Study of Polarized ep Collisions and Combined EW and QCD Fits at HERA

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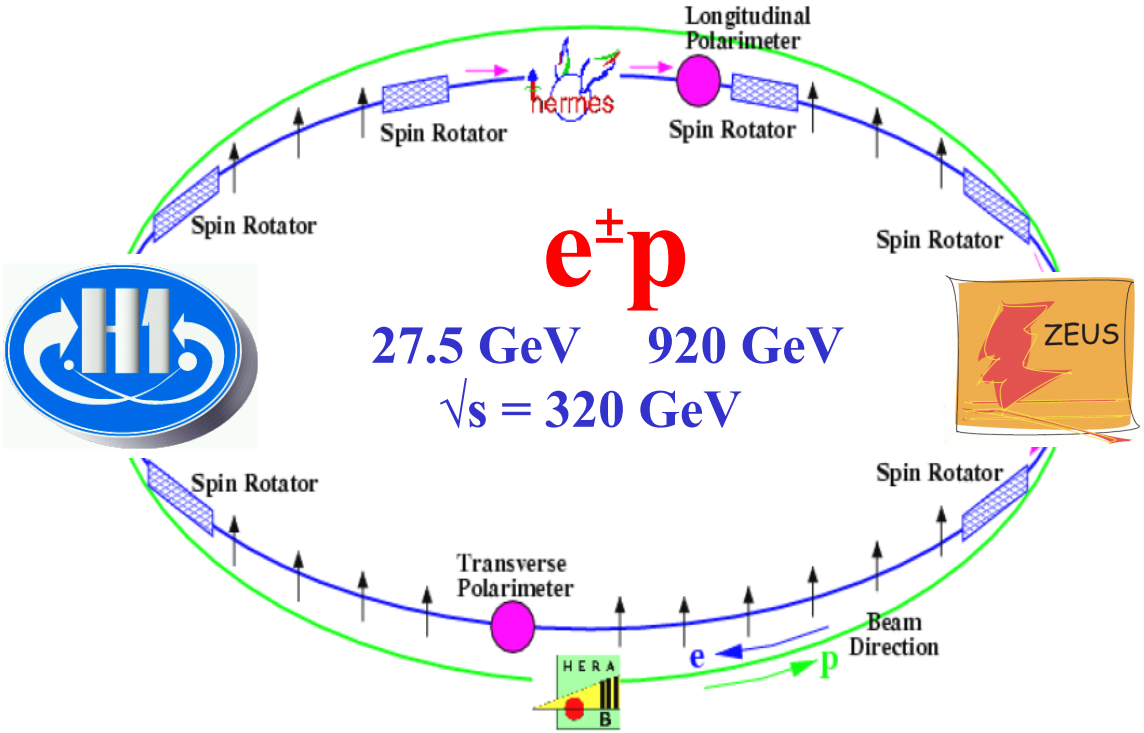
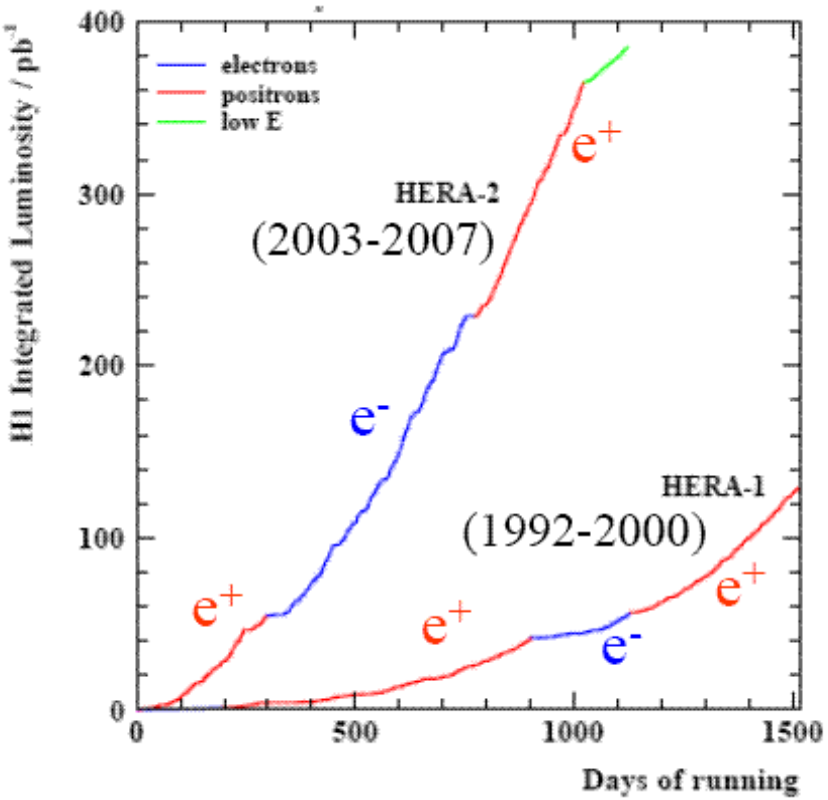
on behalf of the H1 and ZEUS Collaborations



