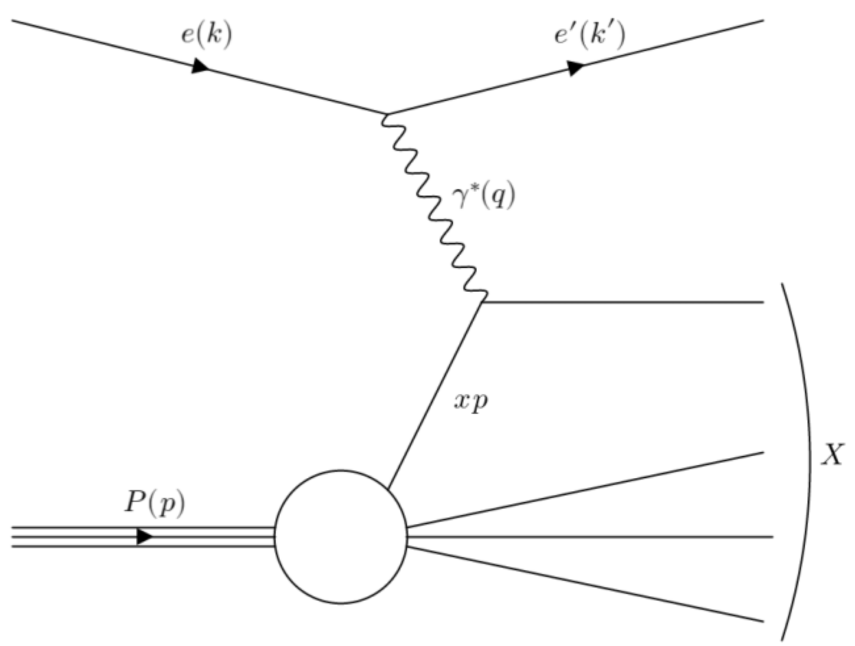
Recent(-ish) Activities in the Inclusive PWG

S. Maple

A (short) Intro to Inclusive Deep Inelastic Scattering



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

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

"Virtuality" $Q^2 = -q^2$

CoM energy

Bjorken x

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!

A (short) Intro to Inclusive Deep Inelastic Scattering

- The inclusive cross section can be related to structure functions:

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

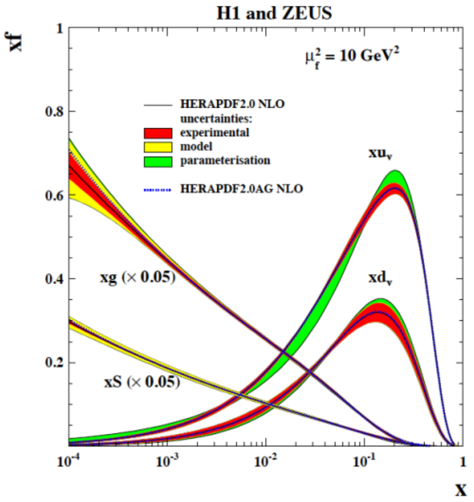
- The structure functions relate to the collinear parton density functions ∴ through measurements of the cross sections we
- constrain PDFs

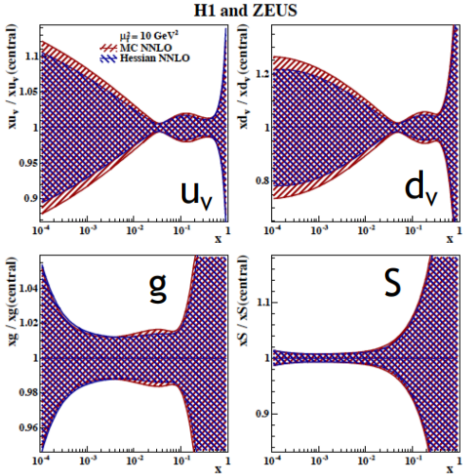
$$F_2 \propto x\sum_q (q+\bar{q})$$

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

$$F_L = 0$$

} LO

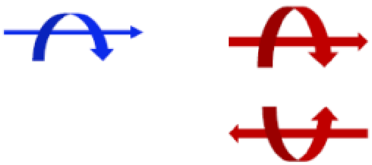




A (short) Intro to Inclusive Deep Inelastic Scattering

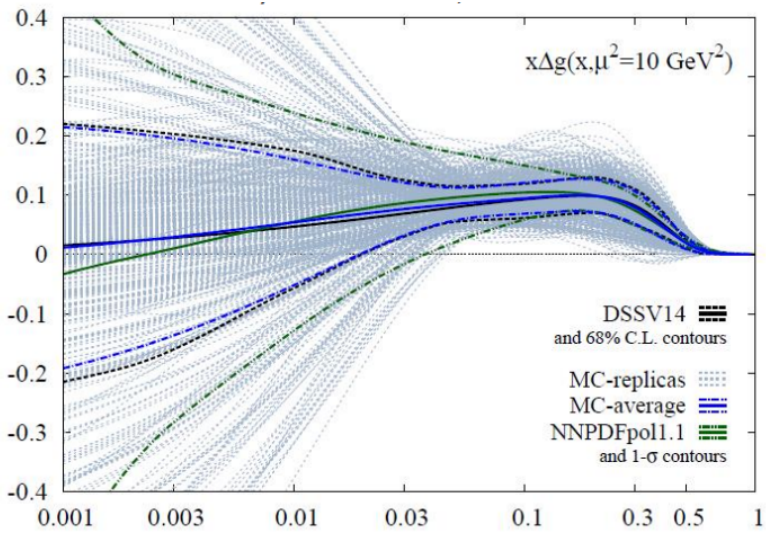
- Similarly, we can study the helicity PDFs by looking at the cross section asymmetry in different polarisation configurations:

$$\Delta\sigma = \frac{d^2\sigma}{dxdQ^2}(\lambda_n = -1, \lambda_l) - \frac{d^2\sigma}{dxdQ^2}(\lambda_n = +1, \lambda_l) = \frac{4\pi\alpha^2}{Q^4 x}\left[-Y_+ g_4 + Y_- 2x g_1 + y^2 g_L\right]$$



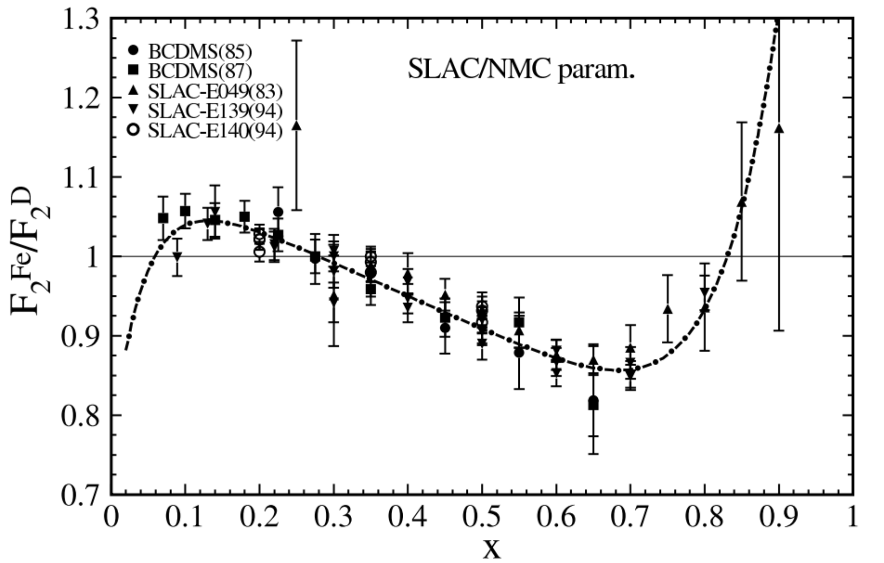
$$A_{||} = \frac{\sigma(\lambda_n = -1, \lambda_l = -1) - \sigma(\lambda_n = +1, \lambda_l = -1)}{\sigma(\lambda_n = -1, \lambda_l = -1) + \sigma(\lambda_n = +1, \lambda_l = -1)}$$

