NC/CC deep inelastic ep-scattering at high Q^2 with ZEUS at HERA

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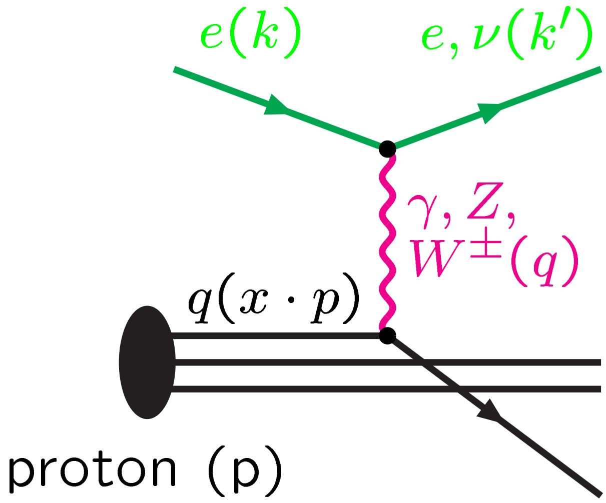
- **Introduction**
- **Charged Current:**
  - Single diff. cross sections
  - Double diff. cross sections
- **Neutral Current:**
  - e^-p analysis
  - Single/double diff. cross sections
  - xF_3 from e^-p & e^+p

Deep Inelastic Scattering



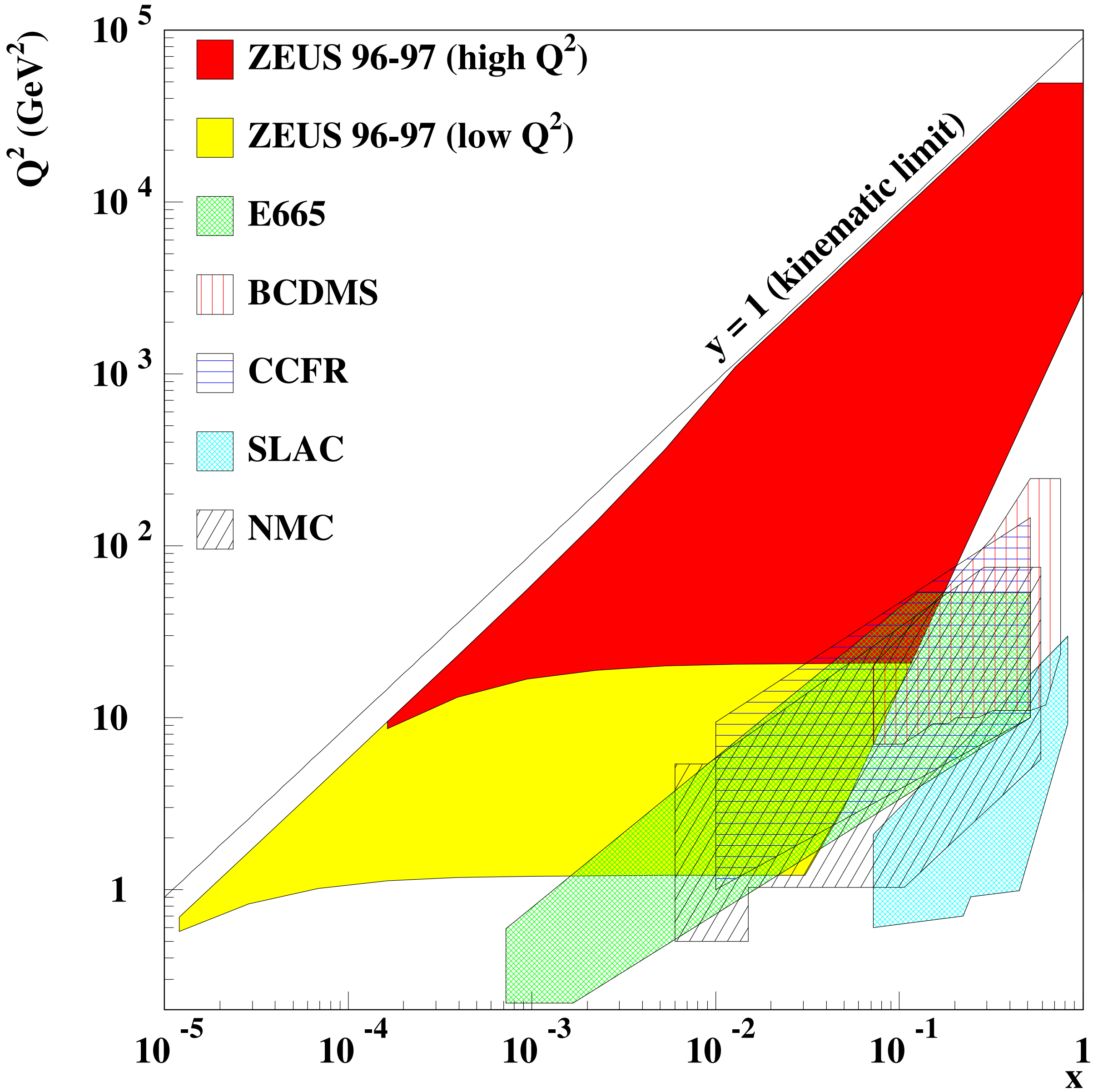
HERA conditions:

1994 – 1997	1998 – 1999
Positrons	Electrons
$E_e = 27.5$ GeV	$E_e = 27.5$ GeV
$E_p = 820$ GeV	$E_p = 920$ GeV
$\sqrt{s} \approx 300$ GeV	$\sqrt{s} \approx 318$ GeV

Kinematic Variables:

- $Q^2 = -q^2 = -(k - k')^2$
  Negative square of four-momentum-transfer carried by virtual boson
- $x = Q^2/\,(2p \cdot q)$
  Momentum fraction of the struck quark
- $y = (p \cdot q)\,/\,(p \cdot k)$
  Energy tranfer between electron and proton
- $s = (k + p)^2$
  Center-of-mass energy squared

HERA Kinematic Plane



For the first time it's possible to investigate the high Q^2 regime in both the e^-p and the e^+p channels.

Charged Current

CC cross section suppressed due to high $W^{\pm}$ mass:

$$\frac{d^2\sigma^{CC}}{dx\,dQ^2} \propto \frac{1}{M_W^4}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2$$

Leading Order Cross Section $e^{\pm}p \to$ '$\overline{\nu}$'X:

$$\boxed{e^+p: \quad \frac{d^2\sigma^{CC}}{dx\,dQ^2} \propto x \cdot \left[(\bar{u}+\bar{c}) + (1-y)^2\,(d+s)\right]}$$

- d valence quark probed
- d suppressed by $(1-y)^2$ factor

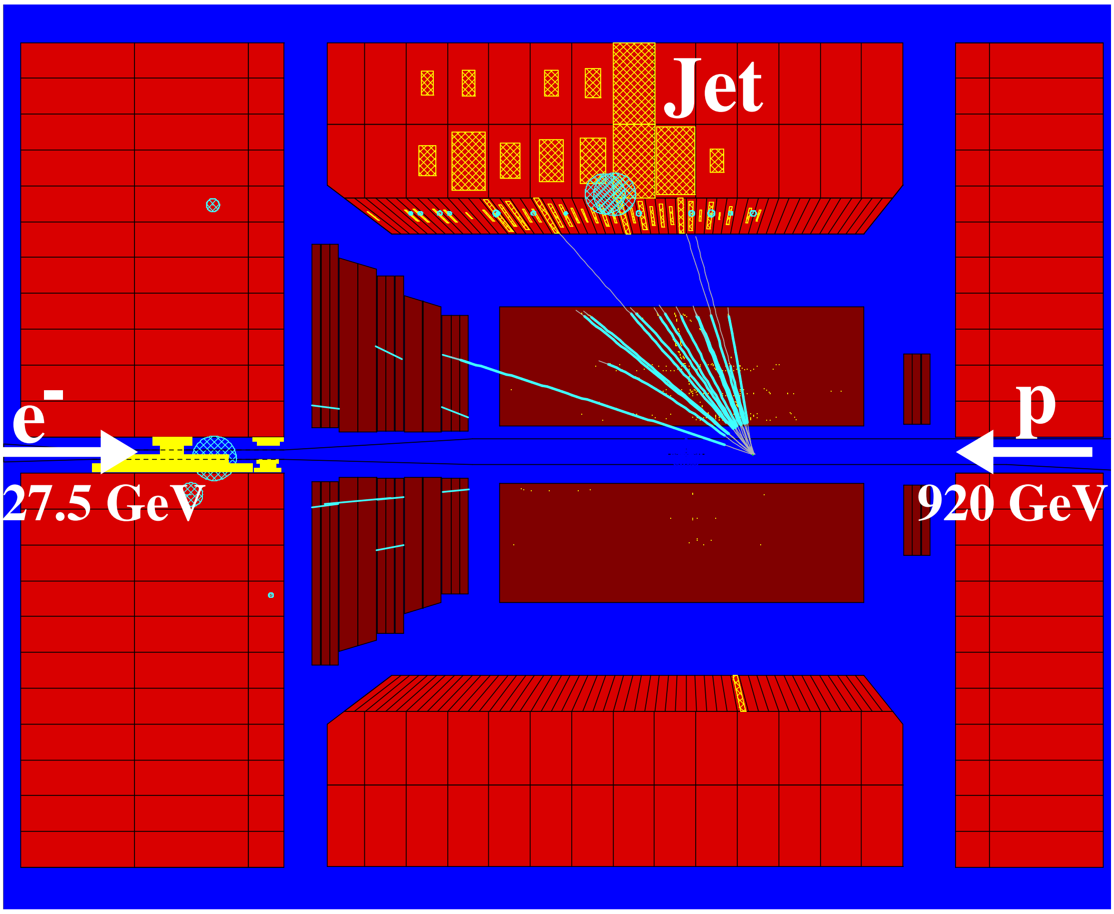
$$\boxed{e^-p: \quad \frac{d^2\sigma^{CC}}{dx\,dQ^2} \propto x \cdot \left[(u+c) + (1-y)^2\,(\bar{d}+\bar{s})\right]}$$

- u valence quark probed
- u unsuppressed

Reduced Cross Section:

$$\boxed{\tilde{\sigma} = \frac{2\pi x}{G_F^2}\left(\frac{M_W^2+Q^2}{M_W^2}\right)^2 \times \frac{d^2\sigma^{CC}}{dx\,dQ^2}}$$

