CC and NC Cross Sections from HERA

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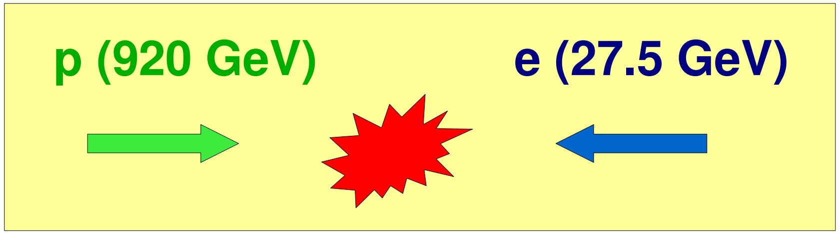
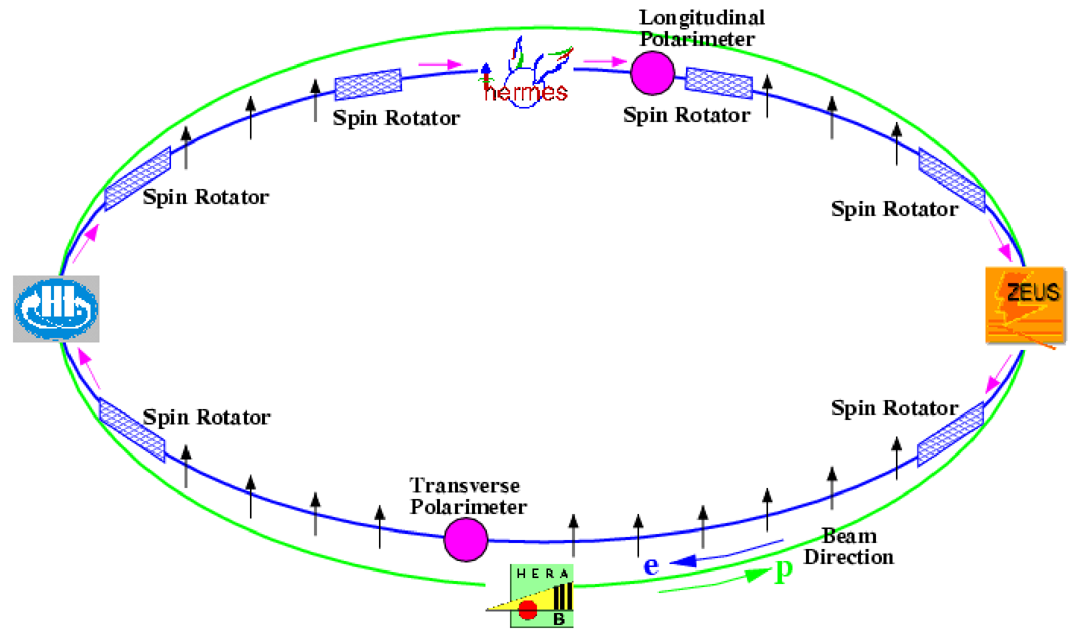
HERA II operation

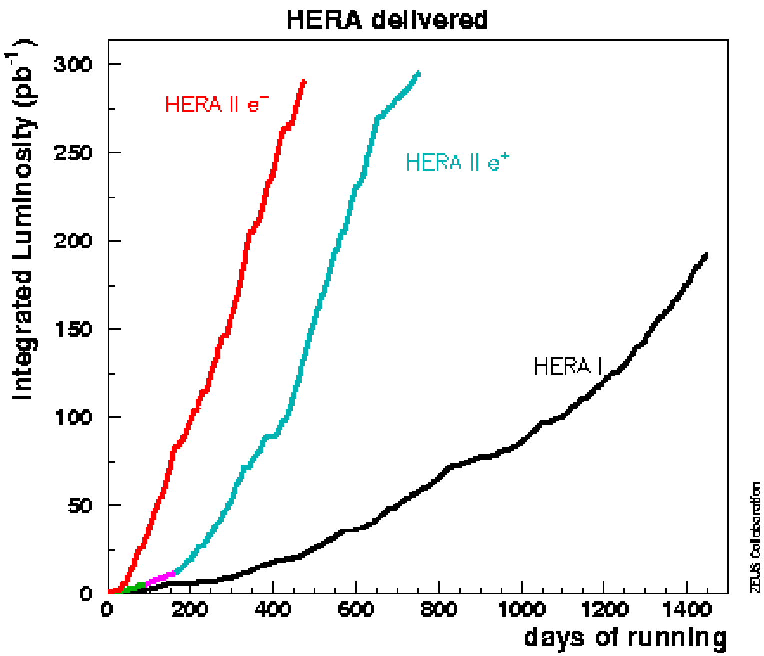


$\sqrt{s}$ = 318 GeV



High luminosity

equal sharing between $e^+ p/e^- p$



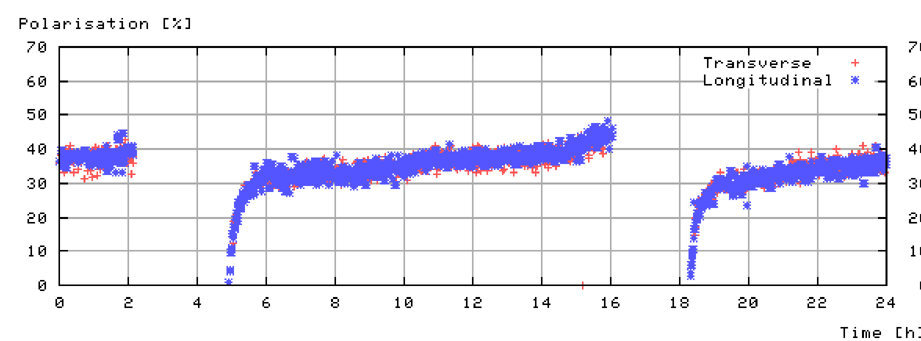
Longitudinal polarisation of the lepton beam

- Transverse P built up naturally (Sokolov-Ternov effect, rise time ~30 min)
- Spin rotators before/after H1&ZEUS
- P_e measured by 2 independent Compton polarimeters

typically P~30-40%

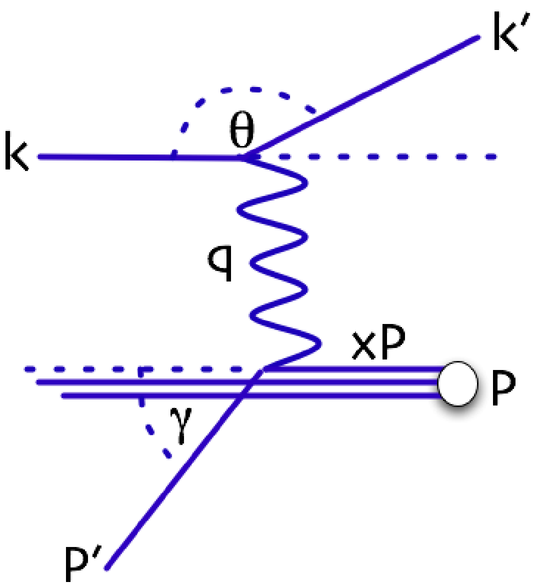
$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

