Proton Structure Functions at HERA

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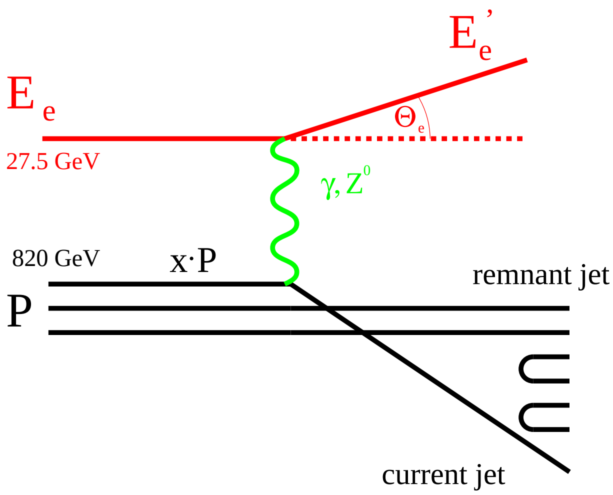
Moriond QCD 1999

on behalf of H1 and ZEUS

- Introduction
- F_2 measurements and phenomenology
- Extraction of F_2^{charm}
- Measurement of xg
- Determination of F_L
- Summary



$$
\begin{aligned}
Q^2 &= \text{squared 4-momentum transfer} \\
x &= \text{parton momentum fraction} \\
y &= \text{fractional energy transfer} \\
W^2 &= \text{squared mass of hadronic system} \\
\sqrt{s} &= \text{c.m.s energy (300 GeV)} \\
\\
Q^2 &= sxy \Rightarrow \text{2 independent variables}
\end{aligned}
$$

$$\frac{d^2\sigma^{NC}(e^{\pm}p)}{dx\, dQ^2} = \frac{2\pi\alpha^2}{x\, Q^4} Y_+ \left[F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3 \right]$$

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

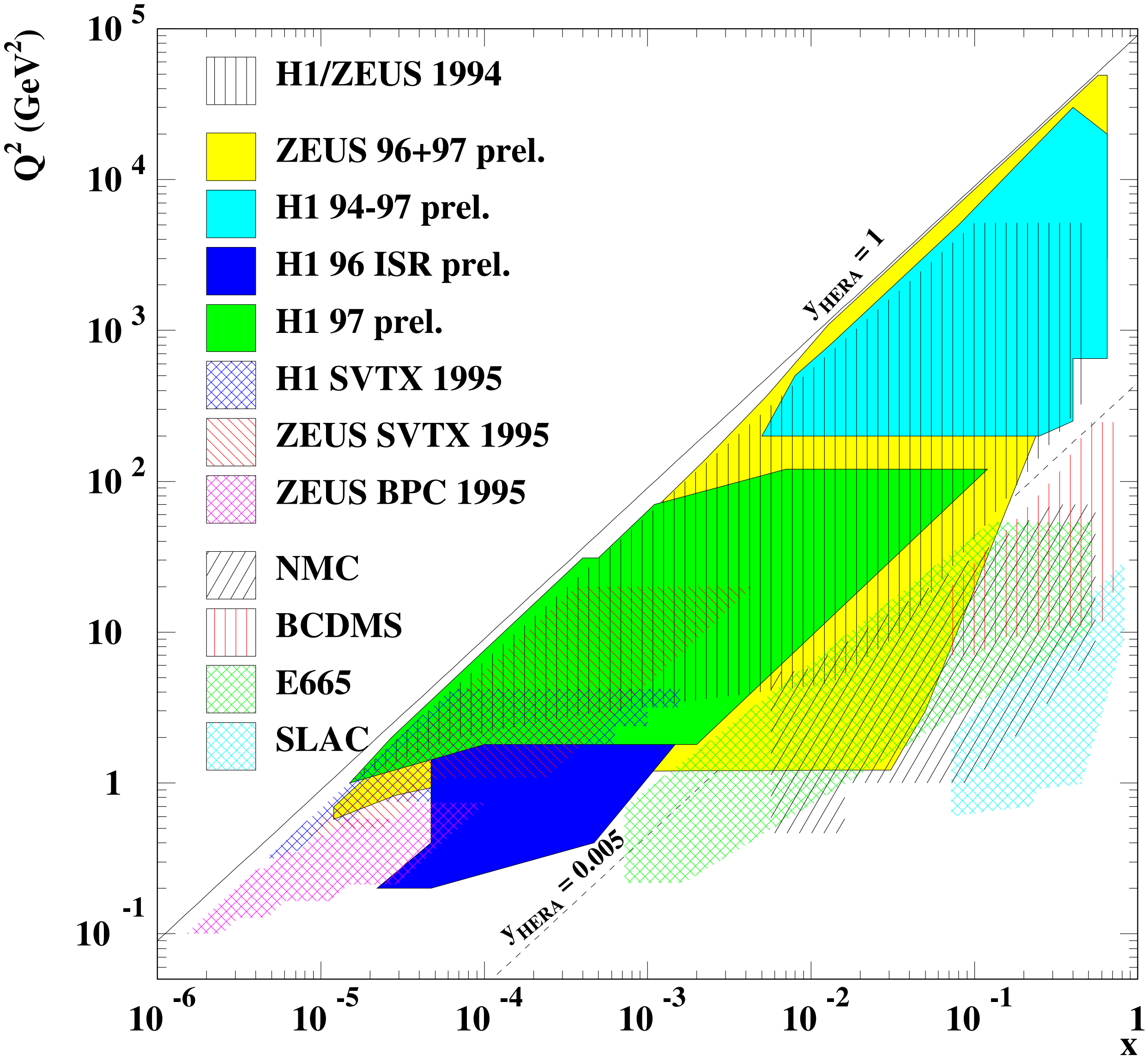
$$
\begin{aligned}
F_L &= \text{longitudinal structure function (=0 in QPM)} \\
xF_3 &= \text{parity violation term arising from } Z^0 \text{ exchange} \\
F_2 &= F_2^{em} + \frac{Q^2}{Q^2 + M_z^2} F_2^{int} + \frac{Q^4}{(Q^2 + M_z^2)^2} F_2^{wk} \\
&= F_2^{em}(1 + \delta_Z)
\end{aligned}
$$

$$F_2^{em}(x, Q^2) = \sum_f e_f^2 \cdot x\, q_f(x, Q^2) \text{ in QPM}$$

Total $\gamma^* P$ cross-section:

