EW Measurements at High Q^2 at HERA

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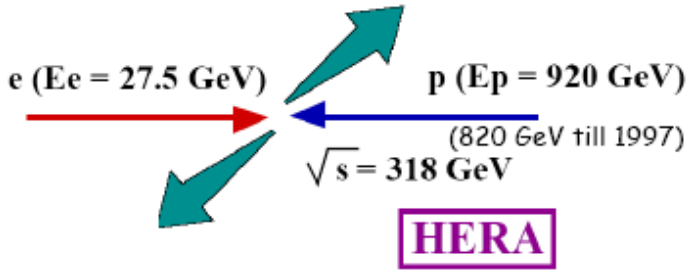
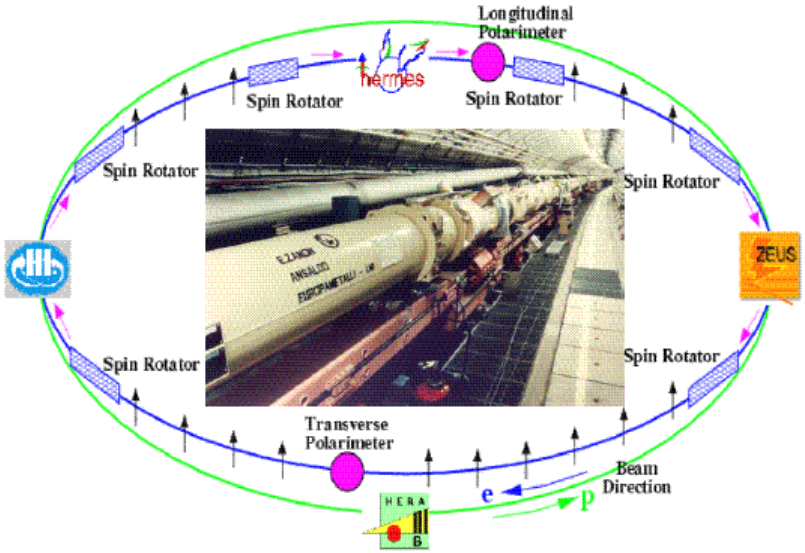
H1 Experiment, DESY

- HERA collider, DIS NC/CC
- Cross sections at high Q^2
- CC polarization dependence
- xF_3
- NC polarization asymmetry
- Electroweak fit

HERA ep Collider (1992-2007)



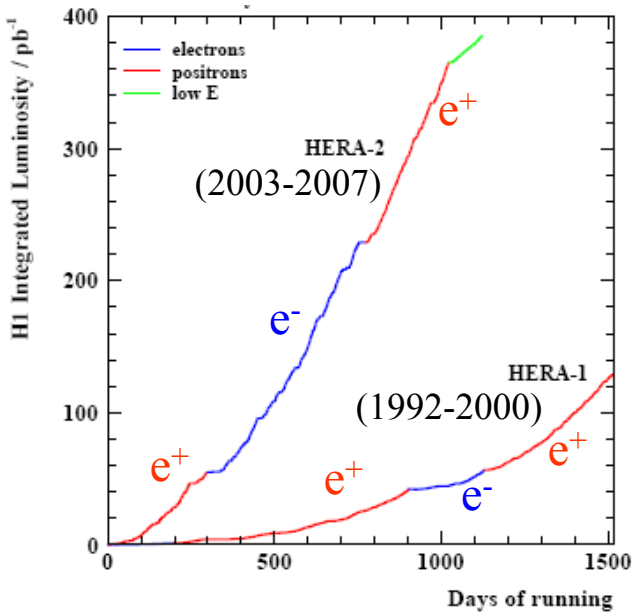


$Q^2_{max} \sim 10^5$ GeV^2

$\lambda_{min} \sim 1/1000\ R_{proton}$

per exp.	HERA I	HERA II
e^+p	100 pb^{-1}	200 pb^{-1}
e^-p	20 pb^{-1}	180 pb^{-1}

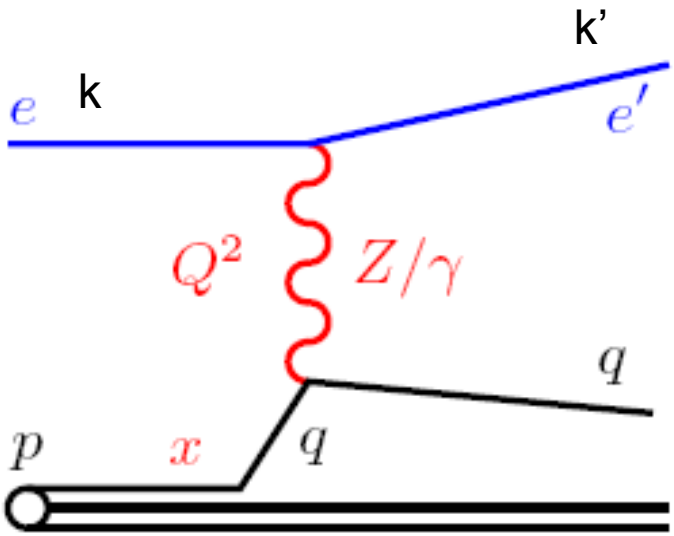
in total ~ 1fb^{-1} for H1 and ZEUS



Longitudinal polarization of electron beam (2003-2007)

$P_e = (N_R - N_L)/(N_R + N_L) \approx 40\%$

Neutral Currents (NC) Deep Inelastic Scattering (DIS)

