Tests of the Standard Model in Inclusive Scattering at Large Transverse Momenta

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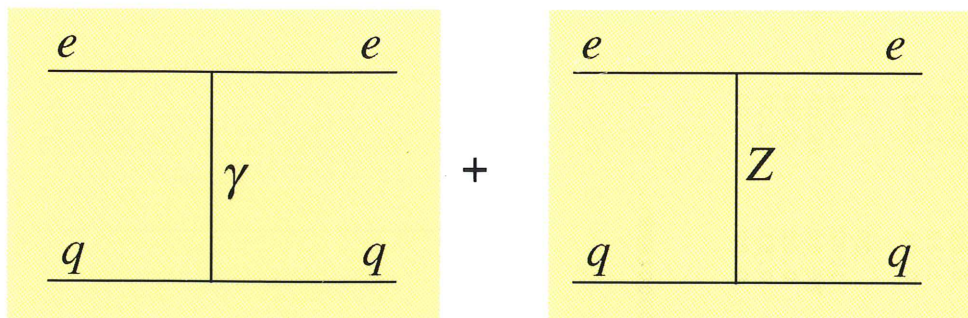
for the H1 and ZEUS Collaborations

HERA results on
Deep Inelastic Scattering

Probing the electroweak model at
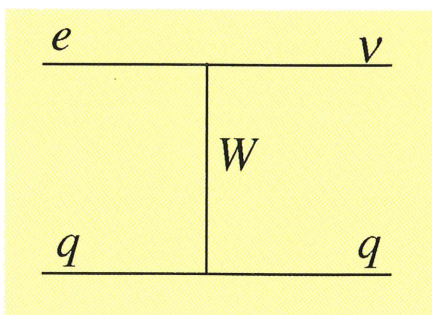10^{-3} fm in space-like interactions

Boson Exchange at HERA

Neutral Current (NC)

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\phi_{\gamma,Z} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x, Q^2) \mp Y_- xF_3(x, Q^2)\right]$$
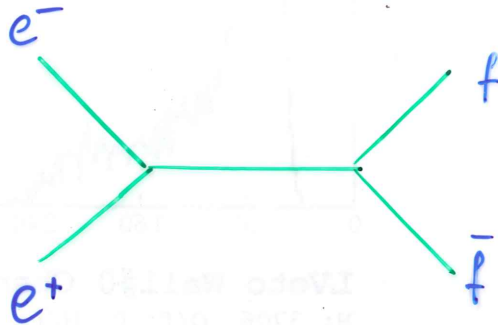
with $\quad Y_\pm = 1 \pm (1-y)^2 \quad$ for $e^{+/-}$

Charged Current (CC)

$$\frac{d^2\sigma}{dxdQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \phi_W$$
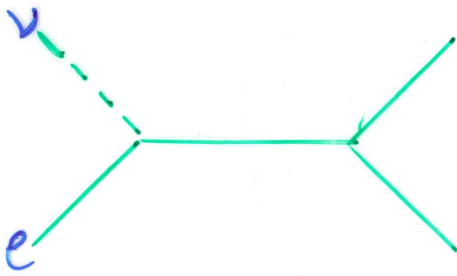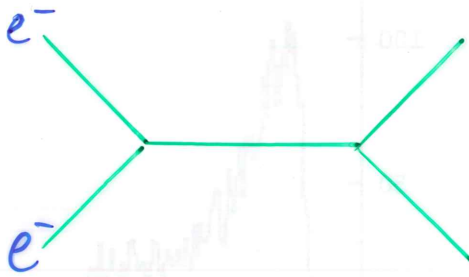
$\phi_{\gamma,Z}, \phi_W$ comprise: structure of the proton

