

XXI International Workshop on Deep-Inelastic Scattering and Related Subjects

Marseille Congress Centre, April 22-26 2013

Inclusive DIS at High Q^2 with Longitudinally Polarised Lepton Beams at HERA

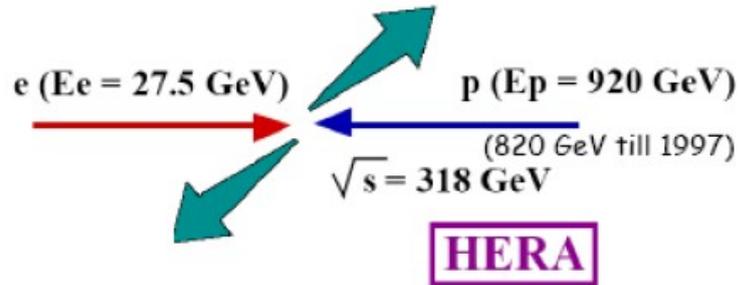


H1 Collab., F.D. Aaron et al., Published in JHEP 09 (2012) 061

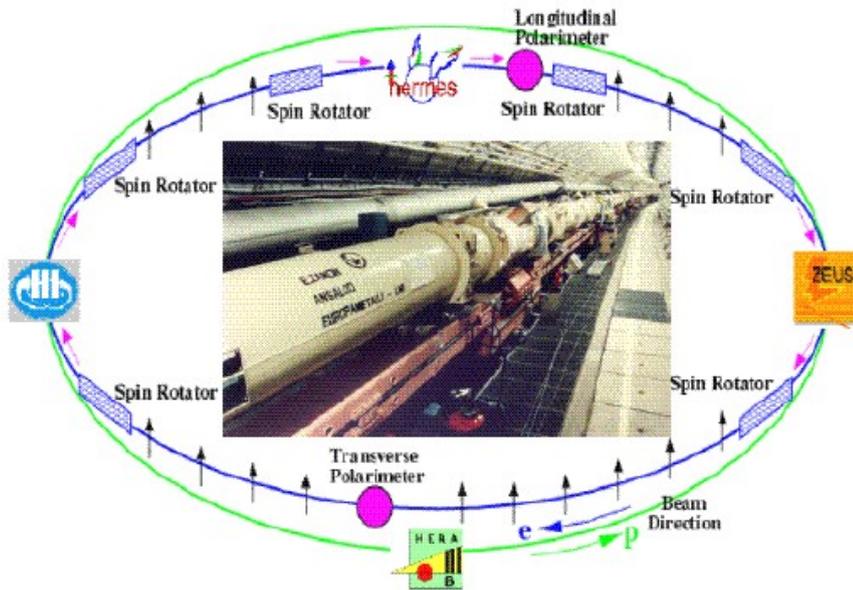
H1 Collab., F.D. Aaron et al., Published in Eur. Phys. J. C72 (2012) 2163

S. Shushkevich, DESY

HERA II with Longitudinal Polarization of e^\pm Beams

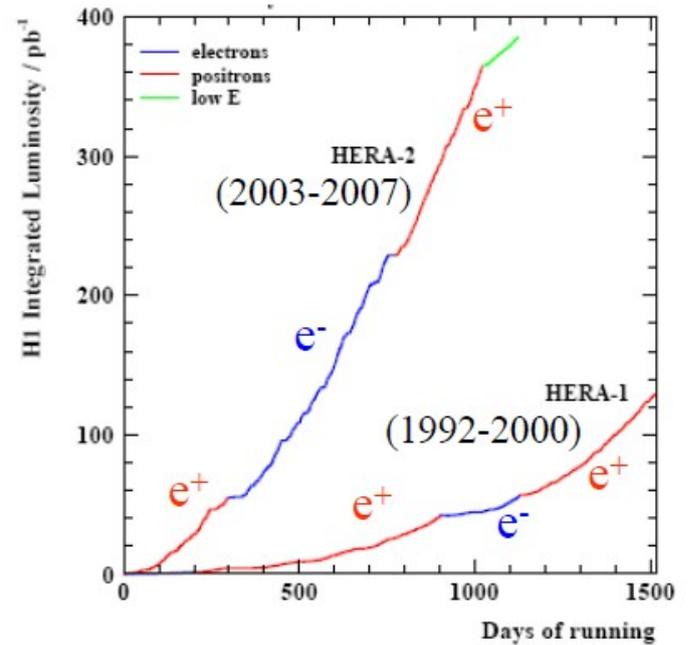


	HERA I	HERA II
e^+p	100 pb^{-1}	200 pb^{-1}
e^-p	20 pb^{-1}	180 pb^{-1}



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

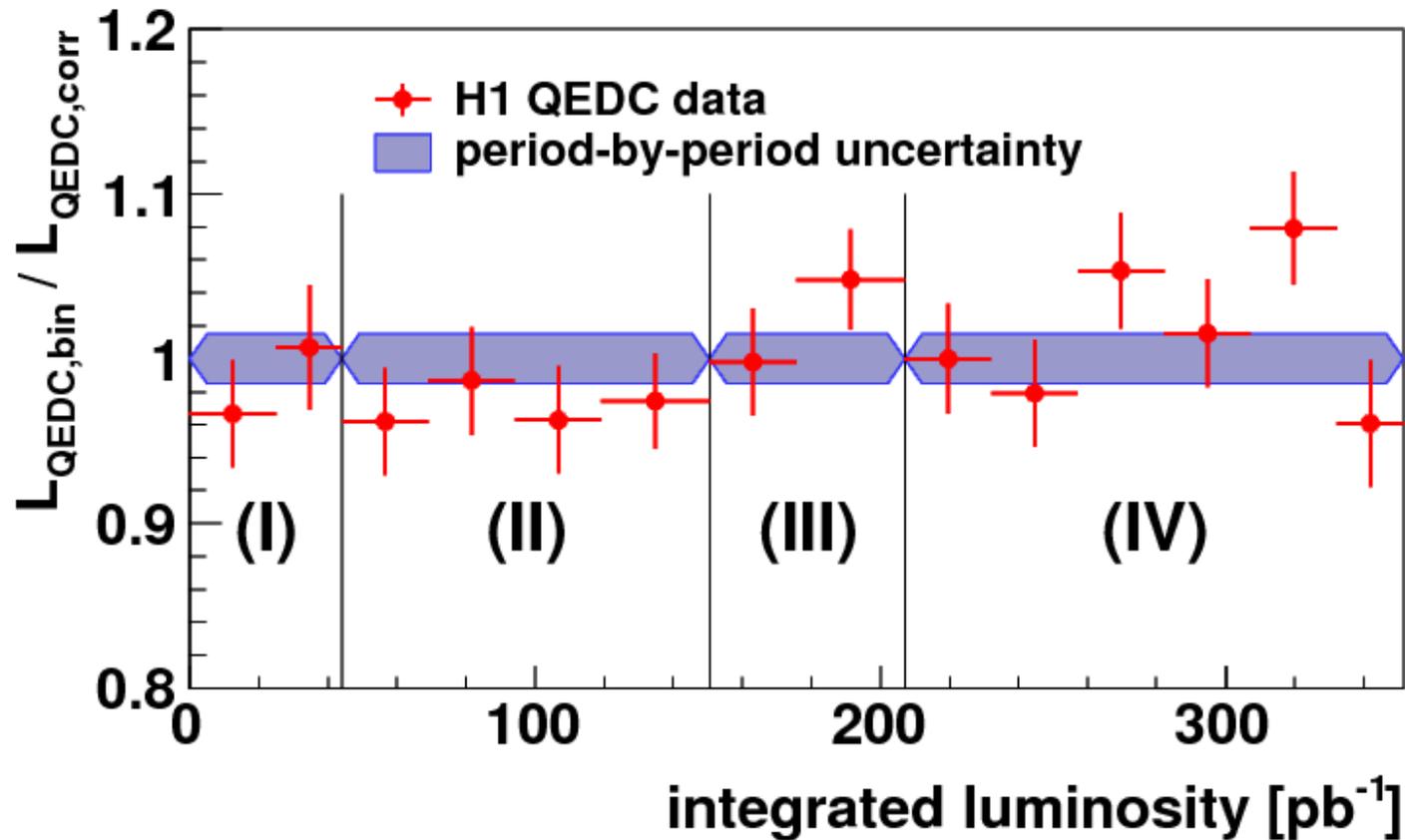
$$\lambda_{\text{min}} \sim 1/1000 R_{\text{proton}}$$



