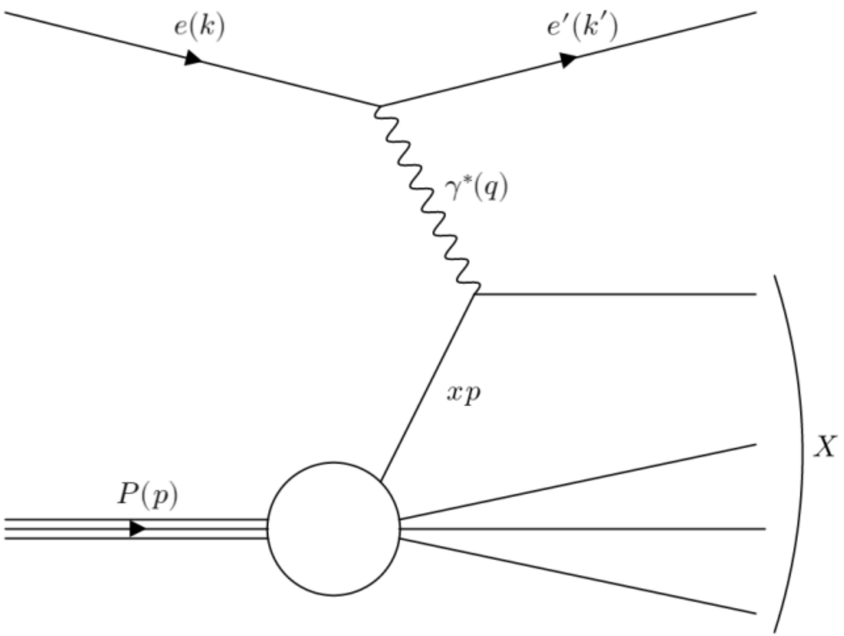
UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

# Reduced cross sections from e-p collisions during EIC early science

S. Maple

*Focusing on unpolarised e-p

# Inclusive Deep Inelastic Scattering (in a nutshell)*




- In **inclusive scattering** no constraints are placed on the hadronic final state
- Inclusive events are described using three **related** kinematic variables:

**$Q^2 = s \cdot x \cdot y$**

- $Q^2$ → **"Virtuality"** $Q^2 = -q^2$
- $s$ → **CoM energy**
- $x$ → **Bjorken x**
- $y$ → **Inelasticity**

$$Q^2 = -(q \cdot q) \qquad x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}.$$

**Typically the goal is to measure the (reduced) xsec in terms of x, y, $Q^2$!**

*Focusing on unpolarised e-p

# Inclusive Deep Inelastic Scattering (in a nutshell)*

- The inclusive cross section can be described in terms of kinematic variables **(x, y, $Q^2$)**, and **three structure functions:**

$$\sigma_r = \frac{xQ^4}{2\pi\alpha^2 Y_+}\left[\frac{d^2\sigma}{dxdQ^2}\right] = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) + \frac{Y_-}{Y_+}xF_3$$

**Dominant contribution to cross section** ($F_2$)

**Longitudinal structure function – contributes more at high y – sensitive to gluons** ($F_L$)

**Parity violating structure function – contributes more at high $Q^2$ – usually small at EIC energies** ($xF_3$)

$$Y_\pm = 1 \pm (1+y)^2$$

- Through measurements of the reduced cross section at multiple c.o.m. energies, we can separate $F_2$ and $F_L$ ($F_3$ neglected – usually measure this through difference of $e^+p$ and $e^-p$ cross sections)

*Focusing on unpolarised e-p

# Inclusive Deep Inelastic Scattering (in a nutshell)*

- The inclusive cross section can be described in terms of kinematic variables **(x, y, $Q^2$)**, and **three structure functions:**

$$\sigma_r = \frac{xQ^4}{2\pi\alpha^2 Y_+}\left[\frac{d^2\sigma}{dxdQ^2}\right] = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) + \frac{Y_-}{Y_+}xF_3$$

- The structure functions allow us to constrain the proton PDFs

$$F_2 \propto x\sum_q (q+\bar{q})$$

$$xF_3 \propto x\sum_q (q-\bar{q})$$

$$F_L = 0$$

} Leading order

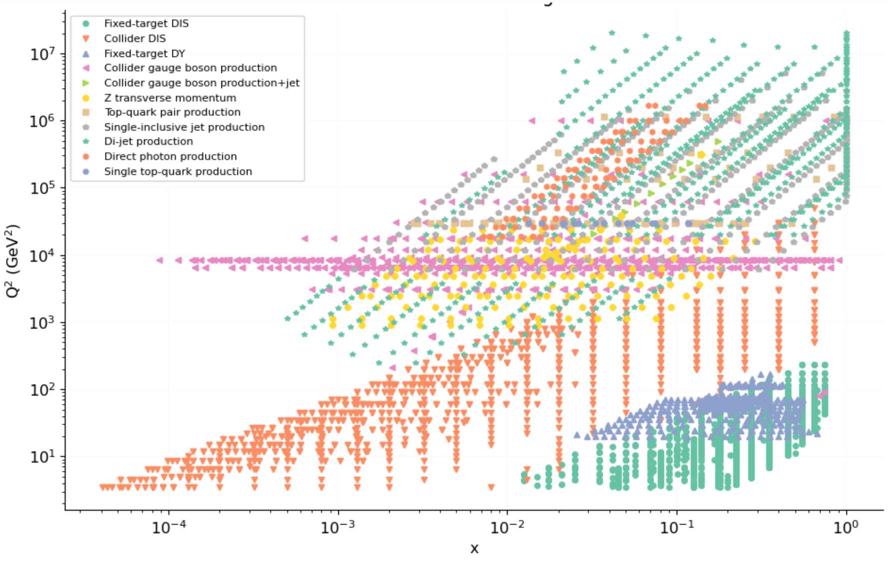
$F_L$ gains its first contribution at NLO, and relates to the gluon approximately as:

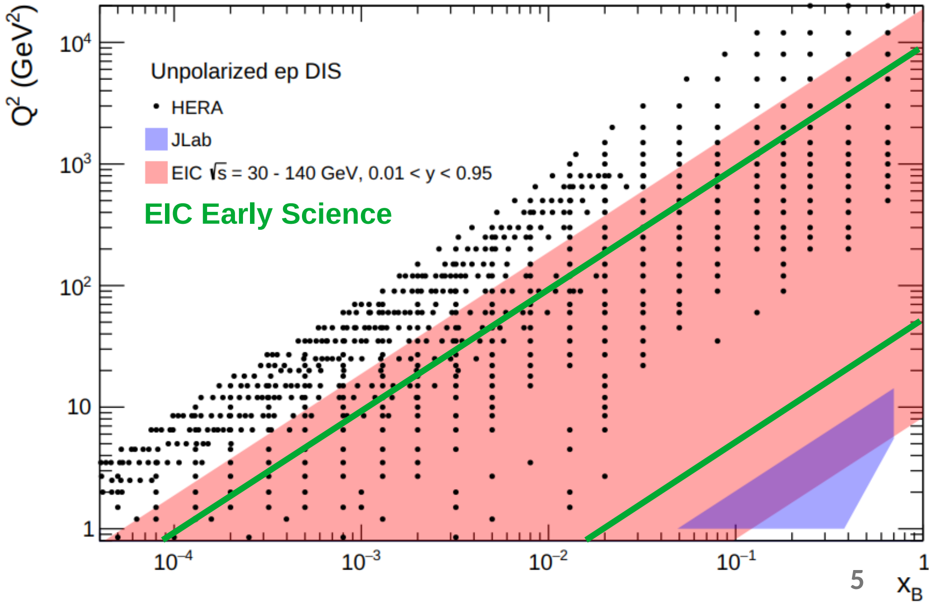
$$F_L(x,Q^2) \propto \alpha_s x g(x,Q^2)$$

# Collinear PDFs and the EIC

- Current knowledge of unpolarised collinear (proton) PDFs has been largely driven by:
  - **Inclusive neutral current (NC) and charged current (CC) DIS**
    - HERA and various fixed target experiments
  - Proton PDF sensitive channels at hadron colliders
    - e.g. **Z $p_T$, high mass Drell Yann, inclusive jets** etc

- HERA DIS data still forms the backbone of global PDF fits – even with the new LHC data
  - Fixed target experiments supplement to constrain high x

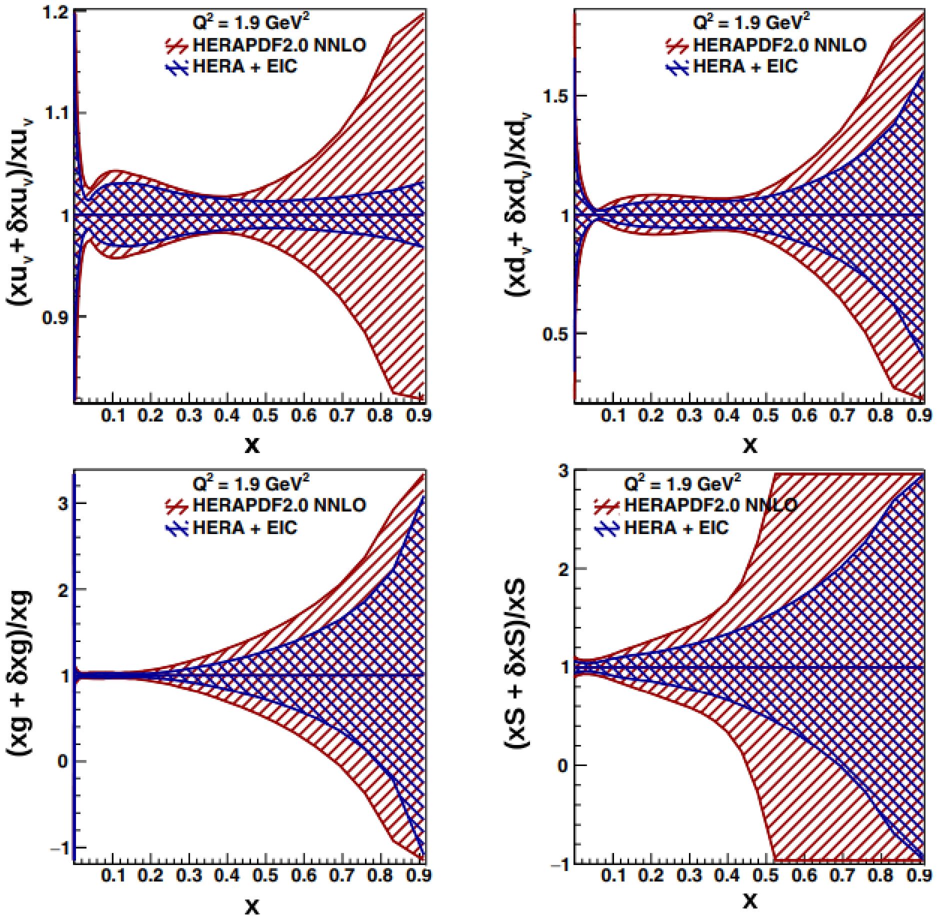


# Collinear PDFs and the EIC

- New, precise data from the EIC at moderate Q
will help in global fits
  - HERA data low precision (statistically limited) at high x due to $Q^2$ dependence of $\sigma_r$
  - EIC could achieve measurements at higher Q than fixed target experiments that currently constrain high x (with less sensitivity to higher twists)

