DIS 2013 - **WG1**

# Measurement of high-$Q^2$ neutral current deep inelastic $e^+p$ scattering cross sections with a longitudinally polarised positron beam at HERA


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23 April 2013


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ZEUS

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# Outline

- Introduction
- Unpolarised $e^+p$ cross-sections
- Polarised $e^+p$ cross-sections
- Electroweak effects from $e^+p$ *vs.* $e^-p$
- Summary

Talk based on ZEUS paper: Phys. Rev. D 87, 052014 (2013)
http://arxiv.org/abs/arXiv:1208.6138 (DESY 12-145)

$e^-p$ ZEUS publication: Eur. Phys. J. C 62 (2009) 625
http://arxiv.org/abs/0901.2385 (DESY 08-202)

# Theory

- Introduction to DIS and kinematics given in previous talk
- Relevant definitions for this talk ($P_e = 0$):
  - Use difference between $e^-p$ and $e^+p$ cross-sections to extract $xF_3$

$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left(\tilde{\sigma}^{e^-p} - \tilde{\sigma}^{e^+p}\right)$$

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

  - For this case ($v_e$ is small)

$$x\tilde{F}_3 \simeq -a_e \chi_Z x F_3^{\gamma Z}$$

$$a_e = -1/2$$

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

# Theory

- Structure functions in terms of quark distributions:

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

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

- Getting at valence quark distributions:

$$xF_3^{\gamma Z} = 2x\left[e_u a_u u_v + e_d a_d d_v\right] = \frac{x}{3}(2u_v + d_v)$$

$$v_u = 1/2 - 4/3 \sin^2\theta_W$$

$$a_u = 1/2, \quad a_d = -1/2$$

# Event selection

- Electron or high $E_T$ trigger
- Scattered electron with $E > 10$ GeV
- $Q_{DA}^2 > 185$ GeV$^2$, $y < 0.9$
- Reject background:
  - $38 < E - P_Z < 65$ GeV
  - $P_T/\sqrt{E_T} < 4\sqrt{\text{(GeV)}}$, $P_T/E_T < 0.7$
- Good event vertex, $|Z| < 30$ cm
- Cut on $\gamma_h$ to minimise effects of hole for beam-pipe in calorimeter

$$E_T = \sum_i E_i \sin\theta_i$$

$$P_T^2 = P_X^2 + P_Y^2$$

$$P_{X,i} = E_i \sin\theta_i \cos\phi_i$$

Sum over cal. cells



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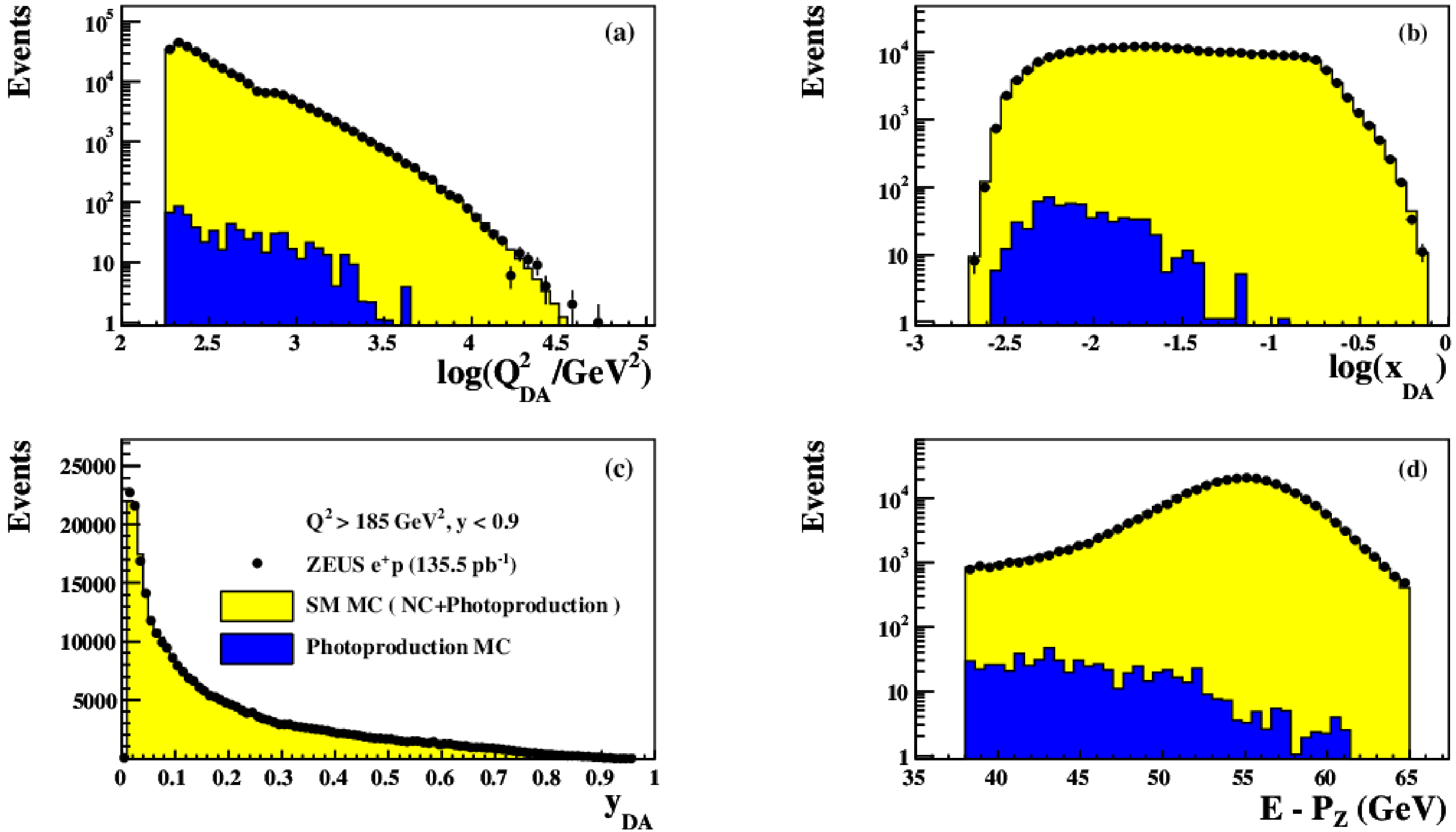
# Monte Carlo

