Imperial College London

Inclusive high Q^2 cross sections and QCD and EW fits at HERA

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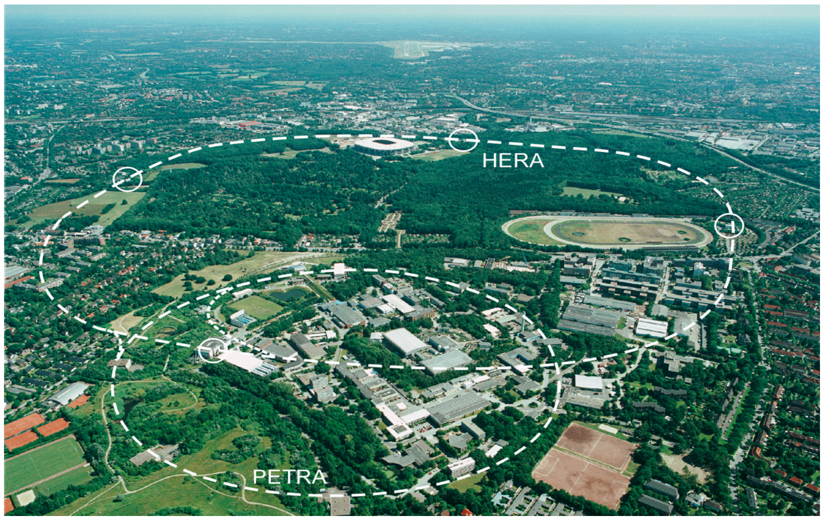
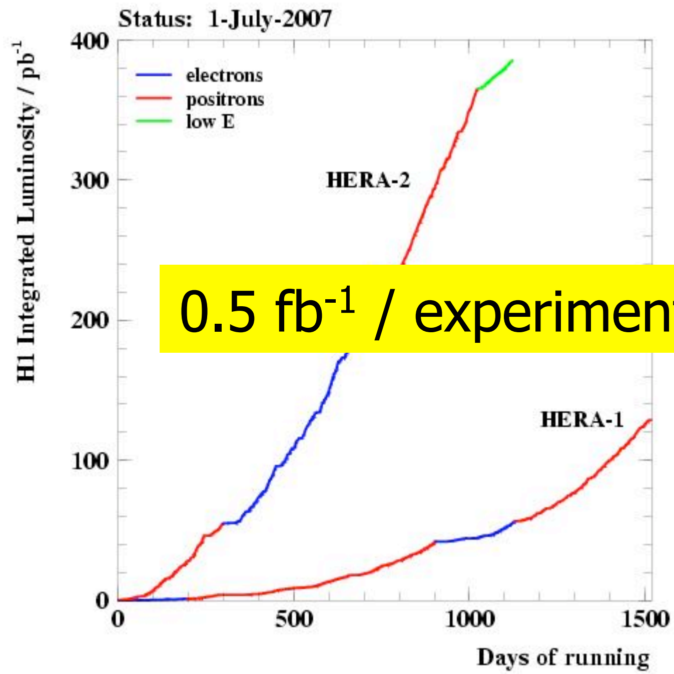
The HERA accelerator