propagators and
electroweak couplings
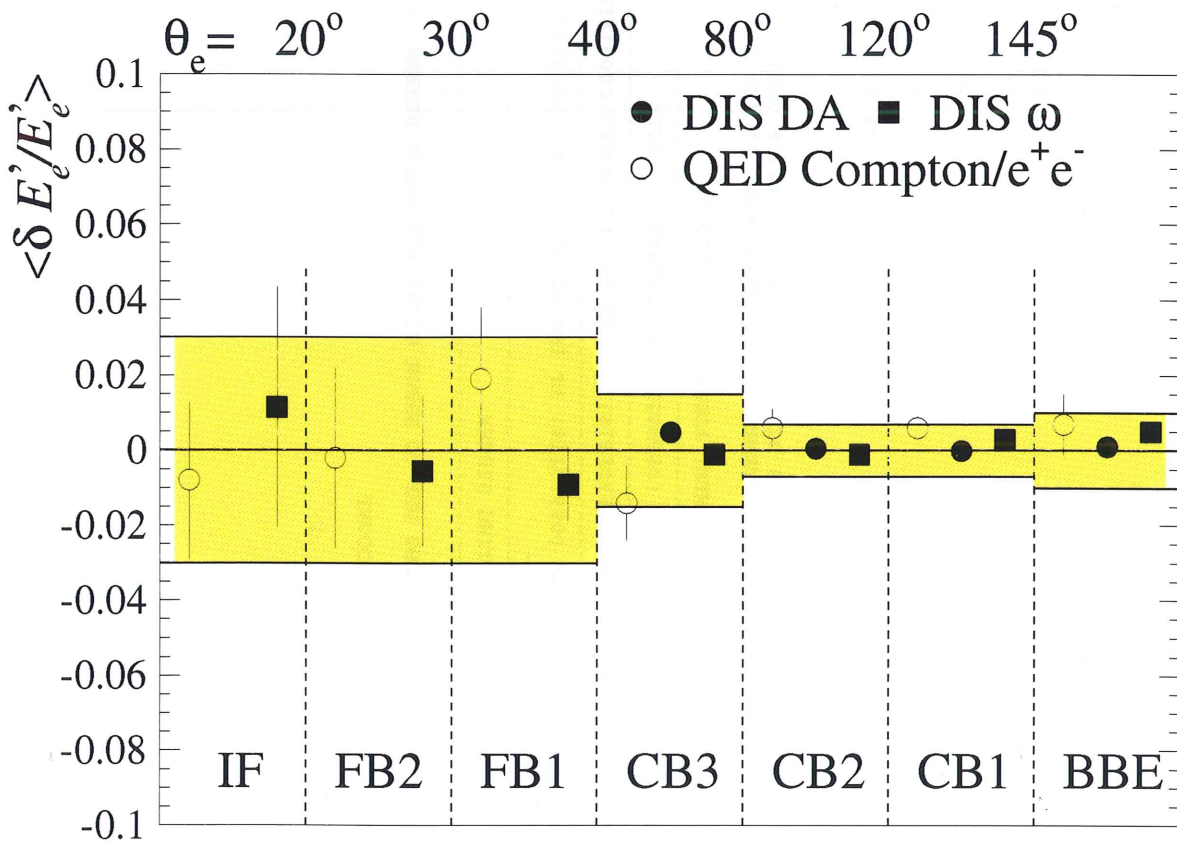
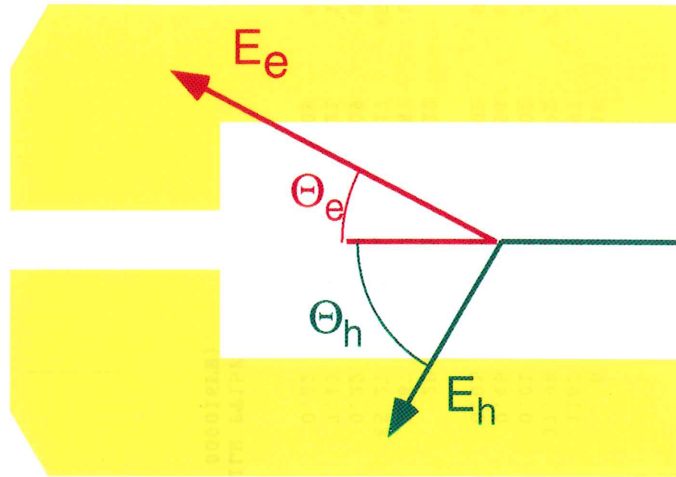$\approx$ quark densities

LEP/SLC ANALOGY

$$\sigma \sim \frac{1}{s^2} R$$

$$R \sim \sum_f \text{coupl} \times \text{propag.} \times \left(1 + \frac{\alpha s}{\pi} \dots\right)$$

Experimental Accuracy

Experimental redundancy in the measurement of the two inclusive scattering parameters provides means for cross calibration.
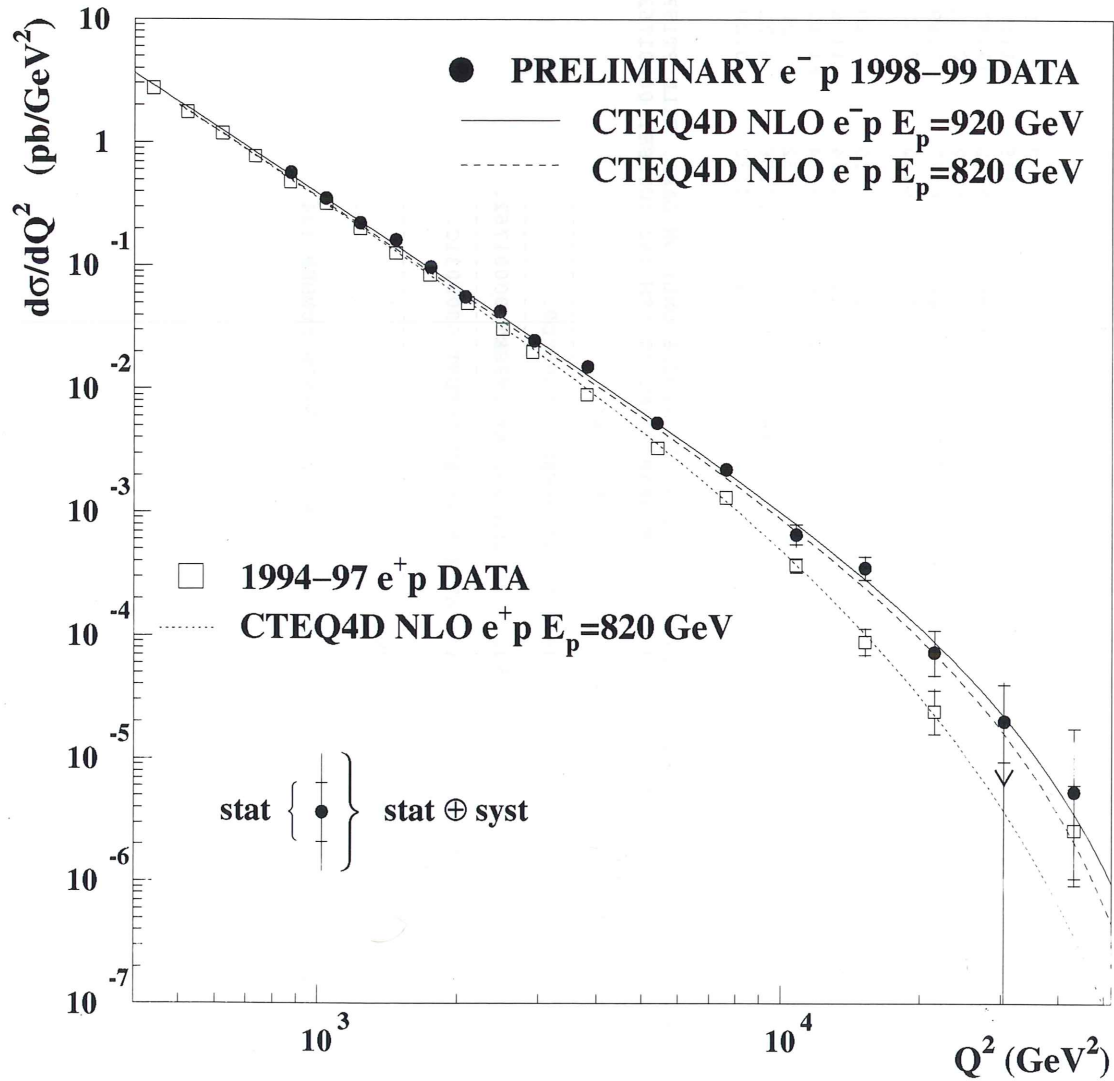