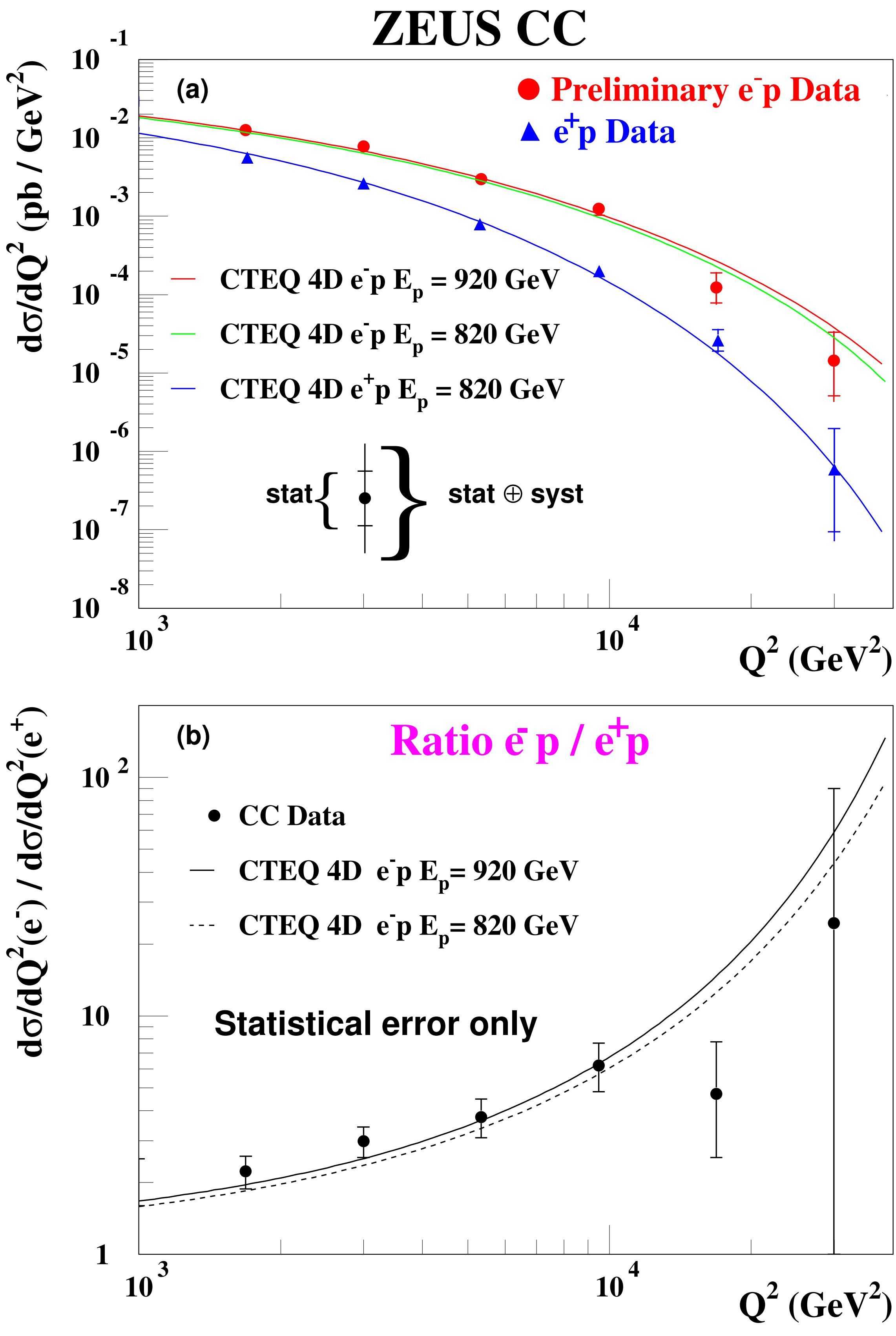
CC Event Selection



Event Selection:

- Missing P_T
- Electron rejection
- Timing cuts, vertex cuts . . .

CC e^+p & e^-p: $d\sigma/dQ^2$



CC e^+p $d\sigma/dQ^2$: Fitting M_W

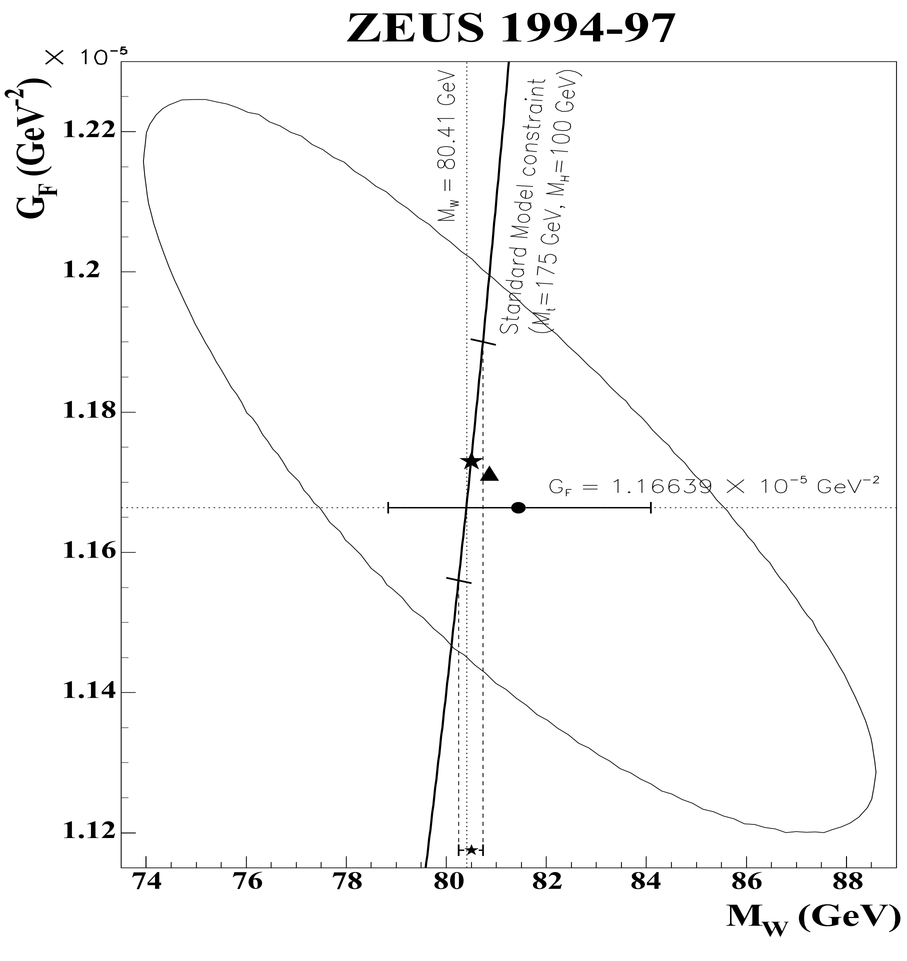
- Q^2 dependence of CC cross section includes prop. term

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

$\Rightarrow$ shape of $d\sigma/dQ^2$ contains information about M_W

- magnitude determined by G_F and PDFs

$\Rightarrow$ fit yields measurement of M_W in SPACE-LIKE region

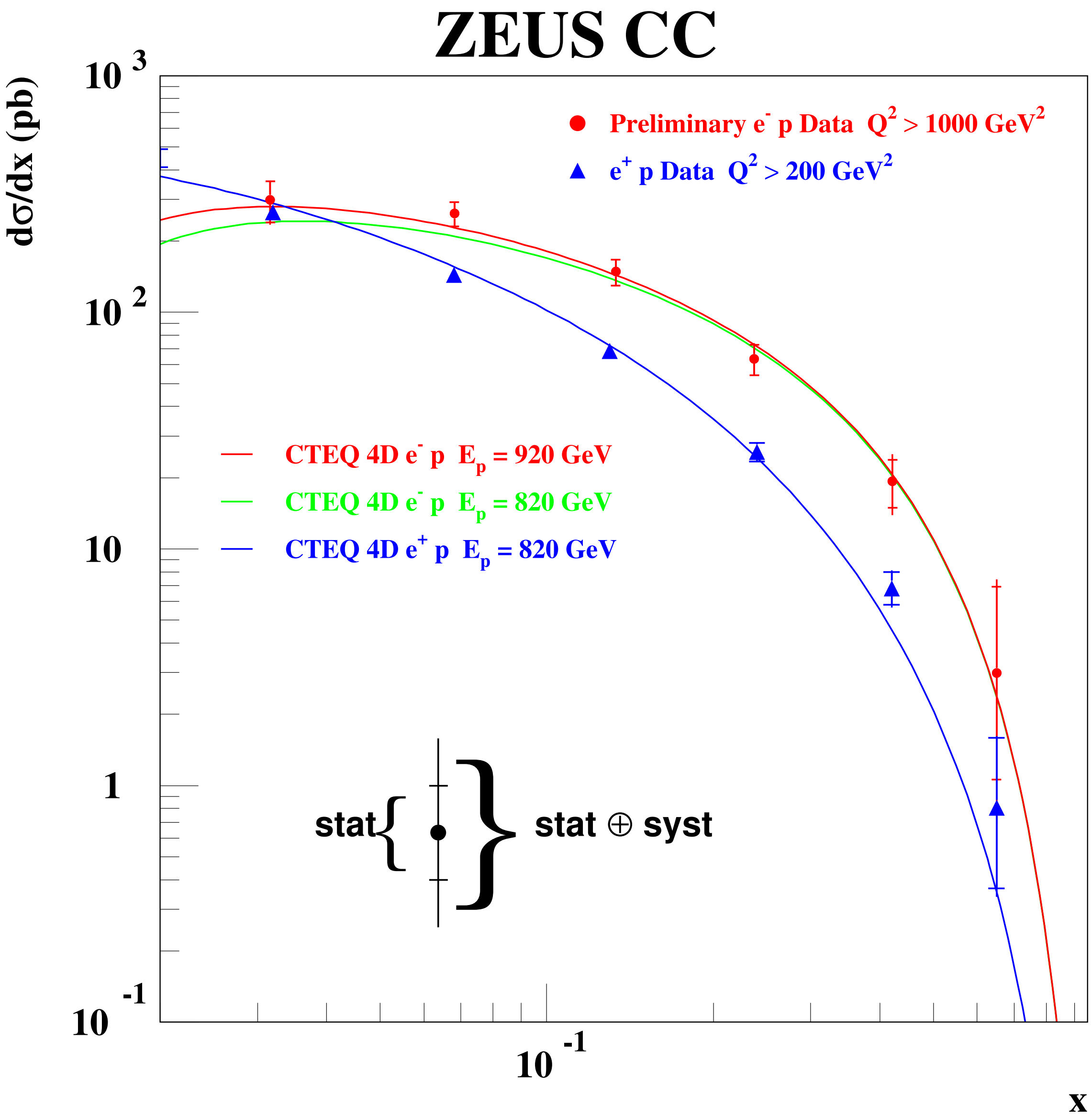


$$M_W = 80.8^{+4.9}_{-4.5}(\text{stat.})^{+5.0}_{-4.3}(\text{syst.})^{+1.4}_{-1.3}(\text{PDF}) \text{ GeV}$$

$$\text{Fixed } G_F : M_W = 81.4^{+2.7}_{-2.6}(\text{stat.}) \pm 2.0(\text{syst.})^{+3.3}_{-3.0}(\text{PDF}) \text{ GeV}$$