- HERA & DIS
- NC & CC
- Polarization dep. of σ_{CC}^{total}
- Polarized σ_{NC}
- Polarization asymmetry in NC
- EW & QCD fits
- Combination of H1 & ZEUS
- Structure function xF_3
- Summary

HERA (1992-2007)



H1+ZEUS in total ~ 1 fb^{-1}

about equally shared between

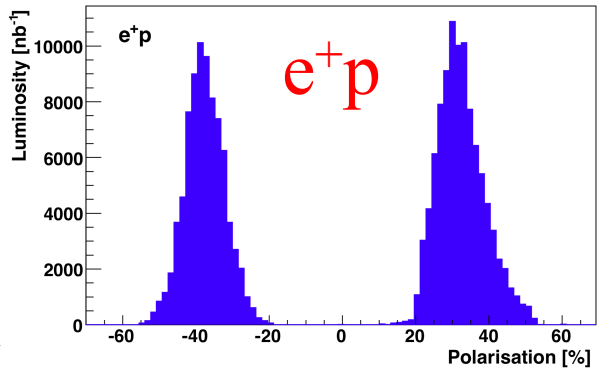
- **experiments (H1, ZEUS)**
- **e^+ and e^-,**
- **positive and negative P_e**

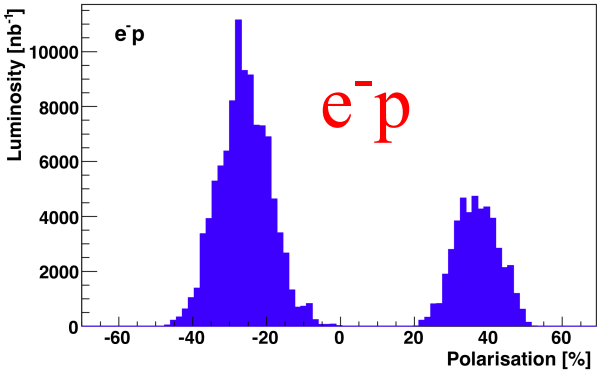
HERA II:

Longitudinal polarization of e beam

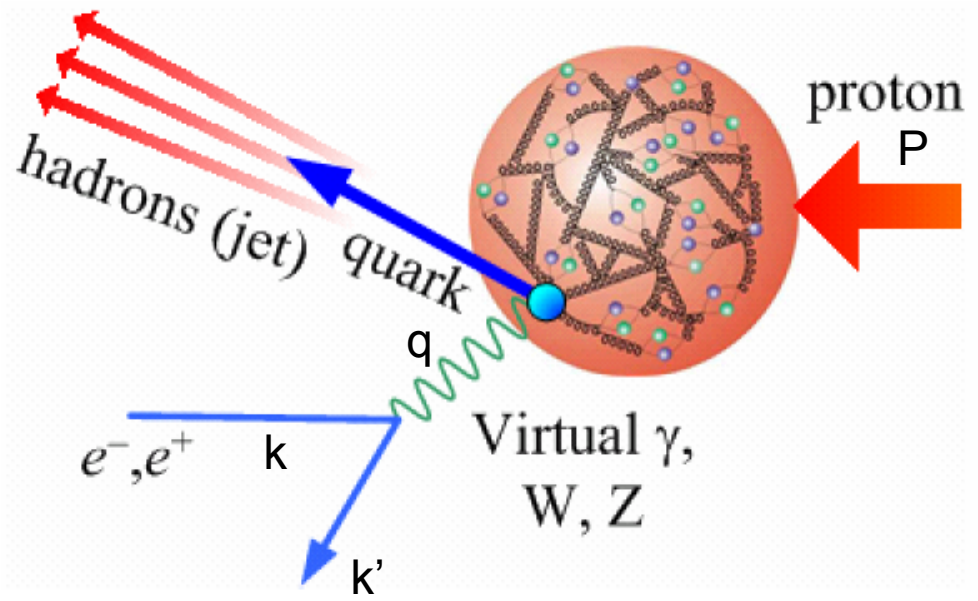
natural transverse polarization
(Sokolov-Ternov effect) & spin rotators

