Recontres de Moriond 2006
Electroweak Interactions and Unified Theories

Electroweak Physics at HERA

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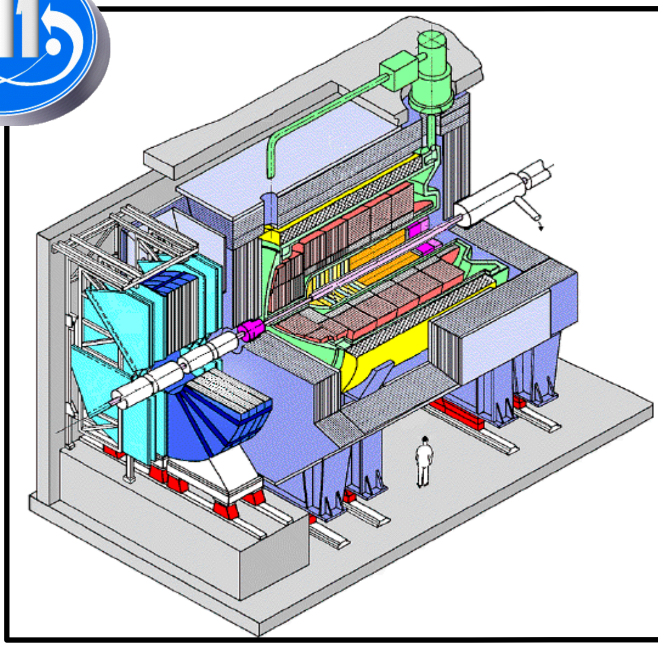
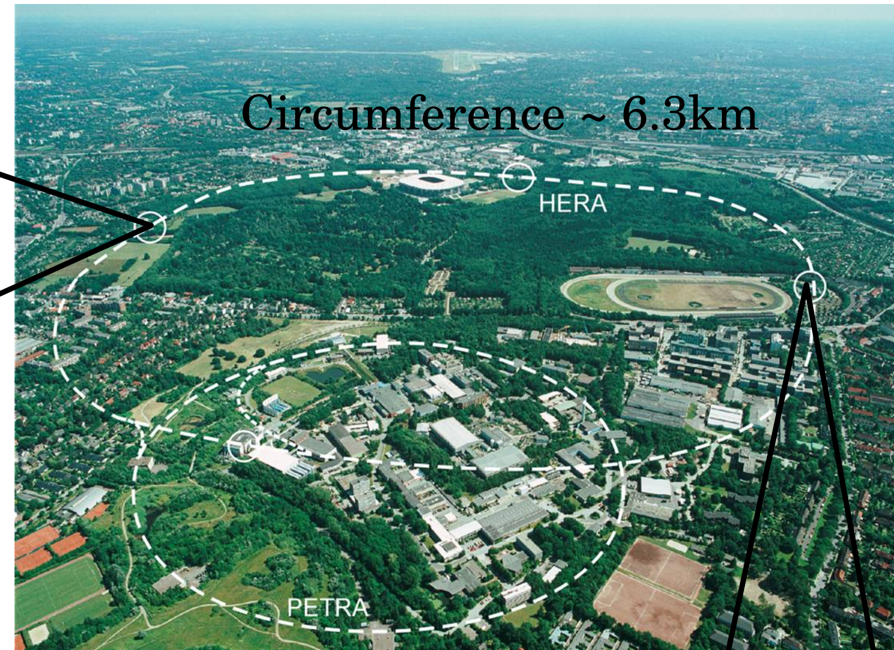
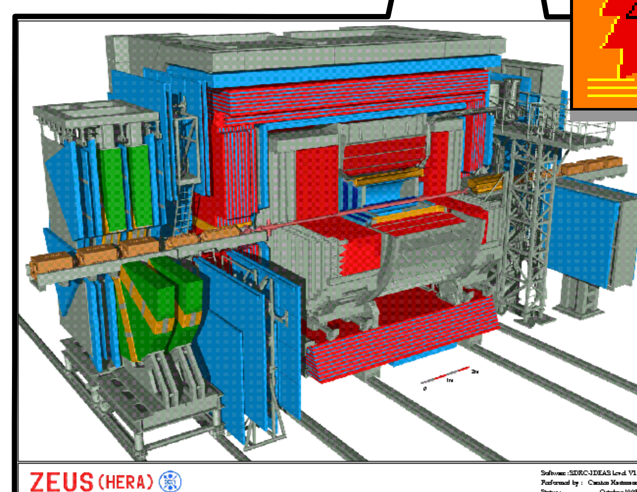
on behalf of the
H1 and **ZEUS** collaborations

- Deep inelastic scattering at HERA
- New results with HERA I data
- Polarized charged and and neutral current cross-sections with HERA II data

