Electroweak physics at HERA

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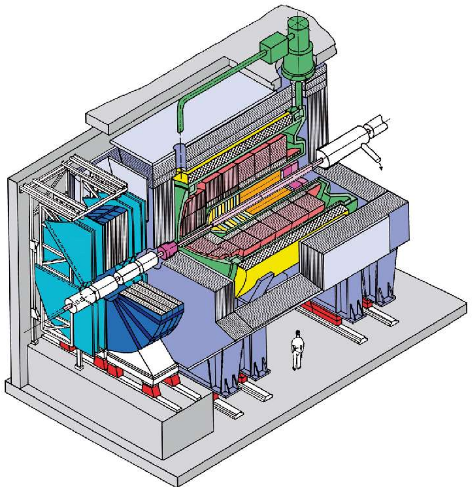
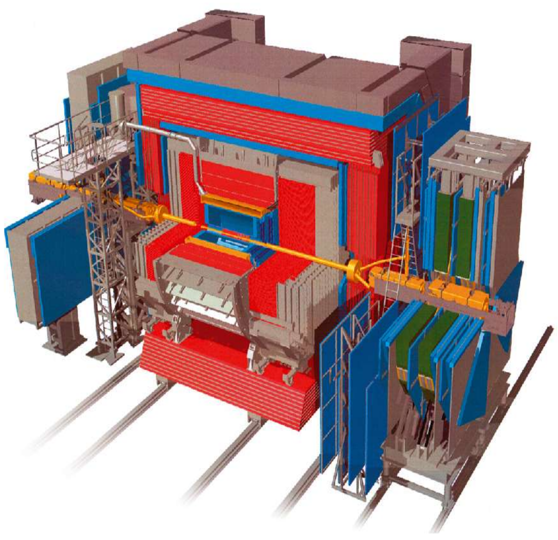
for H1 and ZEUS collaborations



- *Introduction*
- *NC/CC cross section*
- *Effect of polarization*
- *Combined QCD/EW analysis of the data*
- *Conclusions and outlook*



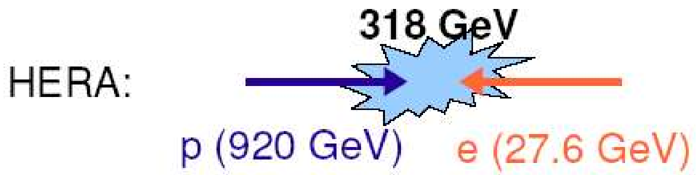
HERA collider at DESY

$P \longrightarrow \quad \longleftarrow e^{\pm}$

920 GeV 27.5 GeV

Central mass energy $\sqrt{s}$ **=318 GeV**

Available data sets



HERA I:(1993-2000)

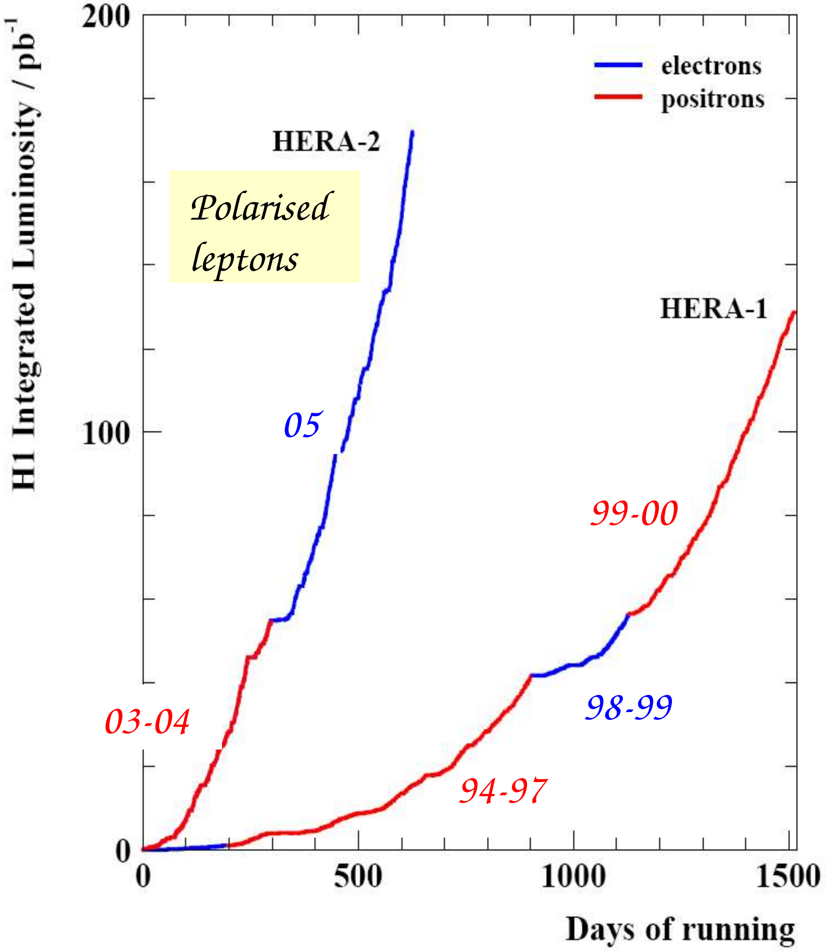
~ 130 1/pb

mainly e+p data

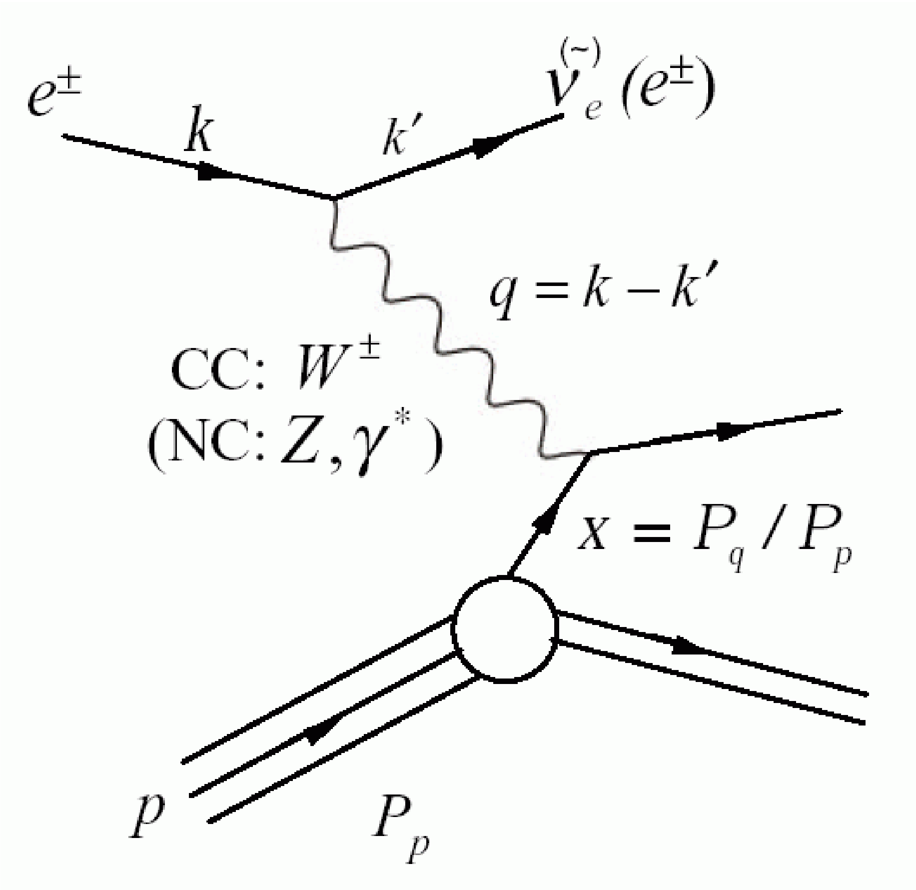
HERA II: (since 2003)

~ 50 1/pb e+p data

~ 100 1/pb e-p data



Kinematics of ep interactions:



Four momentum transfer:

