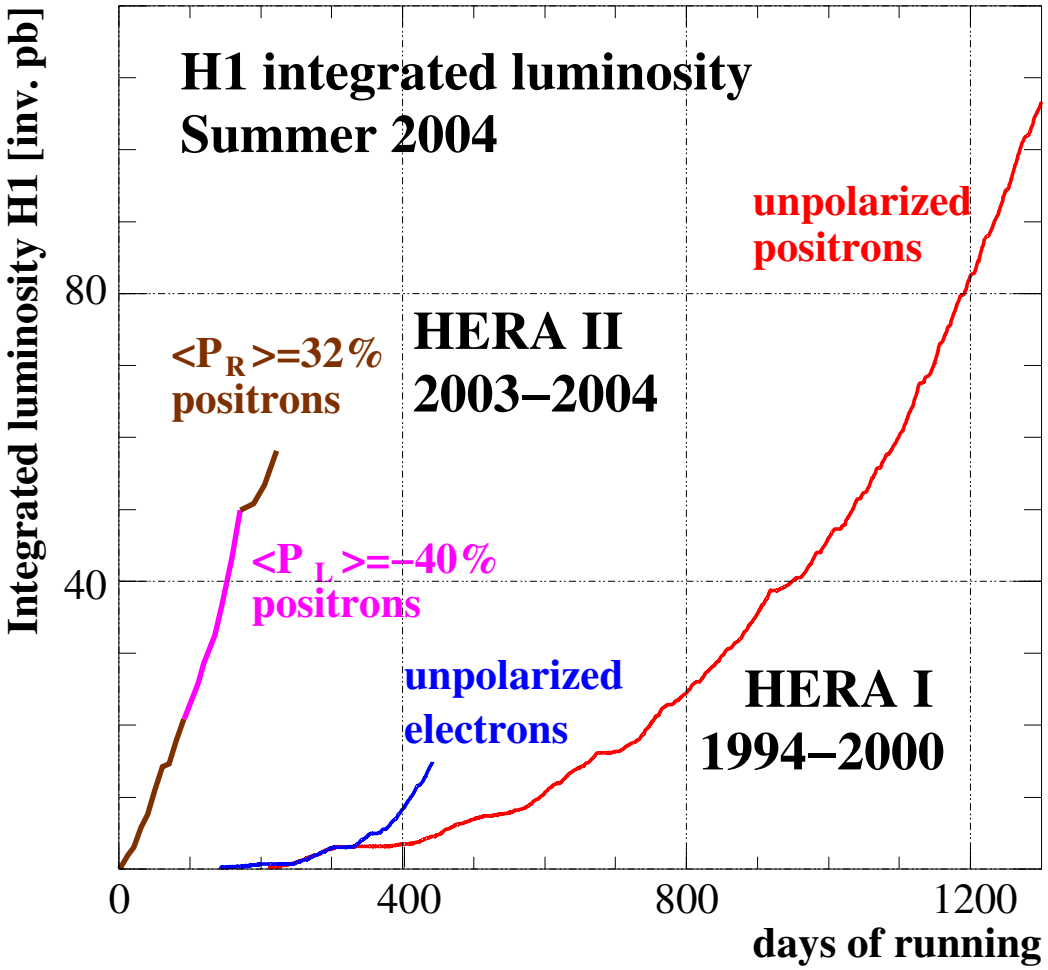
High Q^2 Charged and Neutral Current Cross Sections at HERA I and HERA II

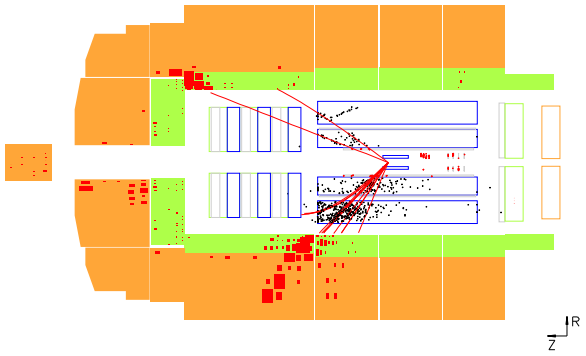
- Introduction
- Cross-sections
- Measurement of xF_3
- Local extraction of xu and xd
- HERA II and polarization
- Polarized cross-sections at high Q^2

Data taking with H1 and ZEUS at HERA

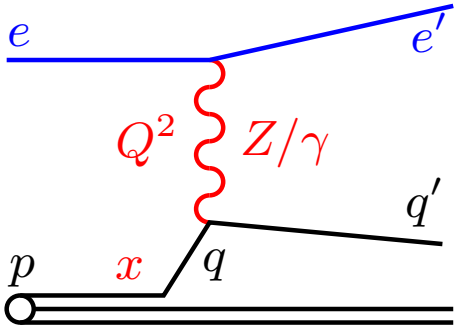


- HERA: $e^{\pm}p$ collider
  $E(e) = 27.6\,\text{GeV}$,
  $E(p) = 920\,\text{GeV}$, $\sqrt{s} = 319\,\text{GeV}$
- Two collider experiments
  H1 and ZEUS
- HERA I (1994-2000):
  - $100\,\text{pb}^{-1}$ $e^{+}p$ per experiment
  - $15\,\text{pb}^{-1}$ $e^{-}p$ per experiment
- HERA II (since 2003):
  - Luminosity upgrade
  - $\mathcal{O}(50\,\text{pb}^{-1})$ per experiment
  - Polarized positrons
    $\langle P_R \rangle = 32\%$ and $\langle P_L \rangle = -40\%$