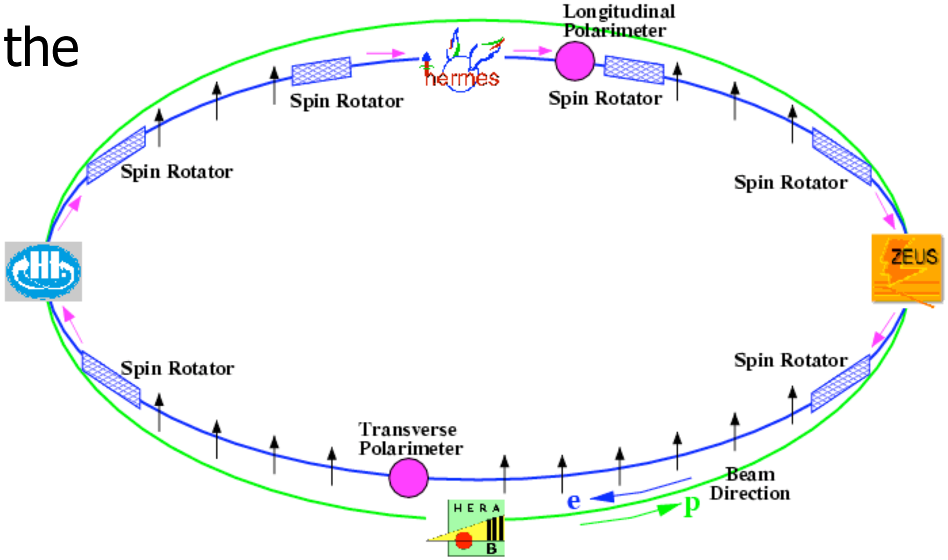
0.5 fb^{-1} / experiment

$\sqrt{s}$=320 GeV

Longitudinal polarisation at HERA

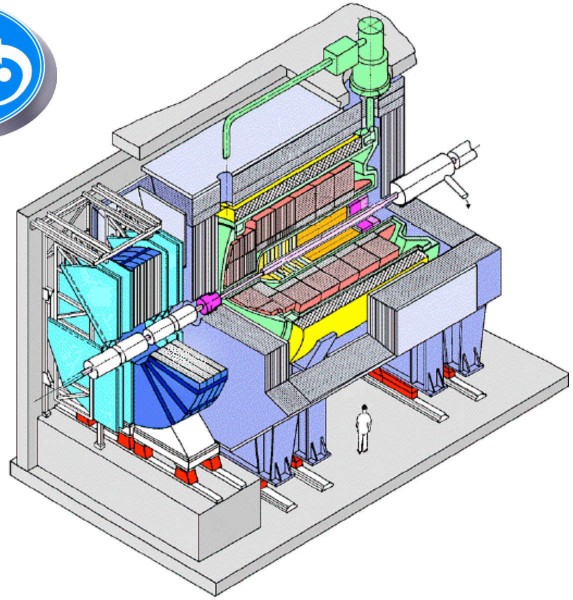
Longitudinal polarisation of the lepton beam at HERA

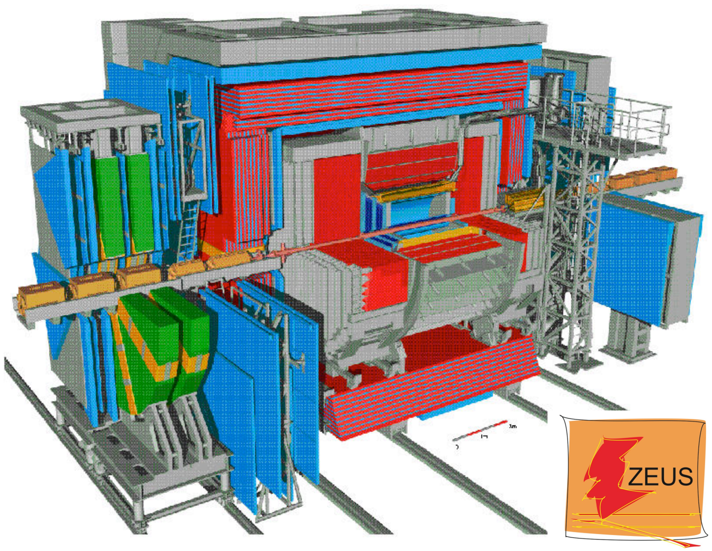
$$P_e = \frac{N_R - N_L}{N_R + N_L}$$



- Transverse polarisation builds up naturally through synchrotron radiation (Sokolov-Ternov effect)
- Spin rotators flip transverse polarisation to longitudinal before interaction regions and back afterwards
- Polarisation measured by two independent Compton polarimeters
- Average polarisation 30-40%

The H1 and ZEUS detectors

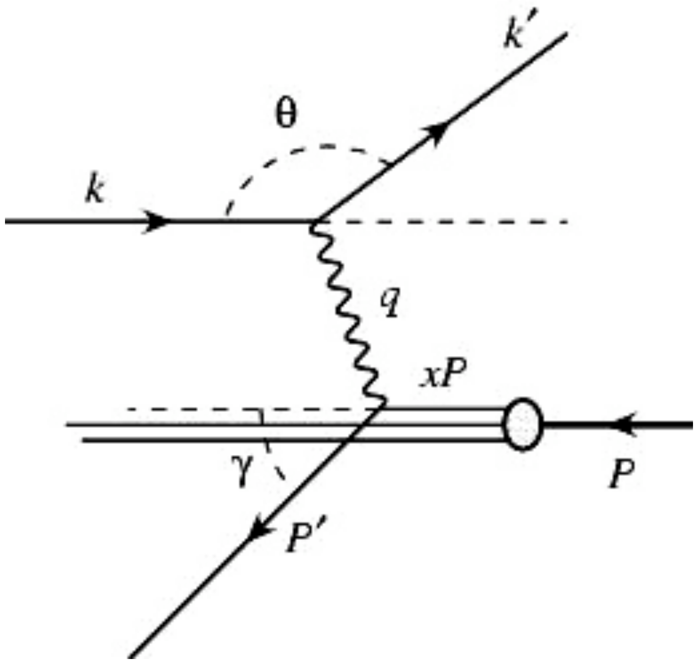




- LAr calorimeter (45000 cells)
- EM $$\frac{\sigma(E)}{E} = \frac{12\%}{\sqrt{E}} \oplus 1\%$$
- HAD $$\frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E}} \oplus 1\%$$

- DU calorimeter (6000 cells)
- EM $$\frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E}}$$
- HAD $$\frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E}}$$

Deep inelastic scattering at HERA



Two deep inelastic scattering processes:

— Neutral current: exchange of γ or Z^0

— Charged current: exchange of $W^{\pm}$

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

$$x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

$$s = (p + k)^2 \qquad Q^2 = x \cdot y \cdot s$$

Q^2 is the probing power
x is the Bjorken scaling variable
y is the inelasticity

Neutral current DIS cross section

$$\frac{d^2\sigma^{NC}(e^\pm p)}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ \left[F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3 \right] \qquad Y_\pm = 1 \pm (1-y)^2$$

Dominant contribution (F_2)

