The soft $\to$ pQCD Interface Region at HERA

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- HERA kinematic range
- pQCD in 'safe' regions
- Gluon density at low Q^2
- F_2 measurement at very low Q^2
- The transition region
- Summary

On behalf of ZEUS and H1

Moriond, 18th - 25th March 2000

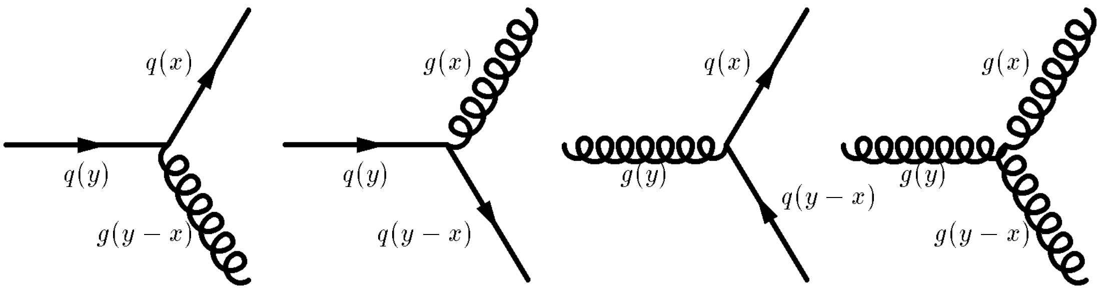
DGLAP and Dynamics

$F_2 = \sum_i^{n_f} e_i^2 x q_i(x,Q^2) = \frac{5}{18} q^{SI} + \frac{1}{6} q^{NS}$

evolve q^{SI}, q^{NS}, xg in coupled equation in DGLAP:

$$\frac{\partial}{\partial ln Q^2} \quad q^{NS} = \frac{\alpha_s}{2\pi} q^{NS} \otimes P_{qq}^{NS}$$

$$\frac{\partial}{\partial ln Q^2} \begin{pmatrix} q^{SI} \\ xg \end{pmatrix} = \frac{\alpha_s}{2\pi} \begin{pmatrix} q^{SI} \\ xg \end{pmatrix} \otimes \begin{pmatrix} P_{qq} & P_{qg} \\ P_{gq} & P_{gg} \end{pmatrix}$$



$P_{qq}\left(\frac{x}{y}\right)$ $\quad$ $P_{gq}\left(\frac{x}{y}\right)$ $\quad$ $P_{qg}\left(\frac{x}{y}\right)$ $\quad$ $P_{gg}\left(\frac{x}{y}\right)$

