F_L Measurements at HERA

DIS06, Tsukuba, Japan

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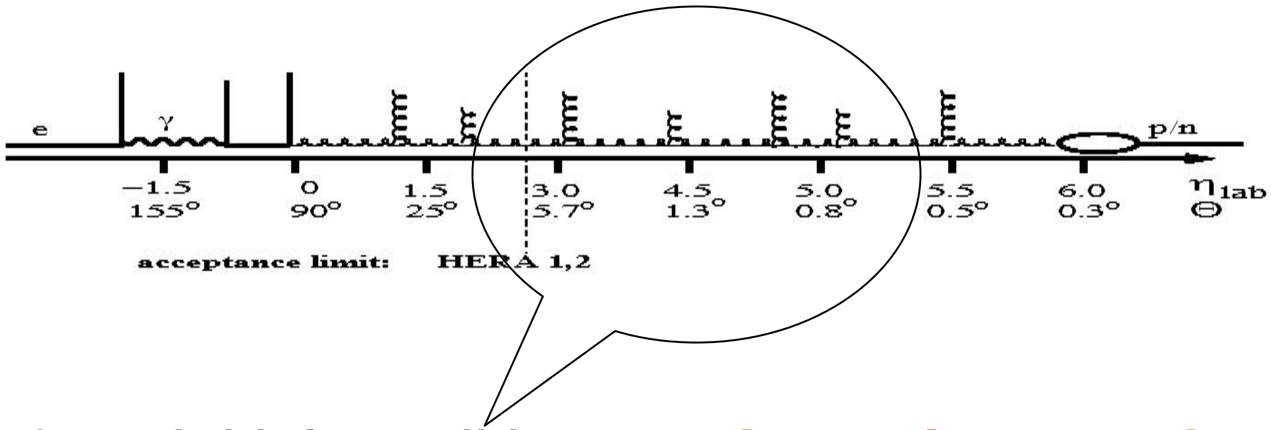
1. Motivation
2. Existing measurements
3. Predictions
4. Measuring F_L at HERA
5. How well we could do

Motivation

A major element of the HERA program is related to the understanding of partons at small-x. At small x, mostly gluons fluctuate in/out of existence.



In this region, far from initial conditions: **universal properties?**

Fundamental aspect of QCD. F_L good probe of this physics.

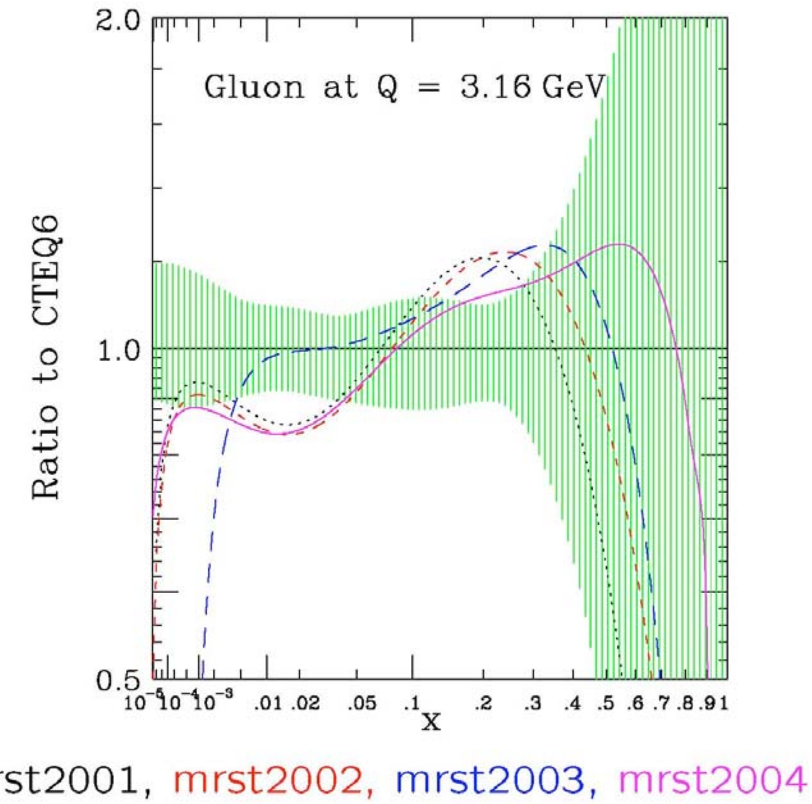
Motivation

How well do we understand the small-x physics ? So far, no theory which predicts the x-dependence of cross sections (PDFs). Guided by data.

There are signs that DGLAP (Q^2 evolution) may be in trouble at small x (negative gluons, high χ^2 for fits).

F_L could be an important ingredient to making progress in the theoretical understanding.

From Pumplin, DIS05



Motivation

In QPM: hadron is made up of quarks with zero P_T

$\sigma_L=0$ Helicity conservation

QCD radiation introduces quark P_T, $\sigma_L \neq 0$

$$F_L = \left(\frac{Q^2}{4\pi^2\alpha}\right)\sigma_L$$

$$F_L = \frac{\alpha_S}{4\pi}x^2\int_x^1\frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum e_q^2(1-{}^x\!/\!_z)zg\right]$$ LO pQCD

Expected to dominate at small-x

F_L measurement will be a good test of our understanding of the small-x parton densities !

Motivation

Unpolarized NC cross section in terms of structure functions

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

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

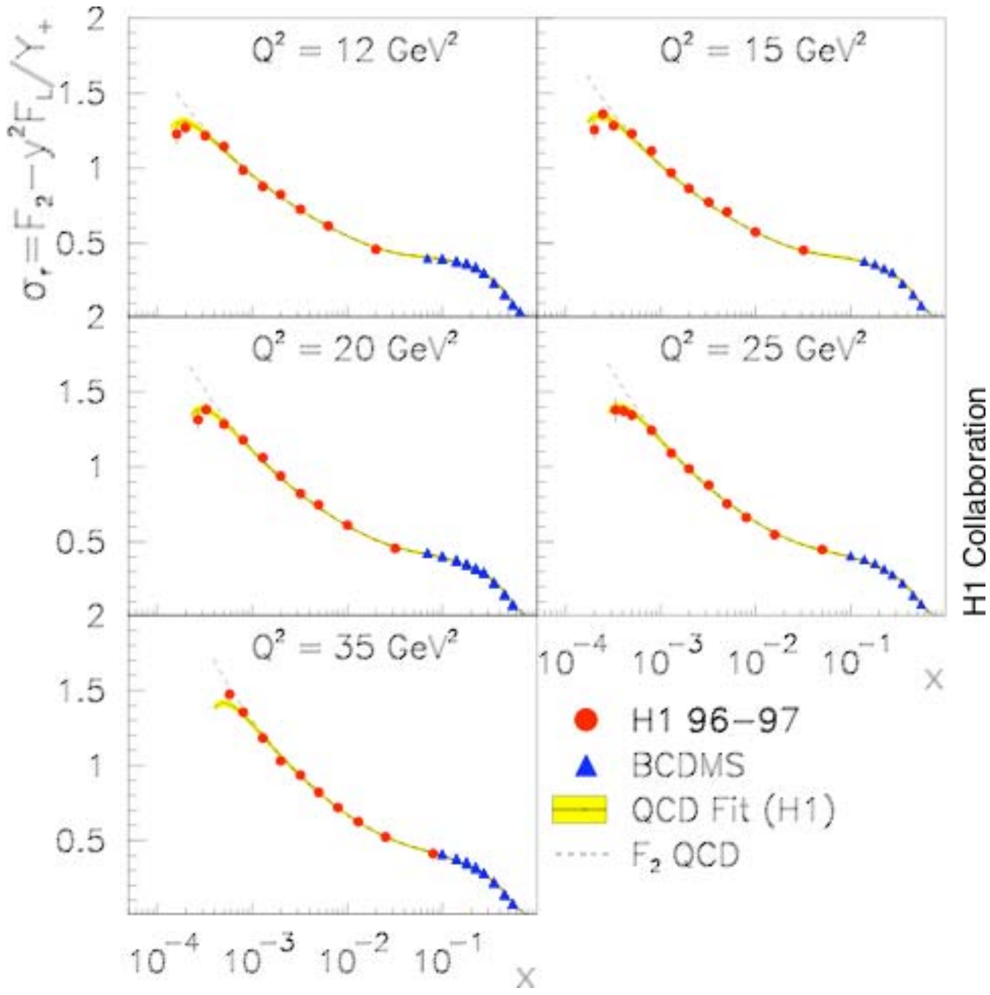
What we measure is the cross section.

xF_3 can be extracted by measuring $\frac{d^2\sigma(e^-p)}{dxdQ^2} - \frac{d^2\sigma(e^+p)}{dxdQ^2}$ HERA II

At small Q^2, negligible.

Assumptions currently made to extract F_2, F_L. OK for F_2 for small enough y, since F_L contribution suppressed. Need fixed (x,Q^2) and different y to separate at high y $\Rightarrow$ **different beam energies**.

High y cross sections



Note the turn-over of the cross section with decreasing x at small x in the H1 data.

