Deep inelastic scattering at high Q^2

Lake Louise Winter Institute 2001

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for the H1 and ZEUS collaborations

- Introduction
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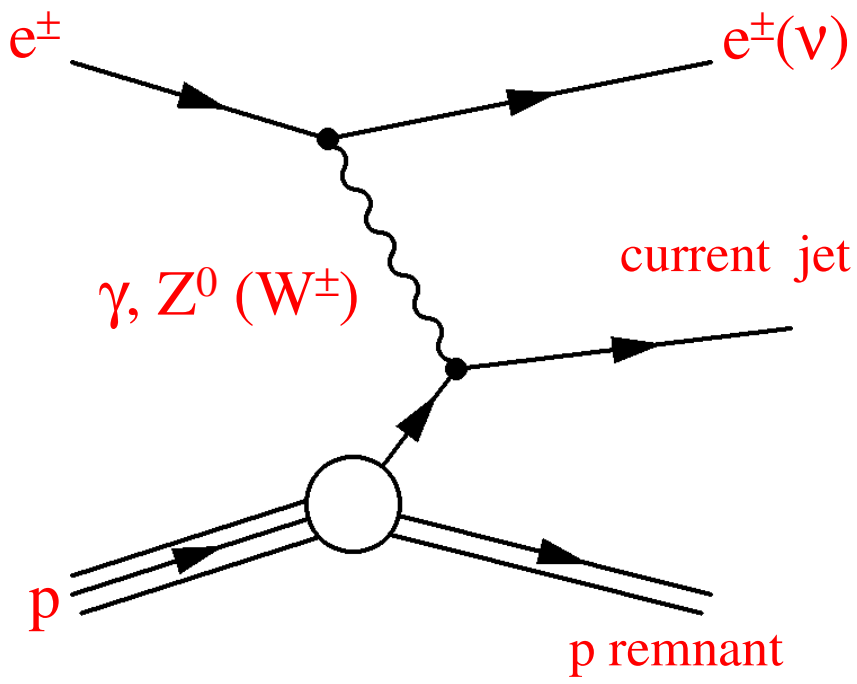
- Experimental details
- Neutral current results
- Charged current results
- Future prospects

Deep inelastic scattering



- Probing the proton at small distance scales
- Q^2 is the "probing power"
- $\Delta r = 1/Q$
- x is the Bjorken scaling variable
- y is related to the scattering angle in CMS ($=\sin^2(\theta^*/2)$)
- HERA CMS energy ≈ 300 GeV

DIS cross sections

- Neutral current (NC)

$$\frac{d^2\sigma_{NC}(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2 \mp Y_-xF_3 - y^2F_L\right] \qquad Y_{\pm} = 1 \pm (1-y)^2$$

- The functions $A(Q^2)$ and $B(Q^2)$ contain the vector and axial couplings of the γ and Z^0 to the lepton and quark

$$F_2 = \sum_q xA(Q^2)[q+\bar{q}] \qquad xF_3 = \sum_q xB(Q^2)[q-\bar{q}]$$

- Z^0 and γZ^0 interference contributions $\propto \left(\frac{Q^2}{Q^2+M_Z^2}\right)^2$ and $\frac{Q^2}{Q^2+M_Z^2}$

- xF_3 changes sign with lepton charge

- Effect of $-y^2F_L$ is small except at high y, and decreases with increasing Q^2

DIS cross sections

- Charged current (CC)

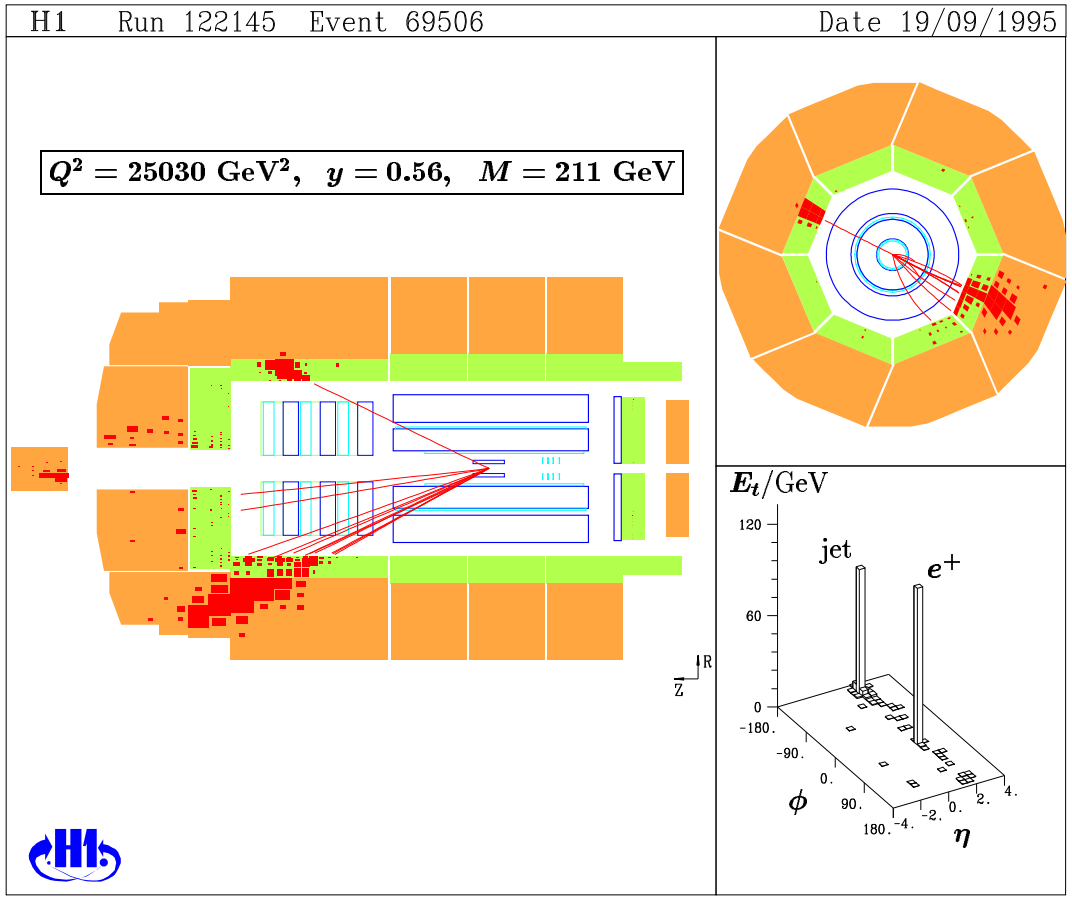
$$\frac{d^2\sigma_{CC}(e^- p)}{dxdQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 x\left[(u+c)+(1-y)^2(\bar{d}+\bar{s})\right]$$