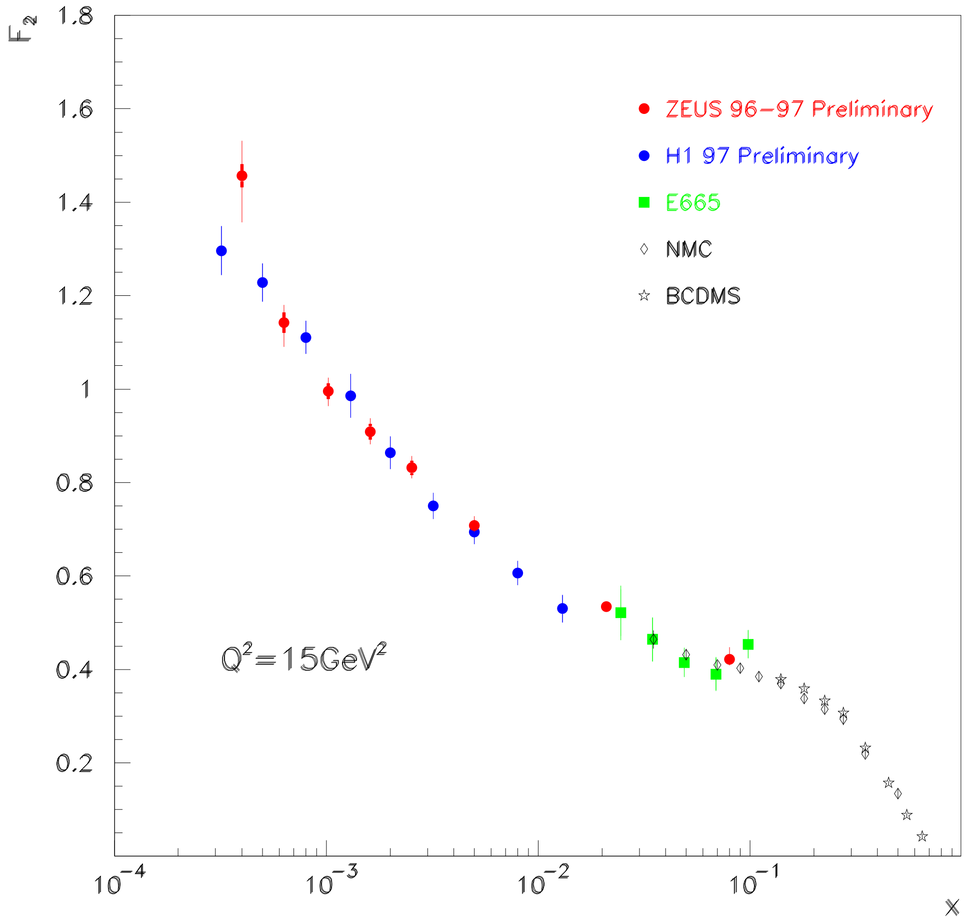
$$
\begin{aligned}
\sigma_{tot}^{\gamma^* P}(W^2, Q^2) &\equiv \sigma_T^{\gamma^* P} + \sigma_L^{\gamma^* P} \\
&\approx \frac{4\pi^2\alpha}{Q^2} F_2(x, Q^2).
\end{aligned}
$$

HERA Kinematic Range

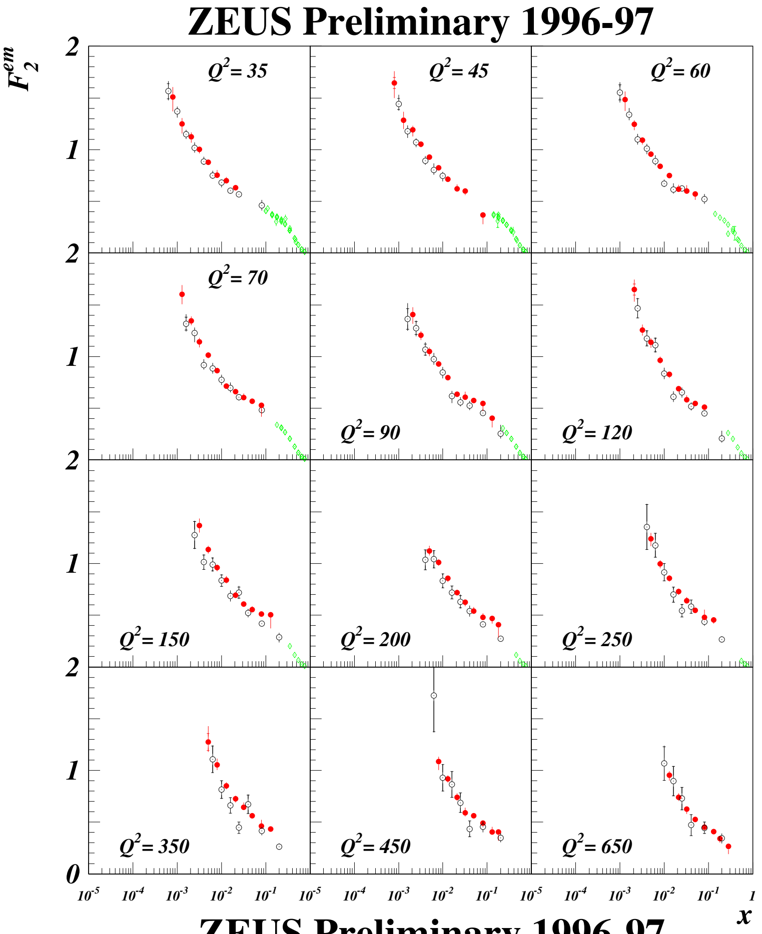


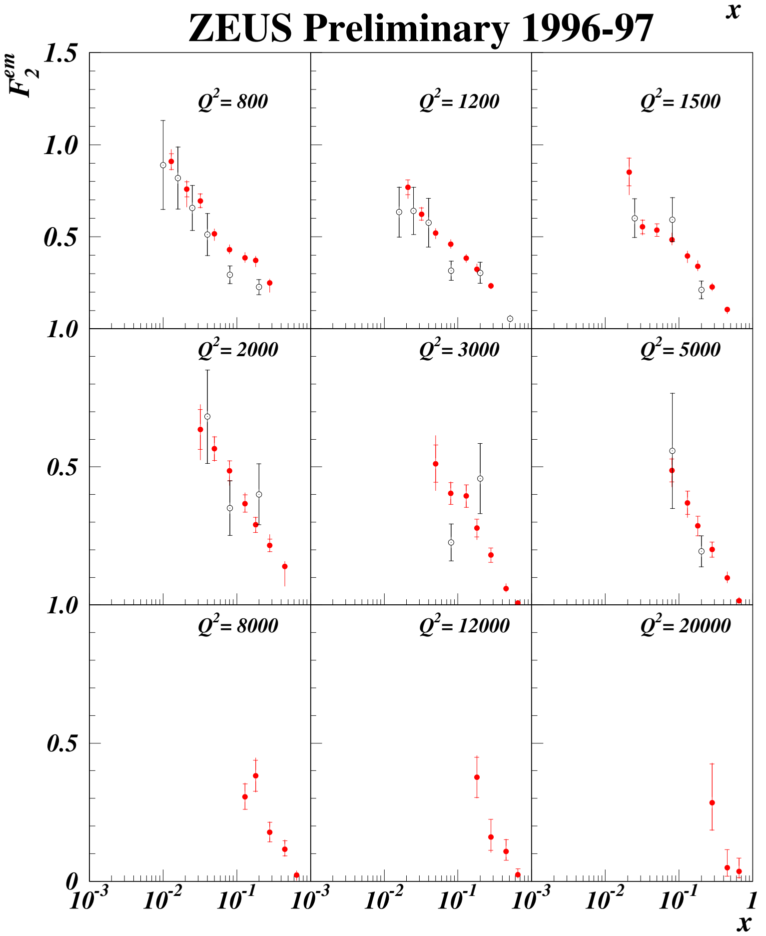
- $Q^2 \rightarrow 0$: transition to γp
- $Q^2 \rightarrow s$: electroweak unification, substructure
- $y \rightarrow 1$: sensitivity to F_L
- $y \rightarrow 0.005$: overlap with fixed target exp.
- $x \rightarrow 1$: probe valence quark at high Q^2

$F_2(x)$ by H1 + ZEUS



- HERA: low x: strong rise of F_2!
- Fixed target: high x: valence quark structure
- Precision: 1% stat. $\oplus$ 3-4% syst.
- H1 and ZEUS agree well


ZEUS Preliminary 1996-97
F_2^{em}
Q^2= 35
Q^2= 45
Q^2= 60
Q^2= 70
Q^2= 90
Q^2= 120
Q^2= 150
Q^2= 200
Q^2= 250
Q^2= 350
Q^2= 450
Q^2= 650
x