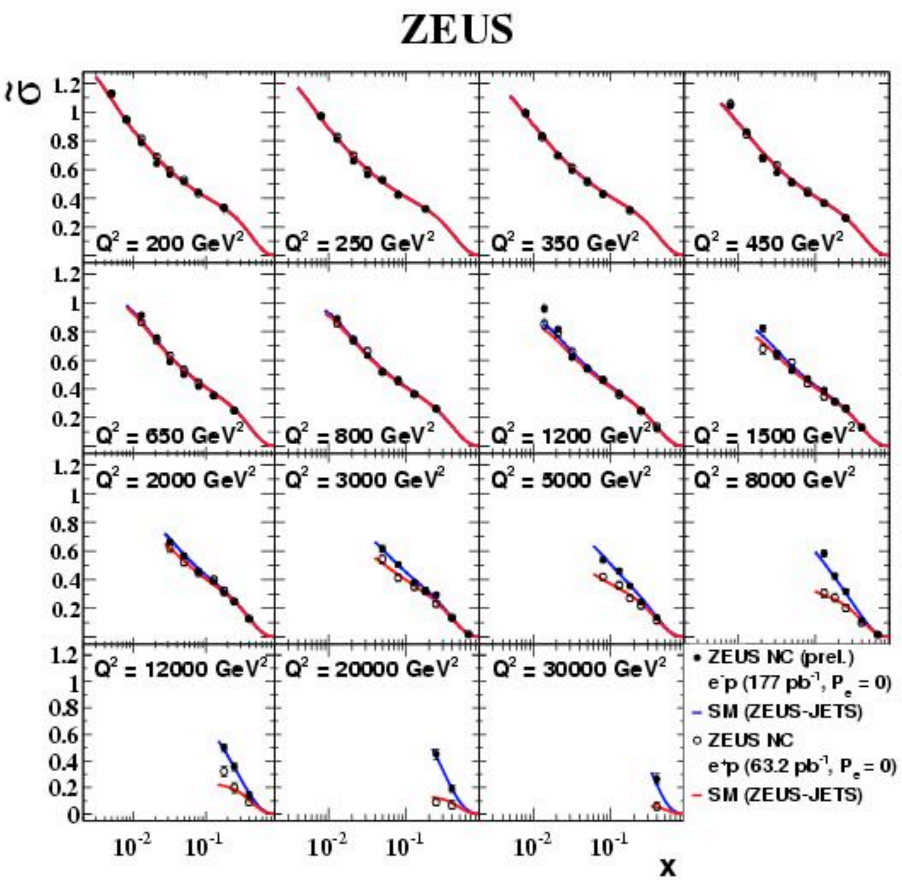
Sizeable only at high y (F_L)

Contribution only important at high Q^2 (xF_3)

$$F_2 = F_2^{em} + \frac{Q^2}{Q^2+M_Z^2} F_2^{\gamma Z} + \left[\frac{Q^2}{Q^2+M_Z^2}\right]^2 F_2^Z \propto \sum_{q=u\ldots b} (q+\bar{q})$$

$$xF_3 = \frac{Q^2}{Q^2+M_Z^2} xF_3^{\gamma Z} + \left[\frac{Q^2}{Q^2+M_Z^2}\right]^2 xF_3^Z \propto \sum_{q=u\ldots b} (q-\bar{q})$$

Neutral current data



- At lower Q^2 e^+p and e^-p cross sections the same
  - F_2 (photon exchange) dominates cross section
  - Directly sensitive to sum of quarks and antiquarks
- At high Q^2 e^+p and e^-p cross sections different
  - Influence of xF_3 term (Z^0 exchange)
  - Sensitive to the valence quarks

Charged current DIS at HERA

CC e^+p cross section:

Sensitive to density of d quark

$$\frac{d^2\sigma^{CC}(e^+p)}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[\bar{u}+\bar{c}+(1-y)^2(d+s)\right]$$

