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

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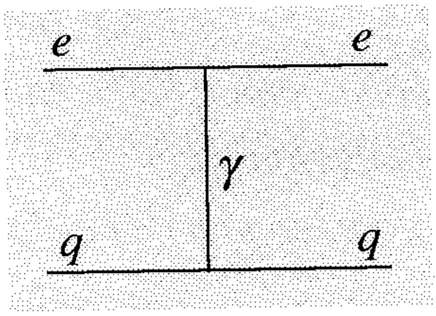
for the H1 and ZEUS Collaborations

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)



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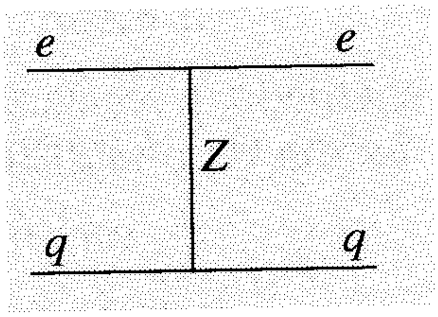
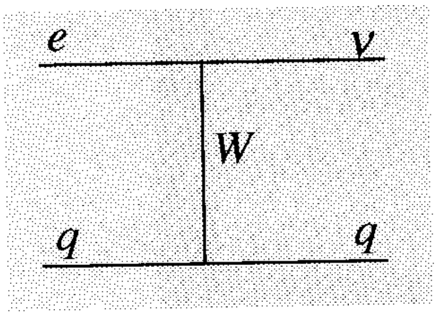


$$\frac{d^2\sigma}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\phi_{\gamma,Z} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2)\right]$$

with $Y_\pm = 1 \pm (1-y)^2$ for $e^{+/-}$

Charged Current (CC)



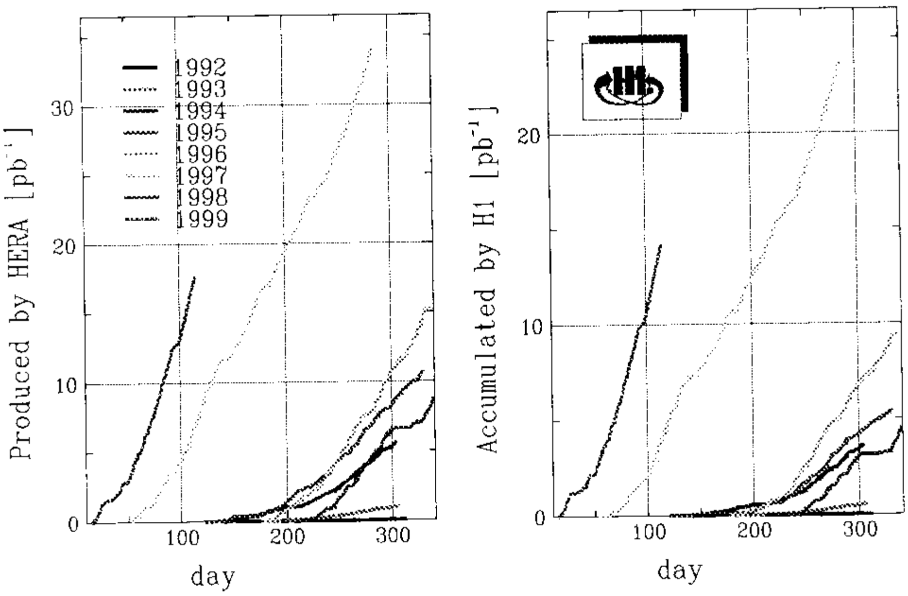
$$\frac{d^2\sigma}{dx dQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \phi_W$$

$\phi_{\gamma,Z}$, ϕ_W comprise: structure of the proton
propagators and electroweak couplings