LAr wheel

Neutral Currents

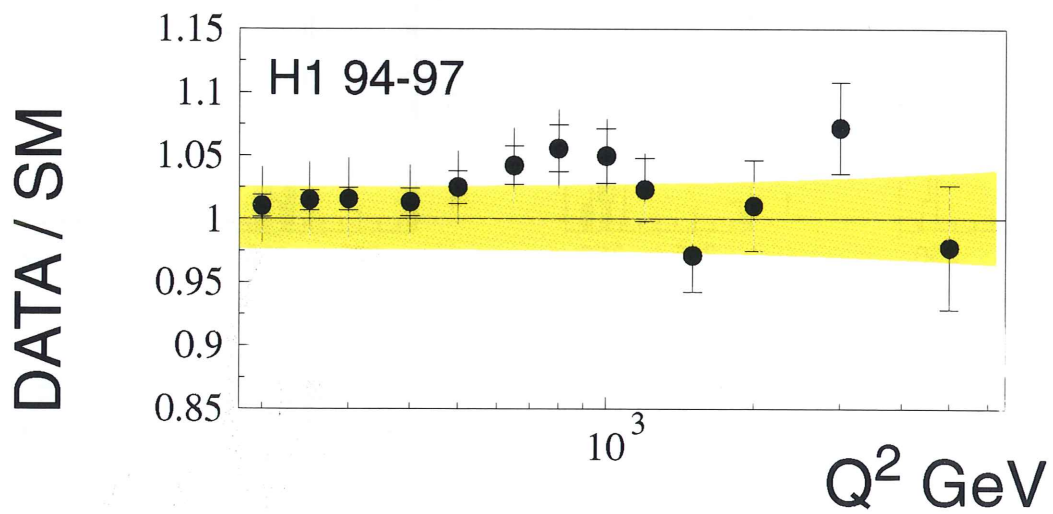$$\frac{d^2}{dxdQ^2}\sigma(e^{\pm}p) = \frac{2\pi\alpha^2}{xQ^4}\phi_{\gamma,Z}$$

Observe the proper charge dependence:

- γZ interference

ZEUS NC

Neutral Currents cont'd
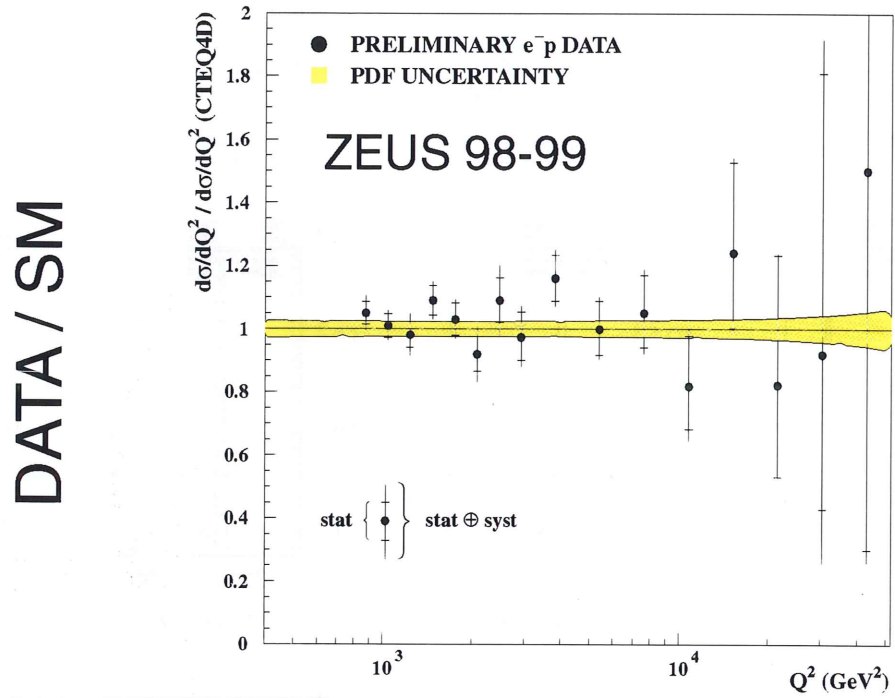
NC at high x

$$\tilde{\sigma} = \left[\frac{2\pi\alpha^2}{xQ^4}Y_+\right]^{-1}\frac{d^2\sigma}{dxdQ^2}$$

