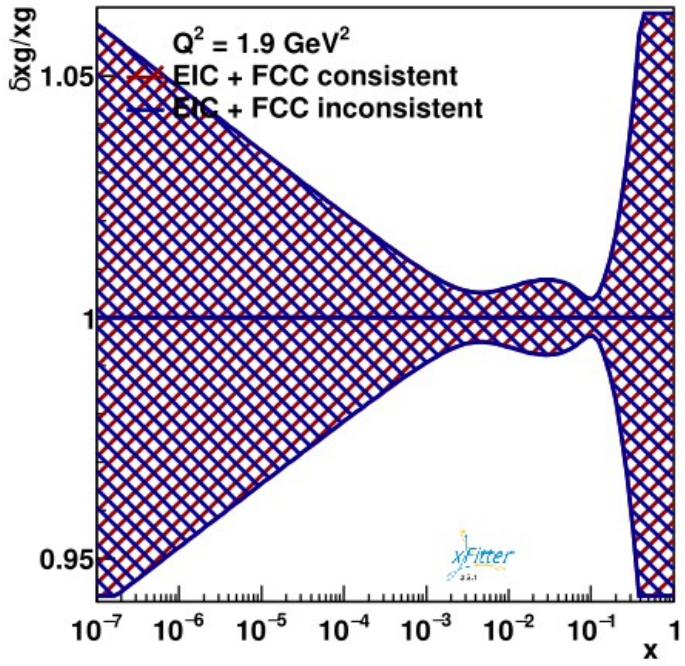


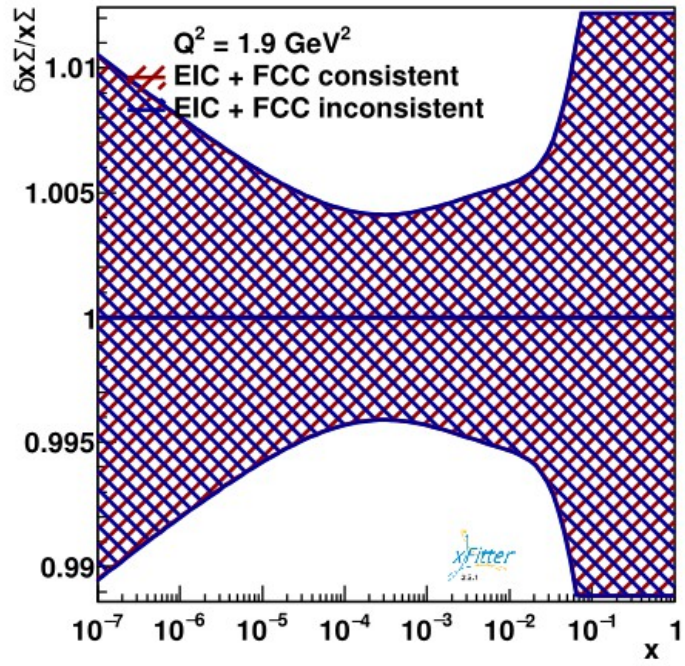


EIC "inconsistent" with NG: FCC

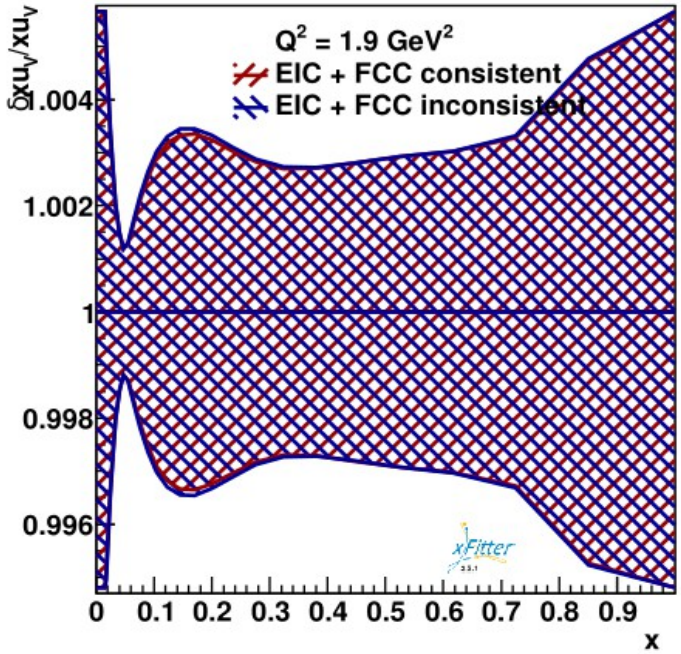


