Measurements of the longitudinal proton structure function, F_L, at HERA

Lake Louise Winter Institute 2009

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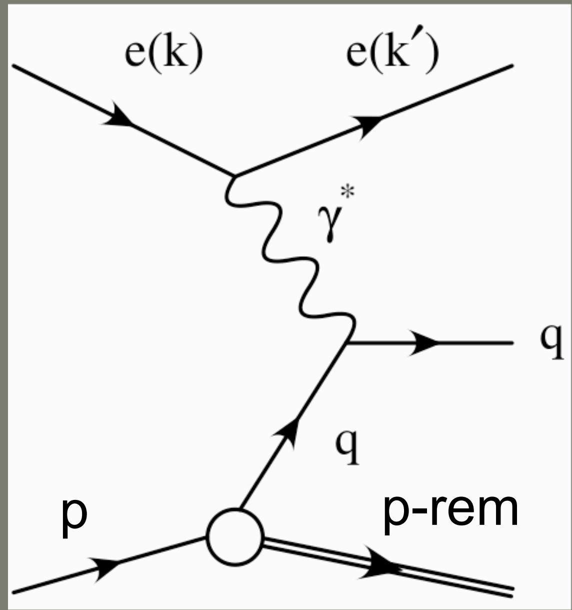
On behalf of the ZEUS & H1 collaborations

Outline

- Framework (structure functions)
- Motivation (to measure F_L)
- Analysis strategy
- Results (from ZEUS & H1)
- Summary

Framework

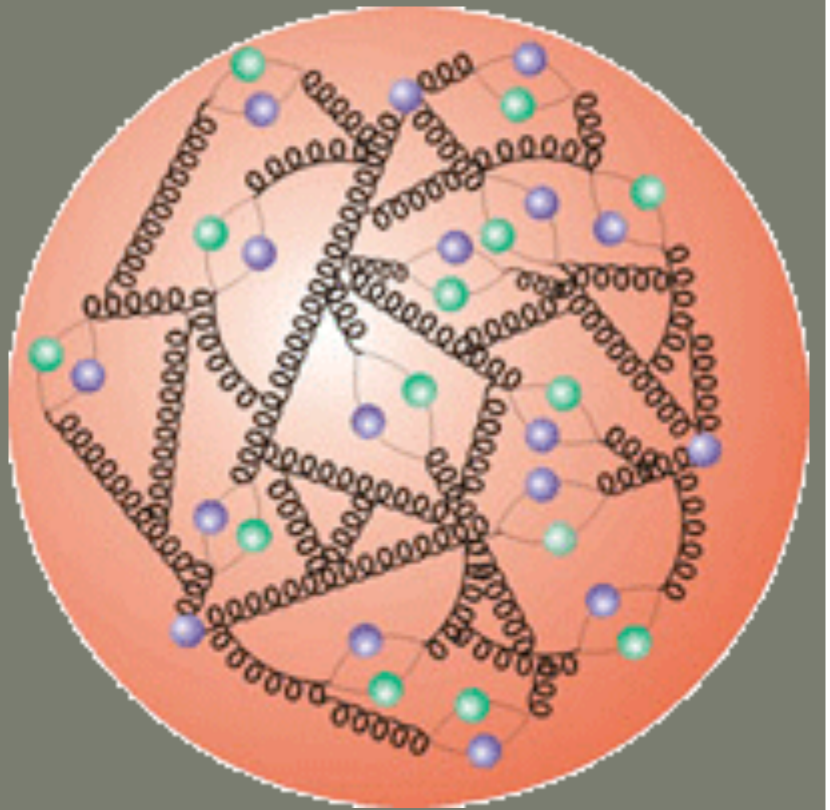
- HERA is an electon-proton (*ep*) collider
- Based in Hamburg, Germany
- 6.3 km long was home to 4 experiments
- Shown here are results from H1 & ZEUS



- Deep-inelastic scattering (DIS)
- Reaction: $ep \longrightarrow eX$
- Here, only consider virtual photon exchange (no weak interactions)
- LO diagram shown above

Framework

- In DIS, the internal quark-gluon structure of the proton is resolved
- Proton structure is fully parameterised by **structure functions**
- Functions of 2 variables. Often described in terms of:
  - Q^2 : the virtuality of exchanged photon
  - x : the Bjorken scaling variable
- 3rd kinematic variable y : inelasticity
- At low Q^2, two structure functions needed, and F_2 and F_L are commonly chosen
- From which…



