QCD Analyses of NC and CC Cross Sections
Determination of PDFs and α_s

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HERA–I Datasets

HERA datasets:

NC & CC e+ data $\sqrt{s}=300$	(94-97)	35 pb^{-1}
NC & CC e- data $\sqrt{s}=320$	(98-99)	16 pb^{-1}
NC & CC e+ data $\sqrt{s}=320$	(99-00)	65 pb^{-1}
NC data at low $Q^2 < 100$	(96-97)	

NC & CC data with different lepton charges provides quark flavour sensitivity

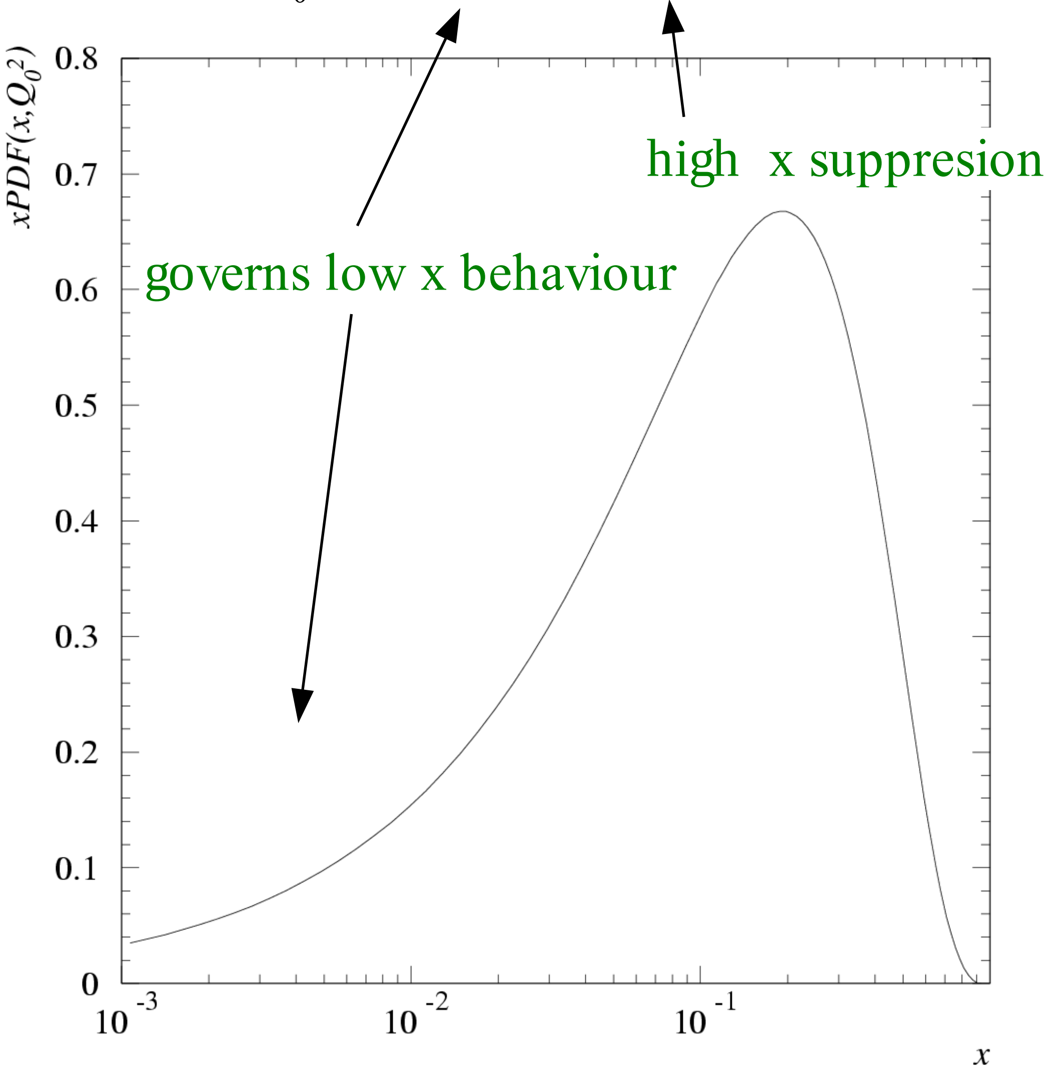
What Do We Learn From QCD Analyses?