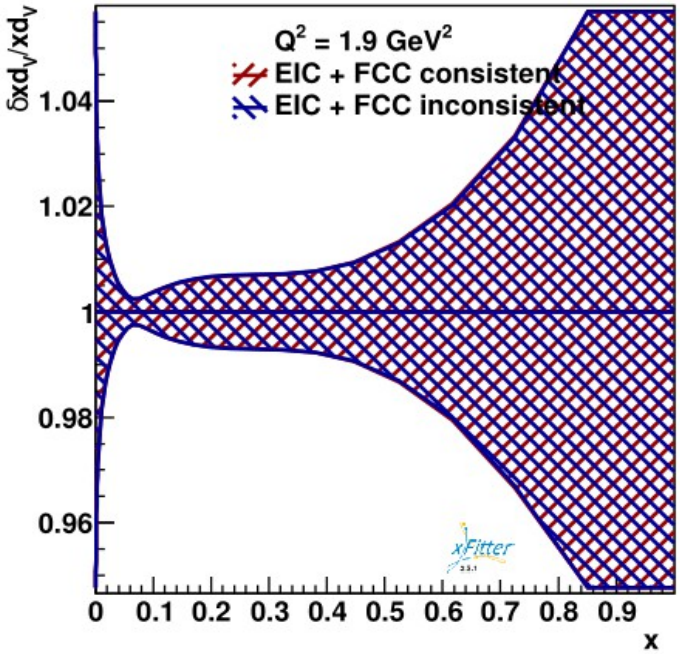


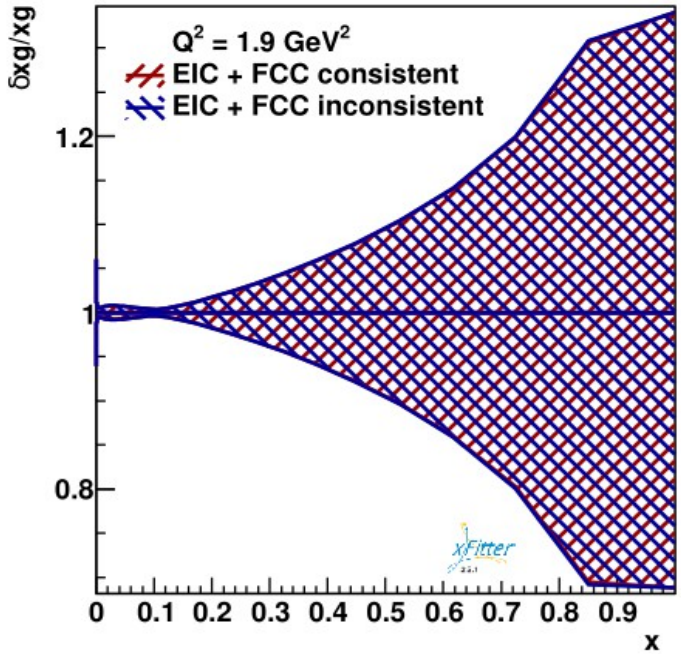


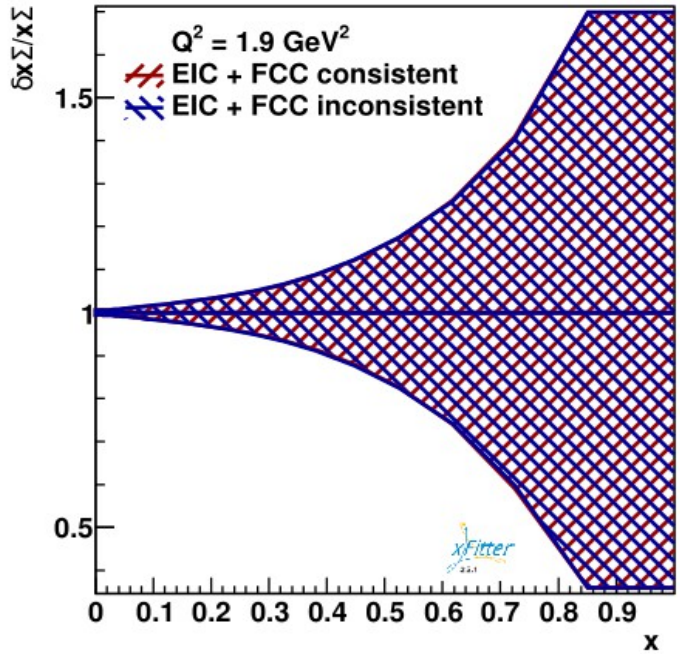


EIC "inconsistent" with NG: FCC