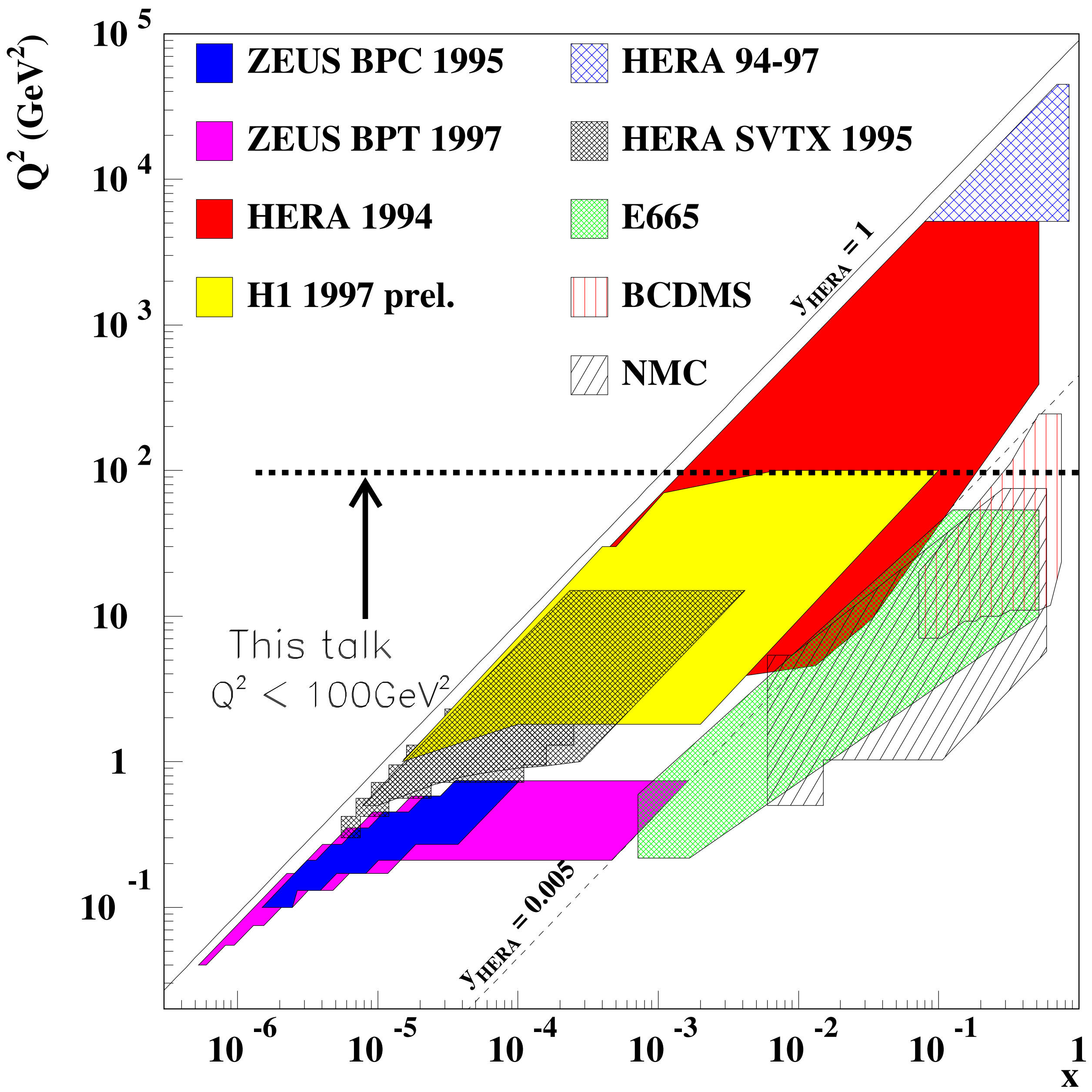
$F_L(x,Q^2) =$

$$\frac{\alpha_s}{\pi}\left[\frac{4}{3}\int_x^1 \frac{dy}{y}\left(\frac{x}{y}\right)^2 F_2(y,Q^2) + 2c\int_x^1 \frac{dy}{y}\left(\frac{x}{y}\right)^2\left(1-\frac{x}{y}\right) yg(y,Q^2)\right]$$

$c = \sum_i e_i^2$

- at low $x < 10^{-3}$ dominant contribution from gluon

HERA kinematic range

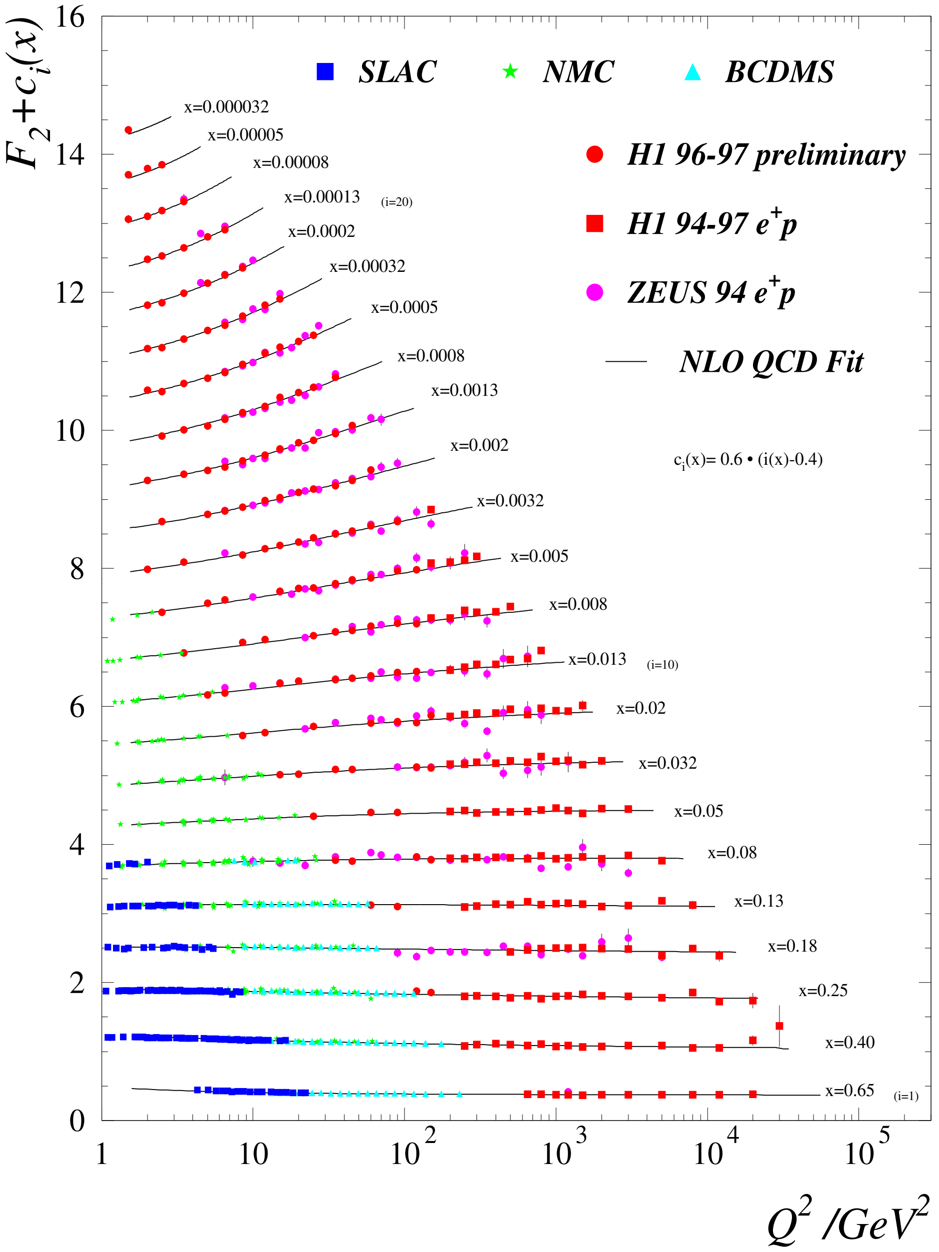


- low Q^2: weak effects can be ignored
- high Q^2: test of pQCD (evolving from low Q^2 to high Q^2)
- low y : overlap with fixed target experiments
- high y: sensitive to F_L

F_2 Measurement at HERA (vs. Q^2)

$$\frac{d^2\sigma(e^+p\to eX)}{dxdQ^2} = \frac{2\pi^2\alpha}{xQ^4}\left(Y_+F_2 - y^2F_L\right) \qquad Y_+ = 1+(1-y)^2$$

