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High Q^2 Charged and Neutral Current Results from HERA

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- **Introduction**
 - Hera, data, detectors.
- **Neutral Current**
 - Cross sections.
 - Effect of Z exchange.
- **Charged Current**
 - Cross sections.
 - M_w measurement.
- **Conclusions.**

Introduction

- The Electron-Proton Collider - HERA:

HERA

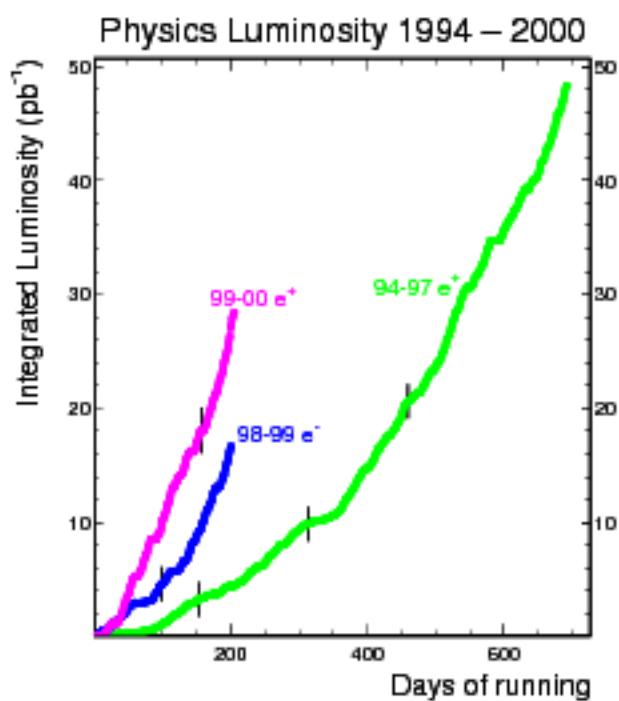
98-99



94-97



Luminosity /pb ⁻¹	
H1	ZEUS
e ⁺ p	35.6
e ⁻ p	15.3



Plus 30pb⁻¹ e⁺p at 920GeV so far.

Deep Inelastic Scattering

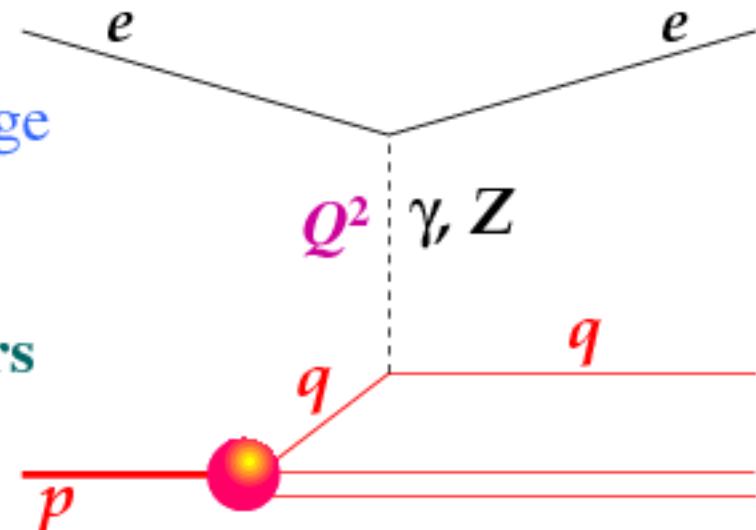
Deep Inelastic Scattering Processes:

Neutral Current

Photon/Z exchange

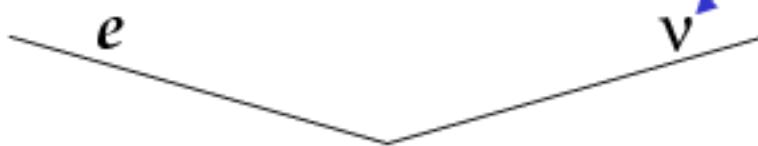
$e^\pm p$: All flavours contribute

Scattered lepton



Charged Current

`invisible' \Rightarrow Missing P_T

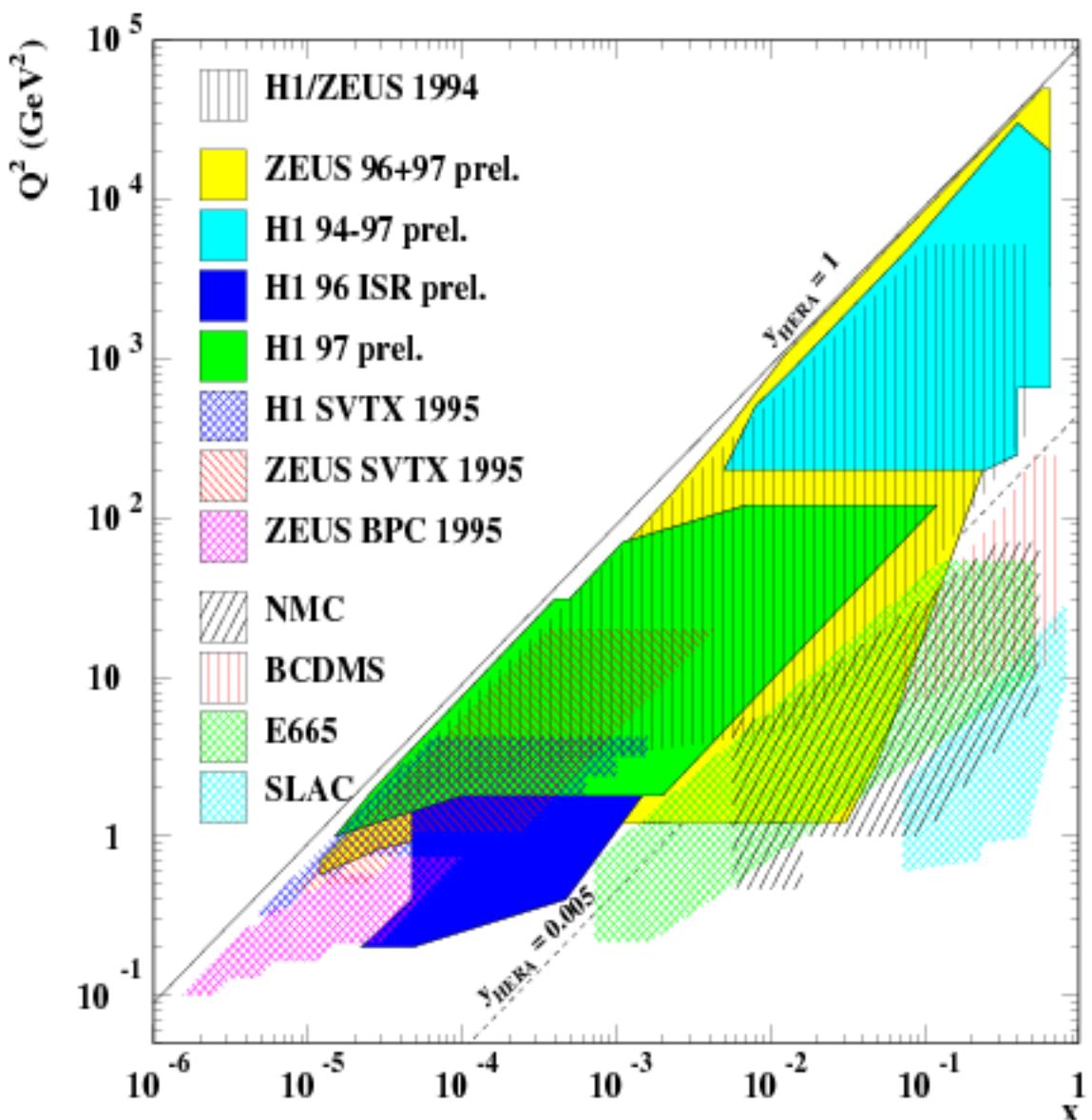


W exchange

$e^+ p$: d, s and \bar{u}, \bar{c}

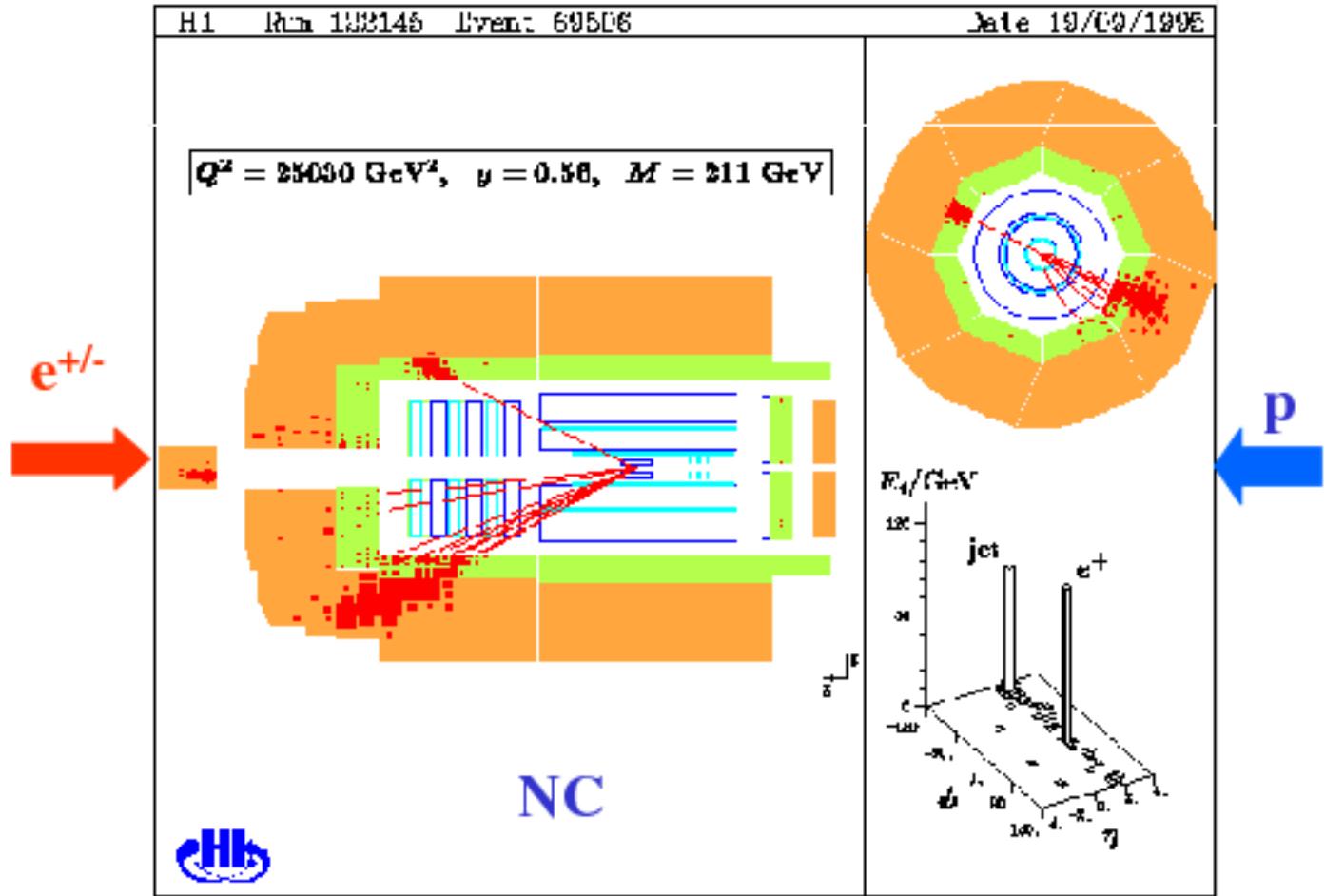
$e^- p$: u, c and \bar{d}, \bar{s}

The HERA Kinematic Plane



- High Q^2 , high x DIS possible with 94-97 data.
- Now also with e⁻p.

Introduction



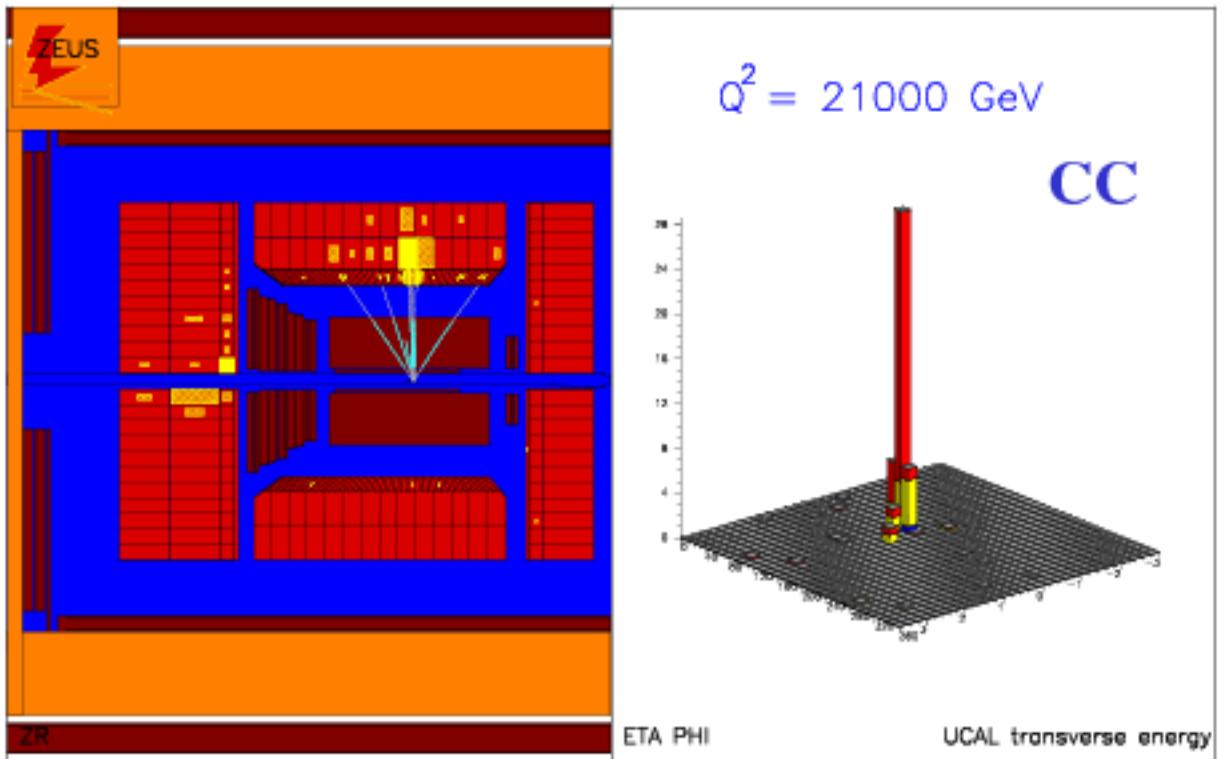
Liquid Argon Calorimeter

EM section $\sigma(E)/E = 12\%/\sqrt{E} \oplus 1\%$

Syst.Unc. :1-3%

HAD section $\sigma(E)/E = 50\%/\sqrt{E} \oplus 1\%$

Syst.Unc. :3-4%



Uranium-Scintillator Calorimeter

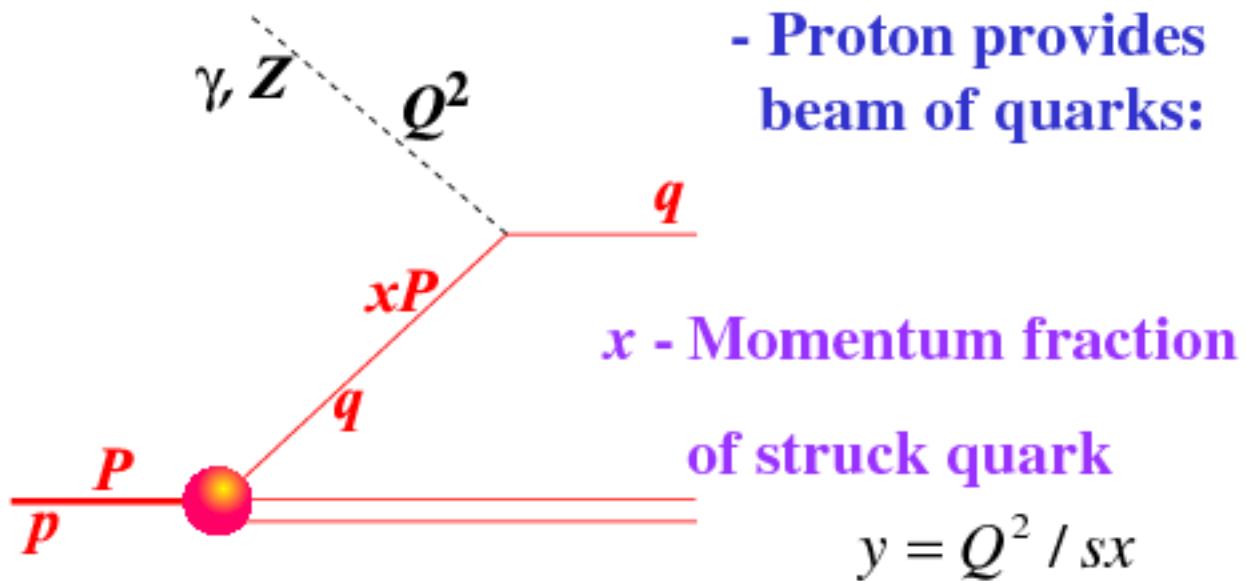
EM section $\sigma(E)/E = 18\%/\sqrt{E}$

Syst.Unc. :1-2%

HAD section $\sigma(E)/E = 35\%/\sqrt{E}$

Syst.Unc. :3%

Neutral Current DIS



$$\frac{d^2\sigma_{Born}^{NC}(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} [Y_+ F_2^{NC}(x, Q^2) \mp Y_- x F_3^{NC}(x, Q^2) - y^2 F_L^{NC}(x, Q^2)]$$

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

Contain PDF's and EW parameters $M_Z, \sin^2\theta_W, \dots$

$y^2 F_L$ is small.