DIS at high Q^2

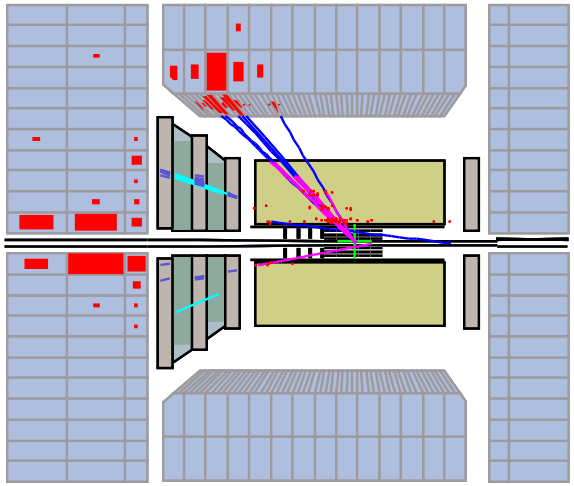


Neutral current

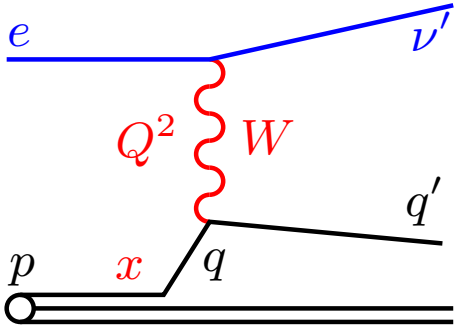


Event topology:

- Neutral current: scattered electron in central part of the detector
- Charged current: neutrino carries away transverse momentum



Charged current

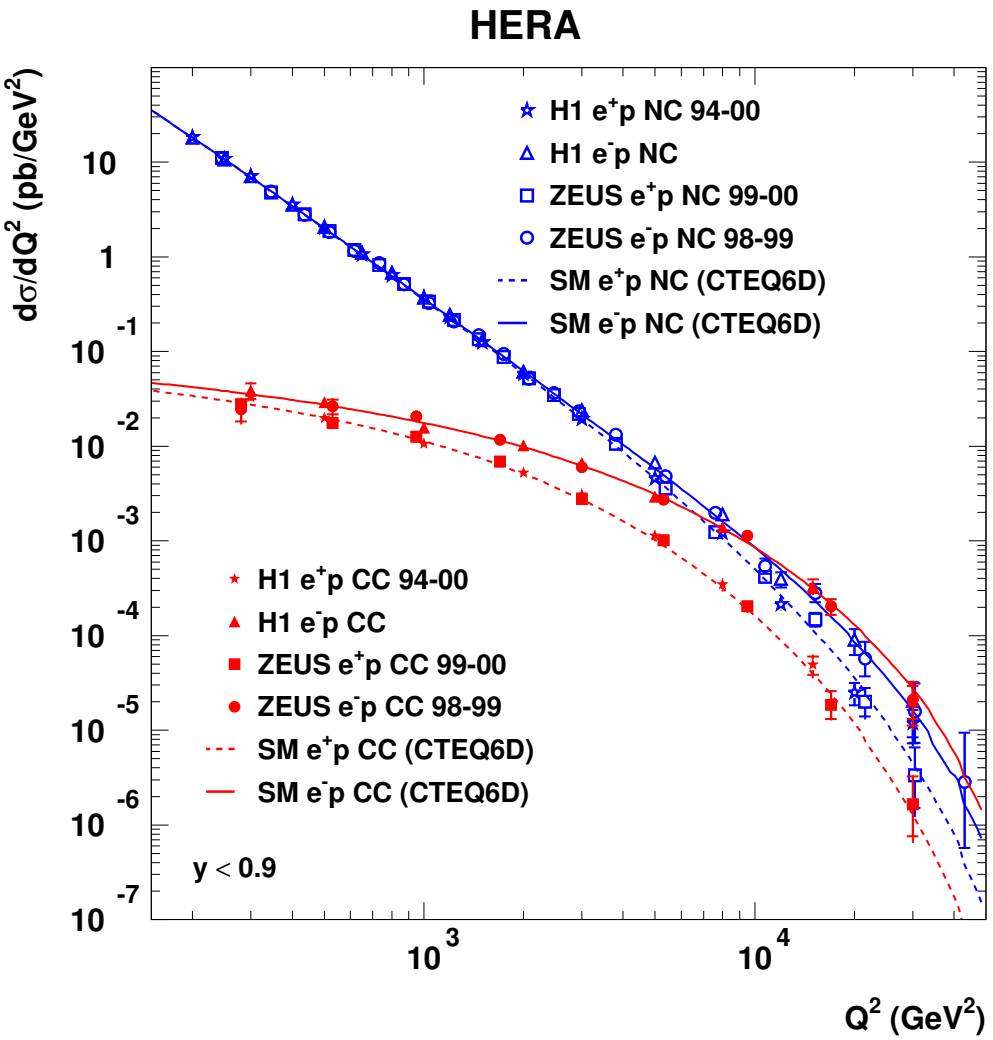


Kinematic variables:

- Momentum transfer squared Q^2
- Fraction of proton momentum x carried by struck quark
- Inelasticity $y = \frac{1-cos\theta^\star}{2}$

Relation $Q^2 = sxy$

CC and NC Cross-sections



Neutral current:

$$\frac{d^2\sigma_{\rm NC}}{dxdQ^2} \sim \alpha_{\rm em}^2 \frac{1}{(Q^2)^2} \frac{1}{x} \tilde{\sigma}_{\rm NC}$$

Charged current:

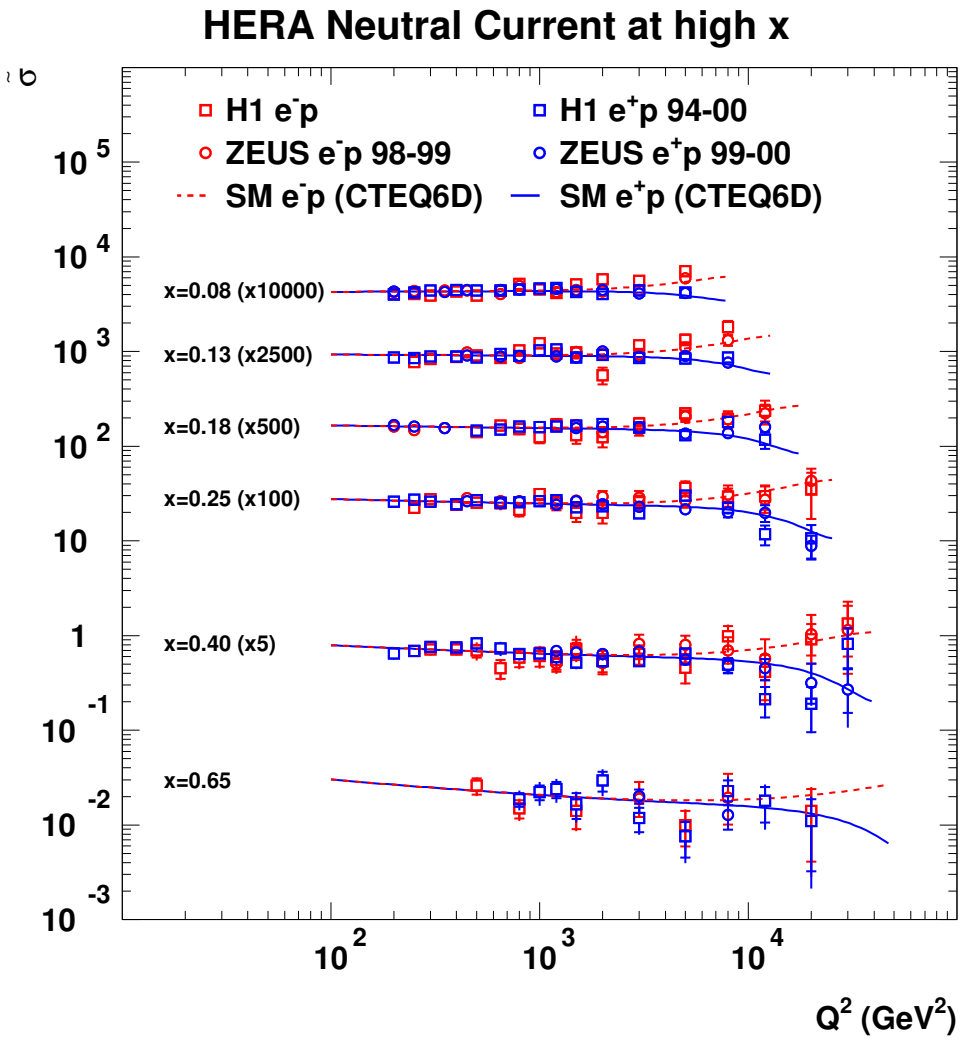
$$\frac{d^2\sigma_{\rm CC}}{dxdQ^2} \sim G_F^2 M_W^4 \frac{1}{(Q^2+M_W^2)^2} \frac{1}{x} \tilde{\sigma}_{\rm CC}$$

Q^2 dependence driven by propagator

NC and CC cross-sections are of similar size for $Q^2 \approx M(W,Z)^2$

Reduced cross-sections $\tilde{\sigma}_{\rm NC}$ and $\tilde{\sigma}_{\rm CC}$: sensitive to proton structure, QCD