Longitudinal polarization of electron beam (2003-2007)

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

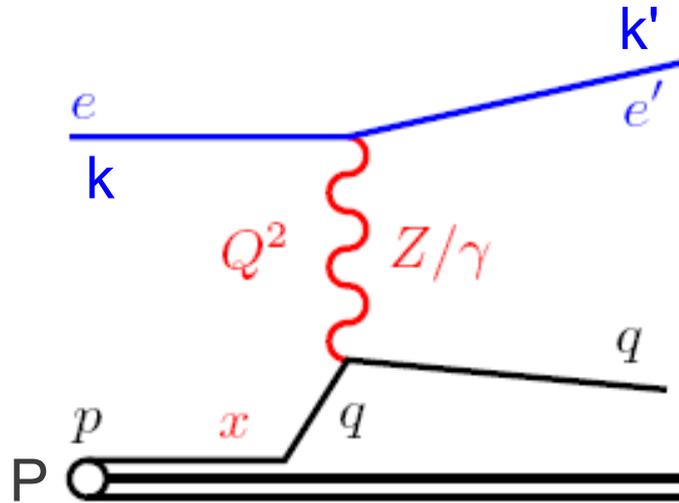
Luminosity measurement with Elastic QED Compton Events



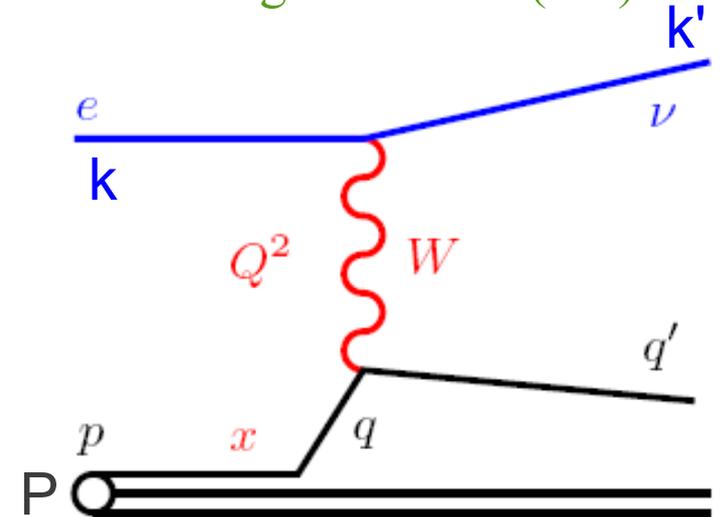
Precision of the integrated luminosity is 2.3%

Deep Inelastic Scattering (DIS)

Neutral Current (NC)



Charged Current (CC)



$$s = (k + P)^2$$

center-of-mass energy squared ($s \approx 320 \text{ GeV}^2$)

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

boson virtuality negative transferred 4-momentum squared

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

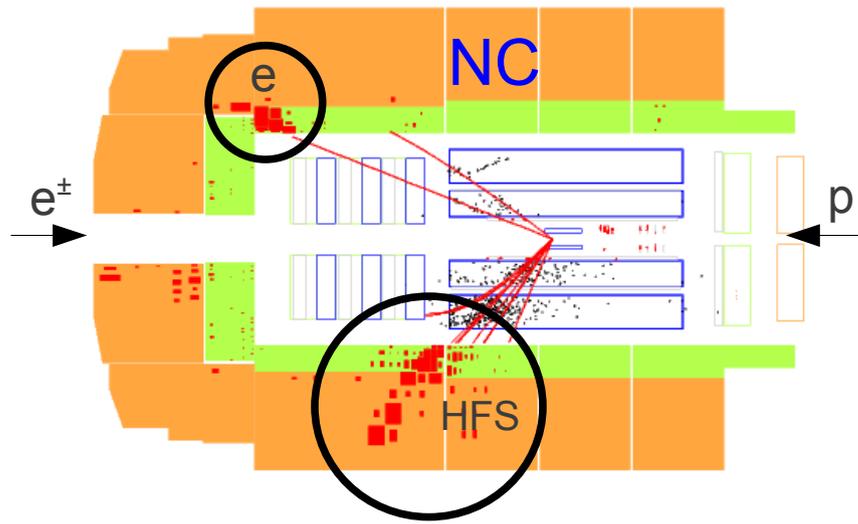
Bjorken x momentum fraction of proton carried by the struck quark

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

inelasticity

related as $Q^2 = sxy$

DIS in the H1 Detector

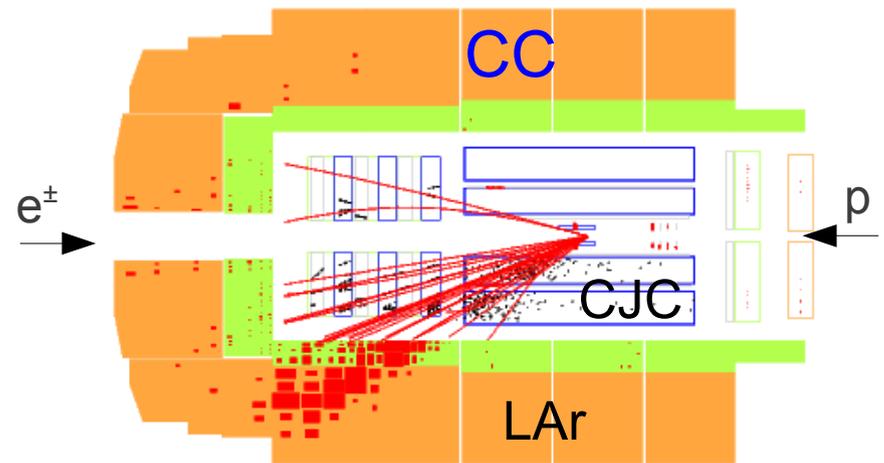


NC scattered electron balanced with hadronic final state (HFS)

