Proton structure at High Q^2 from HERA

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CPPM

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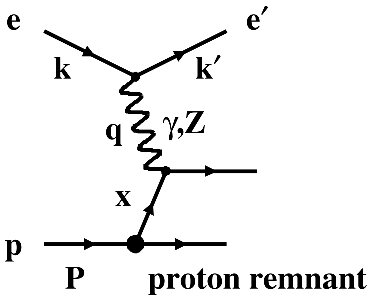
On Behalf of

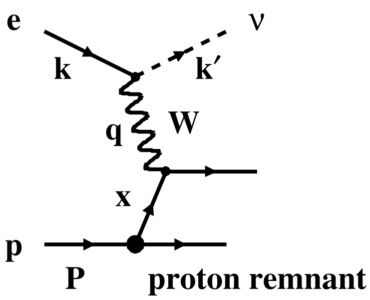
- Introduction
- Experimental Setup
- CC and NC cross sections at high Q^2
- Proton structure at high Q^2
- Summary and Outlook

Deep Inelastic Scattering (DIS)

probe the proton in lepton-proton collisions



NC



CC

Kinematic variables:

$$Q^2 = -(k - k')^2 = -q^2$$ Negative square boson mass

$$x = \frac{Q^2}{2P \cdot q}$$ Bjorken Scaling variable

$$y = \frac{P \cdot q}{P \cdot k}$$ Fraction of energy transfer

Only two independent: $Q^2 = xys$

DIS CC/NC cross sections

DIS Processes:

- Neutral Current (NC): $ep \rightarrow eX$

$$\frac{d^2\sigma^{\pm}_{\mathrm{NC}}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \underbrace{\left[Y_+ F_2(x,Q^2) - y^2 F_L(x,Q^2) \mp Y_- x F_3(x,Q^2)\right]}_{\substack{\tilde{\sigma}_{\mathrm{NC}} \\ \Phi_{\mathrm{NC}}}}$$

with $Y_{\pm} \equiv 1 \pm (1-y)^2\,,\qquad F_2 = F_2^{\mathrm{em}}(1+\delta_Z)$

- Charged Current (CC): $ep \rightarrow \nu X$

$$\frac{d^2\sigma^{\pm}_{\mathrm{CC}}}{dx dQ^2} = \mathcal{K} \underbrace{\left[Y_+ F_2^{\mathrm{CC}}(x,Q^2) - y^2 F_L^{\mathrm{CC}}(x,Q^2) \mp Y_- x F_3^{\mathrm{CC}}(x,Q^2)\right]}_{\substack{\sigma_{\tilde{\mathrm{CC}}} \\ \Phi_{\mathrm{CC}}}}$$

with $\mathcal{K} \equiv \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2$

Experimental Setup

HERA: First ep collider ever built

27.5 GeV e^+ or e^- $\rightarrow$ $\leftarrow$ **820/920 GeV p**

$\sqrt{s}$=300-320 GeV

$\Longleftrightarrow$ ~ 50 TeV lepton beam for a fixed target exp.

New Kinematic Domain explored at HERA

Proton probed down to 10^{-18}m

H1 and ZEUS Detectors:

NC: both scattered electrons and hadronic final state measured
kinematics over constrained by several methods
$150 < Q^2 < 40000$ GeV^2 $0.0032 < x < 0.65$

CC: Neutrinos escaping detection leave measurable missing momentum
kinematics only with hadronic method
$200 < Q^2 < 60000$ GeV^2 $0.01 < x < 0.65$

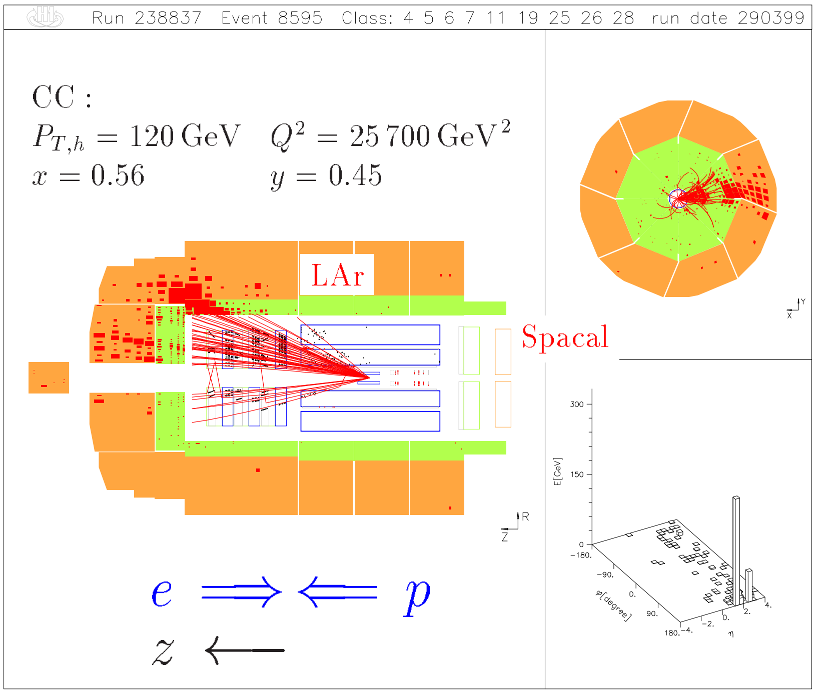
$$\mathbf{Q^2 \nearrow M^2_{W^\pm,Z}}$$

Data Samples

		H1	ZEUS	pb^{-1}
$'94 -' 97 : \sqrt{s} \simeq 300$ GeV	$(27.5\,e^+ \times 820\,p)$	35.6	47.7	
$'98 -' 99 : \sqrt{s} \simeq 320$ GeV	$(27.5\,e^- \times 920\,p)$	15.3	$16_{NC}/6.3_{CC}$	
$'99 -' 00 : \sqrt{s} \simeq 320$ GeV	$(27.5\,e^+ \times 920\,p)$	doubling statistics		

