UNIVERSITY
of
GLASGOW

Structure Functions and Parton Densities at HERA

Chris Collins-Tooth

For the H1 and ZEUS collaborations

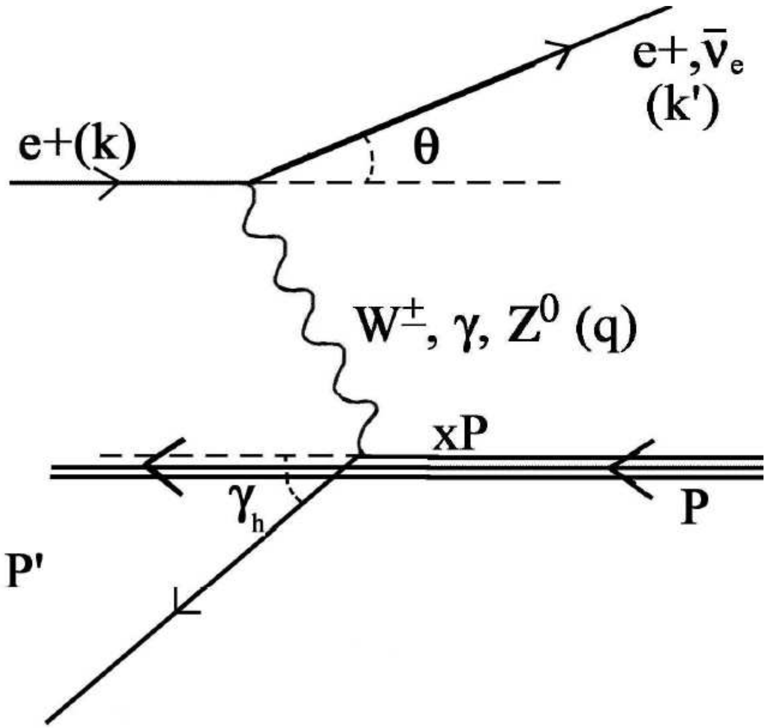
Deep Inelastic Scattering at HERA

DIS kinematic variables:

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

$x = Q^2/2p.q$ $\quad$ $y = p.q/p.k$

$s = (p+k)^2$ $\quad$ $Q^2 = x.y.s$



- Q^2 is the negative square of the 4-momentum transfer (probing power)
- x is the fraction of incident proton momentum carried by struck quark.
- y is the fractional energy transfer to the proton in its' rest frame; it is related to the CM scattering angle θ^* by : $y = \dfrac{1-\cos\theta^*}{2}$

DIS cross sections

- NC cross section:

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

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

F_2: dominant contribution

F_L: only significant at high y

xF_3: only significant at high Q^2

- CC cross section:

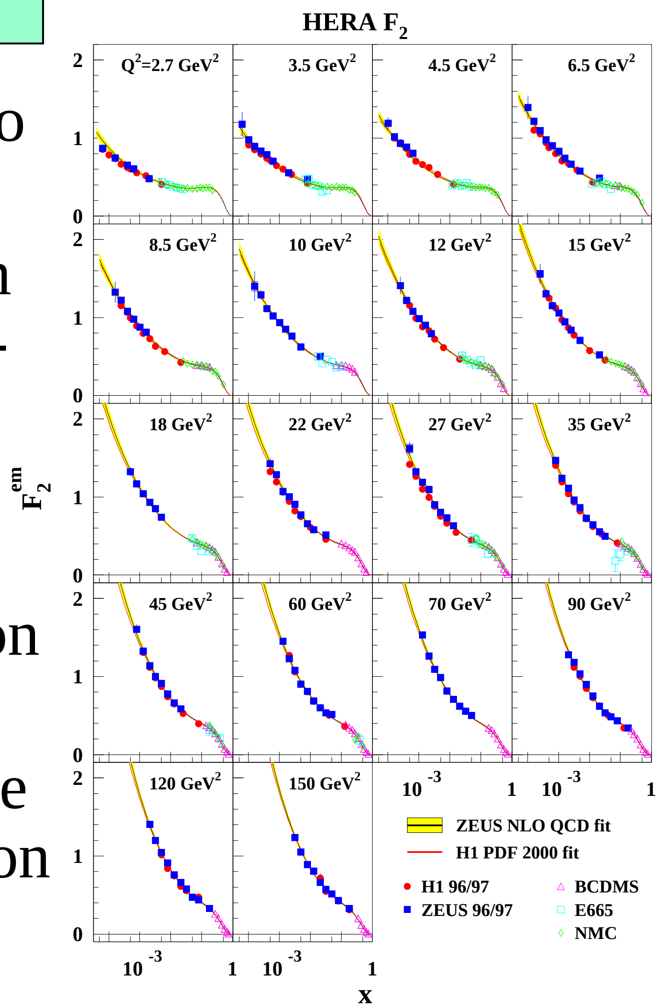
$$\frac{d^2\sigma^{CC}(e^\pm p)}{dxdQ^2} = \frac{G_F^2}{4\pi x} \frac{M_W^4}{(Q^2 + M_W^2)^2} \left[Y_+ F_2^{CC} - y^2 F_L^{CC} \mp Y_- xF_3^{CC} \right]$$