$x F_3 \propto \sigma^{e^+ p} - \sigma^{e^- p}$

Reduced cross

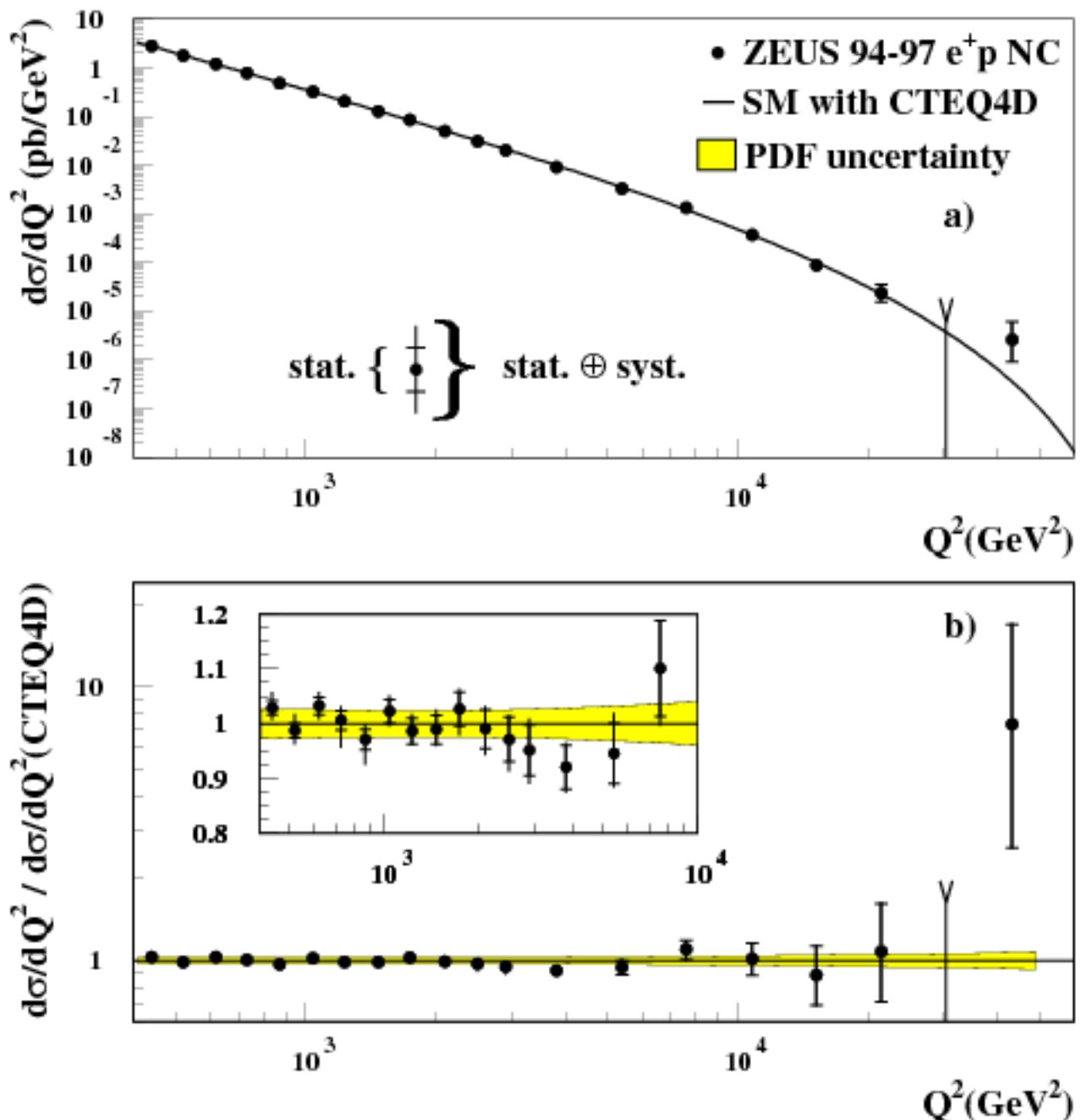
section: $\tilde{\sigma}_{NC}(x, Q^2) = \frac{xQ^4}{2\pi\alpha^2} \frac{1}{Y_+} \frac{d^2\sigma_{NC}}{dxdQ^2}$

$$= F_2^{em}(x, Q^2)(1 + \Delta F_2 + \Delta F_3 + \Delta F_L)$$

$\gamma Z, Z$ exchange.

ZEUS positron data:

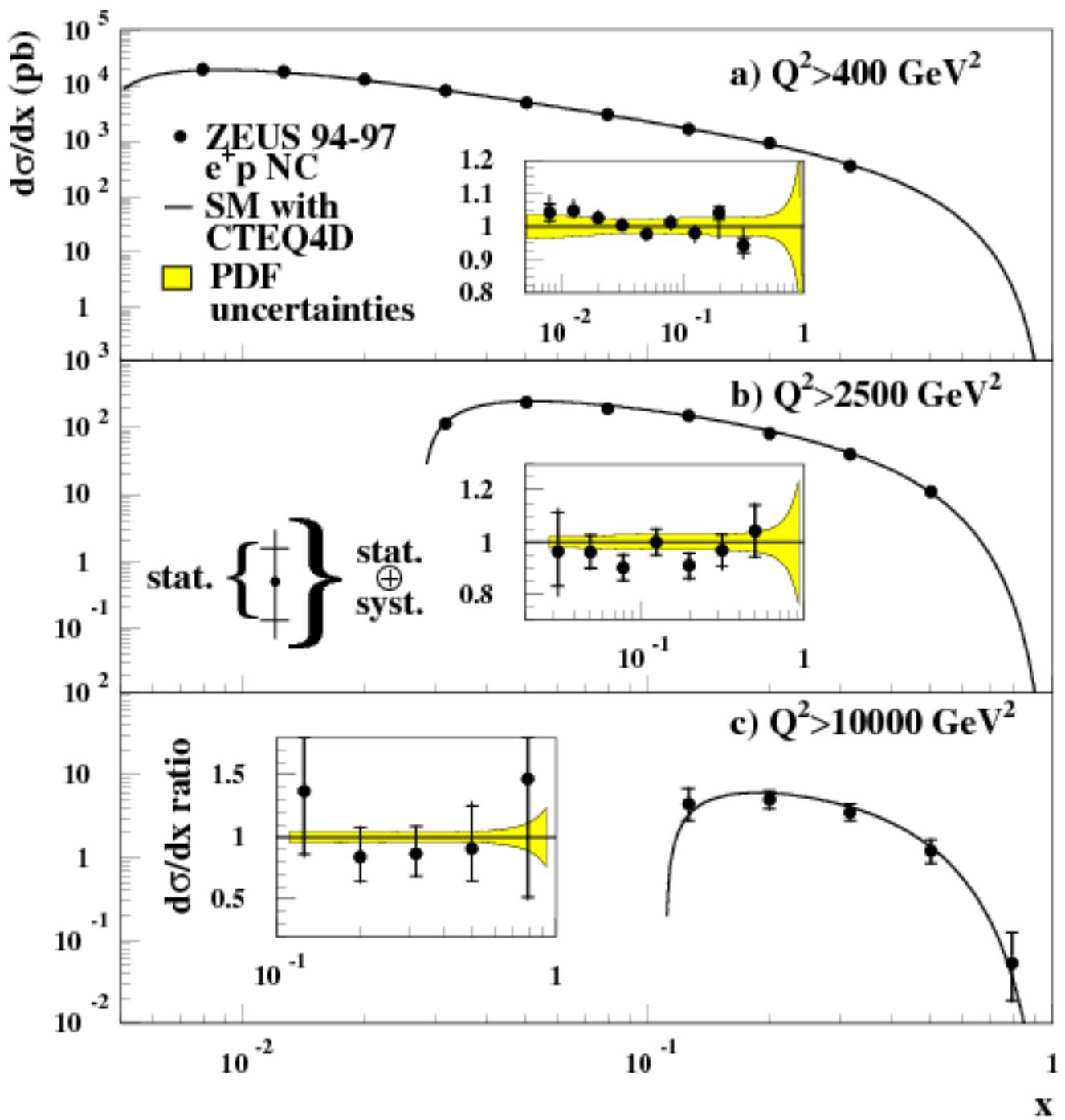
ZEUS NC 1994 – 97



- **Agreement over 6 orders of magnitude.**

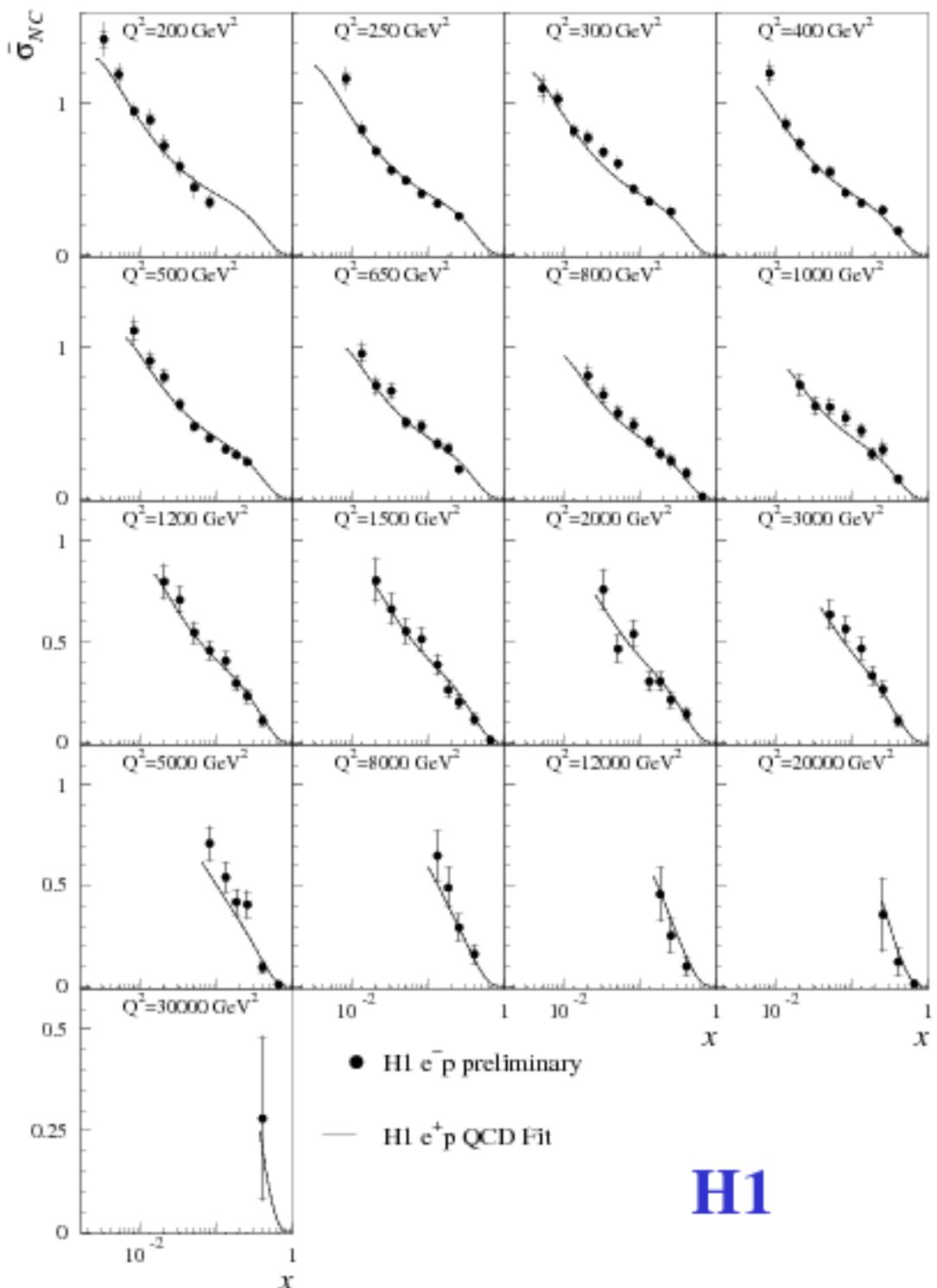
ZEUS positron data:

ZEUS NC 1994 – 97

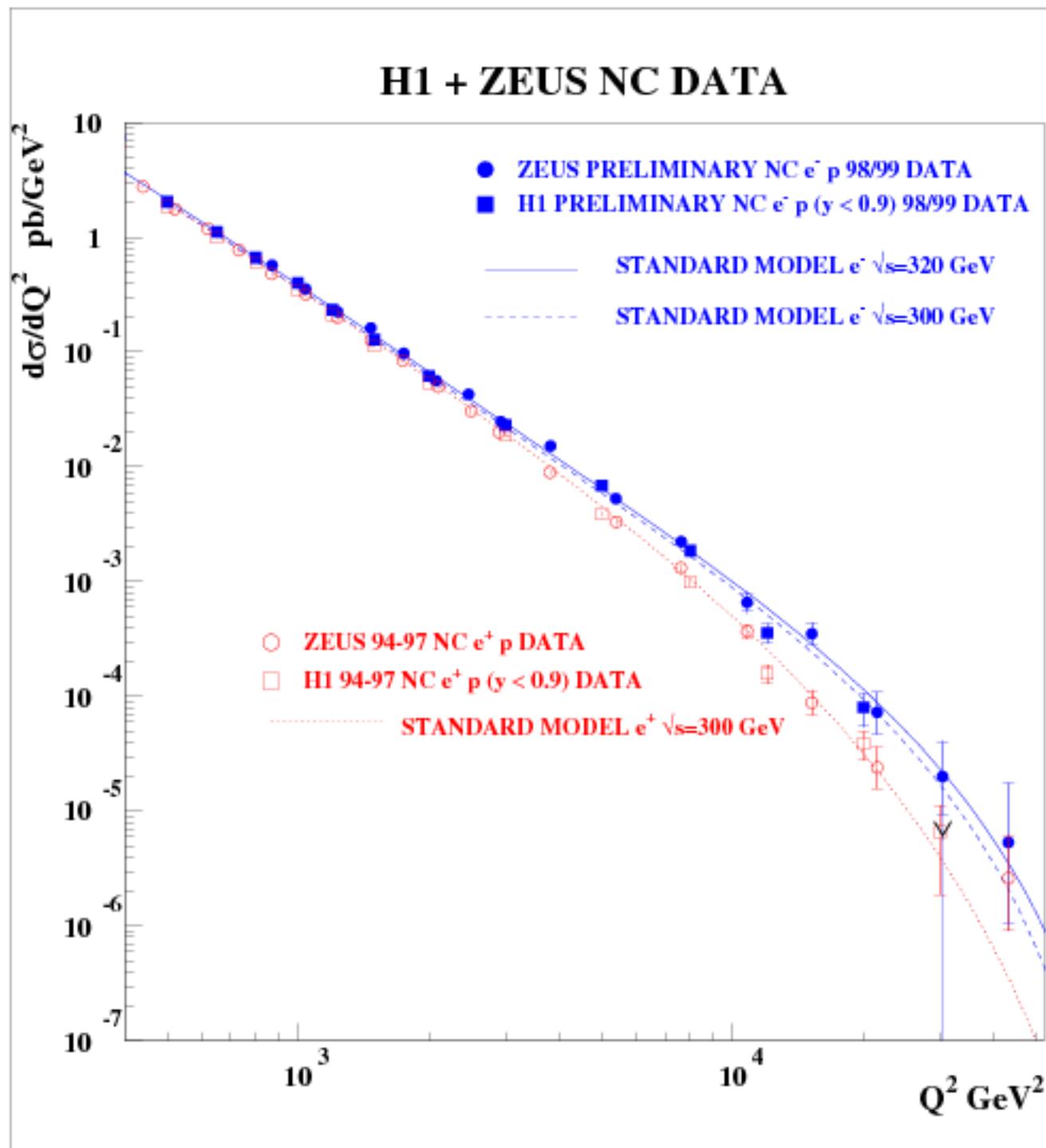


- High Q^2 dominated by valence quarks
- Small errors allow pdf determination.

