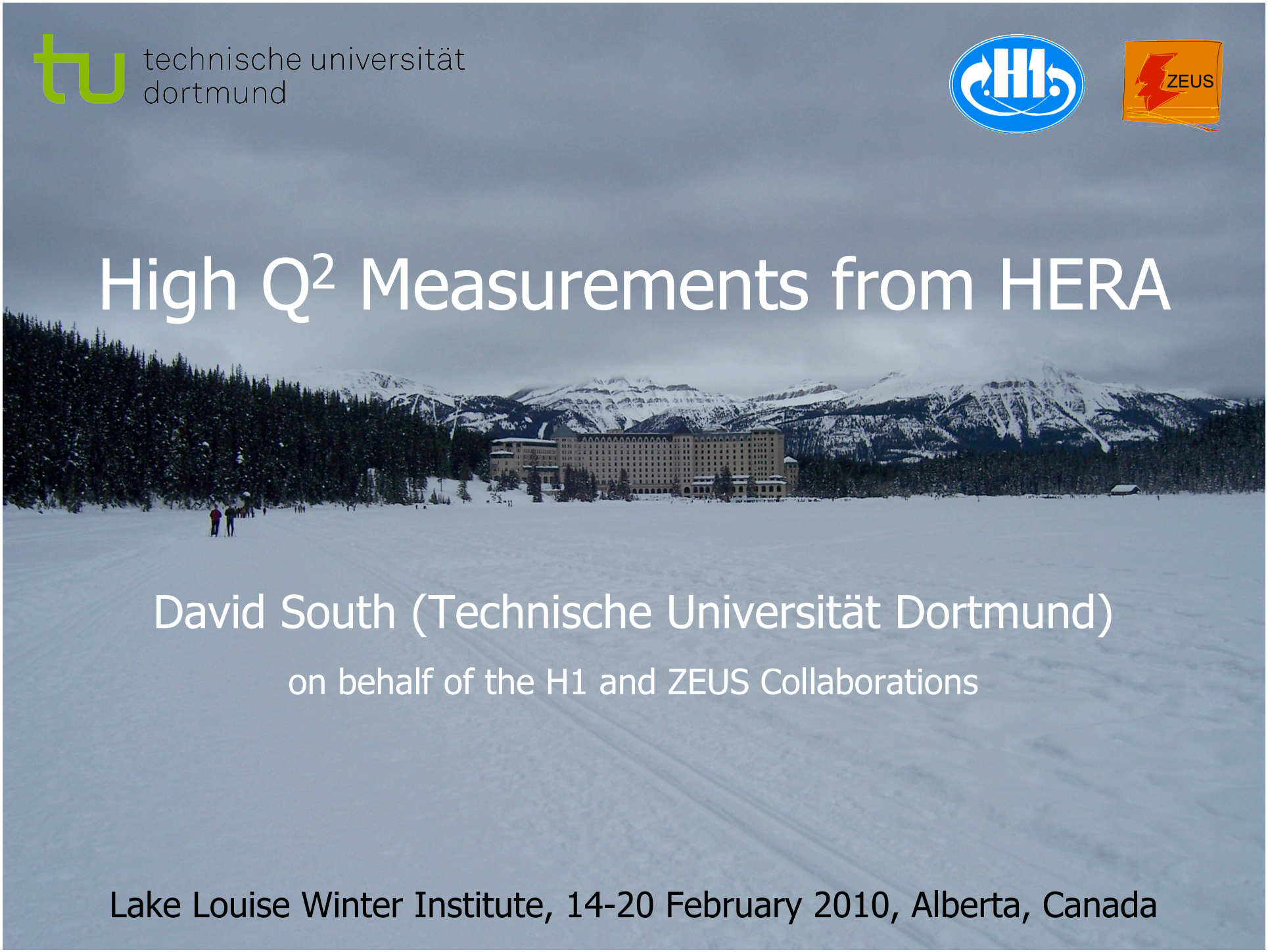
technische universität
dortmund



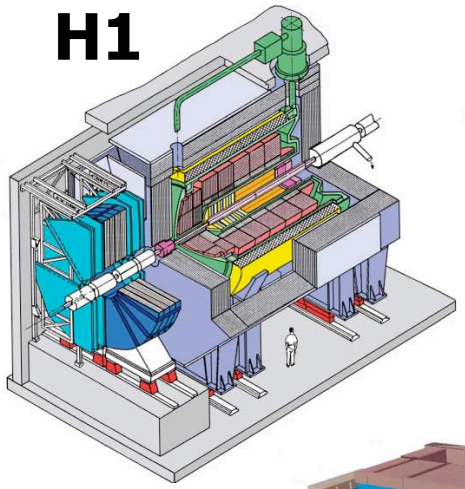
High Q^2 Measurements from HERA

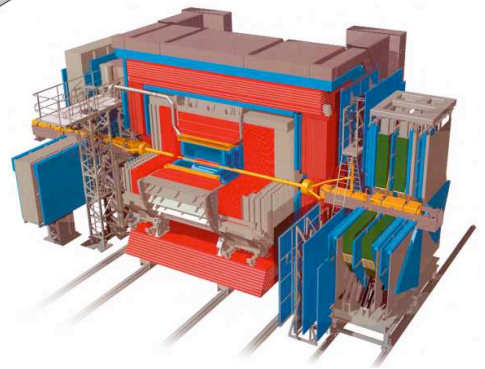
David South (Technische Universität Dortmund)

on behalf of the H1 and ZEUS Collaborations

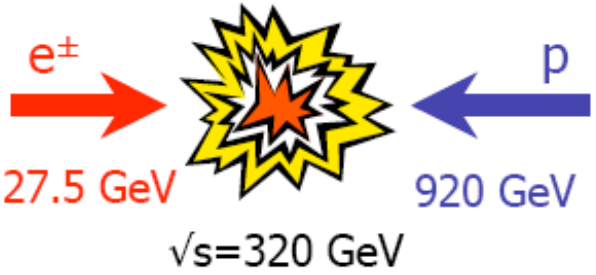
Lake Louise Winter Institute, 14-20 February 2010, Alberta, Canada

The H1 and ZEUS Experiments at HERA

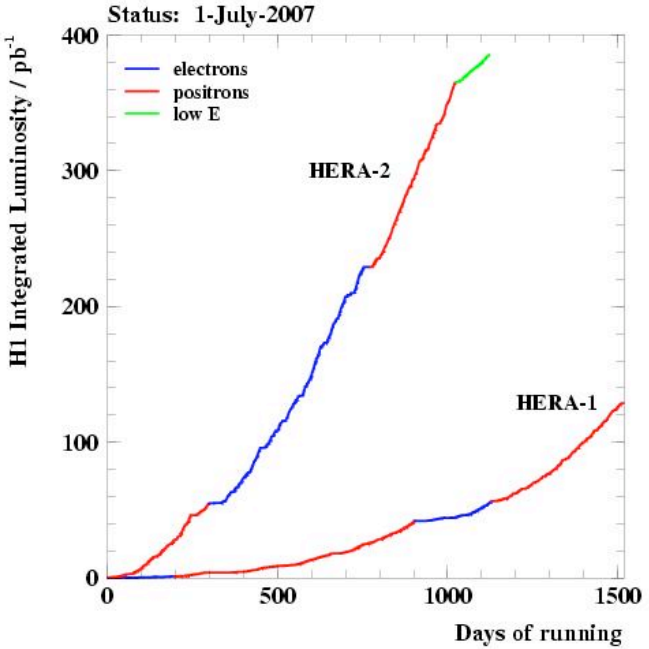




- Two multi-purpose experiments located at the ep interaction points
- The world's most powerful electron microscope, underneath the Volkspark in Hamburg
- Particle energies allow us to probe proton structure down to $\Delta x \approx 10^{-18}$m

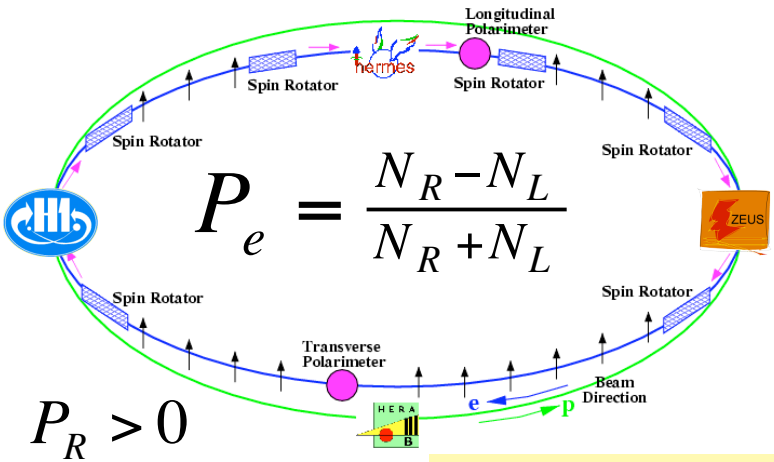


Data Taking at HERA 1994-2007



- Large increase in data per experiment after the luminosity upgrade for HERA II (x3)
- Large increase (x12) in data taken from e^-p collisions: HERA I mostly e^+p data

