New Structure Function Results at Low x and High Q^2 from HERA

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On Behalf of

H1 ZEUS

- Introduction
- Experimental Setup
- Selected Recent Results
- Summary and Outlook

Introduction

Deep Inelastic Scattering (DIS) experiments

- **Historical Roles**

  in establishing/developing QCD and EW sector of the SM

- **Modern Roles**

  in testing the SM and searching for new phenomena beyond SM

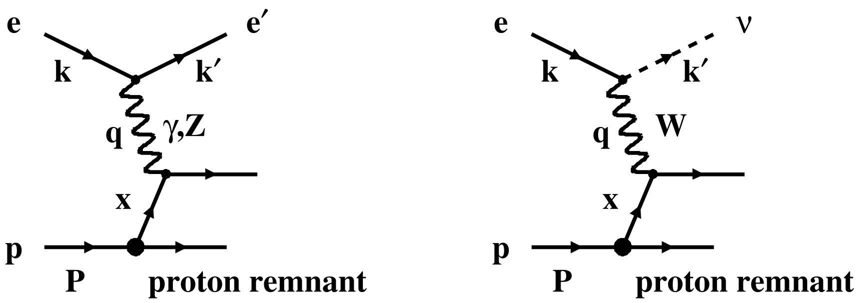
  in providing precise parton densities for reliable predictions
  at future hadron colliders

DIS Event Kinematics

Kinematic variables:

$$Q^2 = -(k-k')^2 = -q^2\,, \qquad x = \frac{Q^2}{2P\cdot q}\,, \qquad y = \frac{P\cdot q}{P\cdot k}$$

Only two independent: $Q^2 = xys$



DIS Processes:

- Neutral Current (NC): $ep \to eX$

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

with $Y_\pm \equiv 1 \pm (1-y)^2\,, \qquad F_2 = F_2^{\rm em}(1+\delta_Z)$

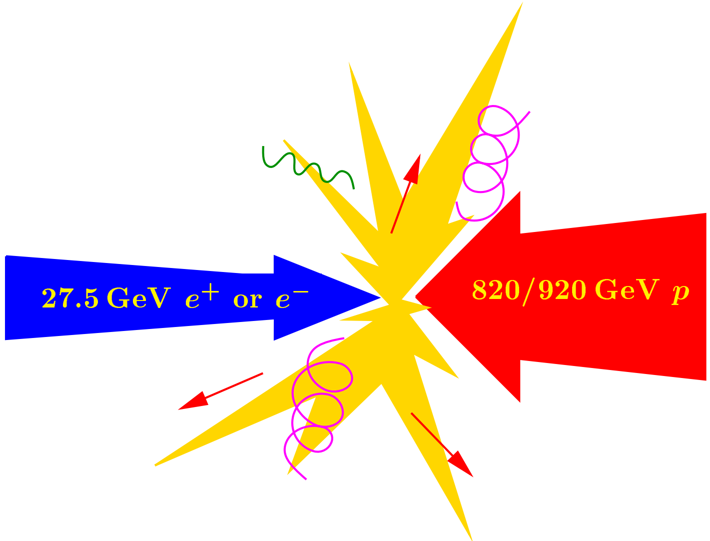
- Charged Current (CC): $ep \to \nu X$

$$\frac{d^2\sigma^{\pm}_{\rm CC}}{dxdQ^2} = \mathcal{K}\left[Y_+F_2^{\rm CC}(x,Q^2) - y^2F_L^{\rm CC}(x,Q^2) \mp Y_- xF_3^{\rm CC}(x,Q^2)\right]$$

with $\mathcal{K} \equiv \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2$

Experimental Setup

HERA: First *ep* collider ever built



Centre-of-Mass Energy:

$'94 -' 97 : \sqrt{s} \simeq 300\,\mathrm{GeV} \qquad (27.5\,e^+ \times 820\,p)$

$'98 -' 99 : \sqrt{s} \simeq 320\,\mathrm{GeV} \qquad (27.5\,e^- \times 920\,p)$

$\Longleftrightarrow$ ~ 50 TeV lepton beam for a fixed target exp.

H1 and ZEUS Detectors:

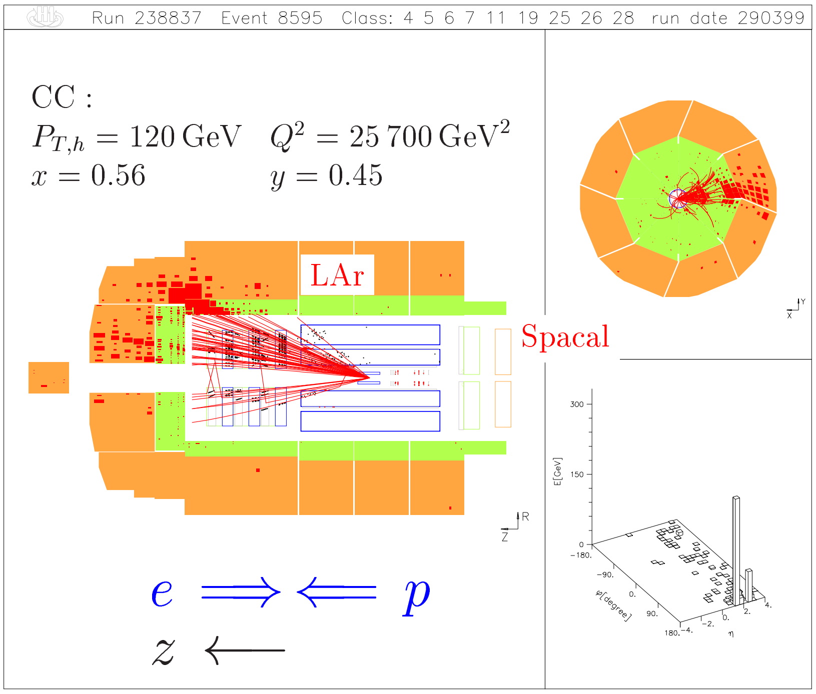
NC: both scattered electrons and hadronic final state measured
kinematics over constrained by several methods

CC: Neutrinos escaping detection leave measurable missing momentum
kinematics only with hadronic method

New Kinematic Domain explored at HERA

H1 and ZEUS Detectors

H1 Spacal, Liquid Argon Calorimeter(LAr):



