UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

Inclusive Systematics Update

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Overview

- Inclusive measurements usually start from the reduced cross section
  - Structure functions for ep/eA: $F_{2,L}$ from xsec and model or Rosenbluth separation, double spin asymmetries from xsec in different beam polarisations
  - Focus on systematics for inclusive NC cross section for now
  - CC to come when we have someone working on the analysis

- Systematics for inclusive cross section measurements in ep were well studied at HERA
  - Where there are no MC studies that can be done to give an informed/justified value for a systematic, we can refer to previous HERA values as (hopefully pessimistic) estimates

What systematics are we concerned with?

- There are many possible sources of systematic uncertainties → just look at H1/ZEUS papers
- Some contribute more than others

- Some of the most impactful ones are:
  - Electron Finding Efficiency
  - Electron Energy scale
  - Electron Polar Angle
  - Hadronic Energy scale
  - Background modelling
  - QED Radiative Corrections

- ...and of course, luminosity/polarisation measurements

Source	**Region**	**Uncertainty**
Electron energy scale	$z_{\rm imp} \leq -150\,$cm $-150 < z_{\rm imp} \leq -60\,$cm $-60 < z_{\rm imp} \leq +20\,$cm $+20 < z_{\rm imp} \leq +110\,$cm $z_{\rm imp} > +110\,$cm	0.5% unc. $\oplus$ 0.3% corr. 0.3% unc. $\oplus$ 0.3% corr. 0.5% unc. $\oplus$ 0.3% corr. 0.5% unc. $\oplus$ 0.3% corr. 1.0% unc. $\oplus$ 0.3% corr.
Electron scale linearity	$E'_e < 11\,$GeV	0.5%
Hadronic energy scale	LAr & Tracks SpaCal	1.0% unc. $\oplus$ 0.3% corr. 5.0% unc. $\oplus$ 0.3% corr.
Polar angle	θ_e	1 mrad corr.
Noise	$y < 0.19$ $y > 0.19$	5% energy not in jets , corr. 20% corr.
Trigger efficiency	*high y* *nominal*	$0.3 - 2\%$ 0.3%
Electron track and vertex efficiency	*high y* *nominal*	1% $0.2 - 1\%$
Electron charge ID efficiency	*high y*	0.5%
Electron ID efficiency	*high y* $z_{\rm imp} < 20$ (> 20) cm *nominal* $z_{\rm imp} < 20$ (> 20) cm	0.5% (1%) 0.2% (1%)
Extra background suppression	$E'_e < 10\,$GeV	$D_{ele} > 0.80 \pm 0.04$ corr.
High y background subtraction	*high y*	1.03 ± 0.08 corr.
QED radiative corrections	$x < 0.1$, $0.1 \leq x < 0.3$, $x \geq 0.3$ *high y*: $y < 0.8$ ($y > 0.8$)	0.3% , 1.0%, 2.0% 1% (1.5%)
Acceptance corrections	*high y* *nominal*	0.5% 0.2%
Luminosity		4% corr.

https://arxiv.org/abs/1312.4821

Systematic uncertainty	Achieved at H1/ZEUS*	Expected at EIC†	Possible studies
Electron finder efficiency	0.2-5% (increase w y)	???	Tighten and relax cuts used in e-finding → study variation in efficiency
Electron energy scale	0.5-1.9% (increase w y) (1-5% on σ)	???	Take single value estimate inspired by HERA?
Electron polar angle	1mrad	???	Take single value estimate inspired by HERA?
Hadronic energy scale	2% (0.5-4% on σ)	???	Take single value estimate inspired by HERA?
Photoproduction background	10% (0.5-3% on σ)	2% on σ	Compare number of events produced by different generators that are reconstructed as DIS
QED radiative corrections	0.3-2% (increase w x,y)	1%	Compare size of radiative correction in bins with two different event generators
Luminosity	1.5%	1%	Use ~~1%~~ 1.5%?
Polarisation	N/A	<1% ?	Use ~~1%~~ 1.5%?