Final HERA I+II dataset ~ 0.5 fb^{-1} / experiment

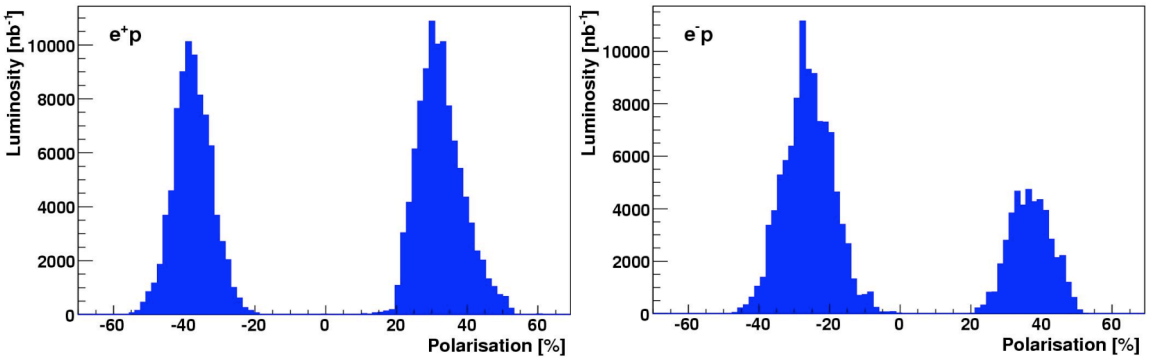


$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

$P_R > 0$

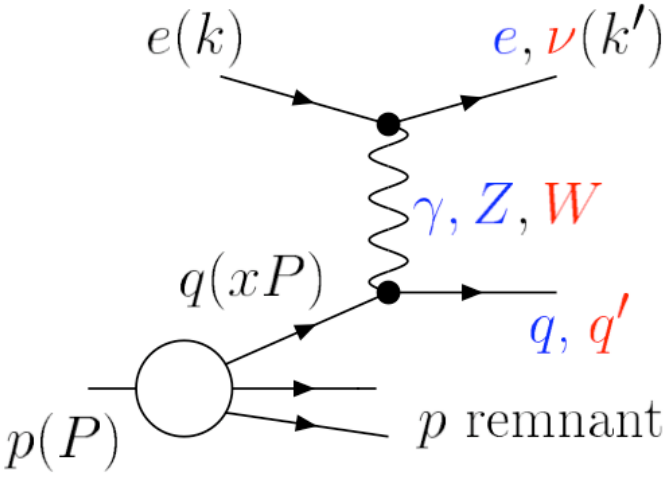
$P_L < 0$

e^+p, -P e^+p, +P e^-p, -P e^-p, +P



HERA II: Longitudinally Polarised Lepton Beam: 4 modes of running

Deep Inelastic Scattering at HERA



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

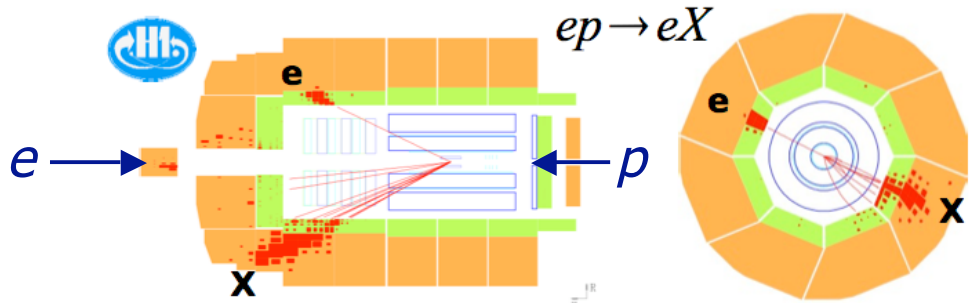
Virtuality of the exchanged boson

$$x = \frac{Q^2}{2P \cdot (k - k')}$$

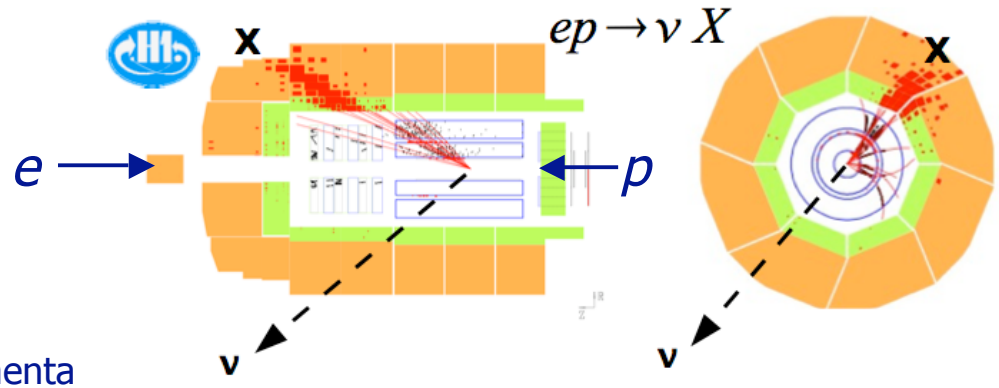
Fraction of proton momenta carried by the struck quark

$$y = \frac{P \cdot (k - k')}{P \cdot k}$$

Inelasticity: fraction of lepton energy transferred in the proton rest frame



Neutral Current interaction



Charged Current interaction

Presented today: NC and CC cross section measurements using up to the full HERA I+II data in the range $200 < Q^2 < 30{,}000$ GeV^2

Neutral Current Cross Sections

$\tilde{\sigma}_{NC}(x,Q^2)$ Reduced cross section

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

The **dominant** contribution

Sizeable only at **high y**
- Measure with special low energy runs

Only important at **high Q^2**
- Measure using difference of e^+p and e^-p cross sections

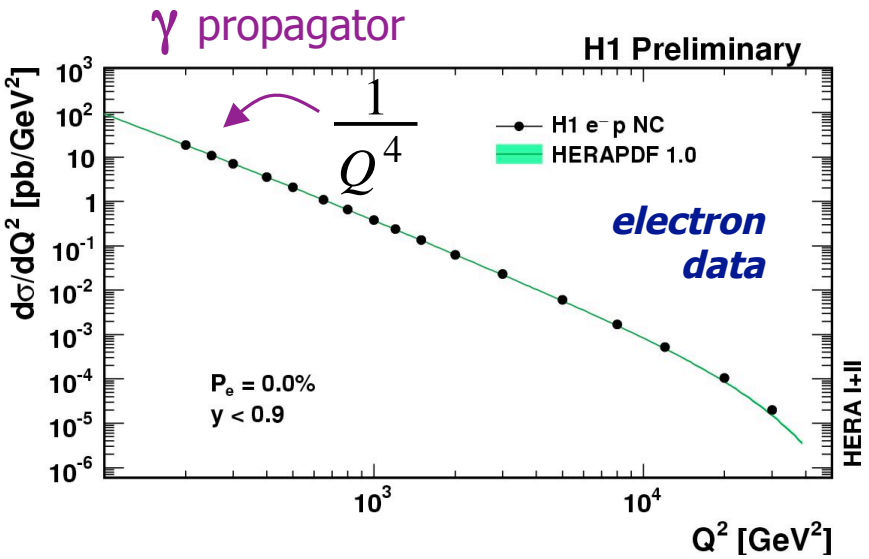
$$F_2 = F_2^{em} + \frac{Q^2}{Q^2+M_Z^2} F_2^{\gamma Z} + \left[\frac{Q^2}{Q^2+M_Z^2}\right]^2 F_2^Z \propto \sum_{q=u\ldots b} (q+\bar{q})$$ Sum of quark densities: PDFs

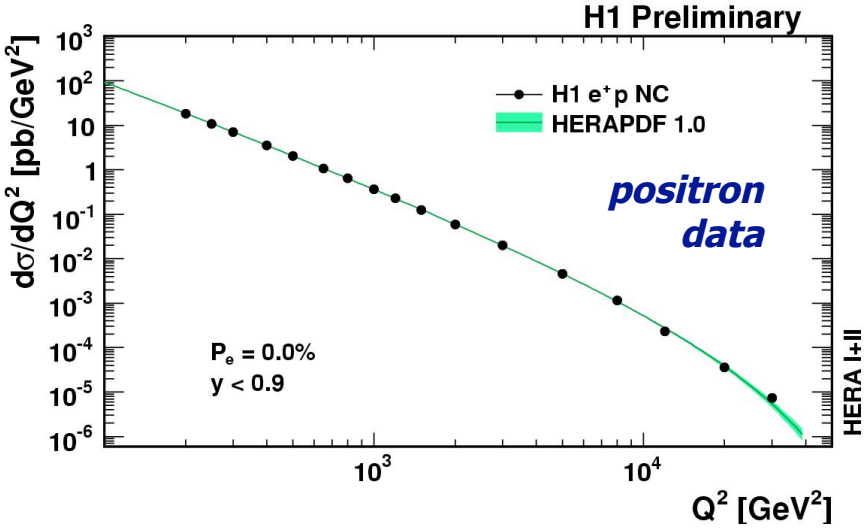
$$xF_3 = \frac{Q^2}{Q^2+M_Z^2} xF_3^{\gamma Z} + \left[\frac{Q^2}{Q^2+M_Z^2}\right]^2 xF_3^Z \propto \sum_{q=u\ldots b} (q-\bar{q})$$

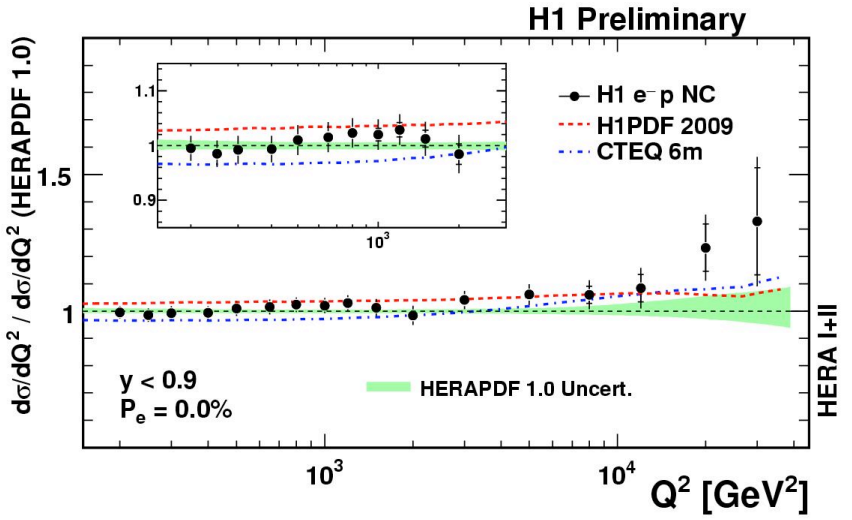
Difference between quark and anti-quark densities