Framework

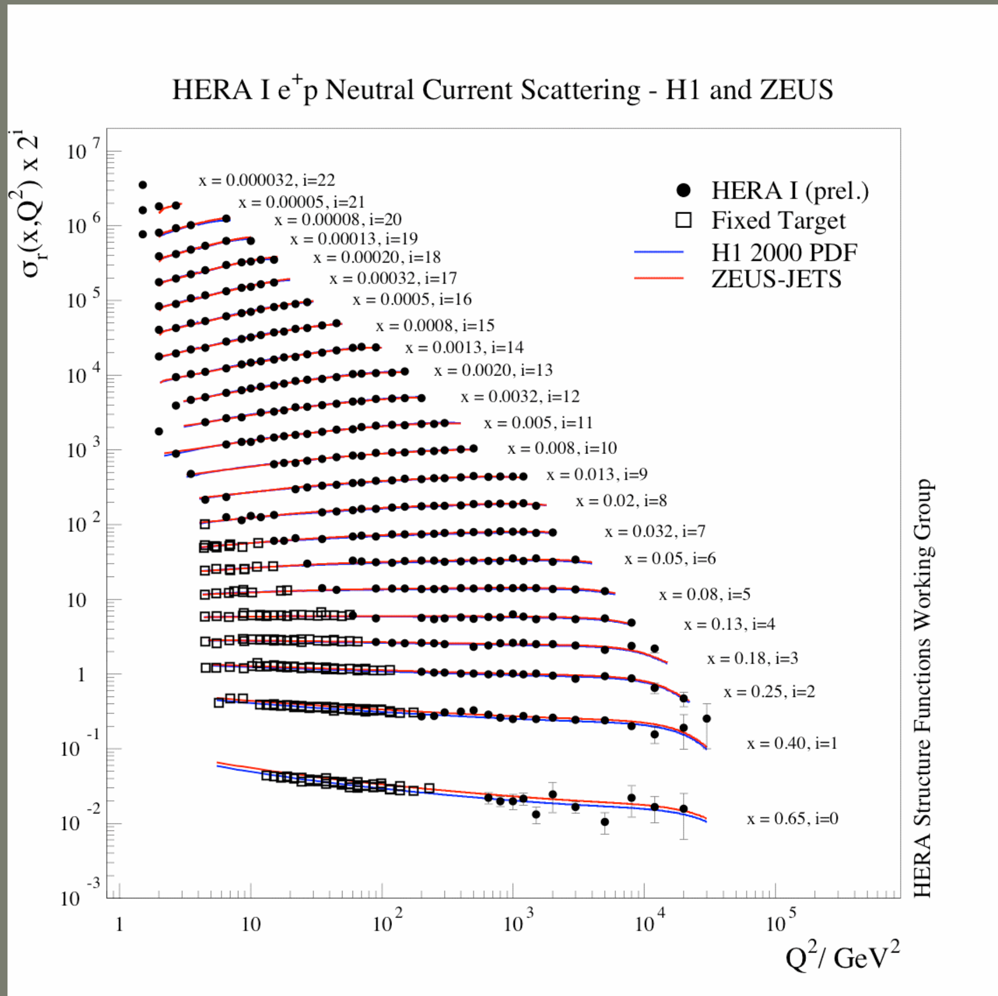
- …the DIS cross section is written as:

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

- where $Y_+ = 1 + \left(1 - y\right)^2$ and σ_r is the **reduced cross section**.
- the structure function $F_L \propto \sigma_L$
- where σ_L is the proton / longitudinally polarised virtual photon cross section
- the structure function $F_2 \propto \sigma_L + \sigma_T$
- where σ_T is the proton / transversely polarised virtual photon cross section
- Also of interest is the ratio $R = F_L / \left(F_2 - F_L\right) = \sigma_L / \sigma_T$

Motivation

- HERA measurements of the reduced cross section provide:
  - basis of F_2 extractions
  - best constraint on gluon PDF at low x
- Previous F_2 measurements depend on model dependent assumptions about F_L
- Similarly, the gluon density extracted depends on the formalism used



Motivation

- Need model independent way to extract F_2 and access the gluon density
- F_L is directly related to the gluon density
- Hence, a direct measurement of F_L would provide:
    1. **confirmation of F_L assumptions**
    2. **model independent access to gluon density**
    3. **important test of the formalisms**

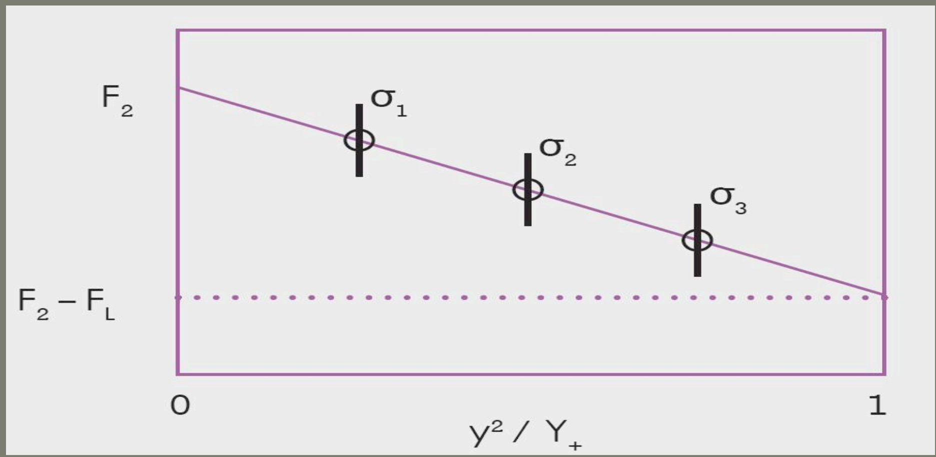
Analysis strategy

- From DIS cross section formula:

$$F_2\left(x,Q^2\right) = \sigma_r\left(x,Q^2,y=0\right)$$

$$F_L\left(x,Q^2\right) = -\frac{\partial\sigma_r\left(x,Q^2,y\right)}{\partial\left(y^2/Y_+\right)}$$

Rosenbluth plot



- hence need to measure σ_r at fixed *(x,Q²)* but with varying *y*
- In *ep* collisions, kinematic variables *(x,Q²,y)* are related via:

$$\sqrt{s} = \sqrt{Q^2/xy}$$

- where $\sqrt{s}$ is the beam centre-of-mass (CoM) energy
- so **need *ep* data at multiple CoM energies**