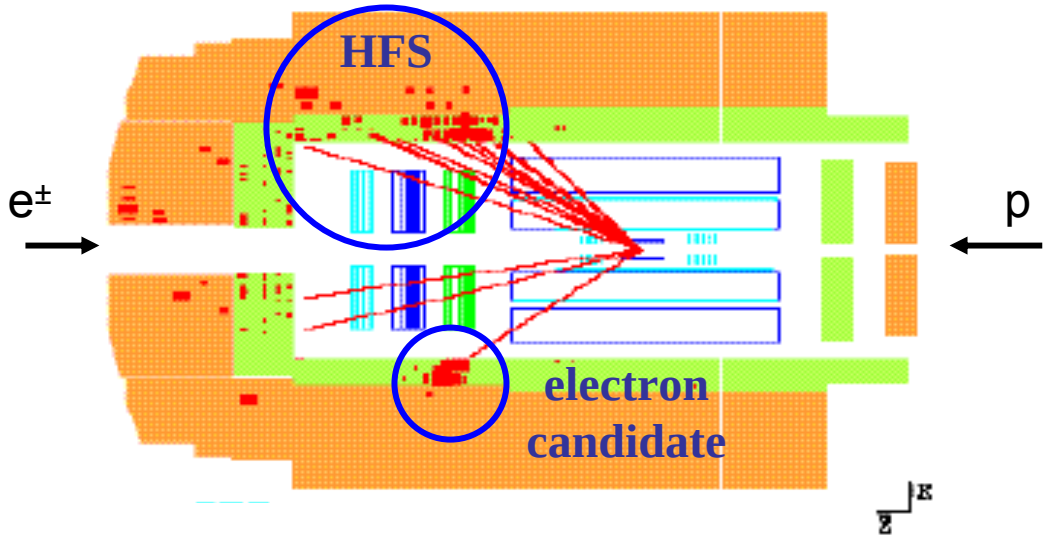


$Q^2 = -q^2 = (k - k')^2$ boson virtuality

$x = \frac{Q^2}{2(Pq)}$ Bjorken x

$y = \frac{(Pq)}{(Pk)}$ inelasticity

$Q^2 = sxy \quad s = (k + P)^2$



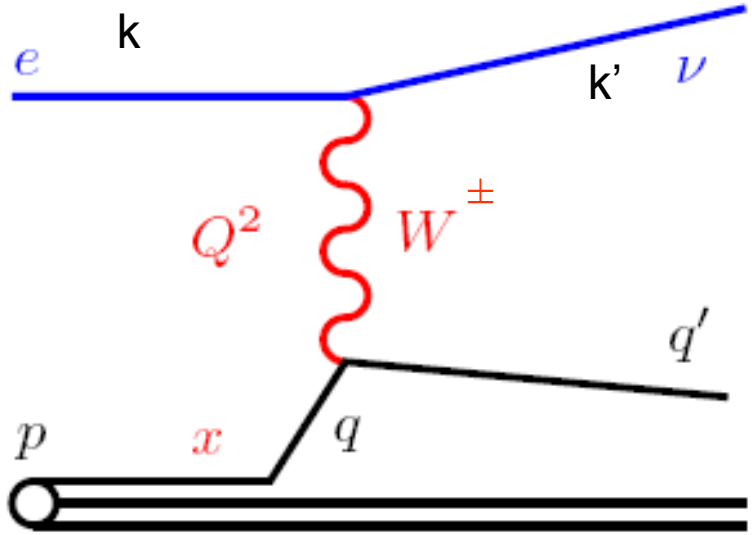
Charge Currents (CC) Deep Inelastic Scattering (DIS)

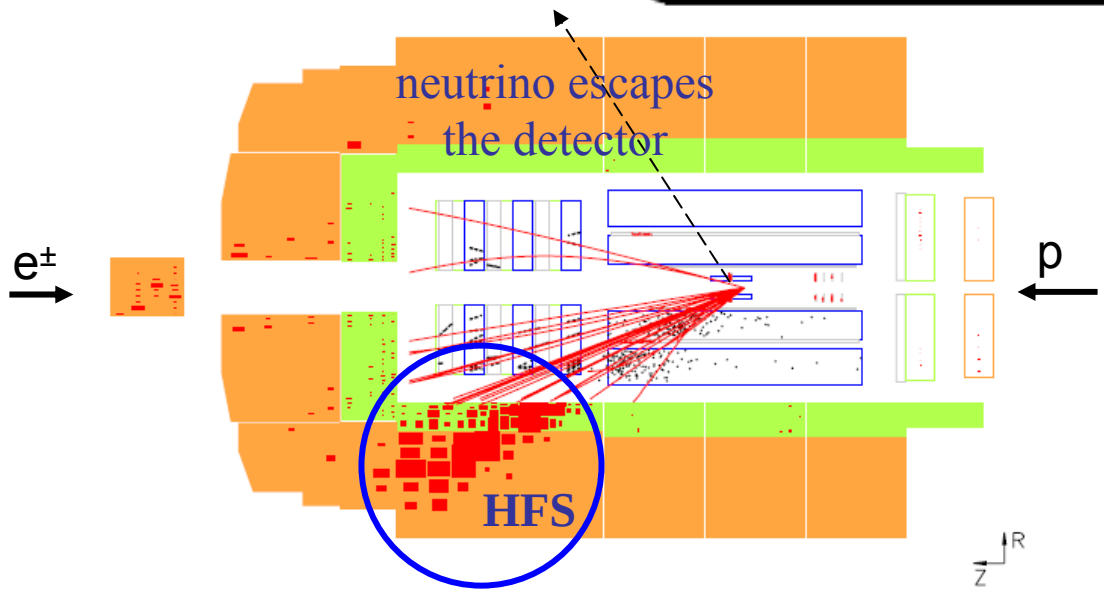
$Q^2 = -q^2 = (k - k')^2$ boson virtuality

$x = \frac{Q^2}{2(Pq)}$ Bjorken x

$y = \frac{(Pq)}{(Pk)}$ inelasticity

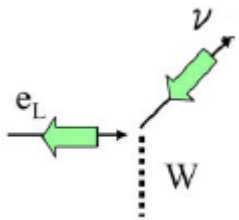
$Q^2 = sxy \quad s = (k + P)^2$





Polarization Dependence of Total CC Cross Section

SM: weak CC is purely left-handed (V-A)

