Measurement of Structure Functions and QCD Fits at H1

Low x Workshop 2003, Nafplion, June 4-7 2003

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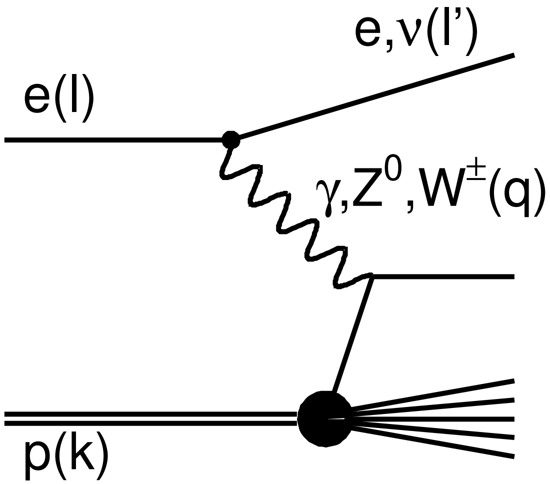
- Introduction
- NC cross section and F_2
- NLO QCD fits $\Rightarrow$ pdf's and α_s
- Determination of F_L
- low x and low Q^2 behaviour of F_2
- Conclusion

HERA Kinematics

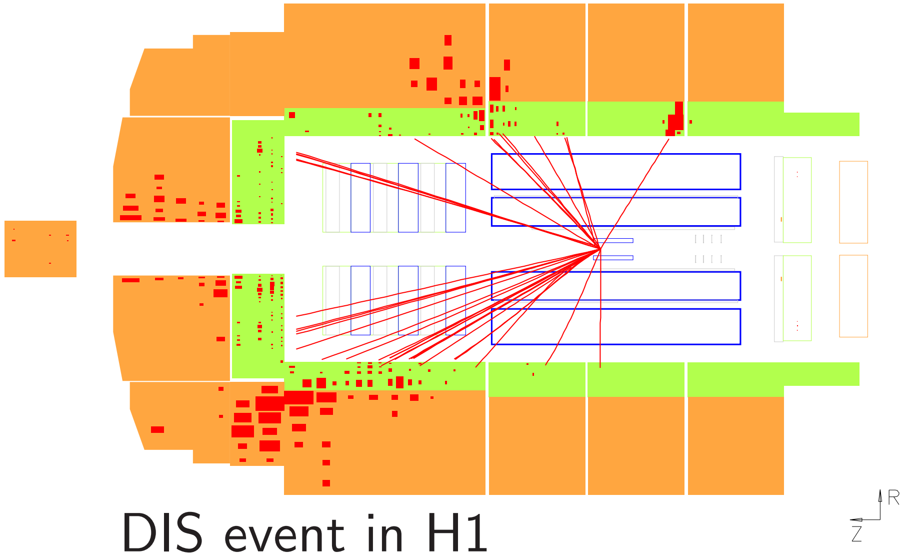


$$Q^2 = -q^2 \quad \text{4-momentum transfer squared}$$

$$x = \frac{Q^2}{2k \cdot q} \quad \text{momentum fraction of parton}$$

$$y = \frac{k \cdot q}{k \cdot l} \quad \text{inelasticity}$$

$$W^2 = Q^2 \frac{1-x}{x} \quad \text{square of inv. mass of had.f.s.}$$



DIS event in H1

$\Longrightarrow \; Q^2 = sxy$ with

ep center of mass energy
$\sqrt{s} = 300 - 318$ GeV

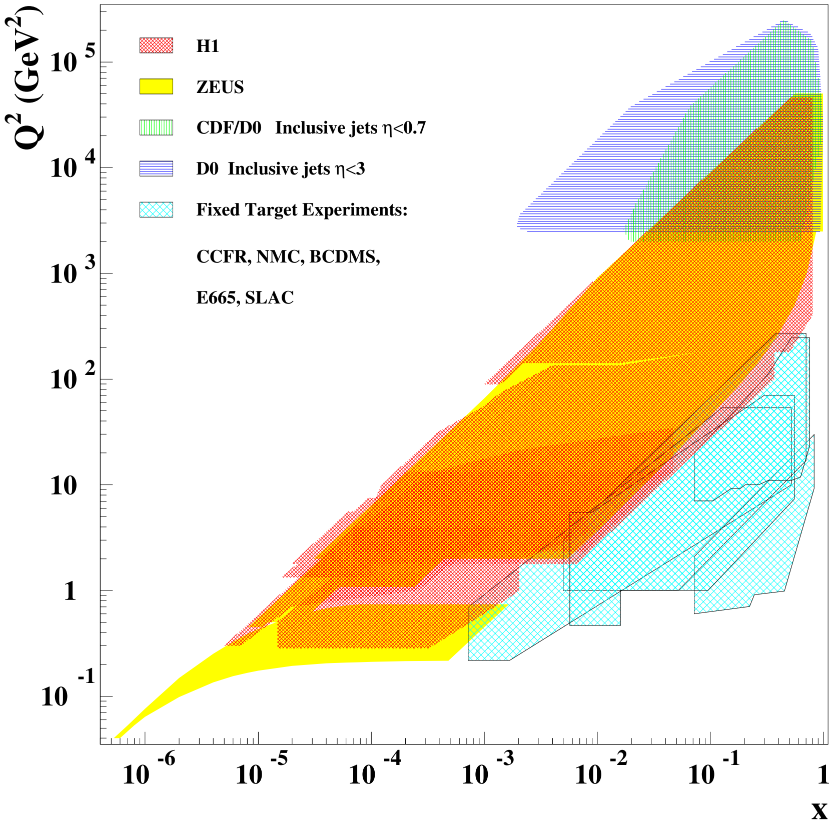
Kinematical Coverage

- Access high Q^2 and low x region compared to fixed target experiments

- $Q^2 > 4$ GeV^2: DIS, Perturbative QCD applicable Determination of pdf's and α_S

- $Q^2 \approx 0$ GeV^2: Photoproduction, phenomenological concepts e.g. soft interactions in Regge theory

- $Q^2 \approx 1$ GeV^2: transition region between photoproduction and DIS, validity of perturbative concepts?



