Neutral Current DIS with polarised e^+/e^- at HERA

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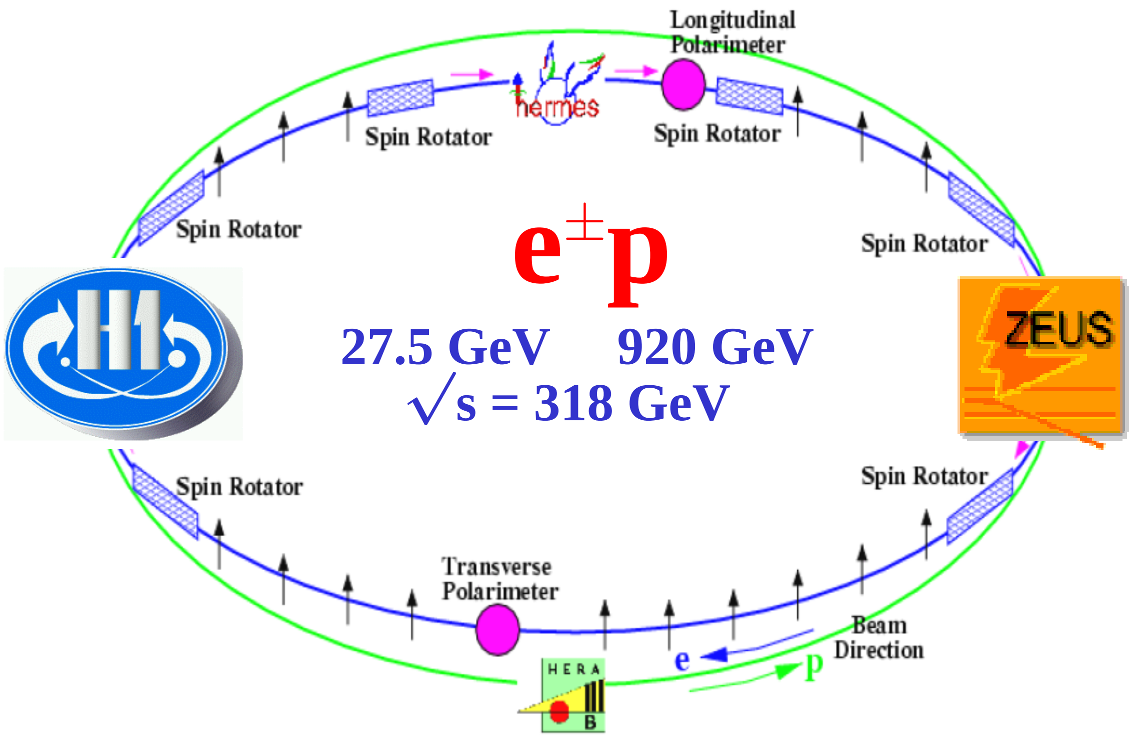


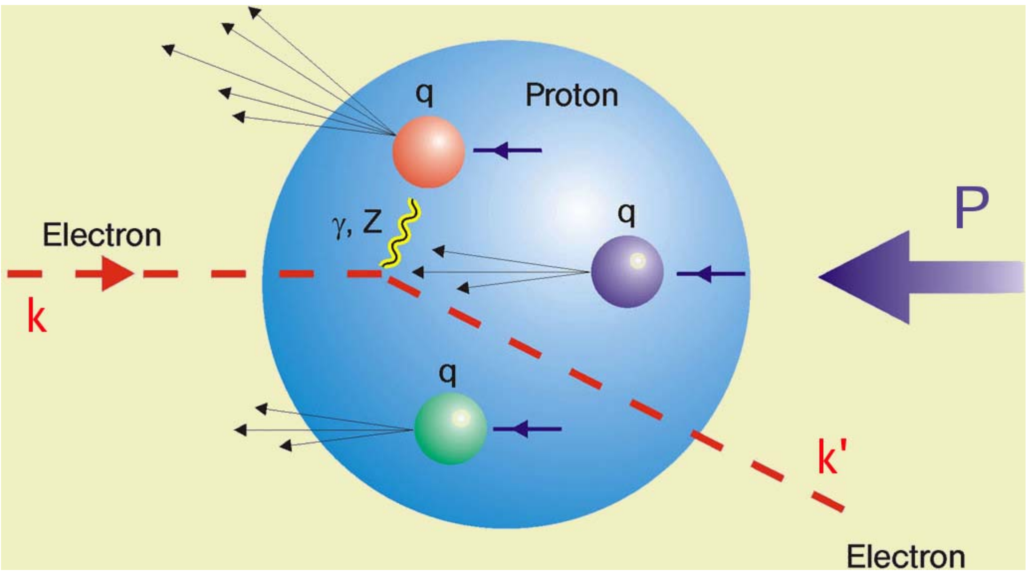
HERA II:
longitudinal polarisation of the lepton beam

- DIS & NC & Polarisation
- Unpolarised DIS: HERA II
- xF_3
- Polarised NC

(for CC see talk of Alex Tapper)

Deep Inelastic Scattering at HERA

Neutral Current (NC) DIS : $e^{\pm} p \to e^{\pm} X$



DIS kinematics:

$Q^2 = -q^2 = -(k-k')^2$	virtuality of γ^*, Z^0
$x = Q^2/2(Pq)$	Bjorken x
$y = (Pq)/(Pk)$	inelasticity
$Q^2 = sxy$	$s=(k+P)^2$

$$\sigma_{DIS} \sim \hat{\sigma} \otimes pdf(x)$$

$\hat{\sigma}$ – perturbative QCD cross section

pdf – universal parton distribution functions

→ probe proton with the spatial resolution of $\lambda \sim 1/Q$

→ probe the EW sector of the Standard Model

NC cross section

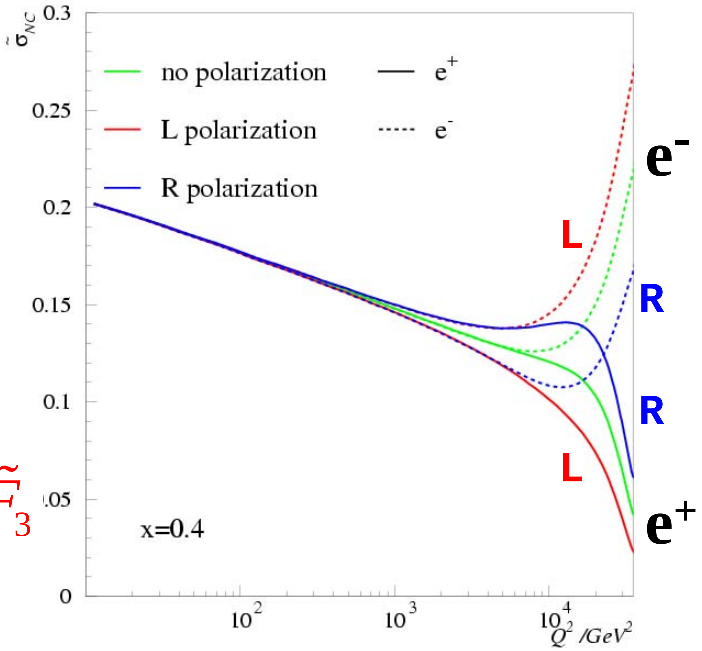
$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2(x,Q^2) - y^2\tilde{F}_L(x,Q^2) \mp Y_- x\tilde{F}_3(x,Q^2)\right]$$

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

- F_2 dominant contribution
- xF_3 important at high Q^2; difference in the sign for $e^\pm$
- F_L important only at high y; expected to be negligible at high Q^2 & x; in QPM **$F_L = F_2 - 2xF_1 = 0$**

Reduced cross section:

$$\tilde{\sigma}_{NC}^{\pm} \equiv \frac{d^2\sigma_{NC}^{e^\pm p}}{dx\,dQ^2}\frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+} \equiv \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3$$



Polarised NC Structure Functions

$$\tilde{F}_2^{\pm} = F_2 - \left(v_e \pm P_e a_e\right)\frac{\kappa Q^2}{Q^2 + M_Z^2} F_2^{\gamma Z} + \left(v_e^2 + a_e^2 \pm P_e 2 v_e a_e\right)\left(\frac{\kappa Q^2}{Q^2 + M_Z^2}\right)^2 F_2^Z$$

$$x\tilde{F}_3^{\pm} = -\left(a_e \pm P_e v_e\right)\frac{\kappa Q^2}{Q^2 + M_Z^2} xF_3^{\gamma Z} + \left(2 v_e a_e \pm P_e (v_e^2 + a_e^2)\right)\left(\frac{\kappa Q^2}{Q^2 + M_Z^2}\right)^2 xF_3^Z$$

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

N_R(N_L)- number of right (left) handed leptons in the beam

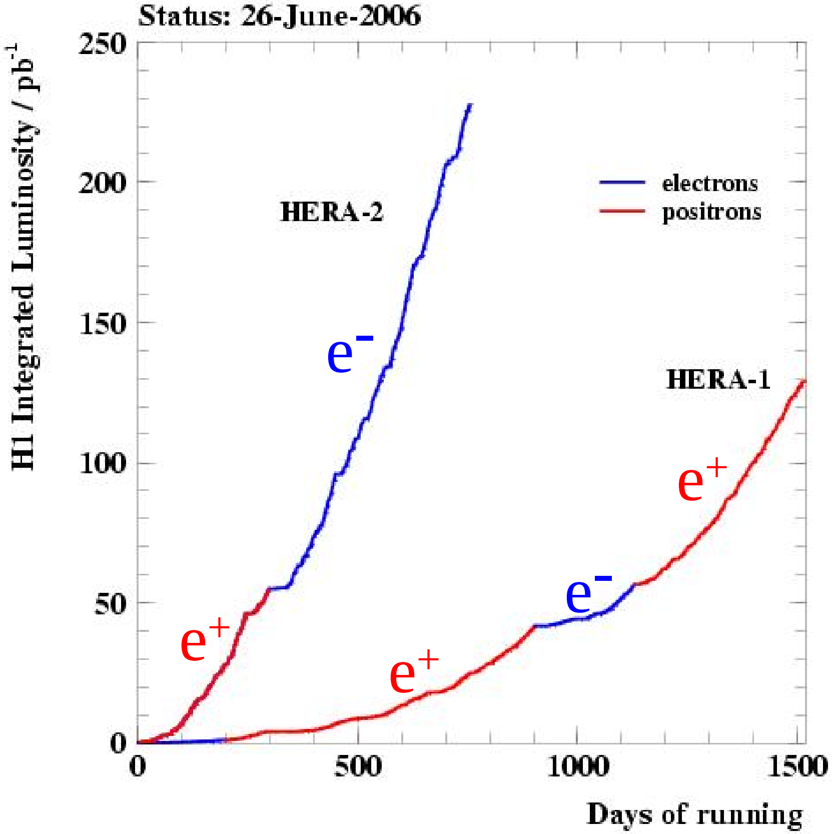
$$\kappa^{-1} = 4\frac{M_W^2}{M_Z^2}\left(1 - \frac{M_W^2}{M_Z^2}\right)$$

in QPM:

$$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right](q + \overline{q})$$

$$\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_q a_q\right](q - \overline{q})$$

HERA II performance



HERA II:

- detectors and luminosity upgrade

Lumi (P_e)	e^+p (2003-04)	e^-p (2004-05)
H1	27 pb^{-1} (+34%) 21 pb^{-1} (-40%)	30 pb^{-1} (+37%) 69 pb^{-1} (-27%)
ZEUS	12 pb^{-1} (+32%) 12 pb^{-1} (-41%)	43 pb^{-1} (+33%) 79 pb^{-1} (-27%)
HERA I	$\approx$ 100 pb^{-1}	$\approx$ 15 pb^{-1}

- longitudinally polarised lepton beams

natural transverse polarisation
(Sokolov-Ternov effect) + spin rotators

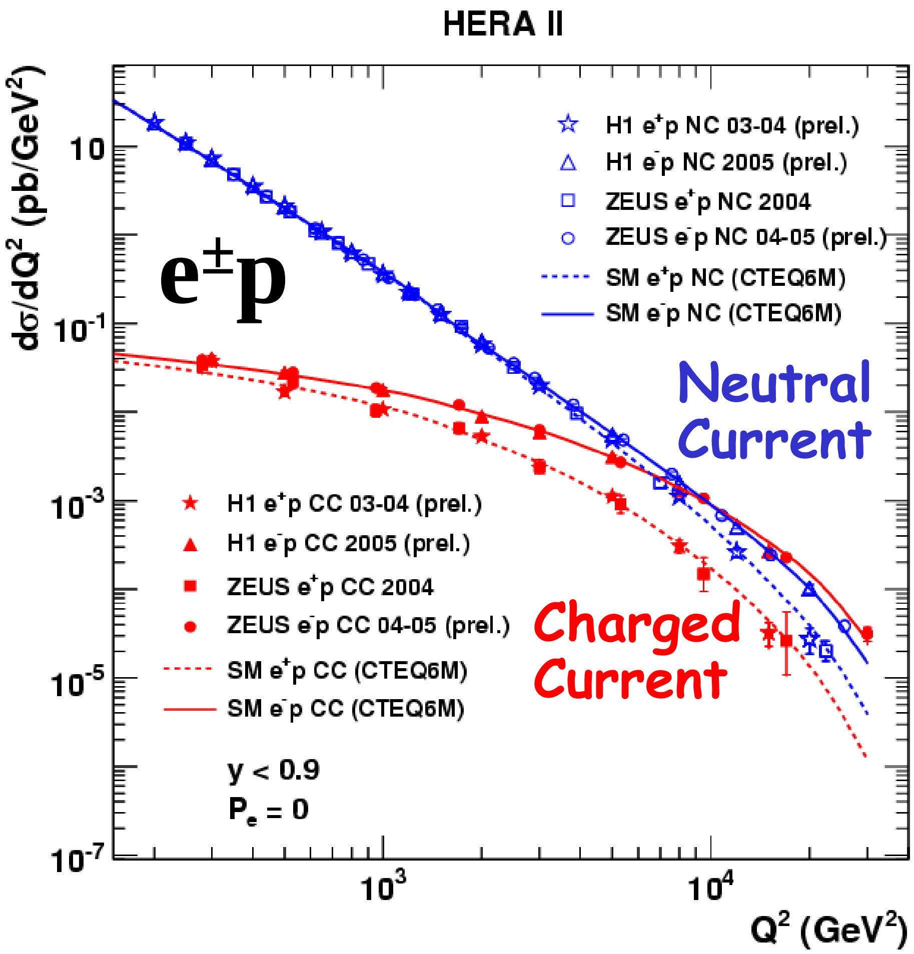
typically P_e = 30-40%
build-up time ~30min

data taking with positrons till mid 2007:

→ **double the sofar collected statistics**

→ **low proton energy run for direct F_L measurement**

NC&CC DIS at HERA II



Unpolarised results:

combine $e^+(e^-)$ data with different polarisations and correct for small residual polarisation

Probe proton:

quarks are pointlike down to 1/1000 of the proton radius $r < 10^{-18}$ m

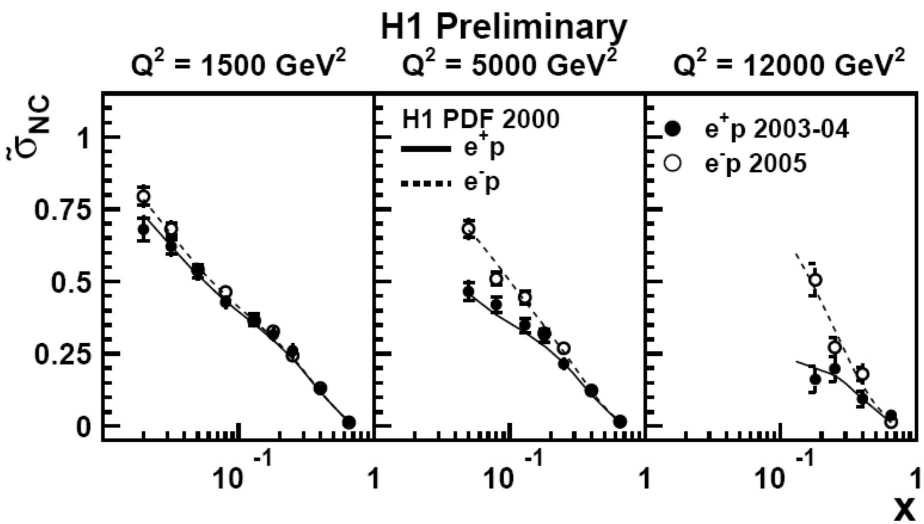
EW component of SM:

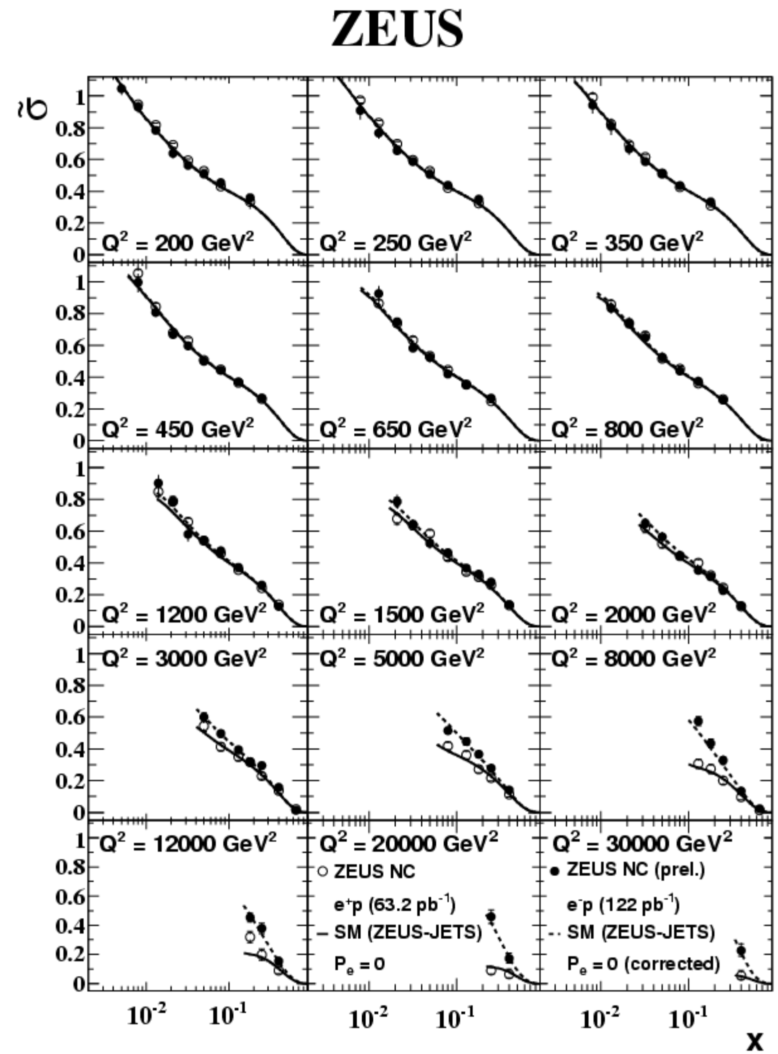
$\sigma_{NC} \approx \sigma_{CC}$ at $Q^2 \approx M_Z^2, M_W^2$

→ electro-weak unification

Unpolarised NC: $d^2\sigma/dxdQ^2$

$$\tilde{\sigma}^{\pm}_{NC} = \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+} x\tilde{F}_3$$



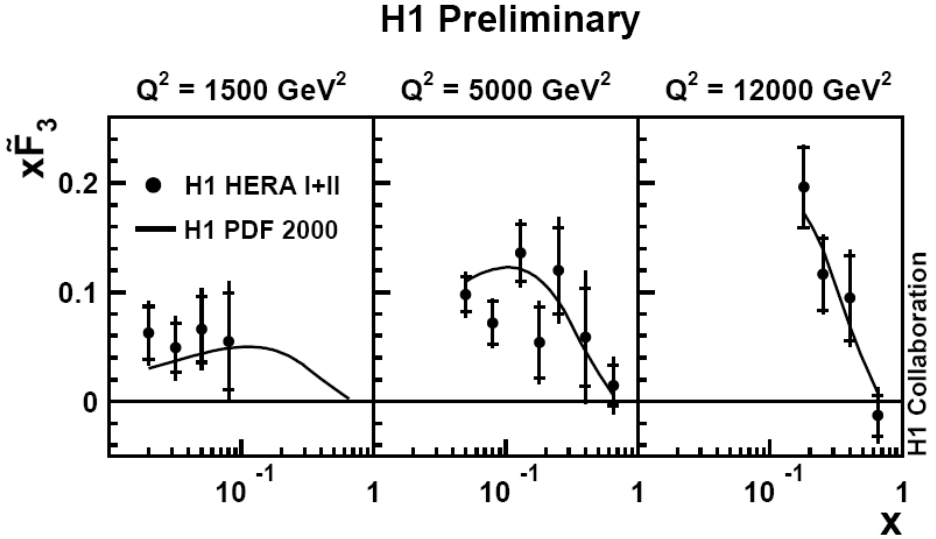


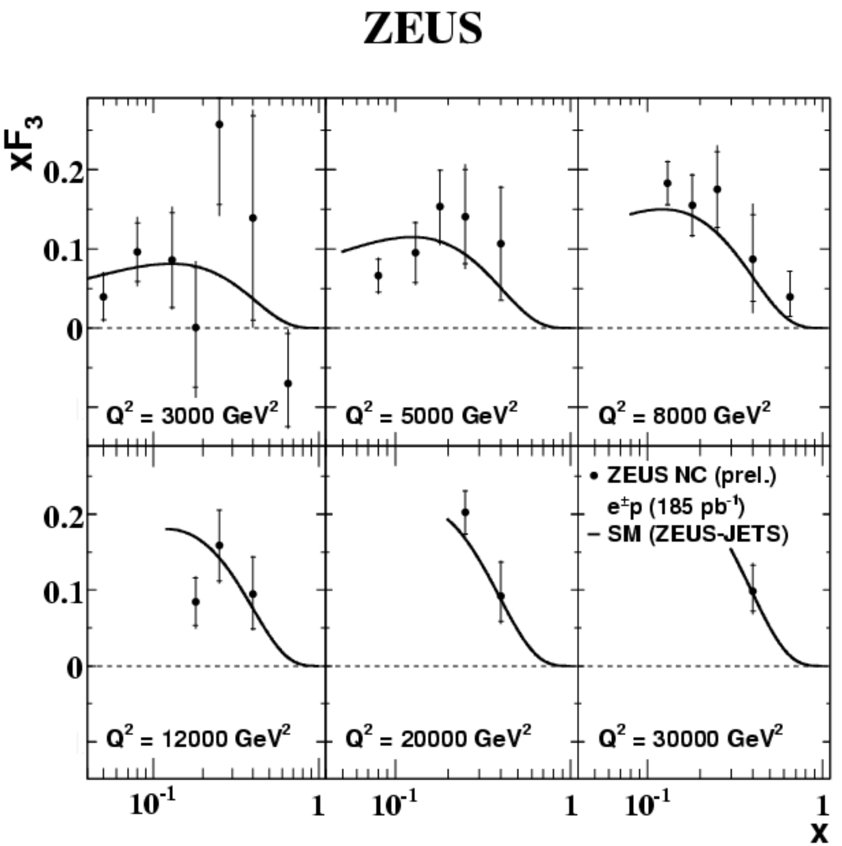
e^-p lumi at HERA II: 6-8 fold of HERA I