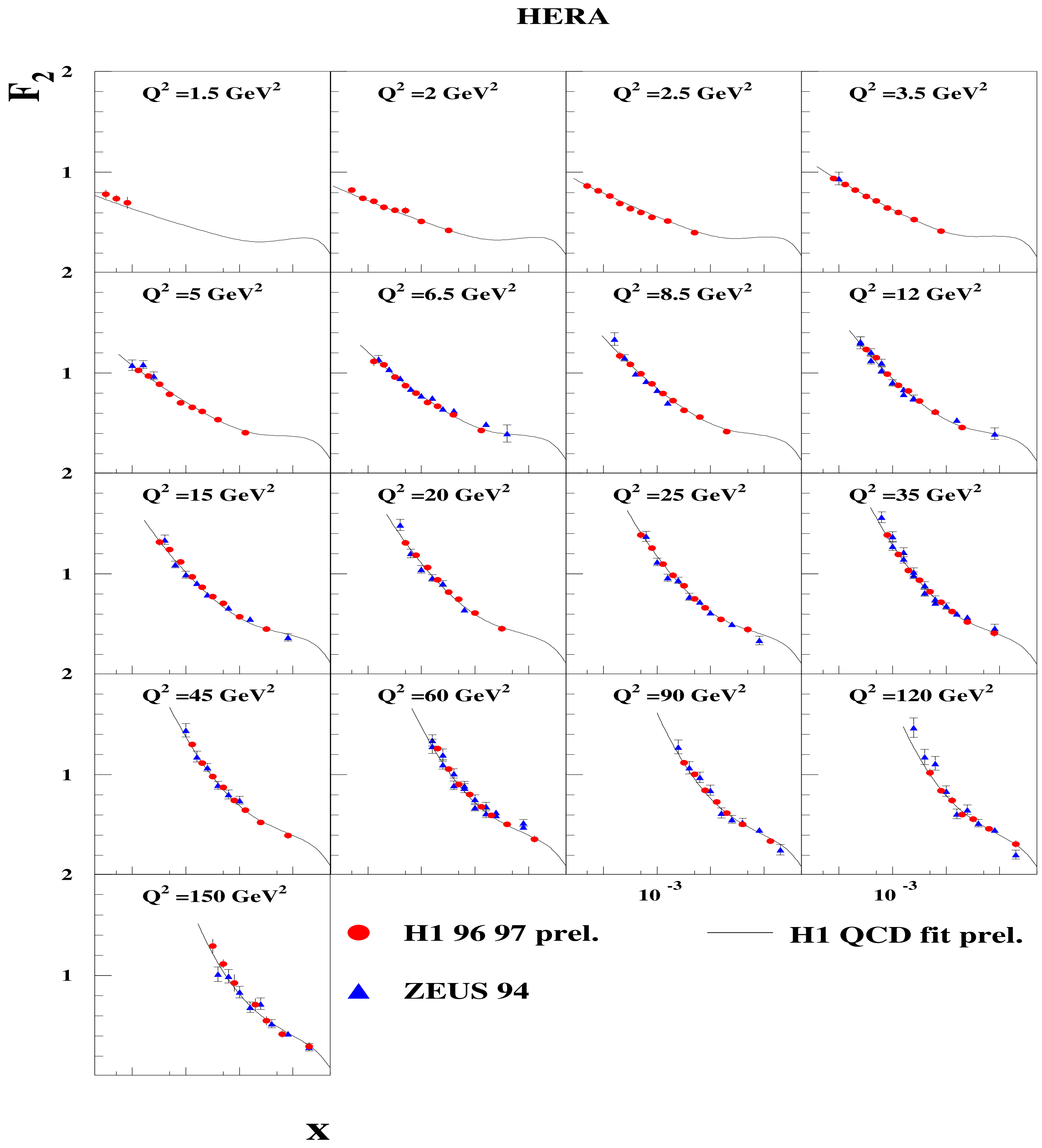
New H1 preliminary data:



- Scaling violation at low x $\to$ increase of gluon
- Fit describes data over 4 orders of magnitude in Q^2

