ZEUS High Q^2 e^+p & e^-p

cross sections

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- Introduction
- ZEUS '94-'97 results for $\mathbf{e^+p}$ (NC & CC)
- ZEUS '98/'99 results for $\mathbf{e^-p}$ (CC)
- Summary

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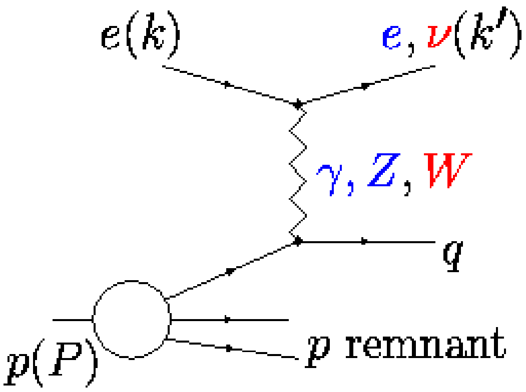
DESY Zeuthen, April 20, 1999

Introduction

DIS $e^{\pm}p \rightarrow l'X$



$$Q^2 = -(k - k')^2$$

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

$$y = \frac{P \cdot (k - k')}{P \cdot k}$$

$$(Q^2 = sxy)$$

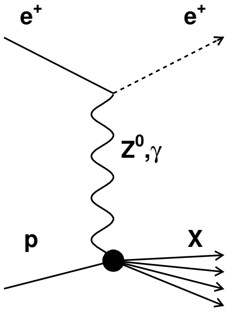
Data Samples:

- **'94-'97 e^+p 47pb^{-1}** (27.5 x 820 GeV)
- **'98-'99 e^-p 6pb^{-1}** (27.5 x 920 GeV)

ZEUS Detector

- **Uranium-Scintillator Calorimeter**
  - **EM section $\sigma(E)/E = 18\%/\sqrt{E}$**
    scale uncertainty 1-2%
  - **HAD section $\sigma(E)/E = 35\%/\sqrt{E}$**
    scale uncertainty 3%
- **Central Tracking Detector: $15^o < \theta < 164^o$**

e^+p NC cross section

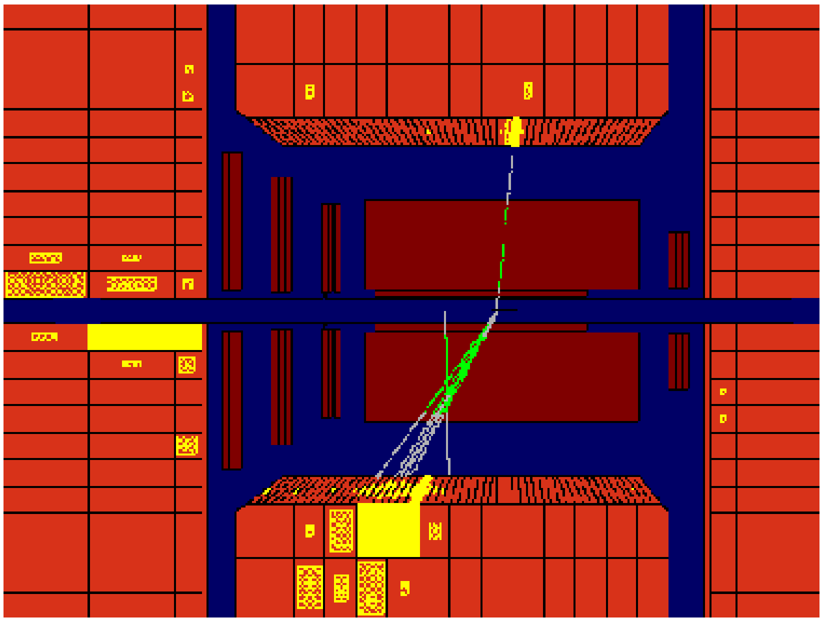


$$\frac{d^2\sigma^{NC}_{Born}(e^+p)}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left\{ \left(1+(1-y)^2\right) F_2^{NC}(x,Q^2) - \left(1-(1-y)^2\right) xF_3^{NC}(x,Q^2) - y^2 F_L^{NC}(x,Q^2) \right\}$$

Uncertainties: parton distributions
higher QCD corrections
electroweak parameters
electroweak radiative corrections

MC simulation:

- HERACLES 4.5.2 + DJANGO 6.2.4
  (NC DIS events + radiative effects)
  + color-dipole model of ARIADNE 4.08
  for hadronic final state simulation
- LEPTO 6.5 with MEPS model
  (as a systematic check)
- HERWIG
  (to estimate photoproduction background)



Kinematic variables reconstructed with the Double-Angle method:

$$Q^2_{DA} = 4E_e^2 \frac{\sin\gamma_h(1+\cos\theta_e)}{\sin\gamma_h + \sin\theta_e - \sin(\gamma_h+\theta_e)}$$

$$x_{DA} = \frac{E_e}{E_p} \frac{\sin\gamma_h + \sin\theta_e + \sin(\gamma_h+\theta_e)}{\sin\gamma_h + \sin\theta_e - \sin(\gamma_h+\theta_e)}$$

$$y_{DA} = \frac{\sin\theta_e(1-\cos\gamma_h)}{\sin\gamma_h + \sin\theta_e - \sin(\gamma_h+\theta_e)}$$

- E_e, E_p - beam energies
- θ_e - electron scattering angle
- γ_h - polar angle of hadronic final state:

$$\cos\gamma_h = \frac{P^2_{T,h} - (E-P_Z)^2_h}{P^2_{T,h} + (E-P_Z)^2_h})$$

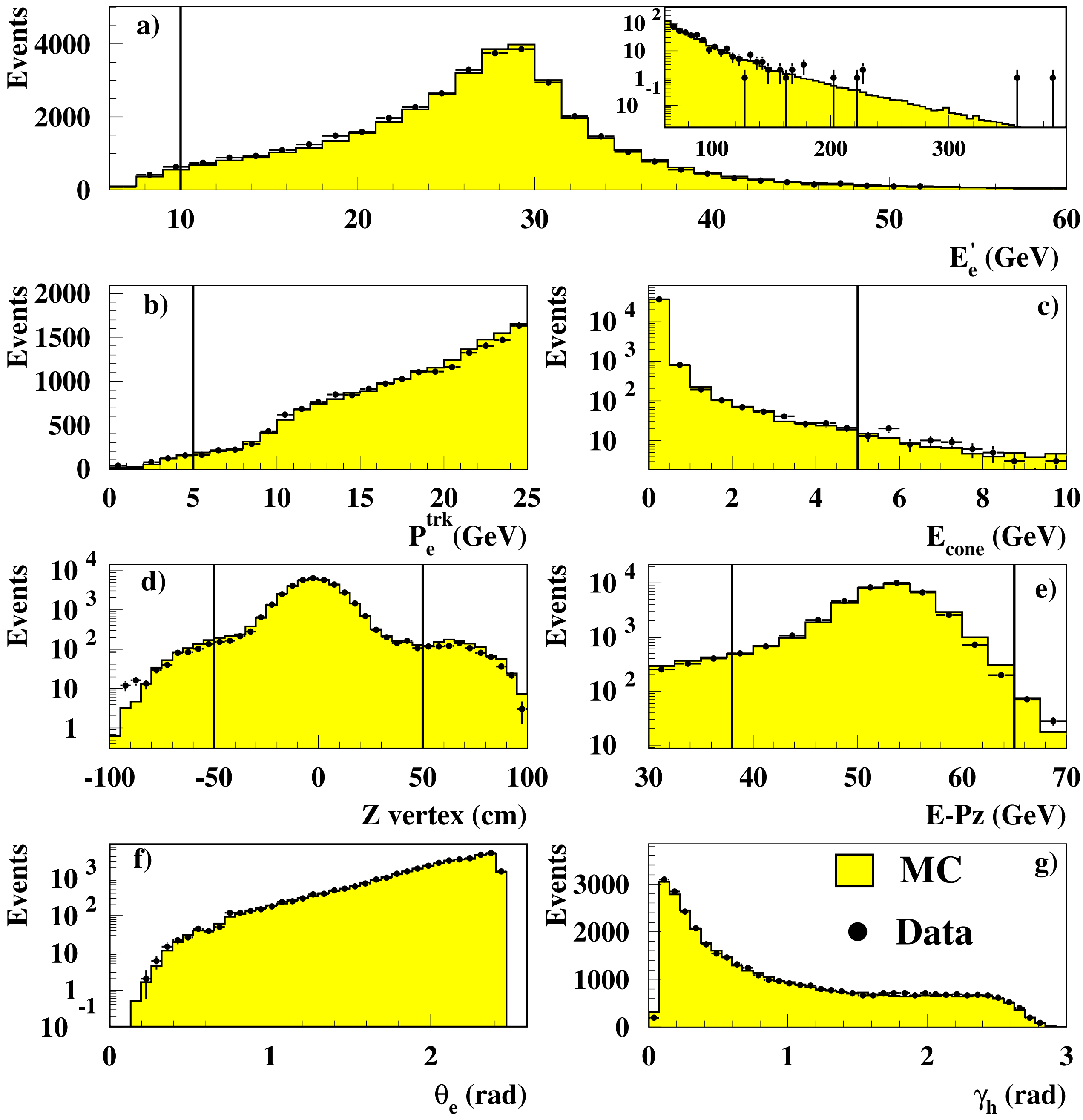
Offline selection

- $|Z_{vtx}| < 50\ cm$
- $38\ GeV\ \ < E - P_Z < 65\ GeV$
- isolated ($E_{cone} < 5GeV$) positron with $E_e > 10GeV$, matched to the track with $p > 5\ GeV$
  For positrons beyond the forward tracking acceptance $P_{T,e} > 30GeV$ and $(E - P_Z) > 44GeV$ cuts are applied
- $y_e < 0.95$
- $P_T/\sqrt{E_T} < 4\ \sqrt{GeV}$