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

Bjorken x: (in LO the fraction of the proton momentum carried by the parton)

$$x = \frac{Q^2}{2P.q}$$

Inelasticity:(in the proton rest frame the fraction of the electron energy loss)

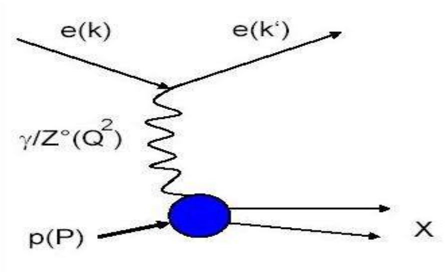
$$y = \frac{P.q}{P.k}$$

At fixed center of mass energy only two of them are independent:

$$Q^2 = sxy$$

Neutral current scattering

γ or Z are exchanged:



Cross section:

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

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

dominant high Q^2 high y

In quark-parton model:

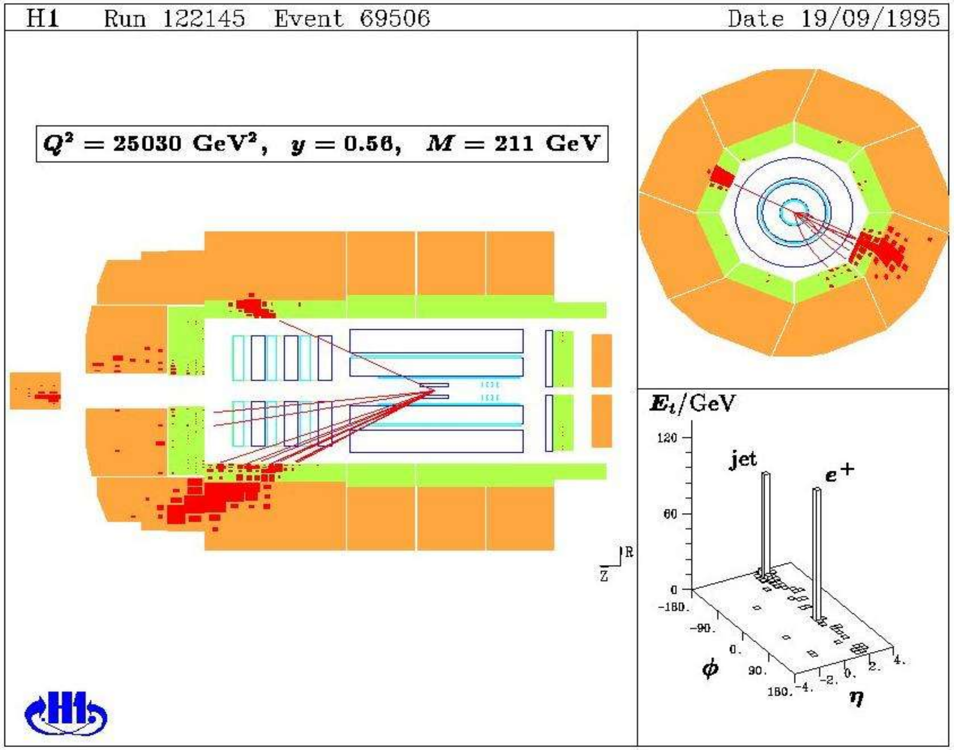
$$F_2 \sim x \sum [q + \bar{q}]$$

$$xF_3 \sim 2x \sum [q - \bar{q}]$$

$$F_L = 0$$

Experimental signatures:

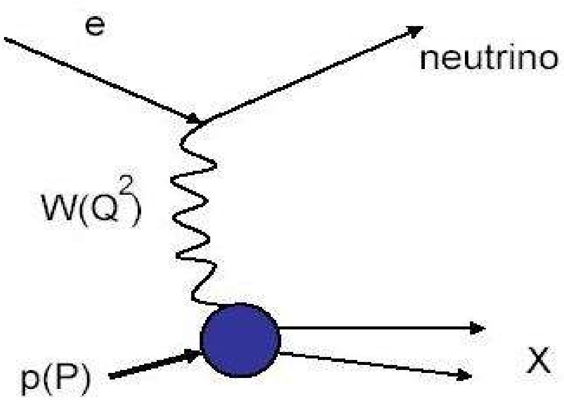
- Scattered electron and hardon jet(s)
- Transverse momentum balance

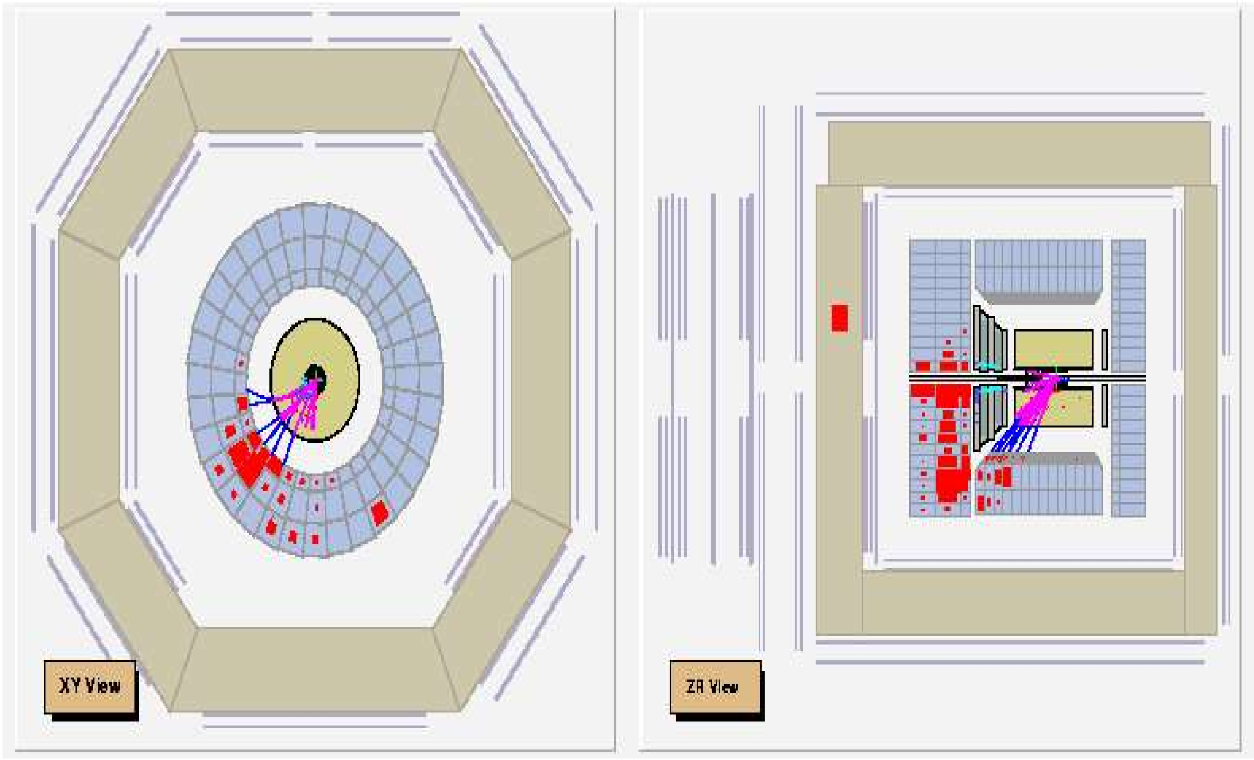


See talk by Yujin Ning

Charged current scattering

W-bosons are exchanged:





Cross section:

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

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

Experimental signatures:

- *Neutrino escapes undetected*
- *Hadron jet(s)*
- *Missing transverse momentum*