HERA Collider at DESY







P	$e^{\pm}$
→	←
920 GeV	27.5 GeV

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

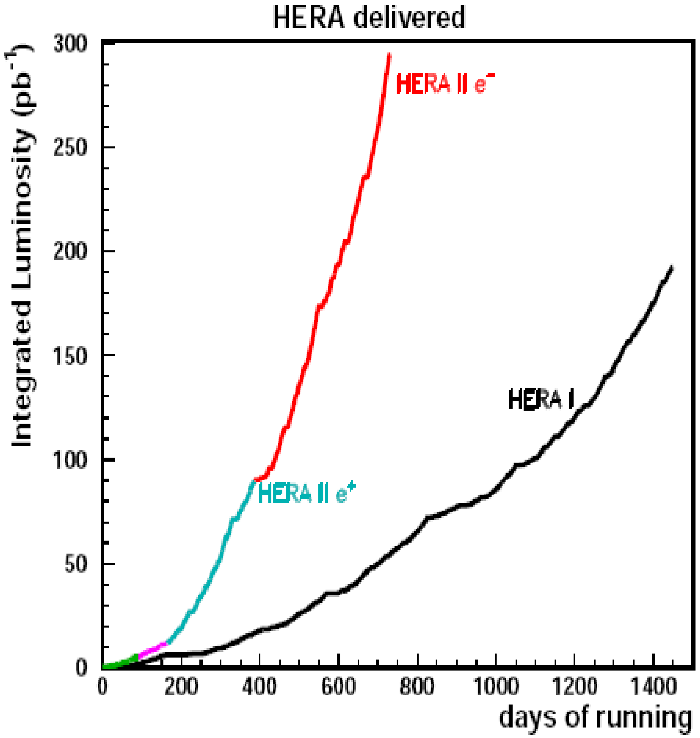
HERA Performance

- HERA has been delivering luminosity since 1993. 2 periods – HERA I and HERA II.
- HERA I: 1993 – 2000
  - Integrated luminosity:

HERA I	Delivered [pb^{-1}]	Used for physics (ZEUS) [pb^{-1}]
Positrons	168	115
Electrons	25	17

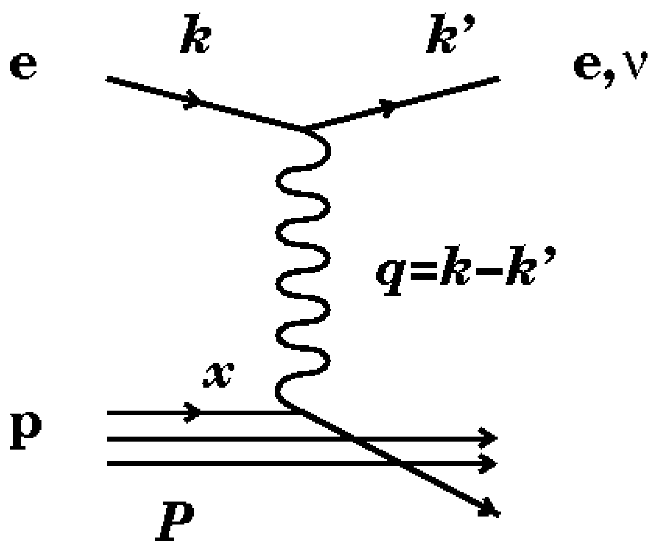
- HERA II: 2003 – 2007
  - Luminosity upgrade + **polarized** lepton beam.
  - Integrated luminosity until the end of 2005:

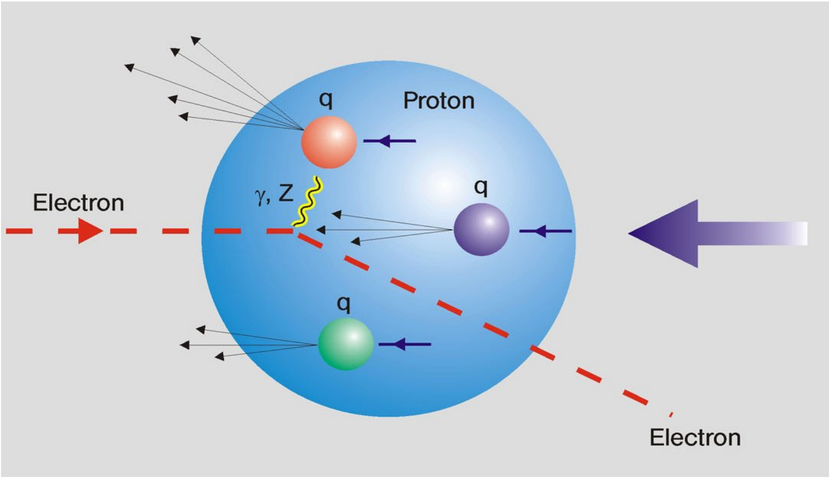
HERA II	Delivered [pb^{-1}]	Used for physics (ZEUS) [pb^{-1}]
Positrons	84	40
Electrons	205	135



HERA is running and performing well. A lot more quality data is expected!

Deep Inelastic Scattering Kinematics





- Momentum transferred:

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

- Fraction of the proton momentum carried by the parton:

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

- Inelasticity (in the proton rest frame, the fraction of the electron energy transferred):

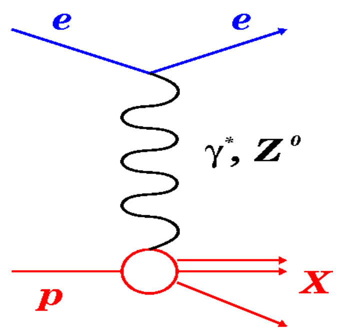
$$y = \frac{P.q}{P.k}$$

- At a given center of mass energy $s=(P+k)^2$ only 2 of these are independent:

$$Q^2 = sxy$$

Neutral Current (NC) DIS

- γ^* or Z boson are exchanged

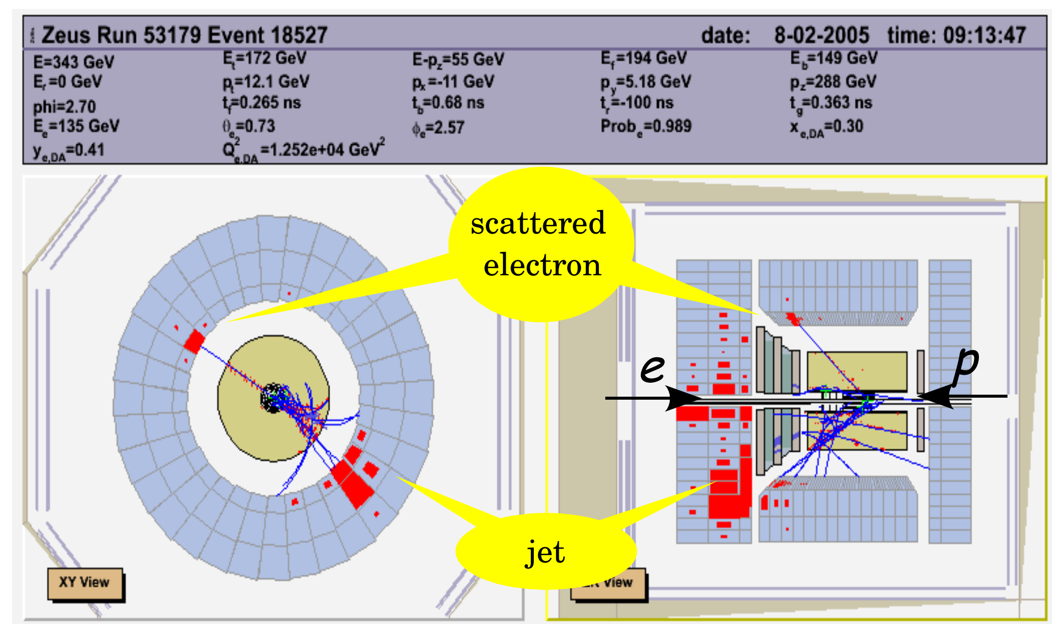


- Cross-section:

$$\frac{d^2\sigma^{NC}(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2^{NC} - y^2 F_L^{NC} \mp Y_- xF_3^{NC}\right]$$

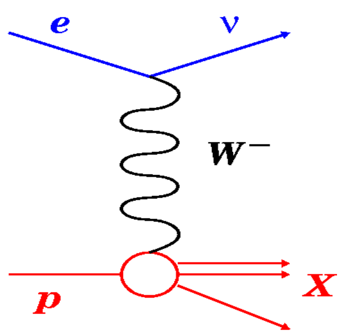
$$Y_\pm = 1 \pm (1-y)^2$$

- Experimental signatures:
  - Scattered electron and hadron jet(s)
  - Transverse and longitudinal momentum balance



Charged Current (CC) DIS

- *W* bosons are exchanged

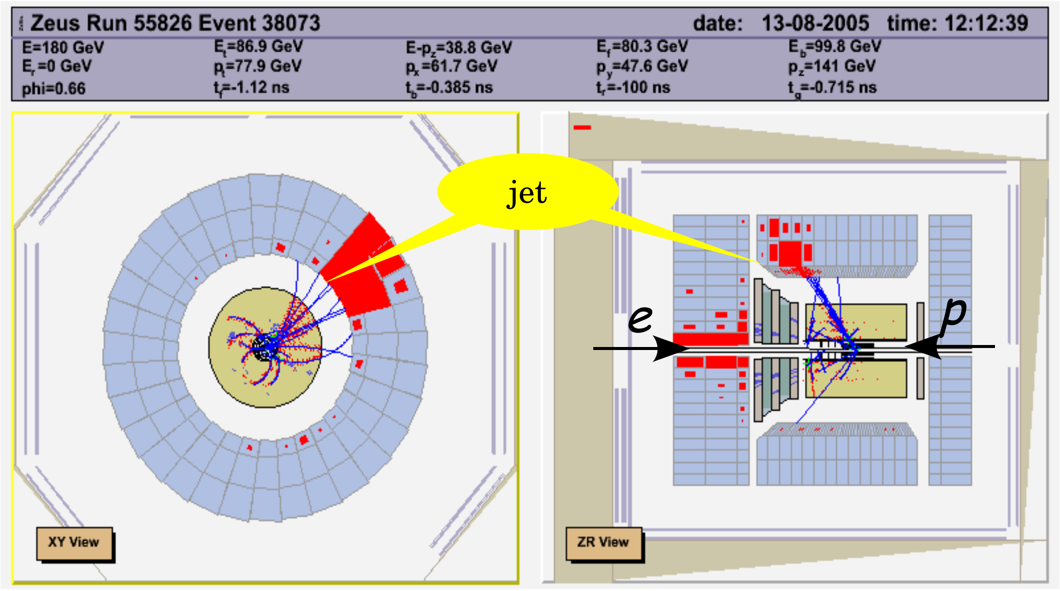


- Cross-section

$$\frac{d^2\sigma^{CC}(e^{\pm}p)}{dxdQ^2} = \frac{G_F^2}{4\pi x}\frac{M_W^4}{(Q^2+M_W^2)^2}\left[Y_+ F_2^{CC} - y^2 F_L^{CC} \pm Y_- xF_3^{CC}\right]$$