- accurate determinations of PDFs allow accurate SM predictions
- PDFs used to calc very different processes for LHC / Tevatron
- precise α_s determination - independent of hadronic final state – ideal case
- understanding the transition region from pQCD to total photon-proton cross section tells us about QCD confinement
- QCD evolution evolves PDFs in Q^2
- QCD does not predict x dependence of PDFs
- x dependence must be extracted from data

PDF Parameterisations

PDFs parameterised at starting scale Q_0^2

$$xPDF\,(x, Q_0^2) = Ax^b(1-x)^c(1 + dx + e\sqrt{x} + fx^2 + gx^3)$$



parameters A,b,c,d,e,f optimised in fit for each PDF

Choosing parameterisation is something of an art!

Unclear how to include choice of parameterisation in PDF uncertainty

some parameters constrained by sum rules e.g. momentum sum = 1

$$\int u_v\,dx = 2 \qquad \int d_v\,dx = 1$$

Assumptions of the QCD Analyses

QCD analyses require many choices to be made

Should be reflected in PDF uncertainty:

- Q_0^2 starting scale
- Choice of data sets used
- Cuts to limit analysis to perturbative phase space (Q^2_{min})
- Choice of densities to parameterise (e.g. u_v, d_v, xg, xS)
- Treatment of heavy quarks
- Allowed functional form of PDF parameterisation
- Treatment of experimental systematic uncertainties
- Renormalisation / factorisation scales
- Choice of α_s
- etc...

ZEUS Global Analysis

- ZEUS perform a new global analysis - use world structure function data
  - ZEUS 96/97 NC e^+ reduced cross sections → gluon / quarks at low x / Q^2
  - F_2 NMC p &D and ratio F_2 D/p → quarks at medium x
  - F_2 E665 p & D → quarks at medium x
  - F_2 BCDMS p only → u quarks at high x / low Q^2
  - xF_3 CCFR ($0.1 < x < 0.65$) → valence quarks at high x / low Q^2
- Standard xg, xu_v, xd_v, Sea, $x(\bar{d} - \bar{u})$ decomposition of proton
- $Q^2_0 = 7$ GeV^2 / $Q^2_{min} = 2.5$ GeV^2
- Additional constraints on valence quark parameters ($b_{uv} = b_{dv} = 0.5$)
- Use functional form = $A . x^b \cdot (1-x)^c \cdot (1 + dx + e\sqrt{x})$
- Experimental systematic uncertainties are propagated onto final PDF uncertainty
- Use Thorne/Roberts variable flavour number scheme.
- $x(\bar{d} - \bar{u})$ params taken from MRST - only normalisation free in fit

H1 Only QCD Analysis

Use only H1 inclusive NC & CC x-sections (e^+p and e^-p)
H1 perform a dedicated fit: tune fitted PDFs to NC/CC cross section sensitivity:

$$
\begin{aligned}
xU &= xu + xc \\
xD &= xd + xs \\
x\bar{U} &= x\bar{u} + x\bar{c} \\
x\bar{D} &= x\bar{d} + x\bar{s} \\
&xg
\end{aligned}
$$

$$
\begin{aligned}
u_v &= U - \bar{U} \\
d_v &= D - \bar{D} \\
F_2 &= \frac{4}{9}(xU + x\bar{U}) + \frac{1}{9}(xD + x\bar{D}) \\
\tilde{\sigma}^+_{CC} &= x\bar{U} + (1-y)^2 xD \\
\tilde{\sigma}^-_{CC} &= xU + (1-y)^2 x\bar{D}
\end{aligned}
$$