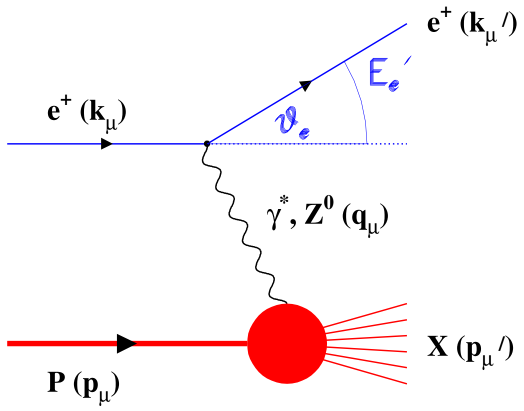

ZEUS Preliminary 1996-97
F_2^{em}
Q^2= 800
Q^2= 1200
Q^2= 1500
Q^2= 2000
Q^2= 3000
Q^2= 5000
Q^2= 8000
Q^2= 12000
Q^2= 20000
x

Experimental access to low Q^2

$$\boxed{Q^2 = 4E_eE_e' \cdot \sin^2\frac{\vartheta_e'}{2}}$$

⇒ Tag **positron** scattered under very small angles

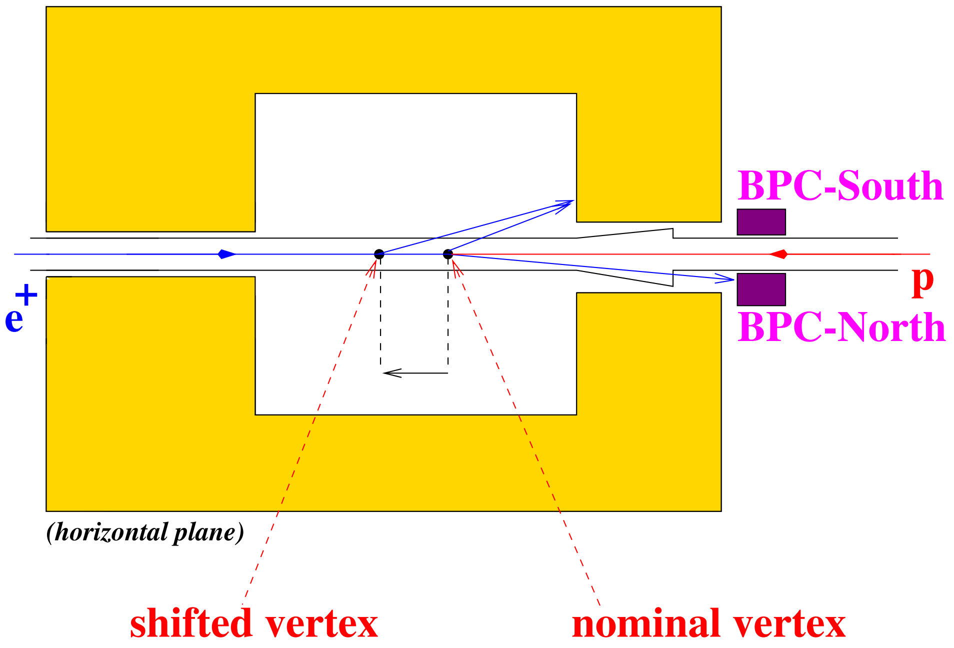
⇒ Measure its **energy** E_e' and **angle** ϑ_e'



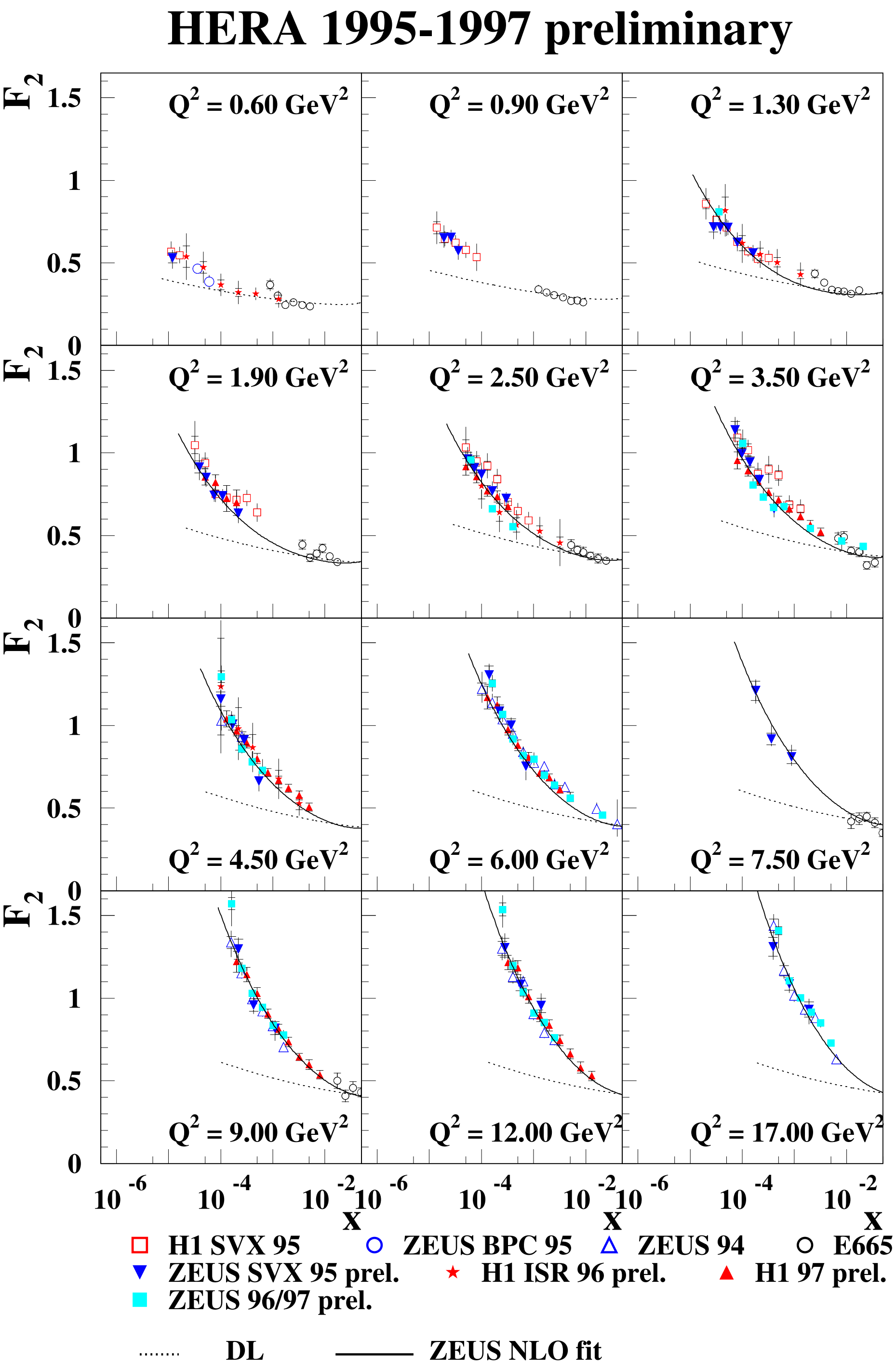
⇒ ZEUS: **B**eam **P**ipe **C**alorimeter (**BPC**) $Q^2_{min} = 0.1\ GeV^2$
(New 1997: **B**eam **P**ipe silicon **T**racker (**BPT**))

H1: Backward Calorimeter (**SPACAL**) $Q^2_{min} = 2\ GeV^2$
(New 1997: **B**ackward **S**ilicon **T**racker (**BST**))

⇒ H1 & ZEUS: Events with shifted vertex $Q^2_{min} \sim 0.4\ GeV^2$



- F_2 keeps rising ...

