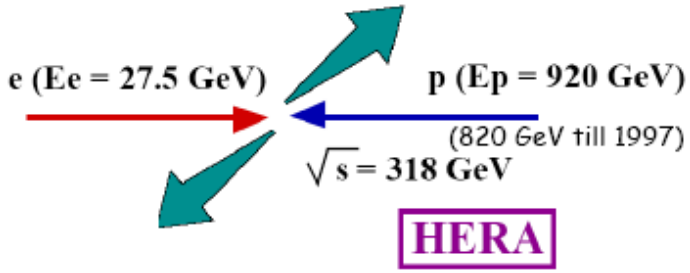
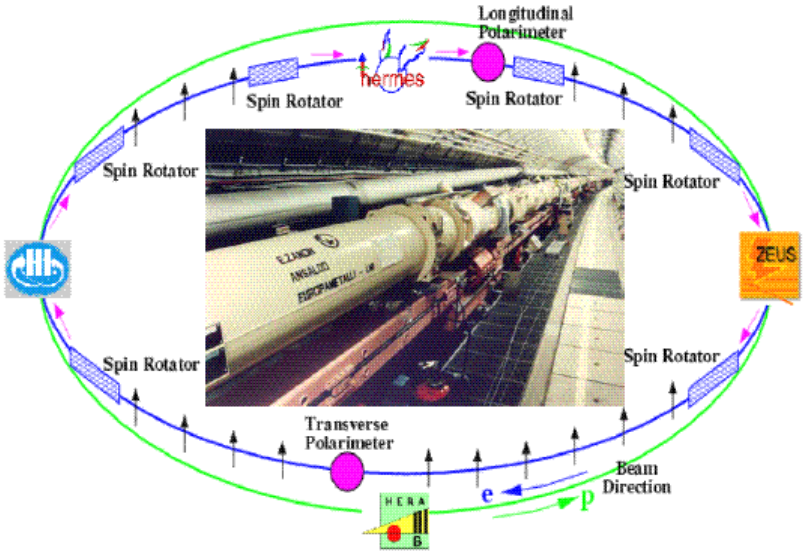
XLVth Rencontres de Moriond, 06.03-13.03.2010, La Thuile

EW Measurements at High Q^2 at HERA

S.Shushkevich, MPIM

HERA ep collider (1992-2007)



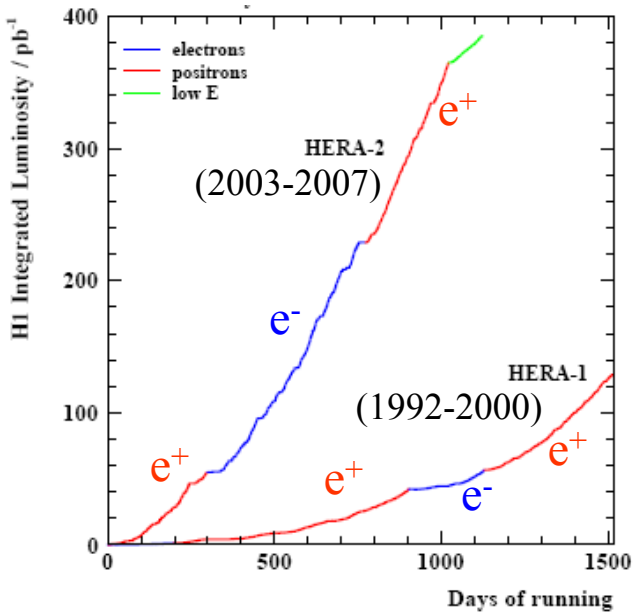


$Q^2_{max} \sim 10^5$ GeV^2

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

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

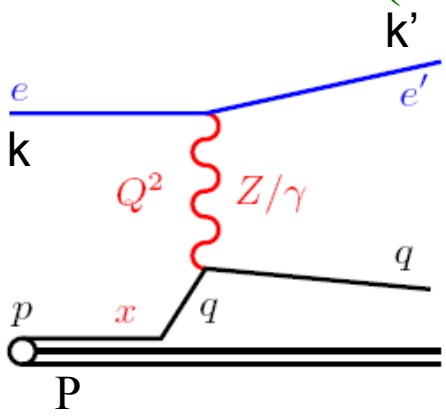


Longitudinal polarization of electron beam (2003-2007)

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

Deep Inelastic Scattering (DIS)

Neutral current (NC)



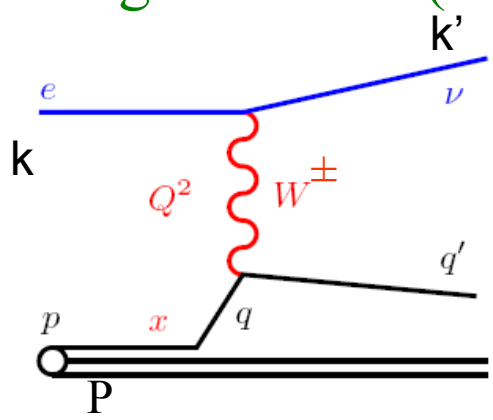
$$Q^2 = -q^2 = (k-k')^2$$ boson virtuality