$$\tilde{\sigma}(x,Q^2)/x$$

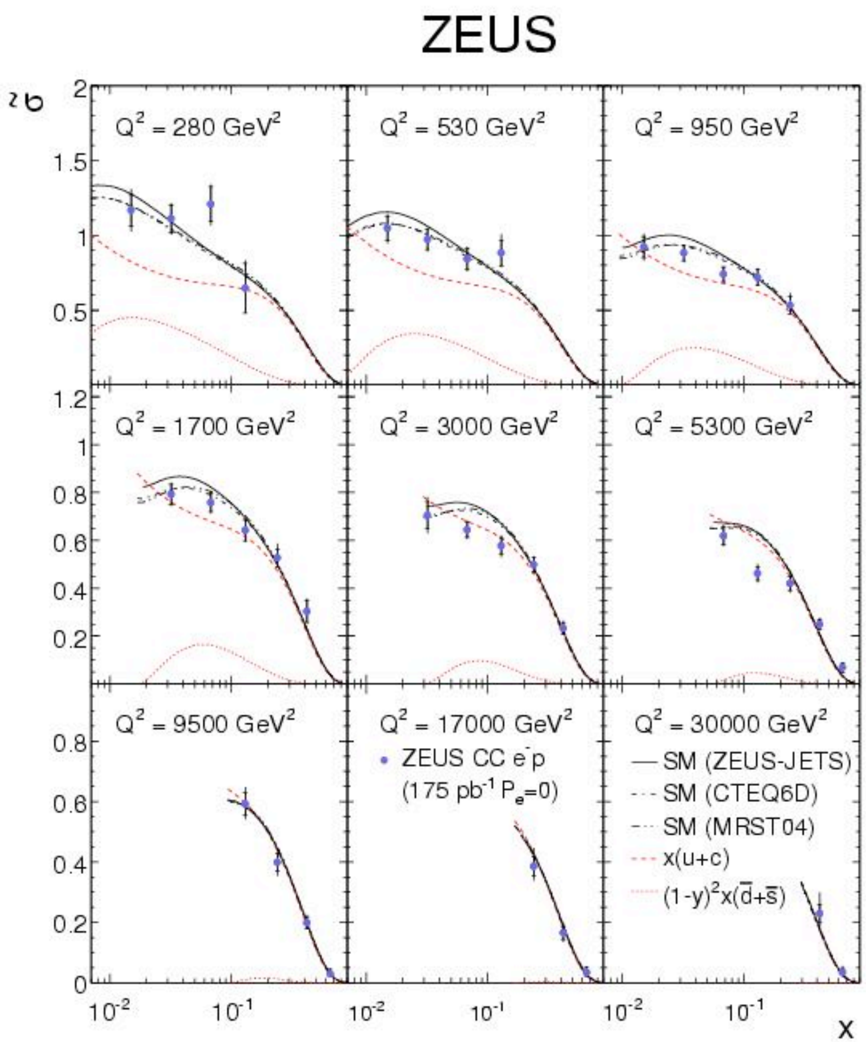
CC e^-p cross section:

$$\frac{d^2\sigma^{CC}(e^-p)}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[u+c+(1-y)^2(\bar{d}+\bar{s})\right]$$

Sensitive to density of u quark

Electron/positron-proton collisions probe different quark content of proton

Charged current data



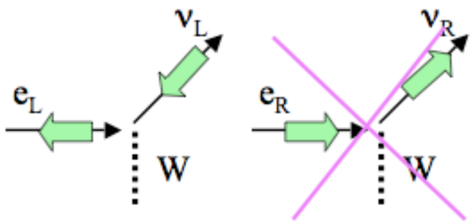
- Charged current cross sections quark-flavour specific
  - e^-p (shown here) sensitive to u-quark
  - e^+p sensitive to d-quark

Polarised charged current DIS

- Polarisation is asymmetry of helicity states

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

- Helicity = chirality (neglecting masses)
- Can use polarised beams to directly test chiral structure of the Standard Model



- Standard Model weak interaction left-handed
  - only LH particles (RH anti-particles) interact

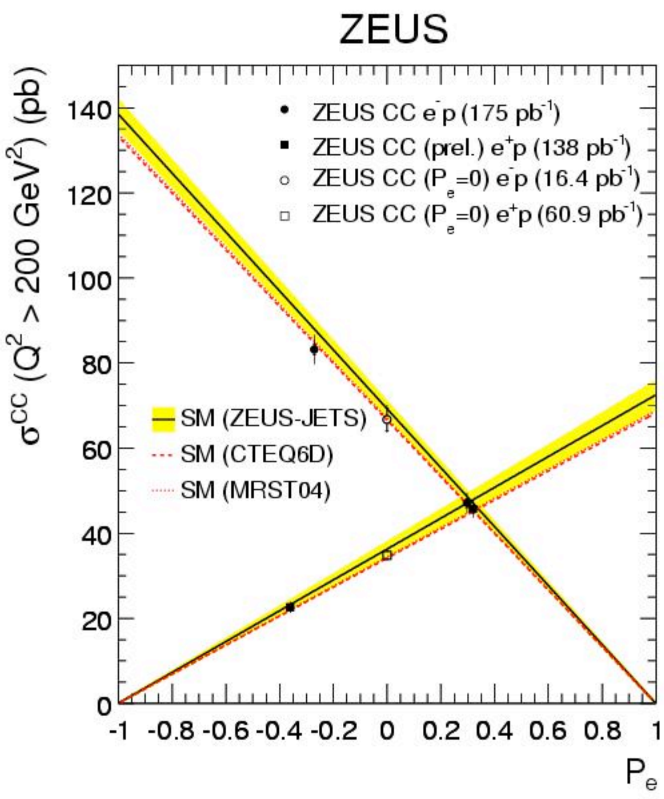
CC cross section modified by P_e:

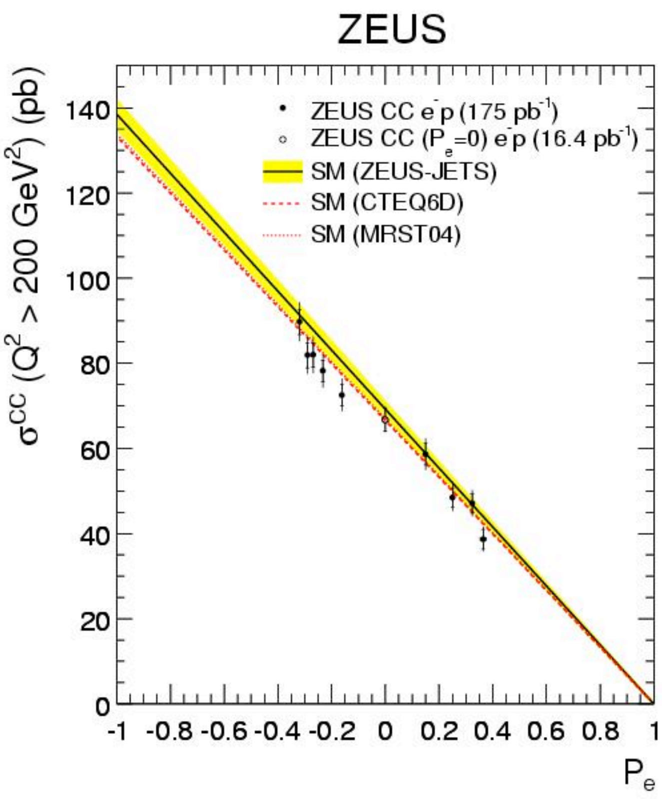
$$\sigma_{CC}^{e^{\pm}p}(P_e) = (1 \pm P_e) \cdot \sigma_{CC}^{e^{\pm}p}(P_e = 0)$$

Polarisation scales P_e=0 cross section linearly - clear and large effect at HERA

Standard Model predicts zero cross section for P_e=+1(-1) in $e^{-(+)}$p scattering

Dependence on P_e





- Clearly demonstrate linear dependence on P_e
- Consistent with Standard Model predictions

Polarised NC DIS cross sections

NC cross section modified by P:

$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[H_0^{\pm} + PH_P^{\pm}\right] \qquad P = \frac{N_R - N_L}{N_R + N_L}$$

Unpolarised contribution

Polarised contribution - only includes Z and γZ terms

$$F_2 = \sum_{q=u...b}\left(e_q^2 - 2e_q v_q v_e P_Z + (v_e^2 + a_e^2)(v_q^2 + a_q^2)P_Z^2\right) \cdot x(q + \bar{q})$$

$$xF_3 = \sum_{q=u...b}(-2e_q a_q a_e P_Z + 4a_q v_q v_e a_e P_Z^2) \cdot x(q - \bar{q})$$

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

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Unpolarised contribution

Polarised contribution - only includes Z and γZ terms

$$F_2^P = \sum_{q=u\ldots b}\left(2e_q a_e v_q P_Z - 2a_e v_e (v_q^2 + a_q^2) P_Z^2\right) \cdot x(q + \bar{q})$$

$$xF_3^P = \sum_{q=u\ldots b}(2e_q a_q v_e P_Z - 2a_q v_q (v_e^2 + a_e^2) P_Z^2) \cdot x(q - \bar{q})$$

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

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Unpolarised contribution

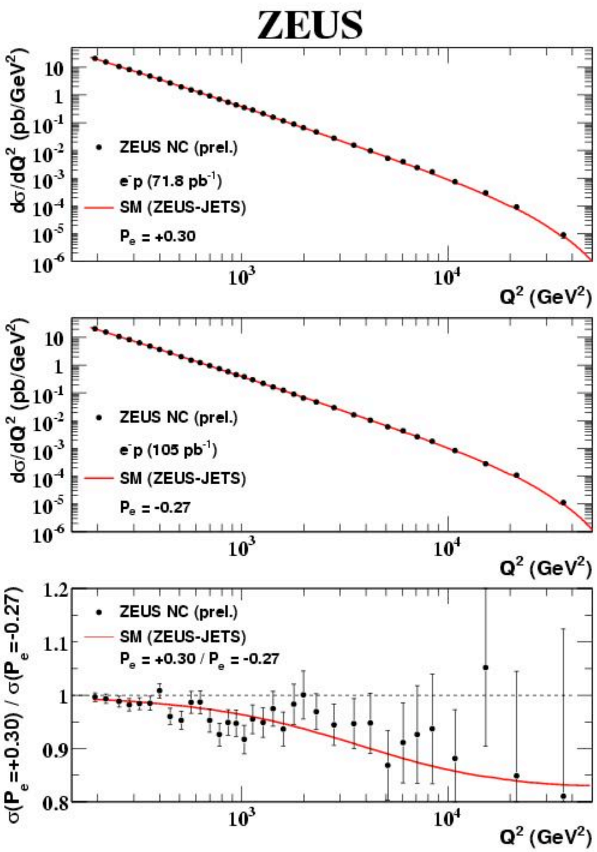
Polarised contribution - only includes Z and γZ terms

