Measurement of High-Q^2 Deep Inelastic Lepton-Proton scattering

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on behalf of
H1 and ZEUS collaborations

Contents

Introduction

High Q^2 lepton-proton Deep Inelastic Scattering(DIS)
= probe proton with small spatial resolution($\lambda \sim 1/\sqrt{Q^2}$).

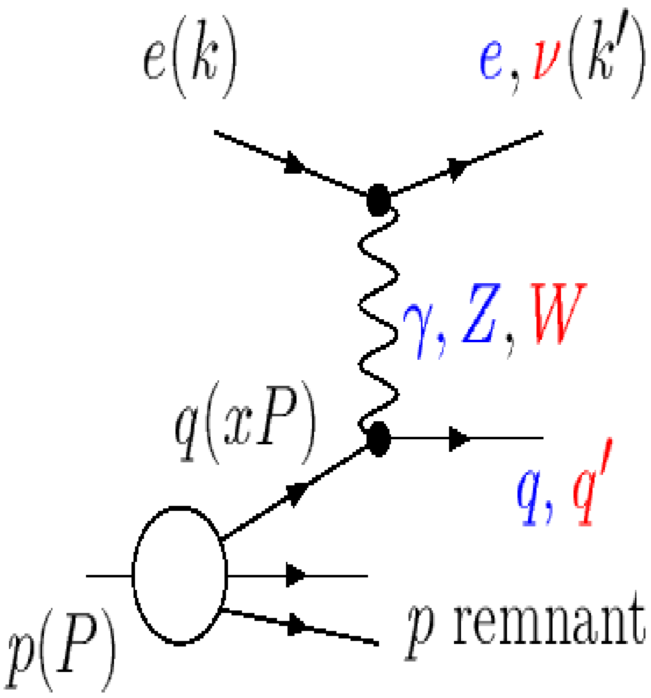
$Q^2_{max} = s \quad \Rightarrow$ HERA, the first ep collider .

$$E_e\text{=27.5 GeV, } E_p\text{=820 GeV}$$
$$\Rightarrow \sqrt{s} \sim 300\,\text{GeV}, \; Q^2_{max} \sim 9 \times 10^4\,\text{GeV}^2.$$

In the Standard Model,
ep DIS = incoherent sum of eq scattering.

$$\sigma(ep\text{–DIS}) \propto \sum \sigma(\text{eq}) \otimes (\text{quark density in proton})$$

$$\text{EW} \otimes \text{QCD}$$



- $Q^2 \equiv -(k - k')^2$.
- Bjorken scaling variable (=momentum fraction)
  $x \equiv Q^2/2pq$.
- inelasticity of electron (reflects scattering angle of e in eq CMS)
  $y \equiv pq/pk$.

DIS Cross Sections

NC($e^{\pm}p \to e^{\pm}X$)

$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \times \{Y_+ {F_2}^{NC} \mp Y_- x{F_3}^{NC} - y^2 F_L^{NC}\}$$

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

- Structure functions, F_2, F_3 include quark structure of proton and quark coupling to gauge bosons as well M_Z.

$$\begin{pmatrix} {F_2}^{NC} \\ x{F_3}^{NC} \end{pmatrix} = \sum_f \begin{pmatrix} xA_f(q_f + \overline{q_f}) \\ xB_f(q_f - \overline{q_f}) \end{pmatrix}$$

- F_3 is a parity violating term. Sign changes in e^+/e^-.
- At high Q^2, F_L is only relevant at high y ($\sim$ 10%).

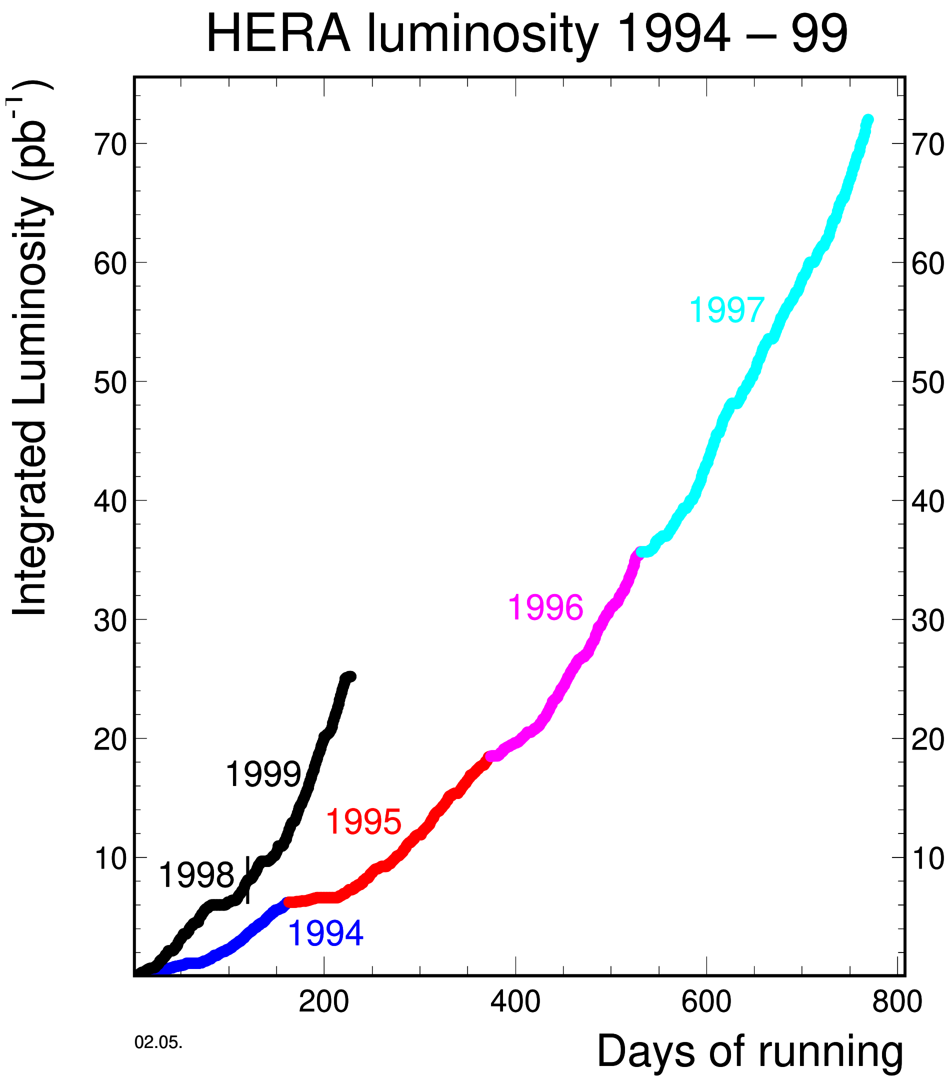
CC($ep \to \nu X$) in LO QCD

$$e^+p : \frac{d^2\sigma}{dxdQ^2} = \frac{{G_F}^2}{2\pi}\left(\frac{{M_W}^2}{{M_W}^2 + Q^2}\right)^2 \times \sum_{i=1,2} [\overline{u_i} + (1-y)^2 d_i]$$

$$e^-p : \frac{d^2\sigma}{dxdQ^2} = \frac{{G_F}^2}{2\pi}\left(\frac{{M_W}^2}{{M_W}^2 + Q^2}\right)^2 \times \sum_{i=1,2} [u_i + (1-y)^2 \overline{d_i}]$$

- Flavor selecting; $d(u)$-quark contributes only to $e^+p(e^-p)$.
- Helicity suppression factor, $(1-y)^2$, is multiplied to quarks(antiquarks) in $e^+p(e^-p)$.