- QCD evolution over 2 orders of magnitude
- high x requires clarification

Electroweak Unification

ZEUS DIS Cross Sections

- for large Q^2 neutral and charged current processes have cross sections of similar size

- details depend on quark content and coupling

Charged Current

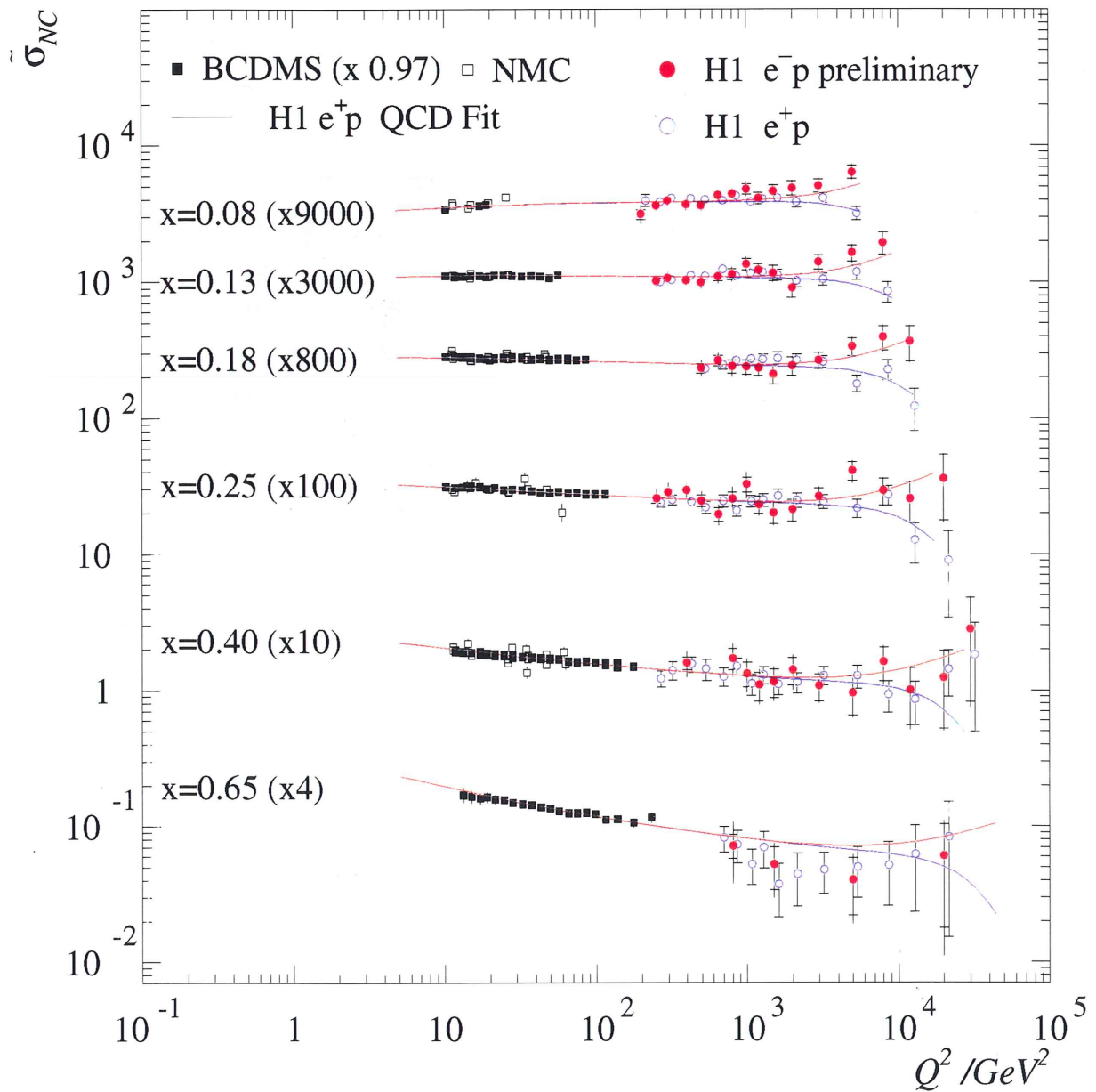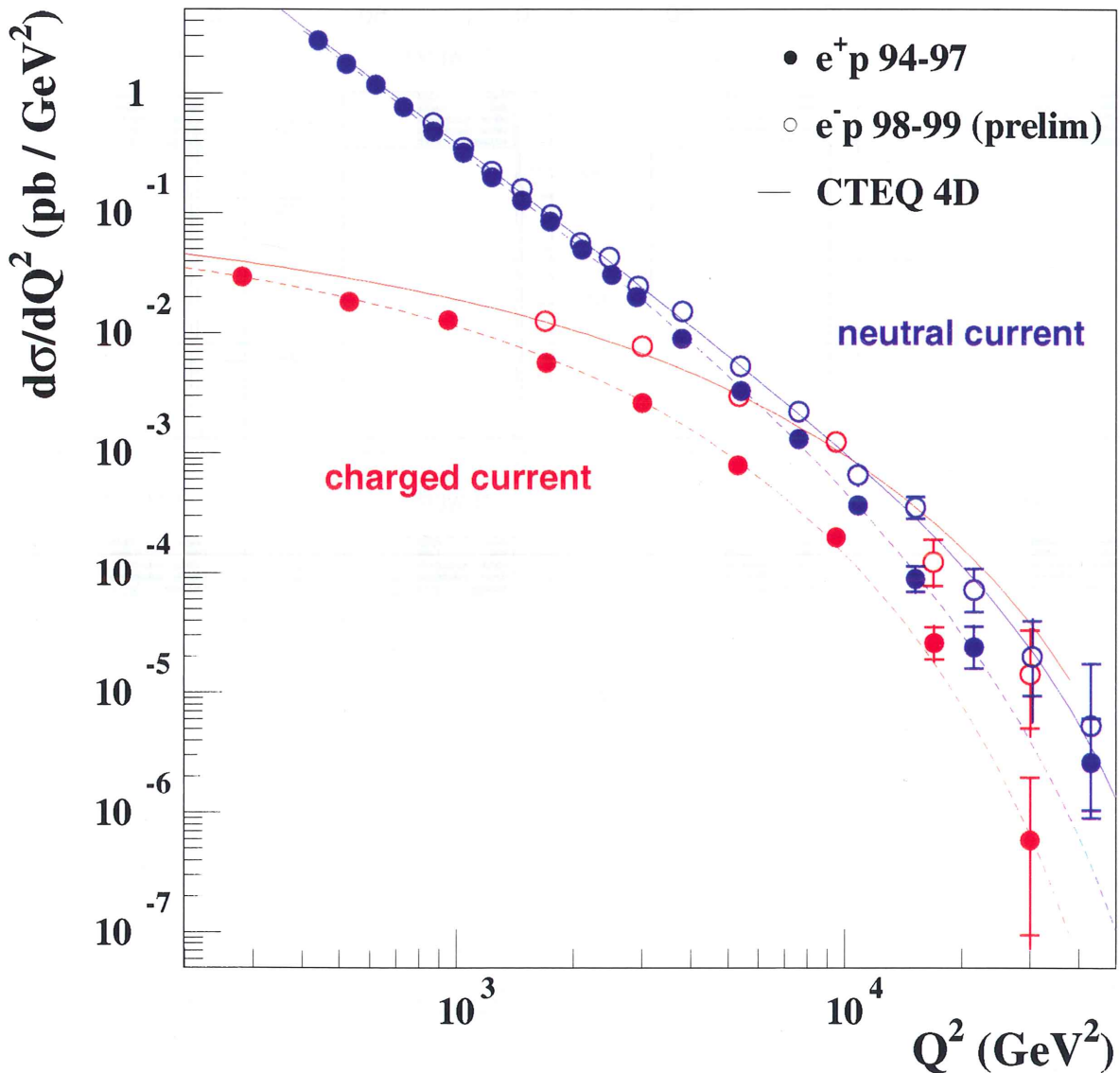$$\frac{d\sigma^{CC}}{dQ^2 dx} \sim G_F{}^2 \left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \frac{1}{x}\phi_W$$