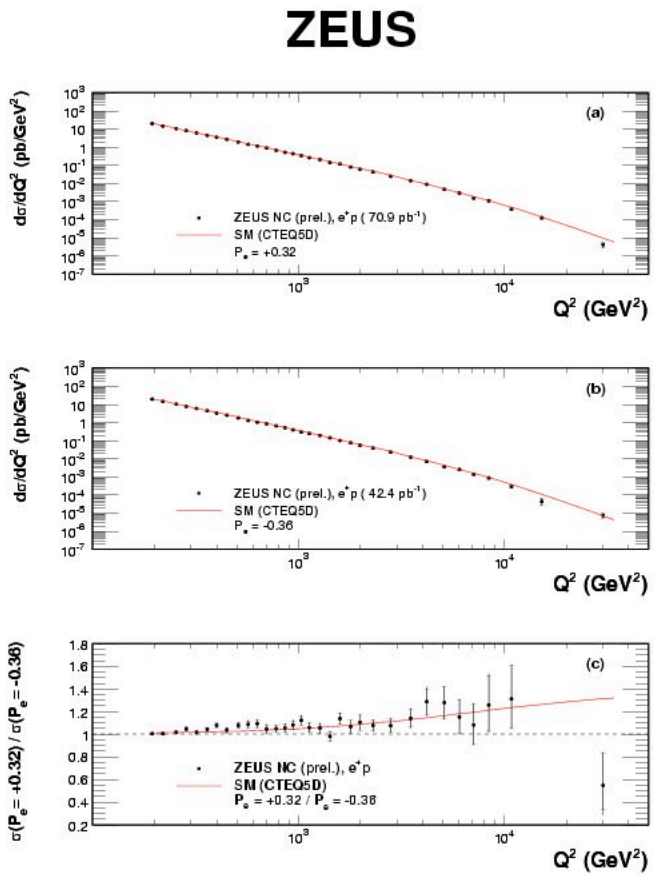
First see if we can observe subtle polarisation dependence!

Then remember that $P_Z >> P^2_Z$ and $v_e \sim 0.04$

- ➔ Axial couplings from H_0
- ➔ Vector couplings from H_P
- ➔ u-quark should have best precision (coupling to charge)

Polarised NC measurements





High precision measurements

➔ polarisation effect observed

Polarised NC measurements

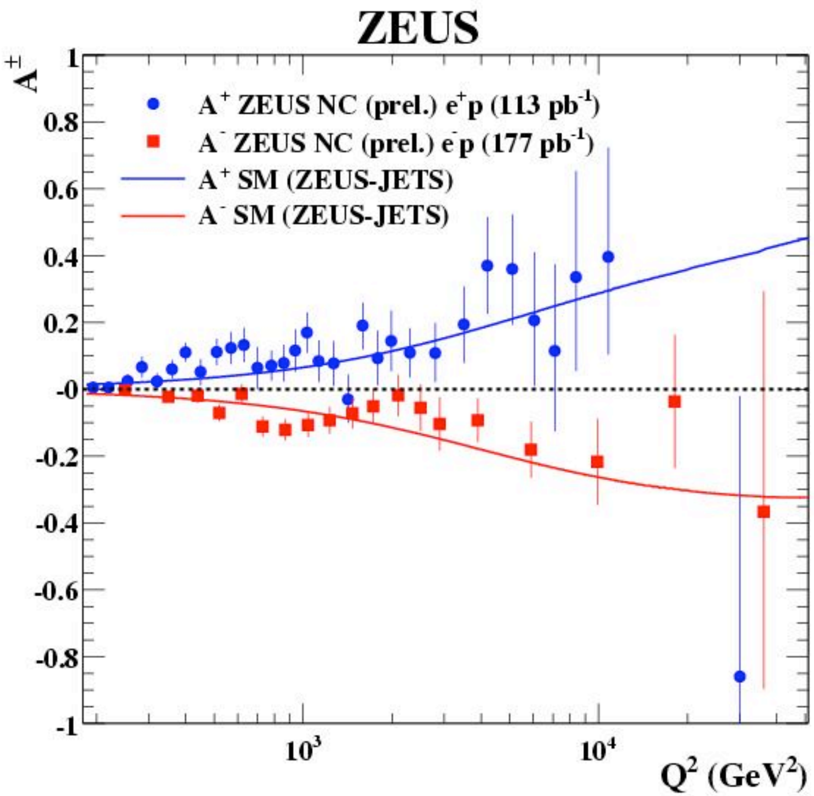
Form the polarisation asymmetry:

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

to a good approximation

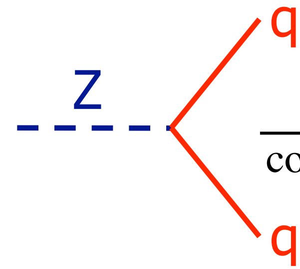
$$A^{\pm} \approx \mp k a_e \frac{F_2^{\gamma Z}}{F_2} \qquad k = \frac{1}{4\sin^2\theta_W \cos^2\theta_W} \frac{Q^2}{Q^2 + M_Z^2}$$

which is quite insensitive to the PDFs and proportional to $a_e v_q$ and therefore a direct measure of parity violation