$\approx$ quark densities

Data Sample

INTEGRATED LUMINOSITY

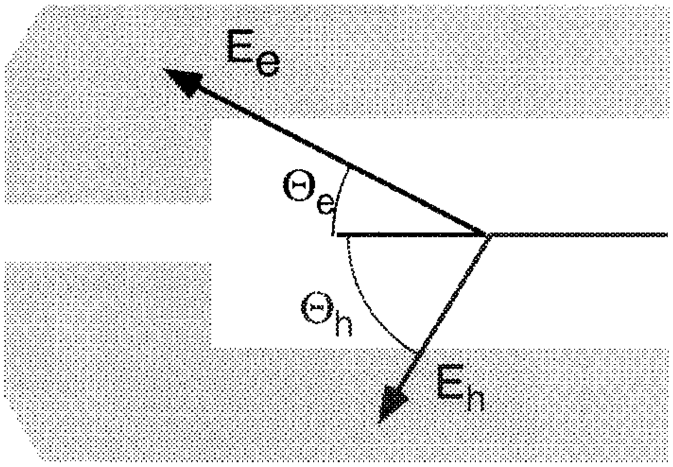


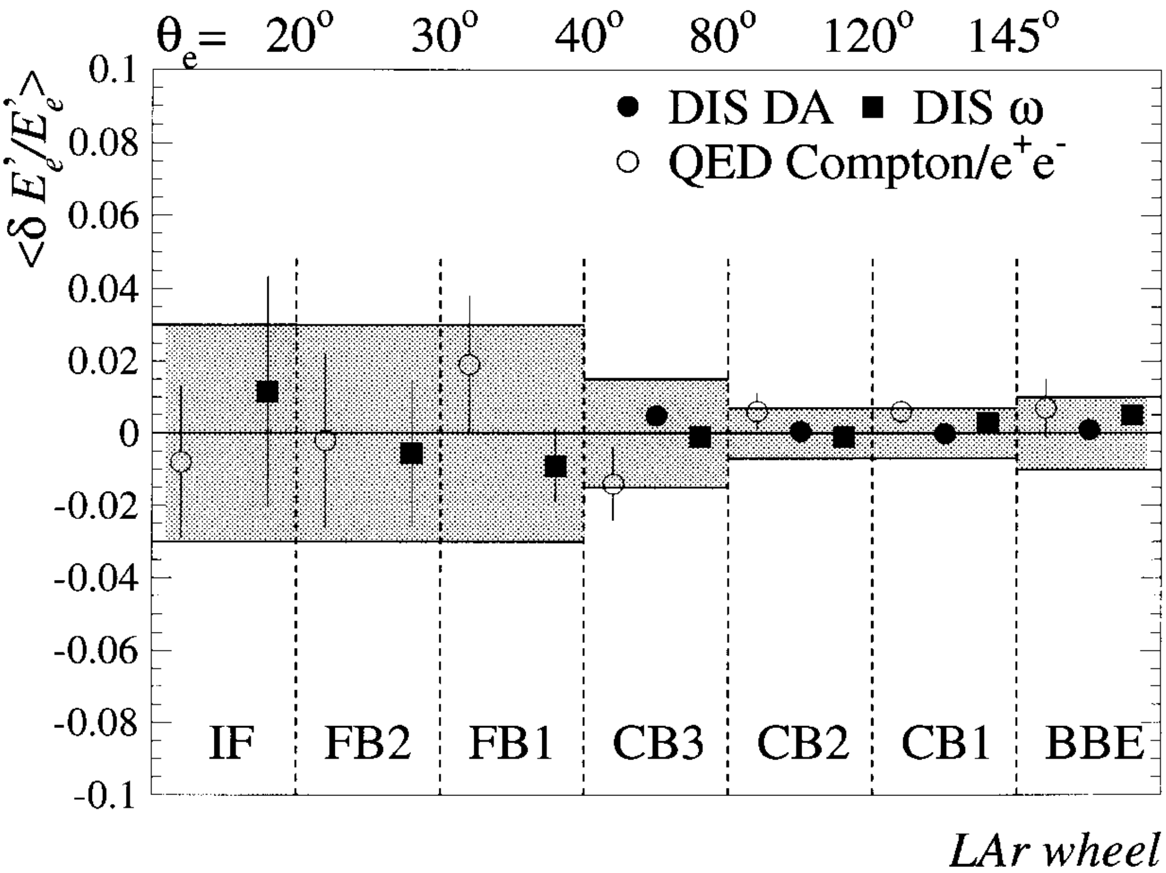
For this conference

	E_p	H1	ZEUS
e^+p	820 GeV	37 pb^{-1}	48 pb^{-1}
e^-p	920 GeV	14 pb^{-1}	6 pb^{-1}