Perform fit in massless scheme - appropriate for high Q^2

Careful choice of parameterisations search for χ^2 saturation

$Q^2_0 = 4\ \mathrm{GeV}^2$ / $Q^2_{min} = 3.5\ \mathrm{GeV}^2$

Use BCDMS p and D data as cross check only

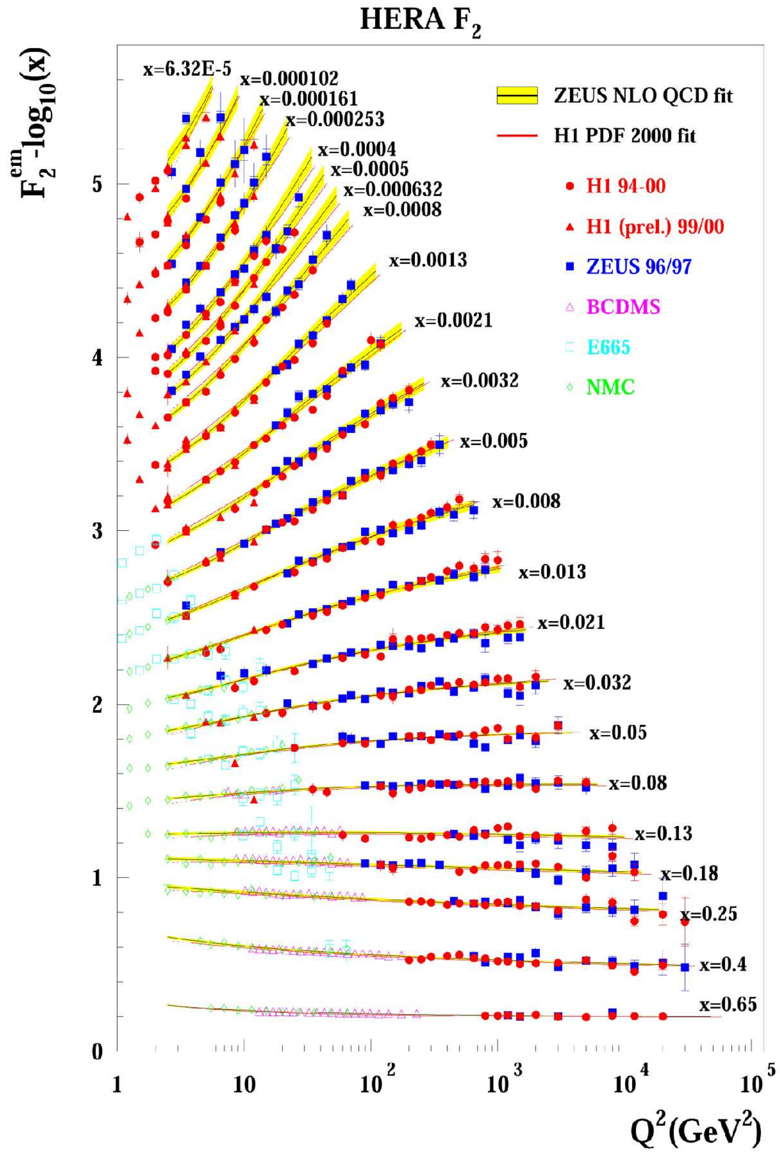
Description of NC Data

Both H1 and ZEUS fits provide good description of inclusive data