- NC DIS events
  - HERACLES + DJANGOH with CTEQ5D PDFs
- Hadronic final state
  - ARIADNE 4.12 (MEPS model of LEPTO 6.5)
- Hadronisation
  - JETSET 7.4
- Photoproduction background
  - HERWIG 5.9

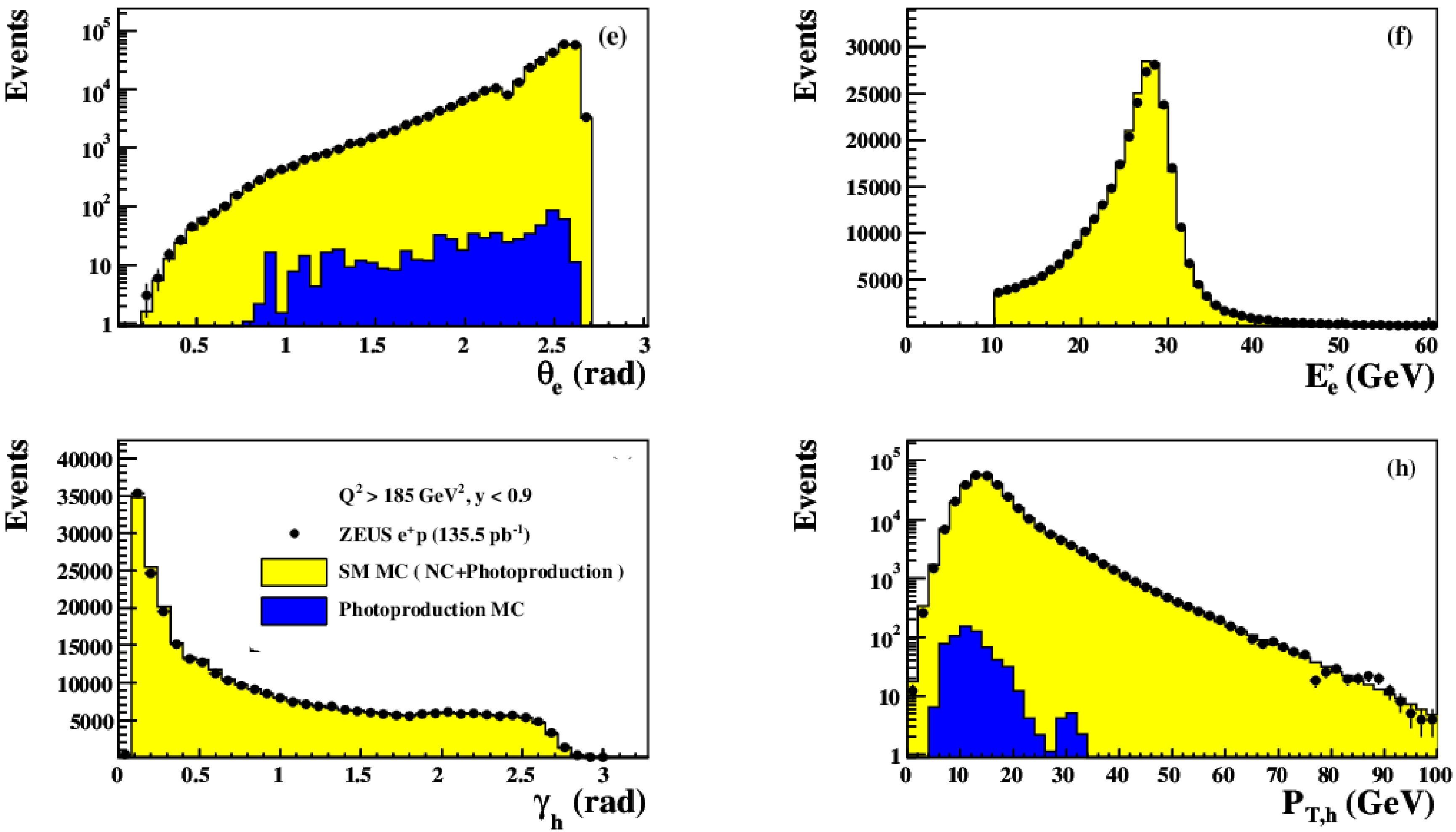
# Data/MC comparisons

135.5 $pb^{-1}$ $e^+p$ data
$Q^2 > 185$ GeV$^2$



# Data/MC comparisons

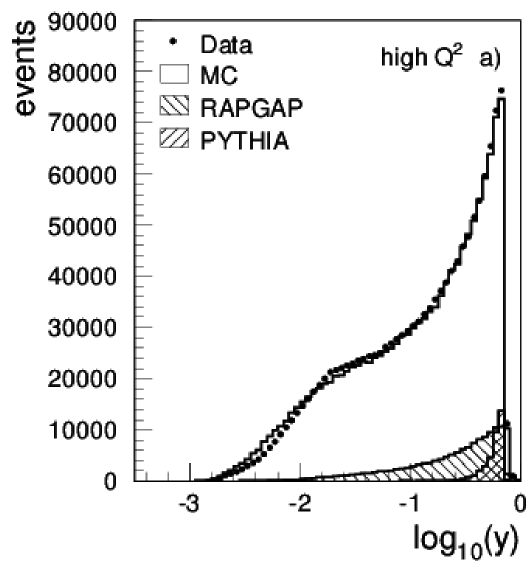
135.5 $pb^{-1}$ $e^+p$ data
$Q^2 > 185\ GeV^2$

