Neutral Current Cross Sections With Polarised Lepton Beam At ZEUS

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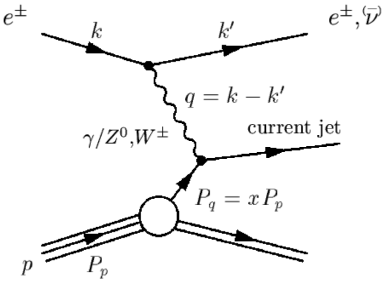
Deep Inelastic Scattering at HERA



- Neutral Current, NC: γ or Z^0 exchange
- Charged Current, CC: $W^\pm$ exchange

- Q^2 is the probing power
  $$Q^2 = -q^2 = -(k - k')^2$$
- x is the Bjorken scaling variable
  $$x = \frac{Q^2}{2p \cdot q}$$
- y is the inelasticity
  $$y = \frac{p \cdot q}{p \cdot k}$$
- They are all related via,
  $$Q^2 = x \cdot y \cdot s$$
- s is the centre-of-mass energy squared
  $$s = (p + k)^2$$

Unpolarised NC DIS Cross Section

- NC DIS cross section

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

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

- Reduced cross section

$$\tilde{\sigma}^{e^\pm p} = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma(e^\pm p)}{dxdQ^2} = F_2 \mp \frac{Y_-}{Y_+}xF_3 - \frac{y^2}{Y_+}F_L$$

- Extraction of xF_3

$$\tilde{\sigma}^{e^-p} - \tilde{\sigma}^{e^+p} = \frac{Y_-}{Y_+}2xF_3$$

- Structure functions F_2, F_L and xF_3
  - F_2: dominant contribution to $\tilde{\sigma}$

$$F_2 = F_2^{em} + \frac{Q^2}{Q^2+M_Z^2}F_2^{\gamma Z} + [\frac{Q^2}{Q^2+M_Z^2}]^2F_2^Z$$

$$\boxed{F_2 \propto \sum_{q=u\ldots b}(q+\bar{q})}$$

  - xF_3: contribution only important at high Q^2

$$xF_3 = \frac{Q^2}{Q^2+M_Z^2}xF_3^{\gamma Z} + [\frac{Q^2}{Q^2+M_Z^2}]^2xF_3^Z$$

$$\boxed{xF_3 \propto \sum_{q=u\ldots b}(q-\bar{q})}$$

  - F_L: sizeable impact only at high y

Polarised NC DIS Cross Section

- NC DIS cross section modified by polarisation, P_e

$$\frac{d^2\sigma(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[H_0^\pm + P_e H_P^\pm]$$

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

$$H_{0/P}^\pm = Y_+ F_2^{0/P} \mp Y_- xF_3^{0/P}$$

- Using polarised and unpolarised structure functions

$$F_2^{0/P} = \sum_i x(q_i + \bar{q}_i)A_i^{0/P} \qquad xF_3^{0/P} = \sum_i x(q_i - \bar{q}_i)B_i^{0/P}$$

- Where $A_i^{0/P}$ and $B_i^{0/P}$ contain the electron and quark couplings

Polarised and Unpolarised Coefficients

- Unpolarised coefficients

$$A_i^0 = e_i^2 - 2e_i v_i v_e P_Z + (v_e^2 + a_e^2)(v_i^2 + a_i^2)P_Z^2$$
$$B_i^0 = -2e_i a_i a_e P_Z + 4a_i v_i v_e a_e P_Z^2$$

v: vector coupling
a: axial coupling

- Polarised coefficients

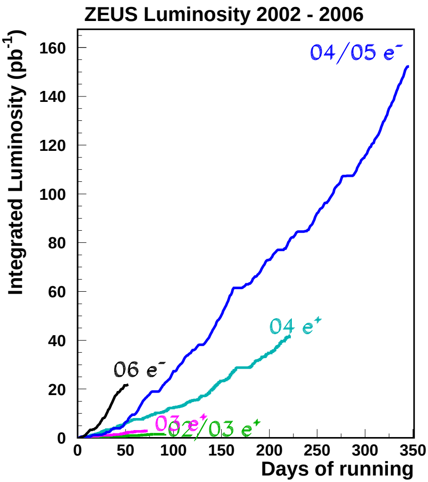
$$A_i^P = 2e_i a_e v_i P_Z - 2a_e v_e (v_i^2 + a_i^2)P_Z^2$$
$$B_i^P = 2e_i a_i v_e P_Z - 2a_i v_i (v_e^2 + a_e^2)P_Z^2$$