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

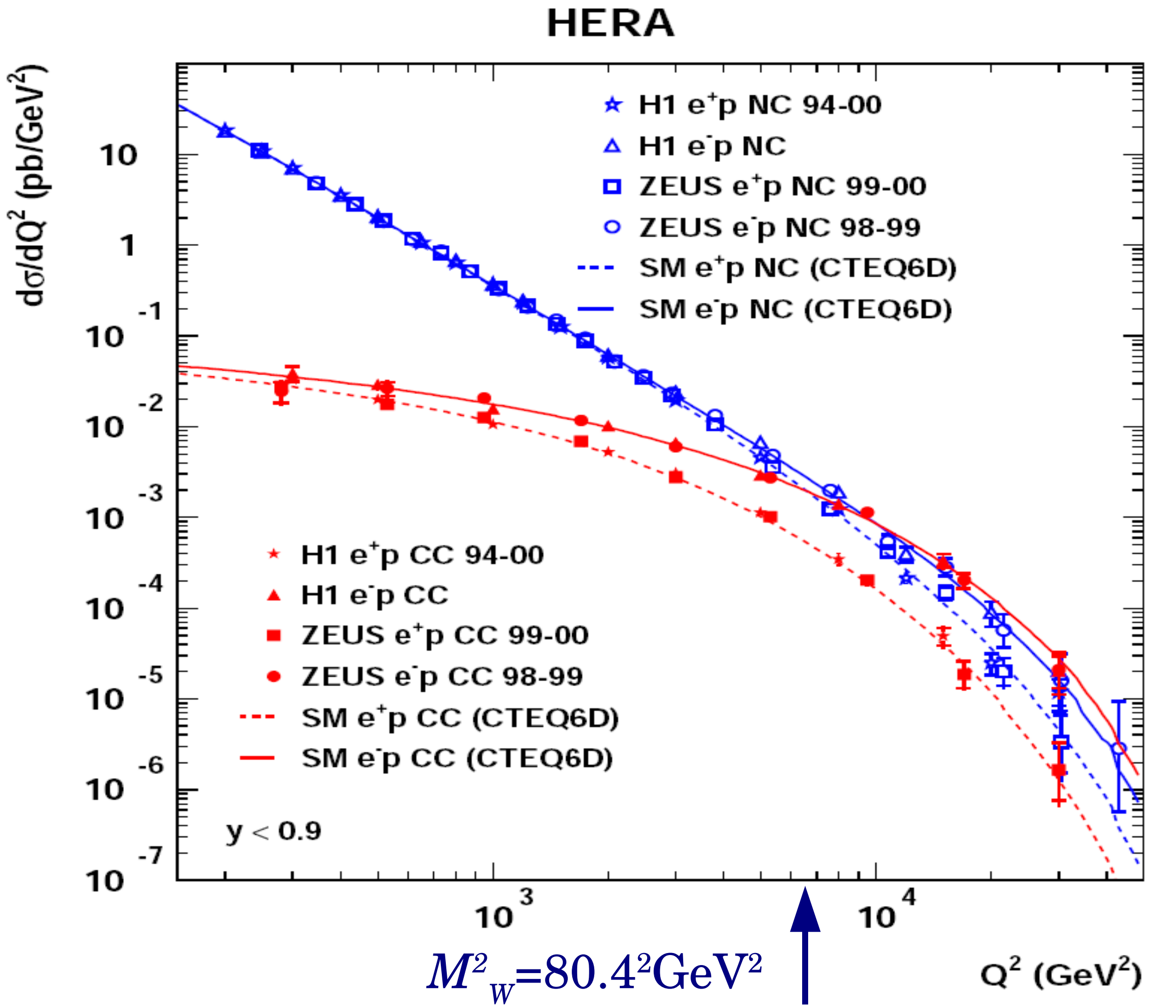
- Experimental signatures:
  - Only hadron jet(s) and no electron
  - Missing transverse momentum carried by the neutrino.



NC and CC comparison

HERA I data

- NC and CC cross-sections are similar above $Q^2 \approx M_w^{\ 2}$:



Quark Couplings to the Z^0 Boson

- Axial (a_q) and vector (v_q) couplings of quarks to Z boson were extracted by fitting the existing NC data-sets.
- The structure functions F_2 and xF_3 can be expressed as:

$$F_2^{NC}=\sum_q \left[e_q^2-2e_q v_q v_e \chi_Z+(v_q^2+a_q^2)(v_e^2+a_e^2)\chi_Z^2\right]x(q+\bar{q})$$

$$xF_3^{NC}=\sum_q \left[-2e_q v_q v_e \chi_Z+4v_q a_q v_e a_e \chi_Z^2\right]x(q-\bar{q})$$

Sensitivity to sign of couplings because of the interference terms

where: $$\chi_Z=\frac{G_F M_Z^2}{2\sqrt{2}\pi\alpha}\cdot\frac{Q^2}{Q^2+M_Z^2}$$

Sensitivity to both v_q and a_q because of the Q^2 dependence of χ_Z

- In SM, the quark couplings are (I^3 is 3rd component of weak isospin):