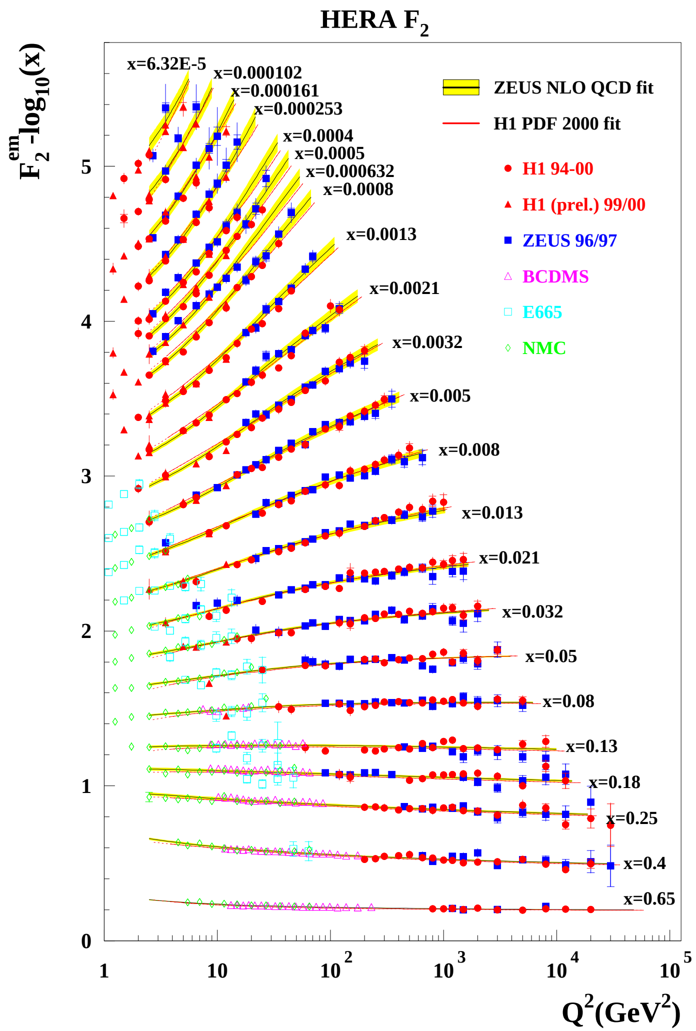
$\tilde{\sigma}^{CC}(x,Q^2)$ = reduced CC xsec.

F_2 measurements

$$F_2 \propto \sum_q e_q^2 x\left(q+\bar{q}\right)$$

- F_2 measurements to within ~2-3%
- F_2 sensitive to sum of quarks and anti-quarks
- Scaling violations largest at low-x, mainly due to gluon
- Gluons radiate $q\bar{q}$ pairs (QCD); hence F_2 sensitive to gluon density.





ZEUS F_L measurement

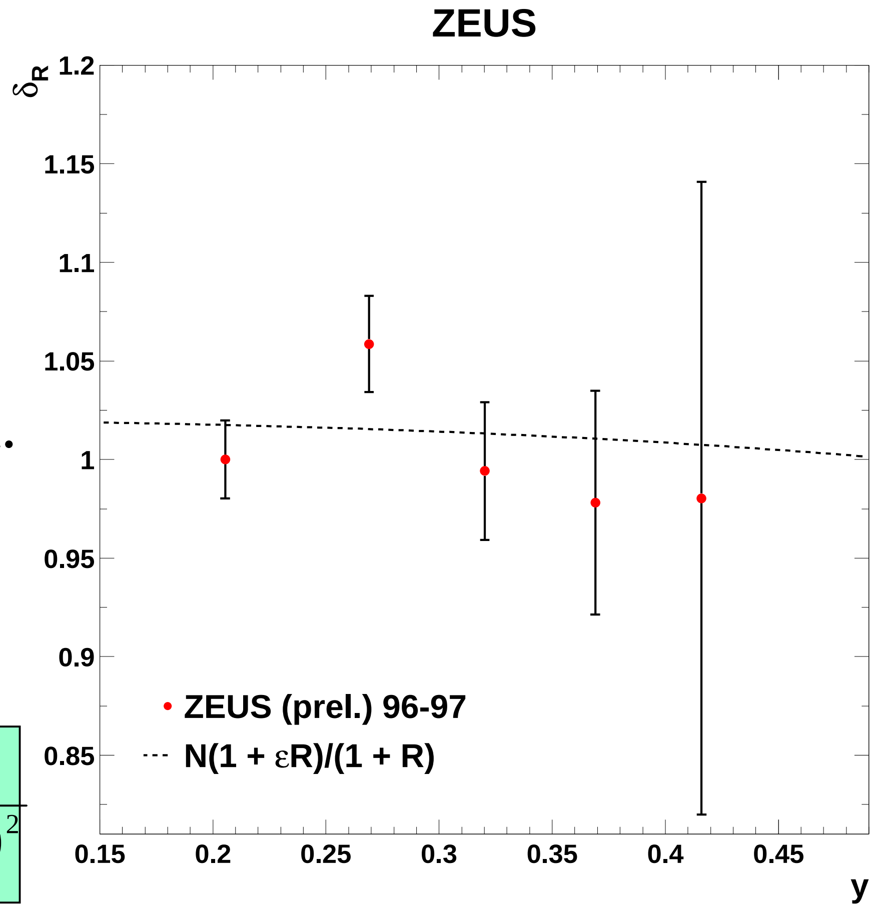
- ZEUS: use NC events with Initial State Radiation (ISR)
- Hard ISR photon emitted from e+, detected in lumi monitor
- Reduced CM energy for e+p inter'n.
- Gives variation in *y* for fixed values of *x*, Q^2
- Define:

$$\delta_{FL} \equiv \frac{\tilde{\sigma}(F_L \neq 0)}{\tilde{\sigma}(F_L = 0)} = \frac{F_2 - F_L(\varepsilon - 1)}{F_2}$$