CC HFS with large missing P_t

LAr Liquid Argon Calorimeter

CJC Central Jet Chamber



Polarized NC Cross Section

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

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

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

$$x \tilde{F}_3^\pm = - (a_e \pm P_e v_e) \frac{\kappa Q^2}{Q^2 + M_Z^2} x F_3^{\gamma Z} + (2v_e a_e \pm P_e (v_e^2 + a_e^2)) \left(\frac{\kappa Q^2}{Q^2 + M_Z^2} \right)^2 x F_3^Z$$

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

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

$$\left[x F_3^{\gamma Z}, x F_3^Z \right] = 2x \sum_q \left[e_q a_q, v_q a_q \right] (q - \bar{q})$$

F_L is important only at high y and moderate Q^2 in quark parton model (QPM) $F_L = F_2 - 2xF_1 = 0$

Polarized CC Cross Section

$$\frac{d^2\sigma_{CC}^{\pm}}{dx dQ^2} = (1 \pm P_e) \frac{G_F^2}{4\pi x} \left[\frac{M_W^2}{M_W^2 + Q^2} \right]^2 \left(Y_+ W_2^{\pm} - Y_{\mp} x W_3^{\pm} - y W_L^{\pm} \right)$$

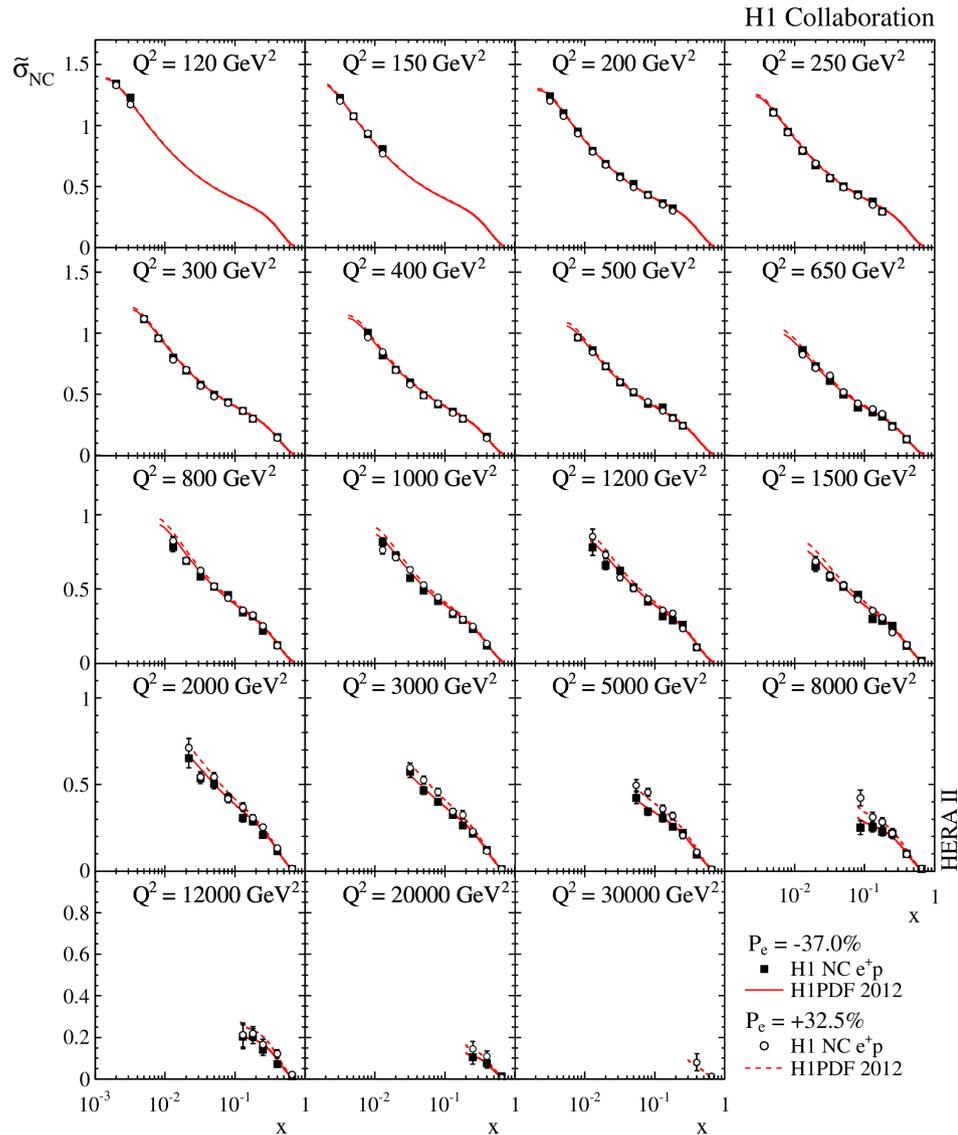
$$Y_{\pm} = 1 \pm (1 - y)^2$$

in QPM:

$$W_2^- = x(u + c + \bar{d} + \bar{s}) \quad W_2^+ = x(\bar{u} + \bar{c} + d + s)$$

$$xW_3^- = x(u + c - \bar{d} - \bar{s}) \quad xW_3^+ = x(d + s - \bar{u} - \bar{c})$$