At high Q^2 coupling to valence quarks prevails:

$\Leftarrow \Rightarrow$ $\Rightarrow \Rightarrow$

e^-: $\phi_W \sim xu$ e^+: $\phi_W \sim (1-y)^2 xd$
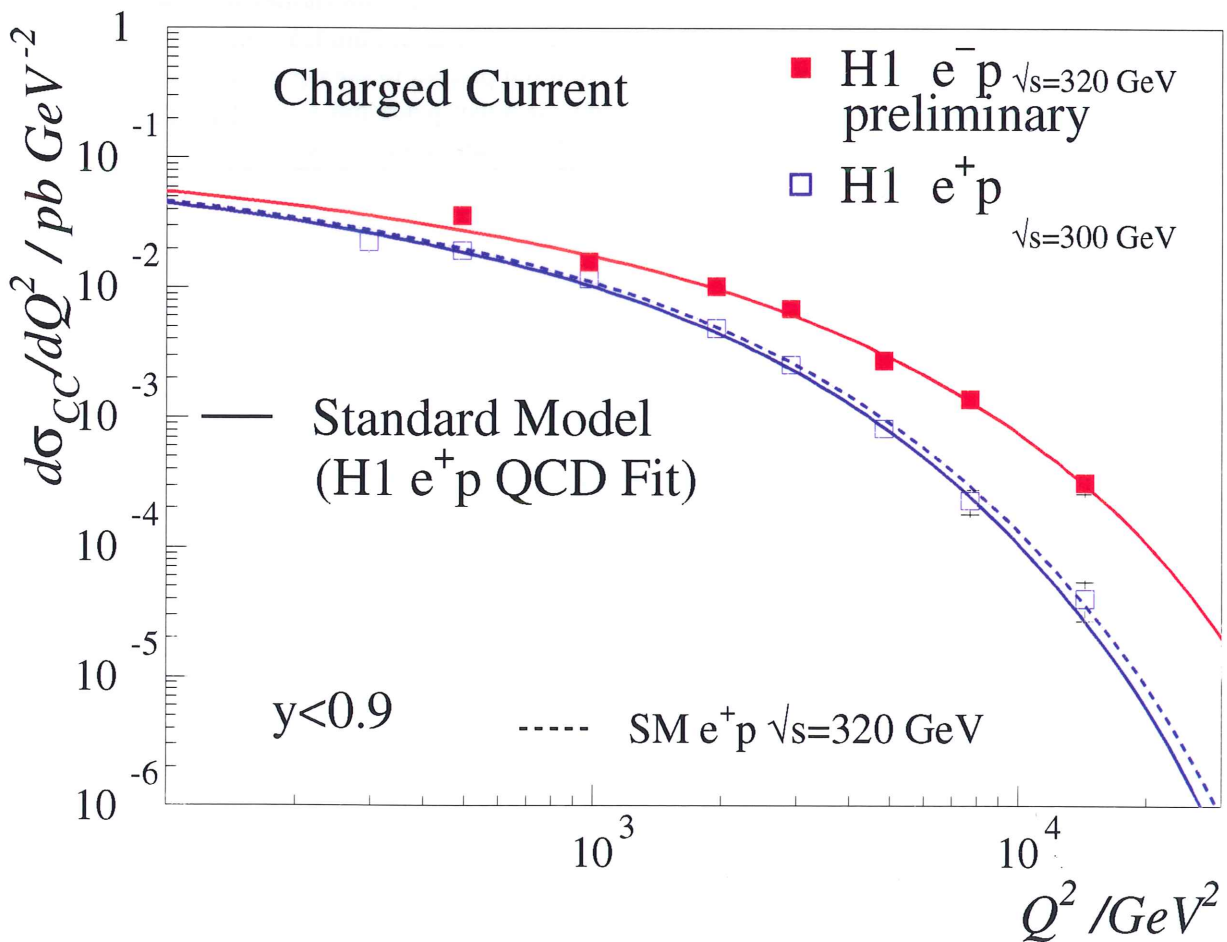
Charged Current x-Distrib.