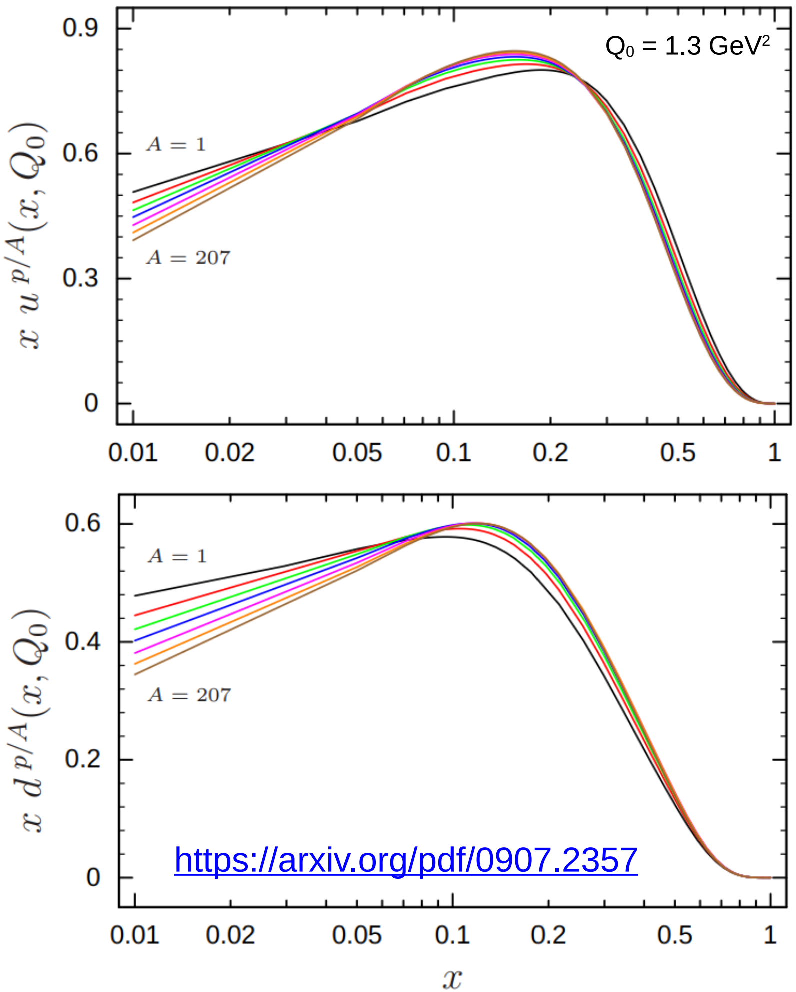
But as before, this ultimately requires the measurement of the (reduced) xsec in terms of x, y, Q^2!



A (short) Intro to Inclusive Deep Inelastic Scattering

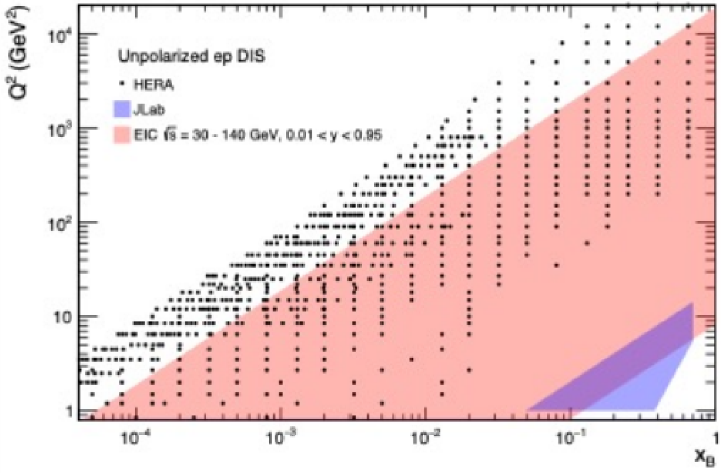
- If we measure the cross sections in e-A scattering we can extract Nuclear Structure functions and study nPDFs
- Structure function ratio provides insights into nuclear effects





https://arxiv.org/pdf/0907.2357

To summarise…



Inclusive ep DIS

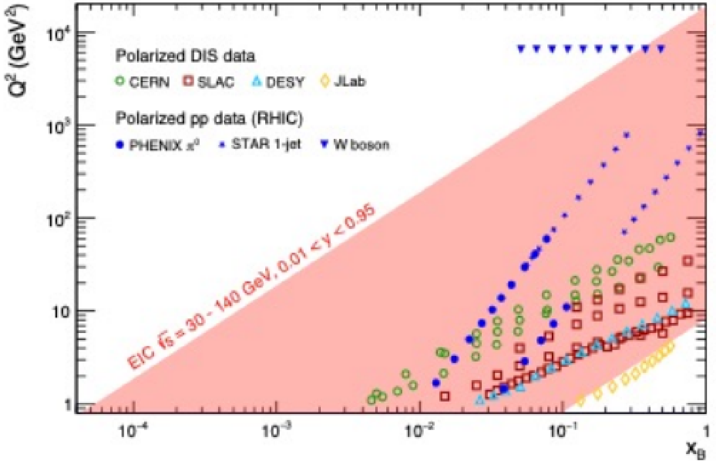
→ Closing gap and overlapping between fixed target & HERA

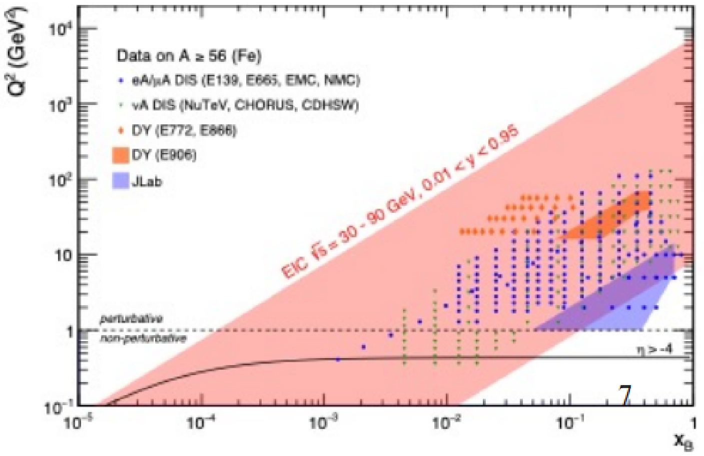
→ High x, moderate Q^2 precision

Polarised target ep & eA DIS

→ Completely unexplored regions, extending to low x

Look at all the unexplored regions!