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

- W couples to LH fermions and RH anti-fermions
- Selects valence quark flavour: $e^- p \Rightarrow u$; $e^+ p \Rightarrow d$
- $e^+ p$ scattering suppressed by $(1-y)^2$ factor and $d<u$ compared to $e^- p$ scattering

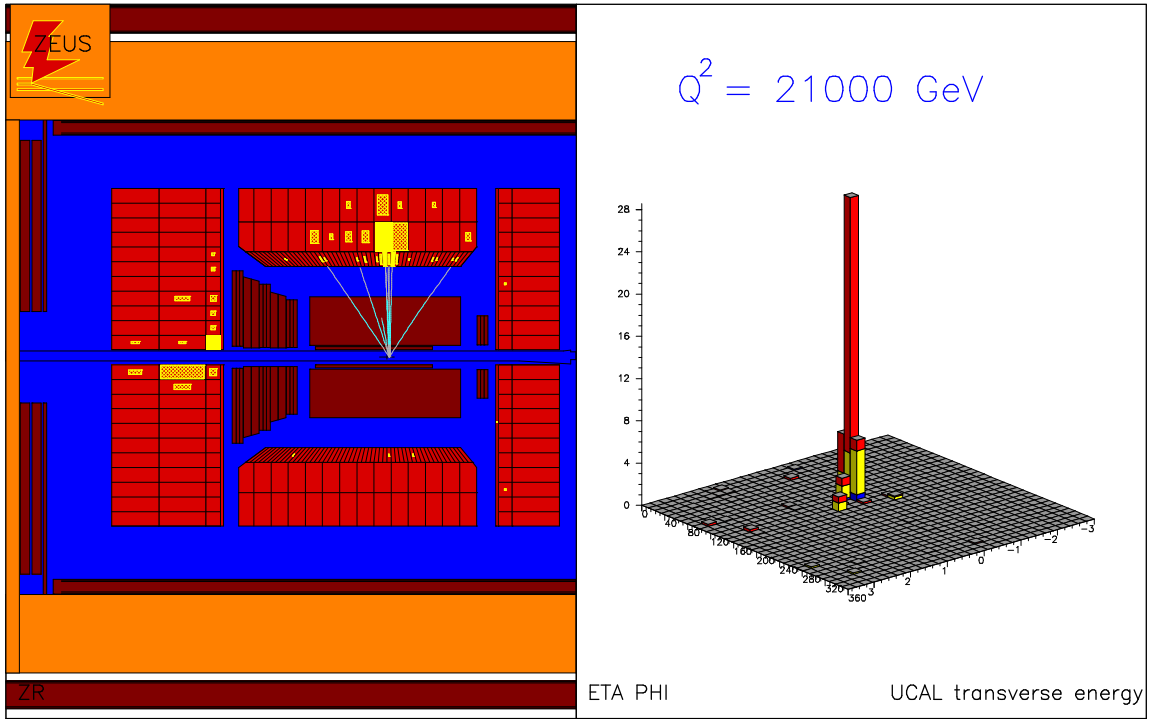
H1 detector

- Liquid argon calorimeter
- 45000 cells
- EM: $\frac{\sigma(E)}{E} = \frac{12\%}{\sqrt{E}} \oplus 1\%$
- Systematic 1-3%
- HAD: $\frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E}} \oplus 1\%$
- Systematic 3-4%