H1 and ZEUS Detectors

H1 Liquid Argon Calorimeter(LAr):



LAr: 45000 cells

$\sigma_{\theta_{e'}}: 1 - 3\,\mathrm{mrad}$

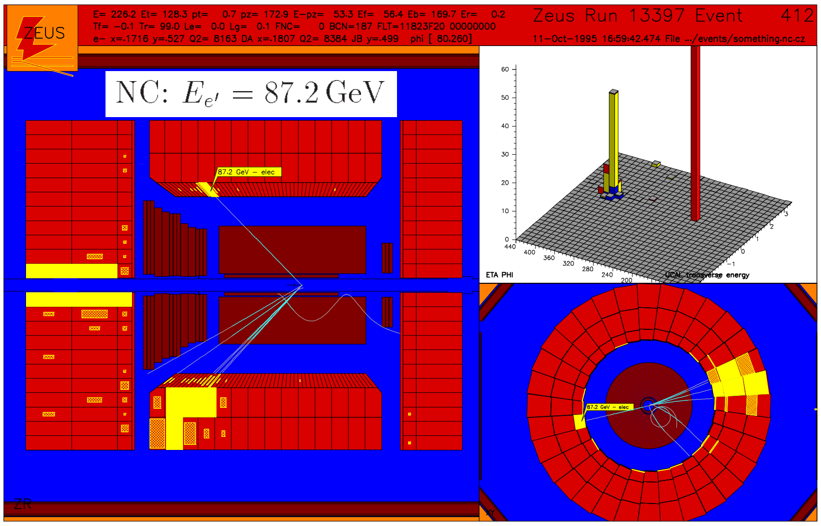
$\sigma(E)/E:$

$$\begin{cases} 12\%/\sqrt{E} & \text{LAr em} \\ 50\%/\sqrt{E} & \text{LAr had} \end{cases}$$

$\Delta E/E(\mathrm{syst}):$

$$\begin{cases} 1 - 3\% & \text{LAr em} \\ 2 - 4\% & \text{LAr had} \end{cases}$$

ZEUS Uranium-Scintillator Calorimeter(UCAL):



UCAL: 6000 cells

$\sigma_{\theta_{e'}}: 1\,\mathrm{mrad}$

$\sigma(E)/E:$

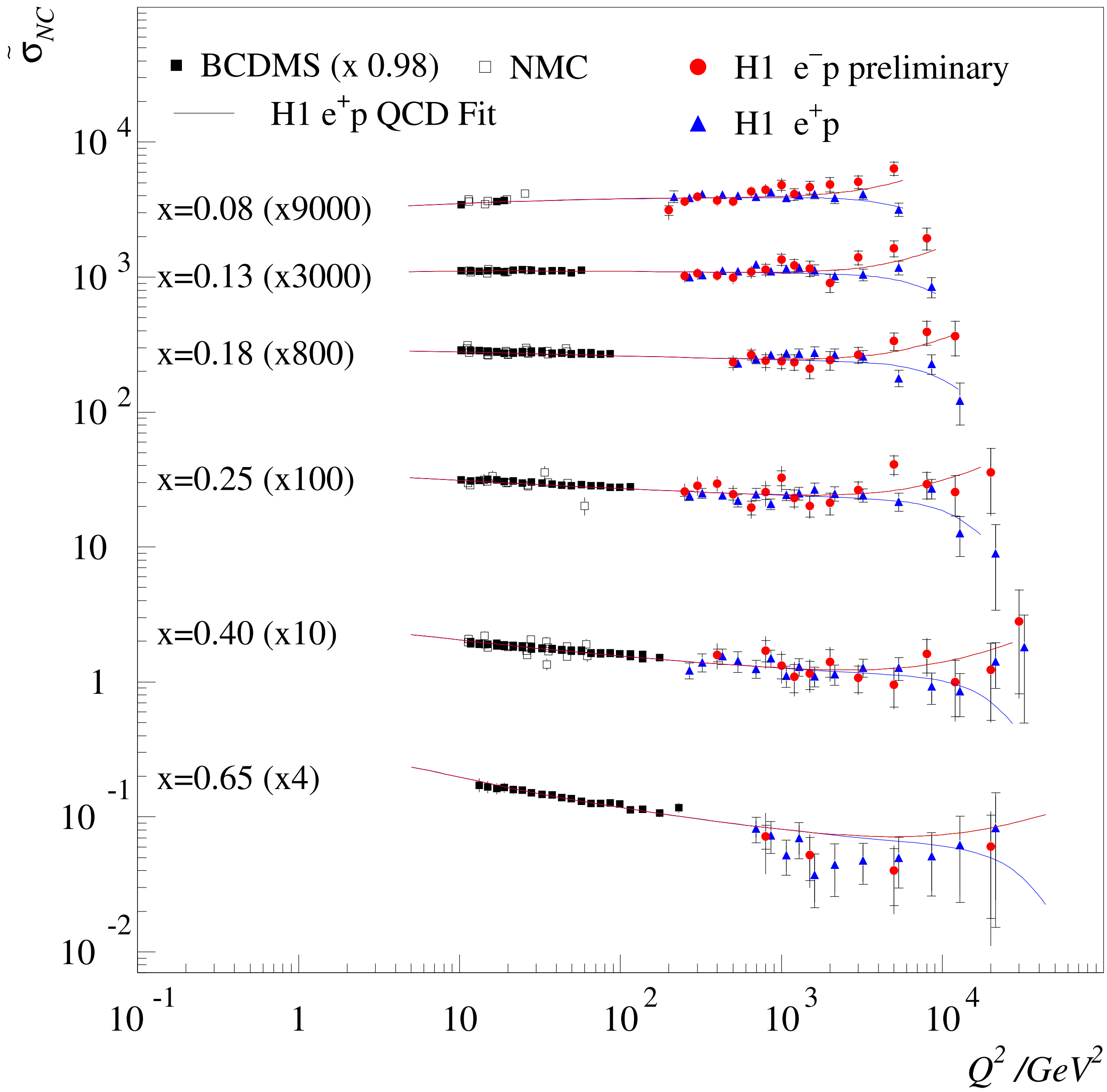
$$\begin{cases} 18\%/\sqrt{E} & \text{em} \\ 35\%/\sqrt{E} & \text{had} \end{cases}$$