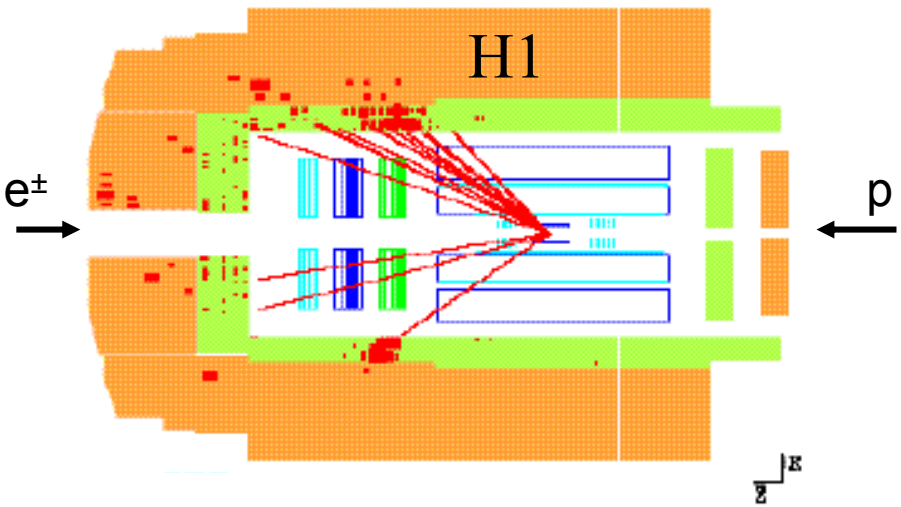
$$x = \frac{Q^2}{2(Pq)}$$ Bjorken x

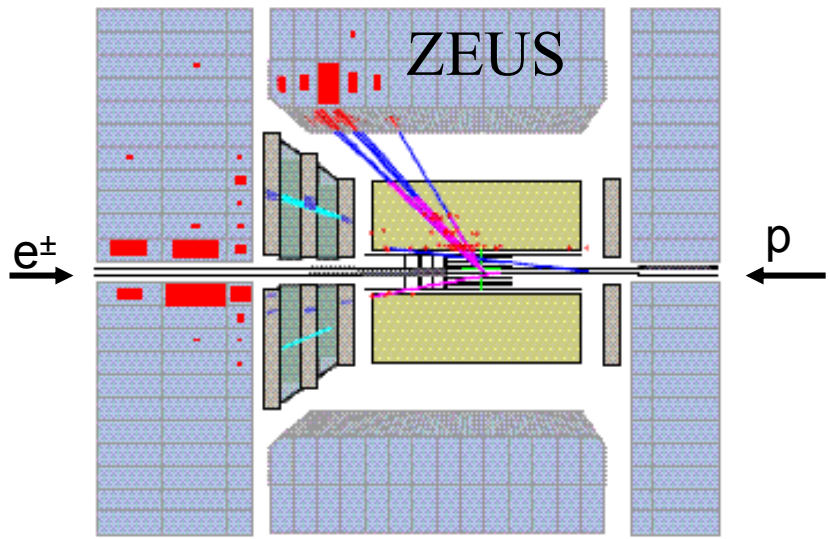
$$y = \frac{(Pq)}{(Pk)}$$ inelasticity

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

Charged current (CC)



