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High Q^2 Charged and Neutral Current Results from HERA

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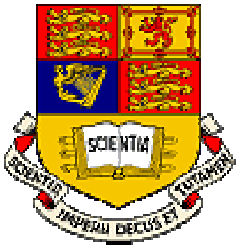

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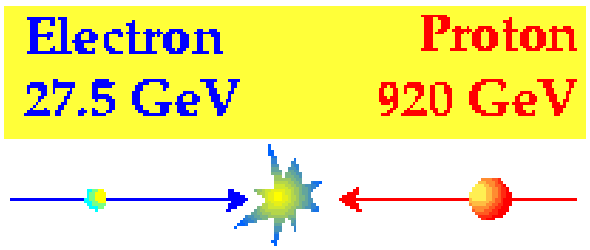
Introduction

- The Electron-Proton Collider - HERA:

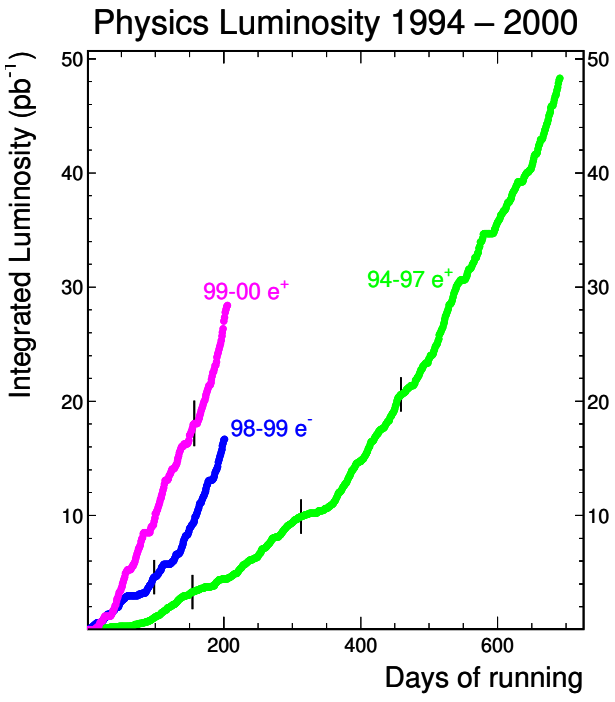
HERA

98-99



94-97

	Luminosity /pb^{-1}	
	H1	ZEUS
e^+p	35.6	47.7
e^-p	15.3	16.0



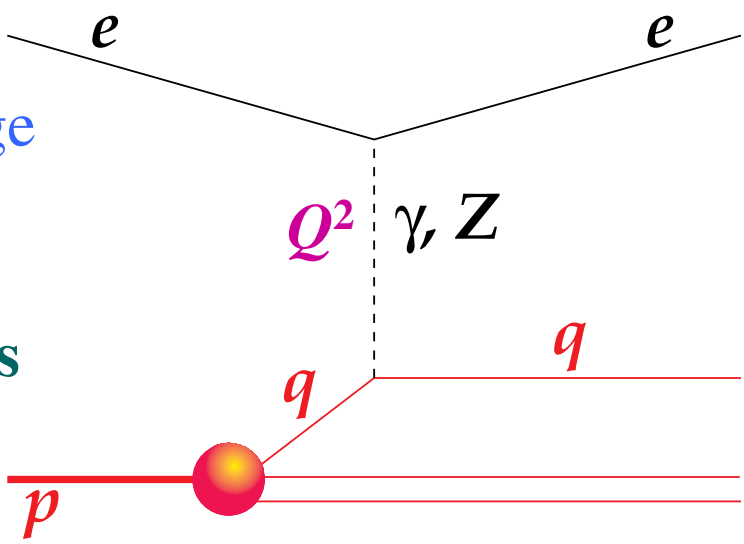
Plus 30pb^{-1} e$^+$p at 920GeV so far.

Deep Inelastic Scattering Processes:

Neutral Current

Scattered lepton

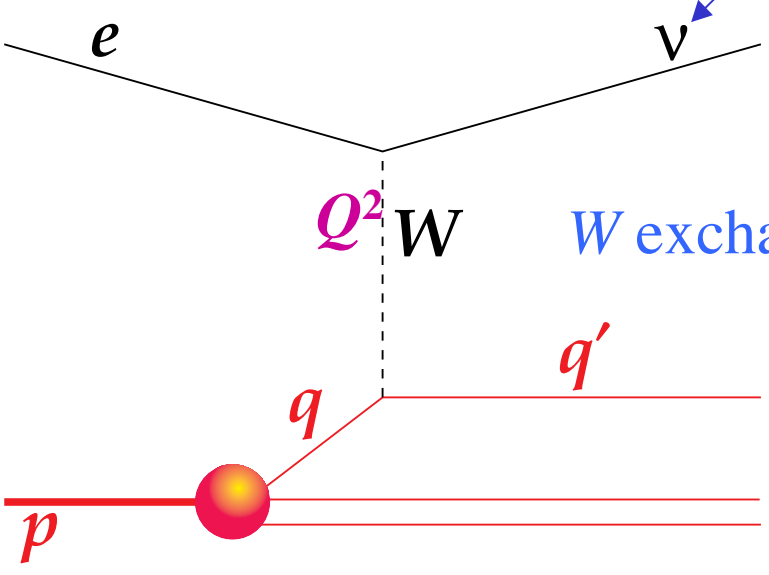
Photon/*Z* exchange



$e^{\pm}p$: All flavours contribute

Charged Current

`invisible`⇒Missing P_T

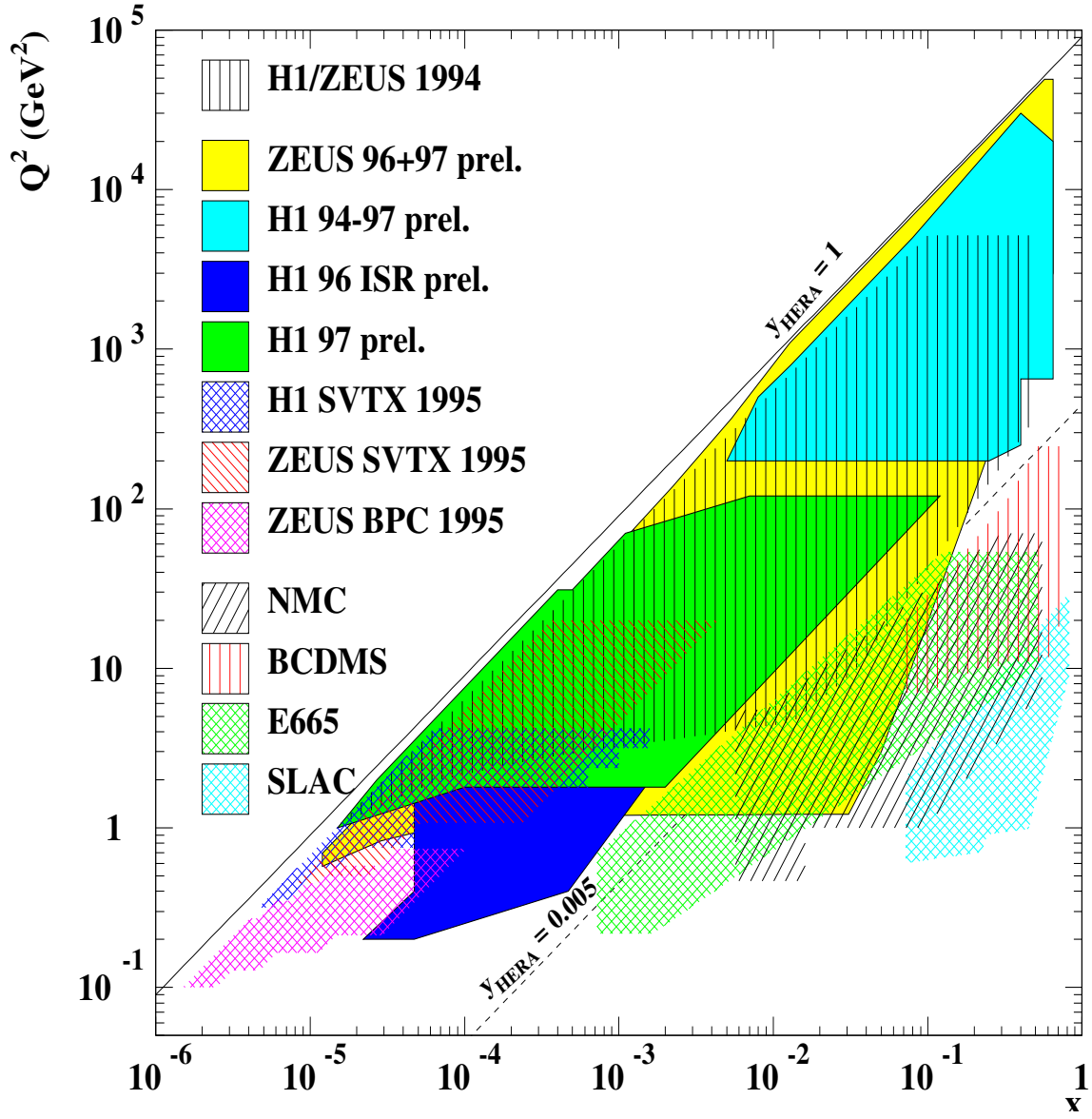


W exchange

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

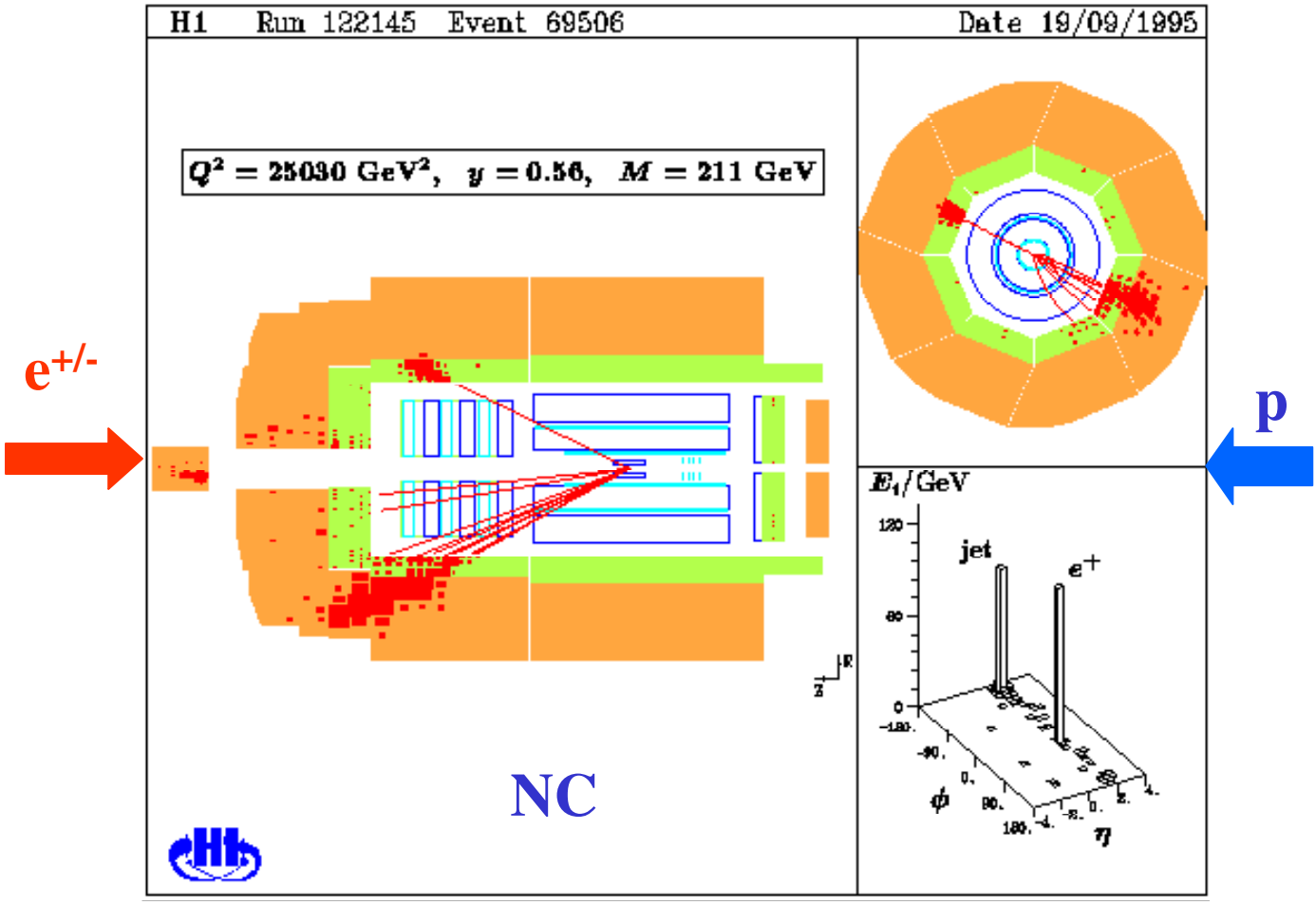
$e^{-}p$: *u*, *c* and $\bar{d}$, $\bar{s}$

The HERA Kinematic Plane



- **High Q2, high x DIS possible with 94-97 data.**
- **Now also with e^-p.**

Introduction



Liquid Argon Calorimeter

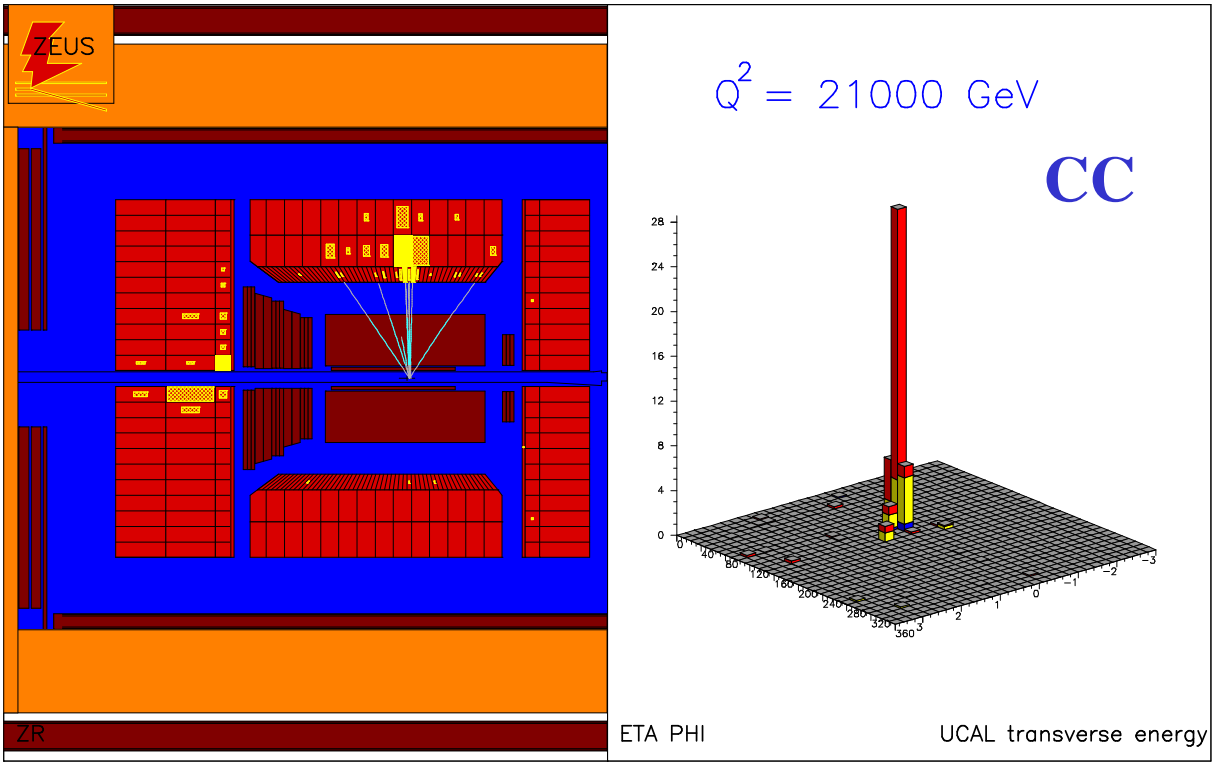
EM section $\sigma(E)/E = 12\%/\sqrt{E} \oplus 1\%$