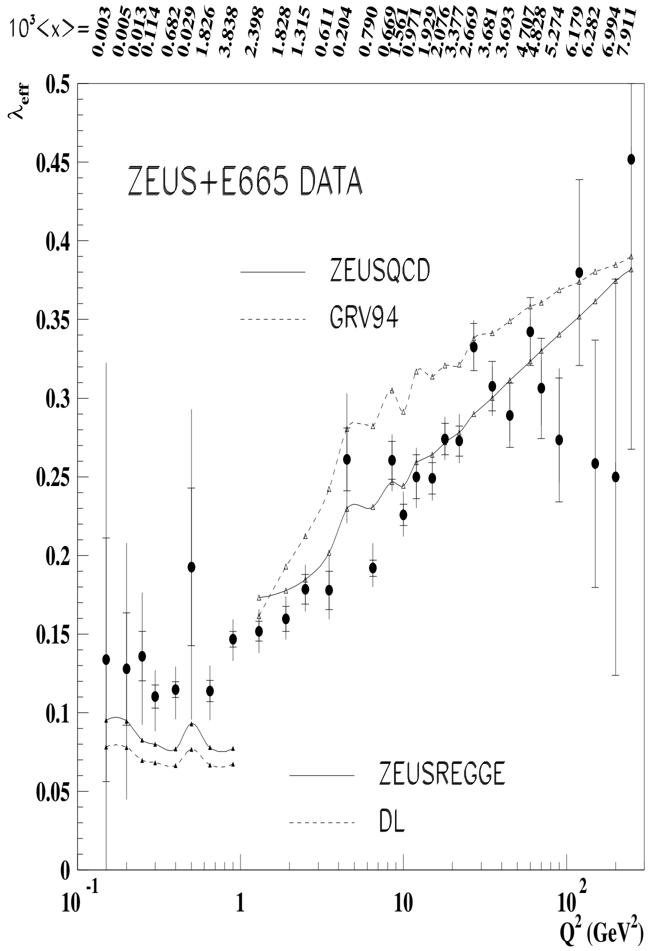


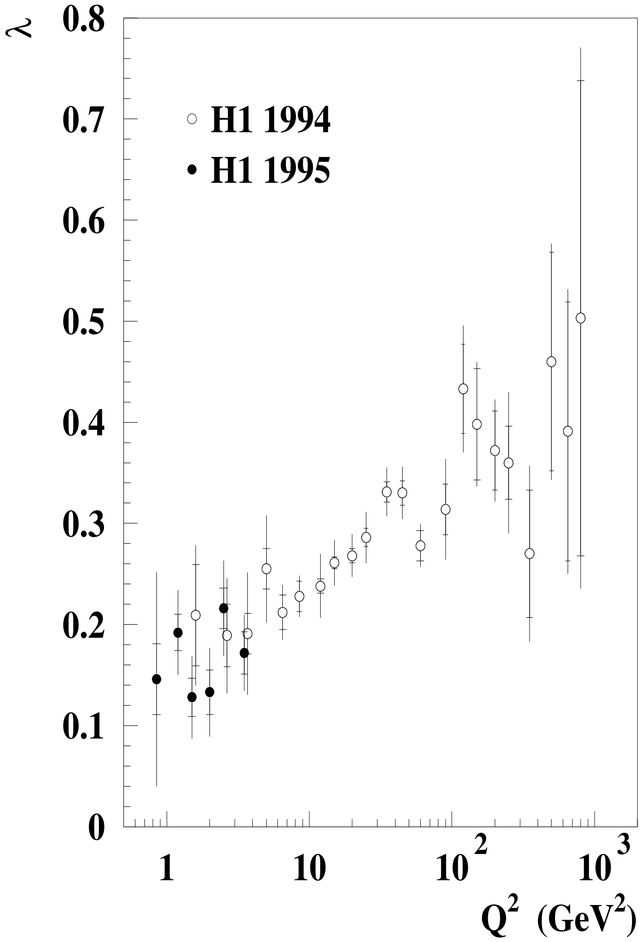
- at very low Q^2 "soft" F_2 rise as $x \to 0$
  $\Rightarrow$ hadronic behaviour.

- at $Q^2 \geq 1$ GeV^2 strong F_2 rise as $x \to 0$
  $\Rightarrow$ parton dynamics.