LAr: 45000 cells

$\sigma_{\theta_{e'}}: 0.5, 3\,\mathrm{mrad}$

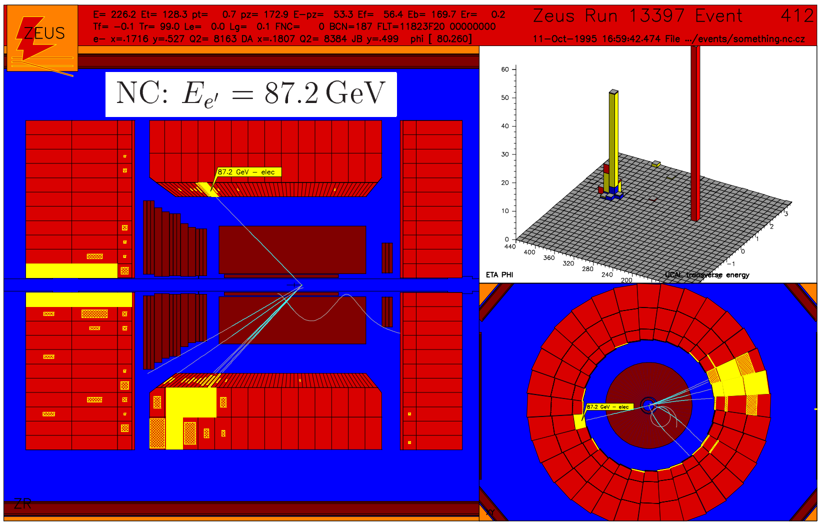
$\sigma(E)/E$:

$$\begin{cases} 7\%/\sqrt{E} & \text{Spacal} \\ 12\%/\sqrt{E} & \text{LAr em} \\ 50\%/\sqrt{E} & \text{LAr had} \end{cases}$$

$\Delta E/E(\mathrm{syst})$:

$$\begin{cases} 0.5-3\% & \text{Spacal em} \\ 5\% & \text{Spacal had} \\ 1-3\% & \text{LAr em} \\ 2-4\% & \text{LAr had} \end{cases}$$

ZEUS Uranium-Scintillator Calorimeter(UCAL):



UCAL: 6000 cells

$\sigma_{\theta_{e'}}: 1\,\mathrm{mrad}$

$\sigma(E)/E$:

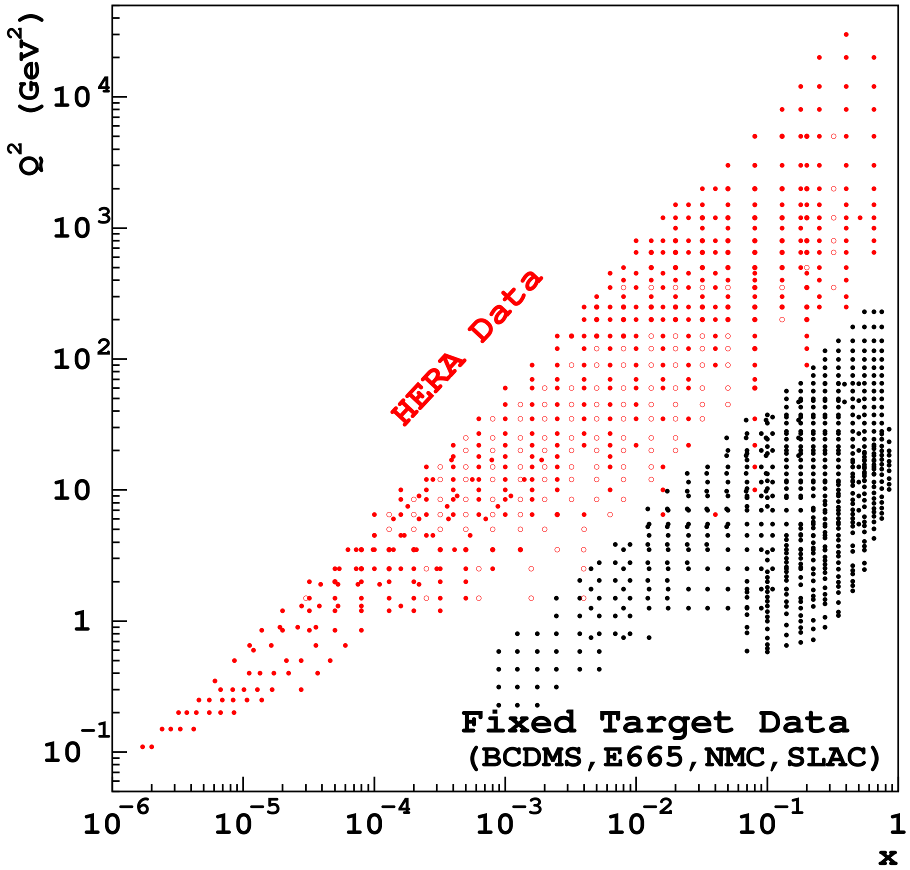
$$\begin{cases} 18\%/\sqrt{E} & \text{em} \\ 35\%/\sqrt{E} & \text{had} \end{cases}$$

$\Delta E/E(\mathrm{syst})$:

$$\begin{cases} 1-2\% & \text{em} \\ 3\% & \text{had} \end{cases}$$

New Kinematic Domain Explored

Smallest distance ($\sim 10^{-3}$ fm) $\Longleftrightarrow$ $Q^2_{\rm max} = s$



Cross-section/Structure Function Measured:

- **Very Low $x, Q^2 (< \mathcal{O}(1)\ \mathrm{GeV}^2)$:**

  Study underlying dynamics in DIS/photoproduction transition region

- **Low $x, Q^2 (> \mathcal{O}(1)\ \mathrm{GeV}^2)$:**

  Constrain parton (in particular gluon) densities

- **High $x, Q^2 (> \mathcal{O}(100)\ \mathrm{GeV}^2)$:**

  Test DGLAP evolution

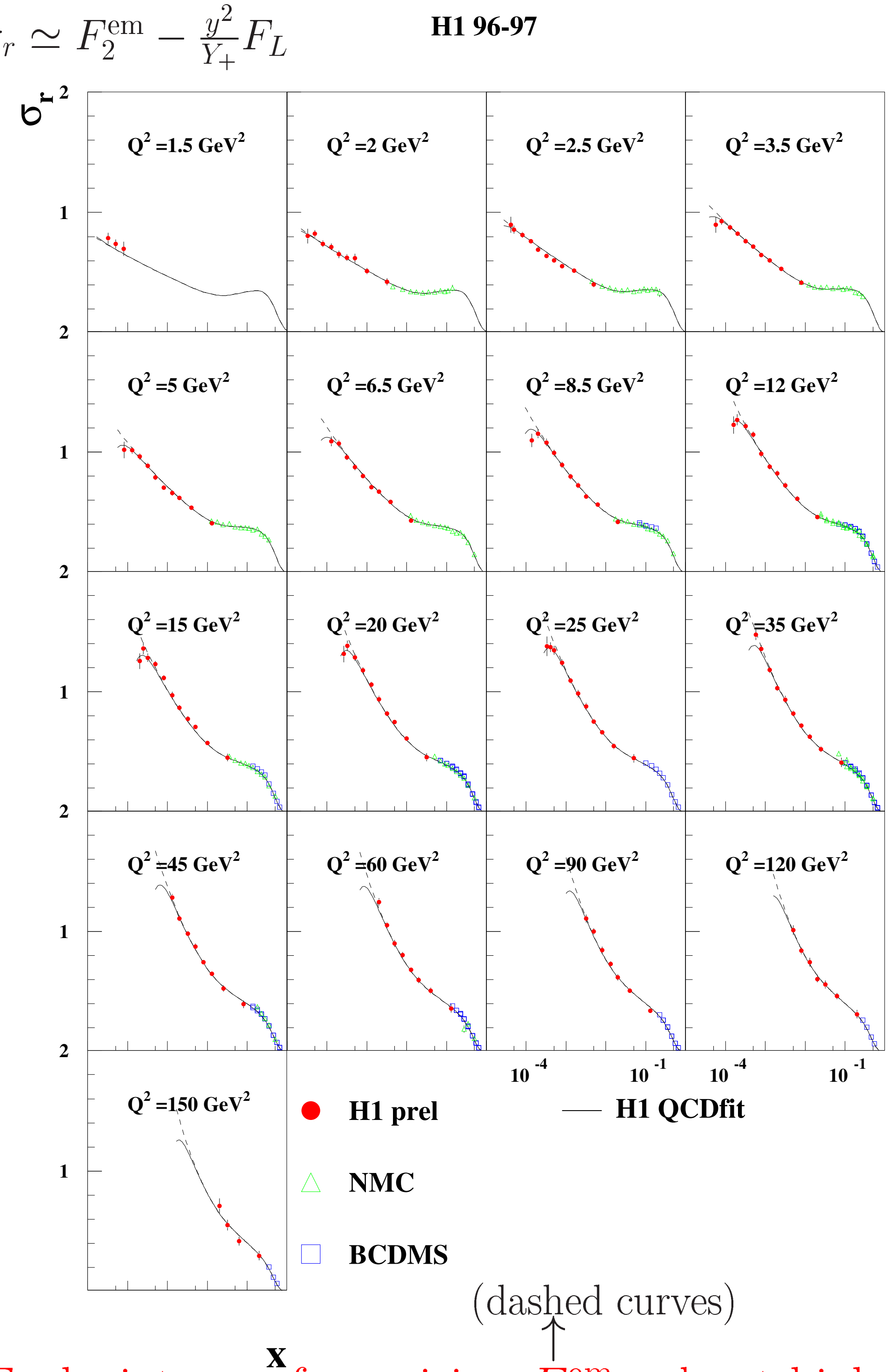
  Constrain valence u/d densities

Selected Recent Measurements

- Precision Structure Function (F_2):
- QCD Analyses and gluon density (xg):
- Charm Contribution to F_2 (F_2^c) and xg
- Longitudinal Structure Function (F_L):
- NC and CC Cross-sections at High Q^2

Precision F_2 at Low x, Q^2

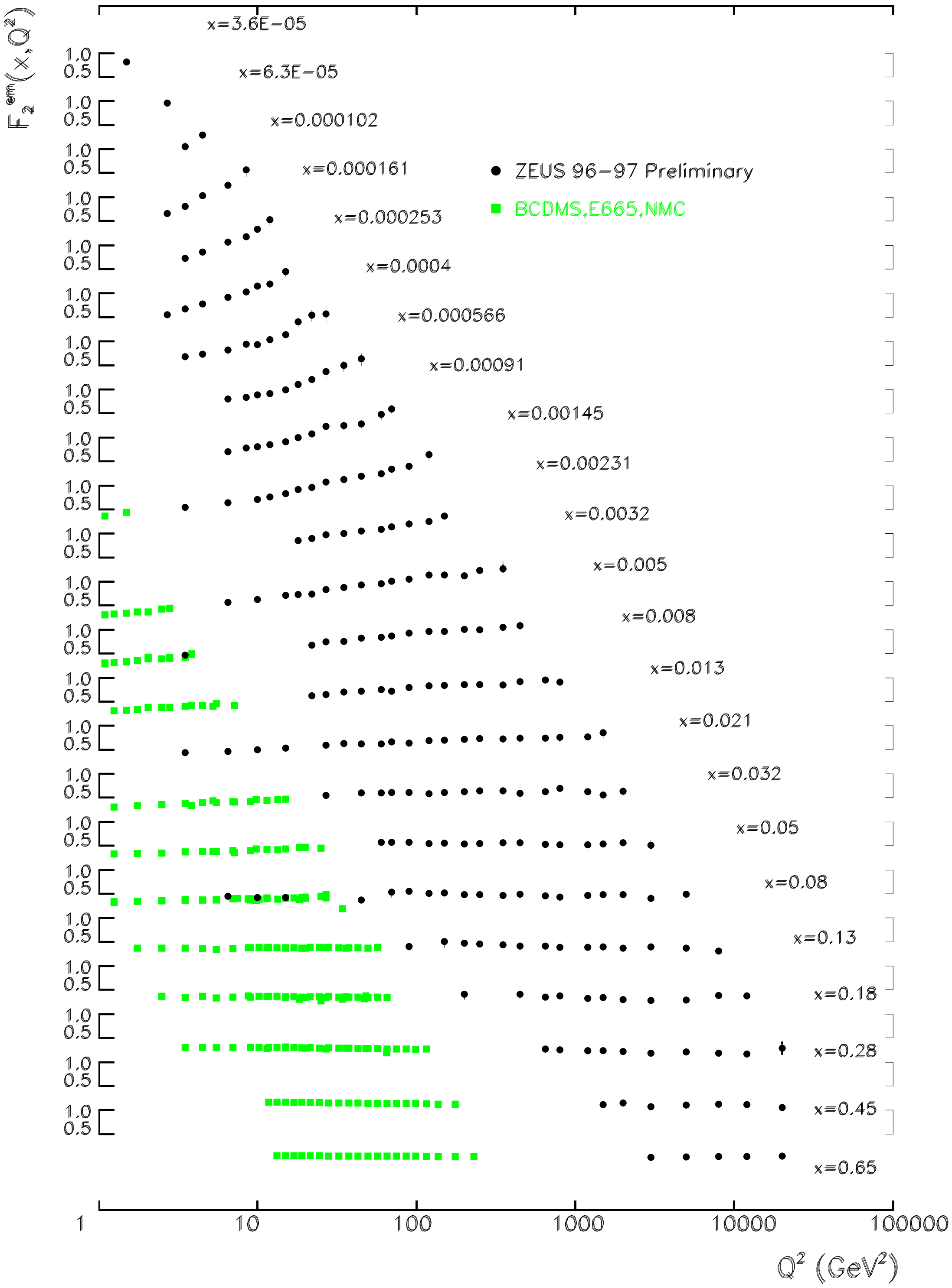
$\sigma_r \simeq F_2^{\text{em}} - \frac{y^2}{Y_+} F_L$



$\Rightarrow$ F_L deviates σ_r from rising F_2^{em} only at high y

$\Rightarrow$ Precision now comparable with fixed target exps.