Syst.Unc. :1-3%

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

Syst.Unc. :3-4%

Introduction



Uranium-Scintillator Calorimeter

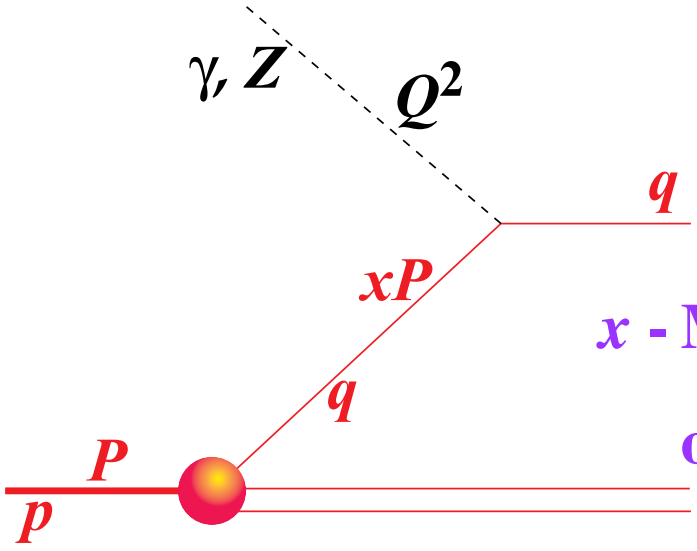
EM section $\sigma(E)/E = 18\%/\sqrt{E}$

Syst.Unc. :1-2%

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

Syst.Unc. :3%

Neutral Current DIS



- Proton provides beam of quarks:

x - Momentum fraction of struck quark

$$y = Q^2 / sx$$

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

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

Contain PDF`s and EW parameters Mz,$\sin^2\theta_W$,....

$y^2 F_L$ is small.

$$xF_3 \propto \sigma^{e^+p} - \sigma^{e^-p}$$

Reduced cross section:

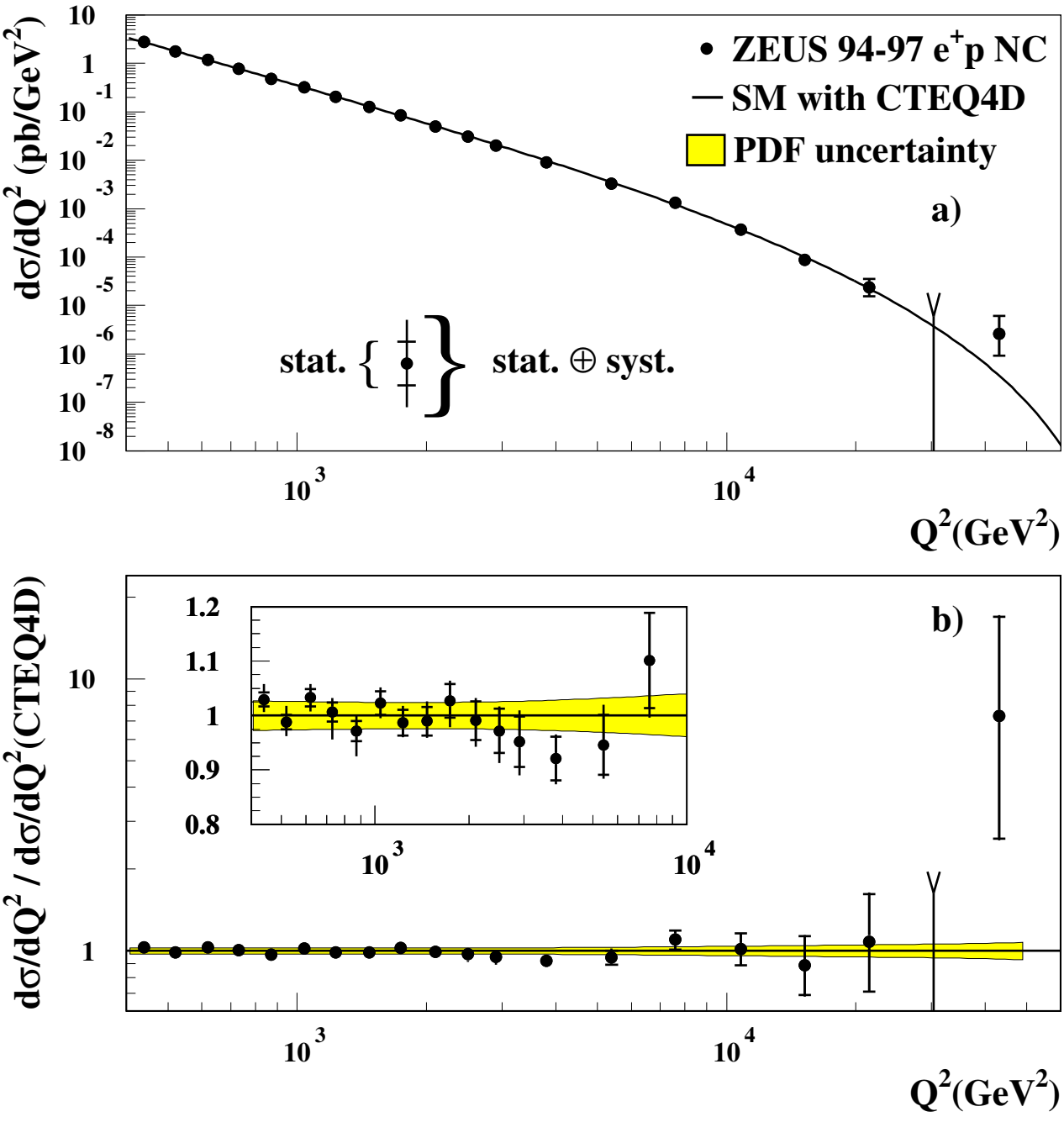
$$\tilde{\sigma}_{NC}(x,Q^2) = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma_{NC}}{dxdQ^2}$$

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

$\gamma Z, Z$ exchange.

ZEUS positron data:

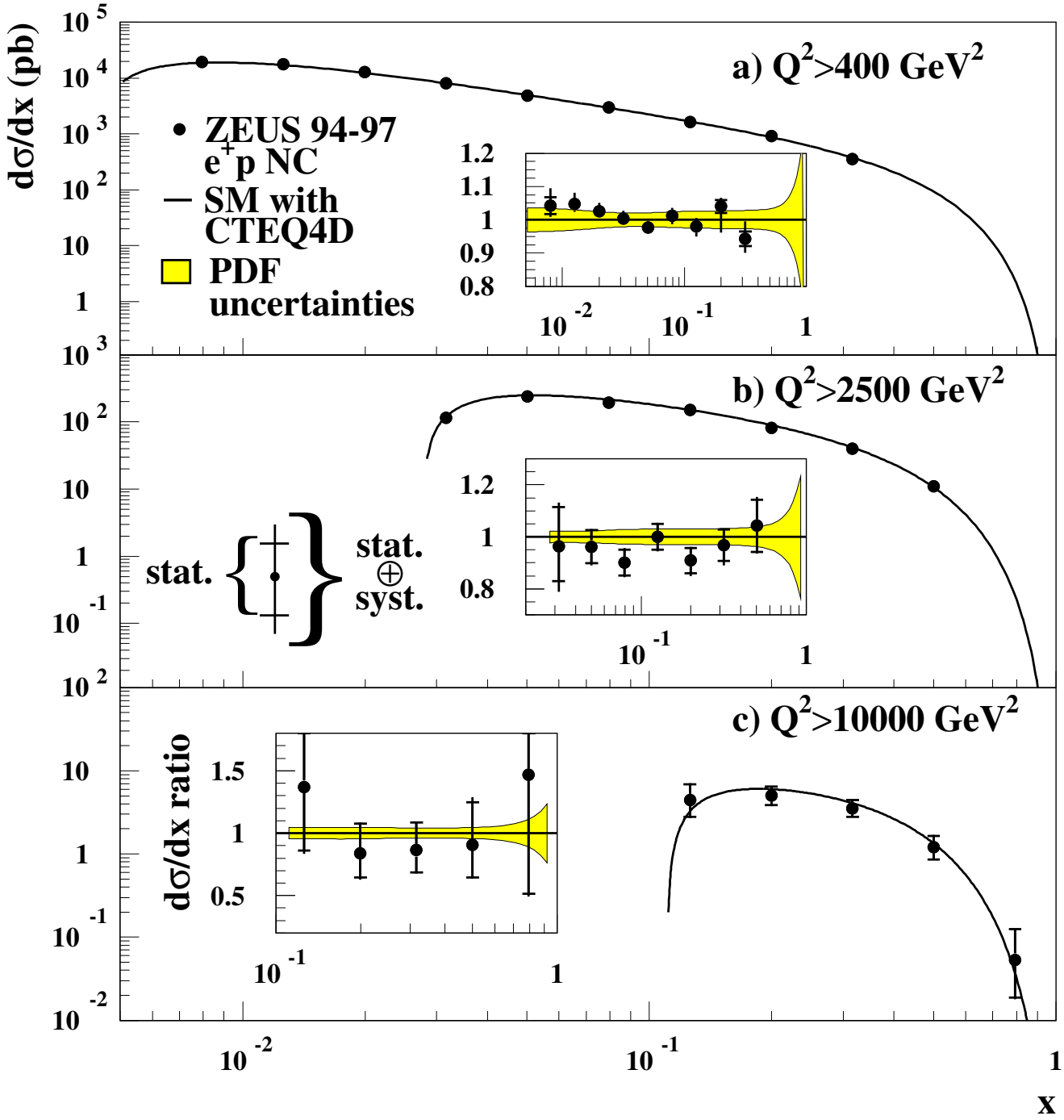
ZEUS NC 1994 – 97



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

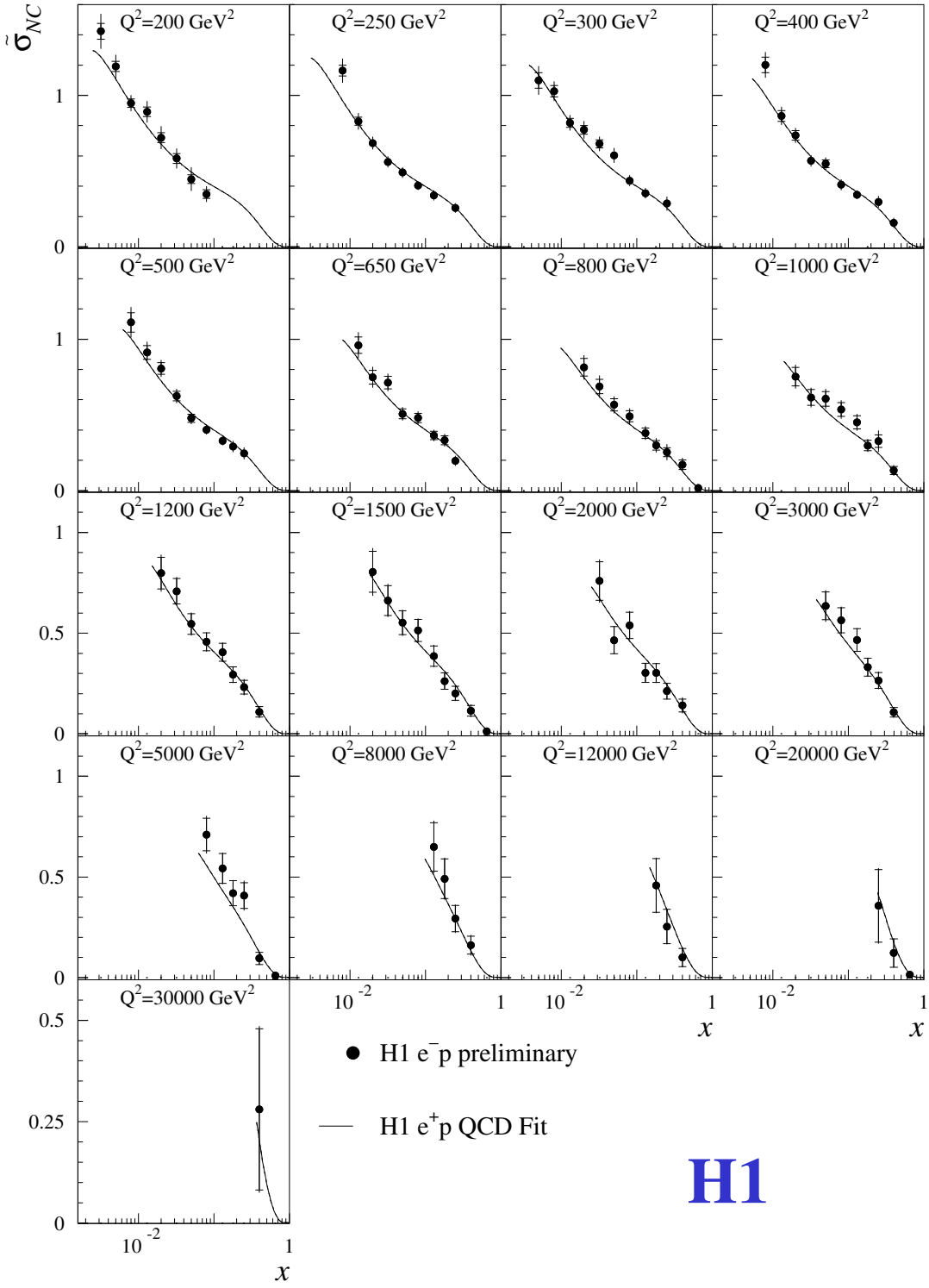
ZEUS positron data:

ZEUS NC 1994 – 97



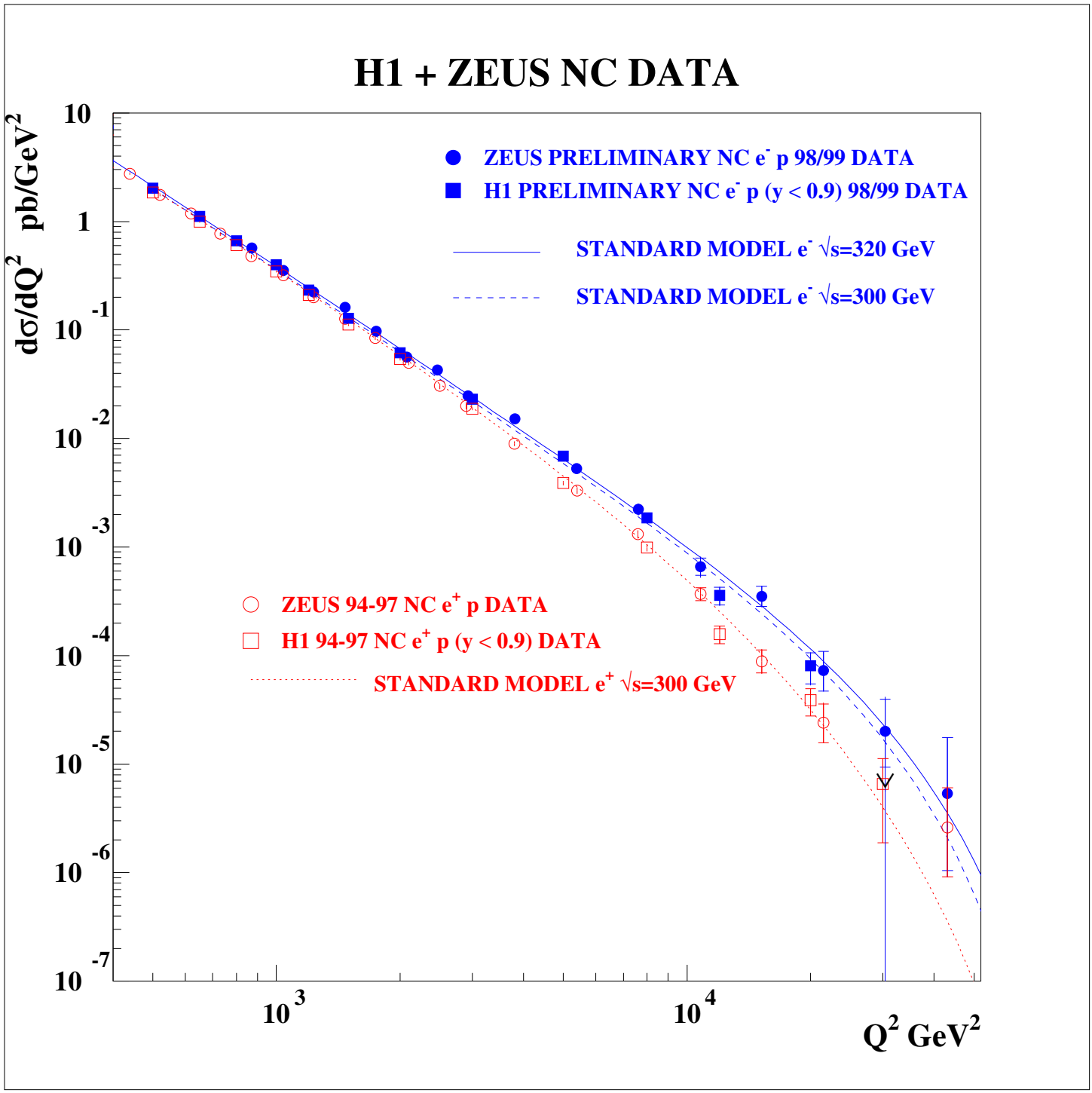
- High Q^2 dominated by valence quarks
- Small errors allow pdf determination.

