Measurement of FL at HERA

Have we seen anything beyond (N)NLO DGLAP?

AM Cooper-Sarkar

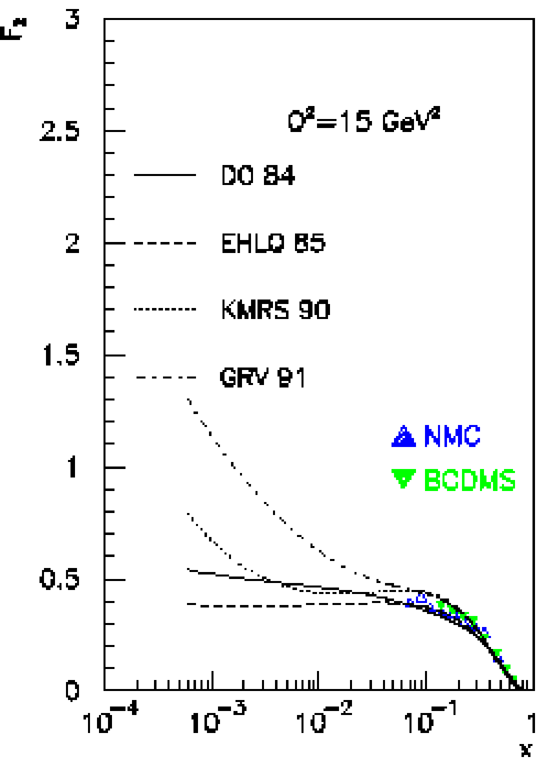
for the ZEUS and H1 Collaborations

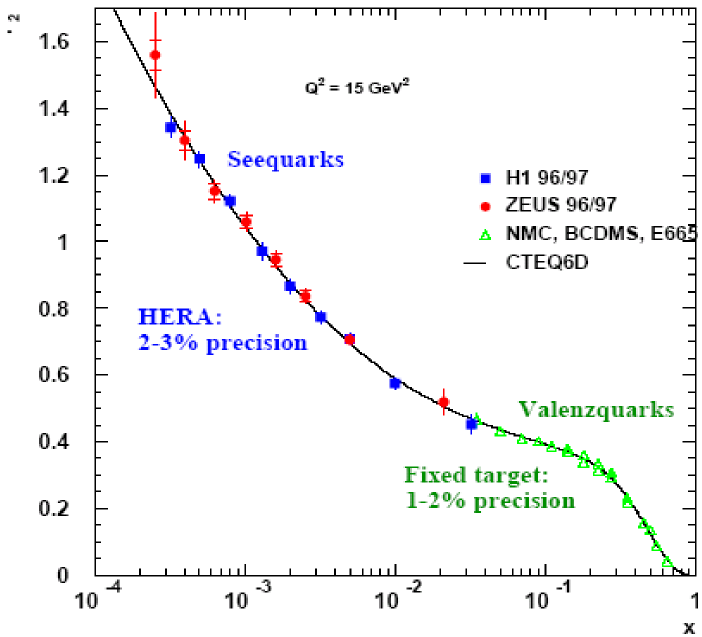
Why measure FL?

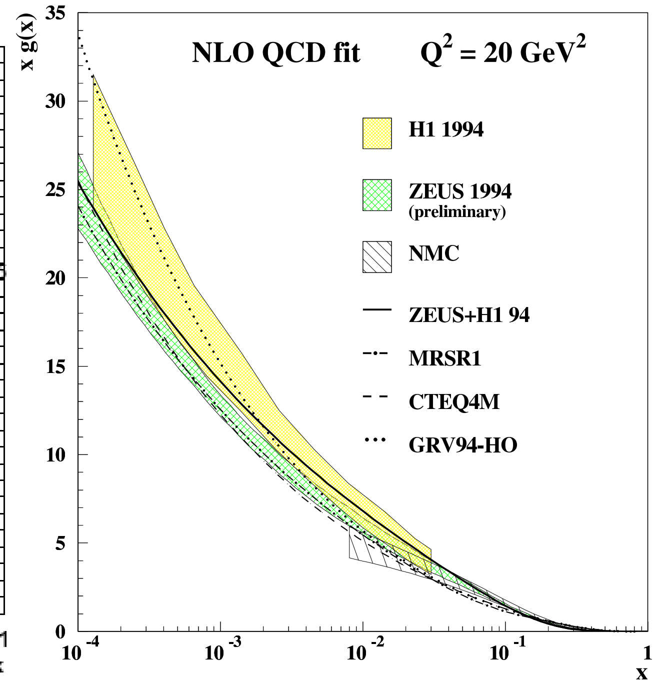
How to measure FL?

FL results and interpretation

Have we seen anything beyond (N)NLO DGLAP at HERA?



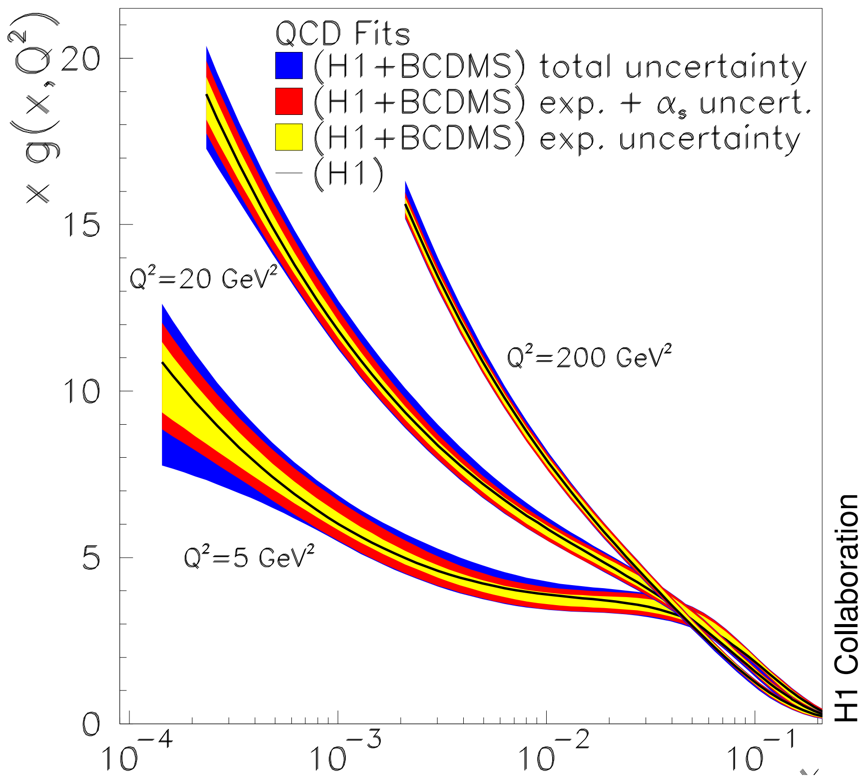


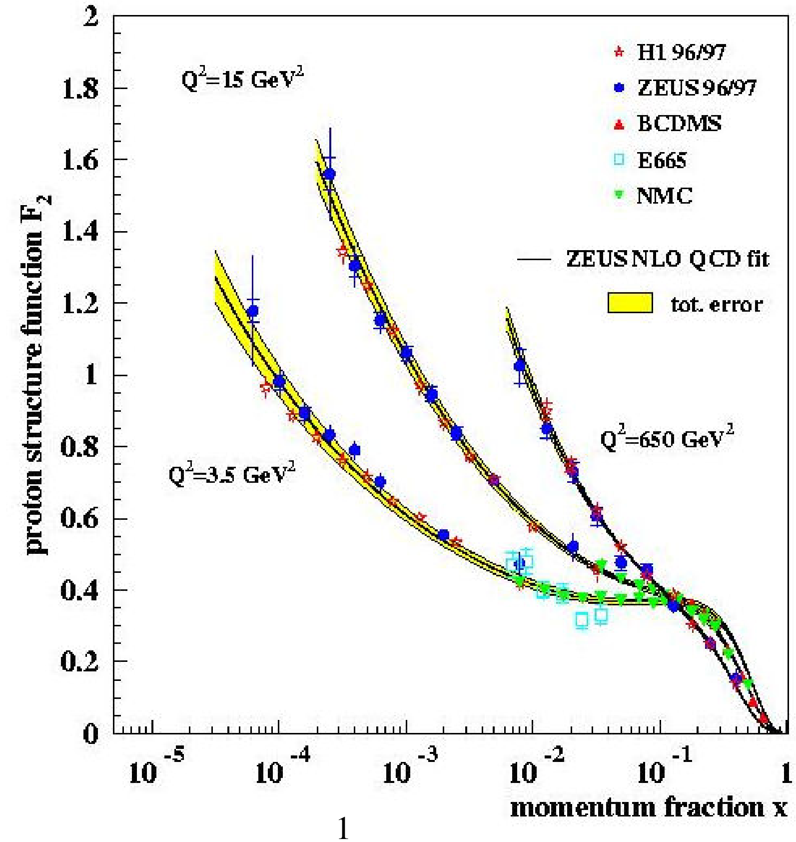


Before the HERA measurements most of the predictions for low-x behaviour of the structure functions and the gluon PDF were wrong – the steep rise at low-x was not expected by most of us..

