High-Q^2 Charged and Neutral Current Cross Sections With Polarised Positron Beam At ZEUS

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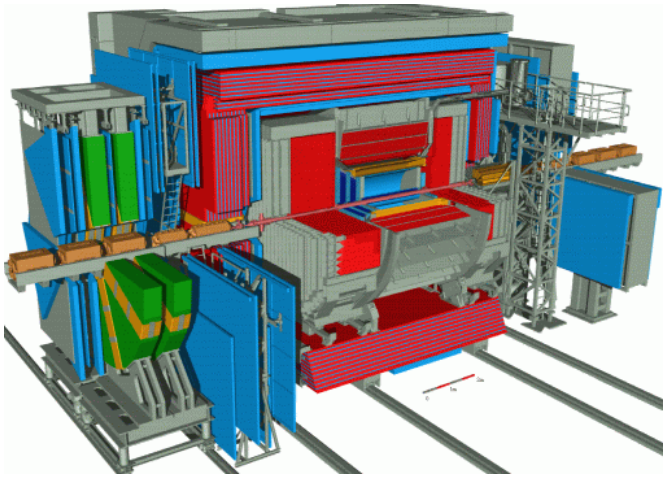
On Behalf of the ZEUS Collaboration

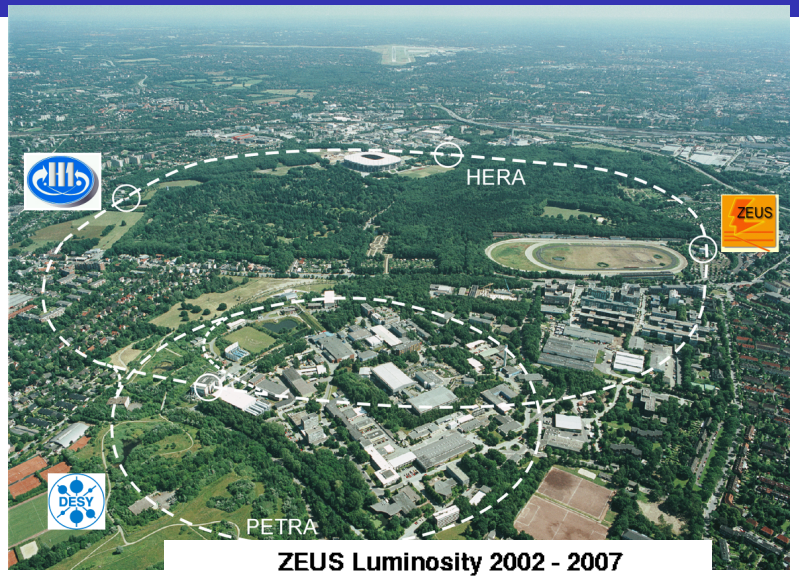


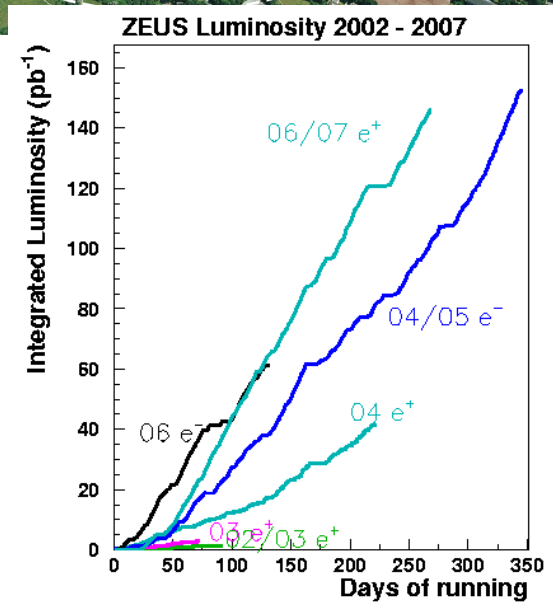
DIS 2011, 11-15 April,
Newport News, VA USA

1. Charged current e^+p.
2. Neutral current e^+p.

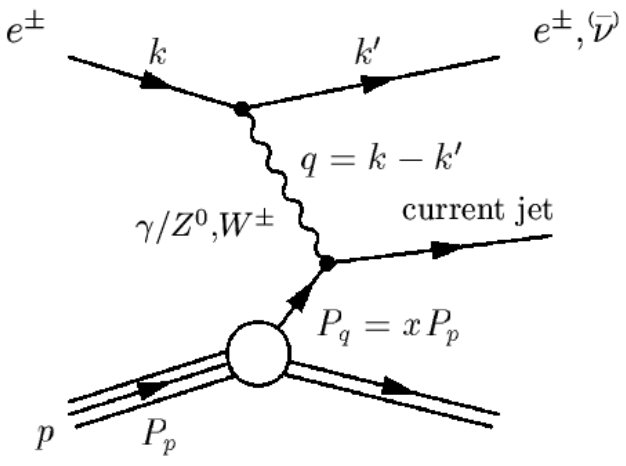
HERA II with Longitudinal Polarised $e^{\pm}$ Beams

- p beam: 920 GeV
- $e^{\pm}$ beam: 27.5 GeV
- centre-of-mass energy: 318 GeV
- Two general purpose experiments, H1 and ZEUS (ZEUS data to be shown).
- $\approx 0.5 fb^{-1}$ taken by each experiment.
- HERA II upgrade:
  - Increased luminosity.
  - Longitudinally polarised $e^{\pm}$ beams.
- Mean longitudinal polarisation, $P_e = (N_R - N_L)/(N_R + N_L) \approx 30 - 40\%$





Deep Inelastic Scattering



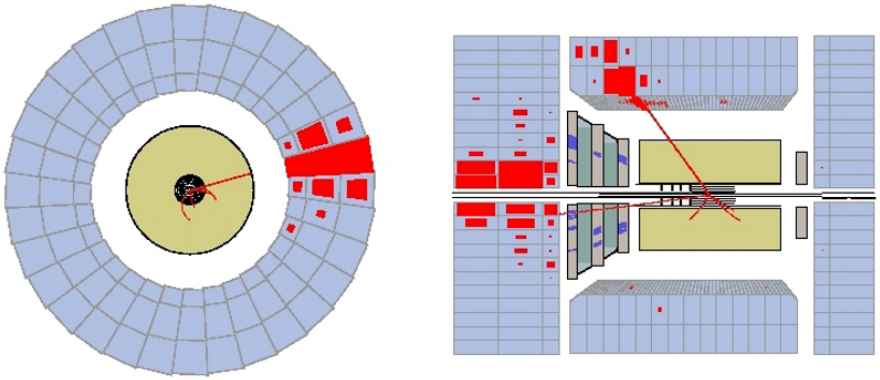
- Neutral Current (NC), γ or Z_0 exchange.
  $e^{\pm}p \rightarrow e^{\pm}X$
- Charged Current (CC), $W^{\pm}$ exchange.
  $e^{\pm}p \rightarrow \nu X$

Variables which characterize DIS:

- Q^2 probing power, negative 4-momentum squared:
  $Q^2 = -q^2 = -(k - k^{'})$
- Bjorken x, momentum fraction of proton carried by struck quark:
  $x = Q^2/2p \cdot q$
- Inelasticity y:
  $y = p \cdot q/p \cdot k$
- s is the centre-of-mass energy squared:
  $s = (p + k)^2$
- These are related by:
  $Q^2 = sxy$

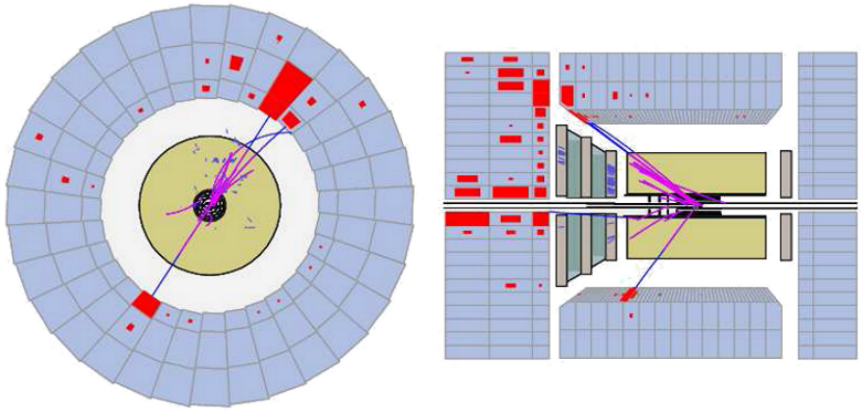
Charged and Neutral Current events in the ZEUS detector

Charged Current



- $\nu(\bar{\nu})$ escapes the detector volume.
- Jet energy deposits not blanced by $e^{\pm}$ deposits.
- Characterised by missing-P_t.