Combined QCD & EW fit

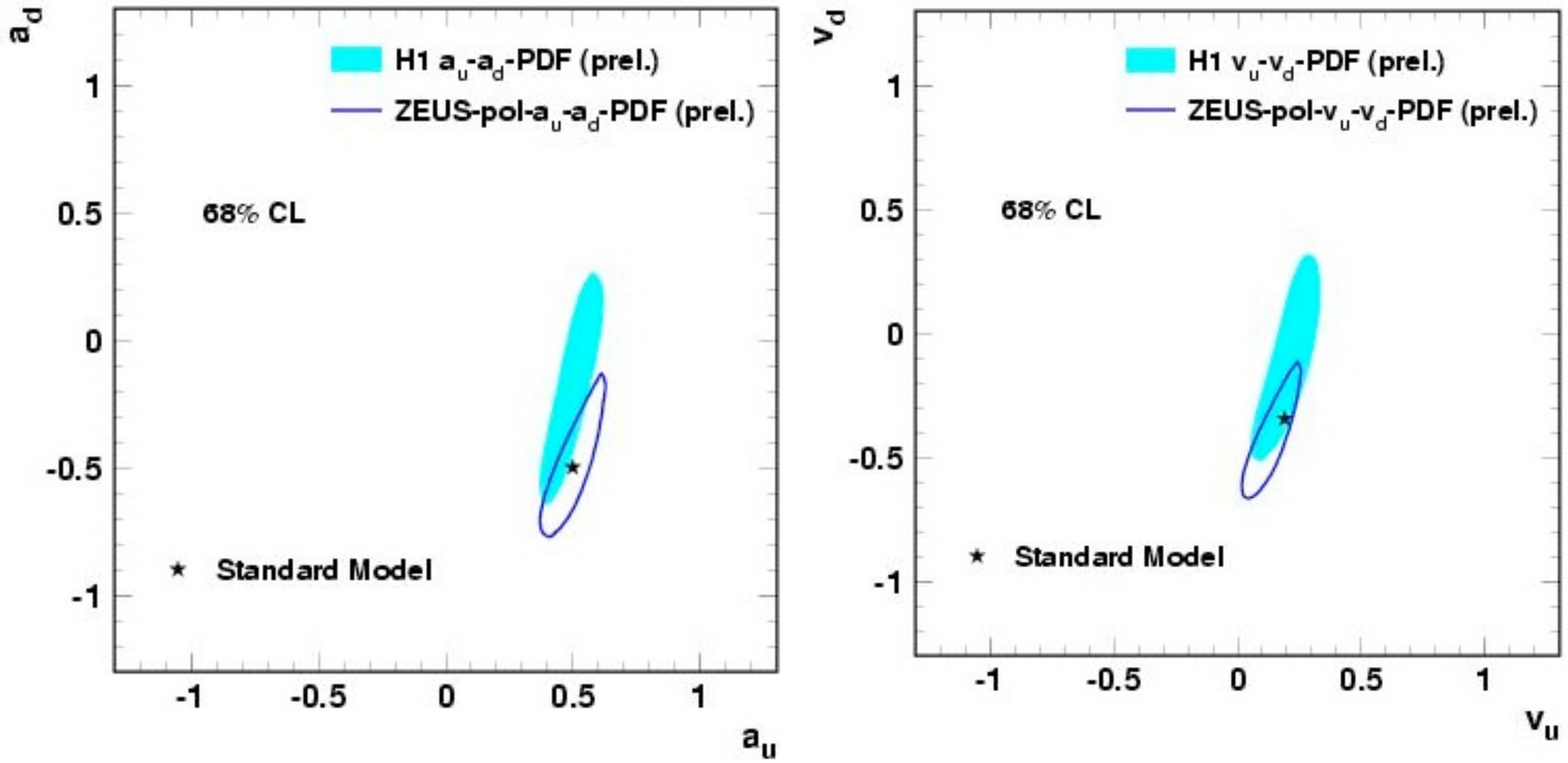
- Simultaneously fit the data for the PDFs and electroweak parameters (Phys. Lett. B 632, 35 (2006))