$\rightarrow\quad +\quad \mathbf{Q^2 > 400\ GeV^2}$

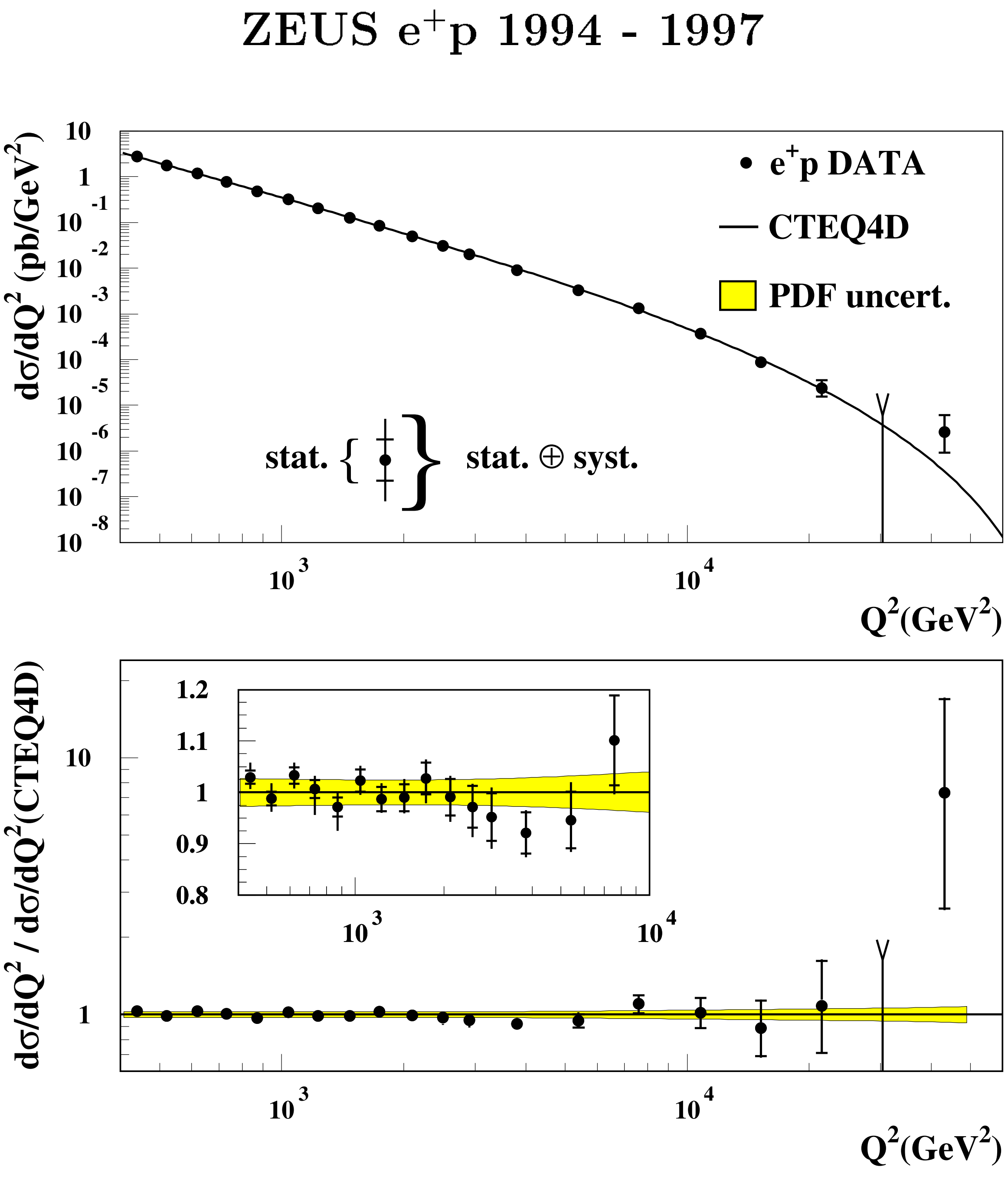
Cuts efficiency is, on average, 80%

Comparison of data and MC simulation



- Good agreement

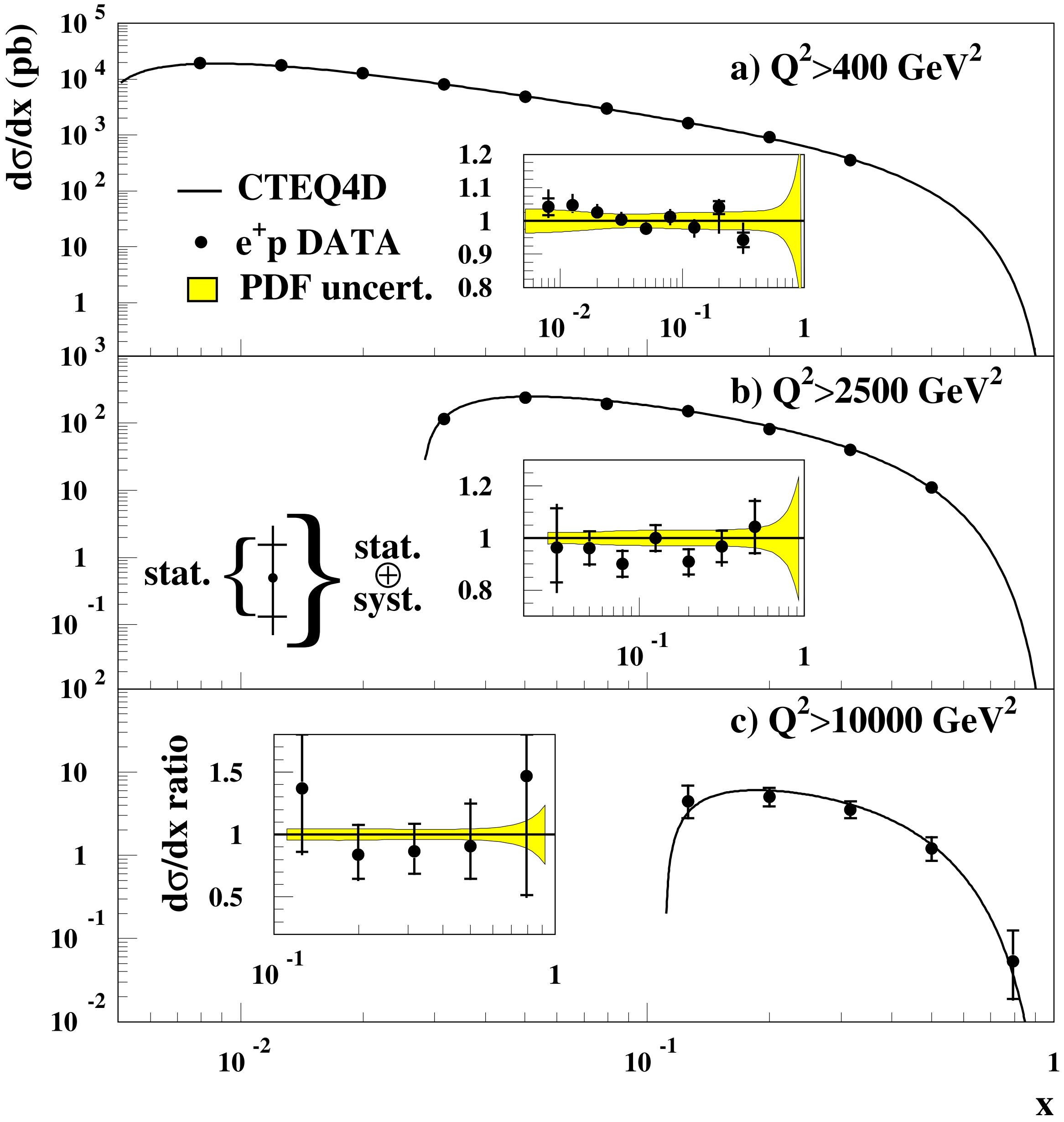
Differential NC cross section $d\sigma^{e^+p}/d\mathbf{Q^2}$



- SM predictions give a very good description except in the highest Q^2 bin (2 events when 0.27 is expected)