Neutral Current

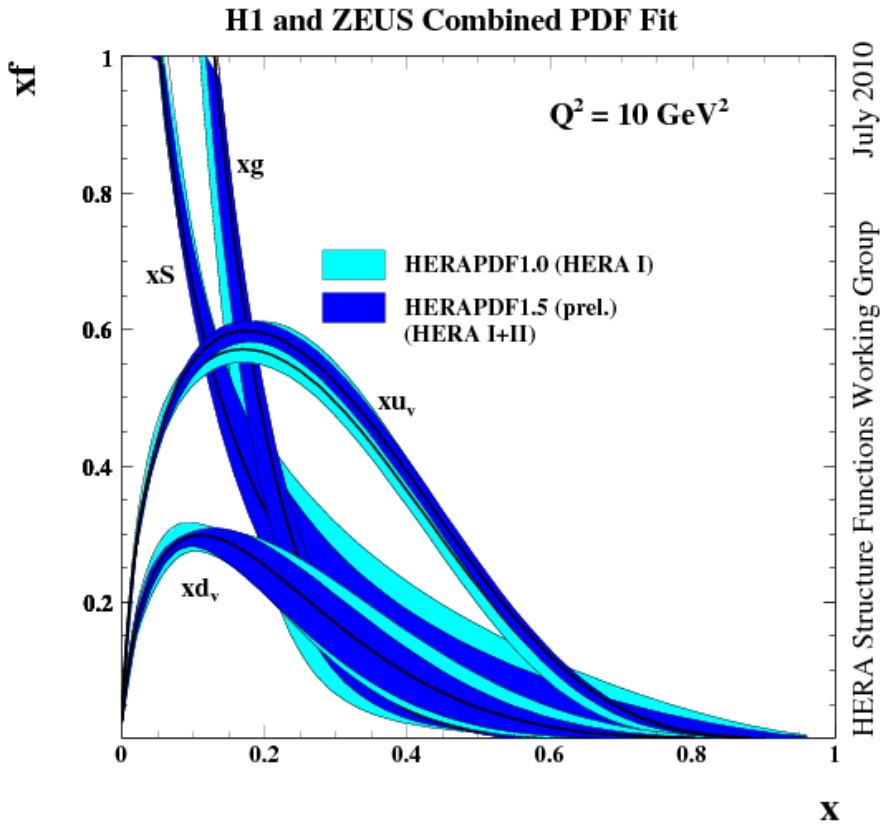


- Well measured scattered $e^{\pm}$.
- $e^{\pm}$ energy deposits and Jet(s) balanced in ϕ.

Motivation

Why are High Precision High-Q^2 CC and NC measurements important?

- The CC cross sections give a powerful probe of the flavour specific parton distributions (PDFs).
- The NC cross sections are sensitive to all flavours.
- The difference between the e^+p and e^-p NC cross sections give direct access to the structure function xF_3.
- The longitudinal polarisation asymmetry, $A^+ \approx a_e v_q$ allows parity violation to be directly measured.



Charged Current Cross Section

In the SM the $W^{\pm}$ interact only with left(right) (anti-)particles.

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

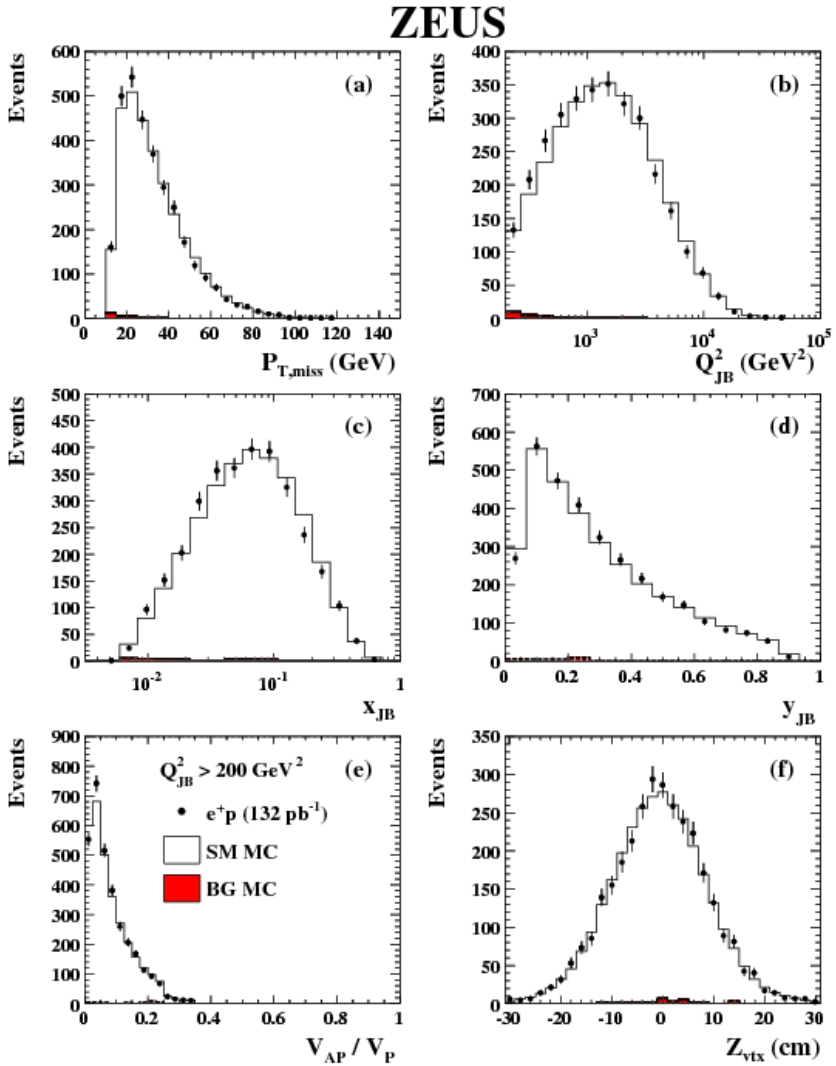
$$\frac{d^2\sigma_{CC}^{e^{\pm}p}}{dxdQ^2} = (1 \pm P_e)\frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \tilde{\sigma}_{CC}^{e^{\pm}p}$$

where $\tilde{\sigma}_{CC}^{e^{\pm}p}$ is the reduced cross section. e^+ and e^- sensitive to different quark densities:

$$\tilde{\sigma}_{CC}^{e^+p} = x[(\bar{u} + \bar{c}) + (1 - y)^2(d + s)]$$

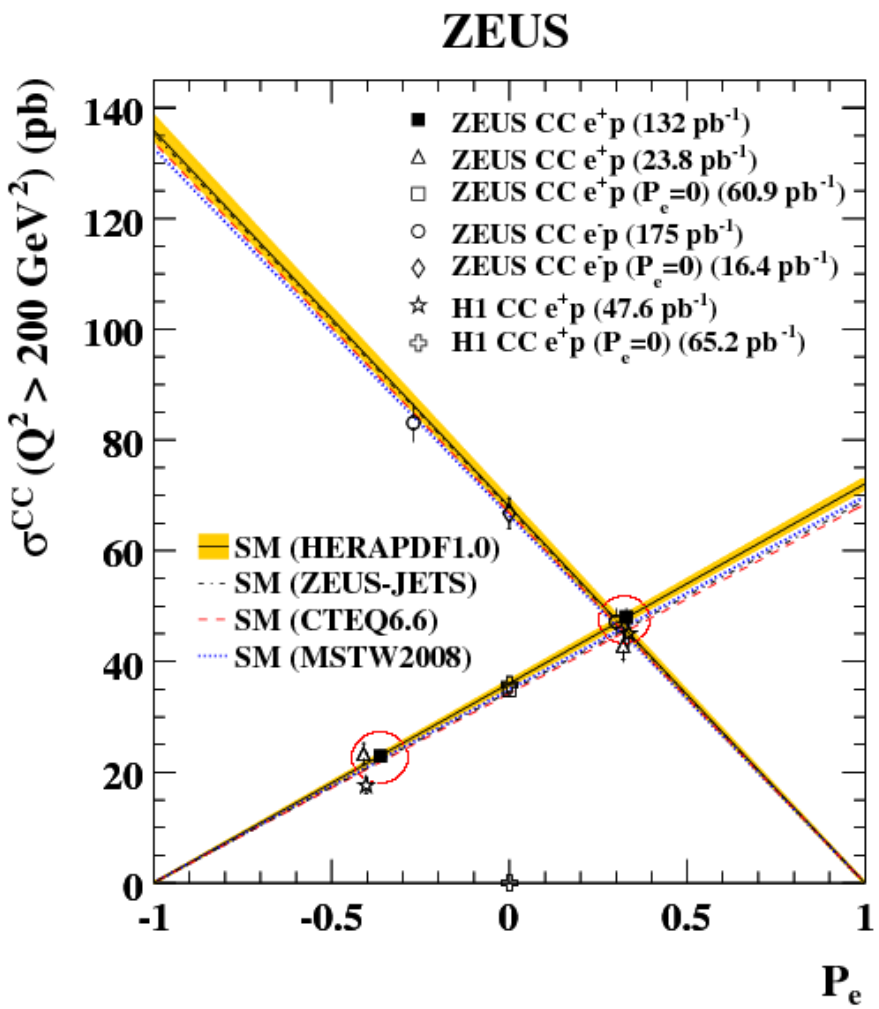
$$\tilde{\sigma}_{CC}^{e^-p} = x[(u + c) + (1 - y)^2(\bar{d} + \bar{s})]$$

Charged Current Sample (e^+p Data)



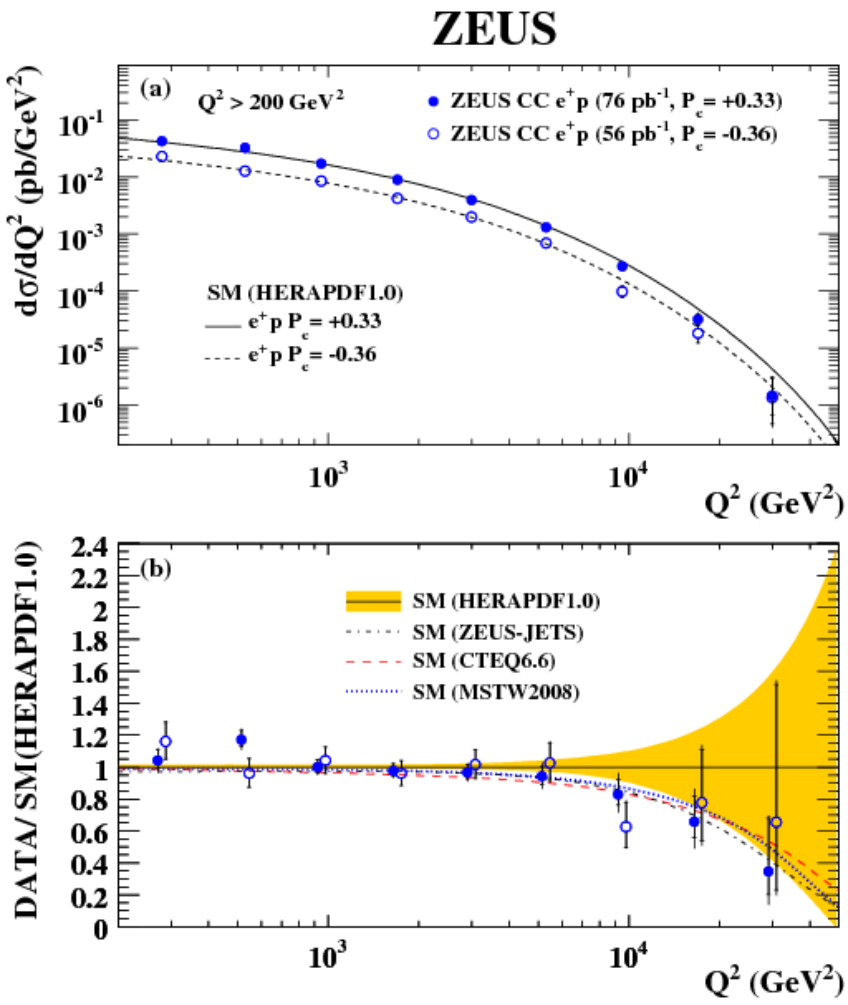
- Results published in 2010.
  - Eur. Phys. J. C (2010) 70: 945963.
- e^+p data, taken 2006-07, $\mathcal{L} = 132pb^{-1}$
  - $P_e = +33\%$, $\mathcal{L} = 75.8pb^{-1}$
  - $P_e = -36\%$, $\mathcal{L} = 56.0pb^{-1}$
- Data well understood.

Total cross section with +ve and -ve P_e



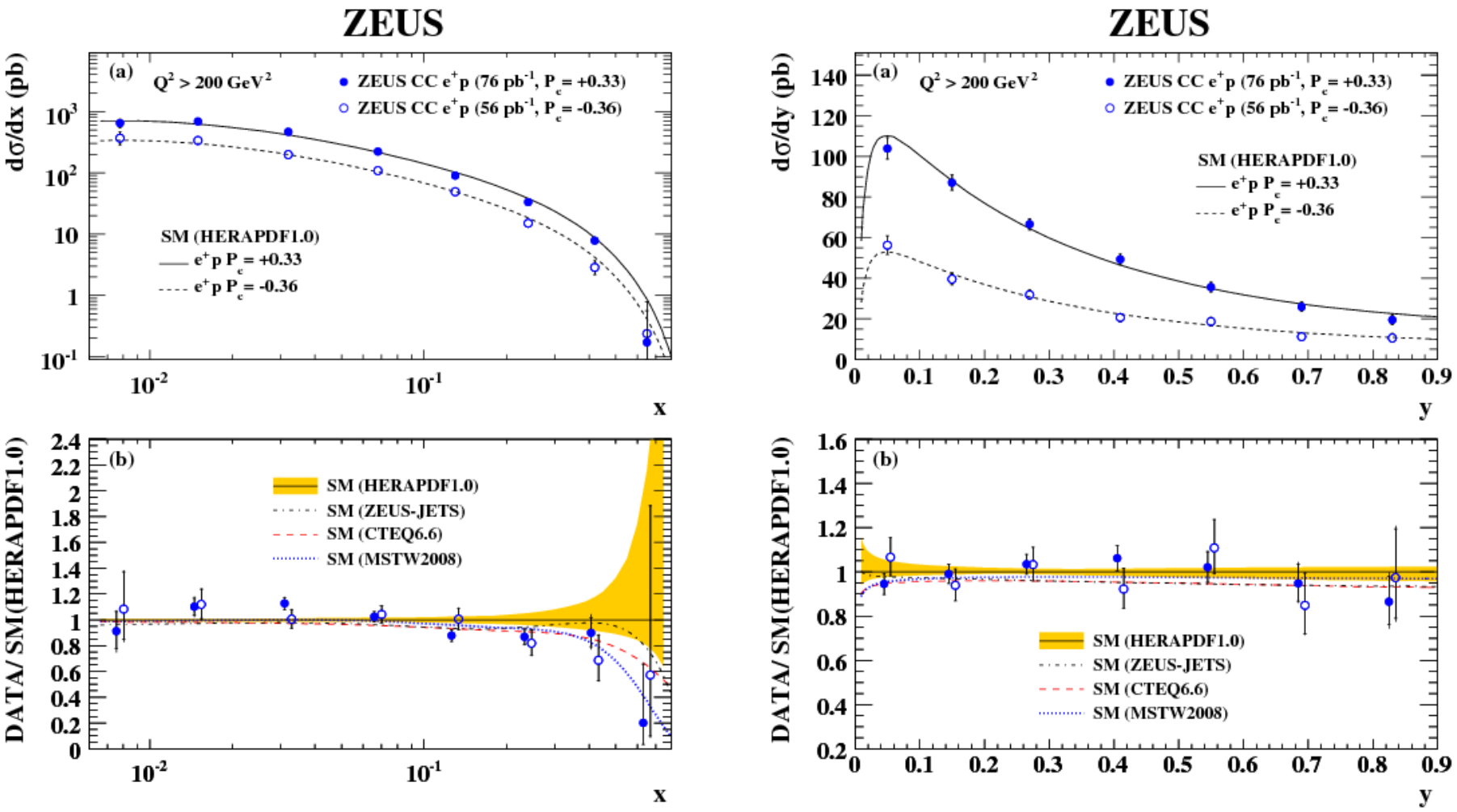
- The total cross section as a function of the longitudinal polarisation of the lepton beam.
  - Results from the e^+p analysis are shown as filled squares for +ve and -ve polarisation (circled in red).
  - Previous e^+p and e^-p results from H1 and ZEUS also shown.
- Results not included in SM predictions (HERAPDF1.0).
  - Measurements consistent with SM expectations.

