Neutral Current Interactions in ep Scattering with Longitudinally Polarised Leptons at H1

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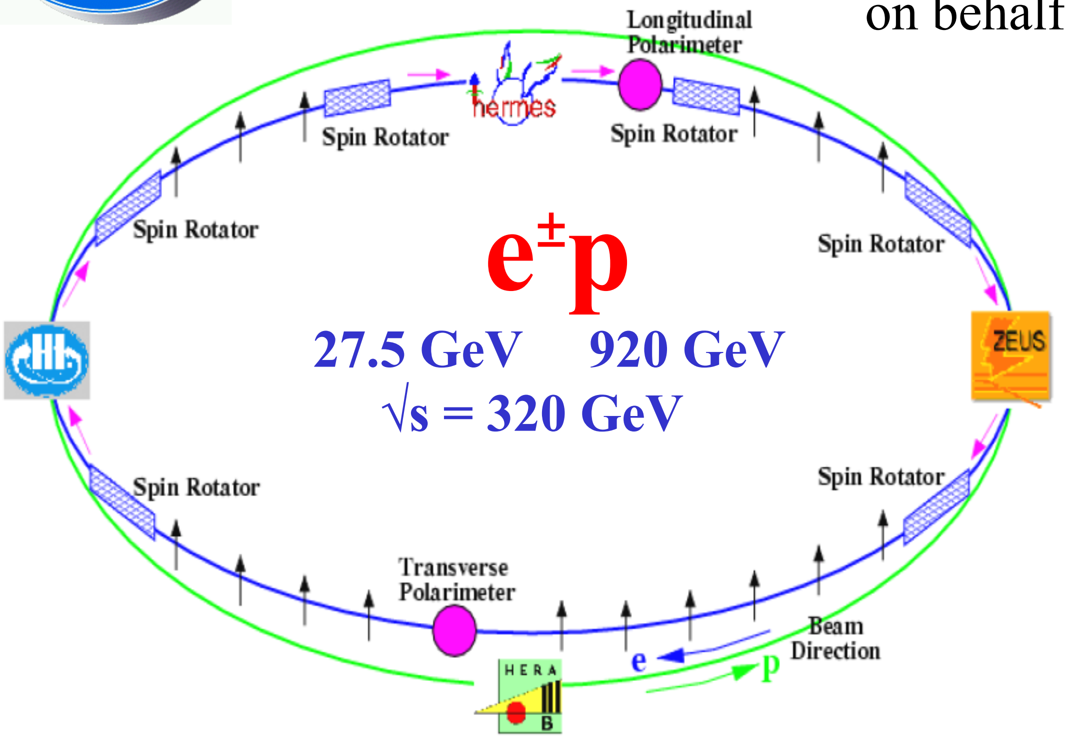
on behalf of the H1 Collaboration

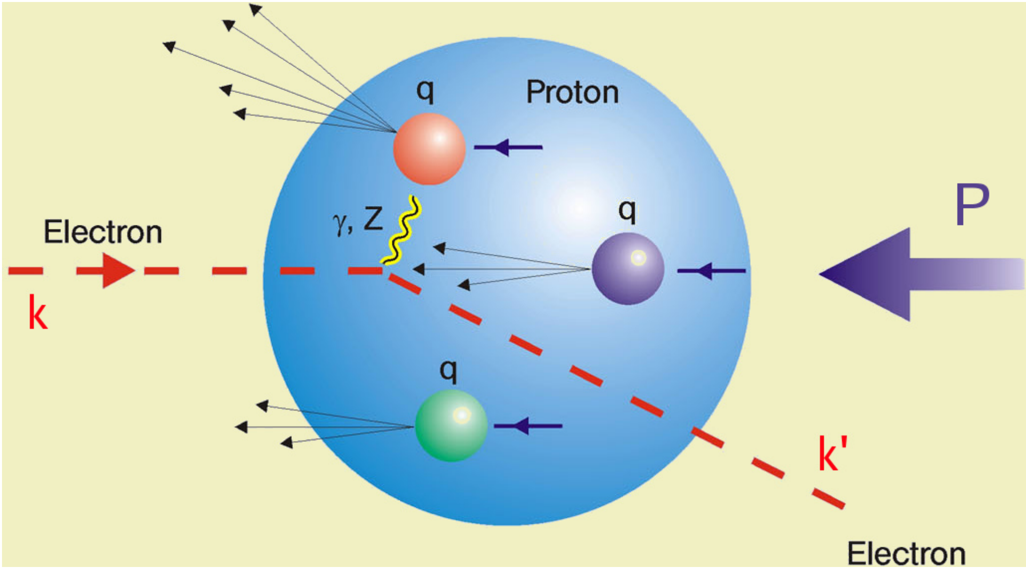


HERA II (2003-2007):
→ lumi upgrade
→ longitudinal polarisation of the $e^{\pm}$ beam

- DIS & NC
- Polarisation asymmetry in NC
- Unpolarised NC: HERA I+II
- Str. function xF_3
- Summary

Deep Inelastic Scattering at HERA

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



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 ~ 1/Q

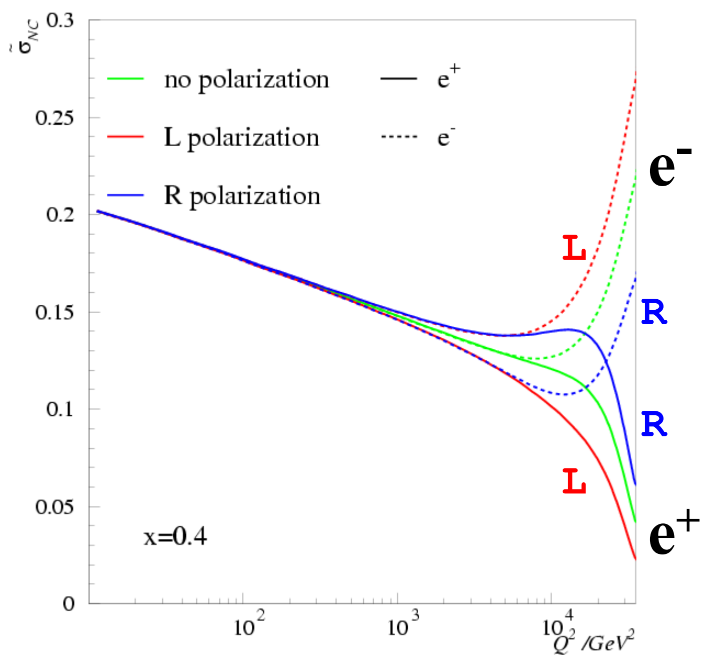
→ probe the EW sector of the Standard Model

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; contributes with different sign for $e^\pm$
- F_L important only at high y; expected to be negligible at high Q^2& x; in QPM $F_L = F_2 - 2xF_1 = 0$