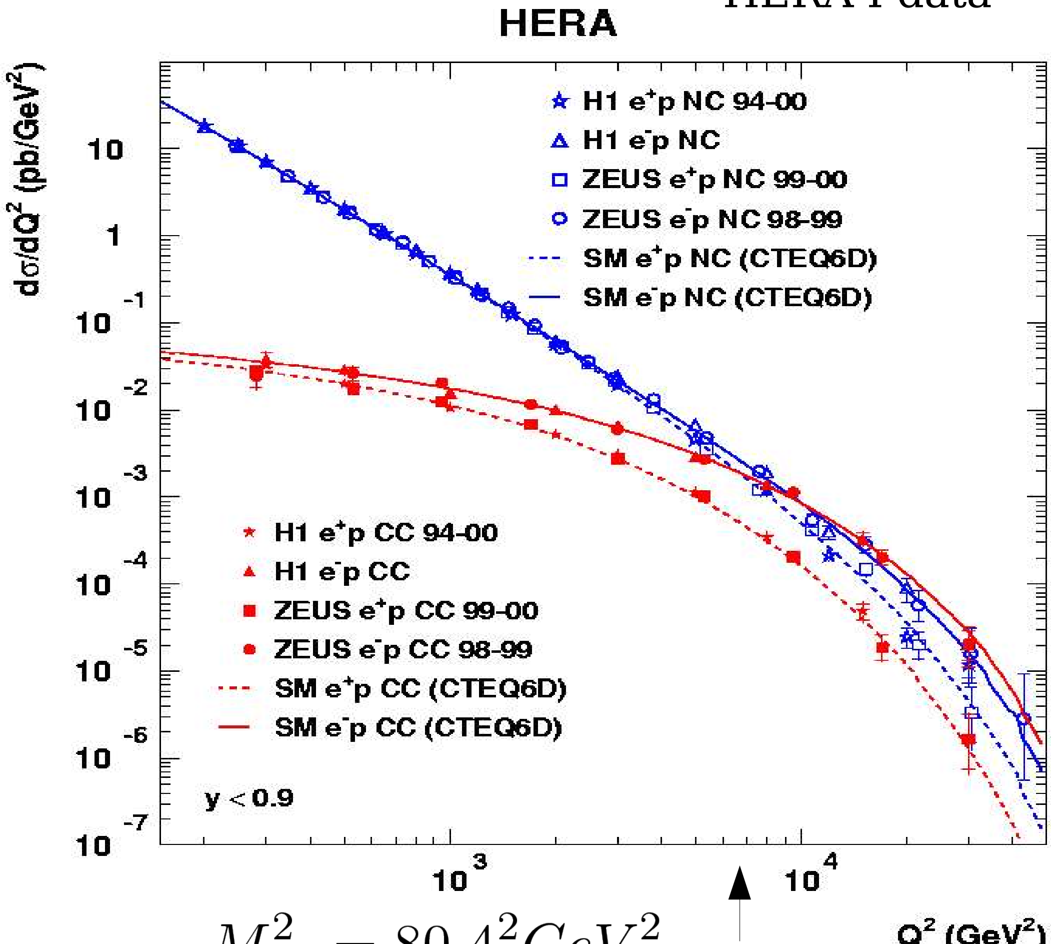
NC/CC at high Q^2

NC/CC cross sections are similar above Q^2 equal to W mass!

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} pdf$$

$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left[\frac{M_W^2}{M_W^2+Q^2}\right]^2 pdf'$$

HERA I data



$$M_W^2 = 80.4^2 GeV^2$$

NC and xF3 at high Q²

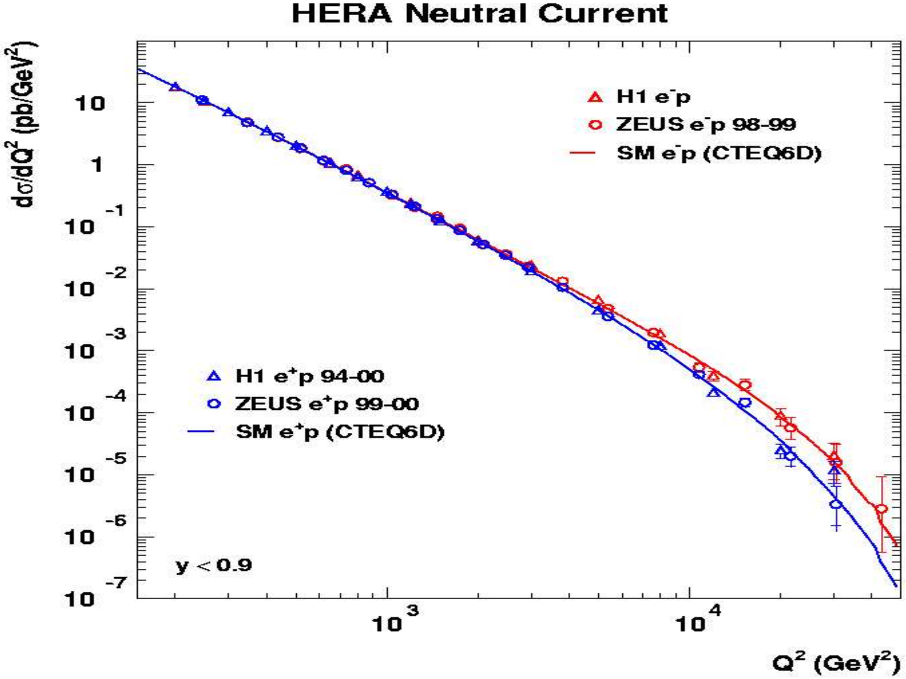
$$\frac{d^2\sigma^{e^\pm p}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[\ldots \mp Y_- x\tilde{F}_3 - \ldots]$$

$$\chi_Z = \frac{1}{sin^2 2\theta_W}\frac{Q^2}{M_Z^2+Q^2}$$

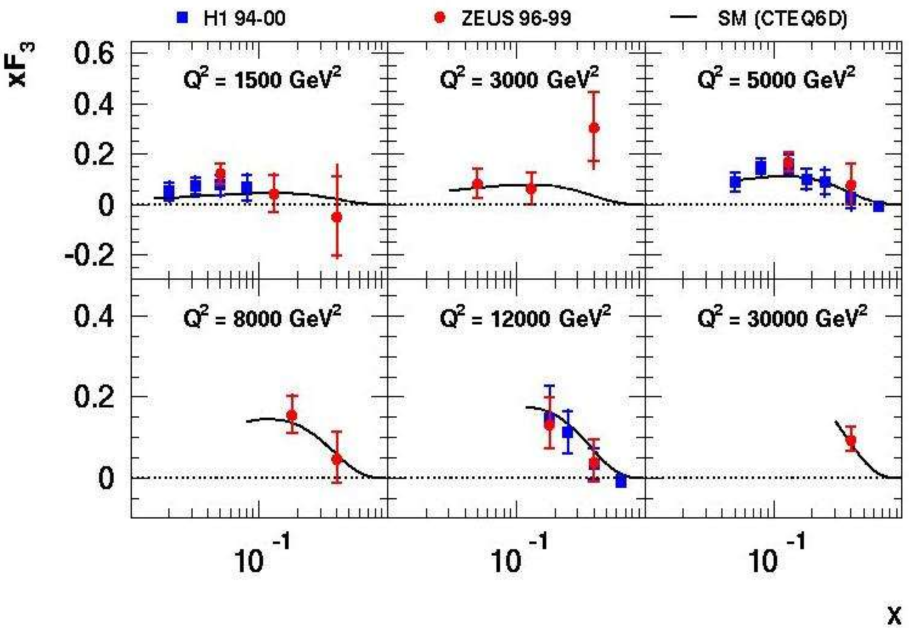
$$x\tilde{F}_3 = -a_e\chi_Z xF_3^{\gamma Z} + 2v_e a_e \chi_Z^2 xF_3^Z$$