$$\varepsilon = \frac{2(1-y)}{1+(1-y)^2}$$

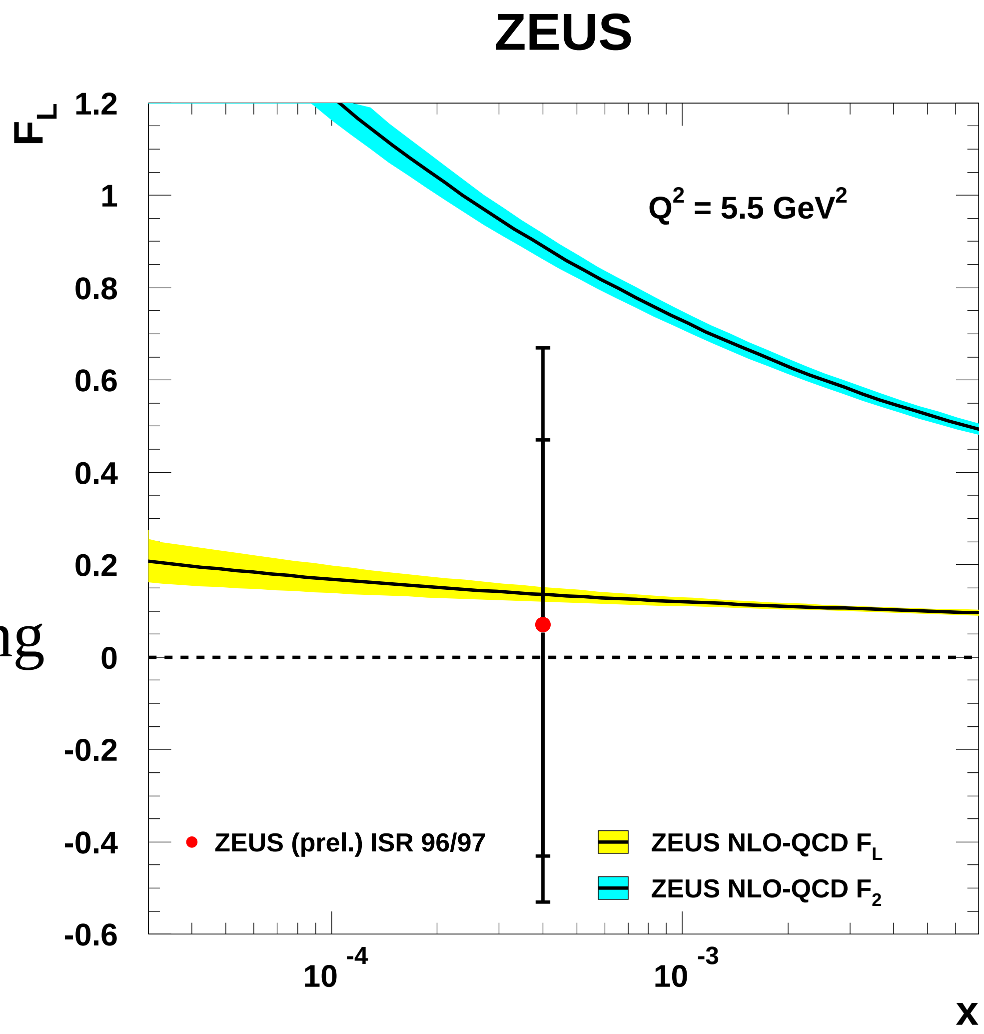
- Fit $\delta_R = \frac{N_{data}}{N_{mc}^{F_L=0}} = N \cdot \delta_{FL}$ (N, F_L free)

as a function of *y*.



ZEUS F_L measurement

- First *direct* measurement of F_L at HERA.
- Using ISR events works in principle.
- More precise measurements could be obtained by lowering the beam energy.