→ determine xF_3

Structure Function xF_3

$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left(\tilde{\sigma}^-_{NC} - \tilde{\sigma}^+_{NC}\right)$$

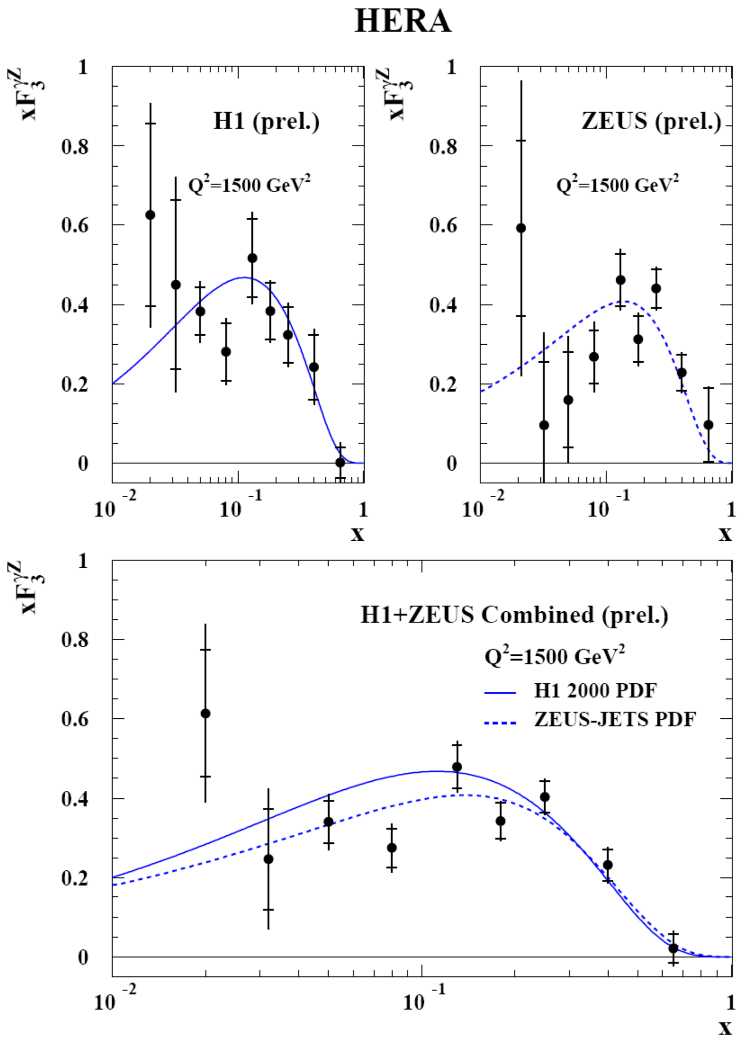




Precision of xF_3 is improved by ~ 20%
due to larger e^-p statistics at HERA II

mostly due to γZ interference →

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



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

Little dependence on Q^2

→ transform to one Q^2 value of 1500 GeV²

→ and average (all Q^2 & H1 & ZEUS)

Sum rule (counting of the valence quarks):

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

$$xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v + \Delta) \qquad \Delta = 2(u_{sea} - \bar{u} + c - \bar{c}) + (d_{sea} - \bar{d} + s - \bar{s})$$

Combined H1 & ZEUS results:

$$\int_{0.02}^{0.65} F_3^{\gamma Z}\, dx = 1.21 \pm 0.09(\mathrm{sta}) \pm 0.08(\mathrm{sys})$$