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

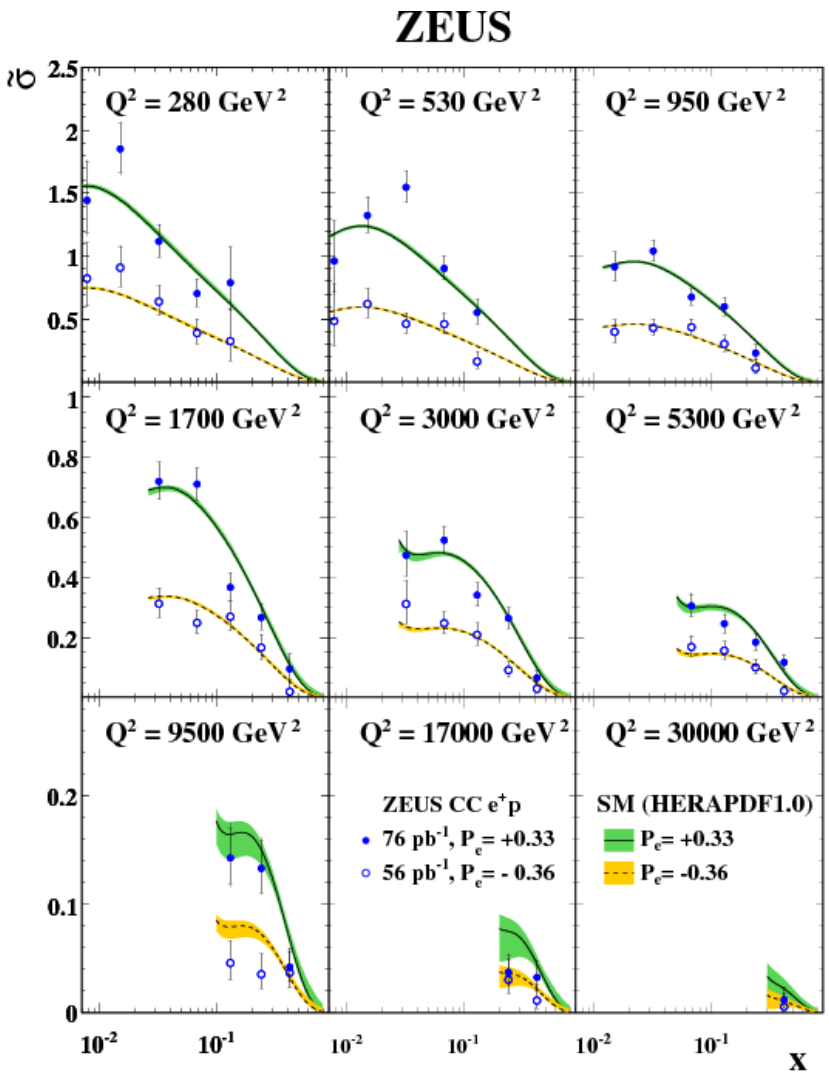


- Overall shift in cross sections due to effect of polarisation.
- Will help constrain PDF fit.
- Good agreement with SM expectation.