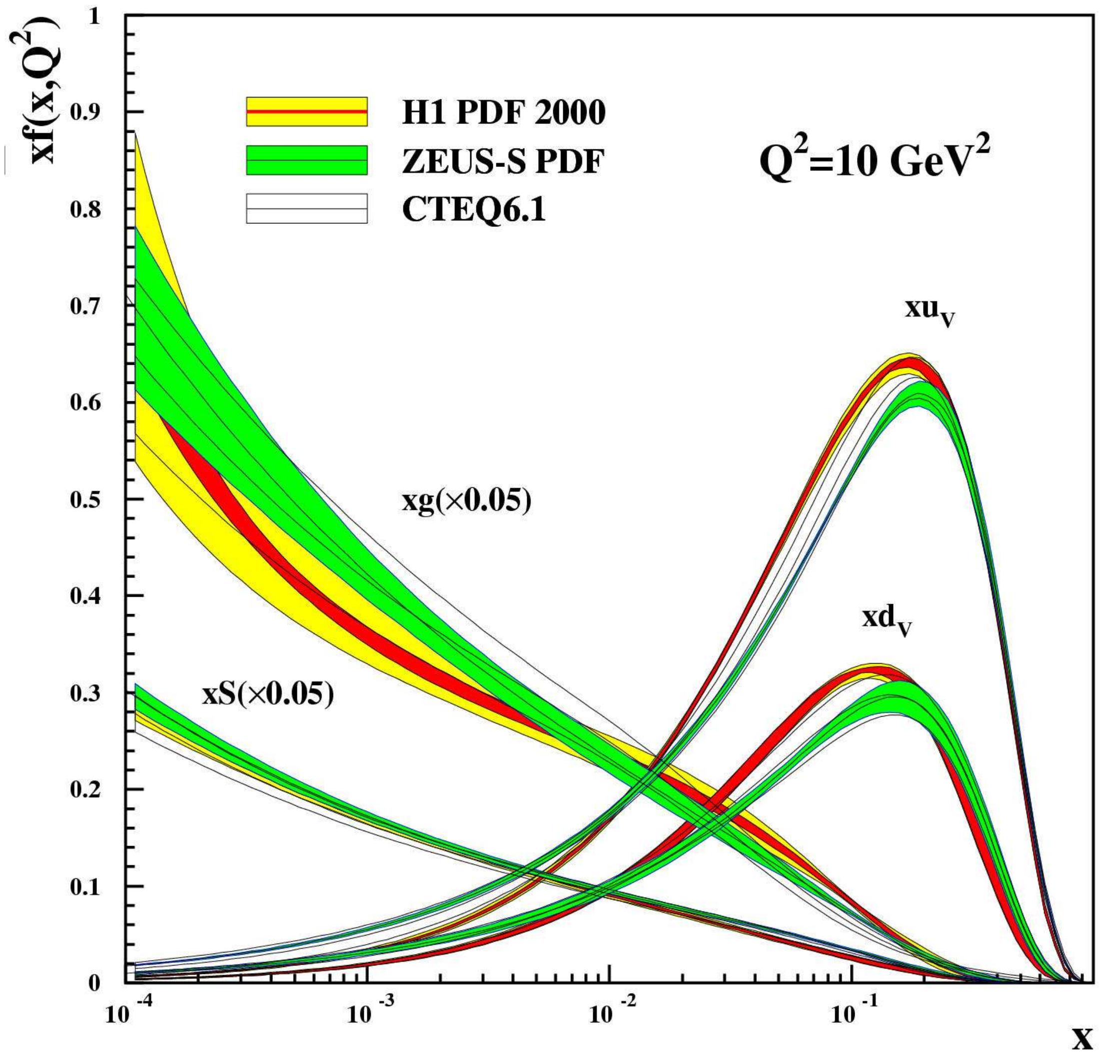
scaling violations of F_2 well described

H1: χ^2 / ndf = 0.88 (621 data points, 10 pars.)

ZEUS: χ^2 / ndf = 0.95 (1263 data points, 11 pars.)



HERA PDFs



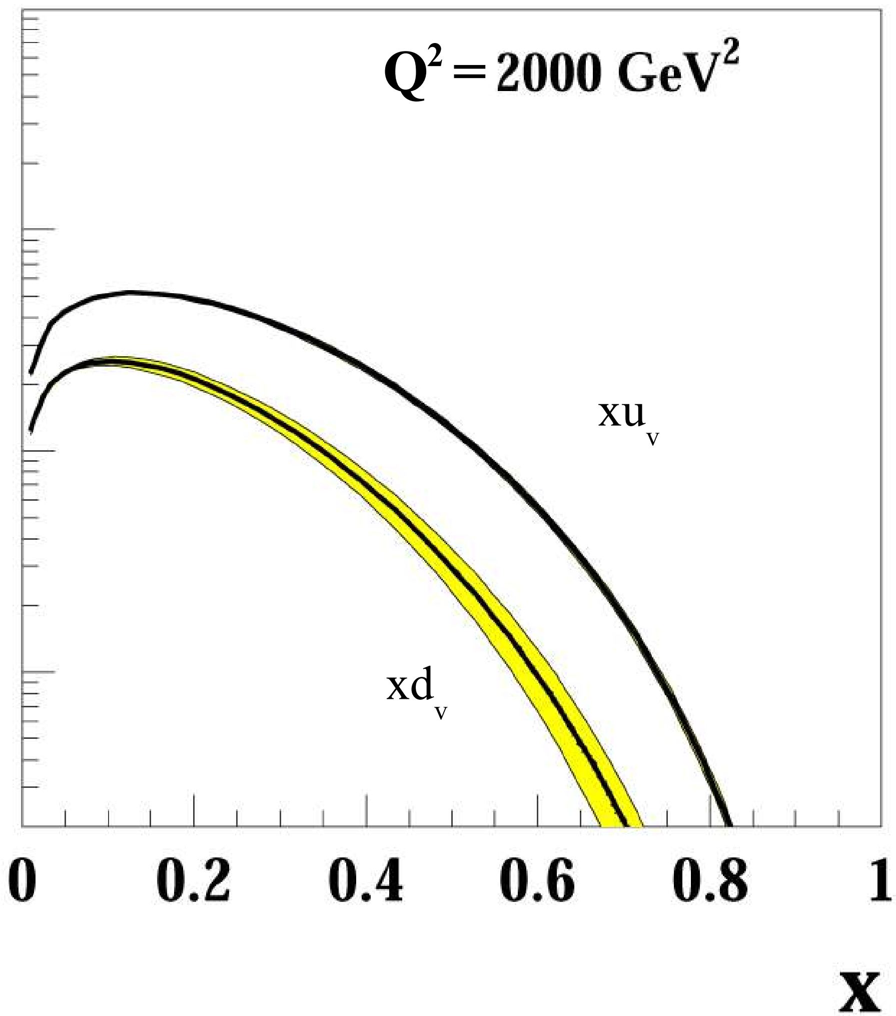
ZEUS/ H1 analyses in agreement for xS and xg at low x – HERA data