Experimental Accuracy

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



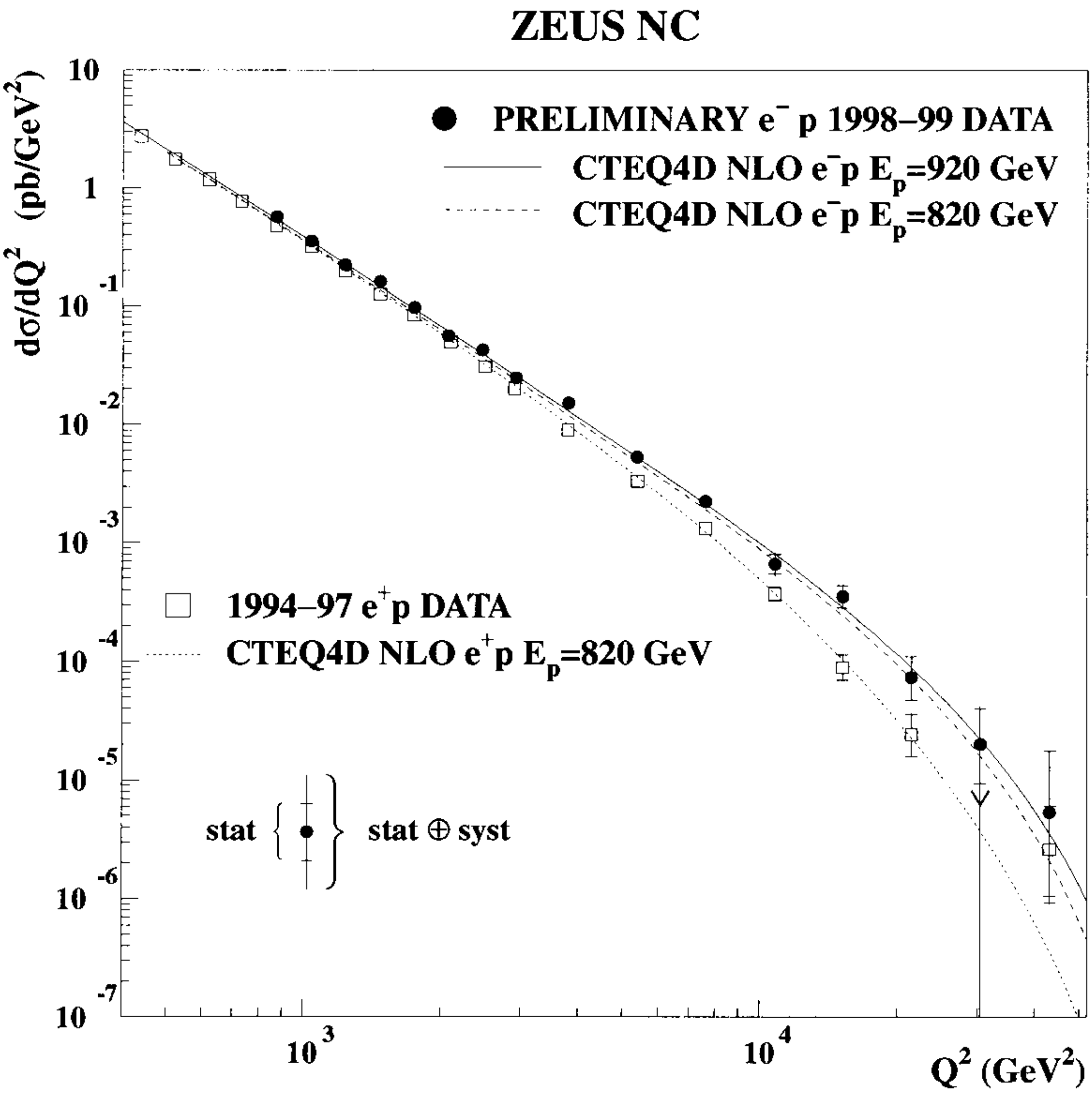


Neutral Currents

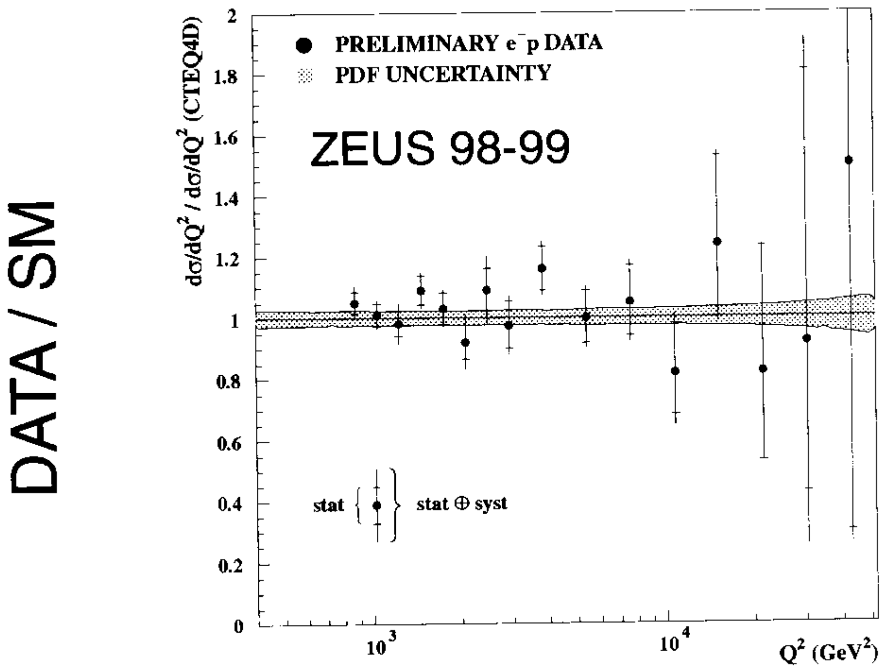
$$\frac{d^2}{dxdQ^2}\sigma(e^{\pm}p) = \frac{2\pi\alpha^2}{xQ^4}\phi_{\gamma,Z}$$