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

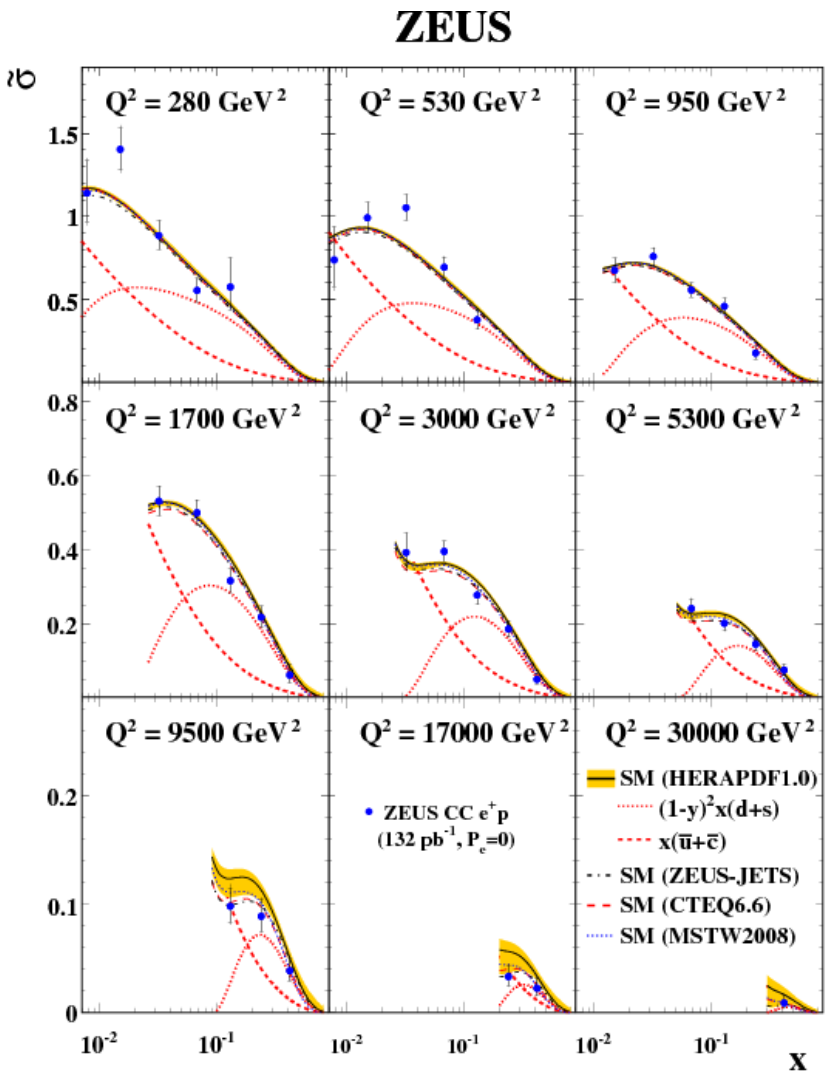


$\tilde{\sigma}$ with +ve and -ve P_e



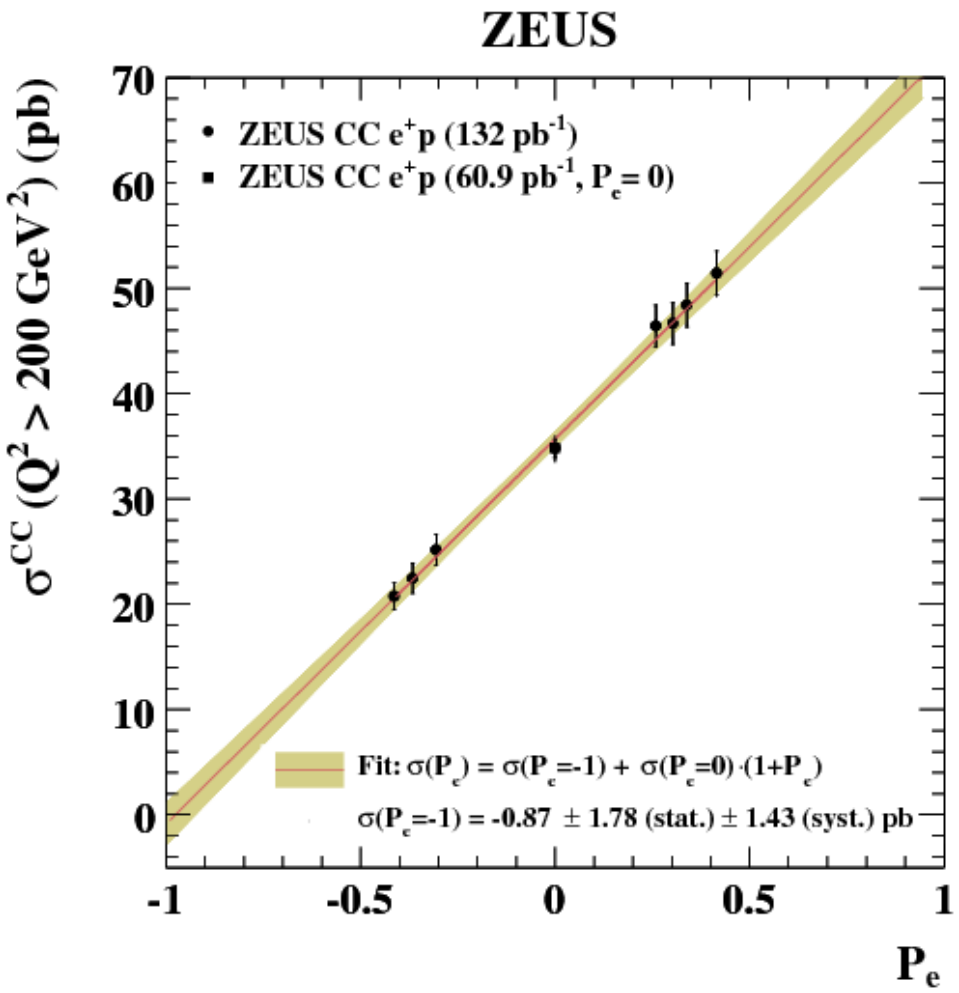
- Effect of polarisation clearly seen.
- Adding this data will further constrain the PDF fits.
- Good agreement with SM predictions

$\tilde{\sigma}$ with $P_e = 0$



- The e^+p CC reduced cross section constrain the d quark density.
- As seen earlier, the reduced cross section, $\tilde{\sigma}$, at LO can be written as a sum of $x(\bar{u}+\bar{c})$ and $(d+s)$ contributions.

Total cross section at multiple polarisation values



- CC e^+p Cross section becomes 0 for $P_e = -1$ positron beam.
  - A non-zero cross section might point to the existance of a right-handed W boson, W_R.
- Extrapolation to P_e=-1 consitant with 0.
- Limit placed on $\sigma^{CC}(P_e = -1)$ and M_{W_R} GeV consistent with other experiments.

Neutral Current Cross Section

- Mediated by both γ and Z_0

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

$$\tilde{\sigma}_{NC}^{e^\pm p} = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma_{NC}^{e^+p}}{dxdQ^2} = \tilde{F}_2 \mp \frac{Y_-}{Y_+}x\tilde{F}_3 - \frac{y^2}{Y_+}\tilde{F}_L$$

- Where $\tilde{F}_2$,$x\tilde{F}_3$ and $\tilde{F}_L$ are the generalised structure functions.
- $Y_\pm$ is given by:

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

Generalised Structure Functions

- The generalized structure functions are given by:

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

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

$$\text{where } \kappa = \frac{1}{sin^2 2\theta_w}\frac{Q^2}{Q^2 + M_Z^2}$$

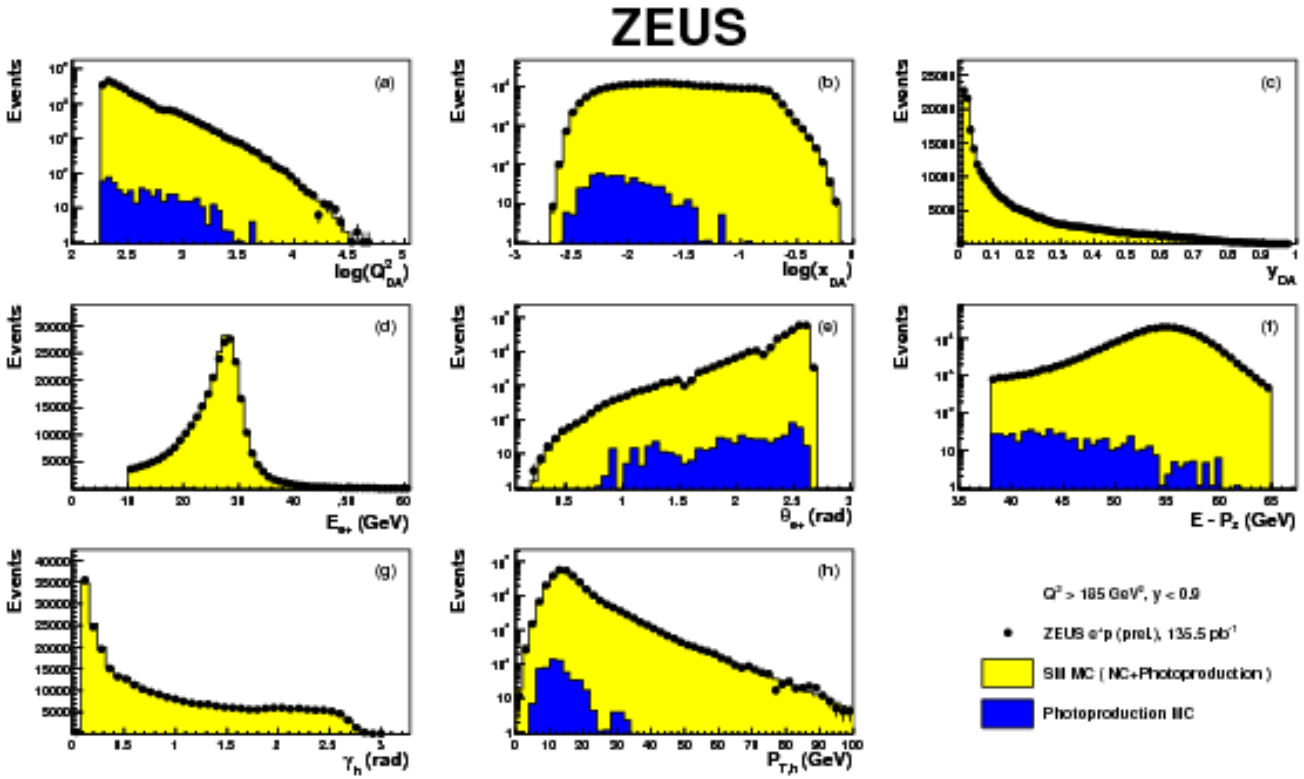
$$\{F_2^{\gamma}, F_2^{\gamma Z}, F_2^{Z}\} = \sum_q \{e_q^2, 2e_q\nu_q, v_q^2 + a_q^2\}x(q + \bar{q})$$

$$\{xF_3^{\gamma Z}, xF_3^{Z}\} = \sum_q \{e_q a_q, v_q a_q\}2x(q - \bar{q})$$

- $\tilde{F}_2$ dominates $\tilde{\sigma}_{NC}^{e^{\pm}p}$.
- $x\tilde{F}_3$ contributes only at high Q^2.
- $\tilde{F}_L$ contributes at high y.