$\to$ confident that pQCD works for Q^2 > a few GeV^2

F_2 at HERA - medium Q^2



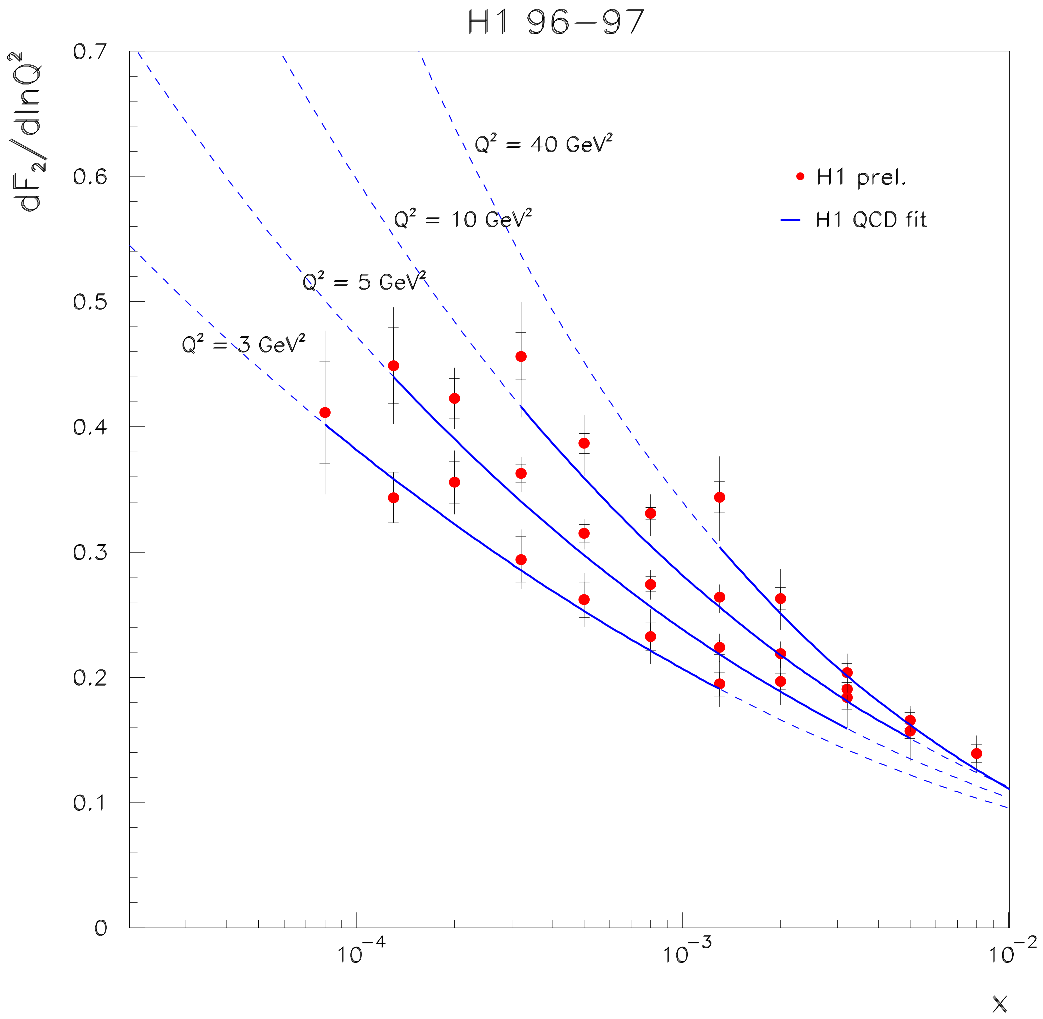
- ZEUS and H1 agree well
- Uncertainty dominated by systematic error
- total Error $\sim 2-3\%$, $\rightarrow$ QCD known to same precision
- strong rise of F_2 ($\propto x^{-\lambda}$), less steep at lower Q^2

$\Rightarrow$ F_2 is driven by the gluon density at low x

Slope of F_2

Look at derivative of F_2:

Use a quadratic approximation to determine $\frac{\partial F_2}{\partial ln Q^2}$



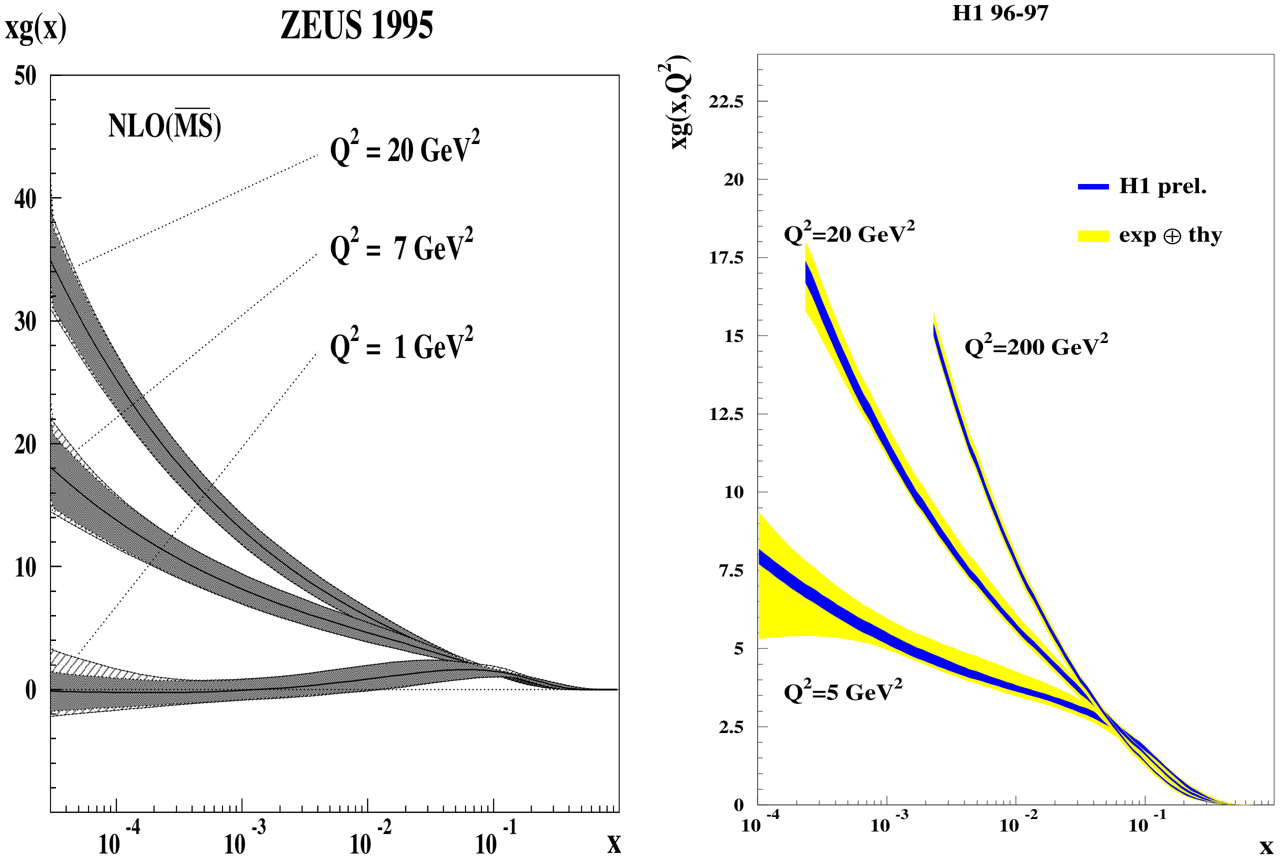
• no departure from the rising behaviour for $Q^2 > 3GeV^2$

• below $Q^2 = 3GeV^2$ the fits depend very much on starting conditions

Extraction of the Gluon Density

• Gluon density can be extracted from a DGLAP fit to measured F_2 Data

The scaling violation of F_2 is dominated by the gluon density (LO): $\frac{dF_2(x,Q^2)}{dlnQ^2} \approx \frac{5\alpha_s(Q^2)}{9\pi}\frac{2}{3}xg(x,Q^2)$
(for $x < 10^{-2}$)



• below $Q^2 = 2\,GeV^2$ the gluon density is not well determined
What do we know about this region? Return to this later.