Analysis strategy

- HERA operated at 3 different CoM energies achieved by varying proton energy, $E_{p:}$
  - high-energy (HER): $\sqrt{s} = 318 \;\; GeV \;\; (E_p = 920 \;\; GeV)$
  - medium- energy (MER): $\sqrt{s} = 251 \;\; GeV \;\; (E_p = 575 \;\; GeV)$
  - low-energy (LER): $\sqrt{s} = 225 \;\; GeV \;\; (E_p = 460 \;\; GeV)$
- electron energy, E_e = 27.5 GeV, kept constant

Analysis strategy

H1 mid-Q^2 analysis

- published Phys. Lett. B
- $12 < Q^2 < 90$ GeV^2
- $0.00024 < x < 0.0036$
- First direct F_L measurement

H1 high-Q^2 analysis

- H1 preliminary
- $35 < Q^2 < 800$ GeV^2
- $0.00028 < x < 0.0353$
- mid- + high-Q^2 analyses span the widest kinematic studied to date

- background statistically removed using wrong charge subtraction technique (data subtracting data)

ZEUS analysis

- submitted to journal
- $24 < Q^2 < 110$ GeV^2
- $0.0005 < x < 0.007$
- First FL analysis by ZEUS
- σ_r @ CoM 318, 251, 225 GeV
- first F_2 extracted at low x without F_L assumptions
- most precise F_2 by ZEUS in kinematic region studied

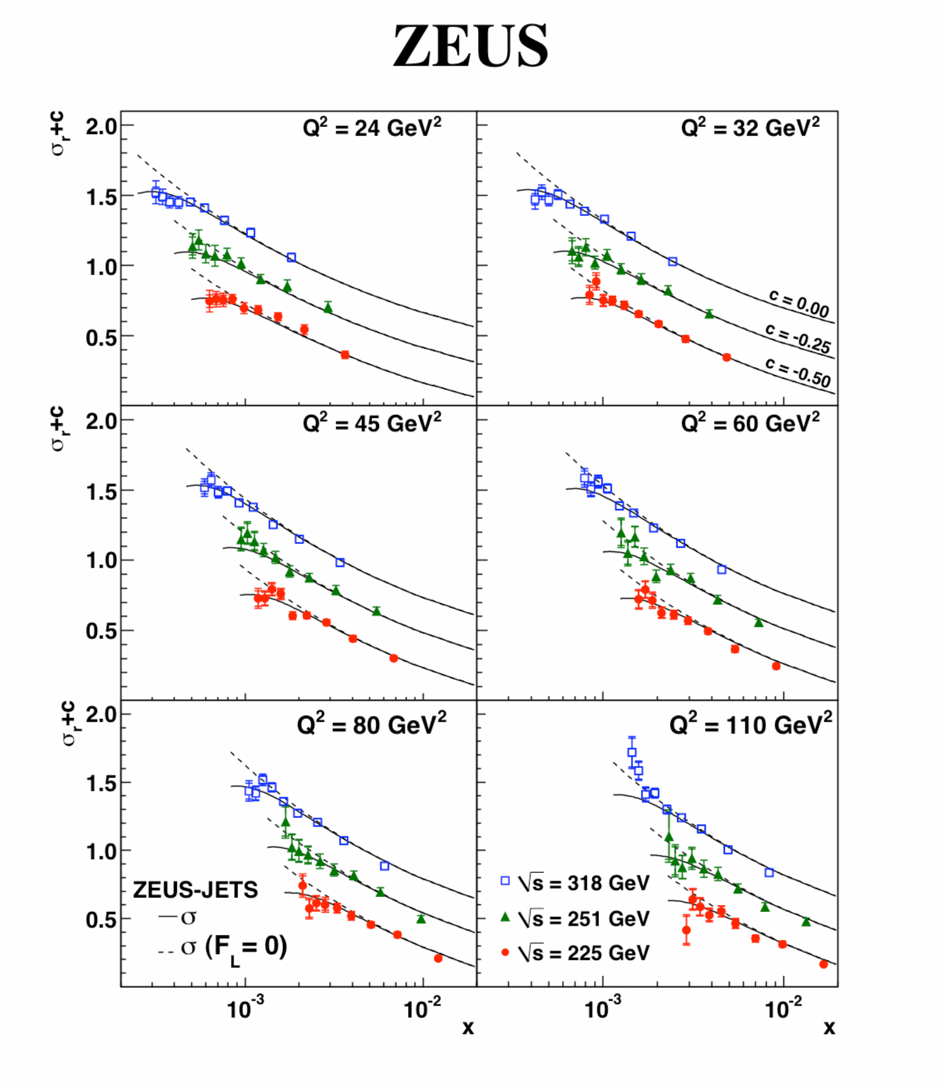
- background statistically removed based on MC simulation