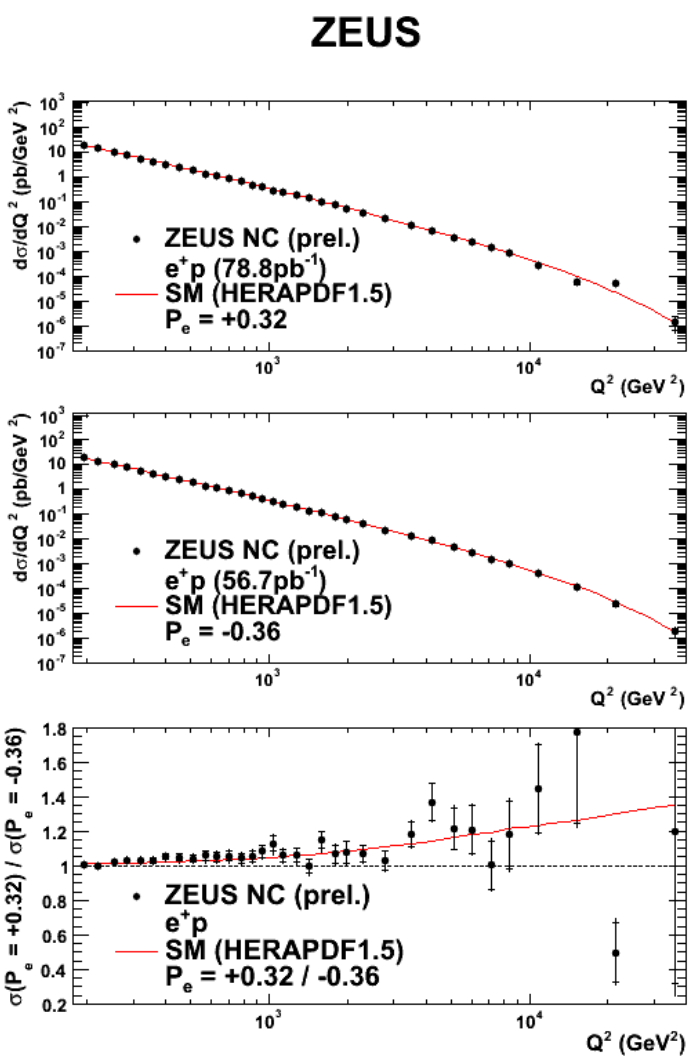
Neutral Current Sample (e^+p Data)

- New result (ZEUS-prel-11-003).
  - Missing result of the HERA-II ZEUS high-Q^2 inclusive analyses.



- e^+p data, taken 2006-07, $\mathcal{L} = 135 pb^{-1}$
  - $P_e = +32\%$, $\mathcal{L} = 78.8 pb^{-1}$
  - $P_e = -36\%$, $\mathcal{L} = 56.7 pb^{-1}$
- Kinematic range: $Q^2 > 185 GeV$ and $y < 0.9$.
- Data well described.

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



- The difference between the two polarisation states clearly seen at higher-Q^2.

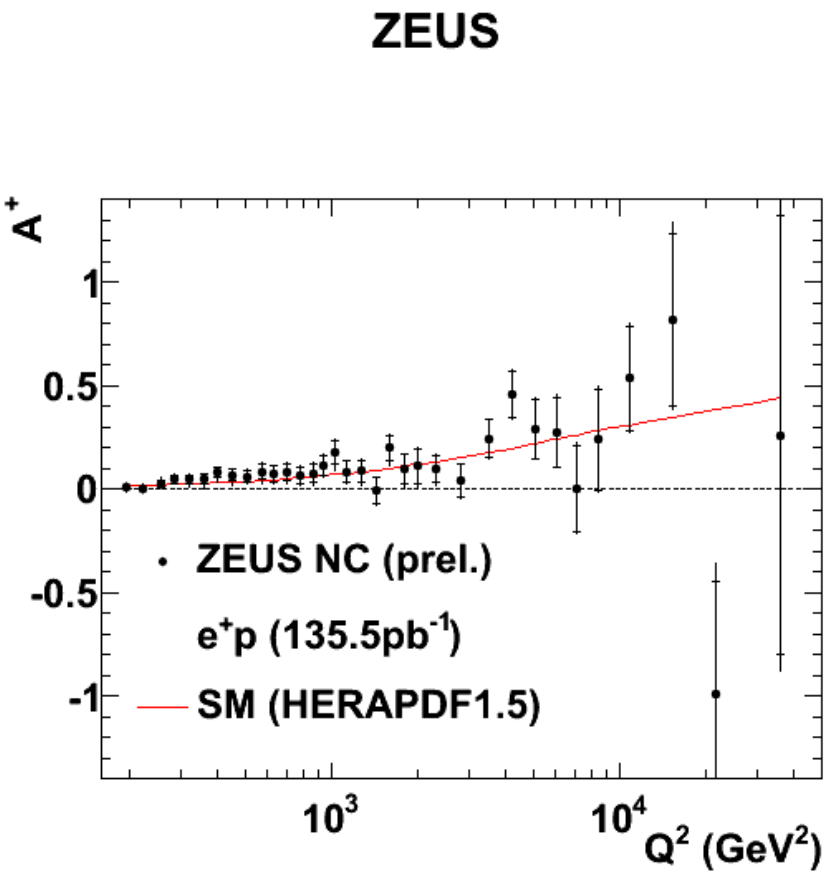
← RH: $d\sigma/dQ^2$ with +ve P_e.

← LH: $d\sigma/dQ^2$ with -ve P_e.

← RH/LH: ratio of cross sections +ve P_e/-ve P_e.

- These results not included in the shown SM expectation (HERAPDF1.5).