$$xF_3 \sim 2x\sum[q-\bar{q}]$$

Dominant   Supressed



HERA I data

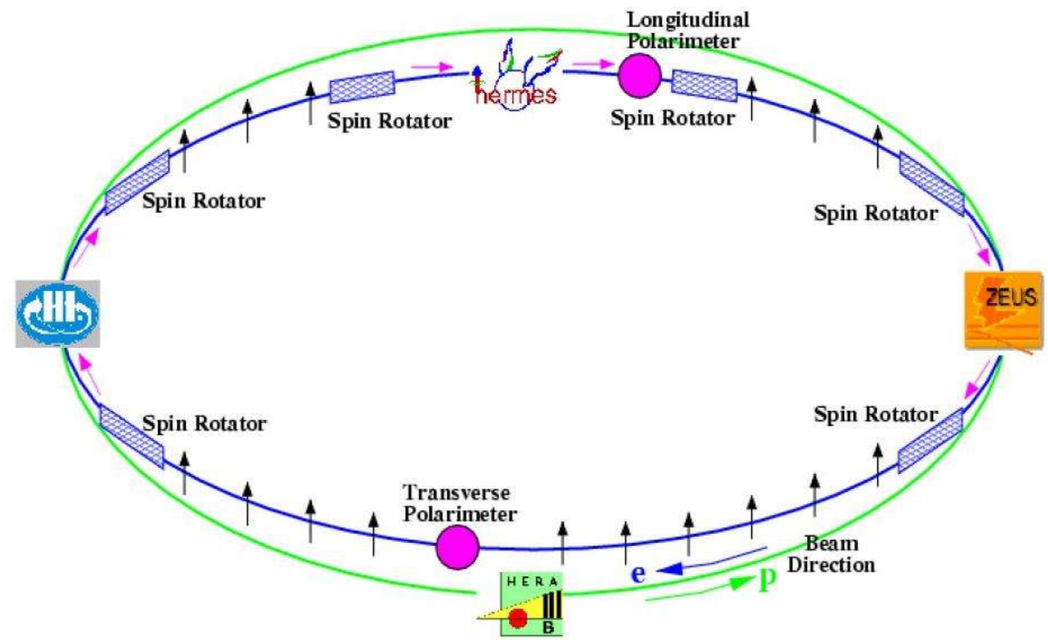


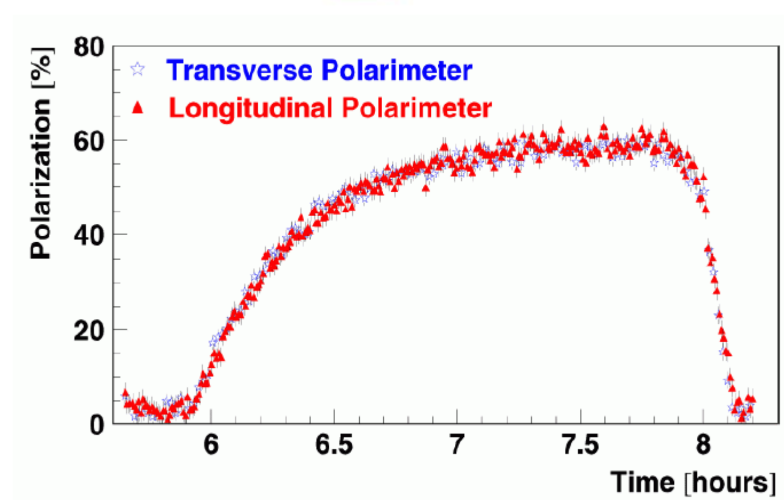
The γ-Z intereference term clearly visible !

Longitudinal polarization at HERA

Longitudinal polarization of lepton beam: new at HERA II.

- *The transverse polarization builds up naturally (Sokolov-Ternov effect)*
- *Typical build-up time ~40 min*
- *Spin rotators flip the polarization to longitudinal just before the interaction regions*
- *Typical level of polarization – 30 – 40 %*



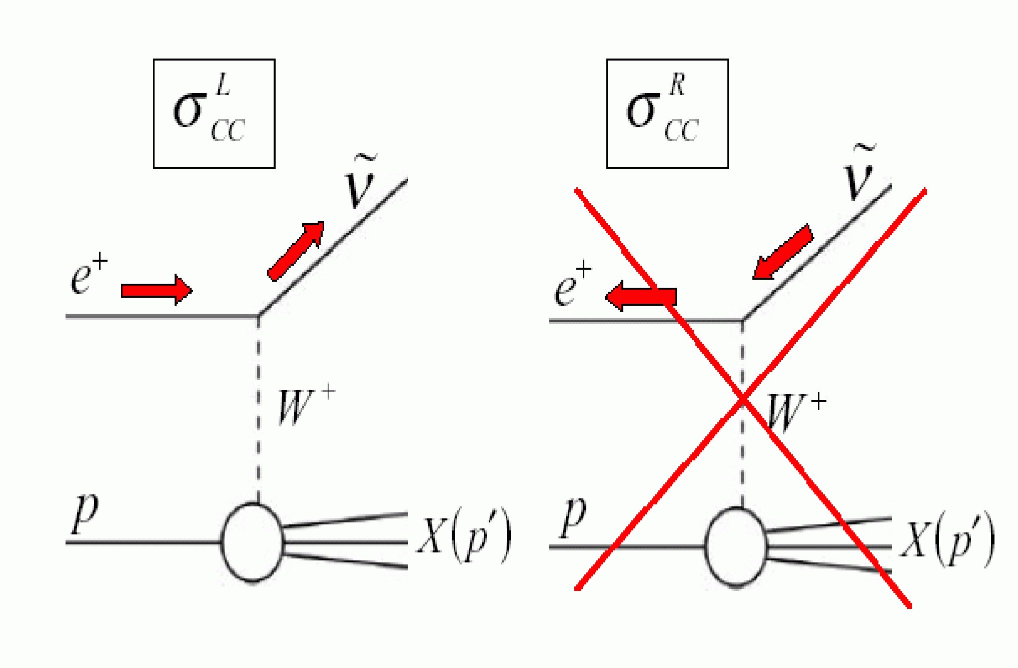


CC cross section with polarization I.

Polarization affects CC cross section in particularly clean way:

- In SM only left handed particles (right handed antiparticles) interact via CC
- Level of polarization $\mathcal{P}$ is defined as

$$P = \frac{N_R - N_L}{N_R + N_L}$$



N_R, N_L - number of lh (rh) leptons in beam

$$\frac{d^2\sigma^{e^\pm p}_{CC}}{dx dQ^2} = [1 \pm P] \frac{G_F^2}{4\pi x} \left[\frac{M_W^2}{M_W^2 + Q^2}\right]^2 [Y_+ W_2 \mp Y_- x W_3 - y^2 W_L]$$

Expect linear dependence of CC cross section on $\mathcal{P}$!

CC cross section with polarization III.

- *Data are in good agreement with SM prediction*
- *Fit by straight line*
- *Allows to determine the limits on W_R mass (assuming the same coupling)*