Luminosity analyzed by H1:

e^-p: $\approx$ 14 pb^{-1} (98-99)

e^+p: $\approx$ 100 pb^{-1} (93-97 & 99-00)

Precision of measurements on few % level

Structure Functions

The Neutral Current cross section is sensitive to the proton structure functions:

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dx dQ^2} = \frac{2\pi Y_+}{x}\alpha^2 \left[\frac{1}{Q^2}\right]^2 \left[\tilde{F}_2 \mp \frac{Y_-}{Y_+} \cdot x\tilde{F}_3 - \frac{y^2}{Y_+} \cdot \tilde{F}_L\right]$$

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

The structure functions are related to the parton densities $q(x, Q^2)$ (pdf's):

$$\boxed{\tilde{F}_2^{\mathrm{LO}} \sim e_q^2 x \sum_q (q+\bar{q}) \qquad x\tilde{F}_3^{\mathrm{LO}} \sim x \sum_q (q-\bar{q}) \qquad \tilde{F}_L^{\mathrm{NLO}} \sim \alpha_S g(x)}$$

$\Rightarrow$ The measurement of cross sections gives access to the parton density functions at a certain Q_0^2

$\Rightarrow$ DGLAP predicts evolution in Q^2: $\left[\frac{\partial F_2(x,Q^2)}{\partial \ln Q^2}\right]_x$ but $\ln\left(\frac{1}{x}\right)$ terms neglected!

$\Rightarrow$ Measure cross section as a function of x and compare to predicted Q^2 dependence

QCD Analyses

- H1 α_S fit (`Eur.Phys.J.C21(2001)33-61`):
  - fit to H1 and BCDMS μp data
  - $Q^2_{min} = 3.5$ GeV^2, fixed heavy flavour
  - fit of valence and sea distributions, gluon $xg(x)$ and α_S

- H1 pdf fit (`hep-ex/0304003`):
  - fit to H1 NC and CC data
  - $Q^2_{min} = 3.5$ GeV^2, massless quarks
  - fit of $u + c,\ \bar{u} + \bar{c},\ d + s,\ \bar{d} + \bar{s},\ xg$
  - 10 free parameters (α_s fixed)

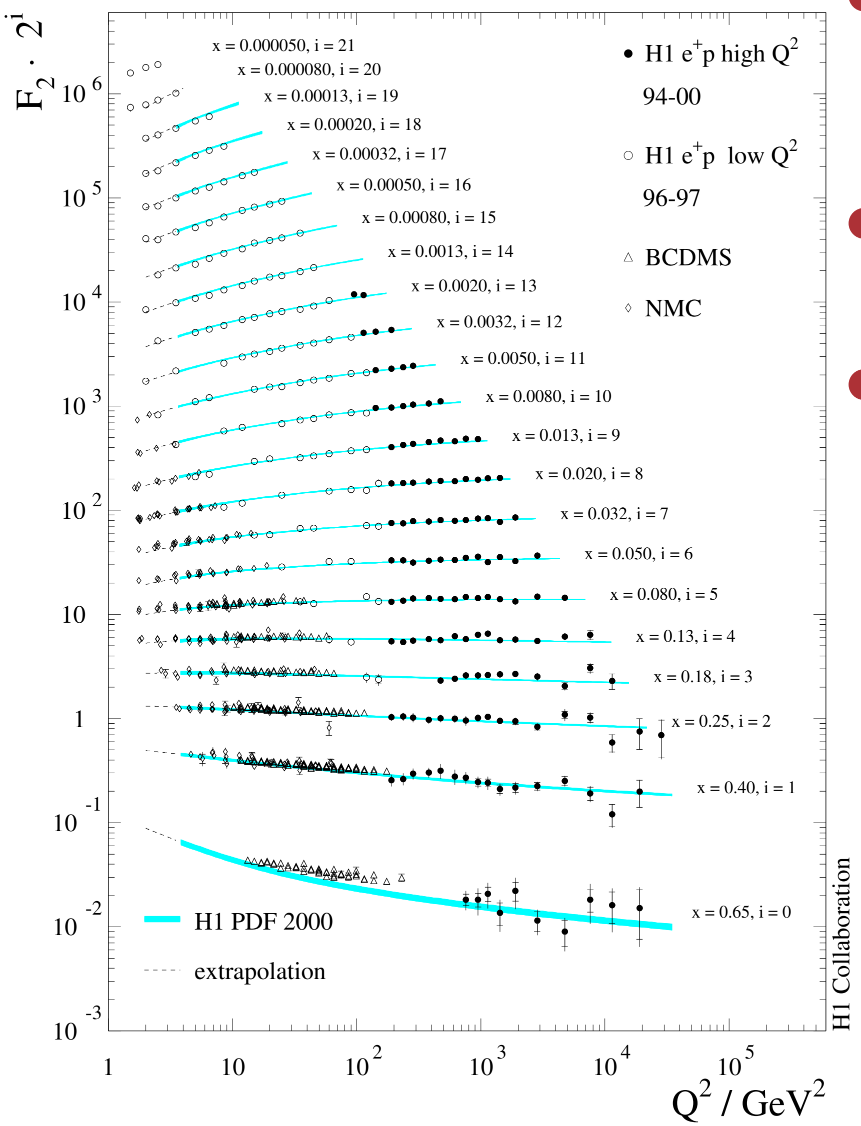
Global fits e.g. CTEQ, MRST
NLO QCD fits to various data sets:
H1, ZEUS, D0, CDF, CCFR, E866, BCDMS, NMC, E605, NuTeV, E665, SLAC

- Procedure:
  - Parameterization of pdf's at $Q^2_0 = 4$ GeV^2:

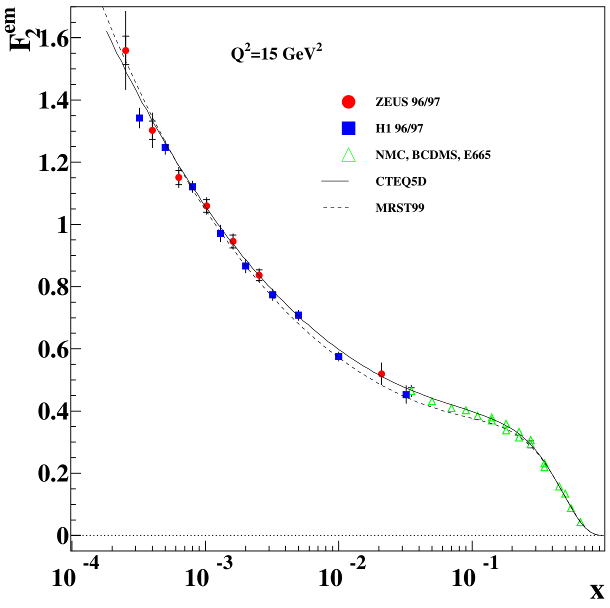
$$xf_q(x, Q^2_0) = Ax^b(1-x)^c[1 + dx + fx^3]$$

  - Q^2 dependence of pdf's by DGLAP evolution in NLO
  - Sum-rules, several assumptions (e.g. on sea distribution)