Results

- Reduced cross sections
- $F_L(x,Q^2)$
- $F_L(Q^2)$
- $R(Q^2)$

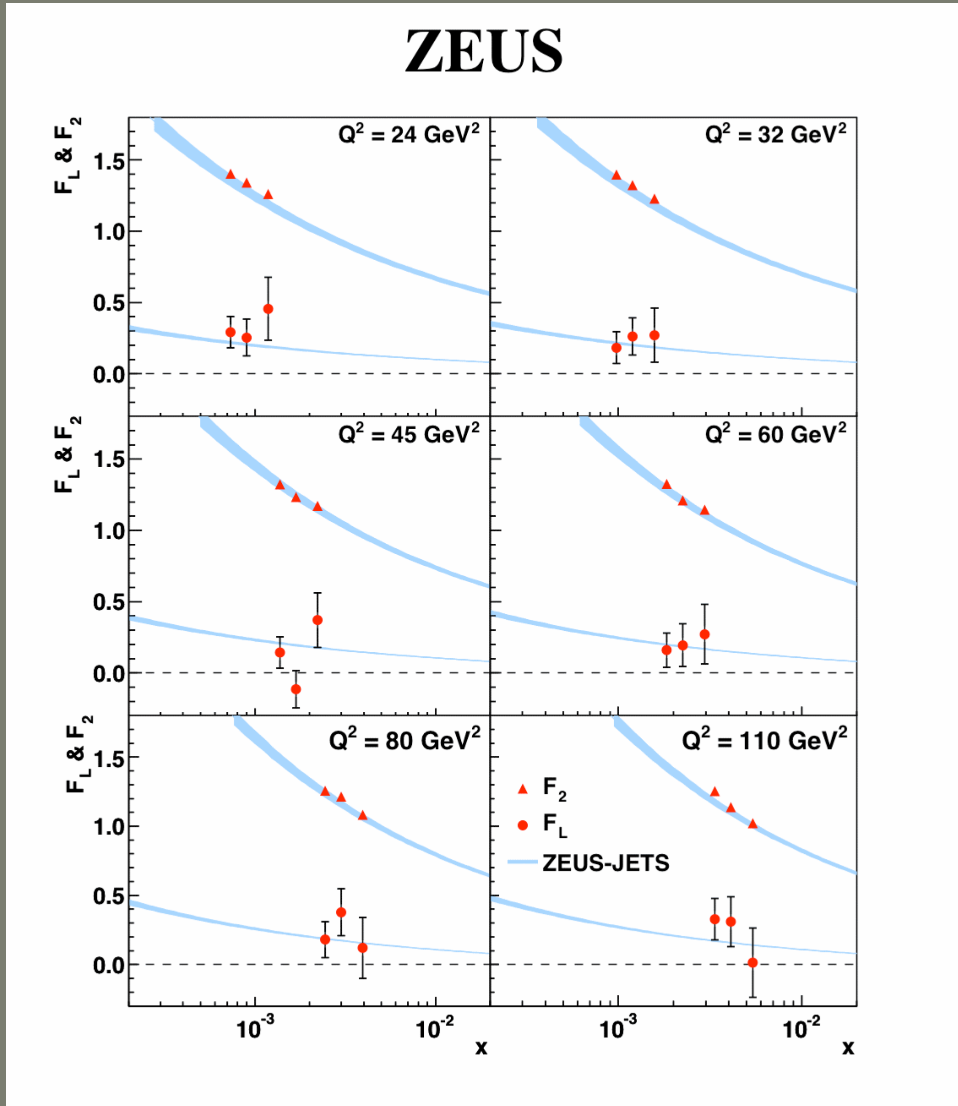
Reduced cross sections - ZEUS

- $\sigma_r(x)$ in bins of Q^2 for each COM energy offset along *y*-axis for clarity
- compared to prediction based on ZEUS-JETS PDF set with expected F_L and $F_L=0$
- F_L causes a suppression at low *x*. Different for each CoM energy - basis of F_L extraction
- small effect but data tend to turn over as expected