Differential NC cross section $d\sigma^{e^+p}/dx$

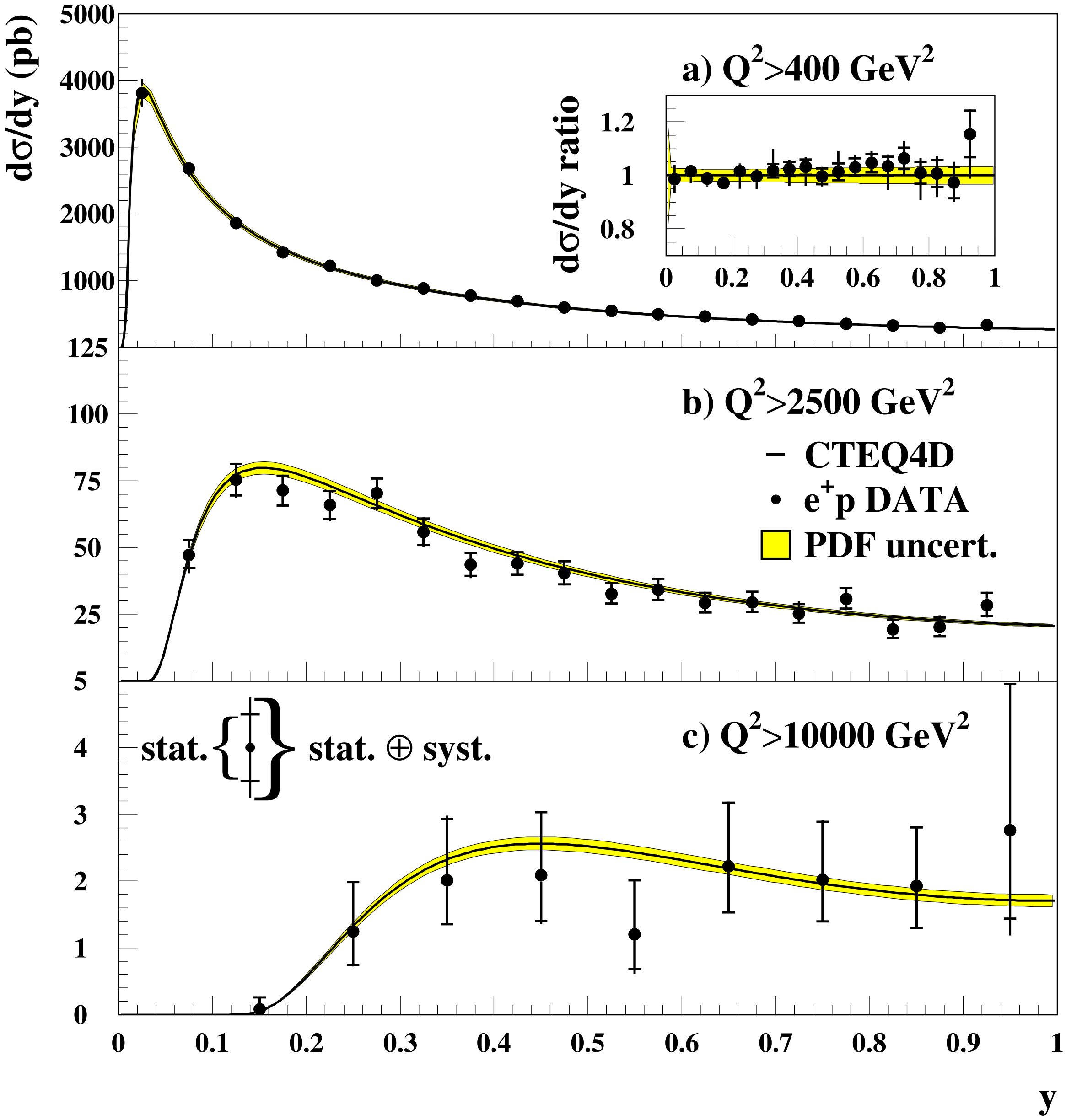
ZEUS e^+p 1994 - 1997



- Very good agreement between measured $d\sigma^{e^+p}/d\mathbf{x}$ and SM predictions

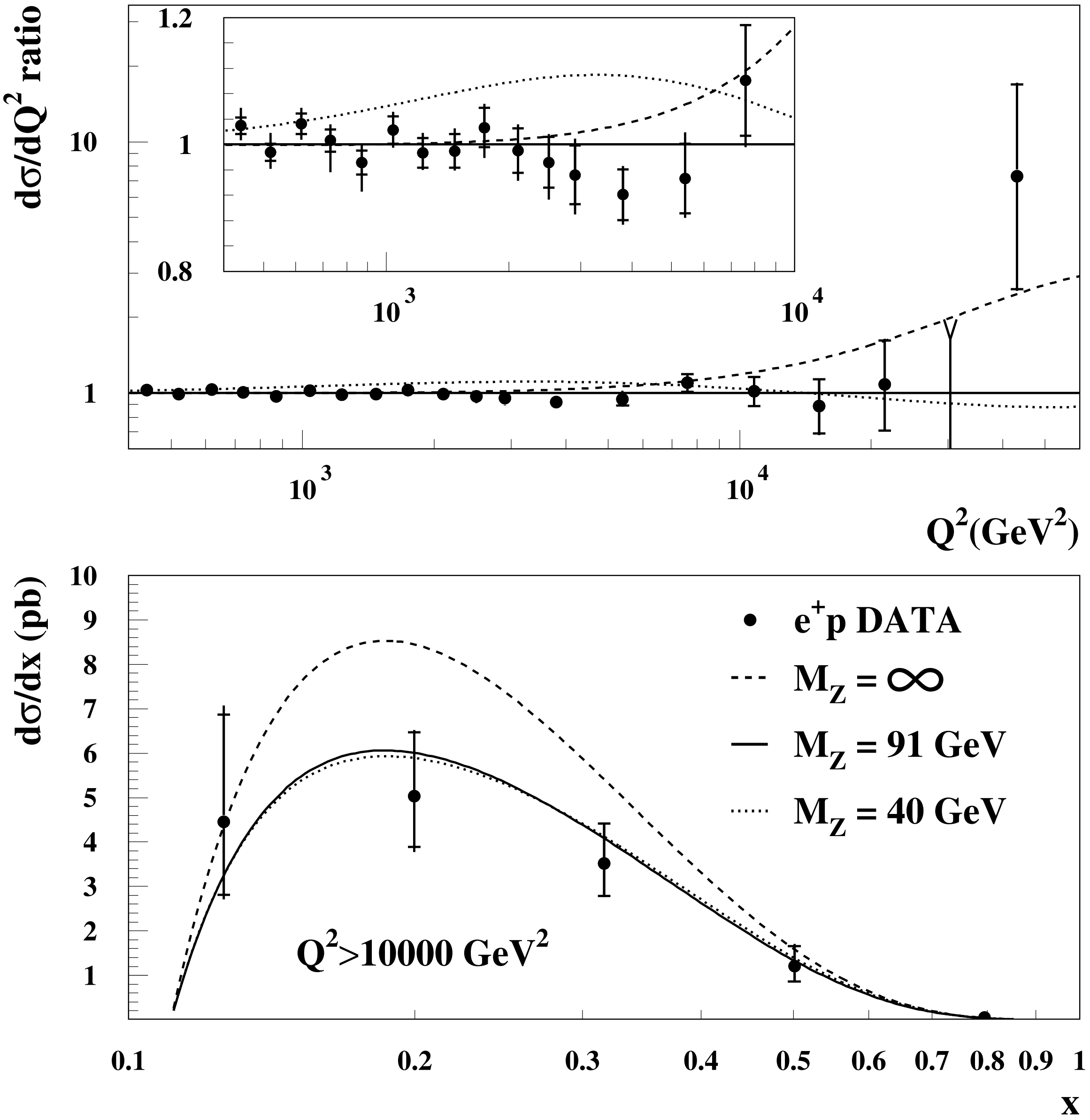
Differential NC cross section $d\sigma^{e^+p}/dy$

ZEUS e^+p 1994 - 1997



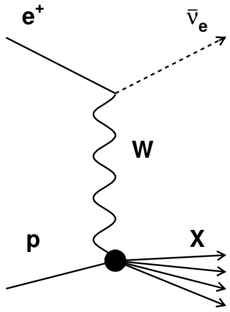
- Very good agreement between measured $d\sigma^{e^+p}/d\mathbf{y}$ and SM predictions

Sensitivity to EW effects



- Electroweak effects are observed in ZEUS experiment.

e^+p CC cross section



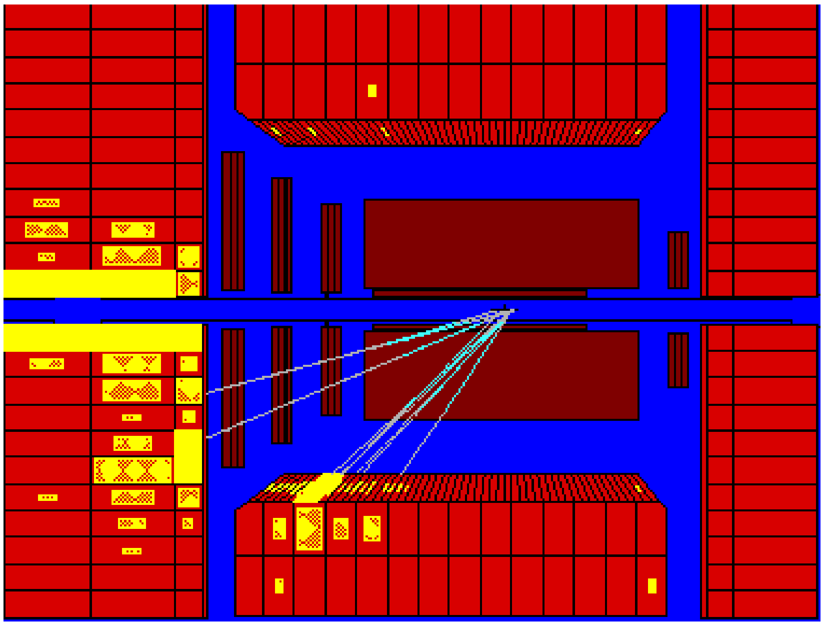
$$\frac{d^2\sigma^{CC}_{Born}(e^+p)}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \Big\{ \left(1+(1-y)^2\right)\ F_2^{CC}(x,Q^2) - \left(1-(1-y)^2\right)\ xF_3^{CC}(x,Q^2) - y^2\ F_L^{CC}(x,Q^2) \Big\}$$

The reduced differential cross section $\tilde{\sigma}$:

$$\tilde{\sigma} = \left[\frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\right]^{-1} \frac{d^2\sigma^{CC}_{Born}(e^+p)}{dxdQ^2}$$

MC simulation:

- HERACLES 4.5.2 + DJANGO 6.2.4
  (CC DIS events + radiative effects)
  + color-dipole model of ARIADNE 4.08
  for hadronic final state simulation
- LEPTO 6.5 with MEPS model
  (as a systematic check)
- HERWIG, EPVEC, LPAIR, DJANGO
  (to estimate various background sources)



Kinematic variables reconstructed with Jacquet-Blondel method:

$$\mathbf{y_{JB}} = \frac{\mathbf{E - P_Z}}{\mathbf{2E_e}}$$

$$\mathbf{Q^2} = \frac{\mathbf{P_T^2}}{(\mathbf{1 - y_{JB}})}$$

$$\mathbf{x_{JB}} = \frac{\mathbf{Q^2_{JB}}}{\mathbf{s y_{JB}}}$$

- Q^2 resolution: $\approx 30\%$ at $Q^2 = 500$ GeV^2
  $\rightarrow 20\%$ at $Q^2 = 2000$ GeV^2
- x resolution: $\approx 25\%$ at $x = 0.01$
  $\rightarrow 10\%$ at $x = 0.8$

Offline selection

With using CTD vertex ($\gamma > 23^o$)

- $P_T > 12\ GeV$ and $P'_T > 10\ GeV$
- $|Z_{vtx}| < 50cm$
- $P_T/E_T > 0.4\ (20GeV < P_T < 30GeV)$
  $P_T/E_T > 0.55\ (P_T < 20GeV)$

Without using CTD vertex ($\gamma < 23^o$)

(the vertex reconstructed from timing measured in forward calorimeter and stricter cuts)