The Rise in F_2

Fit $F_2 \propto x^{-\lambda_{eff}}$ $(1/x \sim W^2)$ for fixed Q^2 $(x < 0.01)$

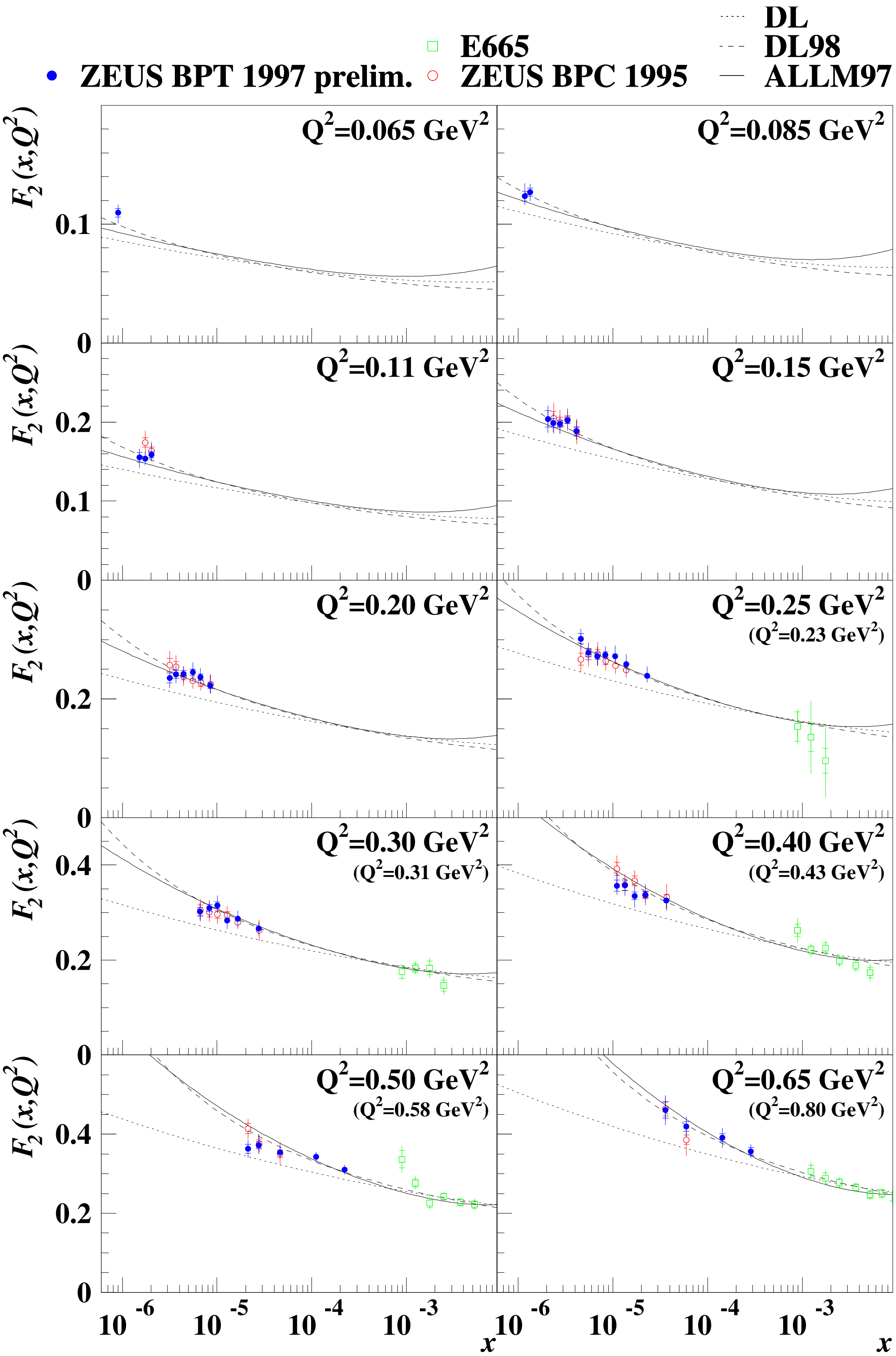




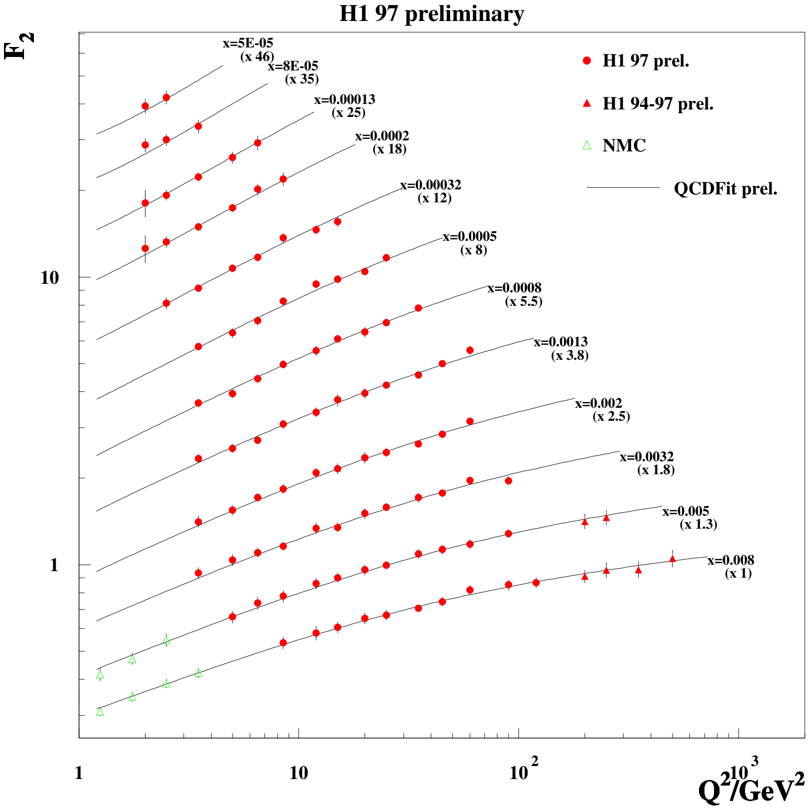
- F_2 rising with $x \to 0$ in agreement with pQCD even at $Q^2 \approx 1$ GeV^2

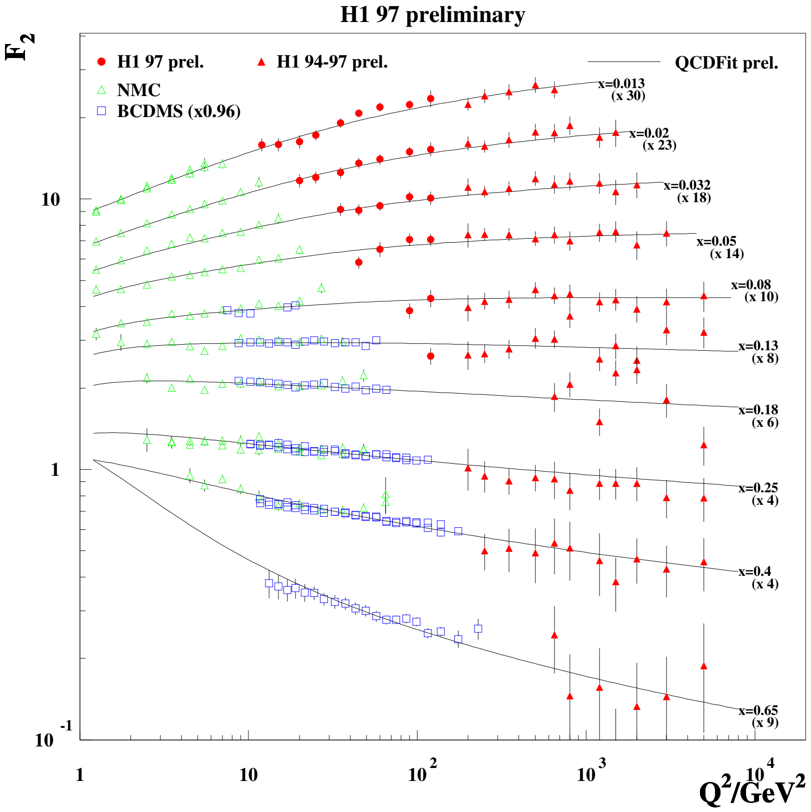
- for $Q^2 < 1$ GeV^2, soft rise consistent with Regge expectations $\lambda_{eff} \sim 0.1$.