HERAII Cross Sections Measurements

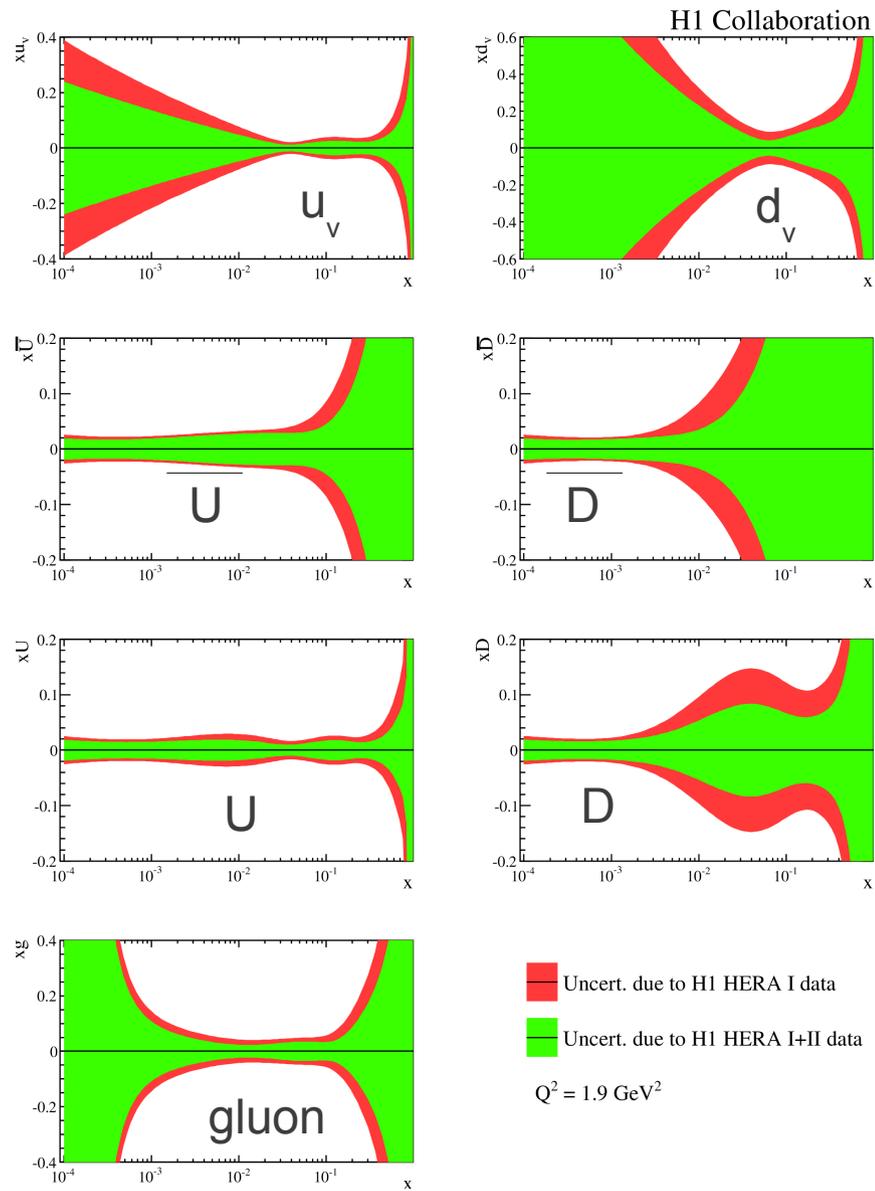


Measure NC/CC polarized cross sections with electron/positron beam

Provide unpolarized cross section
combine lepton data with different polarizations and correct for the small residual polarization

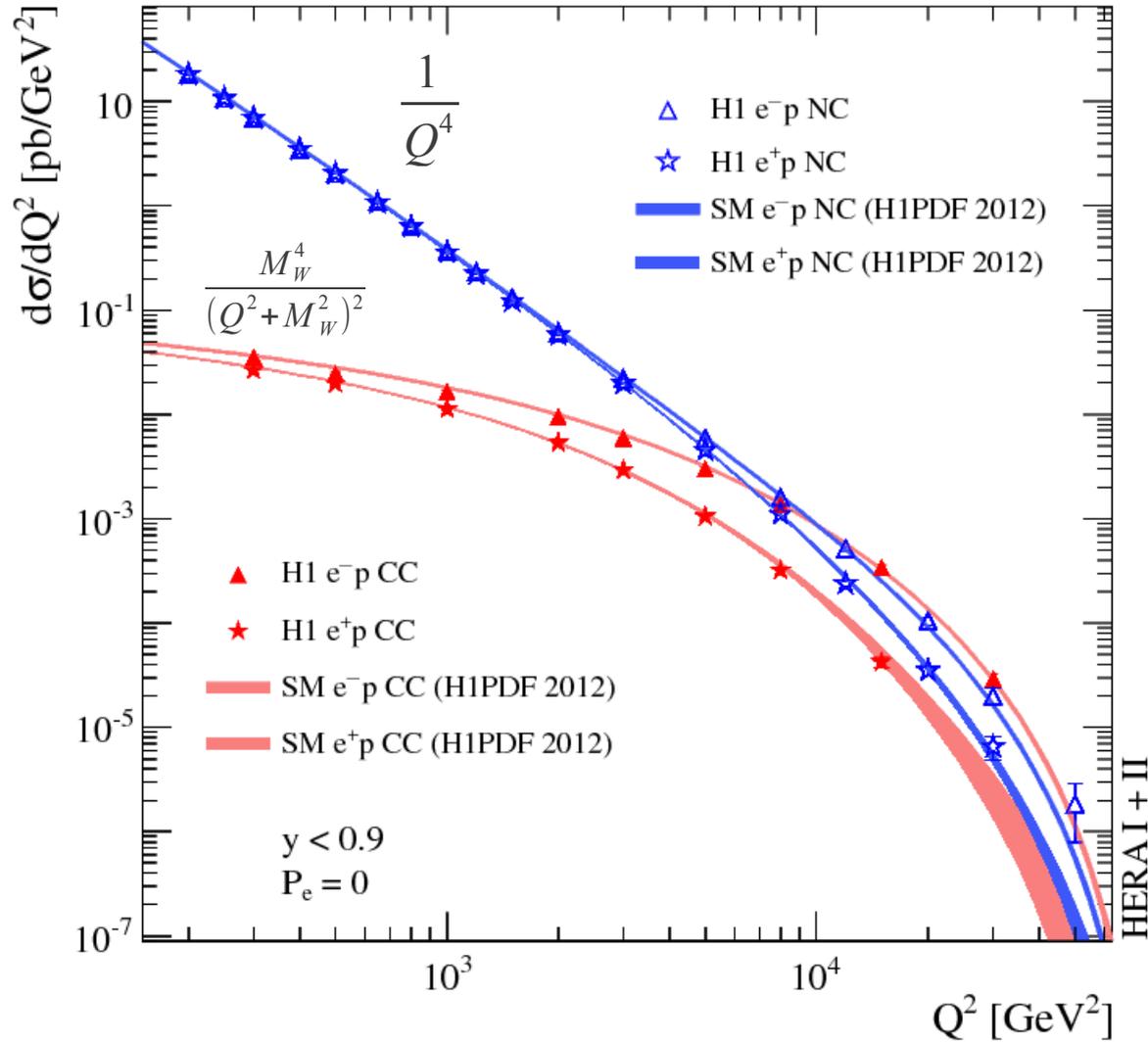
Combine with HERA I

Impact on the PDFs



NC and CC DIS Cross Section

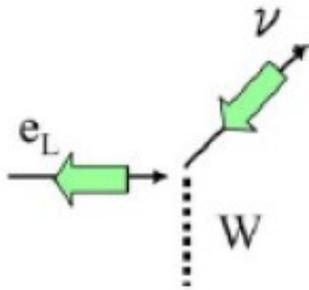
H1 Collaboration



EW component of SM
 NC and CC cross sections become
 similar at $Q^2 \approx M_Z^2, M_W^2$