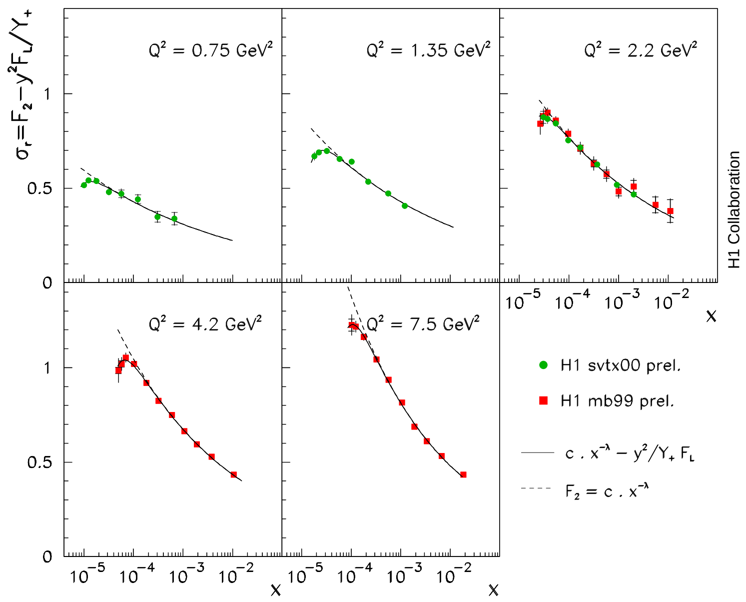


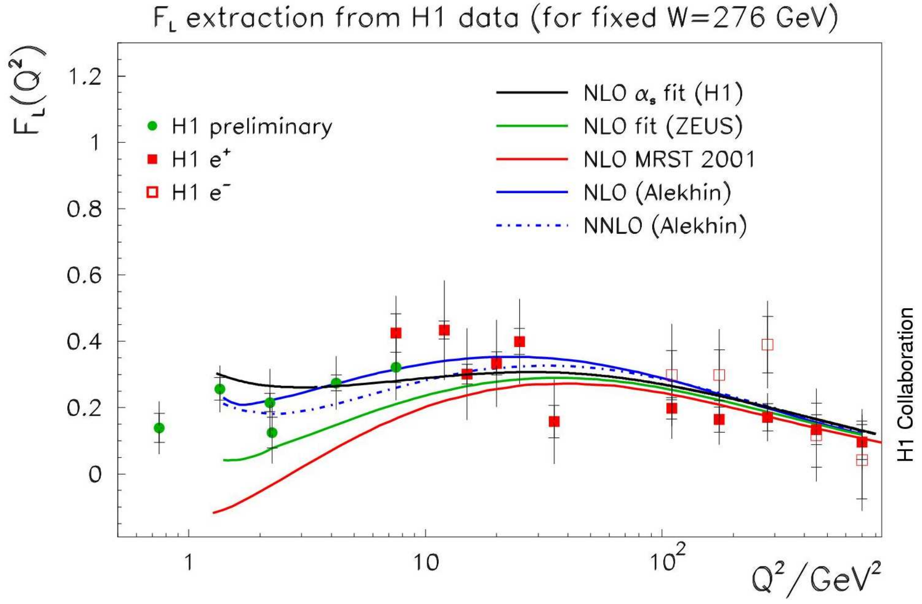
H1 F_L measurements

- H1: 'shape' method - for each Q^2 bin, use shape of cross section.
- At high-y, driven by y^2/Y_+, and by $F_L(Q^2)$ ..
- $F_L(Q^2)$ is an assumption.
- Also assumes $F_2 \sim x^{-\lambda}$ at fixed Q2.
- $\tilde{\sigma}$ in each bin parameterised as:

$$\tilde{\sigma}_{FIT} = c \cdot x^{-\lambda} - \frac{y^2}{Y_+} F_L$$

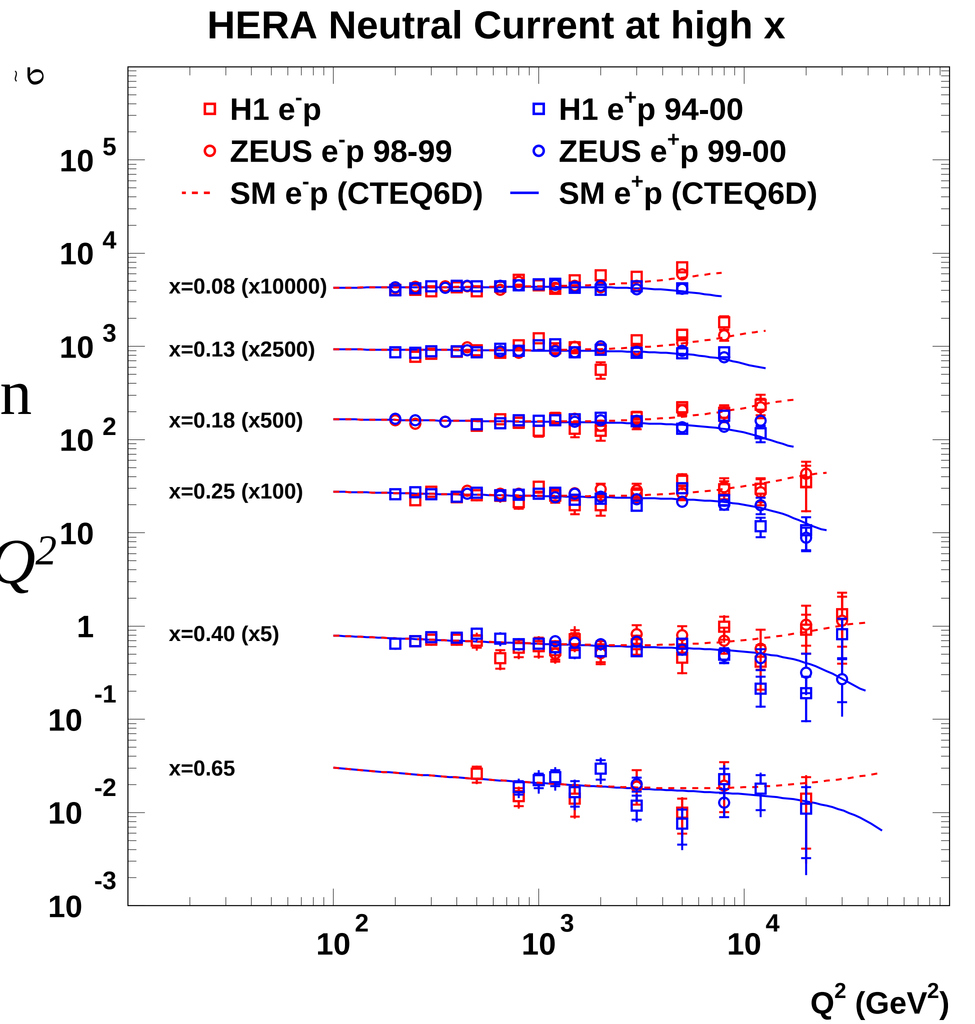
- Fit for one F_L point per Q^2 bin with c, λ and F_L free.
- Fits describe data well.