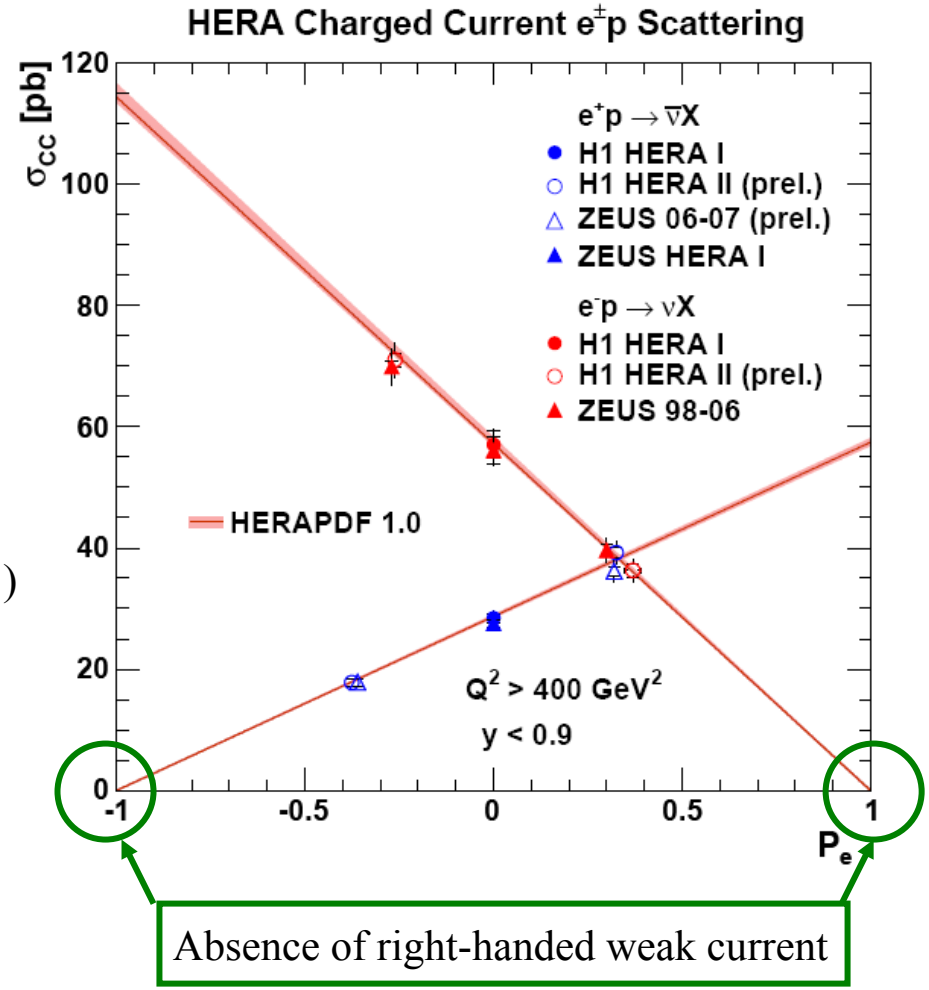


$$\sigma^{CC}(e^{\pm}p) = (1 \pm P_e)\sigma^{CC}_{P_e=0}(e^{\pm}p)$$

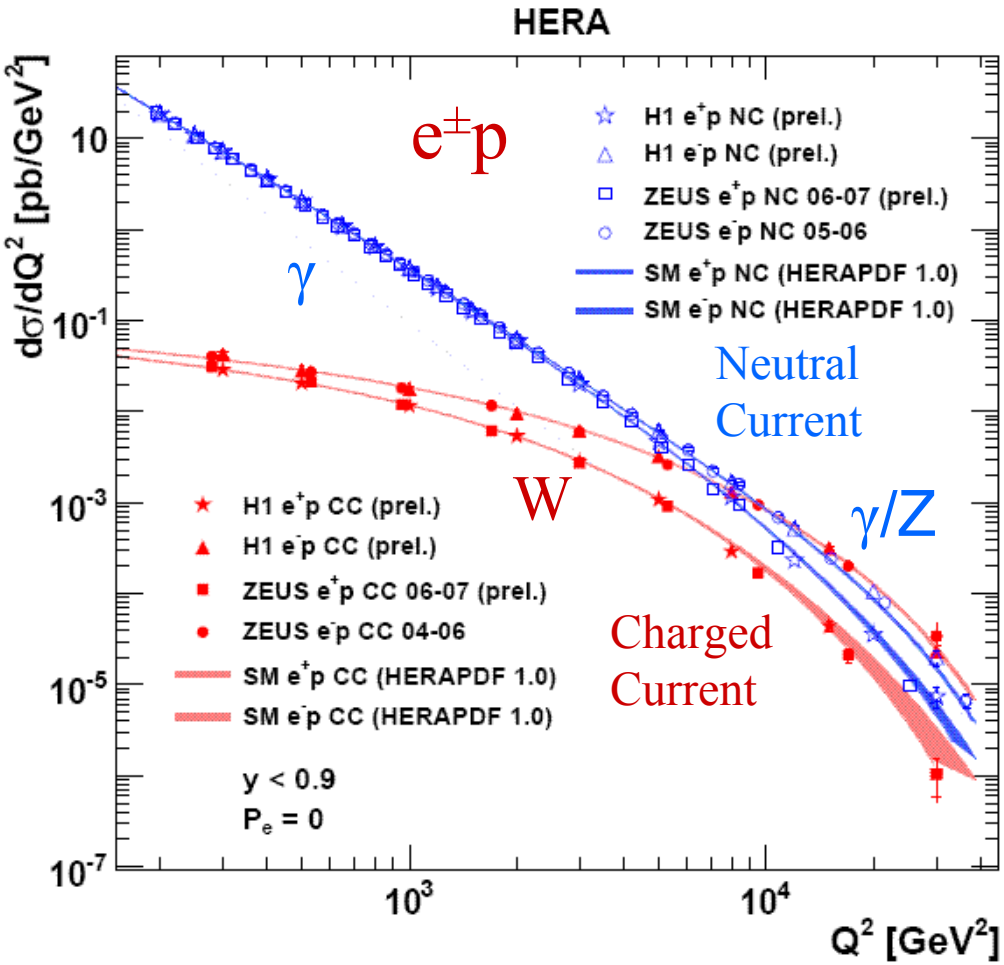
longitudinal polarization $P_e = (N_R - N_L)/(N_R + N_L)$

- Linear dependence σ^{CC} on P_e confirmed
- No right-handed CC observed
- Limit on the W_R boson mass