Reduced NC cross-section



$$\tilde{\sigma}_{\rm NC} = Y^+ F_2 \mp Y^- xF_3 - y^2 F_L$$

$$Y^\pm = 1 \pm (1-y)^2$$

DGLAP equation $\rightarrow Q^2$ evolution of structure functions F_2, xF_3, F_L

Main contribution is $F_2^{\rm em}$

$$F_2 = F_2^{\rm em} + \text{el. weak terms}$$

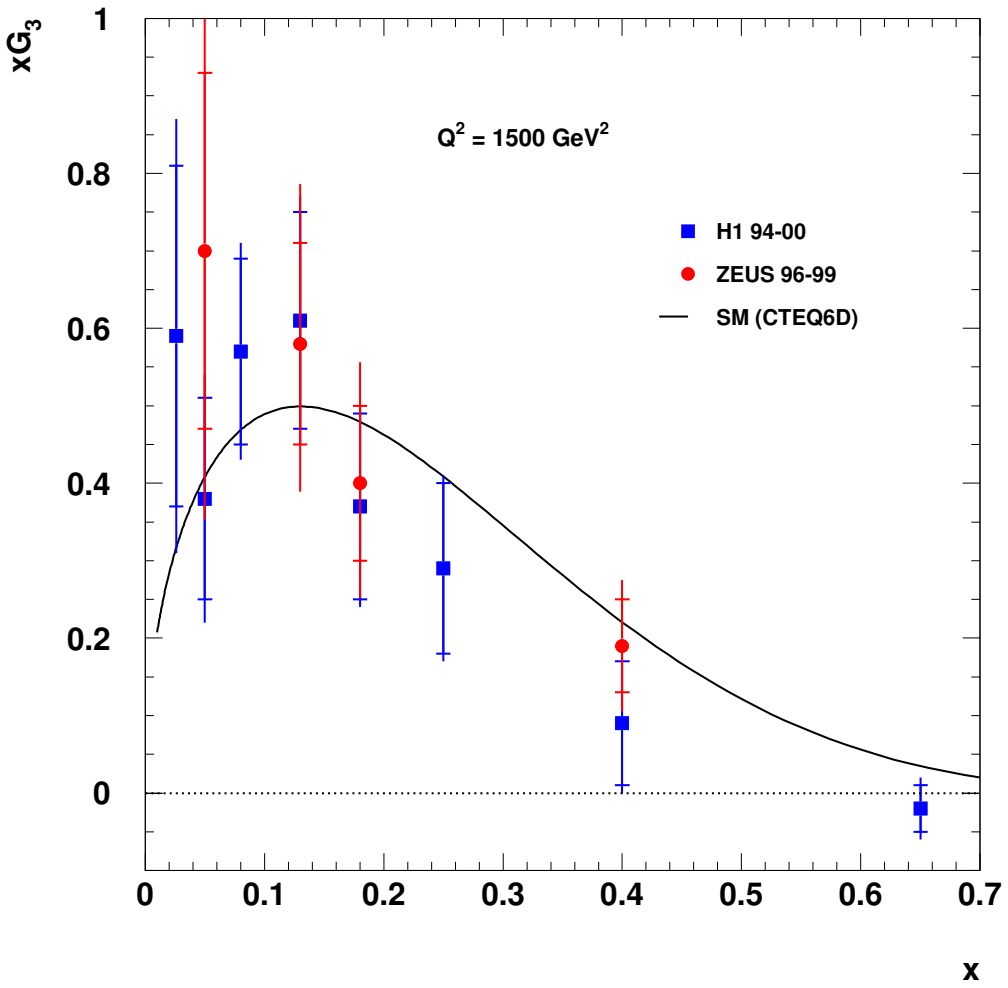
$$F_2^{\rm em} = \sum e_q^2 (q + \bar{q})$$

Sum of sea and valence quarks, dominated by u quarks at high x

Difference between e^+p and $e^-p \rightarrow xF_3$, relevant at high Q^2 only

Contribution from F_L at high y only

Measurement of xF_3



$$xF_3 \sim \tilde{\sigma_{\mathrm{NC}}}^{-} - \tilde{\sigma_{\mathrm{NC}}}^{+}$$

Main contribution from γZ interference:

$$xF_3 = xF_3^{\gamma Z} + Z\text{−exchange}$$

Quark content

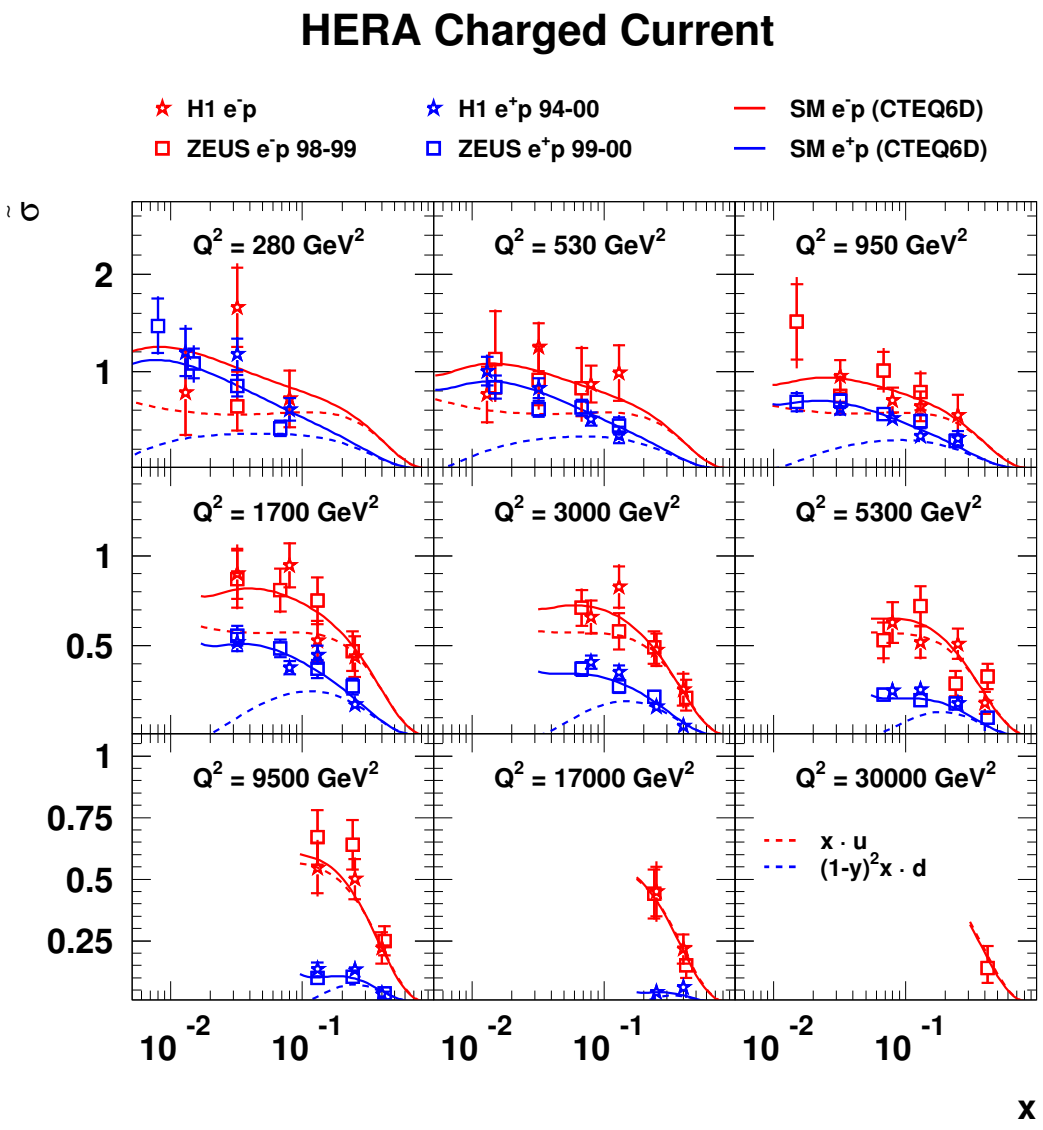
$$xF_3^{\gamma Z} \sim \frac{Q^2}{Q^2 + M_Z^2}\, xG_3$$