Polarised NC Structure Functions

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

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

$P_e = \frac{N_R - N_L}{N_R + N_L}$, $N_R(N_L)$- 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: $$[F_2, F_2^{\gamma Z}, F_2^Z] = x\sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2](q + \bar{q})$$

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

Polarised NC Structure Functions

$v_e \approx 0 \rightarrow$

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

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

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

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

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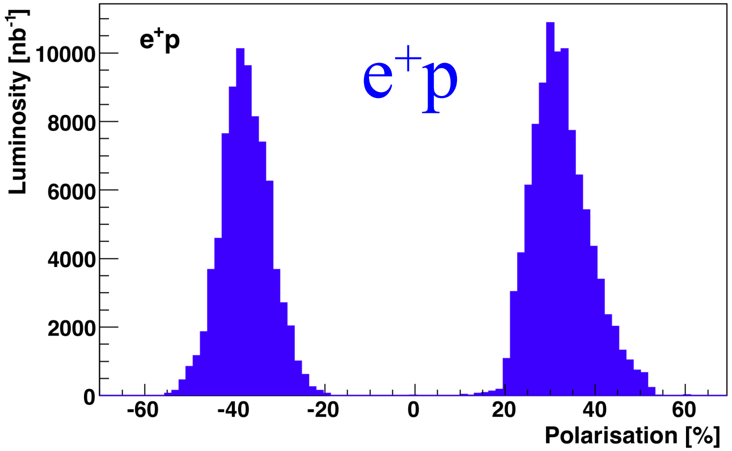
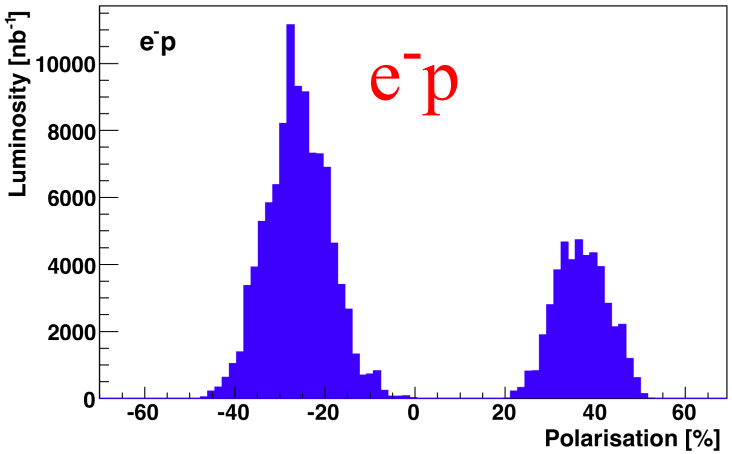
in QPM:

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

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

Longitudinal Polarisation of the Lepton Beam at HERA II





HERA II 2003-2007

Longitudinal polarisation:

transverse polarisation (Sokolov-Ternov effect)
& spin rotators

typically $P_e = (N_R - N_L)/(N_R + N_L) = 30\text{-}40\%$
build-up time ~30 min

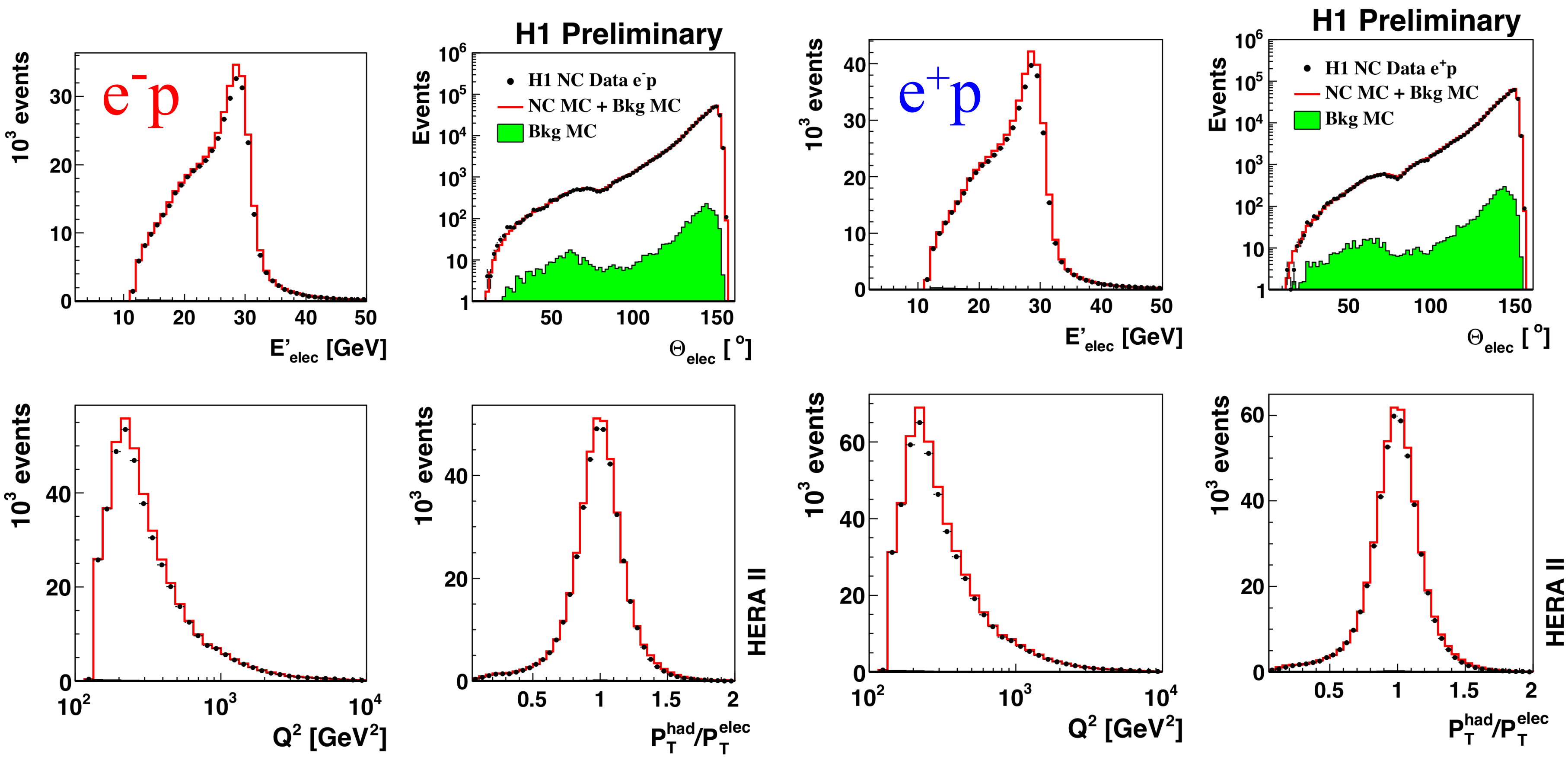
→ about equally shared between e^+/e^-, LH/RH