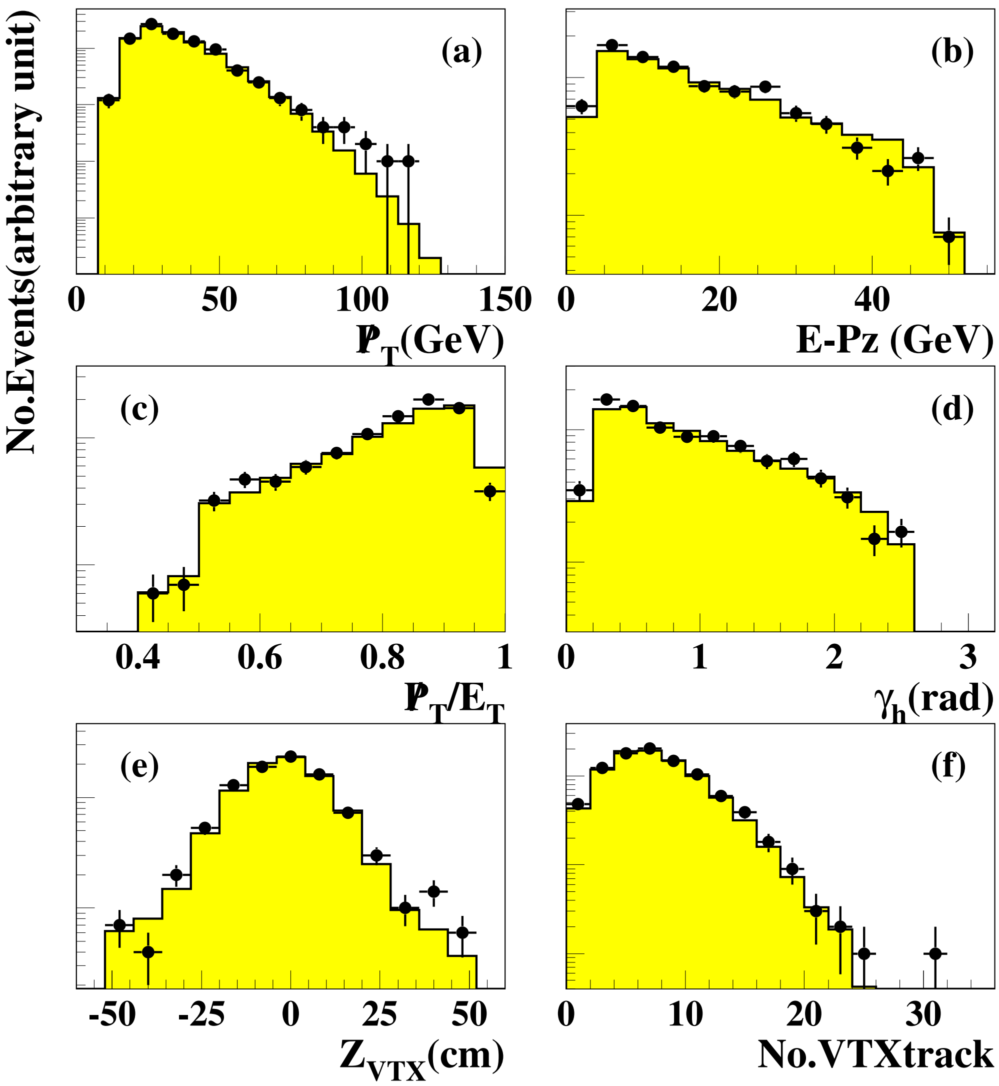
- $P_T > 14\ GeV$ and $P'_T > 12\ GeV$
- $|Z_{vtx}| < 50cm$
- $P_T/E_T > 0.6\ (P_T > 30GeV)$

+

- NC DIS removed by electron identification
- non-ep background rejection

$\rightarrow \quad + \quad \mathbf{Q^2 > 200\ GeV^2} \quad \& \quad \mathbf{y < 0.9}$

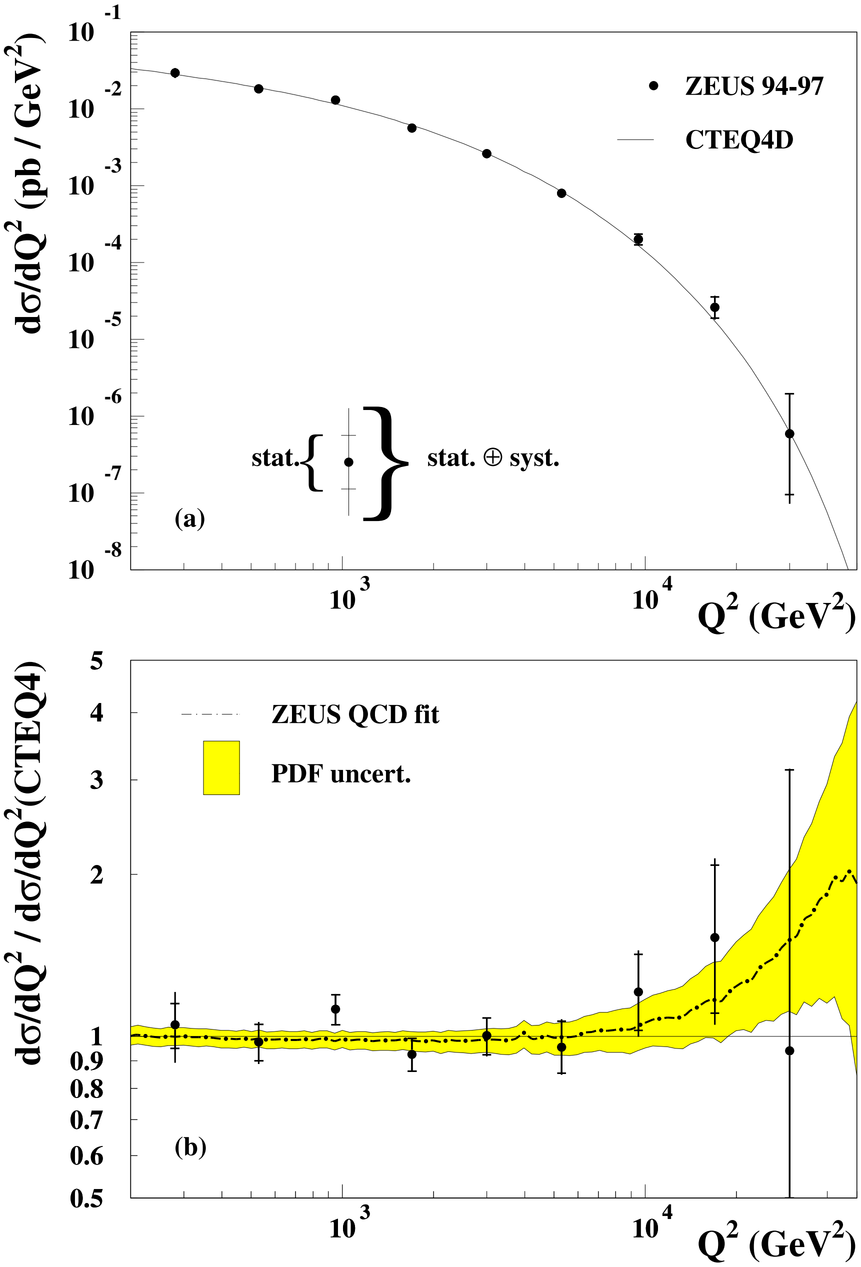
Comparison of data and MC simulation



- Reasonable agreement

Differential CC cross section $d\sigma^{e^+p}/dQ^2$

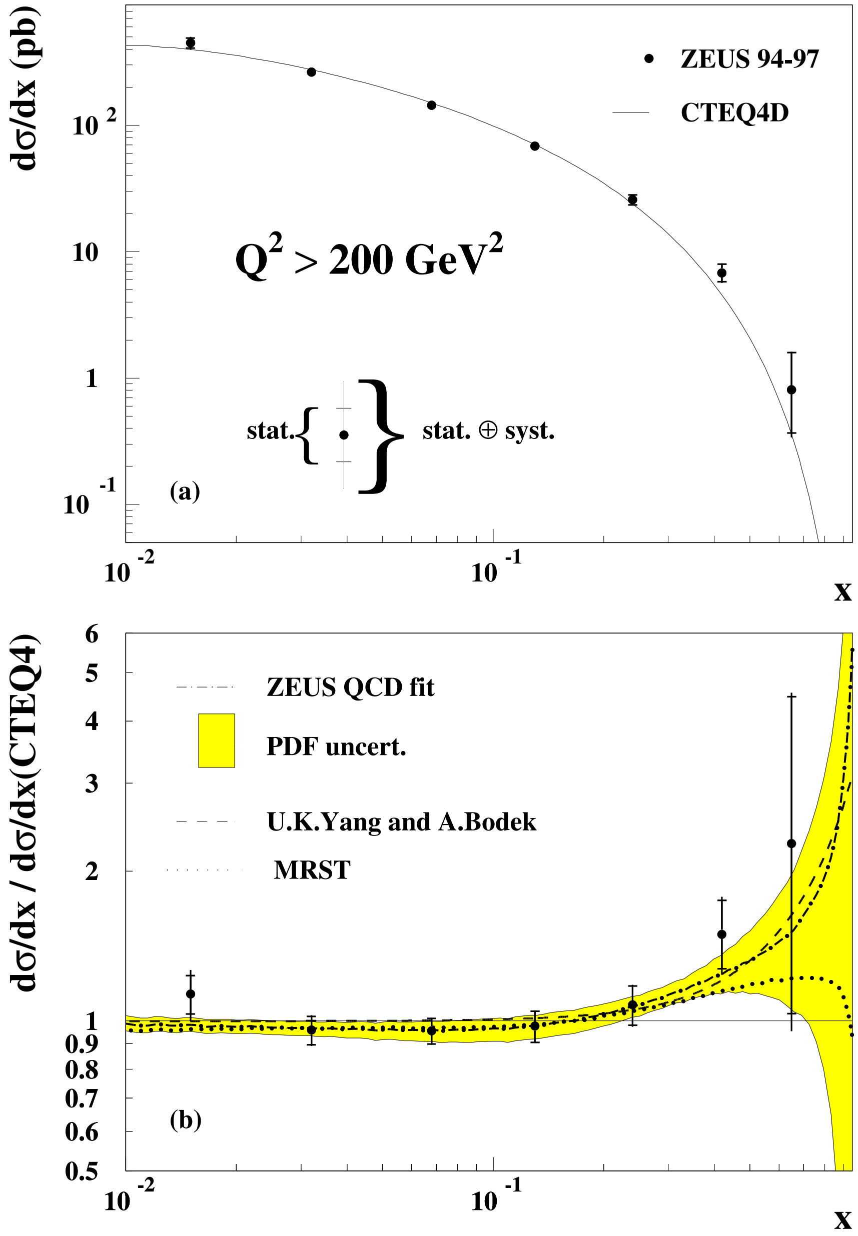
ZEUS preliminary e^+p 1994 - 1997



- Reasonable agreement between SM prediction and measured $d\sigma^{e^+p}/dQ^2$
- ZEUS QCD fit gives better description of ZEUS data