$\Delta E/E(\mathrm{syst}):$

$$\begin{cases} 1 - 2\% & \text{em} \\ 2\% & \text{had} \end{cases}$$

NC Cross-sections at High x, Q^2

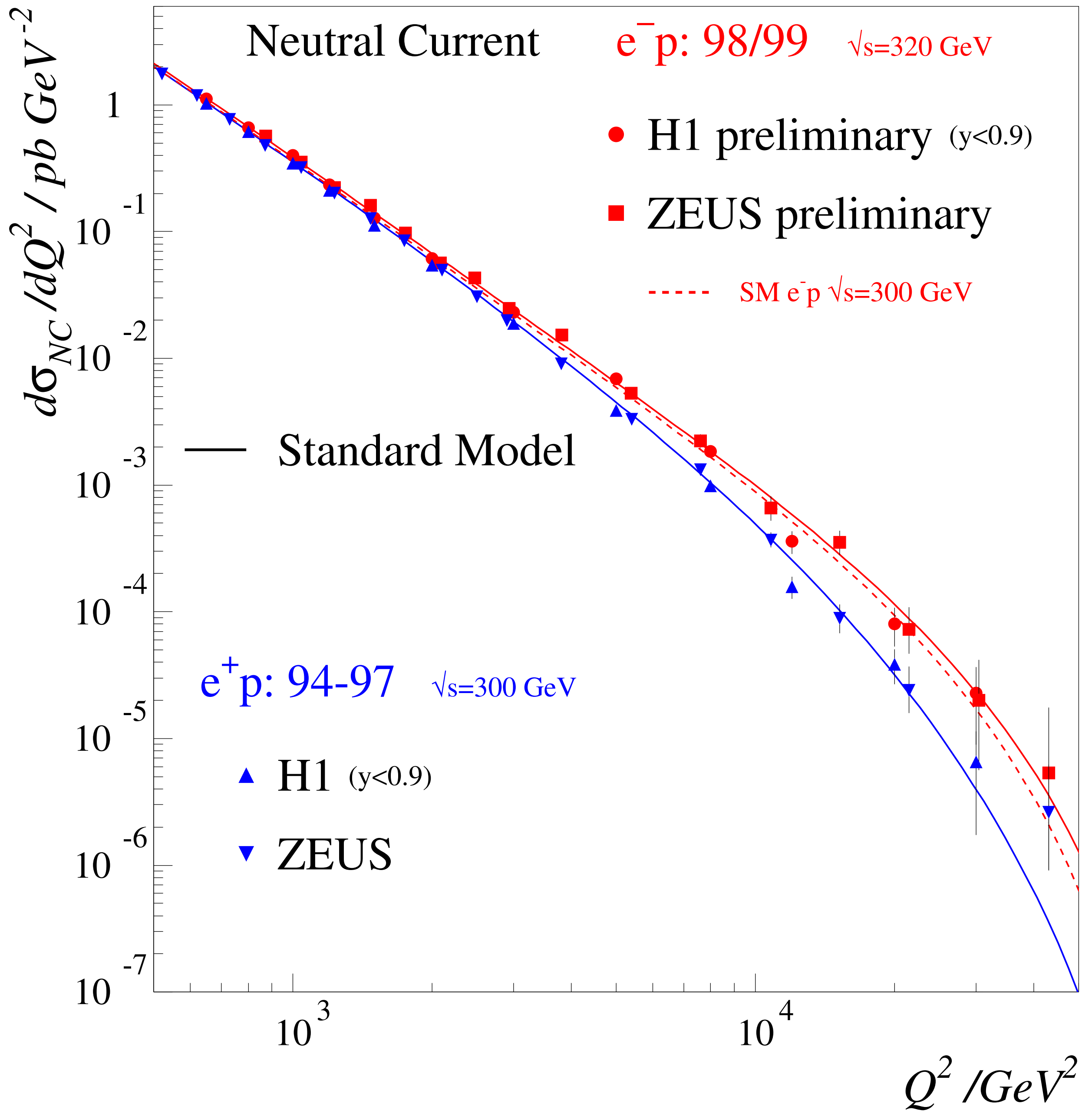
$$\tilde{\sigma}_{NC} = \left[\frac{2\pi\alpha^2}{xQ^4}Y_+\right]^{-1} \frac{d^2\sigma^{\pm}_{NC}}{dxdQ^2} \sim F_2 \mp \underbrace{\frac{Y_-}{Y_+}}_{\text{increase with y}} xF_3$$