Total CC Cross Section

Weak CC is purely left-handed



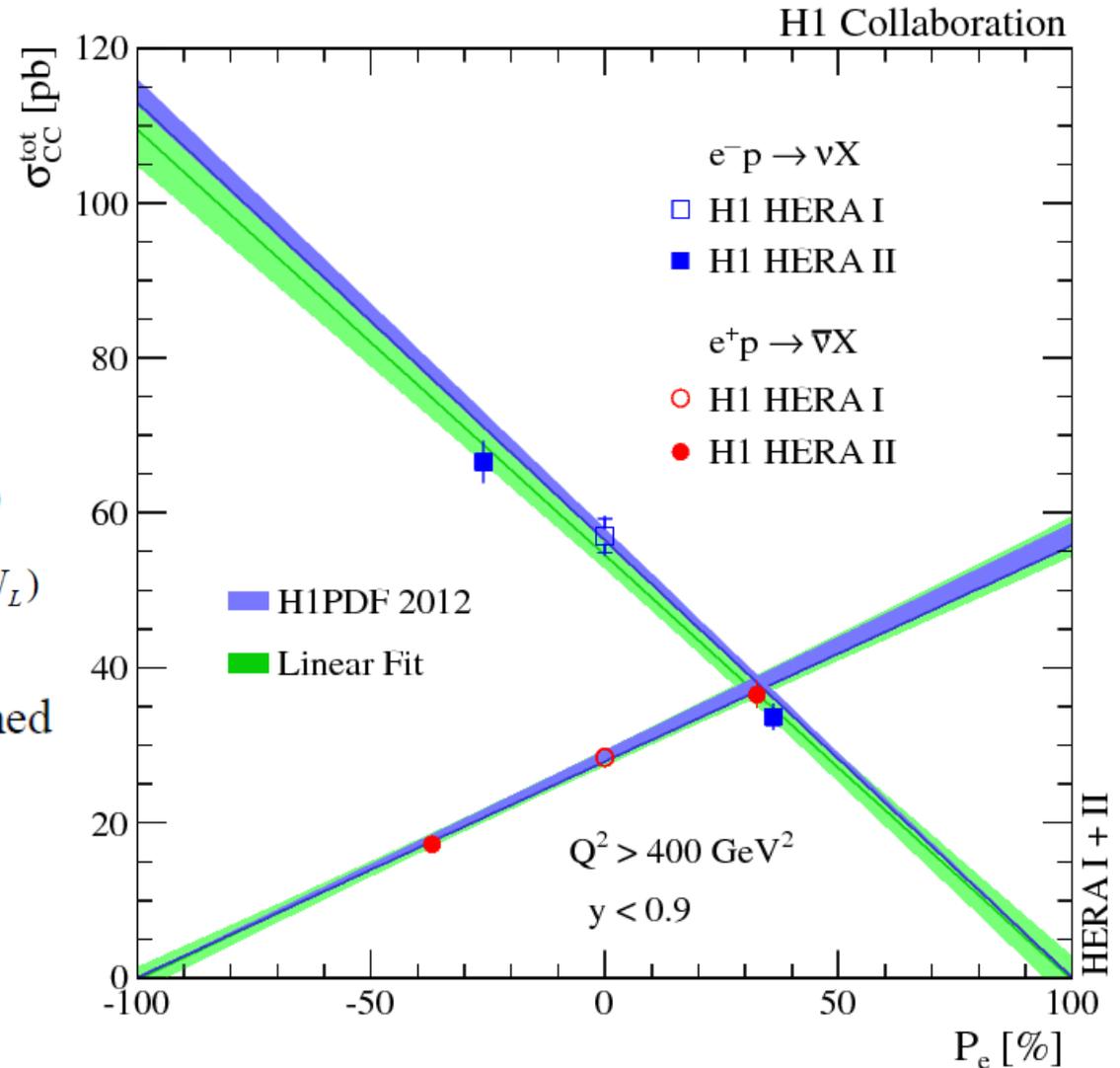
$$\sigma^{CC}(e^\pm p) = (1 \pm P_e) \sigma_{P_e=0}^{CC}(e^\pm p)$$

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

e^-p $M(W_R) > 214 \text{ GeV @ } 95\% \text{ CL}$

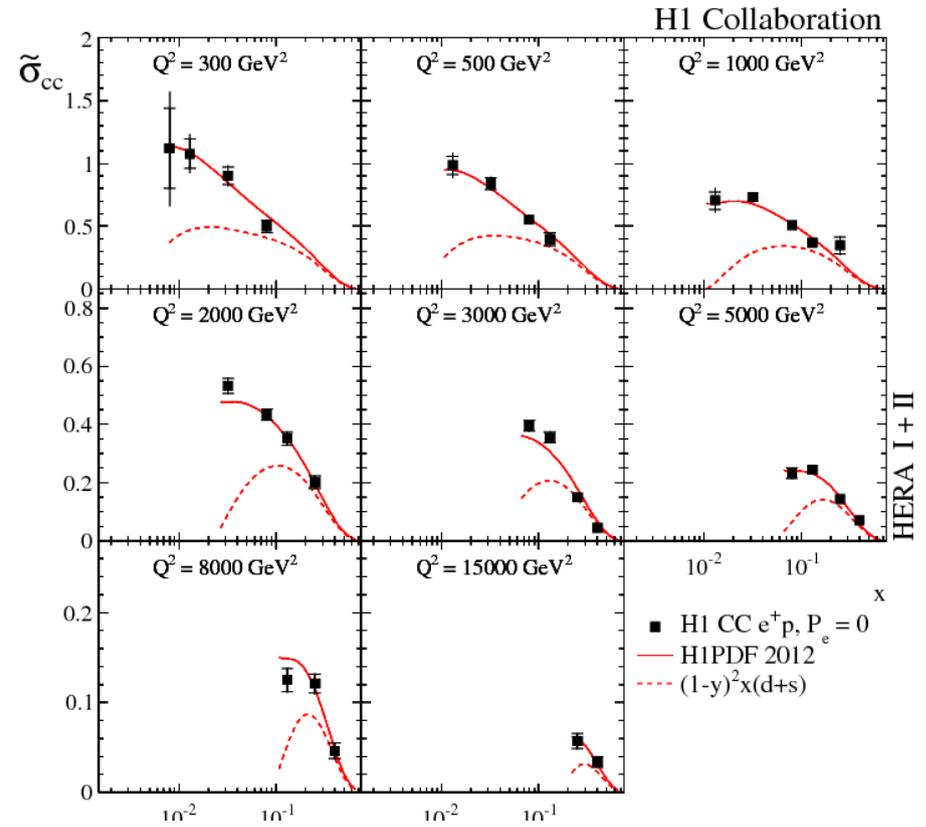
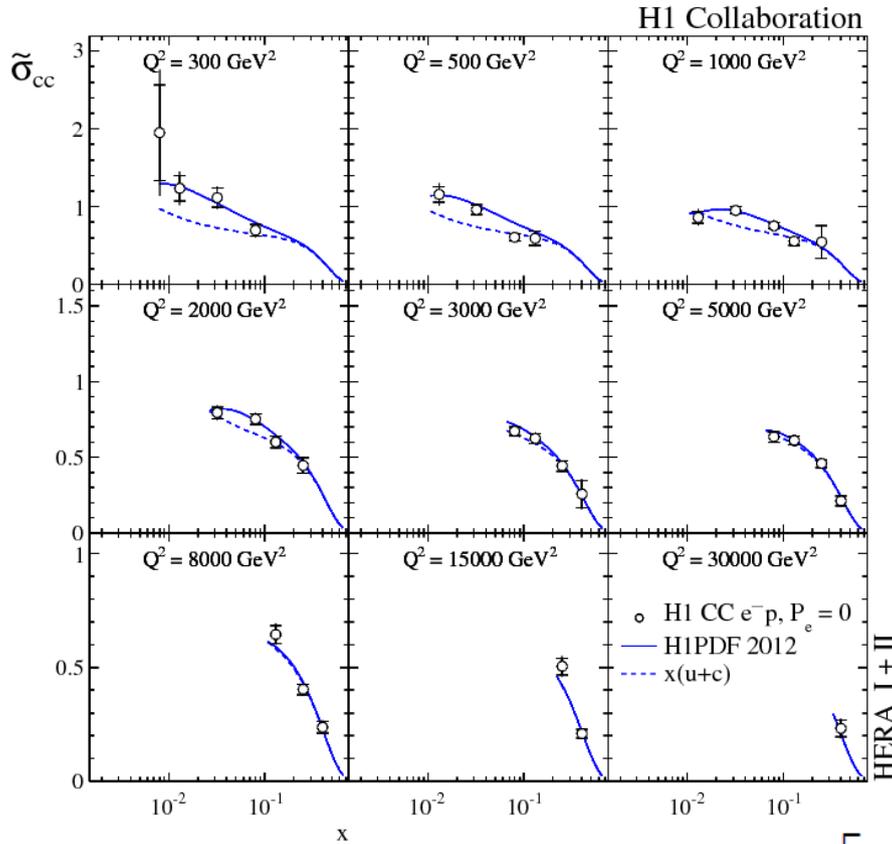
e^+p $M(W_R) > 194 \text{ GeV @ } 95\% \text{ CL}$