$$xG_3 = \sum e_q a_q (q - \bar{q})$$

Only valence quarks contribute.

Compares well to QCD extrapolation of fixed-target and low Q^2 data

Reduced Charged current cross-sections



$e^- p$ scattering:

$$\tilde{\sigma}^-_{\mathrm{CC}} \sim xu + (1-y)^2 x\bar{d}$$

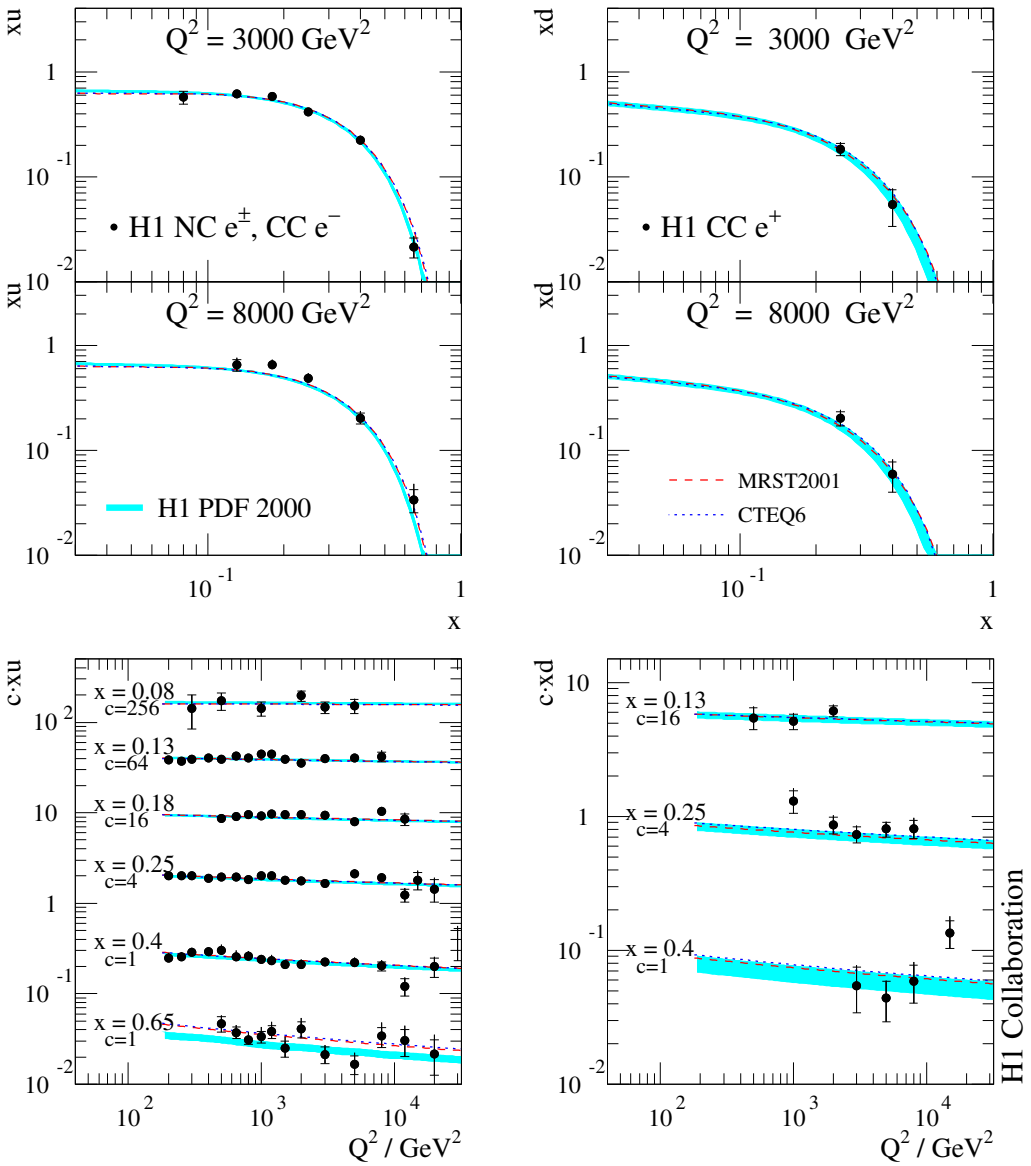
High x: dominated by u quarks

$e^+ p$ scattering:

$$\tilde{\sigma}^+_{\mathrm{CC}} \sim (1-y)^2 xd + x\bar{u}$$

High x: dominated by d quarks, but suppressed by helicity factor $(1-y)^2$ and $xu \approx 2xd$