Differential CC cross section $d\sigma^{e^+p}/d\mathbf{x}$

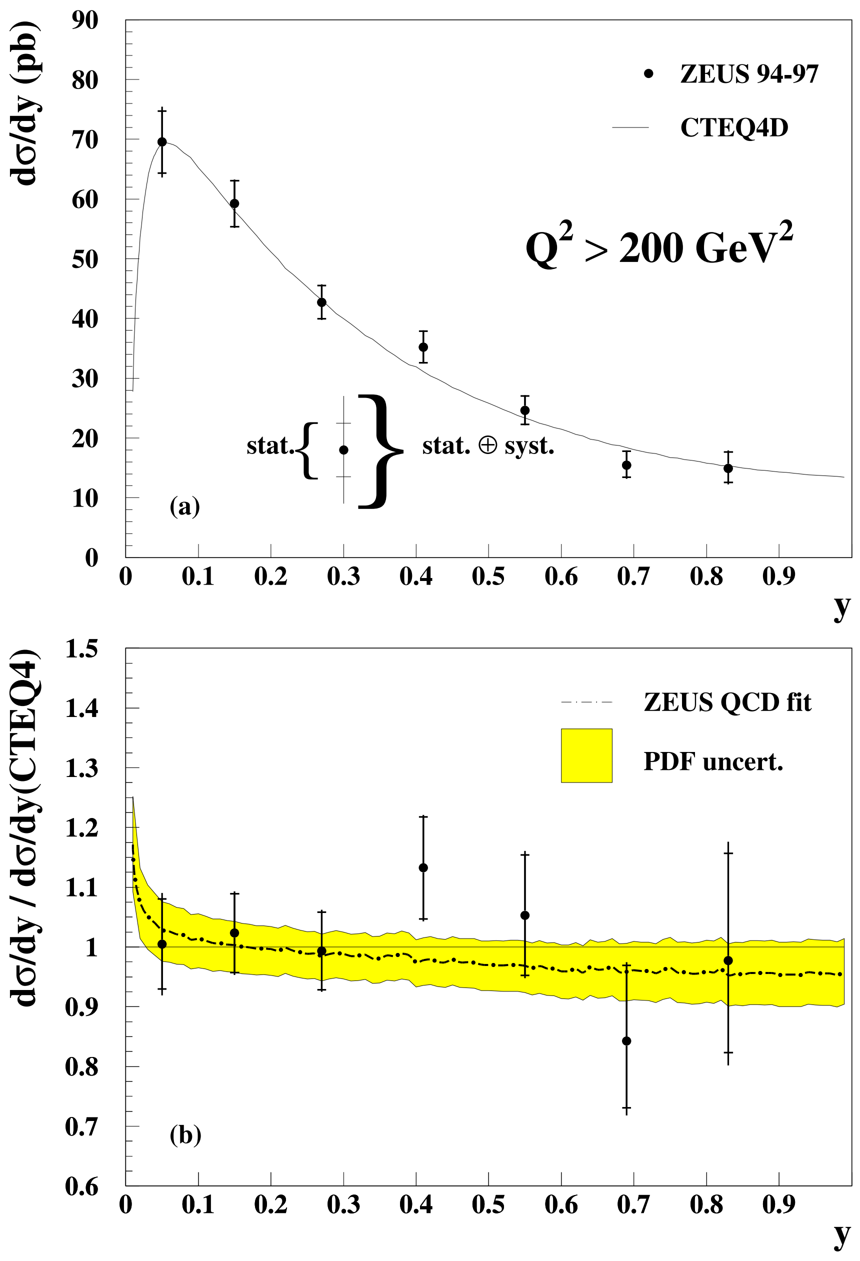
ZEUS preliminary e^+p 1994 - 1997



- For high x data systematically above SM
- ZEUS QCD fit describes $d\sigma^{e^+p}/d\mathbf{x}$ data