Activities in the Inclusive PWG

- There's actually a lot that goes into even an inclusive measurement
  - Finding+reconstructing scattered electrons
  - Reconstructing hadronic final state
  - Optimising kinematic reconstruction
  - Estimating systematics
  - Understanding/correcting radiative effects
  - Extracting structure functions from cross sections (Rosenbluth fit or using a model?)
  - … and more

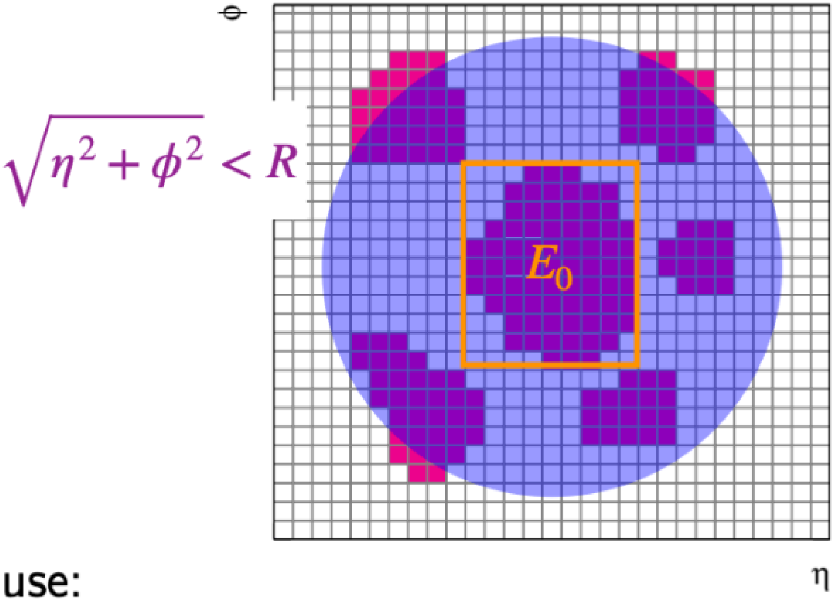
Electron Finding

`edm4eic::ReconstructedParticleCollection ElectronID::FindScatteredElectron()`

- Loop over all reconstructed particles, and apply cuts on:
  - Require negative tracks
  - $0.9 < E/p < 1.2$
  - Isolated cluster

    $R = 0.4$

    $E_0 / \Sigma E_R < 0.9$

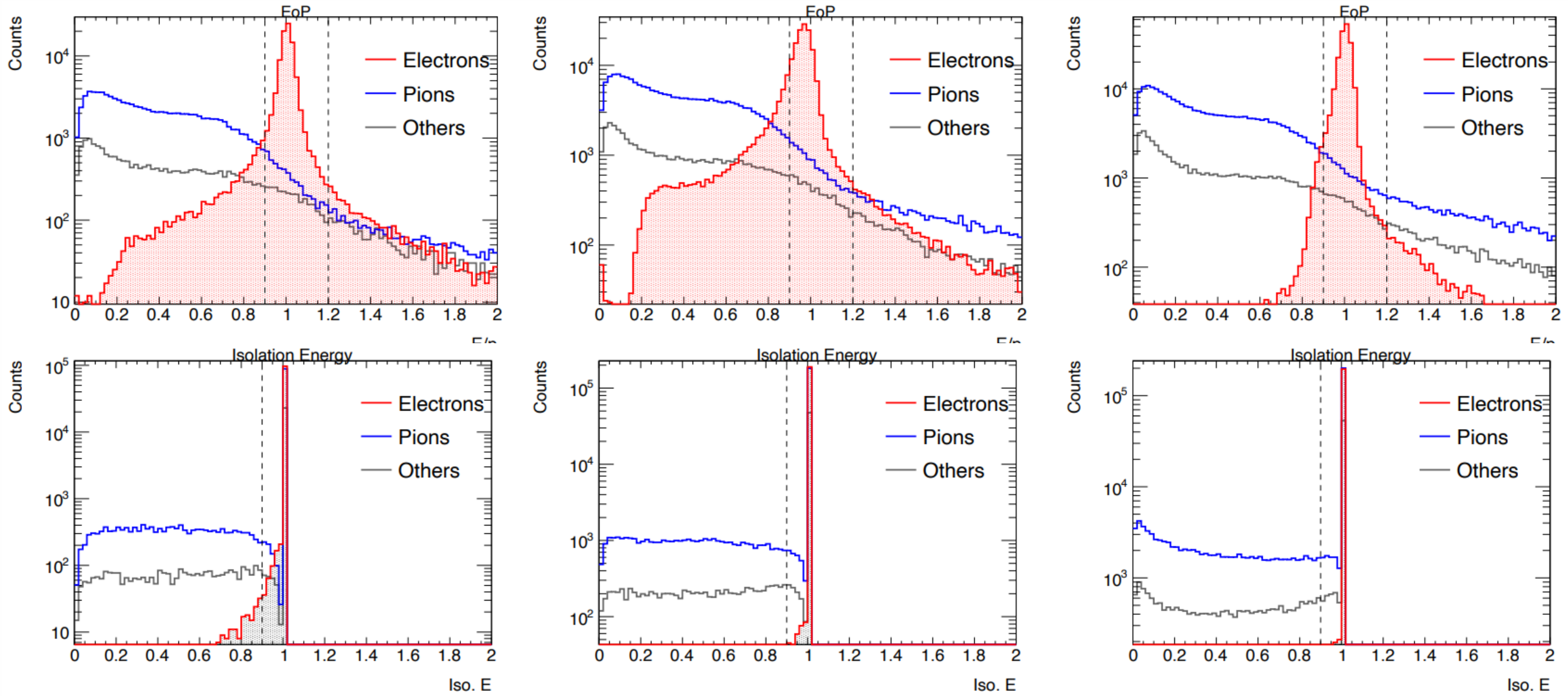


- If > 1 particles in collection, can use:

  `edm4eic::ReconstructedParticle`
  `SelectHighestPT(edm4eic::ReconstructedParticleCollection)`