- All terms in the polarised coefficients depend on P_Z

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

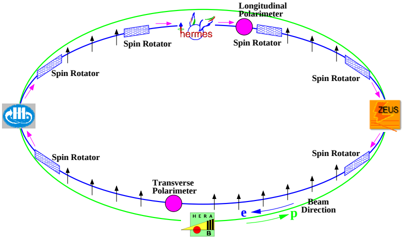
- So polarised structure functions depend only on terms related to Z^0 exchange
- Expect effect of polarisation on the NC cross section to be significant only at high Q^2

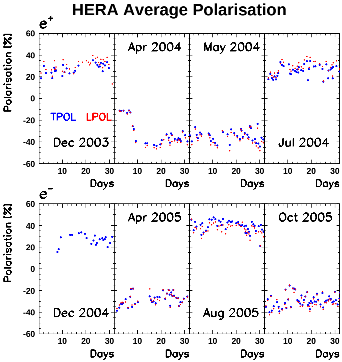
Luminosity



- Collisions between $e^\pm$ and protons
- Energies:
  - $e^\pm \sim 27.6$ GeV
  - p ~ 920 GeV
  - Centre-of-mass ~ 320 GeV
- Will present results based on:
- e^+p, $\mathcal{L} = 23.8$ pb^{-1} from 2004
  - Submitted to Physics Letters B
  - ZEUS Collab, S.Chekanov et al., hep-ex/060226
- e^-p, $\mathcal{L} = 121.5$ pb^{-1} from 2004 and 2005
  - Preliminary results

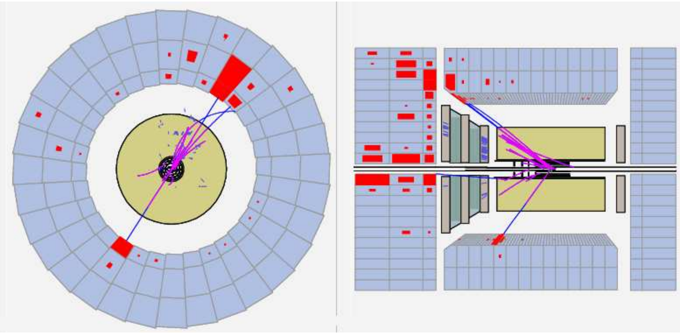
Polarisation





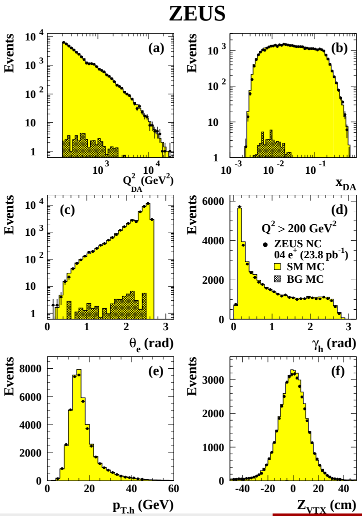
- Transverse polarisation builds up naturally in lepton beam
- Spin rotators turn this into longitudinal polarisation
- e^+p data $\rightarrow \mathcal{L}$ weighted average of +32% and -41%
- e^-p data $\rightarrow \mathcal{L}$ weighted average of +33% and -27%

NC DIS Event in the ZEUS Detector



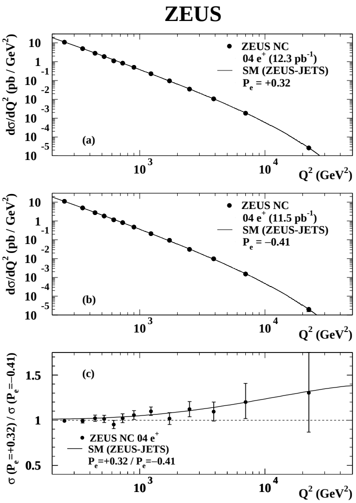
- Well measured scattered electron with high transverse momentum
- Energy deposits of electron and hadronic jet balanced in ϕ

Neutral Current Sample (e^+p Data)