Differential CC cross section $d\sigma^{e^+p}/dy$

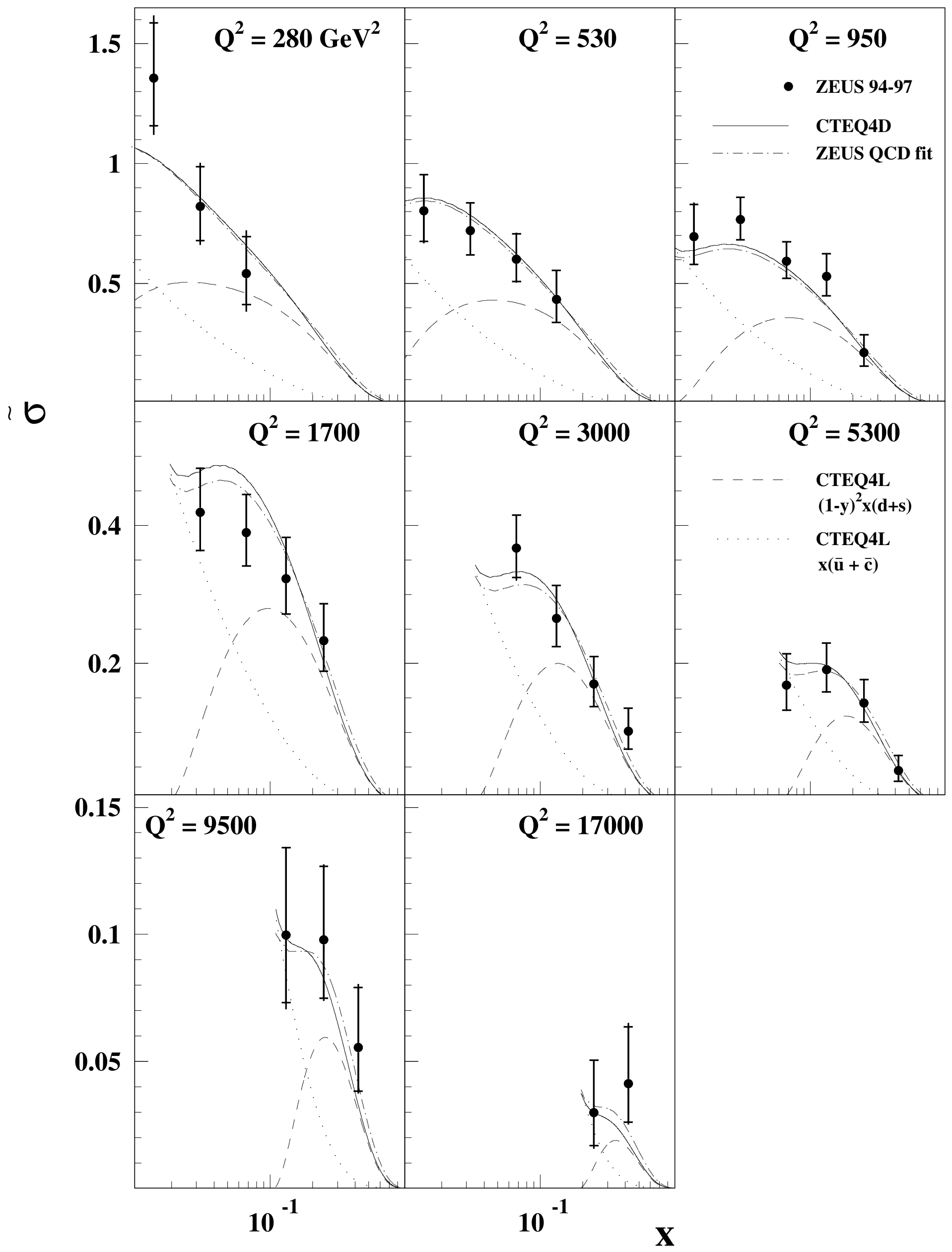
ZEUS preliminary e^+p 1994 - 1997



- ZEUS QCD fit as good as CTEQ4D

The reduced cross section $\tilde{\sigma}(x)$ at fixed Q^2

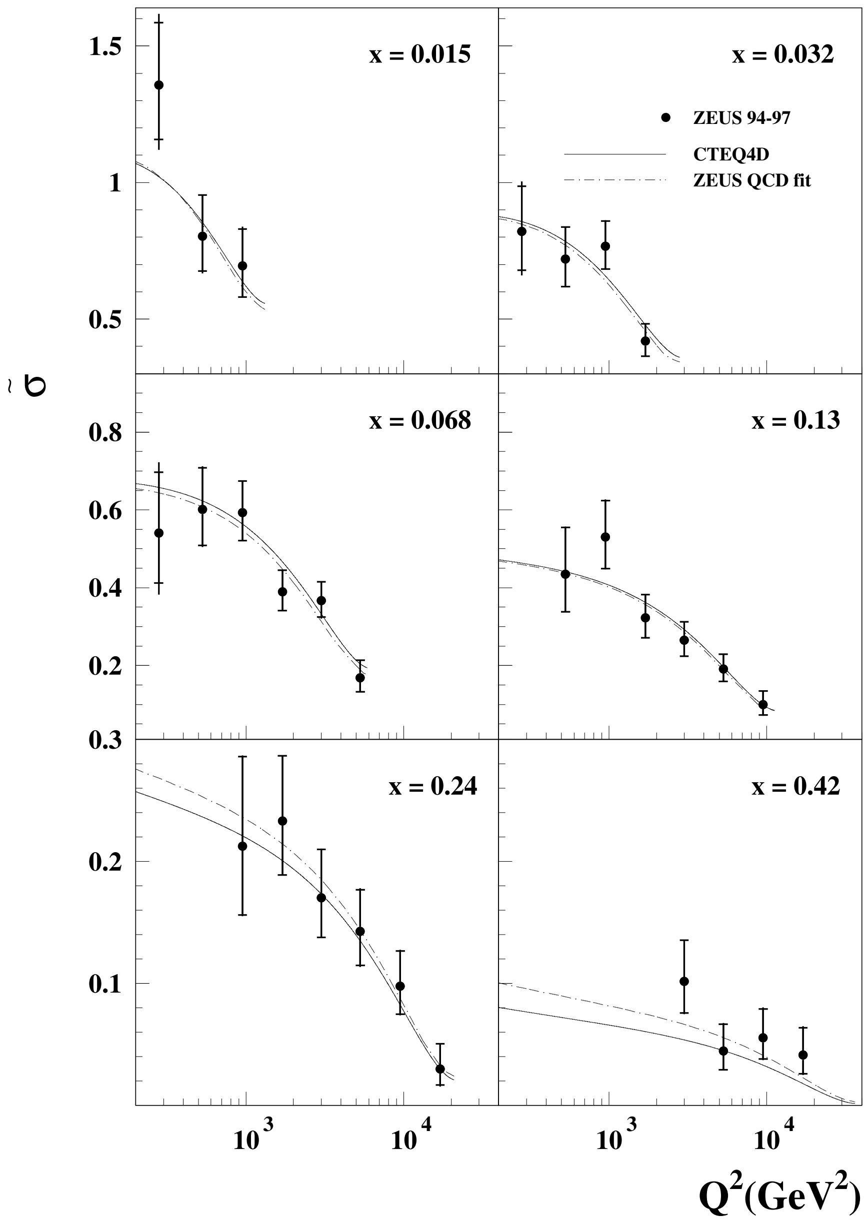
ZEUS preliminary e^+p 1994 - 1997



- $(d + s)$ combination dominates at high x
- $\tilde{\sigma}$ sensitive to the $(\bar{u} + \bar{c})$ at low x

The reduced cross section $\tilde{\sigma}(Q^2)$ at fixed x

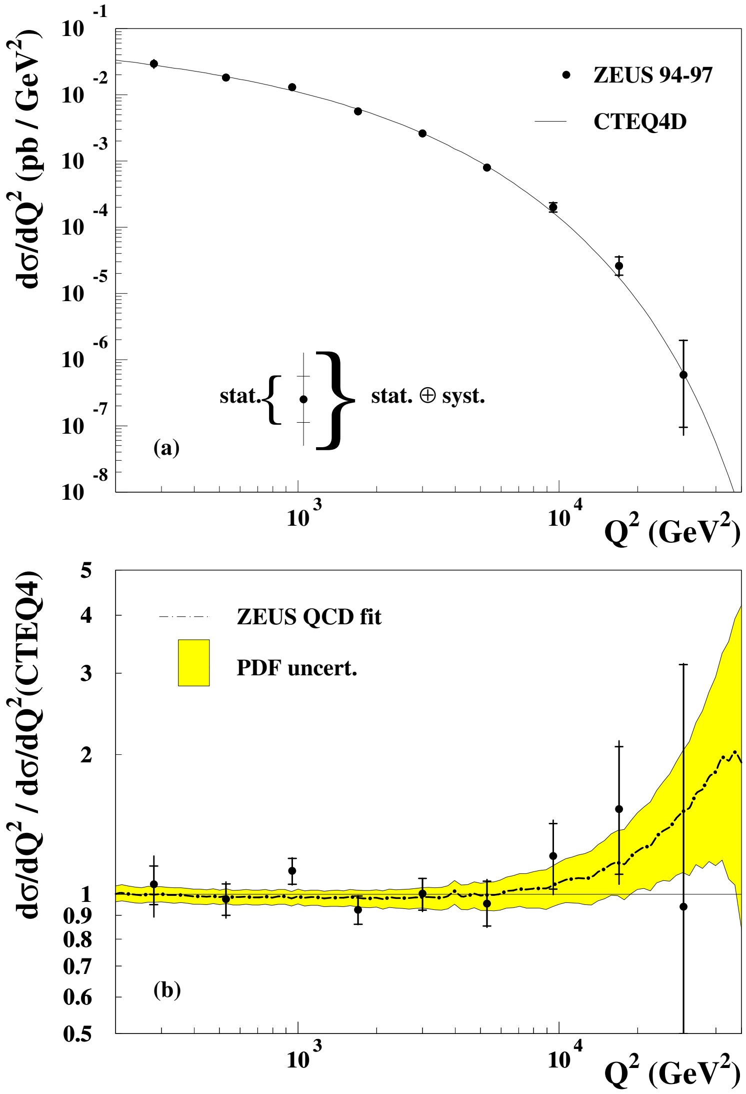
ZEUS preliminary e^+p 1994 - 1997



- At high x the data tend to lie above the SM

M_W from $d\sigma^{CC}/dQ^2$

ZEUS CC 1994-97 preliminary



$$\frac{d\sigma^{CC}}{dQ^2} = \frac{G_F^2}{4\pi} \frac{M_W^4}{(M_W^2 + Q^2)^2} F(Q^2)$$

$G_F \propto$ normalisation, $M_W \propto$ shape

M_W from $d\sigma^{CC}/dQ^2$

- Unconstrained fit to $d\sigma^{CC}/dQ^2$: measurement of the mass of spacelike W ⇒ complementary to e^+e^- and pp measurements of timelike W mass. (G_F statistical error about 3%)

$$\boxed{M_W = 80.9^{+4.9}_{-4.6}\,(\text{stat})\,^{+5.0}_{-4.3}\,(\text{syst})\,^{+1.3}_{-1.2}\,(\text{pdf})\ \text{GeV}}$$

Preliminary

- Fix G_F, fit $d\sigma^{CC}/dQ^2$ for M_W: Fitting the shape. Sensitive only to the propagator of the weak current.

$$\boxed{M_W = 81.4^{+2.7}_{-2.6}\,(\text{stat})\,^{+2.0}_{-2.0}\,(\text{syst})\,^{+3.3}_{-3.0}\,(\text{pdf})\ \text{GeV}}$$

Preliminary

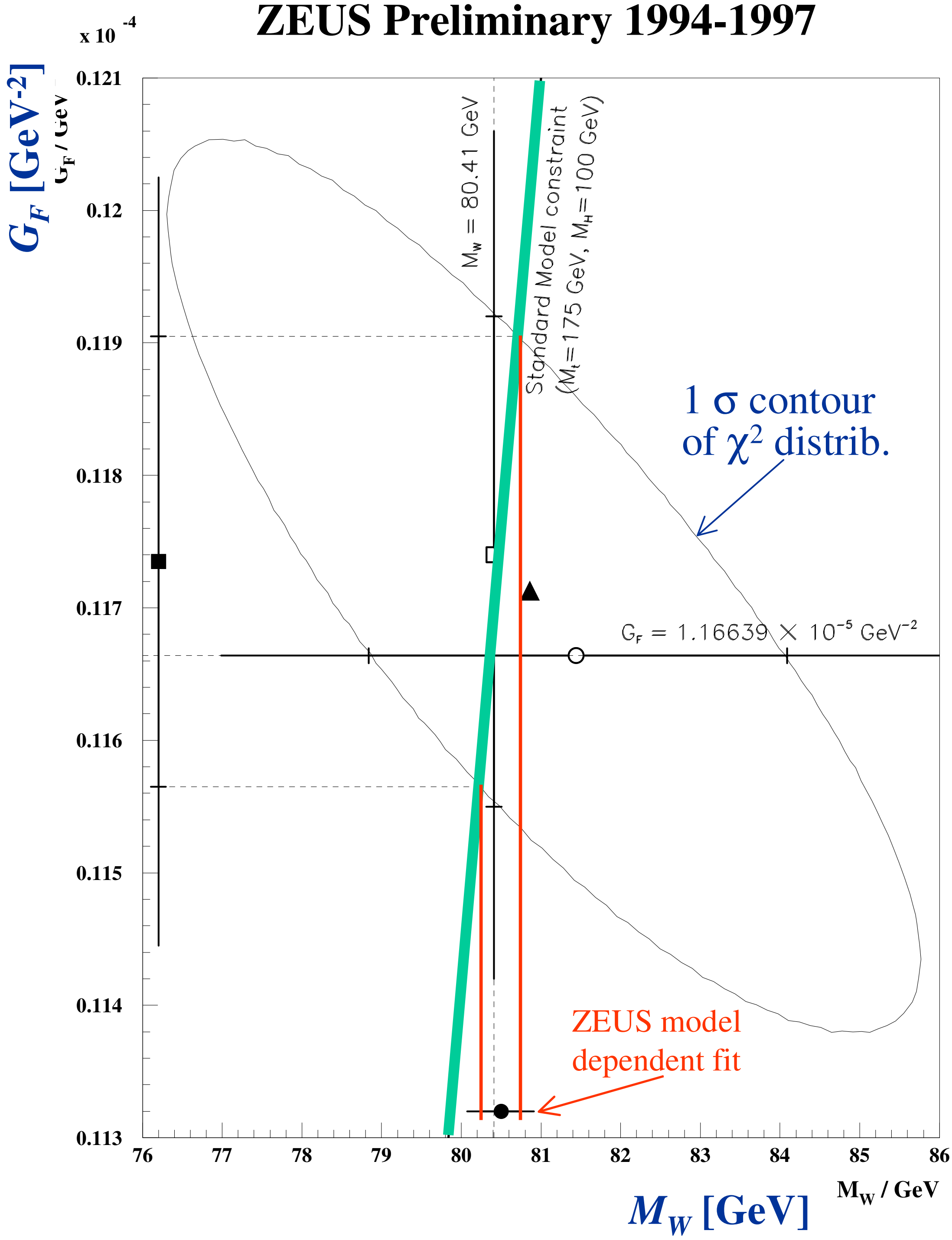
- Use Standard Model relation: $G_F = \frac{\pi\alpha}{\sqrt{2}} \frac{M_Z^2}{M_W^2(M_Z^2 - M_W^2)} \frac{1}{1-\Delta r(M_W)}$
  Exploiting correlation between shape and normalization in a model dependent fit. A sensitive electroweak consistency check!
  Extract M_W at M_H = 100 GeV, M_T = 175 GeV: see figure →

$$\boxed{M_W = 80.50^{+0.24}_{-0.25}\,(\text{stat})\,^{+0.13}_{-0.16}\,(\text{syst})\,^{+0.30}_{-0.31}\,(\text{pdf})\,^{+0.03}_{-0.03}\,(M_T)\,^{+0}_{-0.05}\,(M_H)\ \text{GeV}}$$

(PDG: M_W = 80.41 ± 0.10 GeV) *Preliminary*

Note: the last is not a measurement, but indicate the sensitivity of the CC cross section to M_W assuming the Standard Model.