$$M_{W_R} \gtrsim 200 \text{ GeV}$$



Electroweak Unification

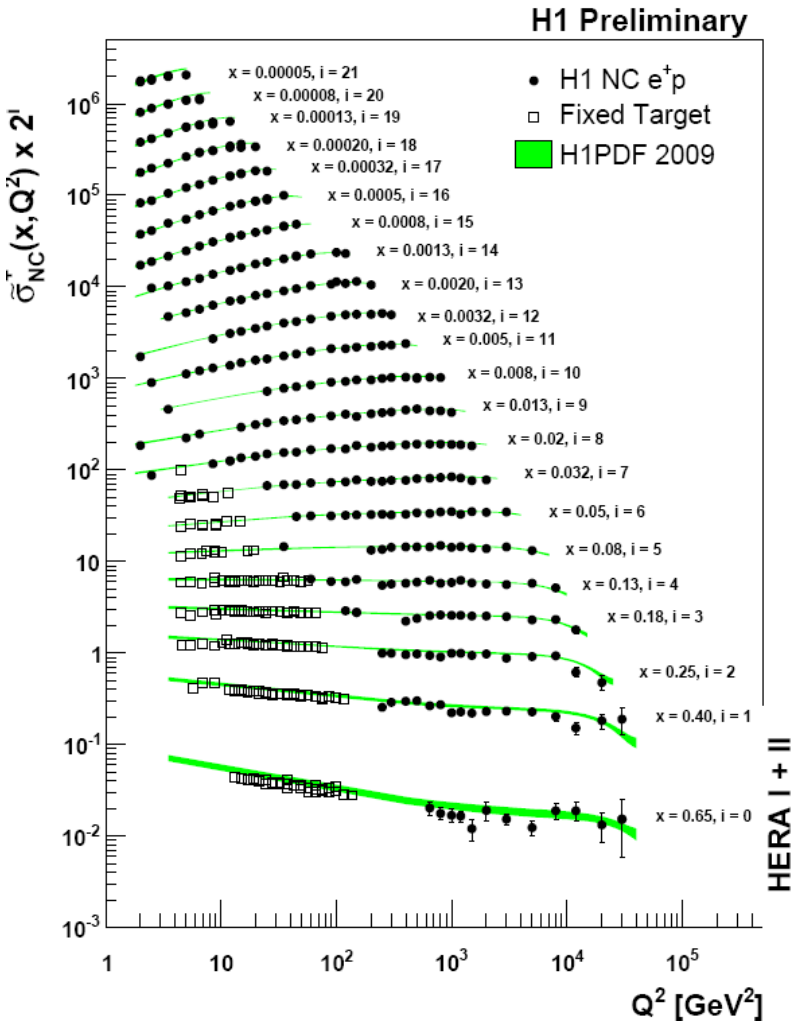


EW component of SM:
NC and CC cross sections become similar at

$$Q^2 \approx M_Z^2, M_W^2$$

Neutral Current Measurements at High Q^2

$$\frac{d^2\sigma(l^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2(x,Q^2) - y^2F_L(x,Q^2) \mp (1-(1-y)^2)xF_3(x,Q^2)]$$



remove kinematical factor

$$\frac{d^2\sigma_{NC}(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha Y_+}{xQ^4}\cdot\tilde{\sigma}^{\pm}_{NC}$$

$$\sigma^{\pm}_{NC} = F_2(x,Q^2) \mp \frac{Y_-}{Y_+}xF_3(x,Q^2)$$

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

Main contribution

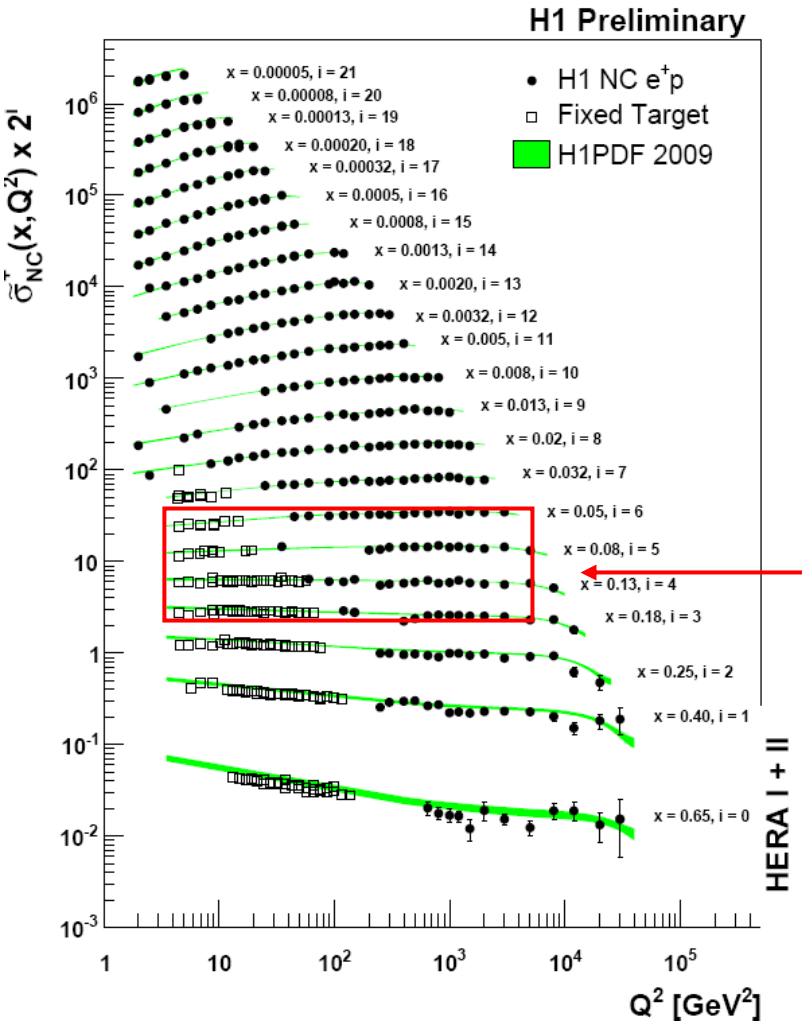
$$F_2(x,Q^2) = \sum_i e_i^2 xq_i(x)$$

Contributes at high Q^2

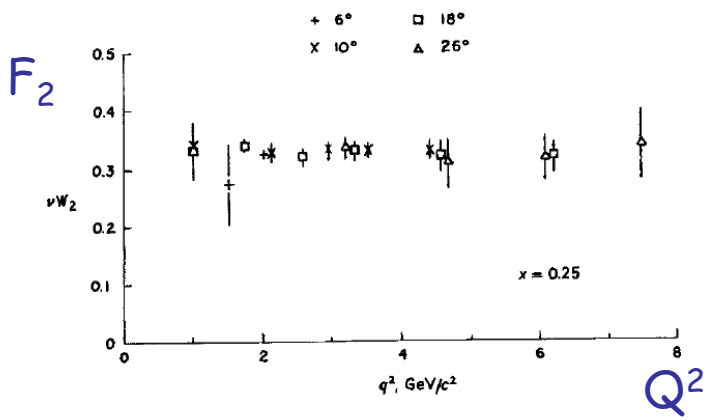
$$xF_3 \approx \sum_q B_q(xq - x\bar{q})$$

Neutral Current Measurements at High Q^2

$$\frac{d^2\sigma(l^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2(x,Q^2) - y^2F_L(x,Q^2) \mp (1-(1-y)^2)xF_3(x,Q^2)]$$