Neutral Current DIS



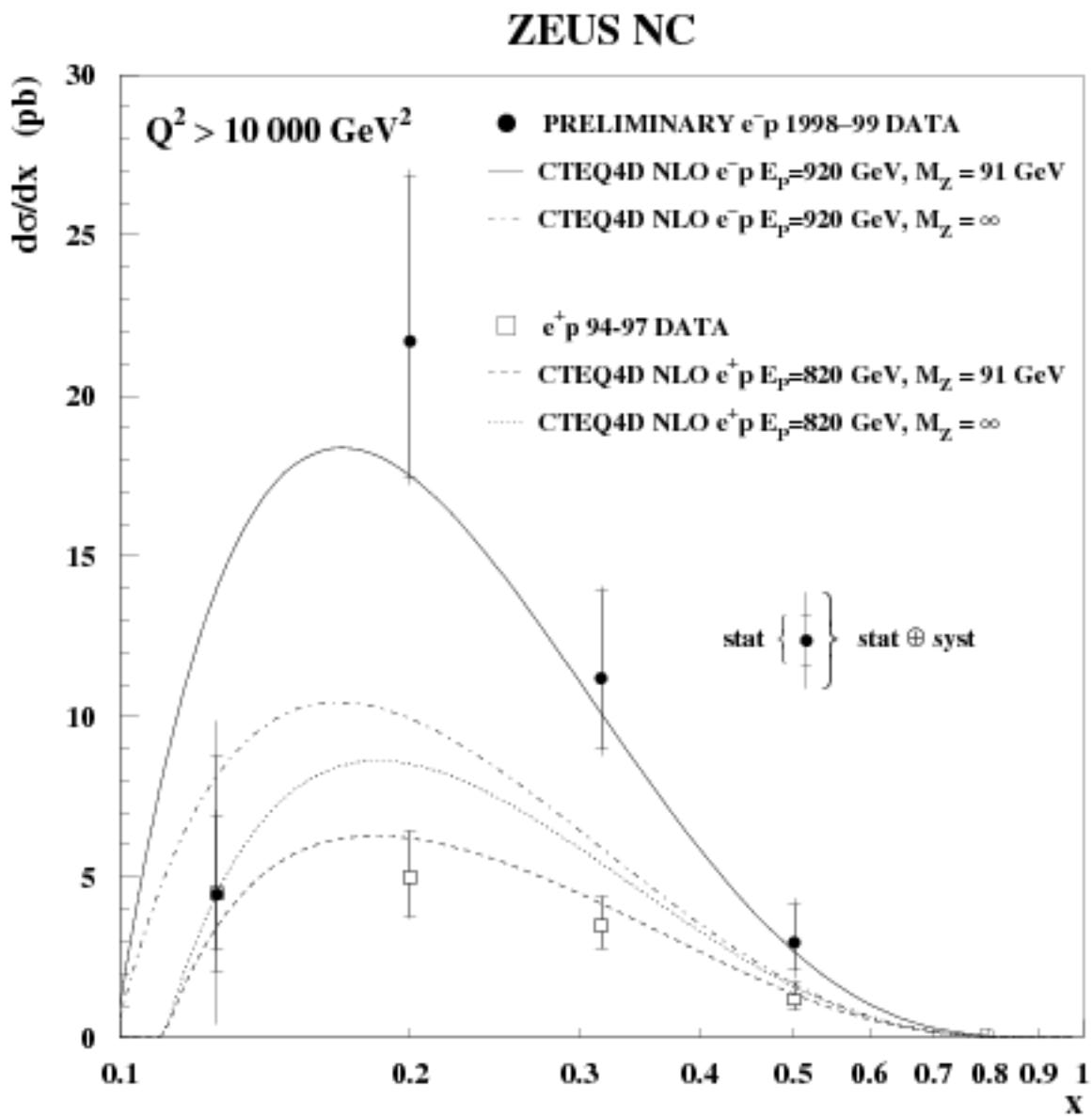
- H1 QCD fit to e^+ data.
- Gives good description of $e^- p$ data



Enhancement of $e^- p$ over $e^+ p$

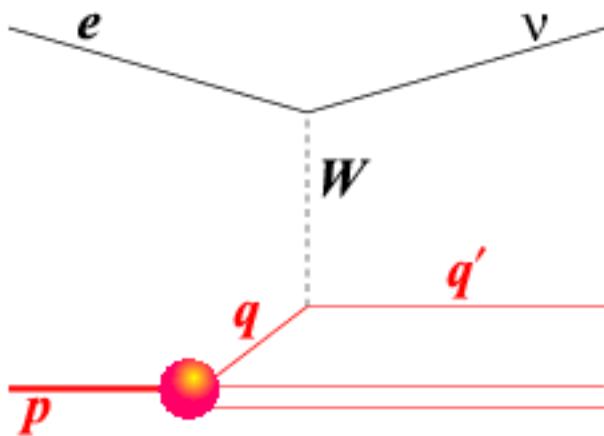
- Effect of Z exchange:

$$\frac{d\sigma_{NC}^+}{dQ^2} \propto \left[\eta_\gamma^+ \frac{1}{Q^2} + \eta_Z^+ \frac{1}{Q^2 + M_Z^2} \right]^2$$



$e^- P$ data require *CONSTRUCTIVE γZ* interference ($e^+ P$ *DESTRUCTIVE*)

Charged Current DIS



$$\frac{d\sigma_{CC}}{dQ^2} \propto G_\mu^2 \left[\frac{M_W^2}{Q^2 + M_W^2} \right]^2$$

Leading order cross section:-

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

Sensitive to
quark
flavours.

Valence d probed.