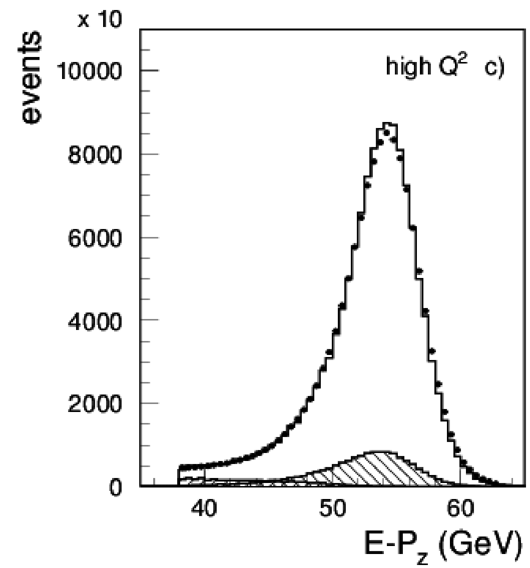


# Improvements?

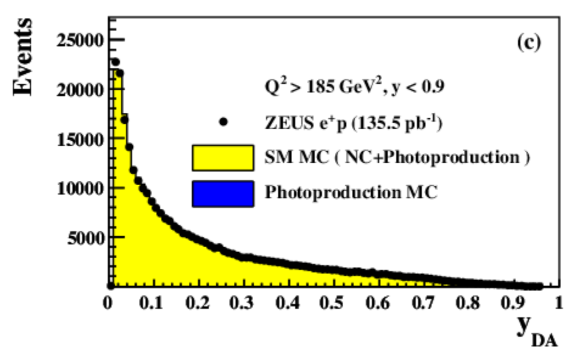
- My first ZEUS PhD student started in 1996 and submitted his thesis in 1999:

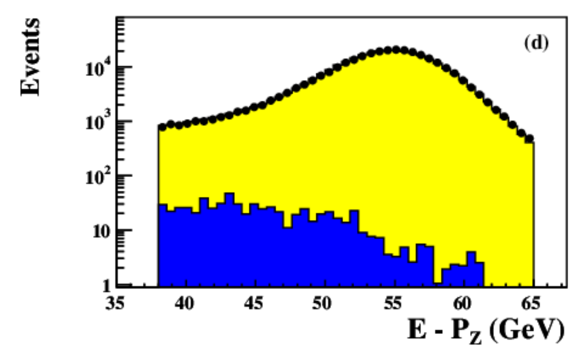
HERA 1: 37 $pb^{-1}$
$Q^2 > 25\ GeV^2$




HERA 2: 135.5 $pb^{-1}$
$Q^2 > 185\ GeV^2$





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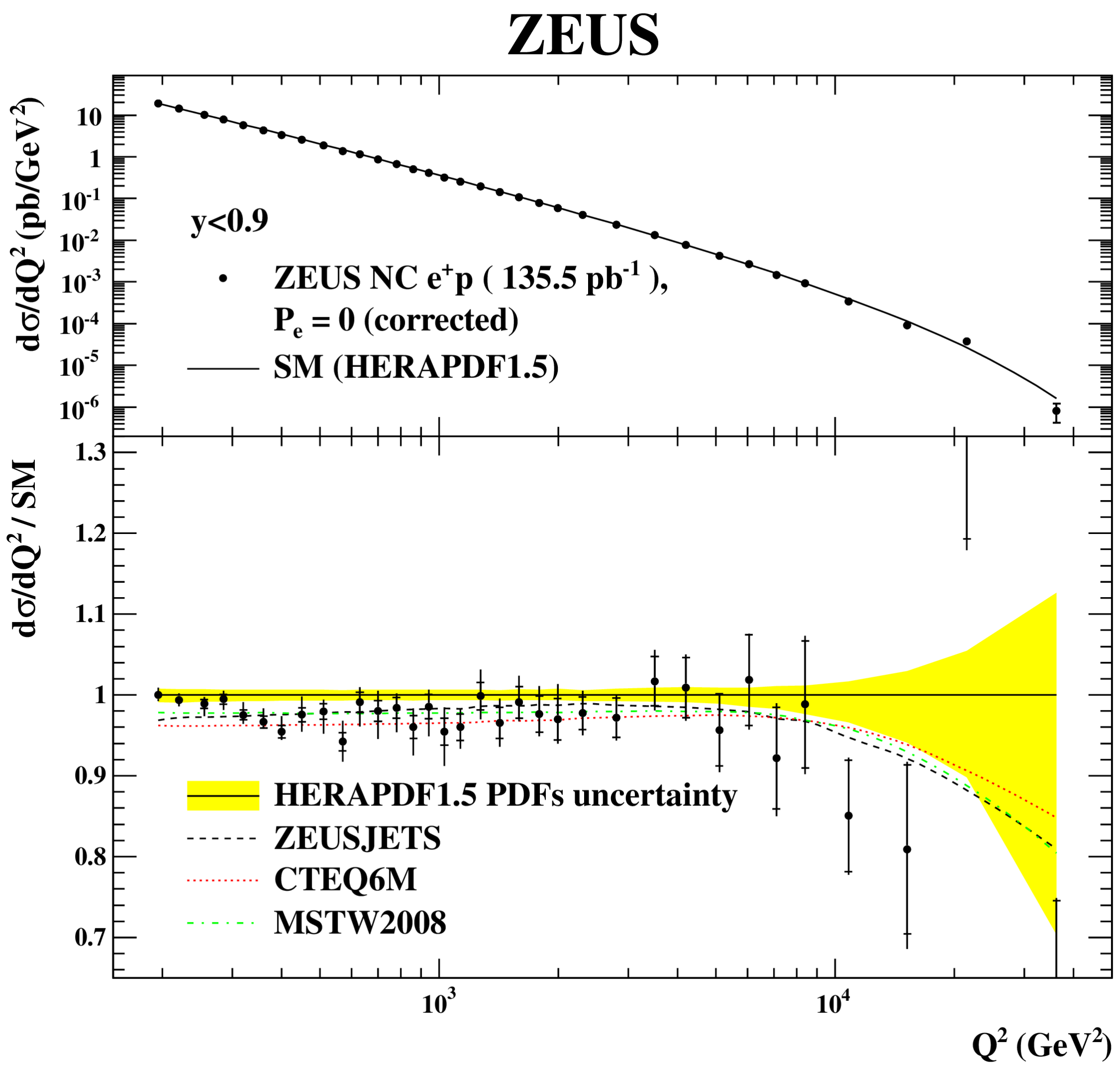
# Improvements?