Neutral Current DIS



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

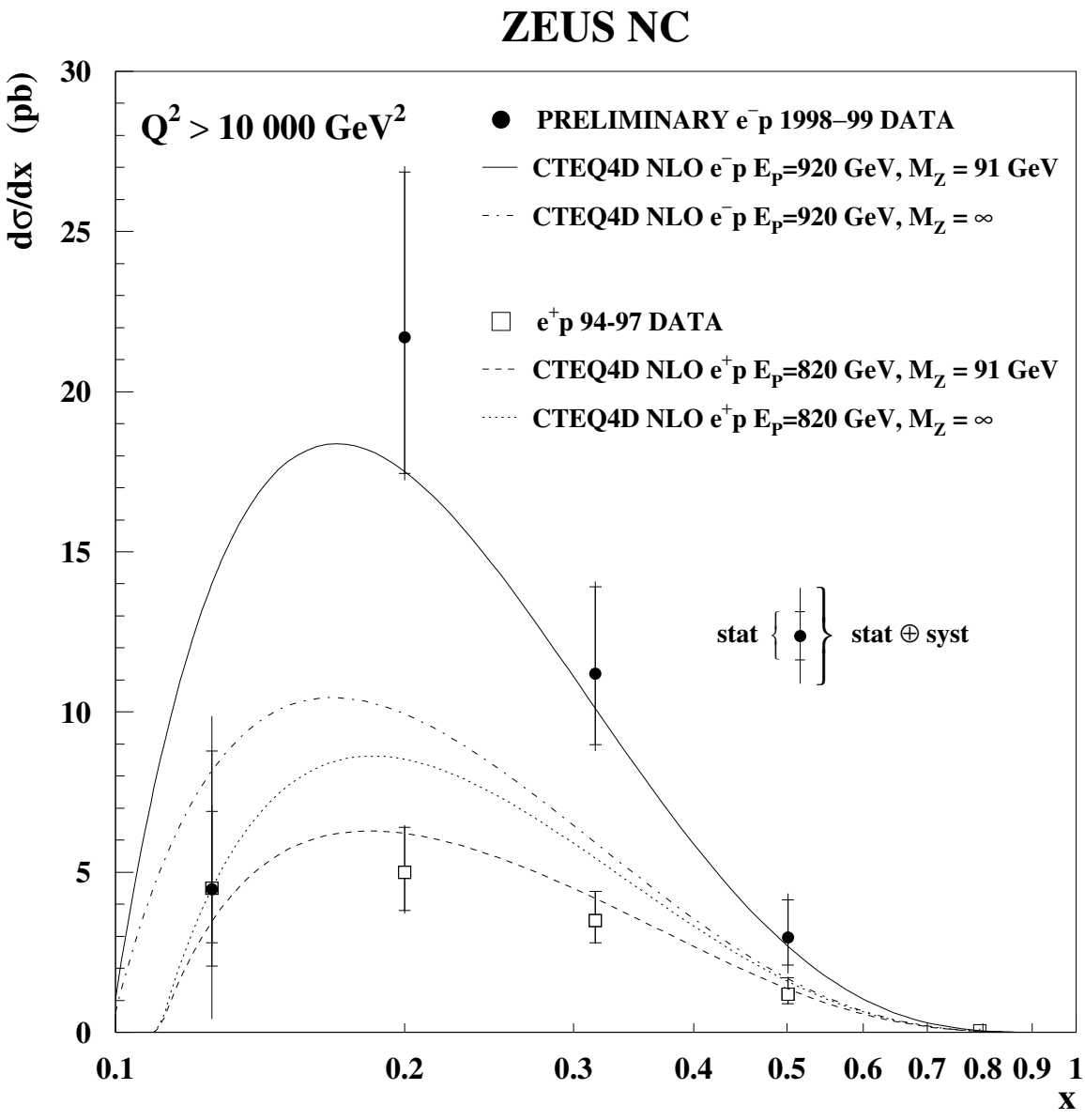
Neutral Current DIS



Enhancement of e^-p over e^+p

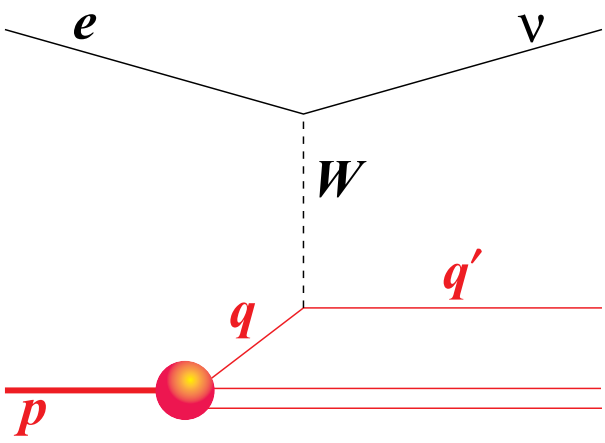
- Effect of Z exchange:

$$\frac{d\sigma^{\pm}_{NC}}{dQ^2} \propto \left[\eta^{\pm}_{\gamma} \frac{1}{Q^2} + \eta^{\pm}_{Z} \frac{1}{Q^2 + M_Z^2} \right]^2$$



***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 $$\frac{d^2\sigma_{CC}}{dxdQ^2} \propto x\left[(\bar{u} + \bar{c}) + (1 - y)^2 (d + s)\right]$$

Valence d probed.