* choosing the better of the values in previous publications from H1, ZEUS

† numbers from YR

Reconstructing the kinematics using the electron

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

- If we simply evaluate the four-momenta directly, we get the **electron method**

$$q^2 = (k - k')^2 \longrightarrow Q_e^2 = 2E_0 E_e (1 + \cos\theta_e)$$

$$p \cdot q = E_p[2E_0 - E_e(1 - \cos\theta_e)] \qquad p \cdot k = 2E_p E_0$$

$$y_e = 1 - \frac{E_e(1 - \cos\theta_e)}{2E_0}$$

$$\frac{\delta Q^2}{Q^2} = \frac{\delta E_e}{E_e} \oplus \tan\frac{\theta_e}{2} \cdot \delta\theta_e$$

$$\frac{\delta y}{y} = \frac{1-y}{y}\left(\frac{\delta E_e}{E_e} \oplus \frac{\delta\theta_e}{\tan\frac{\theta_e}{2}}\right)$$

Problem:

- Resolution of y diverges at small y values

Important systematics:

- Electron energy scale, electron finding efficiency, large radiative corrections at high y, polar angle uncertainty

Double-Angle method

- The DA method reconstructs the kinematics without directly using an energy measurement
  - This makes it a powerful method if you have a poor calorimeter (or track momentum) resolution

- The DA method is defined using the angles

$$\alpha_e = \tan\frac{\theta_e}{2} \qquad \alpha_h = \tan\frac{\gamma}{2} = \frac{\delta_h}{p_{t,h}}$$

as

$$y_{DA} = \frac{\alpha_h}{\alpha_e + \alpha_h} \qquad Q^2_{DA} = \frac{4E_0^2}{\alpha_e(\alpha_e + \alpha_h)}$$

- The electron energy is not used; errors associated with the HFS energy measurement largely cancel out → sensitive to polar angle uncertainty, radiative corrections, electron finding efficiency

(e-)Sigma method

- The Sigma methods, like the DA method, use a mixture of electron and HFS information to optimise the resolution across a large region

- The Sigma method is defined as

$$y_\Sigma = \frac{\delta_h}{\delta_h + E_e(1 - \cos\theta_e)} \qquad Q^2_\Sigma = \frac{E_e^2 \sin^2\theta_e}{1 - y_\Sigma}$$

and the e-Sigma method instead uses

$$Q^2_{e\Sigma} = Q^2_e \qquad x_{e\Sigma} = x_\Sigma$$

- In these methods, the electron beam energy (E_0) is not used (except in Q^2 for e-Σ)
  - This makes these methods resistant to the effect of initial state QED radiation
  - Still impacted by Electron/Hadron energy scale, electron polar angle, etc

My setup for these studies

- Consider pythia6 10x130 ep DIS only sample, passed through simulation+EICrecon, scaled to $1fb^{-1}$
- Default electron reconstruction (track momentum for energy, truth-based eID)

- Since this sample is pure signal, $N_{b/g} = 0$ and the fractional differenc in N gives the fractional difference in σ → this is used to evaluate the systematics here, but a full cross section extraction will be necessary for samples with backgrounds