typically $P_e = (N_R-N_L)/(N_R+N_L) \approx 35\%$
build-up time ~30 min

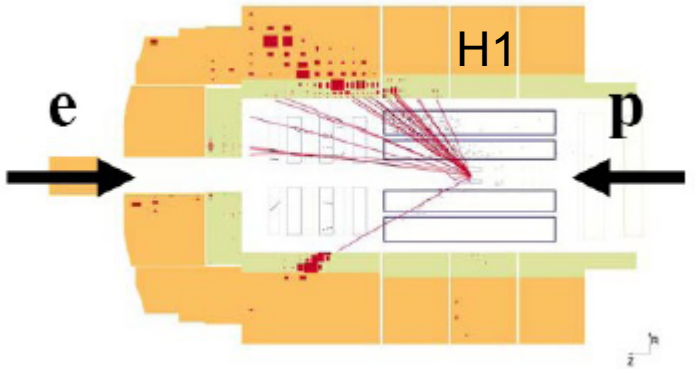




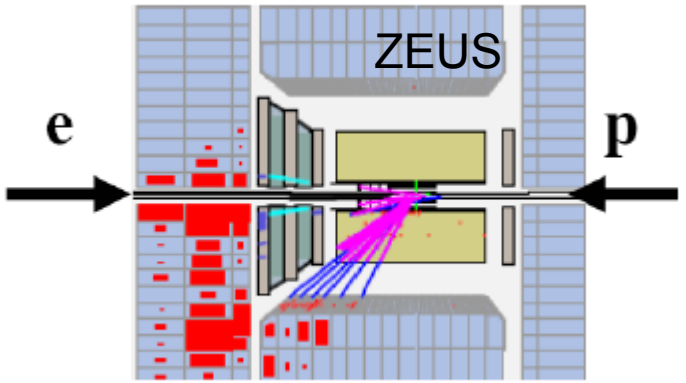
Deep Inelastic Scattering (DIS)



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



Charged Current (CC): $e^{\mp}p \rightarrow \nu X$



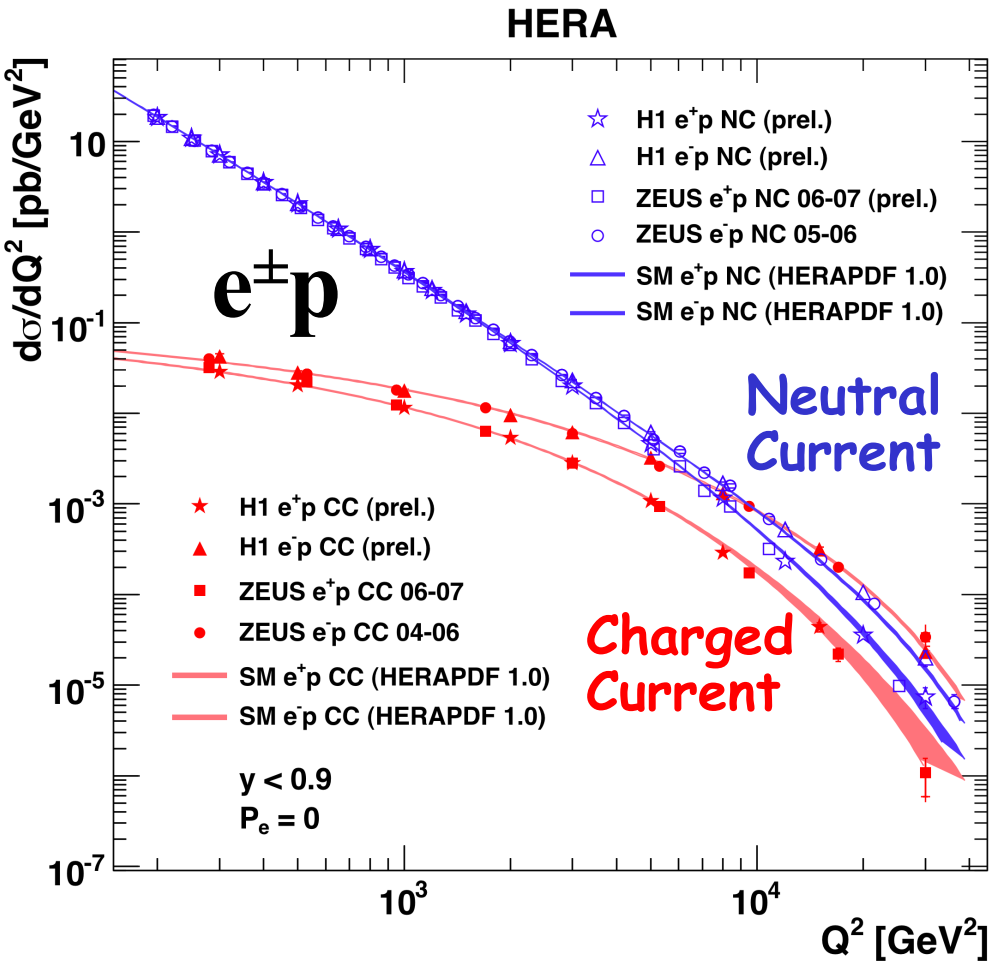
$\mathbf{Q^2 = -q^2 = -(k-k')^2}$	virtuality of γ*, Z^0, W
$\mathbf{x = Q^2/2(Pq)}$	Bjorken x
$\mathbf{y = (Pq)/(Pk)}$	inelasticity
$\mathbf{Q^2 = sxy}$	$s=(k+P)^2$