H1: $(Q^2 > 400\ \mathrm{GeV}^2, y < 0.9)$

$e^+p: \sigma_{CC}(P=-1) = -3.9 \pm 2.3(stat) \pm 0.7(sys) \pm 0.8(pol)\ pb$

$M(W_R) > 208\ \mathrm{GeV}(95\%\mathrm{CL})$

$e^-p: \sigma_{CC}(P=+1) = -0.9 \pm 2.9(stat) \pm 1.9(sys) \pm 2.9(pol)\ pb$

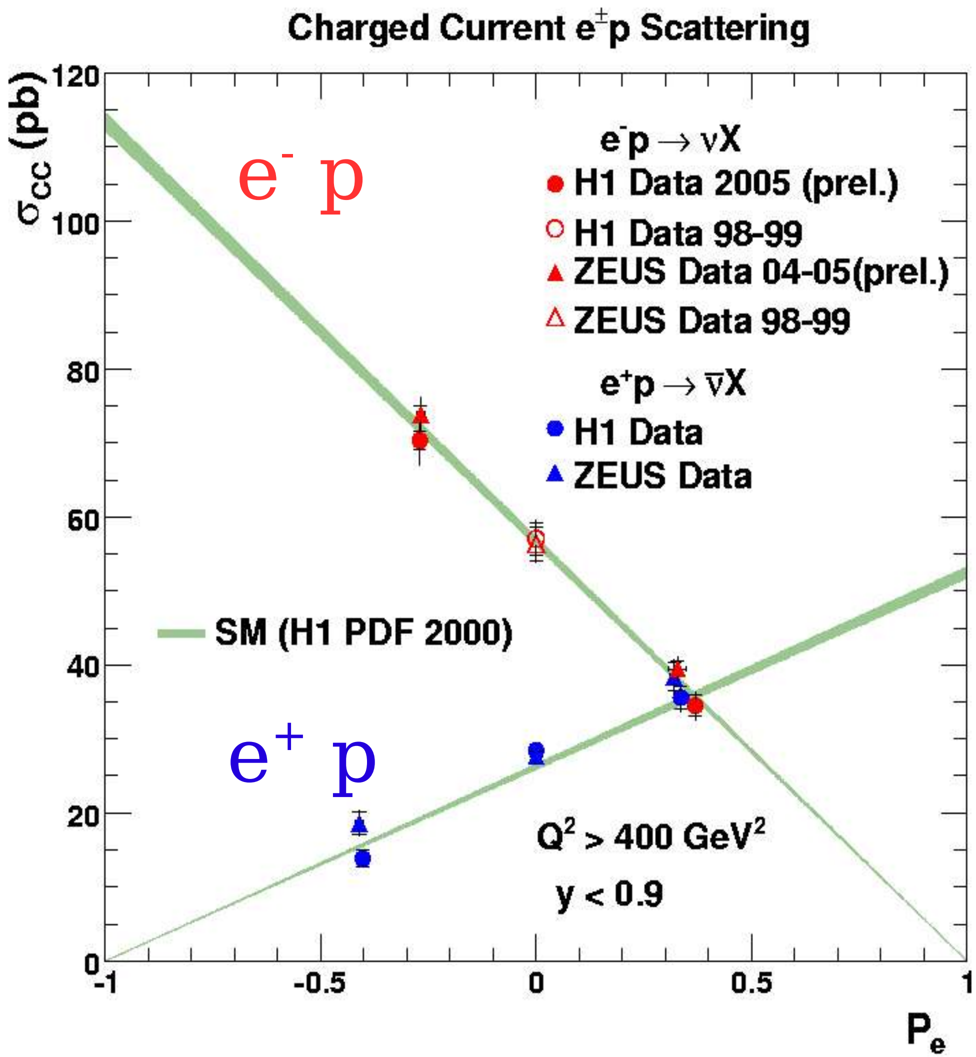
$M(W_R) > 186\ \mathrm{GeV}(95\%\mathrm{CL})$

ZEUS: $(Q^2 > 200\ \mathrm{GeV}^2)$

$e^+p: \sigma_{CC}(P=-1) = 7.4 \pm 3.9(stat) \pm 1.2(sys)\ pb$

$e^-p: \sigma_{CC}(P=-1) = 0.8 \pm 3.1(stat) \pm 5.(sys)\ pb$

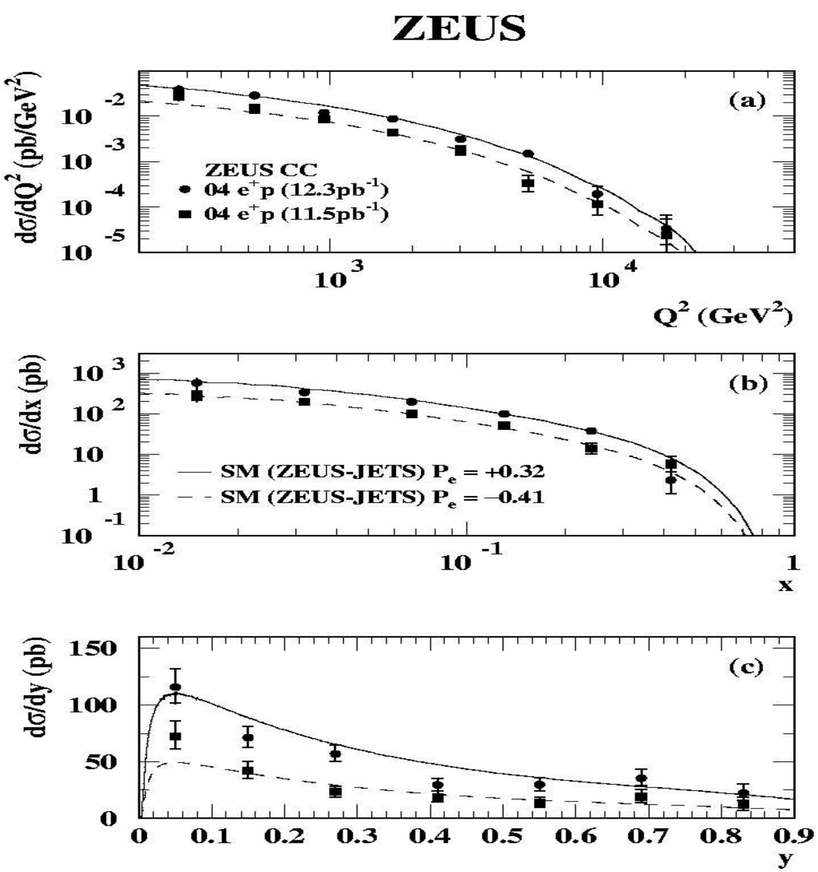
$M(W_R) > 180\ \mathrm{GeV}(95\%\mathrm{CL})$



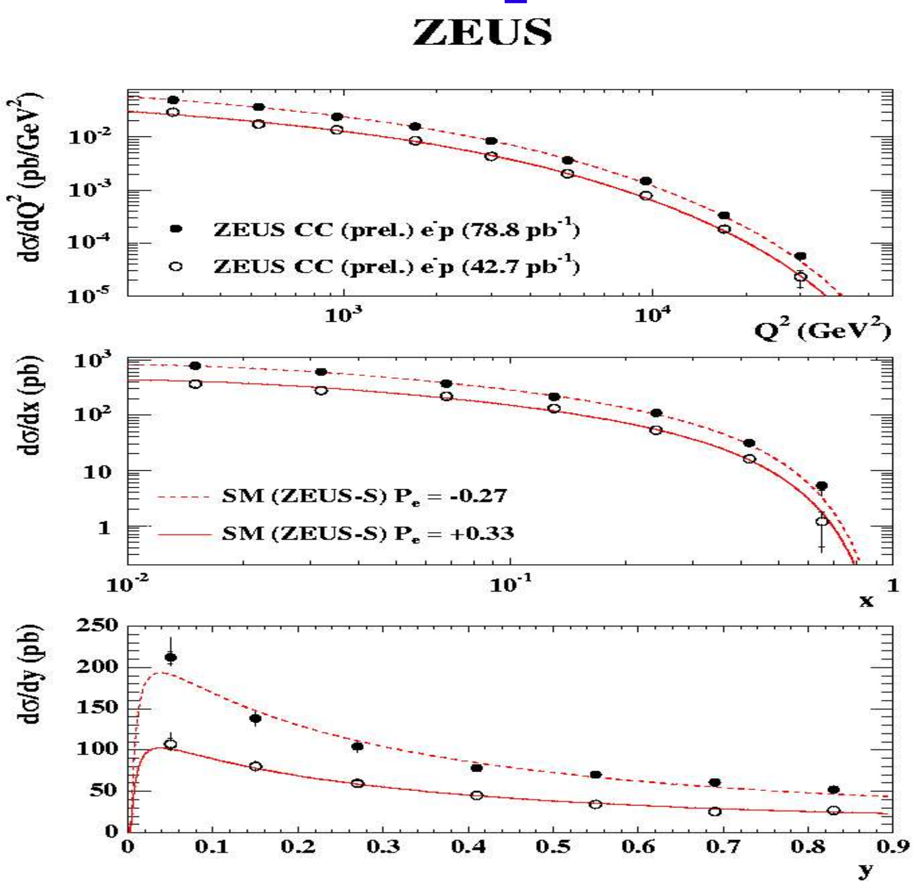
Data are in good agreement with SM

CC cross section with polarization II.

$e^+ p$



$e^- p$



Differential cross sections with different polarizations have the same shape, only the normalization is different

Polarized NC cross section I.