Sensitive to quark flavours. → **d/u ratio**

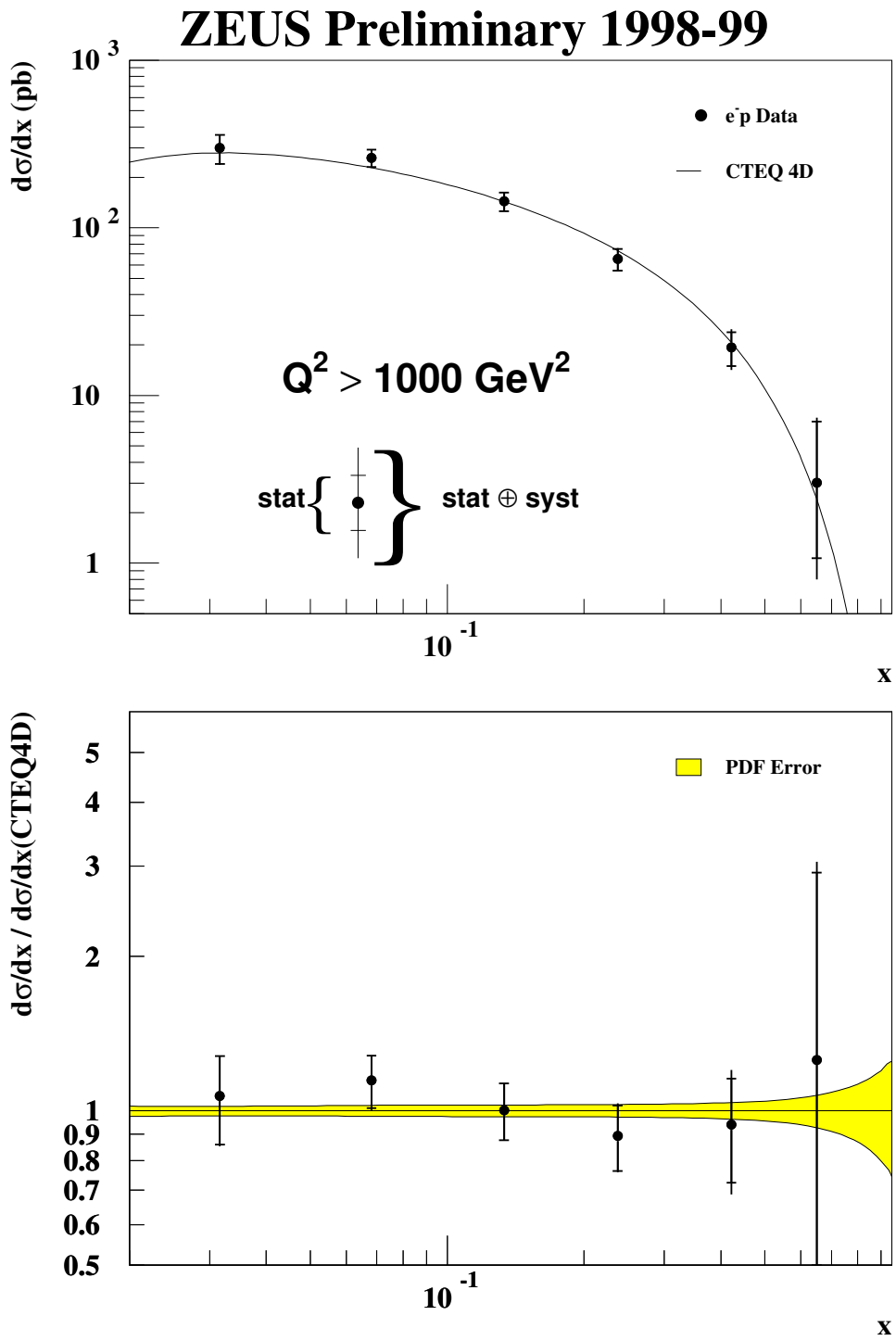
u unsuppressed

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

And the reduced cross section:-

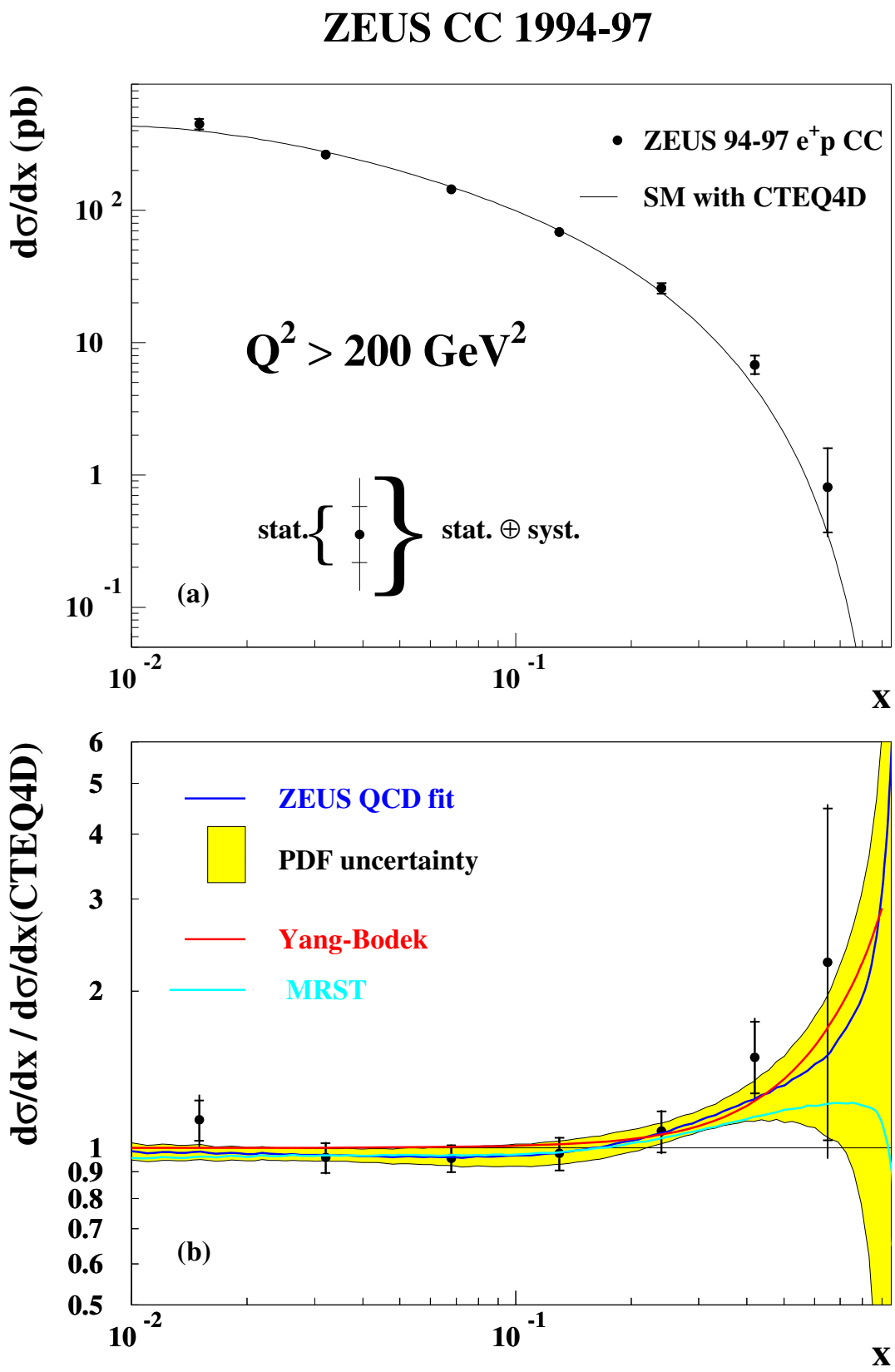
$$\tilde{\sigma}_{CC}(x, Q^2) \equiv \frac{2\pi x}{G_F^2} \left(\frac{M_W^2 + Q^2}{M_W^2}\right)^2 \frac{d^2\sigma_{CC}}{dxdQ^2}$$

Charged Current DIS



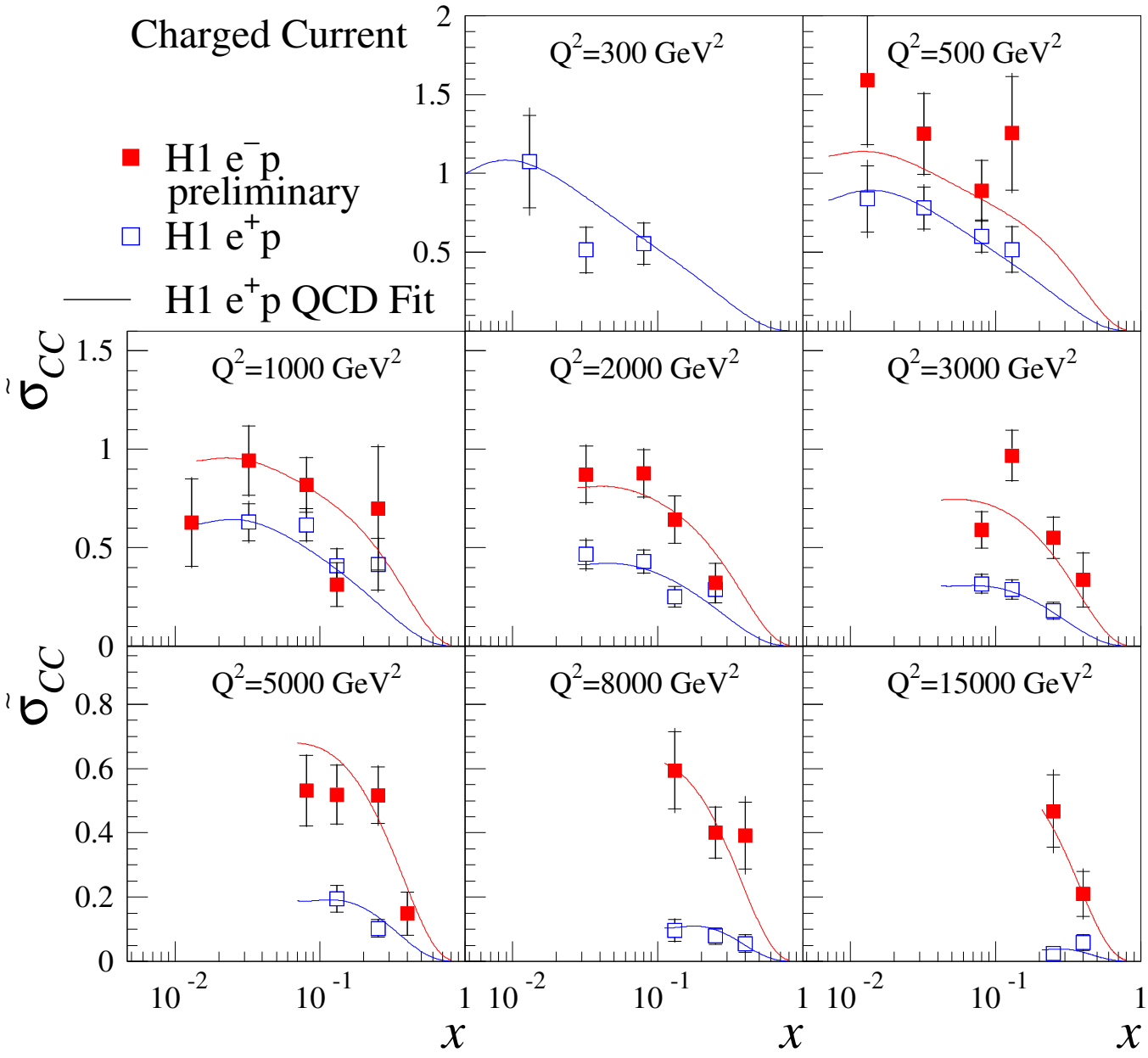
Small pdf error: u well measured, c.f. d in e+p CC.