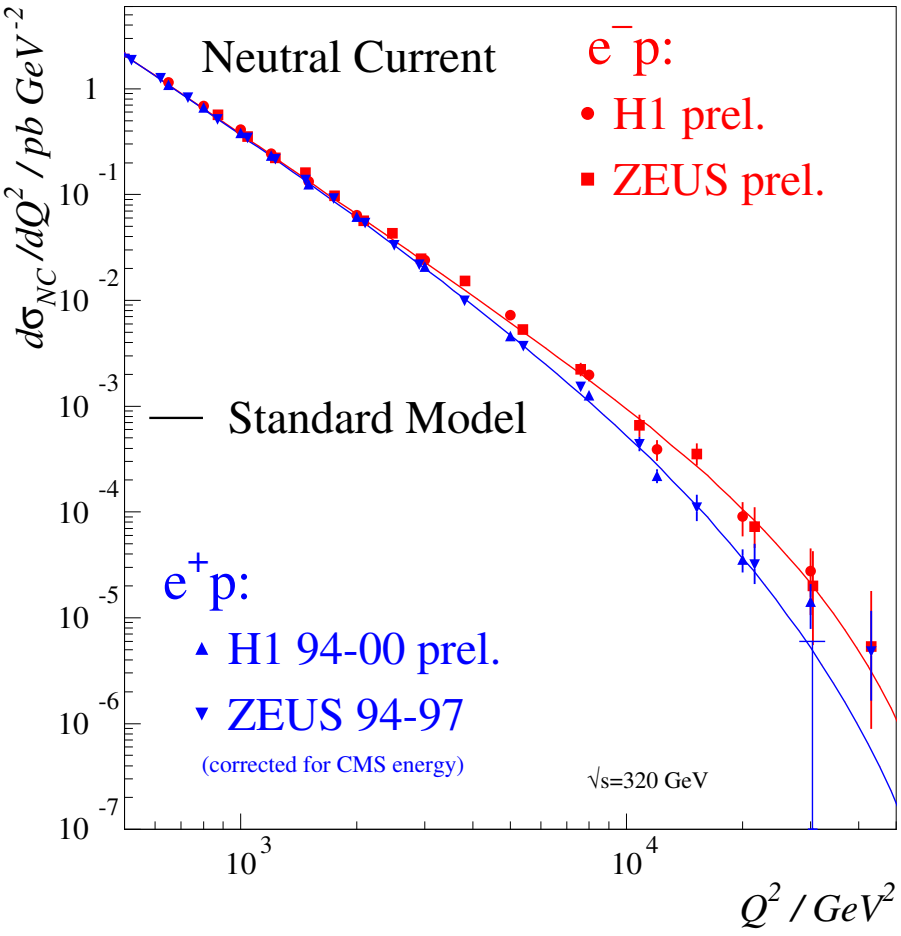


ZEUS detector

- Compensating depleted uranium calorimeter
- 6000 cells
- EM: $\frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E}}$
- Systematic 1-2%
- HAD: $\frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E}}$
- Systematic 2-3%



Neutral current results



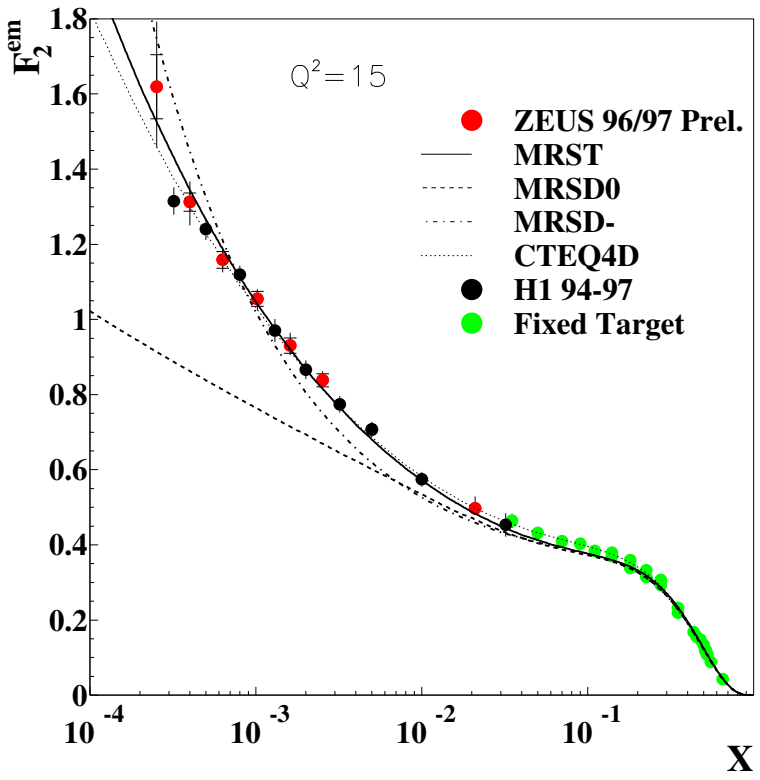
- Data samples (per experiment)
  - $e^+p \approx 100\ pb^{-1}$
  - $e^-p \approx 16\ pb^{-1}$
- Data well described by SM over 6 orders of magnitude
- $\frac{d\sigma_{NC}}{dQ^2} \propto \frac{1}{Q^4}$ $Q^2 << M_Z^2$
- Difference observed between e^+p and e^-p cross section data at high Q^2
  - xF_3 coming soon…...

Parton density functions

- Proton structure described by parton density functions (PDFs)

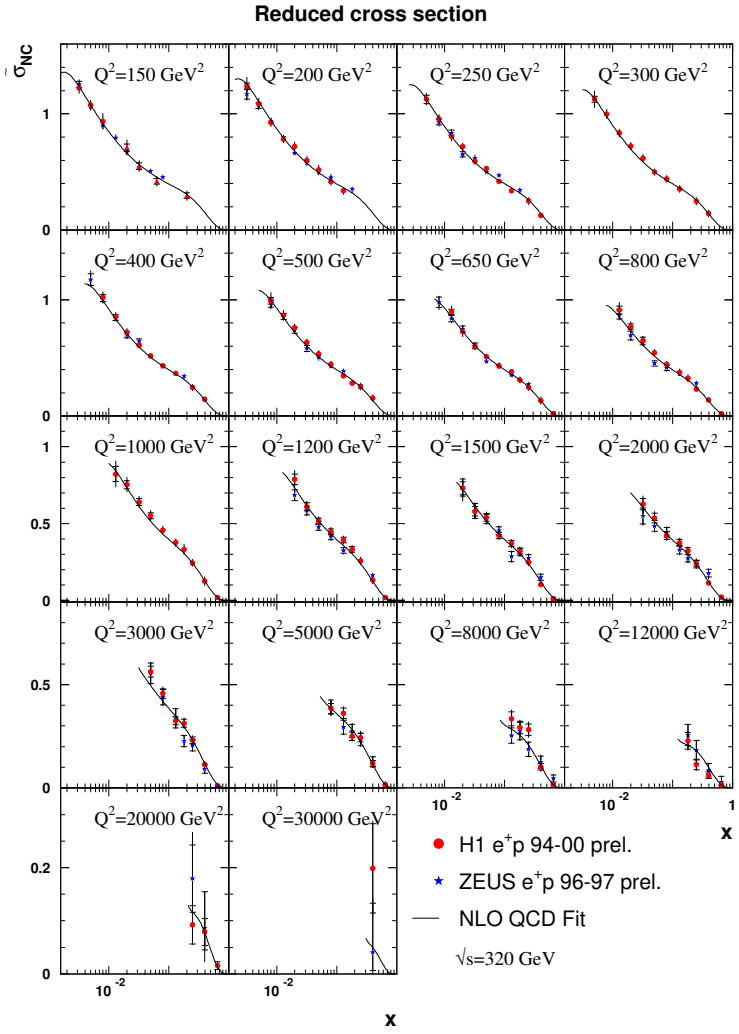
- PDFs cannot be calculated by pQCD
  - Measured at low Q^2
  - Parameterise as a function of x
  - Evolve using DGLAP to all Q^2 where pQCD is valid
  - High Q^2 DIS is test of pQCD