Combined Charged Current Measurement

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

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

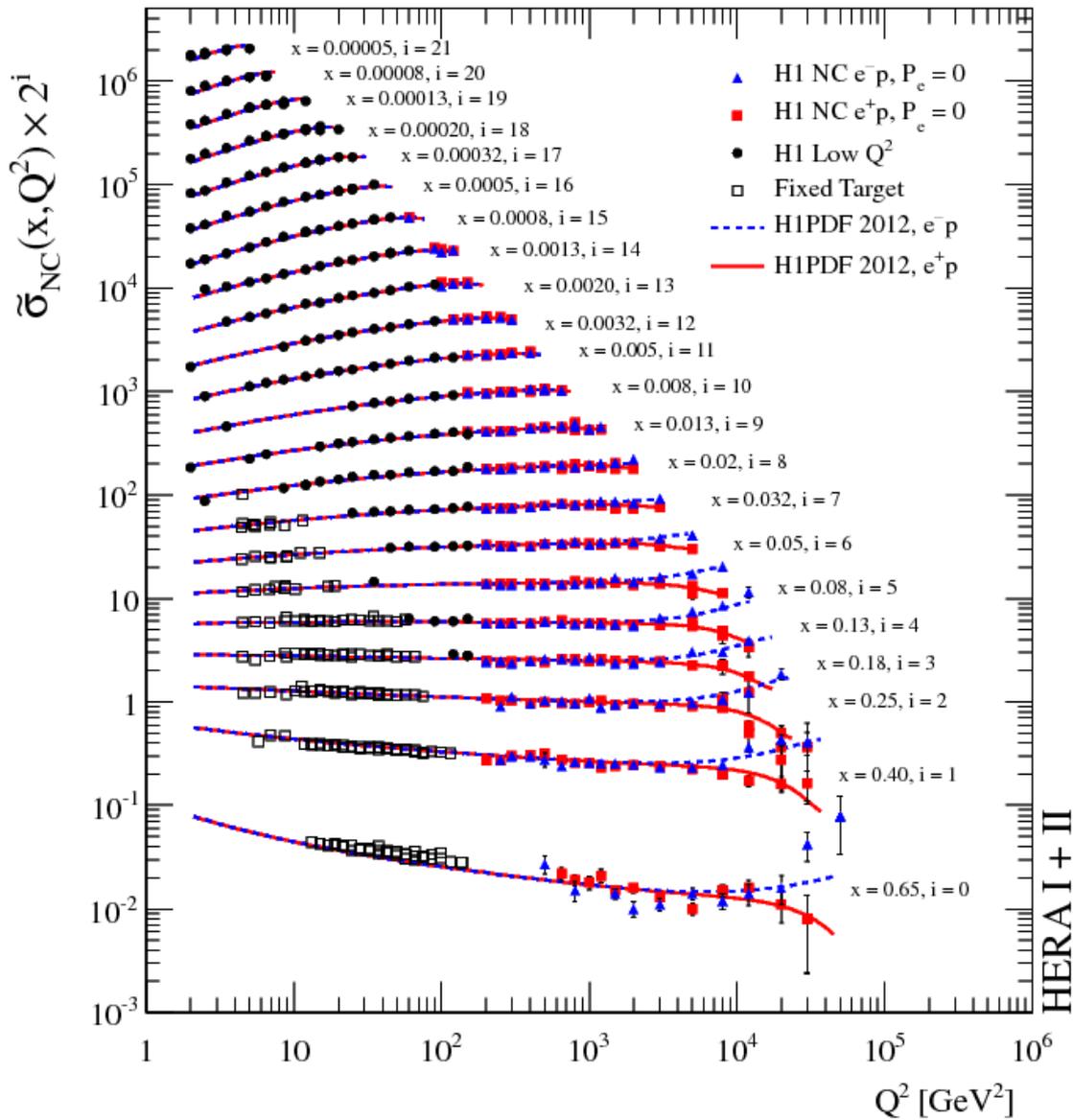


$$\tilde{\sigma}_{CC}(e^\pm p) = \frac{d^2 \sigma_{CC}^{e^\pm p}}{dx dQ^2} \left/ \left[\frac{G_F^2}{2\pi x} \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2 \right] \right. = (1 \pm P_e) \tilde{\sigma}_{CC}^{P=0}(e^\pm p)$$

Constrains u and d quark densities

Combined Neutral Current Measurement

H1 Collaboration



Reduced cross section

$$\tilde{\sigma}_{NC} = \frac{x Q^4}{2 \pi \alpha Y_+} \frac{d^2 \sigma_{NC}}{dx dQ^2}$$