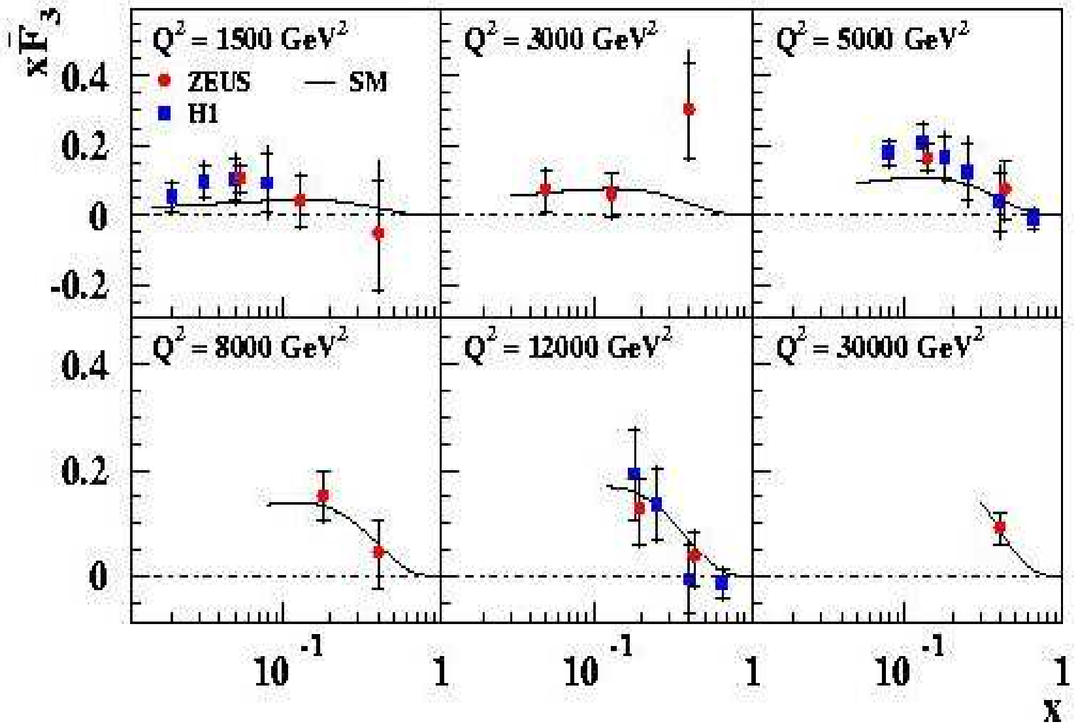
Neutral current cross sections

- NC processes predominantly measure *u* valence
- e^+p and e^-p cross section differences provide information on xF_3
- xF_3 has greatest effect at high Q^2



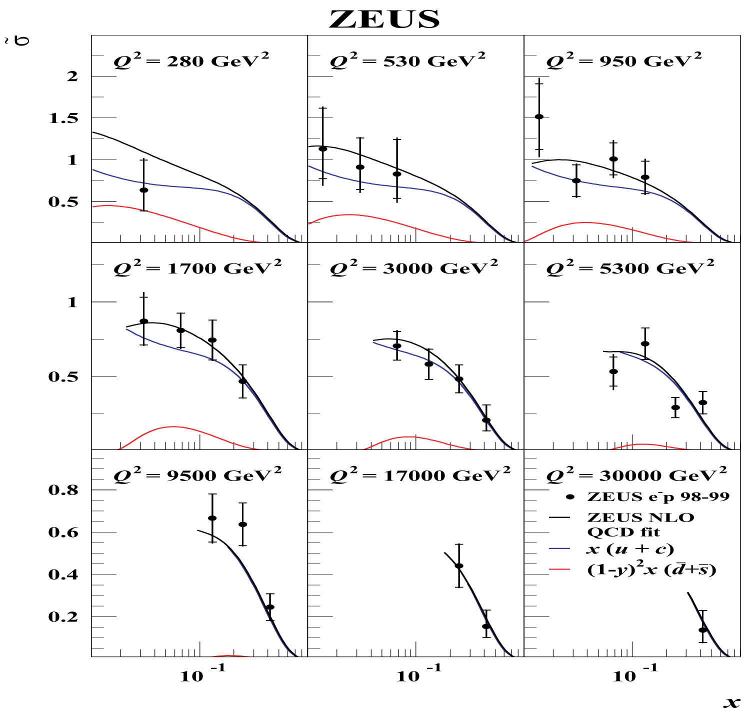
High Q^2 measurements – xF_3

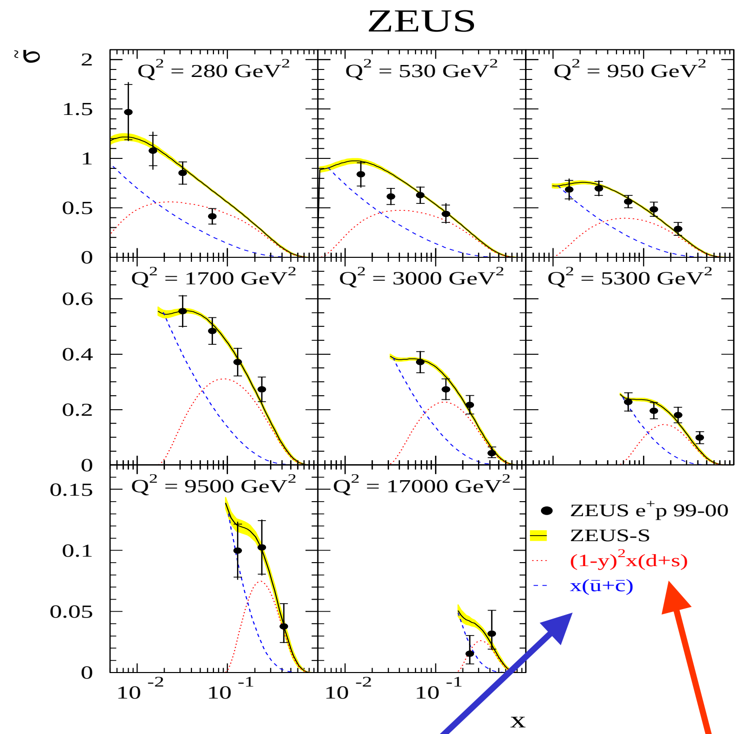
$$xF_3 \propto \sum_q x\left(q - \bar{q}\right)$$