NLO Fit in Comparison to Data

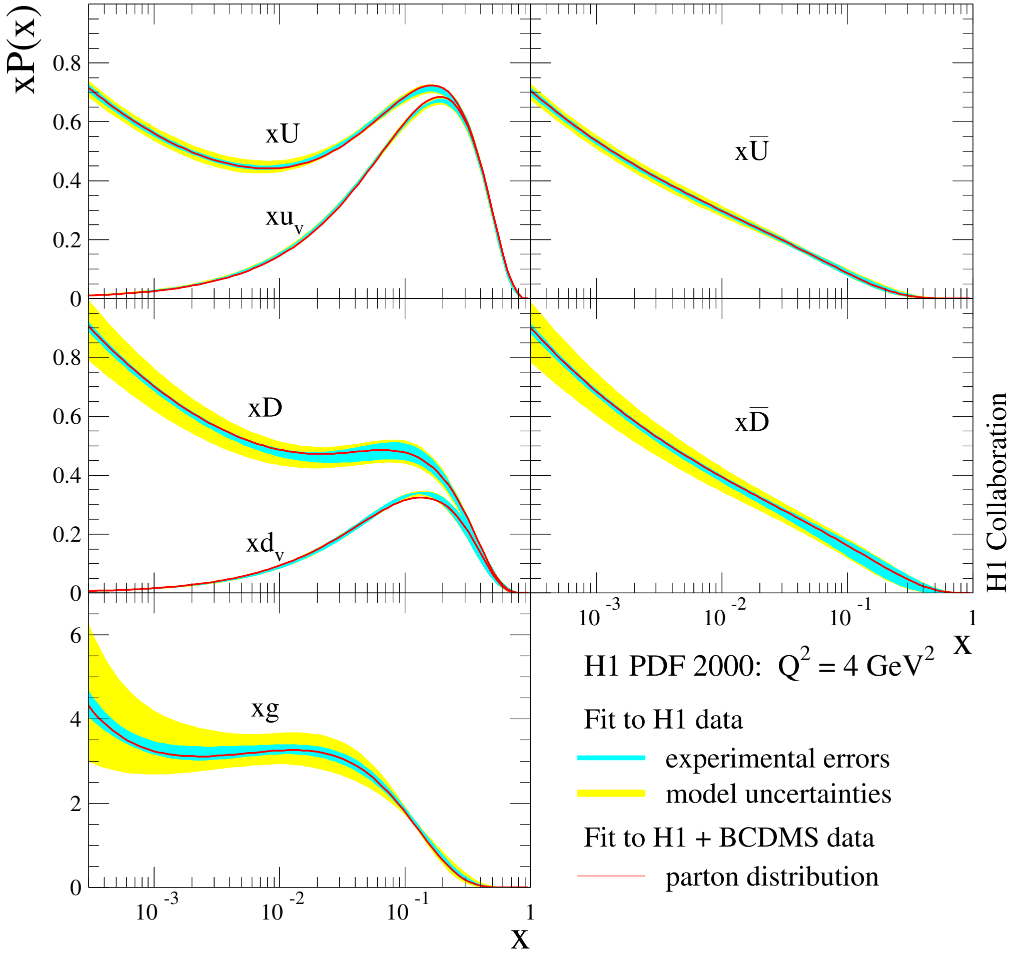


- H1 NLO fit describes HERA and fixed target data well over 4 orders of magnitude
- Strong scaling violation at low x due to gluon radiation
- neglection of $\ln \frac{1}{x}$ terms in DGLAP $\Rightarrow$ applicability in the low x region?



Parton Distributions from QCD Fits

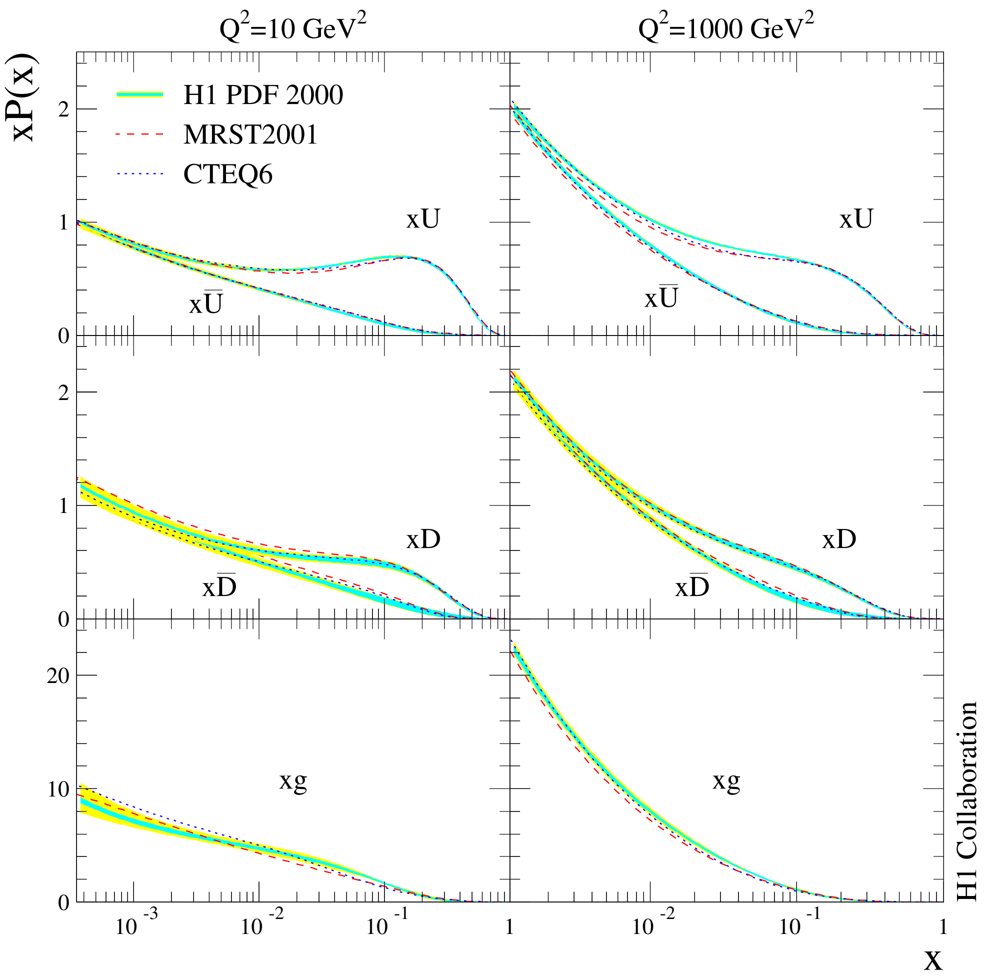
- fit to H1 NC and CC data
- determine at $Q_0^2 = 4$ GeV^2:
  $g \quad U = u + c \quad \bar{U} = \bar{u} + \bar{c}$
  $\quad D = d + s \quad \bar{D} = \bar{d} + \bar{s}$
  $\Rightarrow u_v = U - \bar{U}$
  $\quad d_v = D - \bar{D}$
- 10 free parameters
  $\alpha_S = 0.1185$ fixed
  massless quarks
- consistent result after inclusion of BCDMS data
- $xg(x, Q^2)$ consistent with α_S fit considering heavy flavour treatment