See arxiv:2309.11269 for ultimate EIC impact



# EIC Early Science

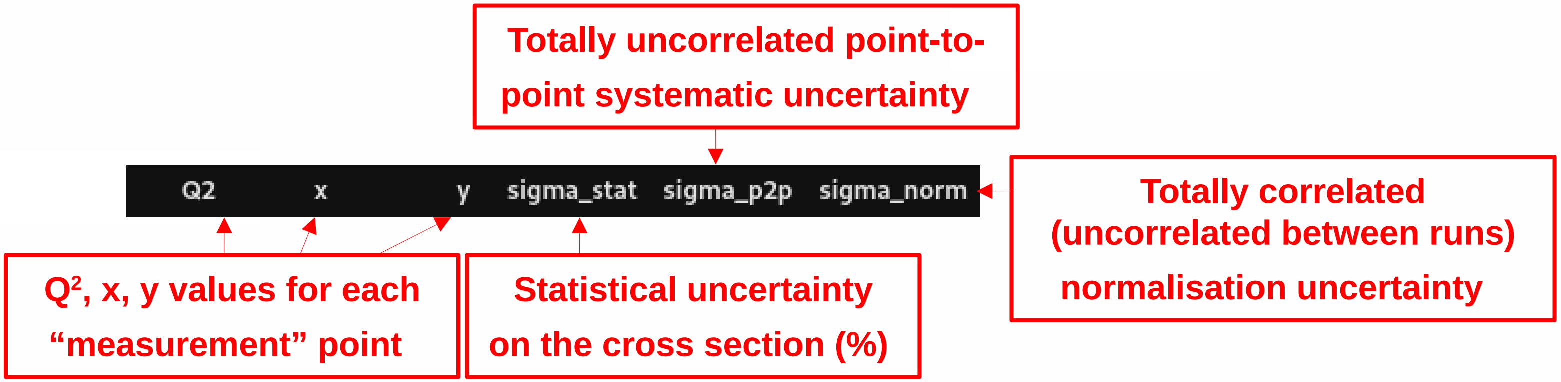
| | Species | Energy (GeV) | Luminosity/year (fb-1) | Electron polarization | p/A polarization |
|---|---|---|---|---|---|
| YEAR 1 | e+Ru or e+Cu | 10 x 115 | 0.9 | NO (Commissioning) | N/A |
| YEAR 2 | e+D<br>e+p | 10 x 130 | 11.4<br>4.95 - 5.33 | LONG | NO<br>TRANS |
| YEAR 3 | e+p | 10 x 130 | 4.95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

**Note: the eA luminosity is per nucleon**

- Early science beam configurations are not final → but the hope of the inclusive PWG is for two (or more) e-p runs with different c.o.m. energies
  - A lower c.o.m. energy 5x130 run would be particularly useful – considered here
- Division of luminosity in years listing multiple species is uncertain – reduced cross section measurement is usually dominated by systematics, so take only modest luminosity of 1 $fb^{-1}$ for each beam config considered here

# The goal of this results release…

- We've had interest from groups involved in PDF fitting who want to include EIC/ePIC "early science" data grids in their fits and see the impact on the uncertainties
- The format of the input grids is something like this*




**… the challenge is that <u>we</u> (in ePIC) need to agree on <u>how many</u> cross section measurements we can take, across <u>what region</u> of the phase space, and with <u>what precision</u>!**

* A value for the <u>cross section</u> itself is generally not needed for PDF fitting impact studies (fitters will use the central value of whatever framework they're working in) → but a cross section column will be included to produce results plots and to facilitate future studies of structure function extraction.

# The goal of this results release...

- The aim is to make cross section + uncertainty grids for early science e-p configurations available for those (within or external to ePIC) who wish to do impact studies

- There are several grids, one for each permutation of
  - Three possible e-p c.o.m. energy configurations
  - Two possible binning schemes
  - Optimistic and pessimistic systematic estimates
  - Predictions from HERAPDF2.0 and NNPDF3.1

- These grids are used to produce cross section vs $x/Q^2$ plots to be used in public talks if approved

- I will conclude by showing some results for a paper that use a binning and statistical uncertainties produced using the methods shown here

# Note: the actual use of ePIC simulation is minimal

- Previously, the creation of such grids has not actually used much in the way of full simulation:
  - A binning scheme would be decided according to the resolutions on the kinematic variables x, y, $Q^2$
  - Statistical uncertainties taken directly from event generator
  - Systematics based on educated guesses from previous experience of DIS experiments

- This work is not intended to revolutionise the way we prepare grids to pass on to fitters – impact studies done with grids prepared this way are still better than no studies at all

  … but this work that does try to add **slightly** more realism:
  - Full simulation used to obtain the statistical uncertainties → efficiency and resolution effects are included at a level that might be expected at the start of EIC operations
  - One of the contributions to the overall P2P systematic uncertainty updated from YR estimate to estimate from some early ePIC systematic studies

# Analysis Part 1 – Statistical Uncertainties

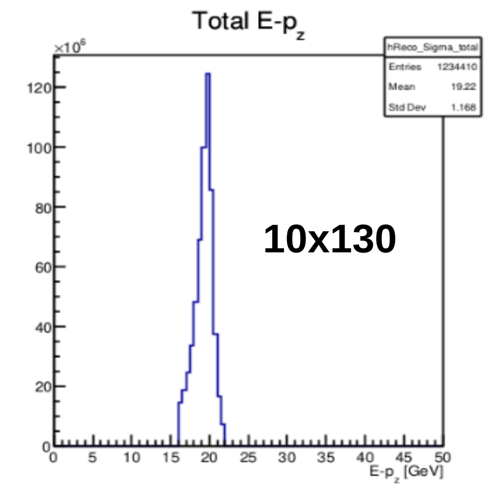
# Event generation + simulation

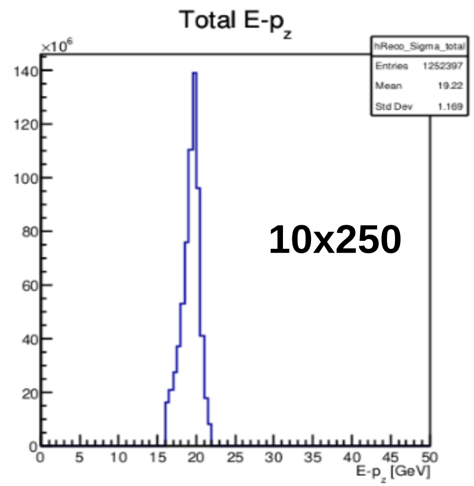
- Neutral Current e-p DIS events generated using Pythia6.428
  - Run cards and meta data now stored at https://github.com/eic/InclusiveEarlyScienceSamples
  - $x>10^{-9}$, $y>10^{-3}$
- Generated for 5x130, 10x130, 10x250 $GeV^2$
- Split as:
  - $1 < Q^2 < 10$ $GeV^2$ : 500k events
  - $10 < Q^2 < 100$ $GeV^2$ : 500k events
  - $100 < Q^2 < 1000$ $GeV^2$ : 500k events
  - $1000 < Q^2 < 10000$ $GeV^2$ : 50k events

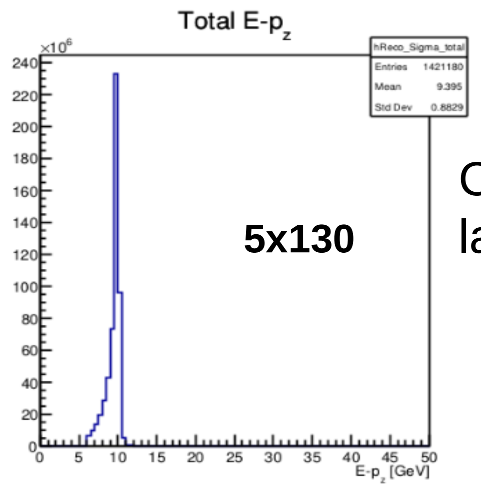
- Events after npsim+EICrecon stored in: /volatile/eic/EPIC/RECO/25.10.4/epic_craterlake/DIS/pythia6.428-1.0/NC/noRad/ep
  - Note 5x130 config not run – used personal simulation production with 25.10.0 version of eic-shell for these events

# Event Selection

- Selection criteria:
  - MC scattered electron has an associated ***ReconstructedParticle***
    - Electron from ***ScatteredElectronsTruth***
  - At least one other particle in ReconstructedParticles (for HadronicFinalState)
  - Total event $E-p_z$ between 16 and 22 GeV (for 10 GeV electron beam) and between 6 and 12 GeV (for 5 GeV electron beam)
    → $E-p_z$ cut is used to remove high energy Initial State QED Radiation (ISR)
    → QED ISR not simulated, but cut also removes poorly reconstructed events




Cut on y applied later in the analysis

# Kinematic Reconstruction

- Selection ensures we have enough information to reconstruct events using both electron-only reconstruction, and also mixed methods that require the hadronic final state
  - Note that $\delta_h$ here is $(E-p_z)_{hfs}$

- Only electron method reconstruction is used for full analysis, but reconstructions with other methods are recorded and could also be used

**Electron method**

$$Q^2 = 2E_e E'_e(1+\cos\theta_e)$$

$$y = 1 - \frac{E'_e}{2E_e}(1-\cos\theta_e)$$

**eΣ method**

$$Q^2_{e\Sigma} = Q^2_e \qquad y_\Sigma = \frac{\delta_h}{\delta_h+\delta_e}$$

$$x_{e\Sigma} = \frac{Q^2_\Sigma}{s y_\Sigma} \qquad Q^2_\Sigma = \frac{p^2_{t,e}}{1-y_\Sigma}$$

**Double Angle method**

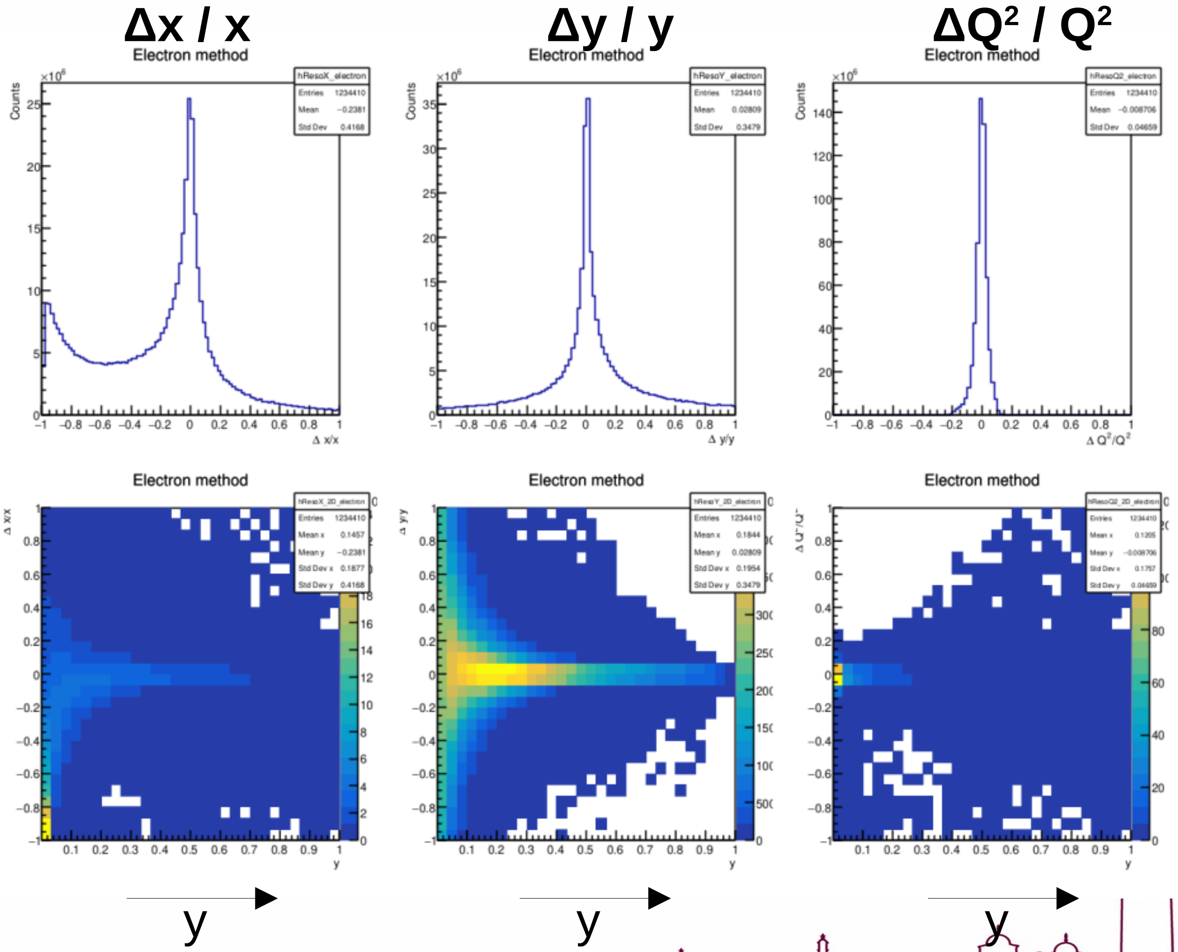
$$y_{DA} = \frac{\alpha_h}{\alpha_h+\alpha_e} \qquad \alpha_{e/h} = \tan\frac{\theta_{e/h}}{2}$$