Lumi (P_e)	e^+p	e^-p
H1	**98.1** pb^{-1} (**+32.5**%)	**45.9** pb^{-1} (**+36.9**%)
	81.9 pb^{-1} (**-37.6**%)	**103.2** pb^{-1} (**-26.1**%)
	180.0 pb^{-1}	**149.1** pb^{-1}
	(**Hera I ≈100** pb^{-1}	**≈15** pb^{-1})

High Q^2 NC at HERA II

$Q^2 > 133\ \mathrm{GeV}^2$ $E'_e > 11$ GeV

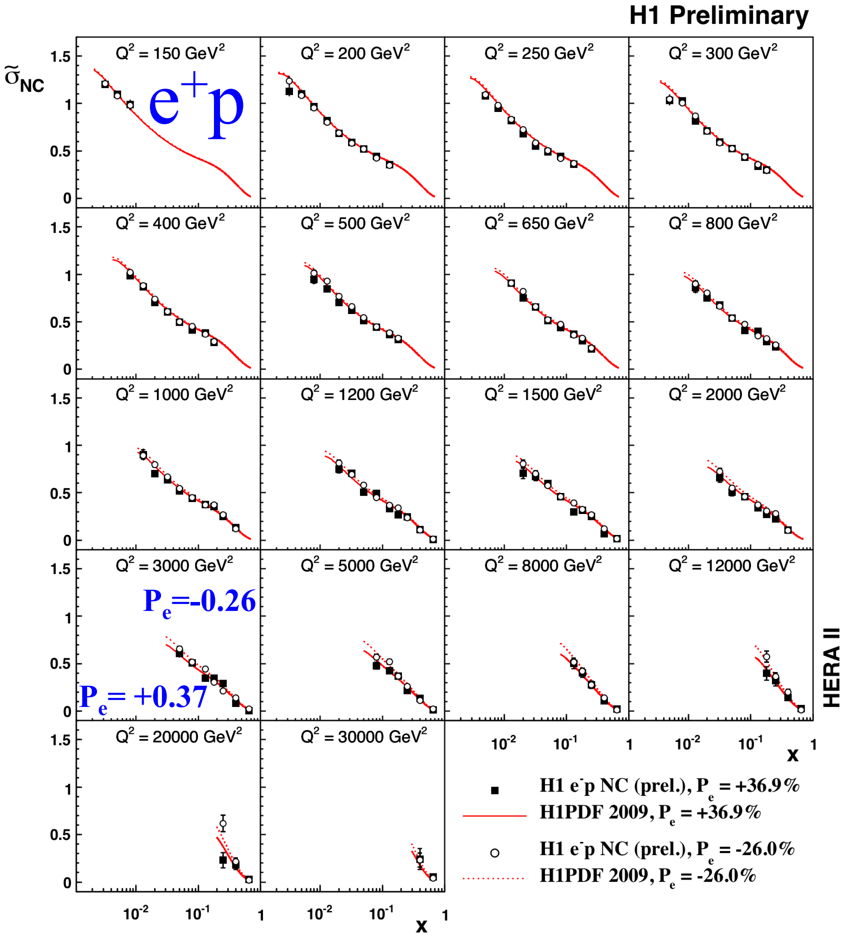
$y < 0.90$ ($y < 0.63$ for $Q^2 < 891\ \mathrm{GeV}^2$)

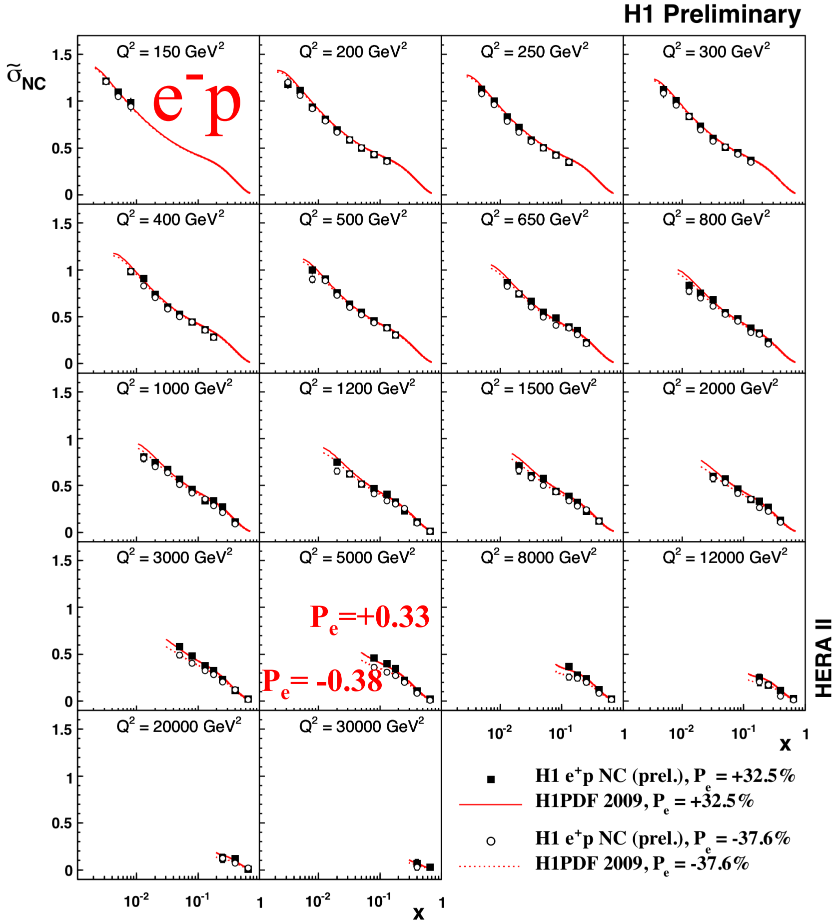


→ *good description of data by MC*

Polarised NC:

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

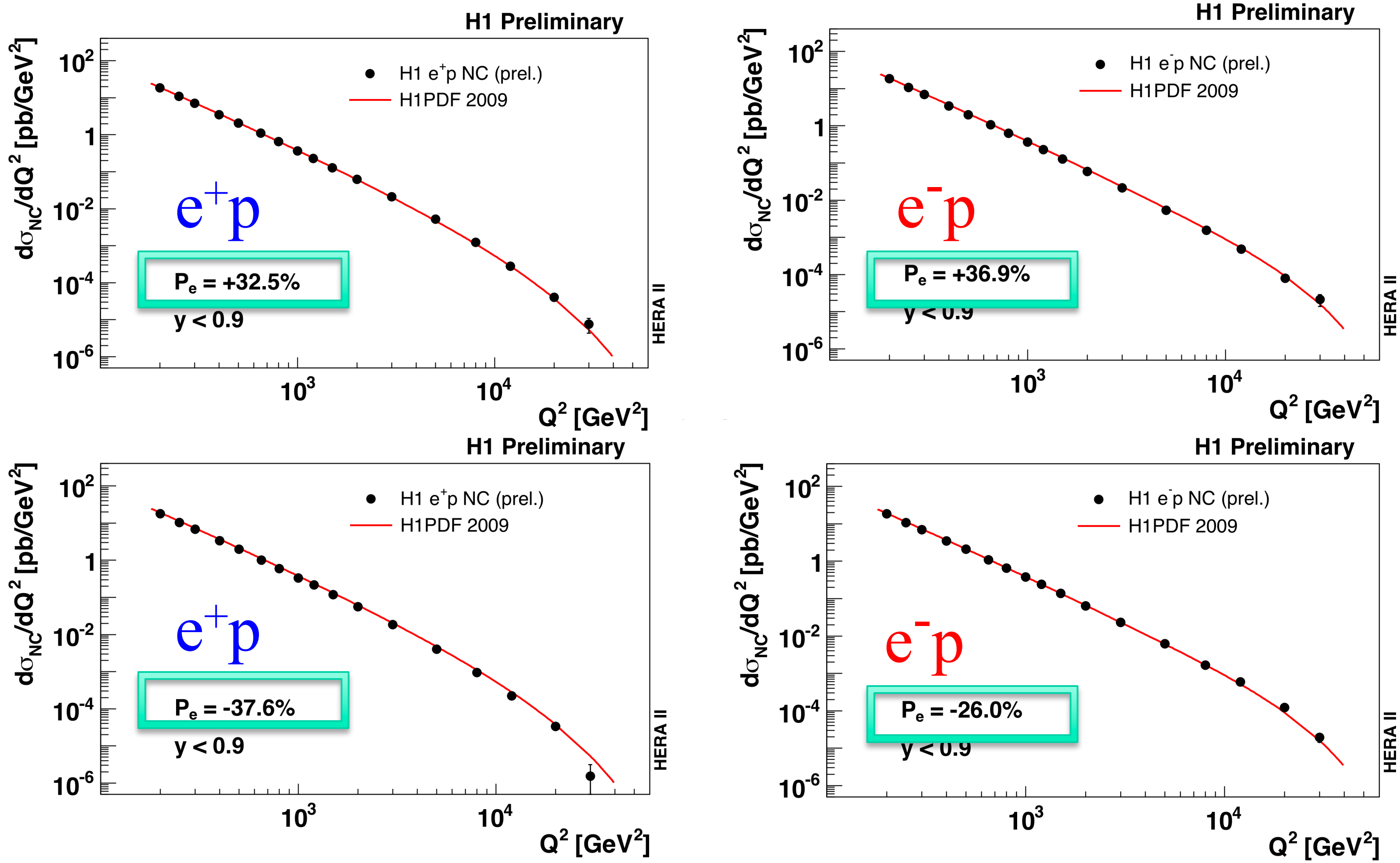




→ four cross sections are measured
e^+ / e^-, LH (P_e< 0) / RH (P_e> 0)

- small differences at highest Q^2 are due to e beam polarisation
- used in the combined EW & PDF fit → talk of Z. Zhang

Polarised NC: $d\sigma/dQ^2$ (y<0.9)

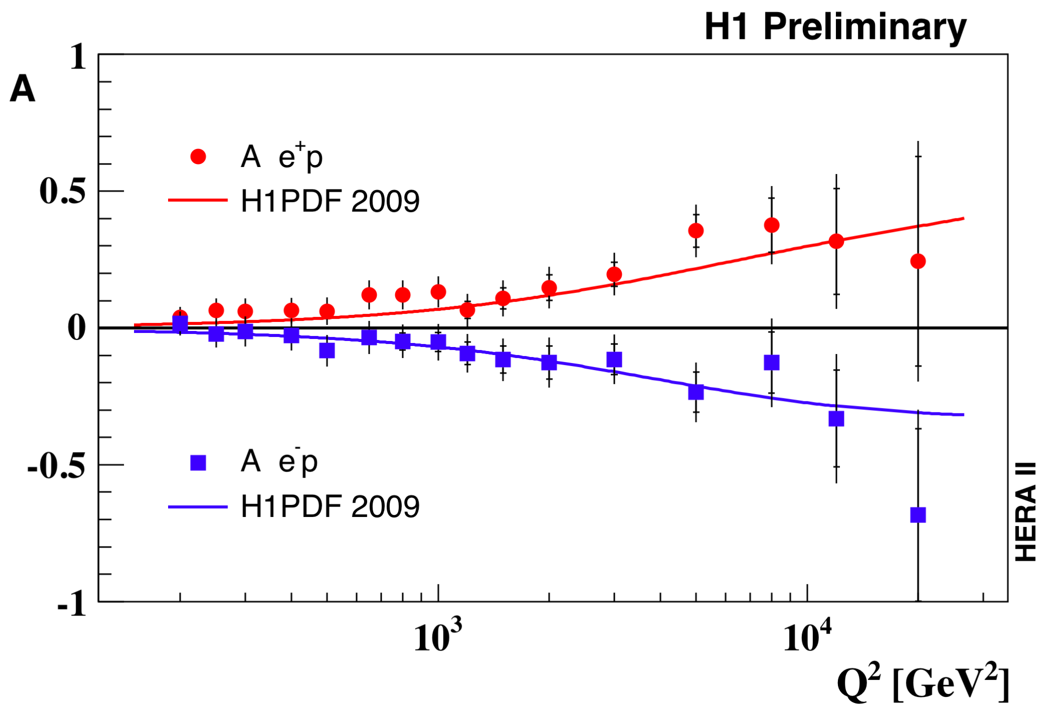


to emphasize an effect of polarisation → make cross section asymmetries

Polarisation asymmetry in NC

$$A(e^{\pm}p) = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}_{NC}(P_R > 0) - \sigma^{\pm}_{NC}(P_L < 0)}{\sigma^{\pm}_{NC}(P_R > 0) + \sigma^{\pm}_{NC}(P_L < 0)}$$