Parton Distributions from QCD Fits

- Good agreement with global fits
- Reasonable agreement between H1 and ZEUS, considering different approaches

  ZEUS NLO QCD fit (2002):
  - fit to ZEUS and fixed target data;
  - $Q^2_{min} = 2.5$ GeV^2;
  - variable flavour scheme
  - fit of $u_v,\ d_v,\ S,\ \bar{d}-\bar{u},\ xg$ and α_S at $Q_0^2 = 7$ GeV^2



Gluon Density $xg(x, Q^2)$

- DGLAP leads to strong rise of $xg(x, Q^2)$ at low x for increasing Q^2

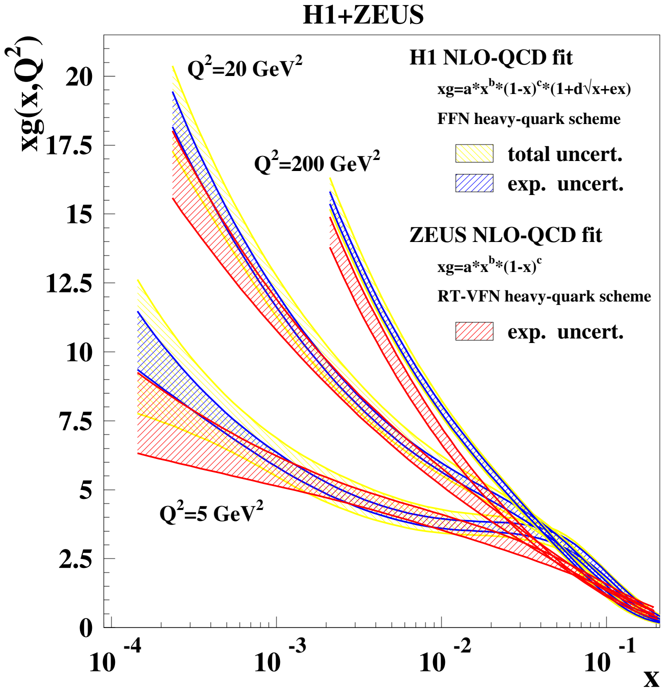
- differences between H1 and ZEUS due to:
  - heavy flavour scheme
  - $xg(x, Q^2)$ parameterisation:

  H1: $xg = ax^b(1-x)^c[1 + d\sqrt{x} + ex]$
  ZEUS: $xg = ax^b(1-x)^c$

- H1 α_s fit:

$$\boxed{\alpha_S(M_Z^2) = 0.115 \pm 0.0017(\text{exp})^{+0.0009}_{-0.0005}(\text{model})}$$

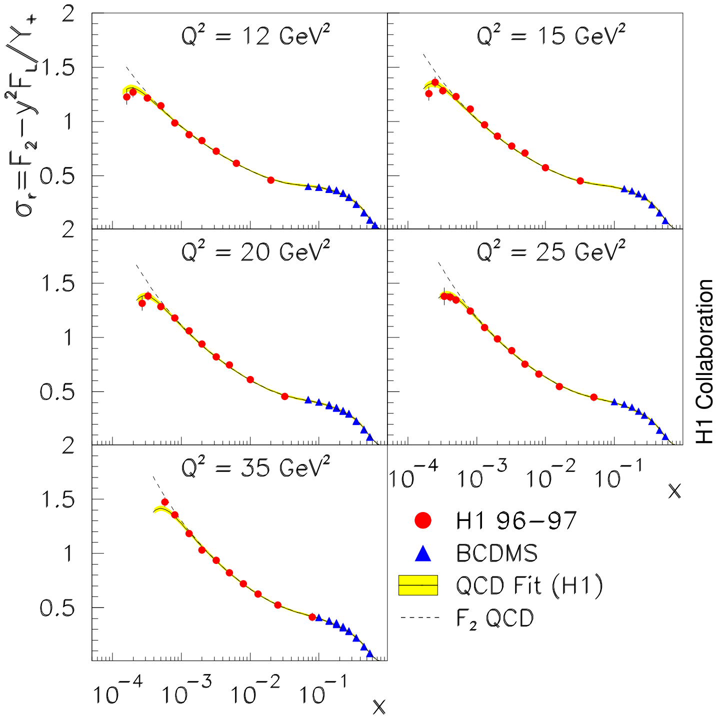
- Variation of renormalization scale leads to add. theoretical uncertainty:
  H1: $\pm$ 0.005 if $\mu_r^2 = (\frac{1}{4}..4) \cdot Q^2$



- α_S error dominated by theoretical uncertainties $\Longrightarrow$ NNLO will provide improvement
- World average (PDG 2002): $\alpha_S = 0.1172 \pm 0.0020$

Determination of F_L

- $F_L \sim \alpha_S g \Leftrightarrow$ direct test for $xg(x)$
- F_L contributes at high y (low x)
- 3 methods for F_L determination:
  - shape - derivative
  - extrapolation

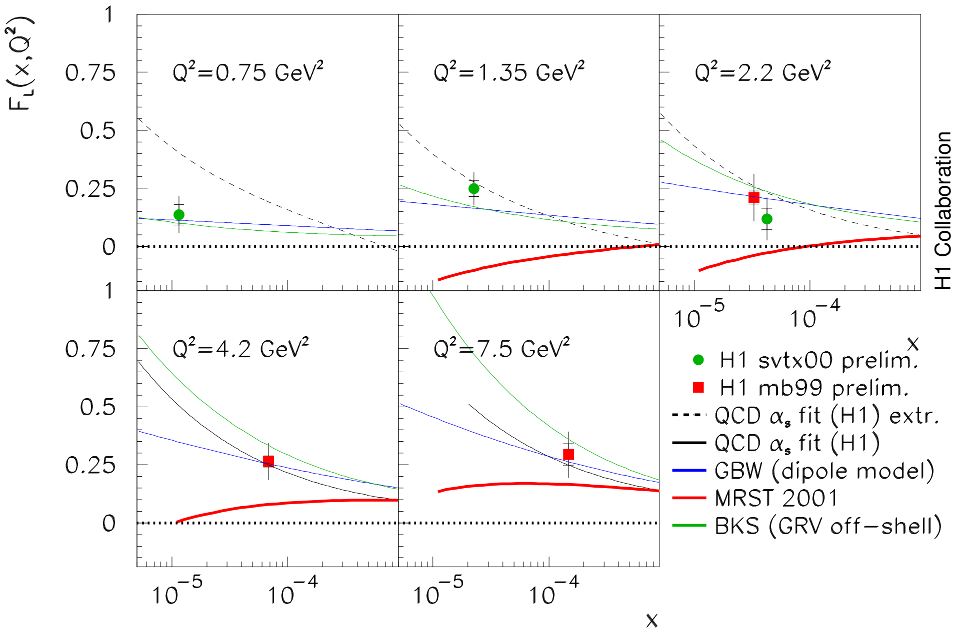


- Fit parameterization to reduced cross section (shape):