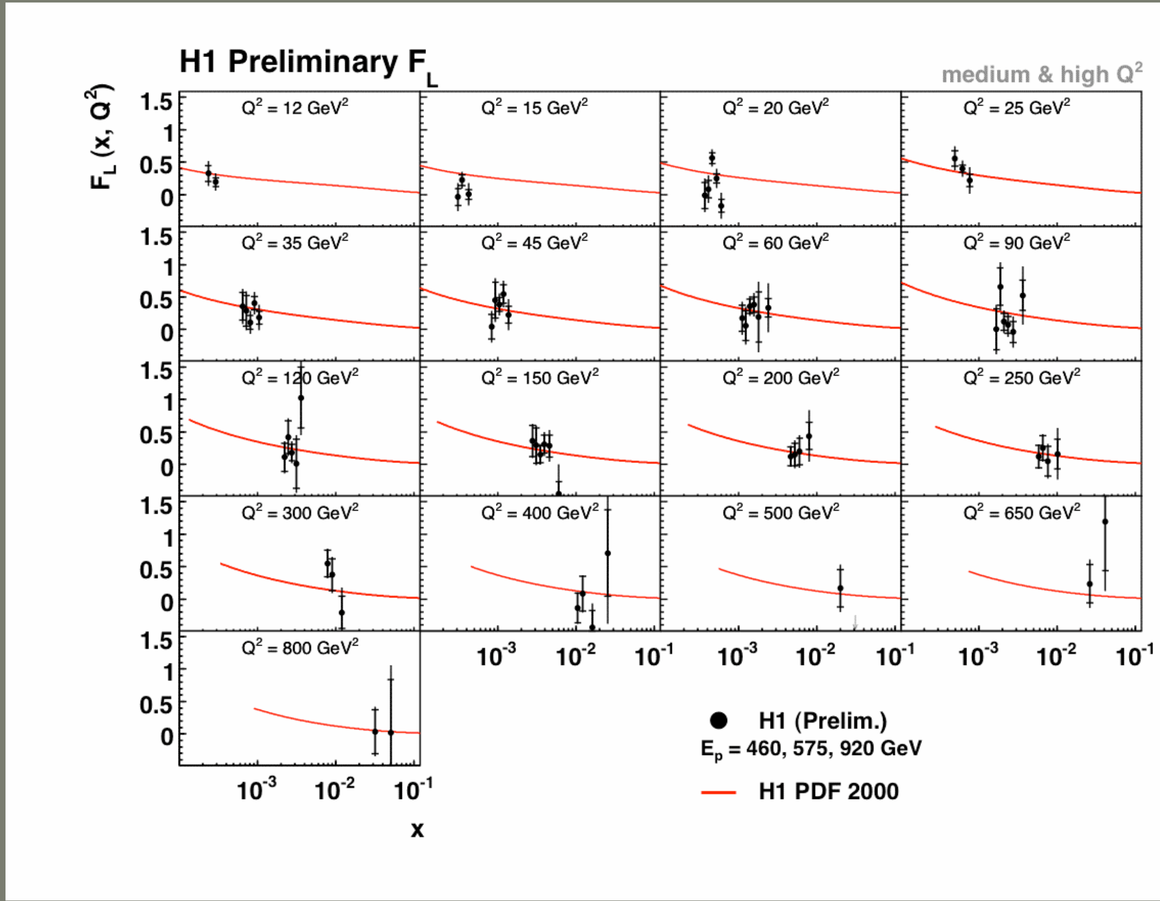
$F_L(x,Q^2)$ - ZEUS

- $F_L(x)$ and $F_2(x)$ in bins of Q^2
- uncertainty bars indicate combined stat. & syst. uncert.
- data support a non-zero F_L
- compared to the ZEUS-JETS PDF prediction (including the theo. uncertainty)
- predictions consistent with F_L and F_2 data



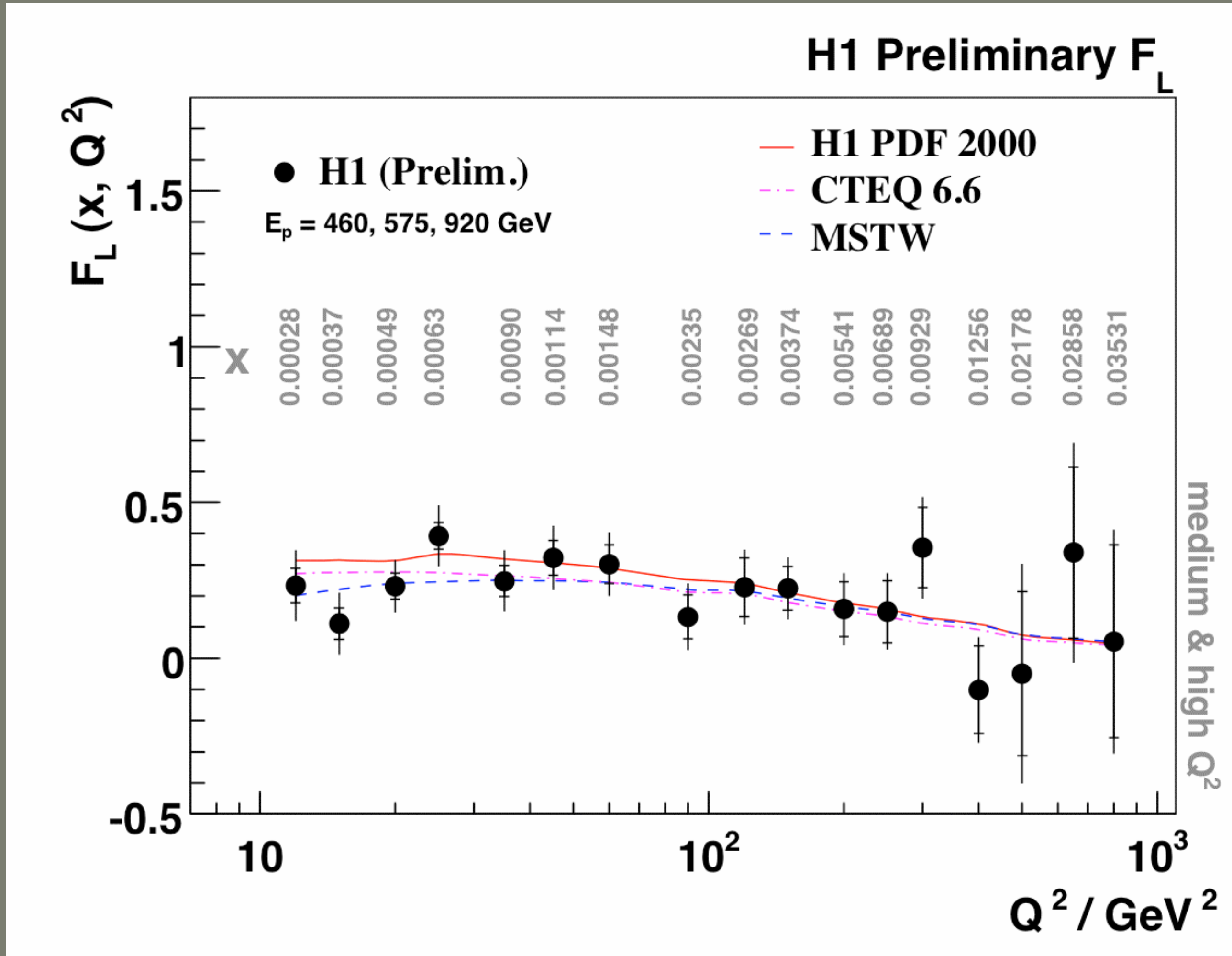
$F_L(x,Q^2)$ - H1

- $F_L(x)$ in bins of Q^2 from mid-/high-Q^2 analyses
- data support a non-zero F_L
- ZEUS data consistent in overlapping region
- compared to the H1 2000 PDF prediction
- prediction consistent with data