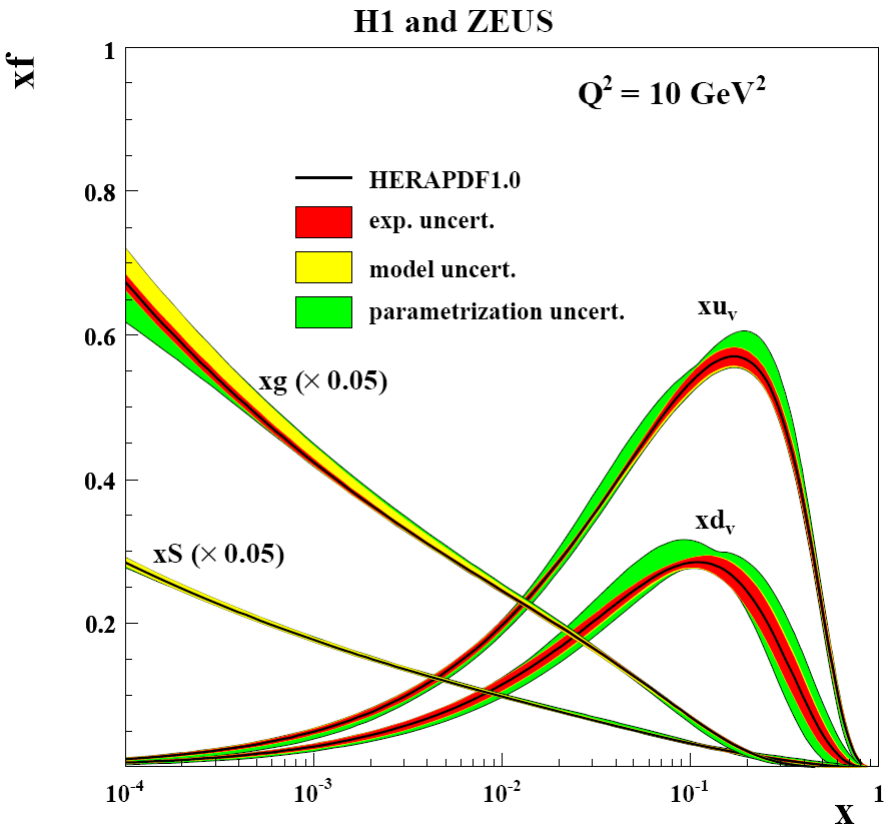




HERAPDF 1.0

→ H1+ZEUS combined data from HERA I

→ Parton distributions unfolded in NLO QCD fit using the HERA $e^{\pm}p$ data only