But perhaps it should have been because this is what DGLAP predicts..

Low-x





$$\frac{dg(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s(Q^2)}{2\pi}\int_0^1 \frac{dy}{y}\left[\Sigma_q Pgq(z)q(y,Q^2) + Pgg(z)g(y,Q^2)\right]$$

At small x,

small z=x/y

$$Pgq \to \frac{C_F}{z}, \quad Pgg \to \frac{2C_A}{z}$$

Gluon splitting functions become singular

$$\frac{dg(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s(Q^2)}{2\pi}\int_0^1 \frac{dy}{y}\frac{6}{z}g(y,Q^2)$$

$xg(x,Q^2) \sim x^{-\lambda g}$

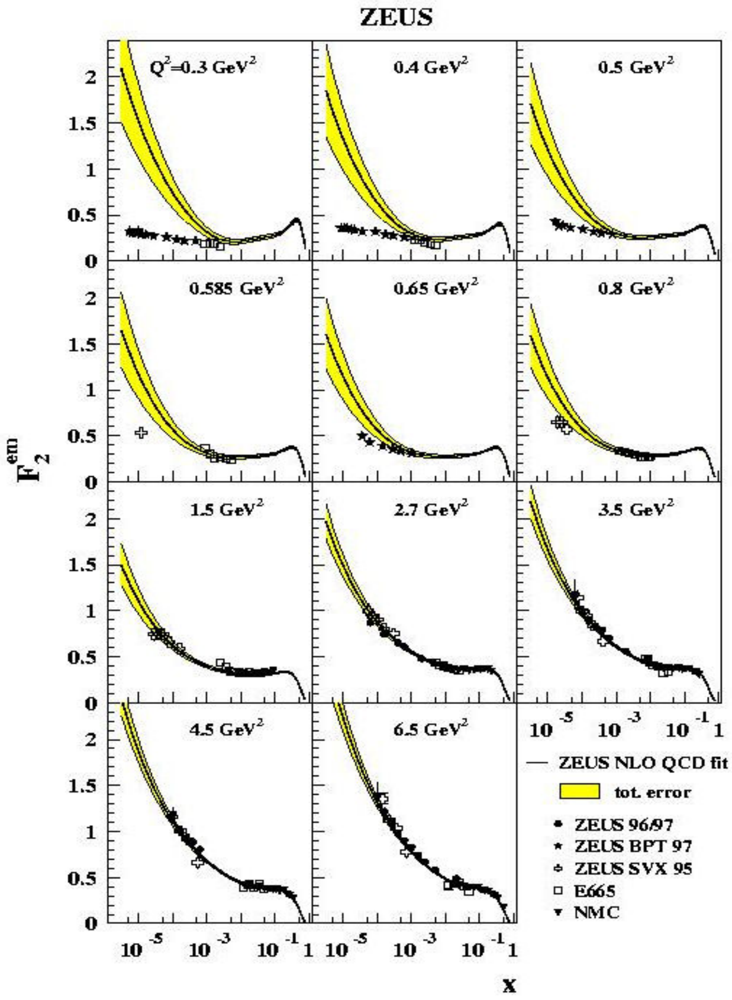
$$\lambda_g = \left(\frac{12\ln(t/t_0)}{\beta_0\ln(1/x)}\right)^{\frac{1}{2}},$$

$t = \ln Q^2/\Lambda^2$

$\alpha_s \sim 1/\ln Q^2/\Lambda^2$

A flat gluon at low Q^2 becomes very steep AFTER Q^2 evolution AND F_2 becomes gluon dominated

$F_2(x,Q^2) \sim x^{-\lambda s}$, $\lambda s = \lambda g - \varepsilon$



Nevertheless the first results were much steeper than had been anticipated

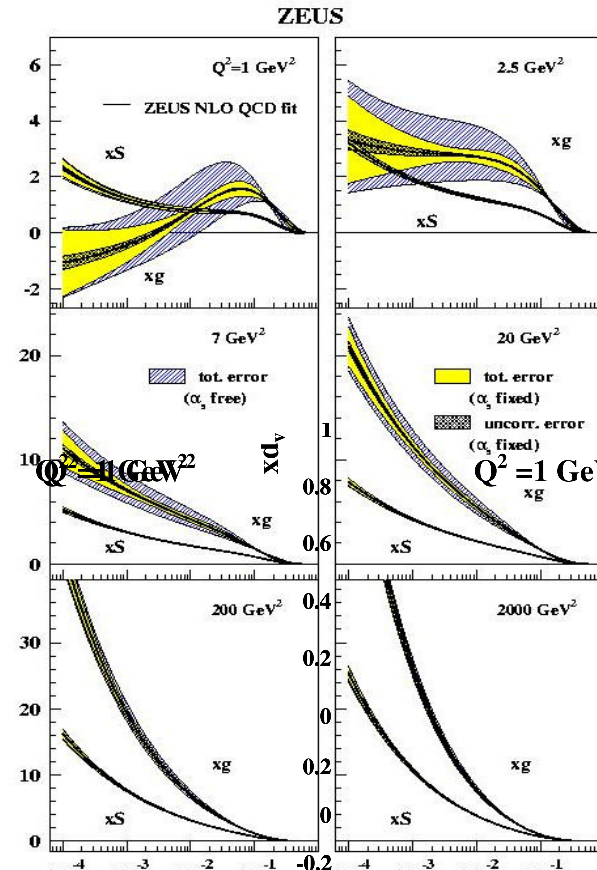
And it was even more of a surprise to see the second results: F_2 steep at small x - for very low Q^2, Q^2 ~ 1 GeV^2

1. Should perturbative QCD work? α_s is becoming large - α_s at Q^2 ~ 1 GeV^2 is ~ 0.4
2. There hasn't been enough lever arm in Q^2 for evolution, so even the starting distribution is steep- **the HUGE rise at low-x makes us think**
3. there **should be** ln(1/x) corrections (BFKL) to the traditional ln(Q^2) summations (DGLAP)
4. and/or there should be non-linear high density corrections for x < 5 10 -3

But is there a 'smoking gun' for new physics at low-x?

When you look at the sea and the gluon deduced from the DGLAP formalism at low Q^2 there are odd features

the gluon is no longer steep at small x – in fact its valence-like or even negative!