→ a direct measure of parity violation in NC



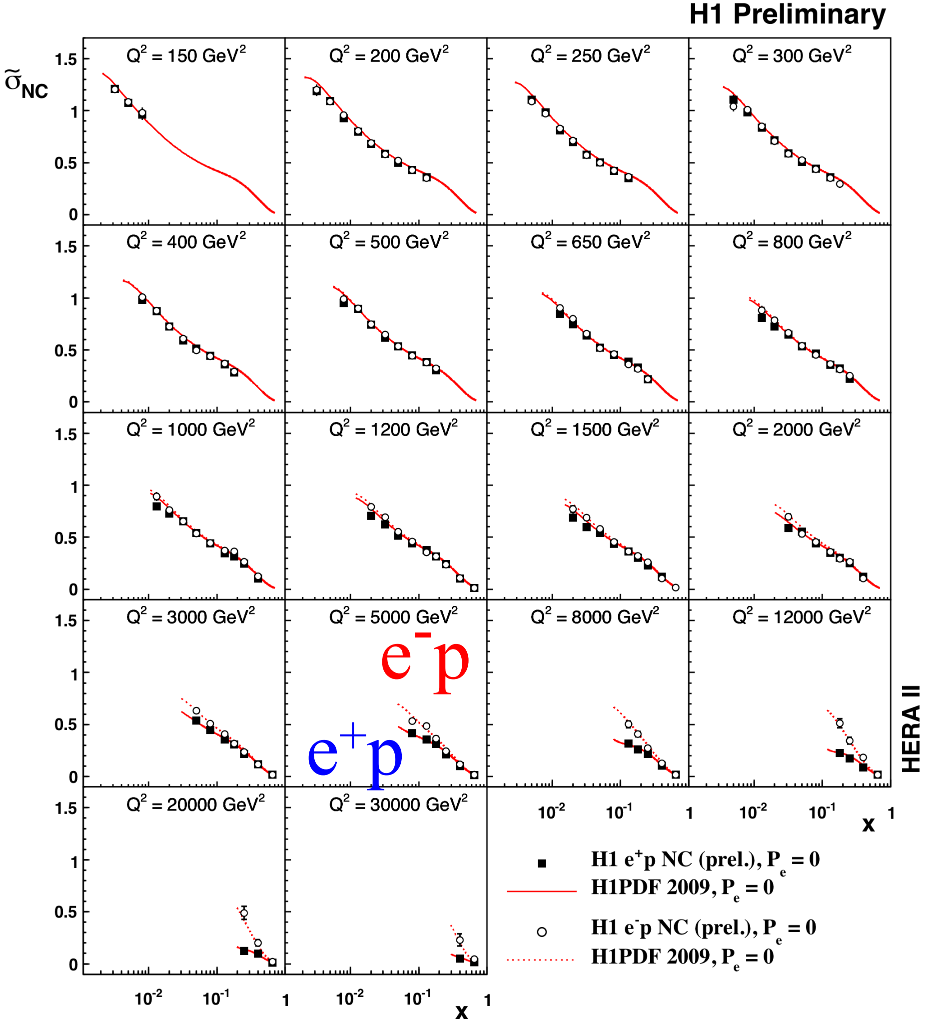
$$A(e^{\pm}p) \simeq \mp \kappa a_e \frac{F_2^{\gamma Z}}{F_2}$$

$$A(e^{\pm}p) \simeq \pm \kappa \frac{1 + d_v / u_v}{4 + d_v / u_v}$$

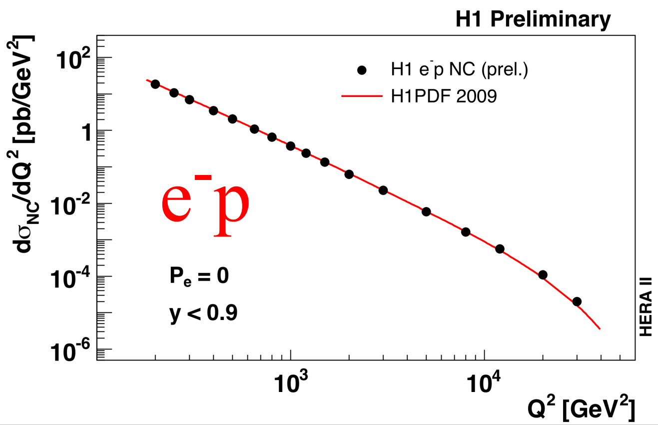
$$\kappa^{-1} = 4 \frac{M_W^2}{M_Z^2}\left(1 - \frac{M_W^2}{M_Z^2}\right)$$

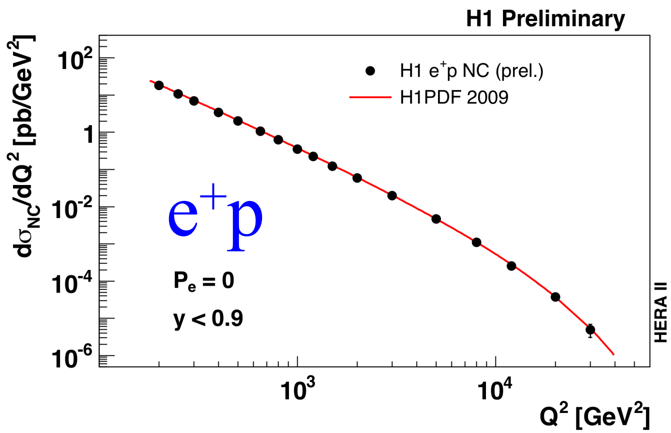
→ **$A(e^+p)$** and **$A(e^-p)$** are of opposite sign; **$A(e^+p)=A(e^-p)$** ≈ 0 at low Q^2;
→ deviation from zero is established at high Q^2 in accord with SM
→ sensitive to the ratio of valence quarks d_v/u_v

Unpolarised NC: $P_e = 0$

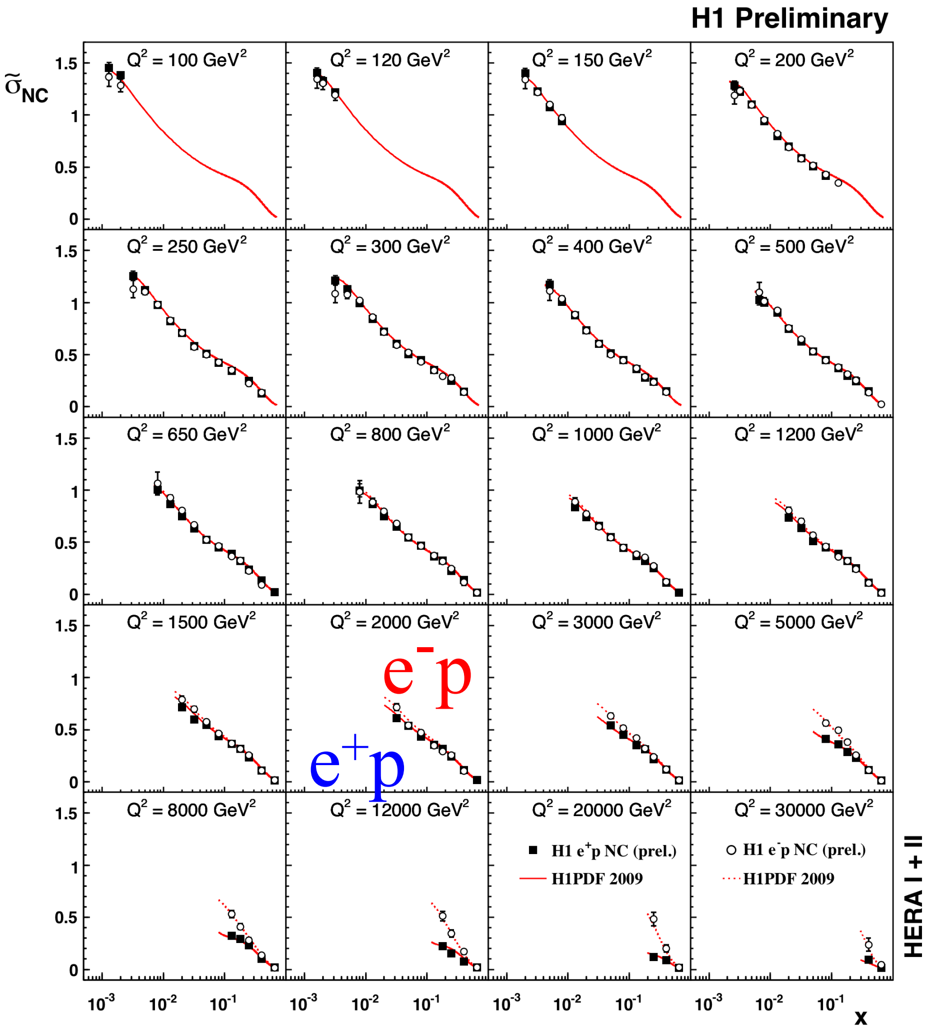


combine $e^+(e^-)$ data with different polarisations and correct for small residual polarisation