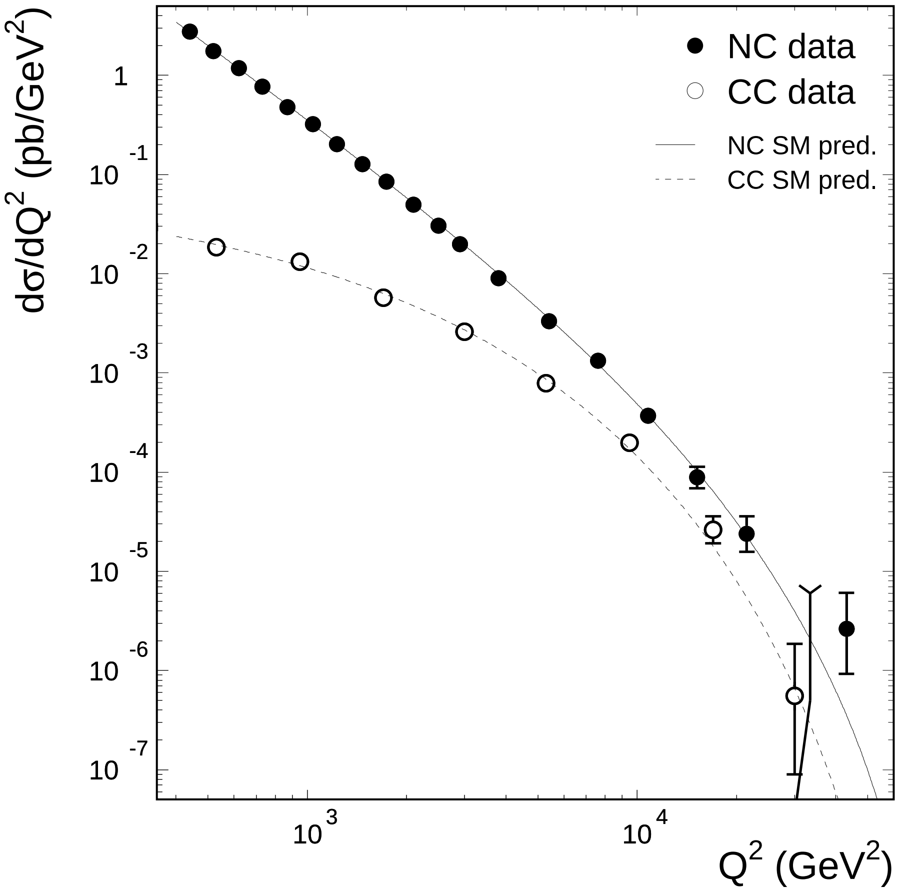
M_W from $d\sigma^{CC}/dQ^2$



G_F depends very strongly on M_W
$\Rightarrow$ sensitivity to M_W

NC and CC $d\sigma^{e^+p}/dQ^2$ cross sections

ZEUS preliminary e^+p 1994 - 1997

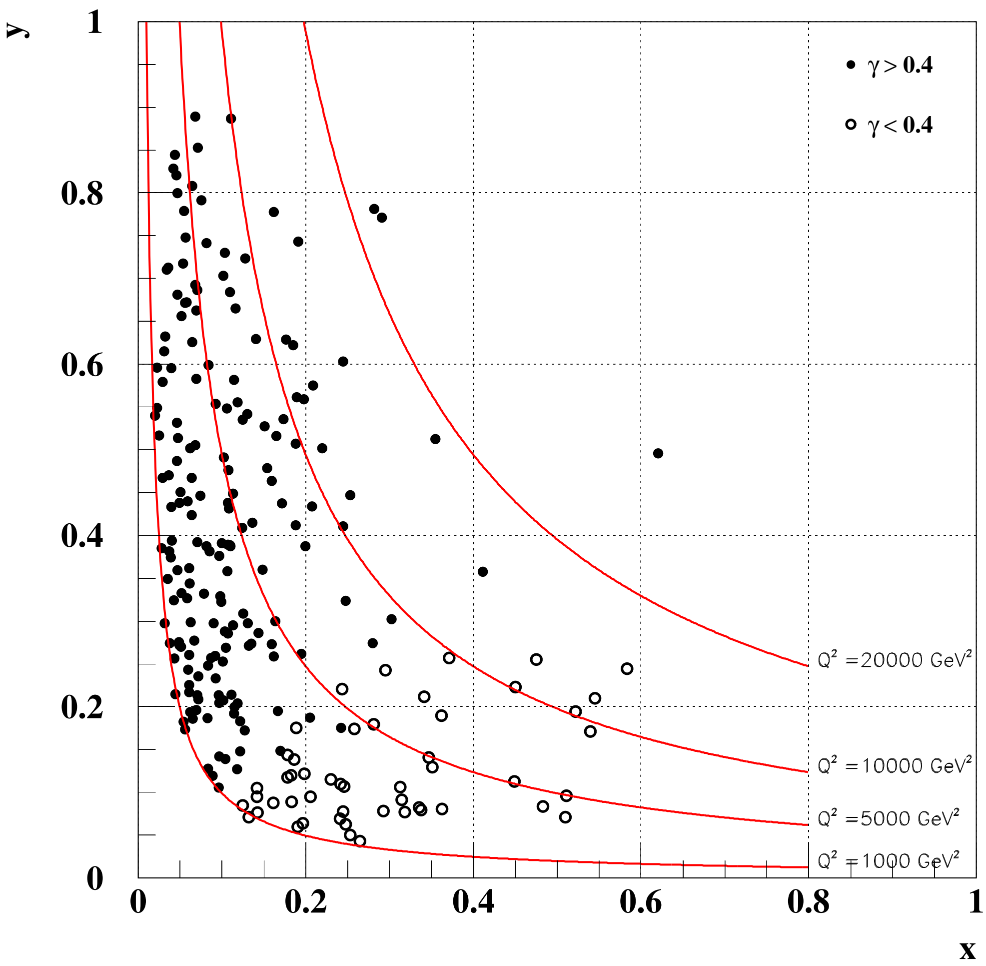


- CC approaching NC with increasing Q^2
- Cross sections measured for Q^2 up to 40000 GeV^2
- Good agreement with the SM predictions

$\mathbf{e^-p}$ CC preliminary results

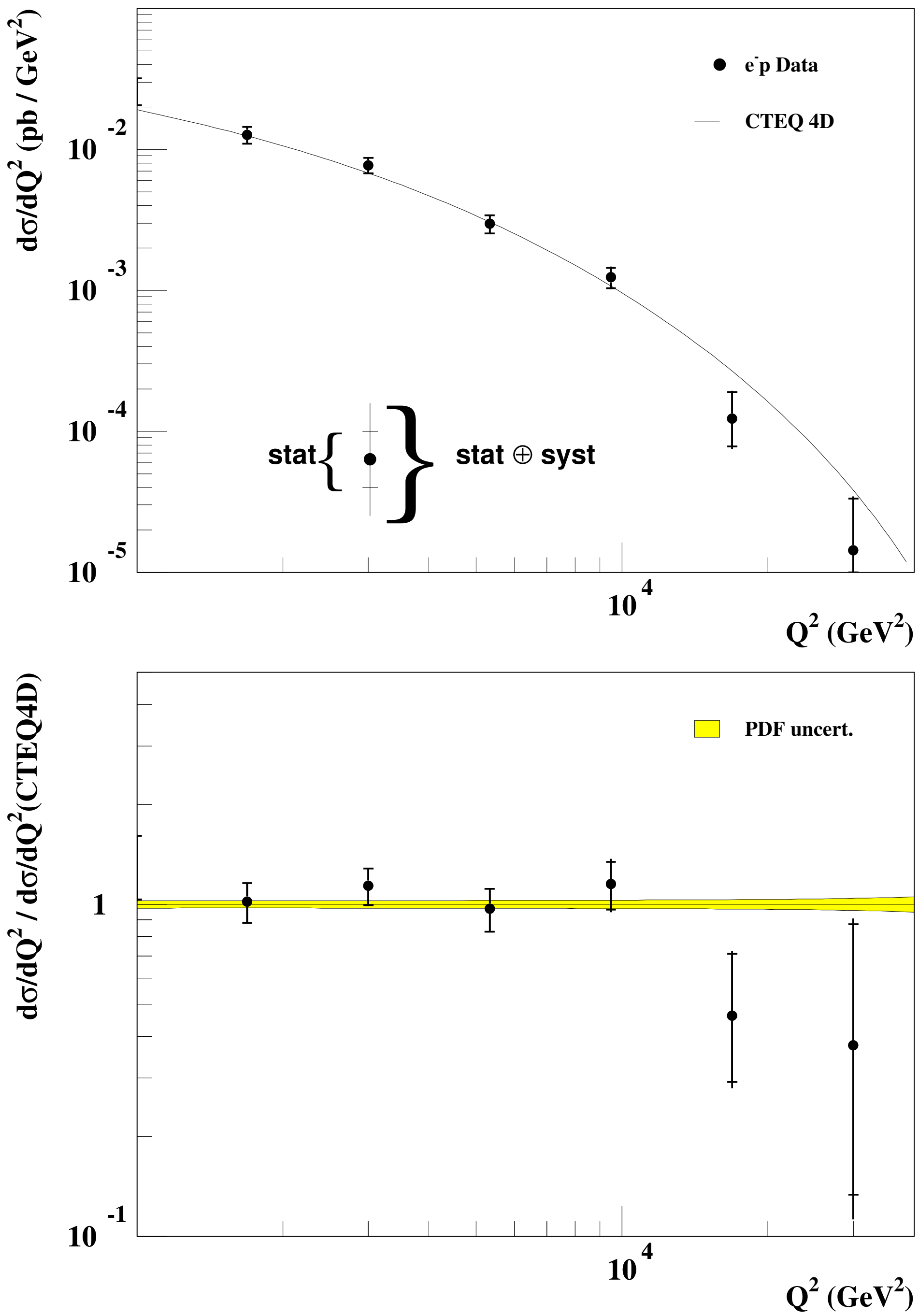
- The same selection as for e^+p
- Data luminosity: $6.3\ pb^{-1}$