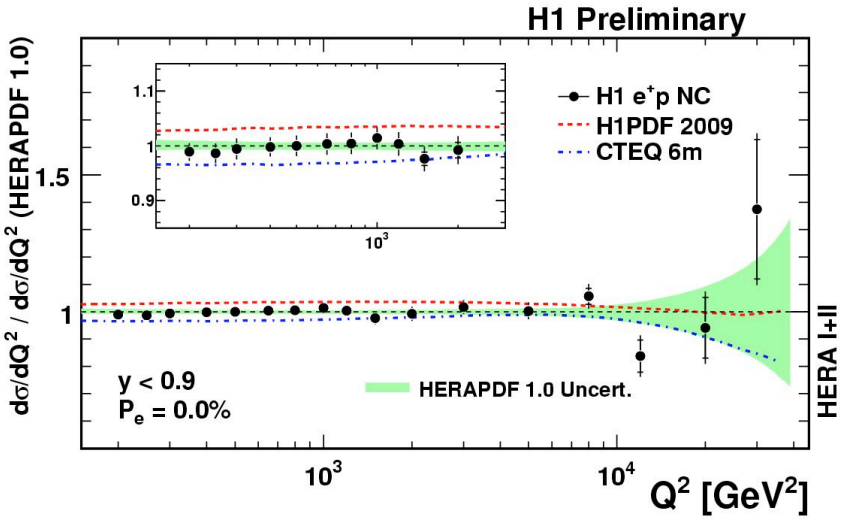
In addition, the NC cross section is also sensitive to the *lepton polarisation*, but only via the Z and γZ interference terms: small effect only visible at high Q^2

Unpolarised Cross Sections: HERA I+II



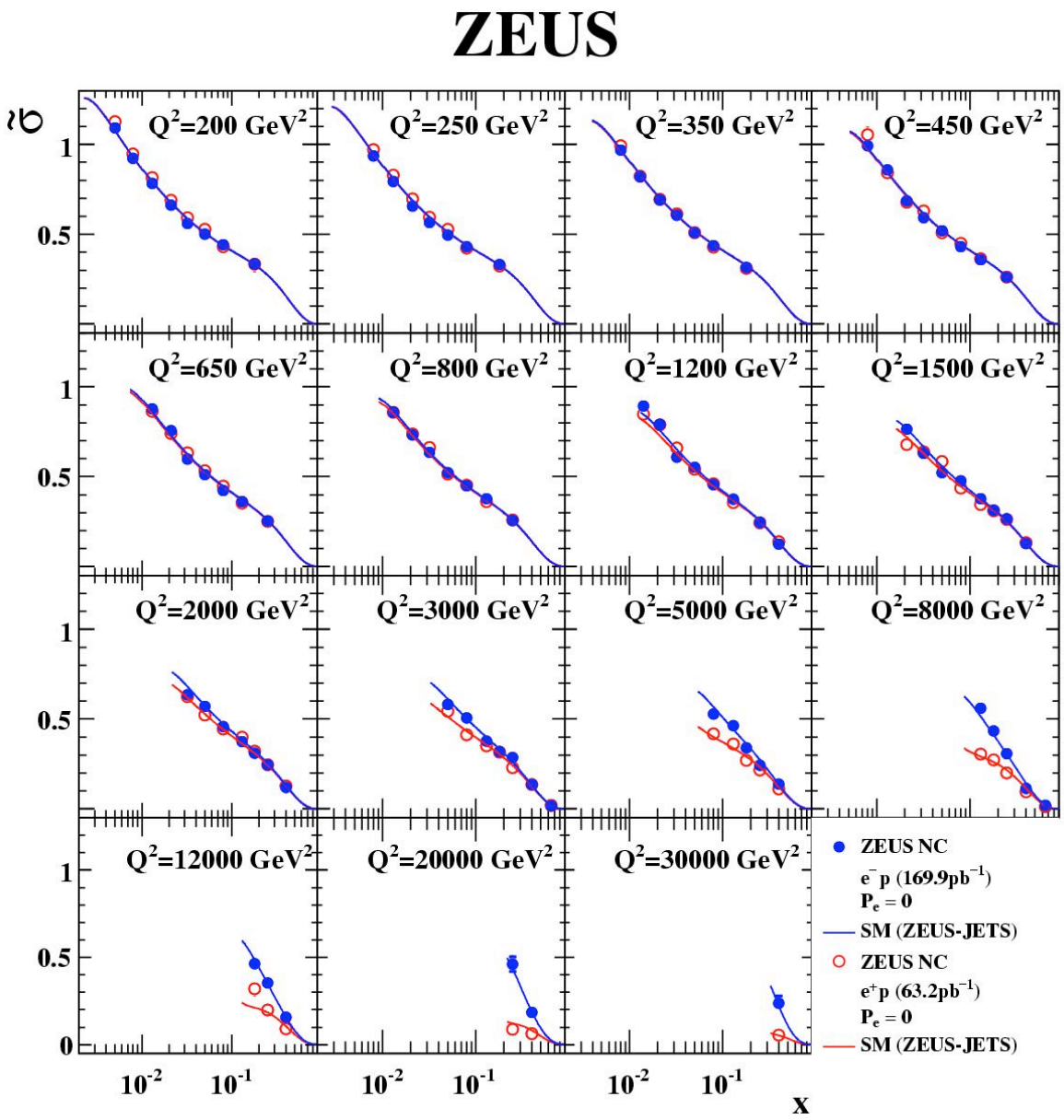






High precision of full HERA I+II data set and comparison to various PDF fits

Unpolarised Reduced NC Cross Section: e^-p vs. e^+p



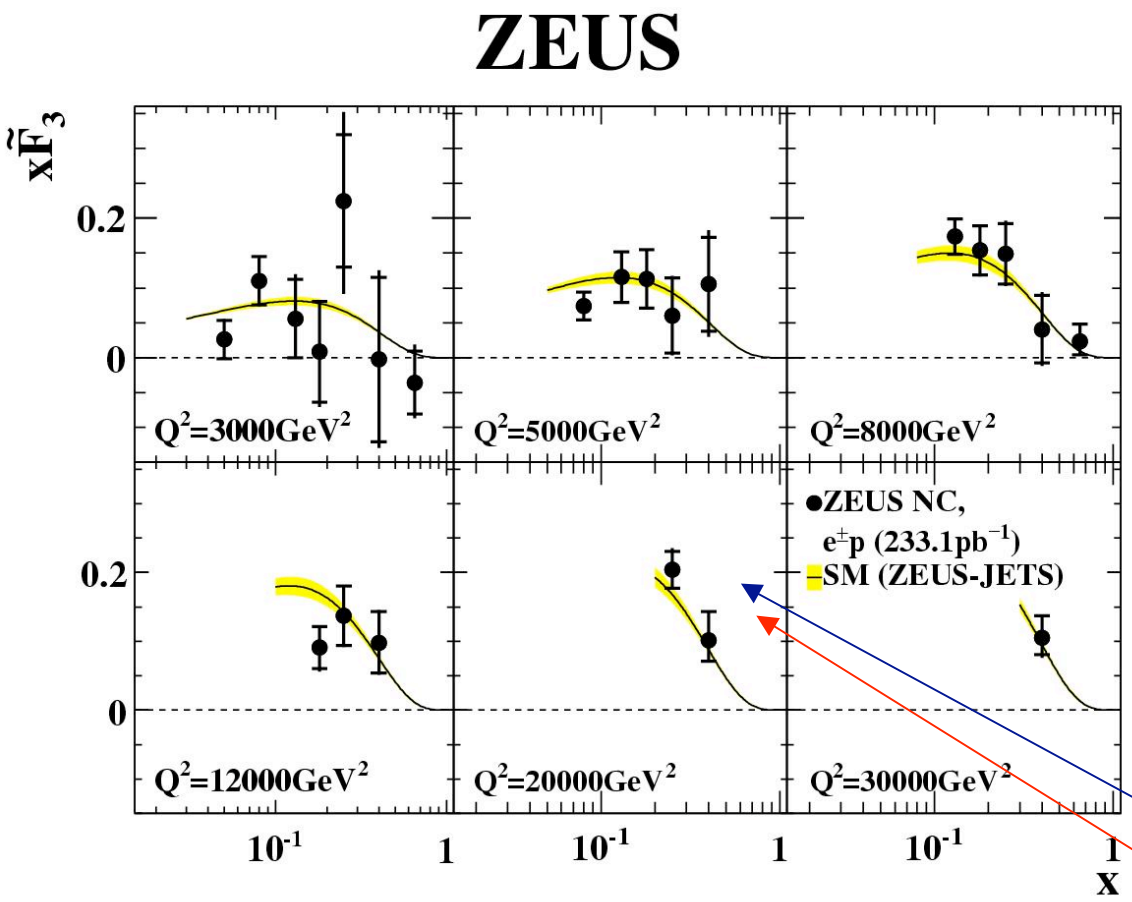
$$\tilde{\sigma}^{\pm}_{NC} = \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3$$

Separation of e^+p and e^-p cross sections at high Q^2

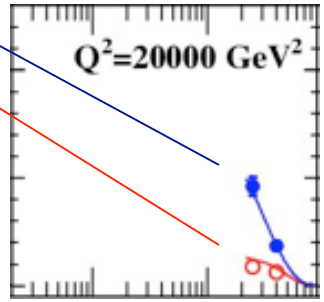
Influence of γZ interference term

Visible difference in the e^+p and e^-p cross sections is described well by the SM predictions