F_2: Scaling Violation

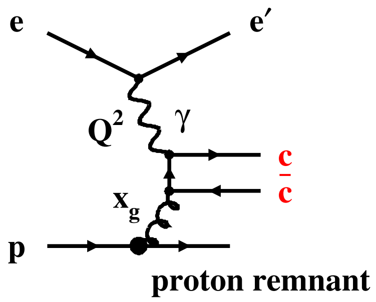


$\Rightarrow$ QCD evolution over 4 orders of magnitude in Q^2

QCD Analyses

H1 and ZEUS QCD Analyses: Similar

e.g. H1 Analysis:



DGLAP Evolution Equation

(NLO, $\overline{\text{MS}}$)

Massive c + Light u, d, s

(γg-fusion) $\rightarrow$

$$xq = A_q x^{B_q}(1-x)^{C_q}(1 + D_q x + E_q\sqrt{x})$$

$$\left(\text{with } \; q = \begin{cases} g\,, \quad D_g = E_g = 0 \\ V \equiv 15(u+\overline{u}) - 9\Sigma\,, \qquad @\, Q^2 = 1.5\,\text{GeV}^2 \\ S \equiv 2\Sigma - 3(u+\overline{u}) \end{cases}\right)$$

Used Data:

H1 + Fixed Target exps. (NMC)

$Q^2_{\text{min}} = 3.5\,\text{GeV}^2$, $W^2 > 10\,\text{GeV}^2$, $Q^2 < 3000\,\text{GeV}^2$

Main Differences wrt Global Fits(MRS(T), CTEQ):

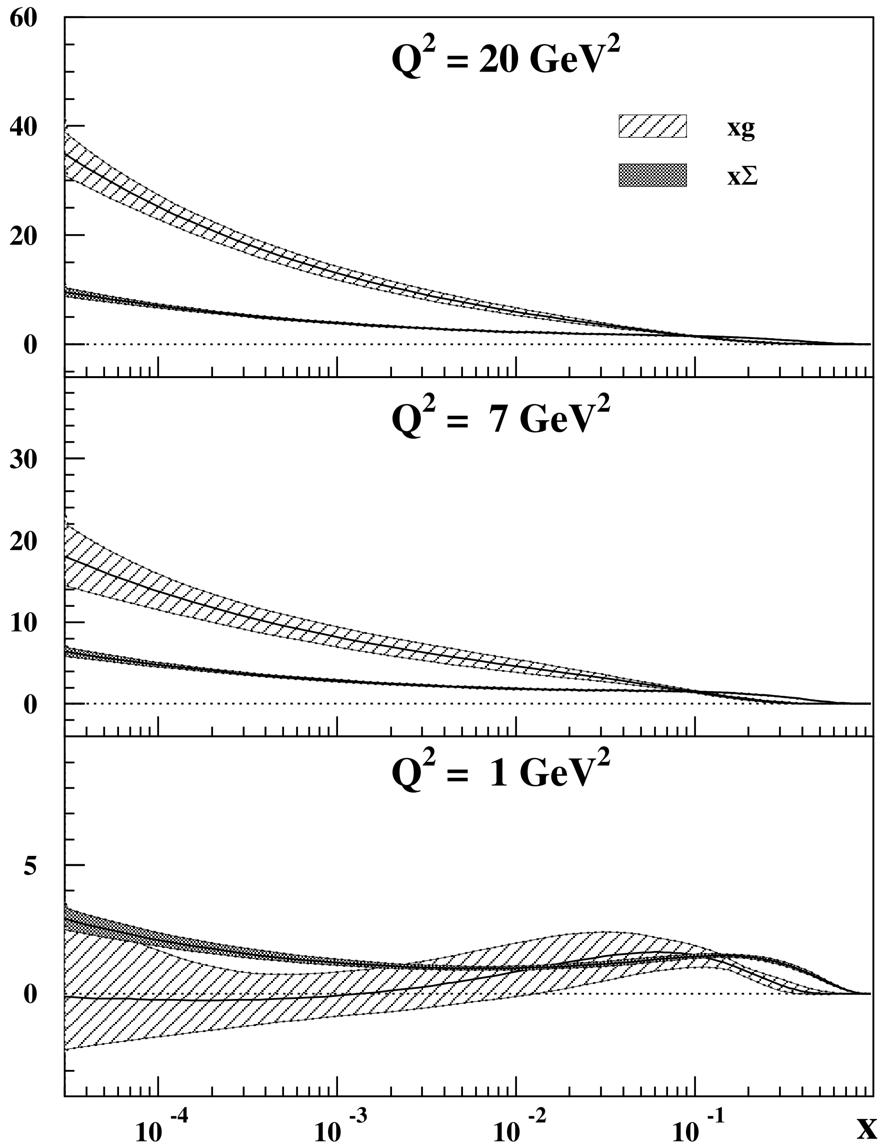
Minimum data from other exps used

Correlated syst. errors taken into account

Emphasis put mainly on xg at low x

Gluon/Sea Densities at Low x, Q^2

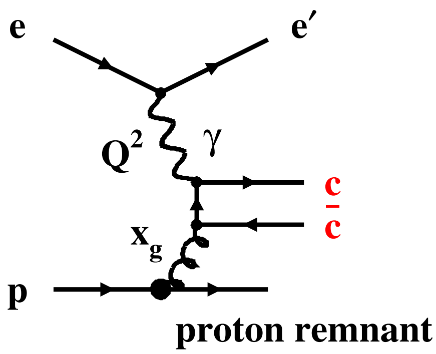
ZEUS 1995 (Eur. Phys. J. C7 (1999) 609):