HERA operation

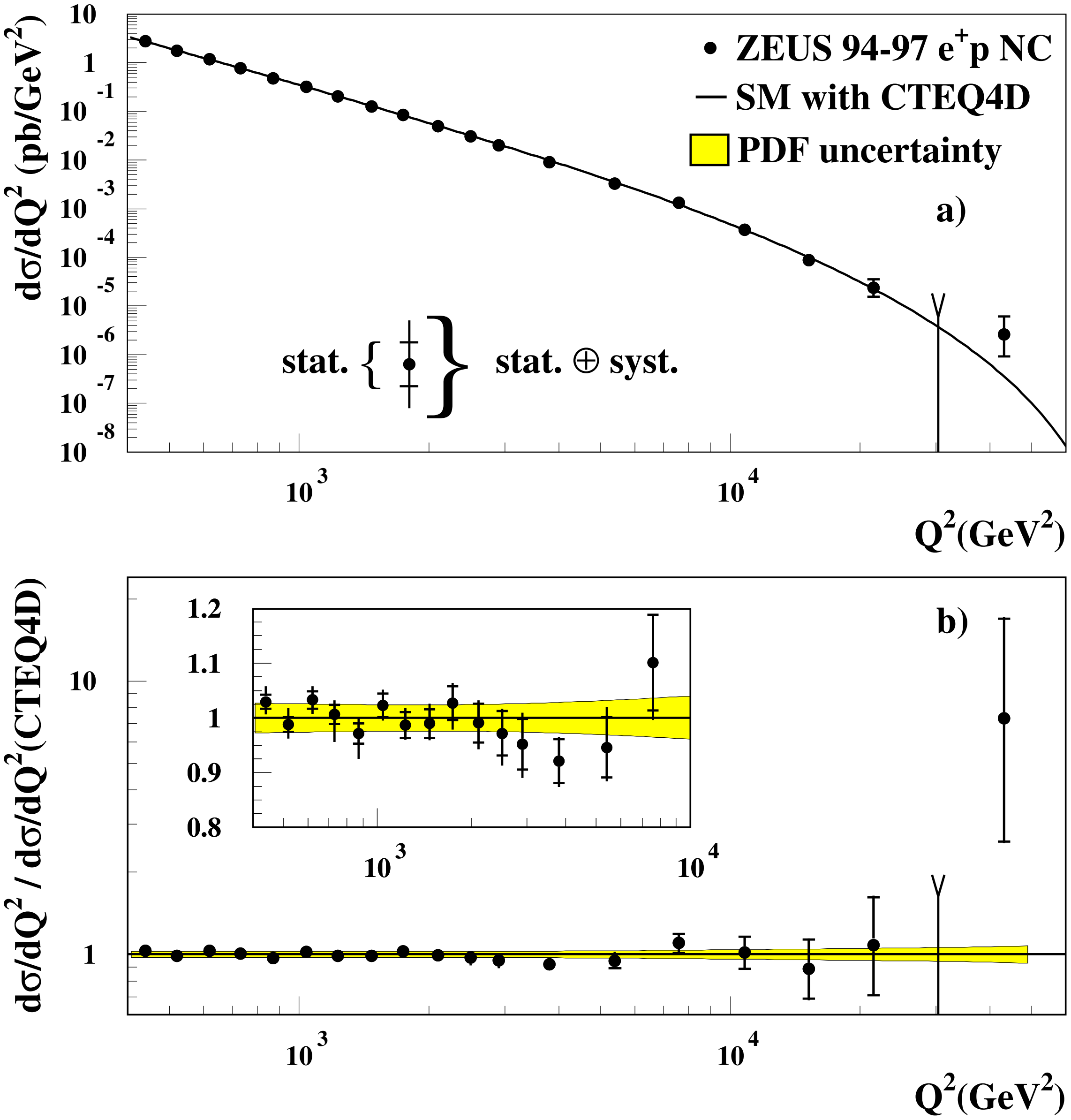


- 94-97 : positron running.
  H1 36.6 pb^{-1}
  ZEUS 47.7 pb^{-1}
- 98-99 : electron running.
  E_p raised to 920 GeV
  ($\sqrt{s} = 320$ GeV)
  H1 5.3 pb^{-1} analyzed.
  ZEUS 6 pb^{-1} analyzed.

This talk contains ... ALL SO FAR!