Evaluation of xF_3

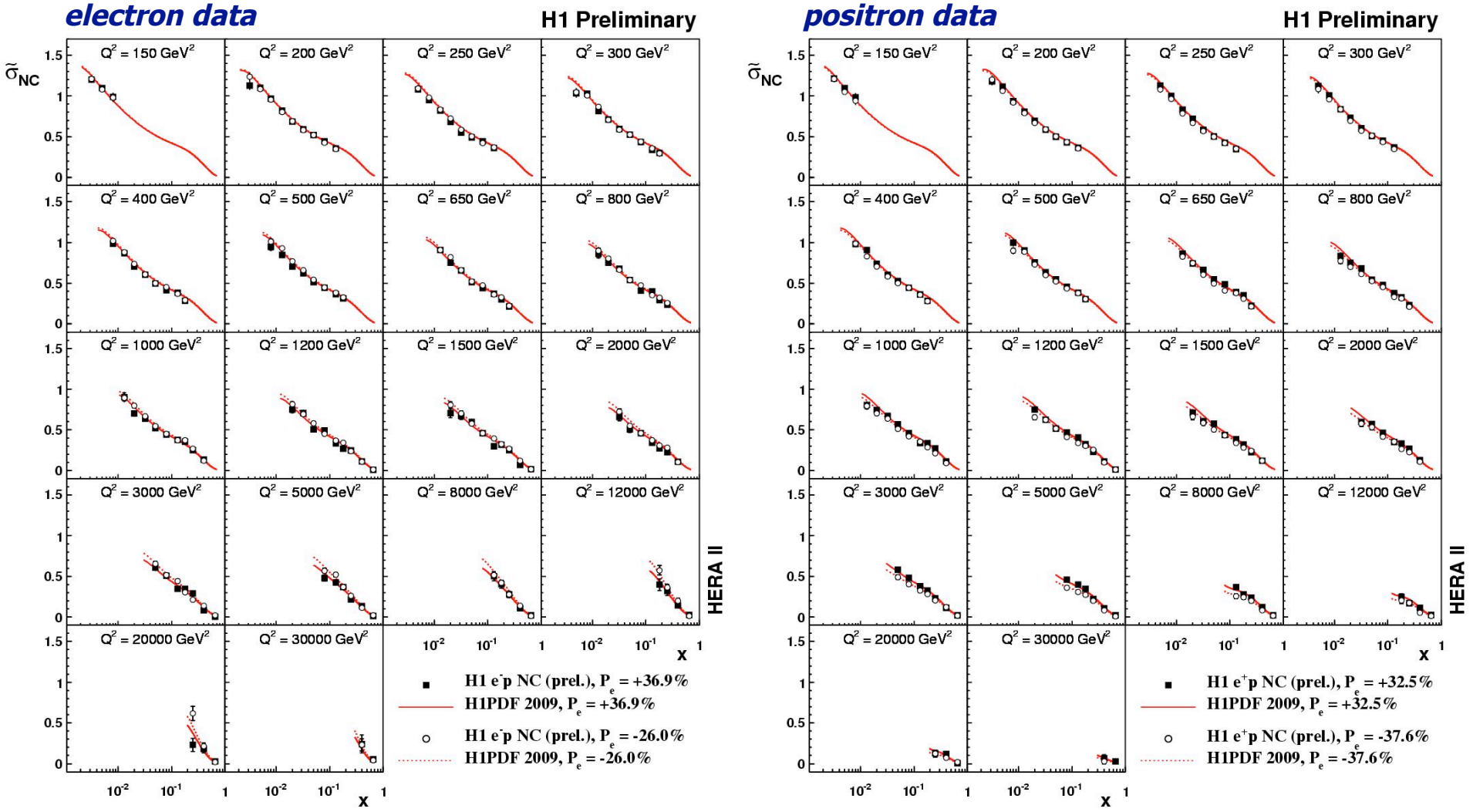


xF_3 is calculated from the difference in the unpolarised reduced cross sections at high Q^2

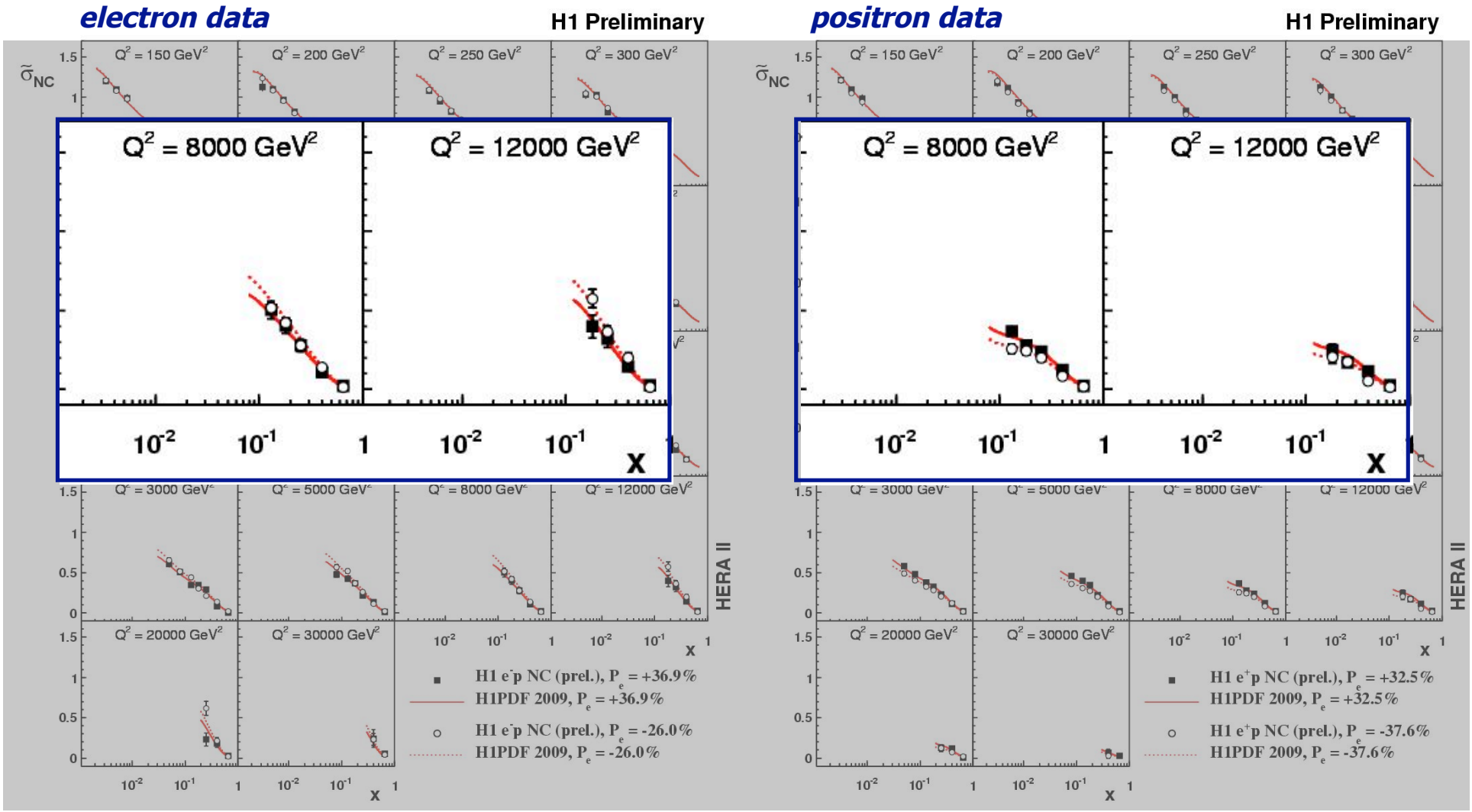


$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left[\tilde{\sigma}^-(x,Q^2) - \tilde{\sigma}^+(x,Q^2)\right]$$

Polarised Reduced NC Cross Section: -P vs. +P



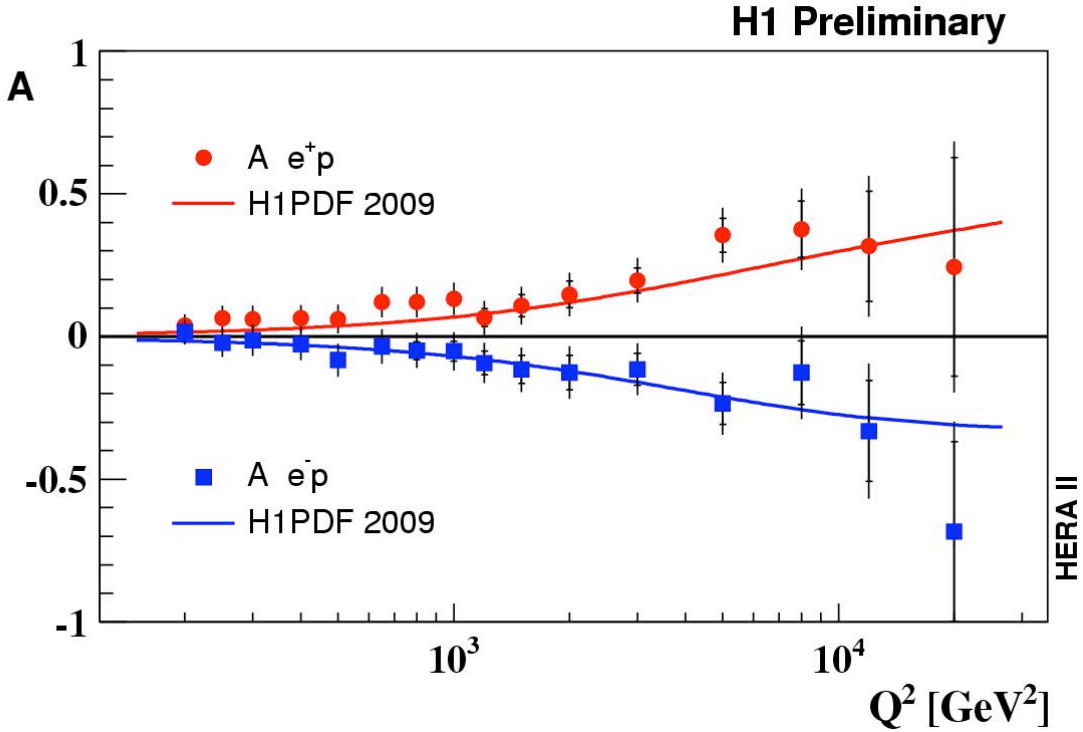
Polarised Reduced NC Cross Section: -P vs. +P