asymmetry of helicity states



Deep Inelastic Scattering at HERA

Two processes: Neutral Current (NC) - exchange γ and Z^0 ($e^{\pm} p \rightarrow e^{\pm} X$)
Charged Current (CC) - exchange of $W^{\pm}$ ($e^{\pm} p \rightarrow \nu X$)



$$Q^2 = -q^2 = (k - k')^2$$

the probing power
virtuality of exchanged boson

$$x = \frac{Q^2}{2p \cdot q}$$

the Bjorken scaling variable

$$y = \frac{p \cdot q}{p \cdot k}$$

the inelasticity

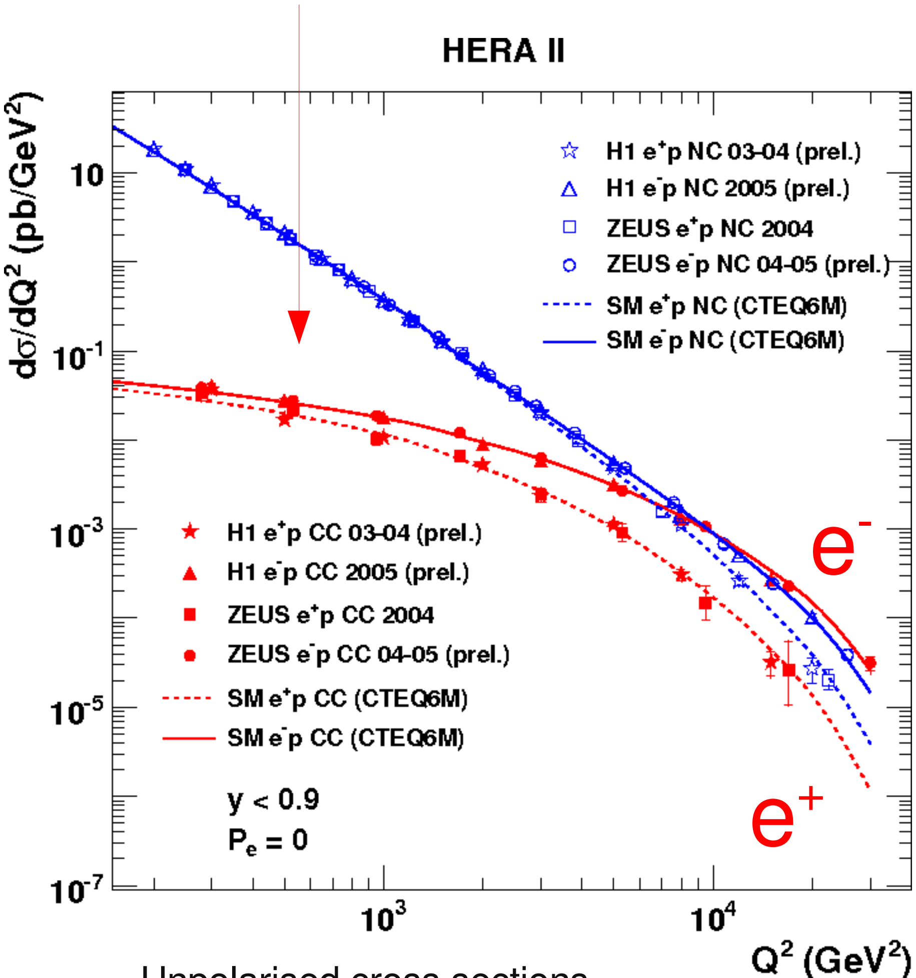
$$Q^2 = s \cdot x \cdot y$$

$$s = (p + q)^2$$

- Probe the proton with the spatial resolution of $\lambda \sim 1/Q$ down to 10^{-18} m (PDFs)
- Study the ElectroWeak sector of the Standard Model at Higher Energies

Charge Current Cross Sections

$e^{\pm} p \rightarrow \nu X$



Unpolarised cross sections

Cross section modified by P_e (chiral structure of SM)

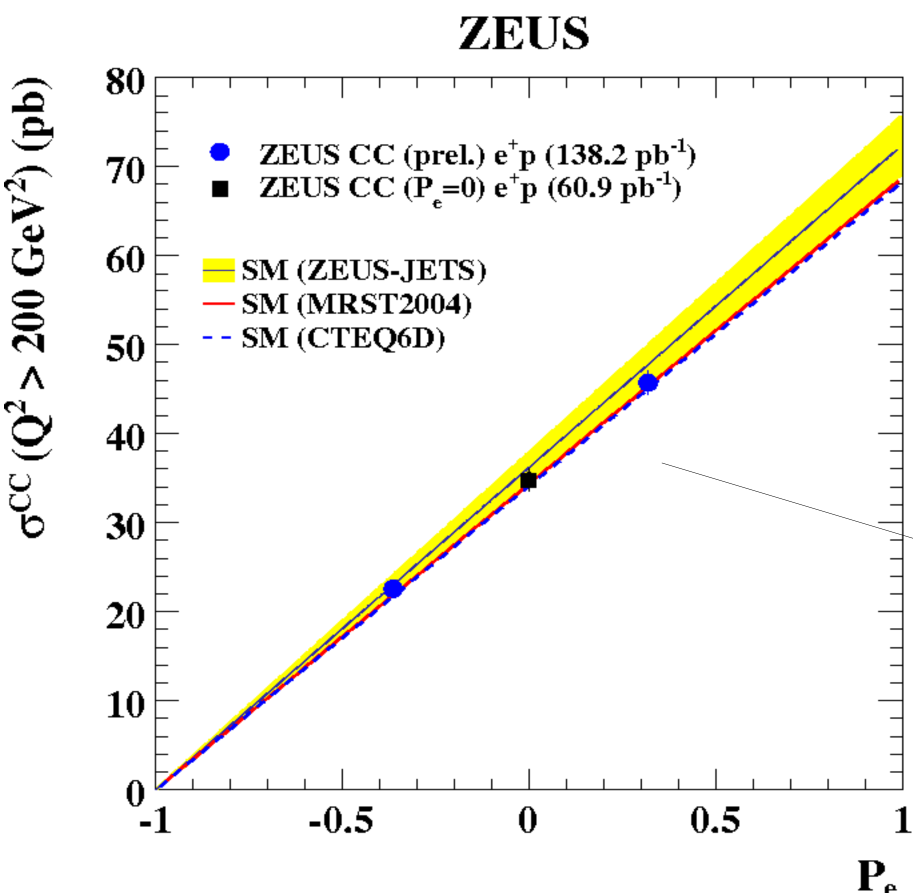
$$\frac{d^2\sigma^{CC}(e^- p)}{dxdQ^2} = (1-P)\frac{G_F^2}{2\pi}\frac{M_W^4}{(Q^2+M_W^2)^2}[(u+c)+(1-y)^2(\bar{d}+\bar{s})]$$

$$\frac{d^2\sigma^{CC}(e^+ p)}{dxdQ^2} = (1+P)\frac{G_F^2}{2\pi}\frac{M_W^4}{(Q^2+M_W^2)^2}[(\bar{u}+\bar{c})+(1-y)^2(d+s)]$$