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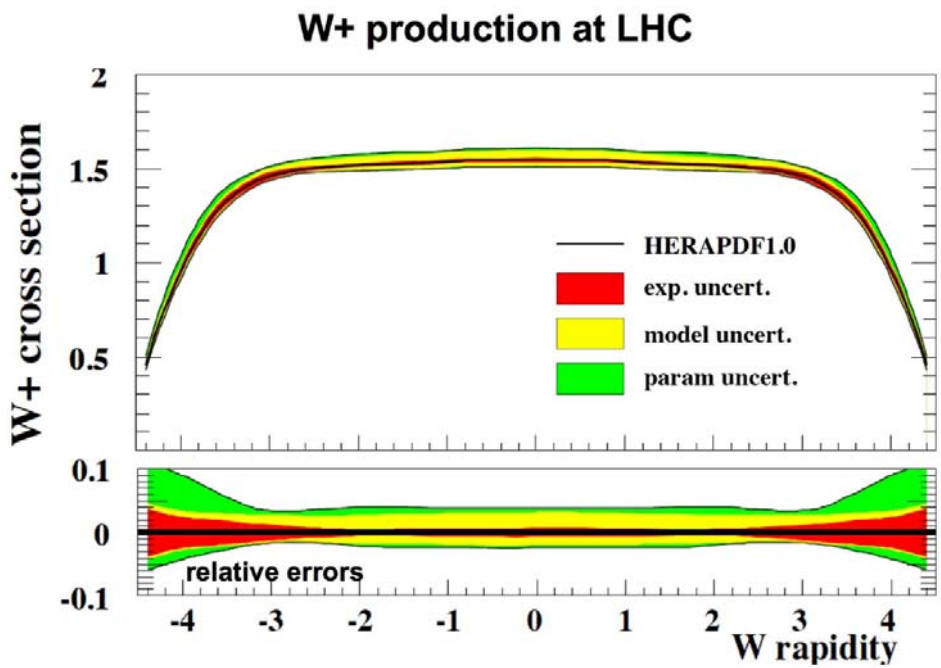
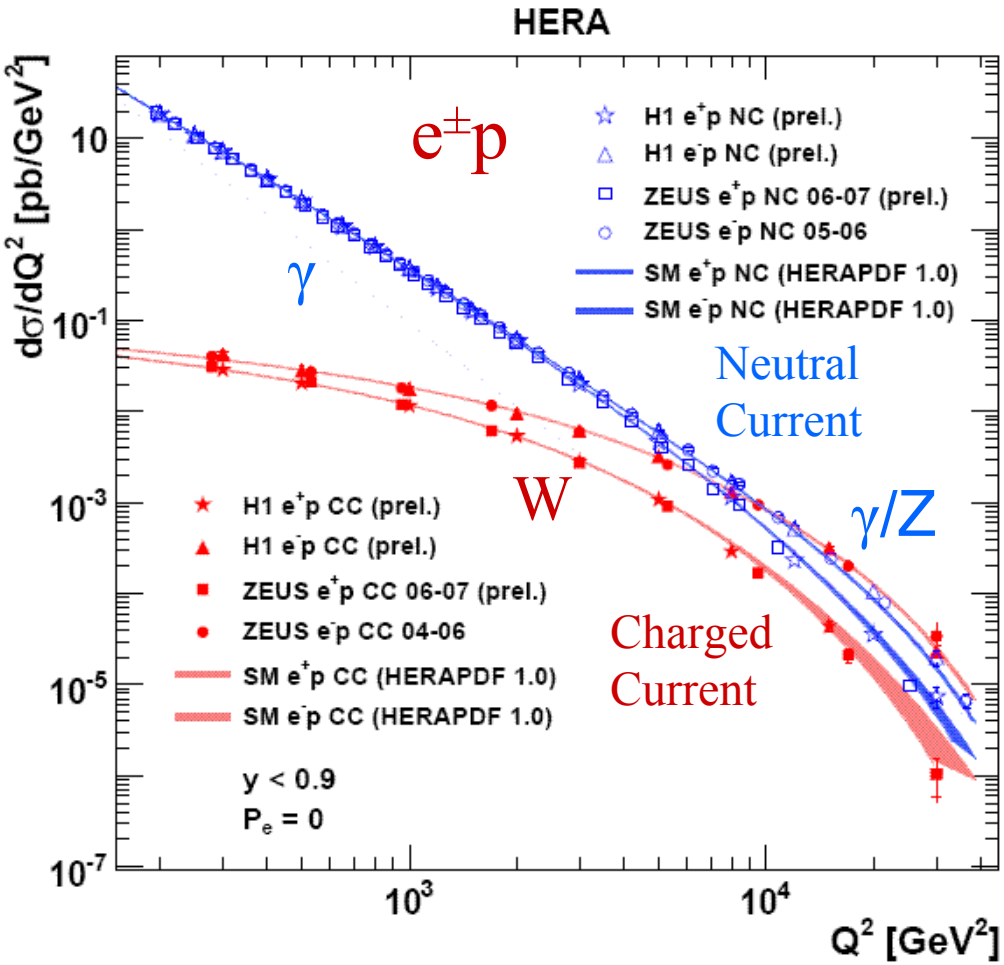