The data can be fit consistently with NLO DGLAP by H1 **assuming** no gluon saturation. The turn-over is due the negative contribution from F_L. **MRST, CTEQ has trouble fitting the H1 low Q^2 data consistently at NLO DGLAP.**

F_L Extraction - H1

$$\sigma_r = \left(\frac{2\pi\alpha^2 Y_+}{xQ^4}\right)^{-1} \frac{d^2\sigma}{dxdQ^2} = \left[F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)\right]$$

Three techniques:

1. Subtraction method: $F_L = \frac{Y_+}{y^2}\left[F_2 - \sigma_r\right]$

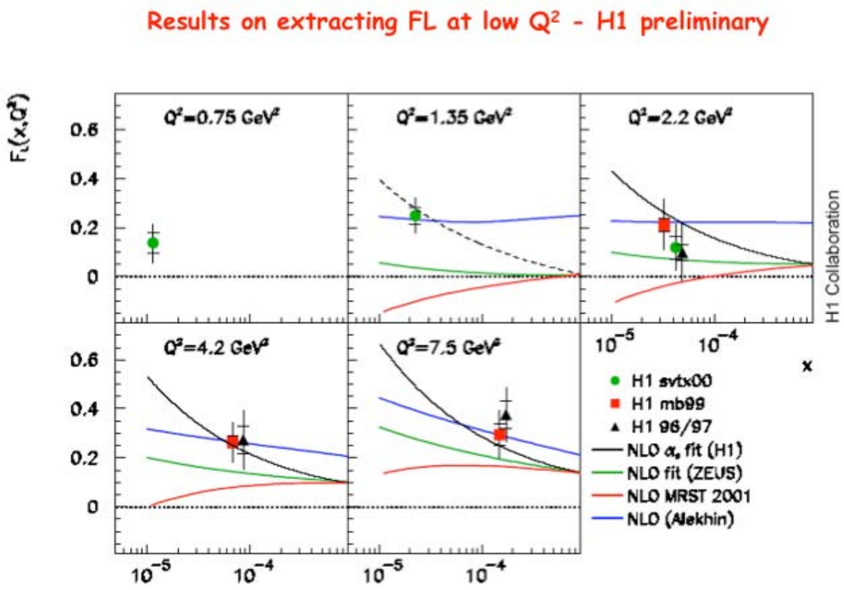
   - Extract F_2 in low y region, extrapolate to higher y (Q^2) using NLO DGLAP

2. Derivative Method: $\left.\frac{\partial \sigma_r}{\partial \ln y}\right|_{Q^2}$

   - F_L dominates the derivative at large y. Subtract contribution from F_2

3. Shape Method: Fit σ_r assuming $F_2 = ax^{-\lambda}$ and $F_L = c$ at high y

F_L Extraction - H1



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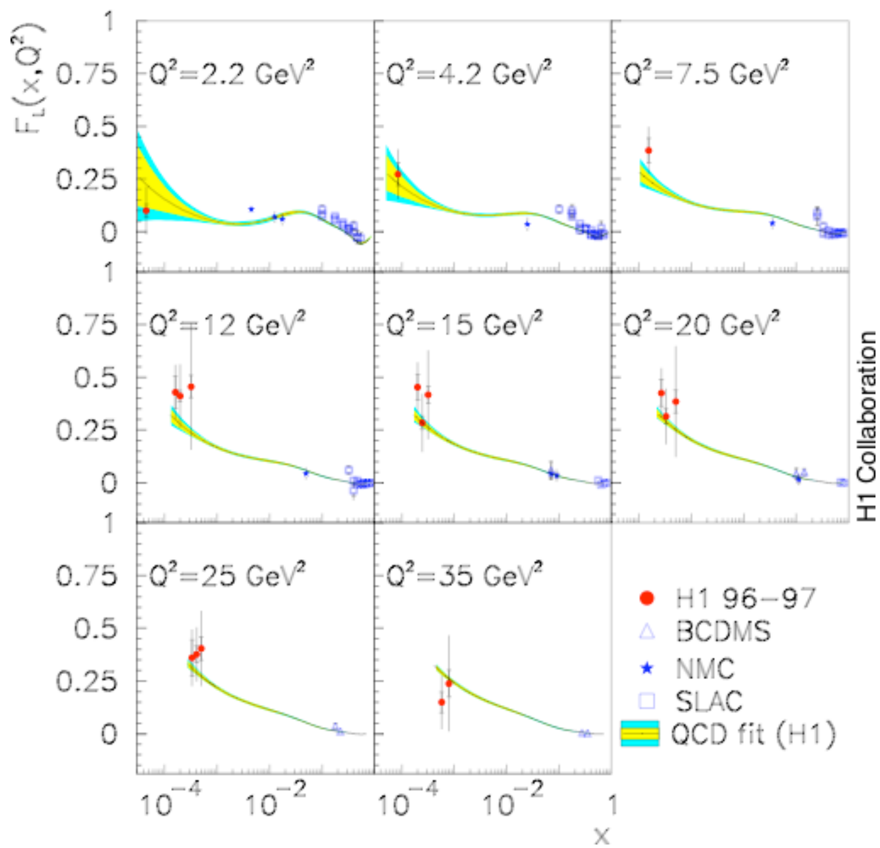
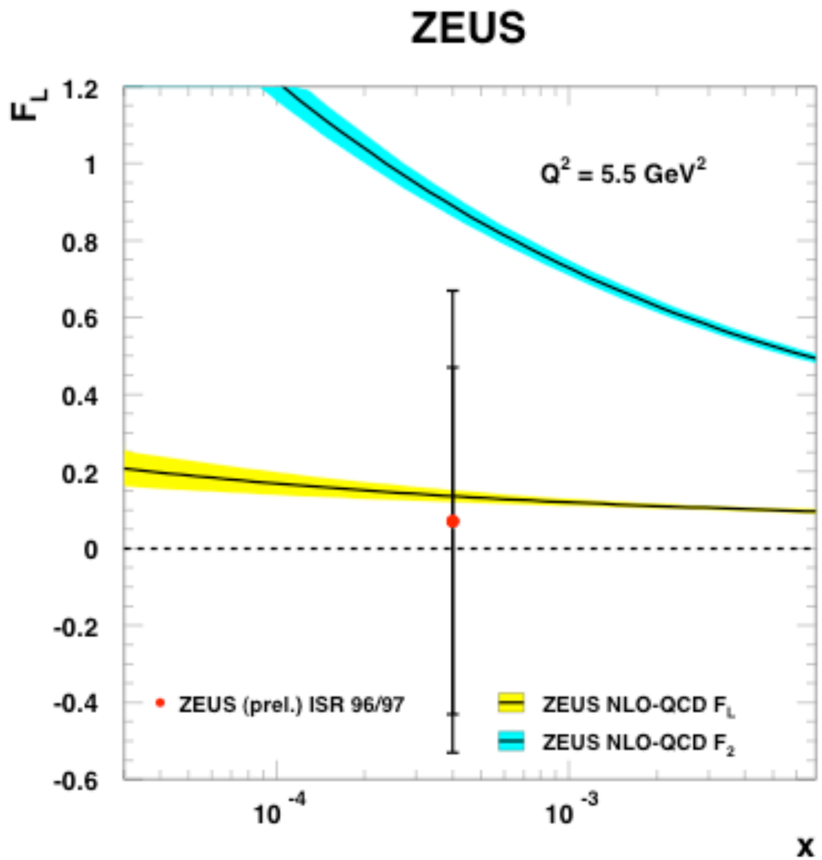


Extraction of F_L with assumptions about behavior of F_2. Could be dangerous since small-x physics not well understood.
Better - direct measurement of F_L by varying the CM energy.

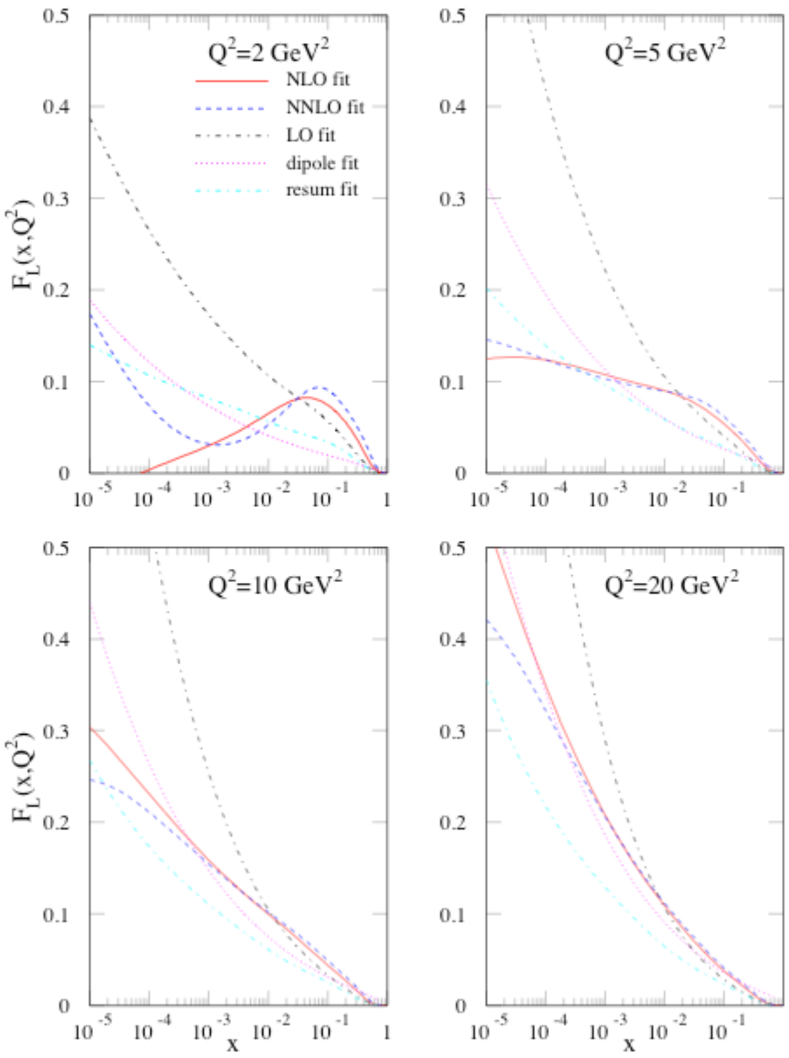
F_L Measurement - ZEUS

Initial State Radiation provides a broad band beam - can be used to extract F_L:

For more precision, need to lower the CM energy by changing beam energies.