Influence of lepton beam polarisation visible at high Q^2: separation of measurements

HERA II Polarisation Asymmetry in NC

γ ⟶ *influence of* Z^0



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

$$P_e = \frac{N_R - N_L}{N_R + N_L} \qquad \begin{matrix} P_R > 0 \\ P_L < 0 \end{matrix}$$

Form polarisation asymmetry from HERA II Neutral Current measurements
- clear observation of parity violation of NC electroweak exchange

Nicely illustrates the properties of the different polarisation and lepton charge data

Well described by the SM prediction

Charged Current Cross Sections

e^+p cross section:

Sensitive to the density of the d quark

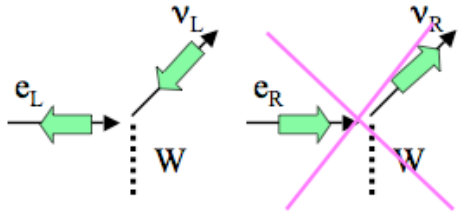
$$\frac{d^2\sigma^{CC}(e^+p)}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[\bar{u}+\bar{c}+(1-y)^2(d+s)\right]$$

e^-p cross section:

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

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

Sensitive to the density of the u quark



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

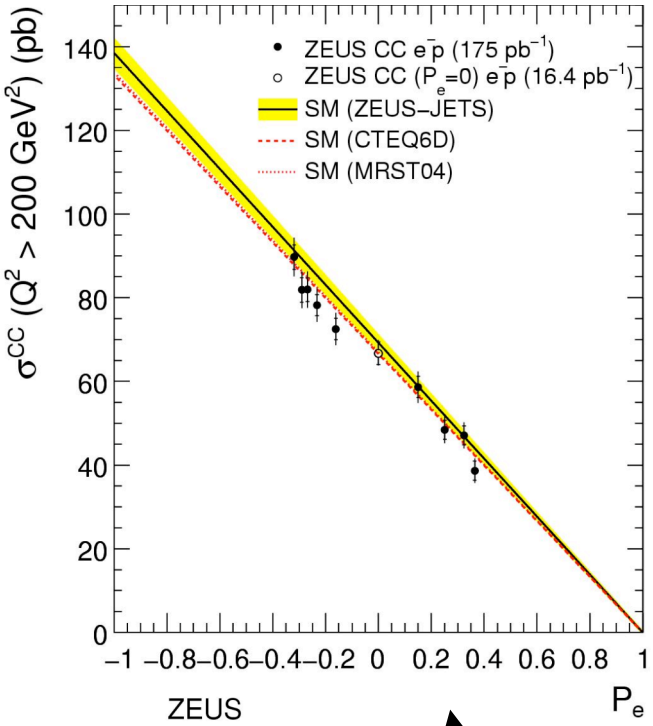
CC cross section modified by polarisation P_e:

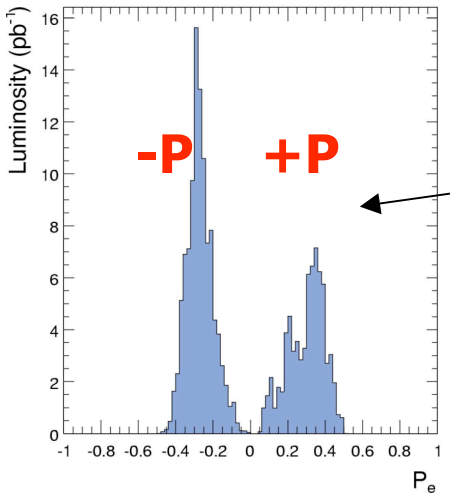
$$\sigma_{CC}^{e^\pm p}(P_e) = (1 \pm P_e)\cdot\sigma_{CC}^{e^\pm p}(P_e = 0)$$

Polarisation scales the P_e=0 cross section linearly: *clear and large effect at HERA*

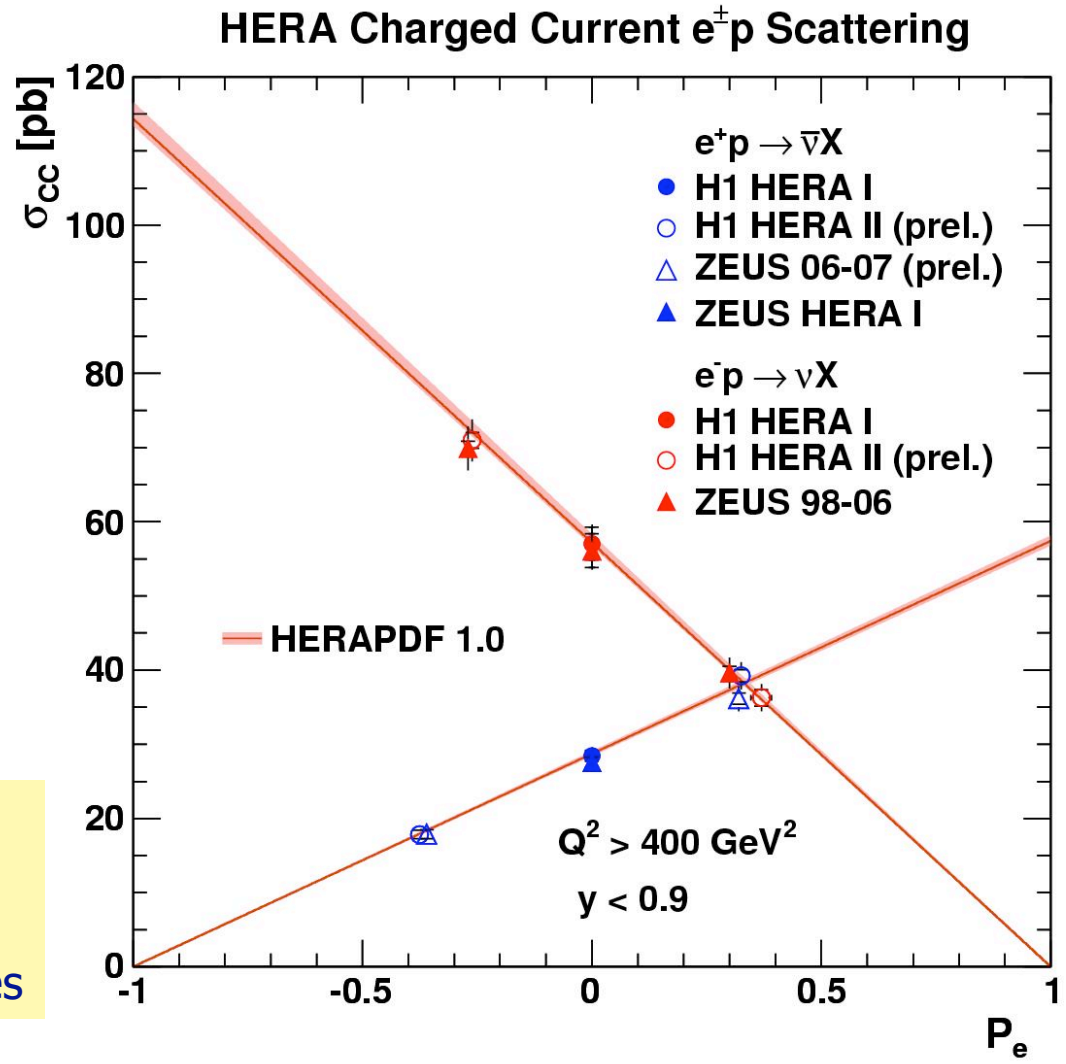
SM predicts zero cross section for P_e=+1(-1) in $e^{-(+)}p$ scattering

Charged Current Cross Section vs. Polarisation





Measurements made by ZEUS using various polarisation values

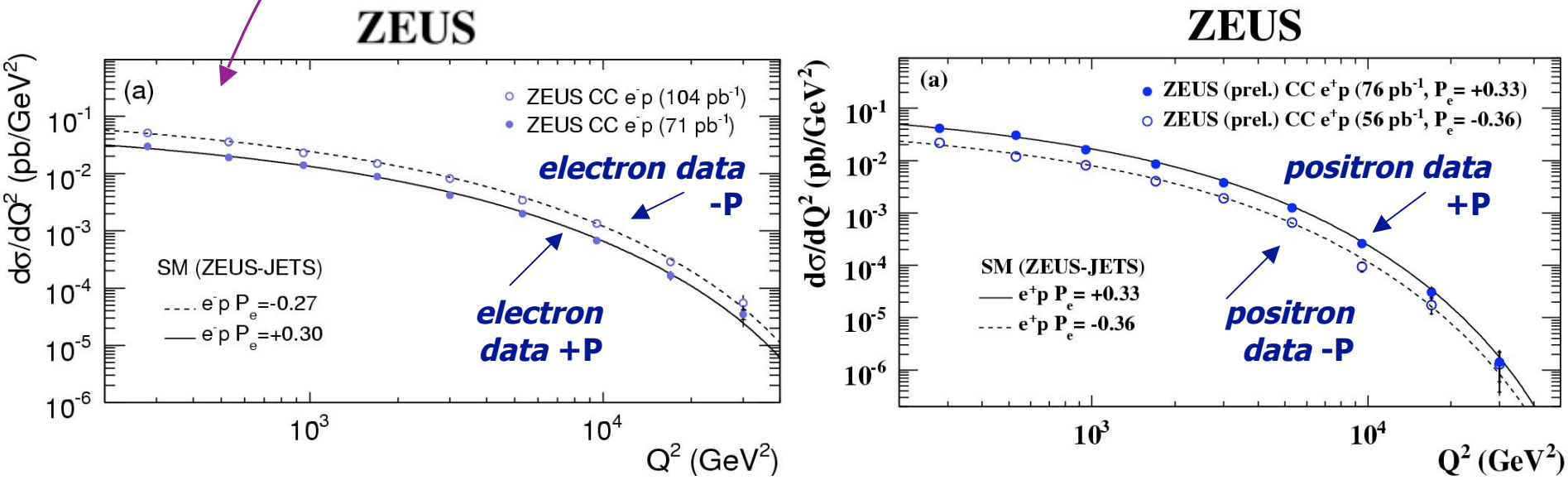


Data exhibit linear dependence of average polarisation and HERA I and II measurements agree with the SM prediction