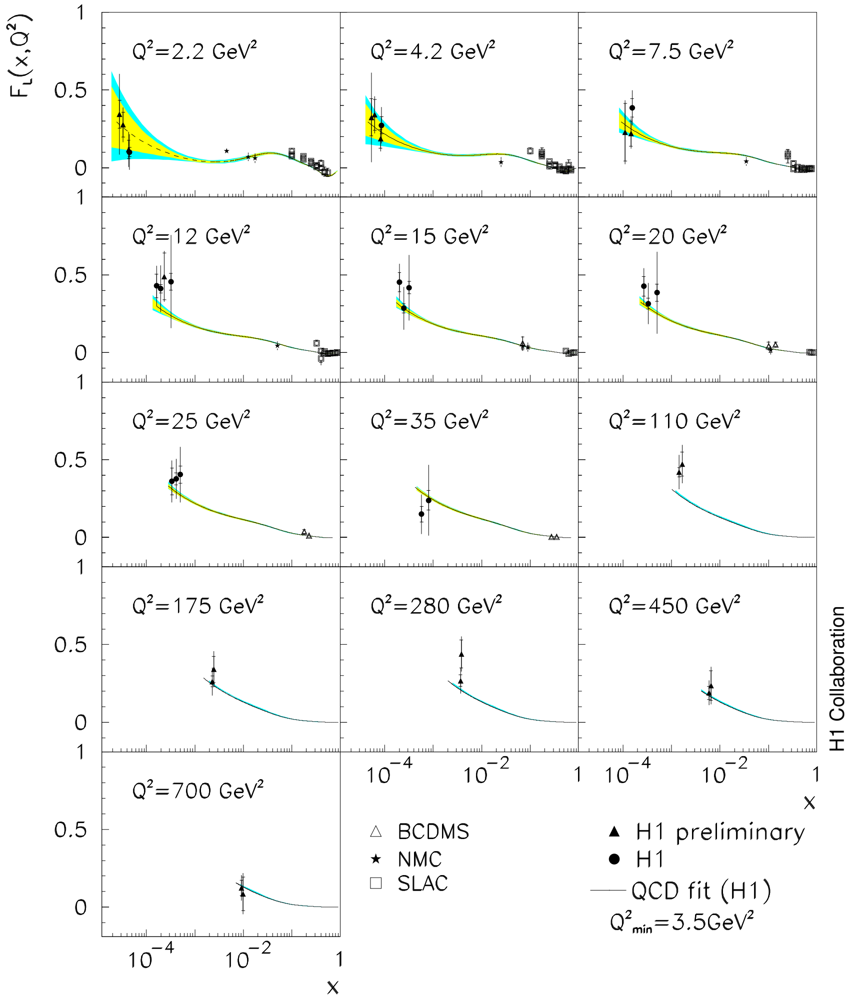
$$\sigma_{\mathrm{FIT}} = c \cdot x^{-\lambda} - \frac{y^2}{1 + (1-y)^2} F_L$$

- Estimate derivative of reduced cross section for $Q^2 < 10$ GeV^2:

$$\left(\frac{\partial \sigma_r}{\partial \ln y}\right)_{Q^2} = \left(\frac{\partial F_2}{\partial \ln y}\right)_{Q^2} - F_L \cdot 2y^2 \cdot \frac{2-y}{Y_+^2}$$

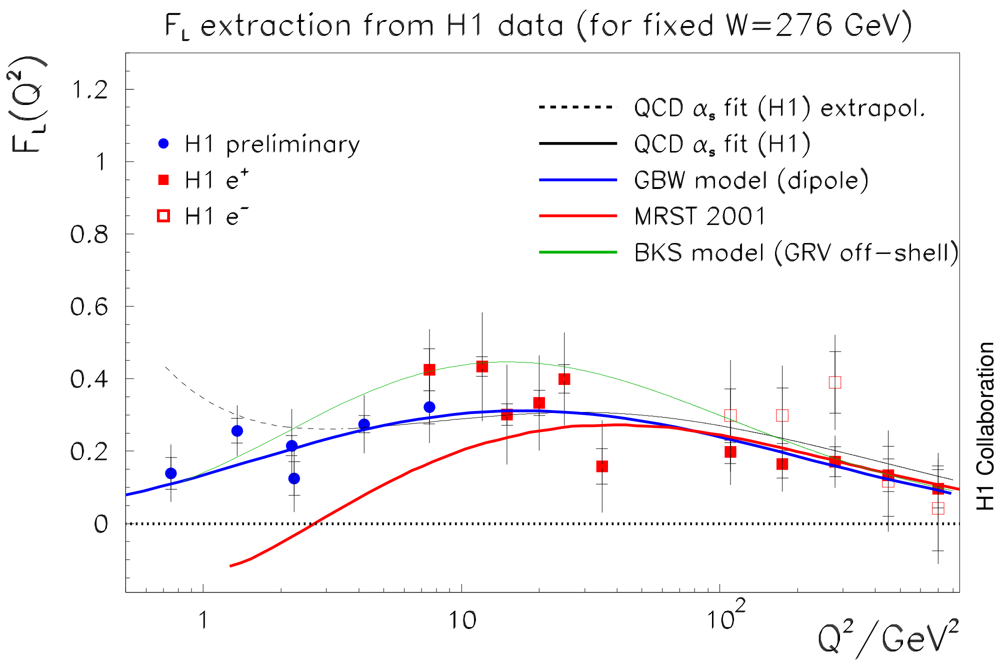


Determination of F_L



- Extrapolate F_2 from QCD fit to high y for $Q^2 > 10$ GeV^2:

$$F_L = \frac{Y_+}{y^2}\left[F_2 - \sigma_r\right]$$



$\Longrightarrow$ Good agreement between data and NLO QCD fit
successful consistency check of QCD fit procedure