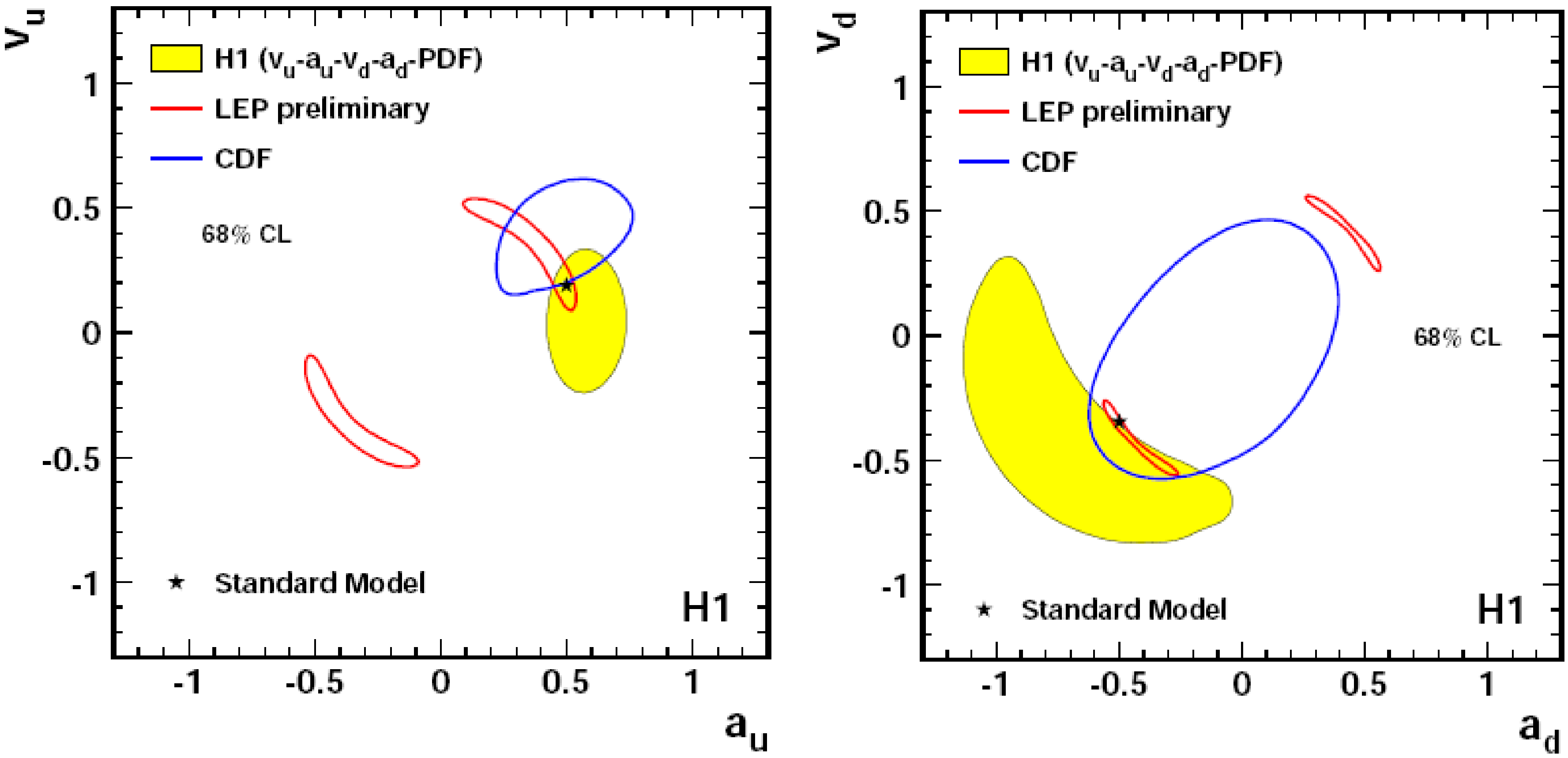
$$a_q=I_q^3 \qquad v_q=I_q^3-2e_q\sin^2\theta_W$$

i. e. for *u* quark: $a_u=1/2$, $v_u=0.196$ and for *d* quark: $a_d=-1/2$, $v_d=-0.346$

Quark Couplings to the Z^0 Boson (H1)

HERA I data

- Result of the fit for u quark (left) and d quark (right) couplings.



W Mass From the Propagator (H1)

HERA I data

- The mass of the W boson can be determined from the Q^2 dependence of the CC cross-section.

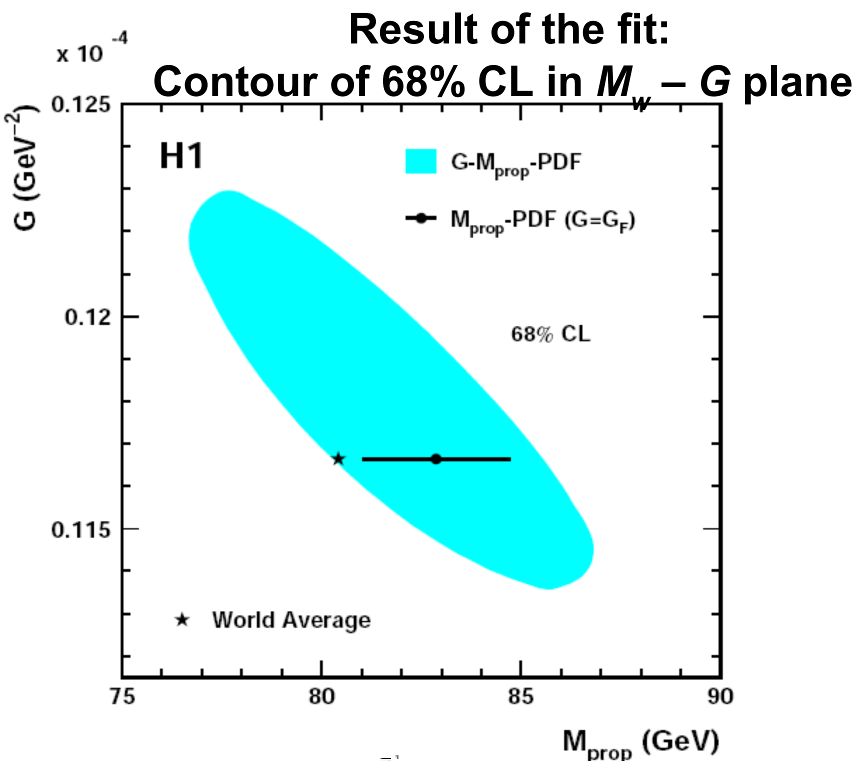
$$\frac{d^2\sigma^{CC}(e^{\pm}p)}{dx dQ^2} = \frac{G_F^2}{4\pi x}\frac{M_W^4}{(Q^2+M_W^2)^2} \times \ldots$$

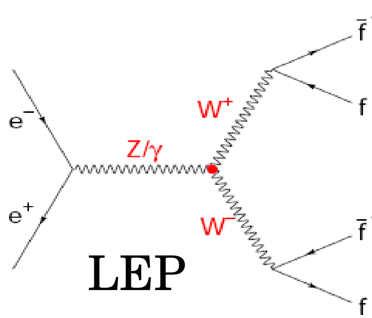
Sensitivity is in the shape of the Q^2 dependence.

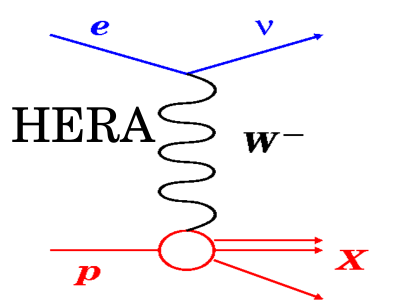
- If G is fixed at PDG value of G_F:

$$M_{prop.} = 82.87 \pm 1.82_{exp.}{}^{+0.30}_{-0.16\,model}\, GeV$$

  - Note that CC is "space like" process in contrast with "time like" processes at LEP where more accurate M_w measurement was done.