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

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

pdf – universal parton distribution functions

NC & CC at HERA



→ unpolarized H1, ZEUS (HERA I+II)

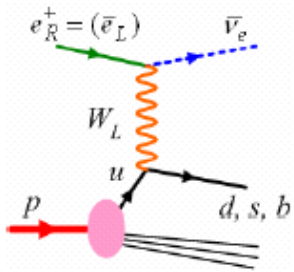
electroweak unification:

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

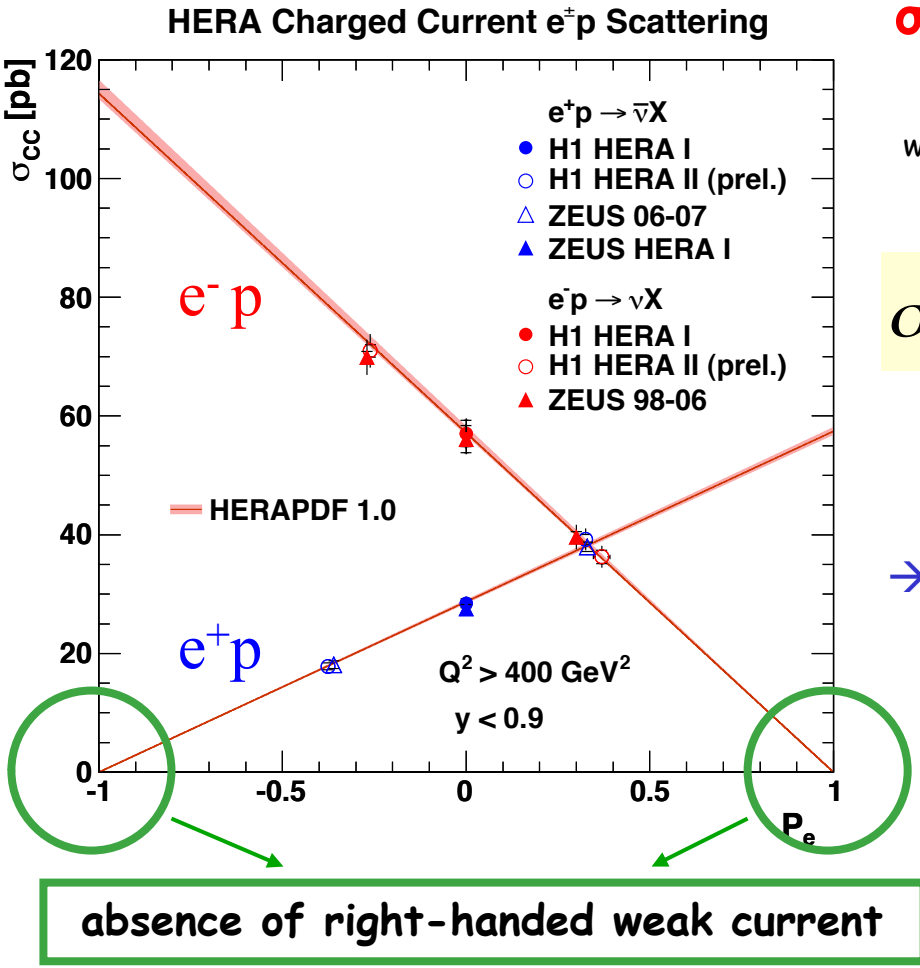
→ residual differences due to u/d flavour asymmetry and helicity factors

NC & CC are described well by the SM

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



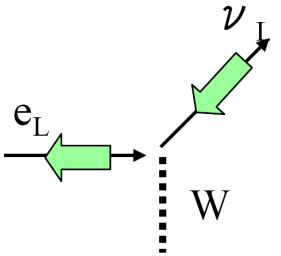
Polarization Dependence of the Total CC Cross Section



absence of right-handed weak current

σ_{CC}^{tot} (Q^2 > 400 GeV^2, y<0.9)