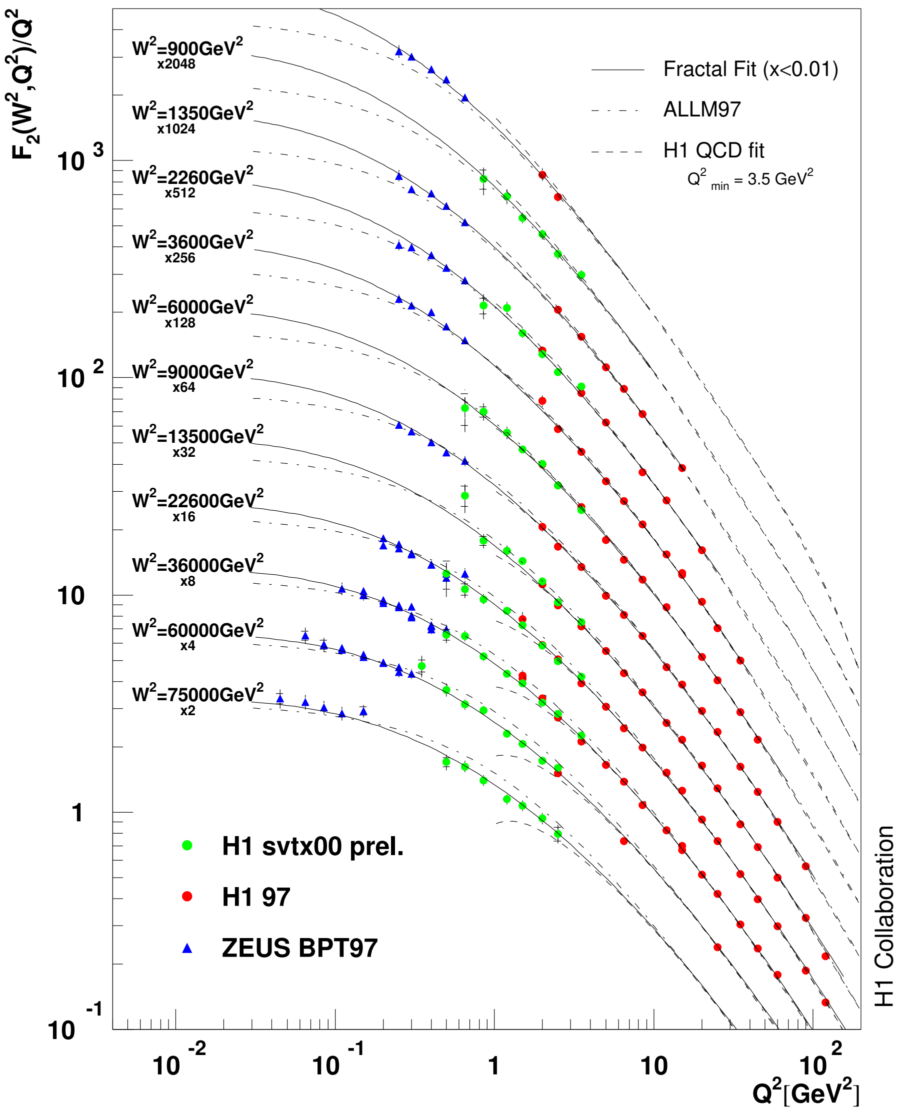
Transition to low Q^2

- $\gamma^* p$ cross section: $\sigma_{\gamma^* p} \sim F_2/Q^2$ at fixed $W^2 \simeq ys$ (at low x)

- good agreement between H1 and ZEUS data $\Rightarrow$ continuous coverage down to $Q^2 = 0.045$ GeV^2

- backward extrapolation of H1 QCD fit ($Q^2_{min} = 3.5$ GeV^2) undershoots data

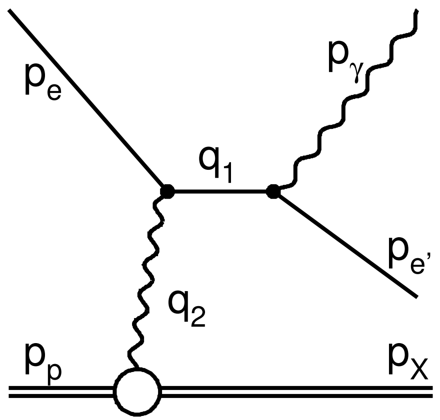
- fractal fit is based on self-similar structure of gluon emissions and splittings at low x
hep-ph/0203260