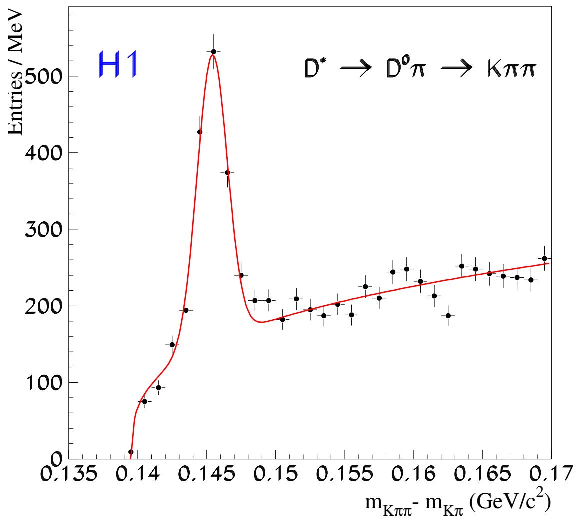


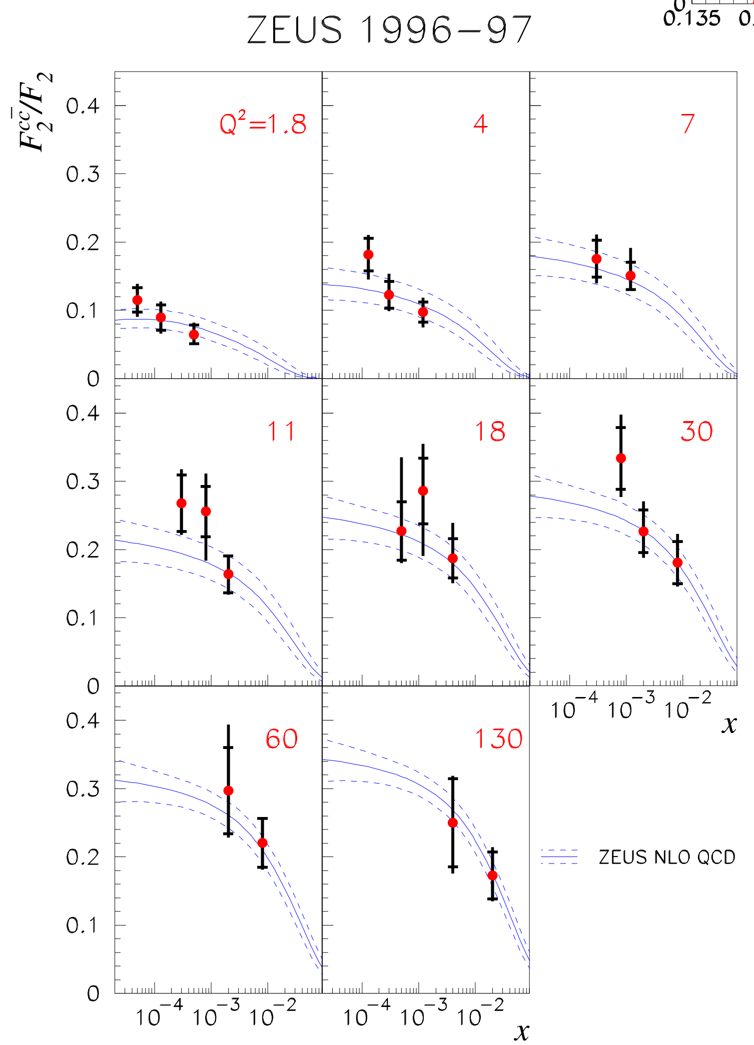
⇒ Smaller gluon density and large uncertainty at lowest Q^2

Not all available data analyzed yet

Charm Contribution to F_2







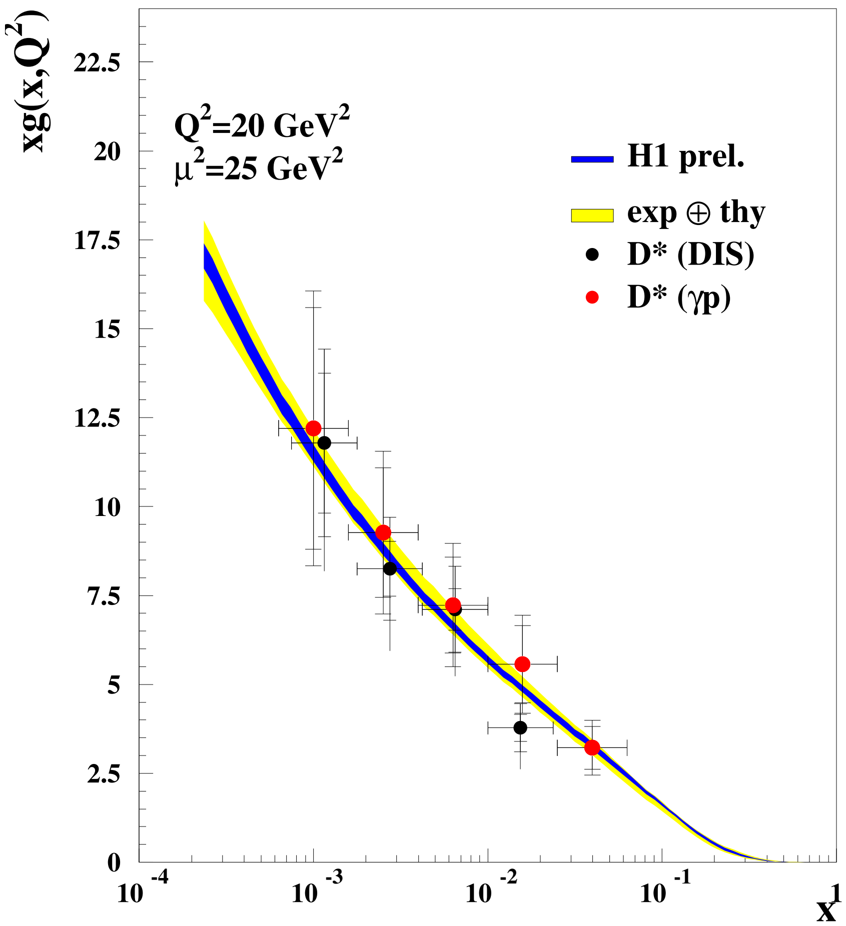
$\Rightarrow$ Increasing charm contribution to F_2 at low x, larger Q^2

Direct Determination of xg

D^* (DIS): Same data and analyses method as for F_2^c

D^* (γp): Photoproduction (γp, $Q^2 \sim 0\,\mathrm{GeV}^2$) with scattered electrons measured in electron taggers
Similar production mechanism as for DIS except γ can be both point-like (direct) and hadron-like (resolved)