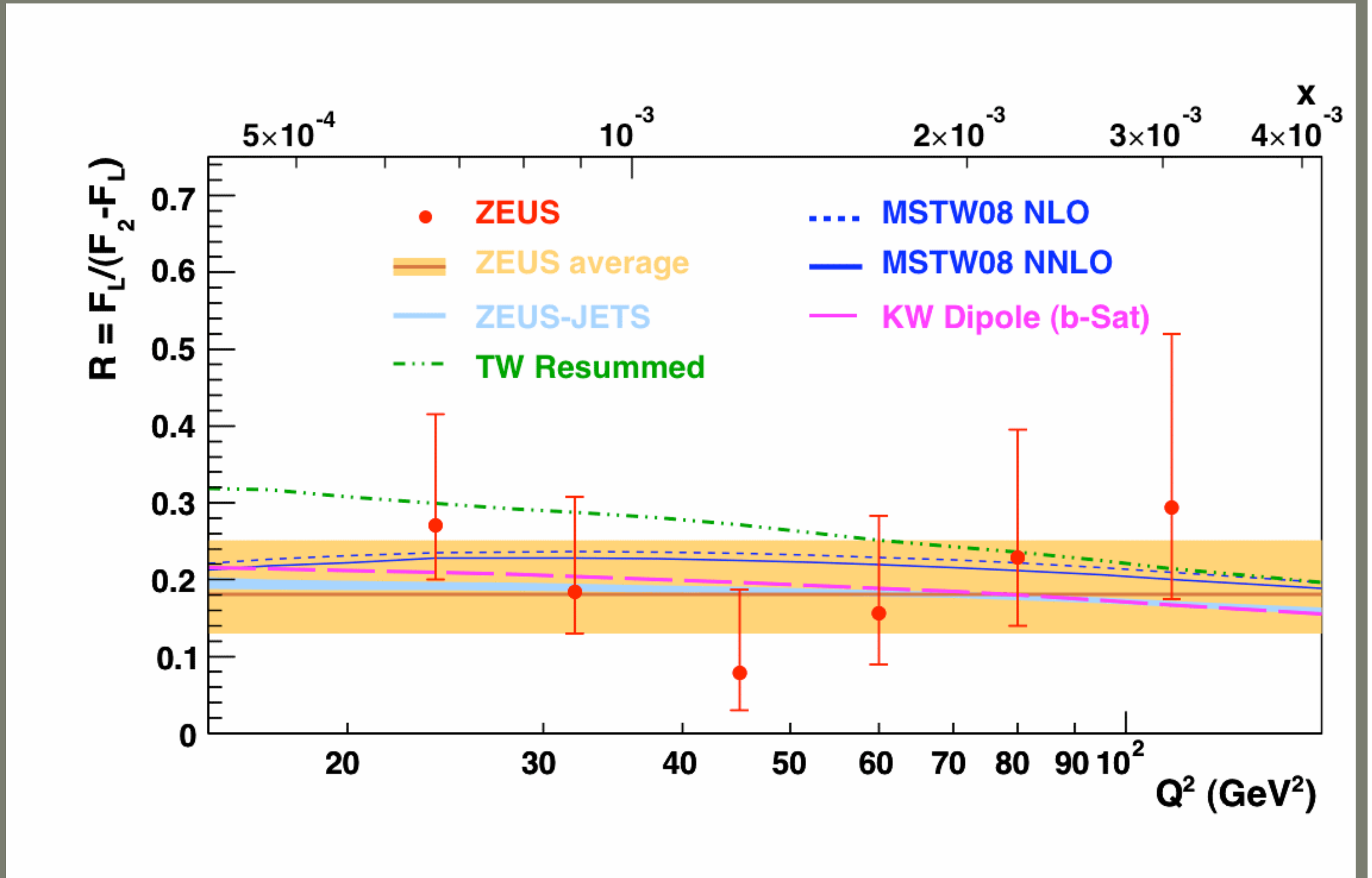
$F_L(Q^2)$ - H1

- $F_L(Q^2)$ formed by averaging and quoted at the *x* values given
- F_L clearly non-zero
- compared with NLO predictions
- all are consistent with the data



$R(Q^2)$ - ZEUS

- $R=FL/(FL-F2)$
- $R(Q^2)$ extracted at the x values given
- compared with several DGLAP (NLO, NNLO and Impact parameter depend dipole saturation model (b-Sat)) and NLL BFKL predictions (Resummed)
- all consistent with data
- single R value 3.5 sigma from zero