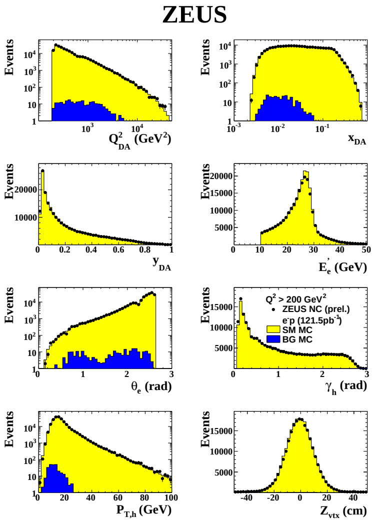
- e^+p data, $\mathcal{L} = 23.8$ pb^{-1}
  - $P_e = +32\%$, $\mathcal{L} = 12.3$ pb^{-1}
  - $P_e = -41\%$, $\mathcal{L} = 11.5$ pb^{-1}
- Q^2 and x from double angle method
- Scattered electron angle with respect to the proton direction
- Hadronic jet angle and transverse momentum
- Z position of the ep interaction vertex
- Data understood well

$d\sigma/dQ^2$ with +ve and -ve P_e



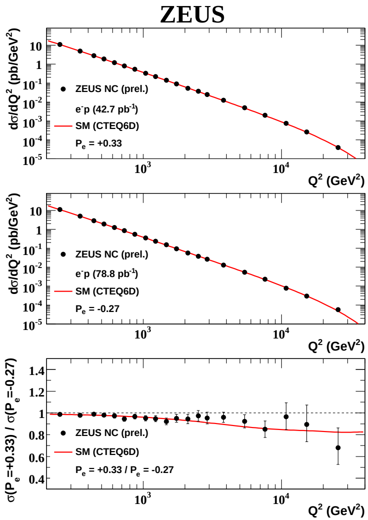
- Top, middle, bottom plots:
  - $d\sigma/dQ^2$ with +ve P_e
  - $d\sigma/dQ^2$ with -ve P_e
  - Ratio of cross-sections, +ve P_e / -ve P_e
- Measurements consistent with SM expectations
- χ^2 test for $Q^2 > 1000$ GeV^2:
- +ve P_e / -ve P_e = 1 case
  - χ^2 / ndf = 1.5
- +ve P_e / -ve P_e = SM case
  - χ^2 / ndf = 0.3

Neutral Current Sample (e^-p Data)



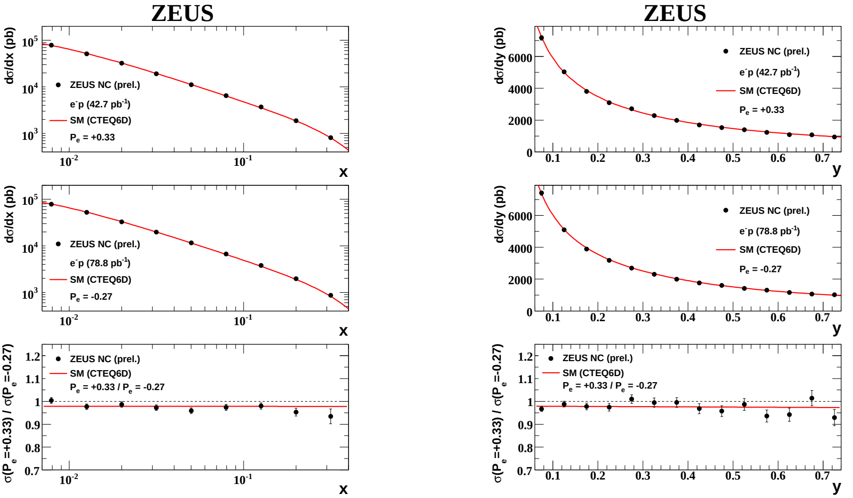
- e^-p data, $\mathcal{L} = 121.5$ pb^{-1}
  - $P_e = +33\%$, $\mathcal{L} = 42.7$ pb^{-1}
  - $P_e = -27\%$, $\mathcal{L} = 78.8$ pb^{-1}
- Q^2, x and y calculated using the double angle method
- Scattered electron energy and angle
- Hadronic jet angle and transverse momentum
- Z position of the vertex
- Data well described