- Uncertainties dominated by statistics of e^-p sample
- HERA measurements on a pure proton target

Charged current cross sections





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

u_v at high x

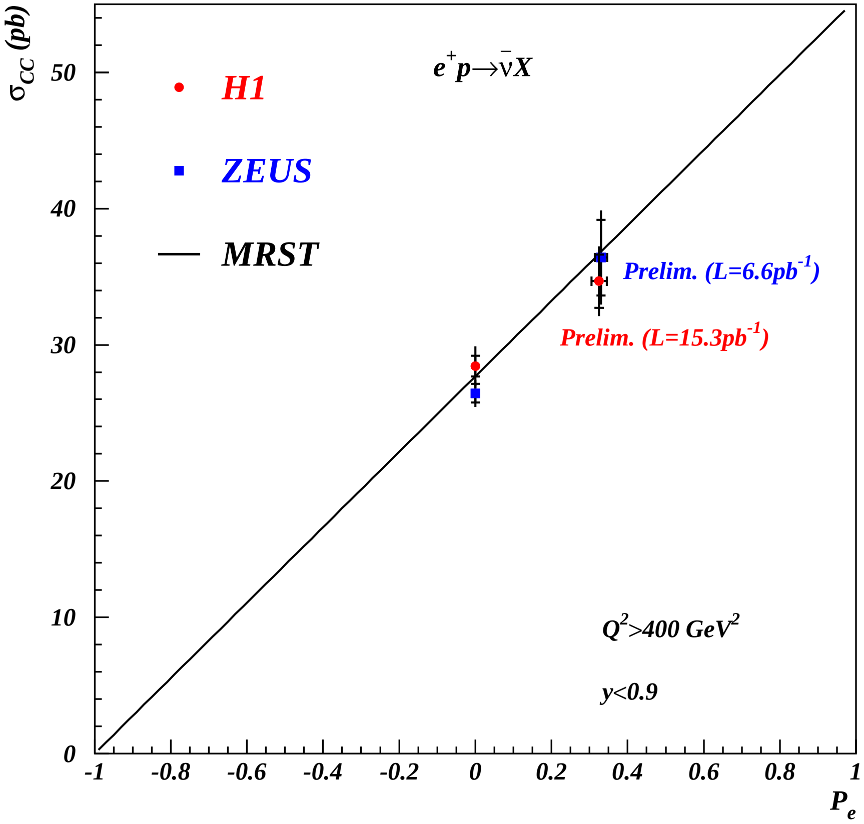
$$\tilde{\sigma}(e^+ p) = x\left[(\bar{u}+\bar{c}) + (1-y)^2(d+s)\right]$$

d_v at high x

- CC processes give flavour information
- Measurements of high-*x* *u* and *d* valence densities

HERA Polarised Charged Current

- Lepton beam at HERA now set up for polarisation.
- Spins naturally polarise transverse to beam dir. due to synchrotron radiation and *Sokolov-Ternov* effect.
- Begun to make first polarised measurements..

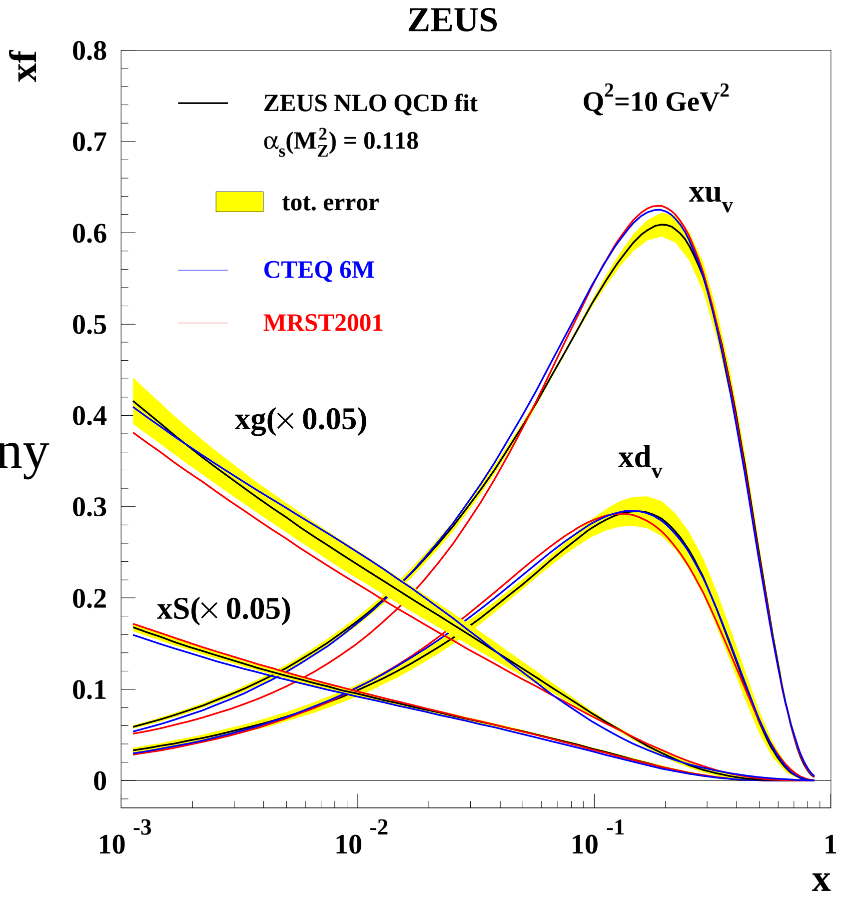


Parton densities

- PDFs are generally determined as follows:
  - decide on distributions to be determined, eg. u,d valence, Sea, gluon etc.
  - parameterise those distns. in x (at some value of $Q^2=Q_0^2$), with an assumed set of PDFs
  - evolve the PDFs in Q^2 (e.g. with DGLAP eqns) to obtain a grid of values in x, Q^2
  - convolute PDFs with coefficient functions to give structure functions and cross sections
  - fit the result to structure function data by minimizing a χ^2
- H1& ZEUS make different choices at many stages of the fitting procedure.

