UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

Update on F_L prospects during early science programme

S. Maple

Rosenbluth method to obtain F_L

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

- Inclusive cross section computed from 3 structure functions:

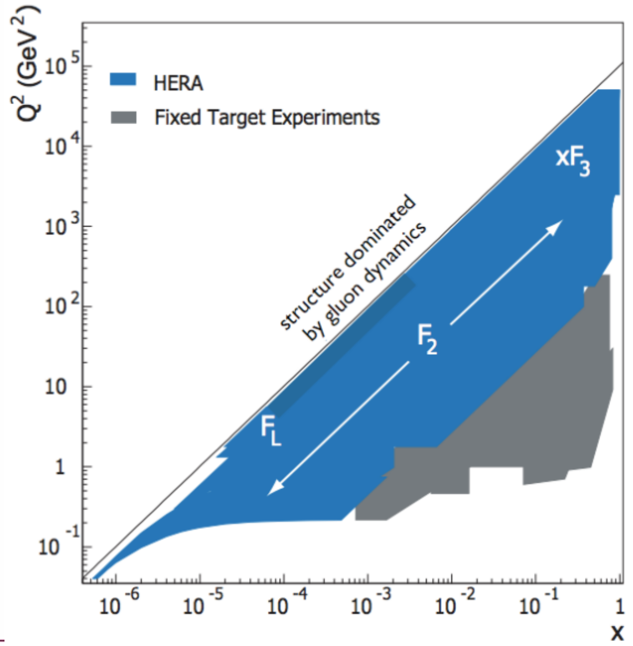
$$\sigma_r = \frac{xQ^4}{2\pi\alpha^2 Y_+}\left[\frac{d^2\sigma}{dx dQ^2}\right] = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) + \frac{Y_-}{Y_+}xF_3$$

- At LO, these are

$$F_2 \propto x\sum_q (q+\bar{q})$$
$$xF_3 \propto x\sum_q (q-\bar{q})$$
$$F_L = 0$$

- F_L is a pure QCD effect → gives an independent way of probing gluons: $xg(x,Q^2) \approx 1.77\frac{3\pi}{2\alpha_S(Q^2)}F_L(ax,Q^2)$

- Direct measurement of F_L via measurement of σ_{red} at same x-Q^2 but different y → different c.o.m. energies



Rosenbluth method to obtain F_L

https://arxiv.org/pdf/2412.16123

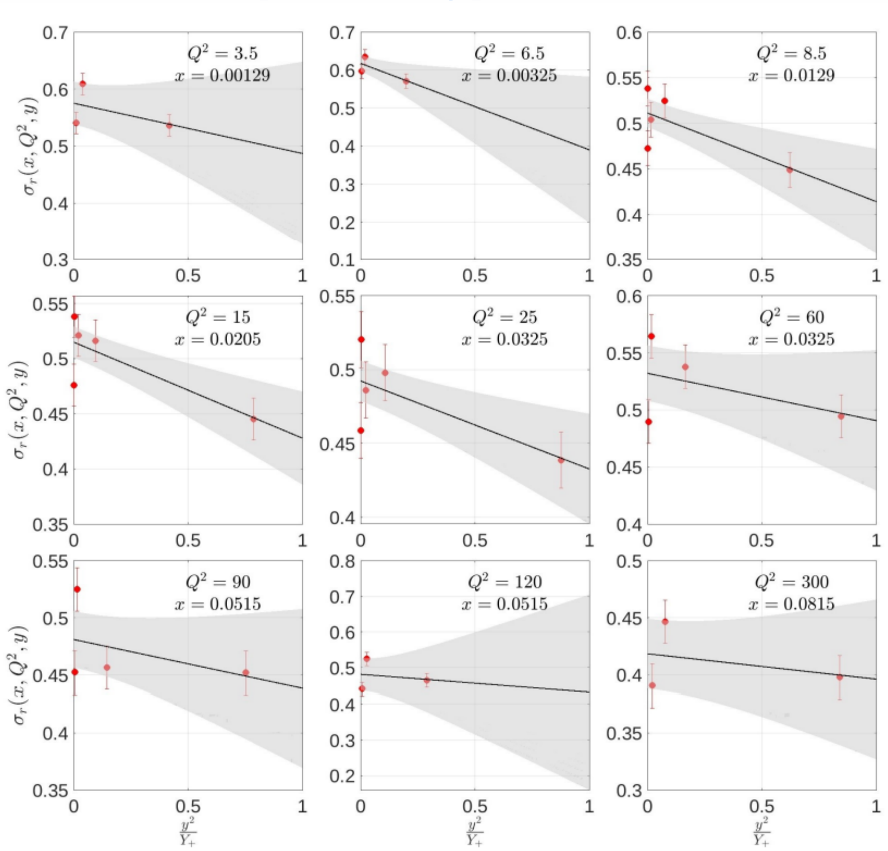
- F_L obtained as slope of σ_{red} vs y^2/Y_+