⇒ **Parity violating term xF_3 at high Q^2 clearly visible**

⇒ **Excess in e^+p at $x = 0.4$ needs clarification**

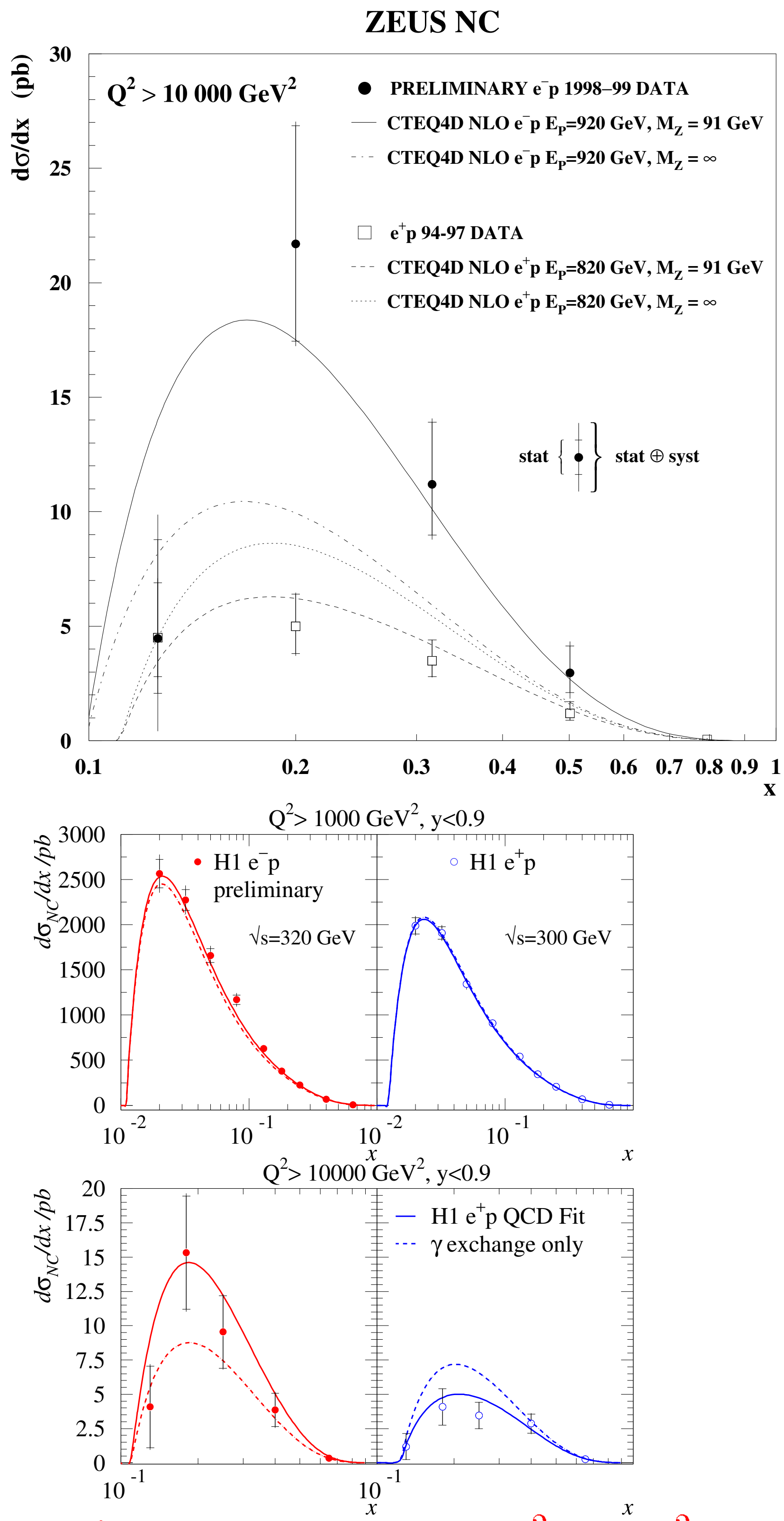
NC Cross-sections: Q^2 Dependence



⇒ **Precision at high Q^2 statistically limited**

⇒ **Charge dependence experimentally established**

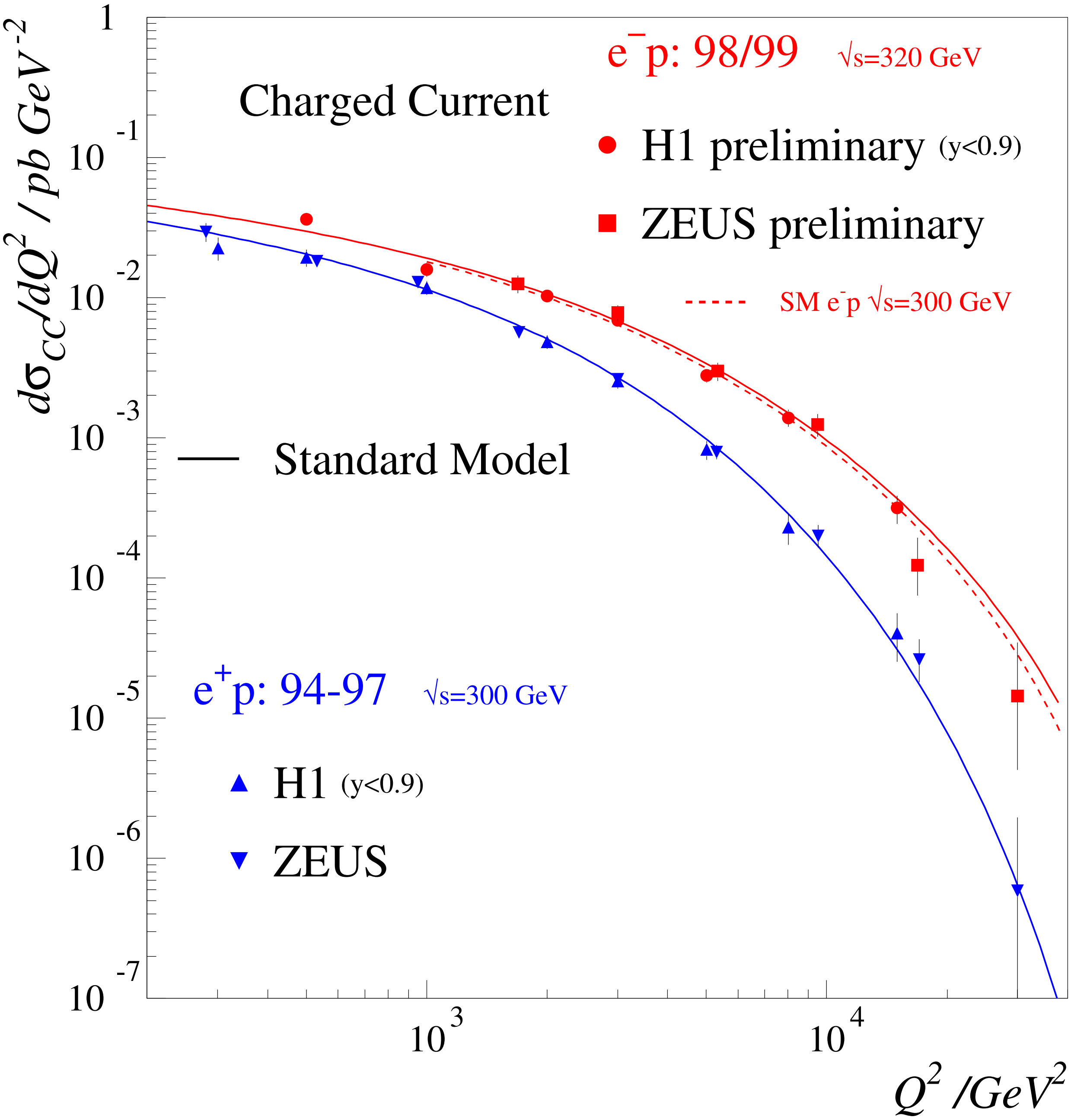
NC Cross-section x dependence



$\Rightarrow$ **γ-Z interference at $Q^2 \sim M_Z^2$**