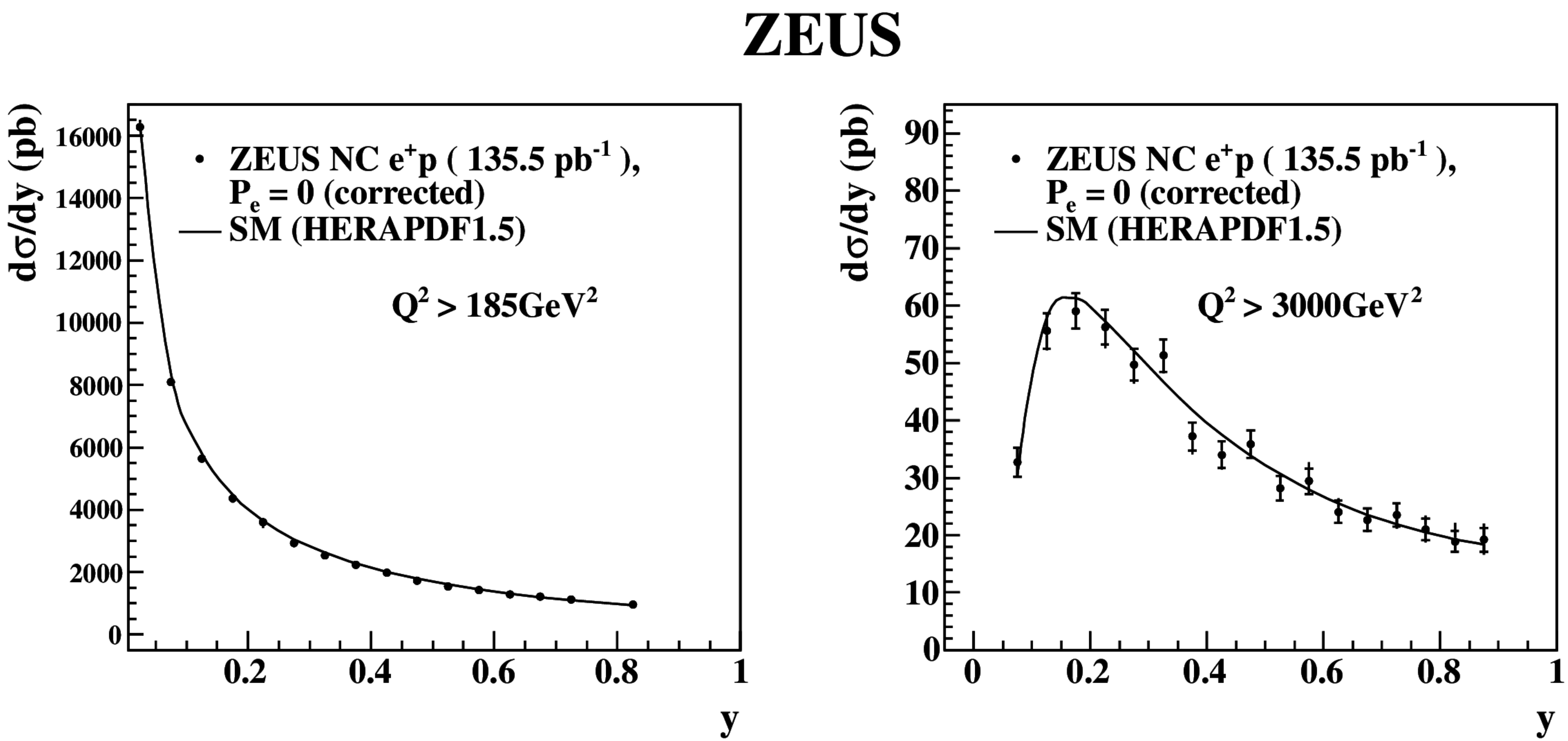
- Then as now reaching per cent precision is a lot of work
- HERA 2 benefits from higher statistics
- Also helped by better and more robust primary vertex determination (MVD detector)
- But more material (including magnet inside detector)
  - Much more detailed (and accurate) material simulation now in Monte Carlo

# $e^+p$ NC DIS cross-section




- $P_e$ = 0 (corrected)
- Systematic uncertainties dominate at lower $Q^2$, statistical at very high $Q^2$
- Luminosity uncertainty (1.8-1.9%) not included in error band
- Good agreement with all PDFs

# $e^+p$ NC DIS cross-section




- Compare cross-sections in dominantly electromagnetic and electroweak regimes
- Precision of measurement clearly visible