$$\frac{ig}{\cos\theta_W}\gamma^\mu \frac{v_q - a_q\gamma^5}{2}$$

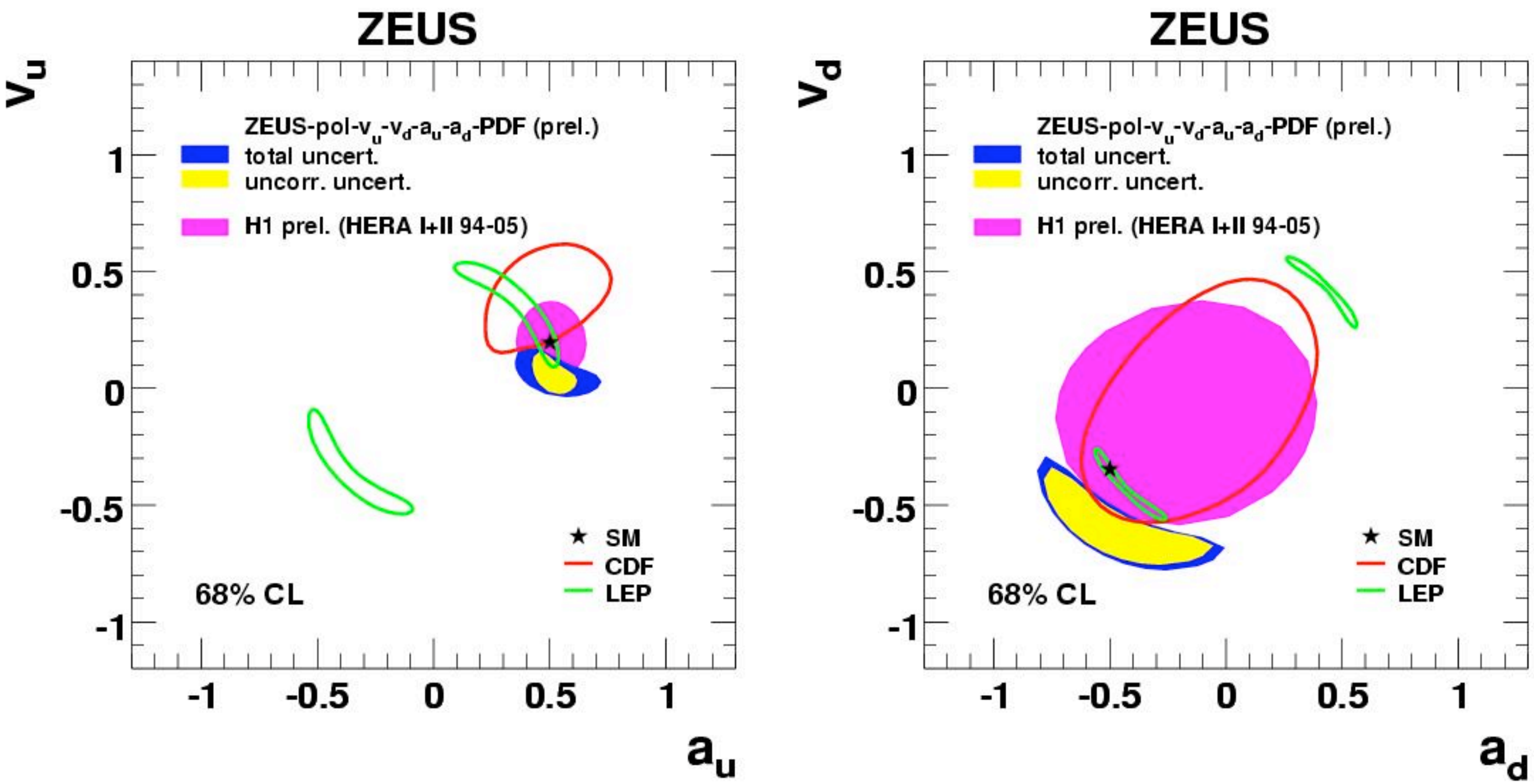
- QCD fits for PDFs well known
  - H1 follows Eur. Phys. J C30 1, (2003).
  - ZEUS follows Eur. Phys. J C42 1, (2005).
  - See talk of Burkard Reisert
- In both cases fits are to H1/ZEUS data only
- For electroweak parameters, exploit the high precision data with logitudinally polarised beams to extract light-quark axial and vector couplings to the Z^0 boson - a_u, a_d, v_u and v_d.

Combined QCD & EW fit



More sensitive to u-quark

Combined QCD & EW fit



HERA measurements competitive with LEP and Tevatron

Phys. Rep. 427, 257 (2006) & Phys. Rev. D71, 052002 (2005)

Summary

- High-precision high-Q^2 measurements
- Simultaneous determinations of the PDFs and EW parameters
- Couplings of u and d quarks to Z^0 competitive with determinations from LEP and Tevatron experiments
- Can expect improvements in precision with full data sets
- Need to combine H1 and ZEUS data

- More still to come from HERA!

Backup slides

Electroweak fit

- Fix G_F, M_W in CC cross sections to PDG
- Fix α, M_Z and M_W in NC cross sections to PDG
- $v_q = I^3_{q,L} - 2e_q \sin^2\theta_W$ $a_q = I^3_{q,L}$
- Weak radiative corrs modify the couplings to dressed couplings
- Form factors ρ_{eq}, κ_e, κ_q, κ_{eq}
- $\rho_{eq}=1$ assumed (good up to $Q^2 < 10\,000$ GeV^2)
- $\sin^2\theta_W = \kappa_q (1 - M_W^2/M_Z^2)$

Electroweak fit

ZEUS (prel.) result (H1 numbers not available)

	a_u	a_d	v_u	v_d
ZEUS	0.51±0.10±0.17	-0.54±0.32±0.18	0.05±0.09±0.05	-0.64±0.20±0.14
SM	0.5	-0.5	0.196	-0.346

H1 PDF 2000 fit

- PDFs fitted
  - U, D, Ubar, Dbar and g
- Form
  - $xq(x) = A_q x^{Bq}(1-x)^{Cq} (1+D_g x+F_q x^3)$
- Starting scale Q_0^2=4 GeV
- 10 free parameters for PDFs
- Data sets: NC and CC e^+p and e^-p DIS

ZEUS-JETS fit

- PDFs fitted
  - u and d valence, sea, gluon, u_{sea}-d_{sea}
- Form
  - $xq(x) = p_1 x^{p2}(1-x)^{p3}(1+p_4 x)$
- Starting scale Q_0^2=7 GeV
- 11 free parameters for PDFs
- Data sets: NC and CC e^+p and e^-p DIS, inclusive jets in NC DIS and γp dijets