- QPM: PDFs are independent of Q^2 "scaling", but functions of x
- QCD: gluon radiation produces quark-antiquark pairs
- Scaling violations: increase in cross section at low x: decrease at high x

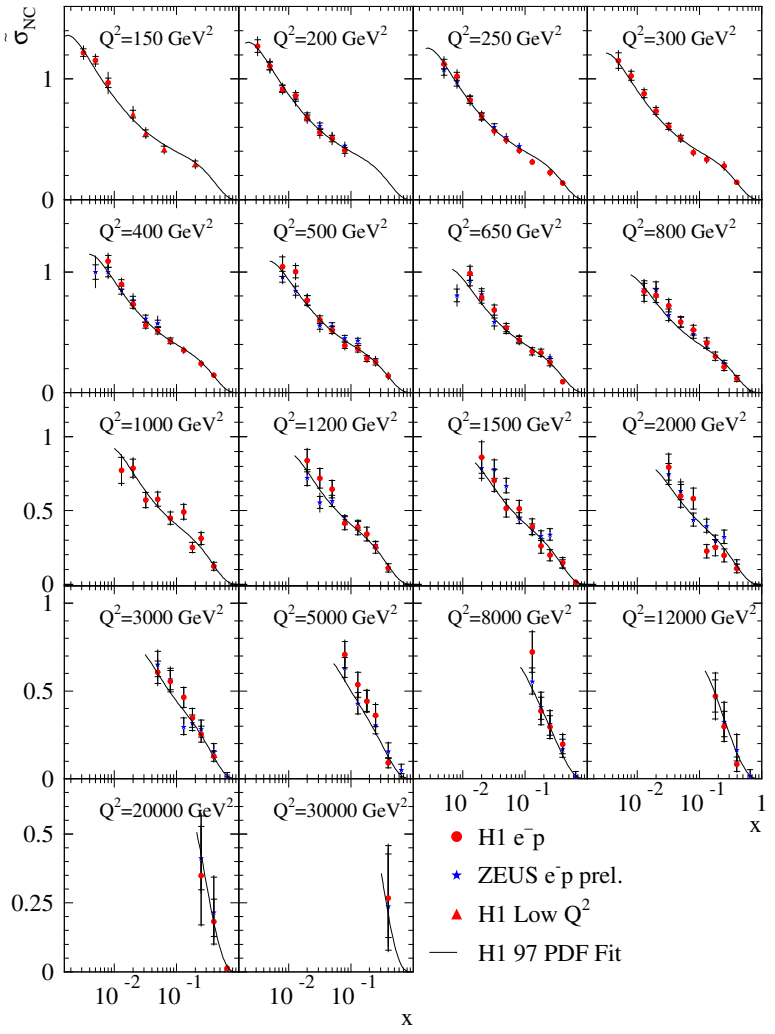


NC reduced cross section $\tilde{\sigma}_{NC} = \frac{1}{Y_+}\frac{Q^4 x}{2\pi\alpha^2}\frac{d^2\sigma_{NC}}{dxdQ^2}$

