Measurements of Proton Structure at HERA

- Deep Inelastic Scattering at HERA
- Structure Functions and Parton Densities

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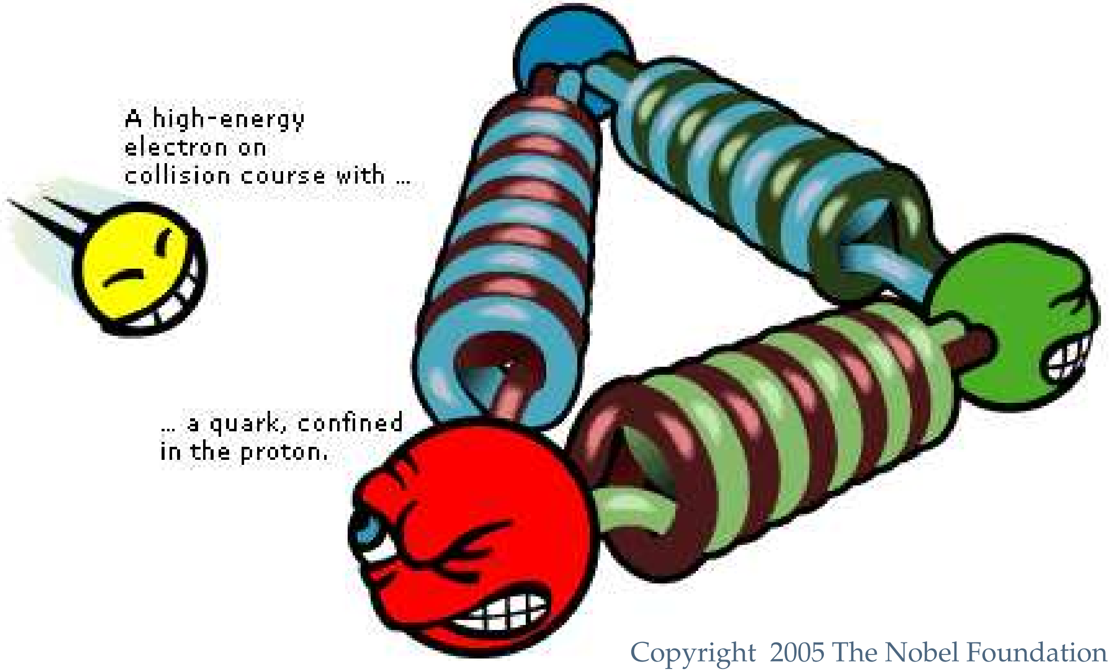
"Fundamental Interactions"
Lake Louise, 23.02.2005