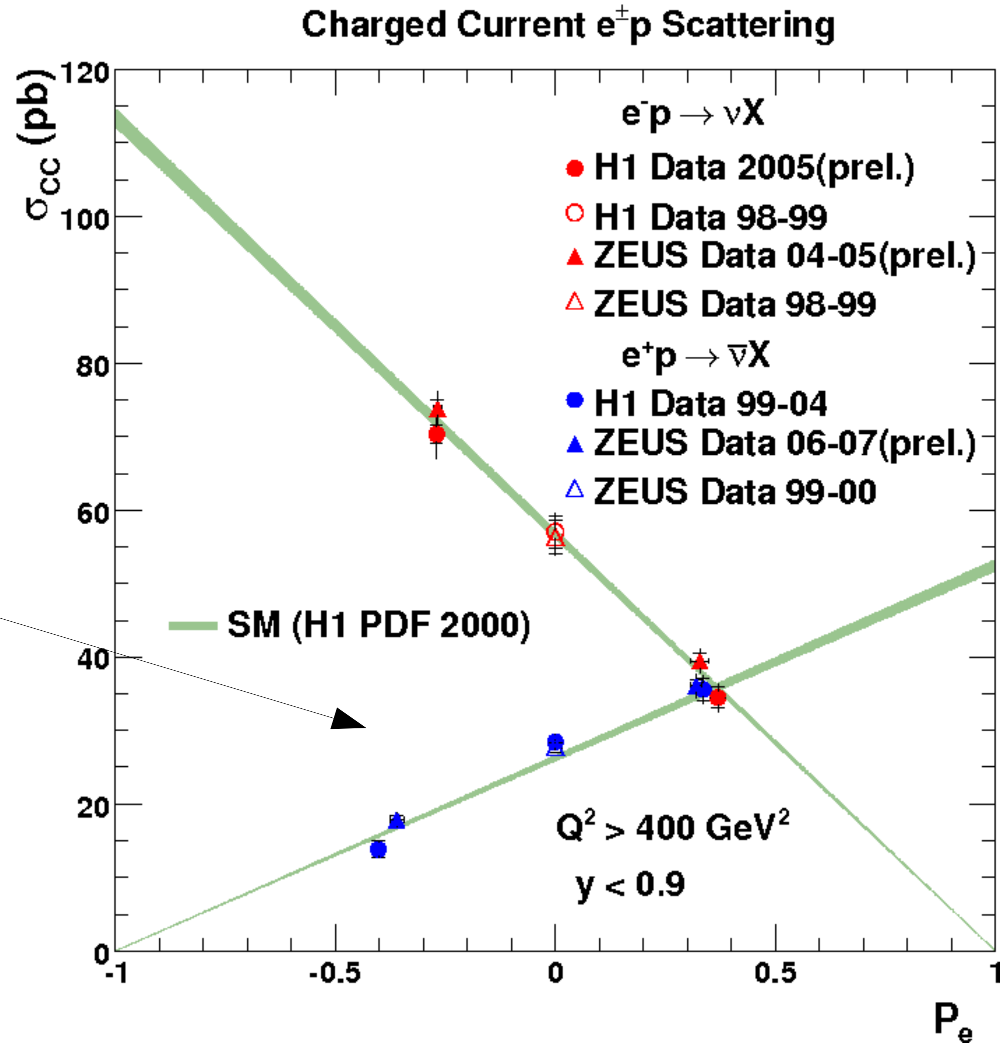
Sensitivity to EW parameters

Difference in cross section magnitude for e^+/e^- :
u-quark density larger than *d-quark* (proton),
d-quark contribution supressed by helicity factor $(1-y)^2$

CC Total Cross Sections



New high precision ZEUS e+p polarised data



Polarisation scales the cross section at P=0 linearly
Clear and large effect at HERA
In agreement with SM predictions

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

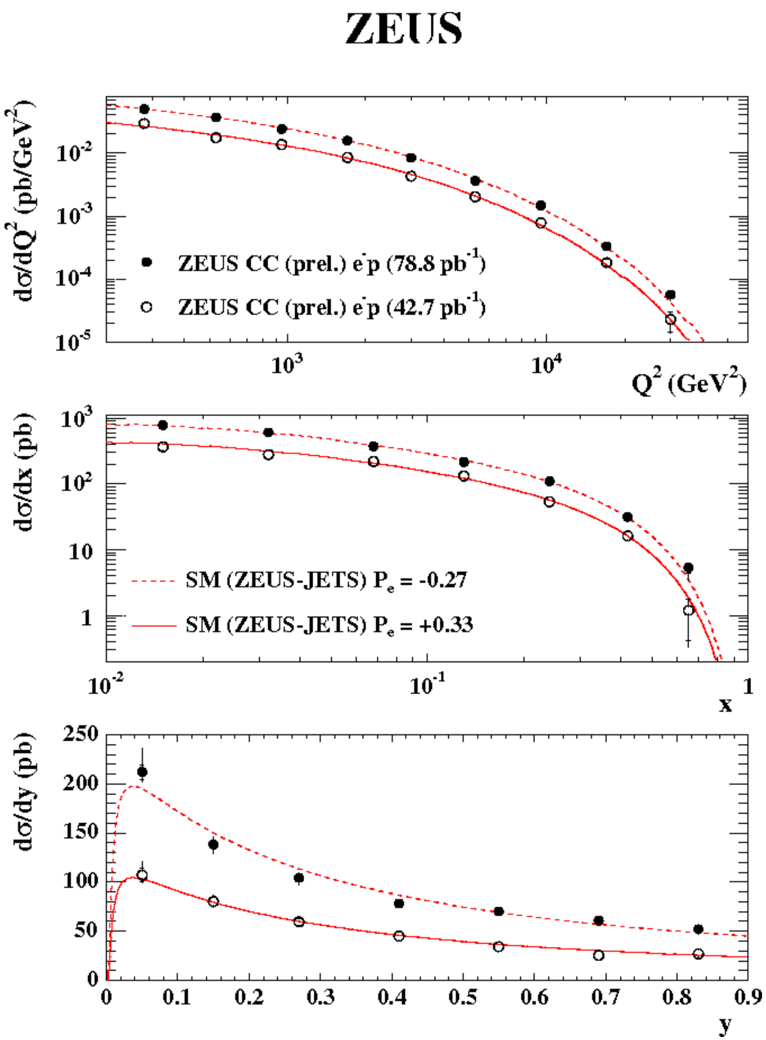
SM: $\sigma(P_e=-1) = 0$ in $e^+ p$ scattering
$\sigma(P_e= 1) = 0$ in $e^- p$ scattering