Single Differential CC Cross Sections $d\sigma/dQ^2$

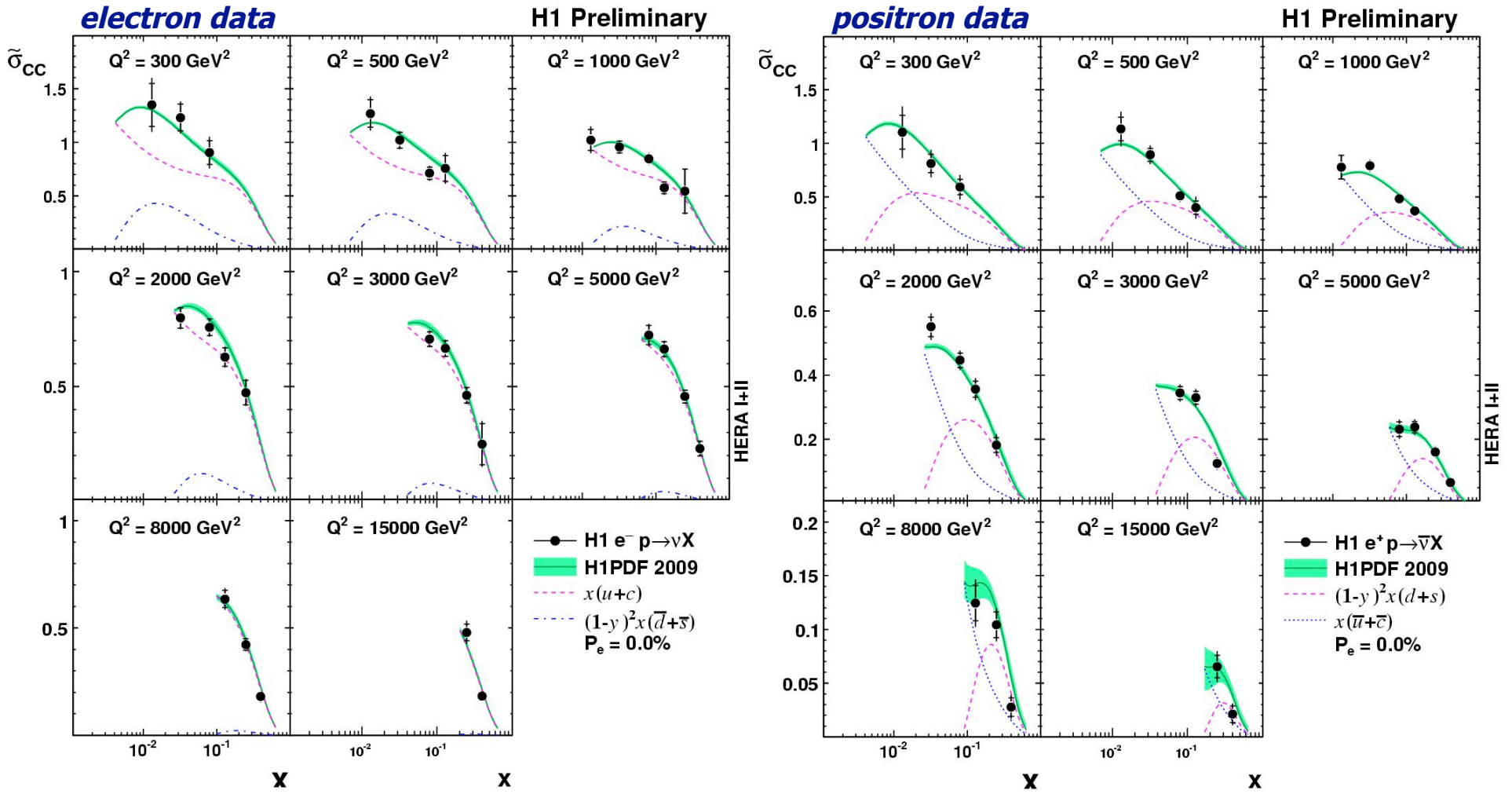
W propagator: cross section much lower than NC

$$\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2$$



Higher cross section of e^-p data visible, difference due to quark content
Opposite polarisation dependence of data sets visible
Good agreement with SM model prediction based on ZEUS-JETS QCD fit

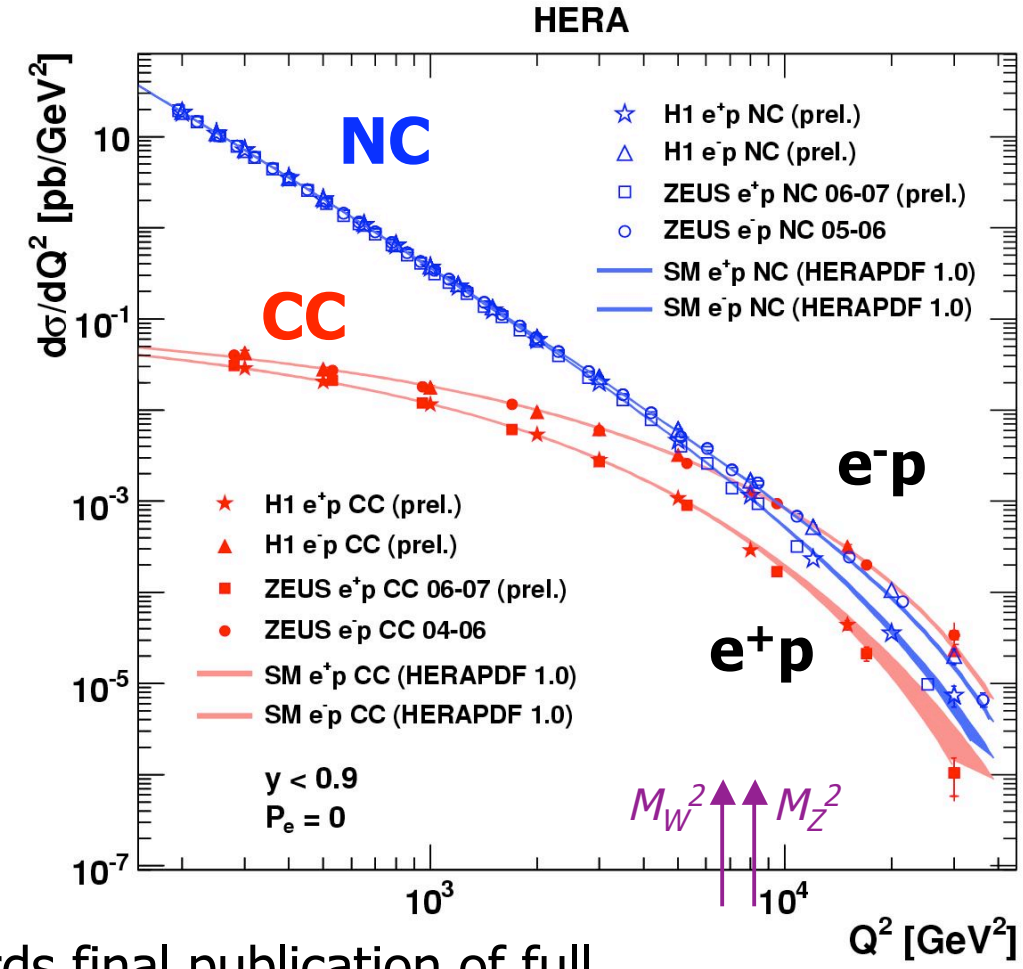
Unpolarised Reduced CC Cross Section: e^-p vs. e^+p



CC interaction allows for a clean flavour decomposition:
e^-p: u-type quarks dominate; e^+p: d-type dominates at high x, sea dominates at low x