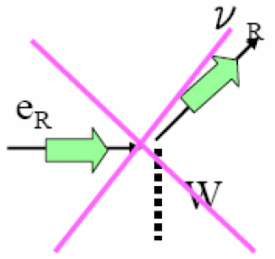
weak CC is pure left-handed (V-A):



$$\sigma_{CC}^{e^{\pm}p} = (1 \pm P_e)\sigma_{CC}^{e^{\pm}p}(P_e = 0)$$

$P_e=(N_R-N_L)/(N_R+N_L)$

→ linear dependence on the longitudinal polarization of e beam both for e^+ and e^-



Polarized NC Structure Functions

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2(x,Q^2) - y^2\tilde{F}_L(x,Q^2) \mp Y_- x\tilde{F}_3(x,Q^2)\right] \quad Y_\pm = 1 \pm (1-y)^2$$

drop terms with $v_e \approx 0$ →

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

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

$$P_e = \frac{N_R - N_L}{N_R + N_L}, \qquad \begin{array}{l}\mathrm{N_R(N_L)}\text{- number of right (left)}\\ \text{handed leptons in the beam}\end{array} \qquad \kappa^{-1} = 4\frac{M_W^2}{M_Z^2}\left(1-\frac{M_W^2}{M_Z^2}\right)$$

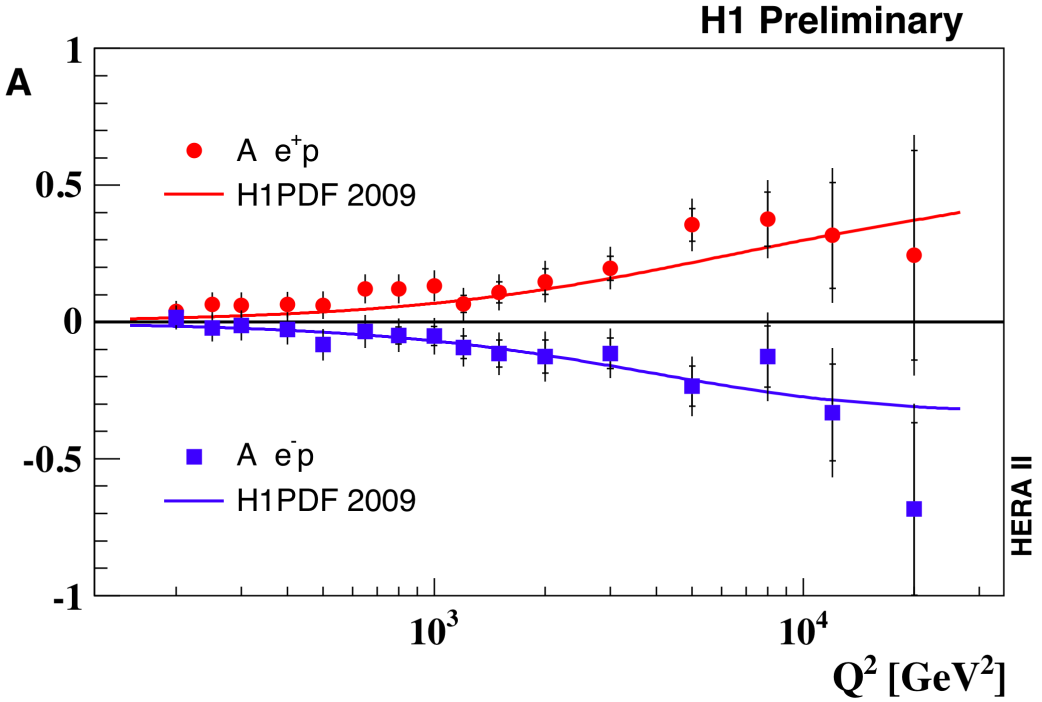
in QPM:
$$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right](q+\bar{q})$$

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

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



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

$$\simeq \pm\kappa \frac{1 + d_v/u_v}{4 + d_v/u_v}$$

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

→ $A(e^+p)$ and $A(e^-p)$ are of opposite sign; $A(e^+p)=A(e^-p) \approx 0$ 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

Combined EW and QCD Fits

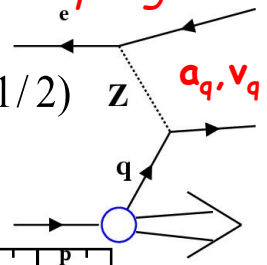
Extend NLO QCD fits of NC/CC HERA data to fit also *the light u and d quark couplings to Z*