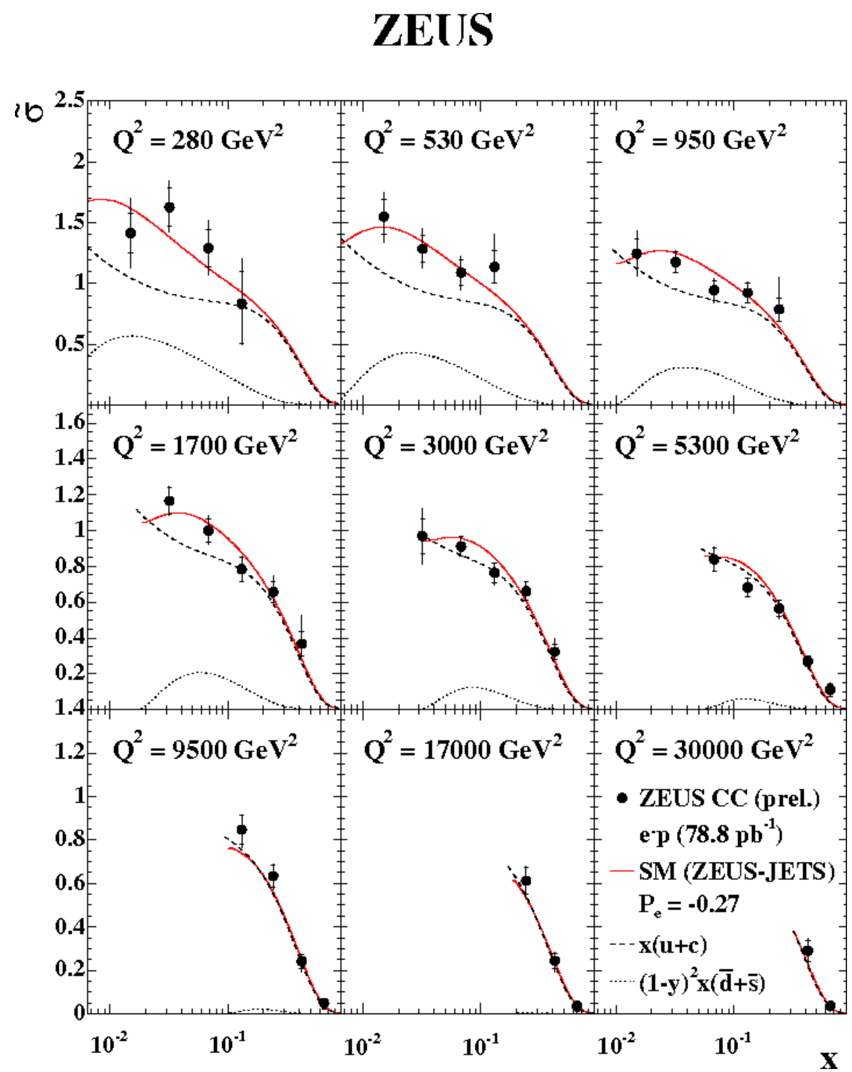
weak interaction left-handed
(only LH particles/RH anti-particles interact)

CC Differential Cross Sections

e^- data (sensitivity to u-quark)

More e^- and full e^+ polarised data to come





Cross sections as a function of Q2, x and y

Scale with polarisations independently of kinematic variables

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

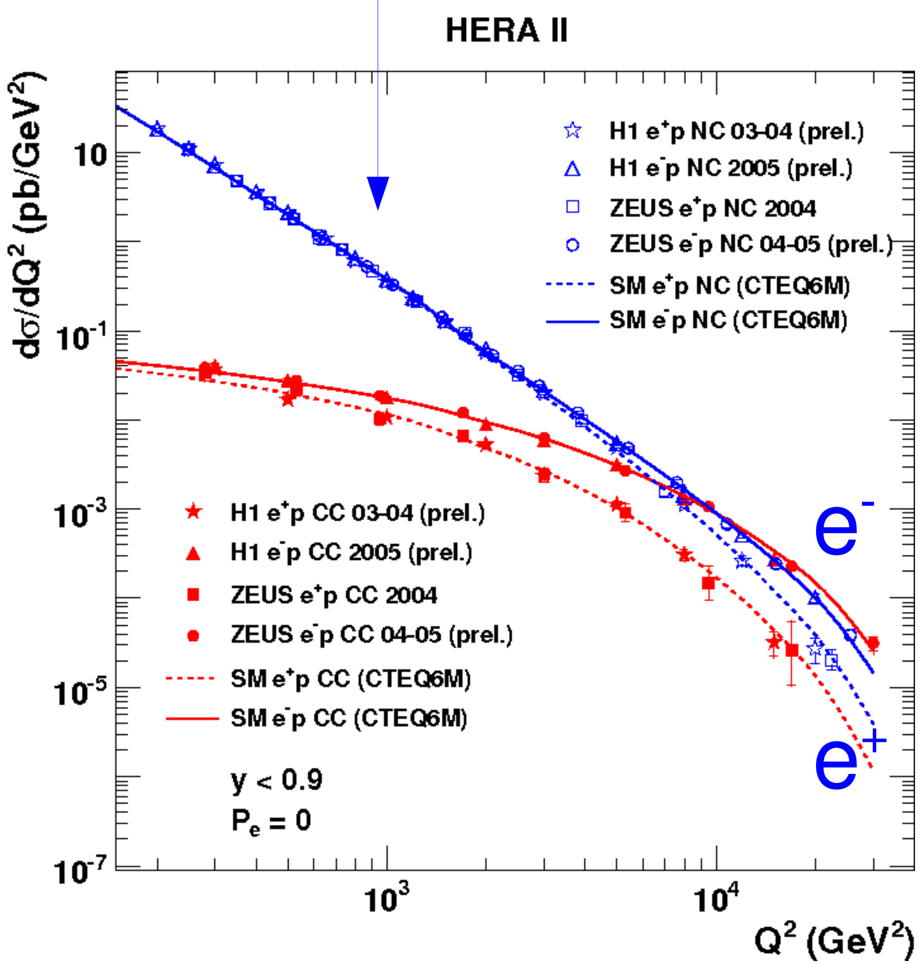
Reduced cross sections = PDF content

Higher precision than ever before in CC DIS

Input to QCD and EW fits (see talk by Z. Zhang)

Neutral Current Unpolarised Cross Sections

(high precision e^+/e^- samples with different polarisations combined and corrected for small residual polarisation)



$e^\pm p \rightarrow e^\pm X$

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

In terms of three Structure Functions

$$\frac{d^2\sigma^{NC}(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2) - y^2 F_L(x,Q^2)]$$