Predictions for F_L



F_L predictions from MRST group at different orders in DGLAP, a fit which resums the leading ln(1/x) and β_0 terms, and a dipole type model. Very large differences at small Q^2 where gluon uncertainty large.

Predictions for F_L

Predictions for the longitudinal structure function

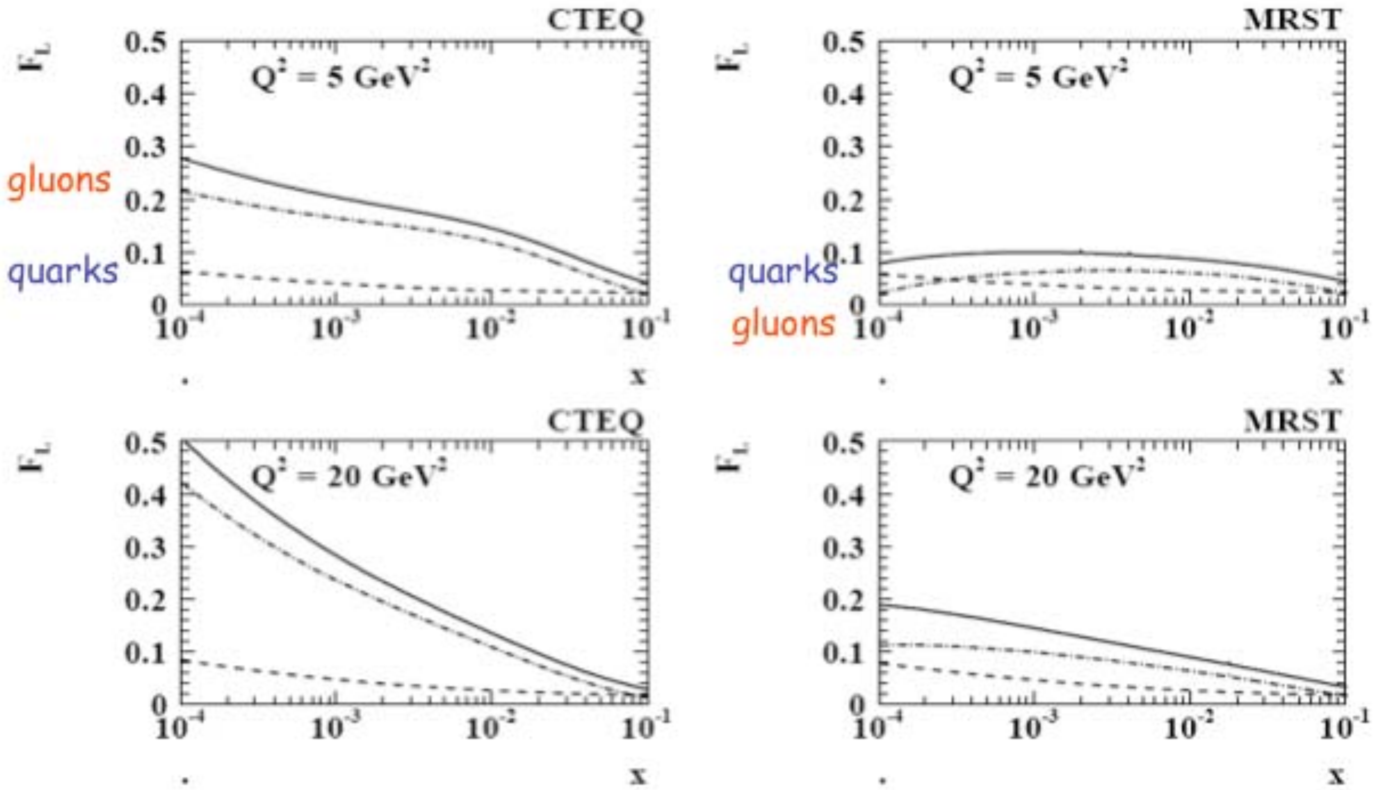


Figure 2. Calculation of the longitudinal structure function $F_L(x, Q^2)$ (solid lines) using the CTEQ6 (left) and the MRST2002 (right) parton distributions and Eq.2 for 4 flavours and α_s to NLO. Note that not only the predicted values for F_L differ but as well drastically the relative contributions from gluons (dashed dotted lines) and sea quarks (dashed lines). For MRST at low x, contrary to common belief, $F_L(x, Q^2)$ is not gluon dominated. Both sets of parton distributions describe the H1 data on F_2 well.

$$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \cdot \left[\frac{16}{3} F_2 + 8 \sum e_q^2 \left(1 - \frac{x}{z}\right) zg\right]$$

G. Altarelli and G. Martinelli, Phys.Lett. B76 (1978) 89.

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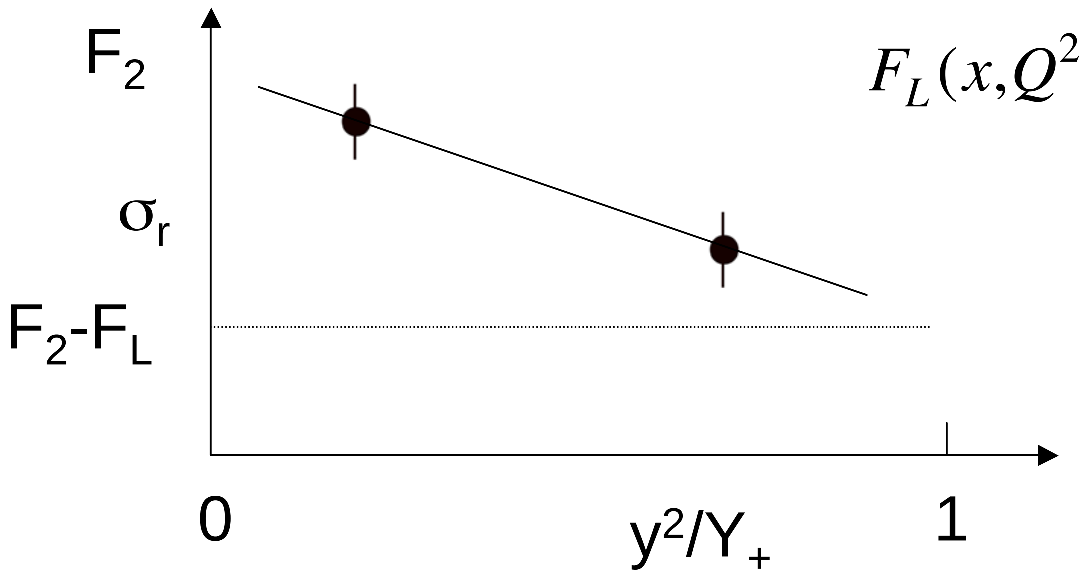
Measuring F_L

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

Small Q^2, ignore F_3

$$Y_+ = \left(1 + (1-y)^2\right)$$

$$\sigma_r = \left(\frac{2\pi\alpha^2 Y_+}{xQ^4}\right)^{-1}\frac{d^2\sigma}{dxdQ^2} = \left[F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right]$$

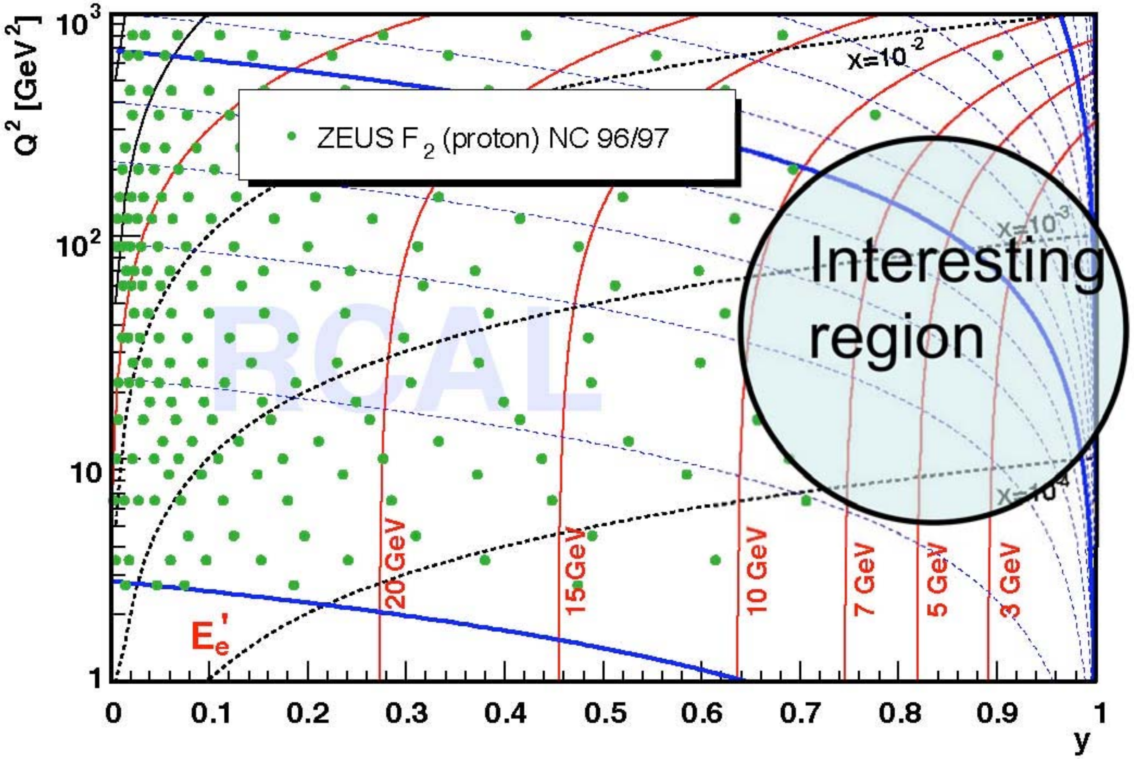


$$F_L(x,Q^2) = \frac{\sigma_r(x,Q^2,y_1) - \sigma_r(x,Q^2,y_2)}{f(y_2) - f(y_1)}$$

$$f(y) = y^2 \big/ Y_+$$

For best sensitivity, maximize lever arm (y-range)