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

- Contribution to σ_{red} is typically small (compared to e.g. F_2)

- Therefore, to measure F_L accurately we require:

→ **Small systematic errors on σ_{red}**
→ **As many data points as possible**
…over a large range in y^2/Y_+



Early science ep runs

- The most recent early science matrix has 3 ep runs at two different energies

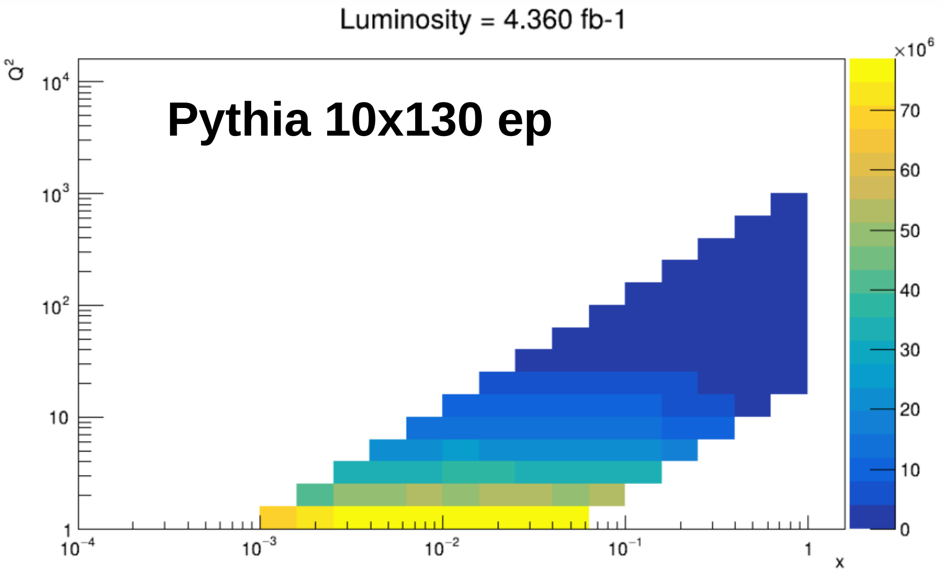
	Species	Energy (GeV)	Luminosity/year (fb-1)	Electron polarization	p/A polarization
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG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

→ **Small systematic errors on σ_{red}**
~~→ **As many data points as possible**~~
~~**…over a large range in y^2/Y_+**~~

→ **Small systematic errors on σ_{red}**
→ **Two data points**
…over up to ~0.2 units in y^2/Y_+