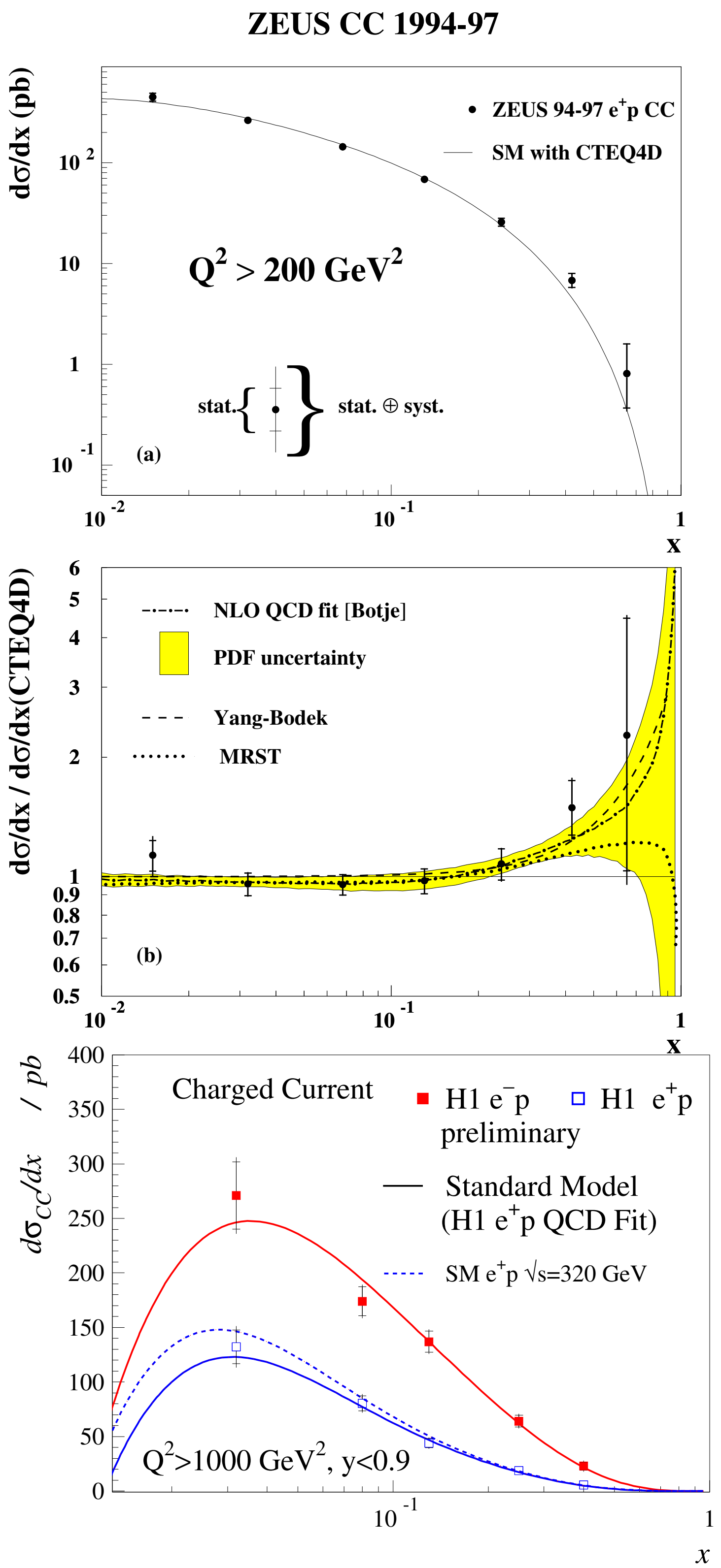
CC Cross-sections: Q^2 Dependence

$e^- p$: $d\sigma/dQ^2 \sim xu$ $\qquad$ $e^+ p$: $d\sigma/dQ^2 \sim (1-y)^2 xd$



⇒ **Flavor dependence experimentally established**

CC Cross-section: x dependence

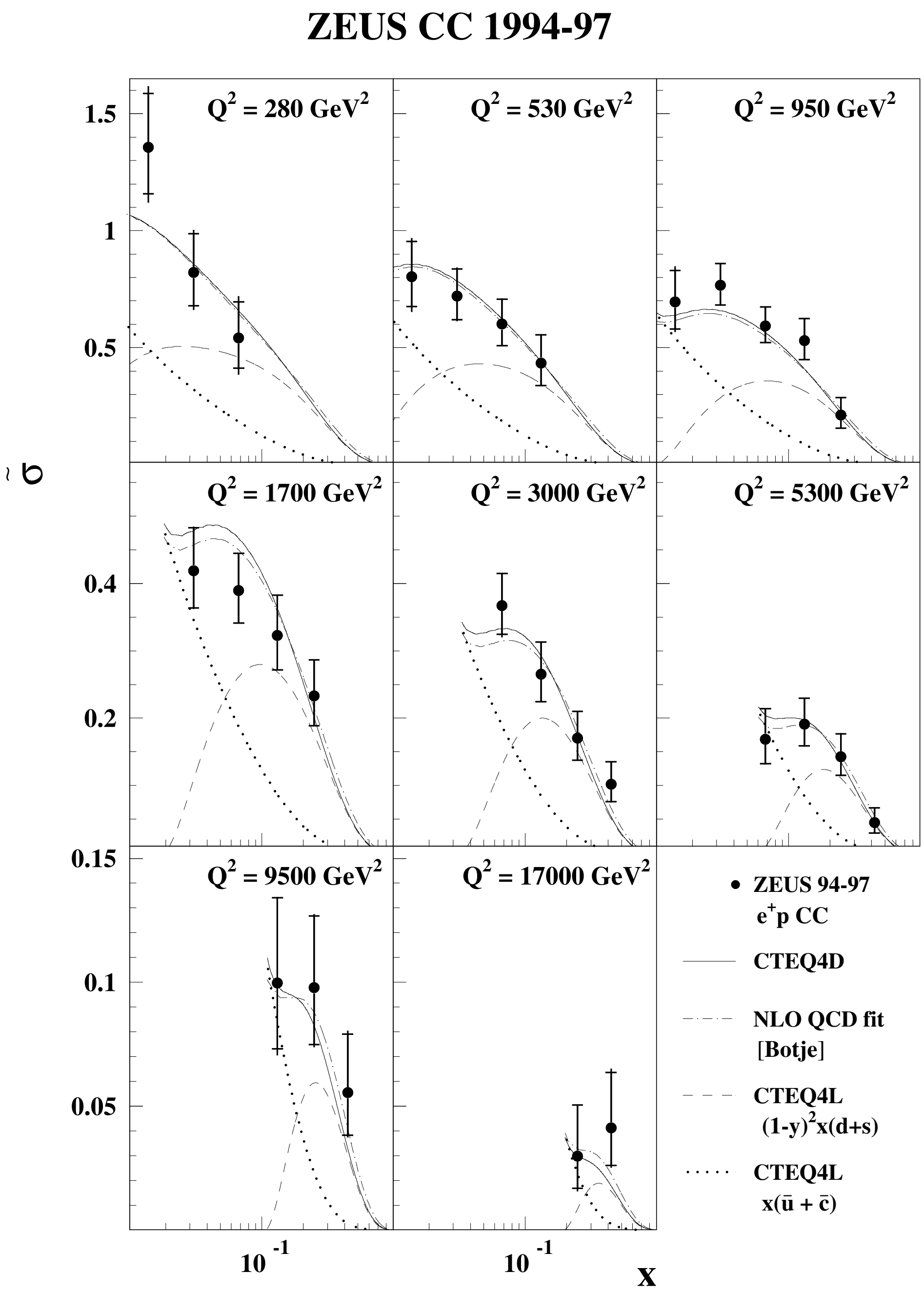


Good agreement to SM

factor 2(4) @ low(high) x between e^-/e^+

$\mathrm{e}^{+}\mathrm{p}$: CC Cross-section Probing xd