Precision of the e$^+$p data disentangles individual quark distributions in the scattering process.

Helicity Structure at Short Distance
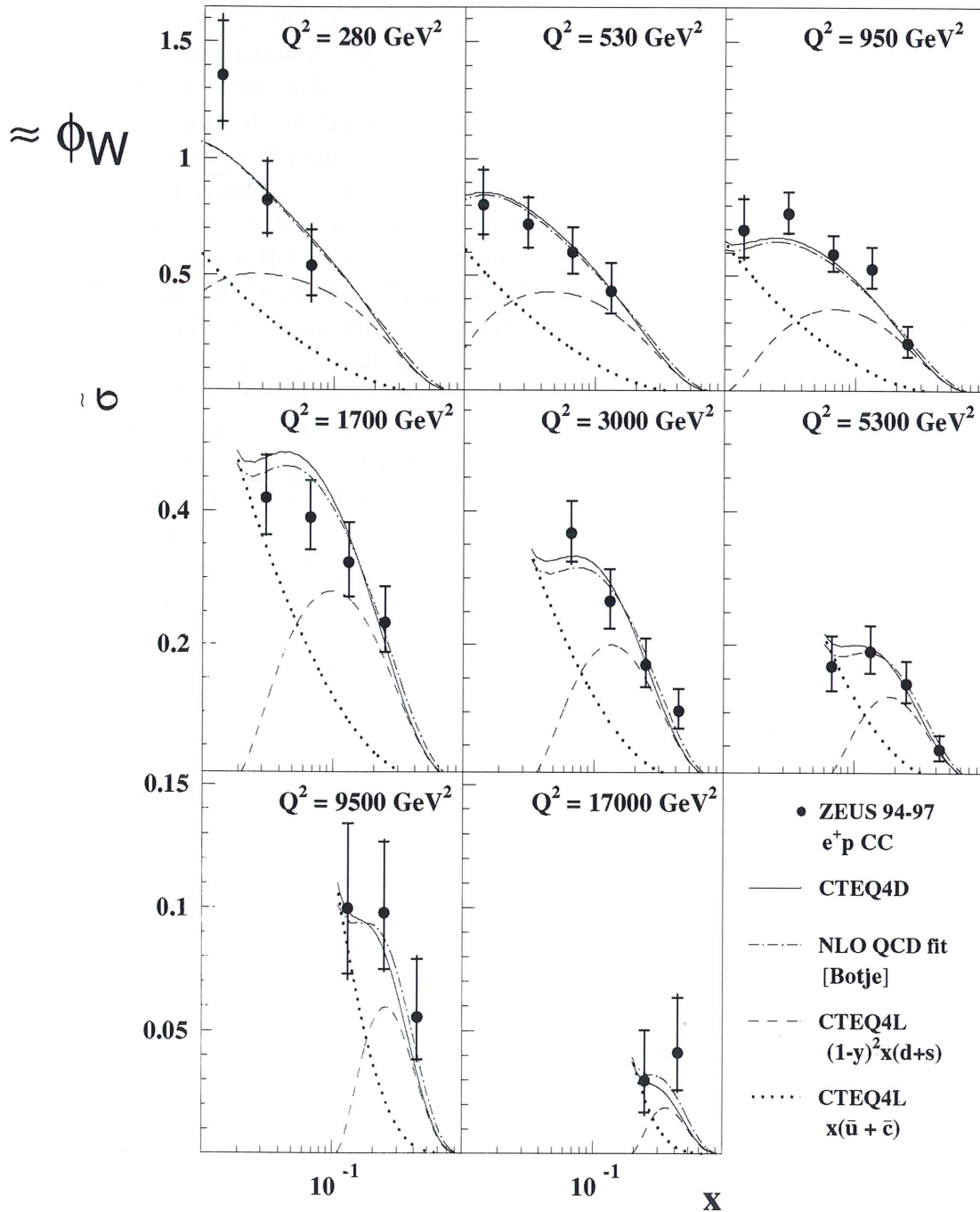
Helicity Structure at Short Distance

NC: $\phi_{\gamma,Z} \sim (1 + (1-y)^2)\left(\dfrac{4}{9}(xu + x\bar{u}) + \dfrac{1}{9}(xd + x\bar{d})\right)$