Slide from T. Kutz

Electron Finding



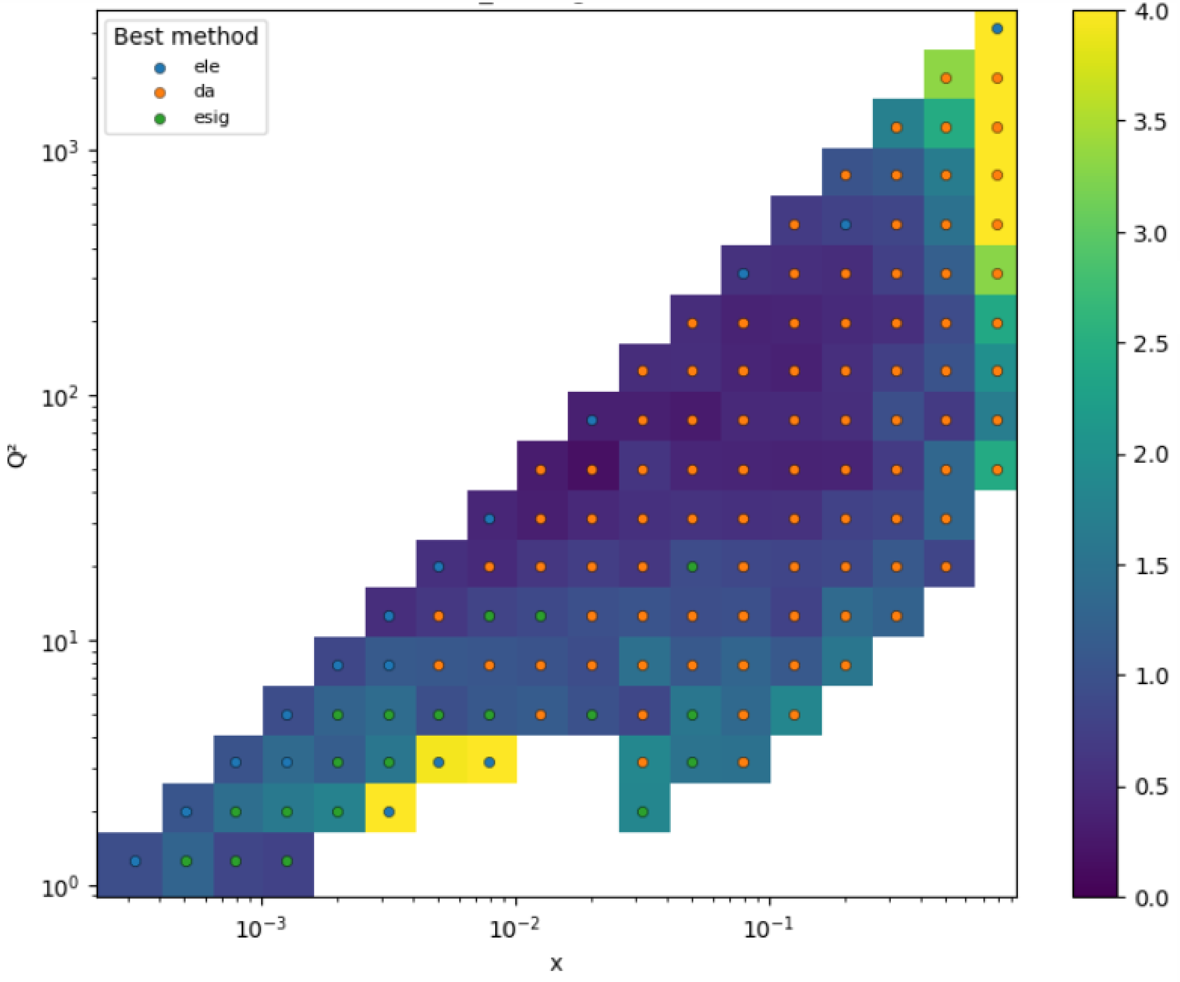
Early systematics studies (Only 3 sources)

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

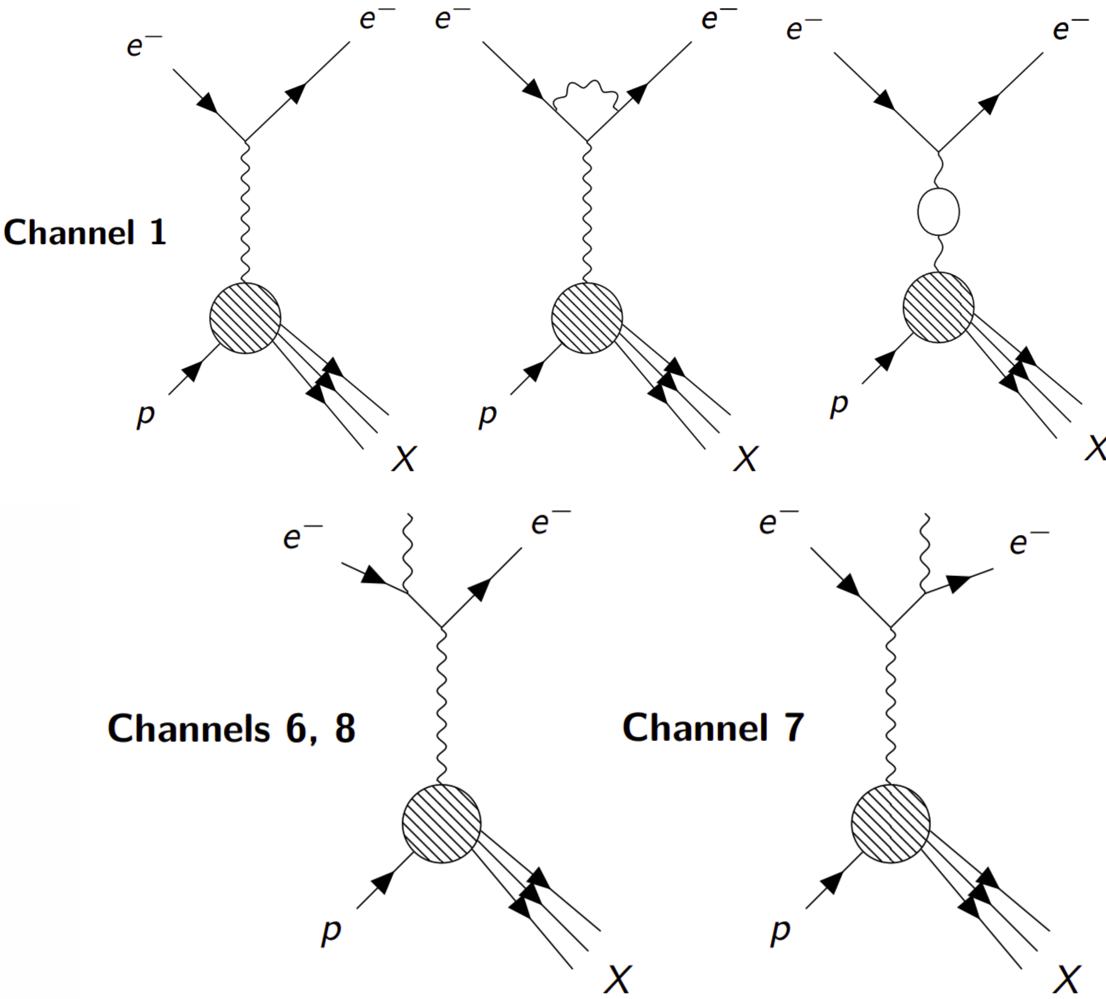
Early systematics studies (Only 3 sources)



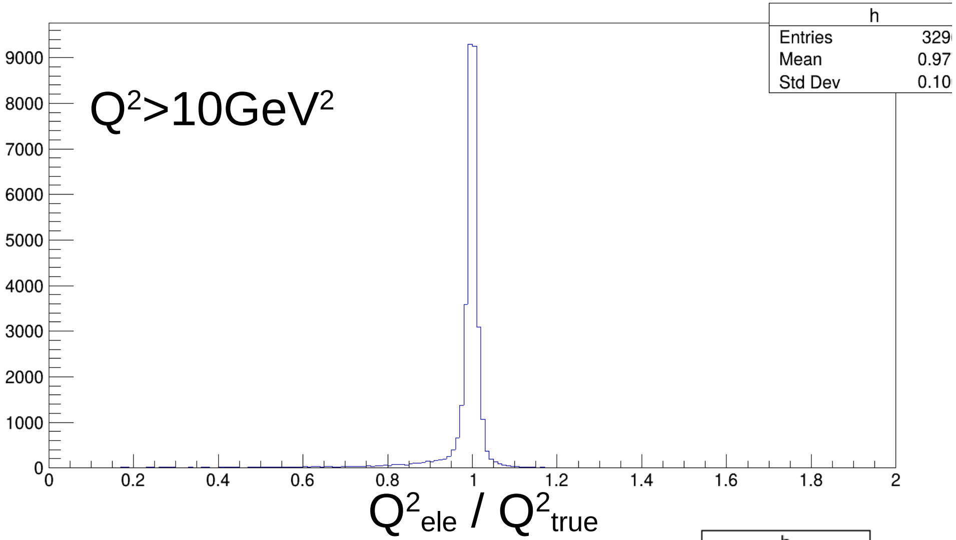
- Total uncertainty taken from sum in quadrature of statistical uncertainty ($1fb^{-1}$) and the average uncertainty from each systematic (0.5*(|+ve| + |-ve|))
- Plot the total uncertainty from the method that gives the best value
  - Require purity & stability > 30%
- Important: only considering 3 sources here, of which only 1 impacts the DA method → this spread will change with inclusion of more systematics