Local extraction of xu and xd from NC and CC cross-sections



- Subtract contributions expected from other quarks

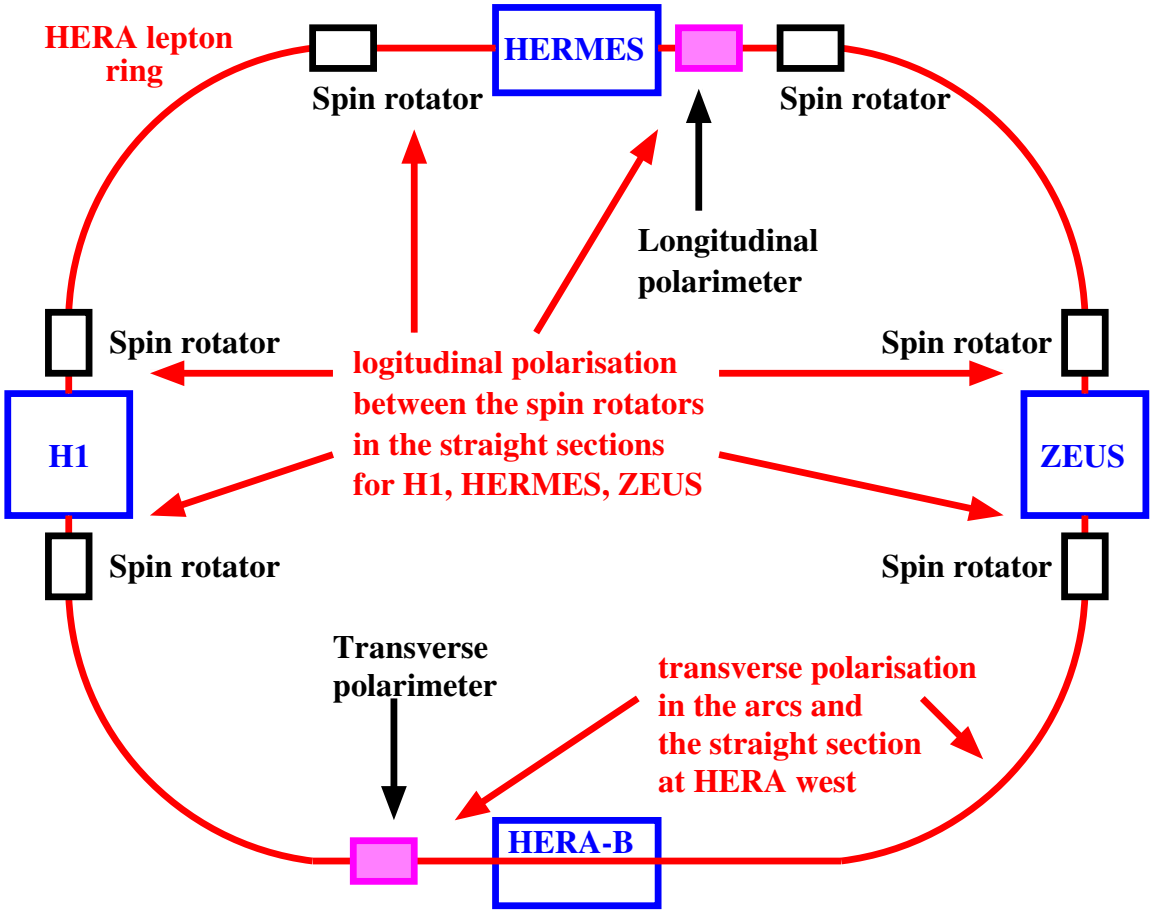
→ direct measurement of u or d quark densities at high Q^2 and high x.

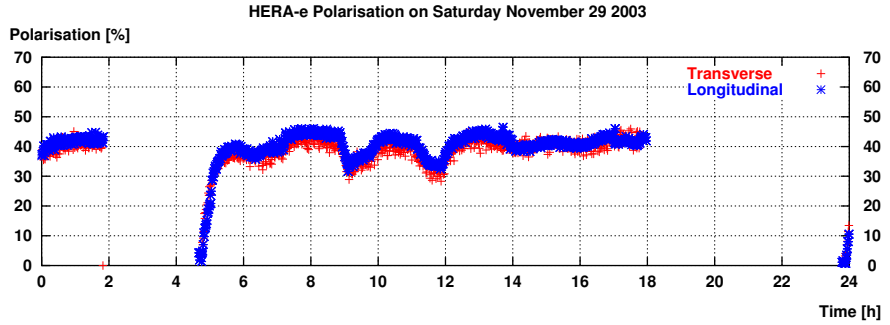
- Restricted to regions where u or d are dominating the cross-section

Direct measurement compares well to results from QCD fits.