Measuring F_L

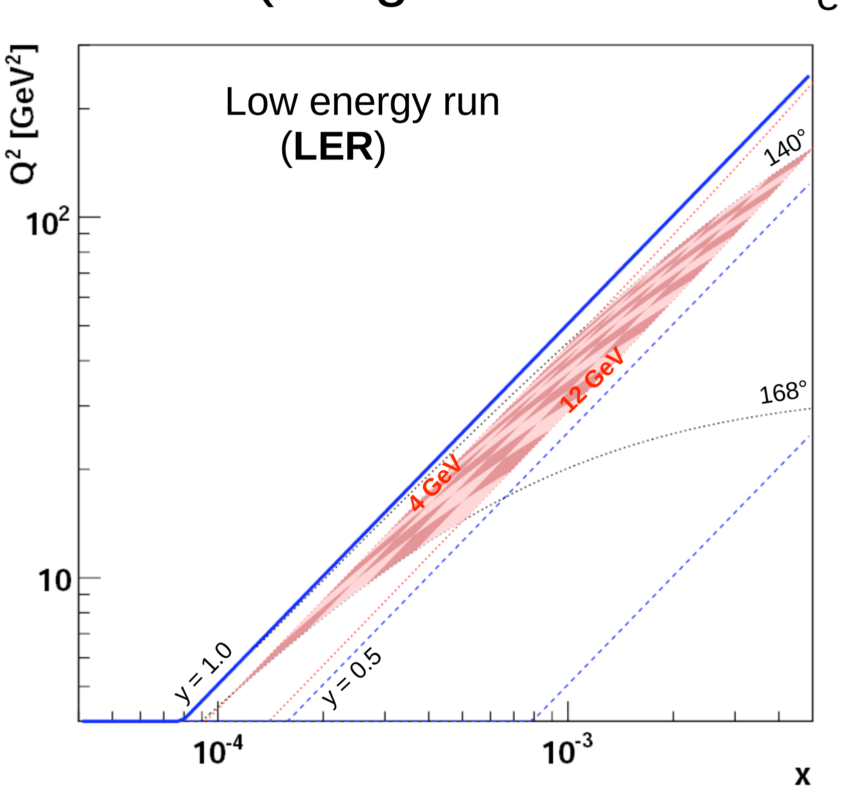


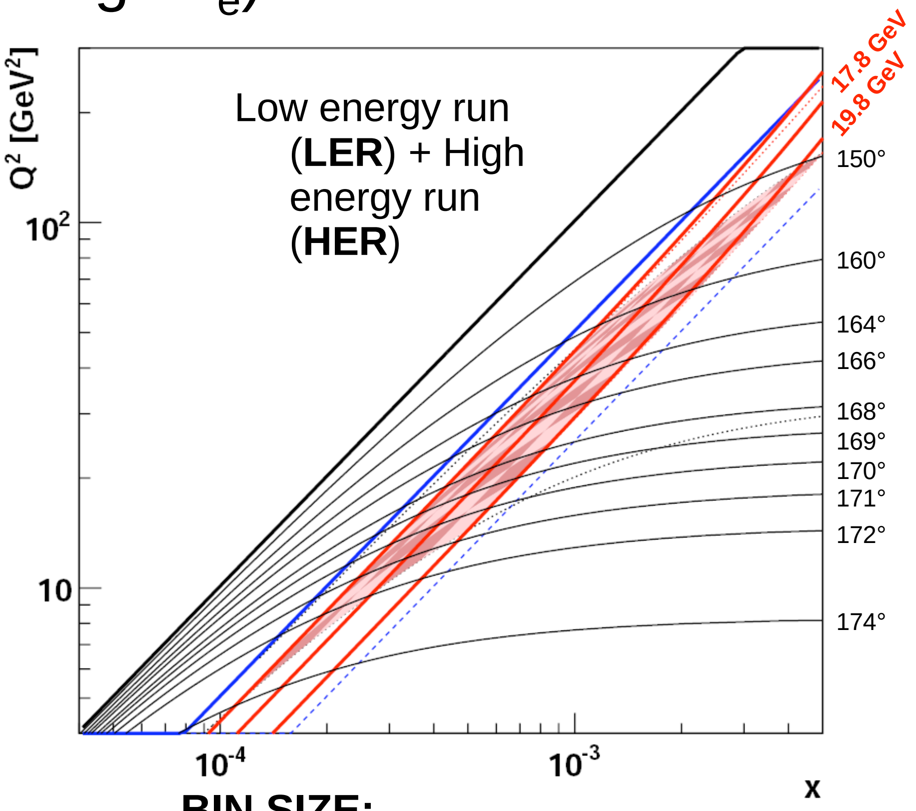
Need to go to lowest possible scattered electron energy:

- lower E_P rather than E_e
- trigger efficiency
- electron finder efficiency
- electron finder purity (photoproduction background, wrong candidate)

Measuring F_L

ZEUS (H1 goes to lower E_e', large θ_e)





		BIN SIZE:
E_p = 460 GeV	→ E_e = 4 – 12 GeV	→ ΔE = 2 GeV
	→ θ_e = 140° – 168°	→ Δθ = 2°
E_p = 920 GeV	→ E_e = 16 – 20 GeV	→ ΔE = 2 GeV
	→ θ_e = 160° – 172°	→ Δθ = 1°

Bins have square shape in E_e and θ_e

Running Conditions

Optimal running energy(ies):

• 2 vs 3+ energy points ? Assume only two since we have uncertainty with setup times, but prepare third energy in case accelerator setup and data taking smooth.

SCENARIO	E_P=920 GeV	E_P=460 GeV	E_P=690 GeV (optimal ?)
1	30 pb^{-1}	10 pb^{-1}	0 pb^{-1}
2	30 pb^{-1}	5 pb^{-1}	5 pb^{-1}

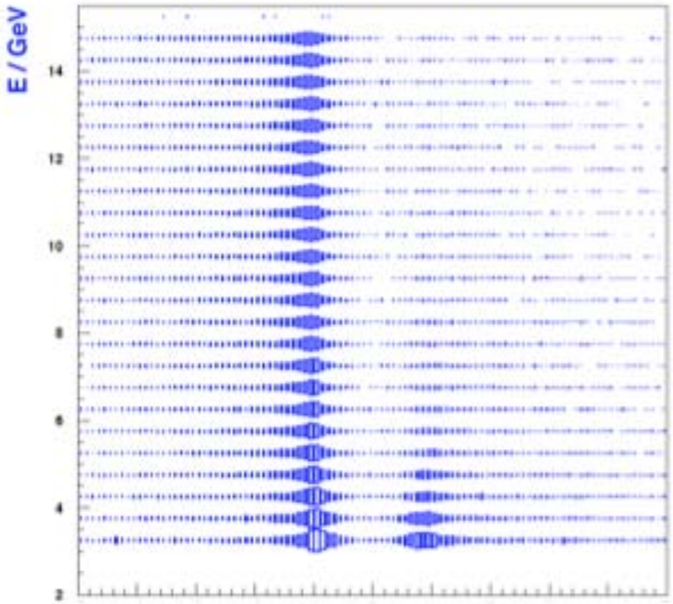
• ZEUS has investigated the optimum energy for the low energy run (LER). Lower energy gives bigger f(y) lever arm. But luminosity expected to scale as $1/E_P^2$, so stat error increases.

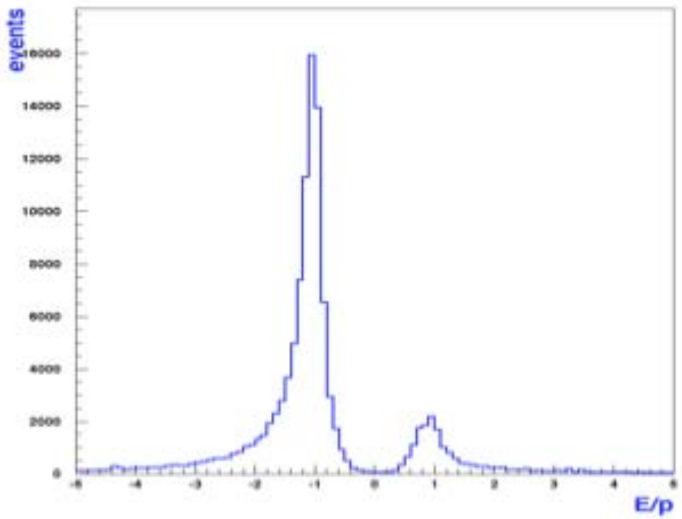
Conclusion: win by reducing energy ⇒ go to lowest energy considered reasonable by HERA.