$d\sigma/dQ^2$ with +ve and -ve P_e



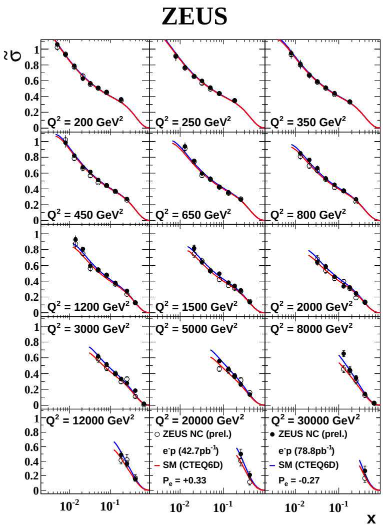
- Top, middle, bottom plots:
  - $d\sigma/dQ^2$ with +ve P_e
  - $d\sigma/dQ^2$ with -ve P_e
  - Ratio of cross-sections, +ve P_e / -ve P_e
- Parity violation now clearly observed in NC data!
- χ^2 test for all points:
- +ve P_e / -ve P_e = 1 case
  - χ^2 / ndf = 50.1 / 20 = 2.51
- +ve P_e / -ve P_e = SM case
  - χ^2 / ndf = 9.44 / 20 = 0.47

$d\sigma/dx$ and $d\sigma/dy$ with +ve and -ve P_e



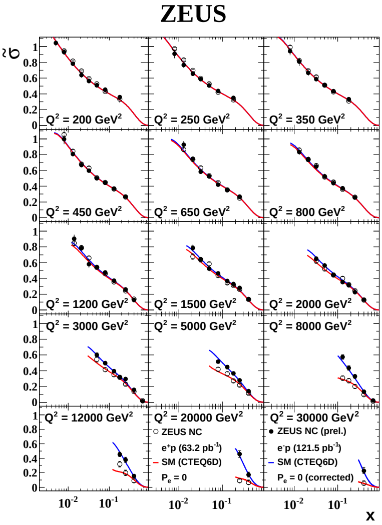
- Overall shift in cross-section ratios due to polarisation

$\tilde{\sigma}$ (Polarised)



- First measurements of reduced cross sections with polarised e^-
- Closed circles $\rightarrow$ -ve P_e data
- Open circles $\rightarrow$ +ve P_e data
- Polarisation gives a small effect on $\tilde{\sigma}$
- Data agrees well with prediction

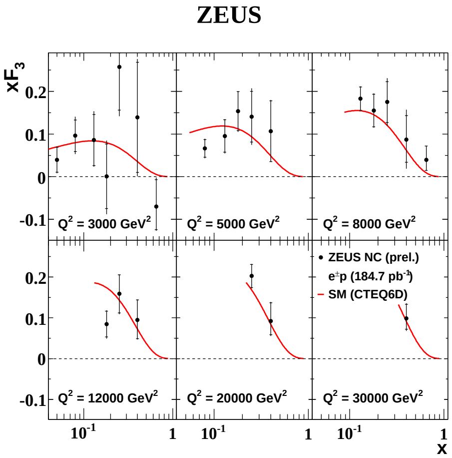
$\tilde{\sigma}$ (Unpolarised)



- Closed circles → Full data set of $\tilde{\sigma}^{e^-p}$ corrected for residual polarization ($P_e \sim$ -6%)
- Open circles → Previously measured unpolarised $\tilde{\sigma}^{e^+p}$
- Difference in $\tilde{\sigma}$ seen very well between e^-p and e^+p
  - This is our xF_3!

$$\boxed{\tilde{\sigma}^{e^\pm p} = F_2 \mp \frac{Y_-}{Y_+} xF_3 - \frac{y^2}{Y_+} F_L}$$

xF_3 Extraction



- $e^{\pm}p$ data combined to extract xF_3

$$\boxed{\tilde{\sigma}^{e^-p} - \tilde{\sigma}^{e^+p} = \frac{Y_-}{Y_+} 2xF_3}$$

- Previous measurement dominated by statistical uncertainties due to limited amount of e^-p data $\sim 16\ \mathrm{pb}^{-1}$
- Now can make use of $\sim 120\ \mathrm{pb}^{-1}$ of e^-p data!
- More precise xF_3 measurement

Summary

- First measurements of the polarised cross sections with e^+p and e^-p data with polarised lepton beam
- Parity violation clearly observed with high luminosity e^-p data!
- xF_3 measurement made combining new e^-p data with previously measured unpolarised e^+p data

- Outlook
  - Look forward to more polarised e^-p running this year with a switch to positrons this summer
  - Hope to achieve precision measurements with full HERA II data set $\mathcal{O}(1\mathrm{fb}^{-1})$