The new measurements for Moriond EW 2010

- Full HERA II data for CC and NC from H1 and ZEUS (preliminary and publications)
  - Cross sections at high Q^2
  - CC polarization dependence
  - xF_3
  - NC polarization asymmetry
  - Electroweak fits
- A significant step in precision, towards full power of HERA

Electroweak unification



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

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

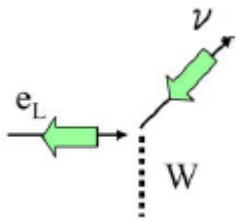
At the highest Q^2

→ Search for deviations from SM

quark radius $r_q < 10^{-18}$ m

Total Charged Current Cross Section

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

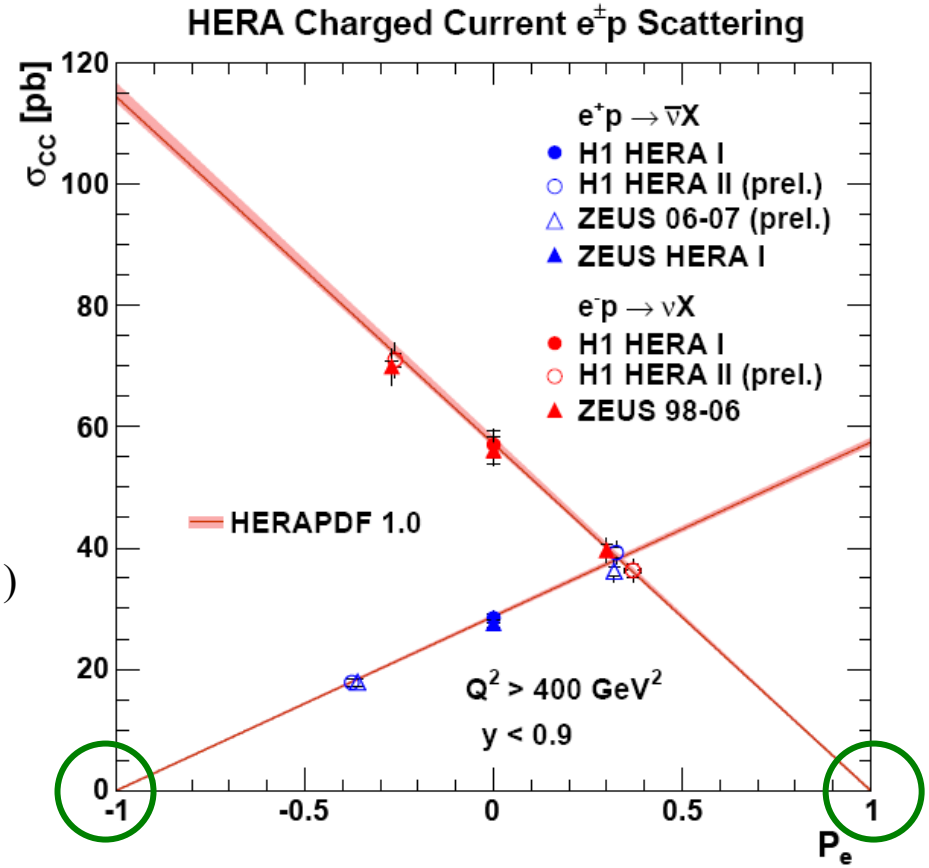


$$\sigma^{CC}(e^{\pm}p) = (1 \pm P_e)\sigma^{CC}_{P_e=0}(e^{\pm}p)$$

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

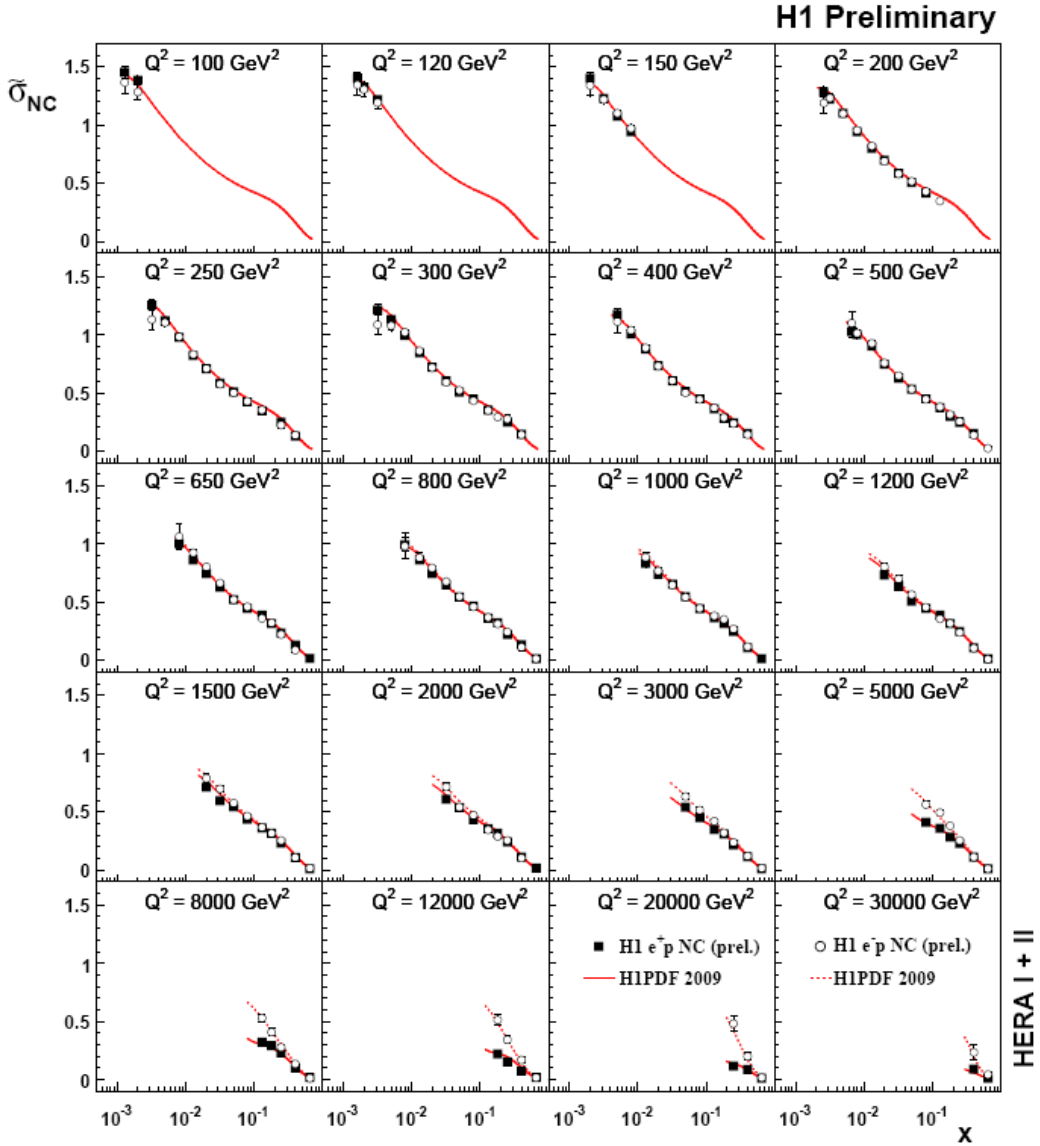
- Linear dependence σ^{CC} on P_e confirmed
- No right-handed CC observed
- Limit on the W_R boson mass