The problem is that we are deducing this from limited information

$xS(x) \sim x^{-\lambda s}$, $xg(x) \sim x^{-\lambda g}$

$\lambda g < \lambda s$ at low Q2, low x

So far, we only used

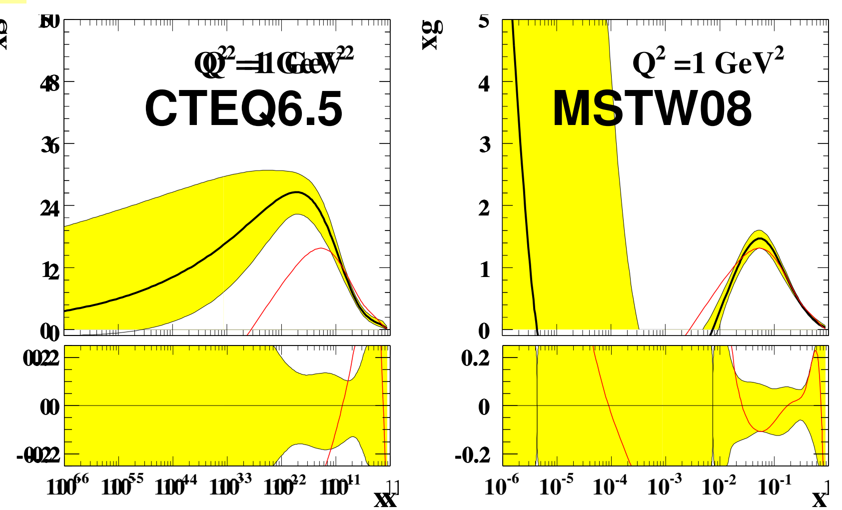
$$F_2 \sim xq$$

$$dF_2/d\ln Q^2 \sim Pqg\ xg$$

Unusual behaviour of $dF_2/d\ln Q^2$ may come from

unusual gluon or from unusual Pqg- alternative evolution?. Non-linear effects?

We need alternative ways to probe the gluon



We need other gluon sensitive measurements like FL

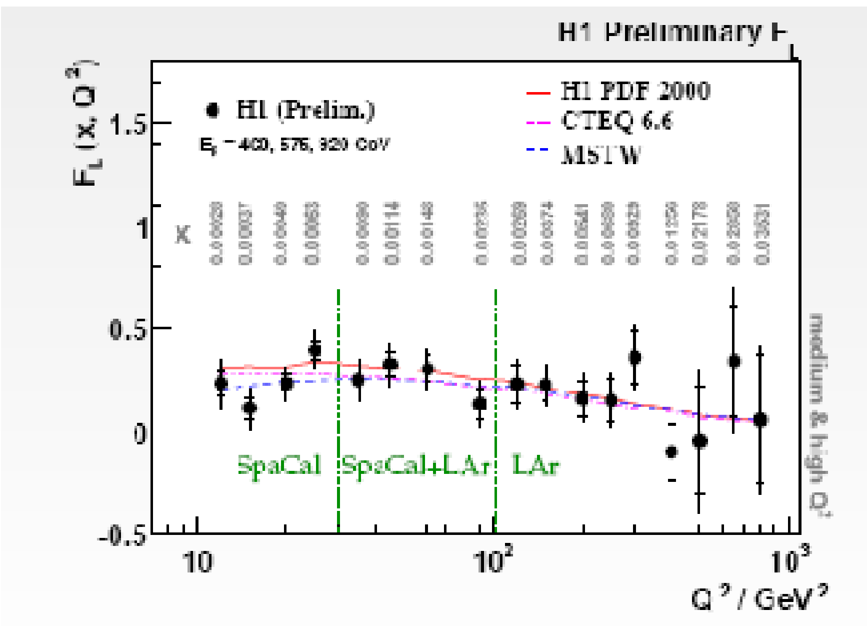
In NLO DGLAP FL is given by

$$F_L(x,Q^2) = \frac{\alpha_s}{x}\left[\frac{4}{3}\int_0^1 \frac{dy}{y} z^2 F_2(y,Q^2) + 2\Sigma_i e_i^2 \int_0^1 \frac{dy}{y} z^2 (1-z)\, yg(y,Q^2)\right]$$

And at low-x this becomes gluon dominated

$$xG(x,Q^2) \approx \frac{3}{5}\, 5.9 \left[\frac{3\pi}{4\alpha_s} F_L(0.4x,Q^2) - ½\, F_2(0.8x,Q^2)\right]$$

LO approx, AMCS et al 1987!!



Even last year I'd have said:

FL looks pretty conventional- can be described with usual NLO DGLAP formalism

BUT there are new FL measurements from HERA ….

So how do we do the FL measurement at HERA?

We measure the NC e+p differentail cross-section at different beam energies

For low Q^2:

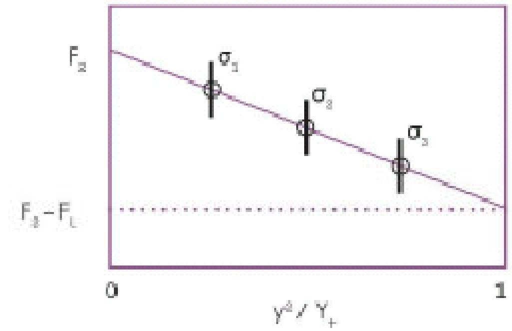
$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\sigma_r$$

$$\sigma_r(x, Q^2; y) = F_2(x, Q^2) - \frac{y^2}{1+(1-y)^2} F_L(x, Q^2)$$

- Measure at the same x, Q^2, different y — use different E_p
- Increase sensitivity by using largest spread in $f(y) = y^2/(1+(1-y)^2)$: $E_p^{max}/E_p^{min} \to$ max, $y \to 1$.

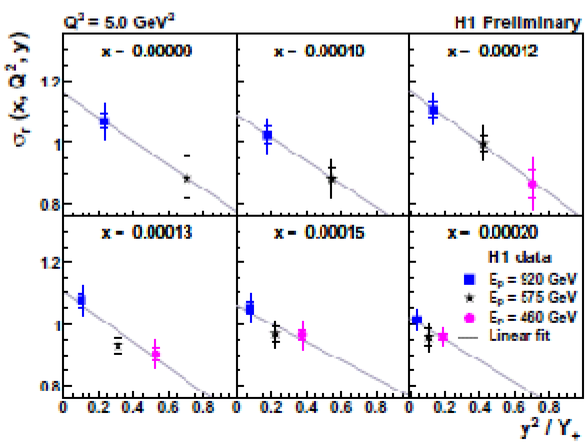
$y=Q^2/sx$

Schematically



At given x and Q^2:
→ F_2 is the intercept at y-axis
→ F_L is the negative slope

And here are H1's actual measurements



$$\sigma_r(y) = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

- Linear fit to get F_2 and F_L
- Relative normalization from low y data

Data used for F_L analysis:

920 GeV → 44 pb^{-1}

460 GeV → 14 pb^{-1}

575 GeV → 7 pb^{-1}

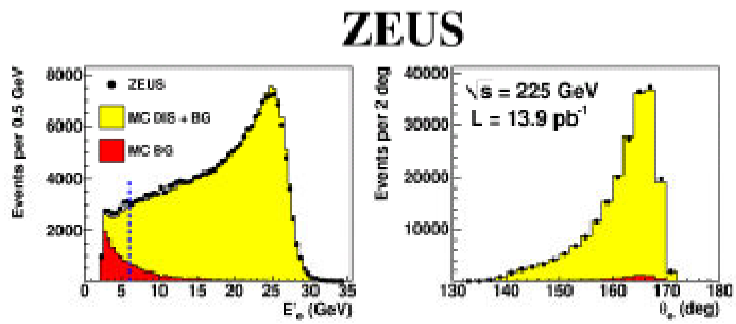
Data at E_p = 575 provides cross check and extends measurement to low x.

Consistent slope   consistent F_L for different x bins.