SLAC results, 1968



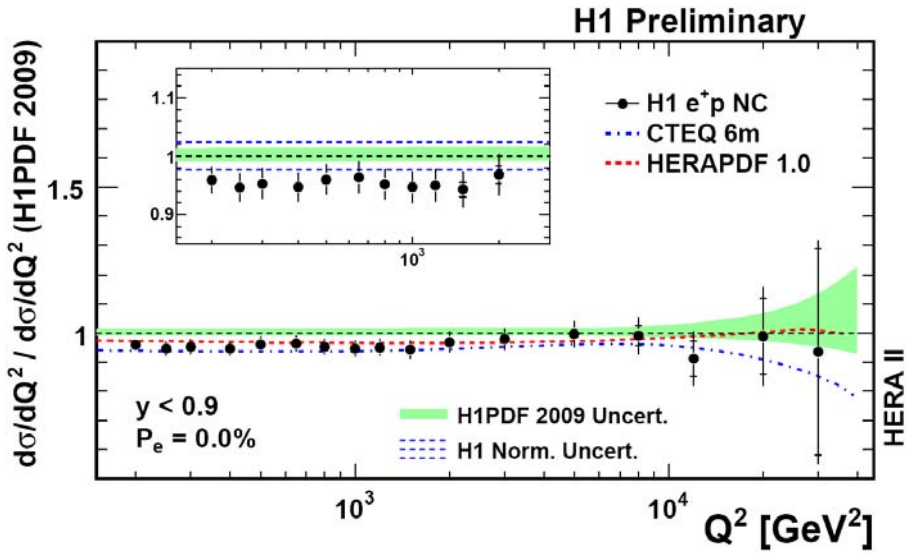
scaling at x ~ 0.15

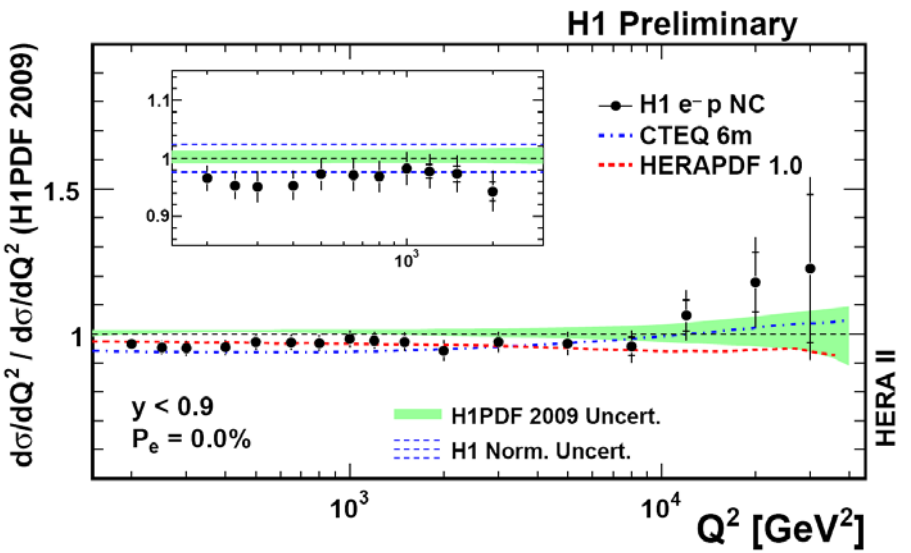
$$x_{min} > \frac{Q^2}{s} = \frac{Q^2}{4E_eE_p}$$

$$x_{min}^{SLAC} \approx 0.1$$

$$x_{min}^{HERA} \approx 0.00005$$

Quark Radius Limit





Quark "form factor" with R_q corresponding to the average radius of the spatial charge distribution

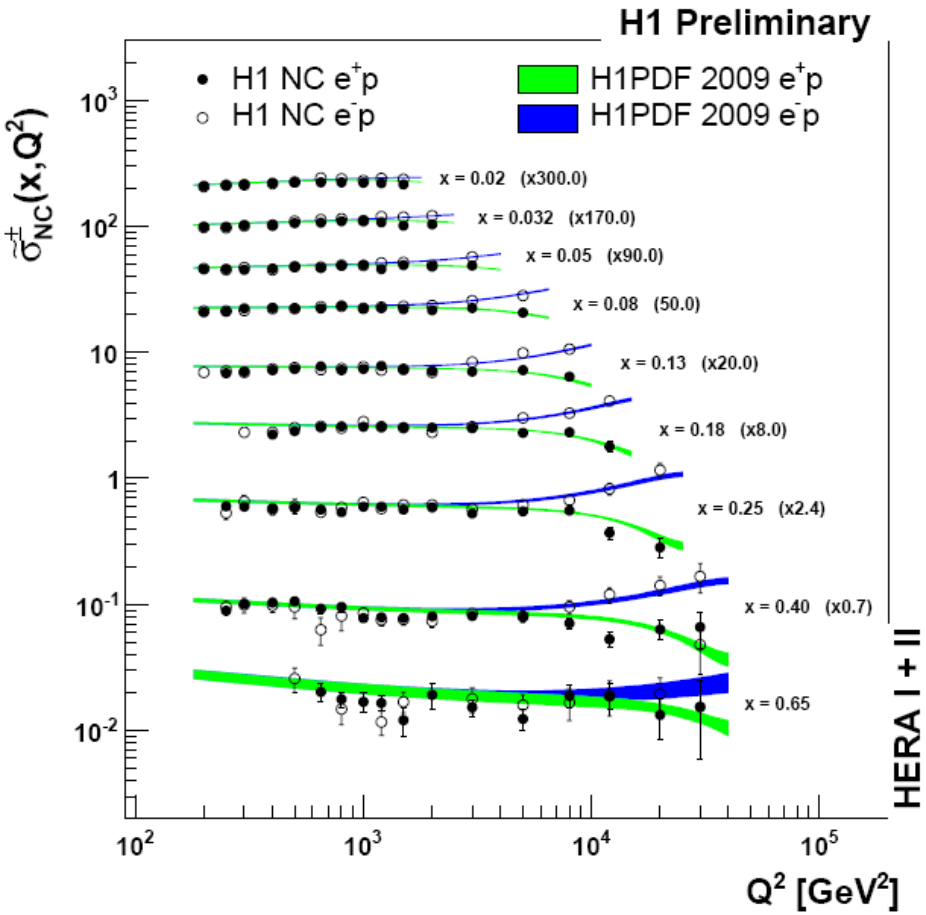
$$\frac{d\sigma}{dQ^2} = \left(\frac{d\sigma}{dQ^2}\right)_{SM} \left(1 - \frac{1}{6} R_q^2 Q^2\right)$$