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



Absence of right-handed weak current

Neutral Current Measurements at high Q^2



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

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

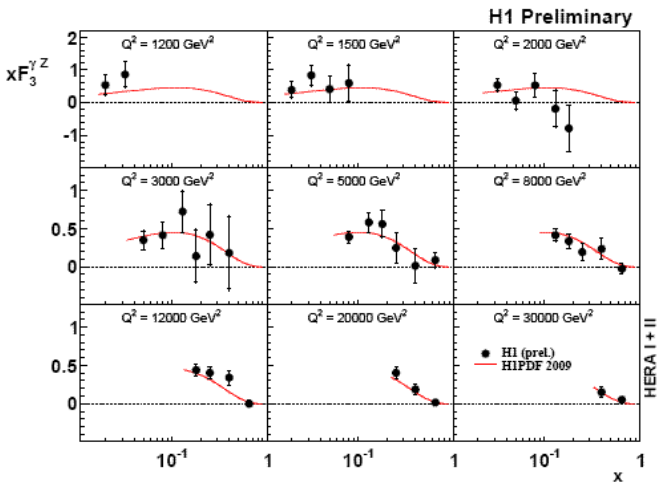
$$Y_{\pm} = 1 \pm (1-y)^2$$

Main contribution

$$F_2 = \sum_q e_q^2(xq + x\bar{q})$$

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

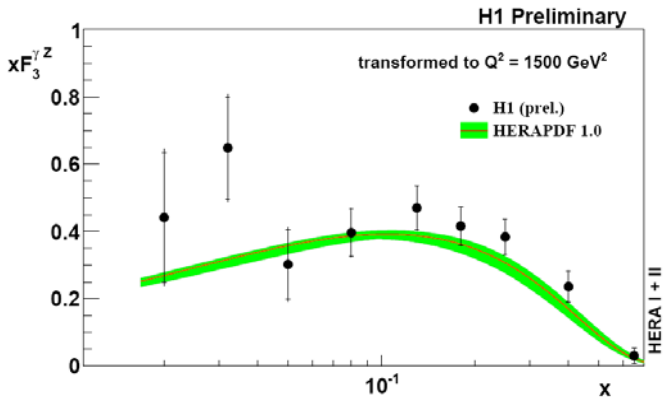
$$\tilde{\sigma}_{NC}(e^{\pm}p) = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3$$

mostly due to γZ interference

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

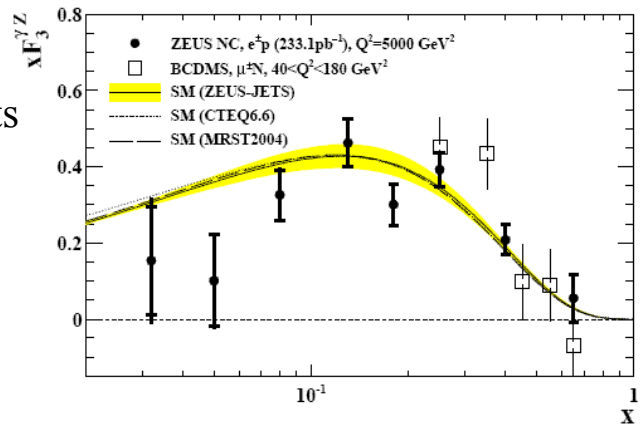
$$\kappa_Z = \frac{Q^2}{Q^2 + M_Z^2} \frac{1}{4\cos^2\Theta_W \sin^2\Theta_W}$$

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



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

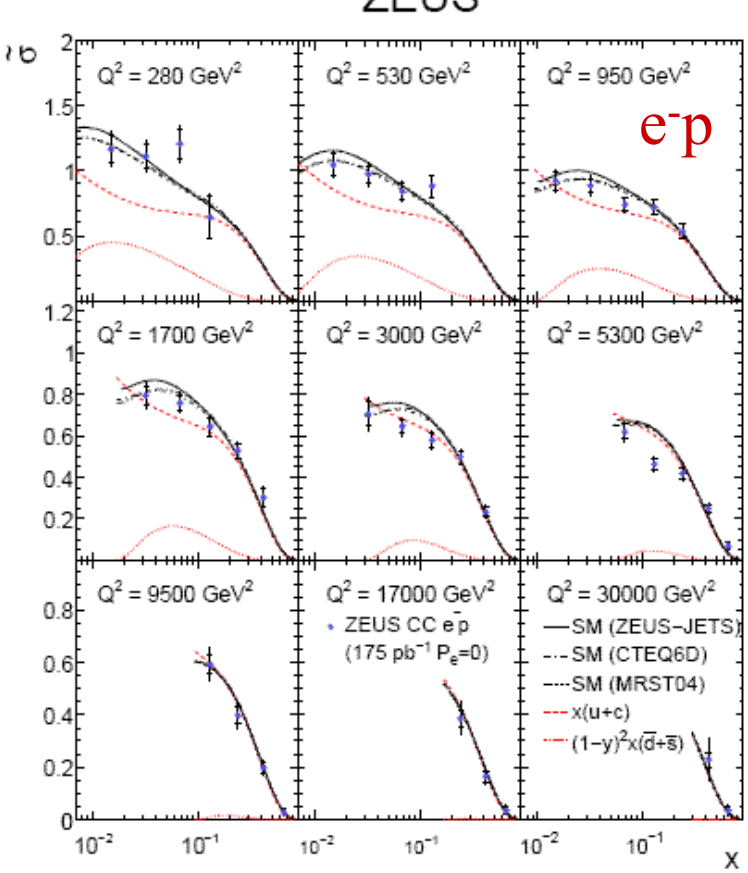
constrain valence quarks u_v, d_v at high x