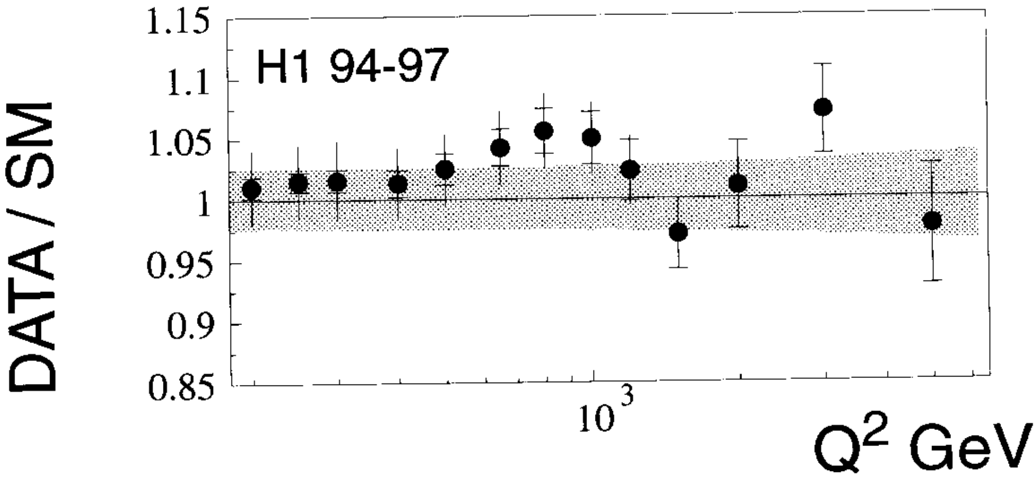
Observe the proper charge dependence:

- γZ interference



Neutral Currents cont'd

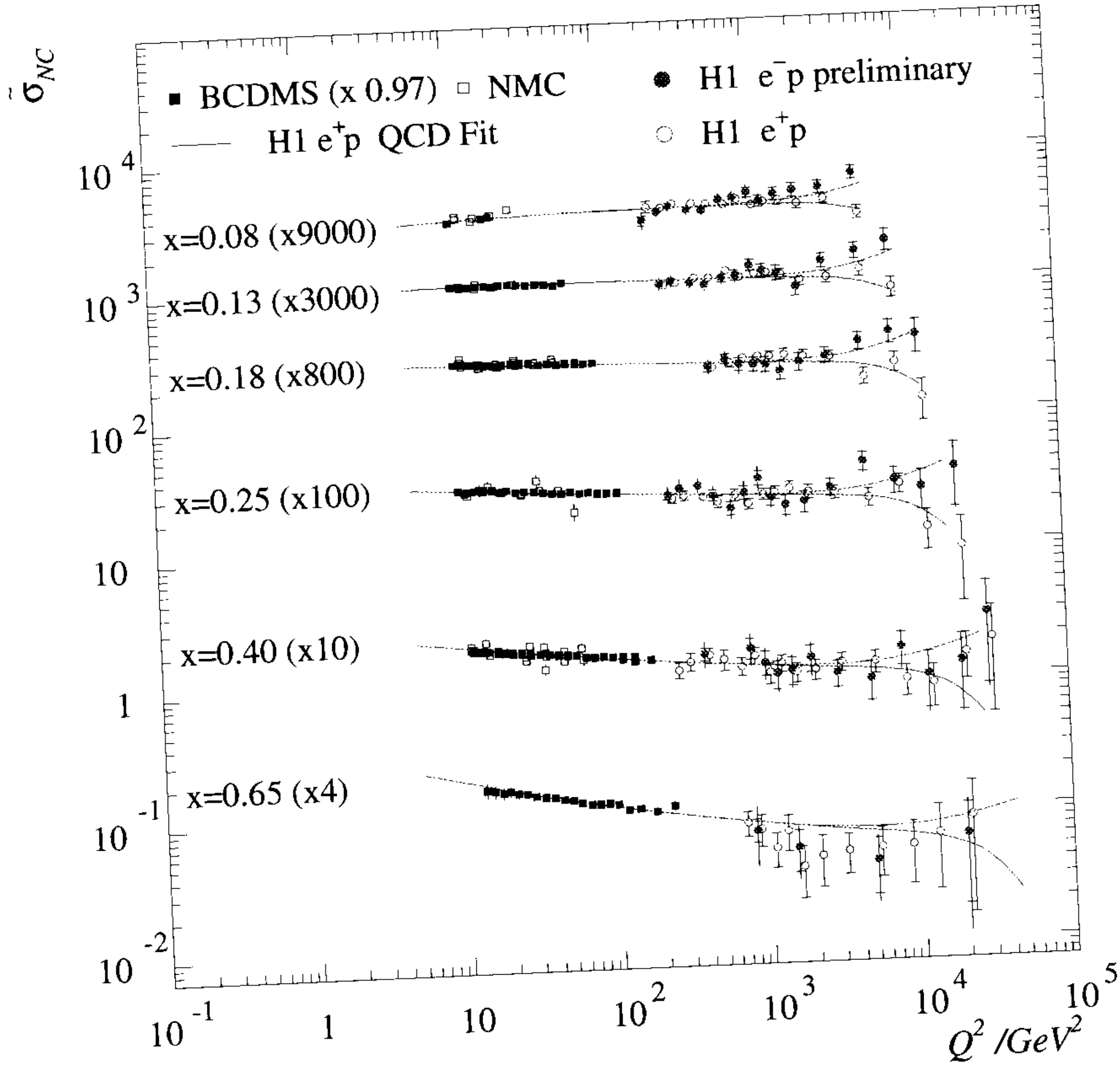




NC at high x

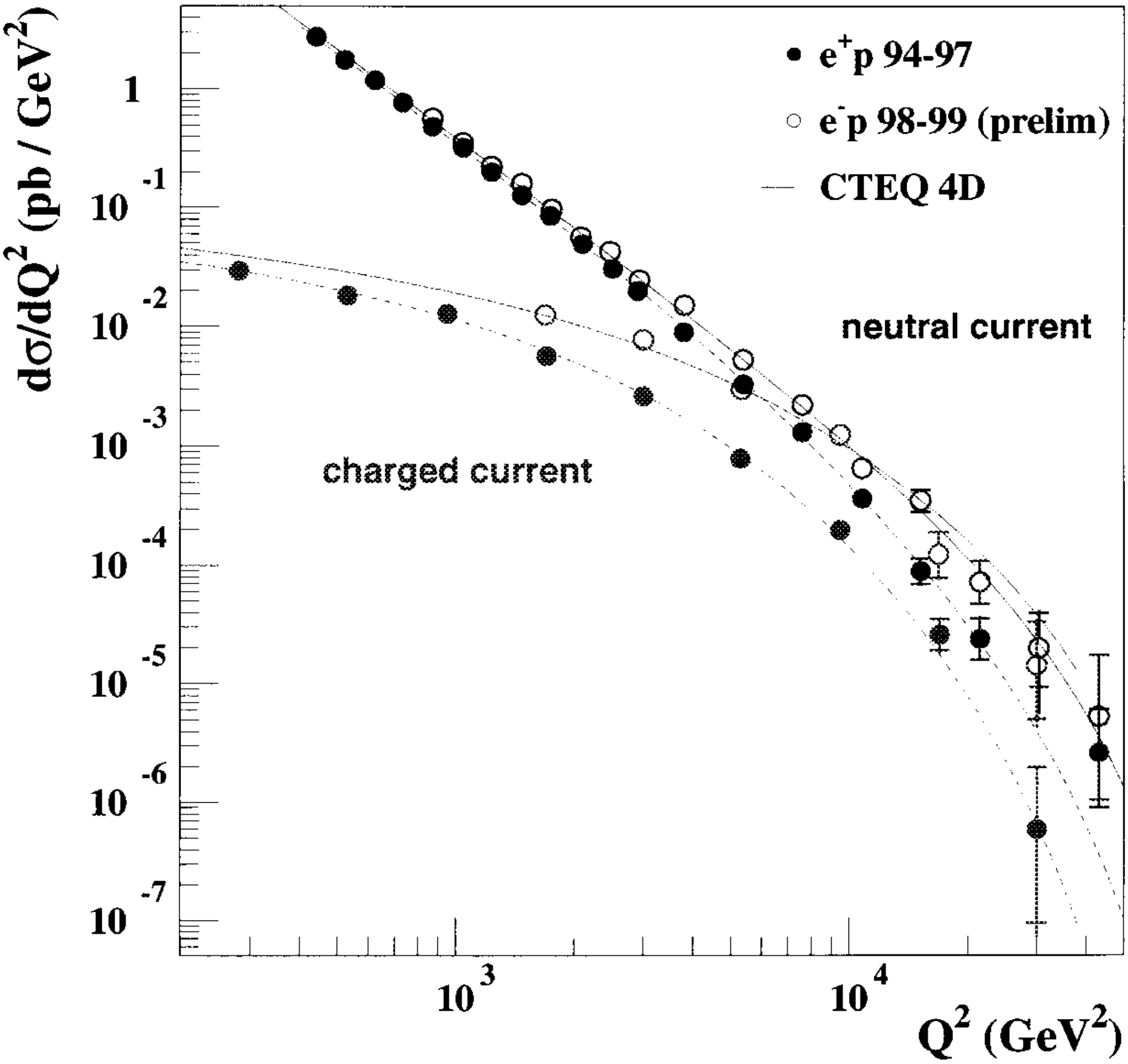
$$\tilde{\sigma} = \left[\frac{2\pi\alpha^2}{xQ^4}Y_+\right]^{-1}\frac{d^2\sigma}{dxdQ^2}$$