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

Generalized structure functions depend on polarization:

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

$$\tilde{F}_2 \sim F_2 \pm P_e a_e \chi_Z F_2^{\gamma Z}$$

To first order the same magnitude and opposite sign for two lepton beam charges

$$x\tilde{F}_3 = -(a_e \pm P_e v_e)\chi_Z xF_3^{\gamma Z} + (2v_e a_e \pm P_e(v_e^2 + a_e^2))\chi_Z^2 xF_3^Z$$

$$x\tilde{F}_3 \sim -a_e \chi_Z xF_3^{\gamma Z}$$

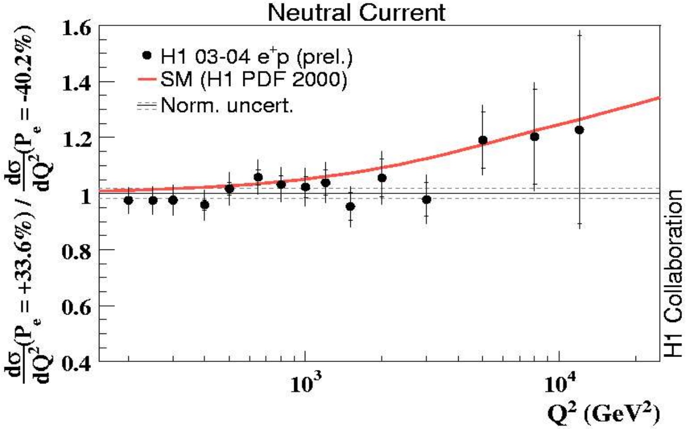
To first order does not depent on P, allows to measure unpolarized xF3

$$a_e = -0.5$$

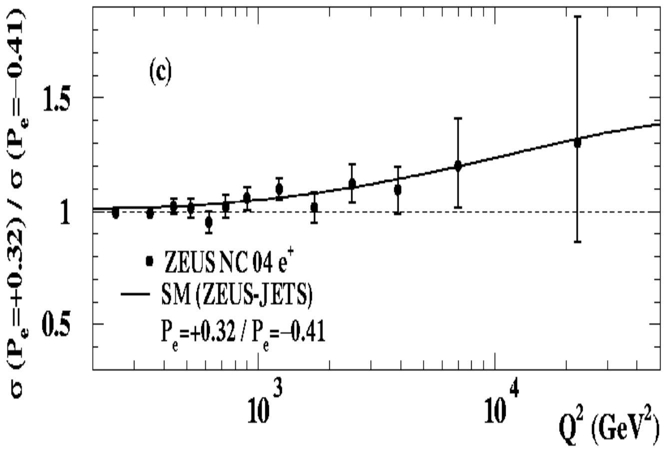
$$v_e \approx -0.04$$

Polarized NC cross section II.