Differences in high x valence – different data used in fits

or missing component in PDF uncertainty?

CTEQ 6.1 lies between ZEUS & H1 fits

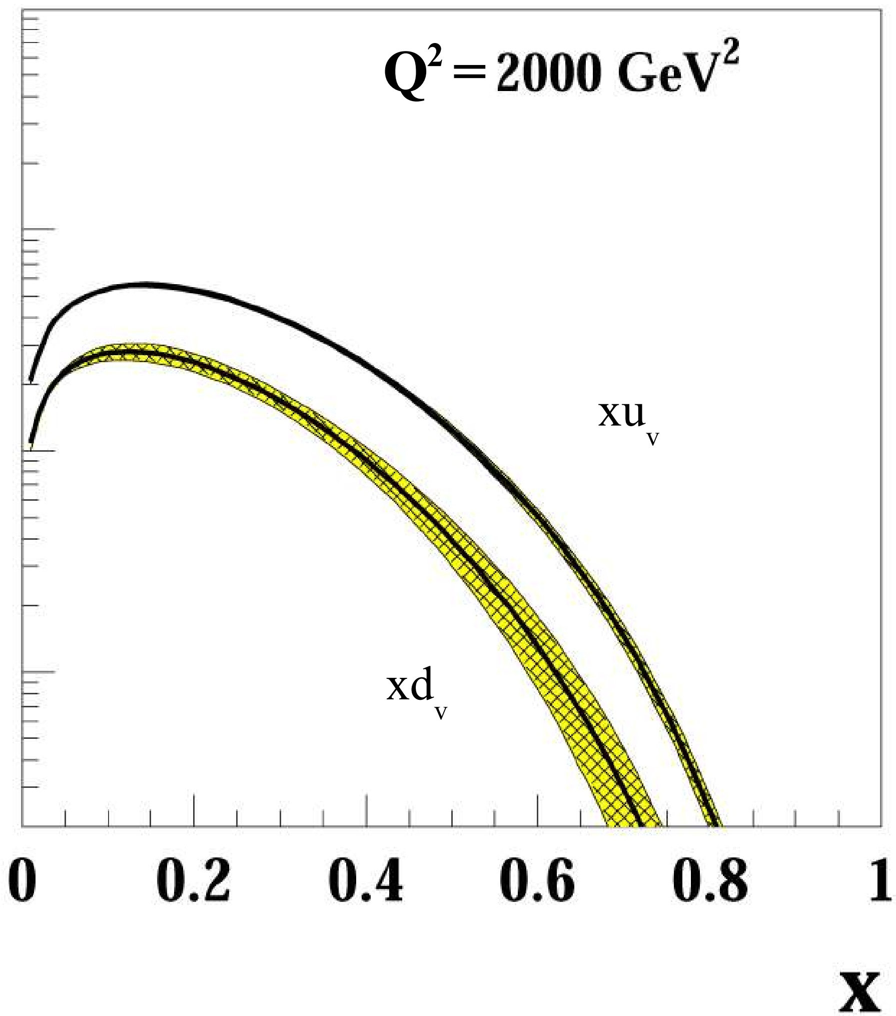
ZEUS Global PDFs



Fit to ZEUS data + global DIS data

Valence distributions well constrained

ZEUS only PDFs

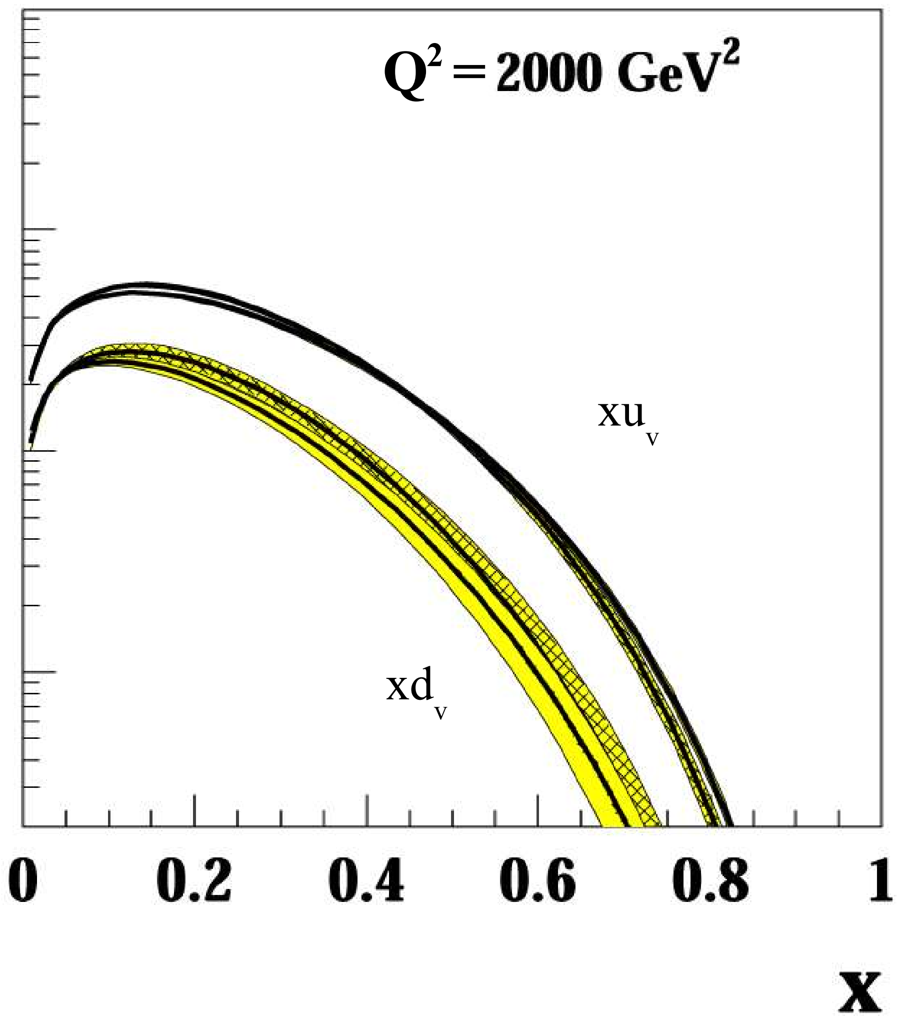


Fit to ZEUS data only

High Q^2 HERA data provide direct valence constraint

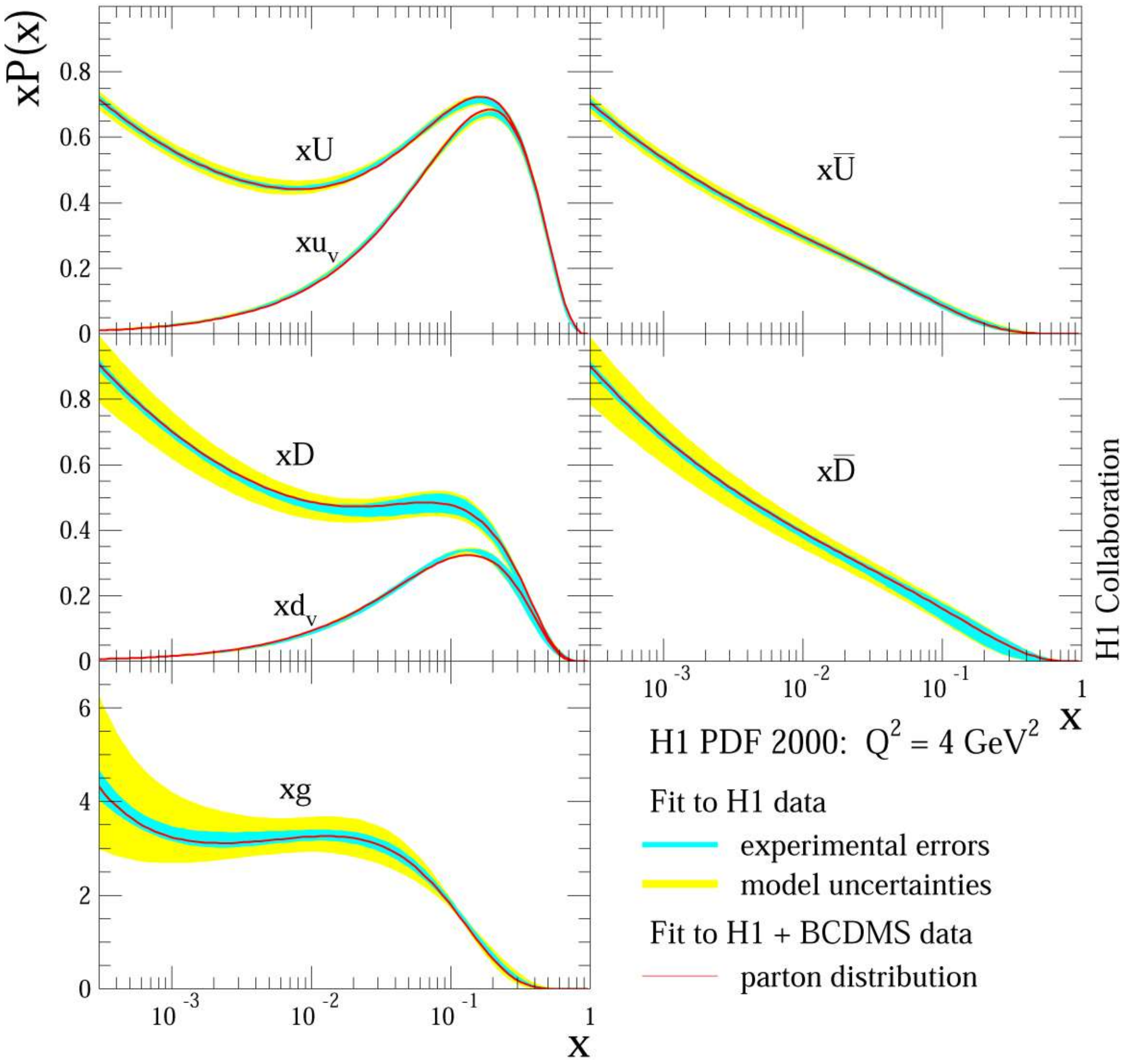
low x parameters fixed in PDF fit

ZEUS Global PDFs



- xd_v found to be larger but in agreement
- Deuteron data subject to nuclear corrections...
- HERA data measure valence at much higher Q^2