CC e^+p: $\tilde{\sigma} \sim \mathbf{x}(\overline{\mathbf{u}}+\overline{\mathbf{c}})+(\mathbf{1}-\mathbf{y})^2\mathbf{x}(\mathbf{d}+\mathbf{s})$



⇒ CC Data have flavor separation power

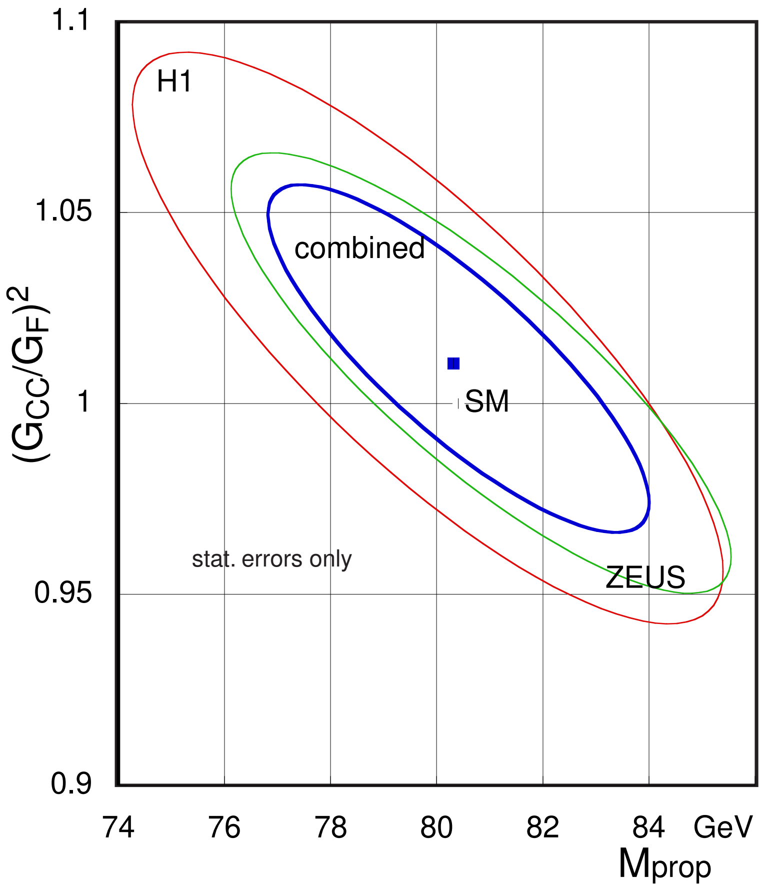
Propagator Mass M_W

$$CC: \quad \sigma \propto G_F^2 \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2$$ Space-like process

G_F fixed to precisely measured value
Measured propagator mass M_W:

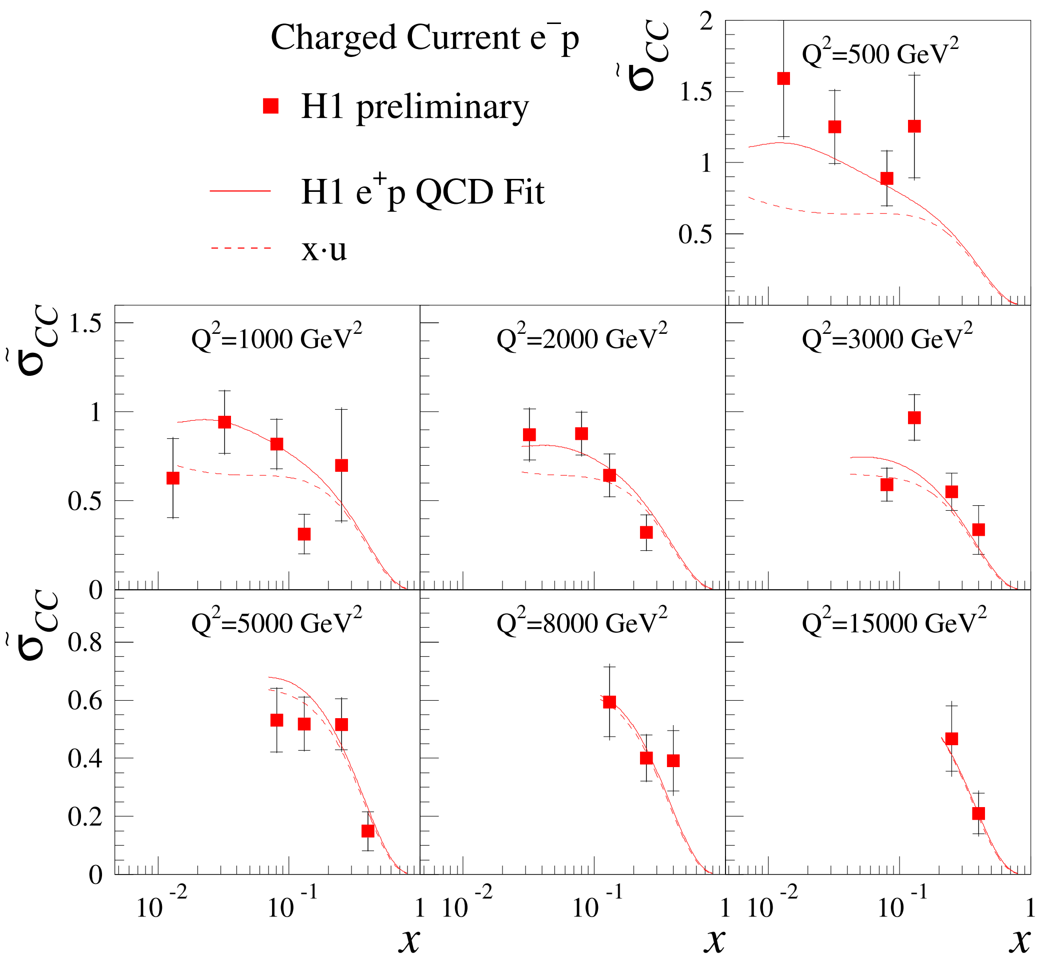
H1: $80.9 \pm 3.3(\mathrm{stat}) \pm 1.7(\mathrm{syst}) \pm 3.7(\mathrm{pdf})$ GeV

ZEUS: $81.4^{+2.7}_{-2.6}(\mathrm{stat}) \pm 2.0(\mathrm{syst})^{+3.3}_{-3.0}(\mathrm{pdf})$ GeV