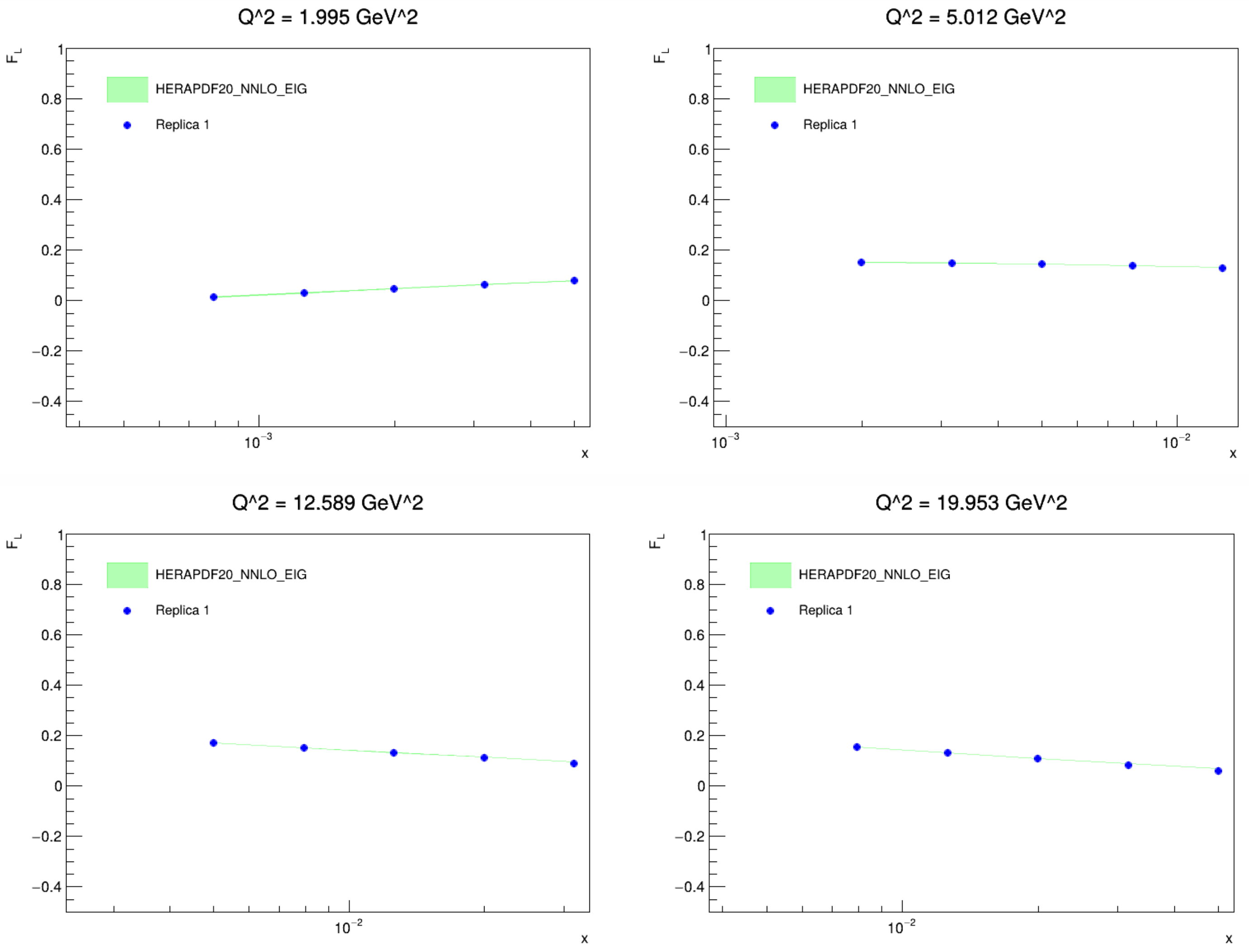
Setup

- Create grids with 5 logarithmically spaced bins per decade in x and Q^2
- Remove bins with any area that doesn't meet cuts Q^2>1GeV^2 and 0.005 < y < 0.96
- Stat errors estimated from pythia
- Systematics use two scenarios:
  - Pessimistic: 3.4% normalisation (uncorrelated between runs), 1.9% point to point
  - Optimistic: 1% everywhere