d/u ratio

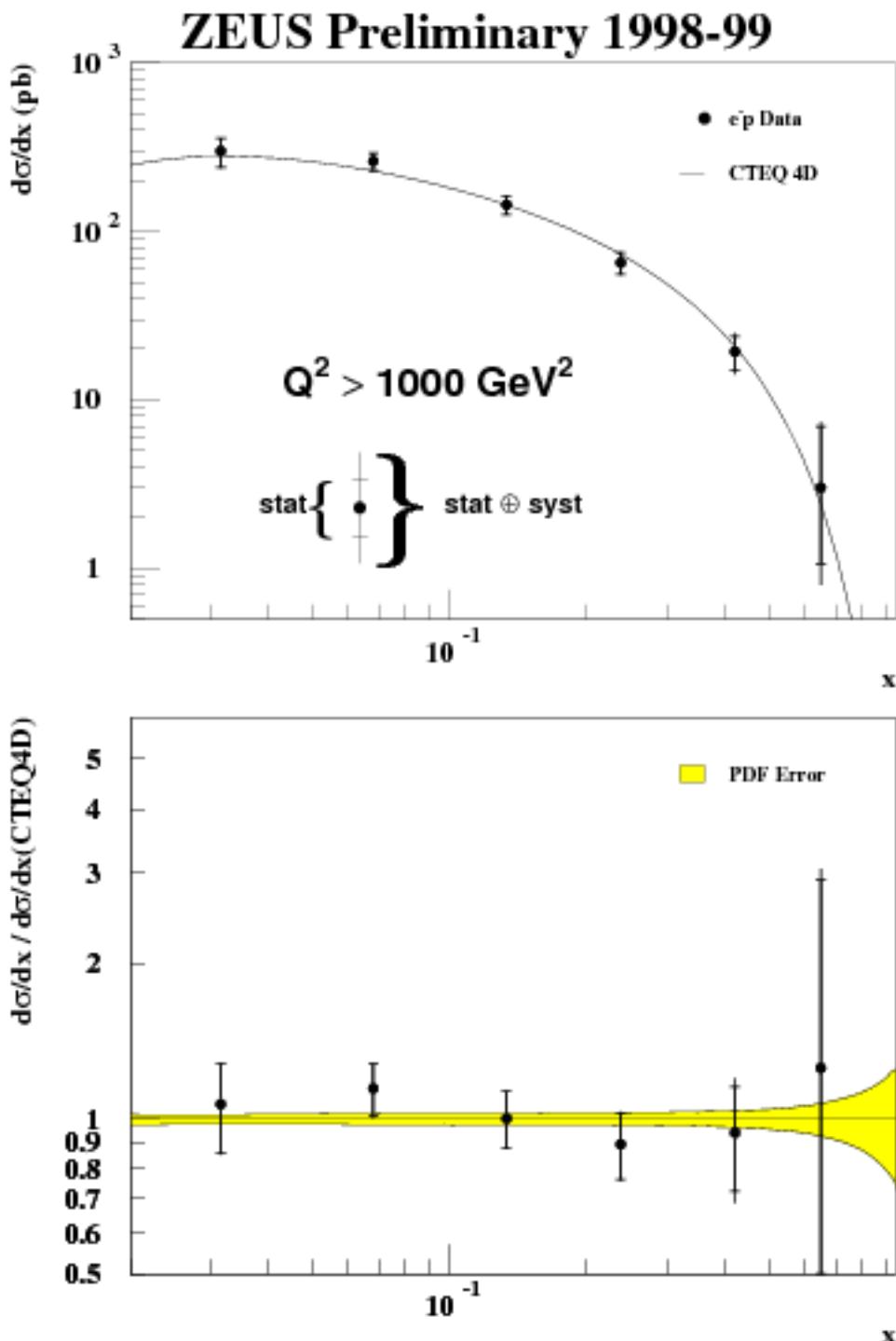
u unsuppressed

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

And the reduced cross section:-

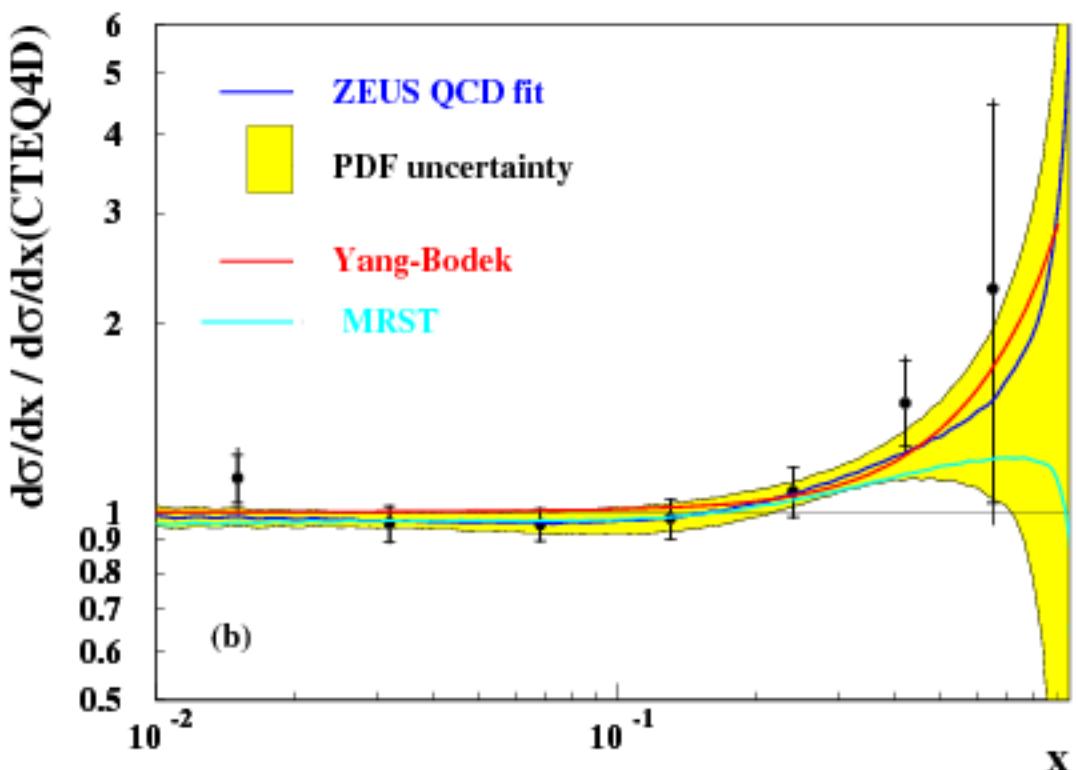
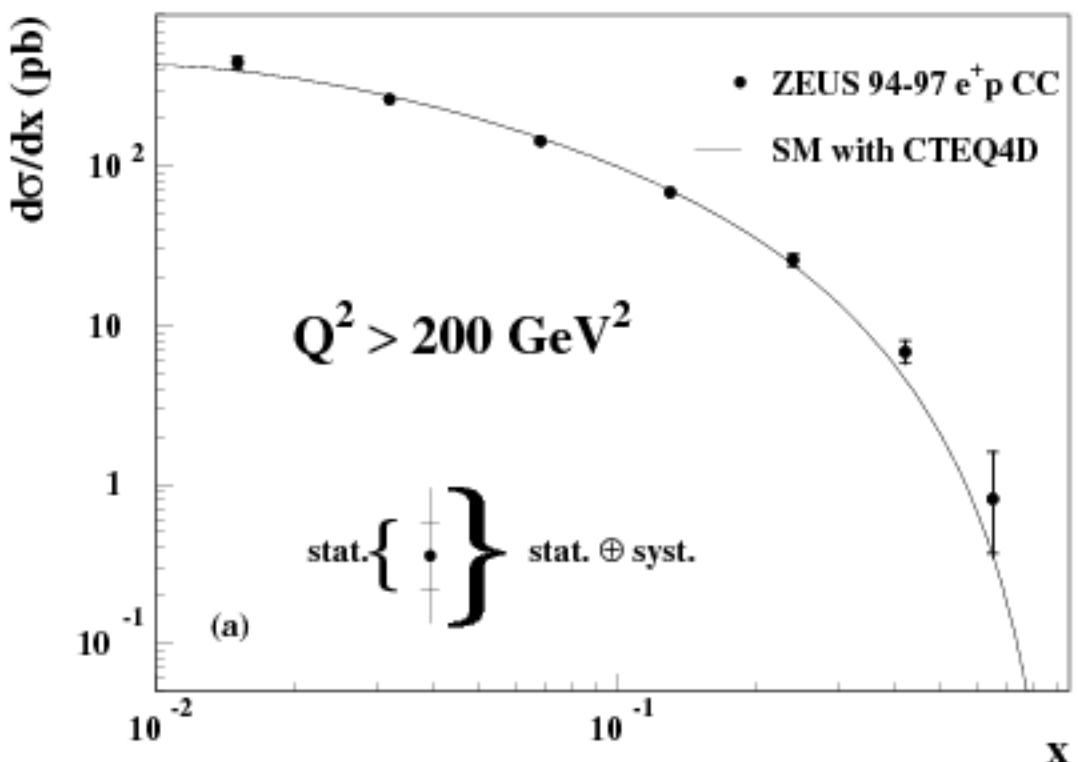
$$\tilde{\sigma}_{CC}(x, Q^2) \equiv \frac{2\pi x}{G_F^2} \left(\frac{M_W^2 + Q^2}{M_W^2} \right)^2 \frac{d^2\sigma_{CC}}{dx dQ^2}$$

Charged Current DIS



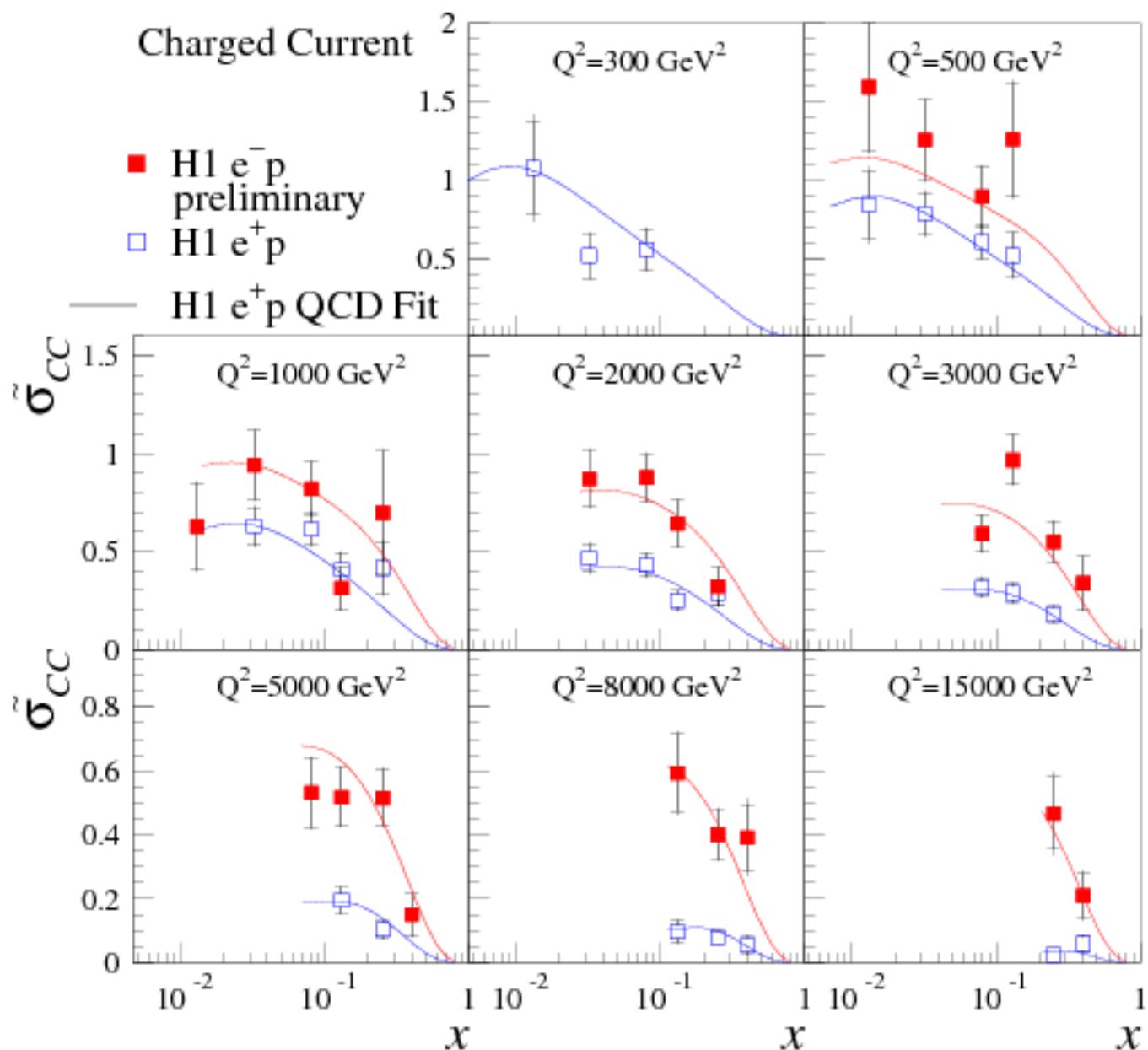
Small pdf error: u well measured, c.f. d in e+p CC.

ZEUS CC 1994-97



More d at high x.