Measurement with H1

- SPACAL finely segmented, good energy resolution
- BST+CJC allows statistical subtraction of background
- Measurement of low E_e' demonstrated (down to 3 GeV)

Measurement with H1





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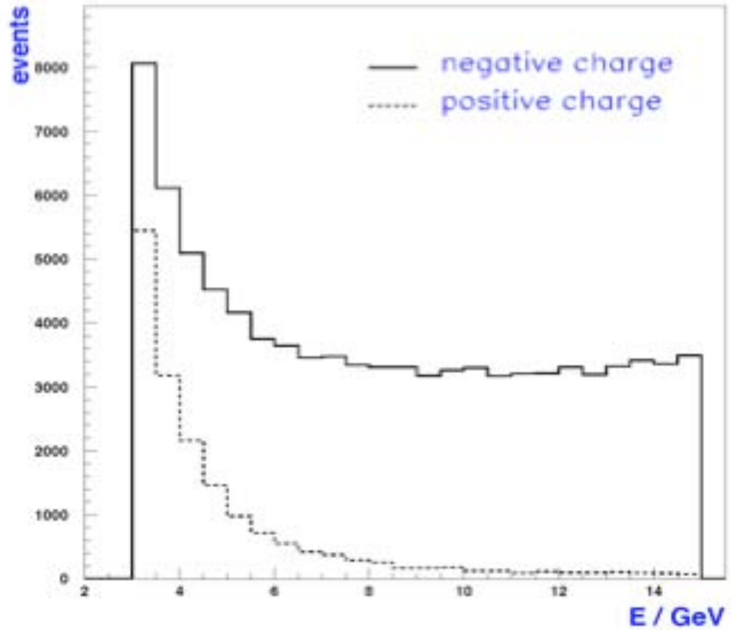
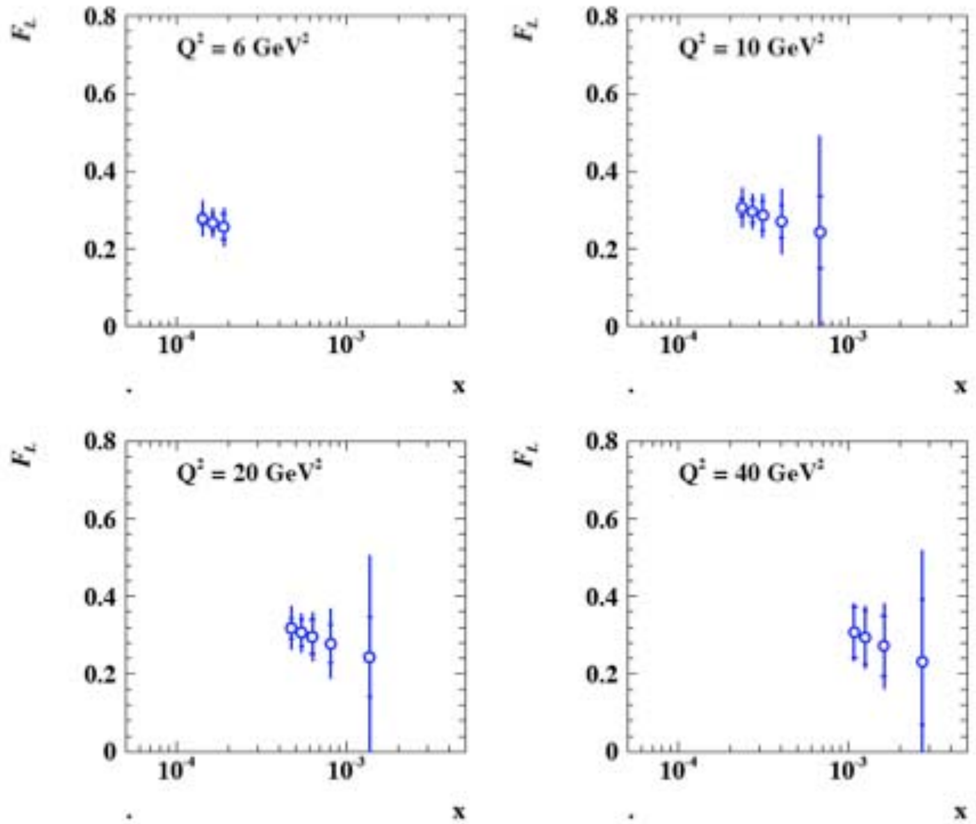
large Q^2 study with e^- 05 data



R_cluster < 4cm - against hadrons, use ISR
E-pz > 35 GeV - against radiative events
BPC-Spacal match
Trigger: E' > 3 GeV, CIP t0 [96% efficiency]
CJC track, matched to Spacal (R > 40 cm)
charge measured with CJC+event vertex -->
statistical subtraction of background
With e+ and e- data no symmetry assumption
on the background is necessary (anti-p)

Measurement with H1

F_L - simulation for two energies



920 GeV
30 pb^{-1}

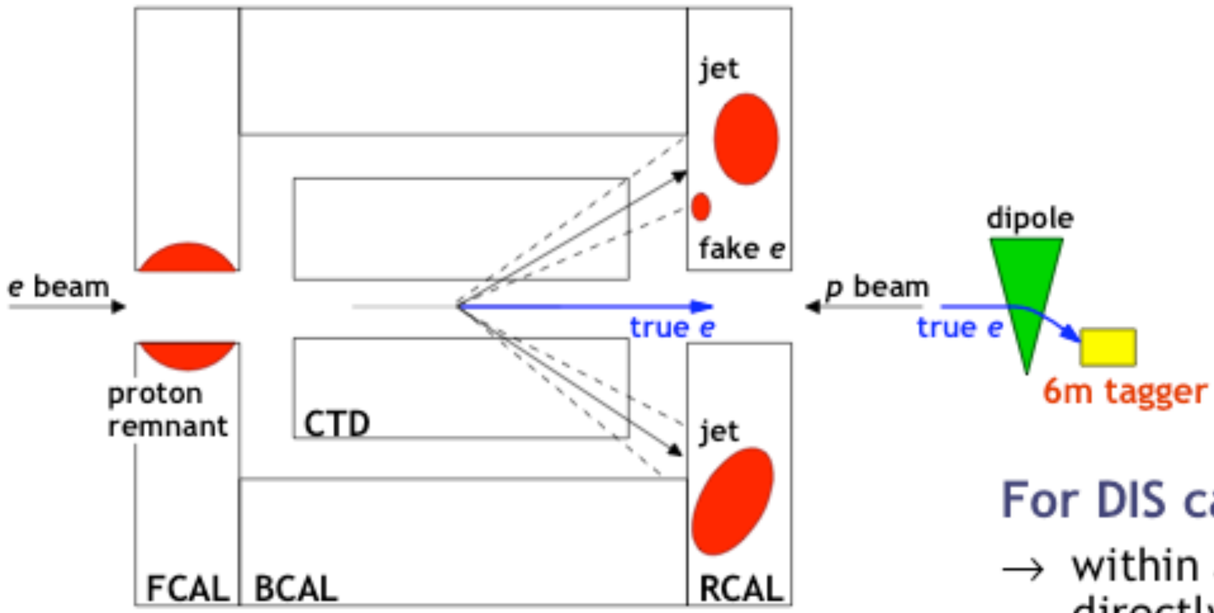
460 GeV
10 pb^{-1}

Error between 0.05 and 0.1, statistical and systematics about matched,
At high y efficiency and yp background sources of uncertainty similar.

Measurement with ZEUS

PhP event:

→ electron irradiates almost a real photon which then interacts with the proton
→ true electron with lower energy goes down the beam pipe
→ one of the particles in the detector recognized as DIS electron



6m tagger

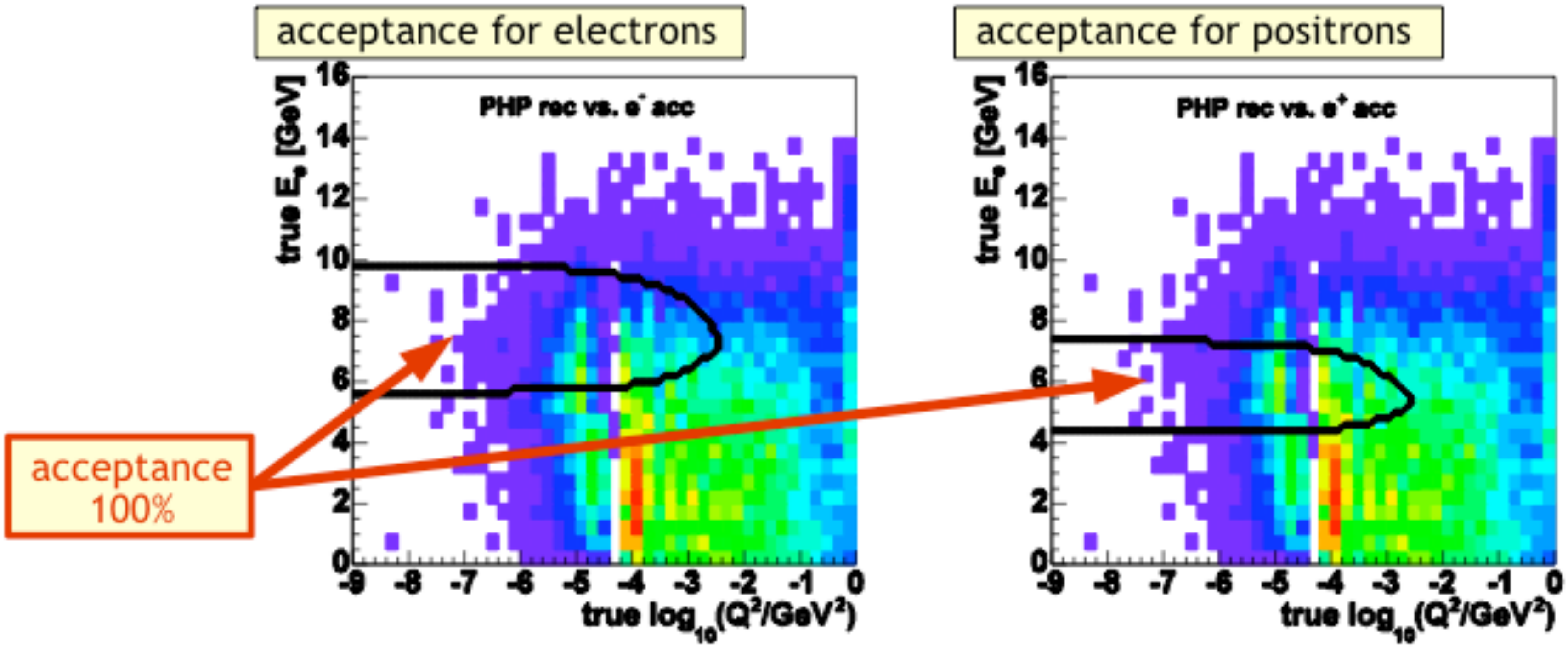
→ working fine
→ agreement with ZEUS luminosity measurement system within 2%