$\rightarrow \quad + \quad \mathbf{Q^2 > 1000\ GeV^2}$



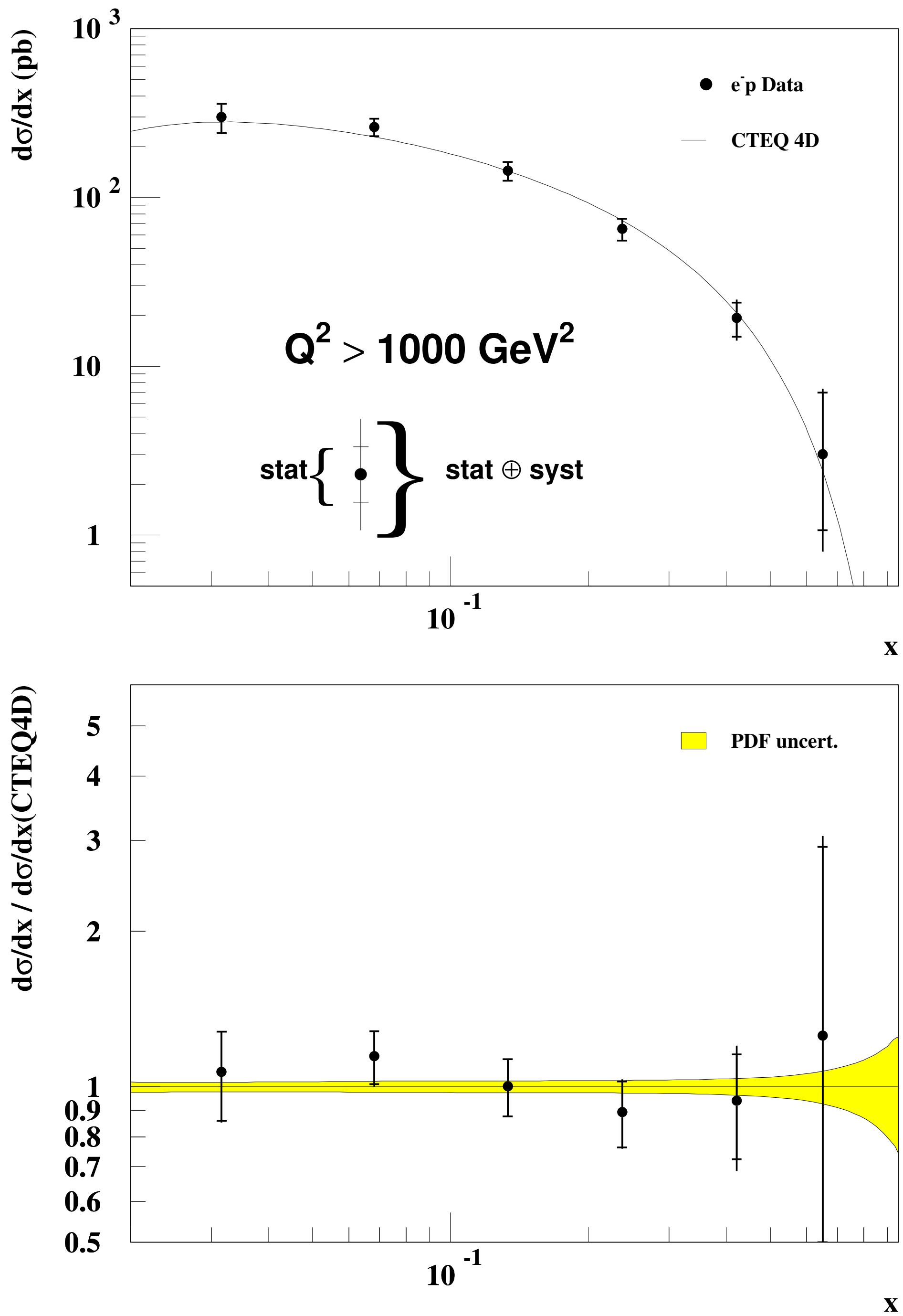
Differential CC cross section $d\sigma^{e^-p}/dQ^2$

ZEUS preliminary e^-p 1998 - 1999



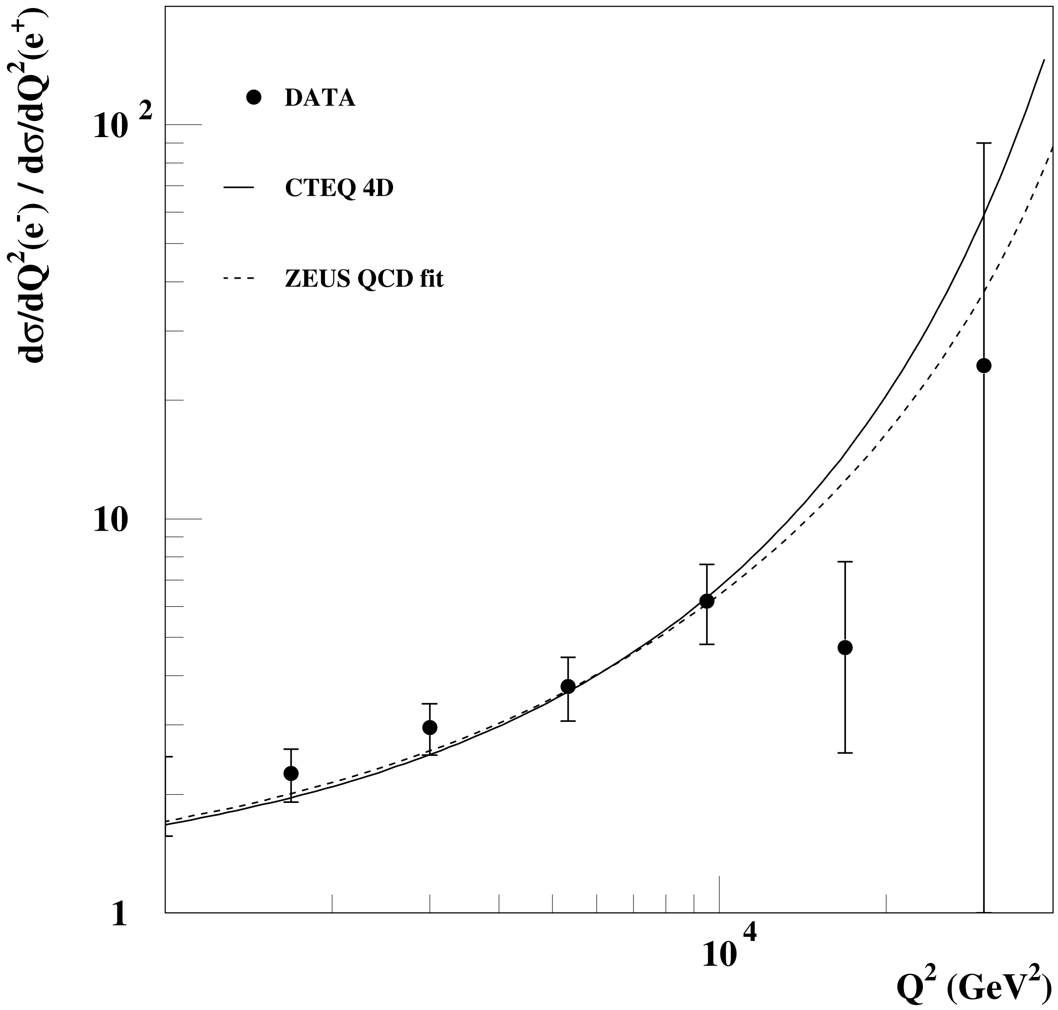
Differential CC cross section $d\sigma^{e^-p}/dx$

ZEUS preliminary e^-p 1998 - 1999



$\mathrm{d}\sigma/\mathrm{d}\mathbf{Q^2}$ $\mathbf{e^-/e^+}$ ratio

ZEUS preliminary



- $\mathbf{e^+p} \quad \longrightarrow \quad \sigma \sim (\mathbf{1-y})^2(\mathbf{d+s})$
- $\mathbf{e^-p} \quad \longrightarrow \quad \sigma \sim (\mathbf{u+c})$

Summary

- **Measurement:**
  - $d\sigma/d\mathbf{Q^2}$, $d\sigma/d\mathbf{x}$, $d\sigma/d\mathbf{y}$ ($\mathbf{e^+p}$ **NC, CC**)
  - $d^2\sigma/d\mathbf{x}\mathbf{Q^2}$ ($\mathbf{e^+p}$ **CC**)
  - **W mass in space-like region**
  - $d\sigma/d\mathbf{Q^2}$, $d\sigma/d\mathbf{x}$ (e^-p **CC**)
  - $d\sigma/d\mathbf{Q^2}$ $\mathbf{e^-/e^+}$ **ratio**
- $\longrightarrow$
  - **Good agreement with the SM**
  - **Evidence of Z boson exchange in the space-like region**
  - **ZEUS QCD fit describe data in high x region**
  - **No surprise in 98/99 $\mathbf{e^-p}$ data**

Outlook

- **More data**
- **Hera Upgrade 2000** $\rightarrow$ **150**pb^{-1}**/year**
- **longitudinal polarization**