- 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

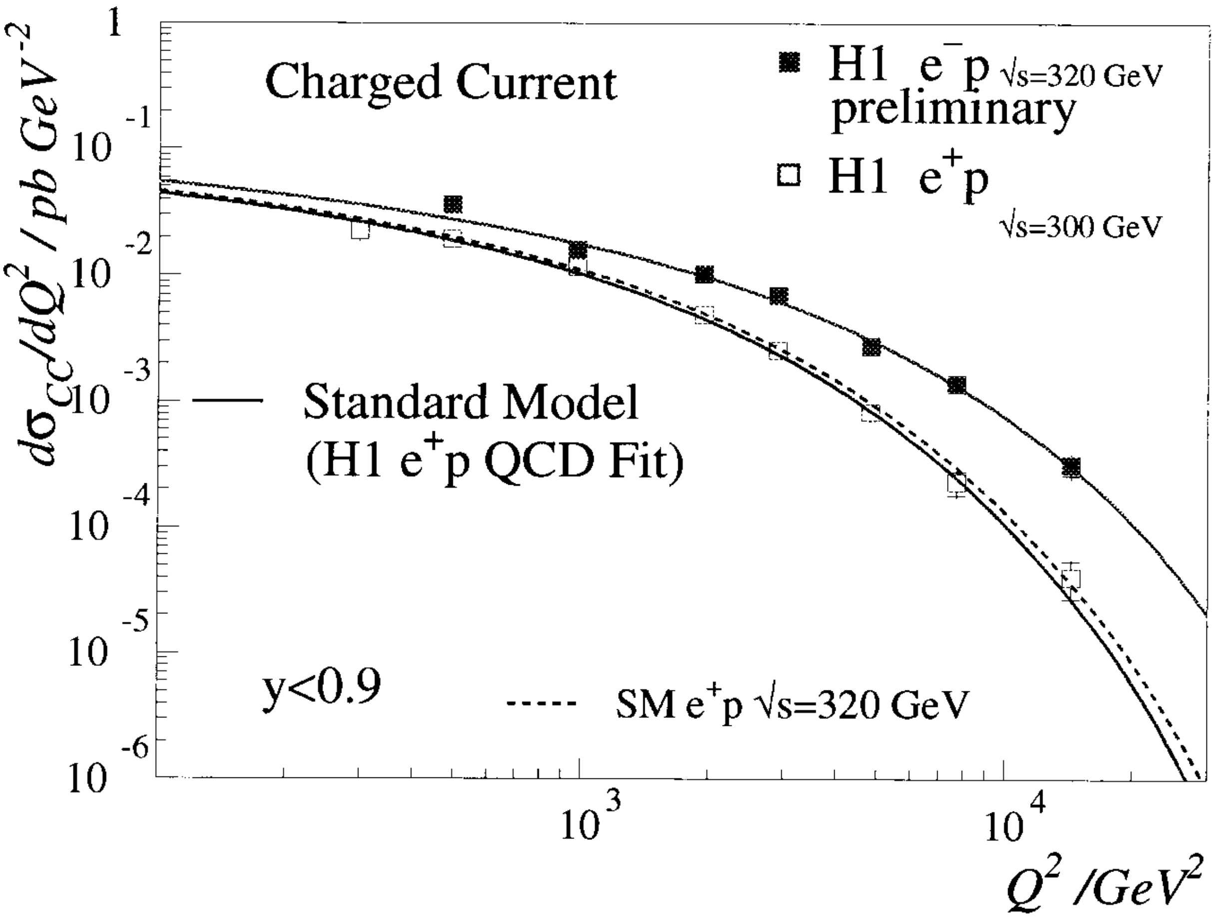
Charged Current

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

At high Q^2 coupling to valence quarks prevails:

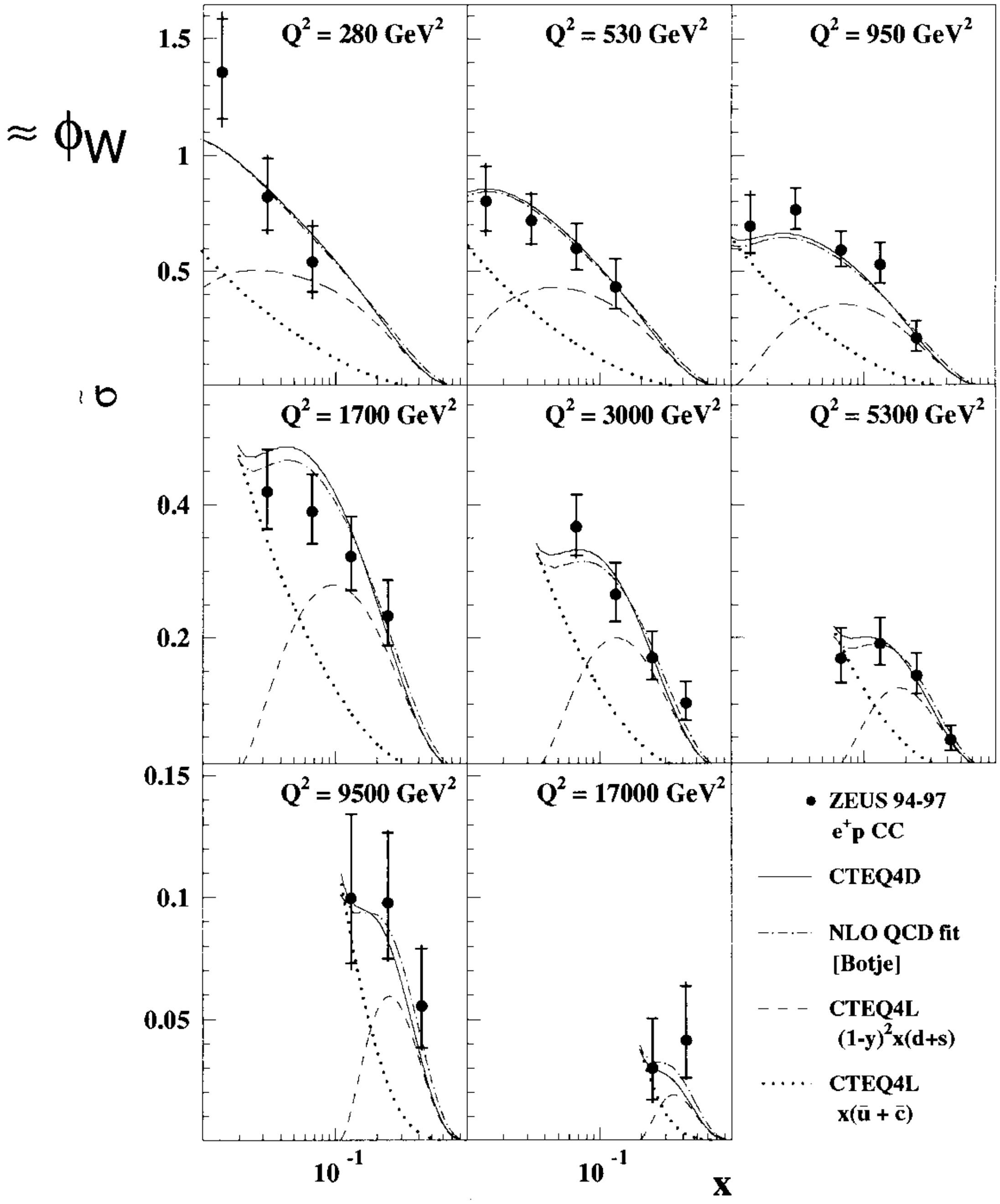
$\Leftarrow \Rightarrow$ $\Rightarrow \Rightarrow$