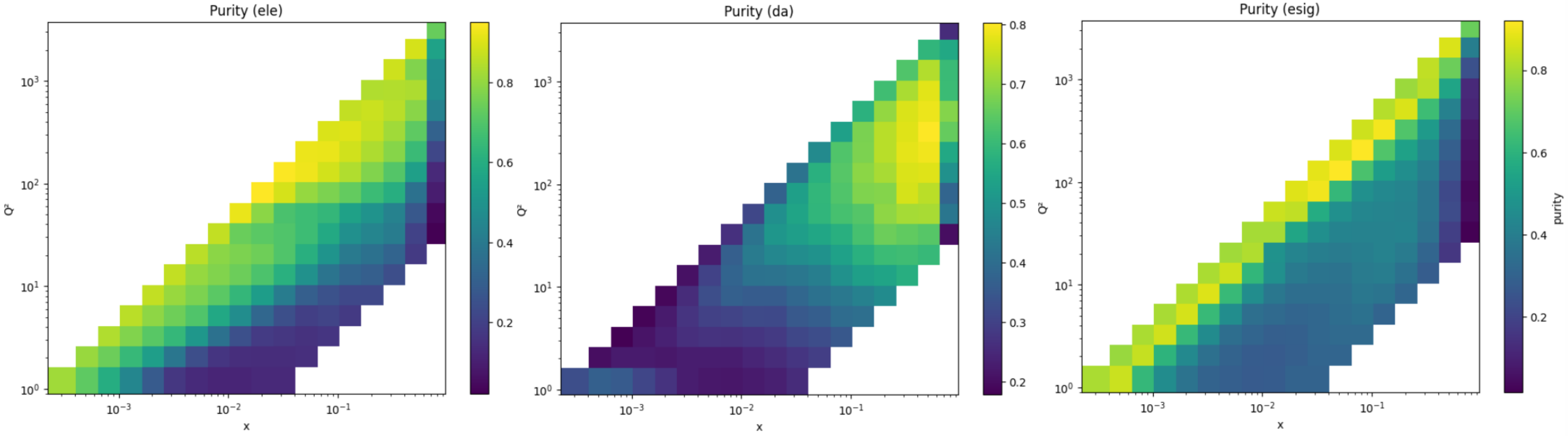
$$\sigma = \frac{N_{obs} - N_{b/g}}{L \,.\, \varepsilon \,.\, A_{cc}}$$

- Compare yields in x-Q^2 bins for 7 scenarios:
  - Basic scenario with no systematic shifts
  - Electron energies all shifted by 0.5% up, and 0.5% down
  - HFS total energy shifted by 1% up, and 1% down
  - Electron polar angle shifted by 1mrad up, and 1mrad down

Purity and Stability

- Bin migration can be understood by considering the purity and stability of each bin
  - These depend on the binning scheme, where here is chosen to be 5 bins per decade in x and Q^2