W Mass in OMS Scheme (H1)

HERA I data

- The CC cross-section can also be rewritten (so called OMS scheme) as:

$$\frac{d^2\sigma^{CC}(e^{\pm}p)}{dxdQ^2}=\frac{\pi\alpha^2}{4\left(1-\frac{M_W^2}{M_Z^2}\right)^2}\frac{1}{(1-\Delta r)^2}\frac{1}{(Q^2+M_W^2)^2}\times Structure\ funct.$$

Extra M_w terms increase the sensitivity – result is sensitive on normalization.

  - $\Delta r=f(M_Z, M_W, m_t, m_H)$ absorbs the radiative corrections
  - In this case, the cross-section is more sensitive to the W mass ⇒ smaller error

- If top mass m_t is fixed at 178GeV and assuming higgs mass M_H=120GeV, the the fit result is:

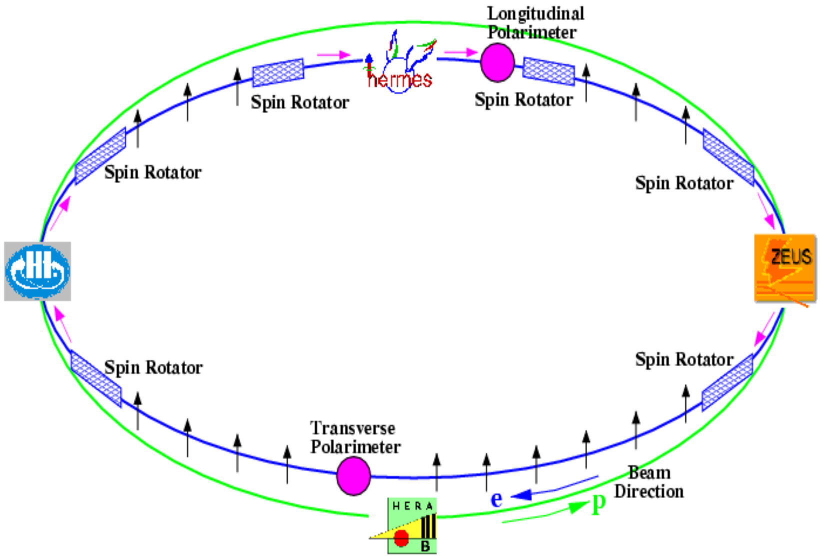
$$M_W=80.786\pm0.205_{exp.}{}^{+0.048}_{-0.029\,model}\pm0.025_{\delta m_t}-0.084_{\delta M_H}\pm0.033_{\delta(\Delta r)}\,GeV$$

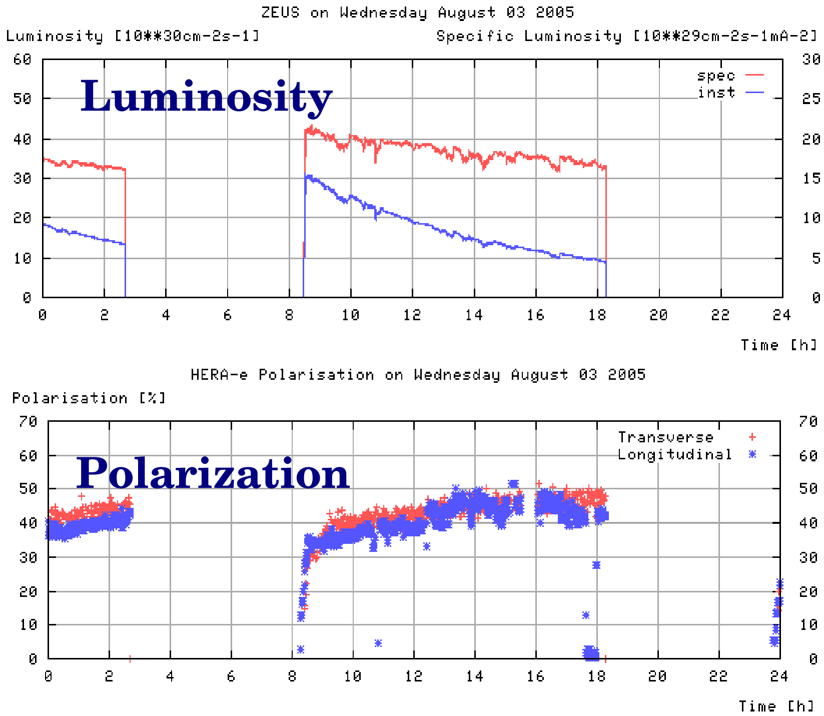
$$\sin^2\theta_W=0.2151\pm0.0040_{exp.}{}^{+0.0019}_{-0.0011\,theor.}$$

  - *Note:* This is an indirect determination rather than a direct measurement.
  - Provides a consistency check of SM.

Polarized Cross-sections

- After the upgrade, HERA provides the experiments with longitudinally polarized lepton beams.
  - The transverse polarization builds up naturally (Sokolov-Termov effect).
  - Spin rotators flip the polarization by 90^0 just before the lepton beam enters the interaction regions of experiments
  - Typical level of polarization is ~40%.





Polarized Cross-sections

- If N_R and N_L are the numbers of right-handed and left-handed electrons, the level of polarization P is defined as:

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

- The CC cross-section can in general be written as superposition of right- and left-handed component:

$$\sigma^{CC}(P) = \frac{1+P}{2}\sigma_{RH}^{CC} + \frac{1-P}{2}\sigma_{LH}^{CC}$$

- In SM σ_{RH} =0 for electrons and σ_{LH} =0 for positrons and the total cross-section changes linearly with polarization.