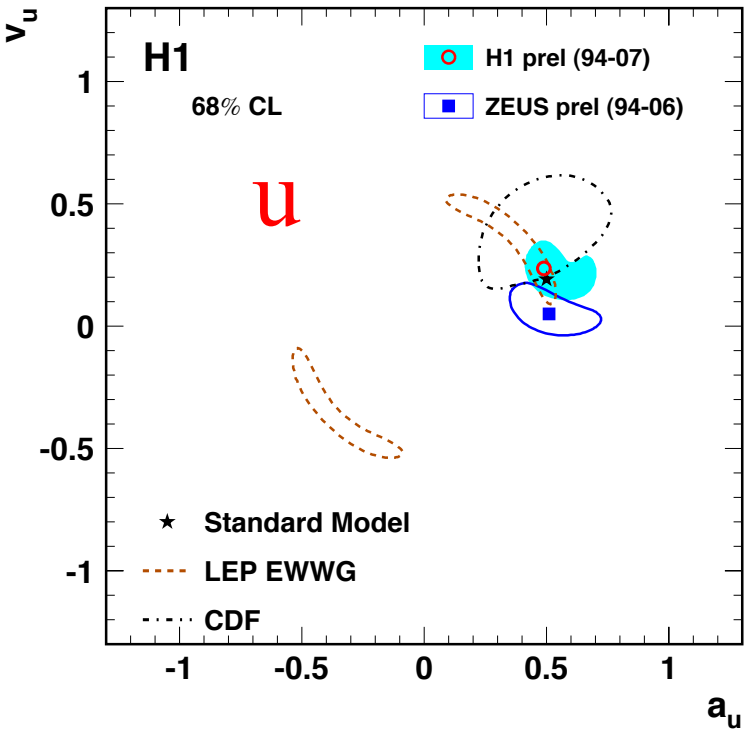
H1: a'la HERAPDF1.0 NLO QCD fit

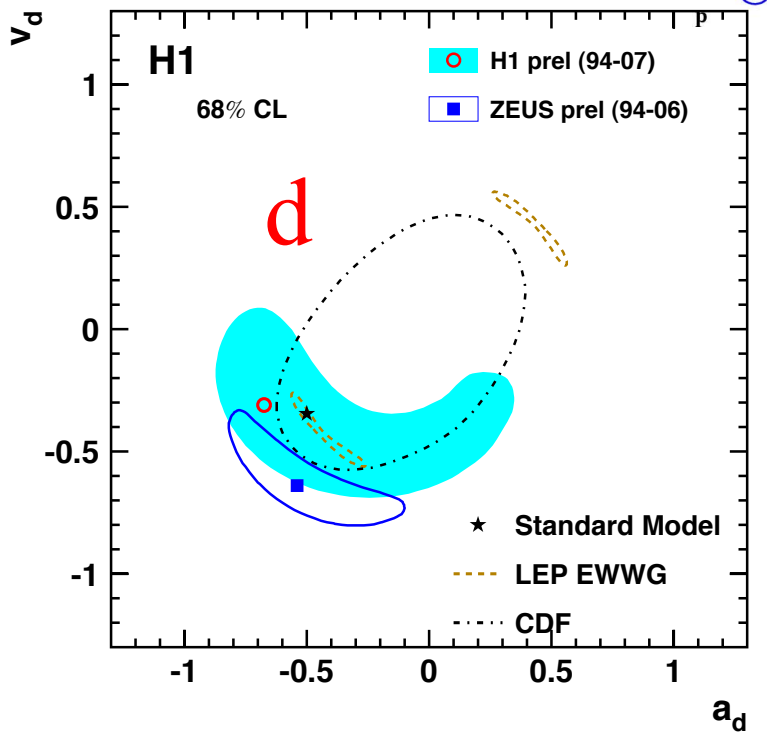
ZEUS: a'la ZEUS-JETS NLO QCD fit

$$a_q = I_q^3 \rightarrow (a_u = +1/2; a_d = -1/2)$$

$$v_q = I_q^3 - 2e_q \sin^2\theta_W$$







CDF: $pp \rightarrow Z/\gamma^* \rightarrow e^+e^-$ (A_{FB})

LEP/SLD: $ee \rightarrow qq$ at Z (a^2v^2, a^2+v^2)

→ HERA: competitive, resolves LEP ambiguity

→ much improved precision due to polarized HERA II

→ will be further improved with combined H1 & ZEUS

Combination of H1 and ZEUS

The ultimate goal is to get combined HERA data set which includes expert knowledge in the treatment of the correlations between many individual data sets from H1 and ZEUS