This is not an easy measurement

Information from scattered electron (E'_e, Θ'_e) is used to reconstruct the kinematics:

$$y = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2}, \quad Q^2 = \frac{E'^2_e \sin^2\theta_e}{1-y}$$



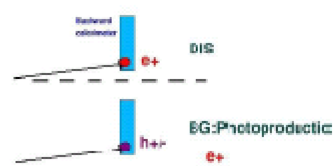
Most of our previous measurements have been at low-y

Low-y high-s
→ high energy well separated scattered electron
→ almost no background

High-y low-s
→ low energy scattered electron
→ lot of hadronic activity around scattered electron
→ large background

- Main background for the measurement is photoproduction:
  - Electron escapes down the beam pipe
  - A hadron or a photon is misidentified as scattered electron

ZEUS DESY-09-046



- Photoproduction events are rejected with cuts and the rest are subtracted statistically using MC
- MC normalisation is checked with 6m-tagger
- Neutral background is rejected with track requirement. ZEUS tracking system acceptance is limited to $\theta < 154°$

  → However, the information about single hits in the tracking detectors can be used up to $\theta < 168°$ (but with no information about the charge)

- Final data samle: 97% signal, 3% background
  - Background contribution is 16% in most affected bin (at low Q^2 and high y)

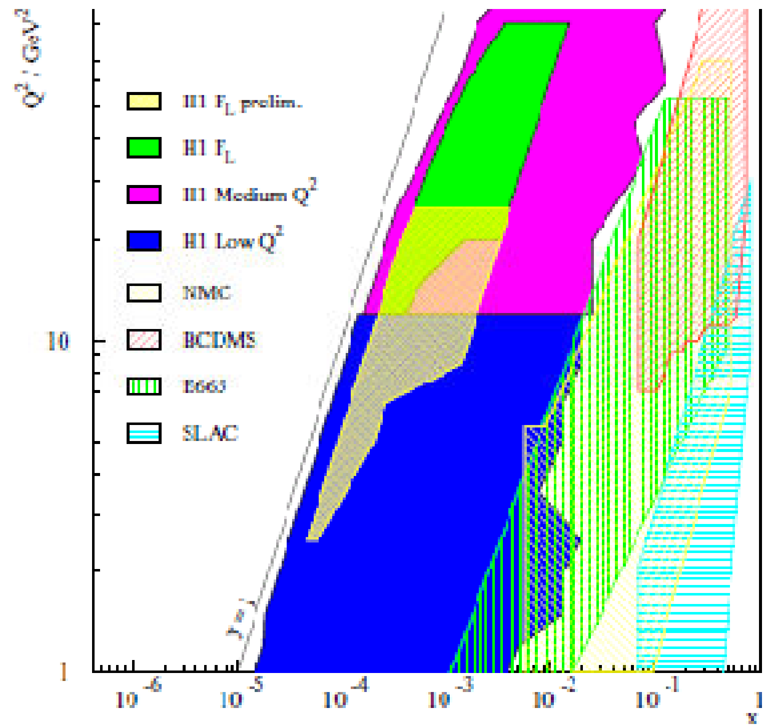
Measurement at both low and high y are required. High y is much more difficult.

$$y \approx 1 - \frac{E'_e}{E_e}$$

Measurement extends down to $E'_e = 3.4$ GeV.

- Trigger efficiency/rate
- Electron identification
- Radiative corrections
- Background

H1prelim-09-044



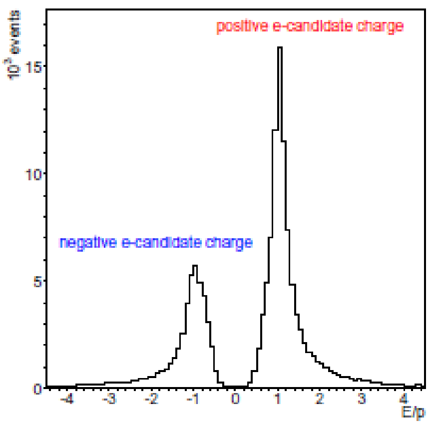
Background Estimation

Measure particle charge using curvature of the associated track.

e^+p scattering:

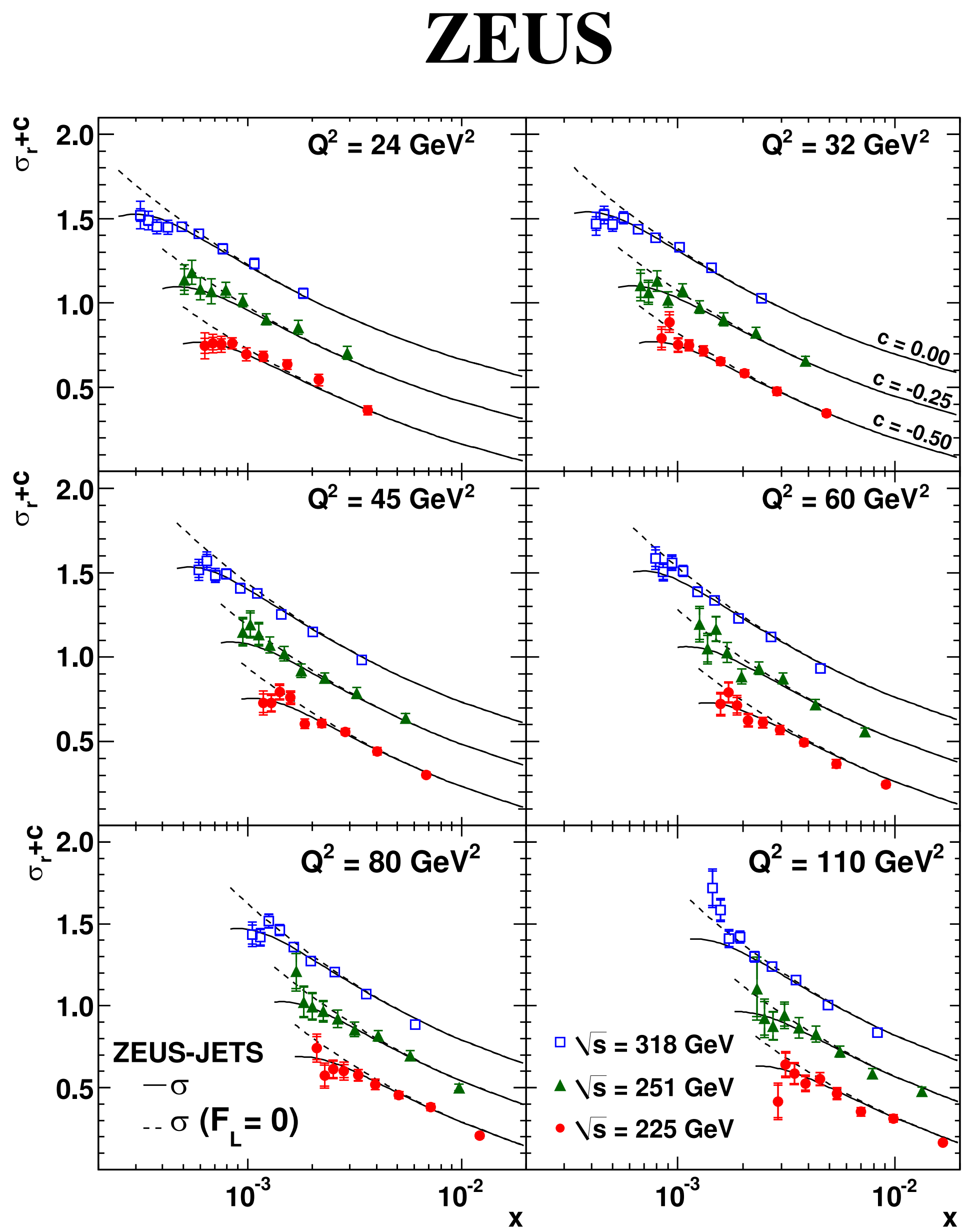
+ Scattered lepton has the beam charge (positive).
– Background from hadronic particles, γ conversions is almost charge symmetric: $N^+_{bg} \approx N^-_{bg}$

→ require positive charge for the signal sample. Estimate remaining background using negative sample.



Three separate measurements, defined by electron measurement techniques:

- Medium Q^2, $12 \leq Q^2 \leq 90$ GeV^2, SpaCal+CT, Phys.Lett.B665:139 (2008)
- High Q^2, $35 \leq Q^2 \leq 800$ GeV^2, LAr + CT (H1 preliminary).
- low Q^2, $2.5 \leq Q^2 \leq 25$ GeV^2, SpaCal+BST+CT.