Point like quark

$R_q \lesssim 0.74 \times 10^{-18}$ m

NC with Electrons and Positrons

$$\frac{d^2\sigma(l^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2(x,Q^2) - y^2F_L(x,Q^2) \mp (1-(1-y)^2)xF_3(x,Q^2)]$$

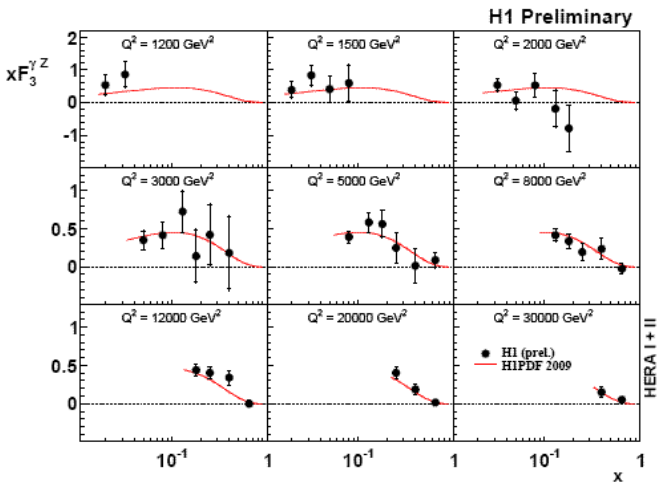


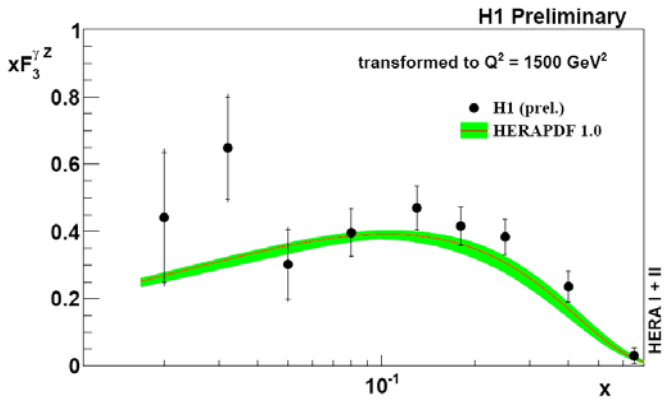
$$\tilde{\sigma}^{\pm}_{NC} = \tilde{F}_2(x,Q^2) \mp \frac{Y_-}{Y_+} x\tilde{F}_3(x,Q^2)$$

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

Difference in cross-sections at high Q^2 between e^+ and e^- is due to xF_3

xF_3 Structure Function





reduced cross section at high Q^2

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

mostly due to γZ interference

$$xF_3^{\gamma Z} = -\frac{Y_+}{2Y_-}[\tilde{\sigma}(e^- p) - \tilde{\sigma}(e^+ p)] / a_e \kappa_Z$$

$$\kappa_Z = \frac{Q^2}{Q^2 + M_Z^2} \frac{1}{4\cos^2\Theta_W \sin^2\Theta_W}$$

$$xF_3^{\gamma Z} \propto 2xu_v + xd_v$$

$xF_3^{\gamma Z}$: little Q^2 dependence
→ transform all measurements to one Q^2 value

constrain valence quarks u_v, d_v at high x

NC with Longitudinally Polarized Leptons

$$\tilde{F}_2^{\pm} = F_2 - (v_e \pm P_e a_e)\kappa_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 \pm 2P_e v_e a_e)\kappa_Z^2 F_2^Z$$

$$x\tilde{F}_3^{\pm} = -(a_e \pm P_e v_e)\kappa_Z x F_3^{\gamma Z} + (2 v_e a_e \pm P_e(v_e^2 + a_e^2))\kappa_Z^2 x F_3^Z$$

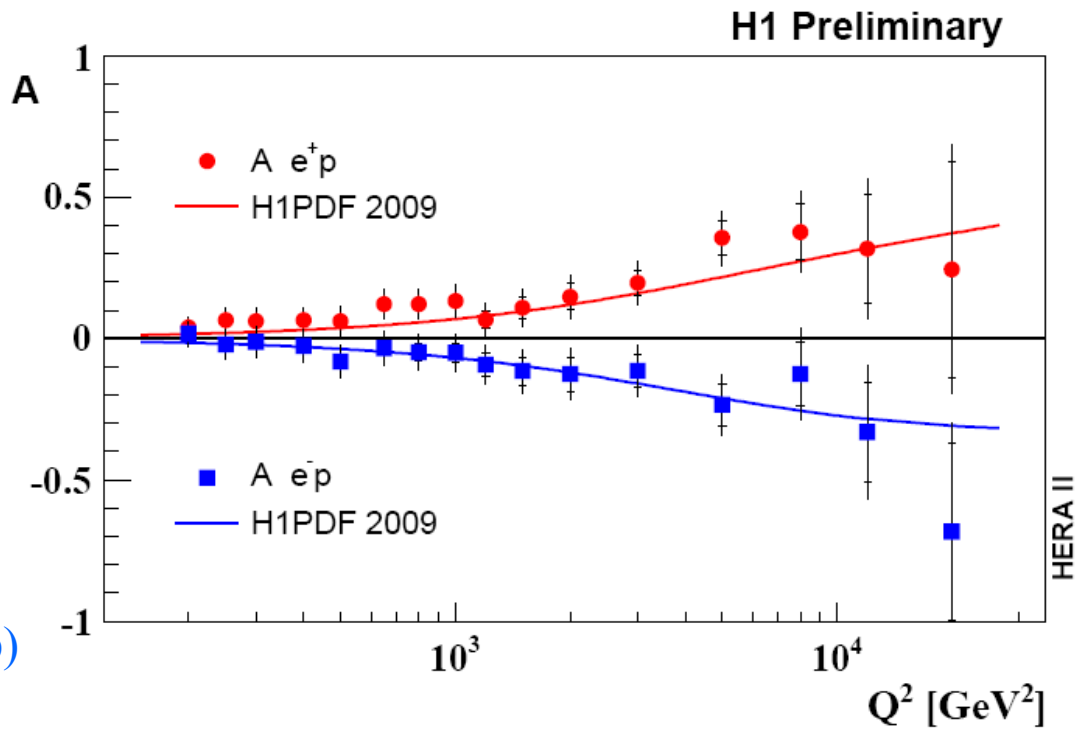
$$P_e = \frac{N_R - N_L}{N_R + N_L} \qquad \kappa_Z = \frac{Q^2}{Q^2 + M_Z^2} \frac{1}{4\cos^2\Theta_W \sin^2\Theta_W}$$