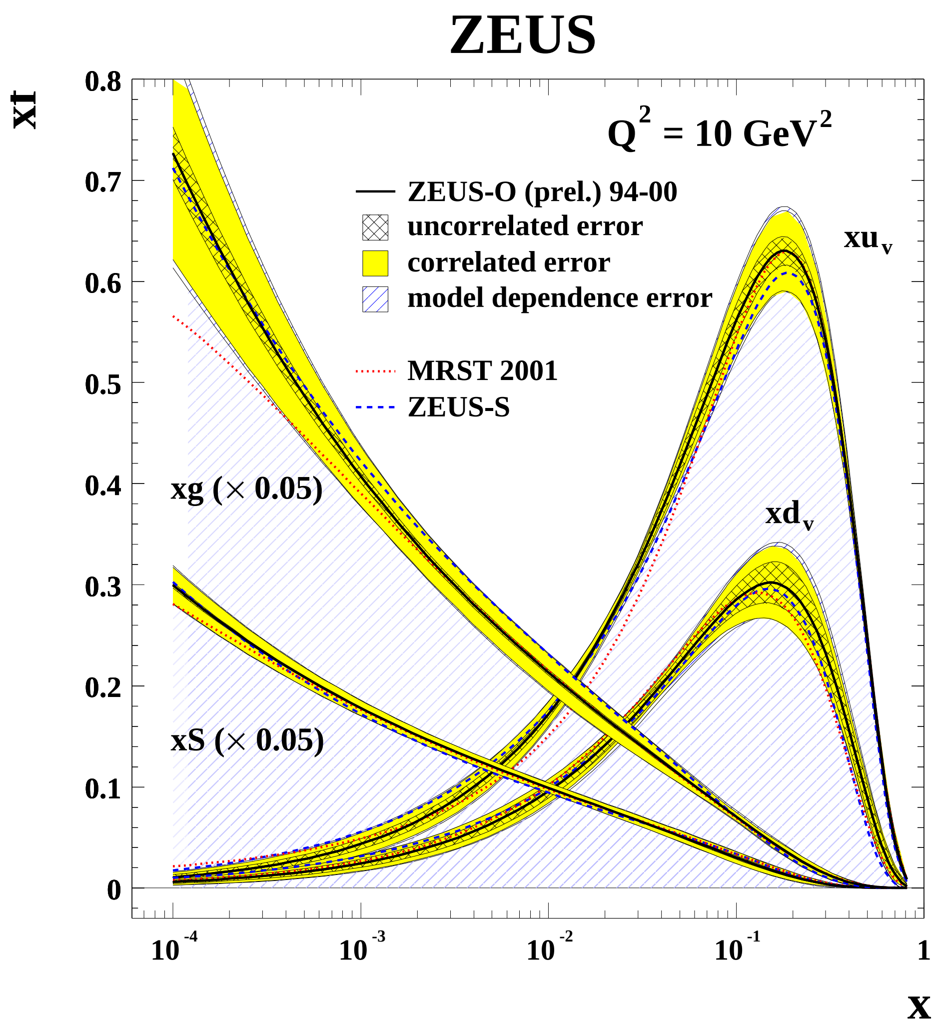
ZEUS-S (2002) ‘global’ fit

- ZEUS 96/97 NC e^+ data
- Fixed target data from:
  BCDMS, E665, NMC (Deut. and P targets)
  CCFR (Fe target)
- Corrections applied to to D and Fe data
- Uncertainty mainly from systematics of many expts, targets etc.
- Compares well to CTEQ, MRST
- Phys. Rev. D67 012007 (2003), hep-ex/0208023
- Available on Durham HEPDATA
  http://durpdg.dur.ac.uk/hepdata/zeus2002.html