CC: $\phi_W \sim xu + (1-y)^2 x\bar{d}$ $\phi_W \sim x\bar{u} + (1-y)^2 xd$

$$(1-y)^2 = \cos^4(\Theta^*/2)$$
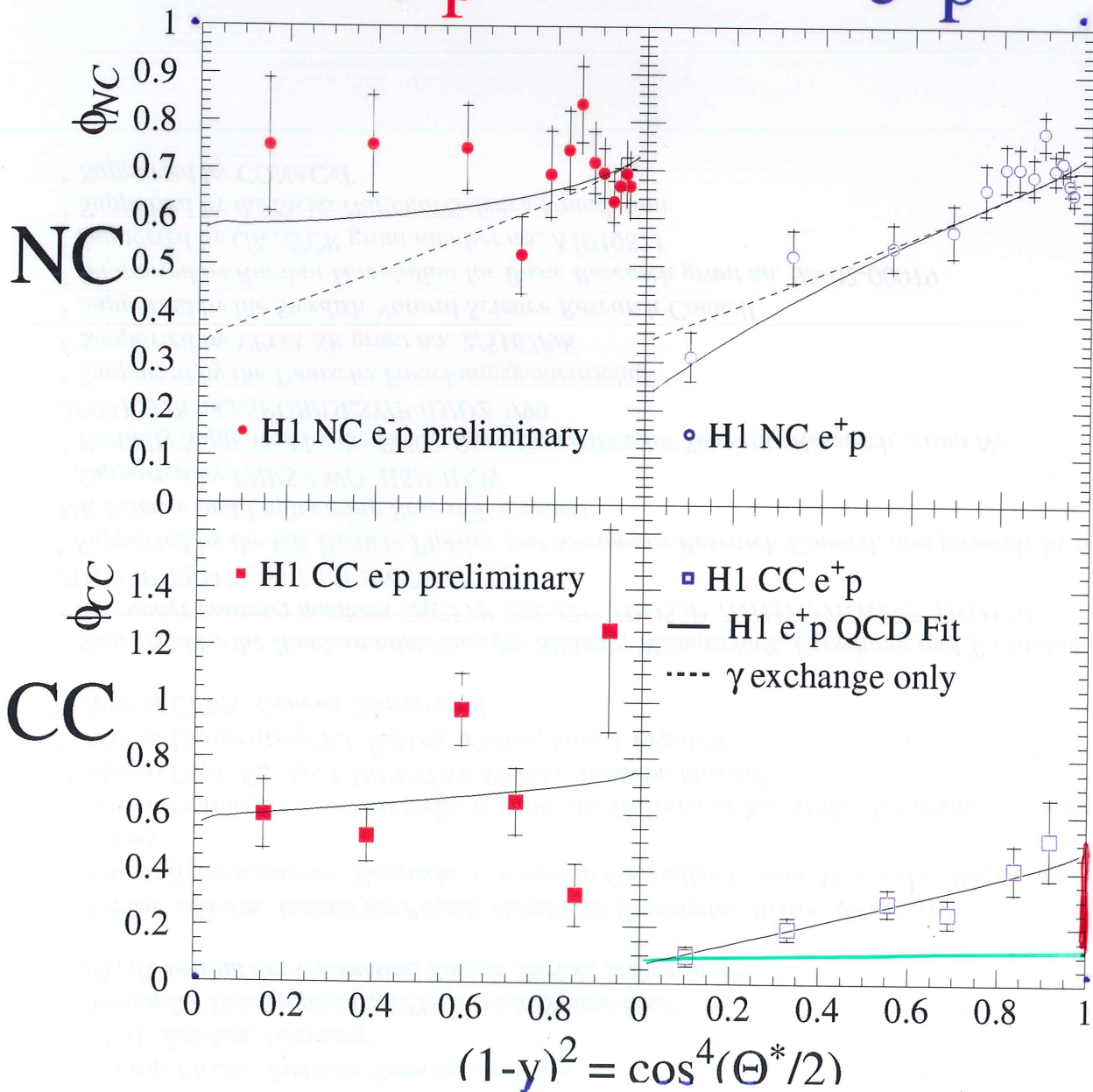
Electroweak Couplings