Reduced cross-section measurements at three different beam energies

Kinematic region:

20 GeV^2 < Q^2 < 130 GeV^2

$5 \cdot 10^{-4} < x < 7 \cdot 10^{-3}$

- First ZEUS F_L publication available
- Most precise cross section measurement from ZEUS in the kinematic region studied
- Measured cross sections are published and available for fits
- Measured cross sections compared to ZEUS-JETS with and without F_L
- **Turnover at low x small but visible**

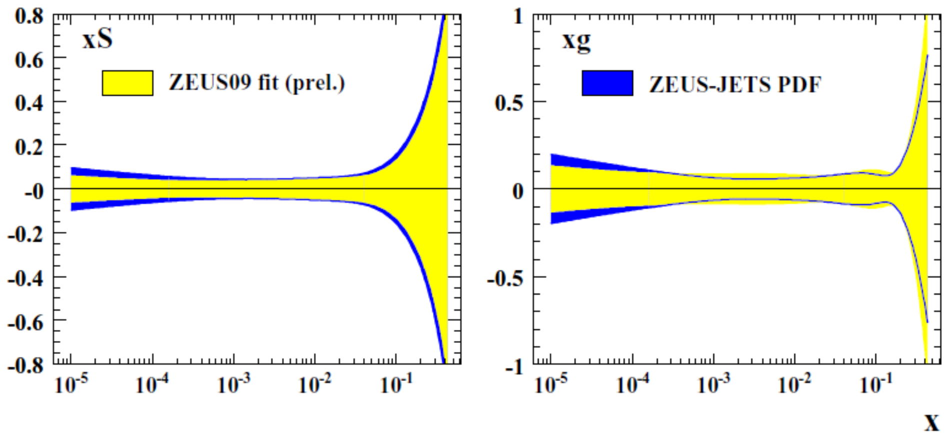
Impact of adding HER (Ep=920,44.5pb^{-1}), MER (Ep=575, 7.1pb^{-1}), LER (Ep=460, 14.0pb-1) : NC e+p ‘FL’ data to the ZEUS-JETS PDF fit

ZEUS-prel-09-010

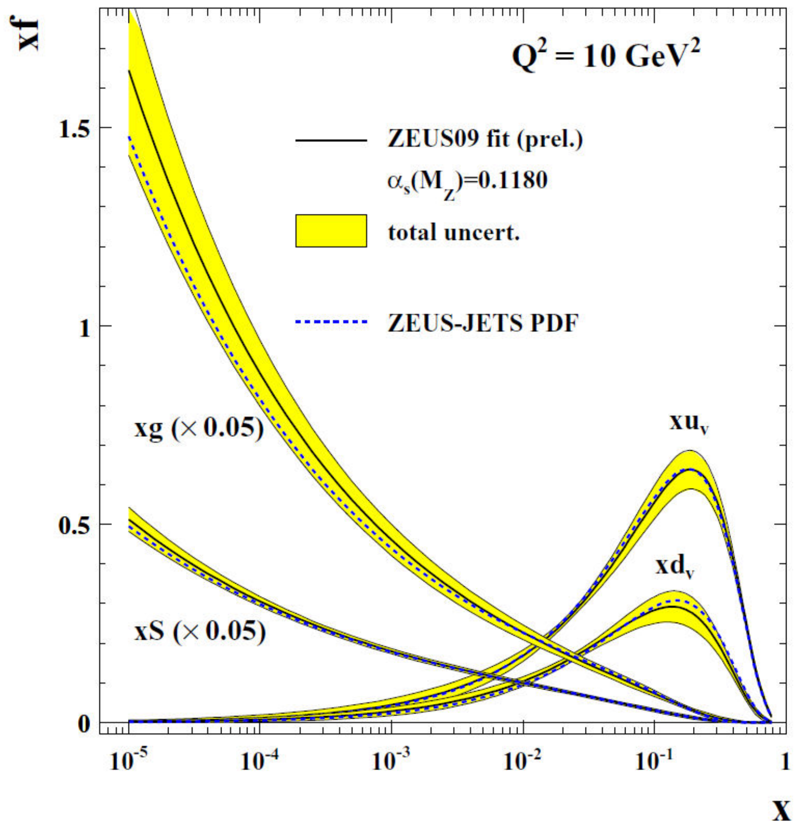
The new ‘FL’ data are well fit by the conventional DGLAP formalism