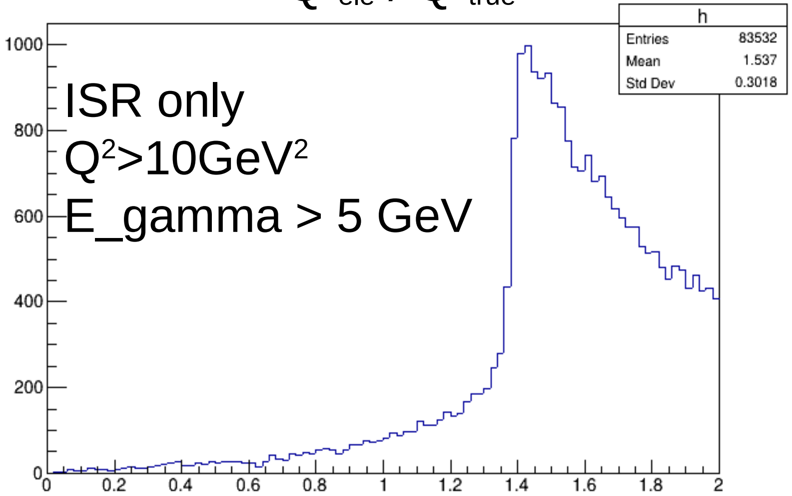
QED Radiative Effects

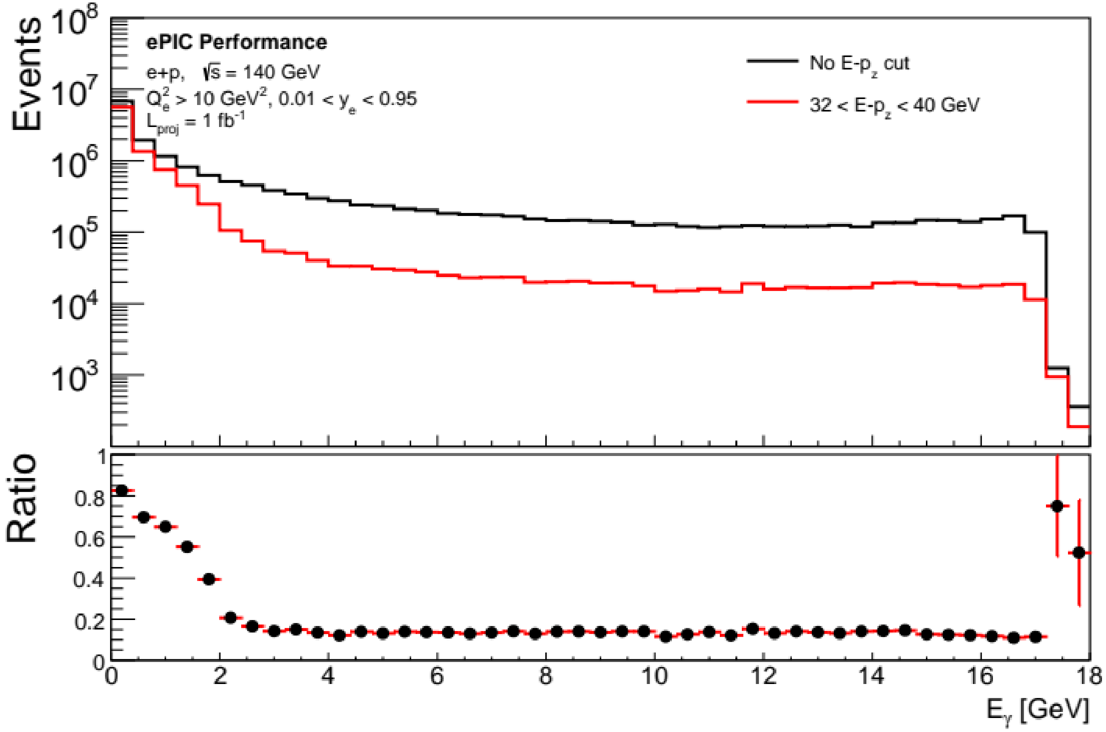
- Djangoh 4.6.21 used to generate 18x275 GeV^2 e-p events
  - ISR/FSR=ON and OFF
  - Q^2>1,10,100,1000
  - W>3GeV
- Channel 1: Non Radiative NC
- Channel 6: ISR
- Channel 7: FSR
- Channel 8: “Compton event”



QED Radiative Effects







- High energy ISR throws off kinematic reconstruction
  - Can suppress through $E\text{-}p_z$ cut

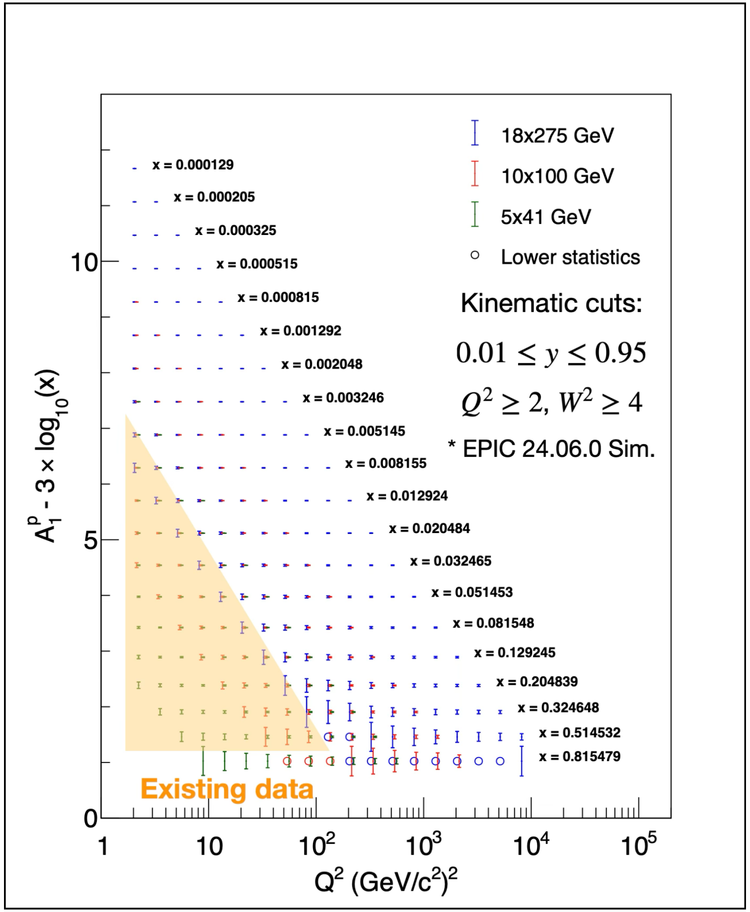
Early Science

- Inclusive DIS is extremely impactful during 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 e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG
Note: the eA luminosity is per nucleon					