What other processes are sensitive to the gluon density?

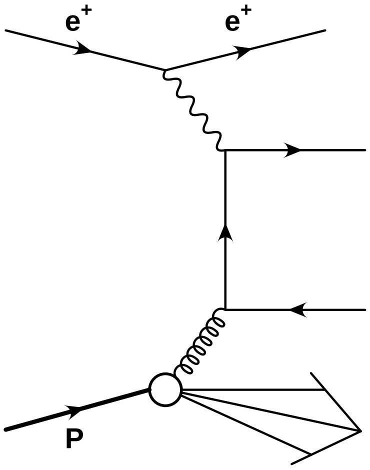
F_2^{charm} from HERA

Charm in the hadronic final state required:

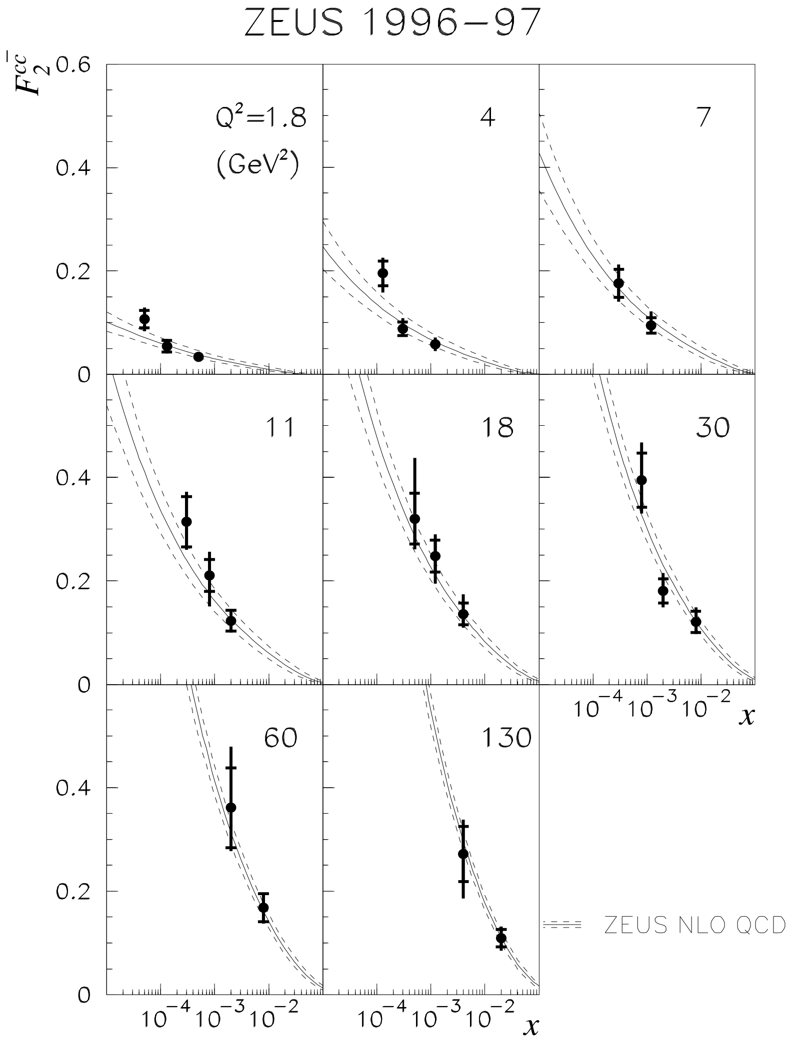
$$\frac{d^2\sigma(ep\to e c\bar{c} X)}{dx dQ^2} = \frac{2\pi^2\alpha}{xQ^4}\left(Y_+ F_2^c - y^2 F_L^c\right)$$

Direct handle on Gluon density :

Boson-Gluon-Fusion (BGF)