d quark still statistically limited
→ requires more e^+p data

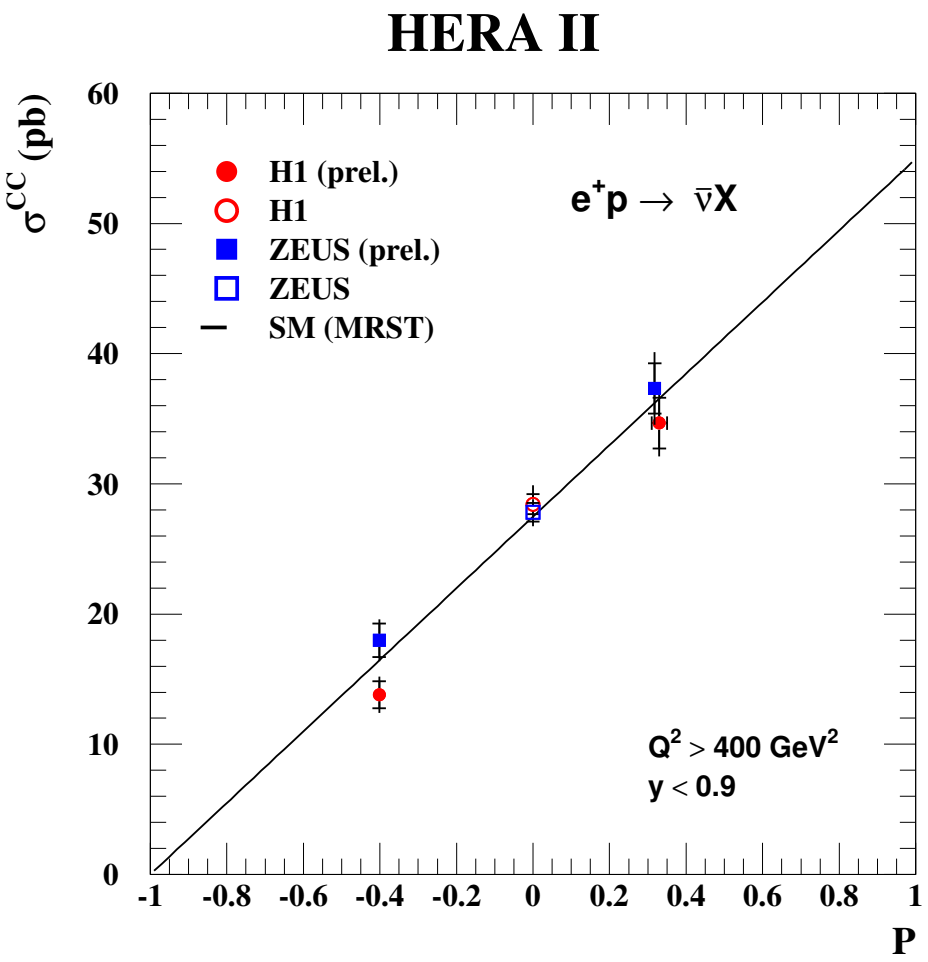
Polarized lepton beam at HERA II





- HERA: polarization is produced in the ring (Sokolov-Ternov effect)
- Spin-rotators
  transverse pol. in the arcs
  longitudinal pol. for physics
- Typical HERA II polarisation is 40%, built-up time 30 minutes.
- Monitoring by two independent Compton polarimeters

HERA II results on polarized CC cross-sections



Cross-section has linear dependence on polarization

$$\sigma^{\pm}_{CC}(P) = (1 \pm P)\sigma^{\pm}_{CC}(0)$$

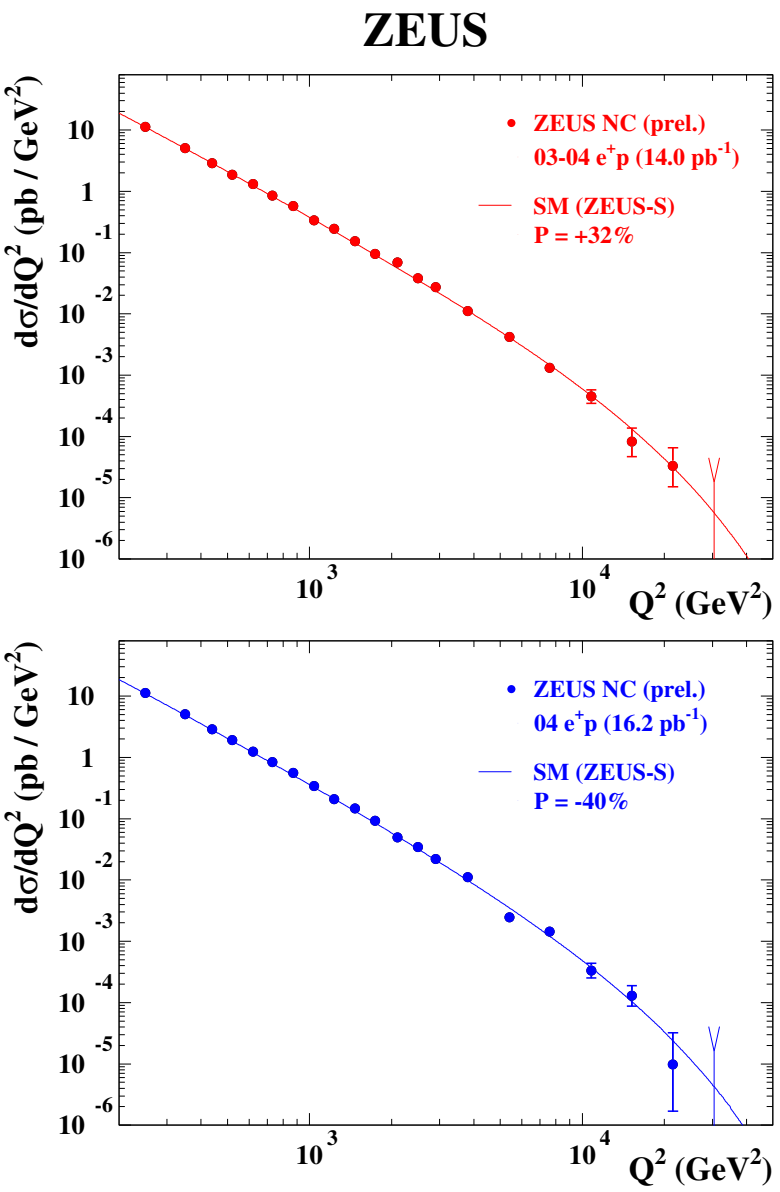
Data are consistent with SM expectation

No hint for right-handed charged currents.

talk by K. Nagano (electroweak session)