e^+p NC $d\sigma/dQ^2$

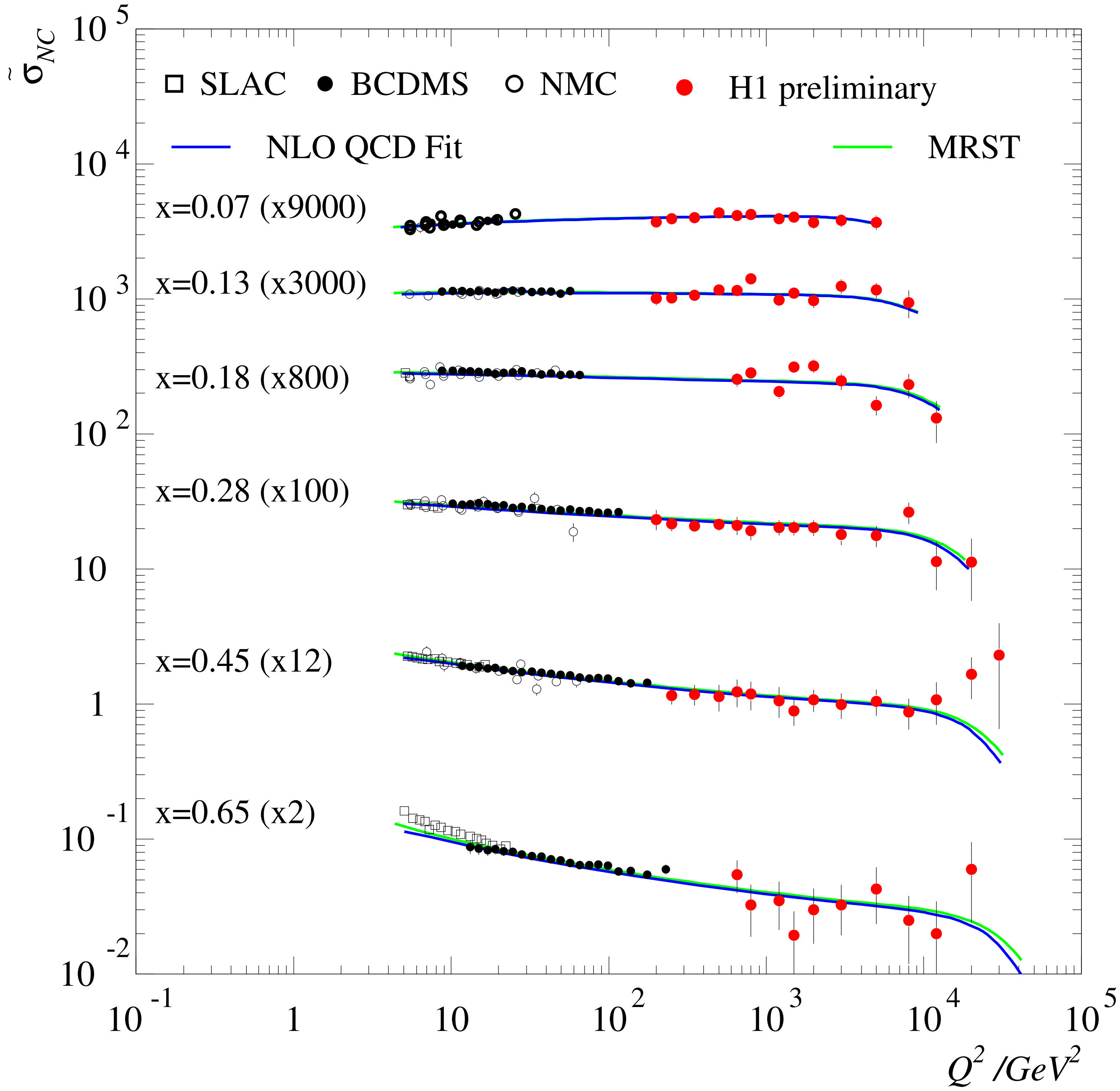
ZEUS NC 1994 – 97



- Measured cross sections agree well with SM predictions 7 orders of magnitude. (error band=PDF uncertainty)
- PDFs are extrapolated according to NLO QCD DGLAP evolution from lower Q^2. $\Rightarrow$ a triumph of QCD.
- Slight excess at the highest Q^2 both in H1/ZEUS.

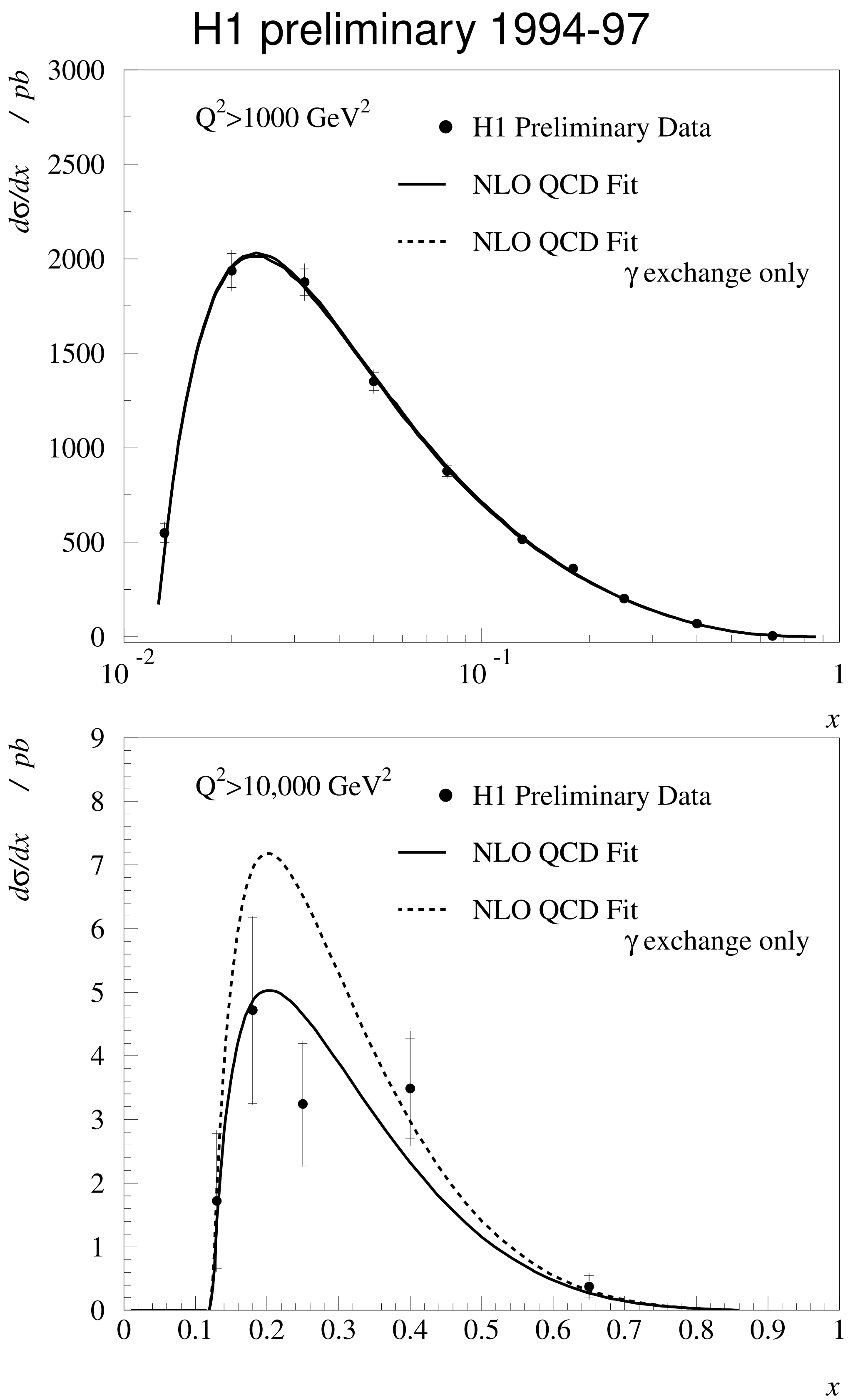
e^+p NC Reduced cross section(H1)

$$\overline{\sigma}_{NC} \equiv \left(\frac{Q^2 x}{2\pi\alpha^2 Y_+}\right)\frac{d^2\sigma}{dxdQ^2}$$
$$= F_2{}^{NC} - \frac{Y_-}{Y_+} x F_3{}^{NC} - \frac{y^2}{Y_+} F_L{}^{NC}$$