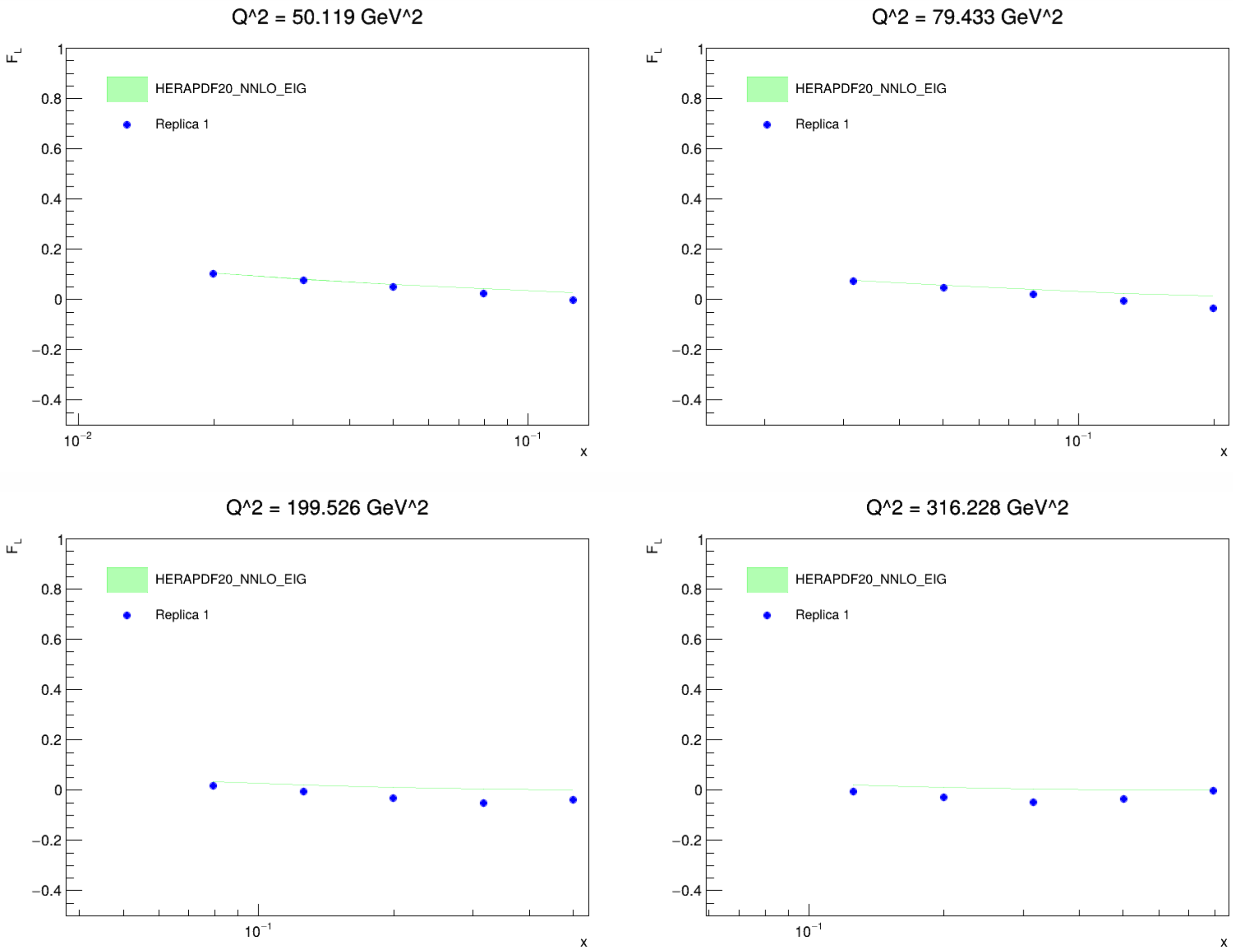
- Procedure: smear cross sections according to total uncertainties → Rosenbluth technique for

Check with no smearing (low Q^2)



Rosenbluth method gives fairly compatible result to PDF prediction **at low Q^2**

Check with no smearing (moderate/high Q^2)