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



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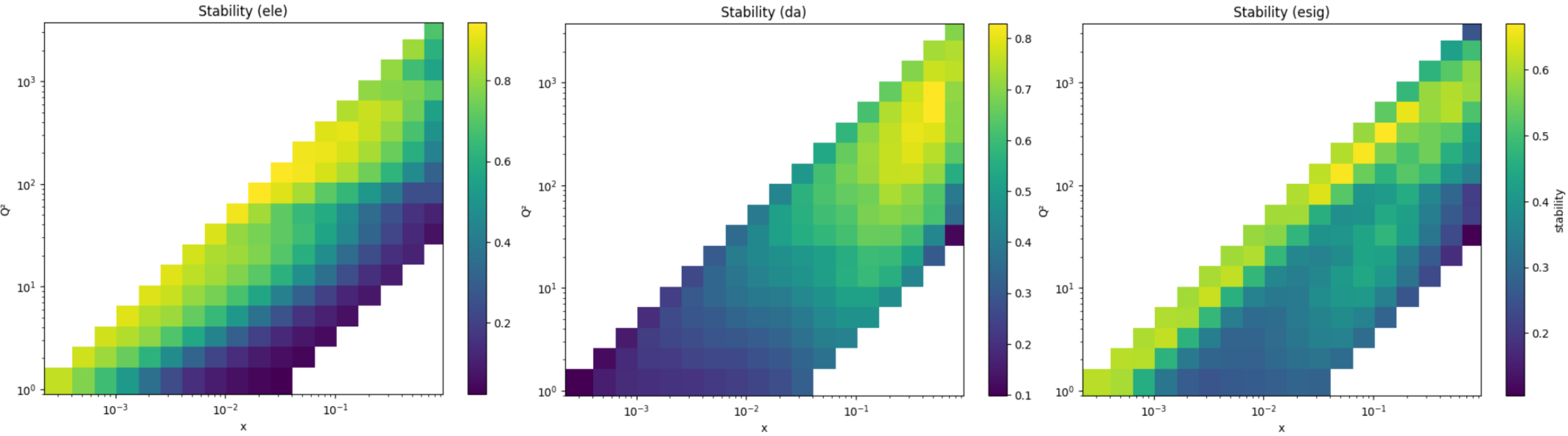
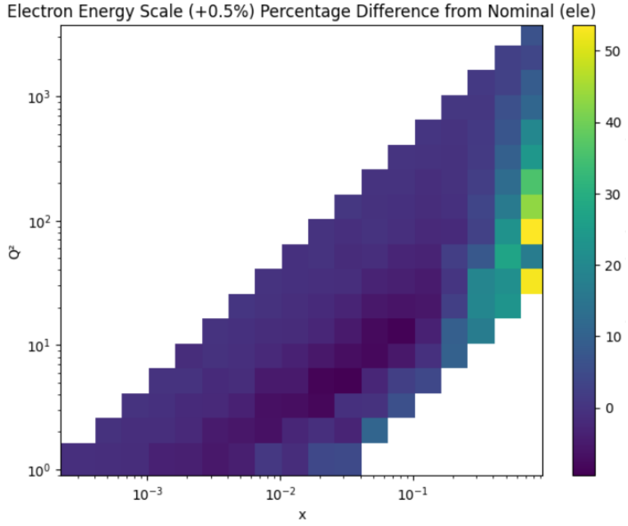
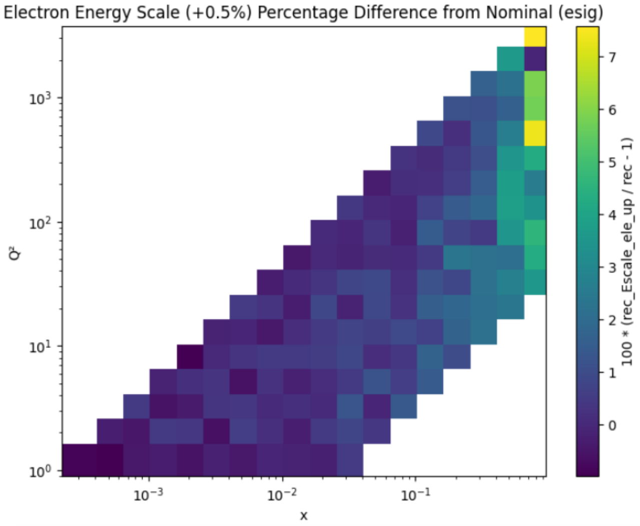
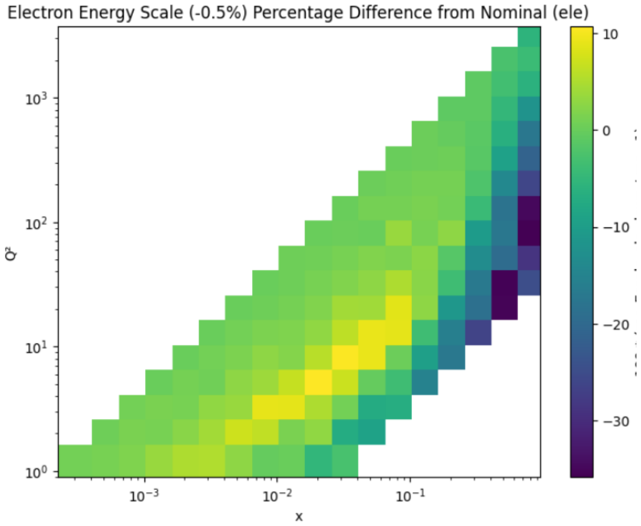
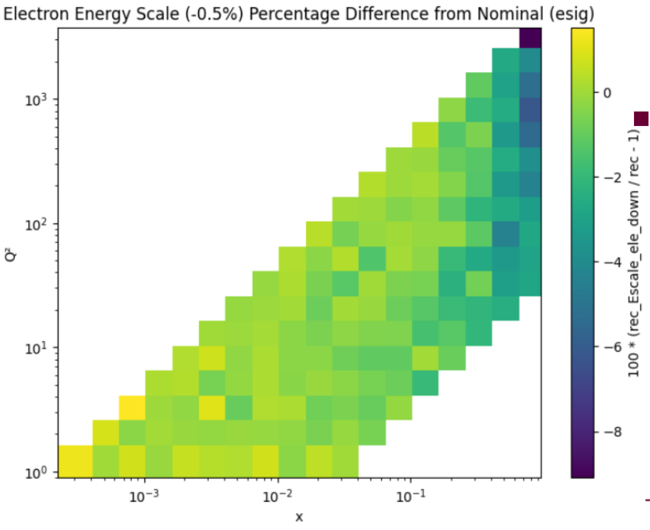