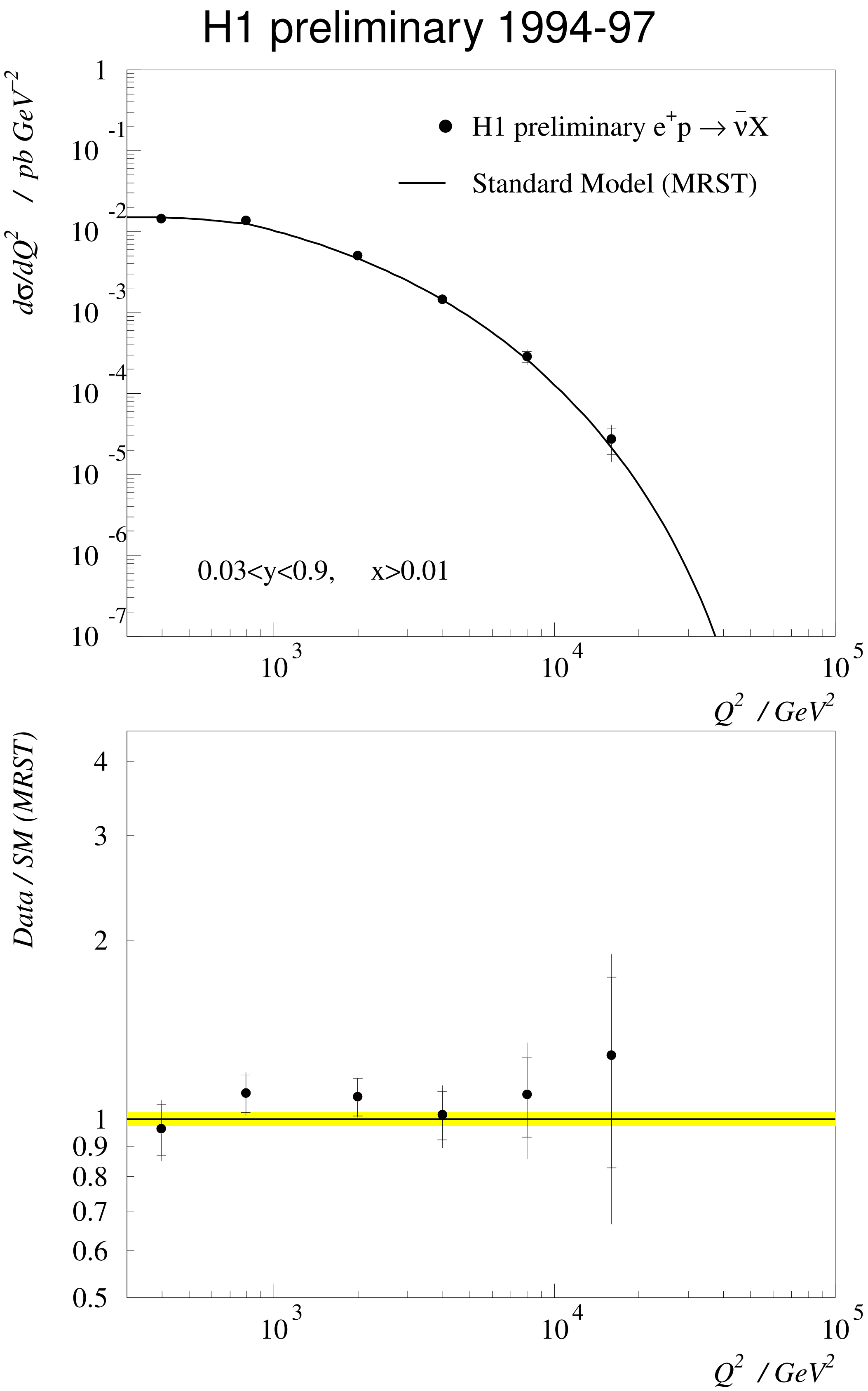
- excess at $x = 0.45$, which corresponds to $M_{eq} \sim 200$ GeV.(and also relates to high Q^2 excess.)

e^+p NC γ-Z interference



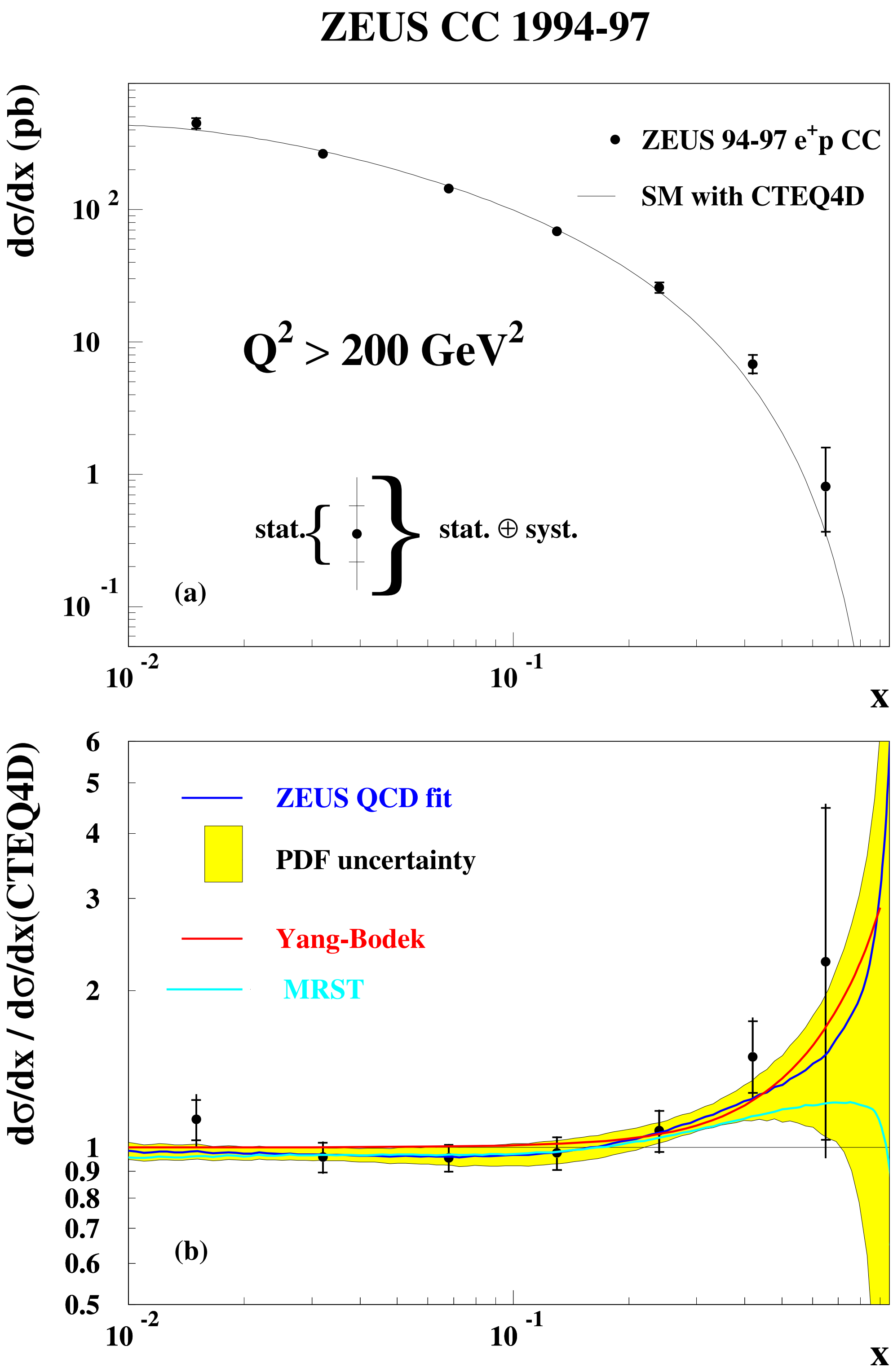
- γ-Z interference was firstly seen in NC DIS.