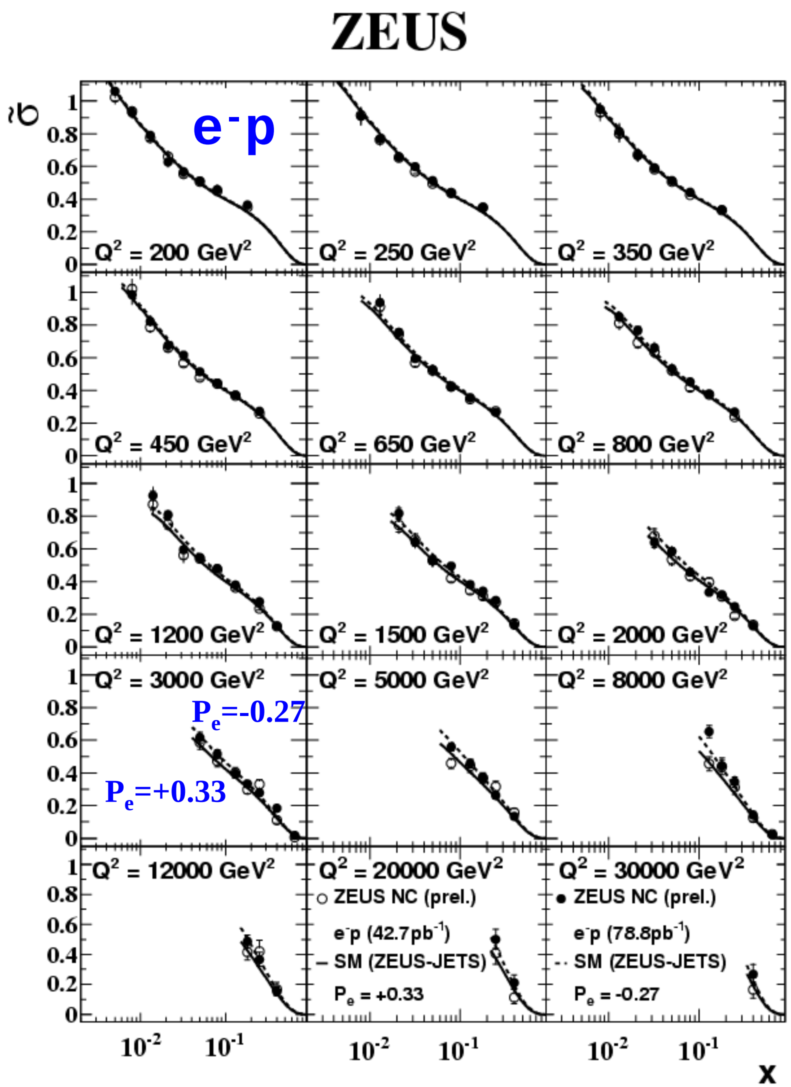
consistent with H1 PDF 2000 fit: 1.12 ± 0.02

ZEUS+Jets fit: 1.06 ± 0.02

$$\int_{0.02}^{0.65} \Delta dx = 0.09 \pm 0.09(\mathrm{sta}) \pm 0.08(\mathrm{sys})$$

consistent with zero

Polarised NC: $d^2\sigma/dxdQ^2$



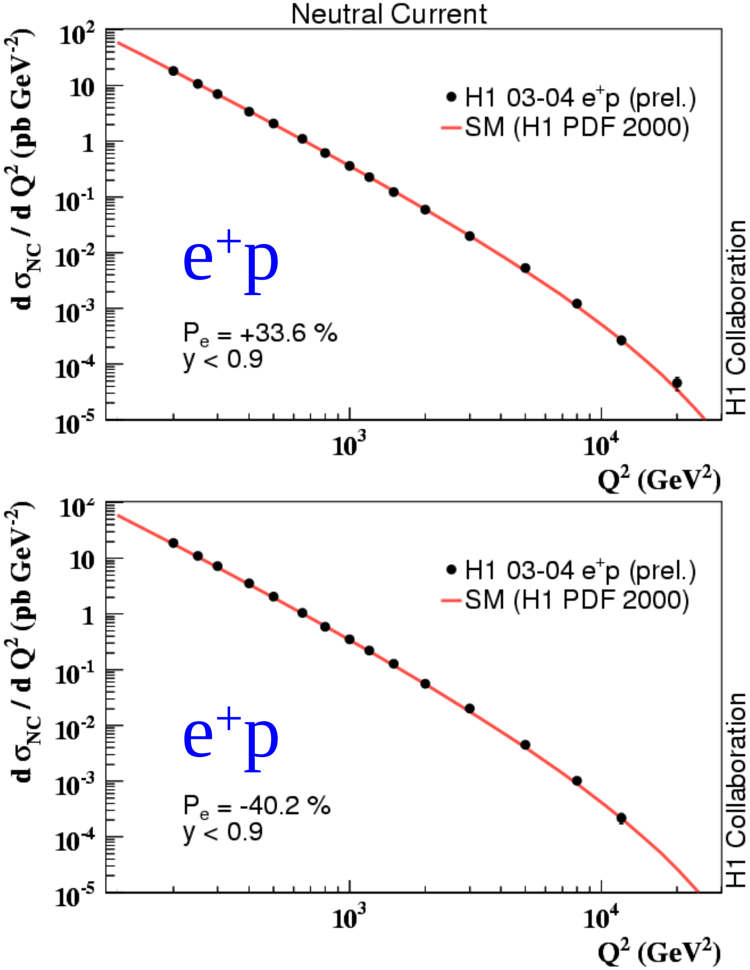
small differences between cross sections at highest Q^2 due to polarisation