Impact of each Electron Energy Scale Systematic



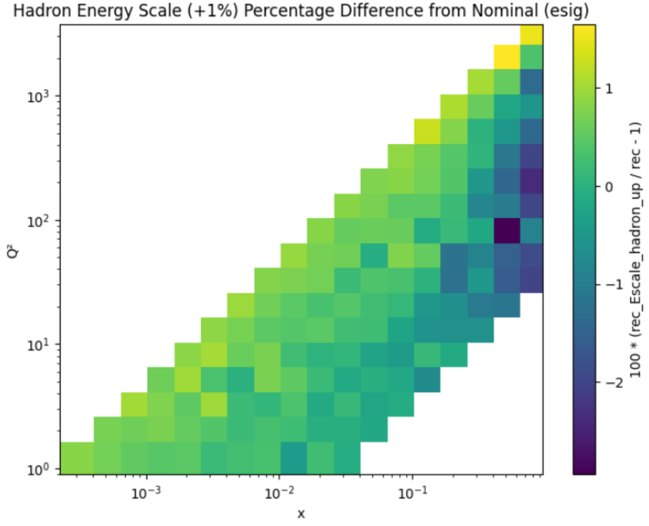


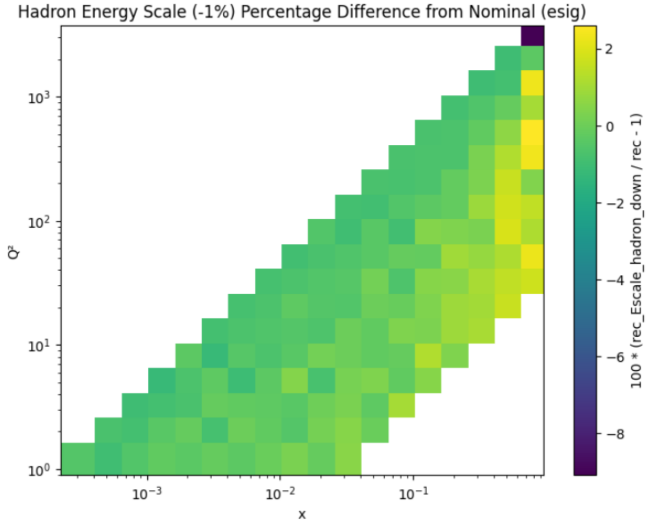




- Electron method strongly impacted at low y (30-50% in most impacted bins), but typically small at moderate and high y
- E-Σ method more consistent across x-Q^2 plane, usually below a couple of percent
- No difference in DA (electron energy not used)