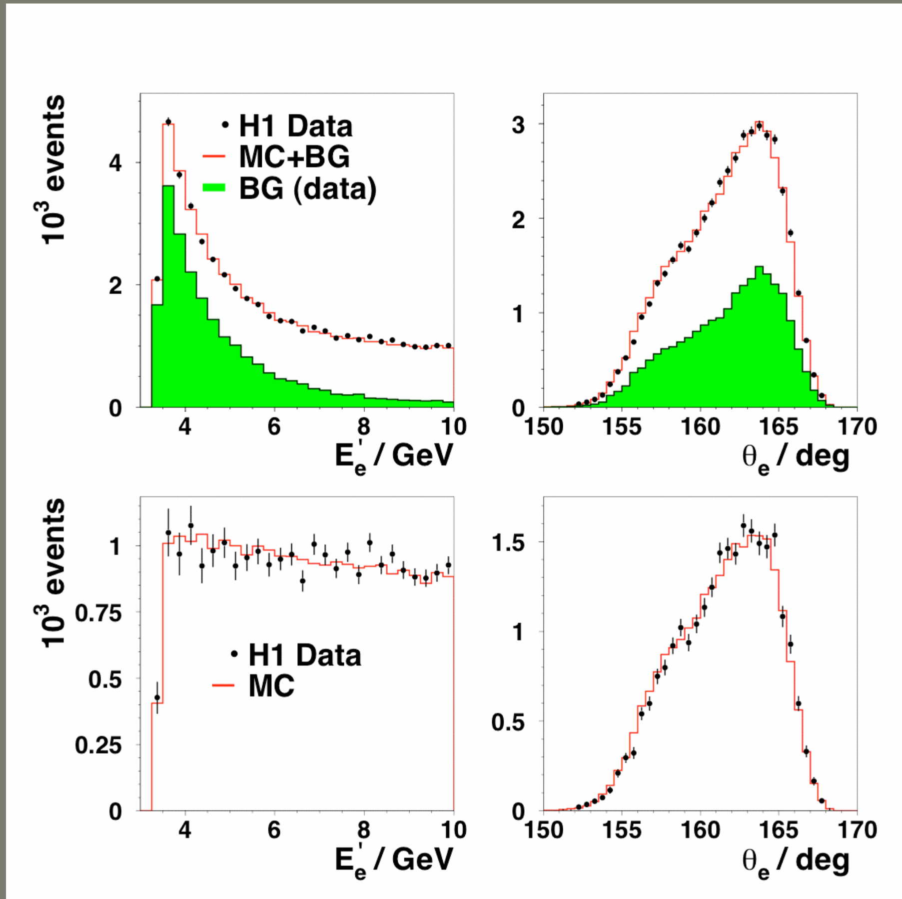
$$R = 0.18^{+0.07}_{-0.05}$$ (from all data)

Summary

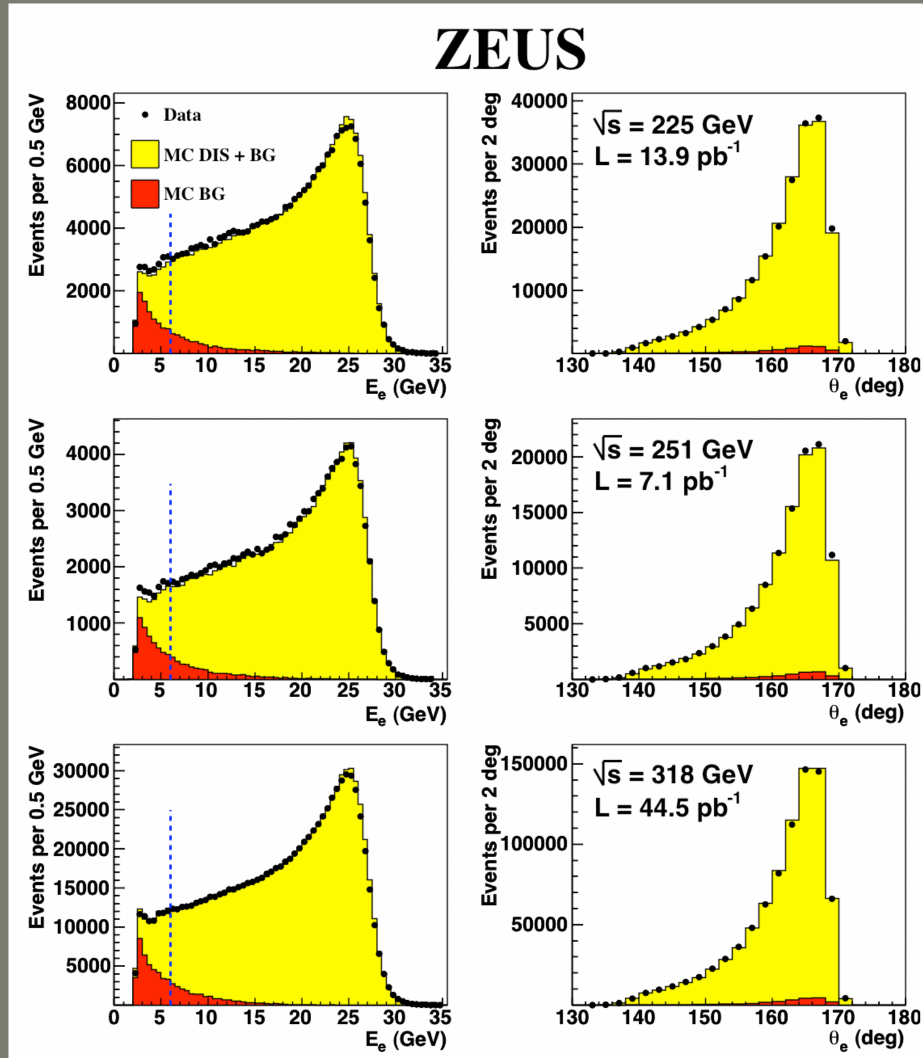
- Both the H1 and ZEUS collaborations have measured the structure function F_L
- H1 made the first direct F_L measurement and the data span a wide kinematic region
- First F_L analysis by ZEUS completed. Also publishing reduced cross sections and the first F_2 measurement without F_L assumptions
- The H1 and ZEUS results are consistent with each other
- Predictions from a range of formalisms consistent with the data
- Both collaborations trying to measure at lower Q^2 where different formalisms lead to diverging predictions