Dataset	χ2/ndp	ndp
LER	0.84	54
MER	0.73	54
HER	0.97	54

The low-x gluon is a little steeper

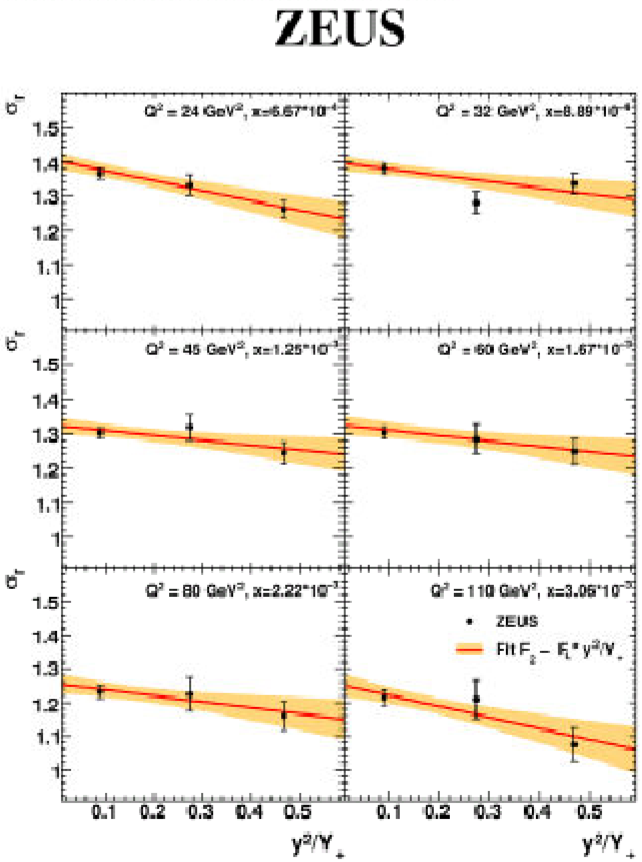


The uncertainties of the low-x Sea and gluon are reduced



ZEUS extract F2 and FL from their reduced cross-section data via a Bayesian fit

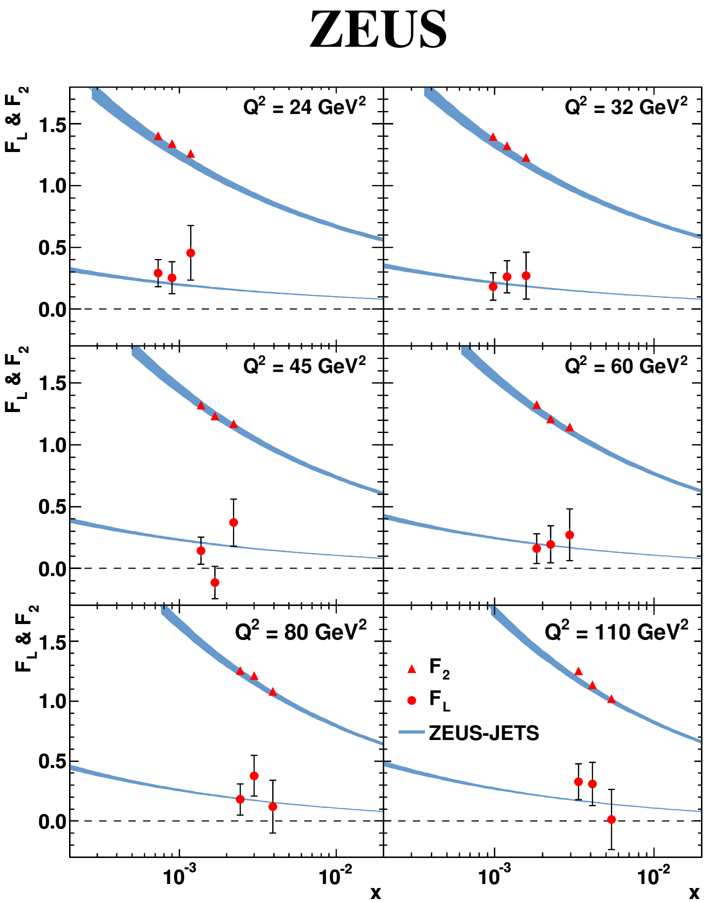
ZEUS DESY-09-046



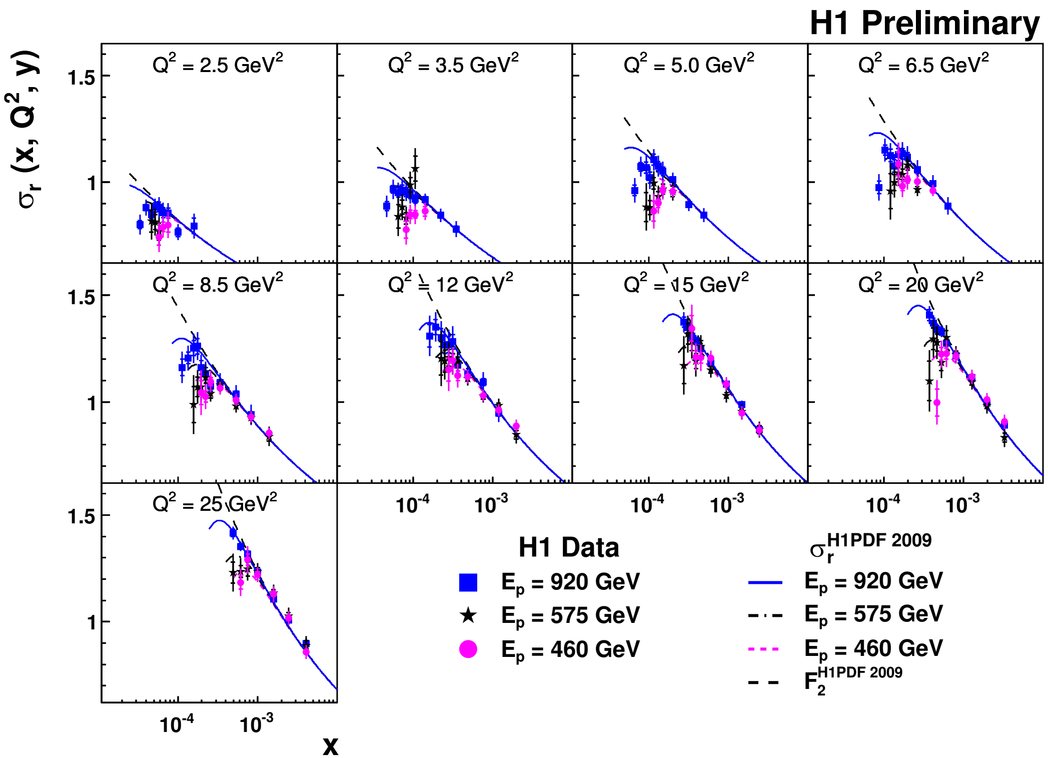
- Before fit three data sets are normalised to luminosity-weighted average at low y (y<0.3)

- Fit was performed within Bayesian approach assuming flat prior probabilities
  - Full information about correlations is taken into account

- To extract F_L and F_2 48 parameters were fit:
  - → 18 F_2 and 18 F_L values
  - → 3 uncertainties on relative normalisation factors
  - → 9 systematic uncertainties



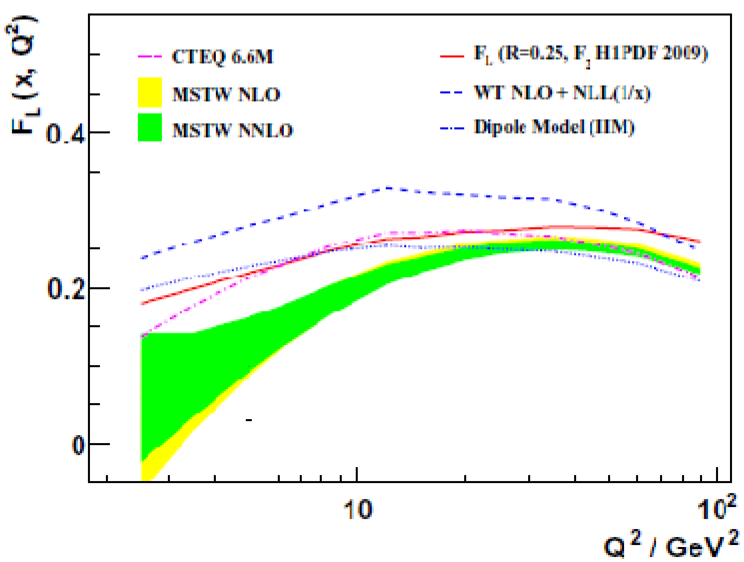
- **Most precise F_2 measurement from ZEUS at kinematic region studied**
- **First F_2 measurement without assumptions on F_L**

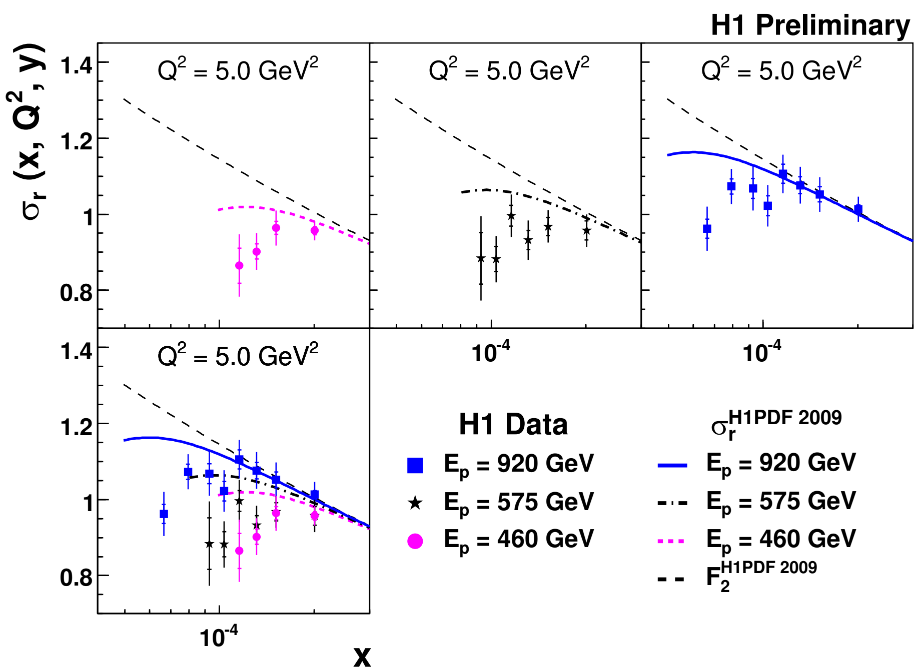


H1 reduced cross-section data goes to lower Q2 than ZEUS

Home in on Q2=5.0 GeV2

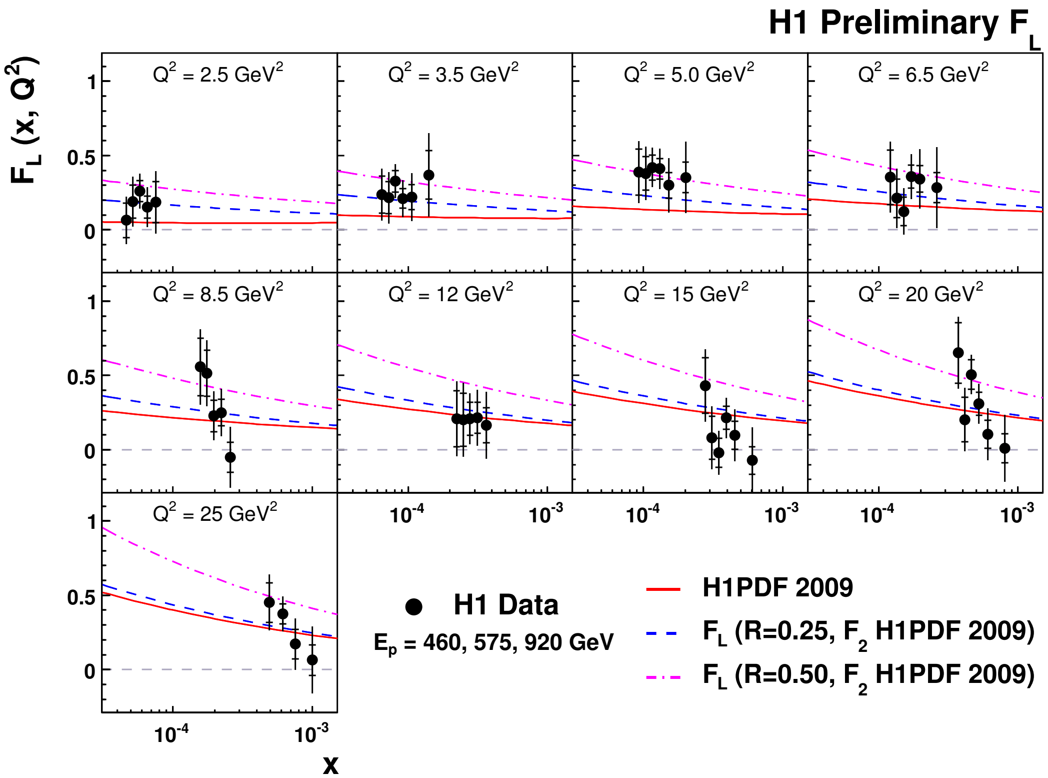
The data is below the H1PDF2009 NLOQCD fit