$$Q^2_{DA} = \frac{4E_e^2}{\alpha_e(\alpha_e+\alpha_h)}$$

# Kinematic Reconstruction

- Reco value peaks at true value

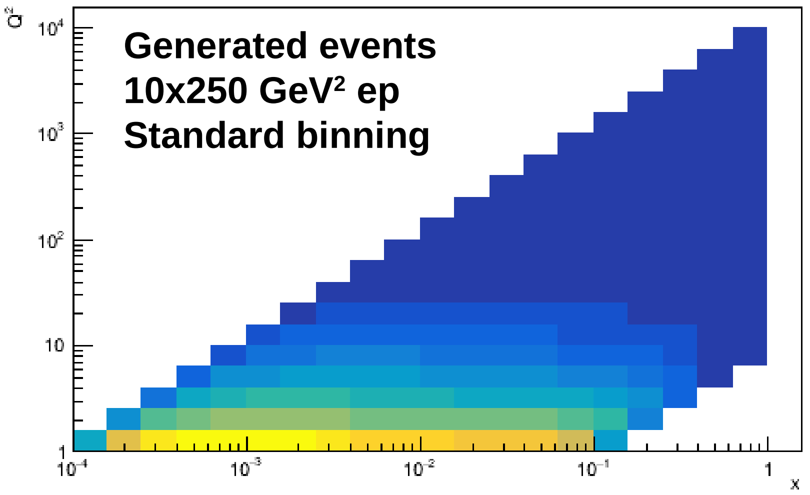
- Rise in counts at Δx / x ~ -1
  - Due to large, positive fluctuations y reconstruction at low y
    → removed by 0.01 < y < 0.95 cut applied later on

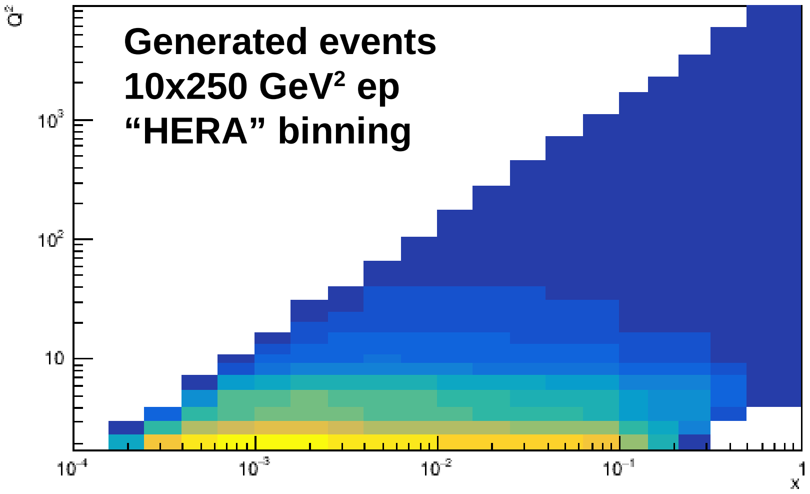


# Binning

- Studies of kinematic resolutions used to determine binning scheme
  - Resolution on x sufficient for ~4-5 bins per decade
  - Resolution on $Q^2$ sufficient for 5-8 bins per decade … for y>0.01 and when the optimal reconstruction method is chosen for a given bin

- Consider two binning schemes here
  - 1. Standard: 5 bins per decade in x and $Q^2$
  - 2. "HERA": x and $Q^2$ bin edges set such that in regions where HERA data exists, no more than one HERA measurement will be in a given bin → useful for $F_L$ studies



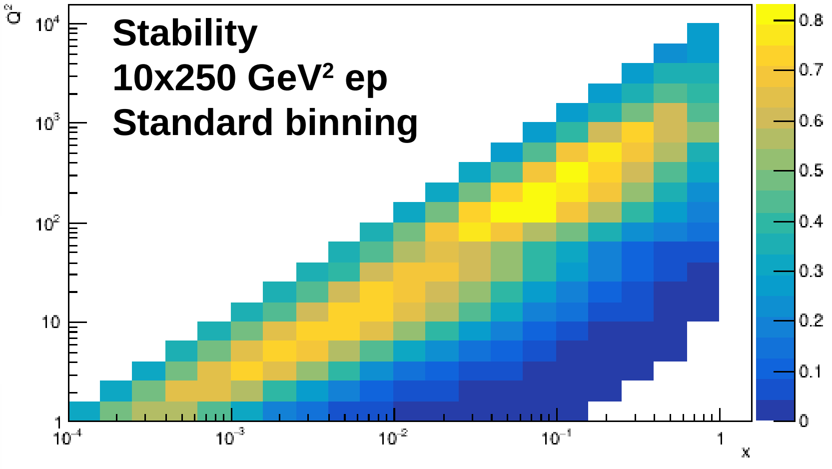



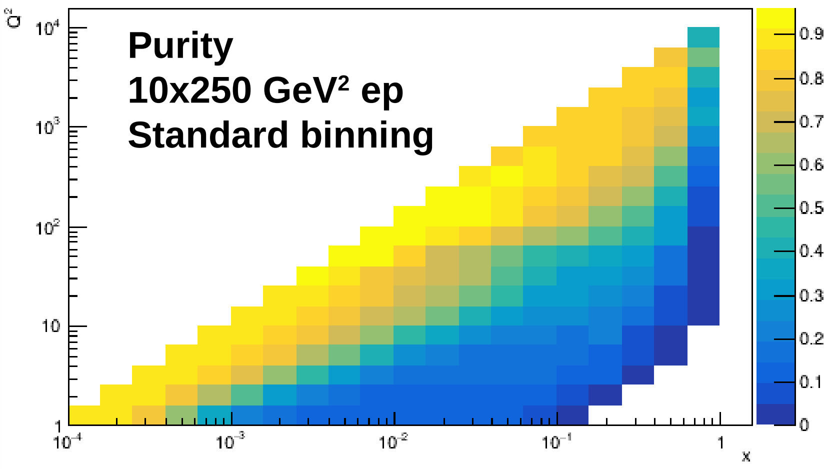
# Binning – purity and stability

Electron method reconstruction

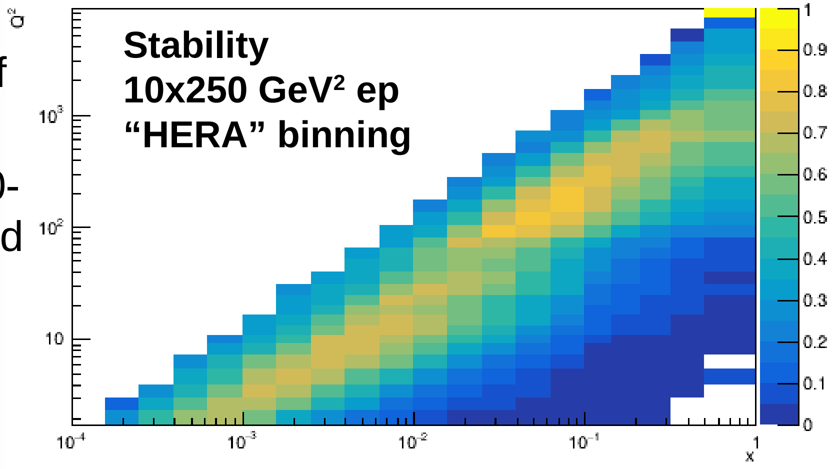
$$Stability = \frac{N_{rec\&gen}}{N_{gen}}$$

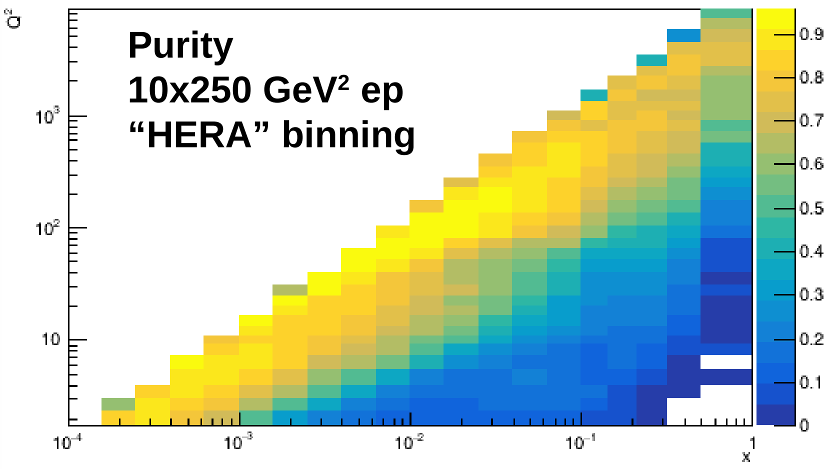
$$Purity = \frac{N_{rec\&gen}}{N_{rec}}$$




- Stability – migration of events out of bin
- Purity – Migration of events into bin
- S&P threshold of 30-40% commonly used in HERA analyses