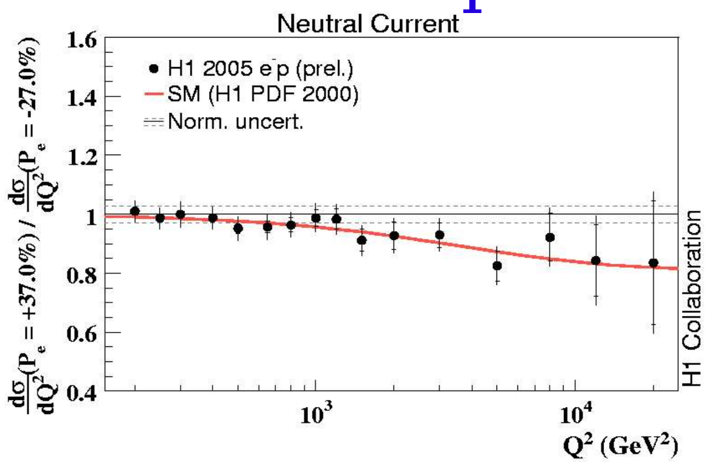
H1:e^+ p



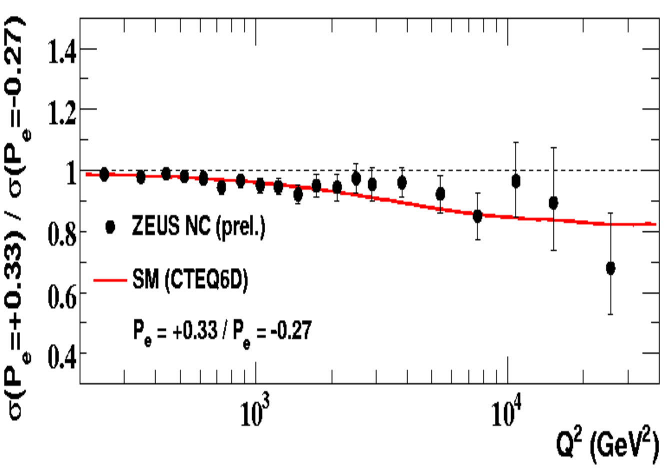
ZEUS:e^+ p



H1:e^- p

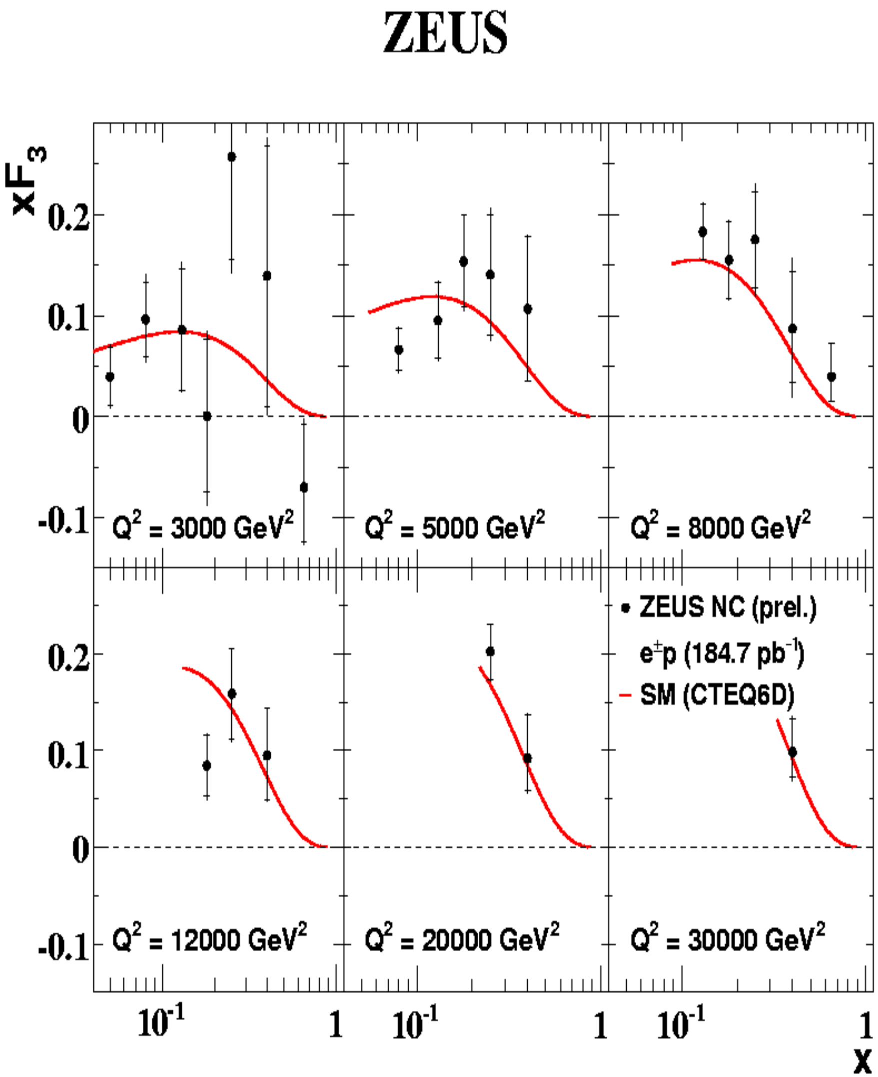


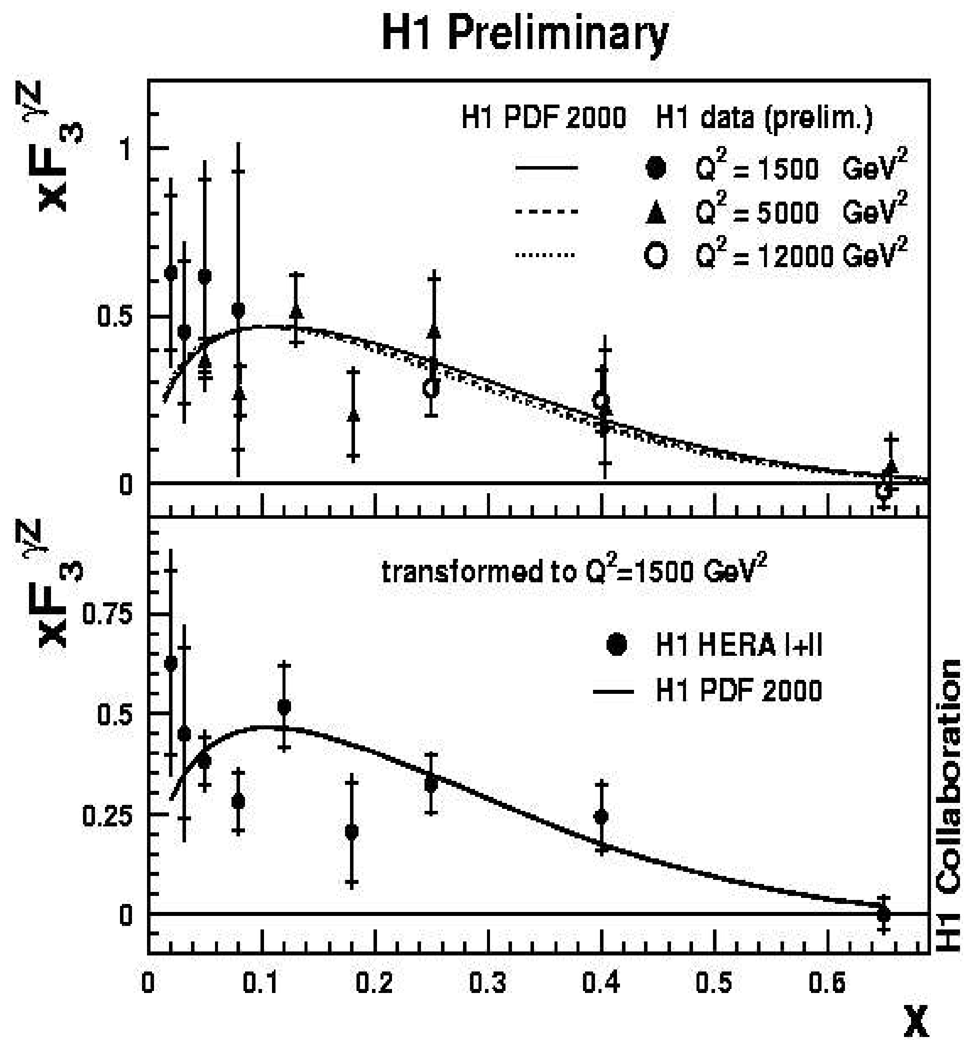
ZEUS:e^- p



Polarization effects start to be visible

Polarized NC cross section III.





Corrected for residual polarization effects, most precize xF3 up to now

The EW/QCD analysis of NC/CC data

Precize data sets allow combined EW+QCD analysis:

- Fit QCD parameters (pdf)
- EW parameters at the same time

Recent results:

- H1 HERA I EW+QCD fit (Phys.Lett.B632(2006)35)
- ZEUS HERAI+II preliminary EW+QCD fit (polarization)

CC is sensitive to Mw:

$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left[\frac{M_W^2}{M_W^2+Q^2}\right]^2 [Y_+ W_2 \mp Y_- xW_3 - y^2 W_L]$$

NC is sensitive to quark axial and vector couplings to Z:

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

The extraction of quark couplings to Z

In QPM:

$$F_2^{\gamma Z} = 2e_i v_i \sum x\left[q_i + \overline{q_i}\right]$$

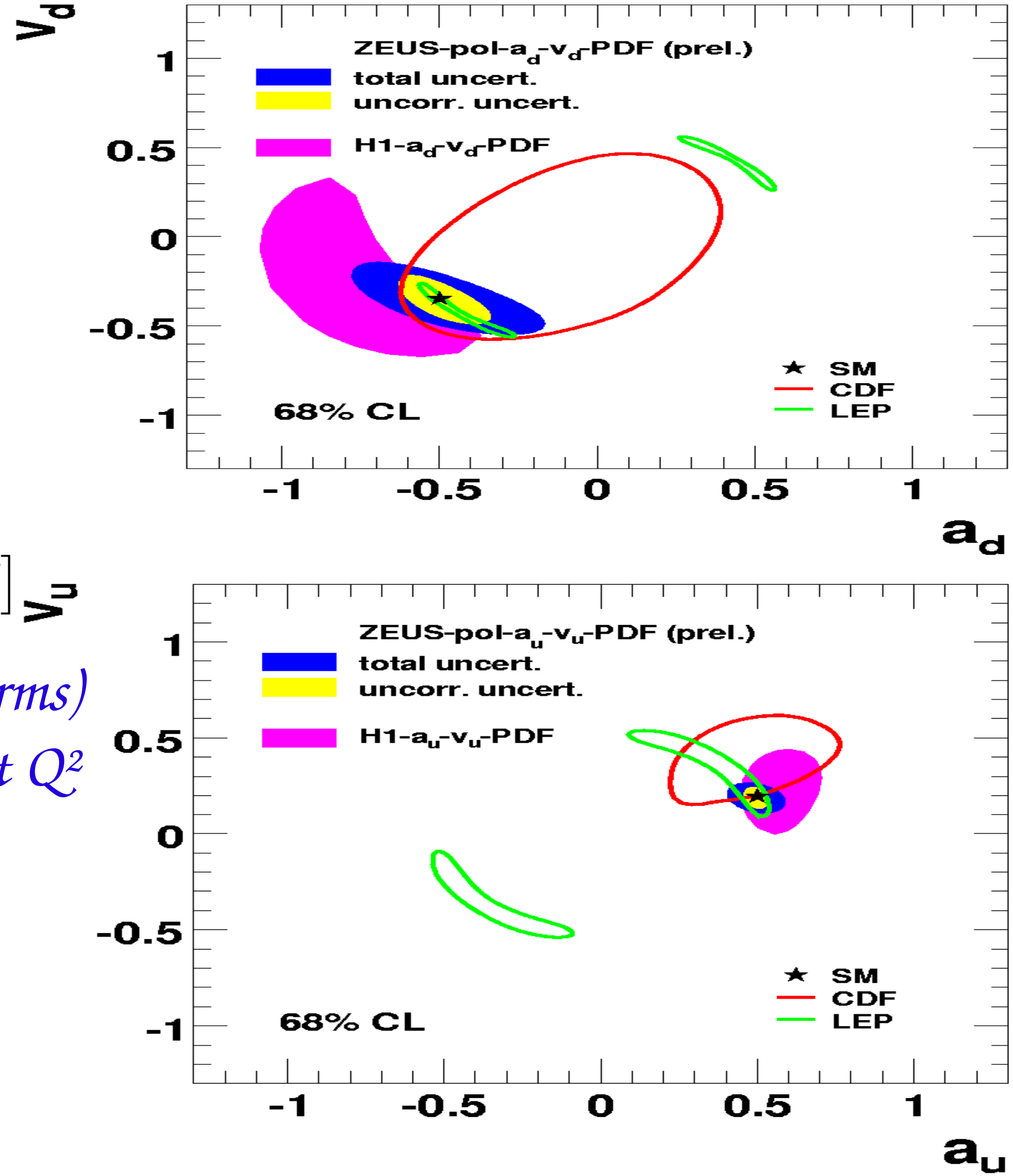
$$F_2^{Z} = (v_i^2 + a_i^2) \sum x\left[q_i + \overline{q_i}\right]$$

$$xF_3^{\gamma Z} = 2e_i a_i \sum x\left[q_i - \overline{q_i}\right]$$

$$xF_3^{Z} = 2v_i a_i \sum x\left[q_i - \overline{q_i}\right]$$

- *No sign ambiguity (interference terms)*
- *Sensitive both to v and a, different Q^2 dependence*
- *Polarization helps with v*

Competitive measurement!