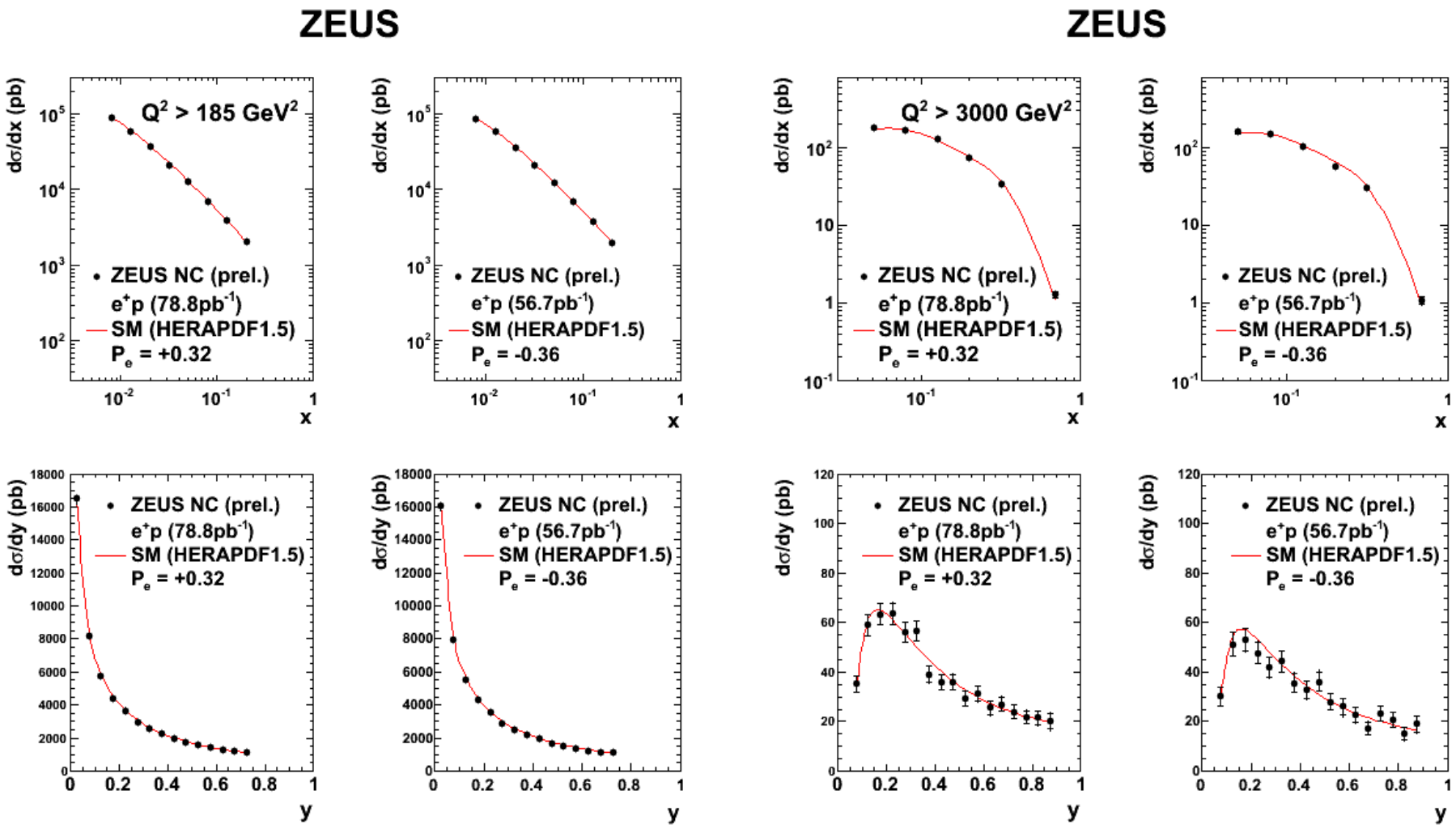
Asymmetry



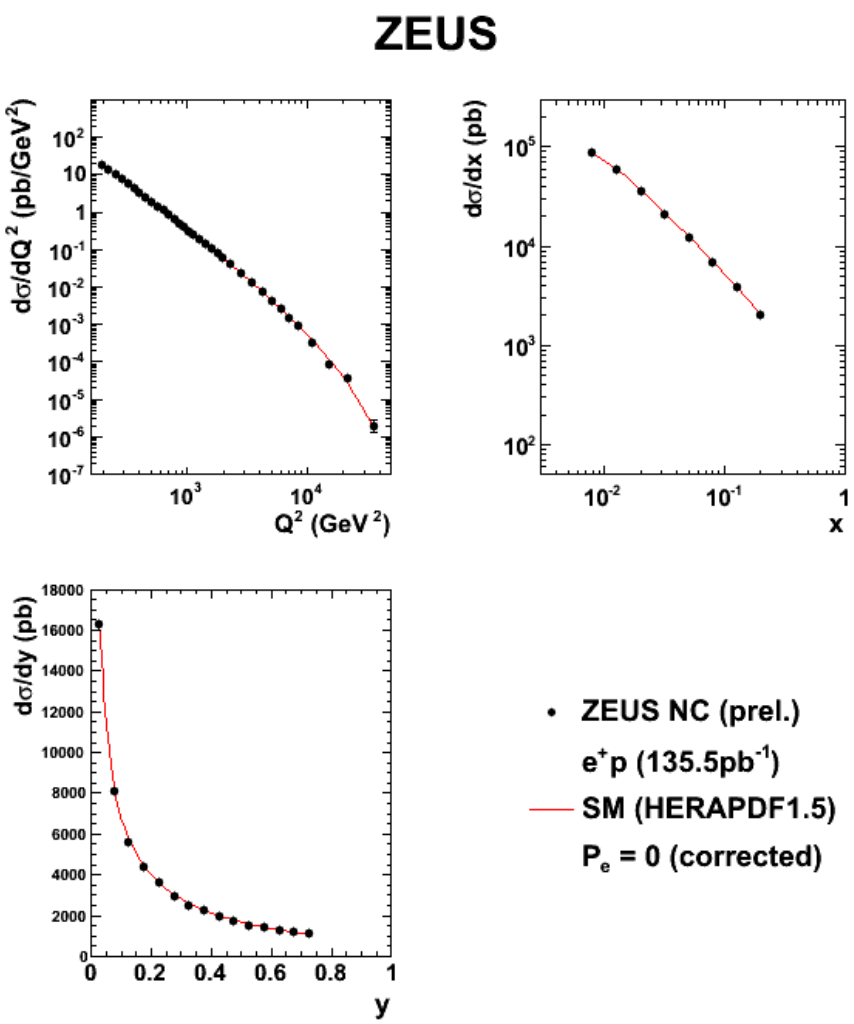
$$A^+ = \frac{2}{P_+ - P_-} \frac{\sigma^+(P_+) - \sigma^+(P_-)}{\sigma^+(P_+) + \sigma^+(P_-)}$$

- $A^+ \approx a_e \kappa \frac{F_2^{\gamma Z}}{F_2^{\gamma}} = a_e \kappa \frac{2 e_q \nu_q}{e_q^2} = \propto a_e \nu_q$
- A^+ sensitive to ν_q.
- A^+ increase with Q^2.

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

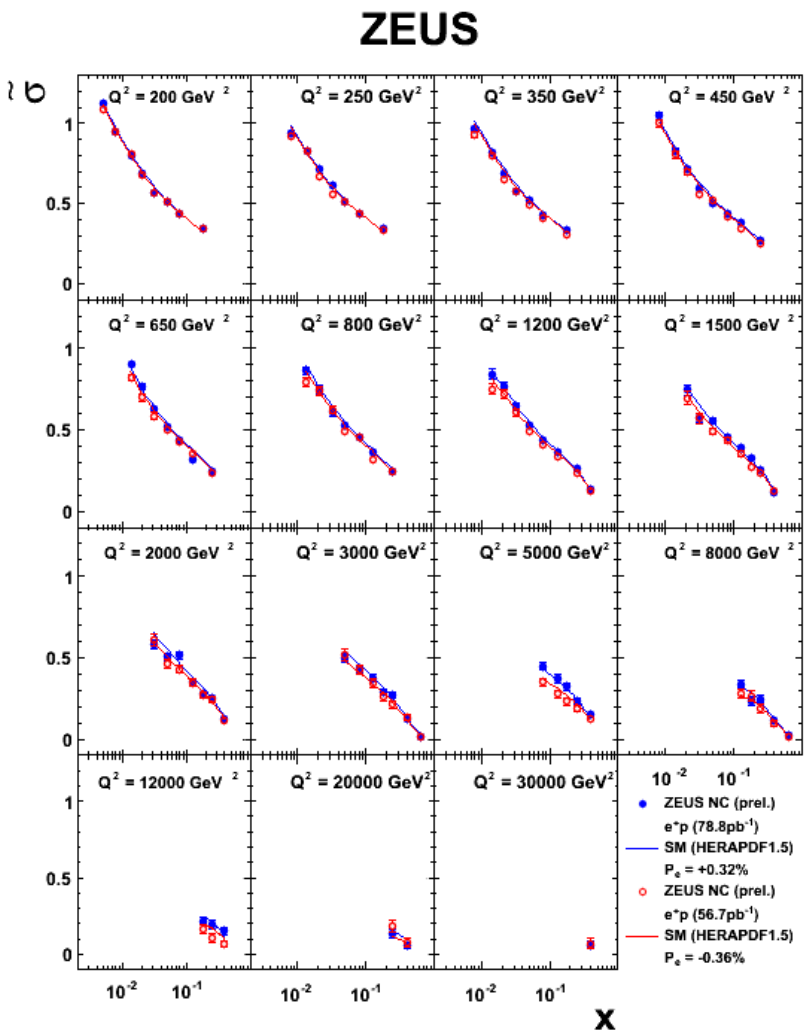


$d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$ with P_e=0

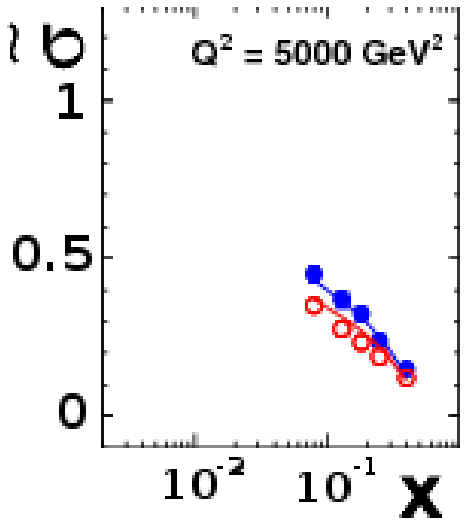


- These results will help constrain the PDFs.