Summary

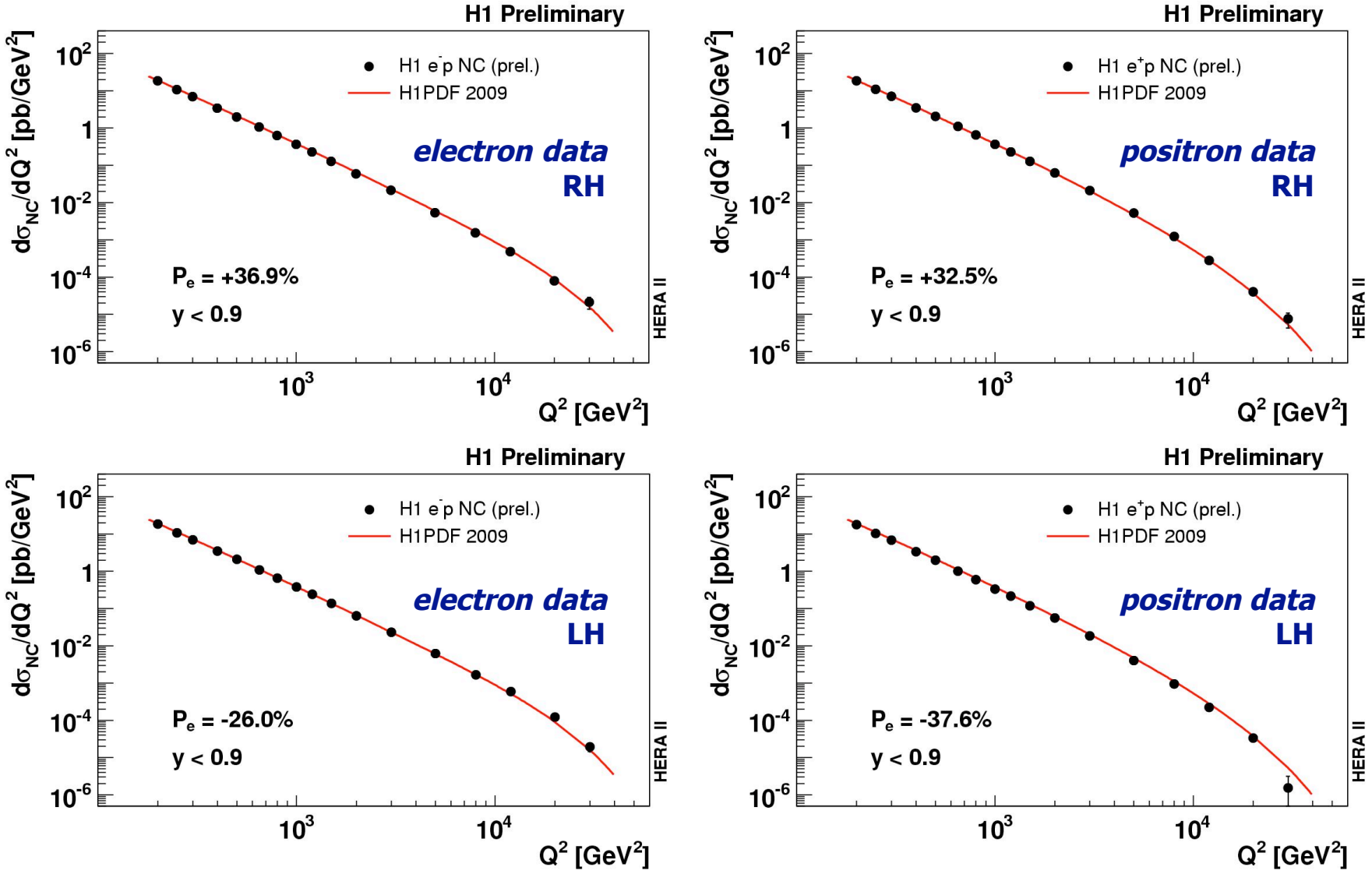
- Measurements of polarised and unpolarised neutral and charged current cross sections at HERA
  - Observed polarisation asymmetry in NC agrees with the SM prediction
  - Polarisation dependence of the CC cross section established in both e^+p and e^-p data: no right handed charged currents
  - The HERA I and II data have been combined to form unpolarised measurements and xF_3 is extracted



- Both H1 and ZEUS heading towards final publication of full HERA data, with more combined measurements to follow
  - Providing more constraints on the proton structure and input into new QCD fits such as HERA PDF