Charm in the final state



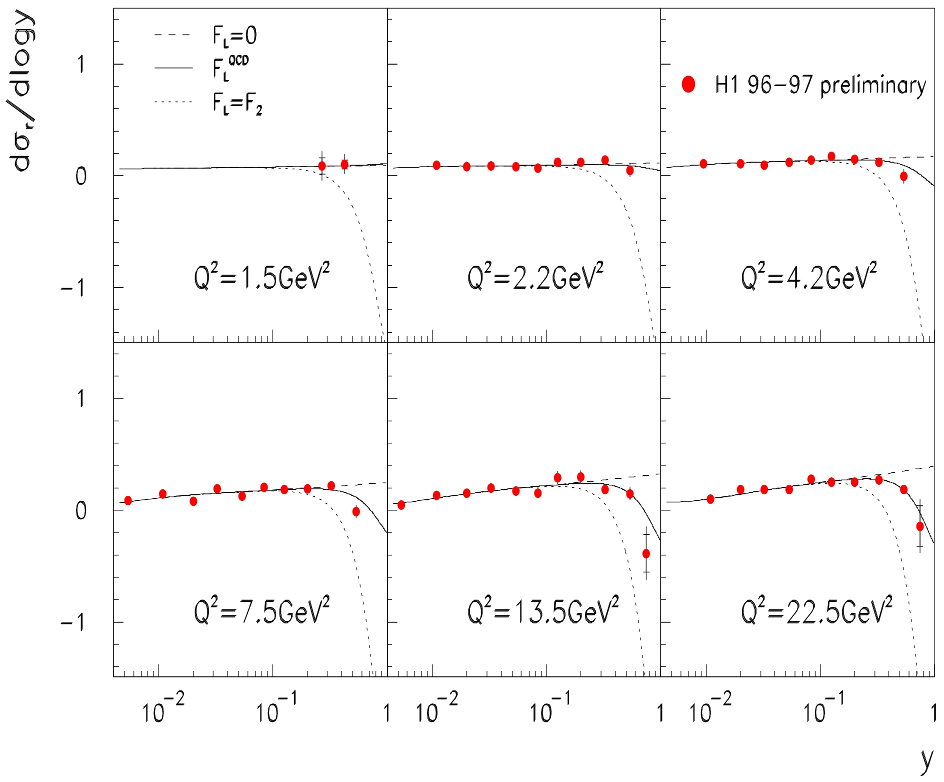
- steep rise of F_2^c $\to$ good description by NLO QCD fit
- consistency check: F_2^c from a global DGLAP fit is compared to measured F_2^c

Extraction of F_L - Derivative Method

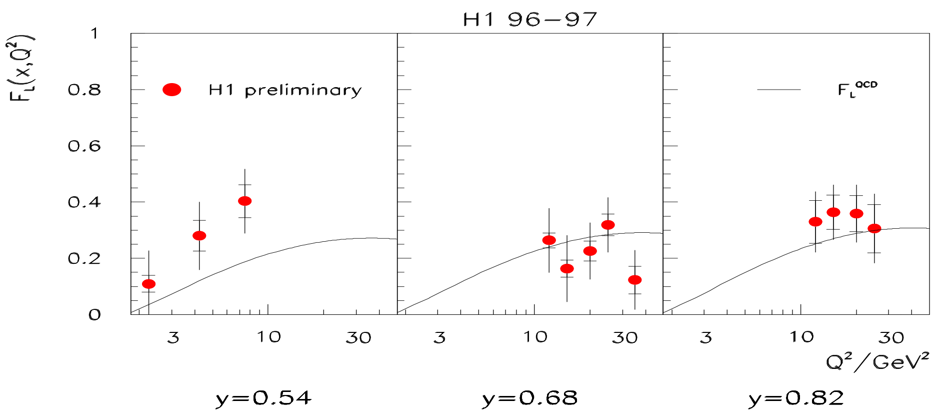
Dominant contribution to F_L at low x is $xg(x, Q^2)$

Determine F_L:

- $\frac{\partial \sigma_r}{\partial logy} = -\frac{\partial F_2}{\partial logy} - F_L \cdot 2y^2 \cdot \frac{2-y}{Y_+} + \frac{\partial F_L}{\partial logy} \cdot \frac{y^2}{Y_+}$
- Straight line fit to $\partial \sigma_r / \partial logy$ in Q^2 bins at $y < 0.2$



Extracted F_L compatible with QCD prediction:

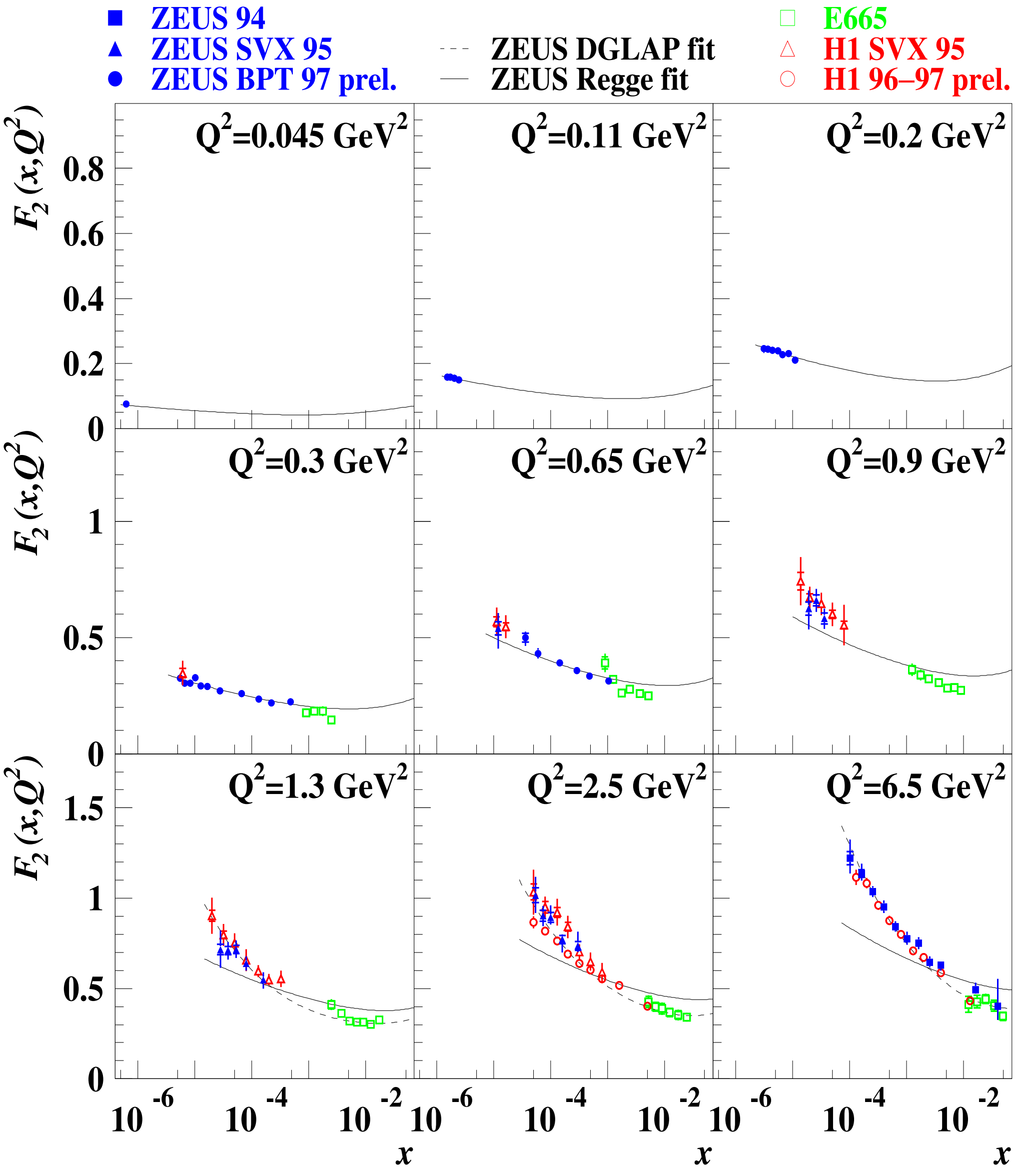


- Direct measurement requires change of beam energies

F_2 at very low Q^2

- study lower limit of validity of pQCD and DGLAP
- already surprising that pQCD works to a few GeV^2

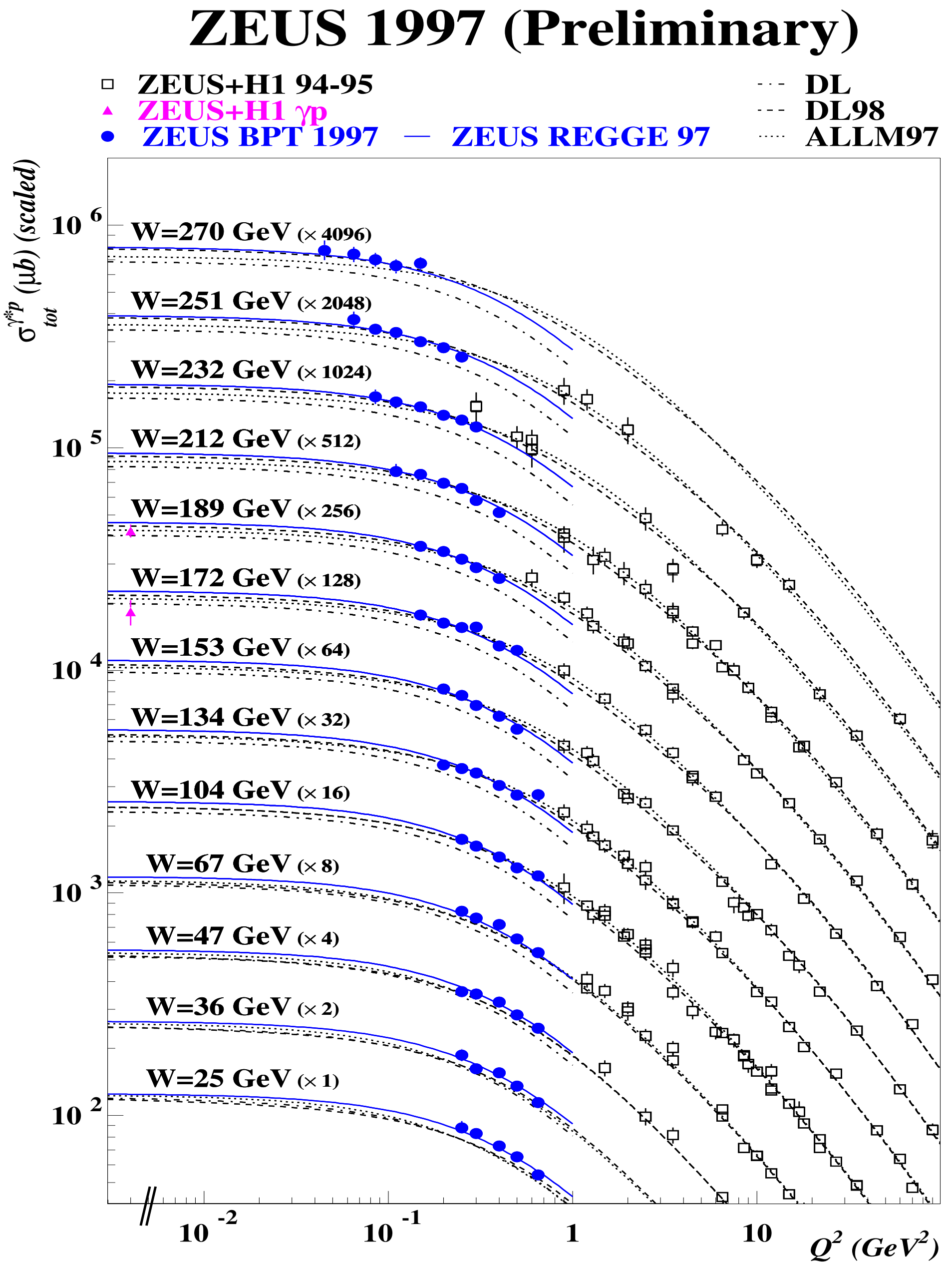
Very low Q^2 region: $0.045GeV^2 < Q^2 < 0.65GeV^2$