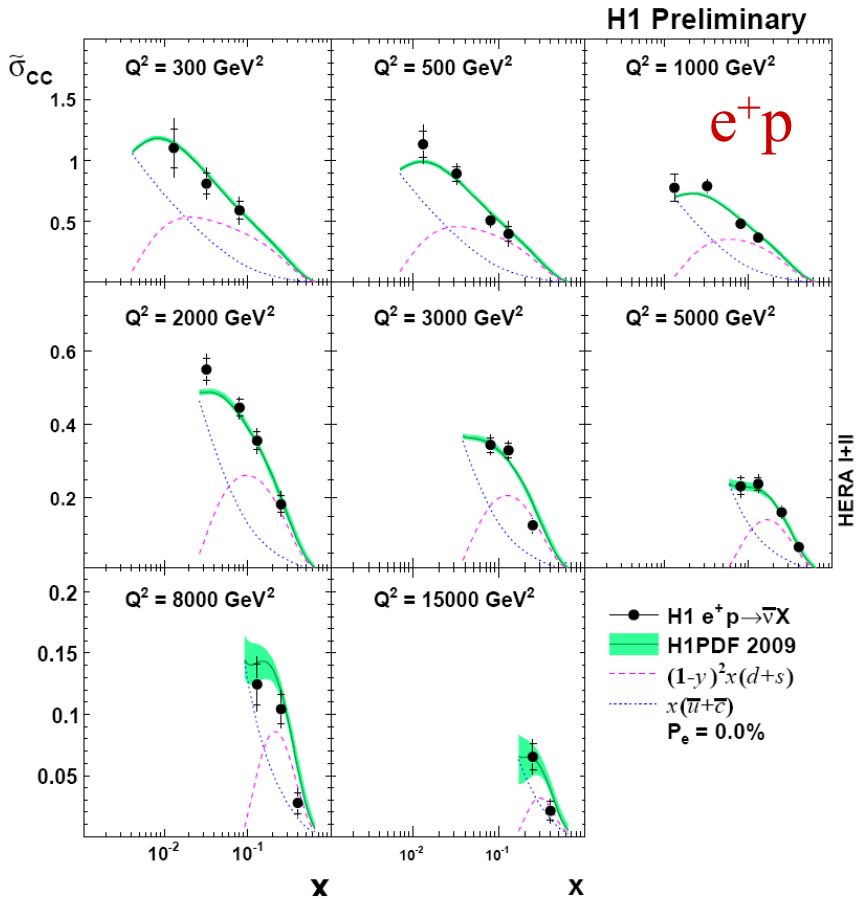


Charged Current Measurements

at high x

$$\tilde{\sigma}_{CC}(e^- p) \propto (xu + xc) + (1-y)^2 (x\bar{d} + x\bar{s}) \qquad \tilde{\sigma}_{CC}(e^+ p) \propto (x\bar{u} + x\bar{c}) + (1-y)^2 (xd + xs)$$





→ constrain d and u quark densities; free of nuclear corrections and isospin assumptions

NC with longitudinally polarized leptons

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

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

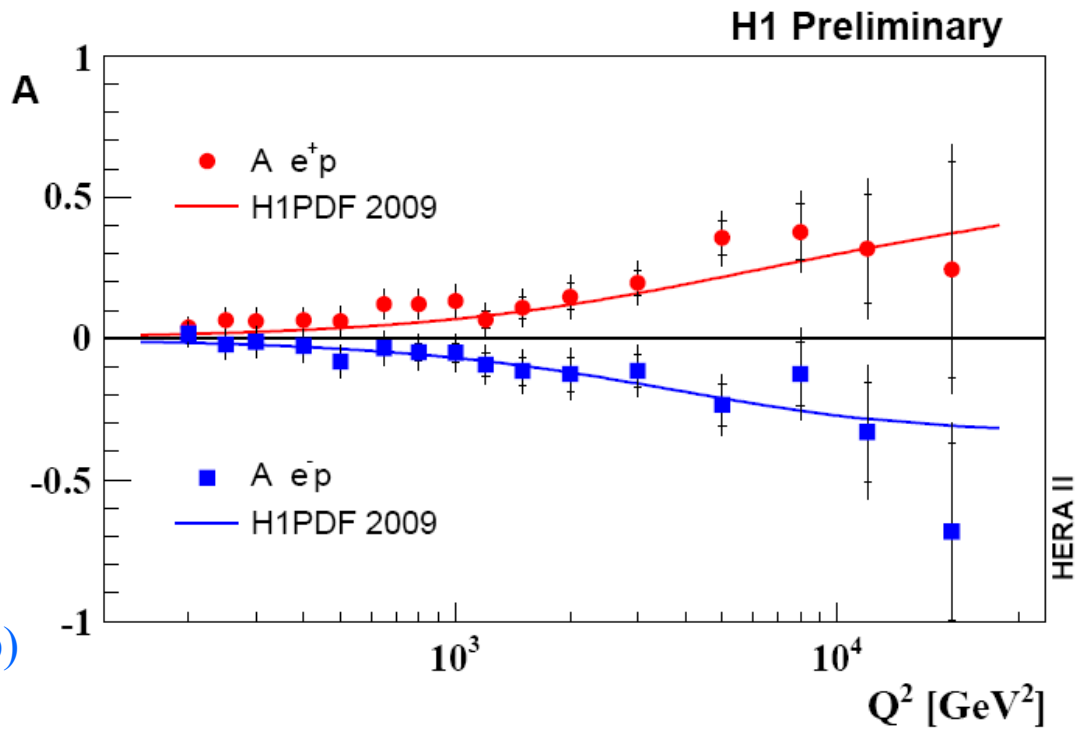
$$P_e = \frac{N_R - N_L}{N_R + N_L} \qquad \kappa_Z = \frac{Q^2}{Q^2 + M_Z^2} \frac{1}{4\cos^2\Theta_W \sin^2\Theta_W}$$