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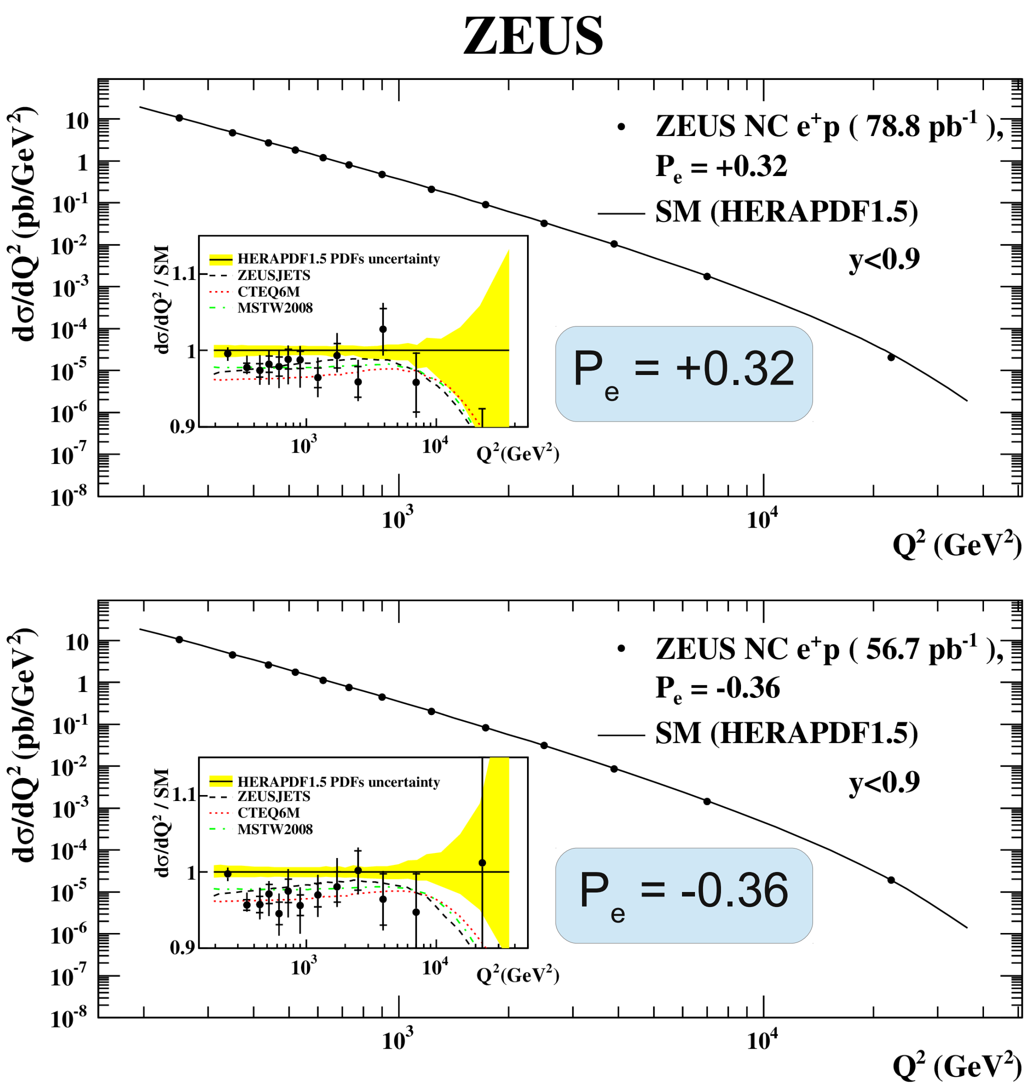
# Comparing positive and negative polarisation




135.5 $pb^{-1}$ $e^+p$ data
$Q^2 > 185$ $GeV^2$

- Take ratio data/SM with HERAPDF1.5 as basis for comparison with other PDFs
- Good agreement with all PDFs seen (within luminosity uncertainty)



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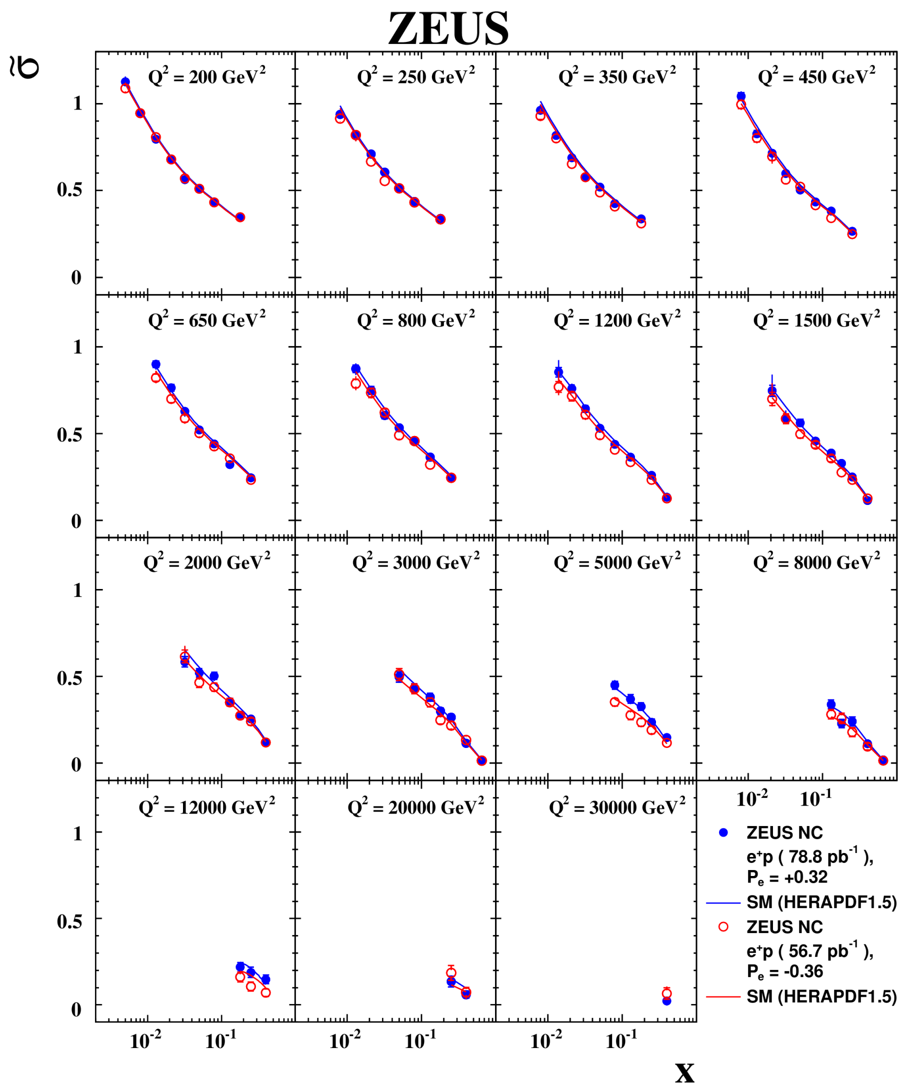
# Reduced cross-sections split according to polarisation