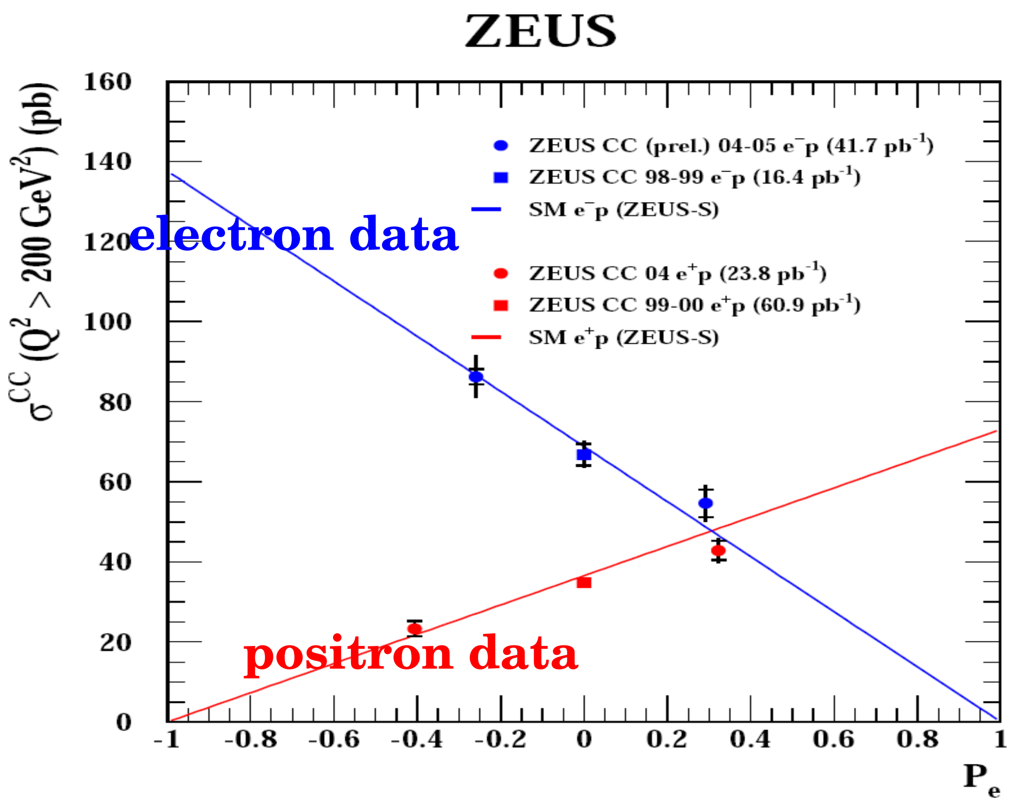
CC Polarized Cross-Section (ZEUS)

HERA II data

- Total CC cross-section (Q^2>200GeV) vs. polarization
- For positron data, the extrapolation to P=-1 yields:

$$\sigma^{CC}(P=-1)=7.4\pm3.99_{stat.}\pm1.2_{sys.}\ pb$$

consistent with SM within 2 std. dev.



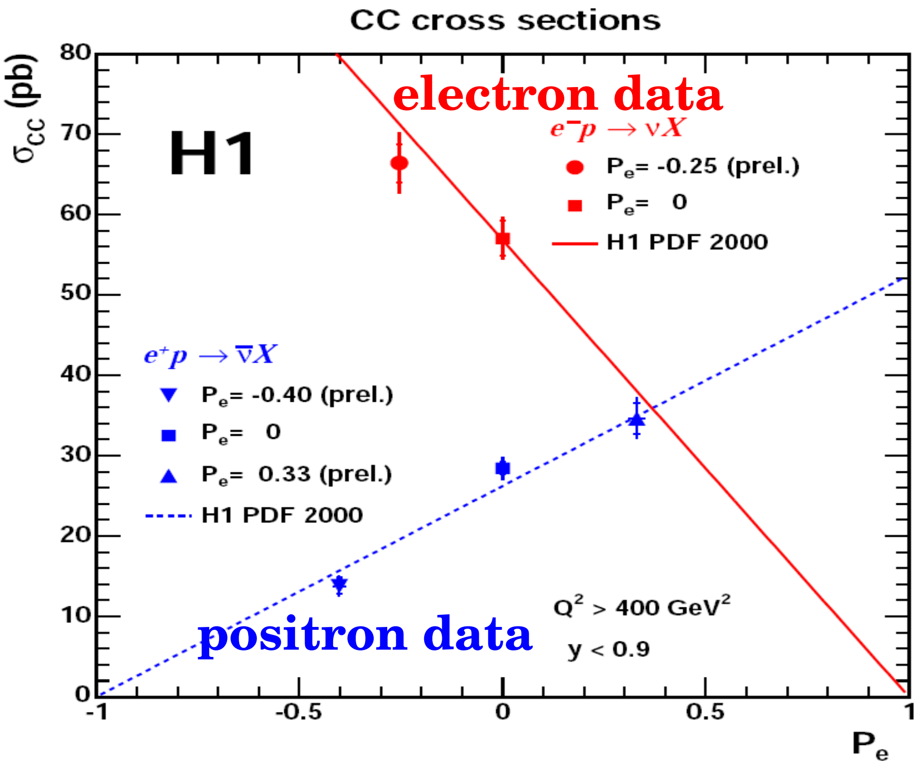
CC Polarized Cross-Section (H1)