Predictions differ more at low Q2

H1prelim-09-044

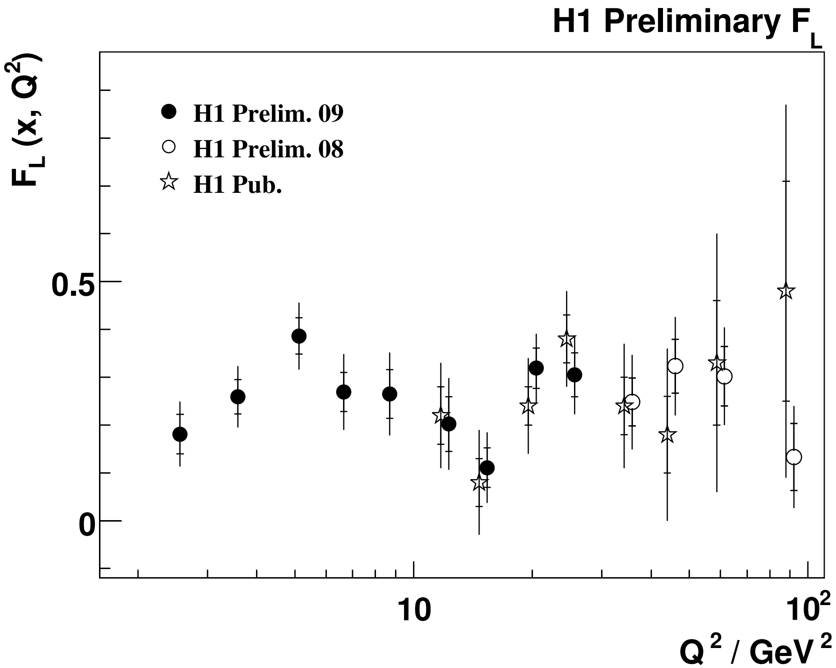


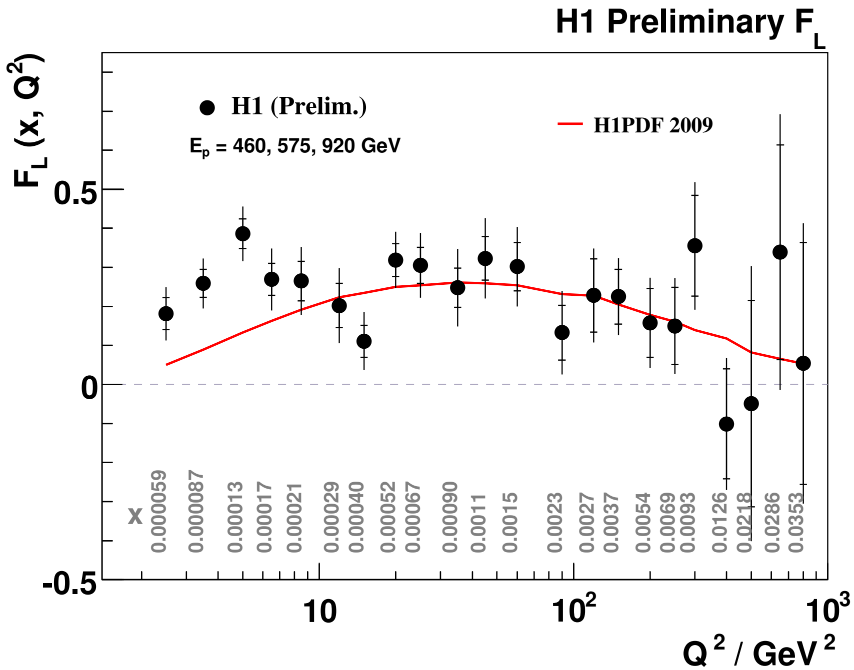
Compare to variants of H1 PDF2009 in which alternative (not NLO DGLAP QCD) values of $R = \sigma_L/\sigma_T$= FL/(F2-FL) are used

Data seem to require a larger value of R/FL than NLOQCD

Now let's compare this year's new result to last year's

Compatible- but the point is the extension of the kinematic range to low Q2





Now let’s take the summary plot and compare it to various predictions

It’s not just H1 PDF 2009 that fails to fit

QCD PDF fits in the conventional DGLAP scheme all fall somewhat low

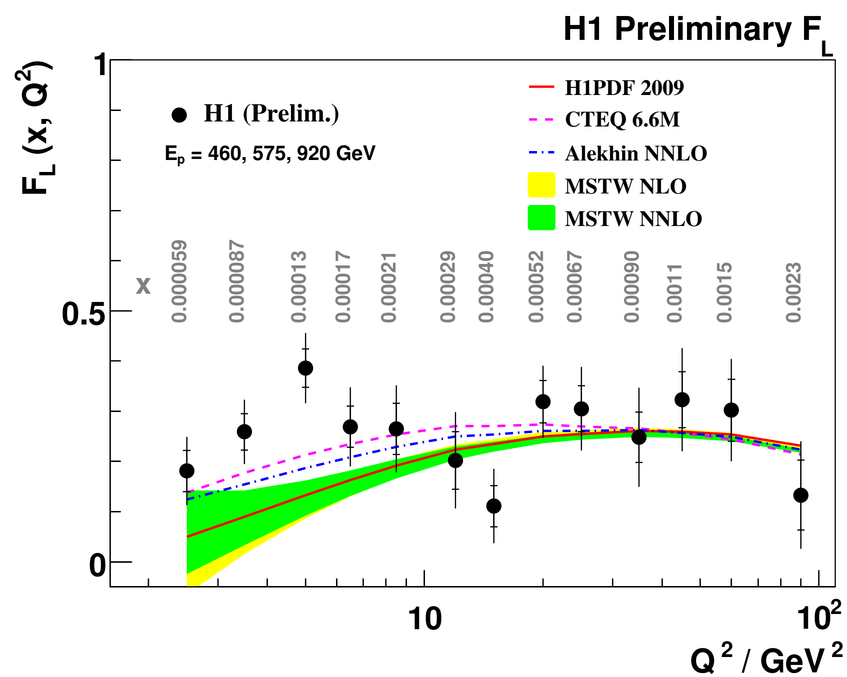
You can of course argue that some fit better than others- but the differences are mostly the order to which FL is calculated