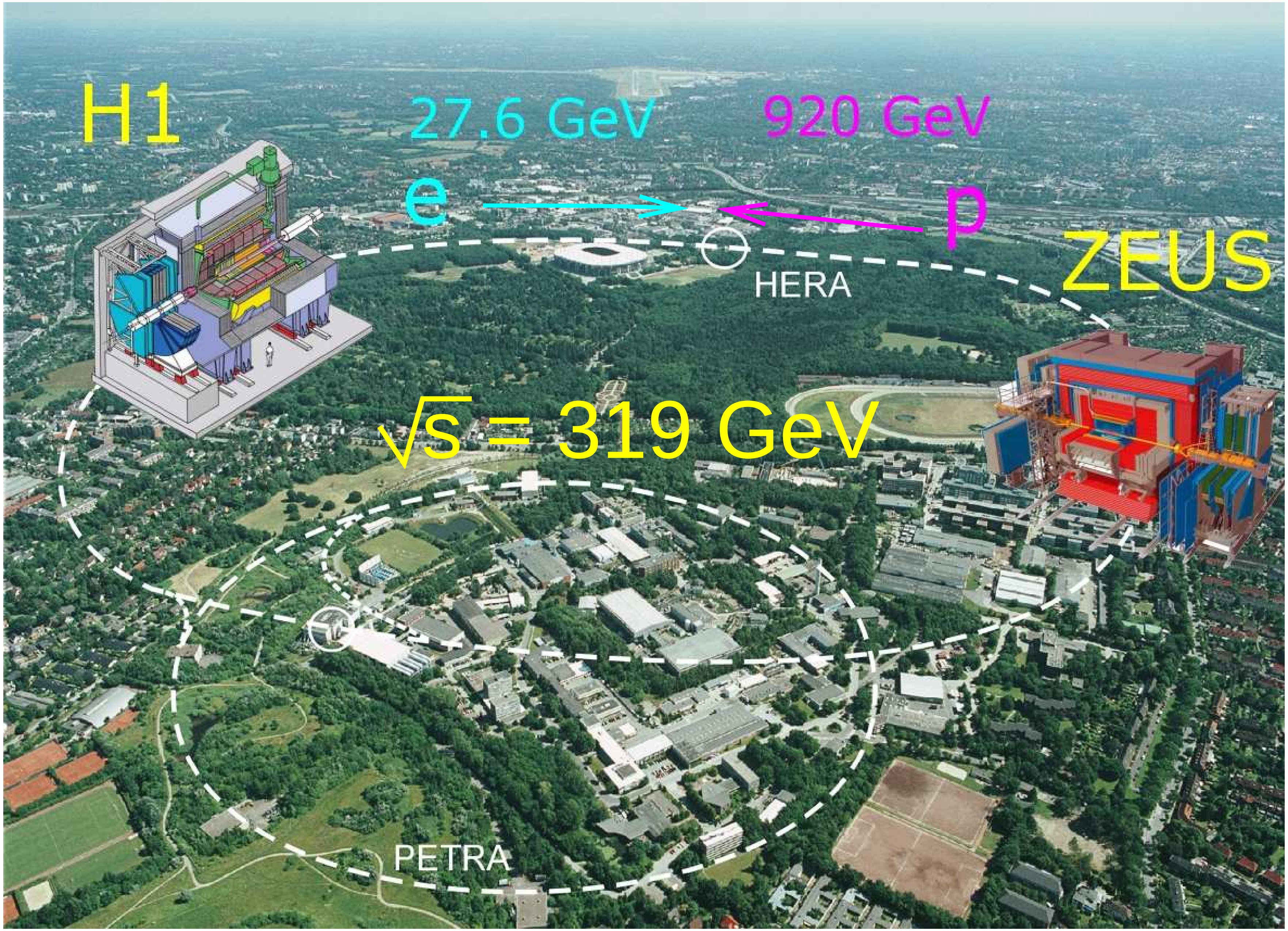
Nobel Prize in Physics 2004

is awarded jointly to
D. J. Gross , H. D. Politzer , F. Wilczek

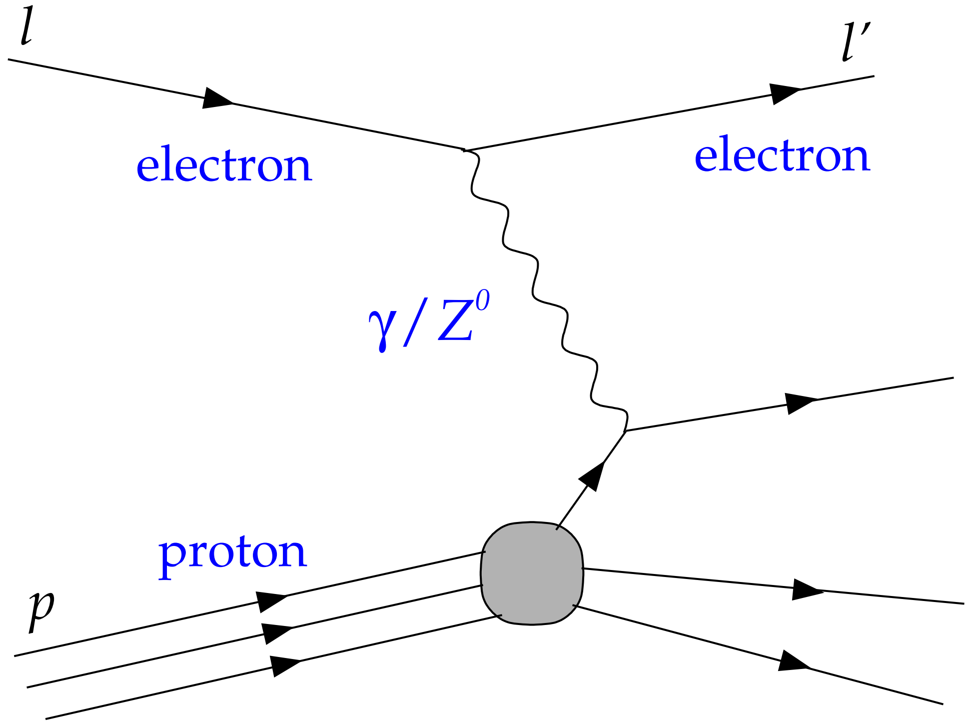
"for the discovery of asymptotic freedom in the theory of the strong interaction"