QCD: possibility to enhance CC cross-section by choosing appropriate sign of polarisation

HERA II results on polarized NC cross-section



$$\tilde{\sigma}^{\pm}_{\mathrm{NC}}(P) = Y^{+} F_2^{\mathrm{em}} + Y^{+} F_2^{\gamma Z}(P) \mp Y^{-} x F_3^{\gamma Z}(P)$$

$+Z$ $-$exchange

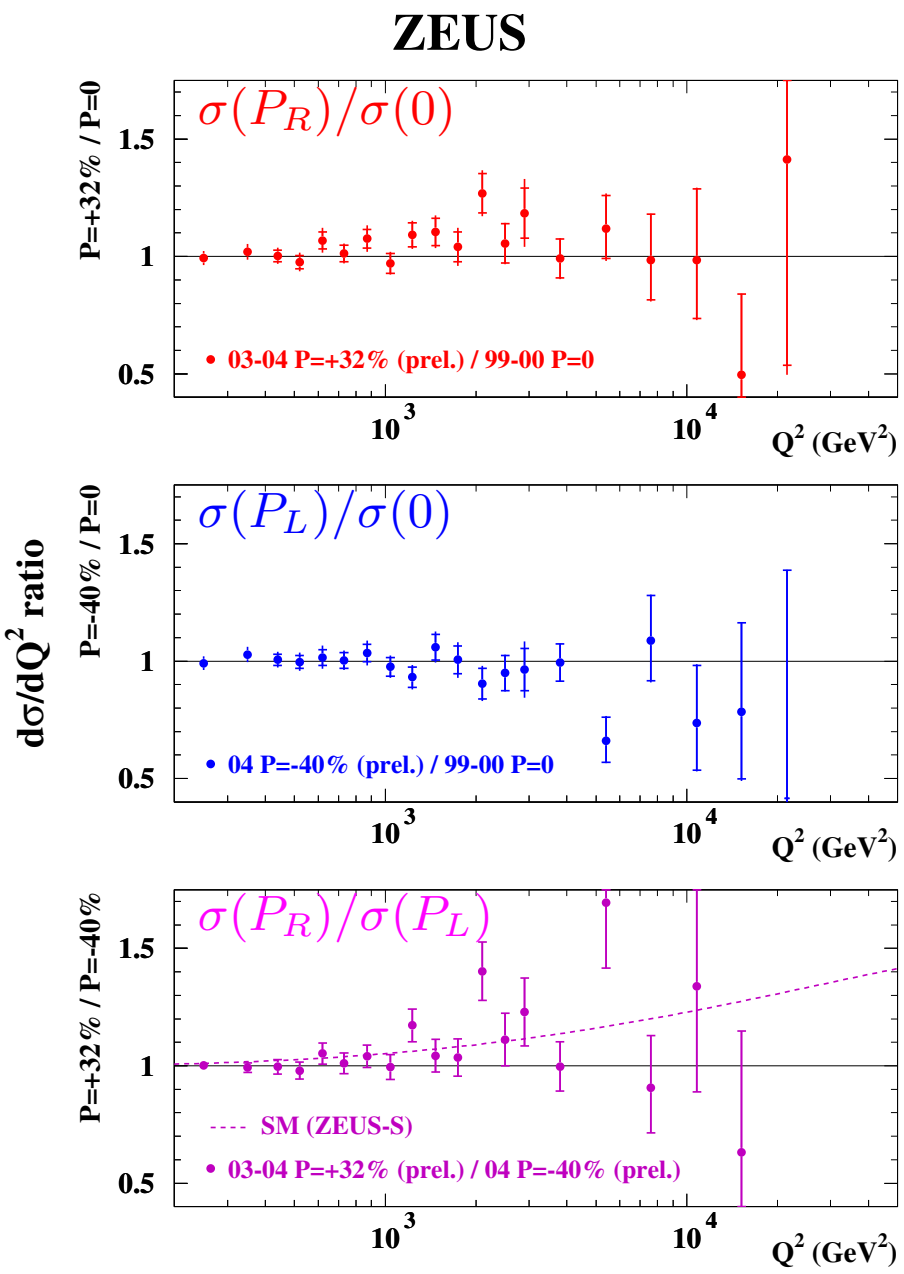
Electroweak terms are sensitive to polarization at high Q^2

$$F_2^{\gamma Z}(P) \sim \frac{Q^2}{Q^2 + M_Z^2}(P a_e - v_e) \sum e_q v_q (q + \bar{q})$$

$$\mp x F_3^{\gamma Z}(P) \sim \mp \frac{Q^2}{Q^2 + M_Z^2}(P v_e - a_e) \sum e_q a_q (q - \bar{q})$$

New possibility to disentangle individual quark flavours at high Q^2

HERA II results on polarized NC (continued)



Measurement still statistically limited.

Difference between left-handed and right-handed data not yet sufficient for dedicated QCD studies

Require high integrated luminosity and high degree of polarisation

Full HERA II program:
constrain u, d, $\bar{u}$, $\bar{d}$ quark densities
measure axial and vector couplings of u and d.

Summary

HERA I inclusive cross-section data at high Q^2 analyzed

- Proton structure well measured over a wide kinematic range
- Only the region of highest x and highest Q^2 is statistically limited
- Measurement of xG_3
- Local extraction of u and d PDF at high x
- d quark at high x requires more e^+p data

HERA II data-taking ongoing

- First results with polarized positrons
- High specific luminosity, plan to collect $\mathcal{O}(1\,\mathrm{fb}^{-1})$
- Polarization $\rightarrow$ new tool for QCD at high Q^2
- Running with $e^-_{L,R}$ after summer 2004