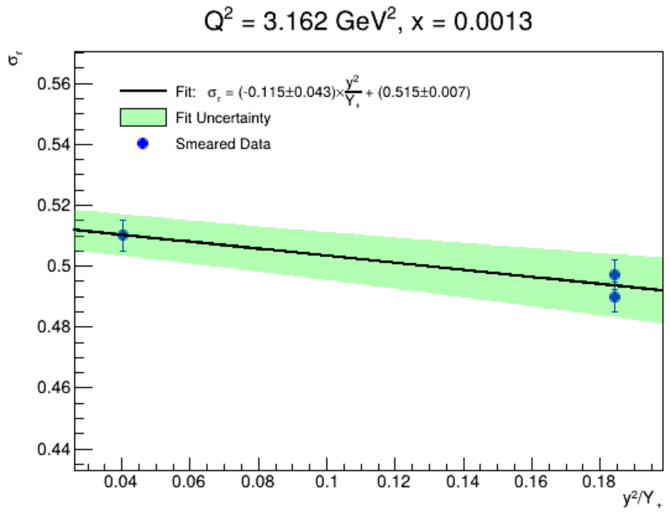


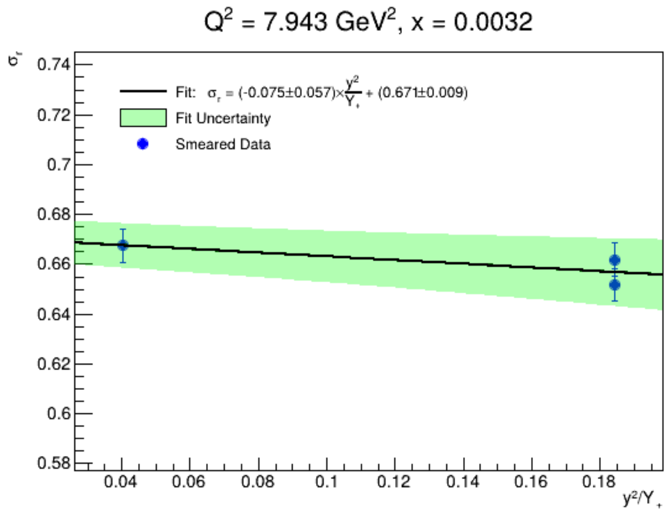
- Not quite as consistent for larger Q^2 / larger x
- Not really the region that we'd look at for F_L but would still be good to understand

Comments welcome!

- Will focus on $Q^2 < 100$ GeV^2 for now

Optimistic scenario (1% errors everywhere)