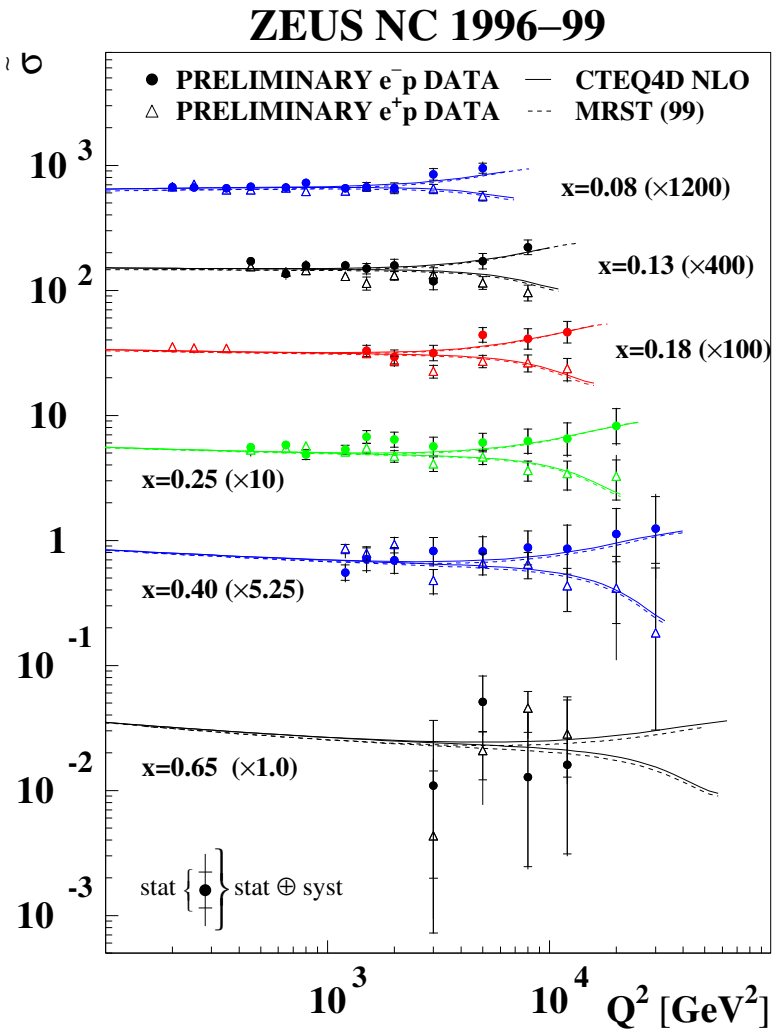
e^+p



e^-p

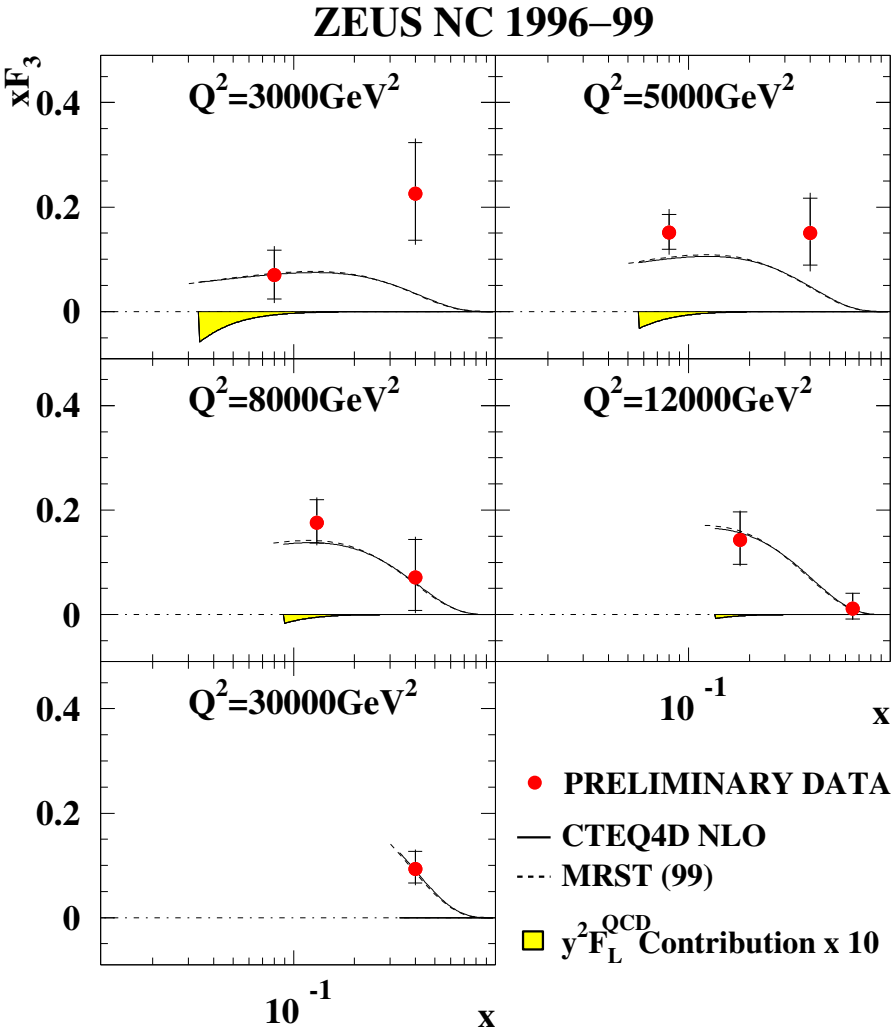


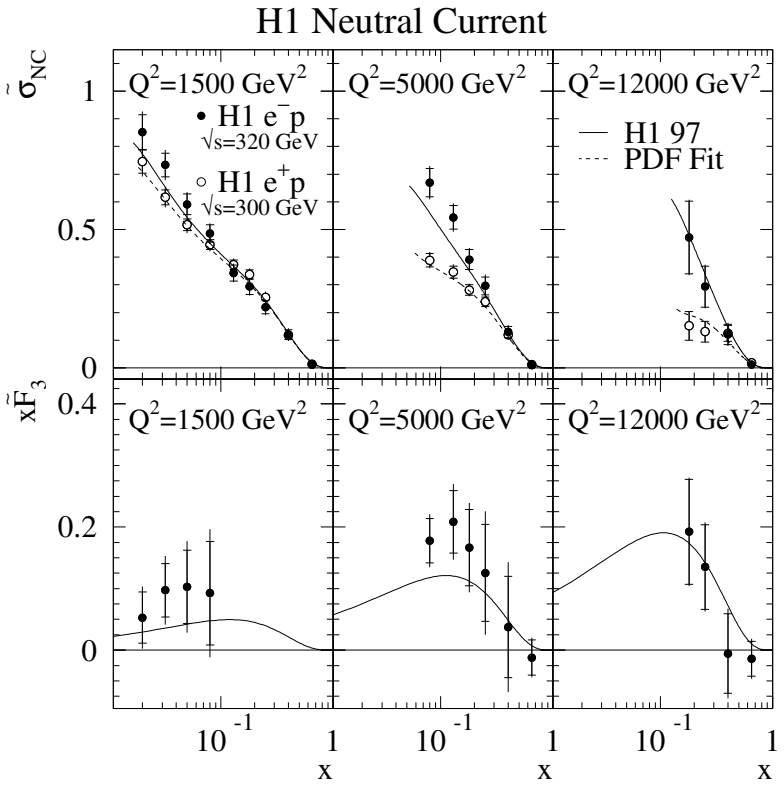
xF_3



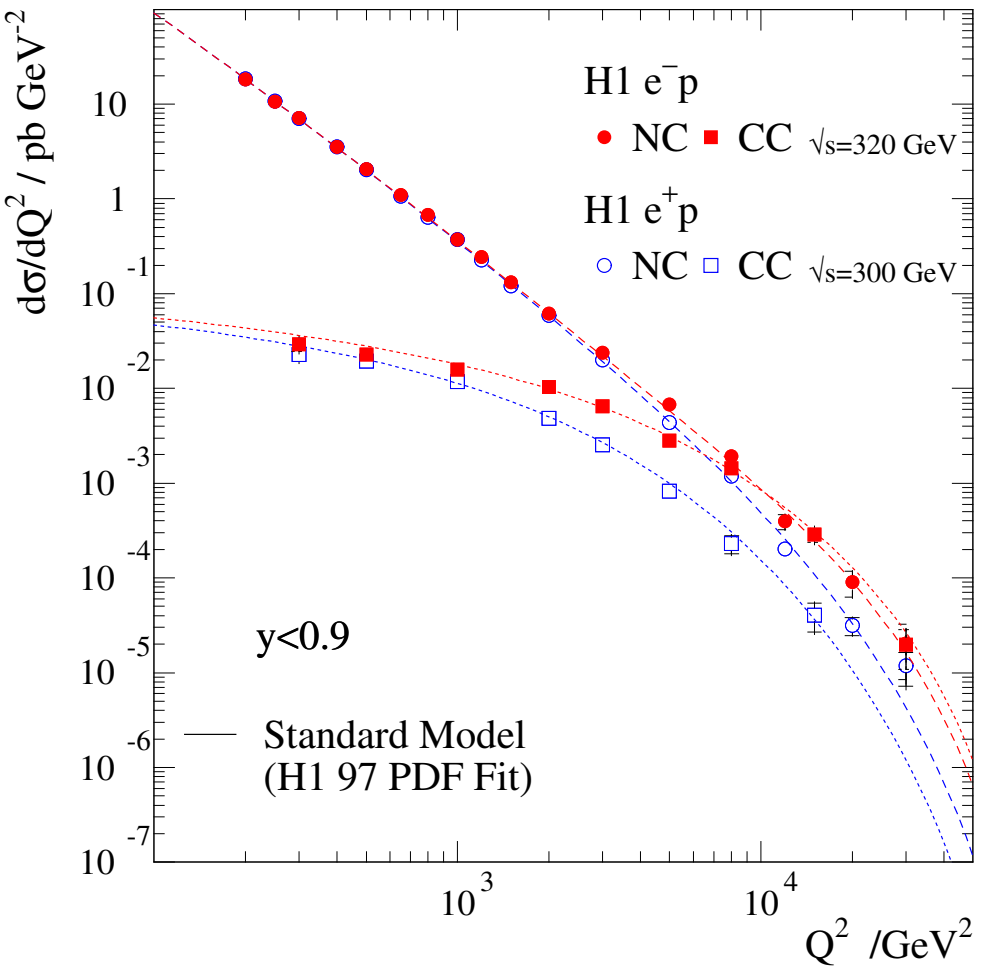
- $\sigma(e^+p) \propto Y_+F_2 - Y_-xF_3$
- $\sigma(e^-p) \propto Y_+F_2 + Y_-xF_3$
- Contributions to xF_3 from Z^0 exchange and γZ^0 interference
- xF_3 by subtracting e^+p from e^-p cross section
- High Q^2 extraction of the valence quarks

xF_3


ZEUS NC 1996–99
xF3
Q2=3000GeV2
Q2=5000GeV2
Q2=8000GeV2
Q2=12000GeV2
Q2=30000GeV2
0.4
0.2
0
10 -1
x
PRELIMINARY DATA
CTEQ4D NLO
MRST (99)
y2FLQCD Contribution x 10


H1 Neutral Current
σ̃NC
xF̃3
Q2=1500 GeV2
Q2=5000 GeV2
Q2=12000 GeV2
H1 e−p
√s=320 GeV
H1 e+p
√s=300 GeV
H1 97
PDF Fit
1
0.5
0
0.4
0.2
10 -1
x