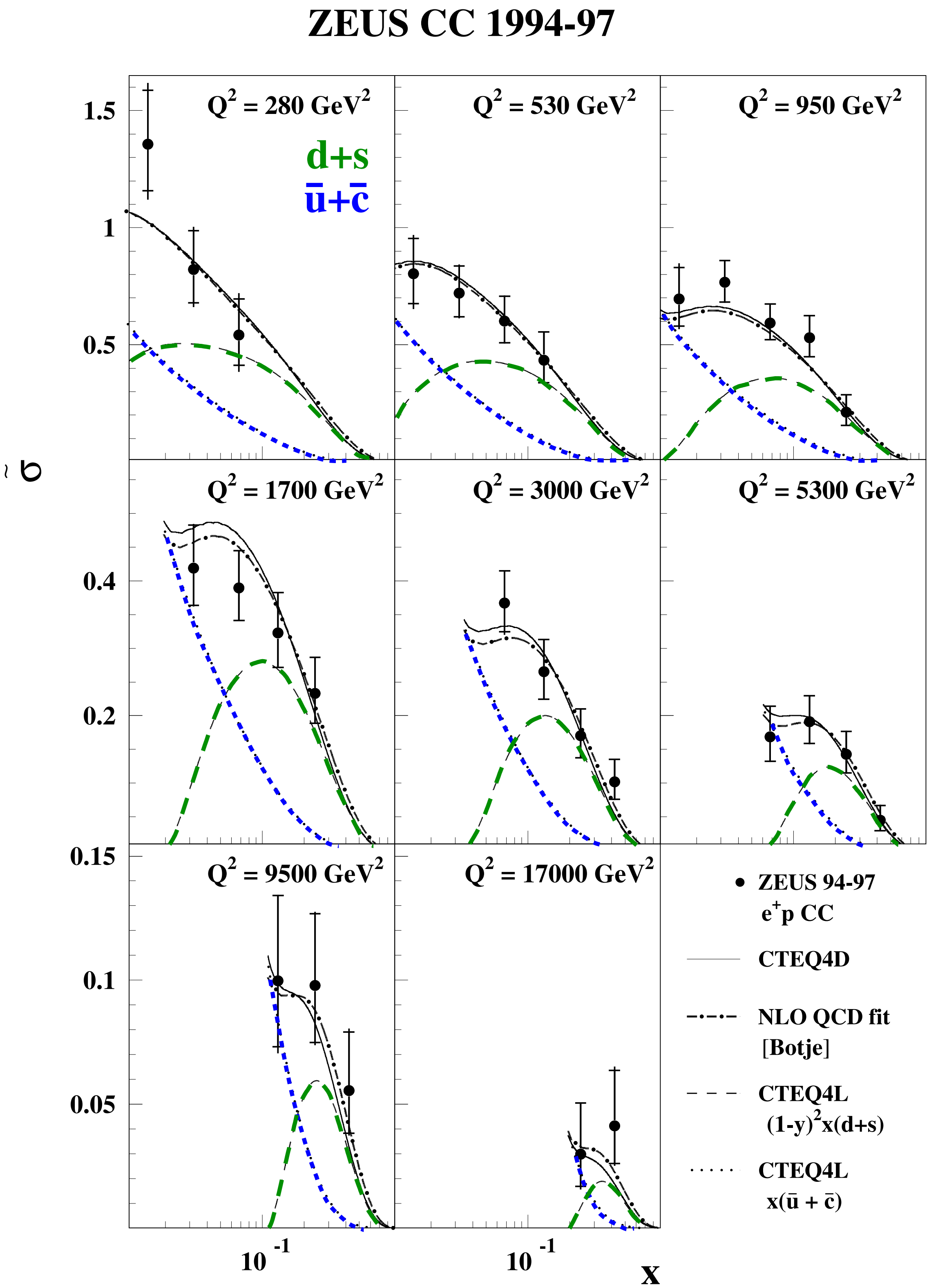
August '99 world average: $M_W = 80.376 \pm 0.039$ GeV

CC e^+p & e^-p: $d\sigma/dx$



Measuring both cross sections yields information about d/u ratio.

CC e^+p: $d^2\sigma/dx\,dQ^2$



Neutral Current

Born Cross-Section for $e^{\pm}p \to e^{\pm}X$:

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

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

In leading order QCD:

- $F_2\left(x, Q^2\right) = x \sum\limits_{\text{Quarks}} A_f(Q^2)\left[q(x,Q^2) + \bar{q}(x,Q^2)\right]$

  γ, Z couple to all quark flavours

- $xF_3\left(x, Q^2\right) = x \sum\limits_{\text{Quarks}} B_f(Q^2)\left[q(x,Q^2) - \bar{q}(x,Q^2)\right]$

  parity violating term, sensitive to valence quarks

- $F_L\left(x, Q^2\right)$

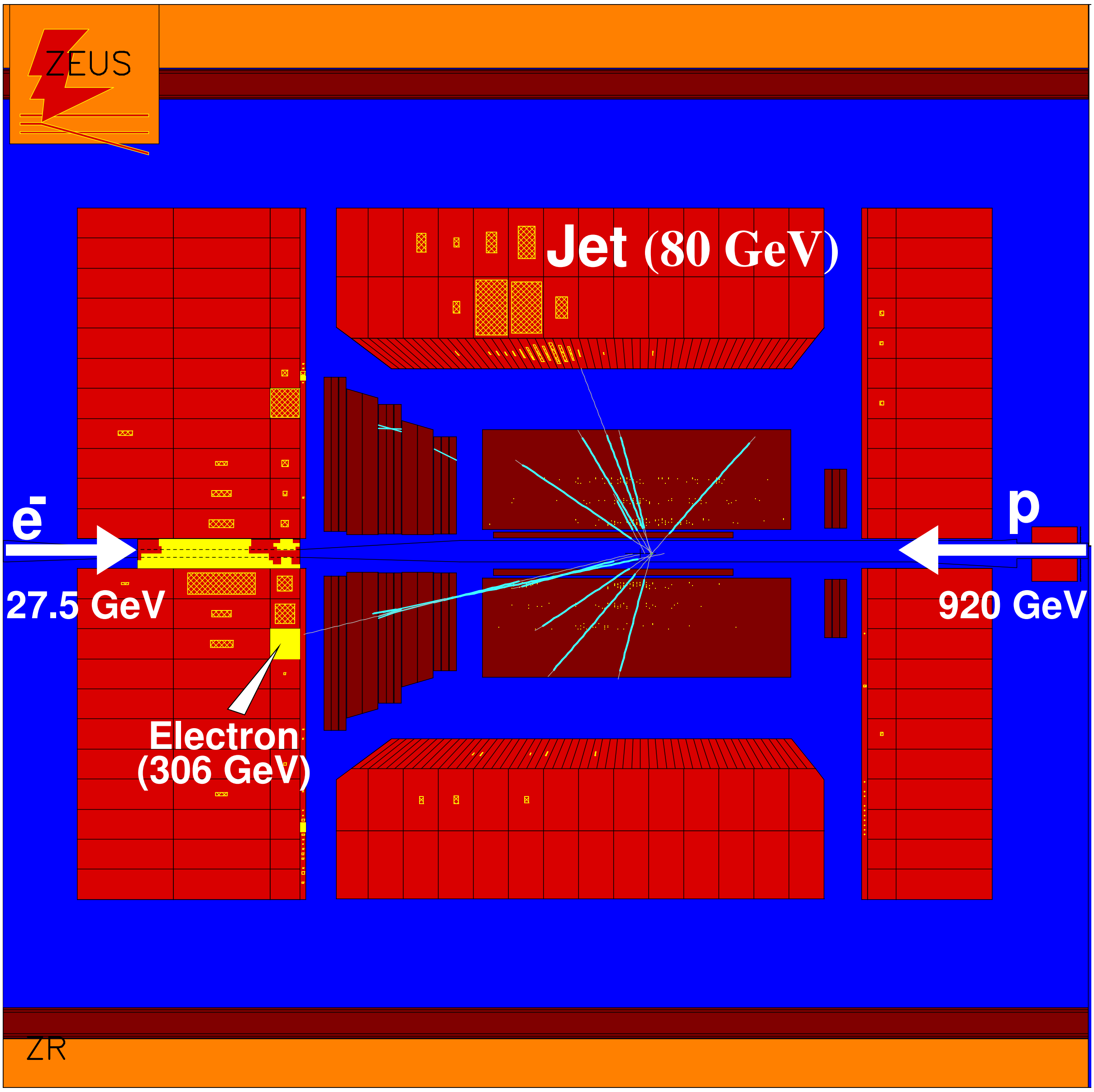
  longitudinal structure function

Reduced Cross Section:

$$\boxed{\tilde{\sigma} = \frac{x\,Q^4}{2\pi\alpha^2}\cdot\frac{1}{Y_+}\cdot\frac{d^2\sigma^{NC}_{\text{Born}}}{dx\,dQ^2} = F_2^{NC} \mp \frac{Y_-}{Y_+} xF_3^{NC} - \frac{y^2}{Y_+}F_L^{NC}}$$

A NC Event

$$Q^2 = 38500\ \text{GeV}^2 \qquad x = 0.45$$



NC: $e^- p$
Data Samples & Event Selection

Data:

- data taking period: 1998–99
- $\mathcal{L} = 16\ \text{pb}^{-1}$

Monte Carlo:

- DJANGOH $Q^2 > 100\ \text{GeV}^2$

Reconstruction method:

Using angles of scattered electron and hadronic system (double angle method)

Selection cuts:

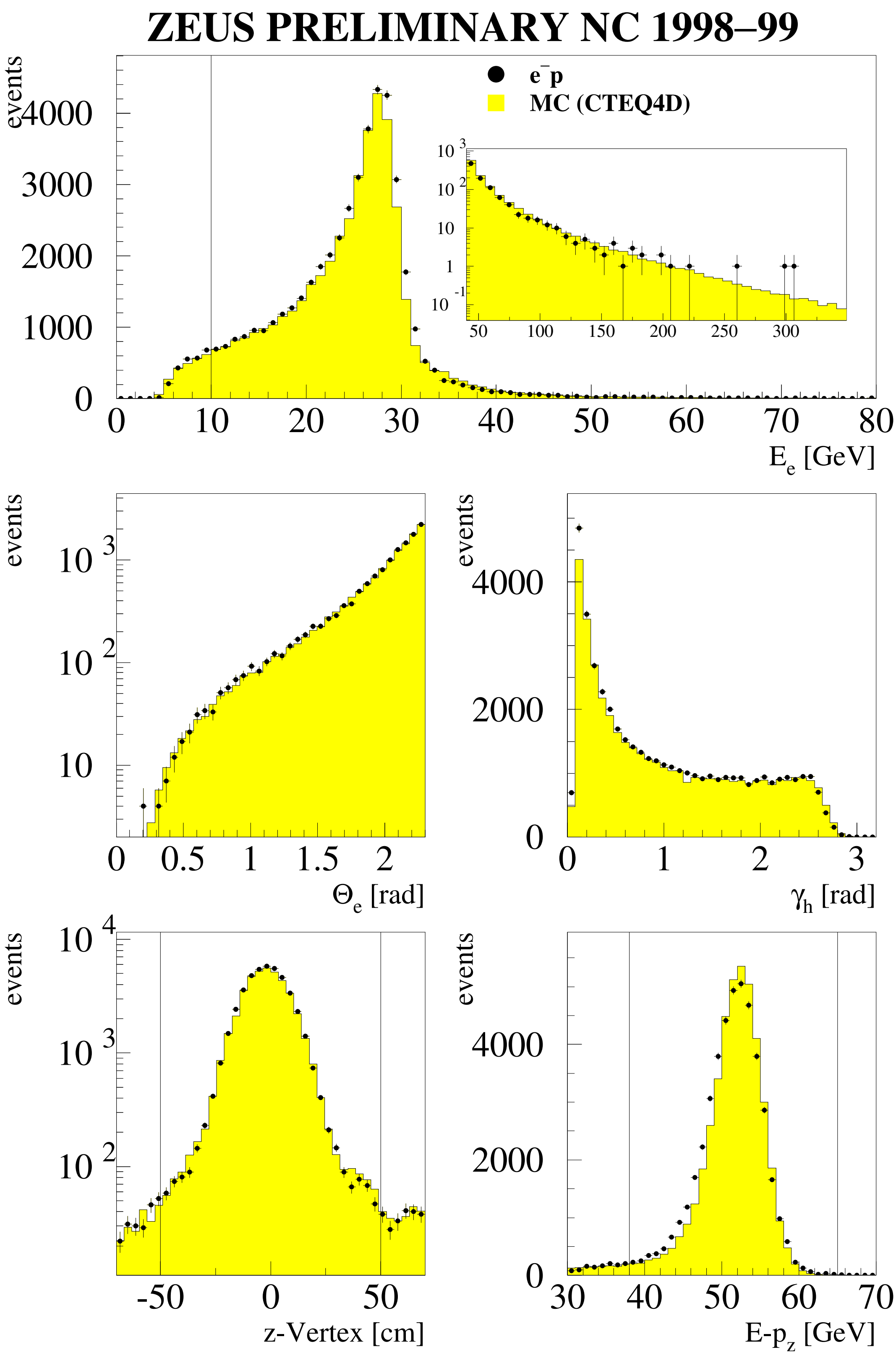
- Electron identification:
  - $E_e > 10\,\text{GeV}$, $E_e^t > 30\,\text{GeV}$ $(\theta_e \leq 17^\circ)$
  - isolation $(E_{cone} < 5\,\text{GeV})$
  - matched track with $p > 5\,\text{GeV}$ $(\theta_e > 17^\circ)$
- $-50\,\text{cm} < z_{\text{vertex}} < 50\,\text{cm}$
- Background suppression:
  - $E - p_z \in [38\,\text{GeV}, 65\,\text{GeV}]$ $(\theta_e > 17^\circ)$
  - $E - p_z \in [44\,\text{GeV}, 65\,\text{GeV}]$ $(\theta_e \leq 17^\circ)$
  - $P_T/\sqrt{E_T} < 4\,\sqrt{\text{GeV}}$
  - $y_e < 0.95$

$$E - p_z = \sum_i E_i\,(1 - \cos\theta_i) \stackrel{!}{=} 2E_e = 55\ \text{GeV}$$

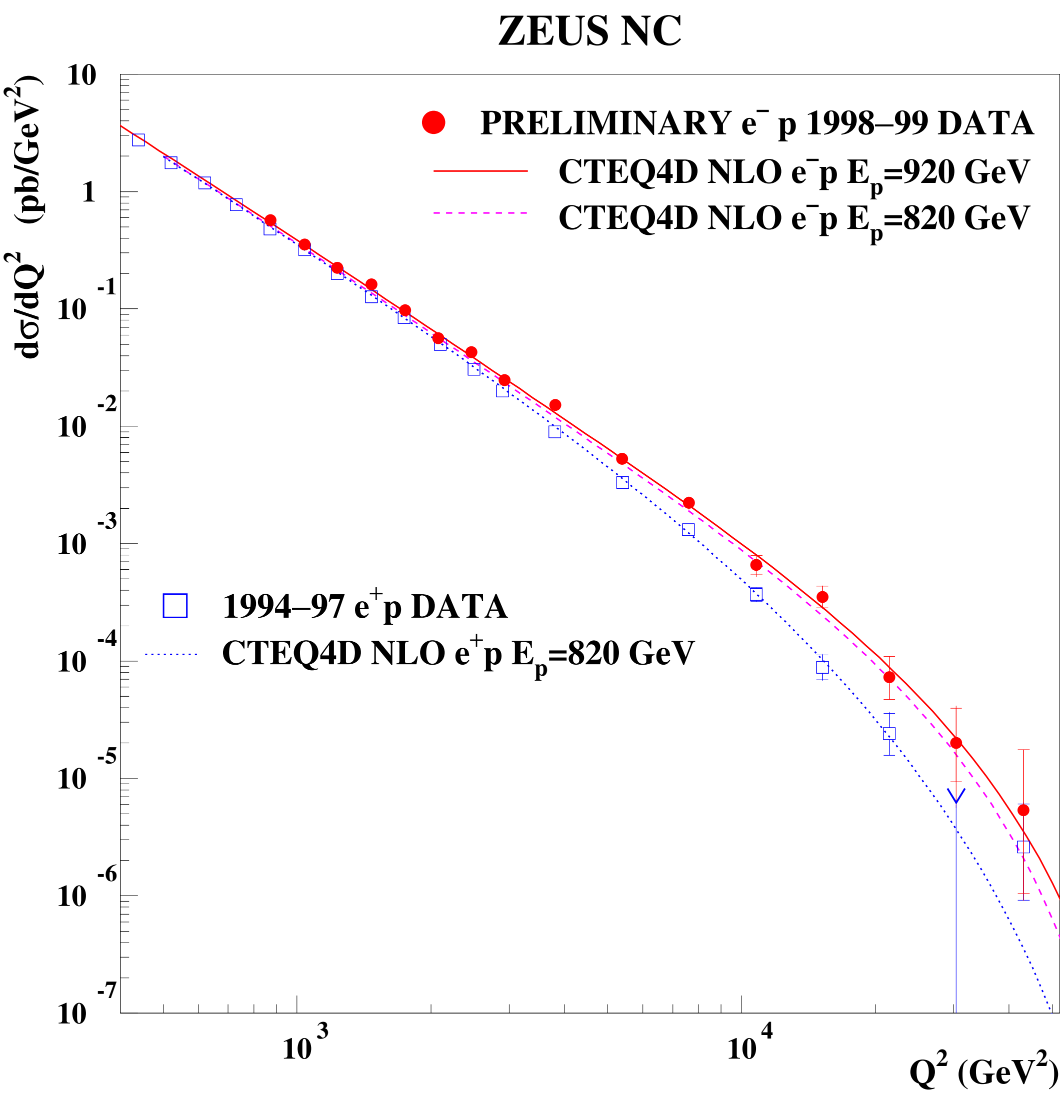
Kinematic Range :

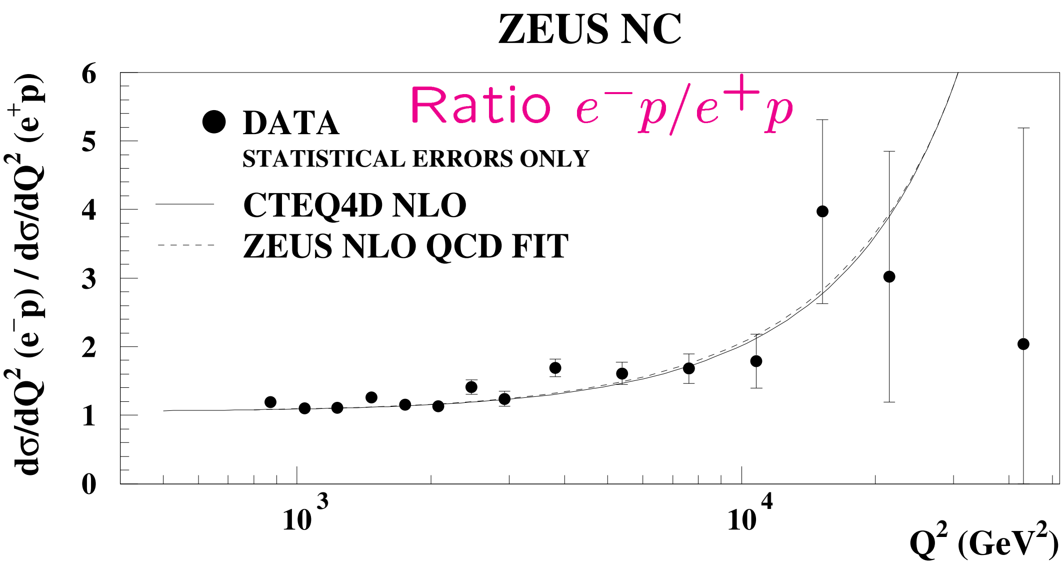
$185\ \text{GeV}^2 < Q^2 < 50\,000\ \text{GeV}^2 \qquad 0.0025 < x < 1$