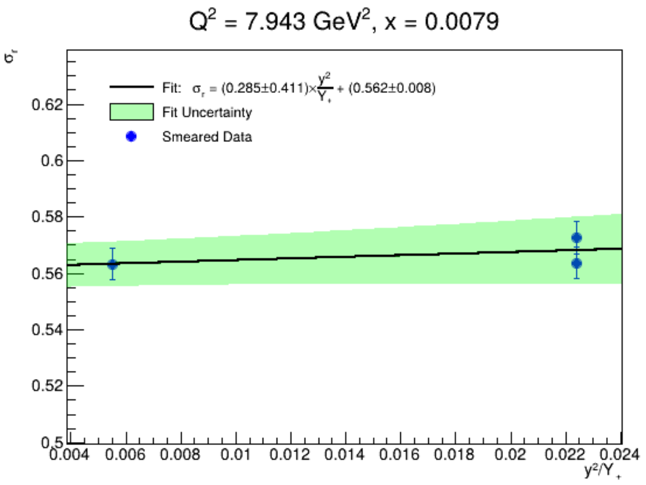




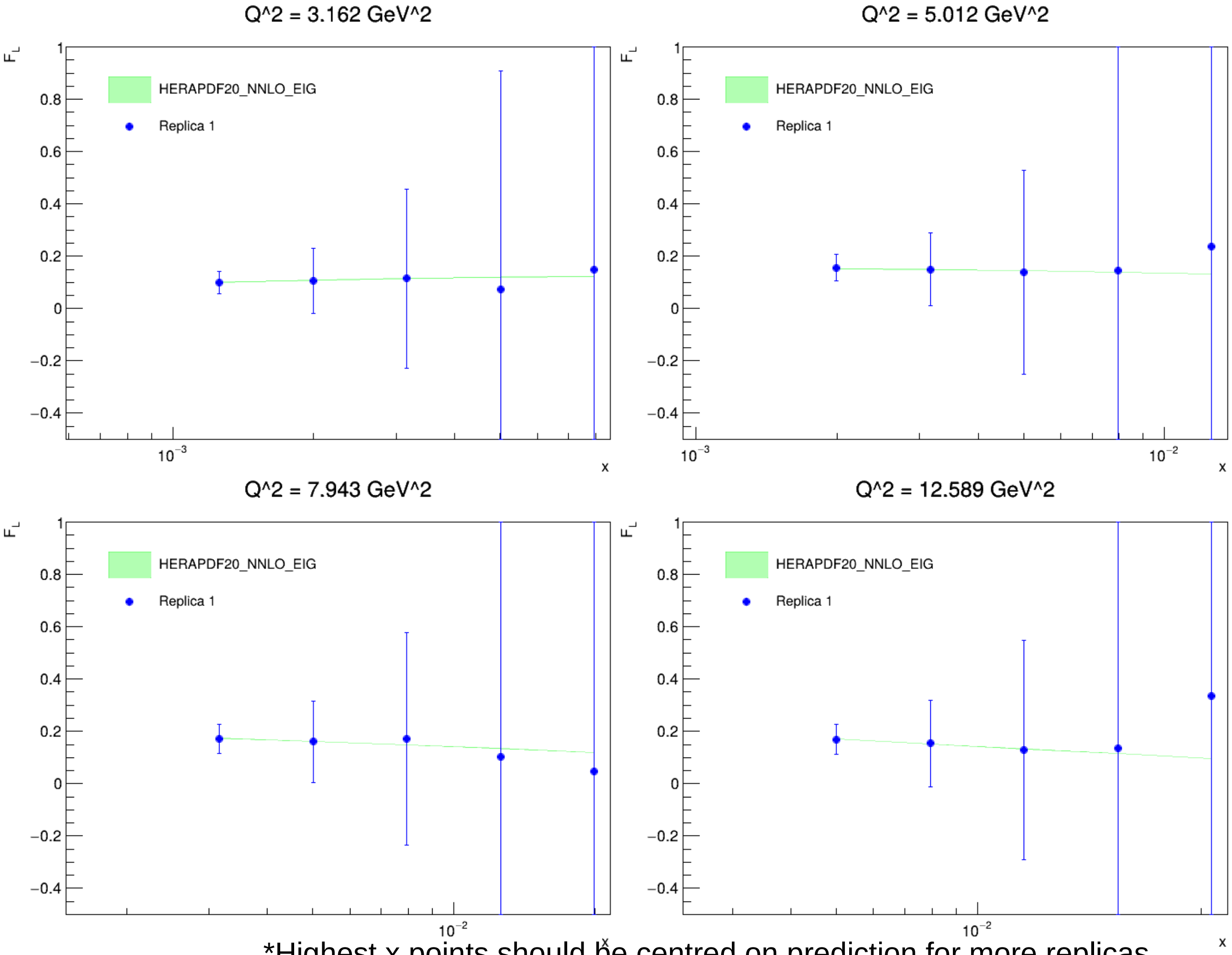
- Only 3 points and 2 c.o.m. energies
  - Left point interesected, right hand points split roughly down middle

- Only ~0.14 range in y^2/Y_+ → lower c.o.m. energies needed to fill this out

- With these settings it's fairly common to get a positive gradient i.e. negative F_L (note tiny range on x axis)