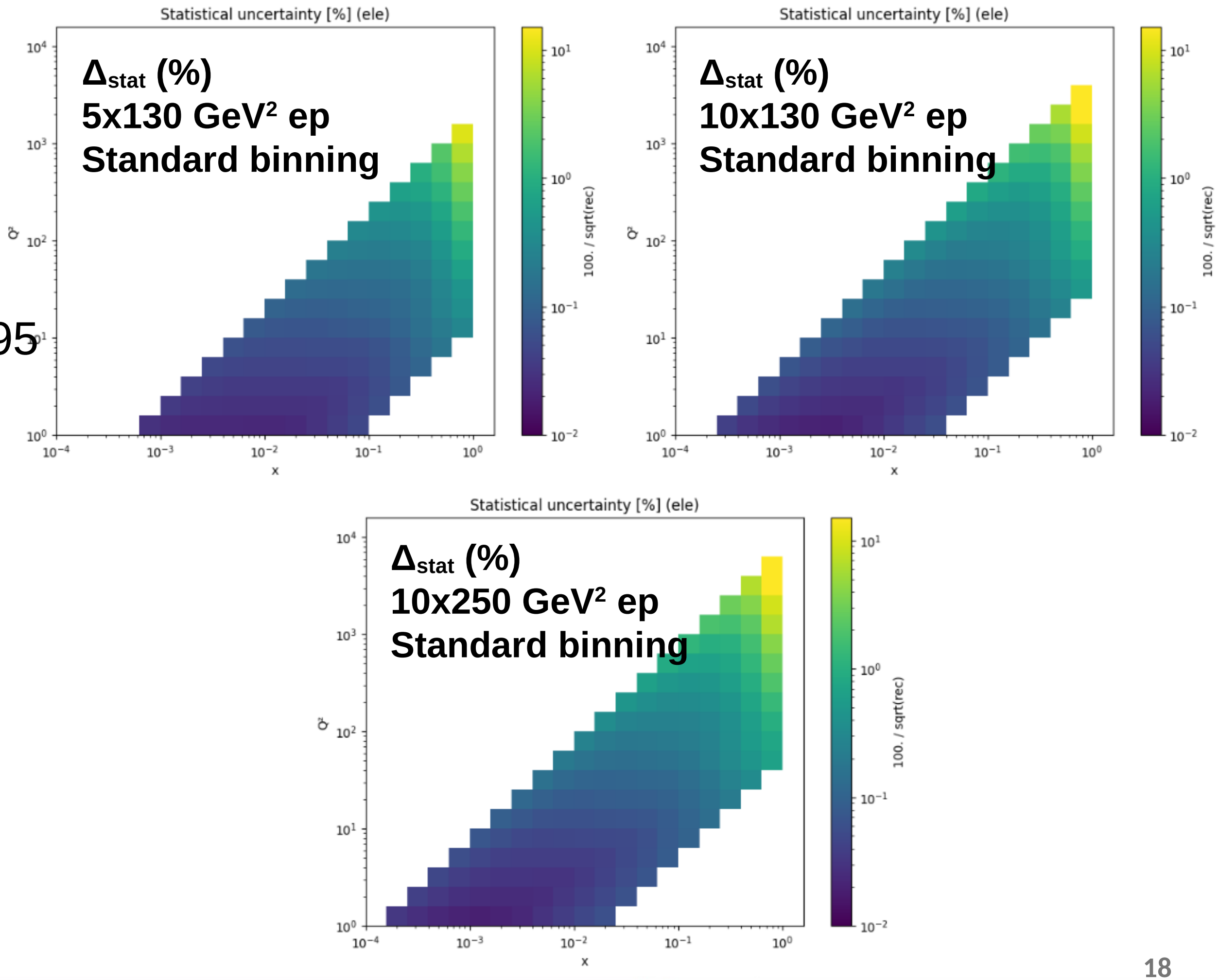

- (Note that y cut not yet applied)

# Statistical uncertainties

- Statistical uncertainties obtained by:

1. Removing bins outside of 0.01<y<0.95
2. Scaling # of reconstructed events by 95% (electron finder efficiency as ScatteredElectronsTruth used)
3. Calculate $\delta_{stat}$ for bin i in percent as

$$100/\sqrt{n_{\mathrm{rec,i}}}$$



# Analysis Part 2 – Cross Section Predictions

# Cross section predictions

- Grids produced in this analysis are intended for use in further studies of structure functions and PDF fitting

- Could get cross sections through full simulation of physics events, but this would simply be corrected back to the cross section from the event generator
- This approach is
  - Time and resource intensive
  - Dependent on specific build and settings of event generator
  - Not a great way of getting PDF uncertainties

- Instead, use computational tools to calculate coefficient functions for certain theory settings, and hence predictions of cross section observable through convolution with PDFs

$$\sigma = \sum_j (f_j \otimes c_j)$$

# Yadism

- For my cross section predictions I use the Yadism python library for calculations of structure functions and cross sections

- Code is open source, allows interpolation grids to be stored in PineAPPL format so there's no need to re-run computation when changing PDF set

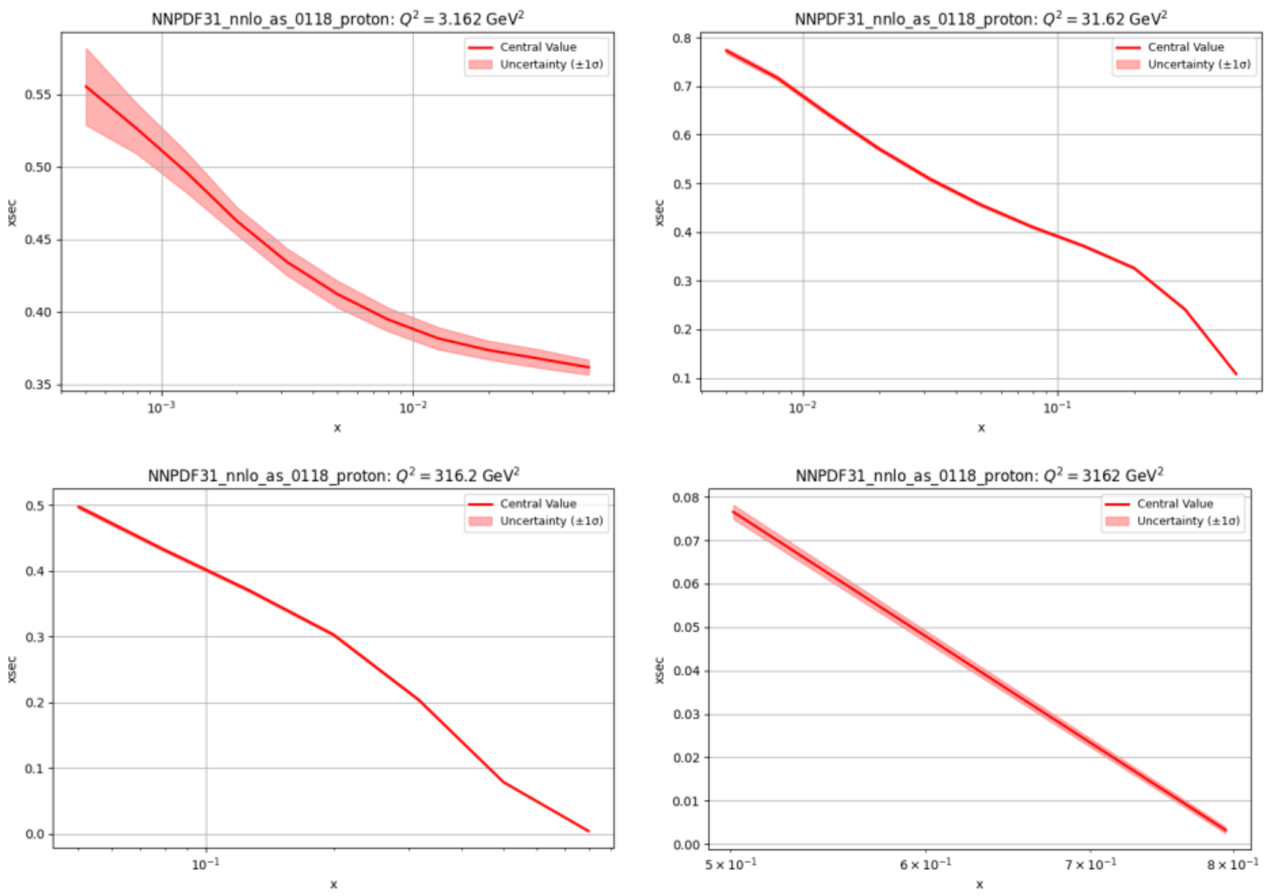
- It's been benchmarked against the widely used APFEL++ and QCDNUM libraries

- I do my predictions at NNLO in the FONLL flavour number scheme, with $\alpha_s(M_Z^2) = 0.118$

```
"PTO": 2,  # perturbative order in alpha_s: 0 = LO (alpha_s^0), 1 = NLO (alpha_s^1) ...

# SM parameters and masses
"CKM": "0.97428 0.22530 0.003470 0.22520 0.97345 0.041000 0.00862 0.04030 0.999152",  # CKM matrix elements
"GF": 1.1663787e-05,  # [GeV^-2] Fermi coupling constant
"MP": 0.938,  # [GeV] proton mass
"MW": 80.398,  # [GeV] W boson mass
"MZ": 91.1876,  # [GeV] Z boson mass
"alphaqed": 0.007496252,  # alpha_em value
"kcThr": 1.0,  # ratio of the charm matching scale over the charm mass
"kbThr": 1.0,  # ratio of the bottom matching scale over the bottom mass
"ktThr": 1.0,  # ratio of the top matching scale over the top mass
"mc": 1.51,  # [GeV] charm mass
"mb": 4.92,  # [GeV] bottom mass
"mt": 172.5,  # [GeV] top mass

# Flavor number scheme settings
"FNS": "FONLL-FFNS",  # Flavour Number Scheme, options: "FFNS", "FFN0", "ZM-VFNS"
"NfFF": 4,  # (fixed) number of running flavors, only for FFNS or FFN0 schemes
"Q0": 1.65,  # [GeV] reference scale for the flavor patch determination
"nf0": 4,  # number of active flavors at the Q0 reference scale

# Alphas settings and boundary conditions
"Qref": 91.2,  # [GeV] reference scale for the alphas value
"nfref": 5,  # number of active flavors at the reference scale Qref
"alphas": 0.118,  # alphas value at the reference scale
"MaxNfAs": 5,  # maximum number of flavors in running of strong coupling
"QED": 0,  # QED correction to running of strong coupling: 0 = disabled, 1 = allowed

# Scale Variations
"XIF": 1.0,  # ratio of factorization scale over the hard scattering scale
"XIR": 1.0,  # ratio of renormalization scale over the hard scattering scale

# Other settings
"IC": 0,  # 0 = perturbative charm only, 1 = intrinsic charm allowed
"TMC": 1,  # include target mass corrections: 0 = disabled, 1 = leading twist, 2 = higher twist approximated, 3 = higher twist exa
"n3lo_cf_variation": 0,  # N3LO coefficient functions variation: -1 = lower bound, 0 = central , 1 = upper bound

# Other EKO settings, not relevant for Yadism
"HQ": "POLE",  # heavy quark mass scheme (not yet implemented in yadism)
"MaxNfPdf": 5,  # maximum number of flavors in running of PDFs (ignored by yadism)
"ModEv": "EXA",  # evolution solver for PDFs (ignored by yadism)
```