Preliminary ZEUS BPT97 F_2 Data

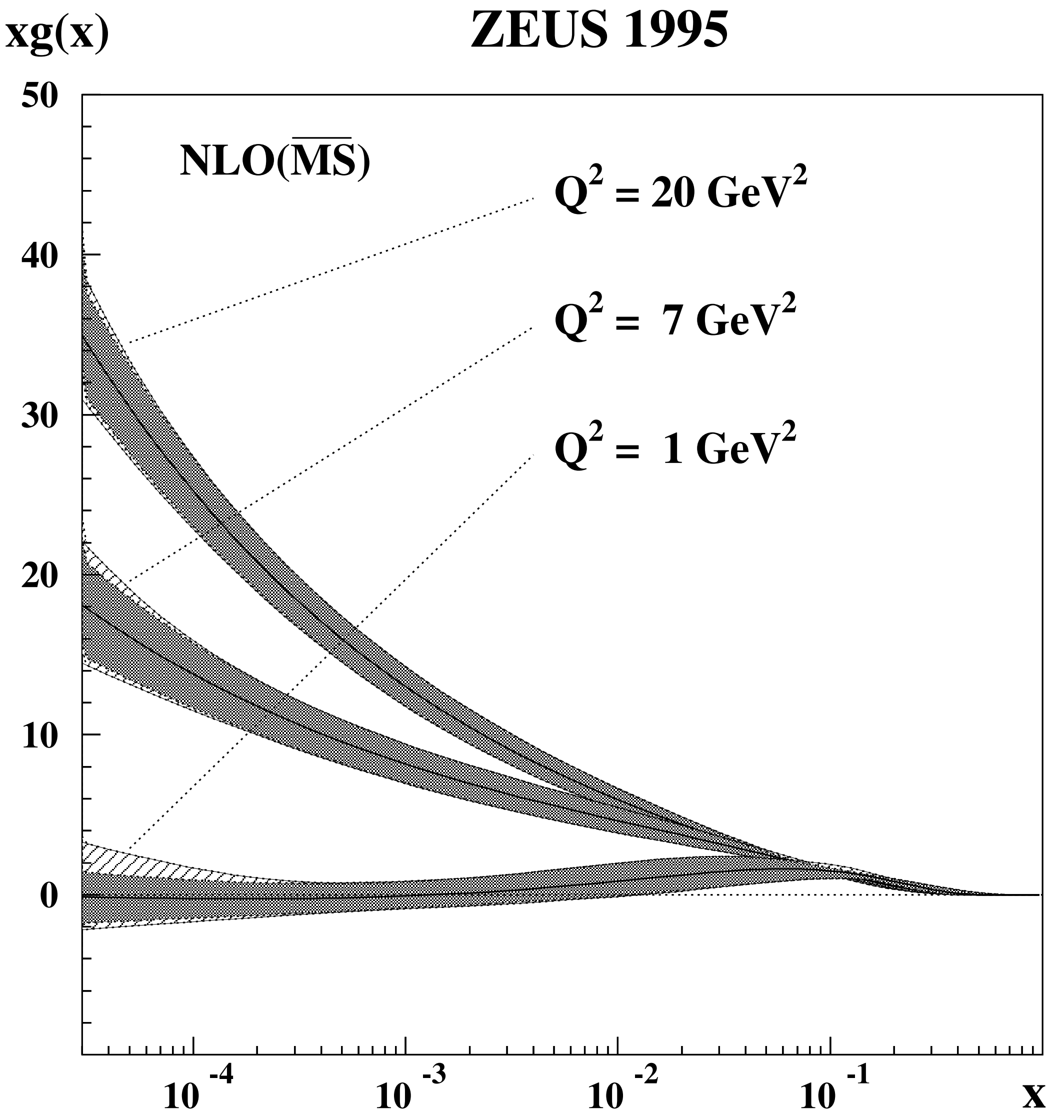


F_2 Scaling Violations





pQCD-fit results



- Precision on $xg(x) \sim 10\%$ at $Q^2 = 20$ GeV^2;

- inner band include statistical, experimental α_s, m_c and strange quark content errors;

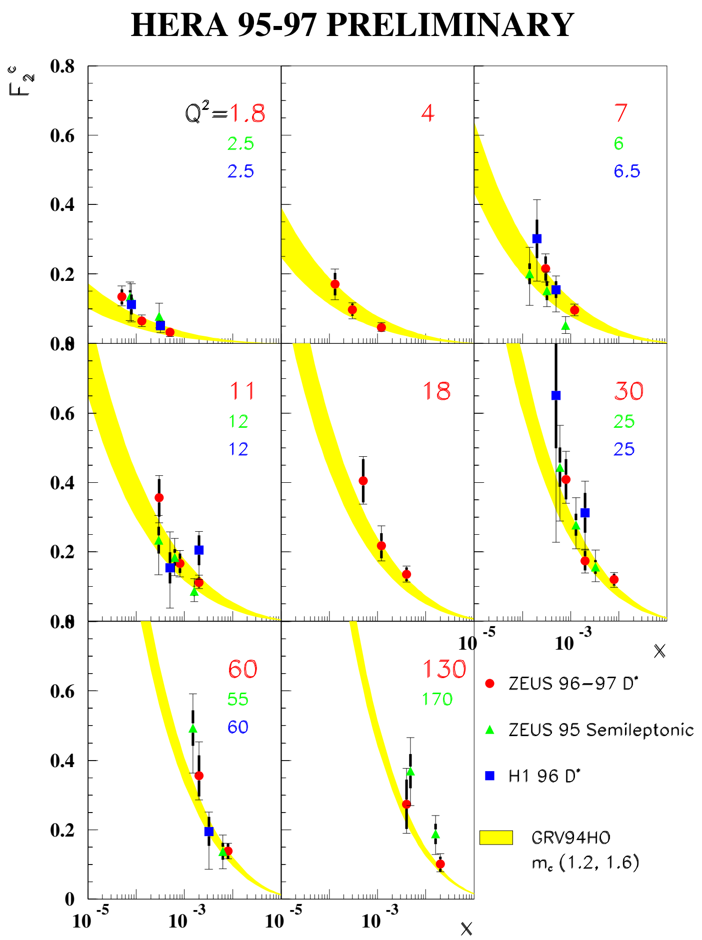
- outer error band includes Q_0^2 changes to 1-4 GeV^2 and more flexible gluon parametrization.

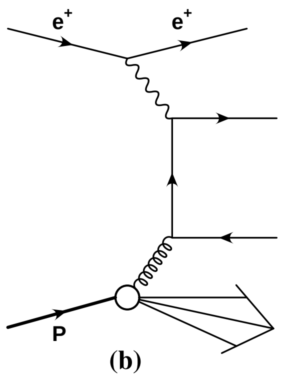
Extraction of F_2^{charm}

$$\frac{d^2\sigma(c\bar{c}X)}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left[1 + (1 - y)^2\right] F_2^c(x, Q^2)$$

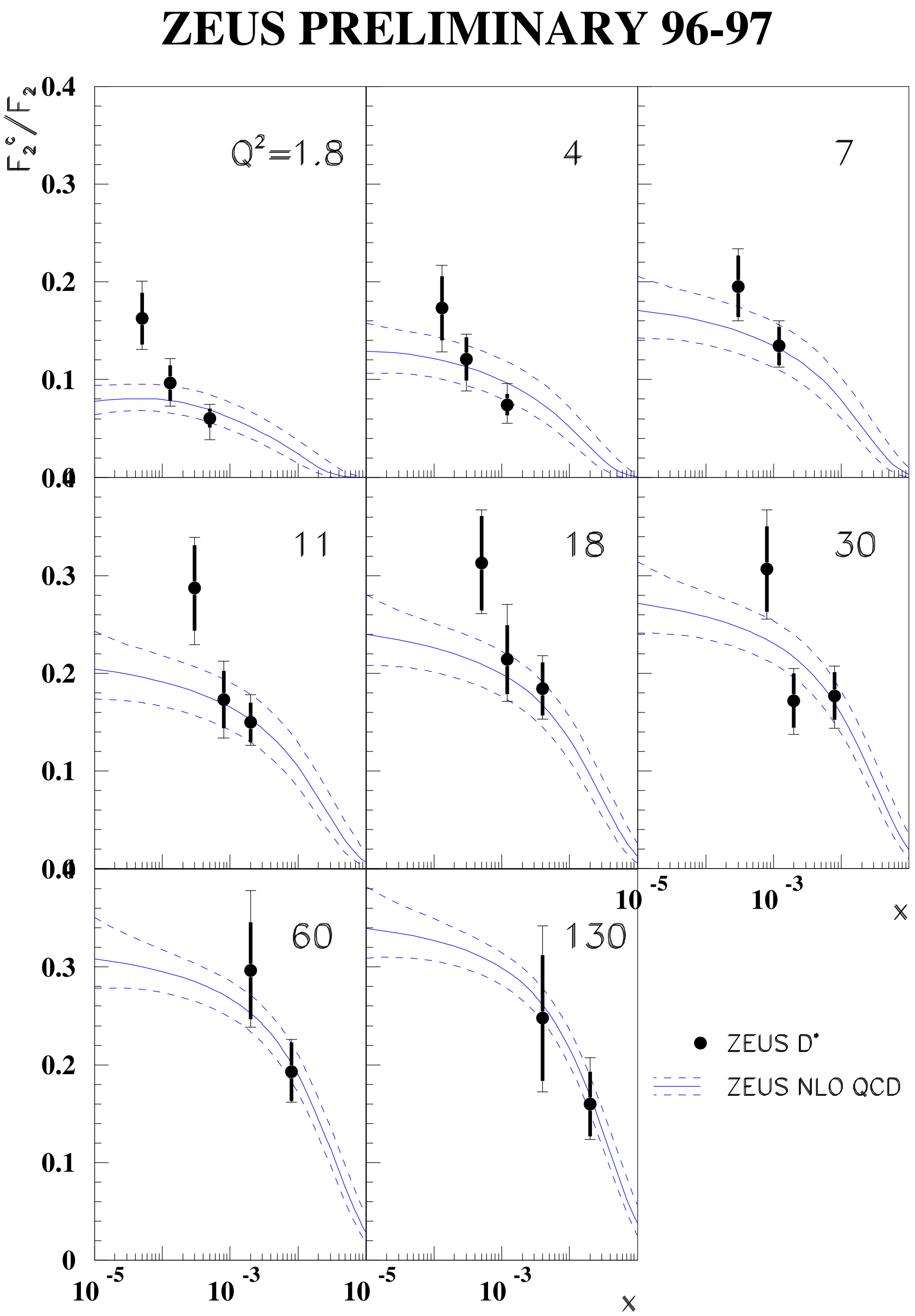
Select inclusive D^* events:

$$D^{*+} \rightarrow D^0\pi^+_{slow} \rightarrow (K^-\pi^+)\pi^+_{slow} \text{ and c.c.}$$