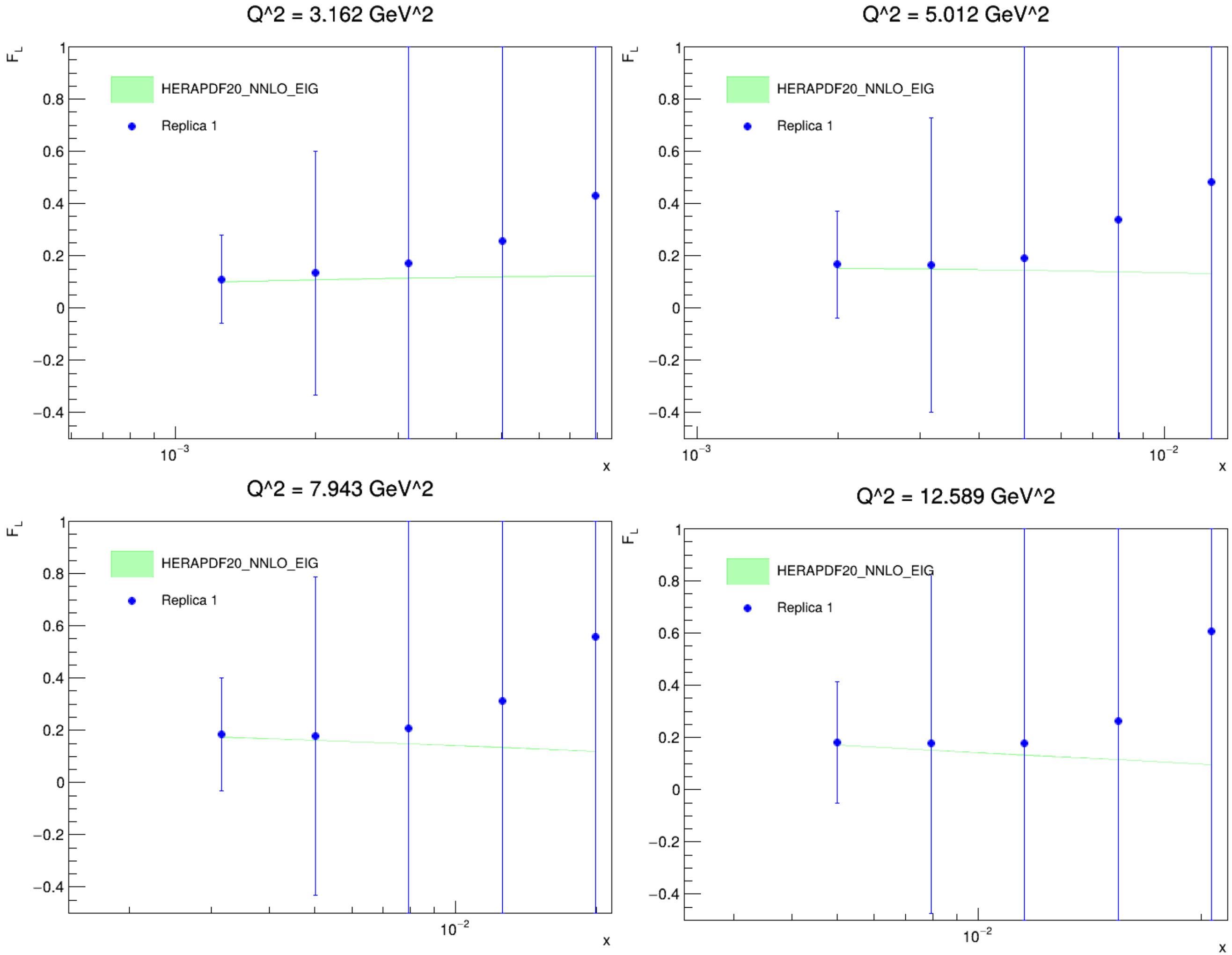
Optimistic scenario (1% errors everywhere)



- Repeat smearing procedure over 1000 replicas
- Central point is mean value reconstructed for F_L
- Error bars are standard deviation of reconstructed values
- With 3 points / 2 energies we get a couple of meaningful points per Q^2 range

*Highest x points should be centred on prediction for more replicas

Pessimistic scenario (1.9% p2p, 3.4% norm)



Same procedure as before

Very difficult to get meaningful measurements out for these settings
→ need more beam energy configurations to get something out with these systematics

Summary

- The early science runs offer 2 different ep beam energies
  - In principle this is enough to extract F_L with the Rosenbluth technique

- Well controlled systematics required to get any useful F_L measurement out using the early science runs alone → we will need to do better than HERA

Next Steps

- A single run with a lower c.o.m. configuration after the early science period may offer significant improvements → verify