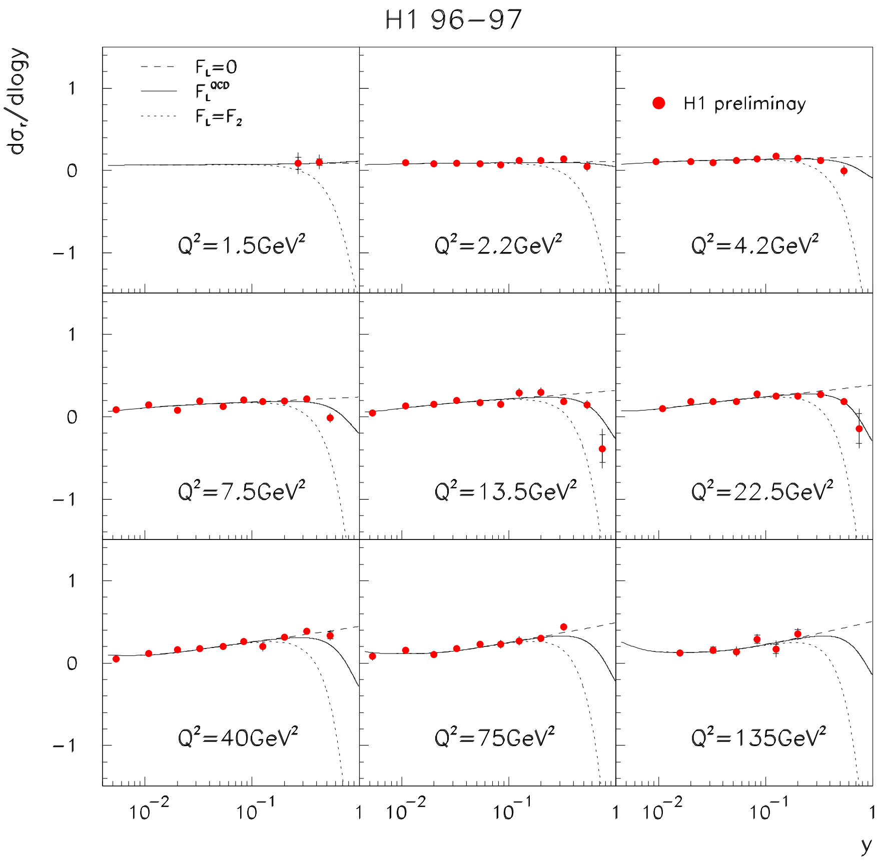
H1 96-97

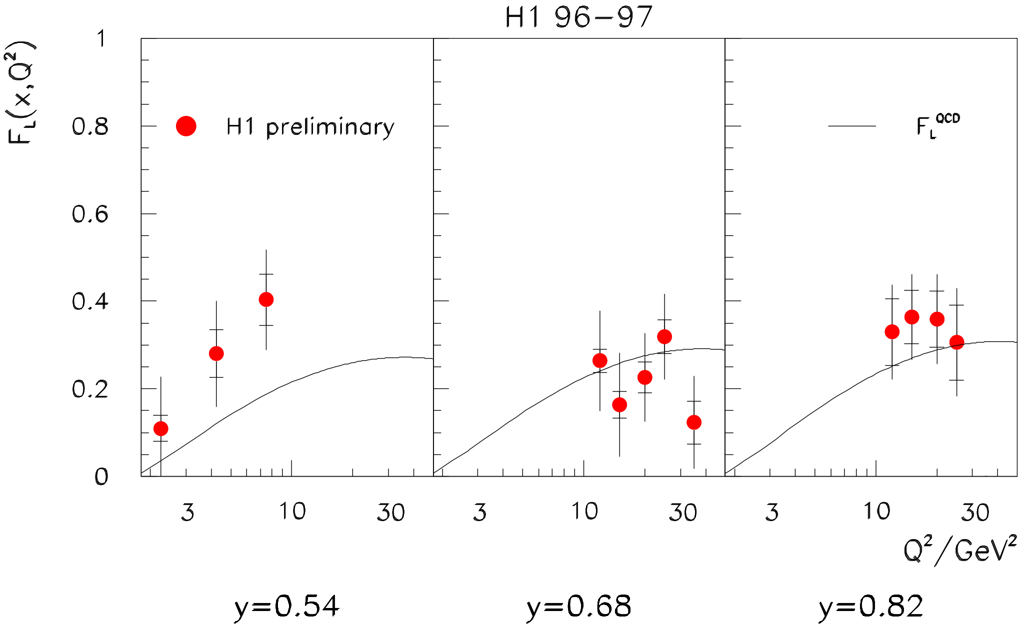


$\Rightarrow$ Universal gluon density

A Determination of F_L

$$\sigma_r = F_2^{\rm em} - \frac{y^2}{Y_+} F_L$$
$$\downarrow$$
$$\frac{d\sigma_r}{d\log y} = \frac{dF_2^{\rm em}}{d\log y} - 2y^2\frac{2-y}{Y_+^2}F_L - \frac{y^2}{Y_+}\frac{dF_L}{d\log y}$$