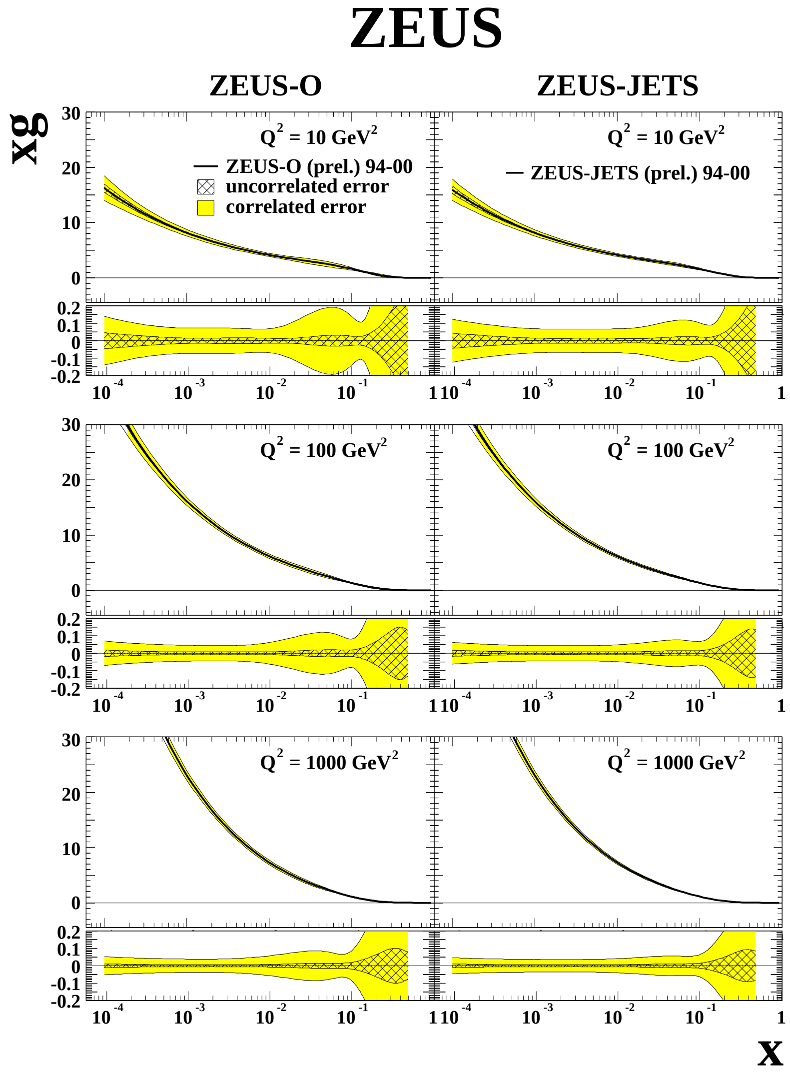
ZEUS-Only fit results

- Lack of information means we fix high-*x* Sea and gluon to the global S-fit values.
- 10 free parameters
- Fit has uncertainties dominated by statistics, not systematics.
- HERA-II data should improve this fit



ZEUS-Only + JETS fit

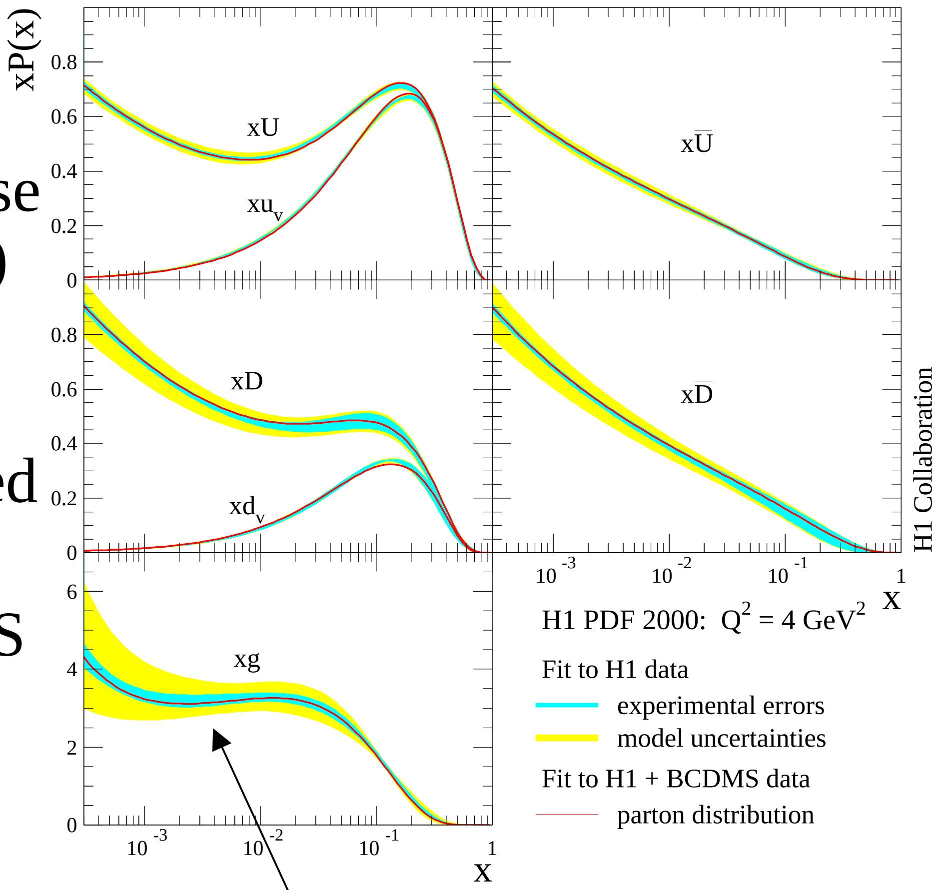
- Instead of fixing high-*x* gluon, keep it free.
- Add in 30 pb^{-1} 96/97 published ZEUS JET data.
  - EPJ C23(2002) 4, p615
  - Phys. Lett. B 547 (2002), p164
- Improvement quite striking for mid & high-*x* gluon.



Improvement in gluon determination
without jets → with jets
(11 parameter fits)

H1 PDF2000 fit

- Total 621 measurements
- H1 parameterise the distributions: g,U=u+c, D=d+s, $\bar{U}$, $\bar{D}$ (since these do not require sep. of u,d valence)
- Parameterised distributions evolved in Q^2, convoluted with coefficient functions and compared to data.
- H1 also do a fit including BCDMS μP data for α_s determination



variation of α_s is the main model uncertainty in the gluon

Summary

- The H1 PDF2000 fit, ZEUS-S and CTEQ6.1 are in reasonable agreement, given the different data and fitting models.
- New data from HERA-II offers polarised data, more lumi, and the possibility of better fits with well understood systematic uncertainties.
- Including Jet data (+ possibly F2charm data) should also improve the fits.