For DIS candidate with valid electron:

→ within acceptance window measure PhP directly
→ normalize PhP Monte Carlo

Measurement with ZEUS

→ PYTHIA PhP background distribution vs. 6m tagger acceptance (reconstructed as DIS events)

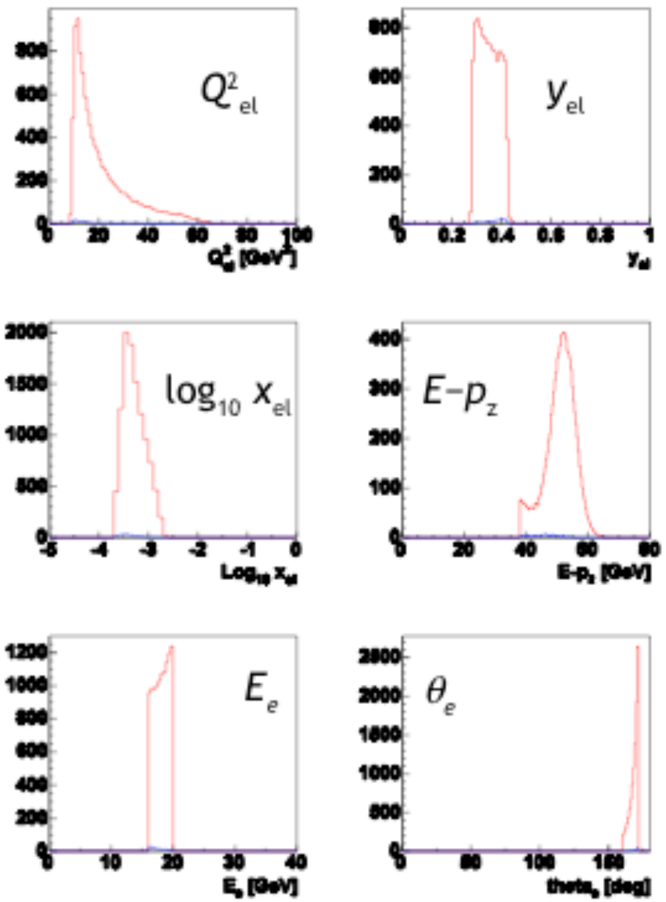


- **positron running advantageous** over electron running
  → lower energy
- for e^+ running 6m tagger identifies 25% of php events
- possibly measure php and normalize MC

D. Kollar

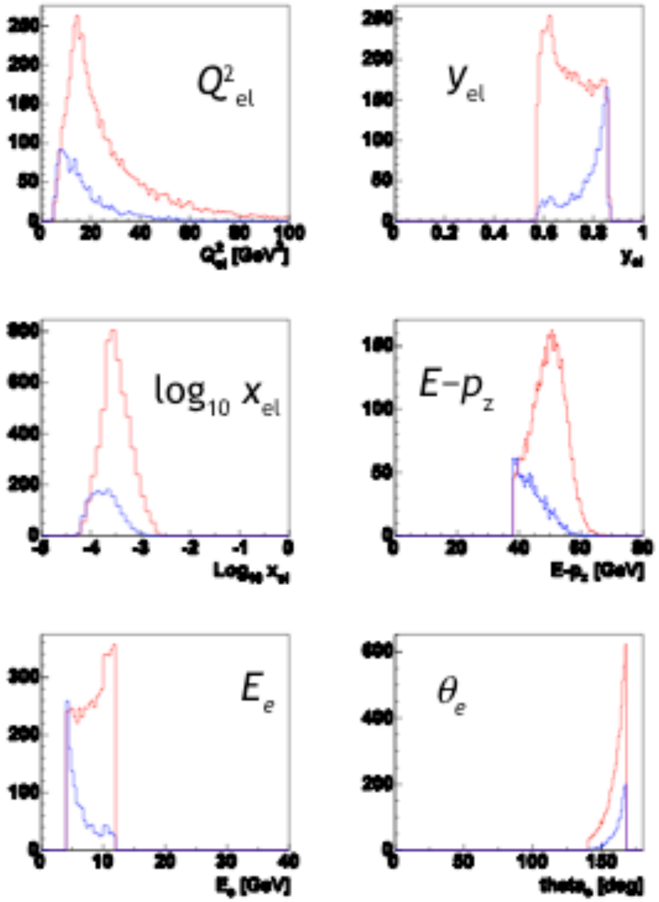
Measurement with ZEUS

High energy run



16 GeV < E_e < 20 GeV
160° < θ_e < 172°

Low energy run



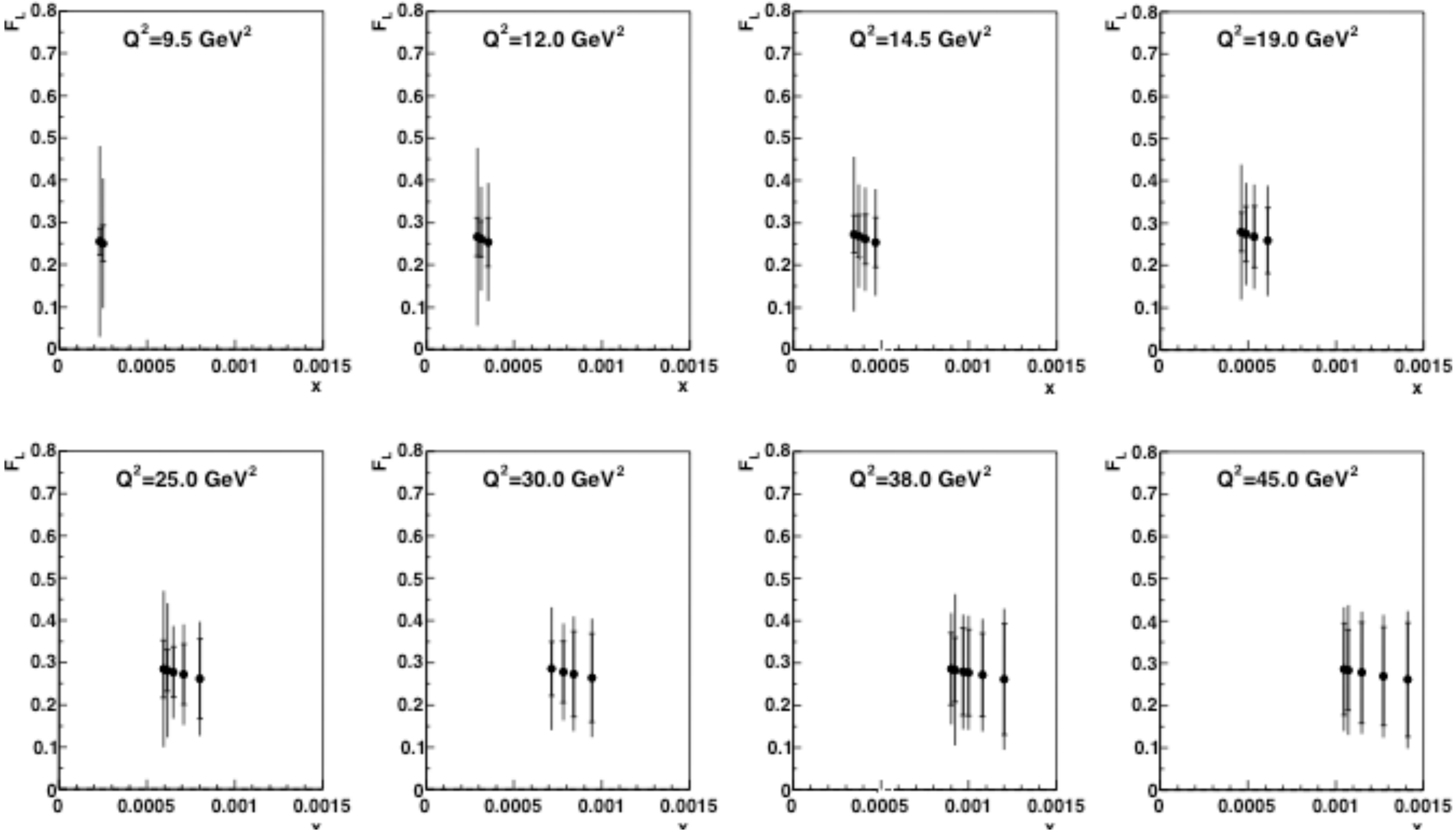
4 GeV < E_e < 12 GeV
150° < θ_e < 168°

PhP background is a problem for Low energy run (for low energy electrons)

DIS
PhP

D. Kollar

Measurement with ZEUS



Note: small stat error at low Q^2, but larger syst error. Smaller Q^2 will require more detailed study.