# Cross section predictions (NNPDF3.1)

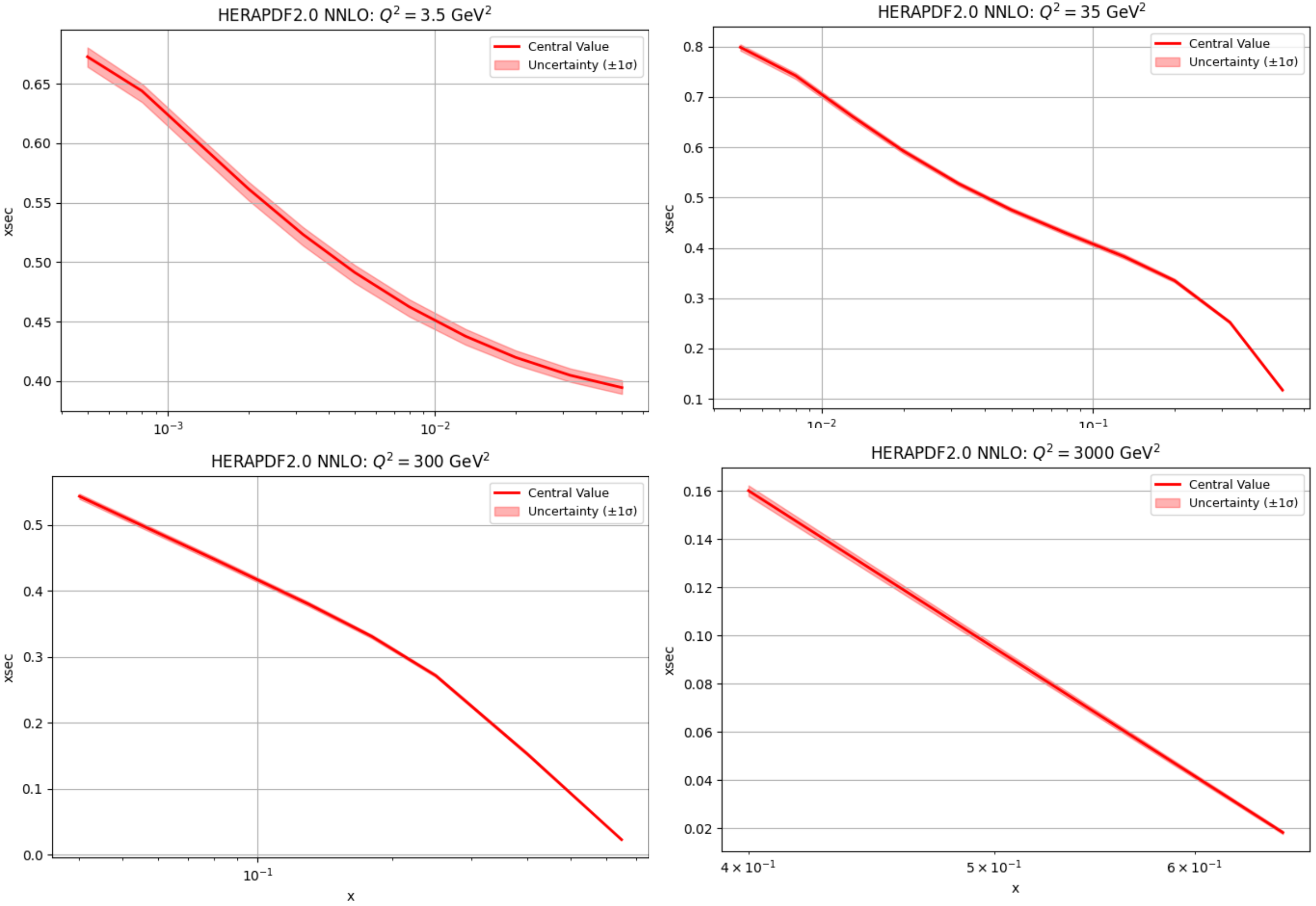
- With these theory settings then get predictions using the NNPDF3.1 PDF set (and symmetric uncertainties using the MC replicas)



# Cross section predictions (HERAPDF2.0)

- I also have some HERAPDF2.0 predictions calculated using xFitter that were kindly shared with me → only used in “HERA” binning studies

  (Note asymmetric uncertainties)



# Analysis Part 3 – Systematic Uncertainties

# Systematic Uncertainties

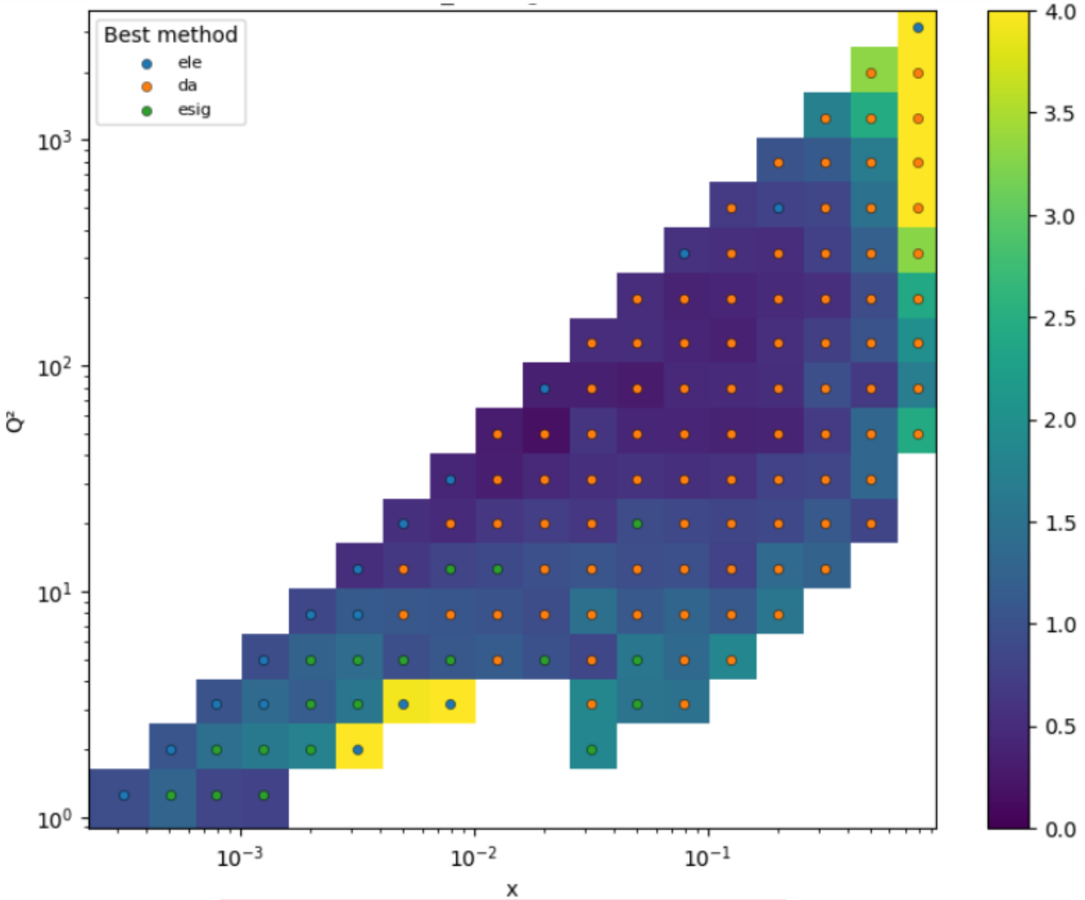
- It's difficult to achieve realistic estimates for the systematic uncertainties for a machine and detector that don't yet exist

- Estimates for systematic uncertainties will change over time, as more information becomes available, and further simulation studies are done

- In the Yellow Report, systematic uncertainties were broken down into
  - Optimistic and pessimistic scenarios
  - Totally uncorrelated point-to-point uncertainties and totally correlated normalisation uncertainties (totally uncorrelated between beam configurations)
  - No effort made to include partially correlated systematics

- These were obtained from the sum in quadrature of the upper and lower bounds of
  - P2P: 1% from radiative corrections and 1-2% from detector effects ≈ 1.5-2.3%
  - Normalisation: 1% on luminosity and 2-4% from detector effects ≈ 2.5-4.3%

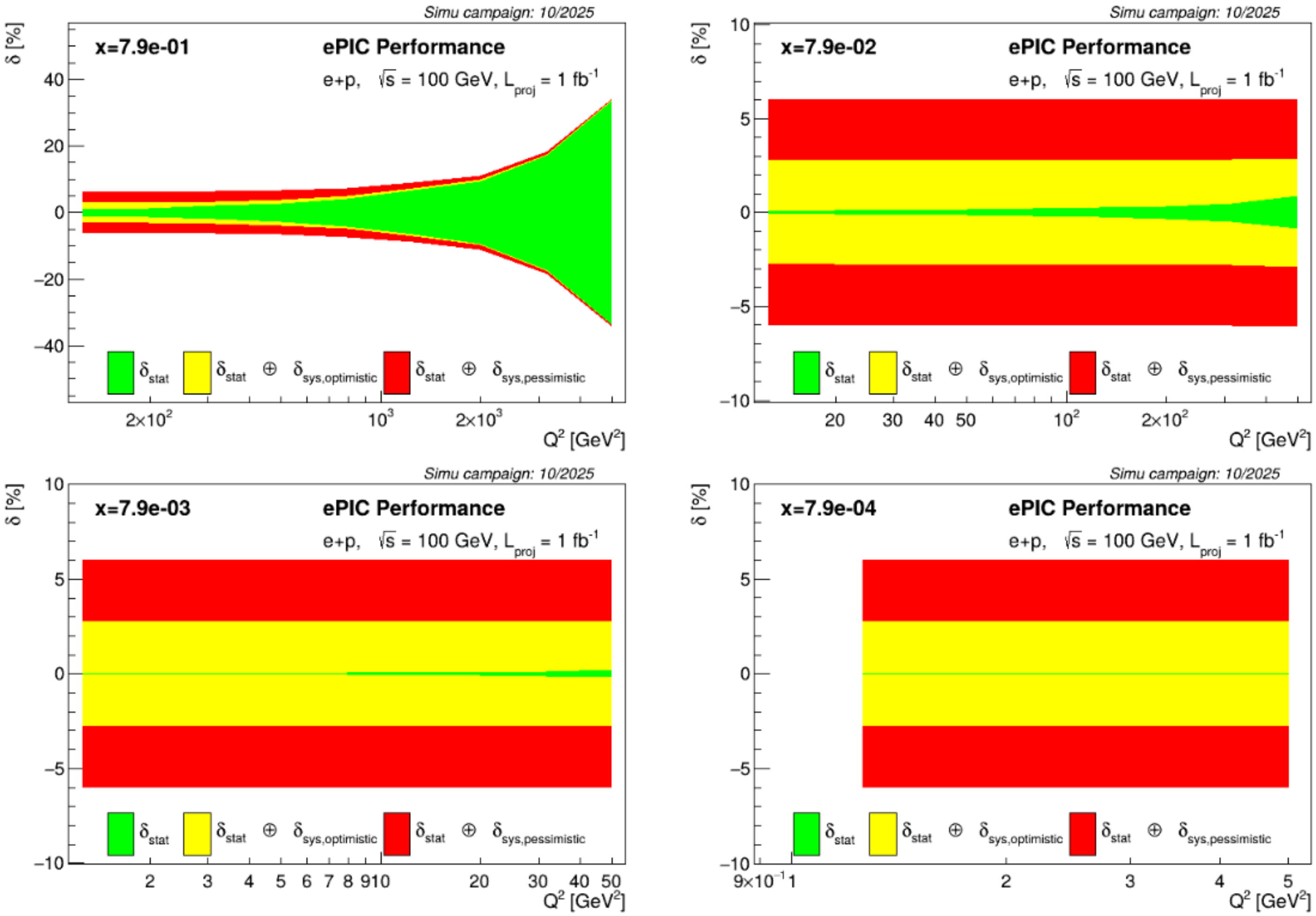
# Early systematics studies (Only 3 sources)




**Contribution ≈ 0.5-4%**

- Update P2P detector effects value based on early studies assuming:
  - Electron/hadron energy scale unc = 0.5/1%
  - Electron polar angle unc = 1mrad
- Total uncertainty taken from sum in quadrature of statistical uncertainty ($1fb^{-1}$) and the average uncertainty from each systematic (0.5*(|+ve| + |-ve|))
- Plot the total uncertainty from the method that gives the best value
  - Require purity & stability > 30%
- Note: only considering 3 sources here, of which only 1 impacts the DA method → this spread will change with inclusion of more systematics