Back-up slides

Control plots

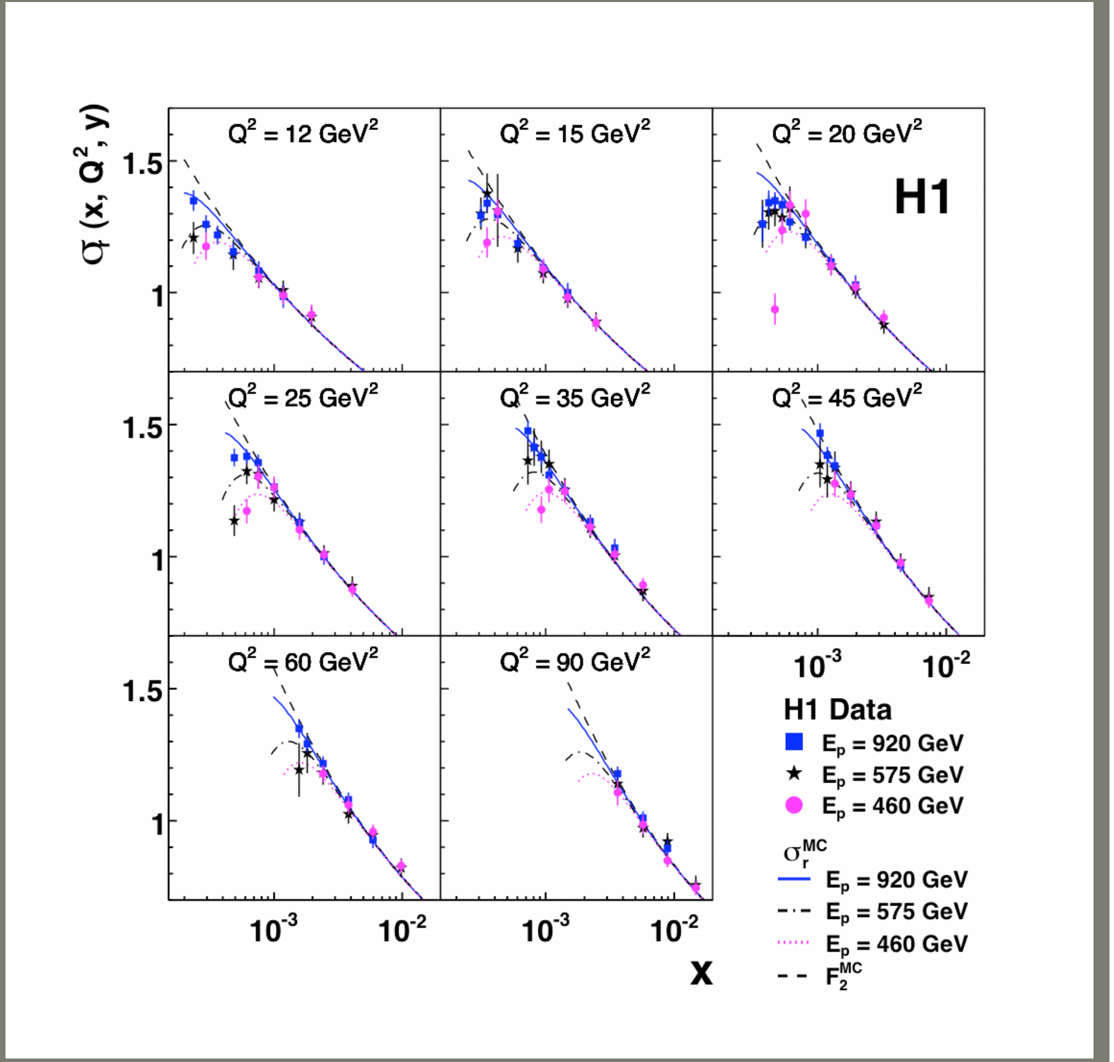


H1 LER: mid-Q^2 analysis



Reduced cross sections - H1

- $\sigma_r(x)$ in bins of Q^2 for each COM energy
- H1 mid-Q^2 analysis
- compared to prediction based on H1 2000 PDF set with expected F_L and F_L=0
- Suppression at low x different for each CoM energy - basis of F_L extraction



Motivation

- HERA measurements of the reduced cross section provide the basis of F_2 extractions and…
- …best constraint on gluon PDF at low *x*
- F_2 scaling violations and gluon density, $g(x,Q^2)$, are related. In DGLAP formalism:

$$\frac{\partial F_2}{\partial \ln Q^2} \sim \alpha_s(Q^2) P_{qg}(x) \otimes xg(x,Q^2)$$

- where $P_{qg}(x)$ is the $g \rightarrow q\bar{q}$ splitting function
- Previous F_2 measurements depend on model dependent assumptions about F_L
- Similarly, the gluon density extracted depends on the formalism used