135.5 pb$^{-1}$ $e^+p$ data
$Q^2 > 185$ GeV$^2$

- Small, but steadily increasing difference seen for $Q^2 \gtrsim 1000$ GeV$^2$
- Again well described by predictions

$$\tilde{\sigma}^{e^\pm p} = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma(e^\pm p)}{dxdQ^2}$$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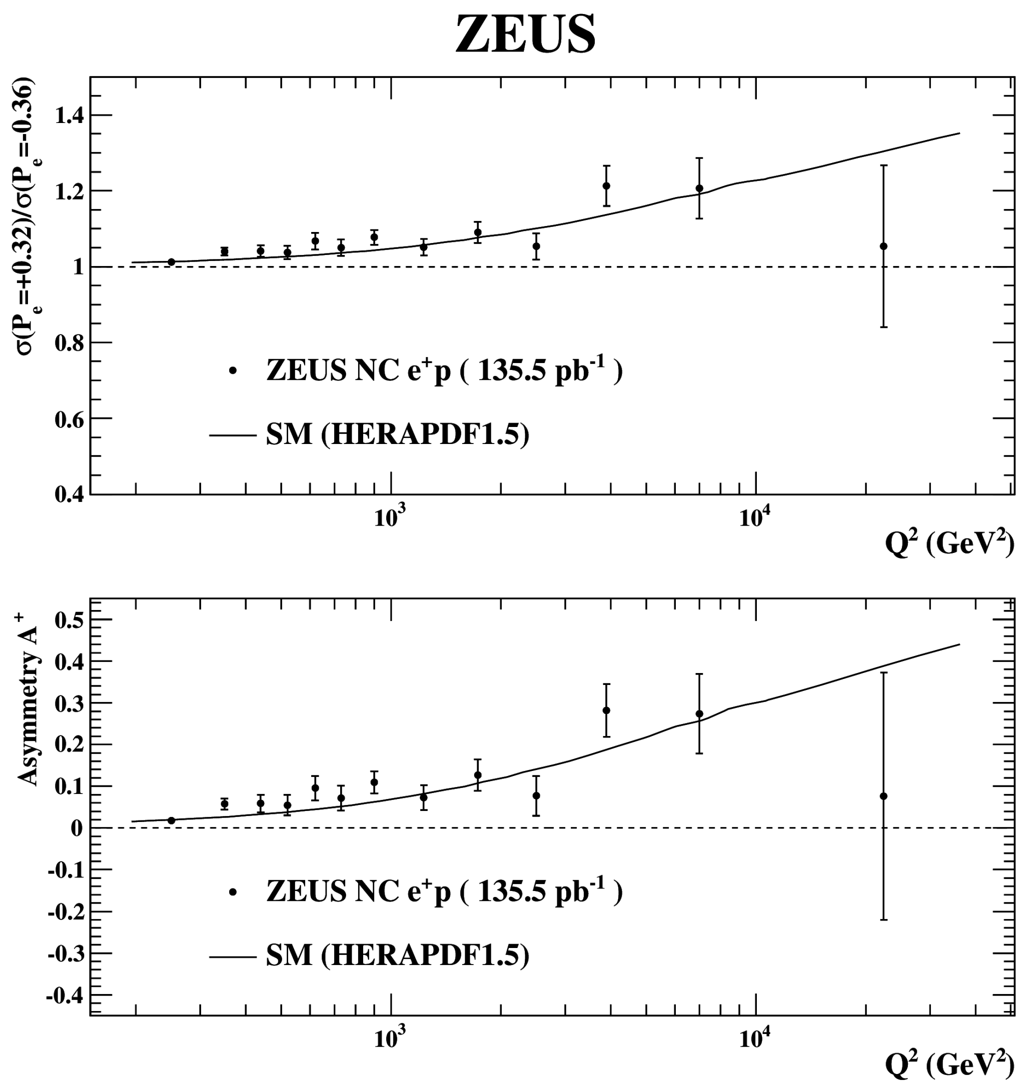
# Polarisation ratio and asymmetry



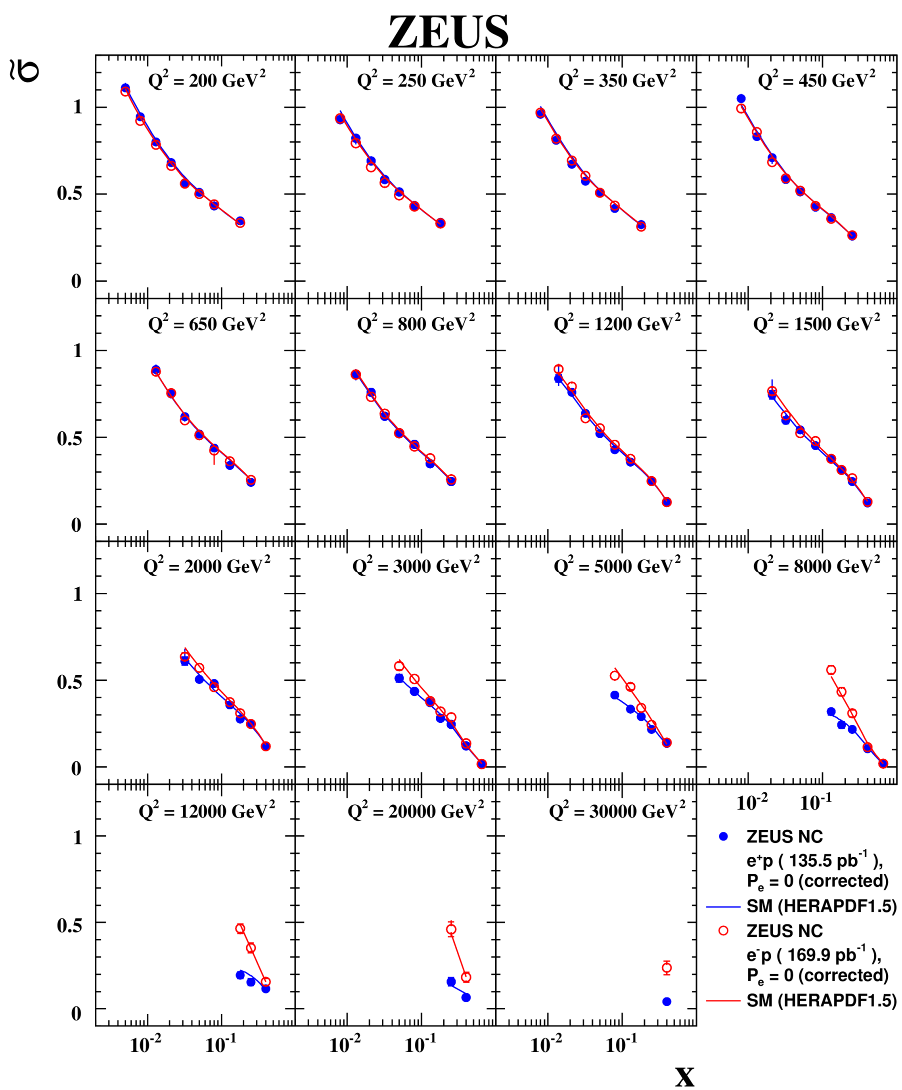

- Extract EW information from cross-section ratio and asymmetry
- $A^+$ insensitive to PDFs (1st order)