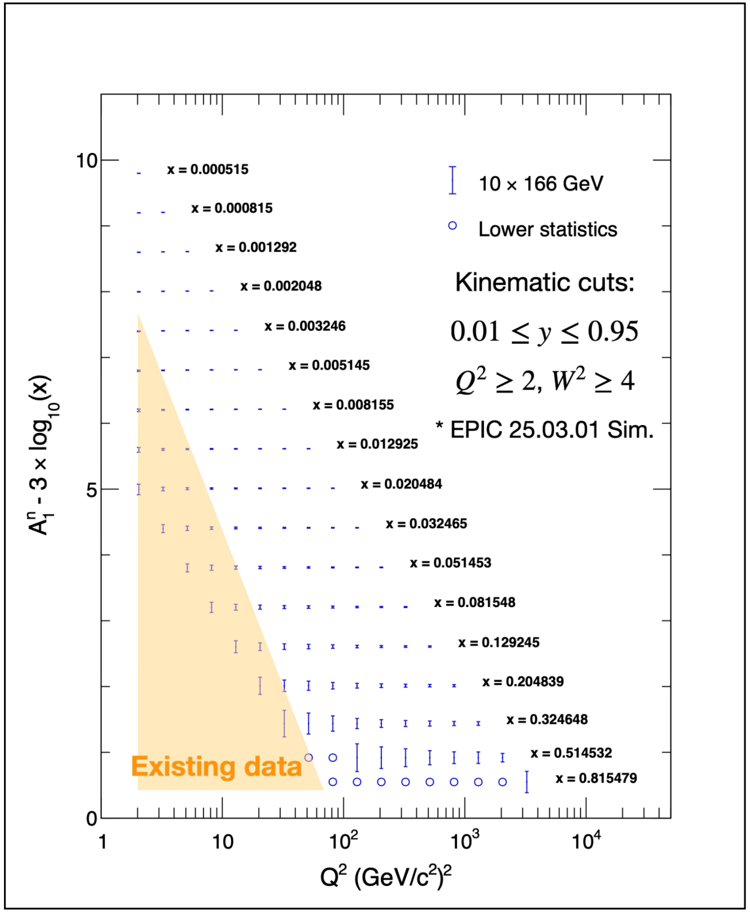
- e-p/A cross sections, F_2, (F_L?)
- A_1^p, g_1^p
- $A_1{}^3He$, A_1^n, g_1^n

Double spin asymmetry (proton)

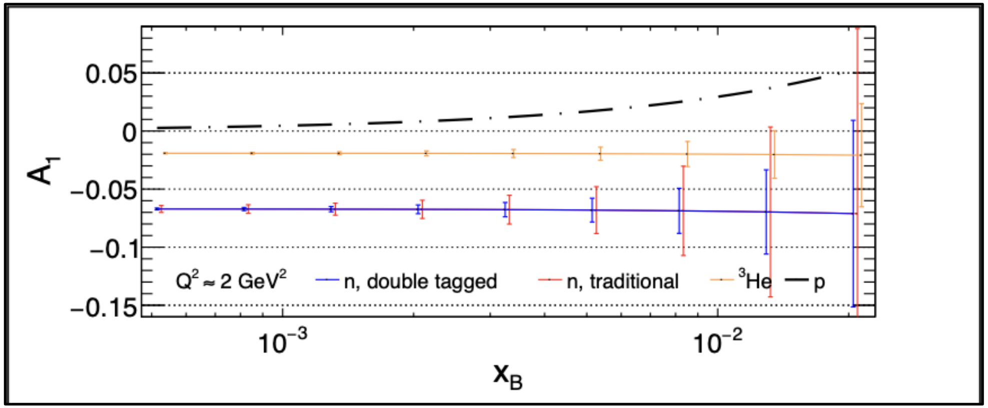


- $A_{||}$ can be measured starting in year 2/3
- $A_{\perp}$ can be measured starting in year 2/3
- Note: plot shows non-early science beam configurations
  - e-p 10x130 GeV will cover area similar to 10x100 GeV
  - e-p 10x250 will cover between 10x100 GeV and 18x275 GeV
- Shown are statistical uncertainties for EIC nominal settings. A_1 uncertainty is statistically dominated.

Double spin asymmetry (neutron)

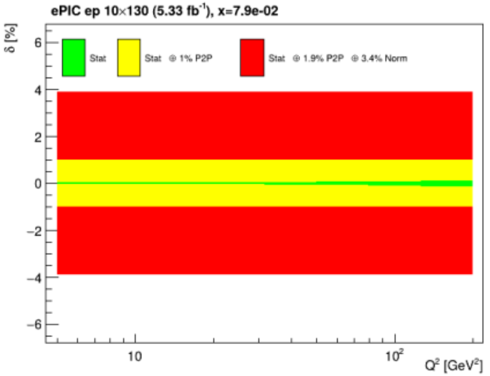


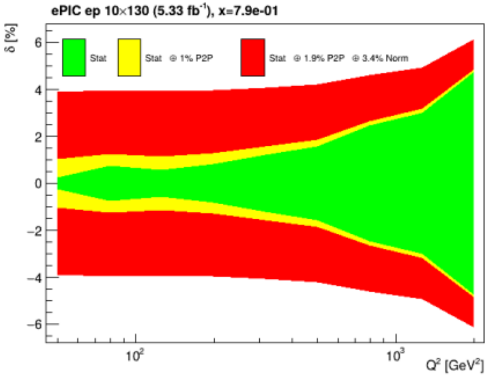
- Can be extracted from A13He using traditional inclusive method or directly measured via double spectator tagging

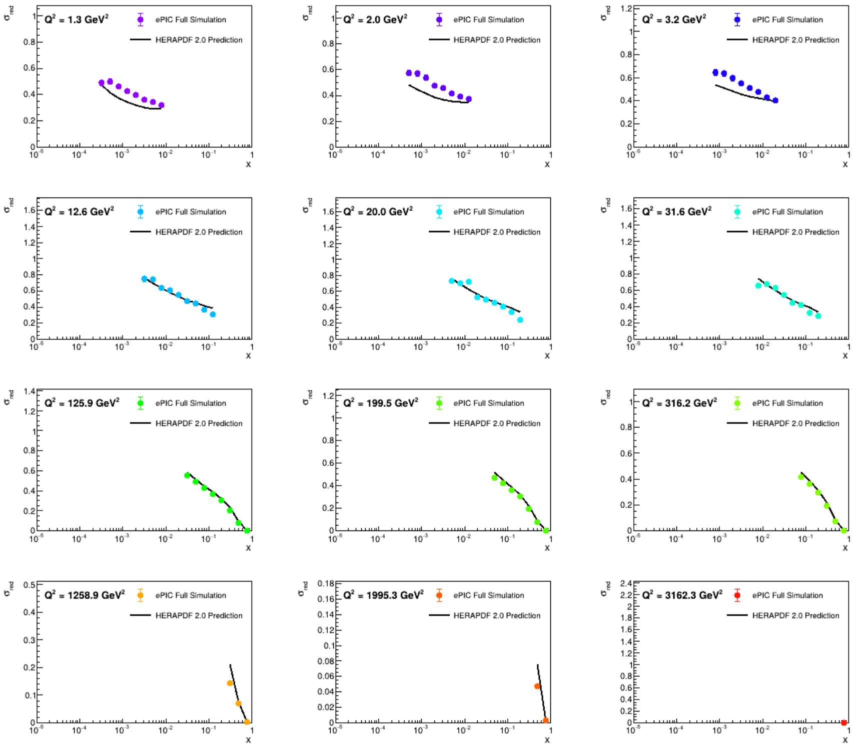


e-p reduced cross sections (hence F_2)