The "original" electroweak parameters

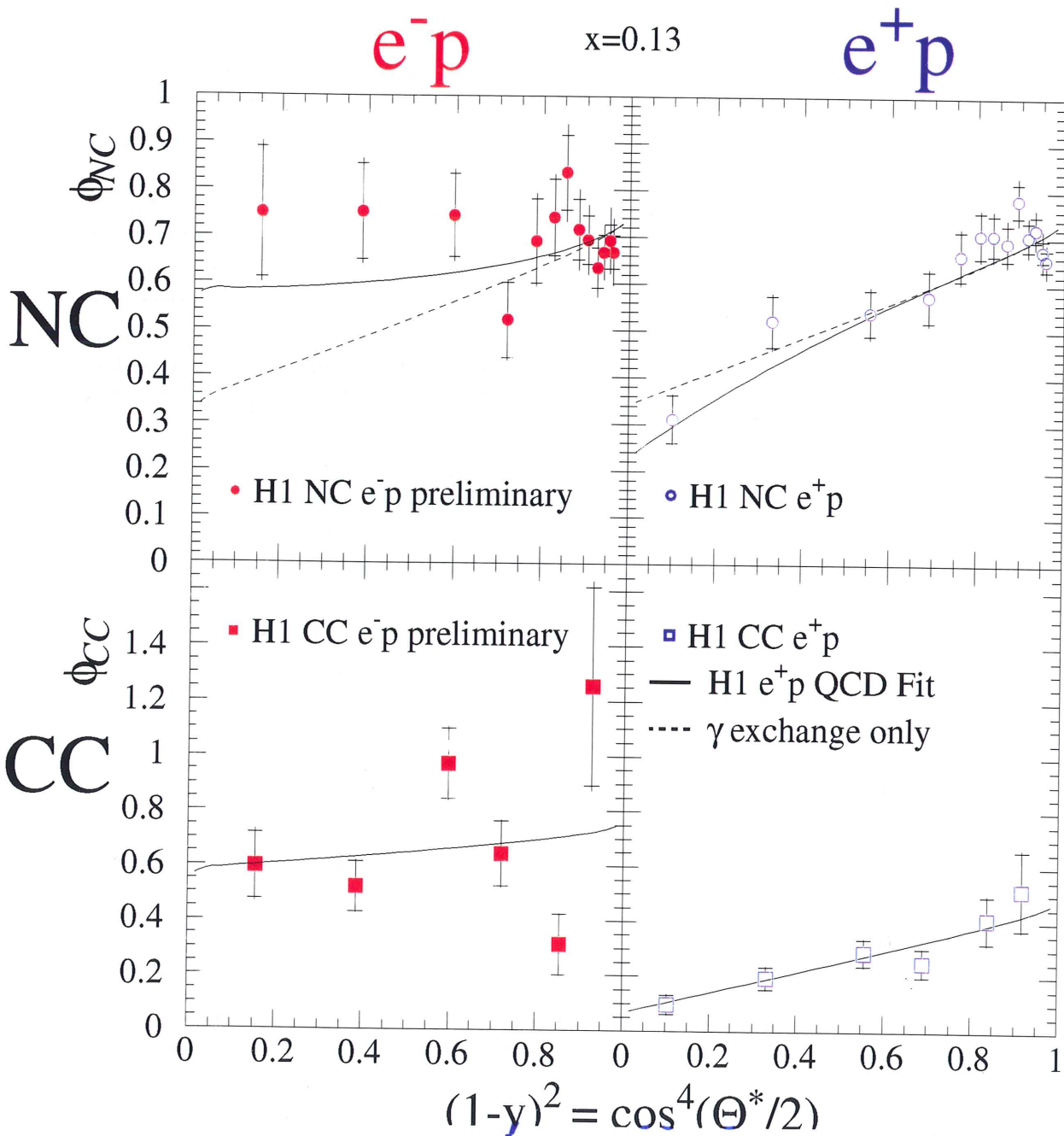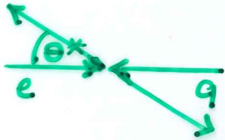$$\alpha, G_F, \sin^2\Theta_W$$

with

$$\Gamma_\mu = G^2 \frac{m_\mu^5}{192\pi^3} \left(1 - \frac{8m_e^2}{m_\mu^2} \right) \left(1 + \frac{\alpha}{2\pi} \left(\frac{25}{4} - \pi^2 \right) \right)$$

have since the advent of LEP/SLC been replaced by the more accurately known parameters

$$\alpha, G_F, M_Z$$

Since then tests of the electroweak model have been performed through its radiative corrections, which may be quoted as a function of other external quantities such as m_{Higgs} and m_{top}, etc.

Electroweak Tests

- LEP/SLC: $\sigma \propto \text{couplings} \times \left(\dfrac{M_Z^2}{s - M_Z^2} \right)^2$, time-like

- HERA: $\sigma \propto \text{couplings} \times \left(\dfrac{M_W^2}{Q^2 + M_W^2} \right)^2 \phi_W$, space-like

Both facilities reach rather similar virtualities.

At HERA Q^2 varies from event to event such that the validity of the model can be simultaneously tested over a large range in Q^2 comparable to the tests in the time-like region at PEP/PETRA, TRISTAN and LEP/SLC.

The purely weak Charged Current process at HERA therefore explores

- the precisely known part at small Q^2 and
- the propagator dependence

$$\frac{d\sigma}{dQ^2} = \sigma^0 \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2 \phi_W$$

assuming precisely known parton distributions and their Q^2 evolution.

Precision of Space-like Tests

A $\approx 3\%$ cross section uncertainty could be cast into an uncertainty of a single electroweak parameter, such as M_W. With

$$\frac{d\sigma}{dQ^2} \propto G^2 \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2 \phi_W \qquad\qquad G = \frac{\pi\alpha}{\sqrt{2}M_W^2 \left(1 - M_W^2/M_Z^2 \right)} \frac{1}{1 - \Delta r}$$

the apparent sensitivity is

$$\frac{\Delta\sigma}{\sigma} \approx 10 \times \frac{\Delta M_W}{M_W}$$

$$3\% \Rightarrow 0.3\%$$

.ZEUS get:

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

as expected.

Note $\frac{\Delta G}{G} = 20 \times 10^{-9}$ from τ_μ.

Conclusion

With luminosities of ≈ 50 pb^{-1} HERA starts to explore the high Q^2 sector of the SM:

- parton distributions extrapolate well into the high Q^2 regime (QCD)

- start to distinguish u and d in a single experiment (flavour separated parton couplings!)

- helicity structure probed at $\approx 10^{-3}$ fm

- Z^0 contributions observed in NC scattering a high Q^2

- Charged Current consistent with a single propagator

- HERA measures propagator mass to ≈ 2 GeV, consistent with M_W

but

- high x, high Q^2 region needs more data for clarification