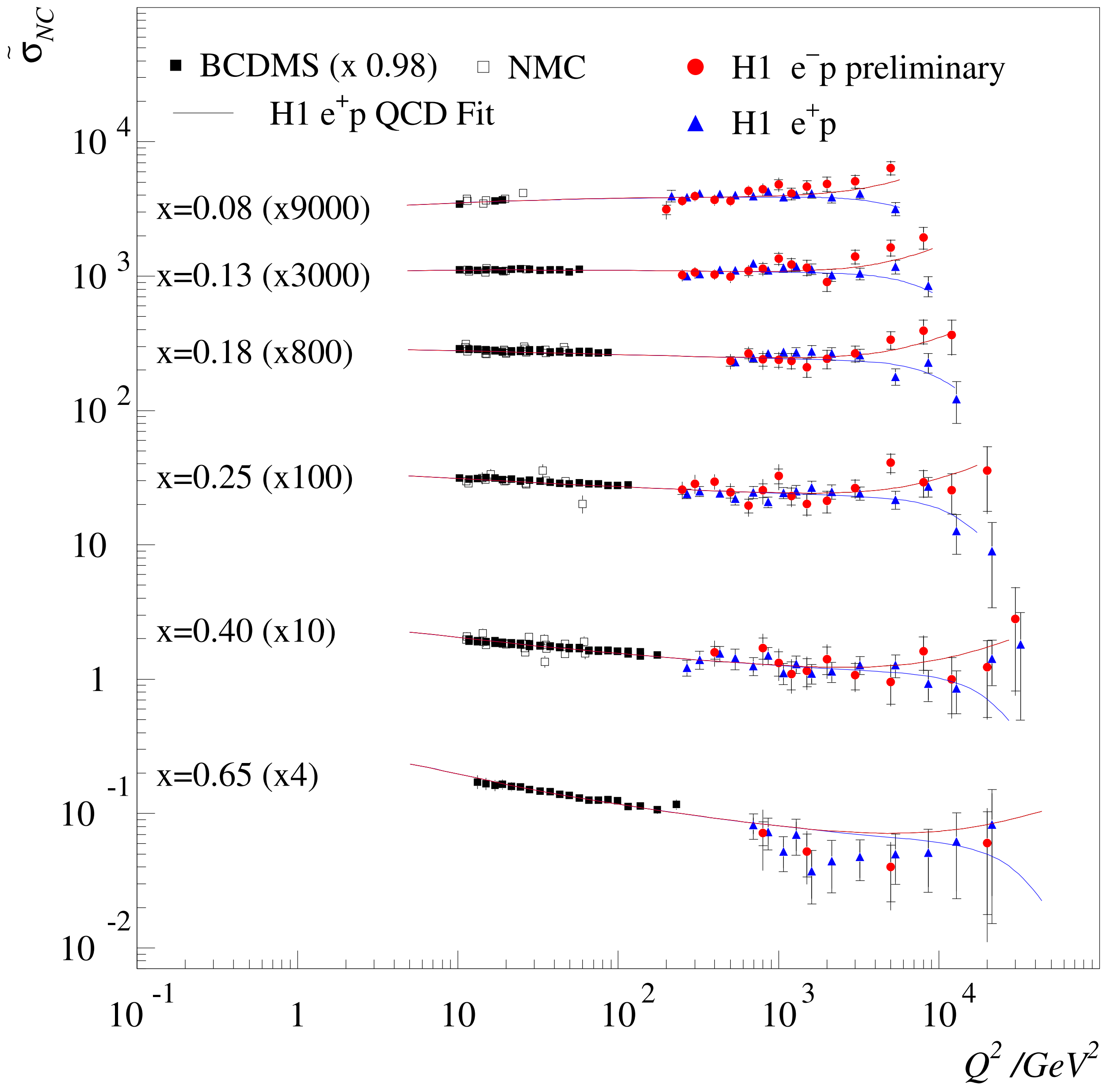




$\Rightarrow$ F_L well in agreement with expectation

NC Cross-sections at High x, Q^2

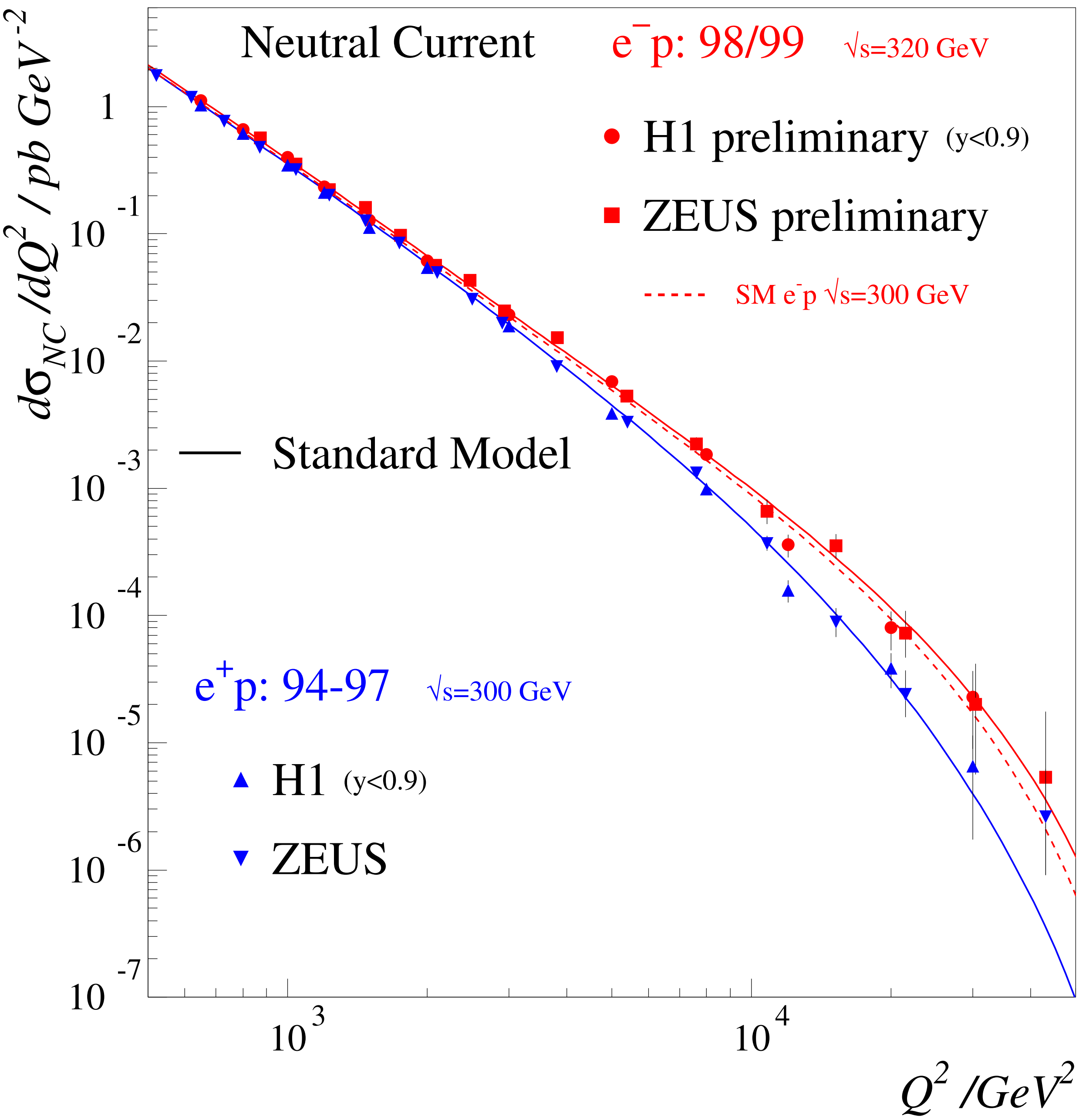
$$\tilde{\sigma}_{NC} = \left[\frac{2\pi\alpha^2}{xQ^4}Y_+\right]^{-1} \frac{d^2\sigma^{\pm}_{NC}}{dxdQ^2} \sim F_2 \mp \frac{Y_-}{Y_+}xF_3$$