10x130 GeV2 e-p



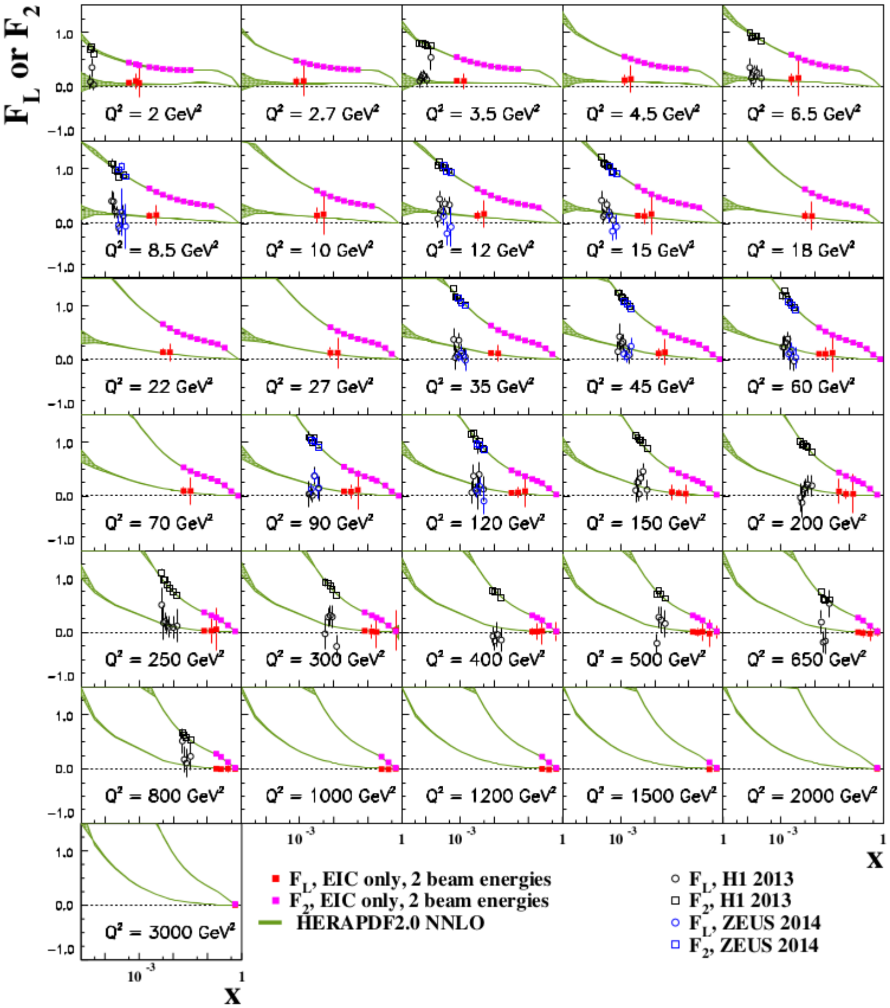




10x250 GeV2 e-p

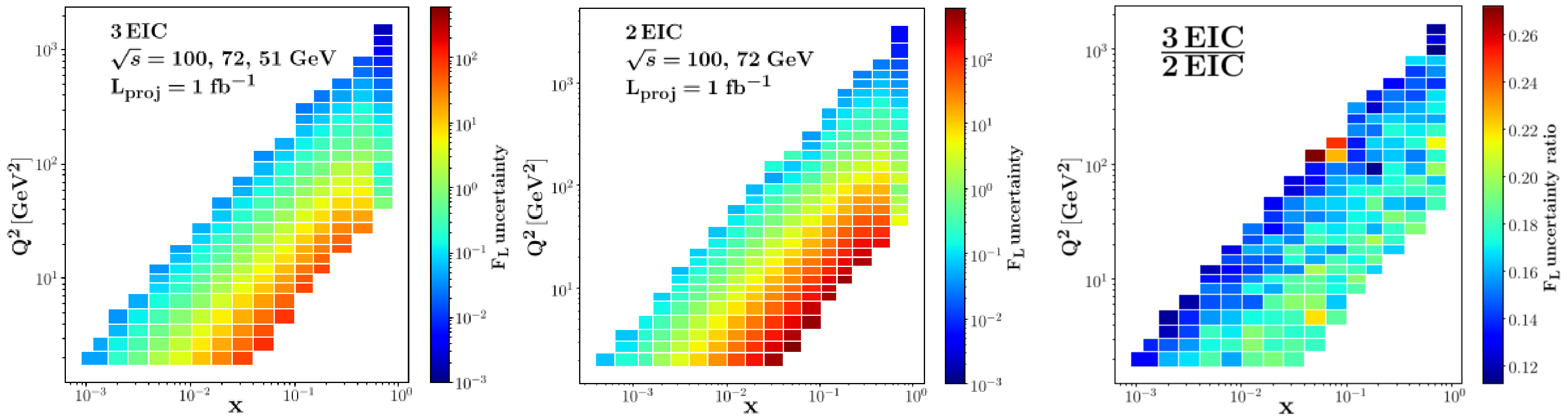
- σ_{red} can measured for any beam config - if F_L taken from theory prediction, F_2 can be extracted in each beam config (model-dependent)
- **Above**: ePIC full sim (pythia6 events) compared to pdf prediction
  - Statistical uncertainties (9.18 fb-1) on plot - but very small (up to a few percent at highest x and Q^2)