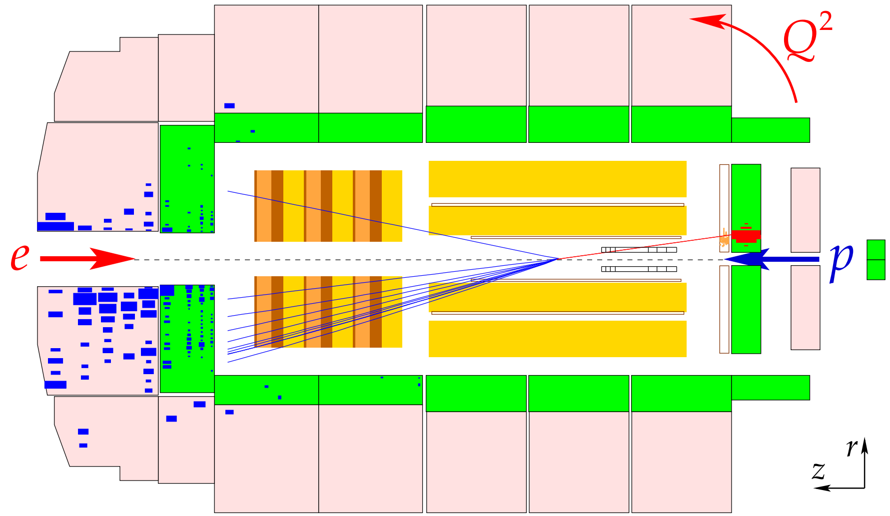


HERA ep Collider at DESY, Hamburg



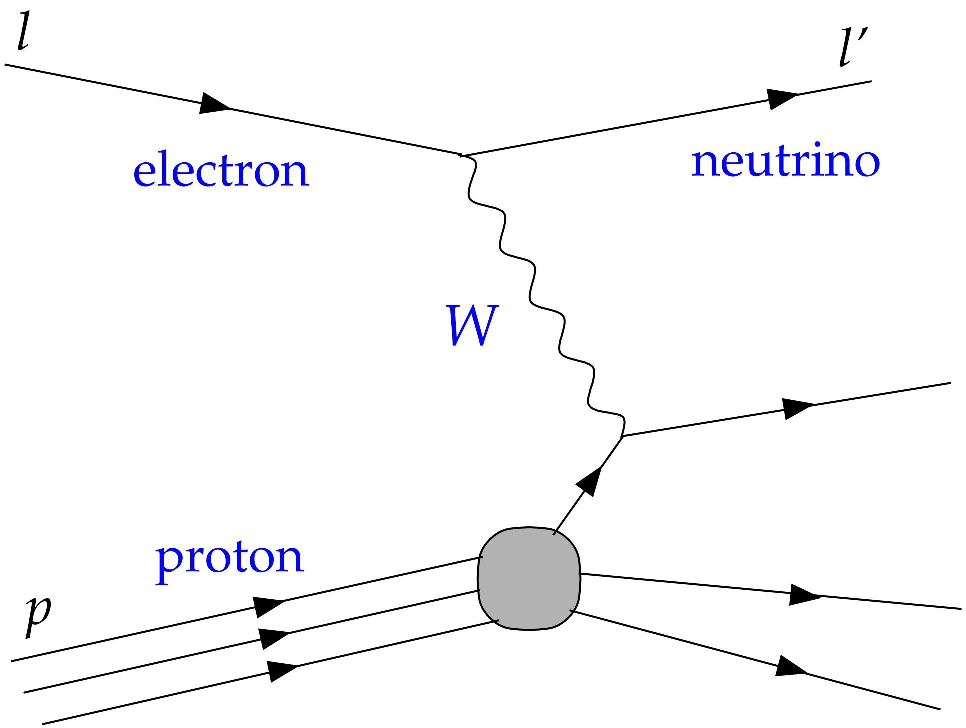
Inclusive DIS – Neutral Current

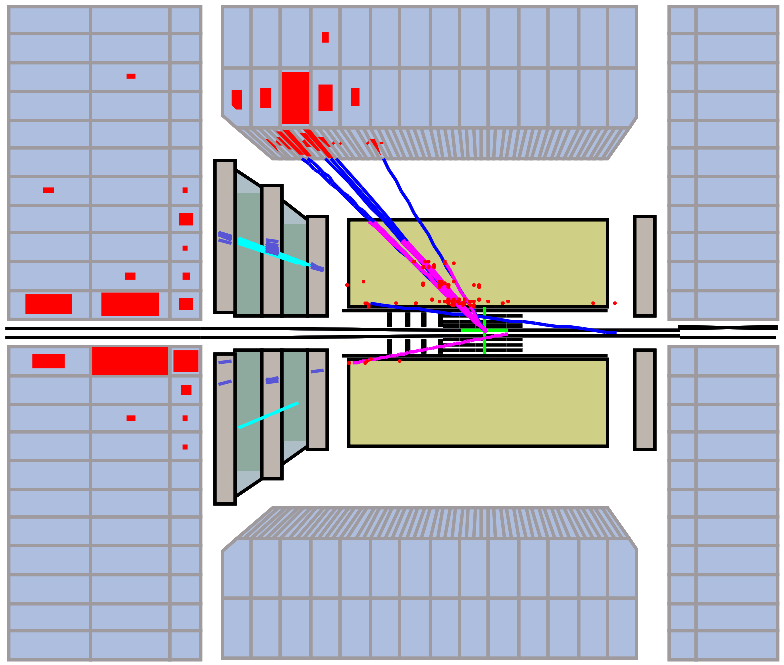




H1 Detector

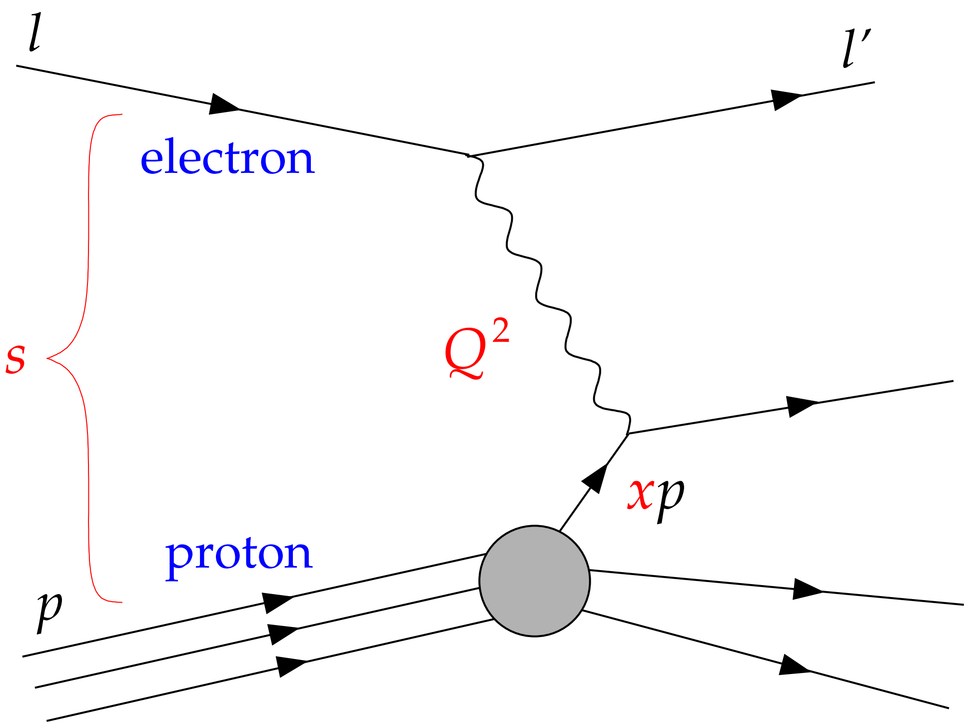
Inclusive DIS – Charged Current





ZEUS Detector

Inclusive DIS Kinematics



- 2 degrees of freedom at fixed s

  Q^2 – boson virtuality

  x – fractional momentum of struck quark

- In addition

$$y \approx \frac{Q^2}{xs} \text{ — inelasticity}$$

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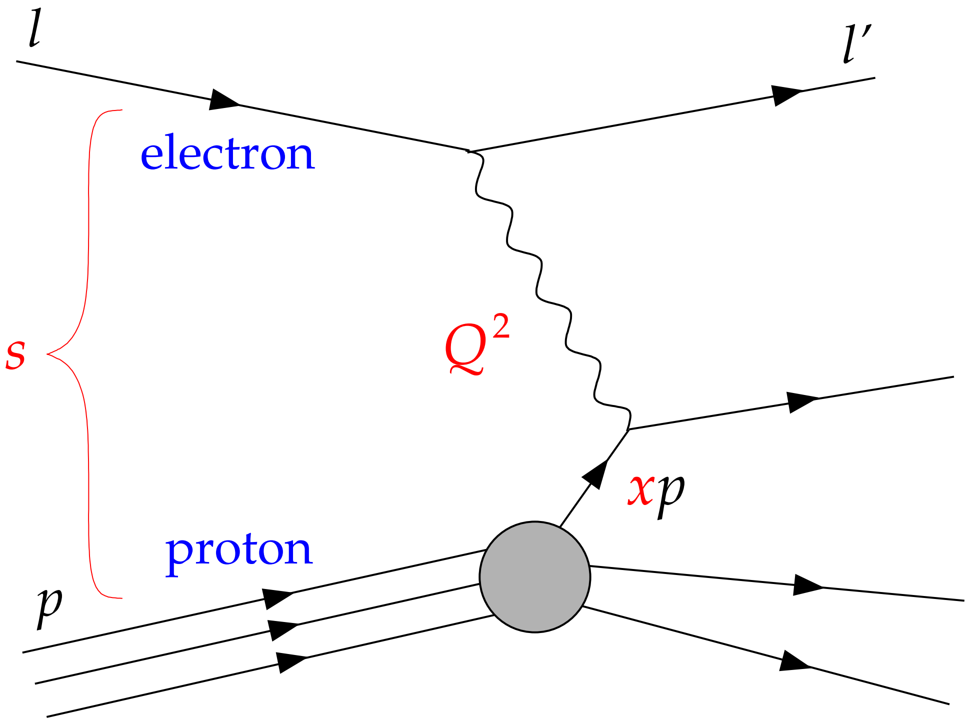