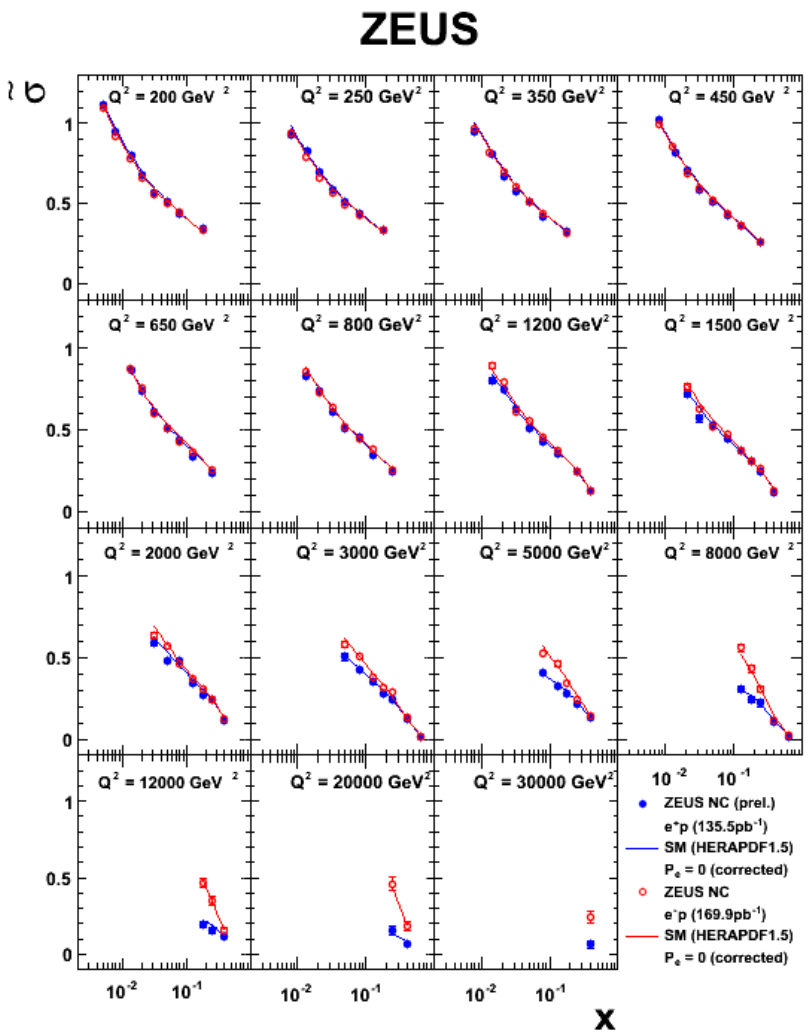
$\tilde{\sigma}$ with +ve and -ve P_e



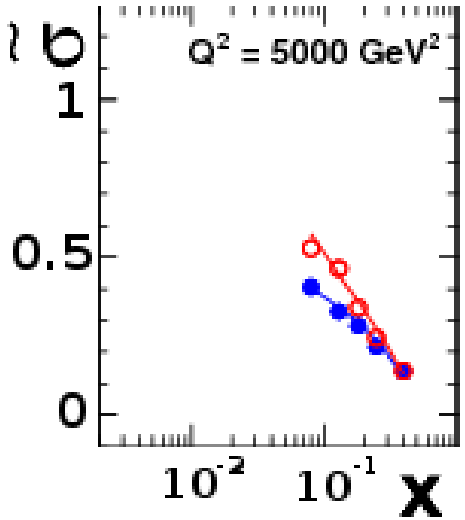
- Closed circles $\rightarrow$ +ve P_e.
- Open circles $\rightarrow$ -ve P_e.
- Effect of polarisation visible at high-Q^2.



$\tilde{\sigma}$ with $P_e = 0$



- Closed circles → Full e^+p data set.
- Open circles → Previously measured unpolarised e^-p $\tilde{\sigma}$.
- Difference between e^+p and e^-p clearly seen.
  - This gives us xF_3.



Summary

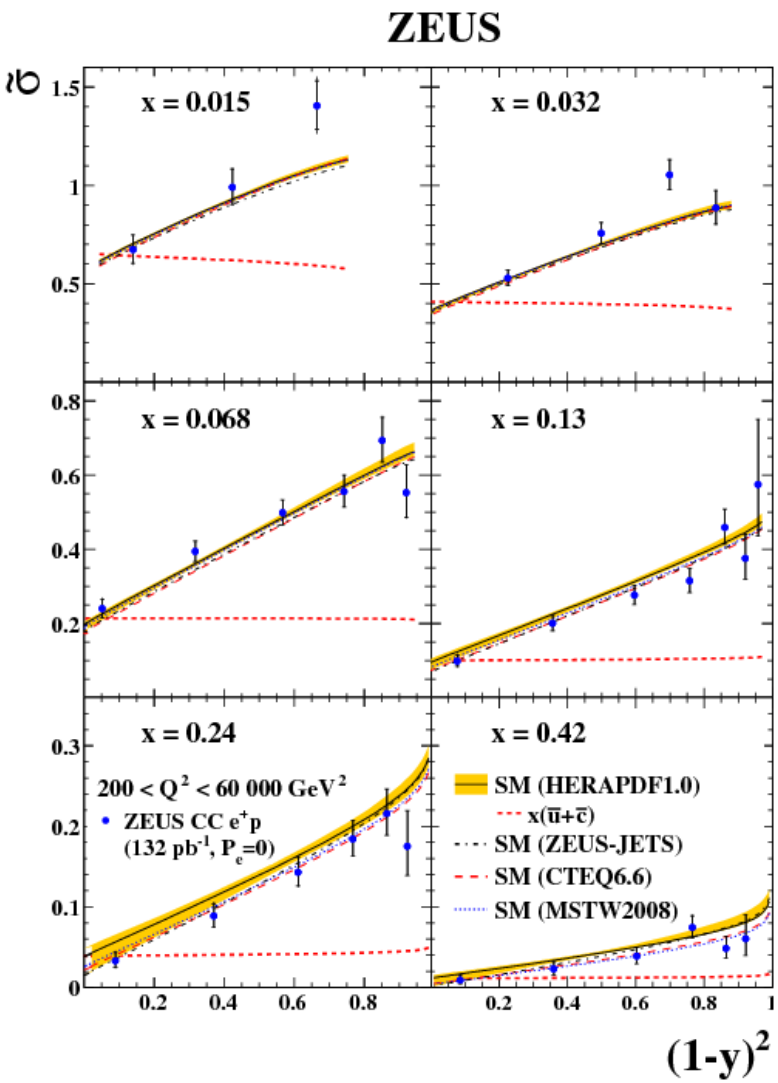
Charged Current:

- Polarised single and reduced CC e^+p cross sections have been measured.
- Results published in Eur. Phys. J. C (2010) 70: 945963.
- Results already included in HERAPDF1.5.

Neutral Current:

- Both the single differential and reduced NC e^+p cross sections have been measured for right and left-handed polarisation.
  - Effects of polarisation clearly seen in the e^+p data.
  - The missing piece from the HERA-II High-Q^2 inclusive data.
  - Data will help better constrain HERAPDF.

$\tilde{\sigma}$ vs. $(1-y)^2$



- Due to the helicity structure of the W boson, it couples only to left(right)-handed (anti-)fermions.
  - The angular distribution of $e^+\bar{q}$ distribution should be flat ($x(\bar{u}+\bar{c})$) in the positron-quark centre-of-mass scattering angle θ^*.
  - The e^+q distribution should exhibit a $(1+cos\theta^*)^2$ as $(1-y)^2 = (1+cos\theta^*)^2/4$.
  - At LO QCD the y-int gives the $(\bar{u}+\bar{c})$ contribution, and the slope the $(d+s)$ contribution.