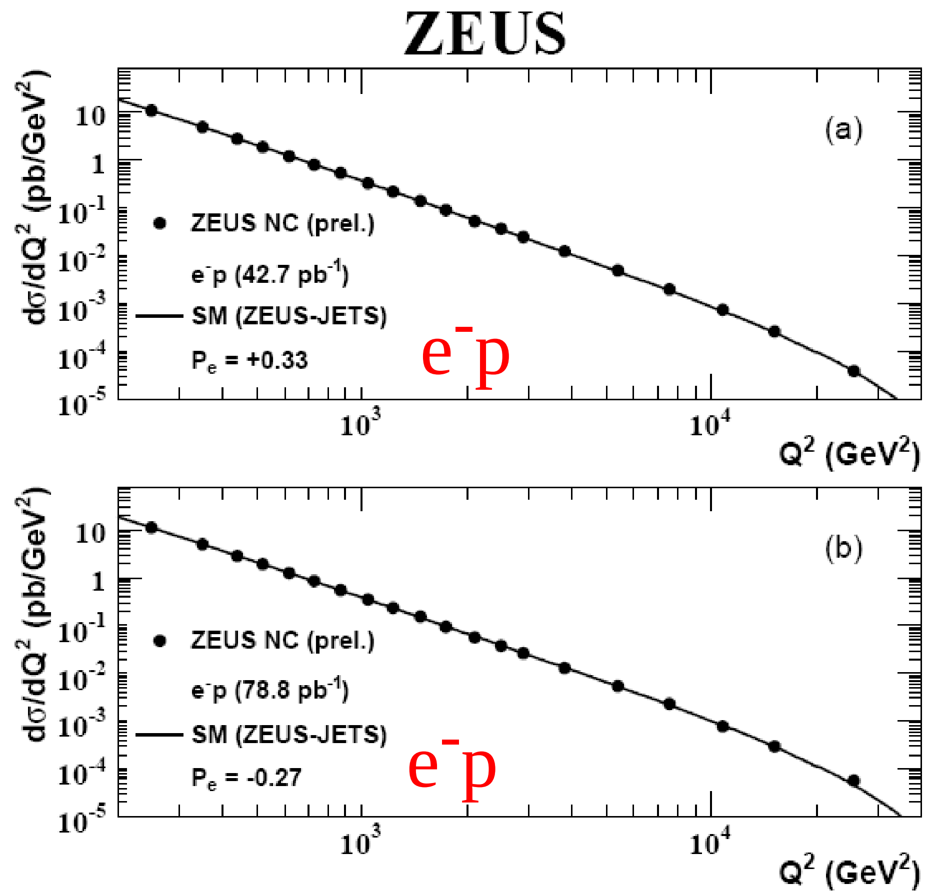
polarised double differential cross sections are used in the combined PDF & EW fit
→ see talk of Yong Dok Ri

to emphasize an effect of polarisation:

single diff. cross sections →

Polarised NC: $d\sigma/dQ^2$



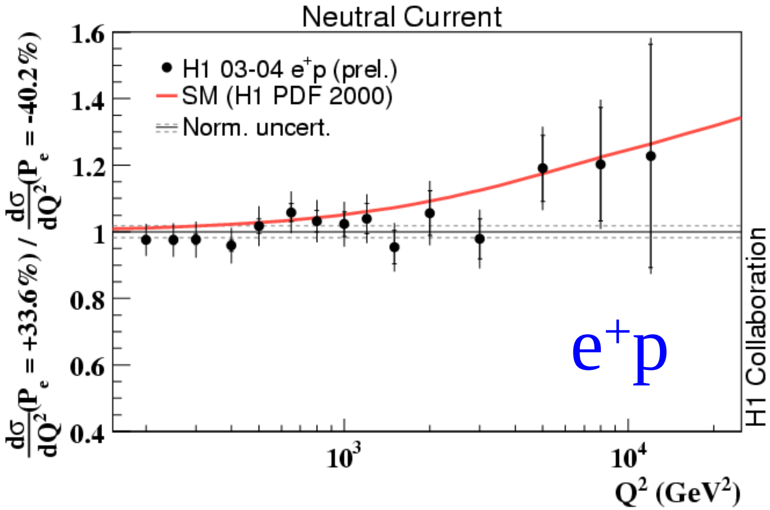


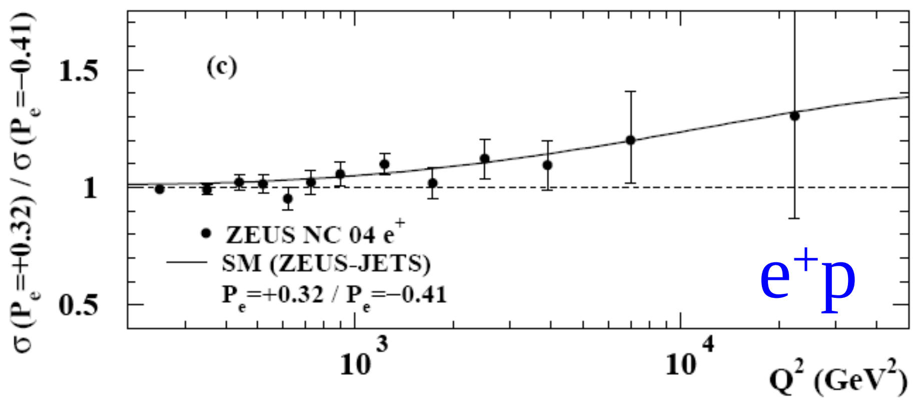
Each experiment: 2 lepton beam polarities and 2 polarisation periods

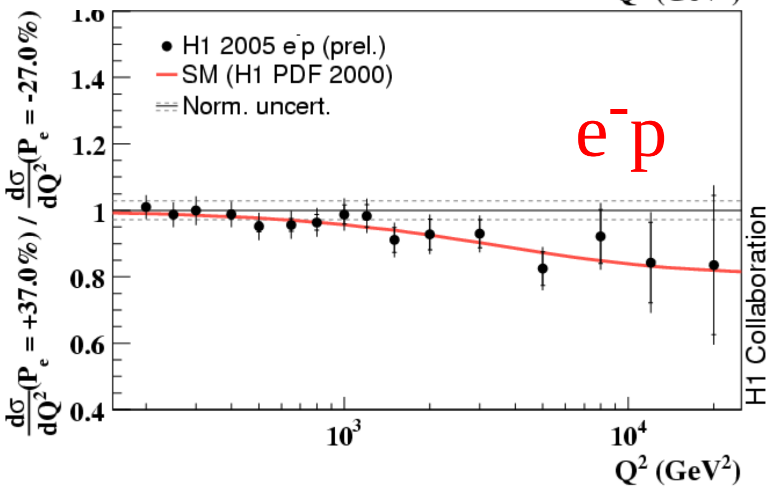
NC: polarisation ratios $\sigma(P_e>0)/\sigma(P_e<0)$