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Neutral Current Cross Section

$$\frac{d^2\sigma_{NC}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left\{Y^+ F_2 \mp Y^- xF_3 - y^2 F_L\right\}$$

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

F_2 Measurements in pQCD Region

- Main contribution is F_2^{em}:

$$F_2 = F_2^{em} + \text{el.-weak terms}$$

$$F_2^{em}(x, Q^2) = x \sum_i e_i^2 (q_i + \bar{q}_i)$$

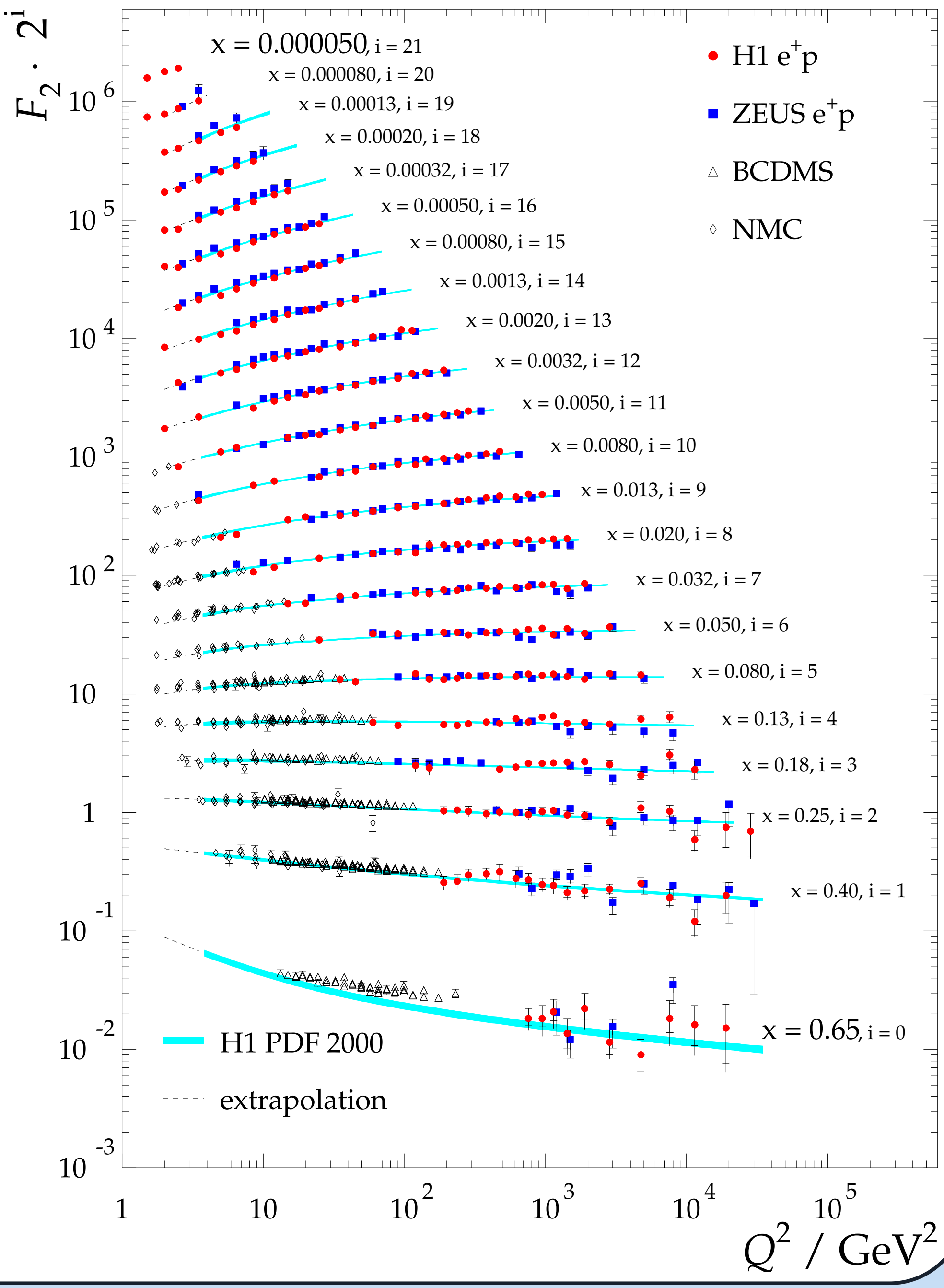
- *Success of perturbative QCD*
  Scaling violations are well described over 4 orders of magnitude in x and Q^2

- Quark substructure ruled out down to $\sim 10^{-18}$ m $\approx 1/1000$th size of proton

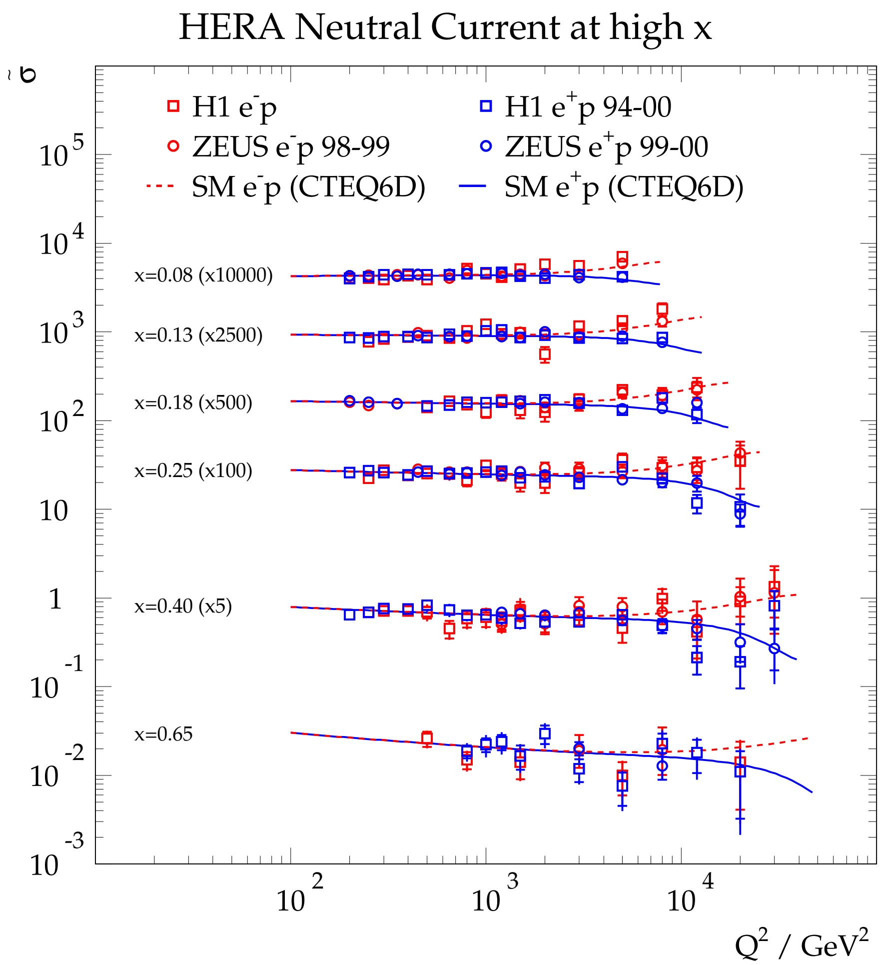
- Precision: $2-3\%$ (in bulk region)
  Still large errors at highest Q^2 and x