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

$$\simeq -\chi_Z a_e \frac{F_2^{\gamma Z}}{F_2^{\gamma}} = -2\chi_Z a_e v_q / e_q$$

# $e^{\pm}p$ reduced cross-sections

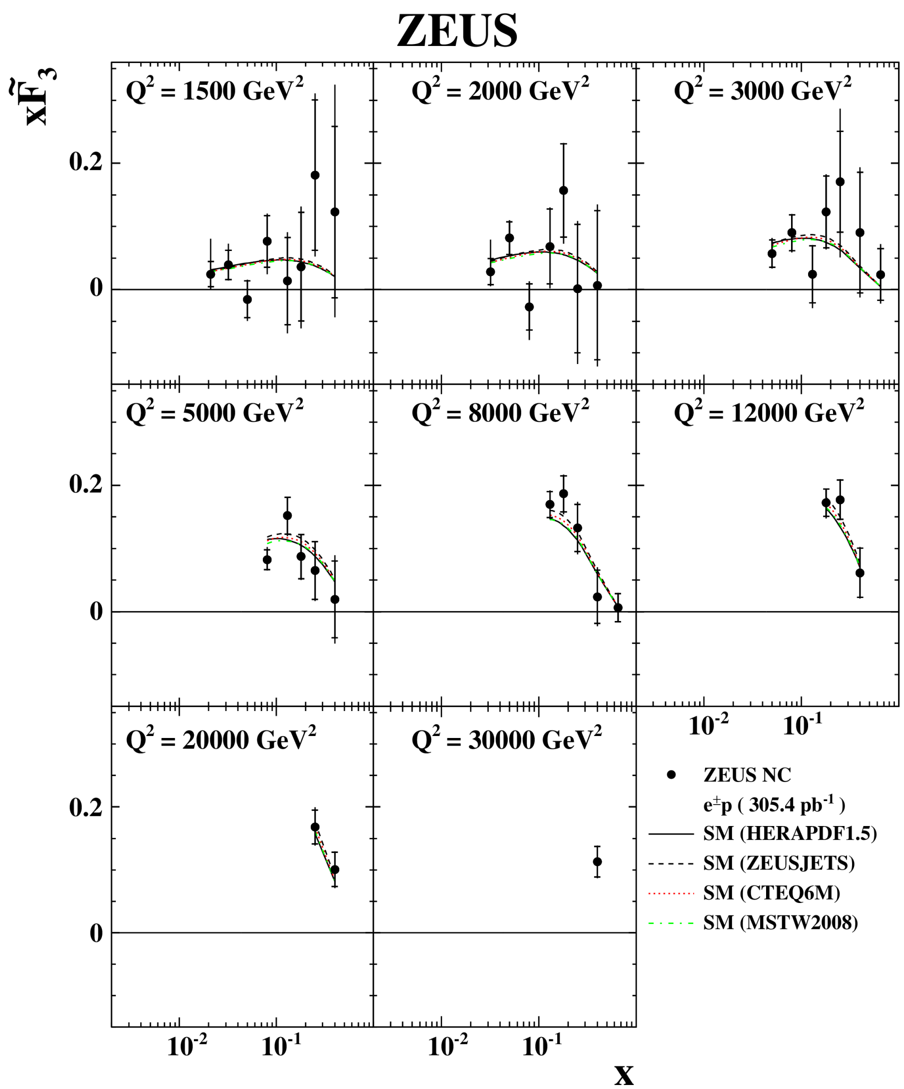
135.5 $pb^{-1}$ $e^{+}p$ data
169.9 $pb^{-1}$ $e^{-}p$ data
$Q^2$ > 185 $GeV^2$




- Compare $e^{+}p$ with previously published $e^{-}p$ results
- Clear effect of electroweak coupling seen at high $Q^2$
- Good agreement with predictions

$$\tilde{\sigma}^{e^{\pm}p} = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{\mathrm{d}^2\sigma(e^{\pm}p)}{\mathrm{d}x\mathrm{d}Q^2}$$

# Structure function $x\tilde{F}_3$




135.5 pb$^{-1}$ $e^+p$ data
169.9 pb$^{-1}$ $e^-p$ data
$Q^2 > 1300$ GeV$^2$

- Structure function obtained from difference of cross-sections
- No large dependence on $Q^2$ seen
  - Combine all bins to obtain better precision

$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left(\tilde{\sigma}^{e^-p} - \tilde{\sigma}^{e^+p}\right)$$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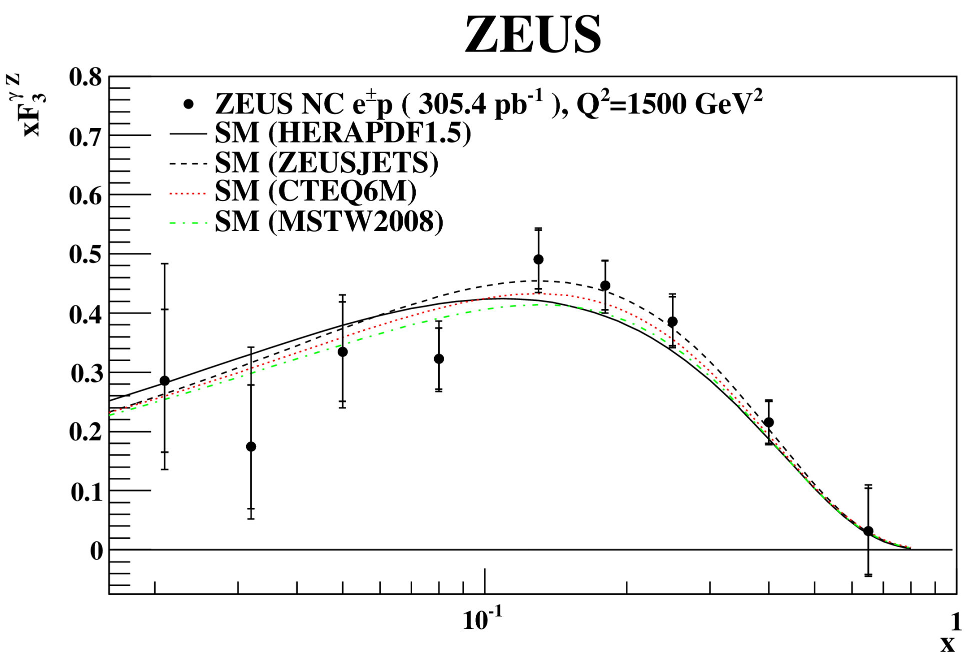
# Structure function $xF_3^{\gamma Z}$