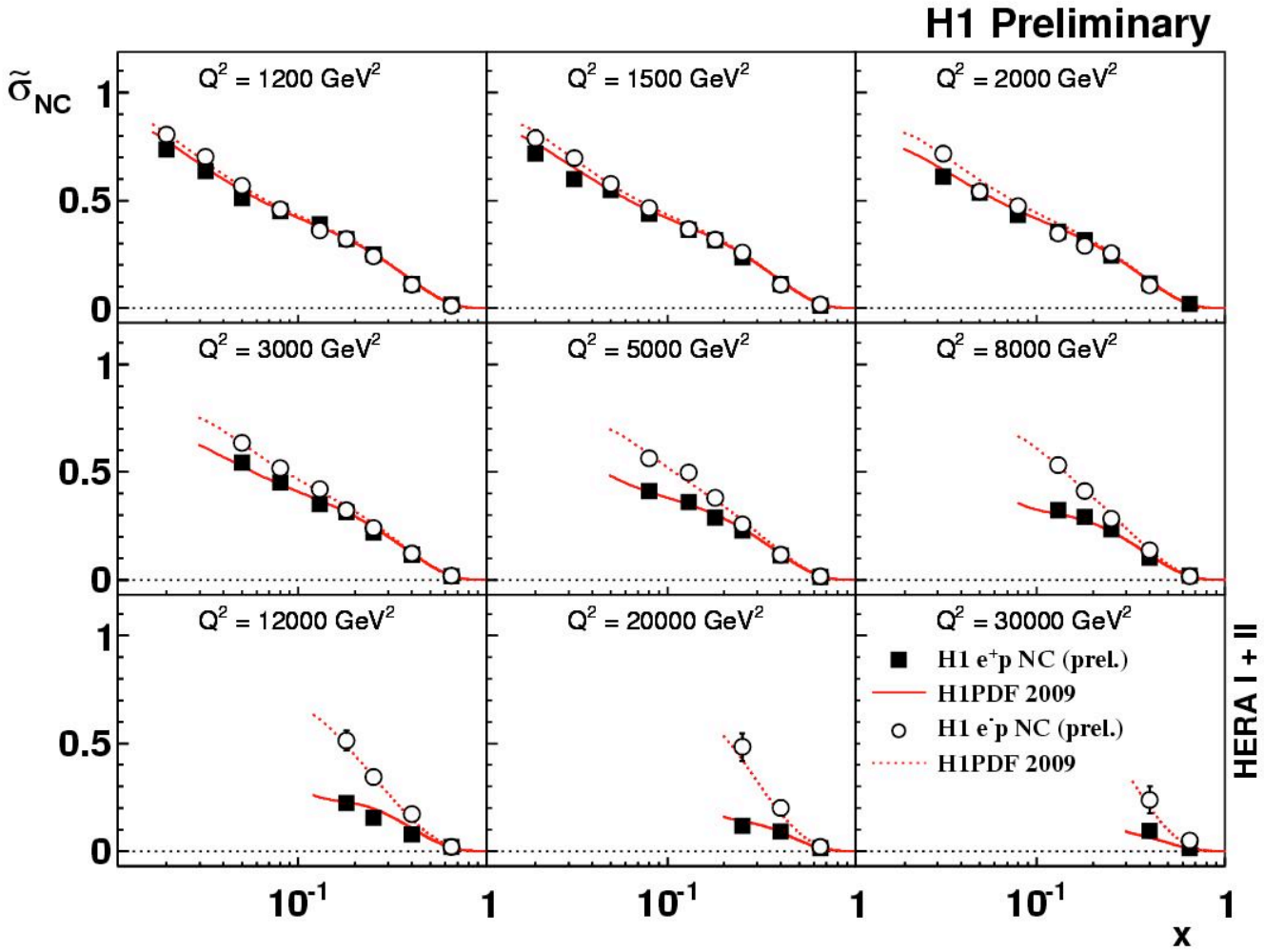
Extras

Single Differential NC Cross Sections $d\sigma/dQ^2$

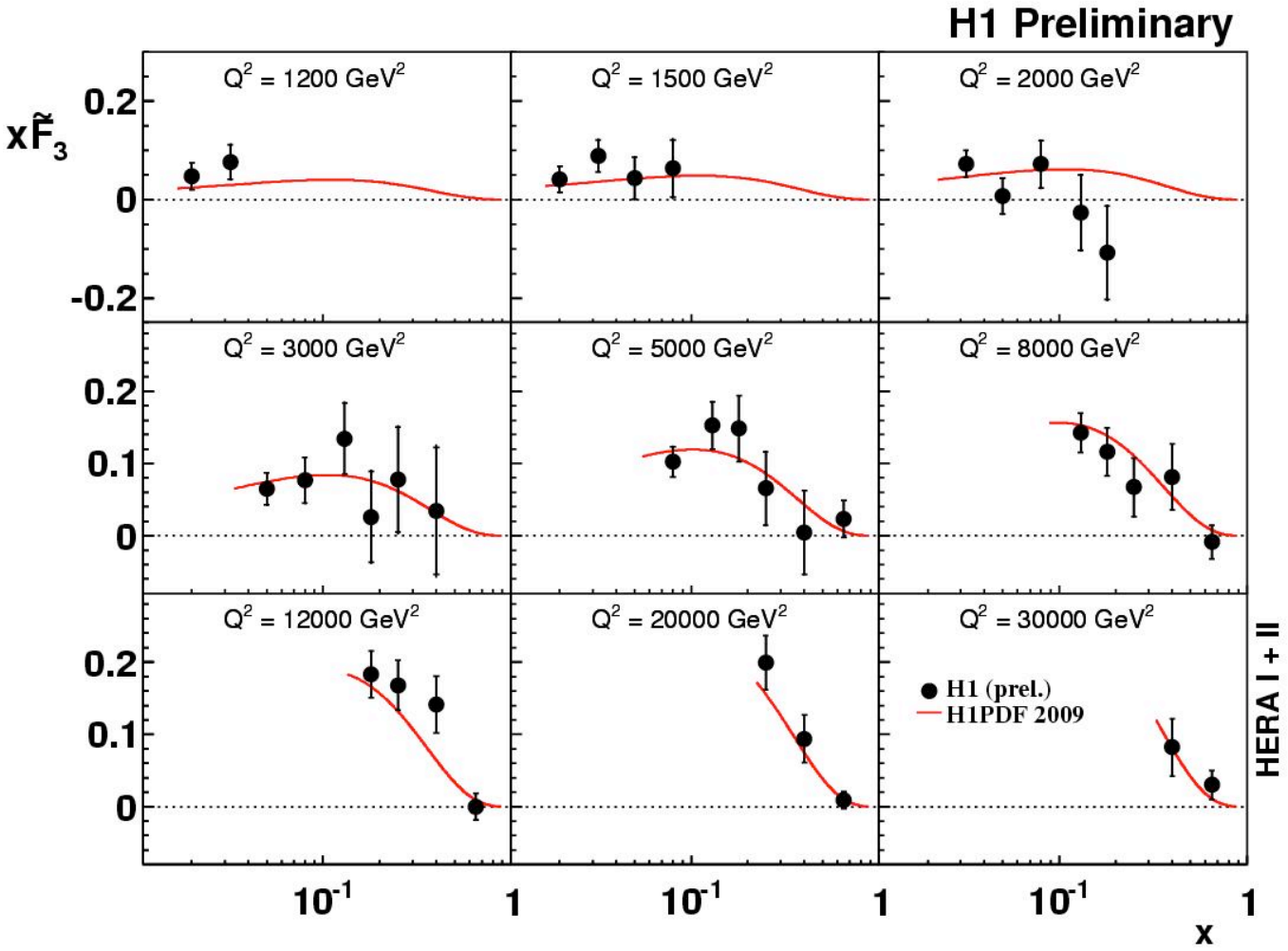


Excellent description of the Q^2 dependence of the data by the SM (from a QCD fit)

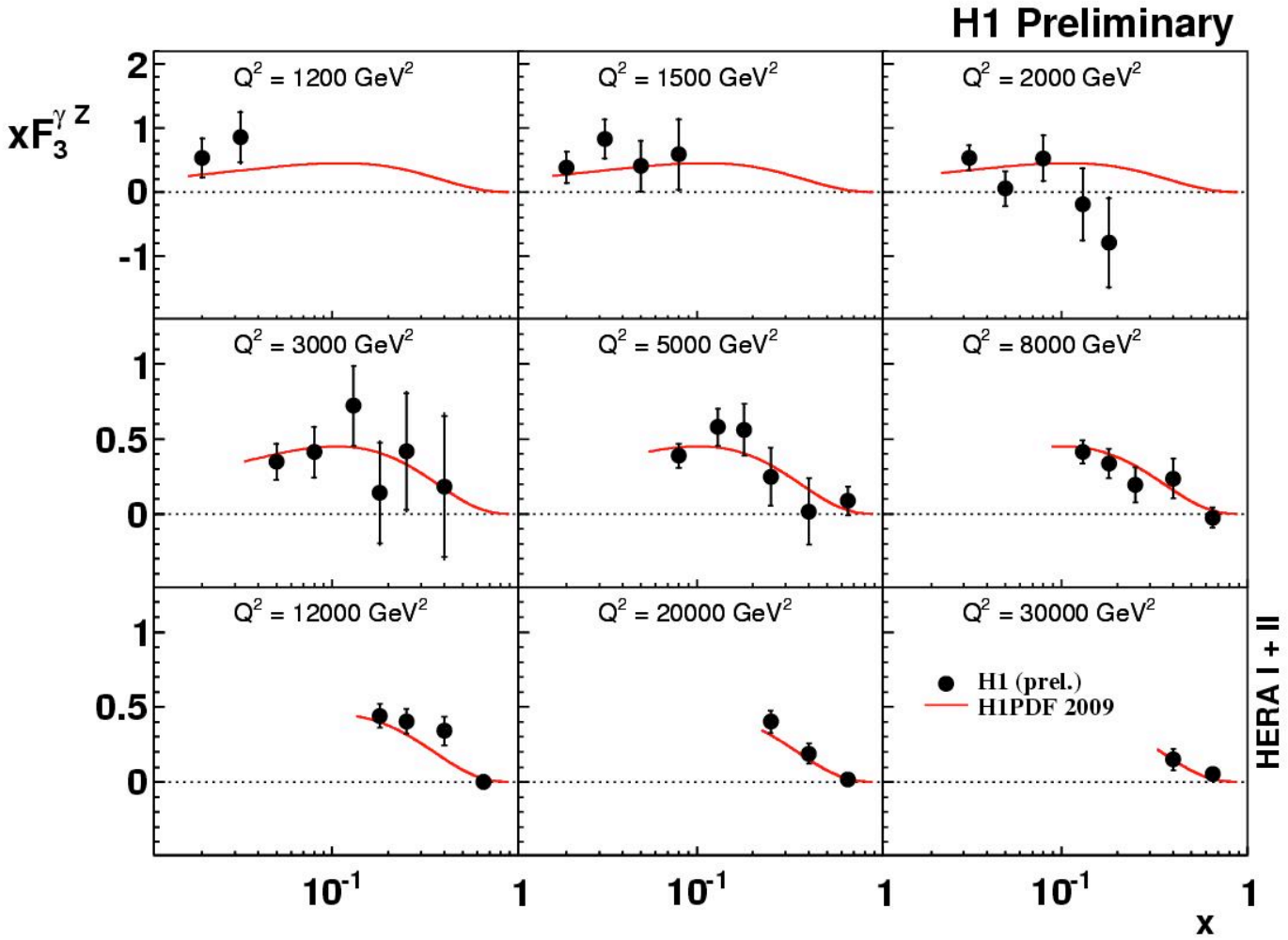
Unpolarised Reduced NC Cross Section: Full HERA I+II



Extraction of xF_3

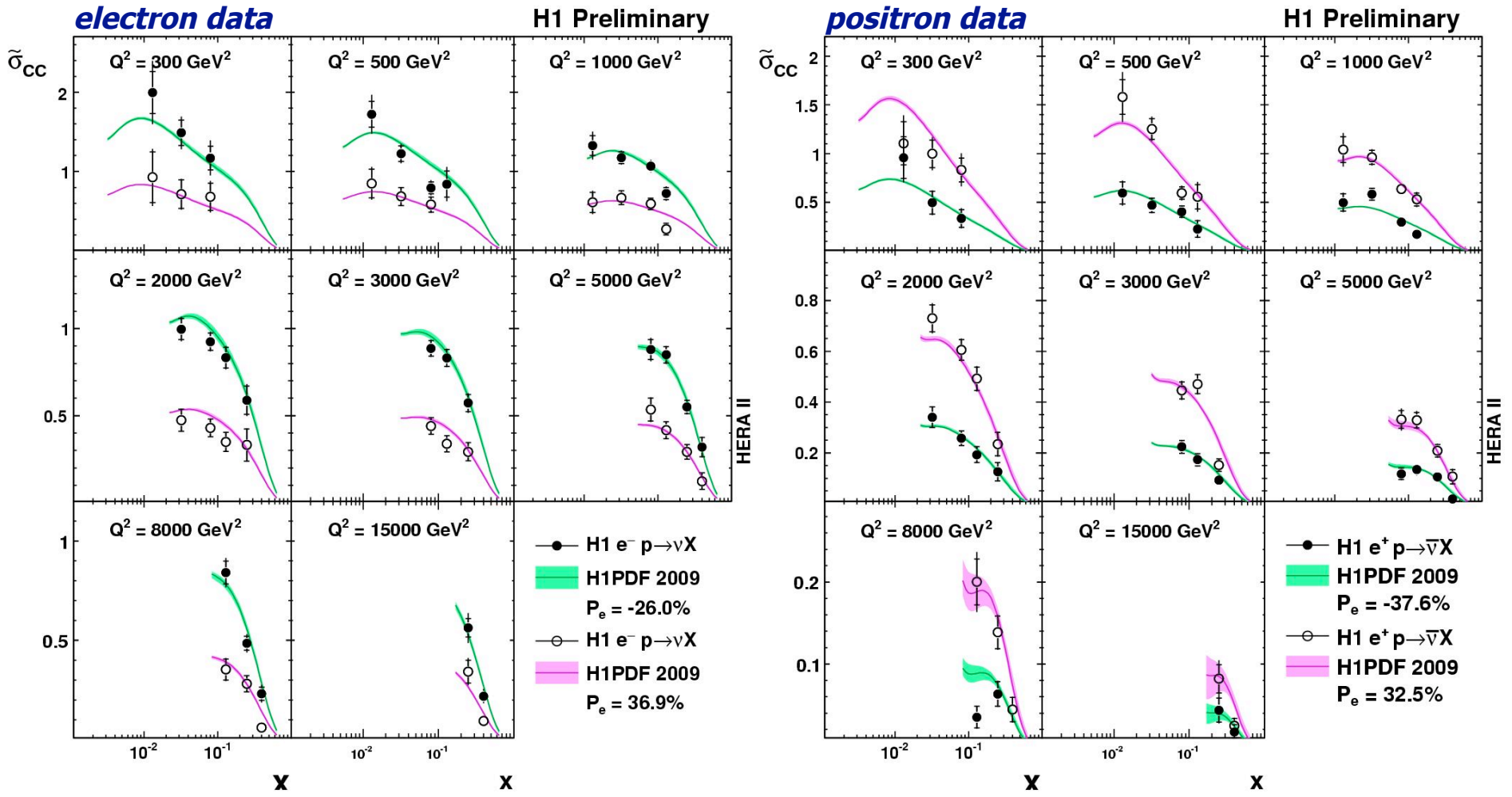


Extraction of $xF_3^{\gamma Z}$



$$xF_3^{\gamma Z} \simeq x\tilde{F}_3 \frac{(Q^2 + M_Z^2)}{a_e \kappa Q^2}$$

Reduced CC Cross Section: -P vs. +P



Similarly from H1, double differential cross sections show clear polarisation asymmetry