→ precise, complete and easy in use

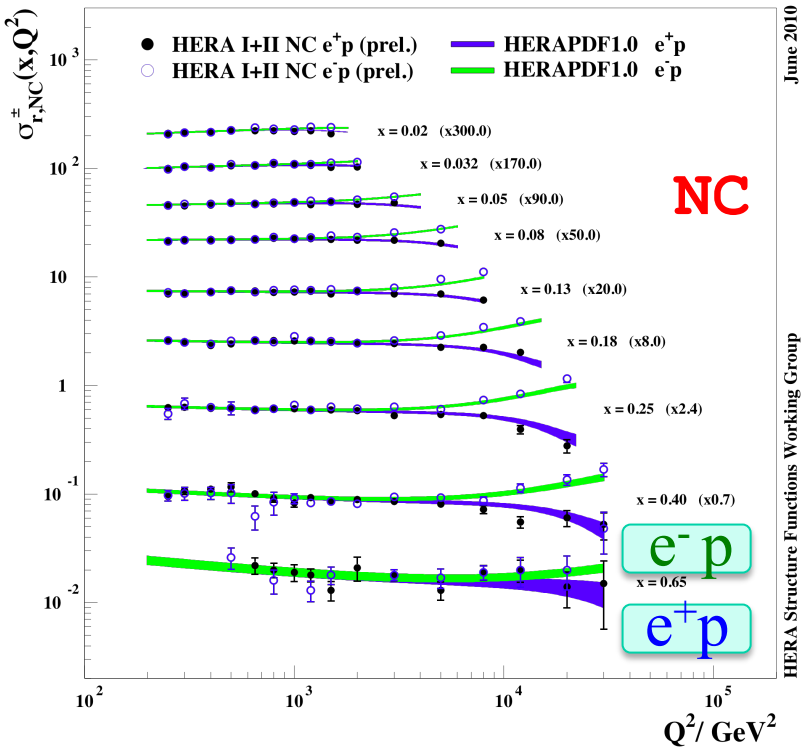
Published: combination of inclusive unpolarized NC & CC cross sections from H1 & ZEUS at HERA I (1994-2000)
Recent: combination of H1 & ZEUS at HERA I and HERA II :

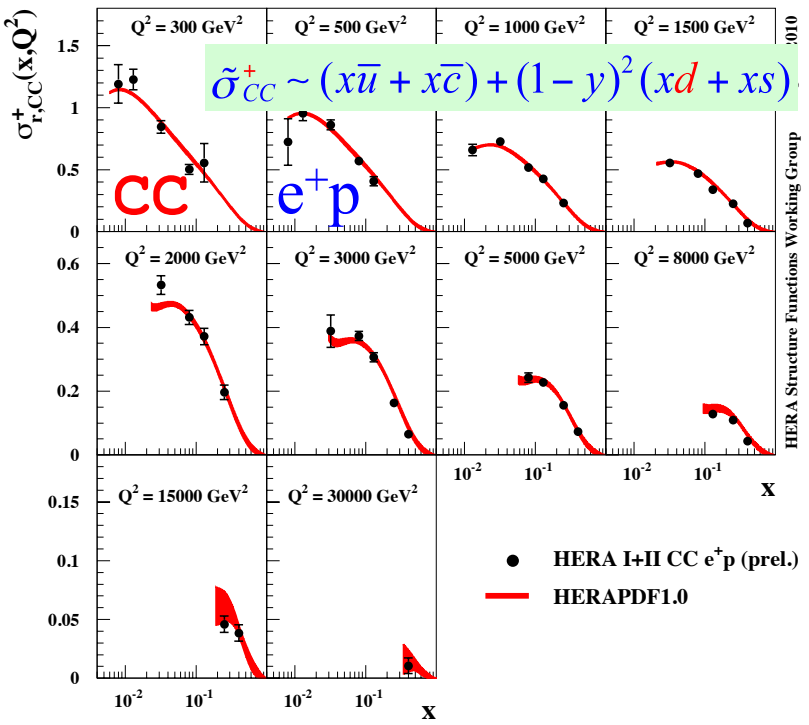
$$\tilde{\sigma}^{\pm}_{NC} \equiv \frac{d^2\sigma^{e^{\pm}p}_{NC}}{dxdQ^2}\frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+} \equiv \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3$$

$$\tilde{\sigma}_{CC} = \frac{2\pi x}{G_F^2}\left[\frac{M_W^2+Q^2}{M_W^2}\right]^2\frac{d^2\sigma_{CC}}{dxdQ^2}$$