Polarization Asymmetry

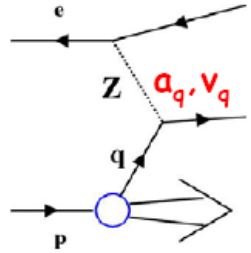
$$A^{\pm} = \frac{2}{P_R - P_L} \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$

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

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



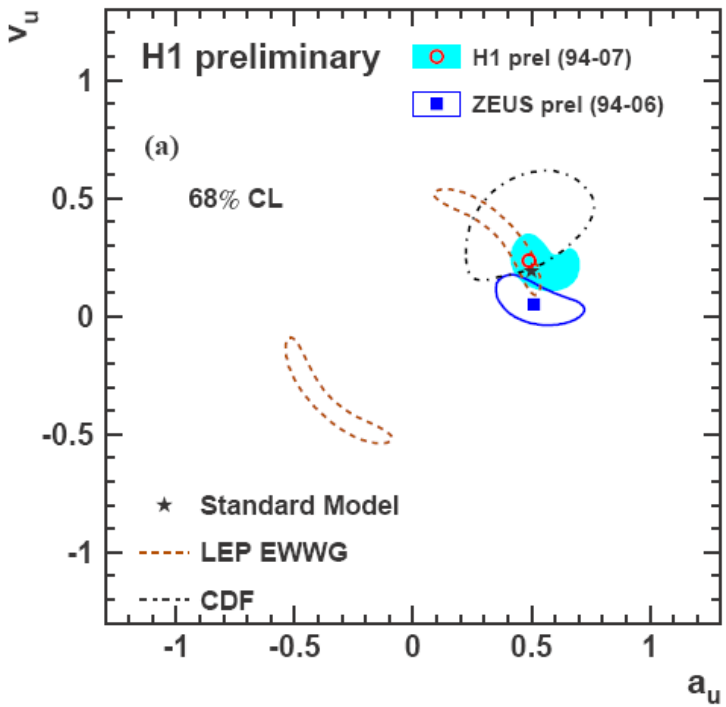
Light Quark Coupling to Z



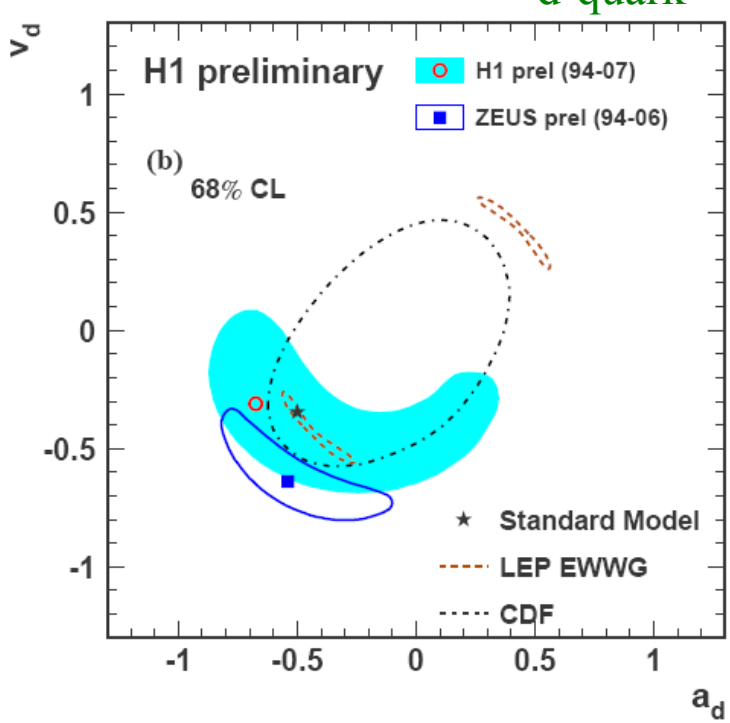
simultaneous EW+PDF analysis of NC and CC data

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

u-quark



d-quark



Tevatron: $qq \rightarrow e^+e^-$ (A_{FB})
LEP EWWG: $ee \rightarrow qq$ at Z (a^2v^2, a^2+v^2)

→ resolves LEP ambiguity
→ 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)
→ Now the full power of this data at high Q^2 is revealed

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

Next step is to combine final H1 and ZEUS data from HERA I and HERA II and improve precision of PDFs.