Charged Current DIS



More d at high x.

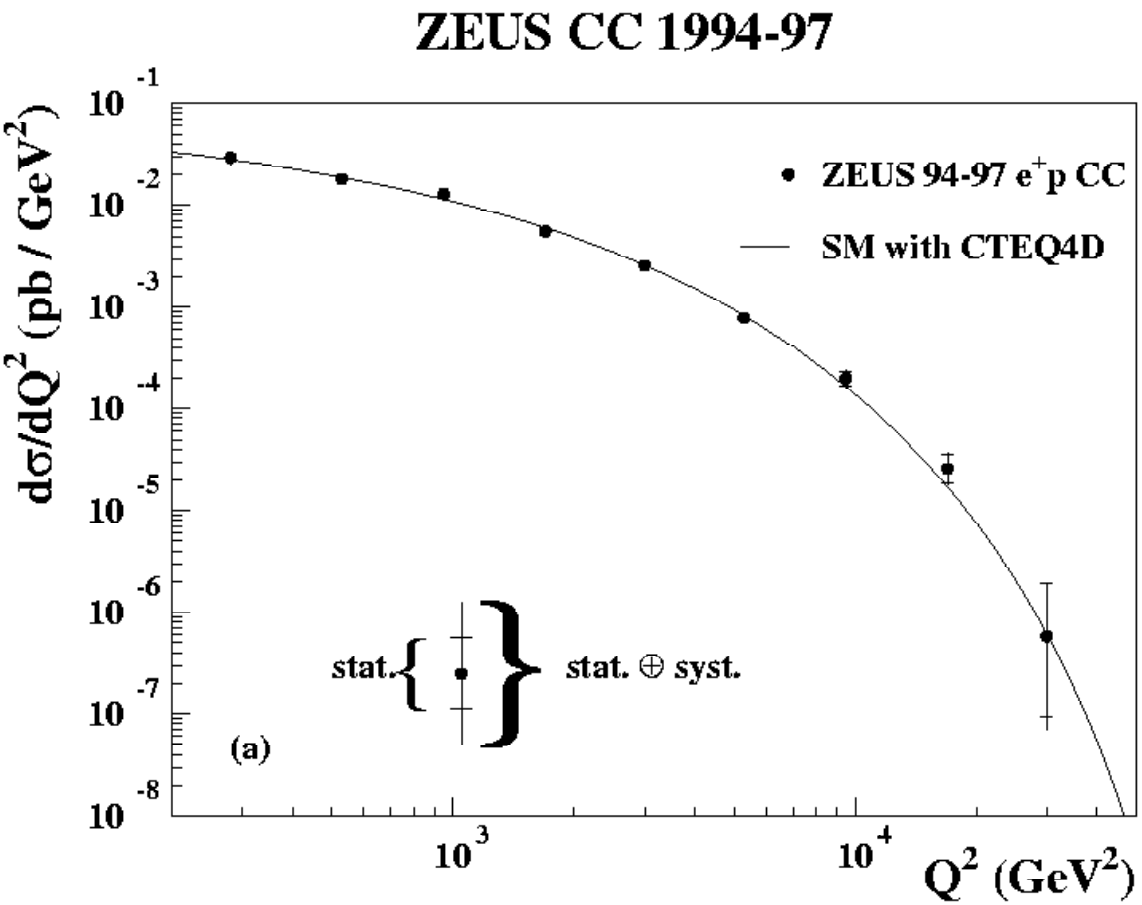
Charged Current DIS



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

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

Charged Current DIS



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

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

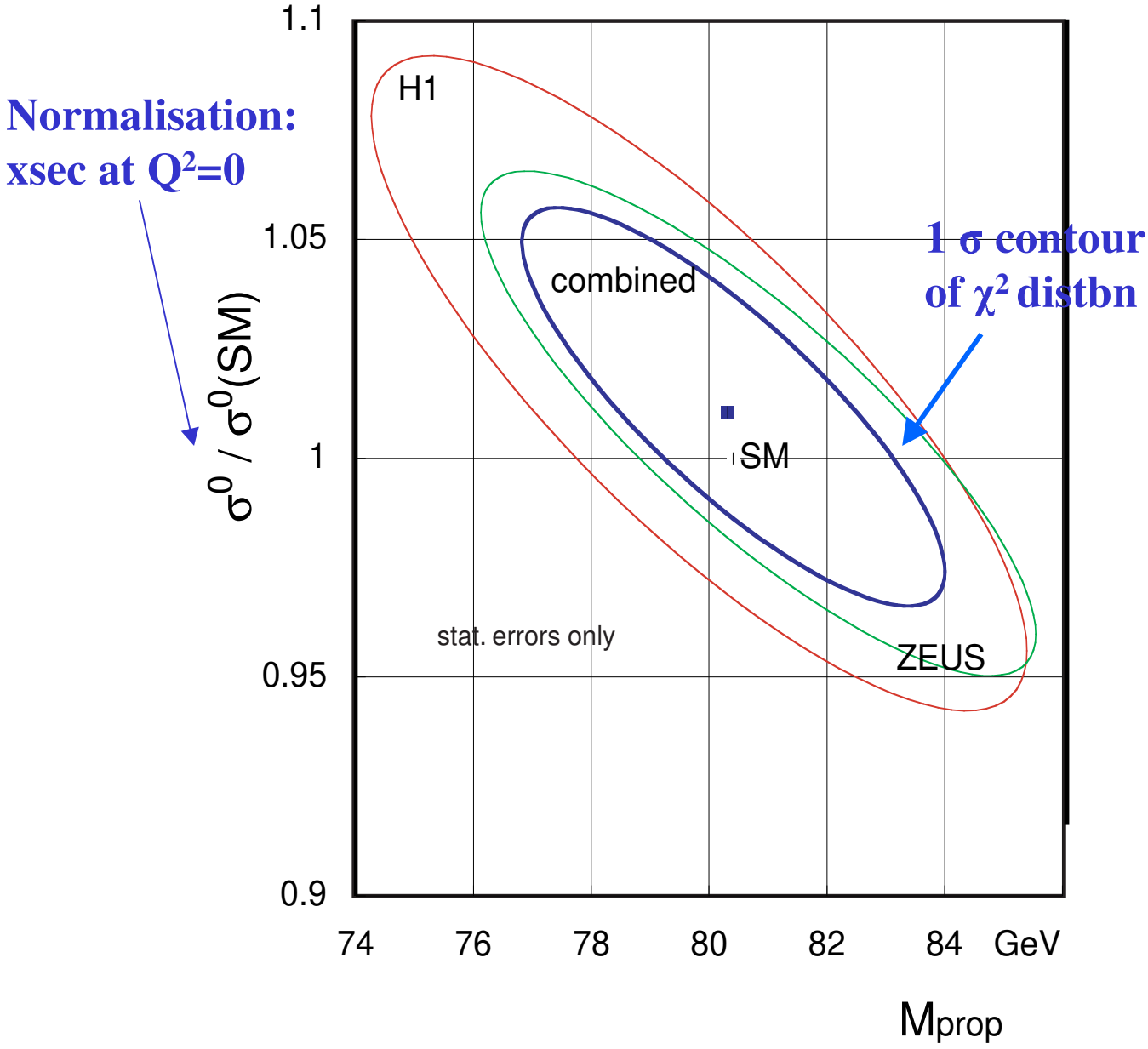
Direct M_W measurement in *SPACE-LIKE* region