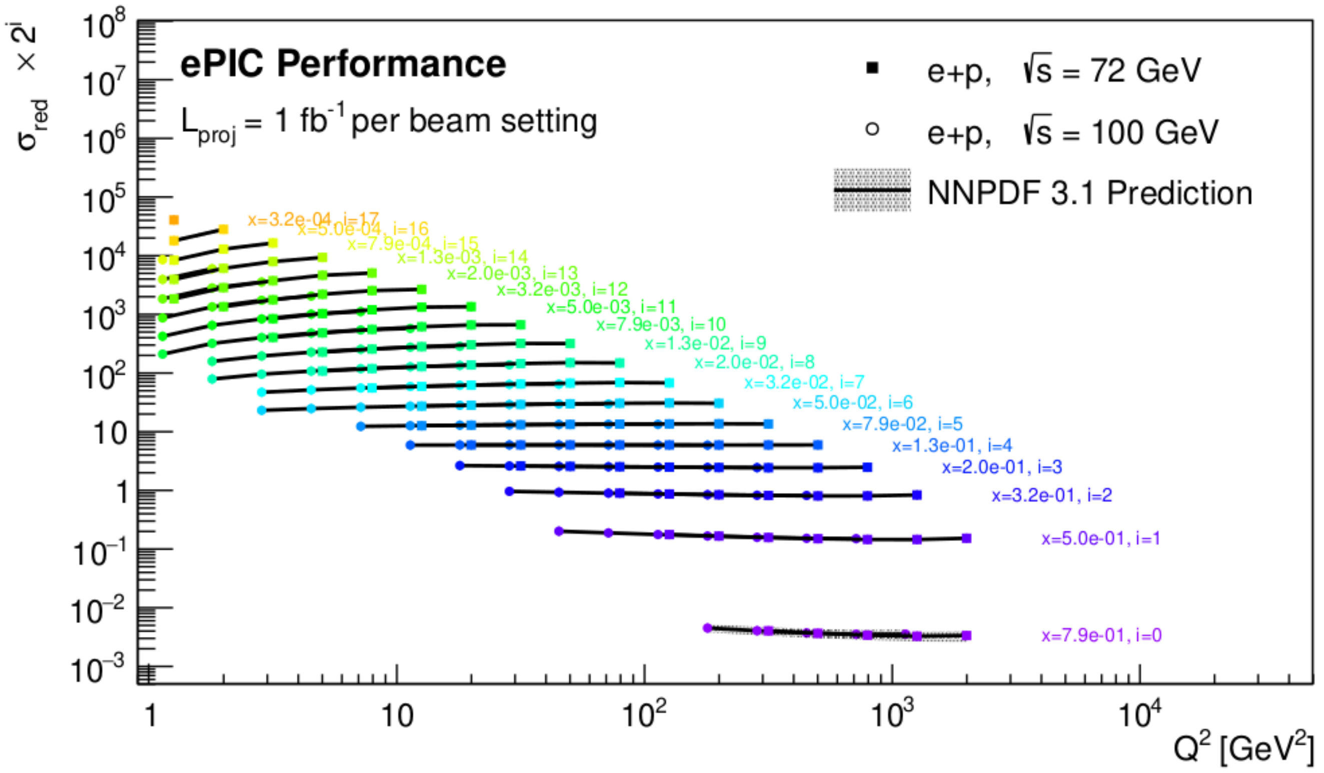
# Total uncertainties




- Total uncertainty taken as sum in quadrature of statistical uncertainties w/ optimistic or pessimistic systematic uncertainty
- Systematic uncertainty dominates except for x≳0.1 when $Q^2$≳1000 $GeV^2$

# Plots for release

# 2 beam configurations (0.01<y<0.95 && PS>0.3)




- Phase space w/ 2 ep configurations from early science table
- Pessimistic total uncertainty on plot
- Purity > 30% and Stability > > 30% (electron method)

Figure 11: Cross sections and uncertainties for the 10x130 and 10x250 GeV$^2$ ep beam configuration as a function of $Q^2$ for bins with purity and stability larger than 30 %. Points are offset in $Q^2$ for visibility.

# 3 beam configurations (0.01<y<0.95 && PS>0.3)

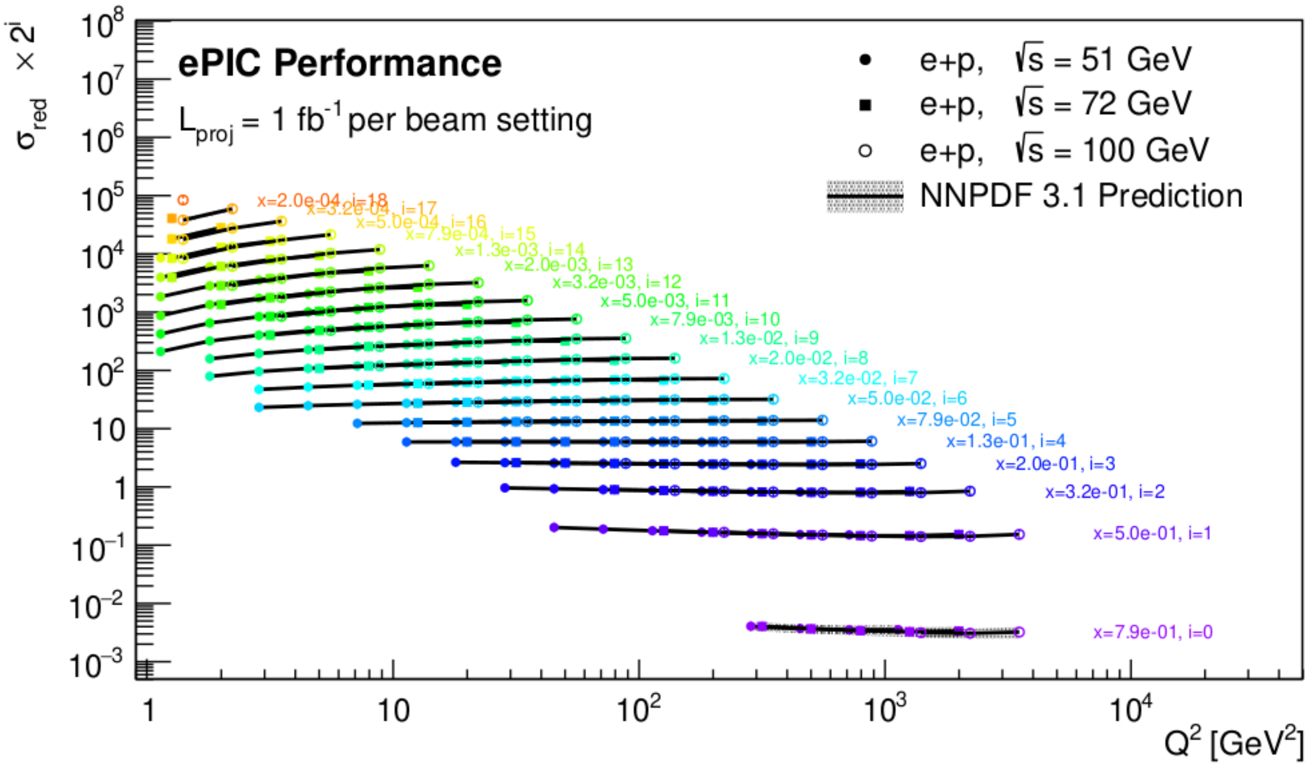



Figure 13: Cross sections and uncertainties for the 5x130, 10x130, and 10x250 GeV$^2$ ep beam configuration as a function of $Q^2$ for bins with purity and stability larger than 30 %. Points are offset in $Q^2$ for visibility.

- Add 5x130 ep config to plot
- Phase space w/ 3 potential early science ep configurations
- Pessimistic total uncertainty on plot
- Purity > 30% and Stability > > 30% (electron method)

# 2 beam configurations (0.01<y<0.95)

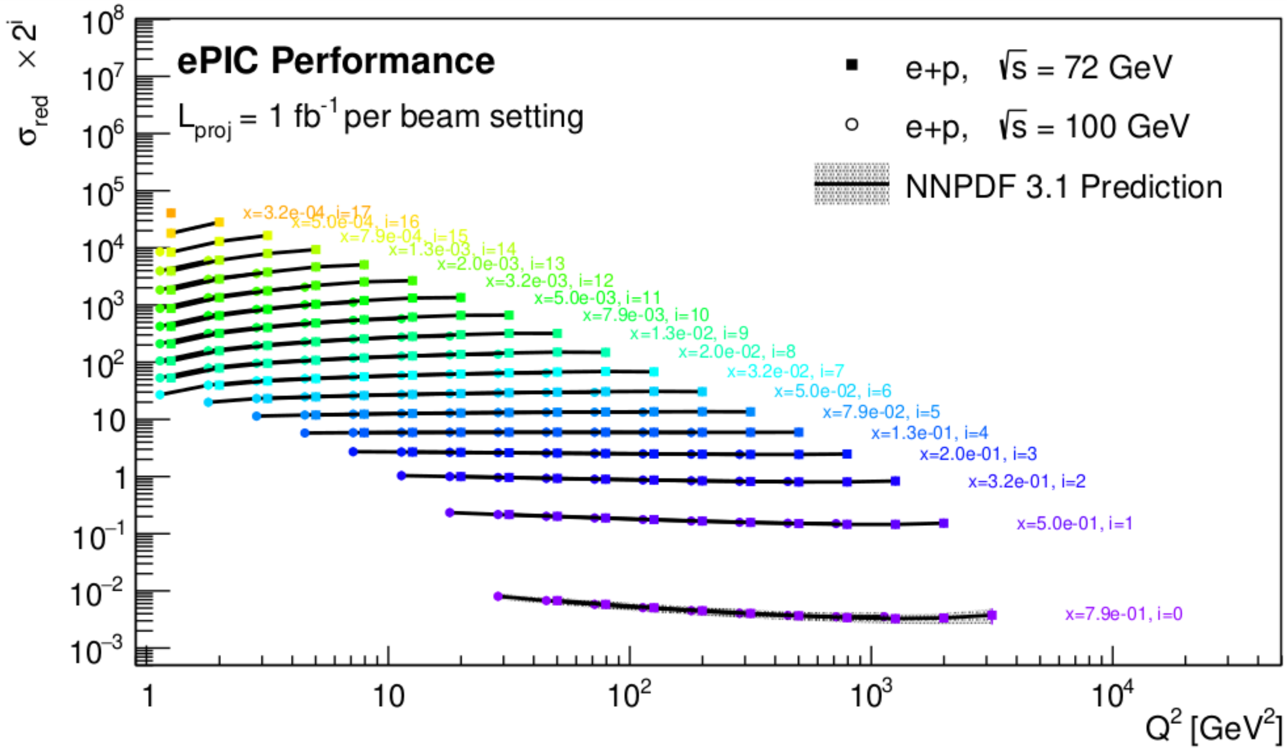



Figure 10: Cross sections and uncertainties for the 10x130 and 10x250 GeV ep beam configuration as a function of $Q^2$ with no purity/stability requirement Points are offset in $Q^2$ for visibility.