(Model-independent) proton structure functions



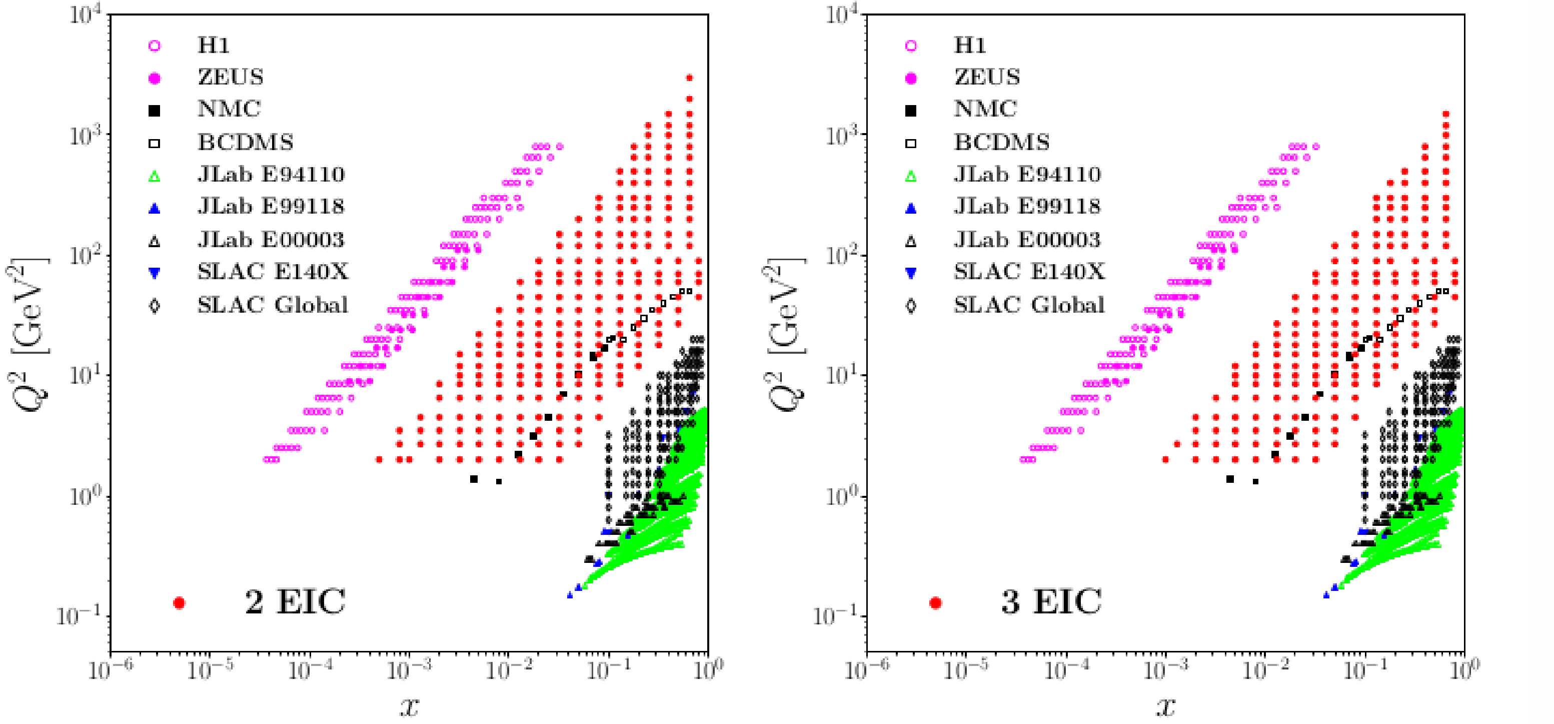
- For 2 (ideally 3+) beam energy configurations, F_L and F_2 can be simultaneously extracted (model independent) in overlap region
- Plot shows possible points and errors, compared to HERAPDF 2.0 and HERA data
  - Assume 10x130 and 10x250 GeV^2 e-p configs and stat errors from 1 fb-1 per config
  - Conservatively assume 1.9% point-to-point uncorrelated uncertainty and 3.4% normalisation fully correlated between configs
  - Only points with δFL<0.5 are plotted - F_L point available for each F_2 point, but large errors

Uncertainty on F_L



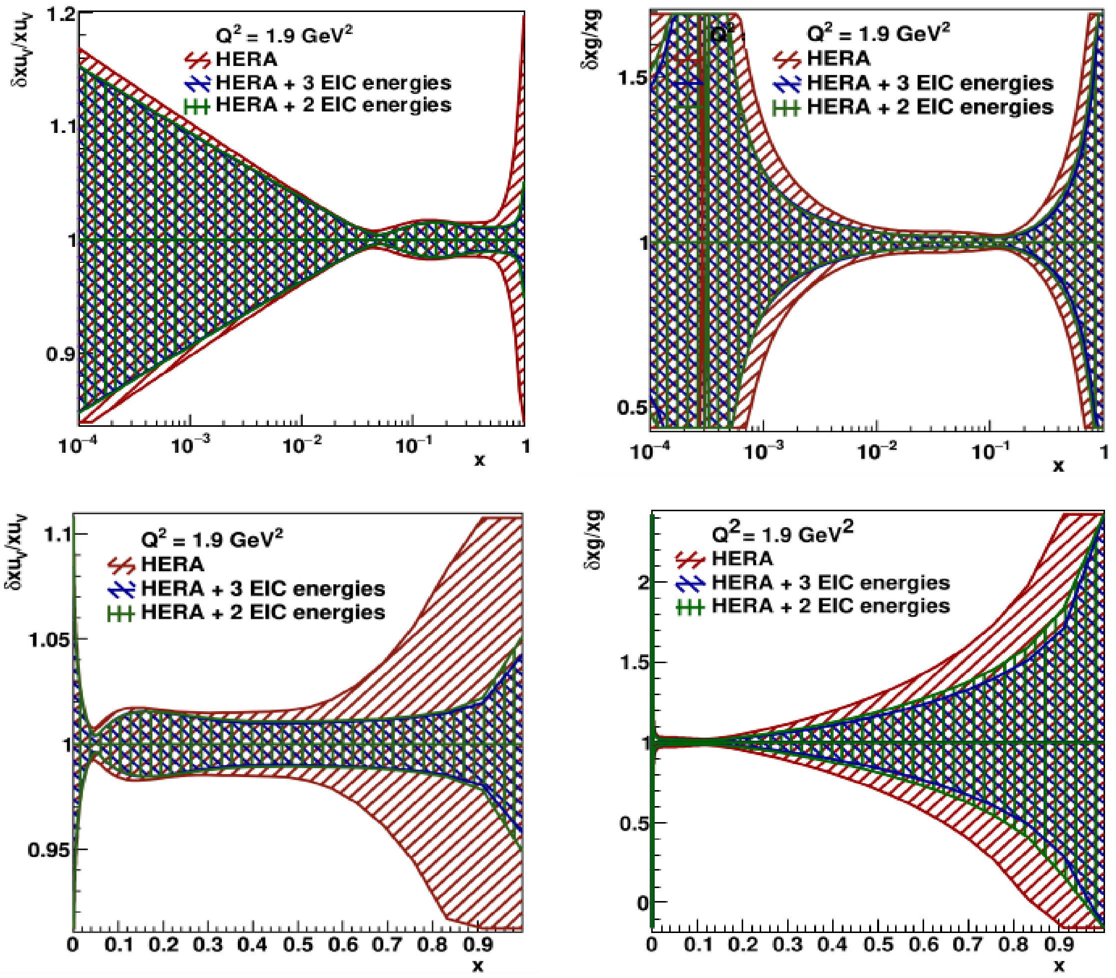
- Require 2 or more σred measurements to extract FL
- Systematics dominate σred precision - only need ~1fb^{-1} per beam config!
- **Adding a third, lower, beam energy config (5x130 GeV^2) offers a factor of ~5 improvement in uncertainty**

Phase space for F_L (and model-independent F_2)



- Early Science EIC bridges gap between fixed target and HERA
- Note that right-hand plot has smaller phase space as a requirement of 3 overlapping σ_{red} measurements is chosen in this case

Impact on proton PDFs (HERAPDF 2.0)



- Potentially large improvement in up-valence and gluon PDFs at large x with 2+ e-p beam configs in early science
- Moderate improvement at low x
- Only small difference for 2 vs 3 e-p configs, and only at large x

Summary

- There's a lot to be learned through inclusive DIS
  - Much will be learned during early science

- The working group is small but active
  - It's been a productive year - but there's lots still to be done

- Some of the top items on the TODO list are:
  - Further develop the electron finder to use other detector subsystems
    - Better integration of electron finding into reconstruction framework
  - More studies of backgrounds – both beam induced and physics
  - Get started on unpolarised e-A – no active analysers for this currently