- Transition region from PhotoProduction ($Q^2 = 0$)
  to Deep Inelastic Scattering ($Q^2 > 0$)
- Rise of F_2 at low x diminishes as Q^2 tends to 0
- Change of behaviour at $Q^2 \approx 1GeV^2$

Extrapolation of $\sigma_{tot}^{\gamma p}$

$\sigma_{tot}^{\gamma^\star p}$ at low Q^2



soft physics:

$\sigma_{tot}^{\gamma^\star p}(W^2,Q^2) = \frac{4\pi^2\alpha}{Q^2}F_2$

$\sigma_{tot}^{\gamma^\star p}$ const. at very low Q^2

$\rightarrow F_2 \propto Q^2$

Deep Inelastic Scattering:

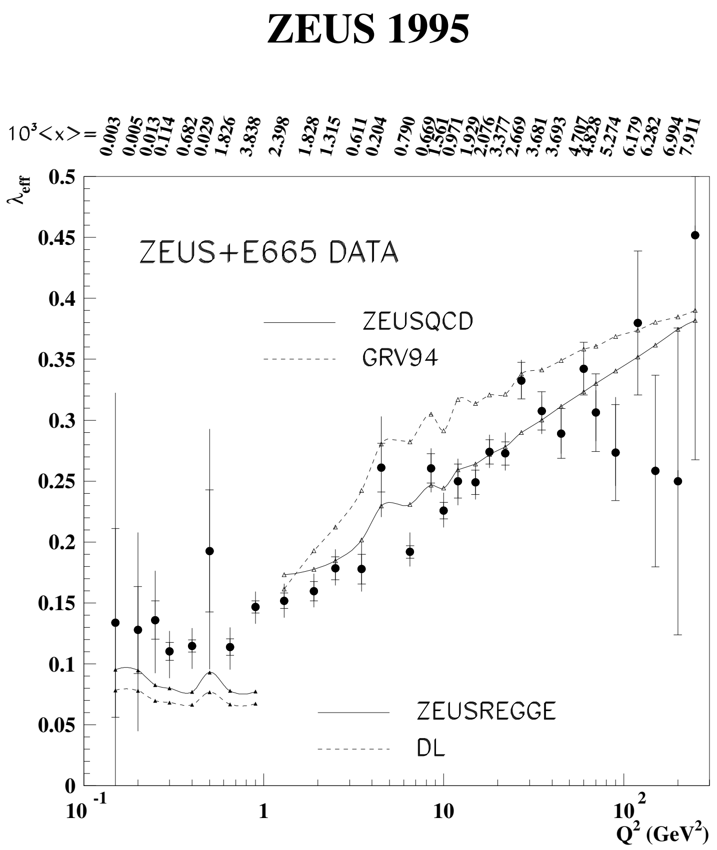
$F_2 \sim x^{-\lambda(x,Q^2)}$

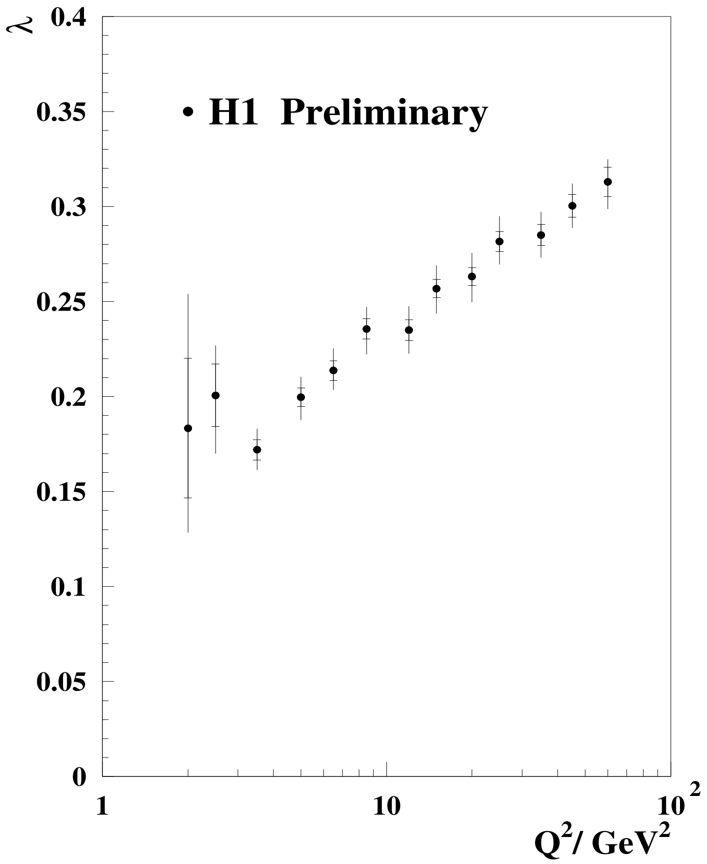
$\lambda \rightarrow 0.1 \approx \alpha_P - 1$

for very low Q^2

Rise of F_2

- quantify striking rise of F_2 at low x: $\lambda_{eff} = \frac{dlnF_2}{dln(1/x)}$





Change of behaviour below a few GeV^2:

- constant at low Q^2
- logarithmic rise with Q^2 at higher Q^2

Summary

pQCD works well

- Scaling violations agree with DGLAP
- Gluon density extracted from NLO QCD fit
- Gives consistent description of:
  - F_2^{charm} from D^* production
  - F_L as extracted by H1

Transition Region

- Transition region at $Q^2 < 2\,GeV^2$: precision data exists from $Q^2 \sim 2\,GeV^2$ down to $Q^2 \approx 0\,GeV^2$
- Clear change in behaviour of F_2 at small x
- Detailed phenomenological studies to be done