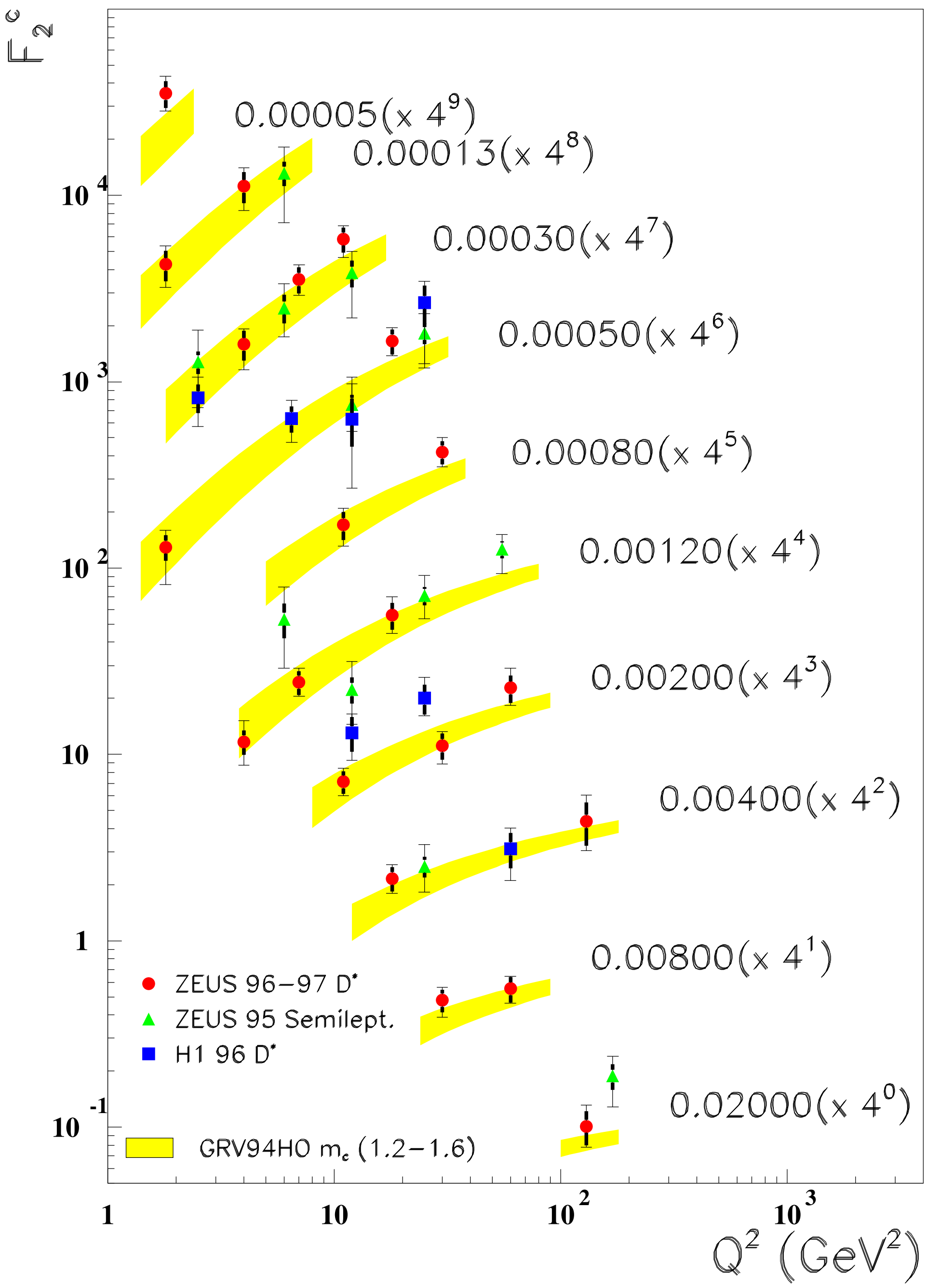


- Steep rise towards low-x → gluons
- Precision ≈ 15–20%.
- Charm mass biggest theoretical uncertainty



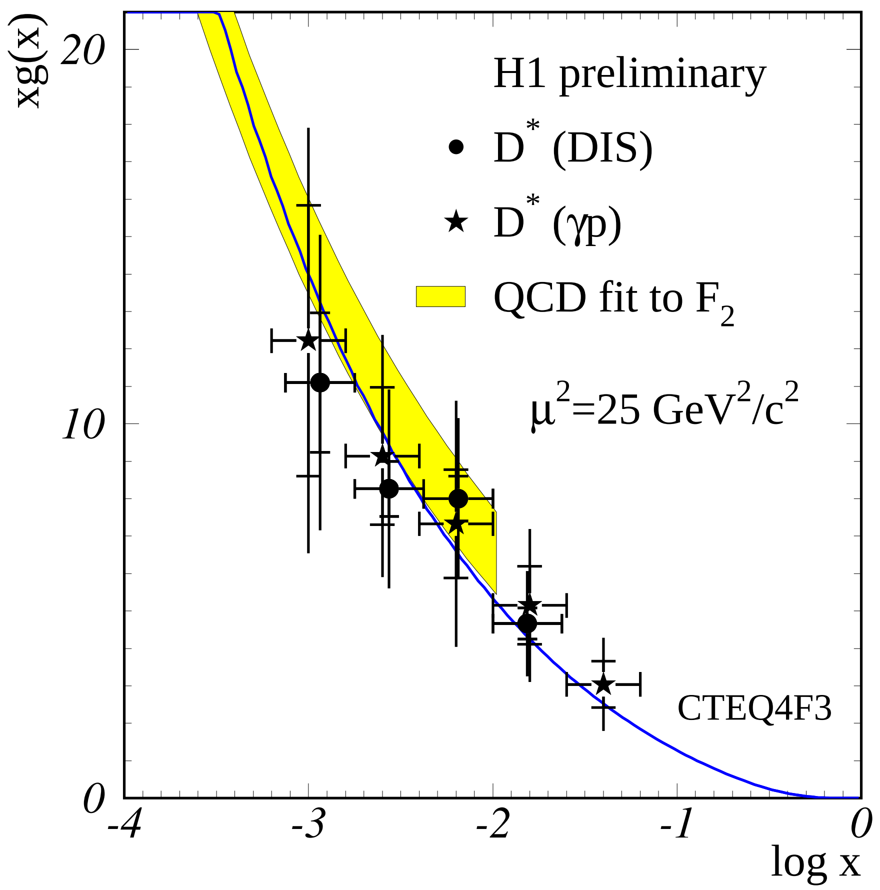
- Inclusive charm production grows from 10 to 25 % of the total between $Q^2 = 1.8$ and 130 GeV^2