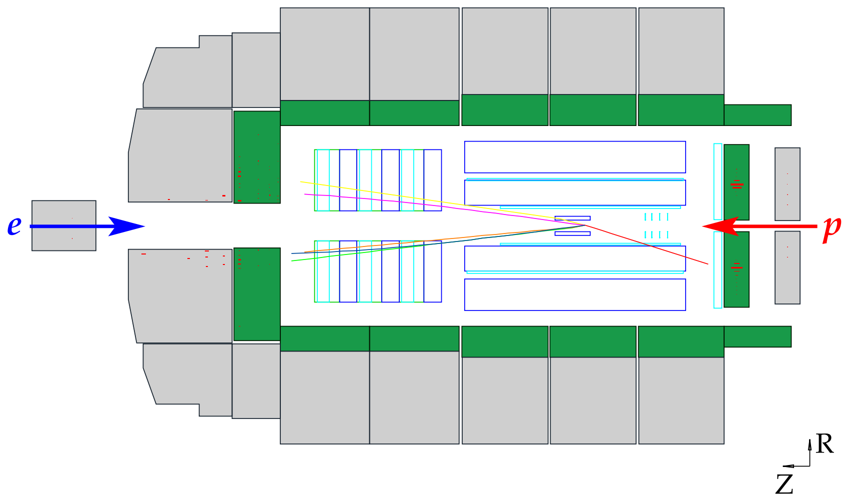


QED Compton at low Q^2

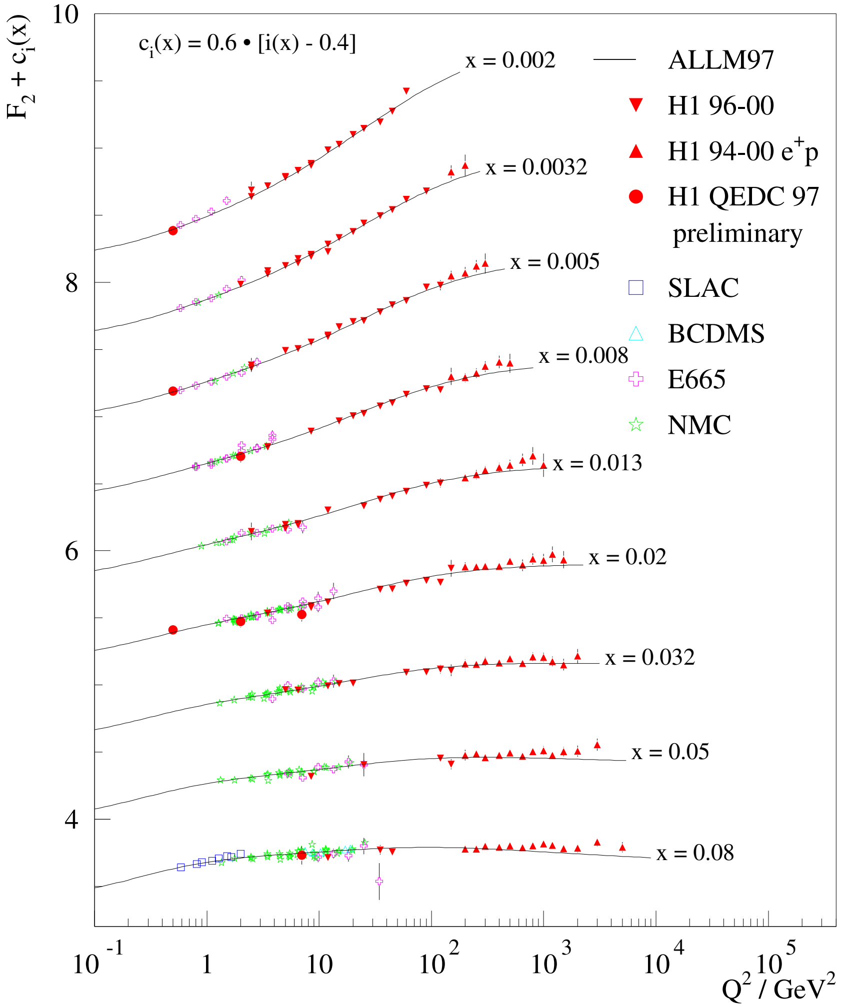
- QED Compton: $q_2 \sim 0$
  Compton scattering of a quasi-real photon off an electron
- Inelastic QEDC scattering:
  at small Q^2 (W>2 GeV): $\sigma_{\text{in}} \sim F_2$
  in transition region of DIS to γp
- Kinematics reconstructed with hadronic final state
- F_2 measured in QED Compton scattering at low Q^2 and medium x:

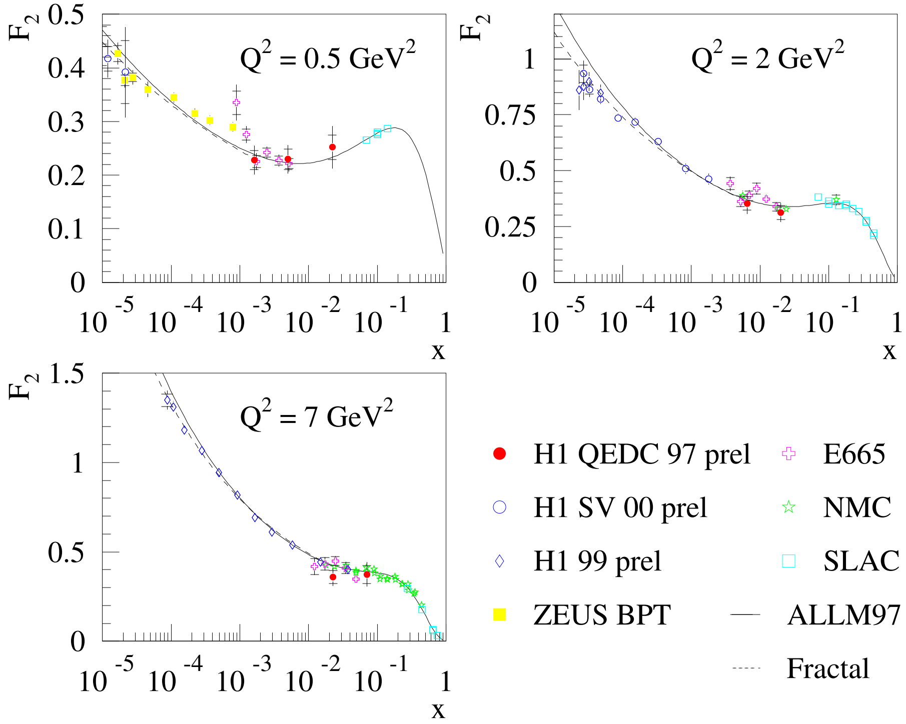
$$Q^2 > 0.1 \text{ GeV}^2$$
$$0.01 < x < 0.1$$





QED Compton at low Q^2



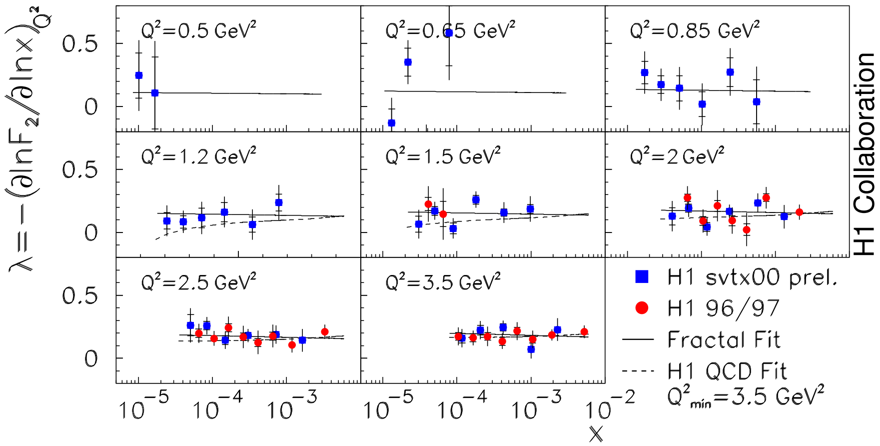


- Extension of kinematic domain complementing standard inclusive measurements
- Good agreement with fixed target data