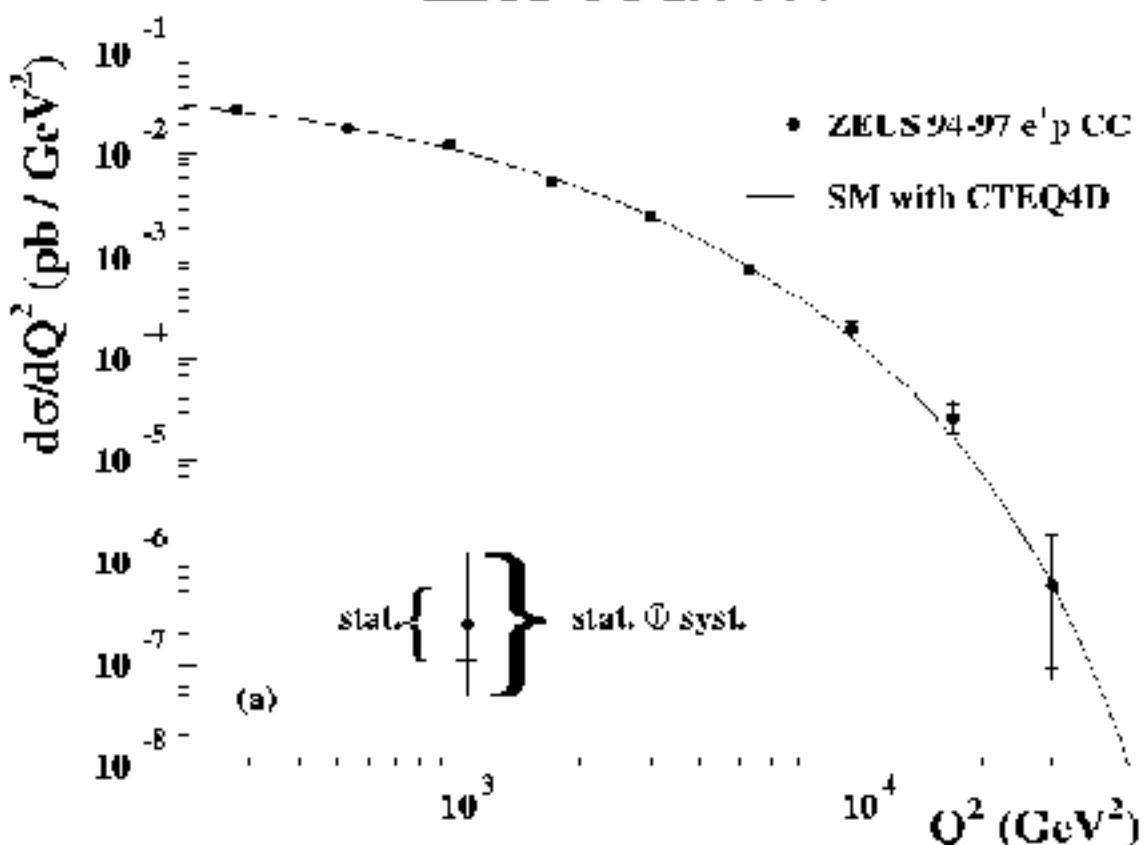
Charged Current DIS



$e^- p$ $\frac{d^2\sigma_{CC}}{dx dQ^2} \propto x [(u + c) + (1 - y)^2 (\bar{d} + \bar{s})]$

$e^+ p$ $\frac{d^2\sigma_{CC}}{dx dQ^2} \propto x [(\bar{u} + \bar{c}) + (1 - y)^2 (d + s)]$

ZEUS CC 1994-97



$$\frac{d\sigma_{CC}}{dQ^2} \propto G_\mu^2 \left[\frac{M_W^2}{Q^2 + M_W^2} \right]^2$$

Fix G_μ : Fit just the shape for $M_W \Rightarrow$

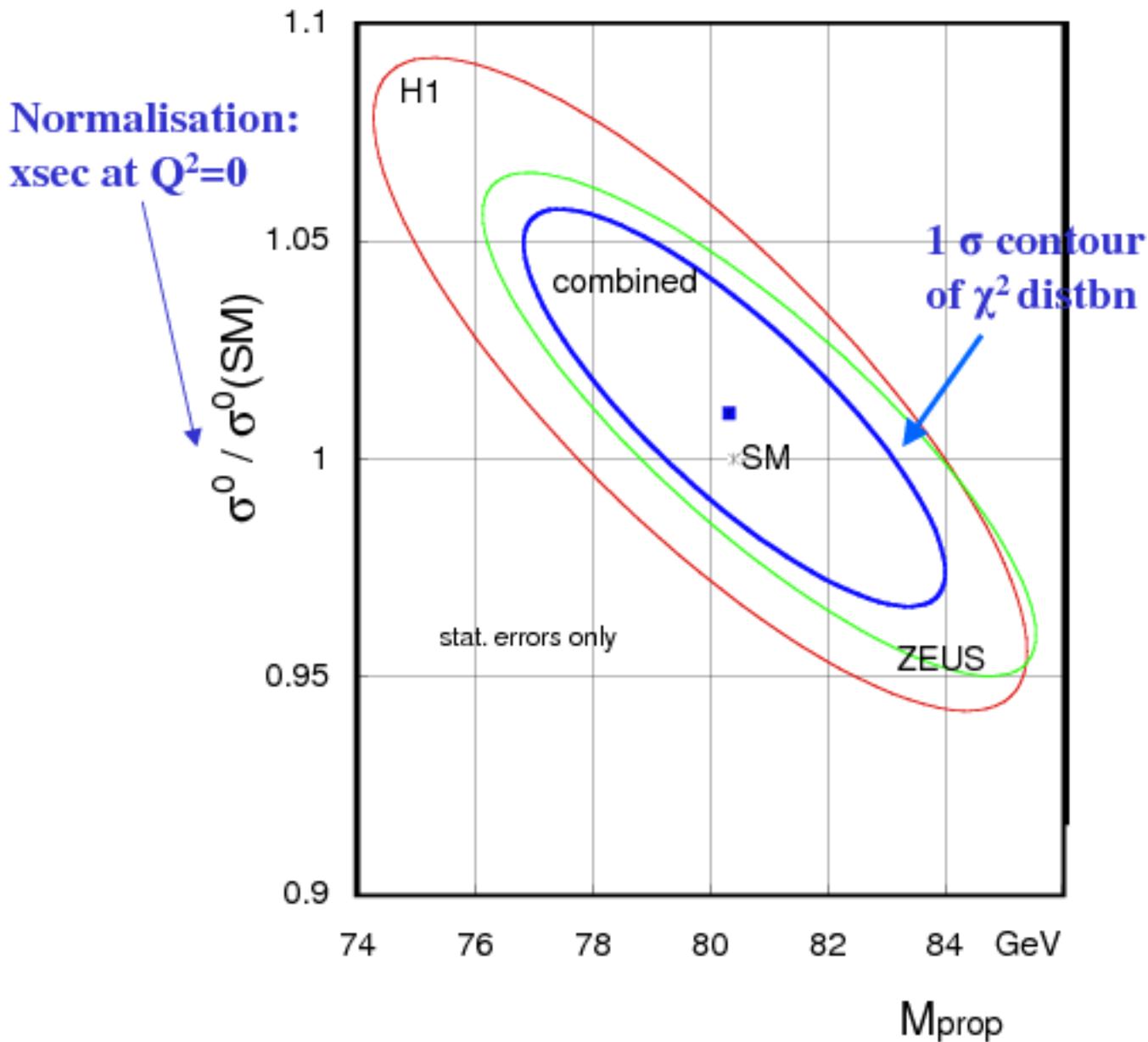
Direct M_W measurement in **SPACE-LIKE** region

Zeus : $M_W = 81.4^{+2.7}_{-2.6}$ (stat.) ± 2.0 (syst.) $^{+3.3}_{-3.0}$ (PDF) GeV.

H1 : $M_W = 80.9 \pm 3.3$ (stat.) ± 1.7 (syst.) ± 3.7 (theo.) GeV.