$$\frac{d^2\sigma_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\{\dots\}$$

$\Longrightarrow$ *Higher luminosity at HERA II*



xF_3 Determination



- Difference between e^+p and $e^-p \Longrightarrow xF_3$
  Significant at high Q^2 only

- Main contribution from γZ interference:

$$xF_3 = xF_3^{\gamma Z} + Z\text{–exchange}$$

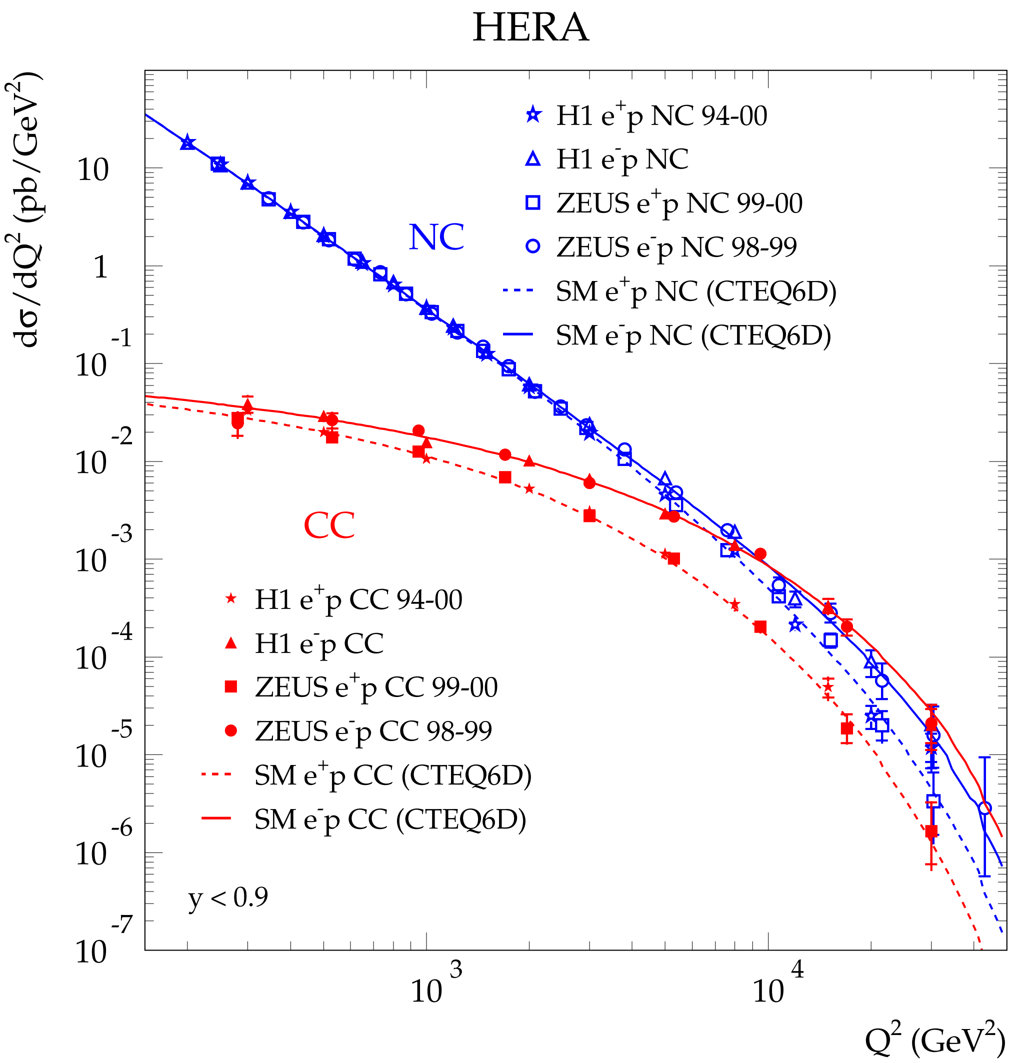
- Constrains the valence quark content:

$$xF_3^{\gamma Z} \sim \frac{Q^2}{Q^2 + M_Z^2} \sum e_q a_q (q - \bar{q})$$

- Results consistent with QCD extrapolation of fixed-target and low Q^2 data

- *Higher luminosity is necessary*
  $\longrightarrow$ HERA II

Charged Current Cross Sections



(high x – high Q^2 kinematically correlated)

- Neutral current:

$$\frac{d^2\sigma_{NC}}{dx dQ^2} \sim \alpha_{em}^2 \frac{1}{x(Q^2)^2} \tilde{\sigma}_{NC}$$

- Charged current:

$$\frac{d^2\sigma_{CC}}{dx dQ^2} \sim G_F^2 M_W^4 \frac{1}{x(Q^2+M_W^2)^2} \tilde{\sigma}_{CC}$$

$\Longrightarrow$ NC $\approx$ CC at $Q^2 \gtrsim M_{Z,W}^2$

- CC e^-p: $\tilde{\sigma}_{CC}^- \sim xu + (1-y)^2 x\bar{d}$
  At high x: u-quarks dominate
- CC e^+p: $\tilde{\sigma}_{CC}^+ \sim (1-y)^2 xd + x\bar{u}$
  At high x: d-quarks dominate