⇒ Parity violating term xF_3 at high Q^2 clearly visible

⇒ Excess in e^+p at $x = 0.4$ needs clarification

NC Cross-sections: Q^2 Dependence

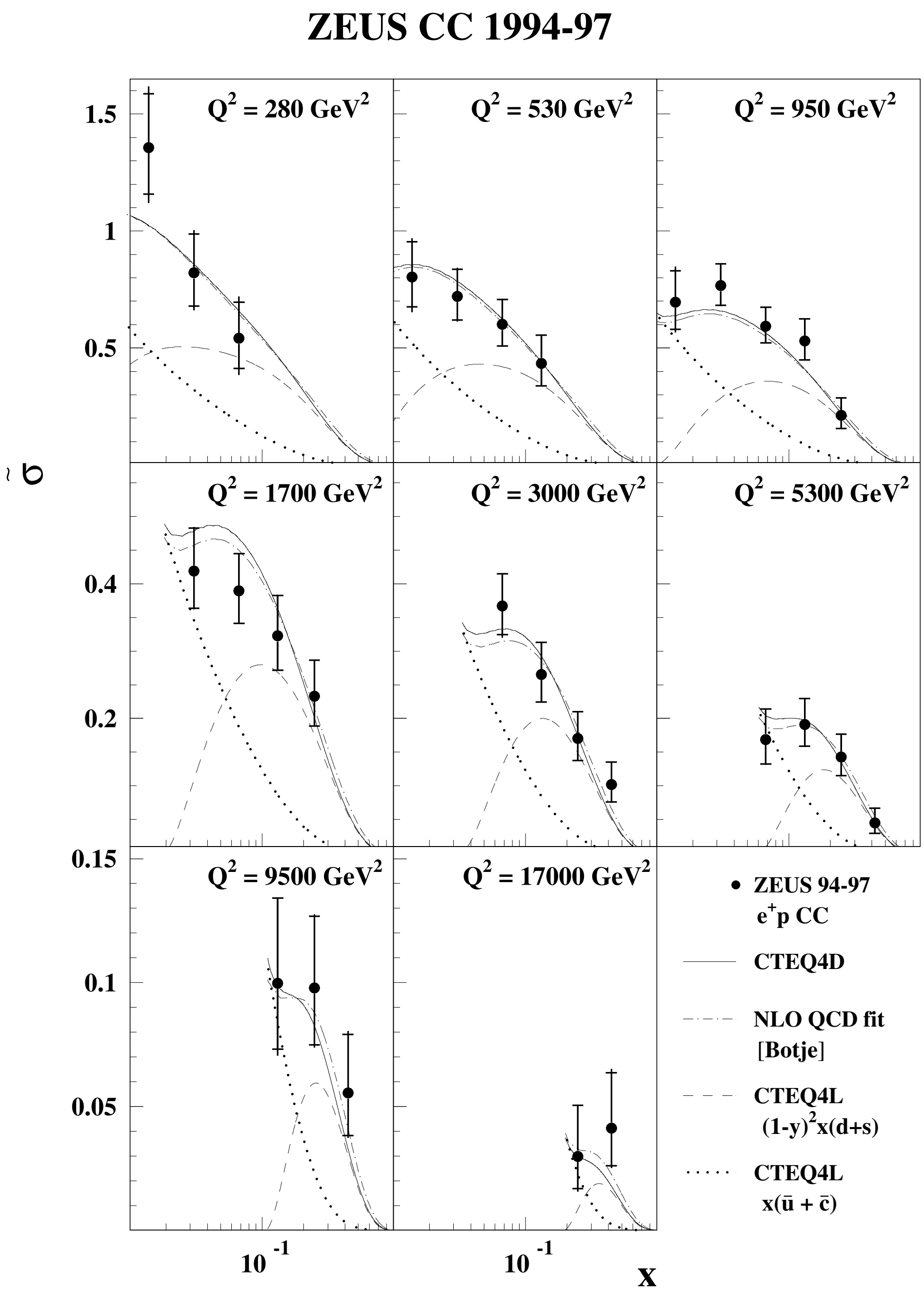


$\Rightarrow$ Precision at high Q^2 statistically limited

$\Rightarrow$ Charge dependence experimentally established

CC Cross-section Probing xd

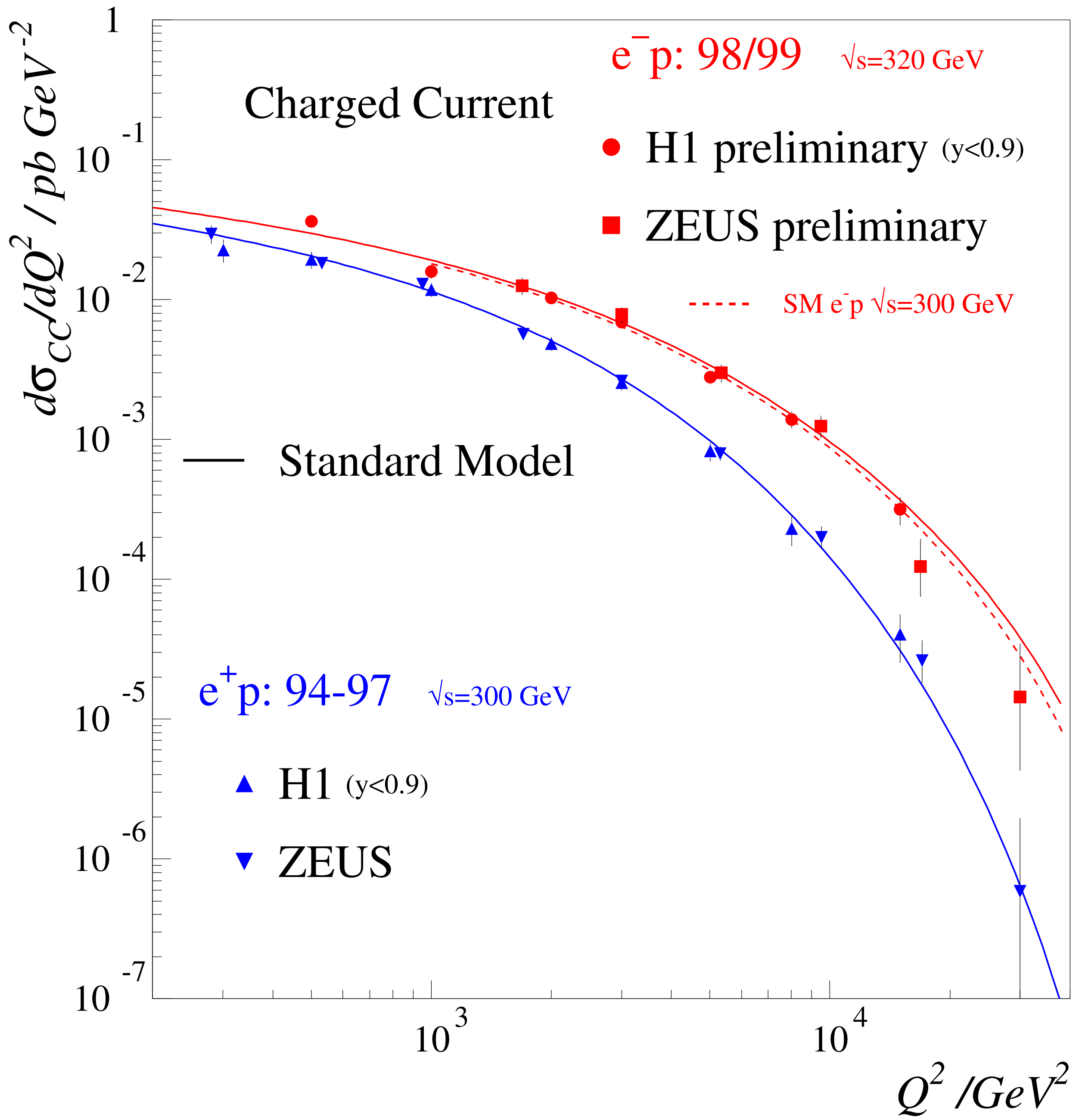
CC e^+p: $\tilde{\sigma} \sim x(\overline{u}+\overline{c}) + (1-y)^2 x(d+s)$



$\Rightarrow$ CC Data have flavor separation power (not with NC)

CC Cross-sections: Q^2 Dependence

$e^- p$: $d\sigma/dQ^2 \sim xu$ $\qquad$ $e^+ p$: $d\sigma/dQ^2 \sim (1-y)^2 xd$



$\Rightarrow$ Flavor dependence experimentally established

Propagator Mass M_W

$$CC: \quad \sigma \propto G_F^2 \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2$$

Space-like process

Varying Q^2 provides a model validity test over large range

G_F fixed to precisely measured value

Measured propagator mass M_W:

H1: $80.9 \pm 3.3(\mathrm{stat}) \pm 1.7(\mathrm{syst}) \pm 3.7(\mathrm{pdf})\,\mathrm{GeV}$

ZEUS: $81.4^{+2.7}_{-2.6}(\mathrm{stat}) \pm 2.0(\mathrm{syst})^{+3.3}_{-3.0}(\mathrm{pdf})\,\mathrm{GeV}$

$\Rightarrow$ Well in agreement with M_W measured in time-like processes

Summary and Outlook

Precision Structure Function F_2:

- As precise as data from Fixed Target Exps

Gluon Density xg:

- Universality tested with independent methods

NC and CC Cross-sections at High Q^2:

- QCD evolution tested over 4 orders of magnitude in Q^2
- Precision and local excess (NC e^+p) need more data
- The effects of γZ interference and xF_3 observed
- Propagator mass M_W provides nontrivial test for SM

Improvements Expected (mainly low Q^2 data):

- by including all available data

Current and Future HERA Running:

- e^+p running since July 1999
- High luminosity run after upgrade in 2000