Unpolarised NC: HERA I+II



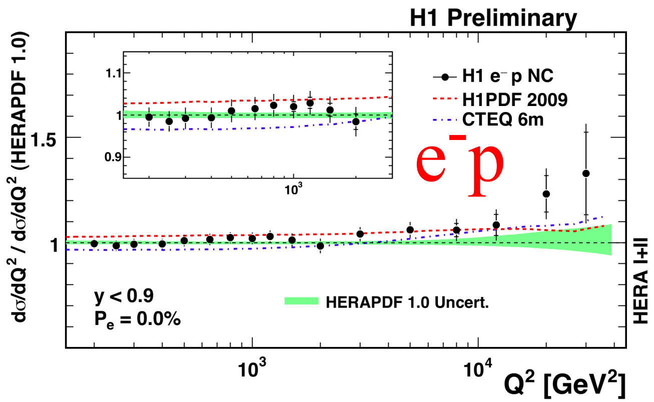
improved accuracy:

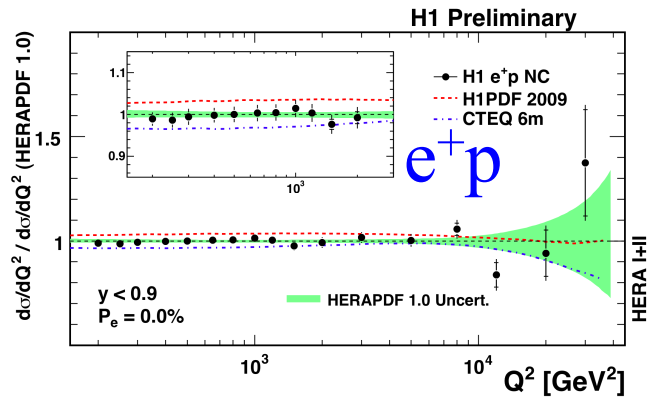
→ total uncertainty is ≥ 2%

combine unpolarised data with HERA I

→ for method see talk of S. Habib

full HERA statistics is ≈ 0.5 fb^{-1}

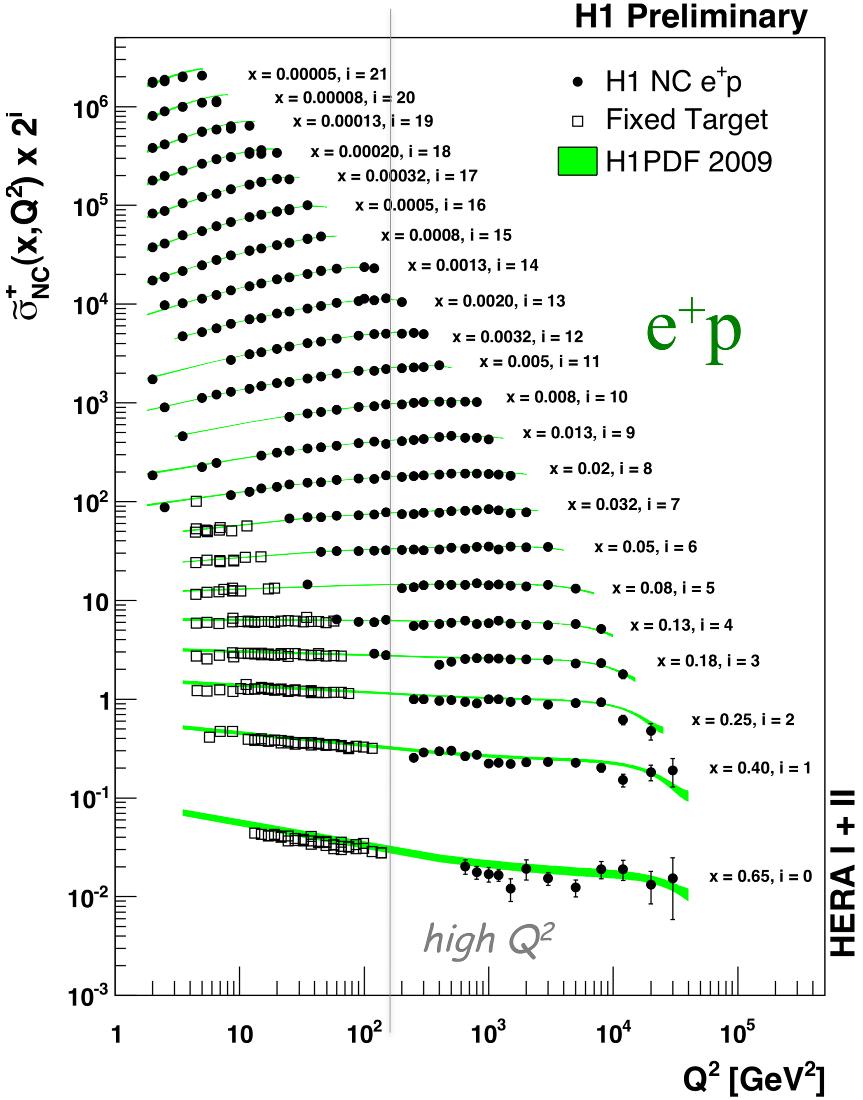




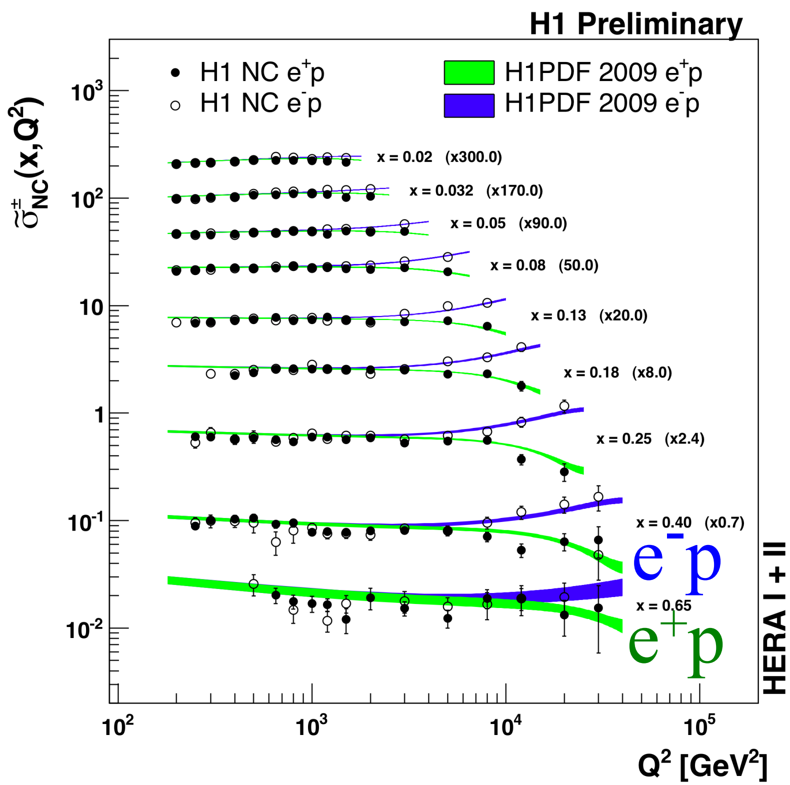
→ H1PDF 2009 slightly above the data

→ good agreement with HERAPDF1.0

Unpol. NC: scaling violation plots



Q² dependence at fixed values of x

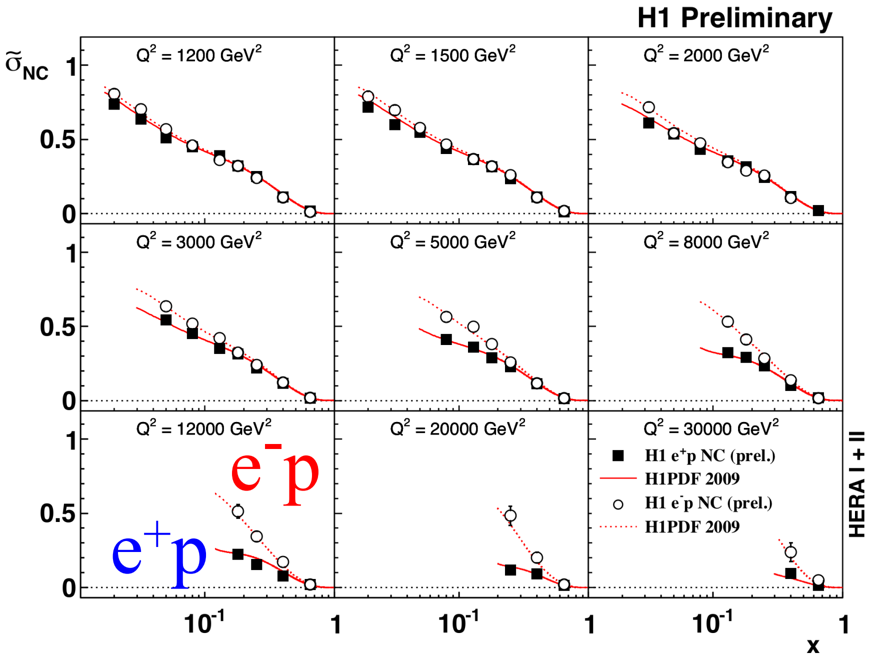


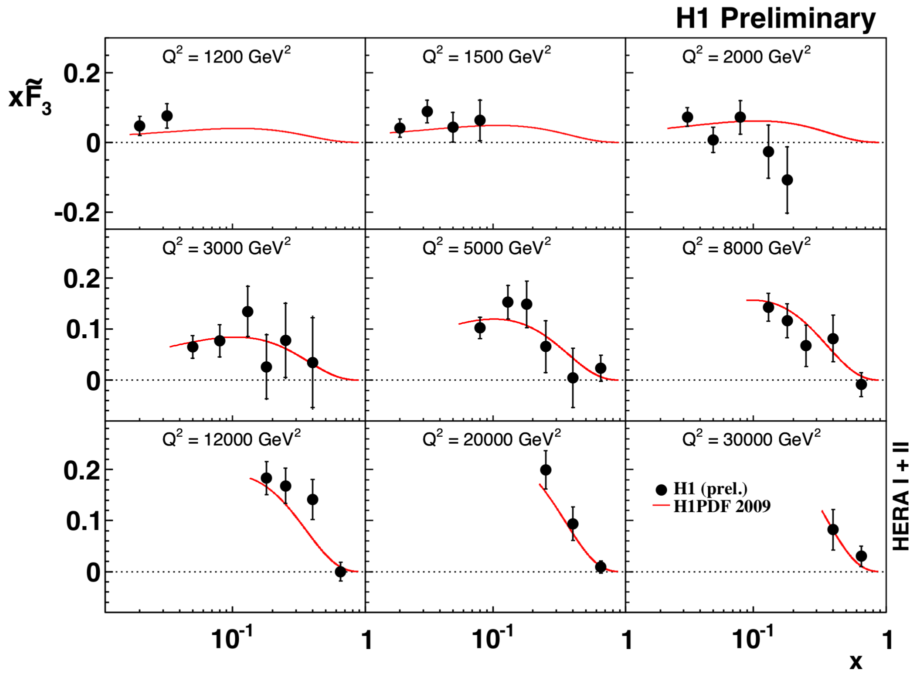
→ good agreement with SM

Structure Function xF_3

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

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

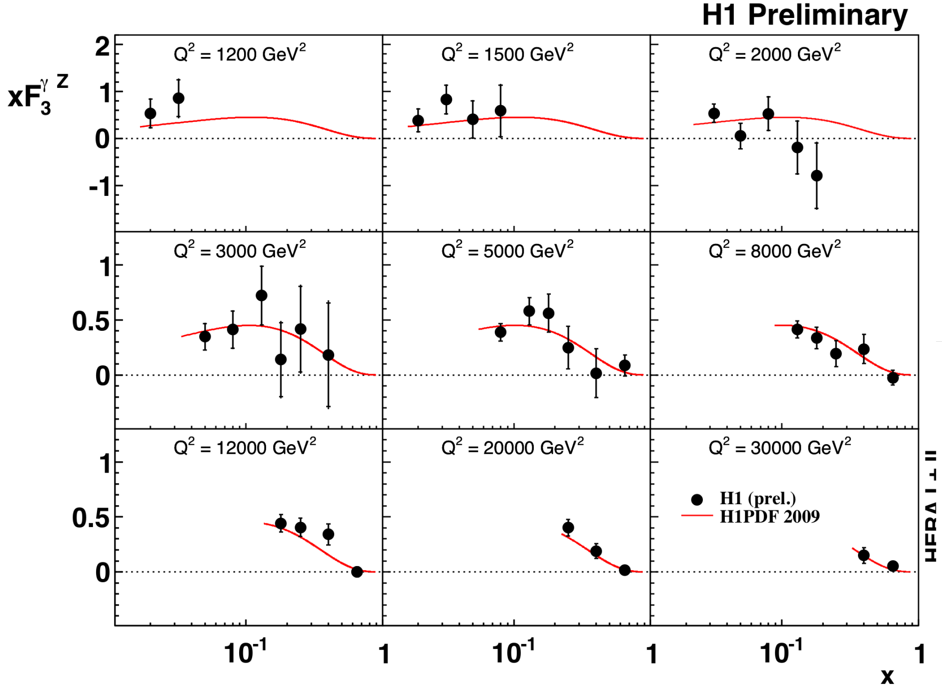