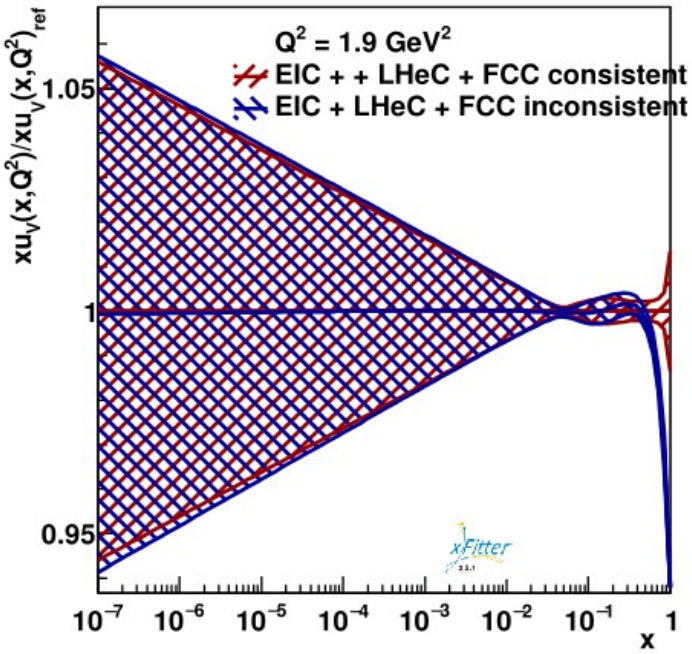


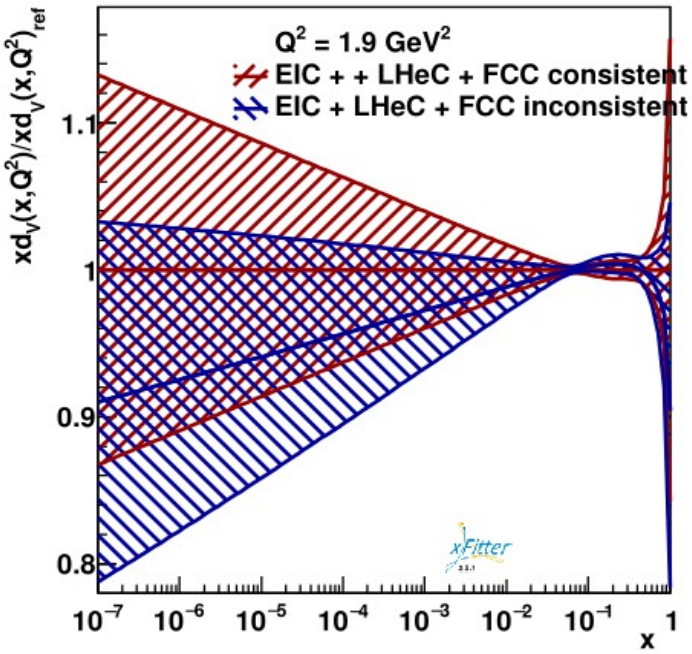


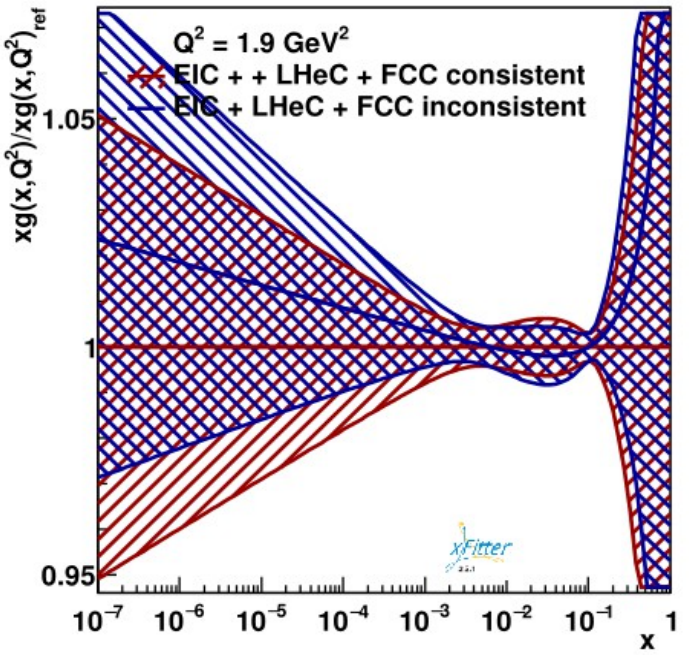


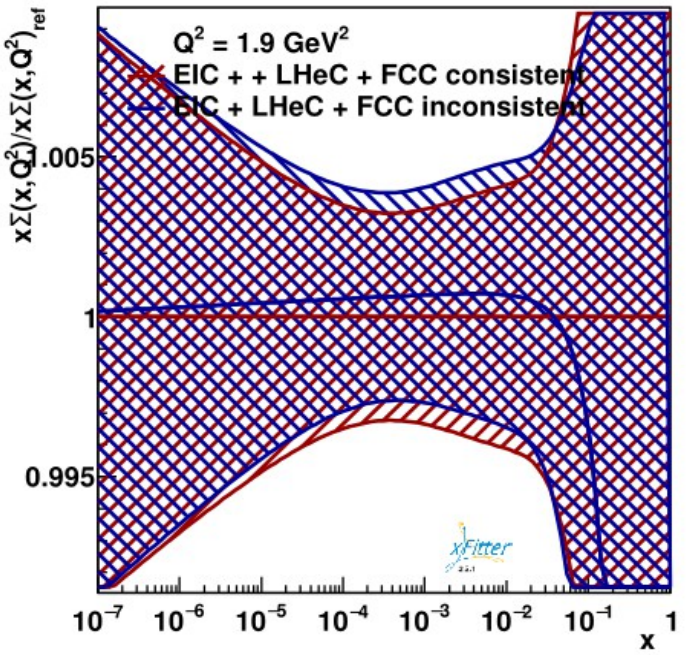