e^-: $\phi_W \sim xu$ e^+: $\phi_W \sim (1-y)^2 xd$



Charged Current x-Distrib.

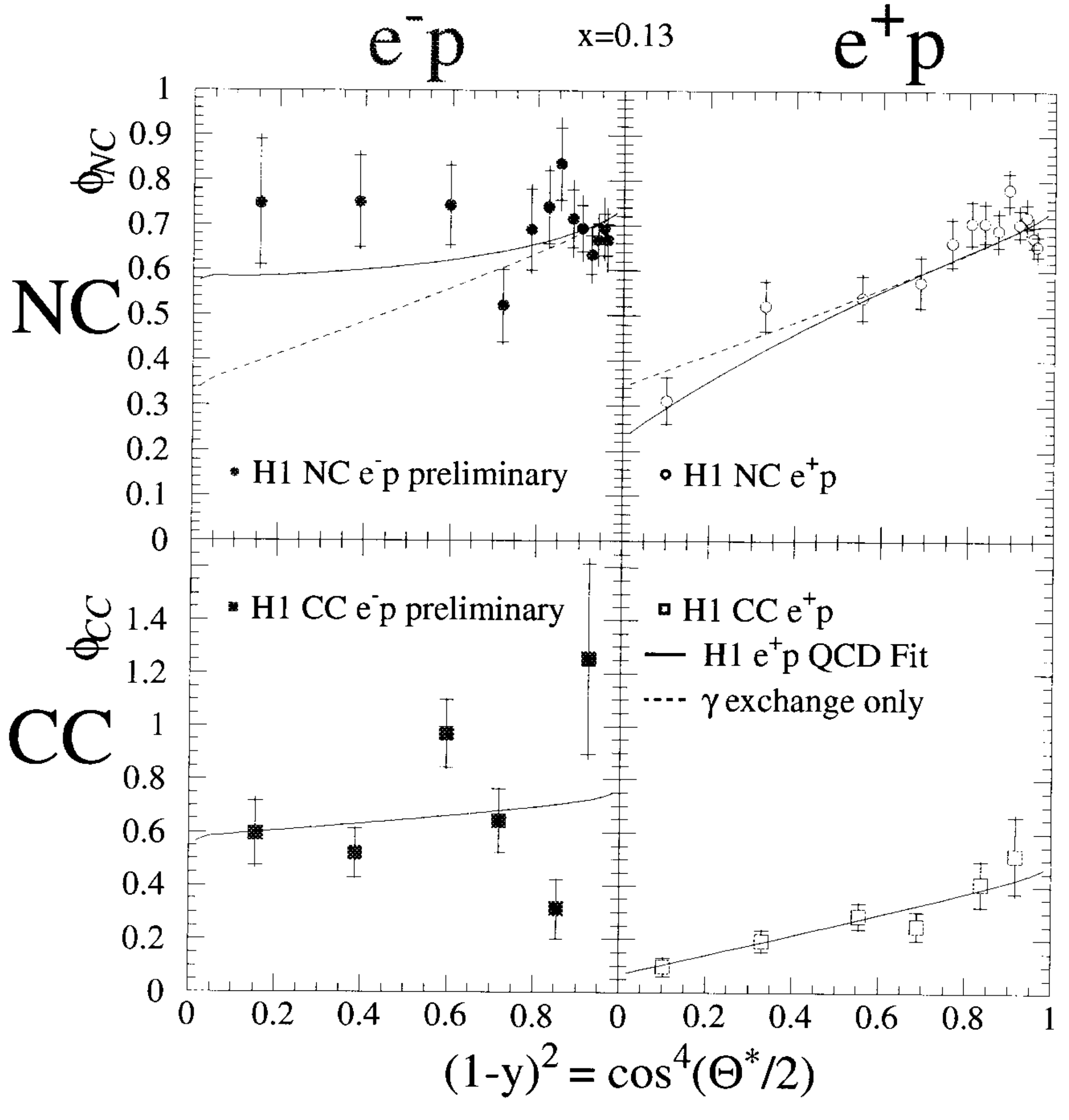
Precision of the e^+p data disentangles individual quark distributions in the scattering process.