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



- Consistent with SM.(error band=luminosity uncertainty)

e^+p CC $d\sigma/dx$(ZEUS)

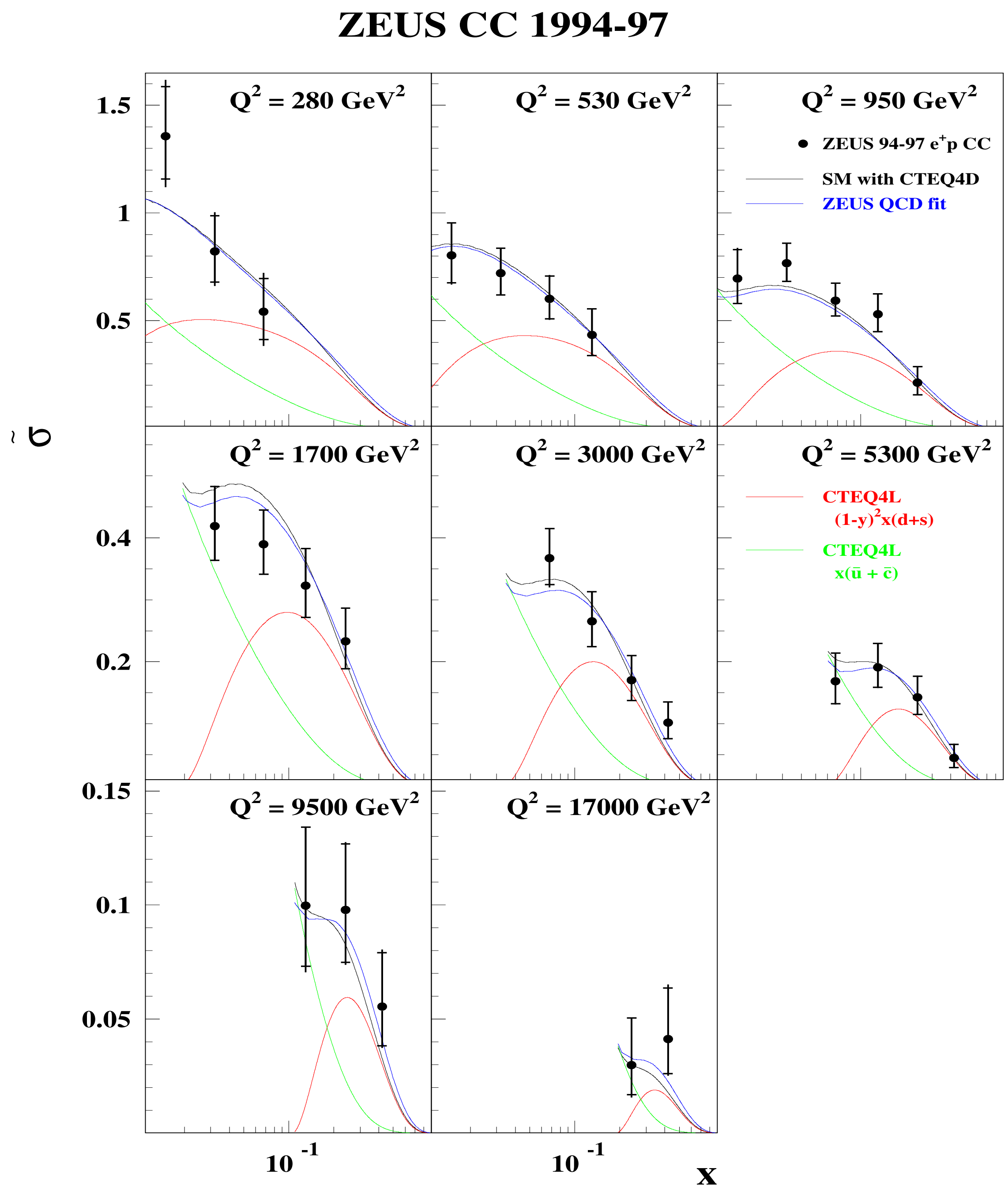


- Slight excess at high x where d-quark contributes dominantly.
- Yang-Bodek (= a reanalysis of NMC ${F_2}^d$)
  $\Rightarrow$ increase d-quark.($d/u \rightarrow 0.2$ at $x \rightarrow 1$).

e^+p CC Weighted Cross Section

$$\overline{\sigma} \equiv x \frac{d^2\sigma}{dxdQ^2} \frac{2\pi}{{G_F}^2} \left(\frac{{M_W}^2}{{M_W}^2 + Q^2} \right)^{-2}$$

$$= x \sum_{i=1,2} [\overline{u_i}(x, Q^2) + (1-y)^2 d_i(x, Q^2)] \text{ (QPM)}$$



- First measurement.
- Sensitivity to flavor compositions; $(1-y)^2(d+s)$ at high-x and $(\overline{u}+\overline{c})$ at low-x.

M_W determination from CC $d\sigma/dQ^2$

$$d\sigma/dQ^2 \propto {G_F}^2 \times (\frac{M_W^2}{M_W^2+Q^2})^2,$$

i.e. coupling and propagator mass.(PDG: $M_W = 80.41 \pm 0.10\,\mathrm{GeV}$)

- Unconstrained fit

$\Rightarrow$ spacelike measurement of M_W.

$\Rightarrow$ complementary to timelike measurements at LEP/Tevatron.

$$M_W = 80.9^{+4.9}_{-4.6}\,(\mathrm{stat.})^{+5.0}_{-4.3}\,(\mathrm{syst.})^{+1.3}_{-1.2}\,(\mathrm{PDF})\ \mathrm{GeV}$$

(G_F statistical error 3%.)