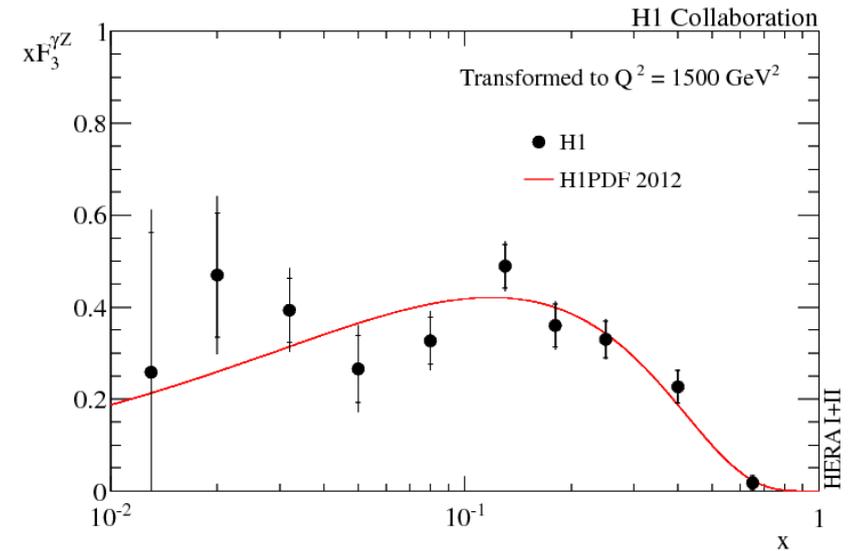
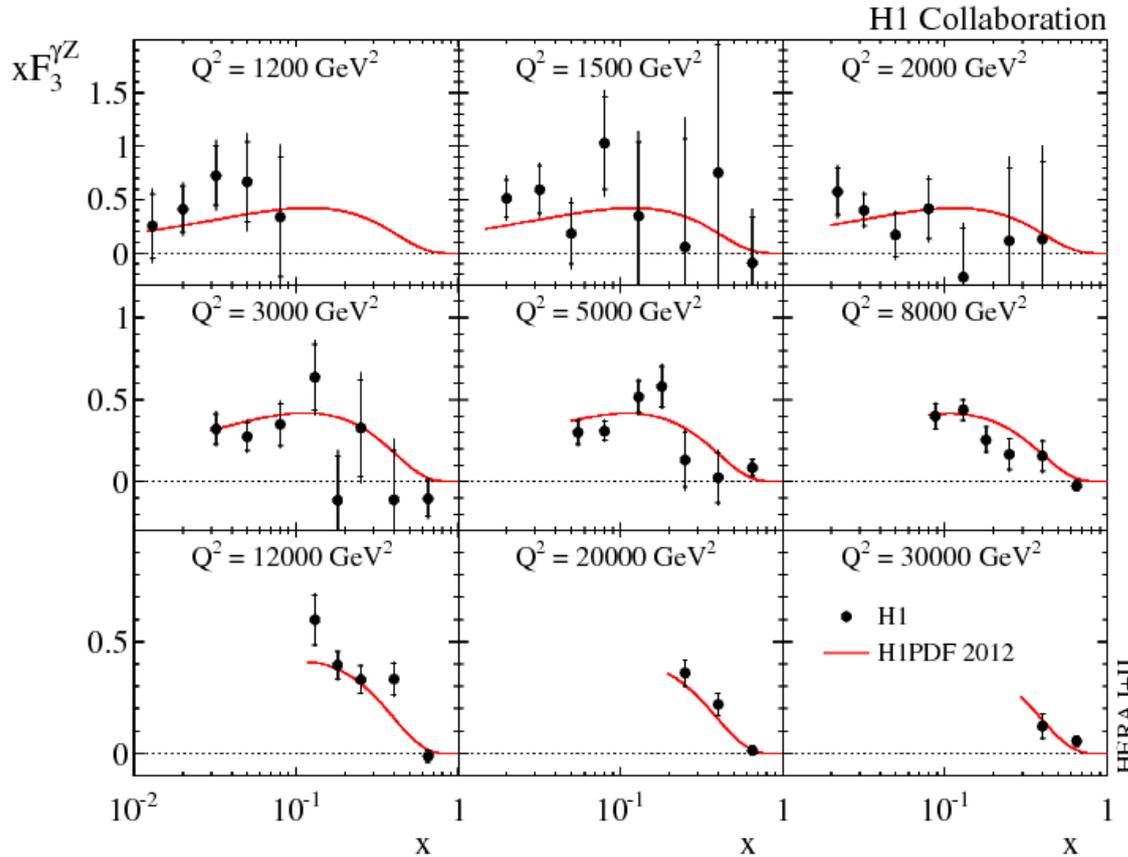
The main contribution

$$\tilde{F}_2 \approx \sum_q e_q^2 (xq + x\bar{q})$$

and charge dependence

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

$xF_3^{\gamma Z}$ Structure Function



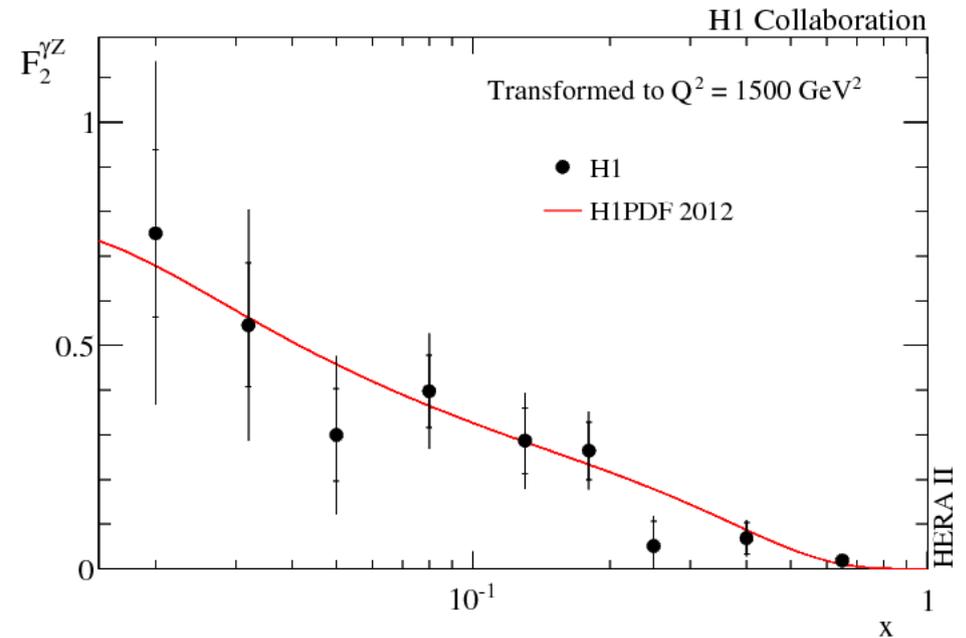
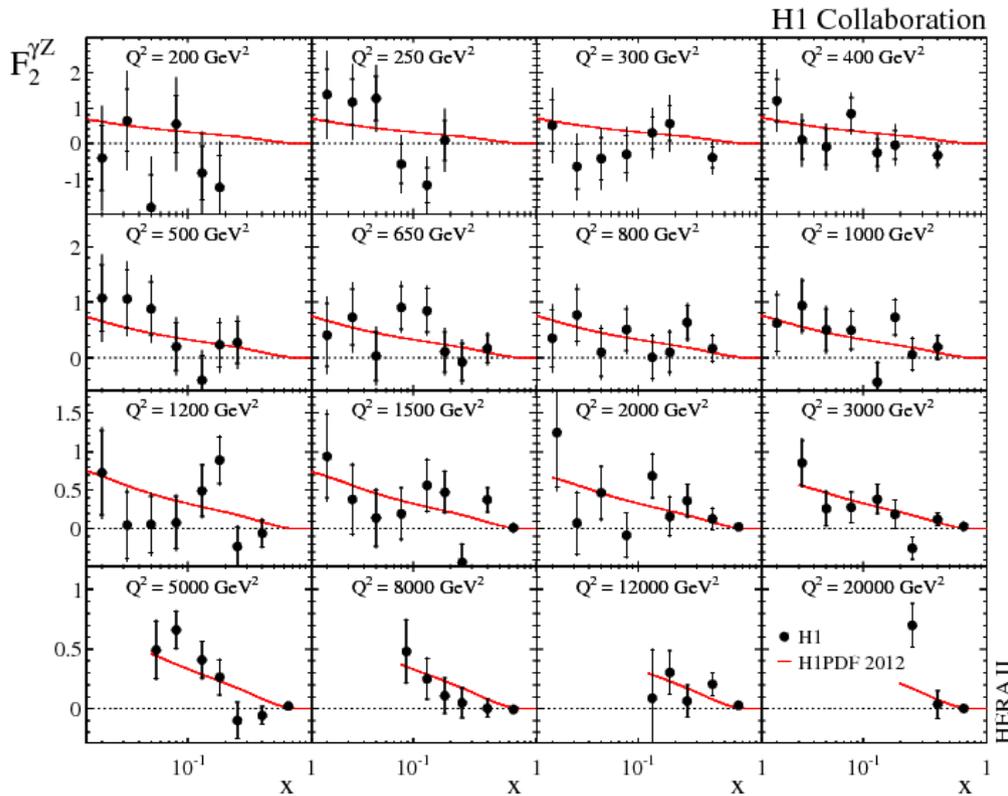
Constrain valence quarks ($2u_v + d_v$)