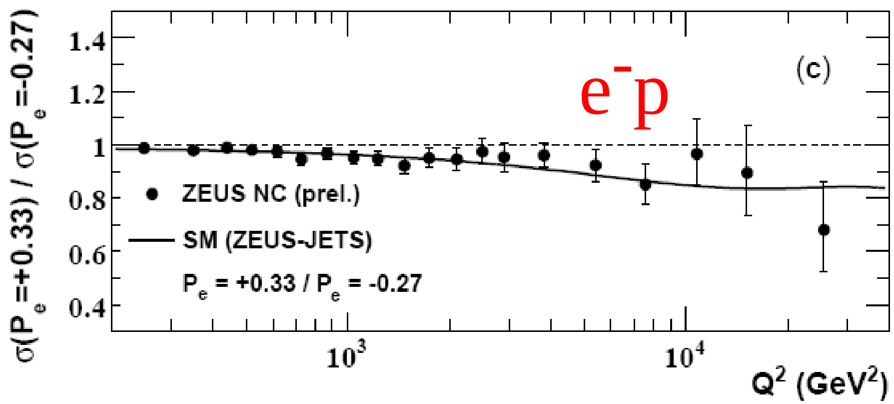
$$\sigma_{NC}^{e^{\pm}p} \simeq F_2 \mp P_e a_e \chi_Z \cdot F_2^{\gamma Z} \mp a_e \chi_Z \cdot xF_3^{\gamma Z}$$

$$\chi_Z = \frac{\kappa Q^2}{Q^2 + M_Z^2}$$





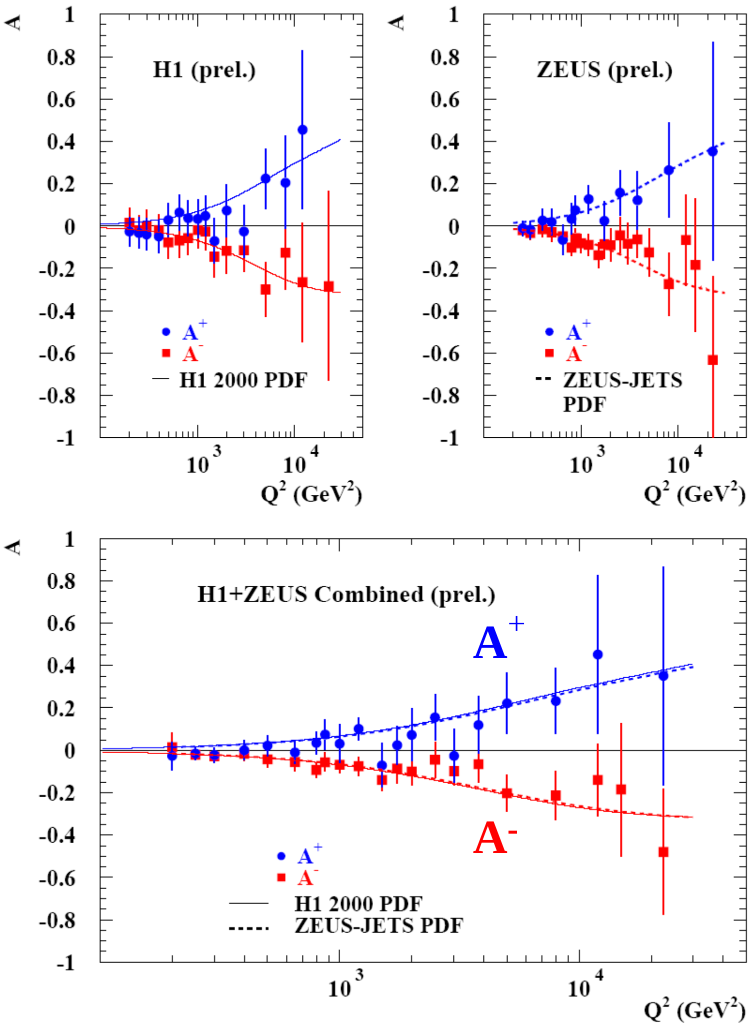




Polarisation effects in NC at HERA are established

Polarisation asymmetry

HERA



Polarisation asymmetry (**H1, ZEUS, H1 & ZEUS**):

$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma_{NC}^{\pm}(P_R) - \sigma_{NC}^{\pm}(P_L)}{\sigma_{NC}^{\pm}(P_R) + \sigma_{NC}^{\pm}(P_L)} \qquad \begin{matrix} P_R > 0 \\ P_L < 0 \end{matrix}$$

→ a direct measure of parity violation in NC

$$A^{\pm} \simeq \mp \frac{a_e \kappa Q^2}{Q^2 + M_Z^2} \cdot \frac{F_2^{\gamma Z}}{F_2} = \pm \frac{\kappa Q^2}{Q^2 + M_Z^2} \cdot \frac{1 + d_v / u_v}{4 + d_v / u_v}$$

$\mathbf{A^+}$ and $\mathbf{A^-}$ are of opposite sign

$\delta\mathbf{A} = \mathbf{A^+} - \mathbf{A^-} \approx 0$ at low Q^2 and

significantly >0 at high Q^2

χ^2 for $\delta\mathbf{A}$ with respect to zero (Q^2 > 5000 GeV^2):

χ^2/dof = **4.0**

probability of **3.1 10^{-3}** for $\delta\mathbf{A}$ to be zero

Summary

- The NC cross sections for $e^{\pm}p$ scattering with longitudinally polarised lepton beams are measured at HERA for the first time.

- The structure functions xF_3, $xF_3^{\gamma Z}$ directly sensitive to valence quark distributions are determined.

- Clear evidence of parity violation in the NC interactions at high Q^2 is observed.

- The results are presented individually for H1, ZEUS and, for the first time, as combined HERA results.

- The Standard Model is able to provide an excellent description of the data.