NC e^-p: Control Plots

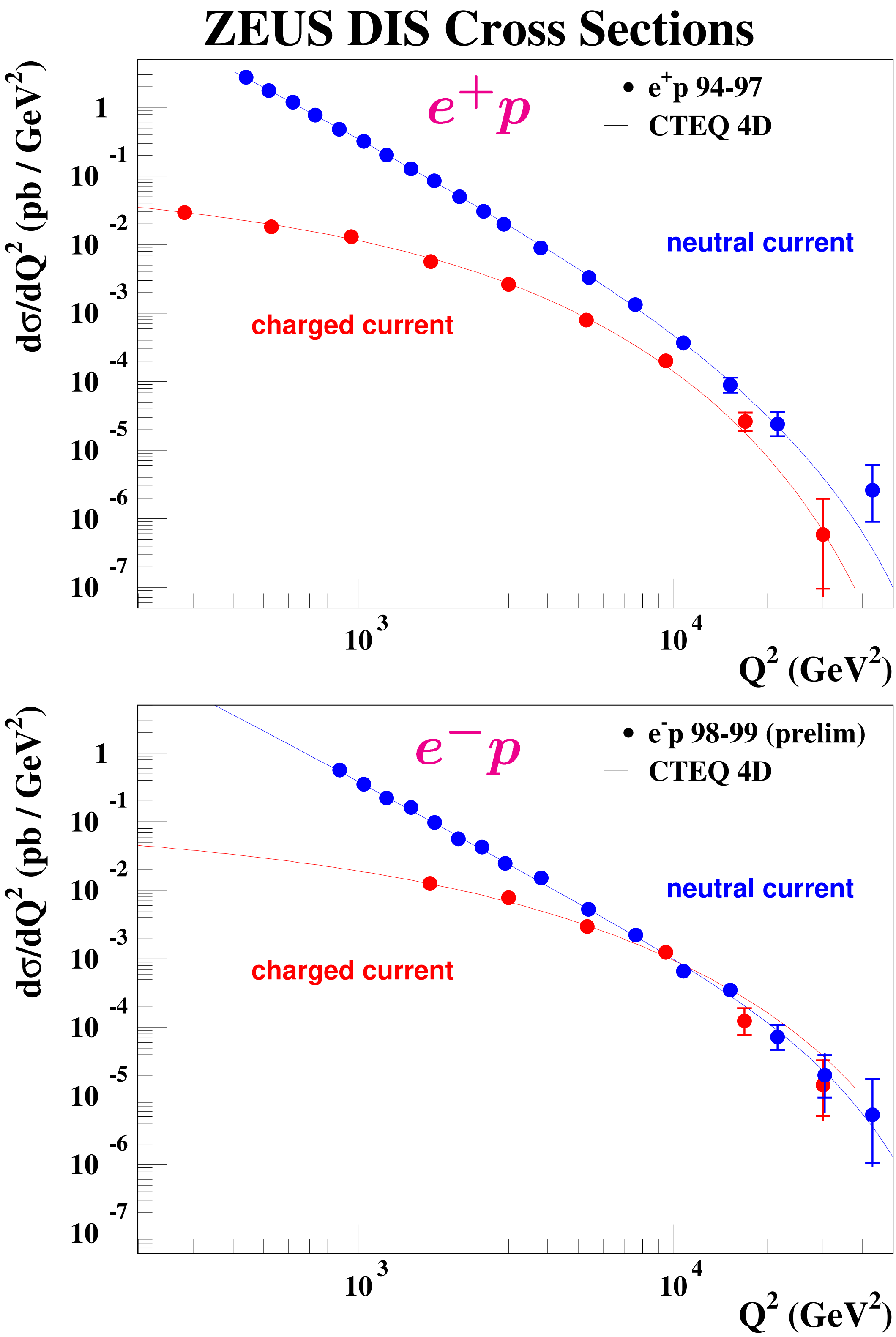


NC: $d\sigma/dQ^2$

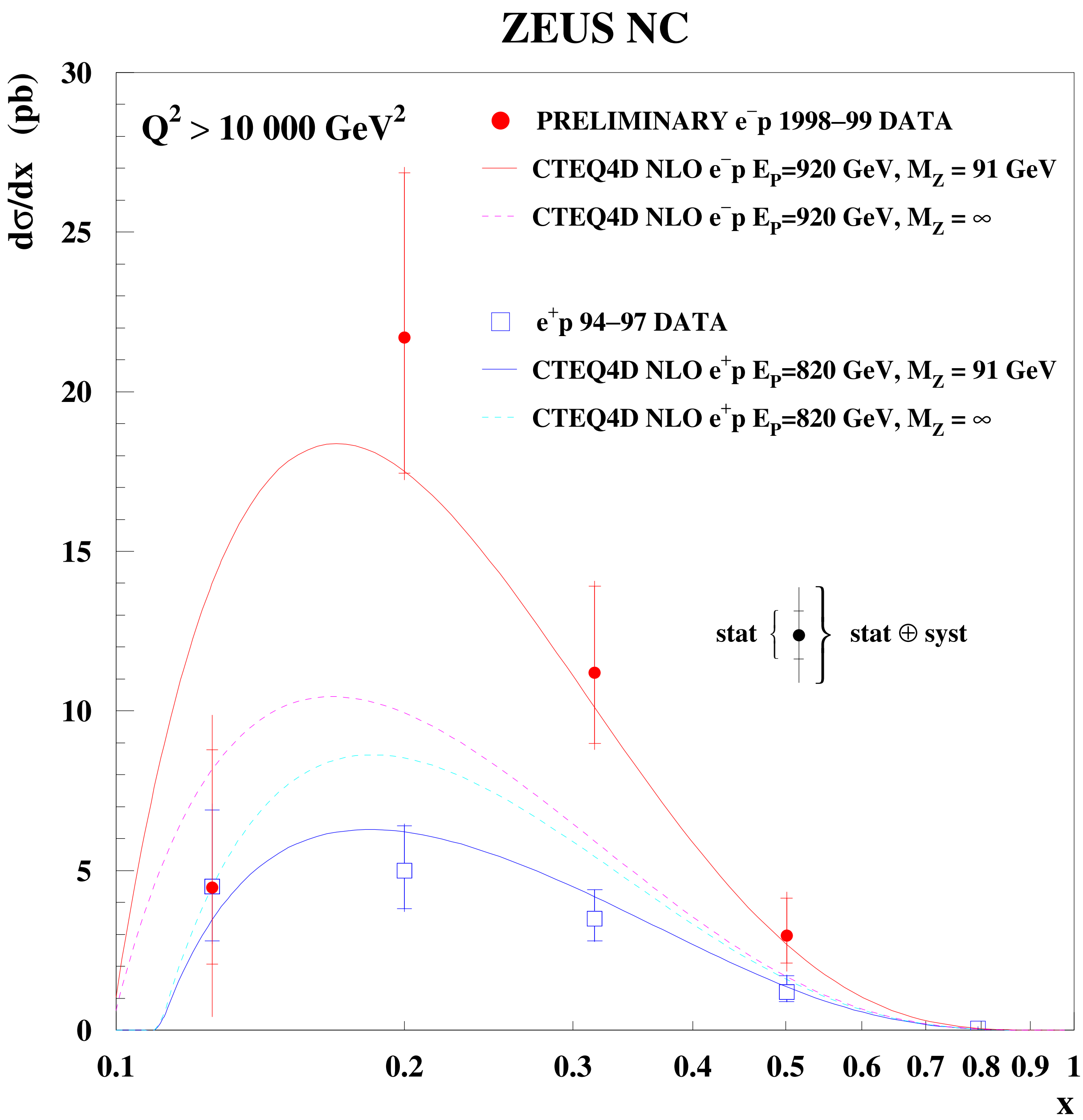




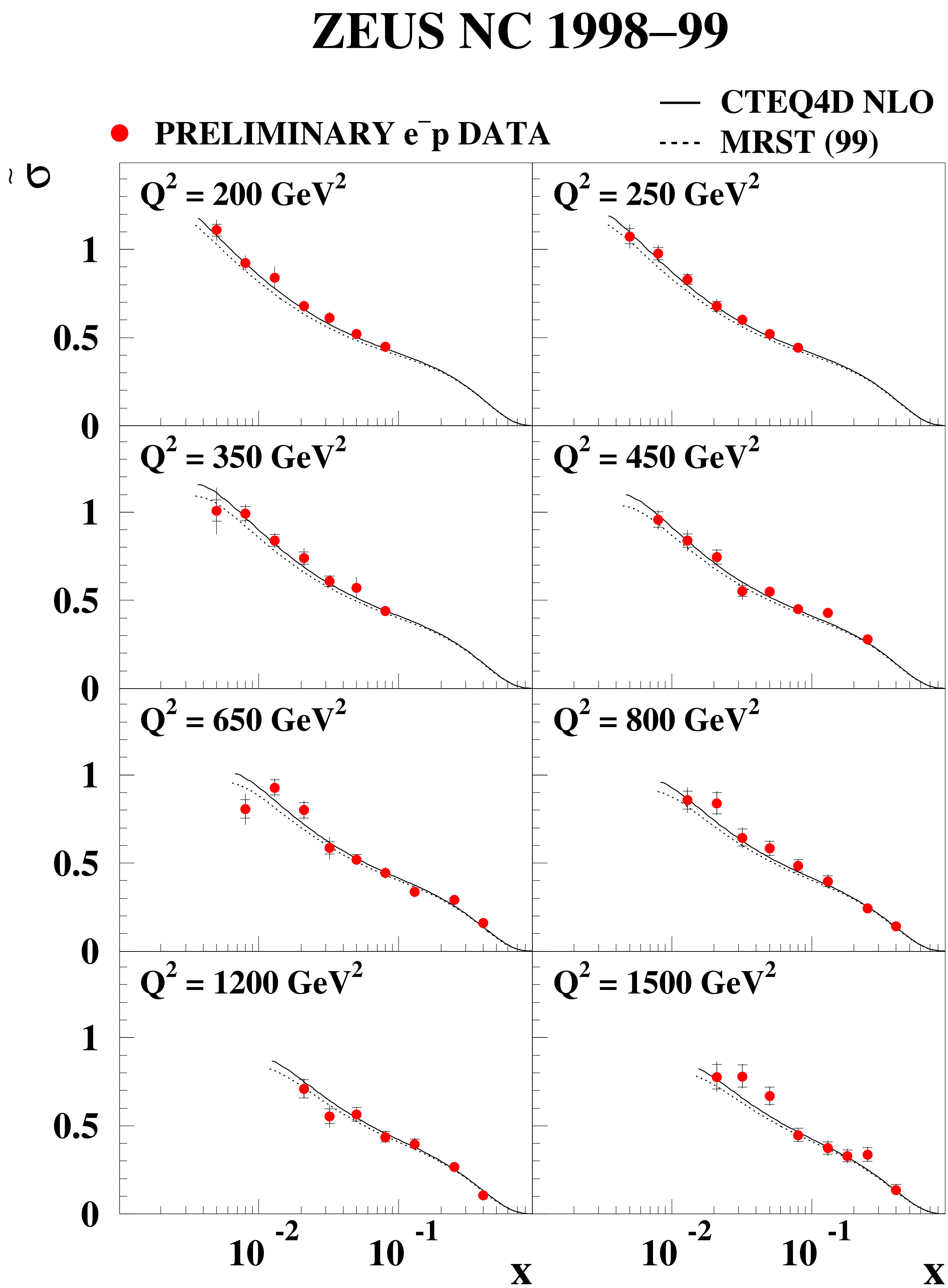
NC & CC: $d\sigma/dQ^2$



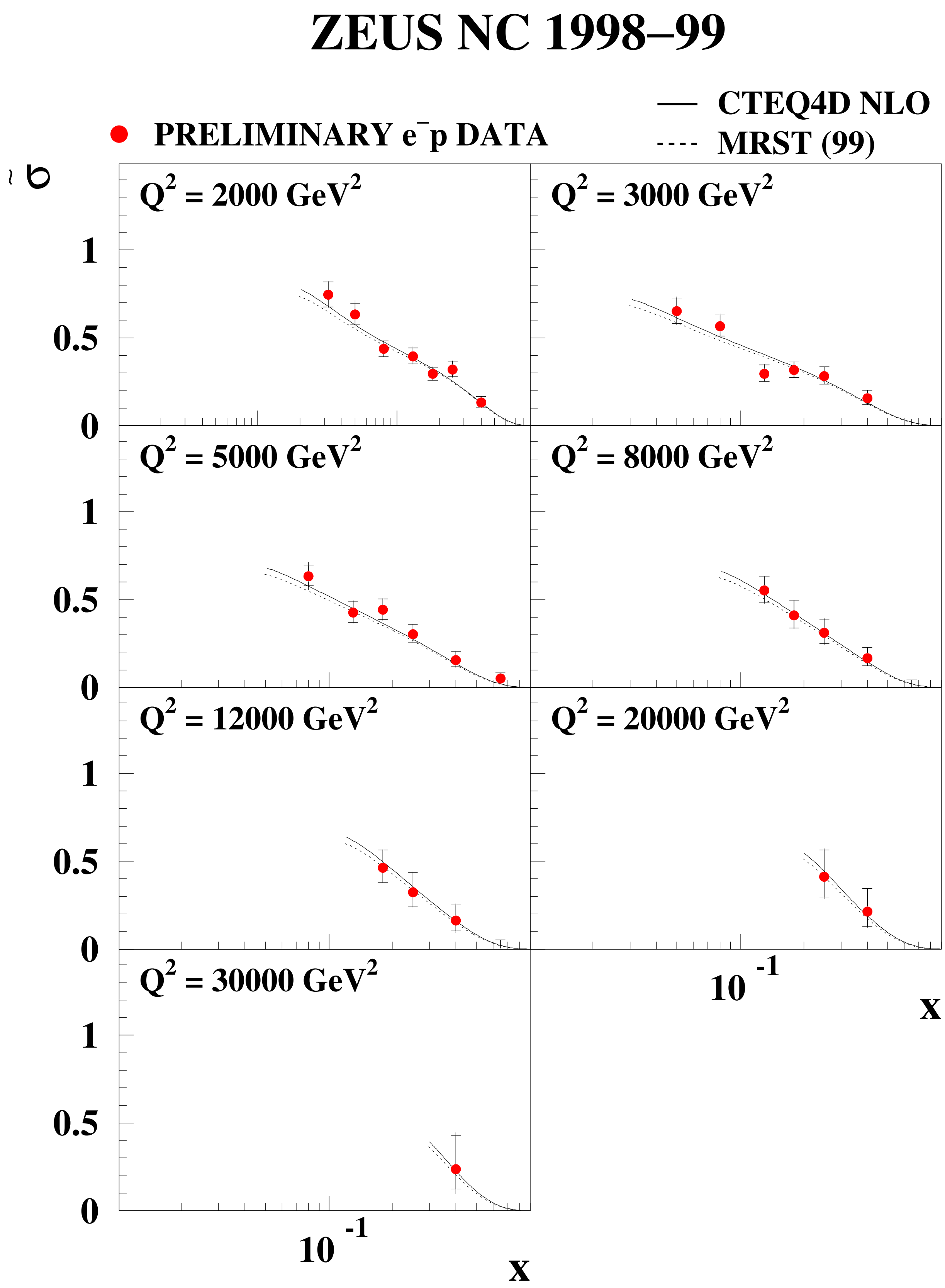
NC: $d\sigma/dx$, $Q^2 > 10\,000$ GeV^2



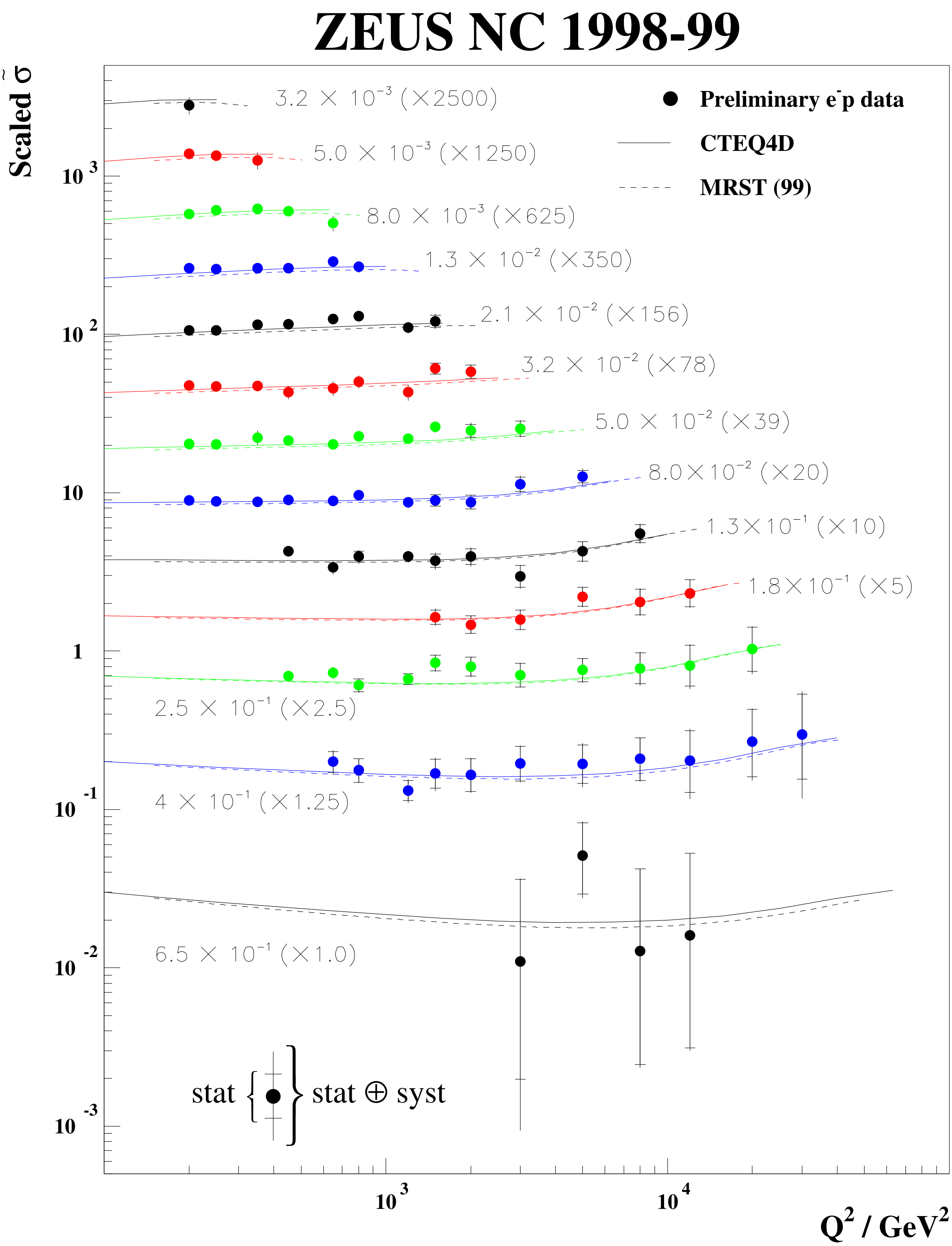
NC $e^- p$: Reduced Cross Section (I)