135.5 pb$^{-1}$ $e^+p$ data
169.9 pb$^{-1}$ $e^-p$ data
$Q^2$ = 1500 GeV$^2$




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

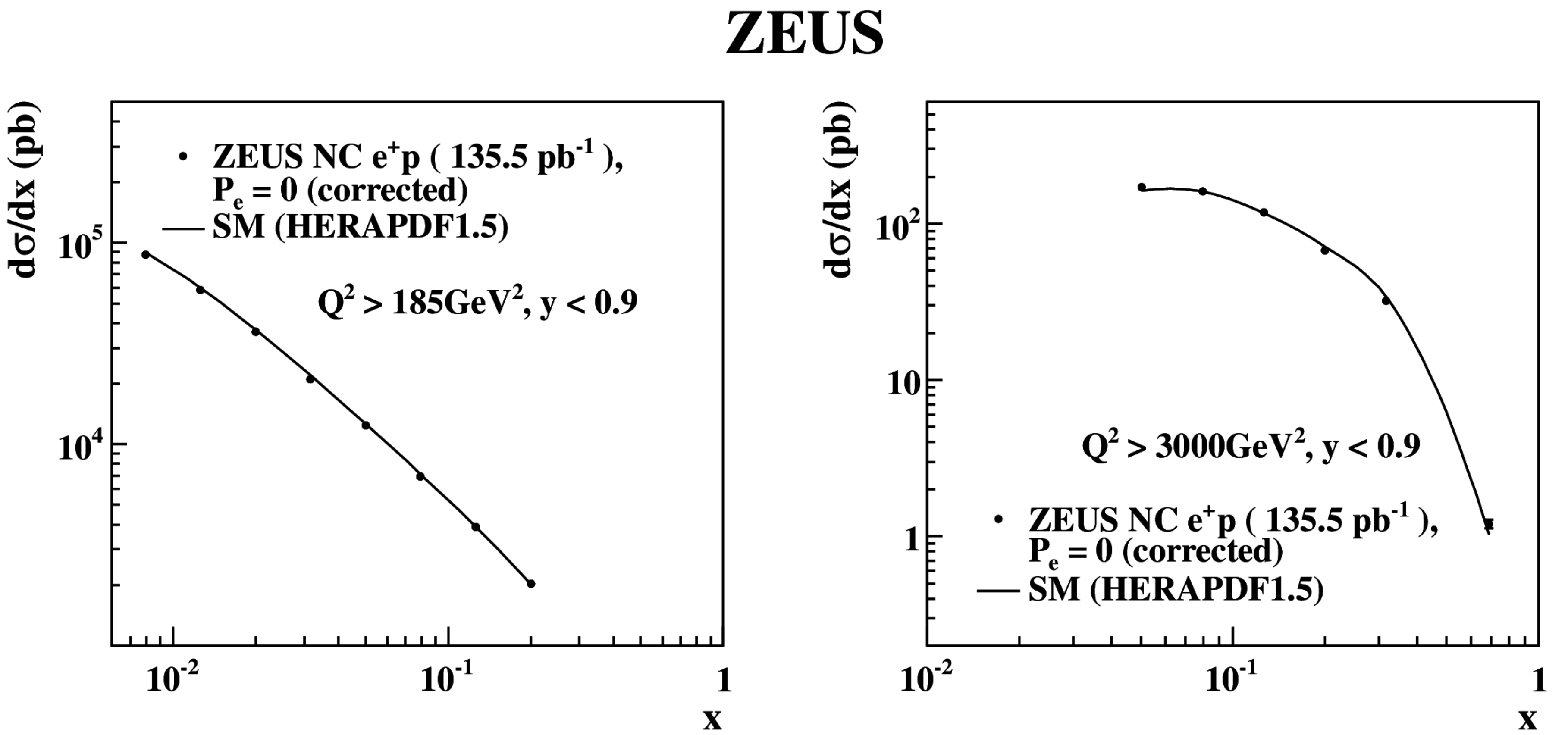
- Take out known EM coupling and relative EM and weak neutral couplings to get $xF_3^{\gamma Z}$
- PDF predictions agree well with data
- Statistical uncertainties typically >2x systematic

# Summary

- $e^+$p measurements presented here complete the set of published ZEUS NC and CC inclusive sections
- Precise measurements of both unpolarised and polarised cross-sections made
- Polarised cross-sections constrain vector couplings of quarks to $Z$
- $e^+p$ and $e^-p$ cross-sections compared and combined to examine electroweak effects

# Backup

# $e^+p$ NC DIS cross-section




- Compare cross-sections in dominantly electromagnetic and electroweak regimes

# Systematic uncertainties

- Luminosity: 1.8-1.9%
- Polarisation: 4%
- Wide range of systematic uncertainties studied
  - In most cases effects are at or below per cent level, except in a few bins.
  - Exception is parton-shower scheme: typically 3% uncertainty
- Treated as uncorrelated

# Systematic uncertainties

1) Electron energy scale
2) Overlay events
3) Photoproduction background normalisation
4) Electron finder
5) Electron-track matching
6) Parton shower scheme (typically 3% effect)
7) Trigger simulation
8) Electron isolation
9) DCA for track to electron at CAL
10) Energy resolution for scattered e in MC
11) Electron track momentum
12) $\gamma_h$ cut
13) Hadronic energy scale
14) Cosmic ray rejection
15) $|Z_{vtx}|$ cut