$\Longrightarrow$ *Extraction of u and d densities*

PDFs from NLO QCD Fits

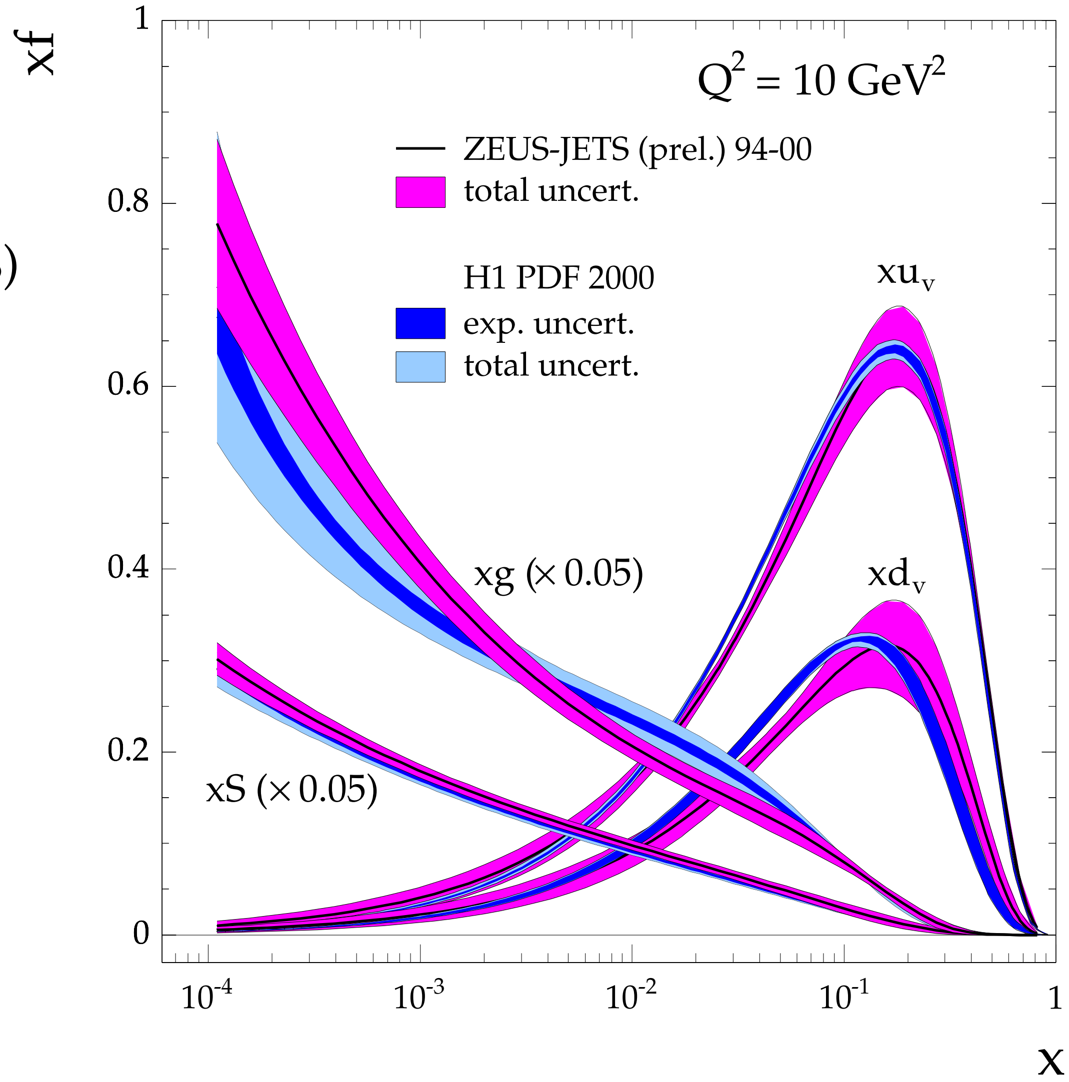
Present knowledge

- ▶ *u* density – best known (→ 3%)
- ▶ *d* density – less well known (∼ 10%)
- ▶ gluon density ∼ 10 – 20%