- Phase space w/ 2 ep configurations from early science table
- Pessimistic total uncertainty on plot

# 3 beam configurations (0.01<y<0.95)

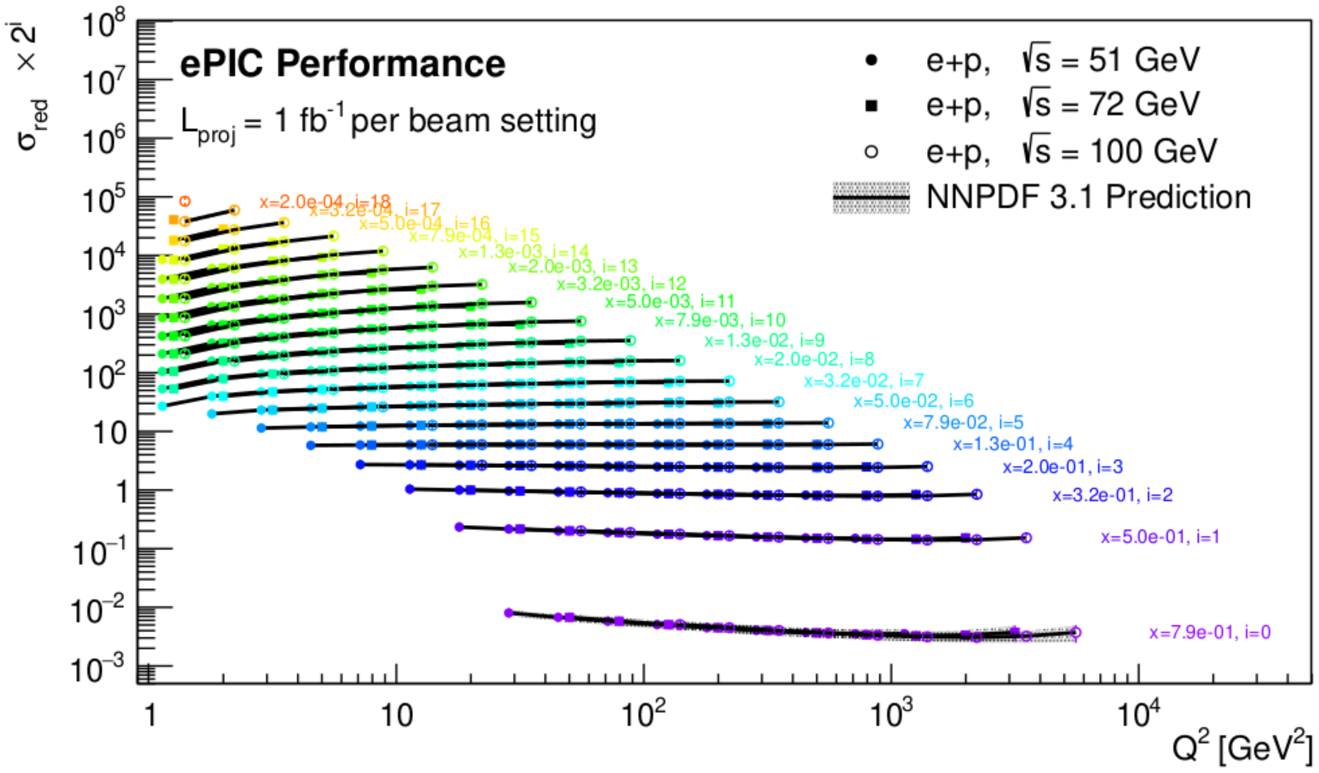



Figure 12: Cross sections and uncertainties for the 5x130, 10x130, and 10x250 GeV$^2$ ep beam configuration as a function of $Q^2$ with no purity/stability requirement. Points are offset in $Q^2$ for visibility.

- Add 5x130 ep config to plot
- Phase space w/ 3 potential early science ep configurations
- Pessimistic total uncertainty on plot

# Grids for sharing

# Grids for sharing

Optimistic 10x250

| Q2 | x | y | purity | stability | sigma_red | sigma_red_pdf_unc | sigma_stat | sigma_p2p | sigma_norm |
|---|---|---|---|---|---|---|---|---|---|
| 1.258925 | 0.000200 | 0.630957 | 0.915340 | 0.473880 | 0.320509 | 0.031323 | 0.033940 | 1.2 | 2.5 |
| 1.258925 | 0.000316 | 0.398107 | 0.819734 | 0.575700 | 0.290023 | 0.026500 | 0.027132 | 1.2 | 2.5 |
| 1.258925 | 0.000501 | 0.251189 | 0.621223 | 0.564724 | 0.270261 | 0.016928 | 0.023246 | 1.2 | 2.5 |
| 1.258925 | 0.000794 | 0.158489 | 0.402142 | 0.453197 | 0.254951 | 0.013751 | 0.020547 | 1.2 | 2.5 |
| 1.258925 | 0.001259 | 0.100000 | 0.239727 | 0.300048 | 0.240664 | 0.012491 | 0.019641 | 1.2 | 2.5 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 1995.262315 | 0.501187 | 0.398107 | 0.817397 | 0.444547 | 0.070988 | 0.001181 | 3.942817 | 1.2 | 2.5 |
| 1995.262315 | 0.794328 | 0.251189 | 0.350225 | 0.409091 | 0.003073 | 0.000597 | 9.453348 | 1.2 | 2.5 |
| 3162.277660 | 0.501187 | 0.630957 | 0.884786 | 0.351429 | 0.076566 | 0.001639 | 6.637194 | 1.2 | 2.5 |
| 3162.277660 | 0.794328 | 0.398107 | 0.437247 | 0.337500 | 0.003222 | 0.000747 | 17.248849 | 1.2 | 2.5 |
| 5011.872336 | 0.794328 | 0.630957 | 0.557276 | 0.257143 | 0.003726 | 0.001159 | 33.728136 | 1.2 | 2.5 |

Pessimistic 10x250

| Q2 | x | y | purity | stability | sigma_red | sigma_red_pdf_unc | sigma_stat | sigma_p2p | sigma_norm |
|---|---|---|---|---|---|---|---|---|---|
| 1.258925 | 0.000200 | 0.630957 | 0.915340 | 0.473880 | 0.320509 | 0.031323 | 0.033940 | 4.2 | 4.3 |
| 1.258925 | 0.000316 | 0.398107 | 0.819734 | 0.575700 | 0.290023 | 0.026500 | 0.027132 | 4.2 | 4.3 |
| 1.258925 | 0.000501 | 0.251189 | 0.621223 | 0.564724 | 0.270261 | 0.016928 | 0.023246 | 4.2 | 4.3 |
| 1.258925 | 0.000794 | 0.158489 | 0.402142 | 0.453197 | 0.254951 | 0.013751 | 0.020547 | 4.2 | 4.3 |
| 1.258925 | 0.001259 | 0.100000 | 0.239727 | 0.300048 | 0.240664 | 0.012491 | 0.019641 | 4.2 | 4.3 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 1995.262315 | 0.501187 | 0.398107 | 0.817397 | 0.444547 | 0.070988 | 0.001181 | 3.942817 | 4.2 | 4.3 |
| 1995.262315 | 0.794328 | 0.251189 | 0.350225 | 0.409091 | 0.003073 | 0.000597 | 9.453348 | 4.2 | 4.3 |
| 3162.277660 | 0.501187 | 0.630957 | 0.884786 | 0.351429 | 0.076566 | 0.001639 | 6.637194 | 4.2 | 4.3 |
| 3162.277660 | 0.794328 | 0.398107 | 0.437247 | 0.337500 | 0.003222 | 0.000747 | 17.248849 | 4.2 | 4.3 |
| 5011.872336 | 0.794328 | 0.630957 | 0.557276 | 0.257143 | 0.003726 | 0.001159 | 33.728136 | 4.2 | 4.3 |

- Tables containing xsec estimates at various x, y, $Q^2$ points, with statistical and systematic uncertainties as discussed, are available for:
  - Standard and “HERA” binning
  - 1fb-1 of 5x130, 10x130, 10x250 $GeV^2$ ep events
- It’s important to be able to share these with fitters if we want impact studies for the early science report!
  - Can easily adjust and rerun as systematics and luminosity estimates change

# Impact studies (to be published)

# Impact of Inclusive early science on proton structure functions and PDFs

## Inclusive electron-proton measurement prospects in the Electron-Ion Collider early science stage

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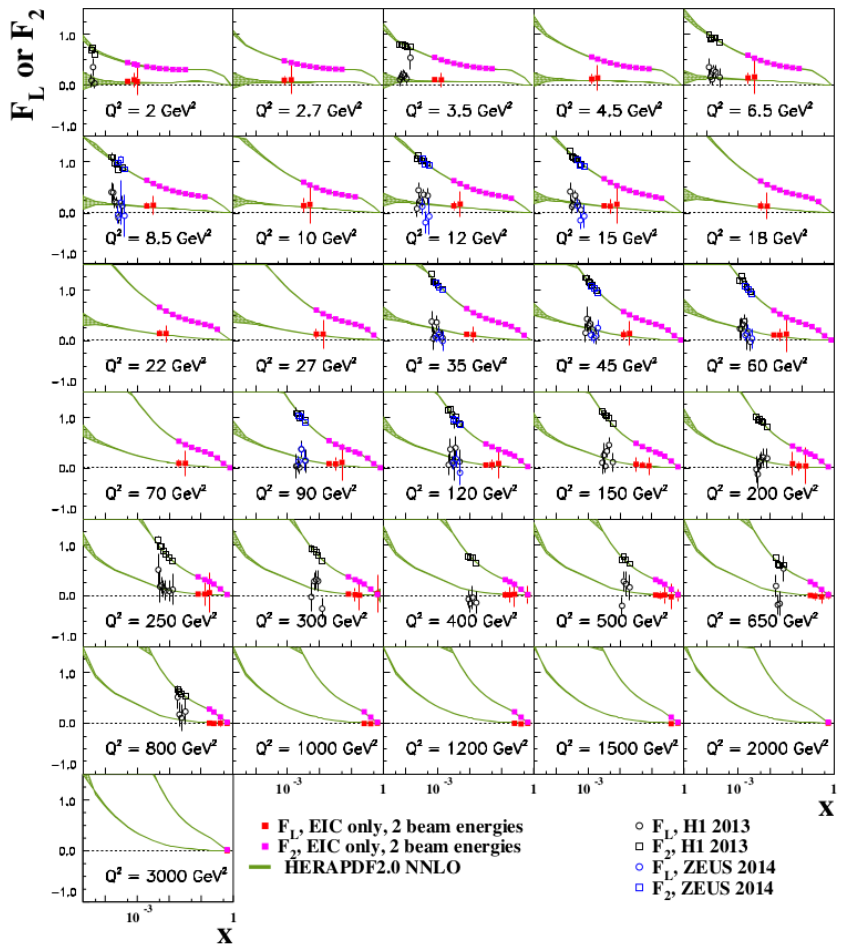
**Abstract**

We explore the potential for extracting proton structure functions, proton parton density functions (PDFs), and the strong coupling $\alpha_s(M_Z^2)$, using early science data from the future Electron-Ion Collider (EIC), both standalone, and in combination with HERA data. Different scenarios are considered in which samples with modest luminosity are collected at either two or three EIC beam energy configurations. The Rosenbluth separation method is used to extract the proton structure functions $F_2$ and $F_L$ from simulated data in a model-independent manner, showing that $F_L$ can be extracted significantly more precisely with three centre of mass energies than with two, whilst also obtaining $F_2$ to higher precision than has been achieved previously. The inclusion of a third beam configuration is also beneficial in the extraction of the strong coupling $\alpha_s(M_Z^2)$ that is obtainable with unprecedented experimental precision with the early EIC data. Additionally, the precision of the proton PDFs is improved when adding these data, especially for large values of Bjorken-$x$, for both two and three EIC beam energy configurations. These studies show that EIC data will already be a highly competitive probe of perturbative Quantum Chromodynamics within the first five years of data taking.