Helicity Structure at Short Distance

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

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



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

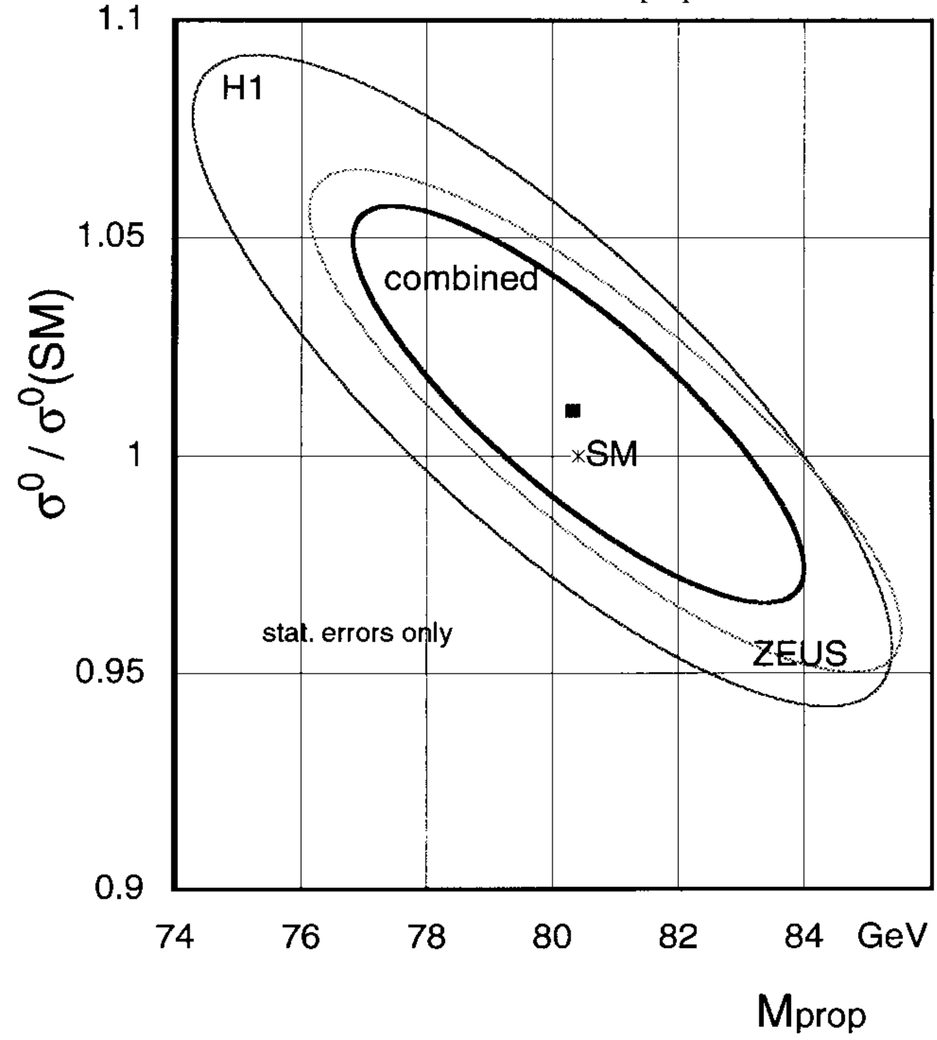
- the precisely known part at small Q^2 and
- the propagator dependence

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

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

CC Cross Section and W-Propagator

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



for fixed normalisation:

$$M_{prop} = \begin{array}{l} 80.9 \pm 3.3(\text{stat.}) \pm 1.7(\text{syst.}) \pm 3.7(\text{pdf})\ \text{GeV}\ \ \text{H1} \\ 81.4^{+2.7}_{-2.6}(\text{stat.}) \pm 2.0(\text{syst.})^{+3.3}_{-3.0}(\text{pdf})\ \text{GeV ZEUS} \end{array}$$

Precision of Space-like Tests

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

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

the apparent sensitivity is

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

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

.ZEUS get:

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

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 ≈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