$\mathbf{e^{-}p}$: CC Cross-section

CC $e^{-}p$: $\tilde{\sigma} \sim \mathbf{x(u+c)+(1-y)^2x(\bar{d}+\bar{s})}$



⇒ $\mathbf{e^{-}p}$ probe u quark at high x

Helicity dependence

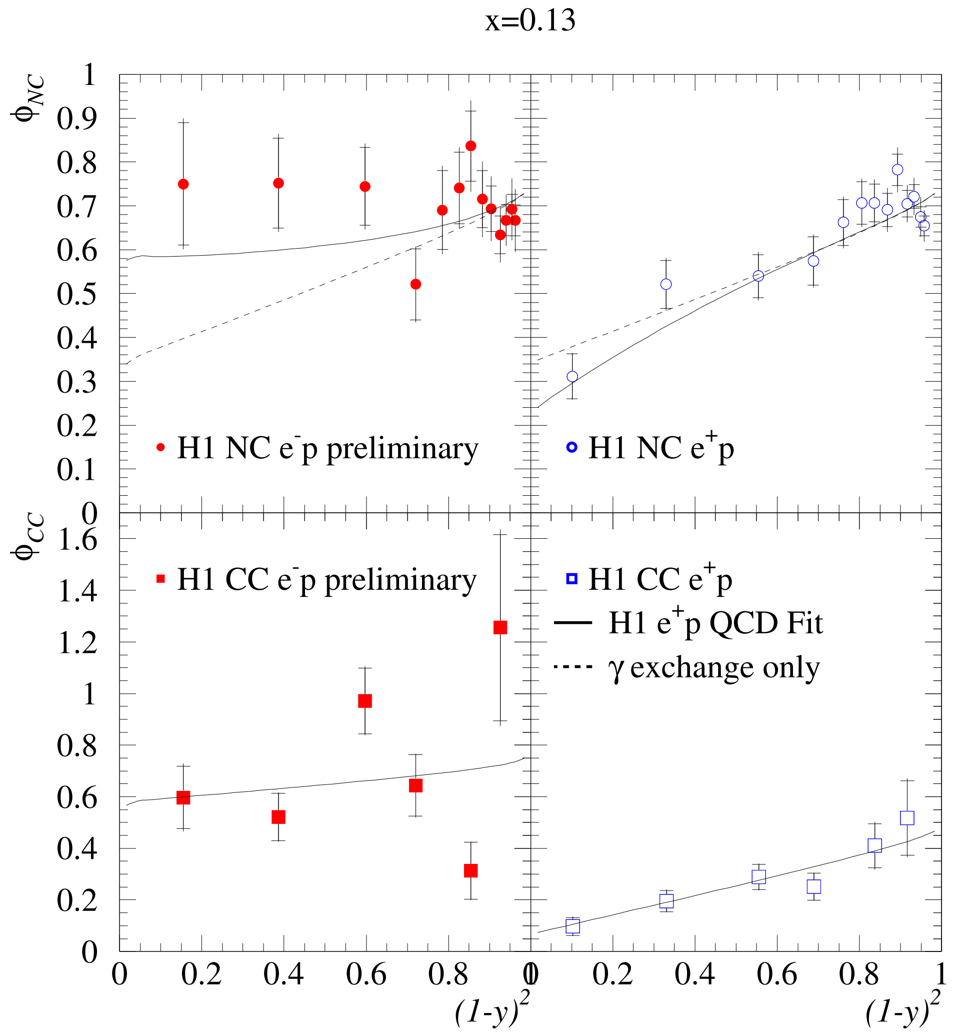
$$1 - y = \cos^2 \frac{\theta^*}{2}$$

$x \sim 0.1 \rightarrow$ **separate helicity dependence from PDF** $\begin{cases} \sim const. \\ \sim (1-y)^2 \end{cases}$

$$\Phi_{NC} = \left[1 + (1-y)^2\right] \times \left[\frac{4}{9}(\underline{\mathbf{u}} + \bar{u}) + \frac{1}{9}(\underline{\mathbf{d}} + \bar{d})\right]$$

$$\mathbf{\Phi_{CC}^{e^-p} = x\left[\underline{(u+c)} + (1-y)^2(\bar{d}+\bar{s})\right]}$$

$$\mathbf{\Phi_{CC}^{e^+p} = x\left[(\bar{u}+\bar{c}) + (1-y)^2\underline{(d+s)}\right]}$$



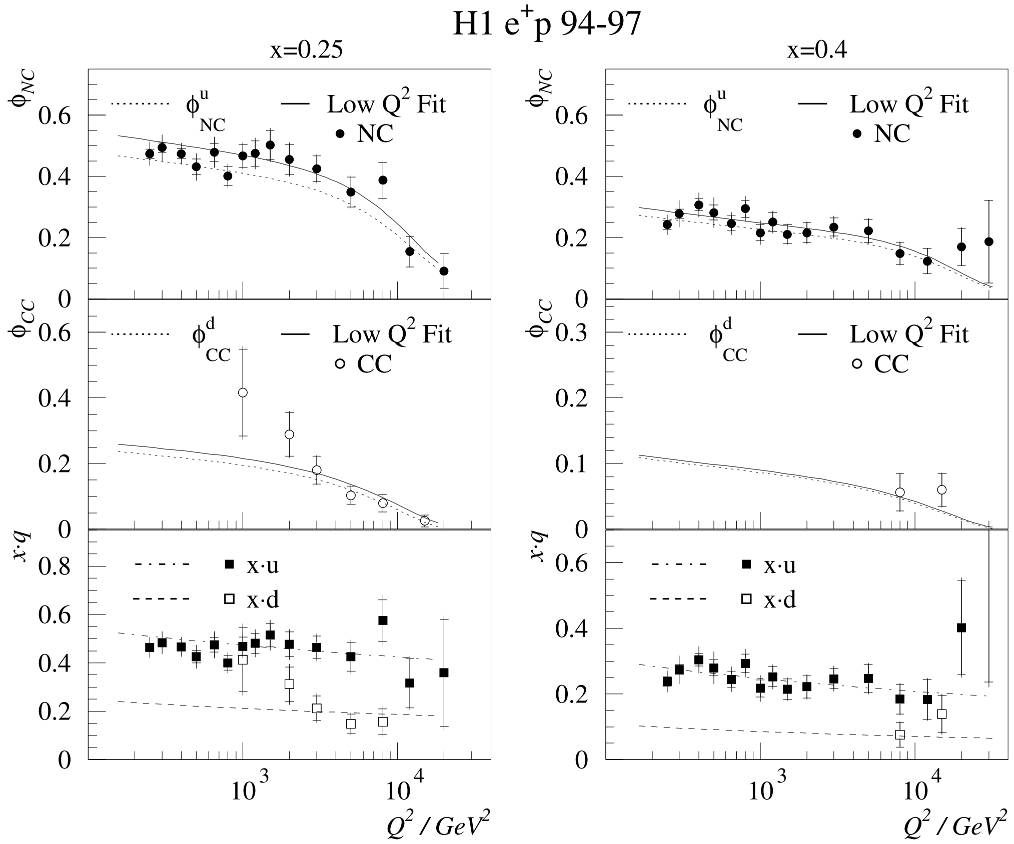
⇒ Data have the expected helicity dependence

Quark densities from high Q2 CC/NC

Extract quark densities in high x region

$\Rightarrow$ e^+ beam: high x

- NC sensitive to u : $xu = \Phi_{NC} \left[\frac{xu}{\Phi_{NC}}\right]_{lowQ^2fit}$
- CC sensitive to d : $xd = \Phi_{CC} \left[\frac{xd}{\Phi_{CC}}\right]_{lowQ^2fit}$



Summary and Outlook

HERA: proton structure investigated at highest Q^2/x

NC and CC Cross-sections :

- QCD evolution tested over 4 orders of magnitude in Q^2
- Precision and local excess (NC e^+p) need more data
- The effects of γZ interference and xF_3 observed
- Quark flavour effects are present at high x

Higher statistics in view...

Current and Future HERA Running:

- e^+p running since July 1999
- High luminosity run after upgrade in 2000

⇒ 2001→2005 e-p physics with:

- **1 fb^{-1}**
- **e$^\pm$-beam polarization**

Brilliant Future for HERA2000!