dominant EM contribution

PDFs

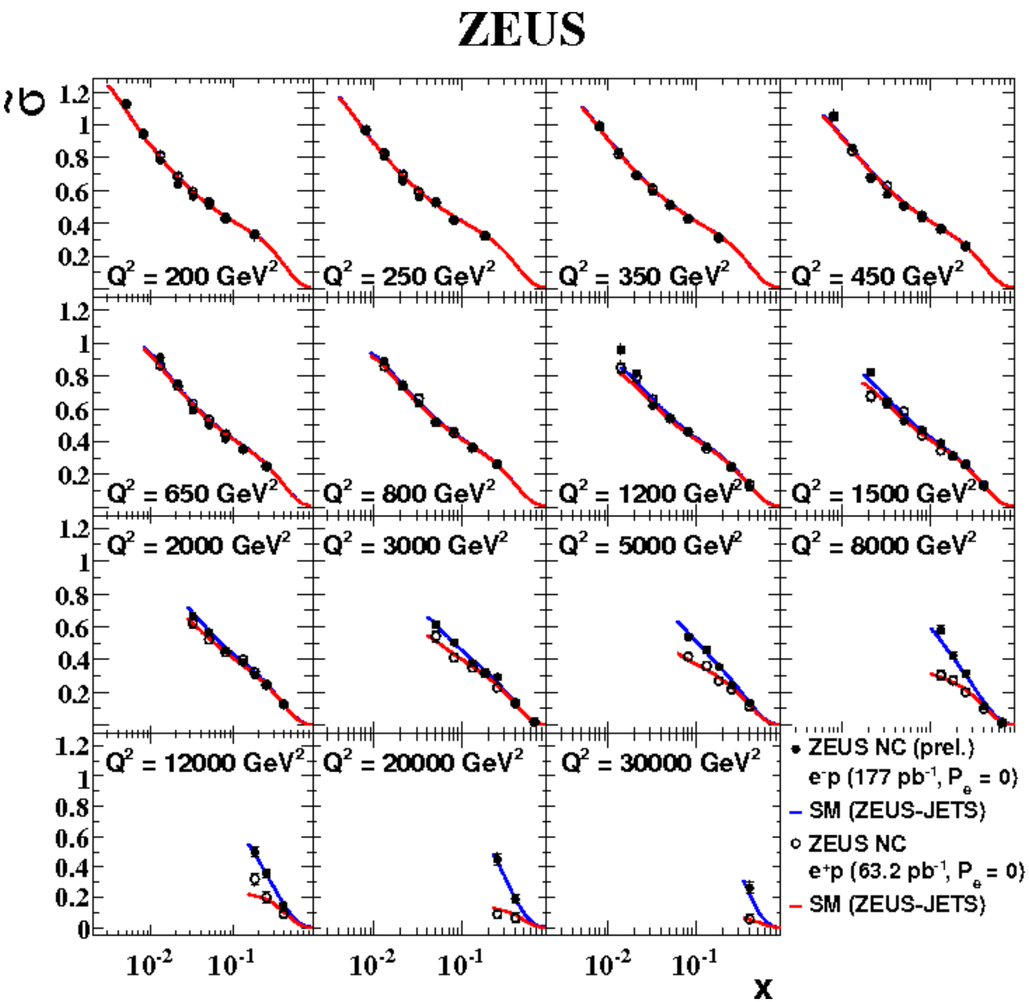
important at high Q2, changes sign for e^+/e^-

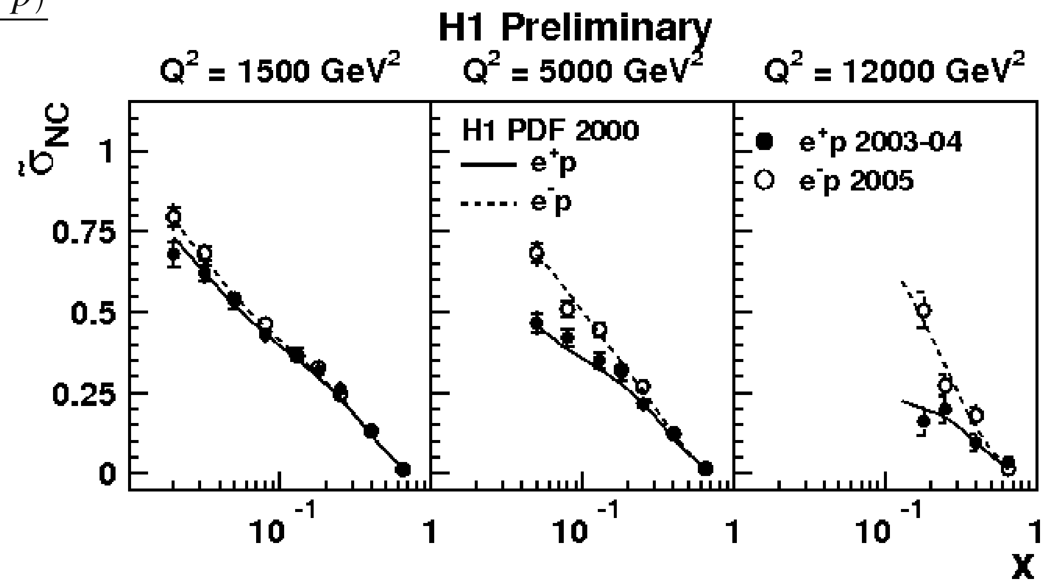
sensitivy to γ-Z interference
sensitivity to valence quarks

negligible at high Q2& x

Unpolarised NC Cross Sections

Reduced cross sections (only PDF content) $\tilde{\sigma}^{NC}(e^{\pm}p) = \frac{xQ^4}{2\pi\alpha^2 Y_+} \frac{d^2\sigma^{NC}(e^{\pm}p)}{dxdQ^2}$





$\sigma(e^-) > \sigma(e^+)$ getting more pronounced with Q^2 (γ–Z interference)

$$\tilde{\sigma}^{NC}(e^{\pm}p) = \tilde{F}_2(x,Q^2) \mp \frac{Y_-}{Y_+} x\tilde{F}_3(x,Q^2)$$