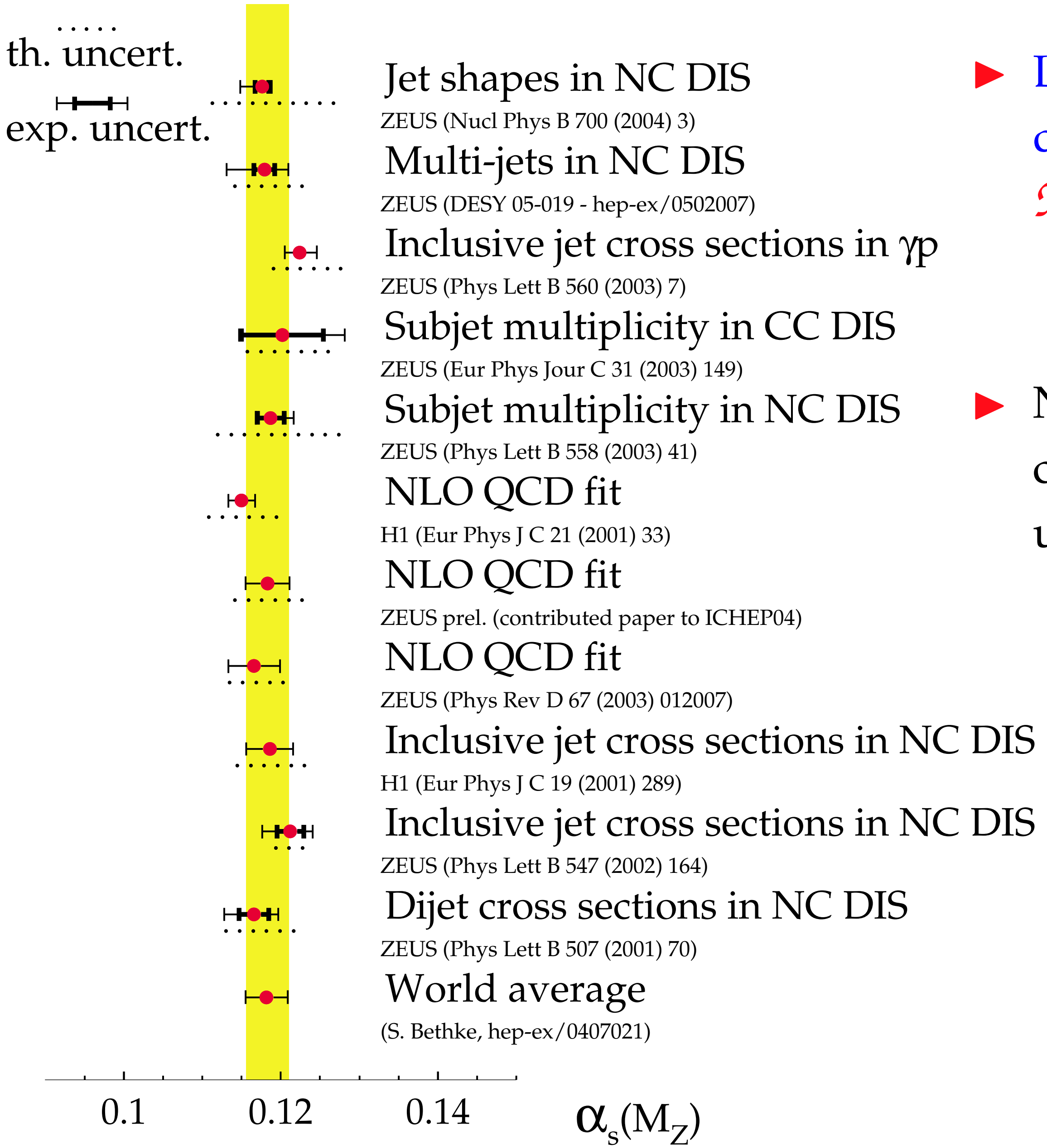
  determined from scaling violations

H1 and ZEUS consistent but many differences in fit approaches

(matter of investigations)



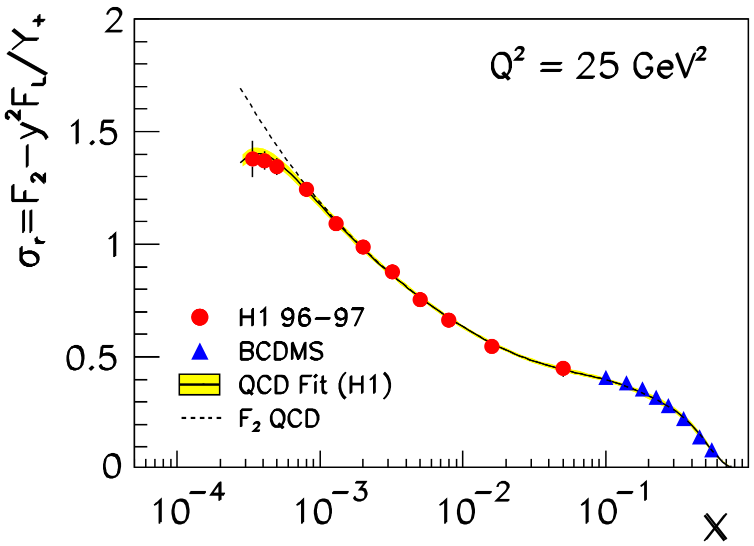
Precise Measurements of α_s



- Largest uncertainty – theoretical dependence on renormalisation scale
  NNLO promises world beating α_s

- New prel. ZEUS analysis: constrain gluon and α_s in PDF fits using jet cross sections

Determination of F_L



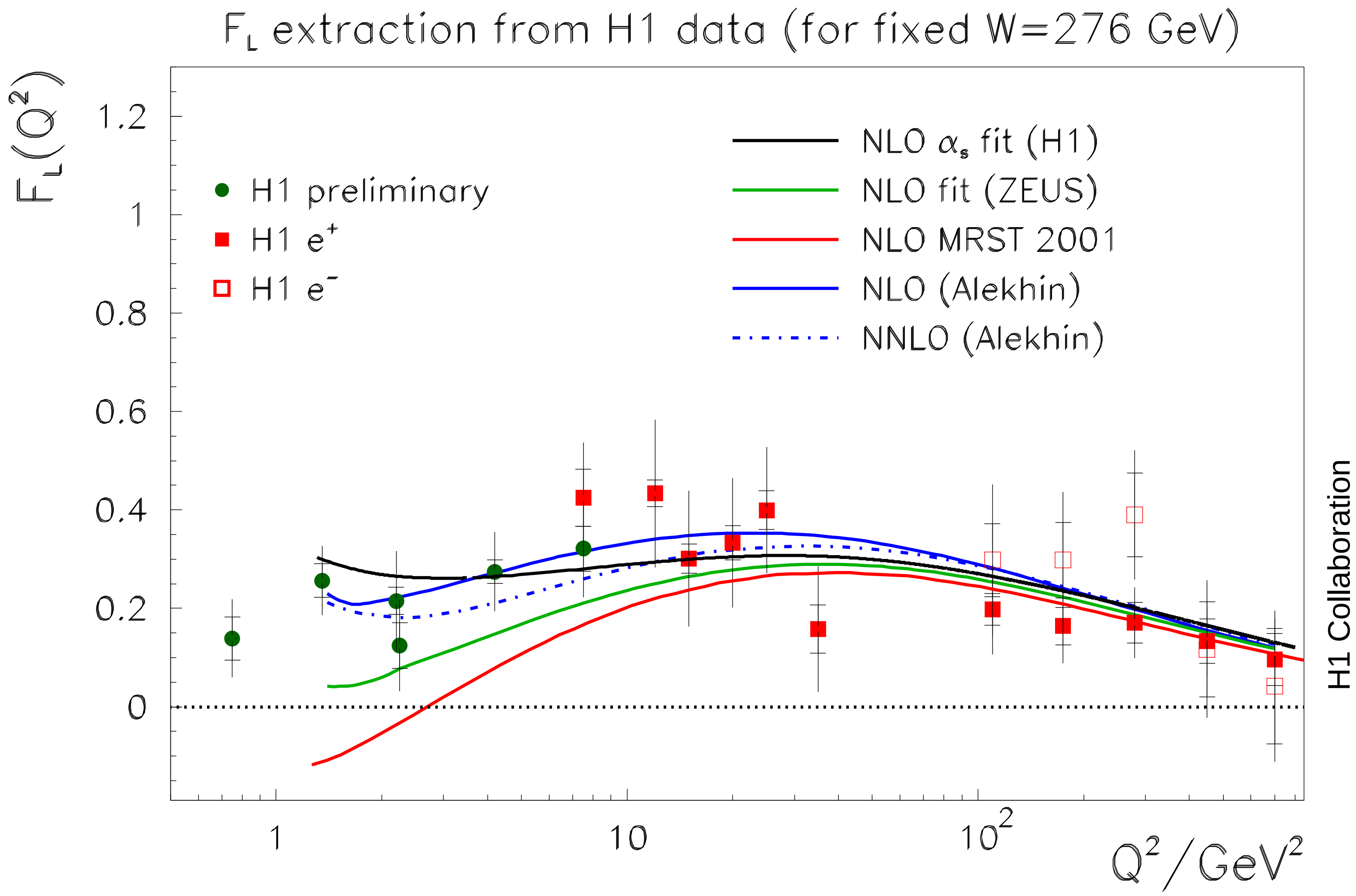
- $F_L \propto \alpha_s x g(x)$ constrains gluon density (especially important at low Q^2)
- Data sensitive at highest y only

$$\sigma_{\rm NC} \propto \left\{ Y^+ F_2 \ldots - y^2 F_L \right\}$$

- Direct measurement requires data at different $s \longrightarrow$ *lower E_p runs*
- Indirect determination extrapolating F_2 to higher y