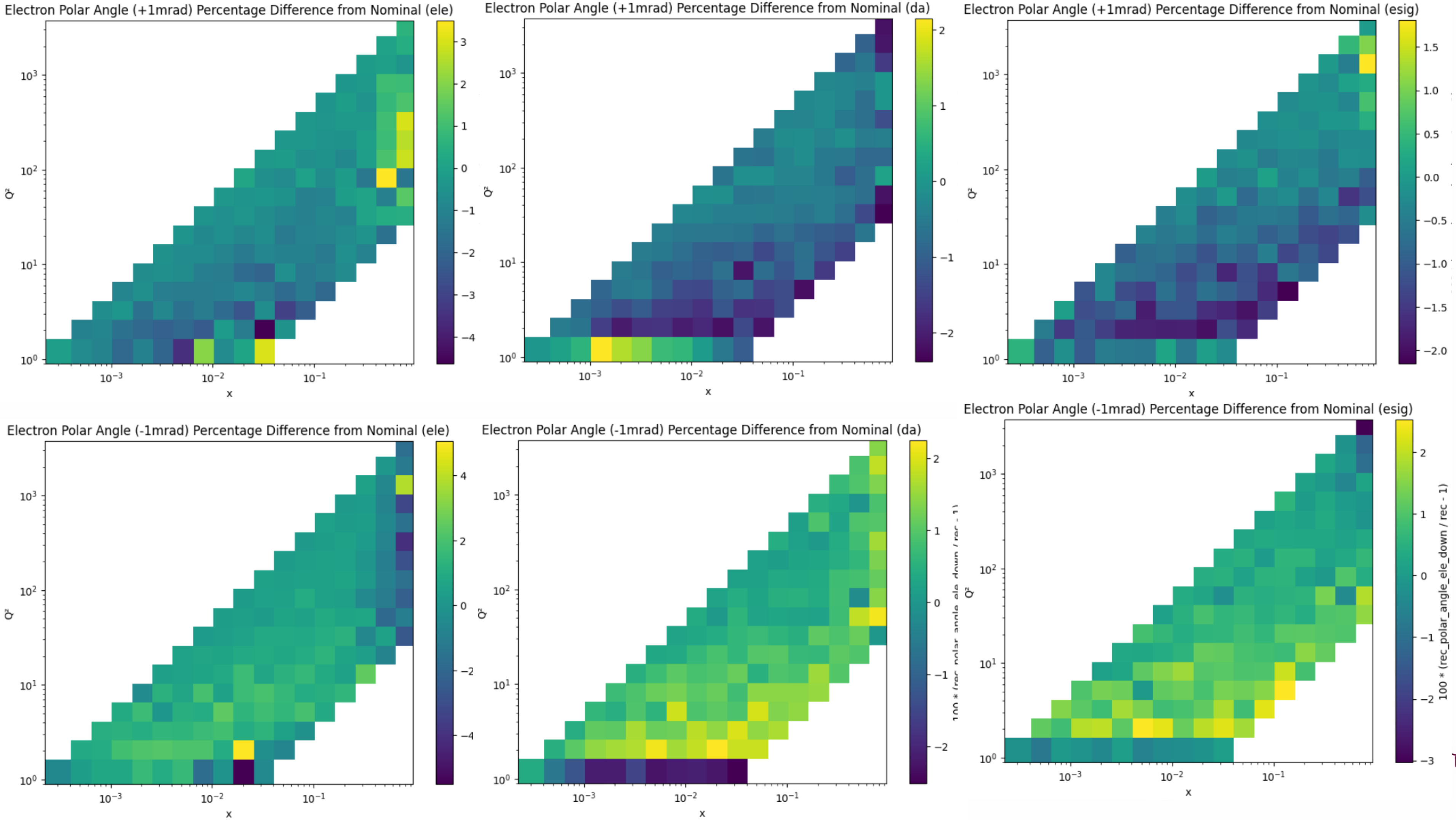
Impact of each Hadron Energy Scale Systematic