EW/QCD analysis: Right handed isospin

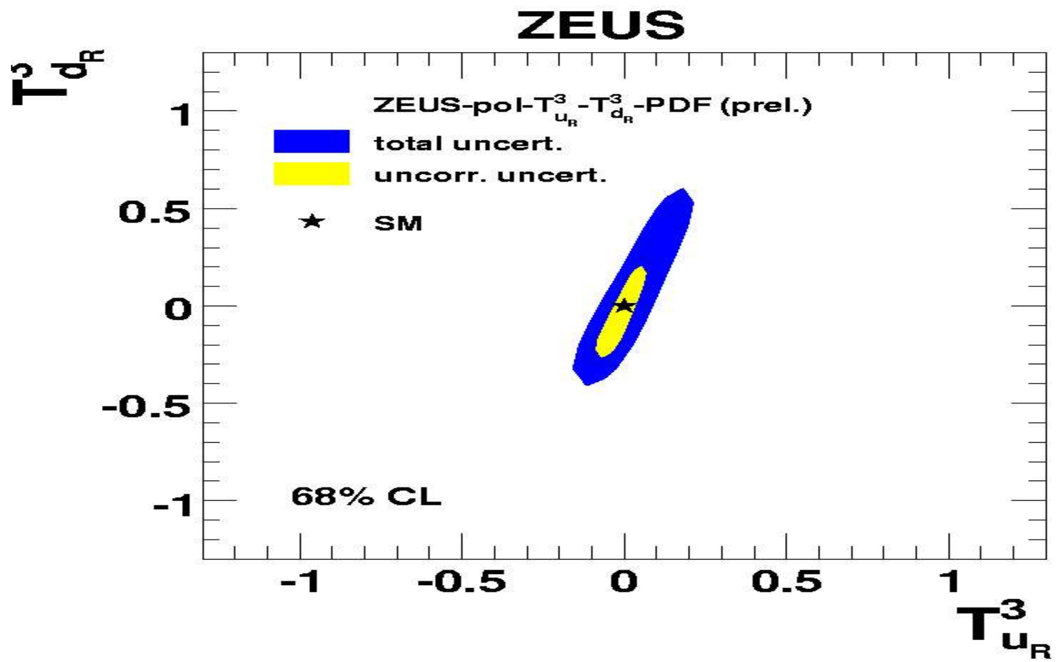
Introduce right handed isospin, should be zero in SM:

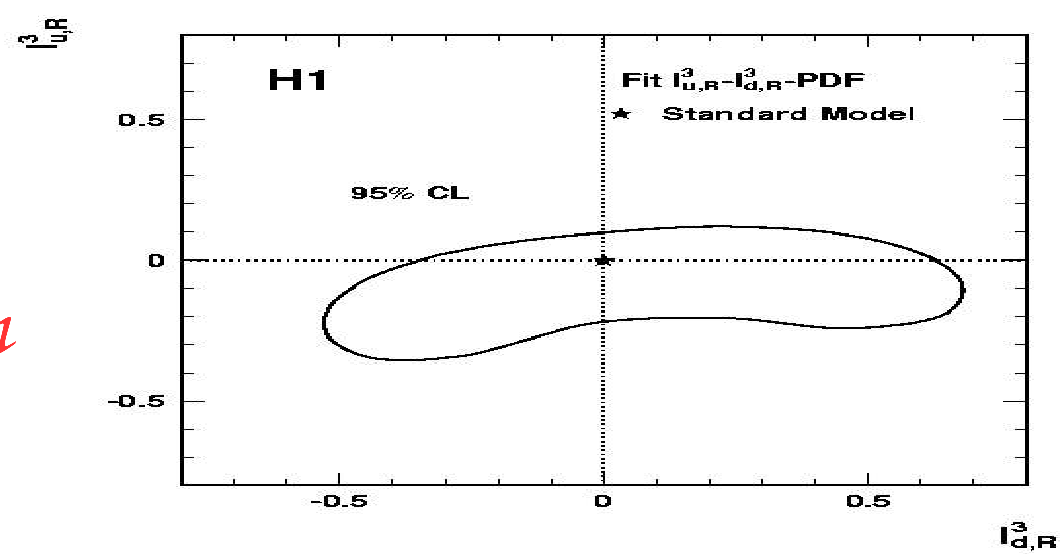
$$a_q = T^3_{q,L} + T^3_{q,R}$$

$$v_q = T^3_{q,L} - T^3_{q,R} - 2e_q sin^2\theta_W$$

$T^3_{q,L}, sin^2\theta_W$ fixed to SM values

No deviation from SM seen





EW/QCD analysis: propagator mass

The mass of the propagator can be determined from the Q^2 dependence of the CC cross section:

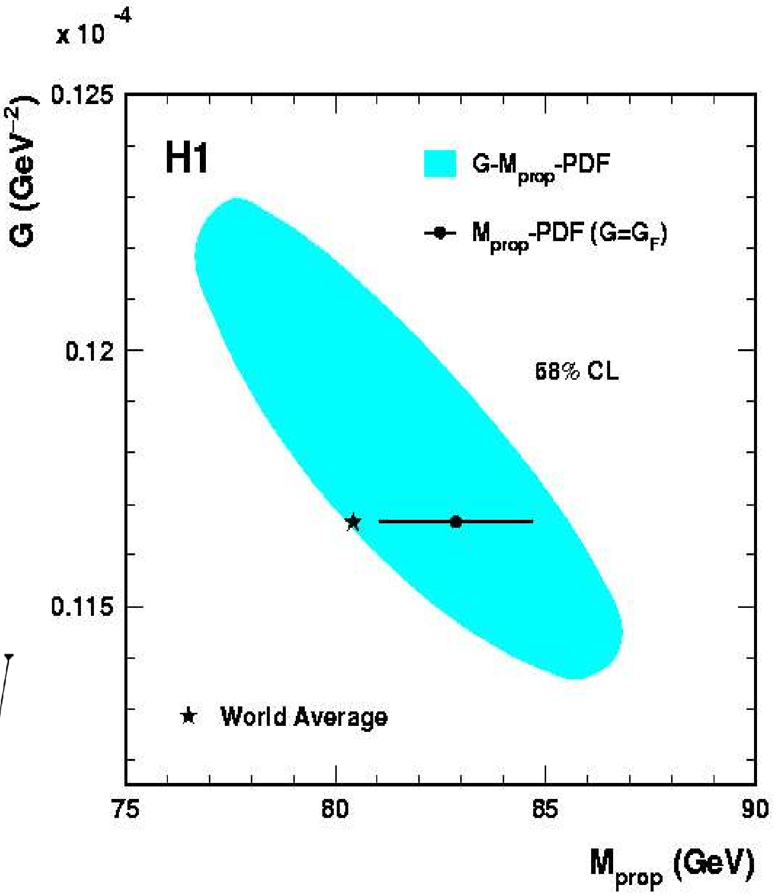
$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dx dQ^2} = \frac{G_F^2}{4\pi x}\left[\frac{M_{prop}^2}{M_{prop}^2 + Q^2}\right]^2 [\ldots]$$

G fixed to world average:

$$\mathrm{H1}: M_{prop} = 82.87 \pm 1.82(\mathrm{exp})^{+0.32}_{-0.18}(\mathrm{model})\ \mathrm{GeV}$$

$$\mathrm{ZEUS}: M_{prop} = 79.1 \pm 0.77(\mathrm{st+uncor}) \pm 0.99(\mathrm{cor.syst.})\ \mathrm{GeV}$$

Fit simultaneously G and M_{prop}:



In good agreement with mass of W

Conclusions and Outlook

- HERA experiments collected interesting data sets with lepton polarization for both lepton beam charges
- Direct sensitivity to RH CC (unique) – data in agreement with SM
- Effects of Z exchange seen in NC:
  - ✓ Beam charge assymetry
  - ✓ Polarization effects
- Competitive determination of EW parameters from combined EW+QCD fits

More data to come soon