EIC "inconsistent" with NG: LHeC + FCC

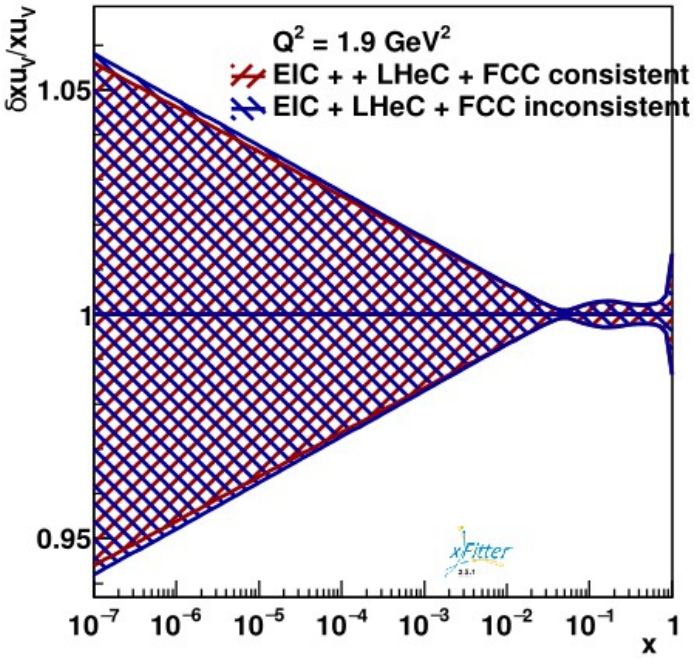


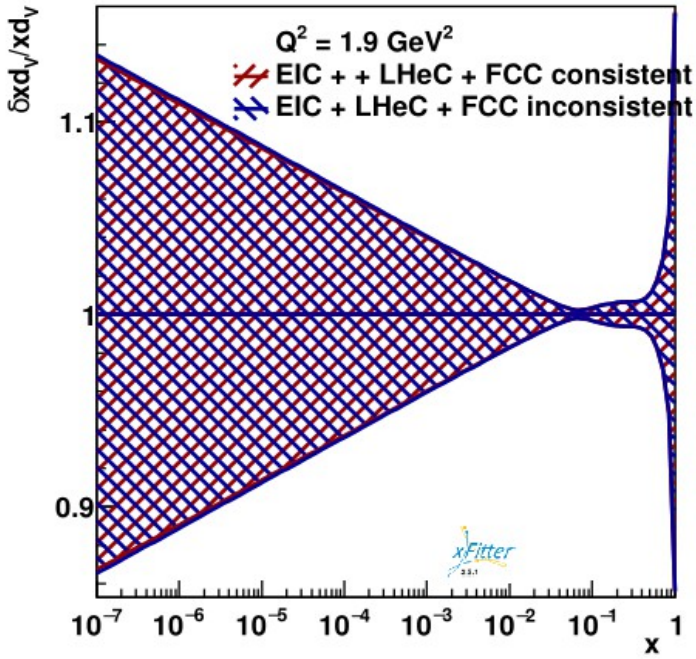