mostly due to γZ interference →

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

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

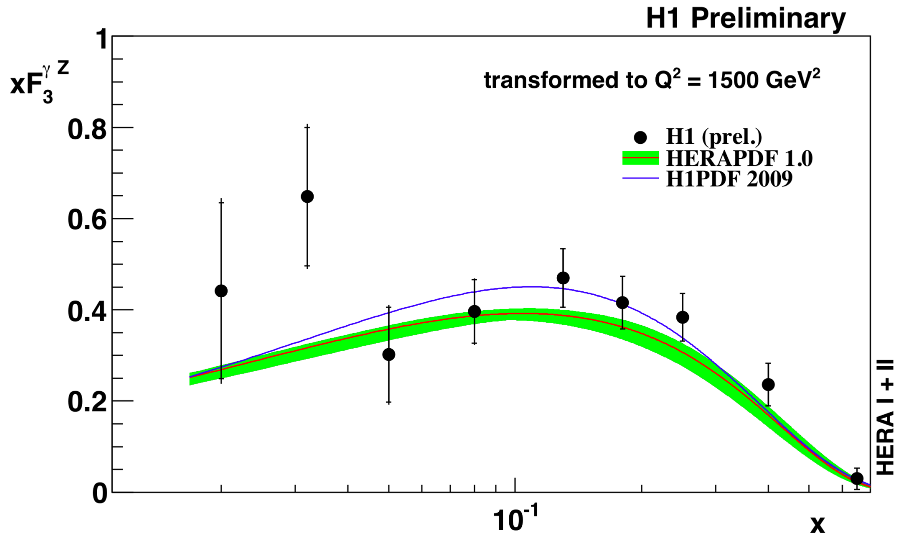


$$xF_3^{\gamma Z} = 2x \cdot \left[e_u a_u (U - \bar{U}) + e_d a_d (D - \bar{D})\right]$$

$$xF_3^{\gamma Z} \approx \frac{x}{3}(2u_v + d_v)$$

counting of the valence quarks:

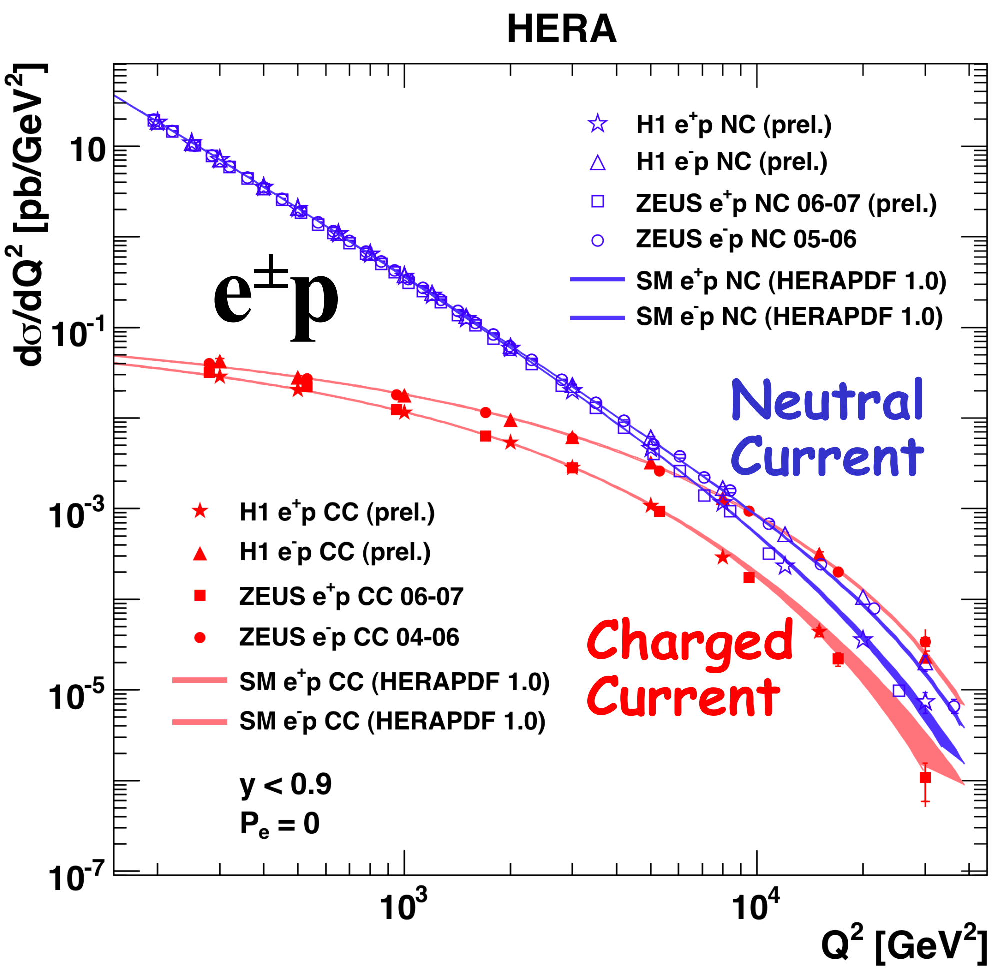
$$\int_0^1 F_3^{\gamma Z} dx \approx \frac{1}{3}\int_0^1 (2u_v + d_v) dx = \frac{5}{3}$$



little dependence on Q^2 :

transform to one Q^2 value of 1500 GeV² →

Unpolarised NC&CC at HERA



Electro-weak unification:

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

→ see talks of S. Shushkevich, K. Oliver, R. Ingbir

Probe proton:

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

Summary

- Four sets of the NC cross sections using electron and positron beams with left- and right-handed polarisations are obtained by H1 at HERA II.

  → polarisation effects at high Q^2 confirm the parity violation in the NC channel in accord with the Standard Model

- The unpolarised NC $e^{\pm}p$ cross sections using the H1 HERA II data are combined with the HERA I results, representing the full HERA statistics of 0.5 fb^{-1}.

  → the structure function xF_3, directly sensitive to the valence quark distributions, is measured

- These new cross section data represent the final HERA precision for NC at high Q^2 and provide an important input to the QCD (+EW) fits and to searches beyond the Standard Model (contact interactions, …)