- G_F-fixed fit : Fitting the shape.

$\Rightarrow$ measurement of the propagator mass.

$$M_W = 81.4^{+2.7}_{-2.6}(\mathrm{stat.})^{+2.0}_{-2.0}(\mathrm{syst.})^{+3.3}_{-3.0}(\mathrm{PDF})\ \mathrm{GeV} \qquad (\mathrm{ZEUS})$$

$$M_W = 81.2 \pm 3.3(\mathrm{stat.}) \pm 4.3(\mathrm{syst.}) \qquad (\mathrm{H1})$$

- Use Standard Model relation:
  $G_F = \frac{\pi\alpha}{\sqrt{2}} \frac{M_Z^2}{(M_Z^2 - M_W^2) M_W^2} \frac{1}{1-\Delta r}$ (i.e. Exploiting correlation between shape and normalization in a model dependent fit.)

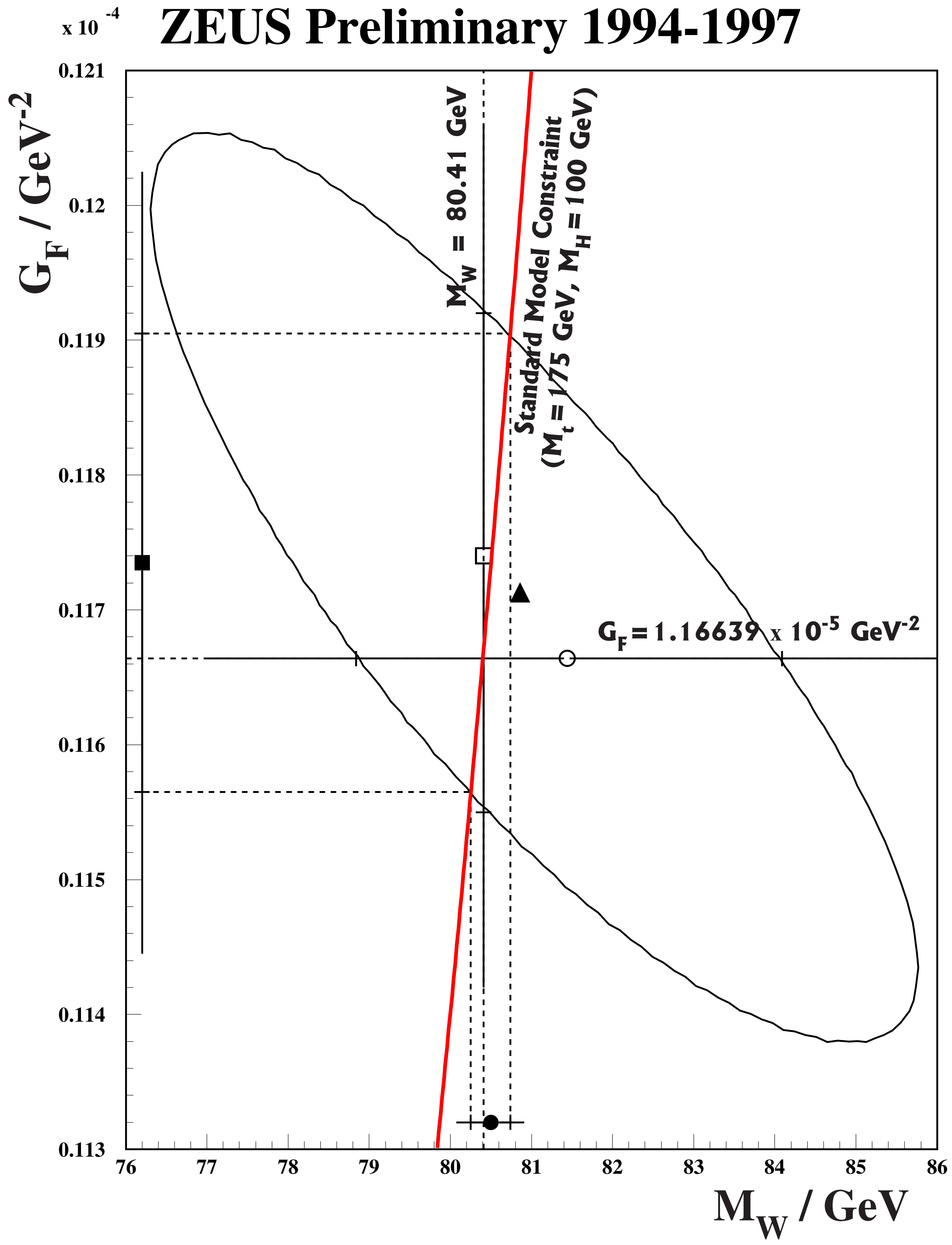
$\Rightarrow$ A sensitive electroweak consistency check.

$$M_W = 80.50^{+0.24}_{-0.25}(\mathrm{stat.})^{+0.13}_{-0.16}(\mathrm{syst.})^{+0.30}_{-0.31}(\mathrm{PDF})$$
$$^{+0.05}_{-0.06}(\Delta \mathrm{M_t}, \Delta \mathrm{M_H}, \Delta \mathrm{M_Z})\ \mathrm{GeV}.$$

($M_H = 100\,\mathrm{GeV}$, $M_T = 175\,\mathrm{GeV}$ were used.)