Polarization Asymmetry

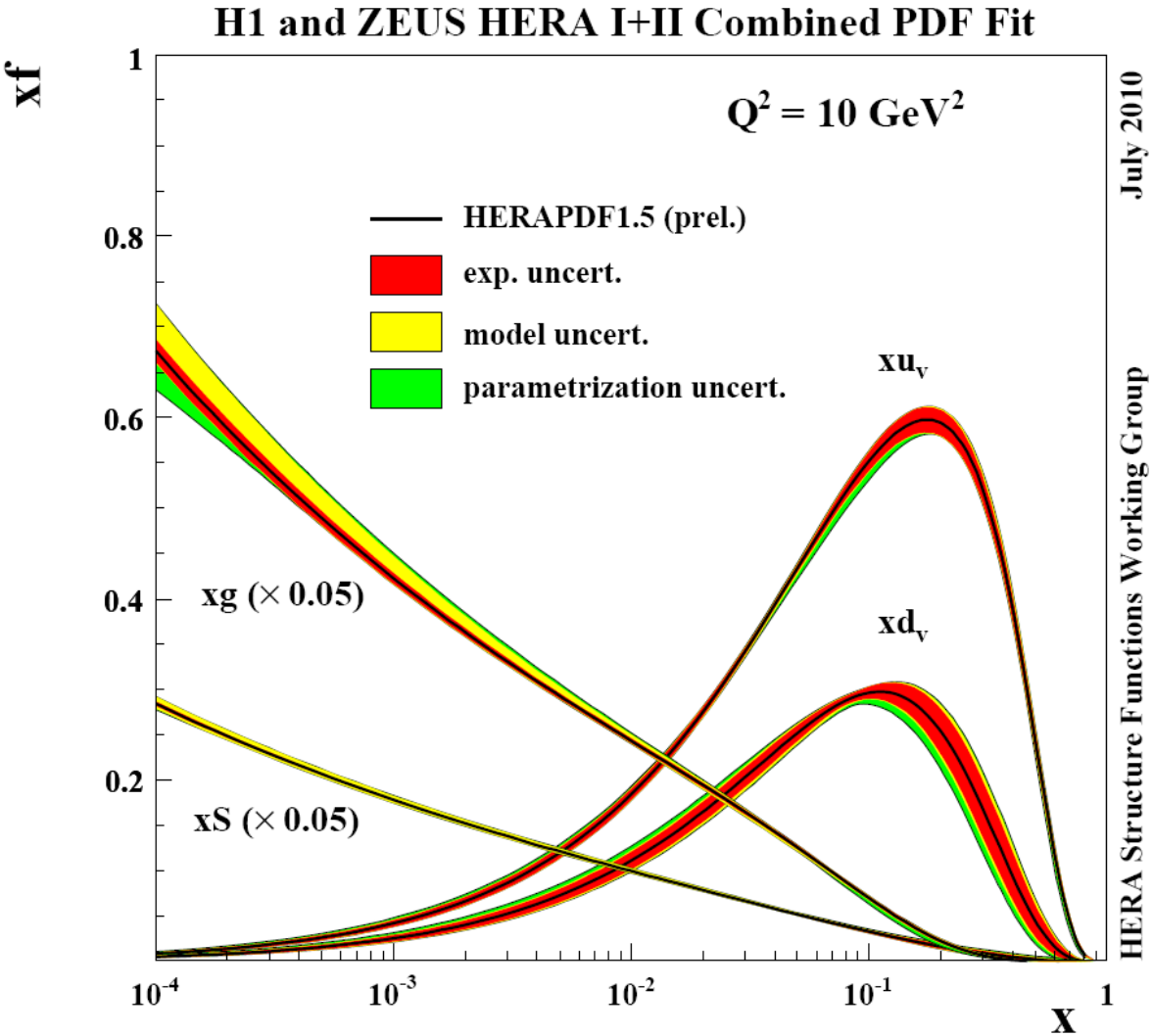
$$A^{\pm} = \frac{2}{P_R - P_L} \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$

$$\approx a_e \kappa_Z \frac{F_2^{\gamma Z}}{F_2} \propto \frac{1 + d_v/u_v}{4 + d_v/u_v}$$

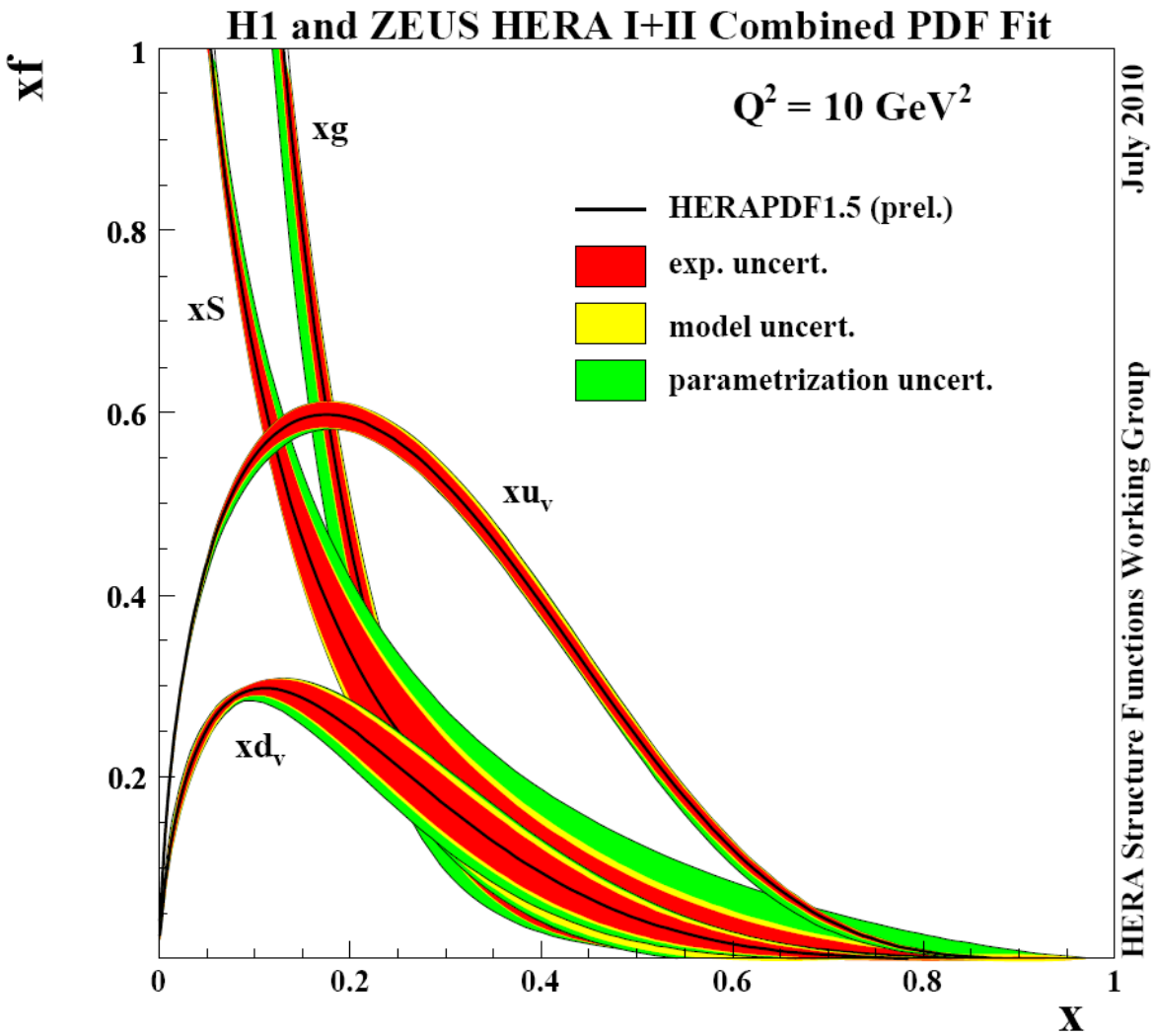
at low Q^2 $A(e^+p), A(e^-p) \approx 0$
at high Q^2 non zero, $A(e^+p) \approx -A(e^-p)$