- We have a paper ready on the impact that early science ep configurations could have on the proton structure functions, PDFs, and $\alpha_s$
- Uses the "HERA" binning, as we consider possibility of combination with HERA cross section measurements
- Work done prior to recent update to systematics – uses HERA inspired values of 1.9% P2P ⊕ 3.4 % norm
  - Consider alternative scenarios with >1fb-1 luminosity, as well as systematic uncertainties that degrade at low y
  - Can reproduce grids using the available analysis code

# Impact of Inclusive early science on proton structure functions and PDFs



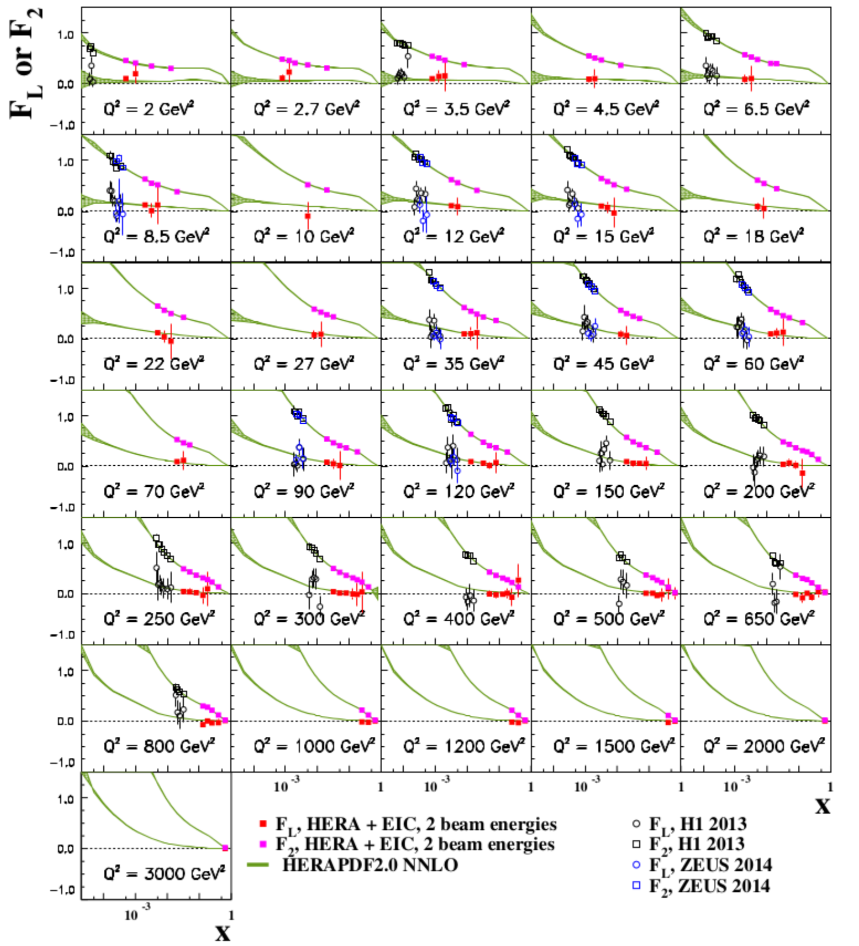

- Cross sections use central value from HERAPDF2.0 from xFitter (used later for PDF impact)

- Cross sections smeared according to estimated statistical and systematic uncertainties

- $F_L$ and model independent $F_2$ extracted from 10x130 and 10x250 GeV$^2$ ep configurations
  - Every $F_2$ point has a corresponding $F_L$ point, but only the $F_L$ points with good resolution are plotted
    → Extend $F_2$ and $F_L$ measurements to higher x values!

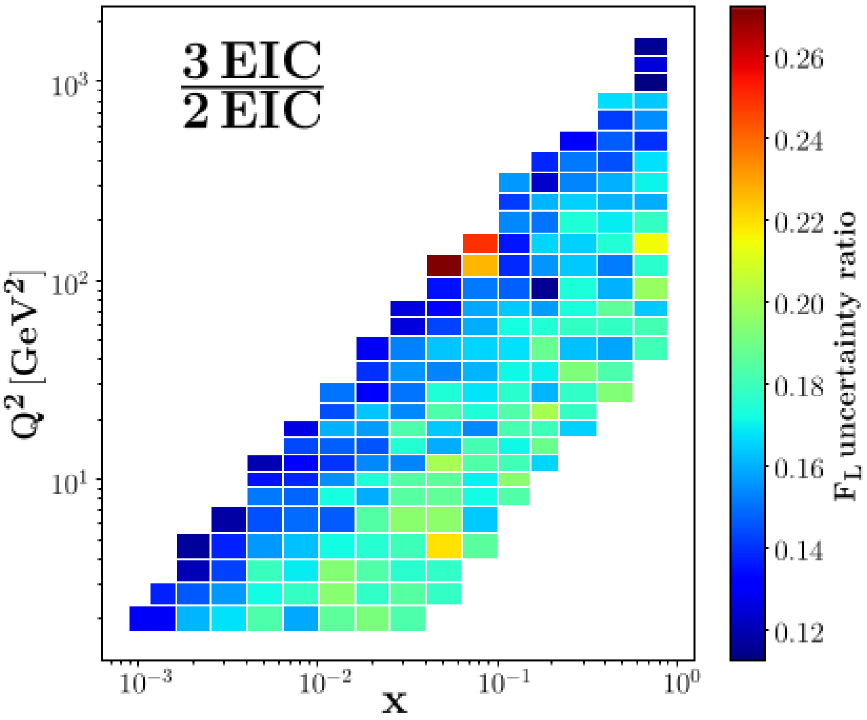
* Note: only 2 points so not a Rosenbluth "fit"

# Impact of Inclusive early science on proton structure functions and PDFs



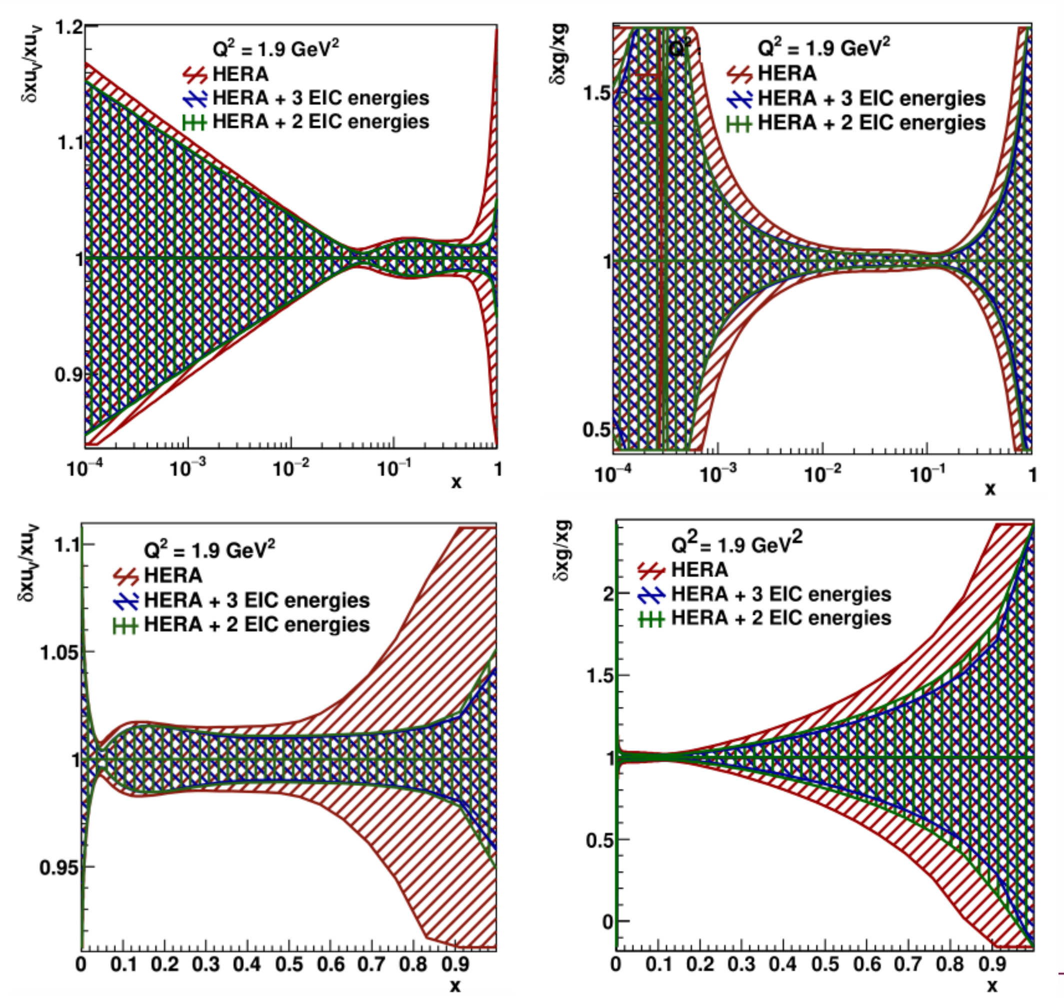

- Can do a proper Rosenbluth separation with 3+ cross sections available in same bin
- Try including HERA data points
- Get more good points for $F_L$!
  - Note that total number of points (see $F_2$) are fewer as only bins that have an available HERA measurement are used

# Impact of Inclusive early science on proton structure functions and PDFs

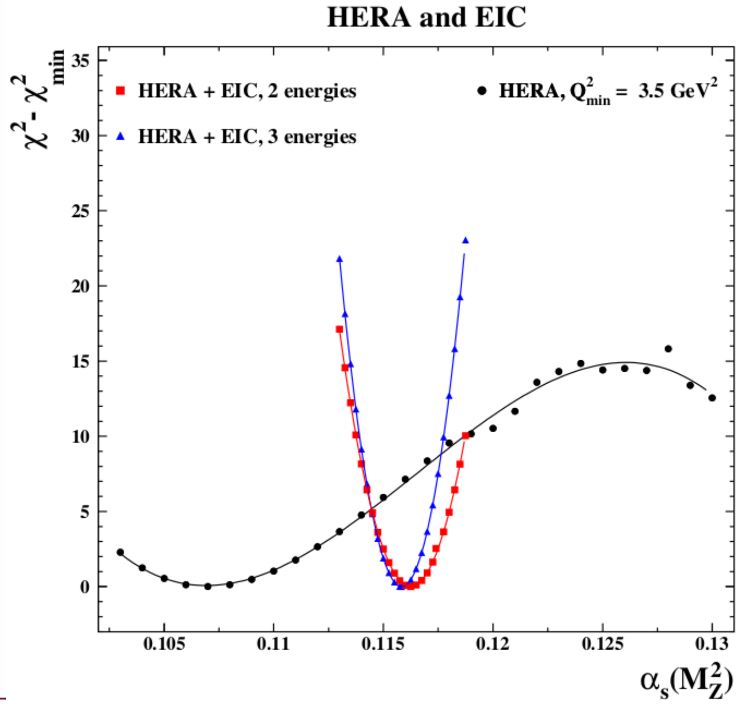



- Instead of adding HERA points, we could add an extra, 5x130 $GeV^2$ ep run during early science
  - Factor of ~5 improvement in $F_L$ uncertainties!

# Impact of Inclusive early science on proton structure functions and PDFs




- 2 or 3 ep configurations also improve $u_V$ and gluon uncertainties in HERAPDF2.0
- … as well as constraining the strong coupling $\alpha_s$!



# Summary

- Walkthrough of procedure used to produce grids of NC reduced cross sections as a function of x and $Q^2$ for early science ep configurations
  - Binning and statistical uncertainties from ePIC simulation
  - Cross section predictions obtained from PDFs – predictions can be used by internal ePIC analysers in structure function studies, or ignored by PDF fitters that who will generate their own central values
  - Systematic uncertainties modelled after Yellow Report, with update to detector effects in P2P uncertainties from early ePIC studies

- Cross sections plots showing x-$Q^2$ range of points produce – **requesting release**
- Tables of cross sections with uncertainties produced – **request to share with fitting groups**

- Shown example of recent studies for which some of the analysis code described here was used (in a previous iteration)