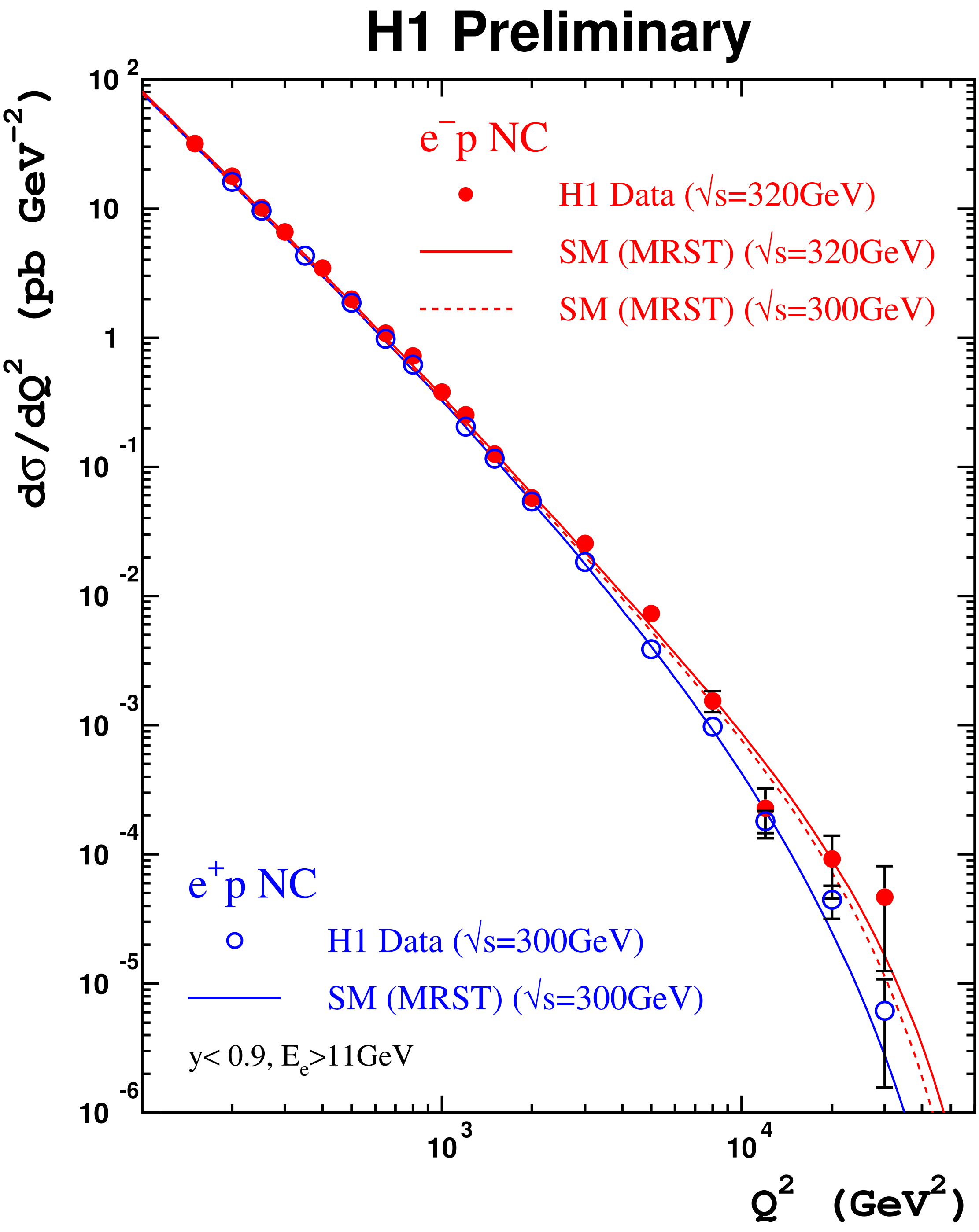
Note the last is not a measurement, but indicate the sensitivity of the CC cross section to M_W assuming the Standard Model.

M_W determination -continued-



e^-p NC $d\sigma/dQ^2$(H1)

$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \times \{Y_+ {F_2}^{NC} \mp Y_- x{F_3}^{NC} - y^2 F_L^{NC}\}$$

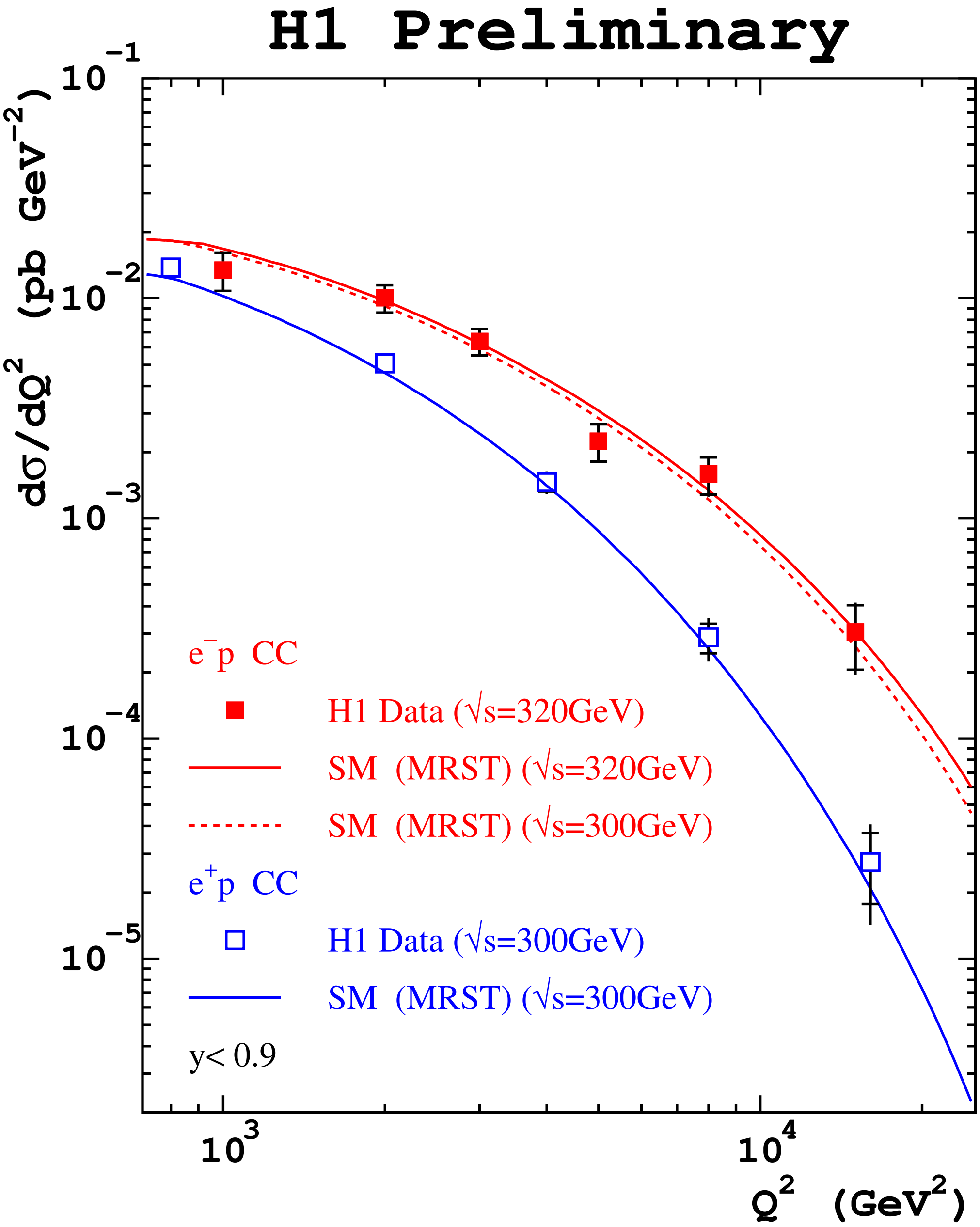


- Evidence for positive γZ^0 interference in the e^-p .
- Better agreement for e^-p at very large Q^2.