From Charge Asymmetry remove pure γ contribution (F_2) and measure

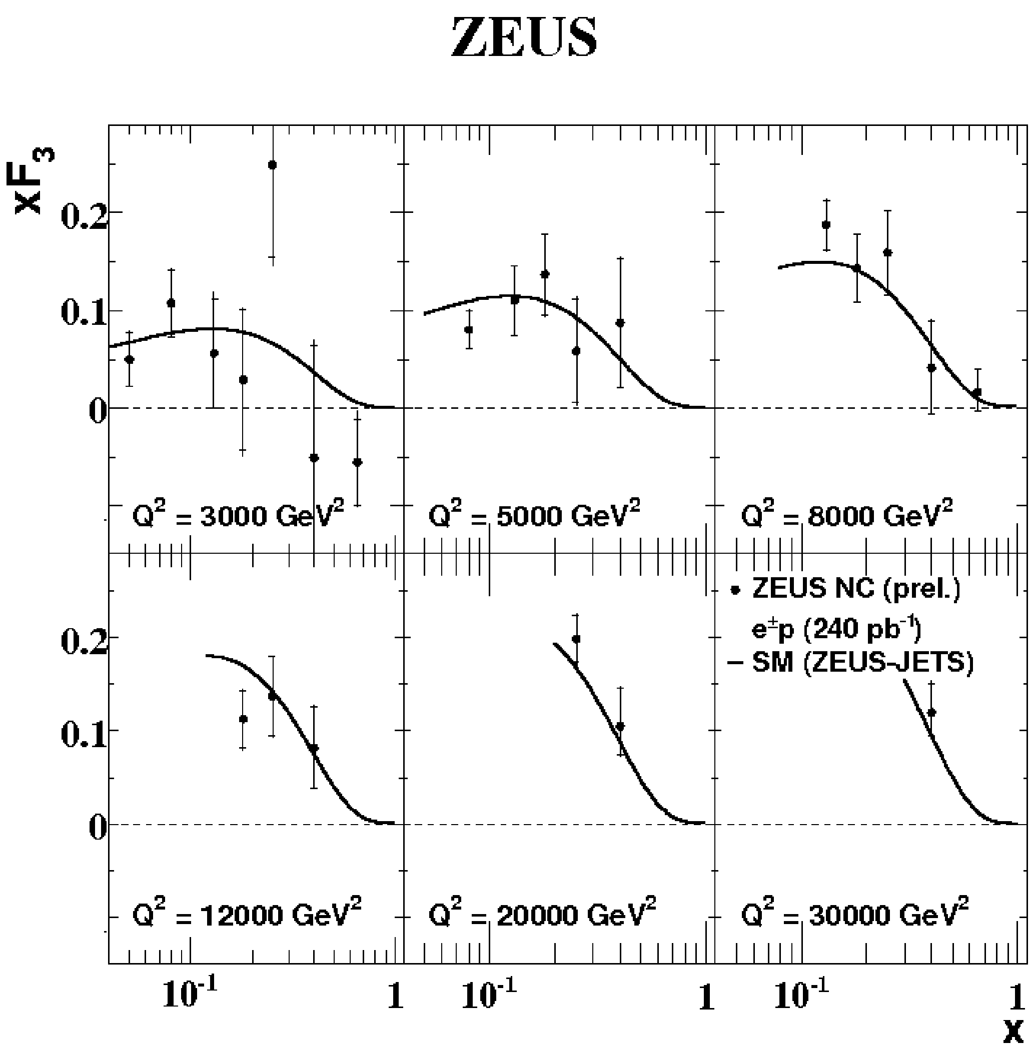
$$x\tilde{F}_3$$

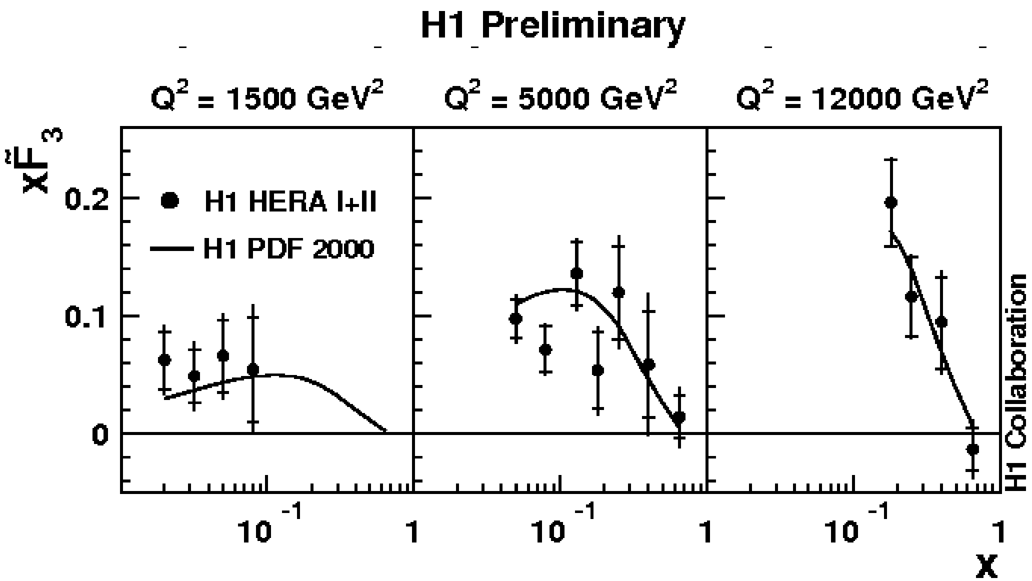
Combine polarised e^- sample to give unpolarised cross sections

Significant increase of statistics wrt. HERA I e^- data

Very good agreement with the SM predictions

Unpolarised NC Cross Sections





$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}[\tilde{\sigma}(e^- p) - \tilde{\sigma}(e^+ p)]$$

Most precise measurement of xF_3 from NC DIS at high Q^2

Sensitivity to valence quark distributions in a region where there were no previous DIS measurements with pure proton target.

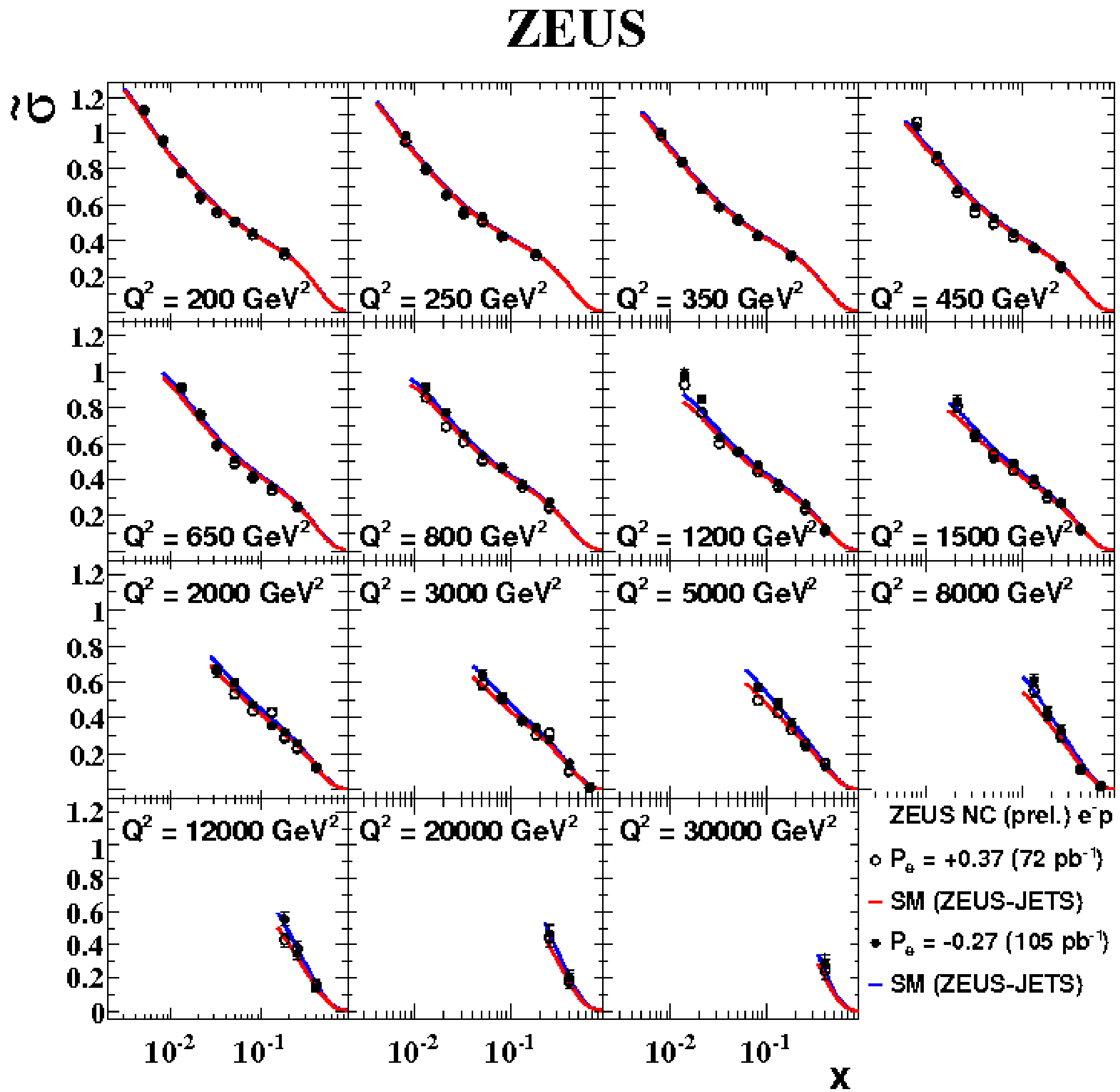
Combine polarised samples to give unpolarised cross sections