Comparison H1-ZEUS

Note: H1 starts at E_e=3 GeV, ZEUS at E_e=4 GeV

Quantity	H1 uncertainty	ZEUS uncertainty	Comment
E scale kin peak	0.2%	1%	0.5% for ZEUS may be possible
E scale low energy	2%	2%	
Photoproduction background	4% @ E_e=3 GeV	10% @ E_e=4 GeV	ZEUS has 6m tagger, H1 tracking (charge)
Electron finder+trigger eff	Part of photoprod	4% at low E_e 1% high E_e	
Rad corr	0.5%	negligible	
Angle meas.	0.2-1 mrad	Not considered	
Uncorrelated syst	1%	1%	
Correlated	Not considered	2%	

Results

Dipole fit produces rather different shape and size prediction for $F_L(x, Q^2)$ from that at NLO and NNLO.

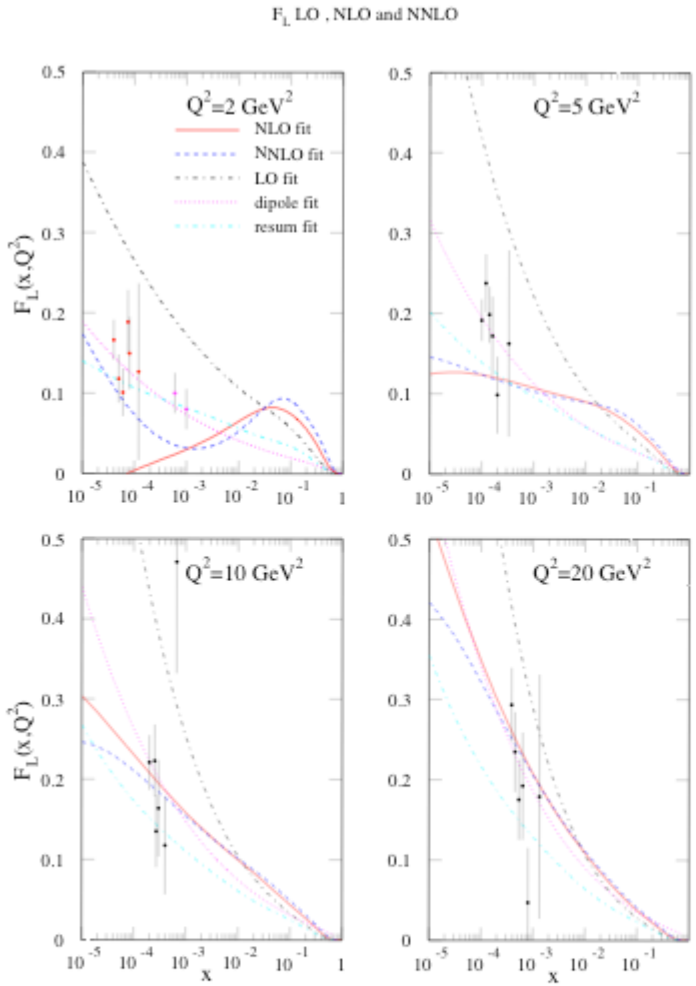
Generate a set of data based around central dipole prediction but with random scatter. $\chi^2 = 20/18$ for dipole prediction. Comparison to other predictions shown opposite.

Also show points at $Q^2 = 2\text{GeV}^2$ which might have been measured at HERA III red and might be at eRHIC pink.

Any points at 40GeV^2 not as useful. Errors bigger, curves converging.

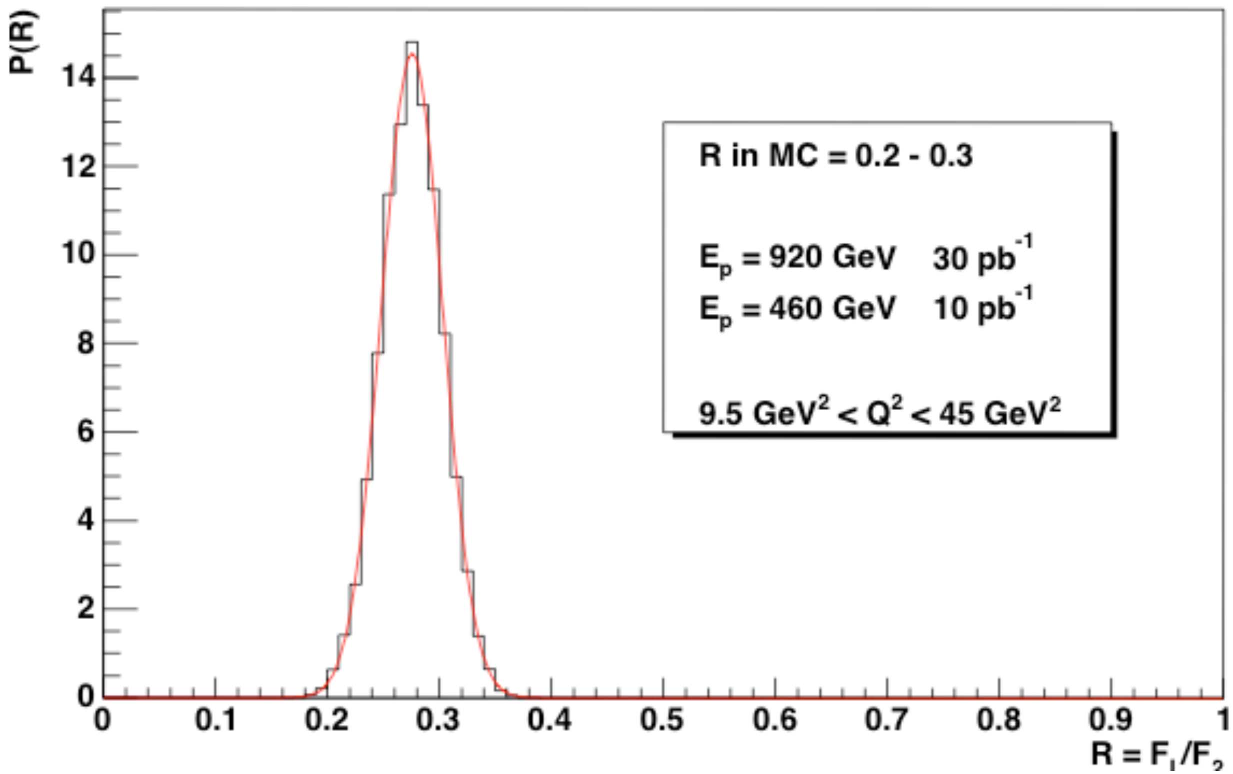
Clearly some reasonable differentiating power.

But these are central predictions.



Results

Attempt to put information in one number



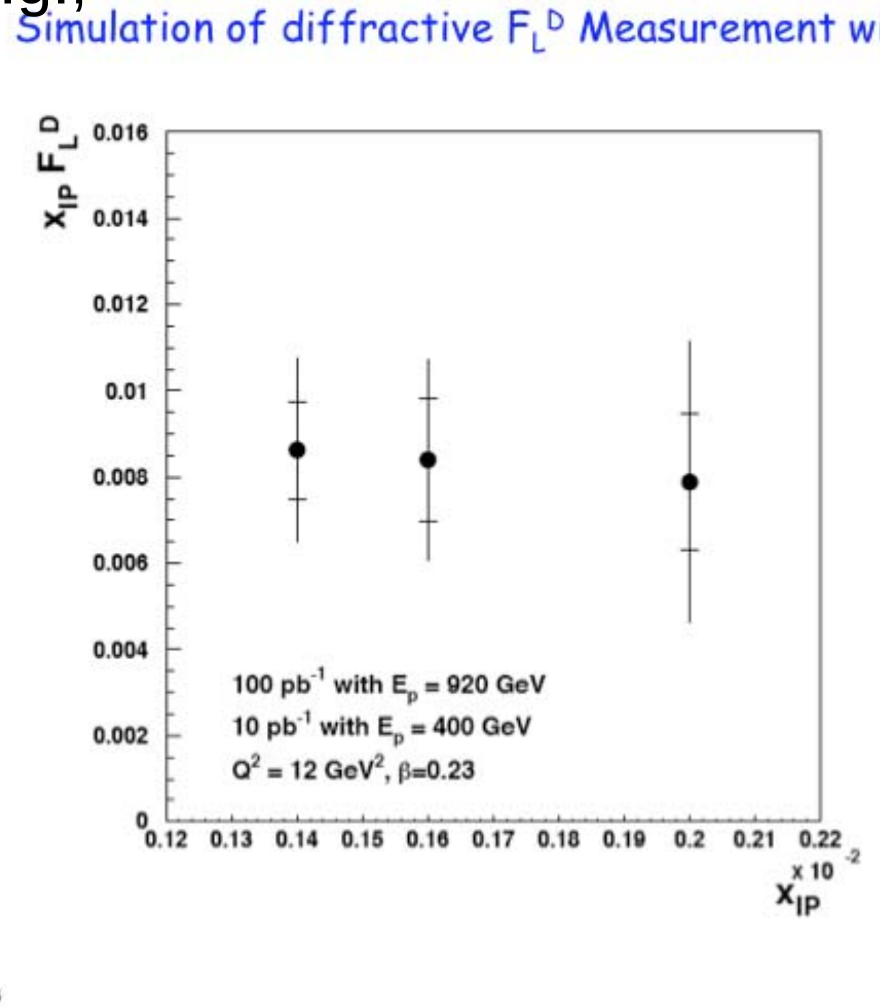
Bayesian analysis using all simulated data, and assuming that F_L/F_2=constant (MC range 0.2-0.3)