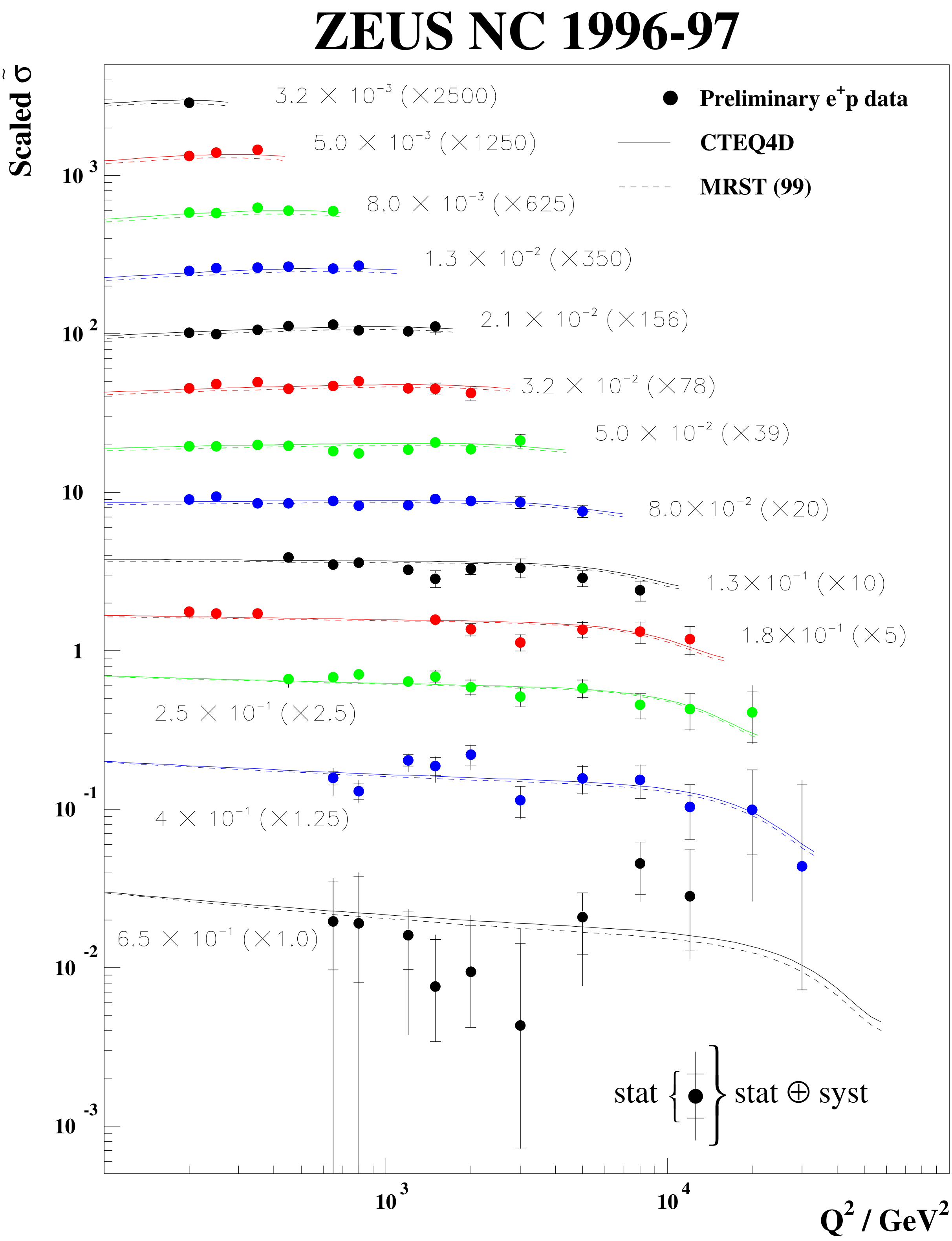
NC $e^- p$: Reduced Cross Section (II)



NC $e^- p$:
Reduced Cross Section (III)



NC e^+p: Reduced Cross Section



Extracting xF_3 from e^-p & e^+p

As a reminder:

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

- sign of xF_3 term depends on lepton charge
- y^2F_L contribution can be neglected at high Q^2