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

Charged Current DIS



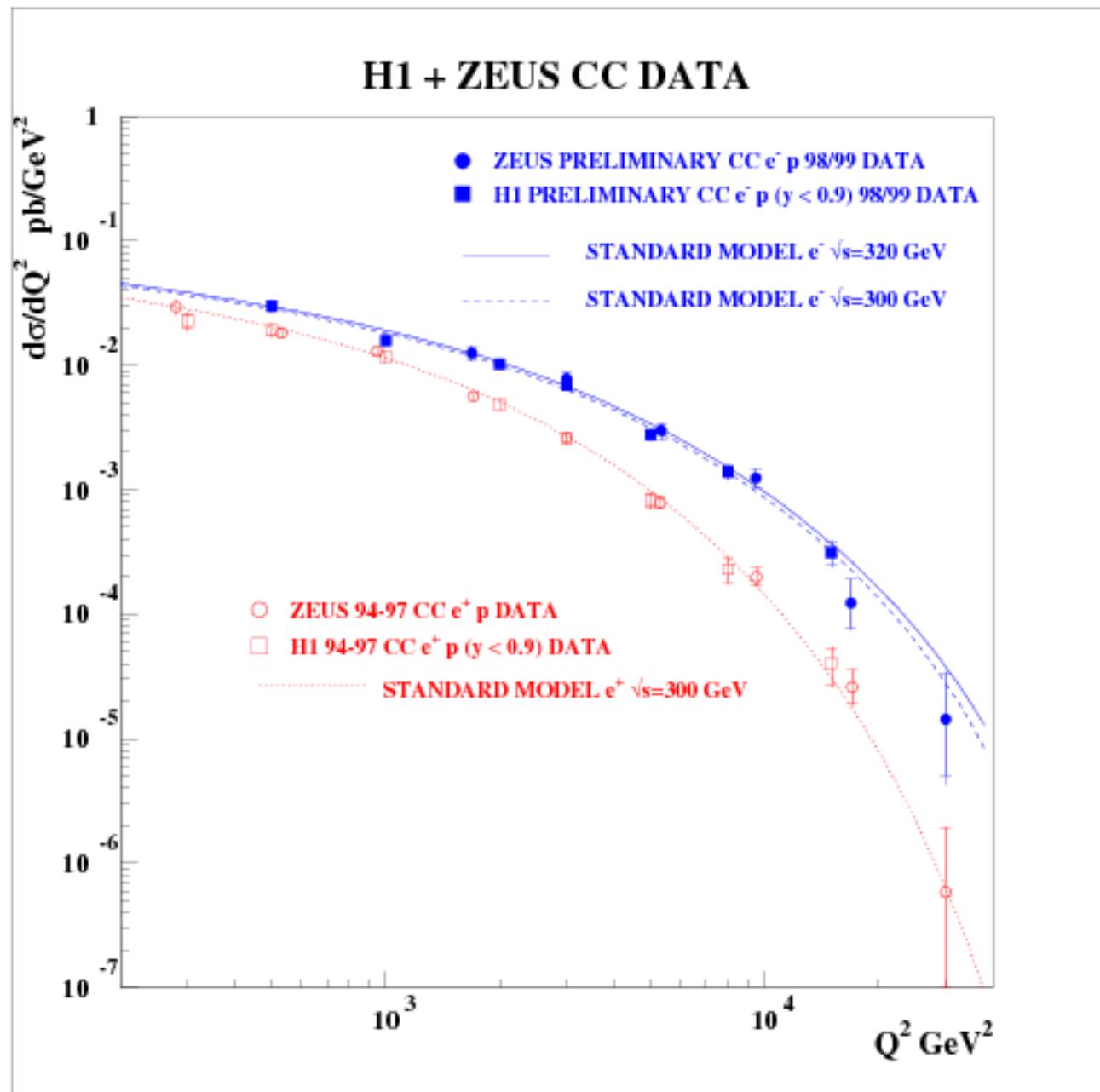
Use $G_\mu = \frac{\pi\alpha}{\sqrt{2}} \frac{M_Z^2}{M_W^2(M_Z^2 - M_W^2)} \frac{1}{1 - \Delta r(M_W)}$

ZEUS

$$M_W = 80.50^{+0.24}_{-0.25} (\text{stat.})^{+0.13}_{-0.16} (\text{syst.}) \pm 0.31 (\text{PDF})^{+0.03}_{-0.06} (\Delta M_1, \Delta M_H, \Delta M_Z) \text{ GeV}$$

August-99 world average: $M_W = 80.376 \pm 0.039 \text{ GeV}$

N.B. Not a measurement: EW consistency check.



- Strong enhancement of e^-p vs e^+p
- e^+p : d quark contribution suppressed by $(1-y)^2$
- e^-p : valence u, no suppression.

Neutral Current at High Q^2 Summary

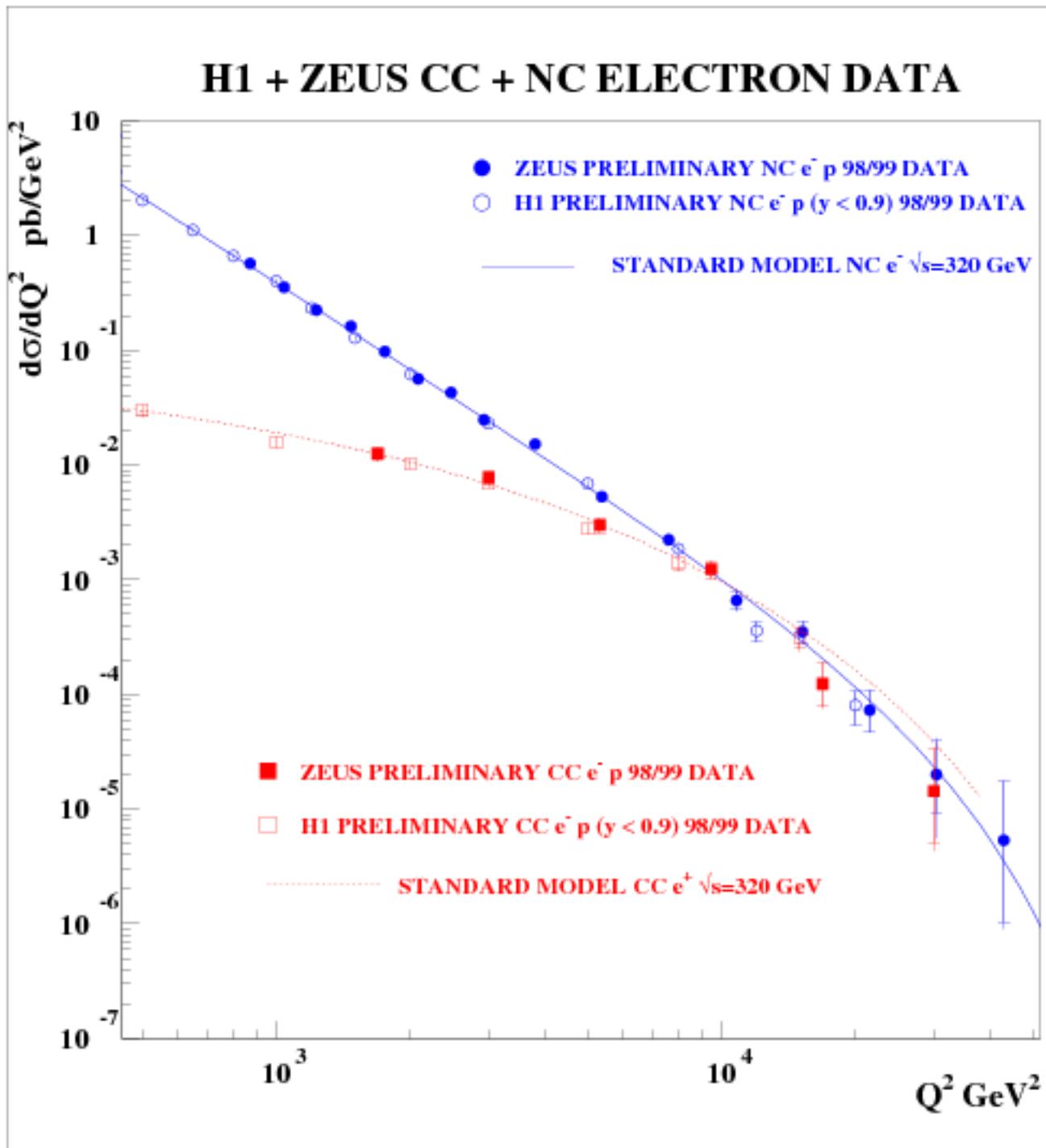
- **Wealth of data has allowed $d\sigma/dQ^2(e^+P)$ to be extracted over 6 orders of magnitude**
- **Good agreement between measured cross sections and Standard Model is observed up to $Q^2 \approx 20,000$ to 30,000 GeV 2**
- **First measurements of $d\sigma/dQ^2(e^-P)$ and $d\sigma/dxdQ^2(e^-P)$ at high Q^2**
 - Good agreement with Standard Model
 - $d\sigma/dQ^2(e^-P) > d\sigma/dQ^2(e^+P)$ at high Q^2
 - Effect of γZ interference observed

Charged Current at High Q^2 Summary

- $d\sigma/dQ^2(e^+P)$ extracted over 4 orders of magnitude
- Good agreement between measured cross sections and Standard Model is observed up to $Q^2 \approx 30,000 \text{ GeV}^2$
- Time-like determination of M_W consistent with direct measurement of M_W .
- SM consistency test performed.
- First measurements of e^-P cross sections at high Q^2 : good agreement with Standard Model observed
- $d\sigma/dxdQ^2(e^{+/l}P)$ measured at high Q^2 : sensitive to d/u -quark densities

Outlook

- 20 pb⁻¹ more e⁻p data.
- xF₃ from NC
- QCD fits, d/u ratio.



HERA upgrade

High Luminosity and Polarisation:

170 pb⁻¹/year per experiment.

⇒ **Through NC:**

Study connection between helicity structure of SM and parity violation in NC

Light quark couplings to Z

⇒ **Through CC:**

Study of origin of parity violation in the weak charged current

Reduced error on M_w measurement.

Exciting future for high-Q² physics at HERA.