$$xF_3^{\gamma Z}(x, Q^2) = -x\tilde{F}_3 \cdot \frac{Q^2 + M_Z^2}{a_e Q^2}$$

Polarised NC Cross Sections

$$\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{\pm}}{dxdQ^2}\frac{Q^4 x}{2\pi\alpha^2 Y_+} = \tilde{F}_2^{\pm} \mp \frac{Y_-}{Y_+} x\tilde{F}_3^{\pm}$$

full e^- sample



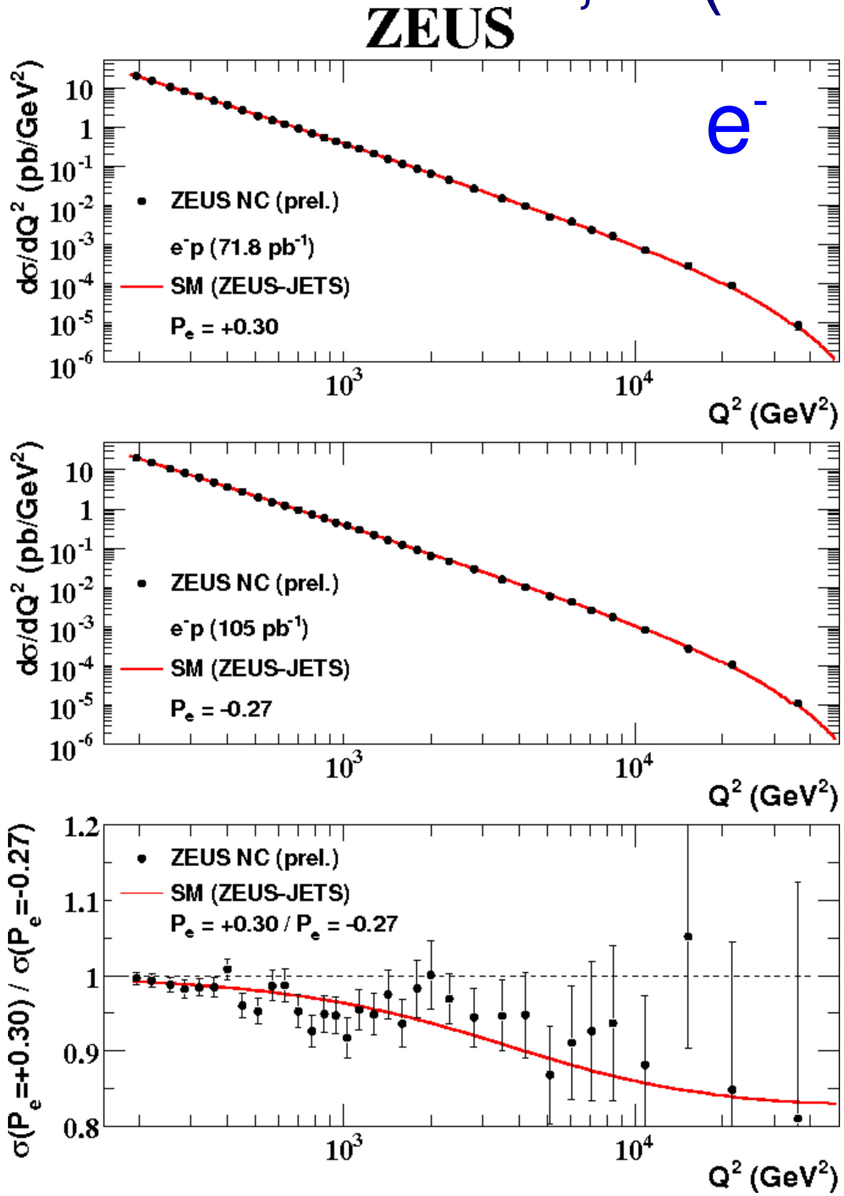
Small differences between cross sections at highest Q2 due to polarisation

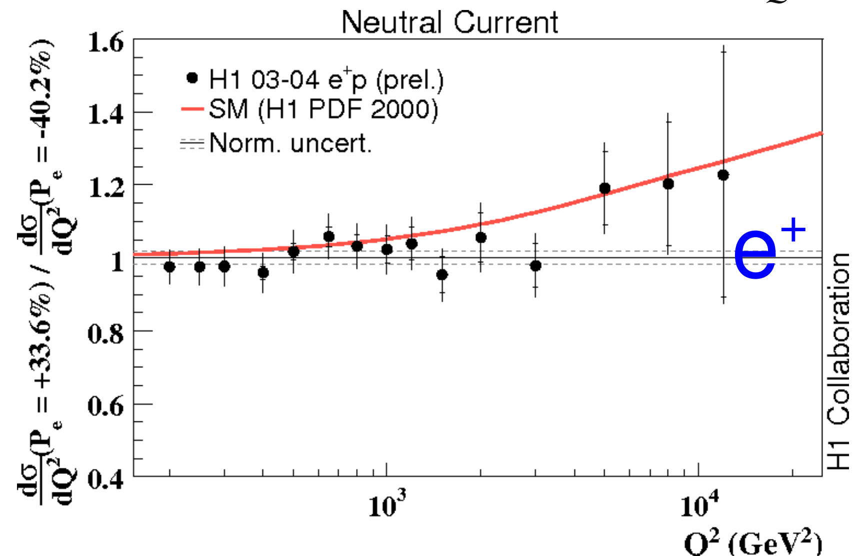
ZEUS complete e^- p data sample. Input to QCD and EW fits (see talk by Z. Zhang)