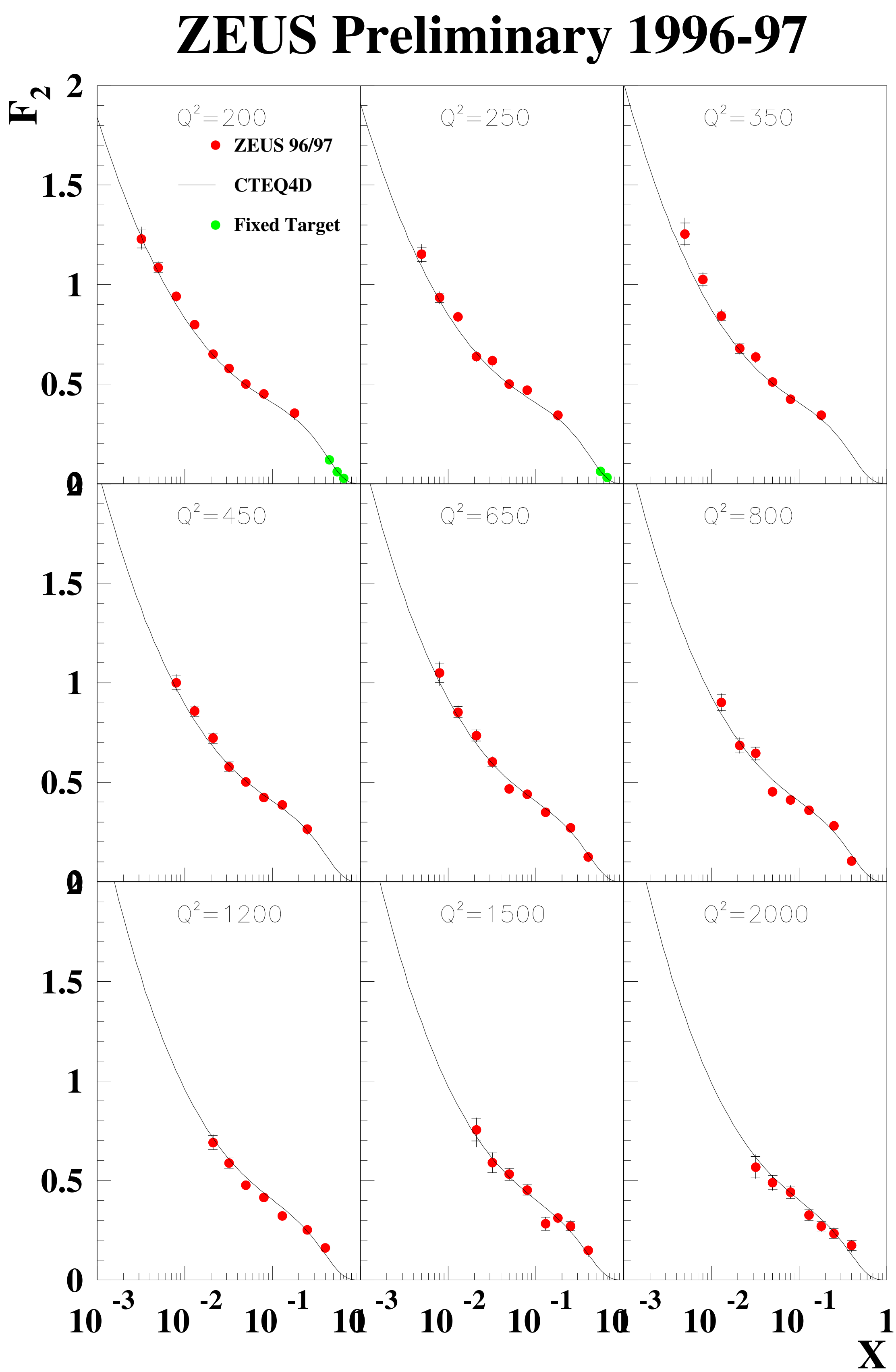
$$\sigma^+ = \frac{d^2\sigma^+}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left[Y_+^{820}F_2 - Y_-^{820}xF_3\right]$$

$$\sigma^- = \frac{d^2\sigma^-}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left[Y_+^{920}F_2 + Y_-^{920}xF_3\right]$$

$$\boxed{xF_3 = \frac{xQ^4}{2\pi\alpha^2}\cdot\left(\frac{Y_-^{820}}{Y_+^{820}} + \frac{Y_-^{920}}{Y_+^{920}}\right)^{-1}\cdot\left(\frac{1}{Y_+^{920}}\cdot\sigma^- - \frac{1}{Y_+^{820}}\cdot\sigma^+\right)}$$

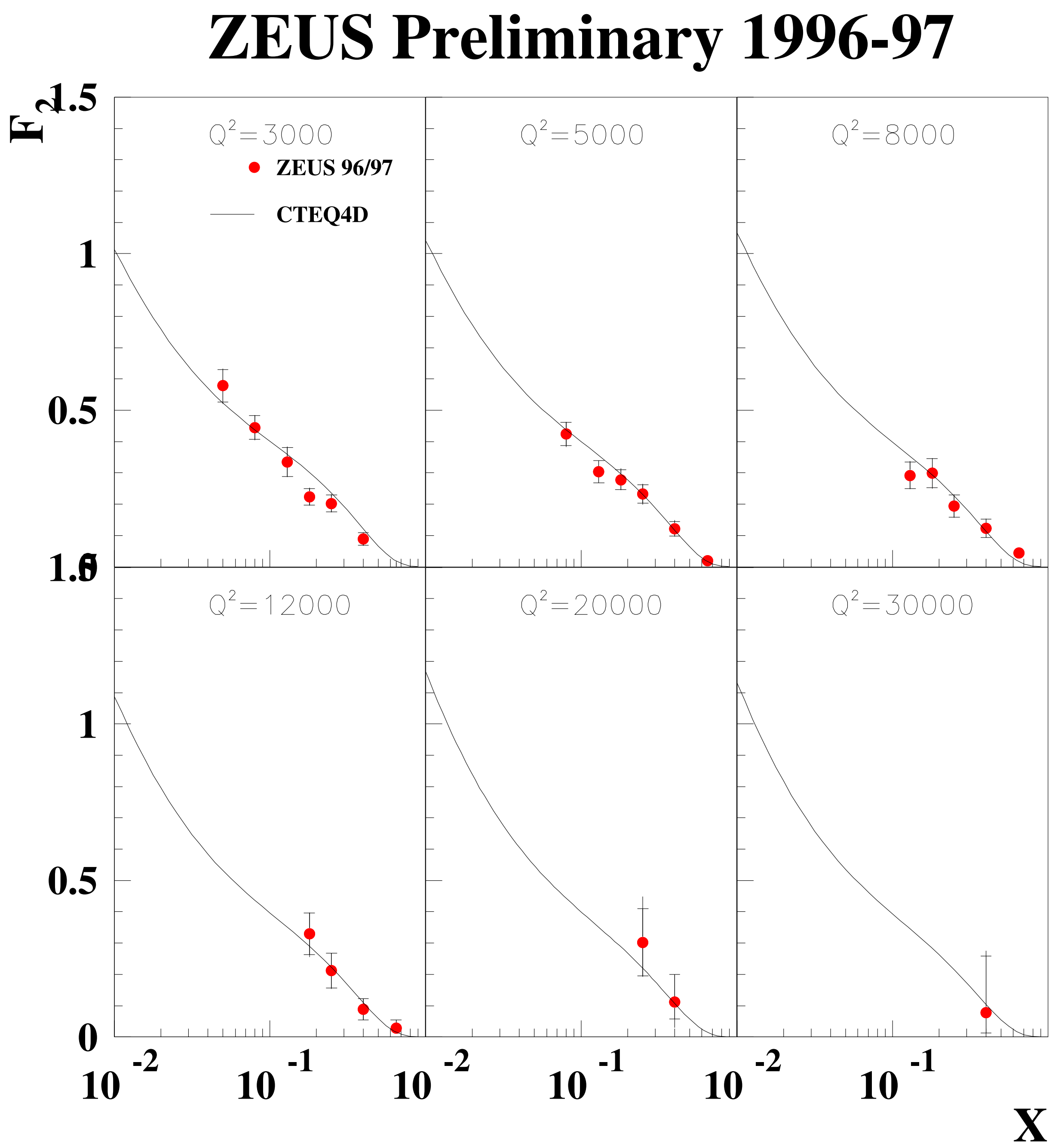
Available Data Sets: 1996–97 e^+p: 30 pb^{-1}
1998–99 e^-p: 16 pb^{-1}

NC e^+p: F_2 (I)



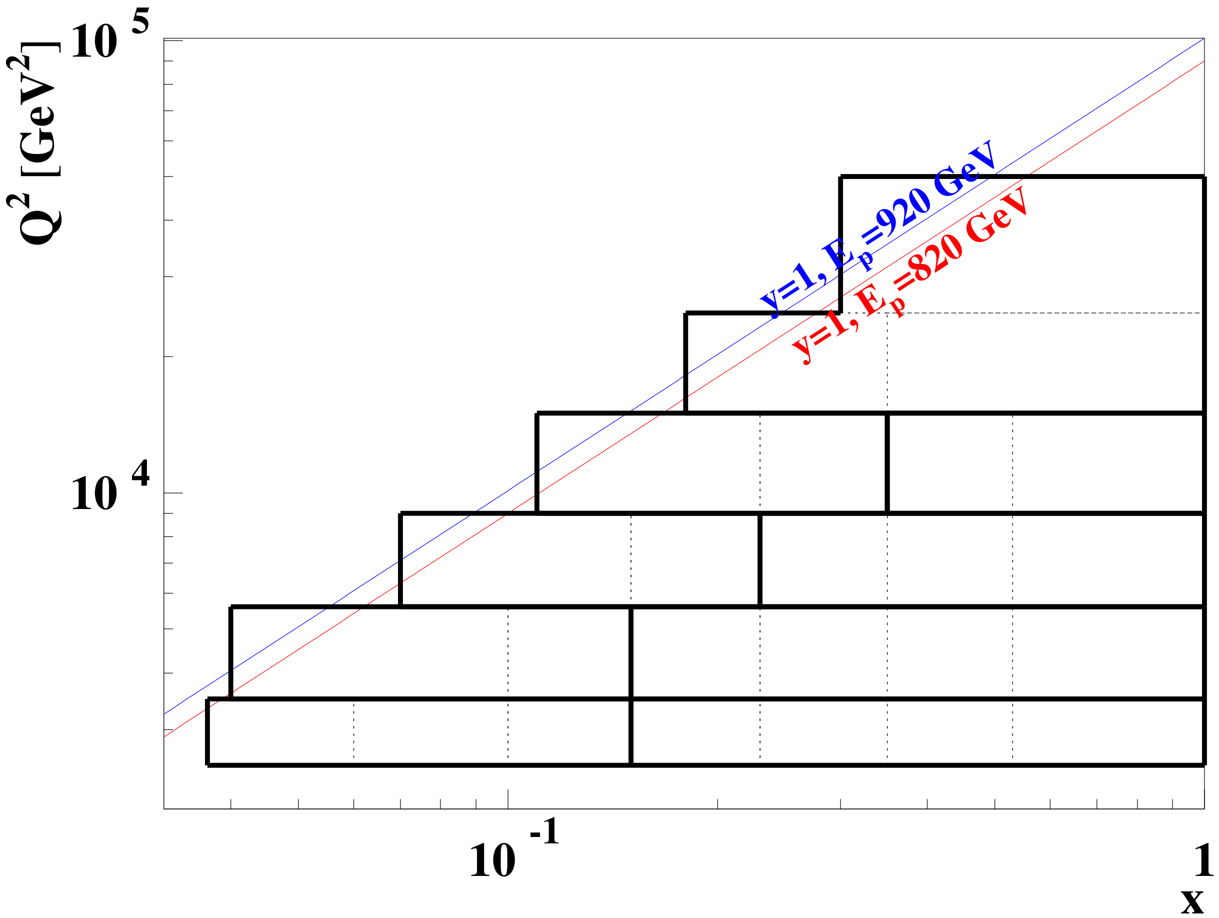
ZEUS Preliminary 1996-97
F_2
Q^2=200
Q^2=250
Q^2=350
Q^2=450
Q^2=650
Q^2=800
Q^2=1200
Q^2=1500
Q^2=2000
ZEUS 96/97
CTEQ4D
Fixed Target
0
0.5
1
1.5
2
10^{-3}
10^{-2}
10^{-1}
1
X