HERA PRELIMINARY 95-97



- Large scaling violations

Gluon Density from the Charm



- Gluon from D^* cross section agrees with
- Gluon from QCD fit to inclusive cross section

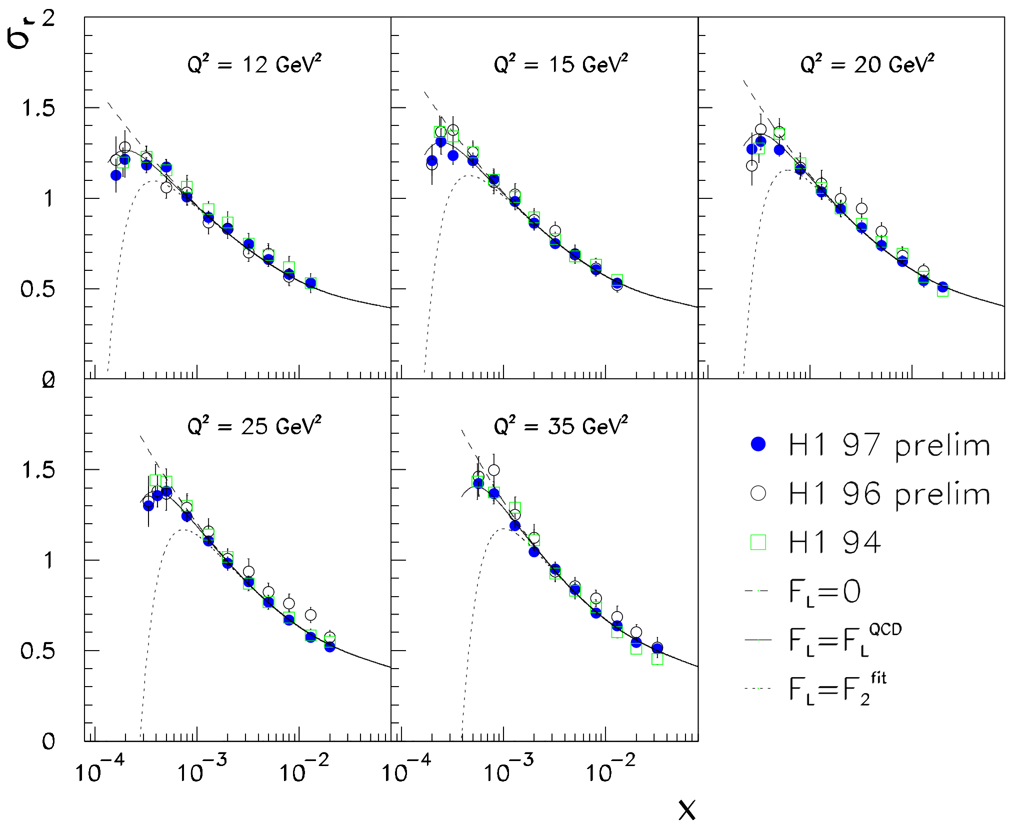
F_L Determination using DGLAP fit

- Reduced cross-section

$$\sigma_r = \frac{Q^4 x}{2\pi\alpha^2 Y_+} \frac{d^2\sigma}{dx dQ^2} = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$

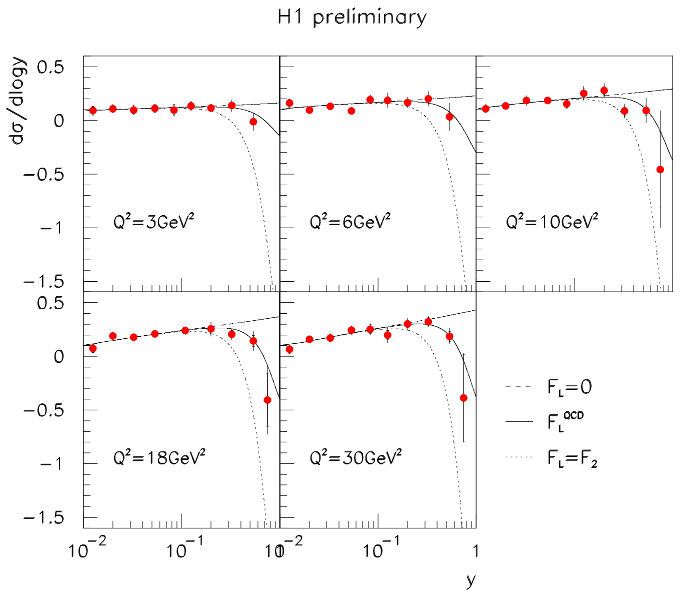
$$Y_+ = 1 + (1-y)^2$$

- H1
  - QCD fit to F_2 where F_L is negligible: $y < 0.35$
  - extrapolate to high y
  - subtract measured reduced cross-section:

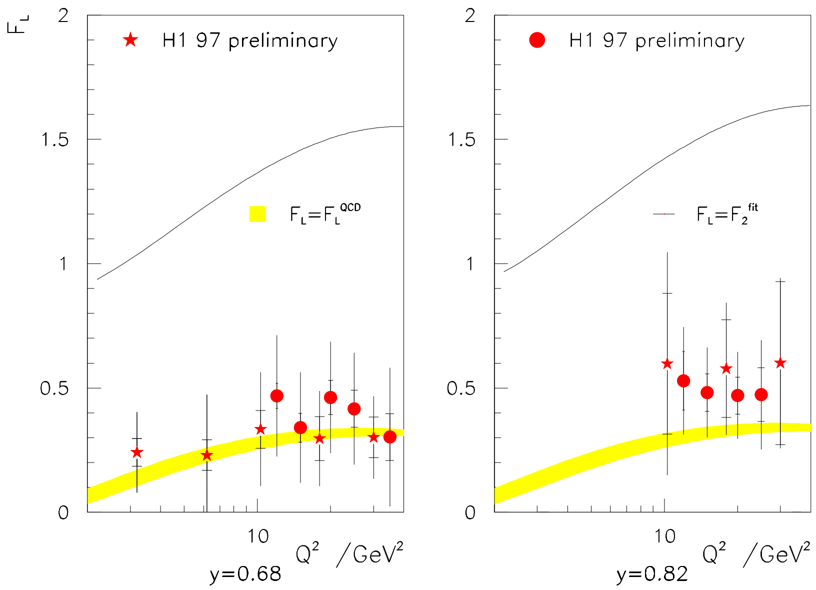


• Can also use

$$\frac{\partial \sigma_r}{\partial \log y} = -\frac{\partial F_2}{\partial \log y} - F_L \cdot 2y^2 \frac{2-y}{Y_+^2} + \frac{\partial F_L}{\partial \log y} \cdot \frac{y^2}{Y_+}$$



• Straight line fit to $d\sigma/dlogy$ in Q^2 bins at y<0.2 to extract F$_L$.



• NLO DGLAP can describe cross section consistently.

Summary

- F_2
  - Steep rise toward low-x for $Q^2 > 1$ GeV^2 Observed transition from perturbative to non-perturbative regime (prelim. ZEUS BPT97)
  - Scaling violations grow toward low-x and are driven by the gluon
  - NLO DGLAP equations work over more than 4 orders of magnitude:
    $2 \times 10^{-5} < x < 0.7$ and $1 < Q^2 < 30000$ GeV^2
- F_2^{charm}
  - F_2^c/F_2 rises from 10 to 25 % for $Q^2 = 1.8$ to 130 GeV^2 in substantial agreement with NLO QCD prediction
- xg
  - Agreement between F_2 scaling violations, charm and dijet (see C. Glasman talk)
- F_L
  - F_L extracted by H1 with two methods
  - Agreement within each other and with NLO DGLAP prediction