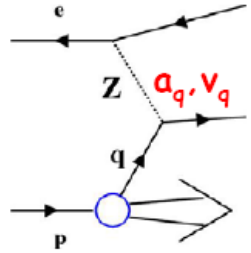
Parton Distribution Functions



Parton Distribution Functions (just to show you the real scale)



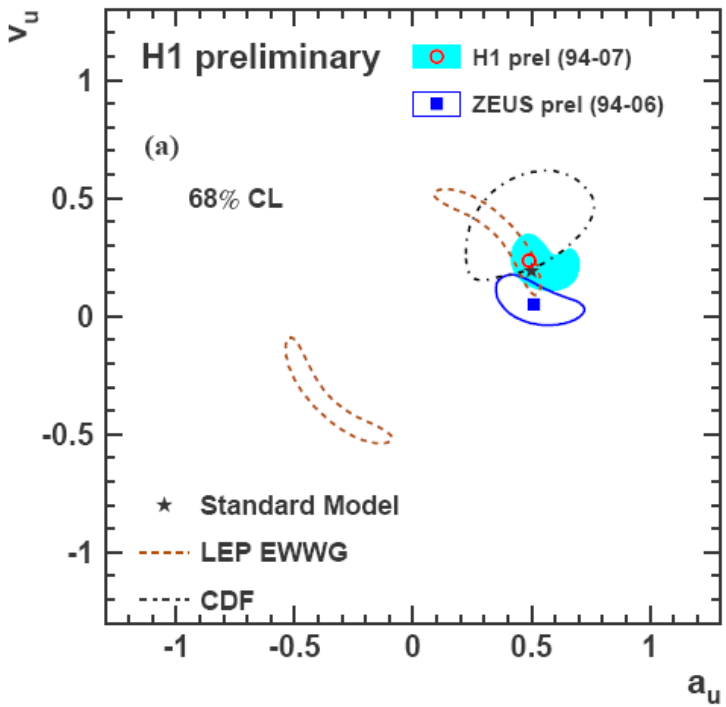
Light Quark Coupling to Z



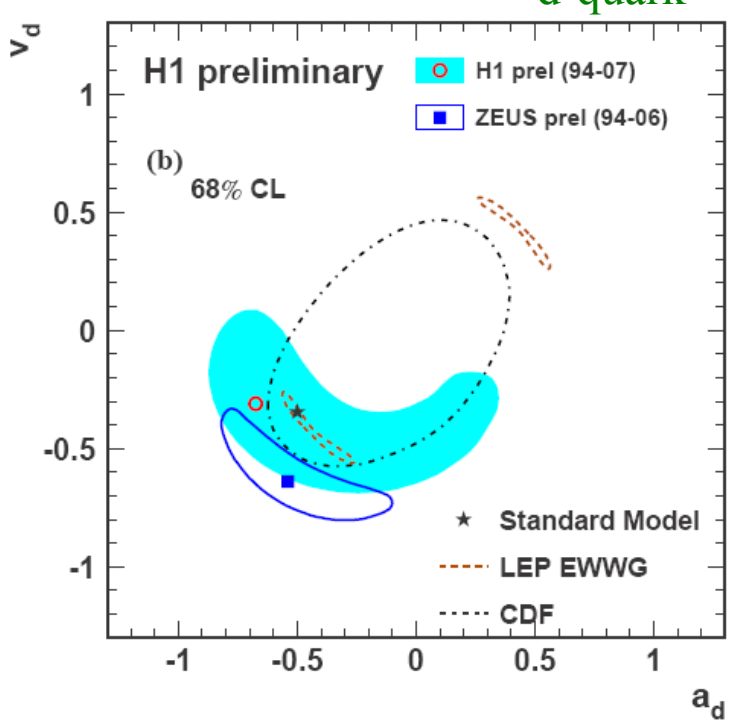
simultaneous EW+PDF analysis of NC and CC data

$$v_q = I_q^3 - 2e_q \sin^2 \Theta_W \qquad a_q = I_q^3$$

u-quark



d-quark



Tevatron: $qq \rightarrow e^+e^-$ (A_{FB}) → resolves LEP ambiguity

LEP EWWG: $ee \rightarrow qq$ at Z (a^2v^2, a^2+v^2) → the best precision on u quark coupling to Z

Conclusions

Over 15 years of HERA operation (1992-2007) H1 and ZEUS collected in total 1fb-1 (electrons/positrons positive/negative longitudinal polarization of the lepton beam)

→ precise measurements of the proton structure functions / PDF's
→ study of EW effects in NC and CC

Publish final H1 results and combine them with the ZEUS final results