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

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

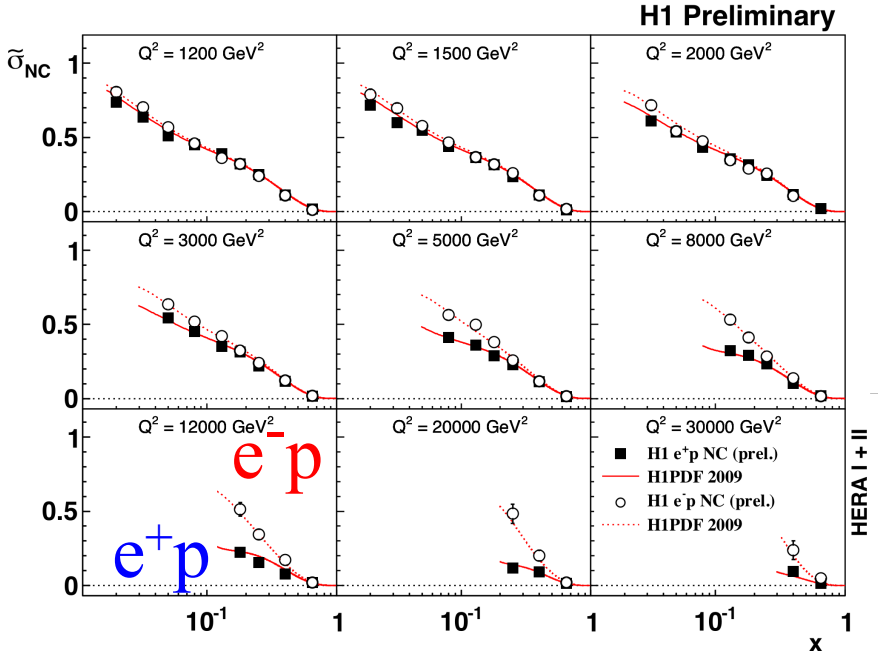




Structure Function $xF_3(x,Q^2)$

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

unpolarized NC $e^{\pm}p$ cross sections



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

sensitive to the valence quark distributions:

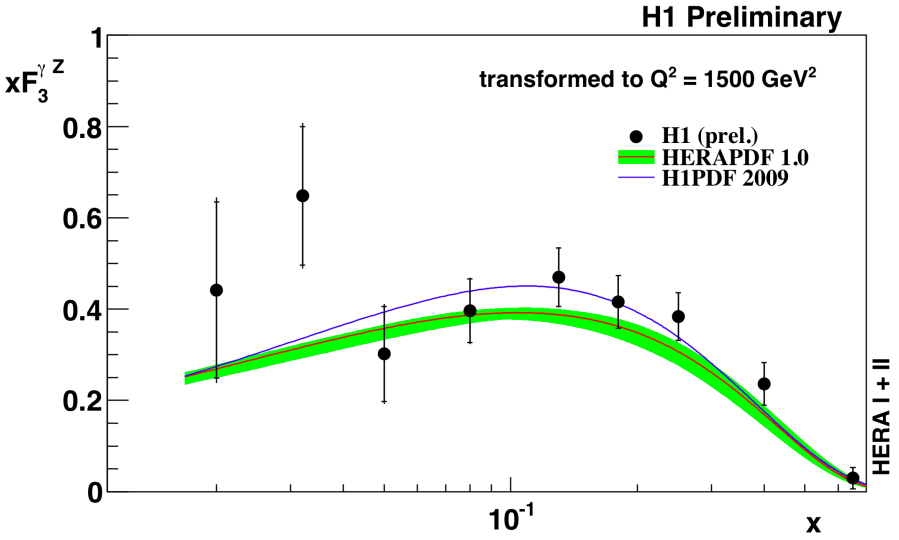
$$xF_3^{\gamma Z} \approx \frac{x}{3}(2u_v + d_v)$$

little dependence on Q^2 :

transform to one Q^2 value of 1500 GeV^2

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

mostly due to γZ interference



Summary

- The polarized NC&CC $e^{\pm}p$ cross sections are measured using HERA II data

  → *linear dependence of σ_{CC}^{total} on P_e is consistent with the absence of the right-handed charged currents*

  → *polarization asymmetry in NC demonstrates the parity violation at small distances, down to about 10^{-18} m*

  → *measurement of the structure function xF_3 is directly sensitive to the valence quark distributions*

- The combined EW and QCD fits are performed by H1 and ZEUS using polarized and unpolarized data from HERA

  → *the light quark couplings to the Z boson are measured*

- The combination of the H1 and ZEUS data :

  → *published for HERA I and on the way for the entire data from HERA*