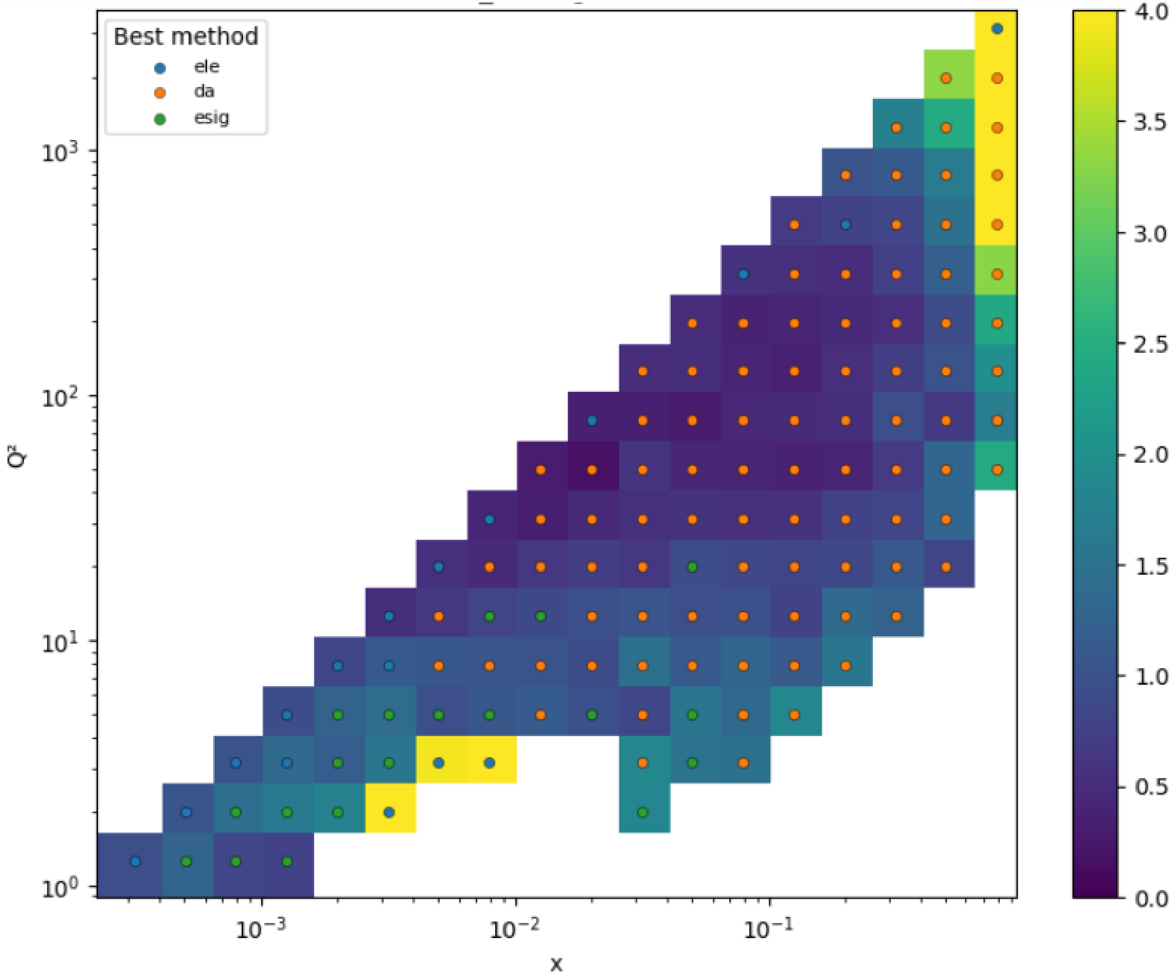


- HFS not used in electron method → no impact
- HFS angle calculated as $\delta_h/p_{t,h}$ → HFS energy cancels out → no impact on DA
- E-Σ method impacted mostly at large x-Q^2, at most a couple of percent

Impact of each Electron Polar Angle Systematic



Total Uncertainty from these 3 sources



- 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%
- Important: only considering 3 sources here, of which only 1 impacts the DA method → this spread will change with inclusion of more systematics

Summary

- Estimated impact of three possible systematic uncertainties on NC σ_{red} measurement
- Impact of a given systematic changes between reconstruction methods
- From the three uncertainties, vast majority of bins have <3% total uncertainty
  - Will have to see how this changes as more systematics are evaluated and included

Next Steps

- Need to understand impact of beam and physics backgrounds
  - Djangoh samples, photoproduction samples need to be generated and passed through sim/recon/analysis
  - Must use electron finder in these studies