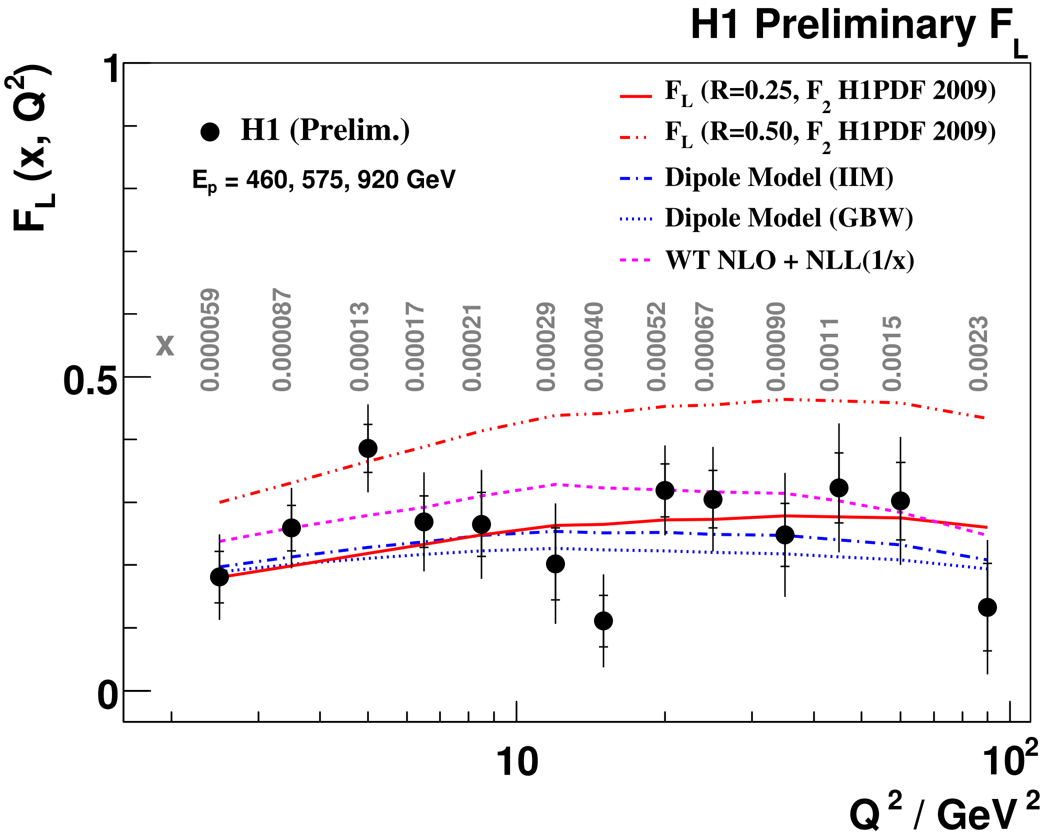
CTEQ6.6 (NLO) $O(\alpha_s)$

MSTW08 (NLO) $O(\alpha_s^2)$

MSTW08 (NNLO) $O(\alpha_s^3)$

And since more orders should be better this doesn’t help





And finally look at the alternative theoretical predictions:

White and Thorne (WT) which has NLL ln1/x resummation included

Dipole Models which can accommodate saturation eg IIM colour glass condensate

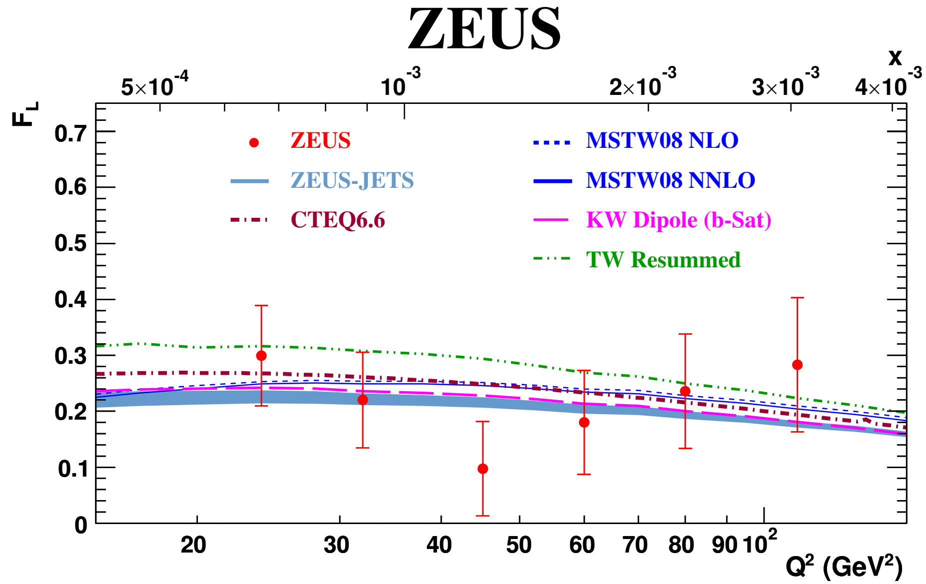
So do we have a smoking gun?

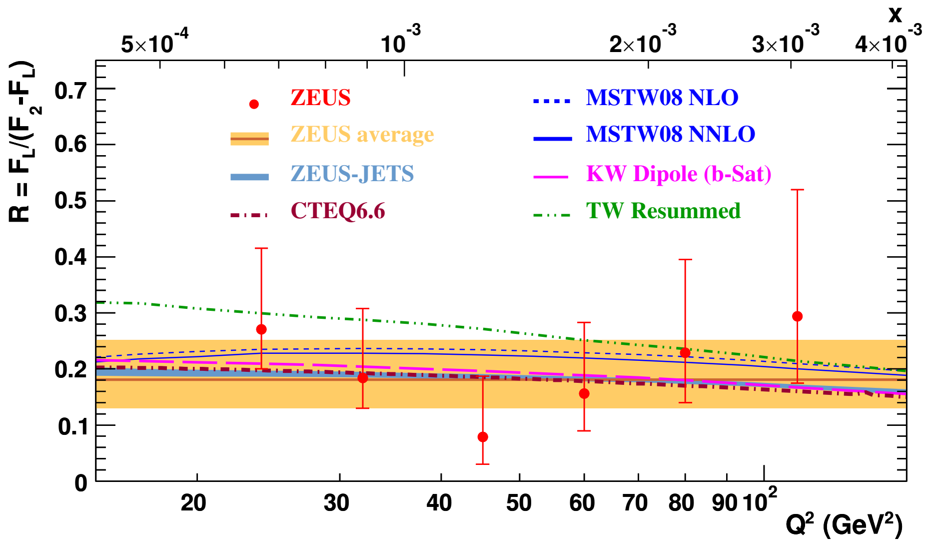
Maybe not- but the circumstantial evidence is building up

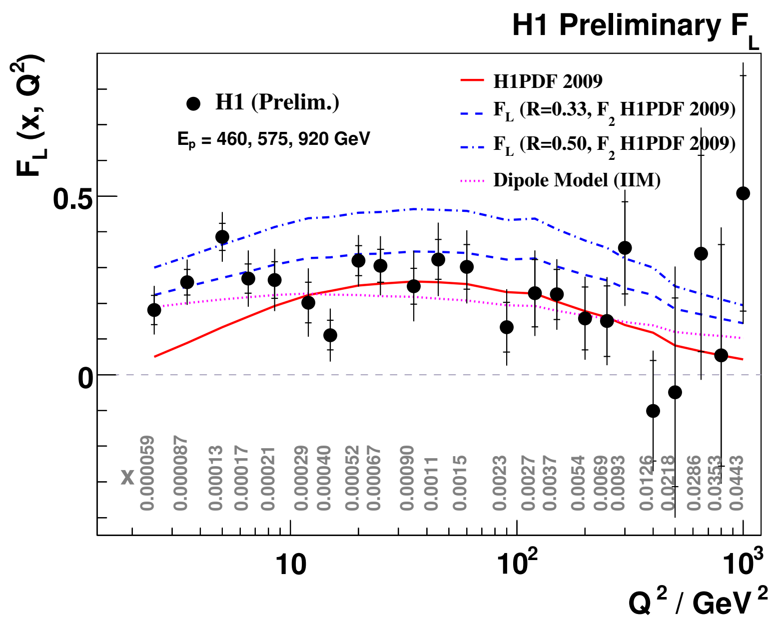
Summary

- HERA has now measured FL to low Q2 and hence to $x < 3\ 10^{-4}$
- The lowest x points are not well fit by NLO DGLAP

EXTRAS


ZEUS
F_L
ZEUS
ZEUS-JETS
CTEQ6.6
MSTW08 NLO
MSTW08 NNLO
KW Dipole (b-Sat)
TW Resummed
x
Q² (GeV²)


R = F_L/(F_2-F_L)
ZEUS
ZEUS average
ZEUS-JETS
CTEQ6.6
MSTW08 NLO
MSTW08 NNLO
KW Dipole (b-Sat)
TW Resummed
x
Q² (GeV²)


H1 Preliminary F_L
F_L (x, Q²)
H1 (Prelim.)
E_p = 460, 575, 920 GeV
H1PDF 2009
F_L (R=0.33, F_2 H1PDF 2009)
F_L (R=0.50, F_2 H1PDF 2009)
Dipole Model (IIM)
Q² / GeV²