NC and CC results



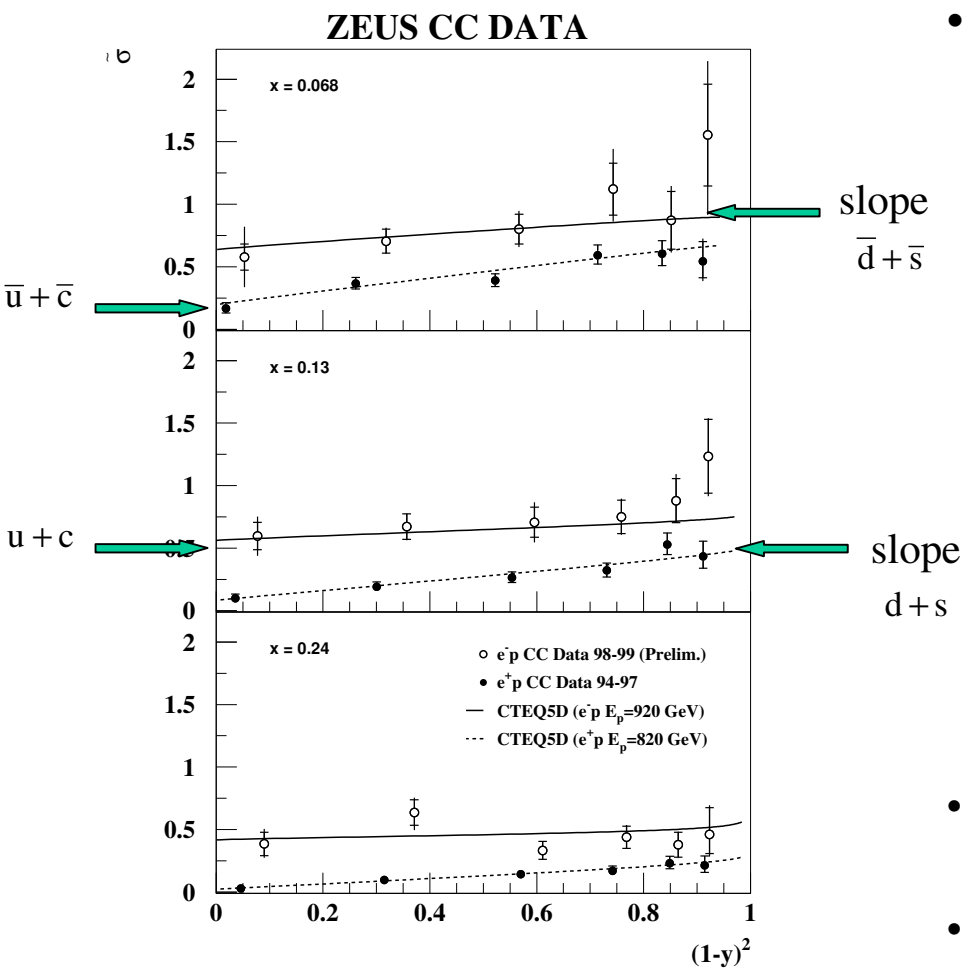
- CC DIS suppressed by large mass of W at low Q^2
- Electroweak unification
  - $\sigma_{NC} \approx \sigma_{CC}$ @ $Q^2 \approx M_W^2 \approx M_Z^2$
- $\frac{d\sigma_{CC}}{dQ^2} \propto \left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 (1\text{-}y)^2 d\,[u]$
- Sensitive to M_W
  - fit shape for M_W in space-like regime

$M_W = 79.9 \pm 2.2(stat) \pm 0.9(syst) \pm 2.1(theo.)\text{GeV}$ (H1 e^-p)

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

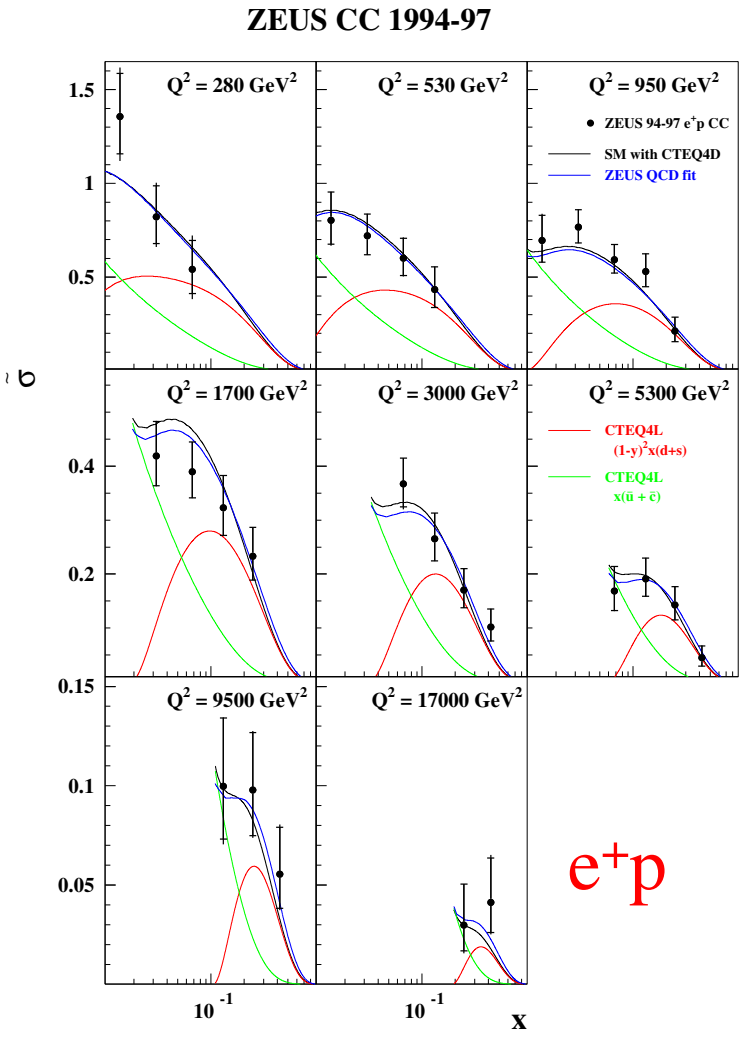
- Complementary to time-like measurements at LEP and Tevatron (PDG: M_W=80.4 GeV)