- Determine xF_3
- Effect is mostly from γZ interference
- Little Q^2 dependence \rightarrow transform all to the same $Q^2 = 1500 \text{ GeV}^2$

$x F_2^{\gamma Z}$ Structure Function

The measurement becomes possible due to all four NC cross sections: LH/RH with e^+/e^-

$$\frac{\sigma^\pm(P_L^\pm) - \sigma^\pm(P_R^\pm)}{P_L^\pm - P_R^\pm} = \frac{\kappa Q^2}{Q^2 + M_Z^2} \left[\mp a_e F_2^{\gamma Z} + \frac{Y_-}{Y_+} v_e x F_3^{\gamma Z} - \frac{Y_-}{Y_+} \frac{\kappa Q^2}{Q^2 + M_Z^2} (v_e^2 + a_e^2) x F_3^Z \right]$$



Polarization Asymmetry

$$\begin{aligned} \tilde{F}_2^\pm &= F_2 - (v_e \pm P_e a_e) \kappa_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 \pm 2P_e v_e a_e) \kappa_Z^2 F_2^Z \\ x\tilde{F}_3^\pm &= -(a_e \pm P_e v_e) \kappa_Z xF_3^{\gamma Z} + (2v_e a_e \pm P_e(v_e^2 + a_e^2)) \kappa_Z^2 xF_3^Z \end{aligned}$$

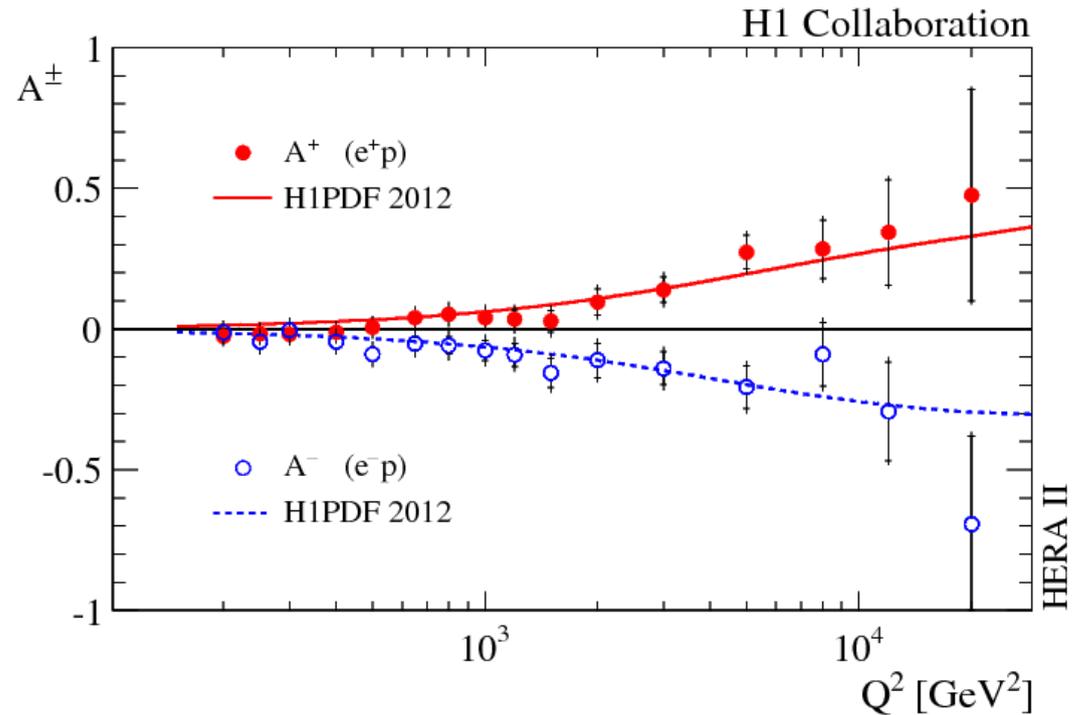
$$P_e = \frac{N_R - N_L}{N_R + N_L} \quad \kappa_Z = \frac{Q^2}{Q^2 + M_Z^2} \frac{1}{4\cos^2 \Theta_W \sin^2 \Theta_W}$$

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

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

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

at high Q^2 $A(e^+p) \approx -A(e^-p)$



Summary

- The NC and CC cross sections for $e^\pm p$ scattering with longitudinally polarized lepton beams are measured
- At high Q^2 the structure functions $xF_3^{\gamma Z}$ sensitive to the valence content of the proton are extracted
- The structure function $xF_2^{\gamma Z}$ is measured for the first time using lepton beam polarisation
- The NC lepton polarization asymmetry A^\pm , sensitive to parity violation, is determined
- The polarisation dependence of the CC total cross section is measured and the limits on the right-handed interactions are obtained
- The Standard Model provides an excellent description of the data