e^-p CC $d\sigma/dQ^2$(H1)

$$e^+p: \frac{d^2\sigma}{dxdQ^2} = \frac{{G_F}^2}{2\pi}\left(\frac{{M_W}^2}{{M_W}^2+Q^2}\right)^2 \times \sum_{i=1,2}[\overline{u_i} + (1-y)^2 d_i]$$

$$e^-p: \frac{d^2\sigma}{dxdQ^2} = \frac{{G_F}^2}{2\pi}\left(\frac{{M_W}^2}{{M_W}^2+Q^2}\right)^2 \times \sum_{i=1,2}[u_i + (1-y)^2 \overline{d_i}]$$

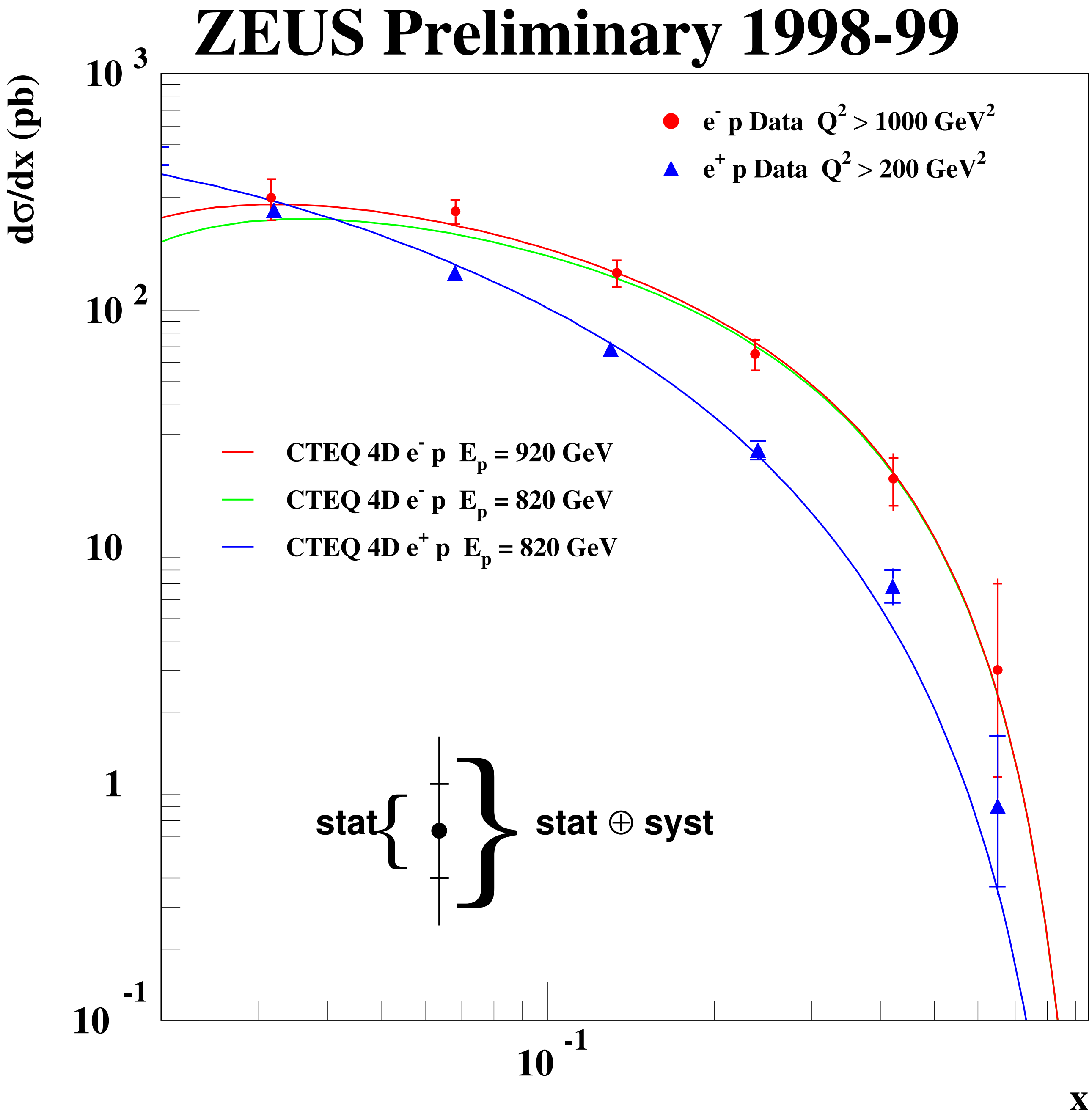


- e^-p data order of magnitude above e^+p due to: $\sigma(e^-p) \propto (u+c)$ while $\sigma(e^+p) \propto (1-y)^2(d+s)$.
- Sensitivity to different quark flavors by e^+/e^-.

e^-p CC $d\sigma/dx$(ZEUS)

$$e^+p : \frac{d^2\sigma}{dxdQ^2} = \frac{{G_F}^2}{2\pi}\left(\frac{{M_W}^2}{{M_W}^2+Q^2}\right)^2 \times \sum_{i=1,2}[\overline{u_i}+(1-y)^2 d_i]$$

$$e^-p : \frac{d^2\sigma}{dxdQ^2} = \frac{{G_F}^2}{2\pi}\left(\frac{{M_W}^2}{{M_W}^2+Q^2}\right)^2 \times \sum_{i=1,2}[u_i+(1-y)^2\overline{d_i}]$$



- Sensitive to d/u-ratio at high-x.

Summary

NC e^+p 94-97,
we presented : $d\sigma/dQ^2$, $d^2\sigma/dxdQ^2$ and $d\sigma/dx$

- Slight excess was observed at the highest Q^2 both by H1/ZEUS.
- $x = 0.45$ excess at high Q^2 was observed by H1.
- γ-Z^0 interference was firstly observed in DIS.

CC e^+p 94-97,
we presented : $d\sigma/dQ^2$, $d\sigma/dx$, $d^2\sigma/dxdQ^2$ and M_W

- Consistent with SM for $d\sigma/dQ^2$.
- Slight excess at high x was observed by ZEUS.
- Our spacelike measurement of M_W was consistent with Tevatron/LEP.
- First measurement of $d^2\sigma/dxdQ^2$, which was found to be reasonably described by NLO-QCD.

e^-p 98-99, HERA and H1/ZEUS are running smoothly!
we presented : NC/CC $d\sigma/dQ^2$ and CC $d\sigma/dx$

- Positive γ-Z^0 interference can be seen in NC.
- About an order of higher CC cross section is seen than e^+p.

Outlook

-1999 : End of HERA 1st era.

e^+p/e^-p, NC/CC

$\Rightarrow$ all structure functions, more precise M_W, d/u-ratio etc...

2000- : HERA upgrade, high luminosity + e-polarization

$\Rightarrow$ high precision measurement at midium-high Q^2.

$\Rightarrow$ EW physics, e.g. quark-couplings to Z^0 etc...