$\sigma \approx 0.025$

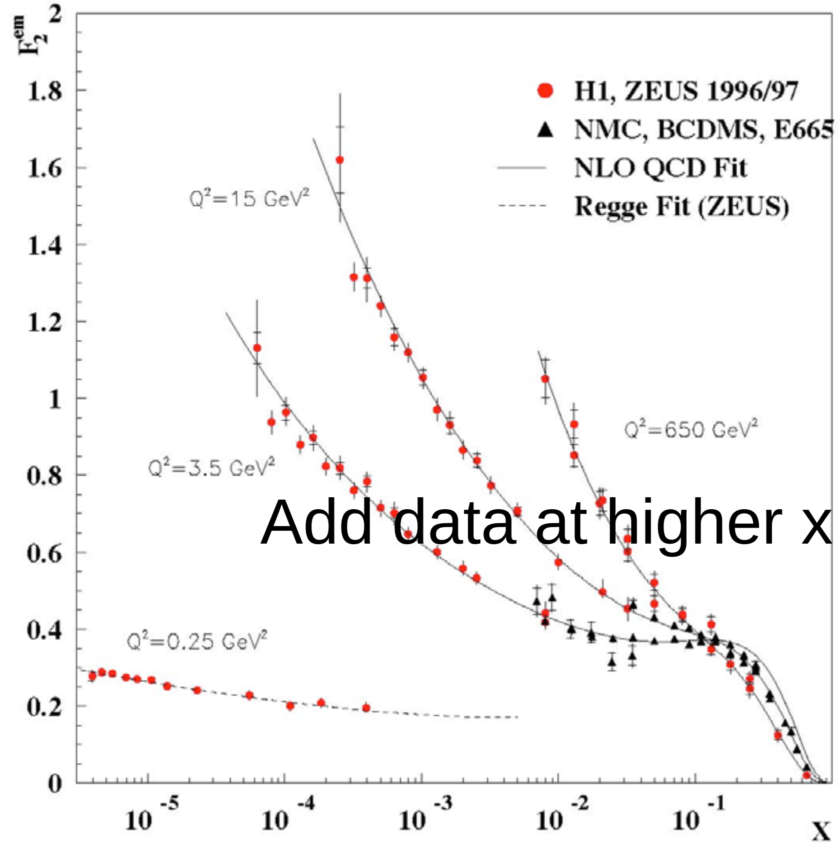
	CTEQ5D	R=0.25
Average values	MRST2002(LO)	0.3
	MRST2004(NLO)	0.18
	MRST2004(NNLO)	0.18

Results

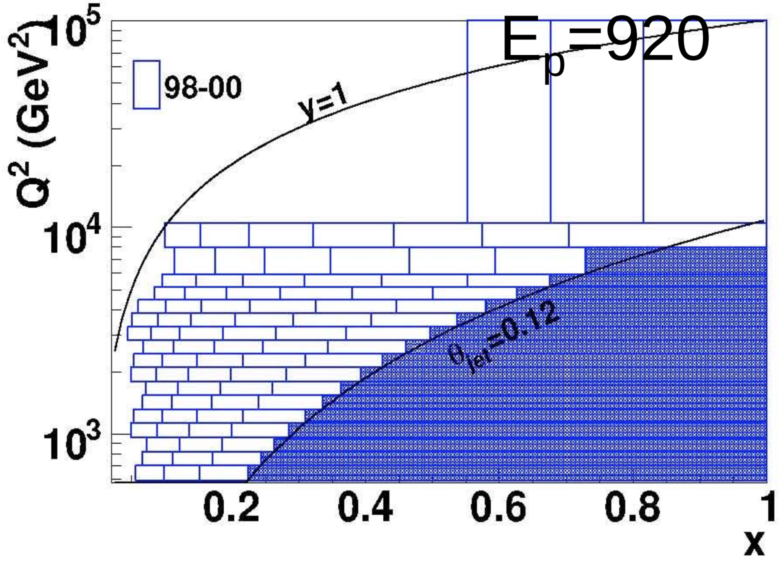
• There are many other measurements which would benefit from a low energy run. E.g.,



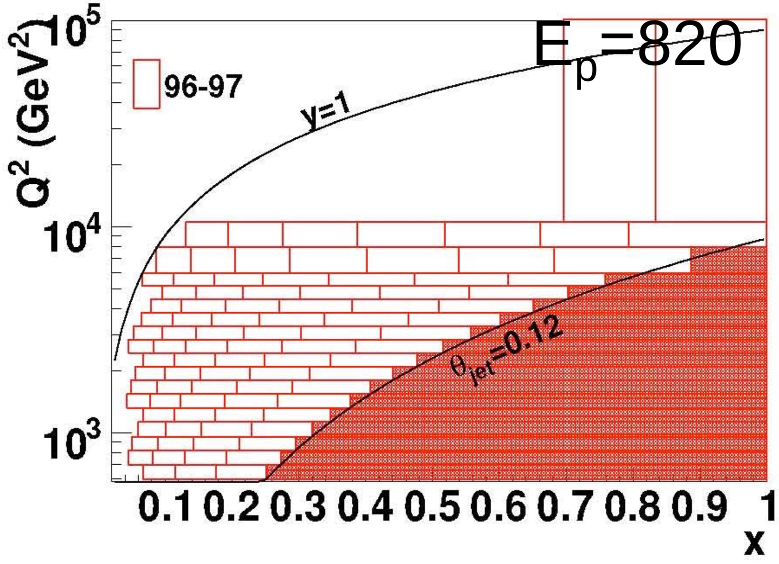
Results



Add data at higher x



(a)



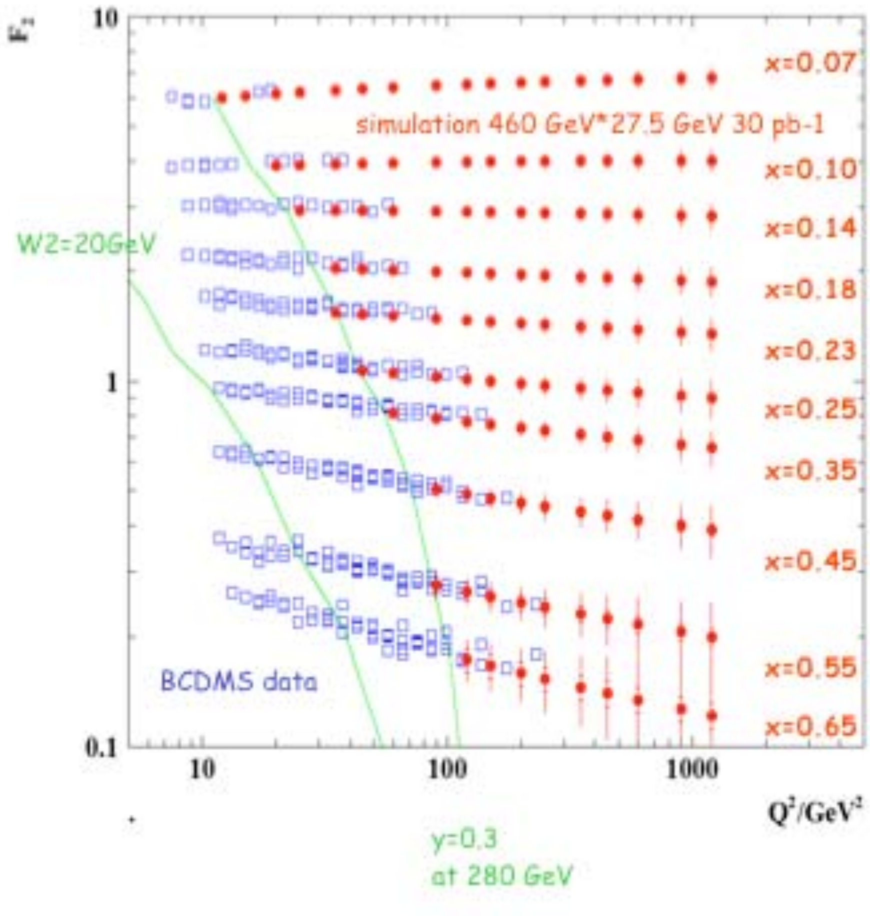
(b)

Parametrize

$F_2 \sim x^{-\lambda}$ for x<0.01

More precision on λ_{eff}, more data for PDF fits

Results



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More overlap with fixed target.

Additional possibilities: new W points for σ_{tot}, VM, …

Conclusions

- The measurement of F_L is a must for HERA - **agreed by both H1 and ZEUS !**
- The measurement is difficult, and will require a long fight with backgrounds & systematics
- The detectors are not optimal for the measurement (final focus magnets, etc). This is one reason why some of us have dreamed of new detectors/accelerators
- The accuracy will be moderate but interesting
- F_L is the prime motivator, but other interesting results expected from low energy run
- Discussion at next PRC if/when to perform the low energy running.