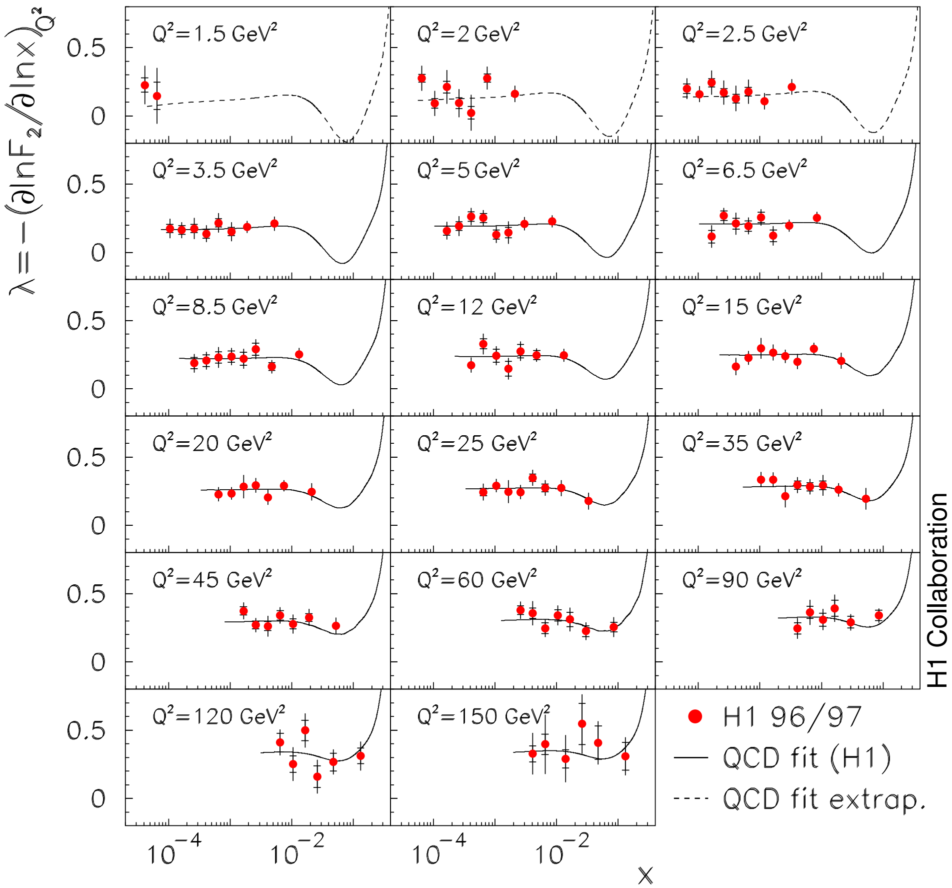
x Dependence of F_2

- BFKL predicts:
  F_2 rises as power of x at low x
- saturation of $g(x)$ would lead to taming of F_2 for $x \to 0$
- $\lambda(x,Q^2) = \left(\frac{\partial \ln F_2(x,Q^2)}{\partial \ln x}\right)_{Q^2}$
- λ const. at fixed Q^2 for x <0.01

  $\Rightarrow F_2(x,Q^2) = c(Q^2)x^{-\lambda(Q^2)}$



- transition to valence quark region at large x
- no taming of gluon rise towards low x $\to$ no saturation yet



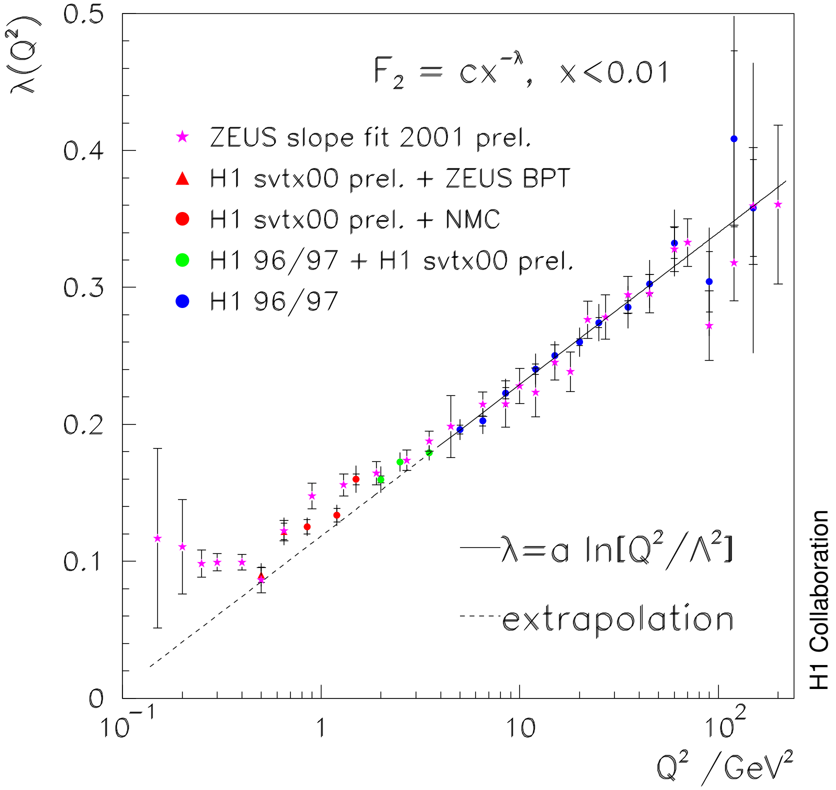
Behaviour at low Q^2

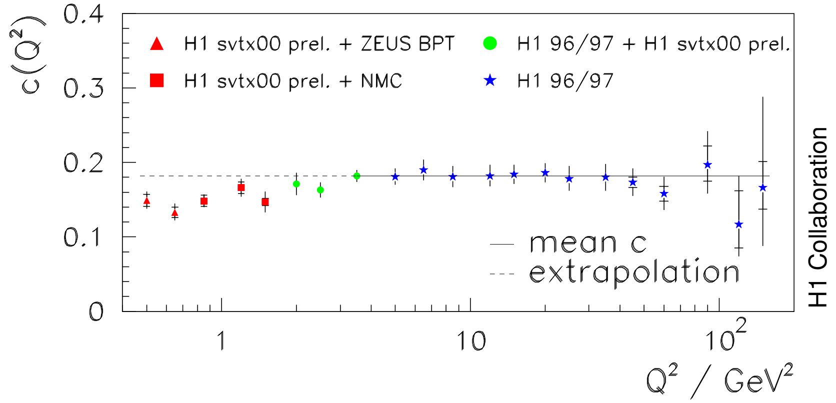
- At low Q^2:
  $F_2(x, Q^2) = c(Q^2)x^{-\lambda(Q^2)}$

- λ rises with $\ln Q^2$ in DIS region

- At $Q^2 \lesssim 3$ GeV^2:
  - λ deviates from log-dependence
  - λ constant at very low Q^2
  - decrease of c
    expect $c \sim Q^2$ for $Q^2 \to 0$

- For fixed Q^2 Regge theory predicts:
  $F_2(x, Q^2) \sim x^{-(\alpha_{I\!P}(0)-1)}$ with
  $\alpha_{I\!P}(0) - 1 \approx 0.08$ (Donnachie Landshoff)
  $\Rightarrow \lambda \approx 0.08$





Conclusion

- H1 provides precise measurements of inclusive NC (and CC) cross sections over several orders of magnitude: $0.3 < Q^2 < 30000$ GeV^2 and $6 \cdot 10^{-6} < x < 0.65$
- Good agreement between HERA I data and expectations from QCD
- NLO QCD fits, based on DGLAP evolution, to H1 and fixed target data describe data well $\Longrightarrow$ extraction of pdf's and α_S with high precision
- Measurement of F_L over a wide range in Q^2
- Extension of F_2 measurement to large x with QED Compton events
- Low Q^2 data reach limit of applicability of pQCD $\Longrightarrow$ need theoretical development
- No saturation seen at very low x
- HERA II will provide higher luminosity $\mathcal{L} \approx 1$ fb^{-1}, beam polarization and improved experimental conditions