NC e^+p: F_2 (II)


ZEUS Preliminary 1996-97
F2
1.5
1
0.5
0
Q²=3000
Q²=5000
Q²=8000
Q²=12000
Q²=20000
Q²=30000
ZEUS 96/97
CTEQ4D
10 -2
10 -1
X

NC: xF_3 Binning

- xF_3 suppressed by Z-propagator
  $\Rightarrow$ small contribution at low Q^2
- Statistics low at high Q^2

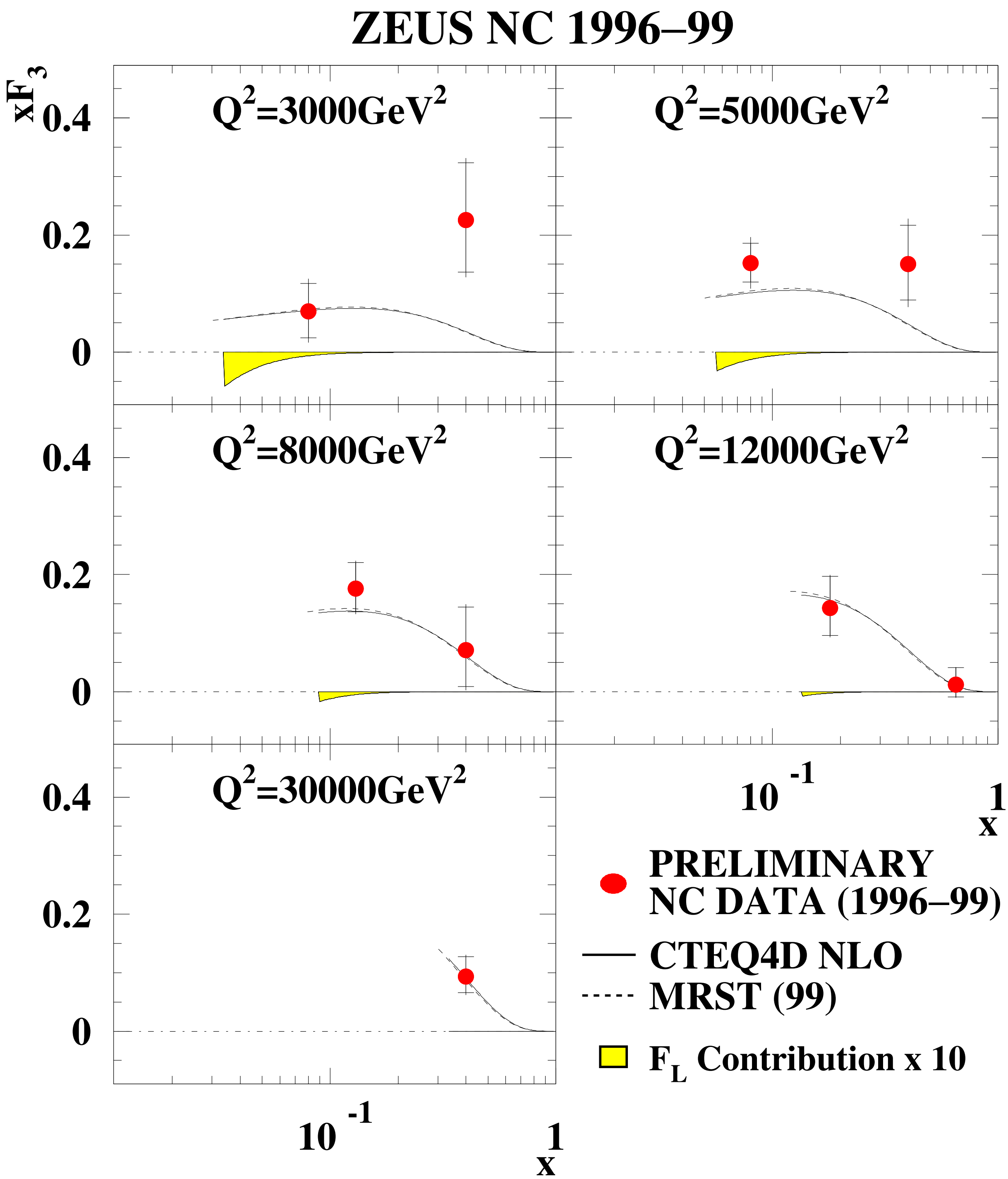


Kinematic Range:

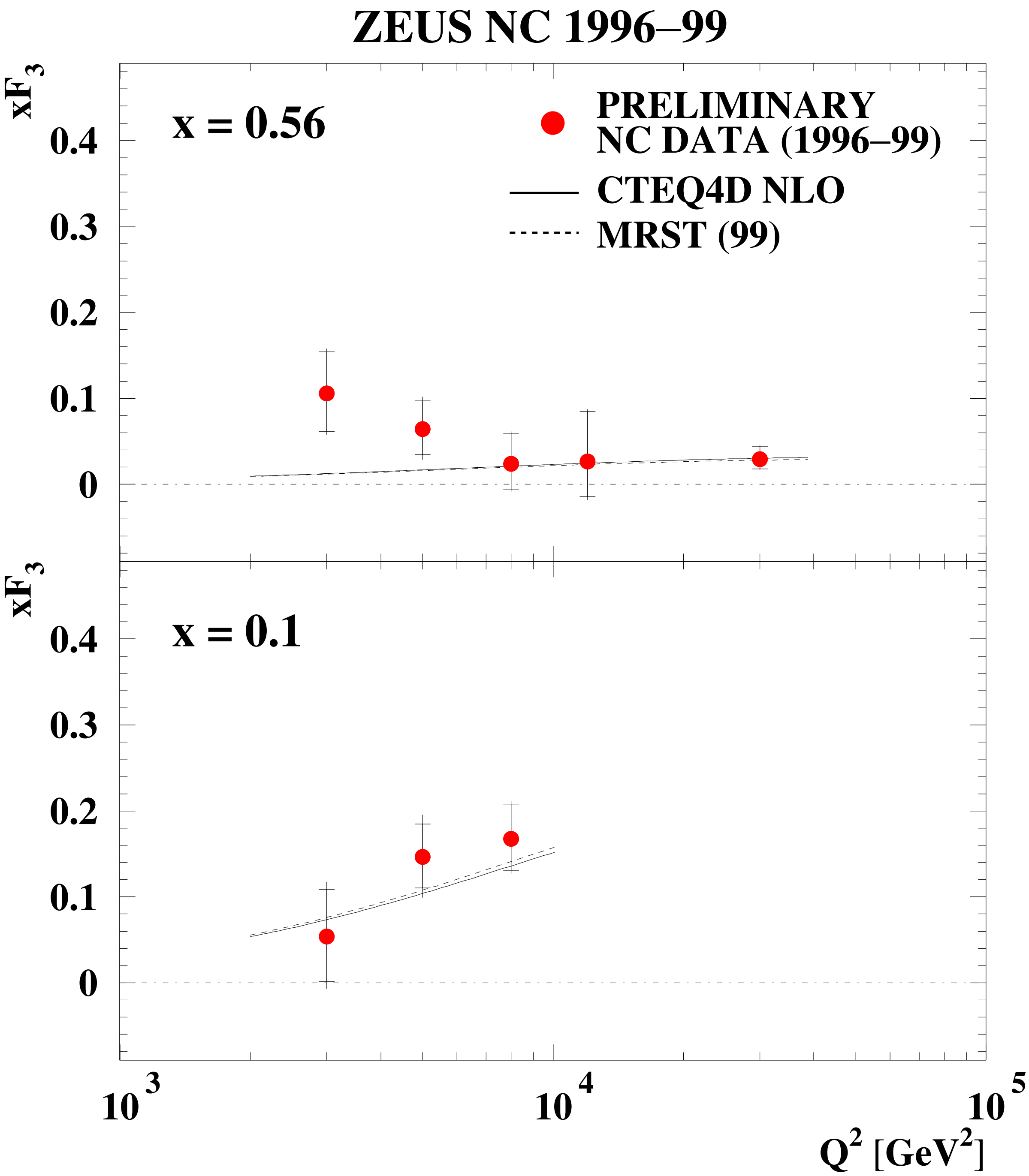
$$2500 \text{ GeV}^2 < Q^2 < 50\,000 \text{ GeV}^2$$

$$0.037 < x < 1$$

NC $e^- p$ & $e^+ p$: xF_3 (I)


ZEUS NC 1996–99
xF3
0.4
0.2
0
Q2=3000GeV2
Q2=5000GeV2
Q2=8000GeV2
Q2=12000GeV2
Q2=30000GeV2
10 -1
1
x
PRELIMINARY
NC DATA (1996–99)
CTEQ4D NLO
MRST (99)
FL Contribution x 10

NC e^-p & e^+p: xF_3 (II)



Summary

16 pb^{-1} of e^-p data allow for the first time at HERA to investigate the high-Q^2 regime in both the e^-p and the e^+p channels.

CC e^-p and e^+p cross sections were shown. Both data sets have comparable statistics.

M_W in the space-like region was extracted using a fit to $d\sigma/dQ^2$ CC e^+p data.

First reduced cross sections for the e^-p data for $Q^2 > 200$ GeV^2 have been presented.

For the first time xF_3 for $Q^2 > 3000$ GeV^2 was extracted from combined NC e^+p & e^-p data sets.

All measured cross sections and structure functions are in good agreement with Standard Model predictions using standard PDFs.