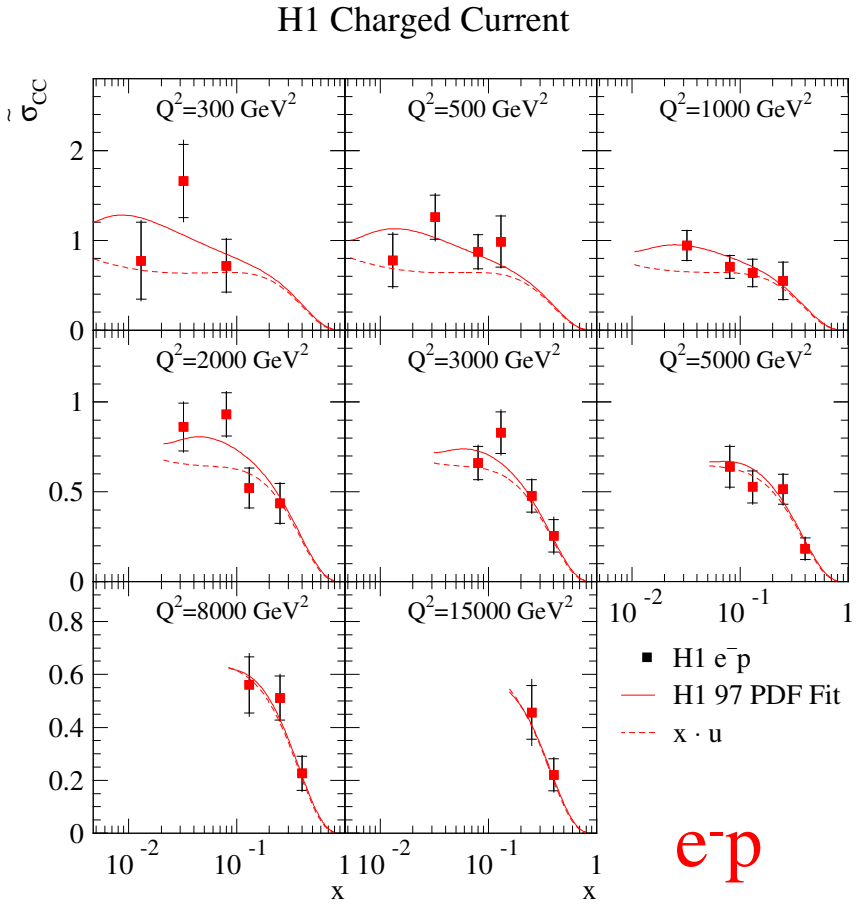
Quark flavour investigation

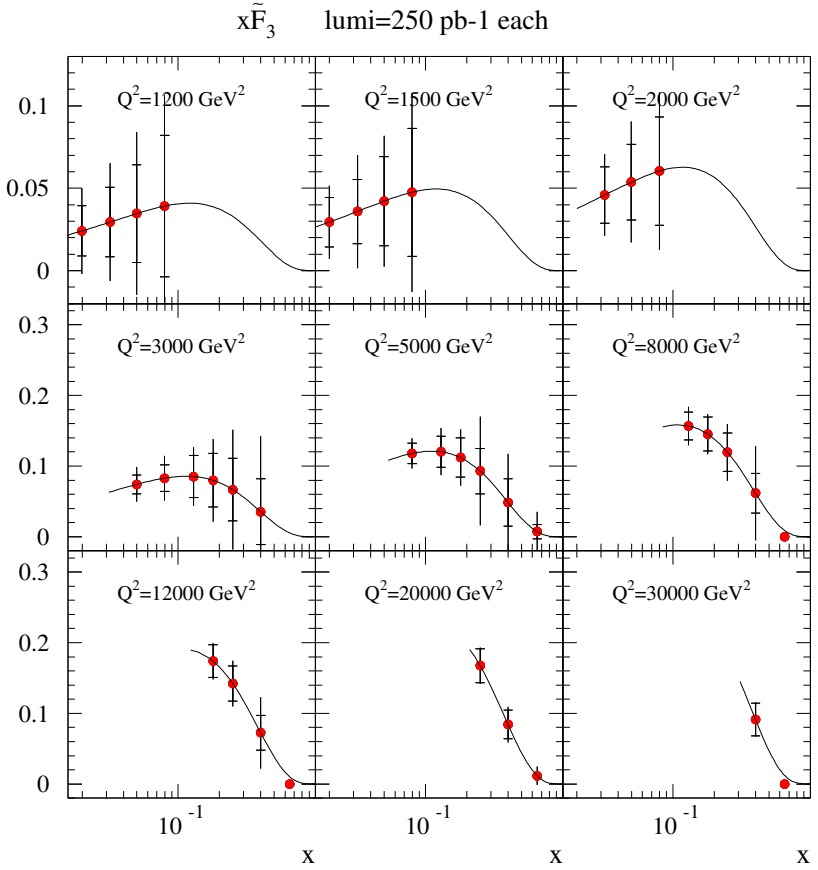


- Intuitive look at PDFs
  - $\tilde{\sigma}_{CC}(e^- p) = x\left[(u+c)+(1-y)^2(\bar{d}+\bar{s})\right]$
  - $\tilde{\sigma}_{CC}(e^+ p) = x\left[(\bar{u}+\bar{c})+(1-y)^2(d+s)\right]$
  - At x ≈ 0.1 approximate Bjorken scaling - PDFs are independent of Q^2
  - plot $\tilde{\sigma}_{CC}$ at fixed x as a function of $(1\text{-}y)^2$
  - e^-p: slope = $\bar{d}+\bar{s}$ intercept = u + c
  - e^+p: slope = d + s intercept = $\bar{u}+\bar{c}$
- NLO QCD describes the data well
- QPM gives an intuitive picture of the PDFs

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





Future prospects

- Detector upgrades for H1 and ZEUS and upgrade to the HERA accelerator
- Higher luminosity
  - Improved precision in structure function measurements at high Q^2
- Longitudinally polarised lepton beams
  - Measure polarisation dependence of CC and NC deep inelastic scattering cross sections