HERA II data

- Total CC cross-section (Q^2>400GeV, y<0.9) vs. polarization
- For positron data, the extrapolation to P=-1 yields:

$$\sigma^{CC}(P=-1)=-3.9\pm2.3_{stat.}\pm0.7_{sys}\pm0.8_{pol}\ pb$$

consistent with SM



Effect of Polarization on NC

- Only Z^0 contribution is sensitive to polarization and this is suppressed by its big mass, so the effect is smaller than in CC.
  - The polarized NC cross-section can be expressed as a sum of polarized and unpolarized contribution:

$$\frac{d^2\sigma^{NC}(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[H_0^\pm - P\cdot H_P^\pm\right]$$

lepton beam polarization

  - Unpolarized: $H_0^\pm = Y_+ F_2^0 \mp Y_- xF_3^0$

dominated by photon exchange

$$F_2^0 = \sum_q x(q+\bar{q})\left[e_q^2 - 2e_q v_q v_e \chi_Z + (v_q^2 + a_q^2)(v_e^2 + a_e^2)\chi_Z^2\right]$$

$$xF_3^0 = \sum_q x(q-\bar{q})\left[-2e_q a_q a_e \chi_Z + 4v_q a_q v_e a_e \chi_Z^2\right]$$

  - Polarized: $H_P^\pm = Y_+ F_2^P \mp Y_- xF_3^P$

$$F_2^P = \sum_q x(q+\bar{q})\left[2e_q v_q a_e \chi_Z + (v_q^2 + a_q^2)v_e a_e \chi_Z^2\right]$$

$$xF_3^P = \sum_q x(q-\bar{q})\left[2e_q a_q v_e \chi_Z - 2v_q a_q (v_e^2 + a_e^2)\chi_Z^2\right]$$

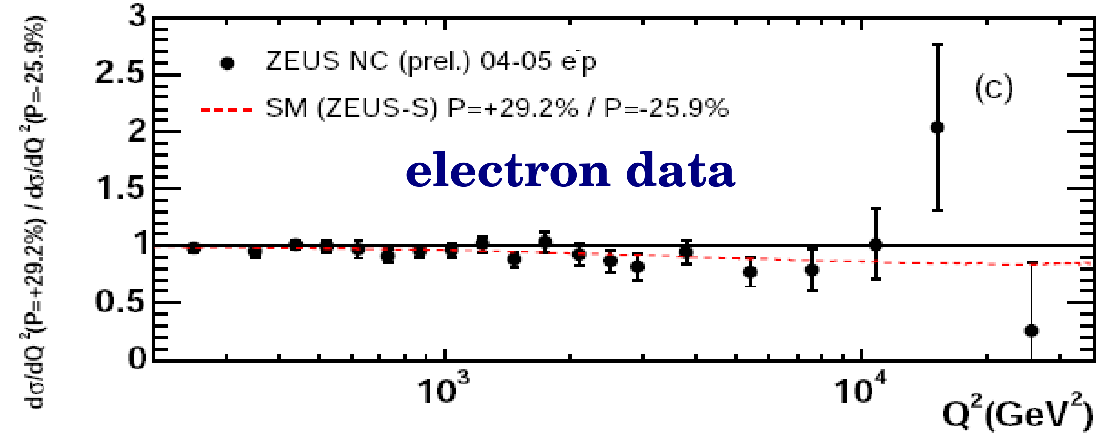
Z^0 contribution suppressed at low Q^2 because of the high Z^0 mass.

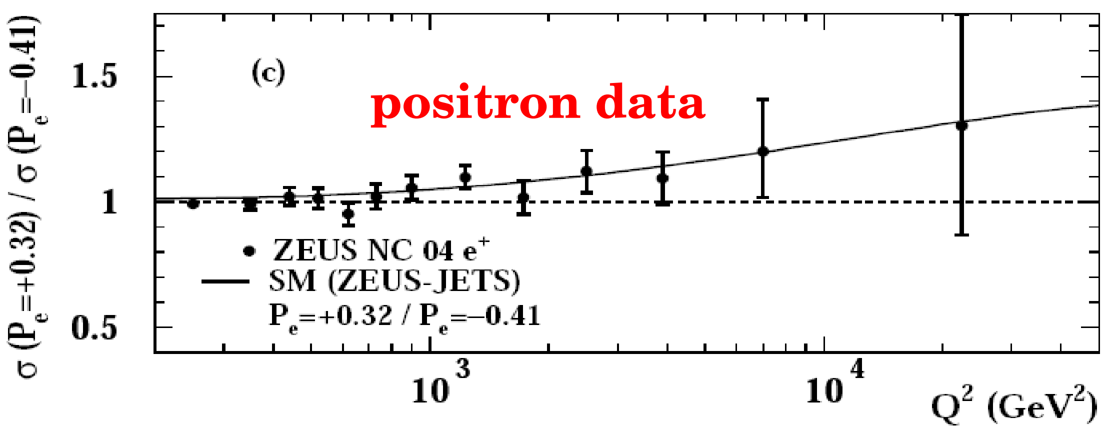
  - χ_Z is proportional to ratio of Z^0 and photon propagators: $\chi_Z = \frac{1}{\sin^2 2\theta_W}\frac{Q^2}{M_Z^2 + Q^2}$

Effect of Polarization on NC (ZEUS)

HERA II data

- Ratio of positive over negative helicity cross-section – the polarization effect at high Q^2 is visible and consistent with SM.





Summary

- DIS at HERA provides as unique possibilities of measuring the electroweak parameters and checking the Standard Model.
- Existing unpolarized data were used to fit the quark couplings to Z^0, W boson mass and other EW parameters.
- Polarization dependence of CC cross-sections is used to demonstrate their parity violating nature. It was confirmed for both positrons and electrons.
- Effect of polarization is observed also in NC interactions as expected by SM.
- *HERA will be running until summer 2007. We expect a lot more luminosity which can increase precision of many results by factor of ~2!*