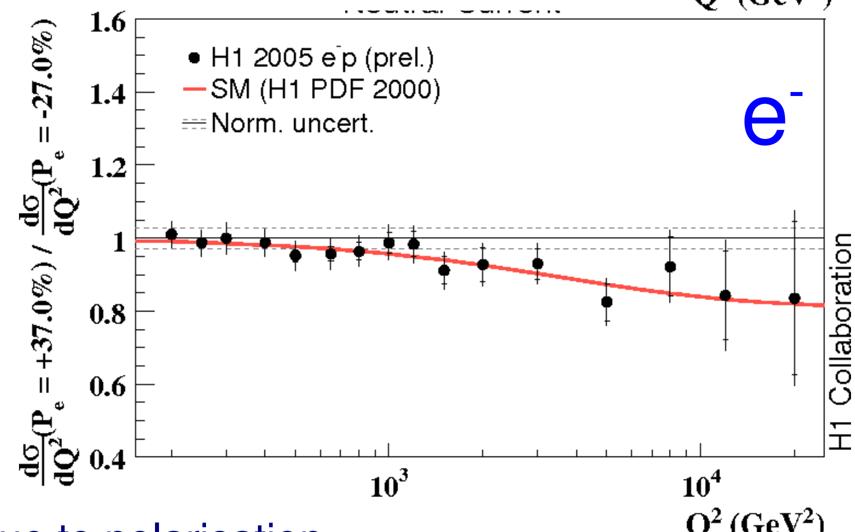
Polarised NC, σ(P>0)/σ(P<0)

$$\tilde{\sigma}^{\pm} = F_2^{\pm} \mp kP\, a_e F_2^{\gamma Z} \pm \frac{Y_-}{Y_+} k\, a_e\, x F_3^{\gamma Z}$$

$$a_e = -1/2 \qquad k = \frac{1}{\sin^2 2\theta}\frac{Q^2}{Q^2+M_Z^2}$$







Small differences between cross sections at highest Q^2 due to polarisation

Effect of parity violation in NC DIS seen at the EW scale

Summary & Outlook

- The CC and NC cross sections for $e^{\pm}p$ scattering with longitudinally polarised lepton beams measured at HERA

Charged Current scattering:

- Clear effect of the linear cross section dependence on polarisation, independently of kinematic variables
- High Precision CC data → input to PDF and EW fits

Neutral Current scattering:

- The structure function $xF_3^{\gamma Z}$ measured → sensitivity to valence quarks distributions
- Clear evidence of parity violation in polarised NC interactions at high Q2 observed

- Measurement in good agreement with SM predictions

- More e^- and e^+ data to analyse , higher precision measurements to come
- Combined Results of H1 and ZEUS with L ~ 1fb $^{-1}$ to come

Unpolarised NC Cross Sections

H1+ZEUS Combined Analysis (L ~ 0.5 fb $^{-1}$)

Measure the "interference structure function" $xF_3^{\gamma Z}$
to study the valence quark distributions

$$xF_3^{\gamma Z}(x,Q^2) = -x\,\tilde{F}_3 \cdot \frac{Q^2+M_Z^2}{a_e Q^2} \quad \text{measured}$$

$$xF_3^{\gamma Z}(x,Q^2) = 2x\left[e_u a_u (U-\bar{U}) + e_d a_d (D-\bar{D})\right]$$

Little Q^2 dependence:

- transform all measurements to $Q^2 = 1500$ GeV^2
- take average of H1 and ZEUS measurements

Sum rule (over the valuence quarks)

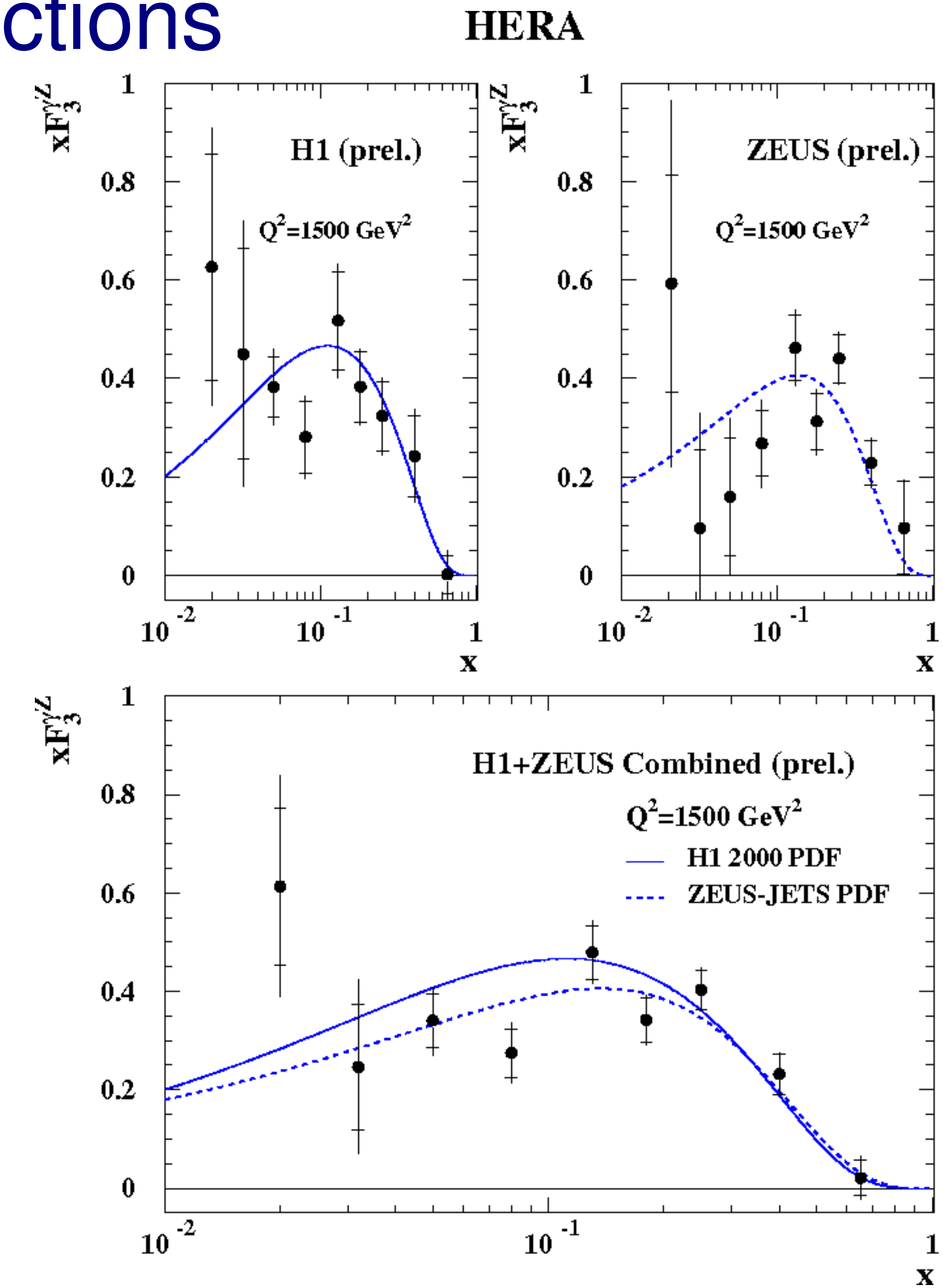
$$\int_0^1 xF_3^{\gamma Z} \cdot \frac{dx}{x} = \frac{1}{3}\int_0^1 (2u_v + d_v)\,dx = \frac{5}{3}$$

neglecting
see contrib. δ

$$\int_{0.02}^{0.65} xF_3^{\gamma Z}\,dx = 1.21 \pm 0.09\,(stat.) \pm 0.08\,(syst.)$$

In agreement with SM expectations:
H12000 PDF: 1.12 ± 0.02
ZEUS-JETS PDF: 1.06 ± 0.02

$$\int_{0.02}^{0.65} \delta\,dx = 0.09 \pm 0.09\,(stat.) \pm 0.08\,(syst.)$$



More e- data and new e+ data of both experiments to come.