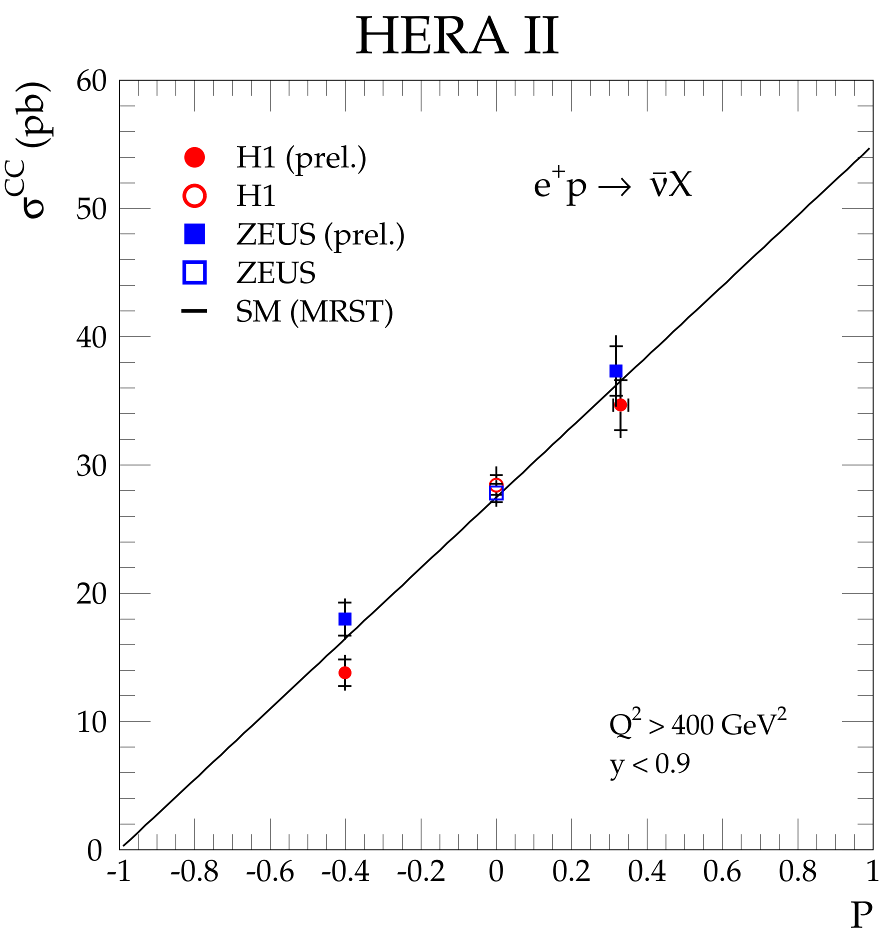
$$\sigma_{\rm fit} = c x^{-\lambda} - \frac{y^2}{1+(1-y)^2} F_L$$

F_L at Fixed $y = 0.75$



- F_L spans 3 orders of magnitude in Q^2
- Basic agreement with NLO pQCD fits
- H1: non-negligible F_L at low Q^2

HERA II – First Results



- HERA II is running and collecting data
  Major beam background problems solved
- New: longitudinal polarization of $e^{\pm}$-beam
  Typically $\sim 40\%$
- CC data are consistent with SM:

$$\sigma^{\pm}_{CC}(P) = (1 \pm P)\sigma^{\pm}_{CC}(0)$$

No hint for right-handed CC

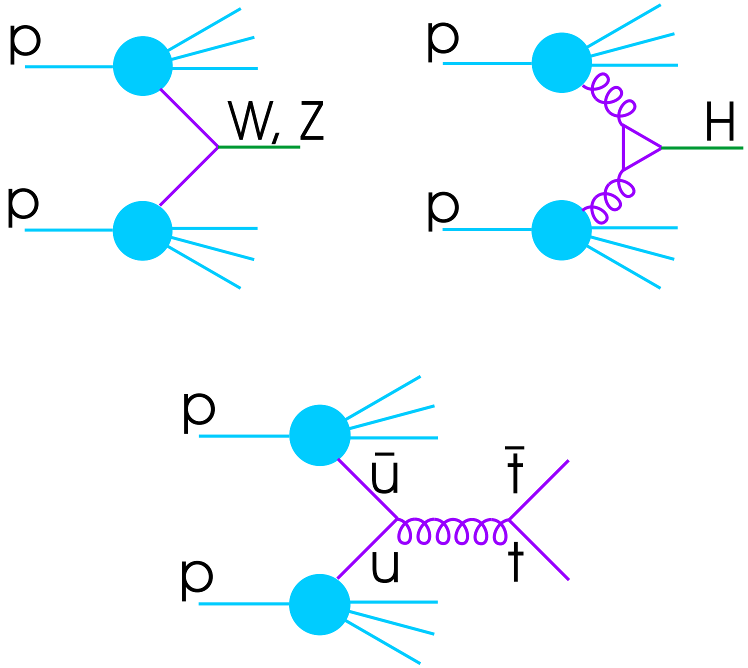
- Also el.-weak terms in σ_{NC}
  are sensitive to polarization
  New possibility to disentangle individual quark flavours at high Q^2

Summary

- Proton structure functions are measured at HERA in a wide range of x and Q^2
- Scaling violations are well described by pQCD
- Parton density functions can be extracted using HERA data only
- High x, high Q^2 still statistically limited. Expect improvements by HERA II – collect $\mathcal{O}(1\,\text{fb}^{-1})$
- e-beam polarization – new tool at HERA II. Expect improved extraction of parton densities
- Hope to reach highest precision for α_s

Additional Information

PDFs for LHC



Precise quark and gluon densities are required in the whole x range to understand signal and background