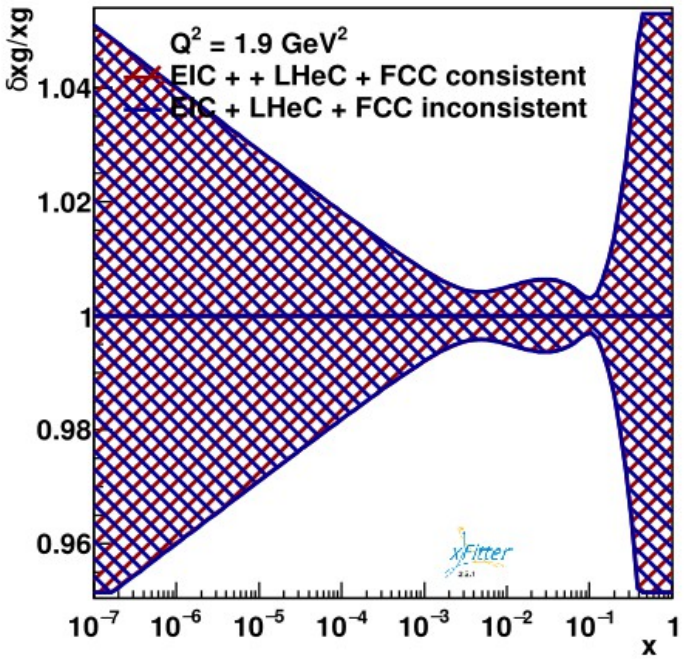


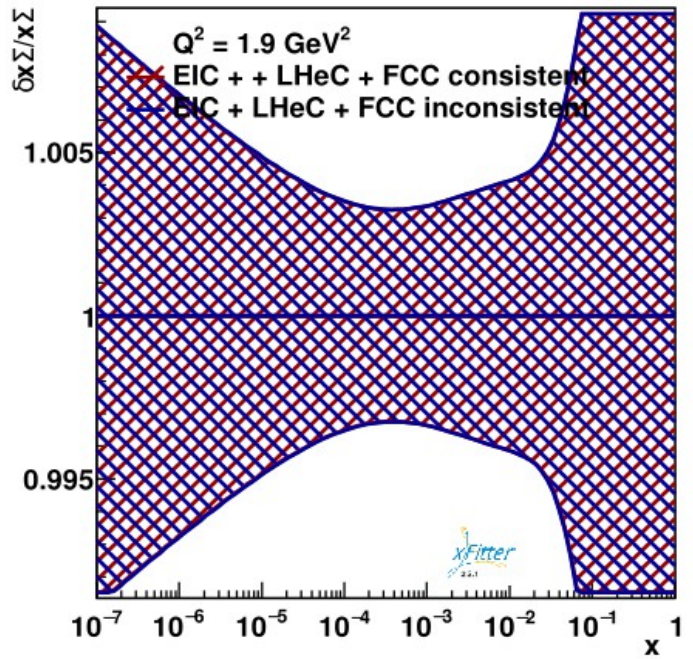


EIC "inconsistent" with NG: LHeC + FCC









EIC "inconsistent" with NG: LHeC + FCC