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

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

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

Charged Current DIS



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

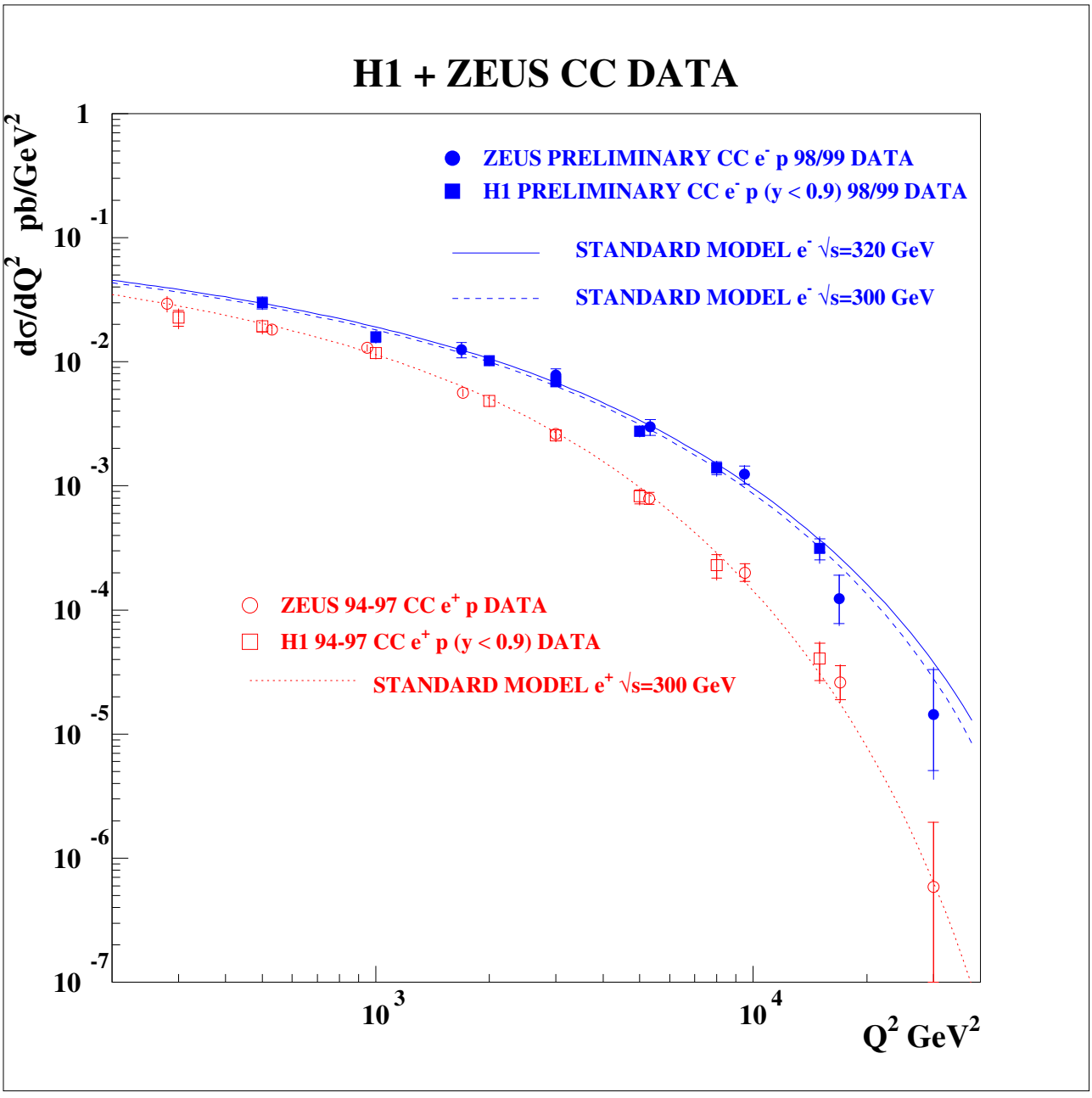
ZEUS

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

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

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

Charged Current DIS



- **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

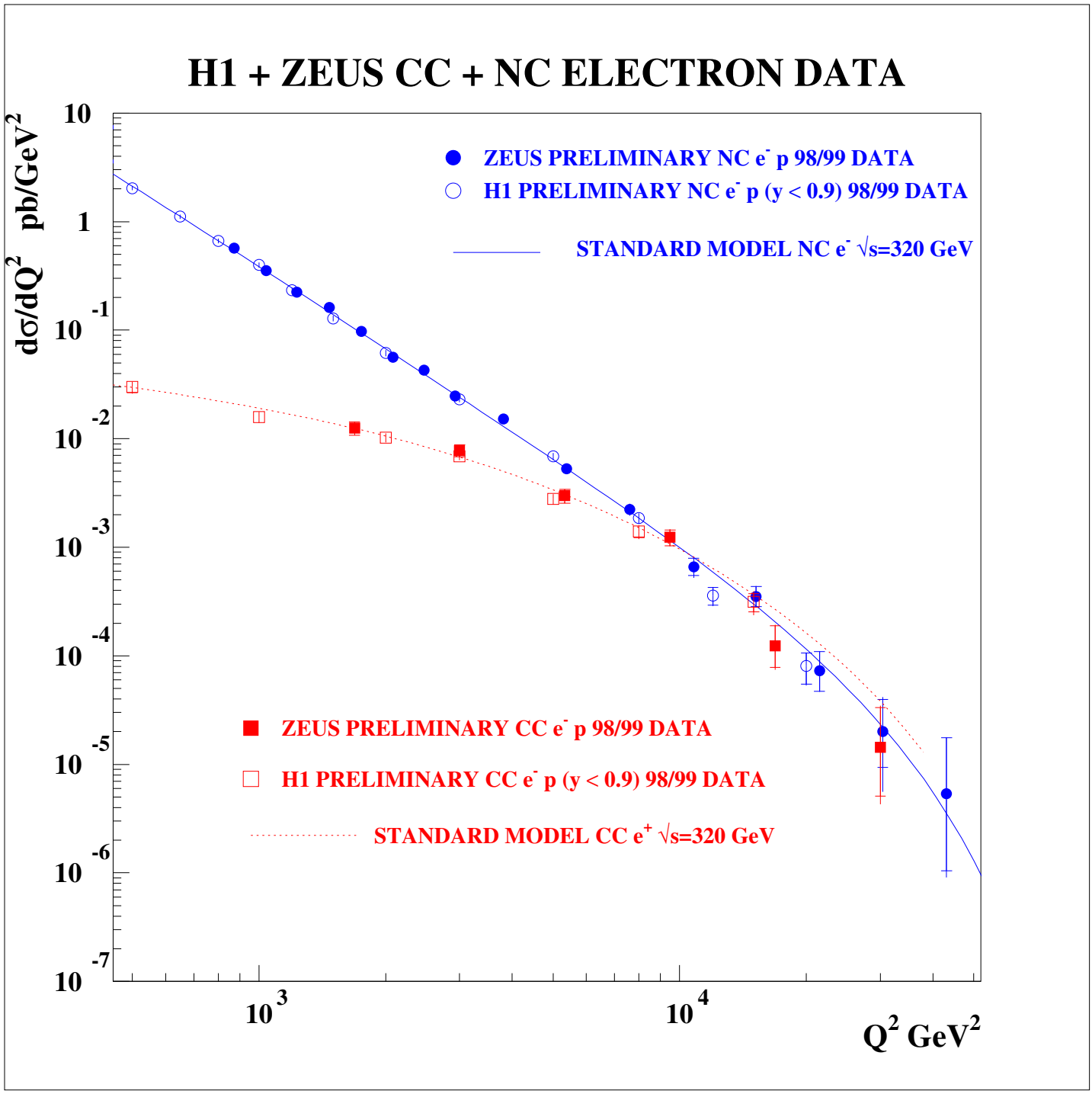
- **Wealth of data has allowed $d\sigma/dQ^2(e^+P)$ to be extracted over 6 orders of magnitude**
- **Good agreement between measured cross sections and Standard Model is observed up to $Q^2 \approx 20,000$ to $30,000$ GeV^2**
- **First measurements of $d\sigma/dQ^2(e^-P)$ and $d\sigma/dx dQ^2(e^-P)$ 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 $Q^2 \approx 30{,}000$ 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
- $d\sigma/dxdQ^2(e^{+/-}P)$ measured at high Q^2: sensitive to d/u-quark densities

Outlook

- **$20pb^{-1}$ more e^-p data.**
- **xF_3 from NC**
- **QCD fits, d/u ratio.**



HERA upgrade

High Luminosity and Polarisation:

170pb^{-1}/year per experiment.

$\Rightarrow$ **Through NC:**

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

Light quark couplings to *Z*

$\Rightarrow$ **Through CC:**

Study of origin of parity violation in the weak charged current

Reduced error on M_W measurement.

Exciting future for high-Q^2 physics at HERA.