- With HERA-I data uncertainties on valence are ~ factor 2 larger than global anaysis

H1 PDFs



Fit provides tight constraint on xU and xD at high x

xD ~ 10%

xU ~ 3%   at x=0.4

Including precise BCDMS data yields same PDFs – smaller uncertainties

H1 Gluon and α_s

Different approach: Minimise theory uncertainty - minimise data sets

- Perform dedicated QCD analysis for simultaneous α_s and xg fit at low x / Q^2.
- Use precise H1 and BCDMS-p F_2 data to constrain valence region.
- Check consistency of data sets.
- Tune fitted PDFs to measured cross sections.
  - xg
  - $xV = \frac{9}{4}u_v + \frac{3}{2}d_v$
  - $xA = \bar{u} + \frac{1}{4}(u_v - 2d_v)$

$$F_2 = \frac{1}{3}xV + \frac{11}{9}xA$$

no nuclear correction required

used for systematic checks

- Use parametric form of: A x^b $(1\text{-}x)^c$ $(1 + dx + e\sqrt{x} + fx^2)$
- Use 3-flavour number scheme - optimal choice in region of precision H1 data
- Experimental systematics are fitted → PDF error bands

HERA Determinations of α_s From Inclusive Data

H1

0.1150 +−0.0017(exp) +0.0009 −0.0007(model)

if: systematíc errors are not fitted: +0.0005

EPJ C21(01)33

NMC replaces BCDMS 0.116+-0.003 (exp)

4 light flavours: +0.0003

BCDMS deuteron data added: 0.1158 +- 0.0016 (exp)

ZEUS

0.1166 +−0.0008(unc) +−0.0032(corr) +−0.0036(norm) +−0.0018(model)

systematíc errors are not allowed to vary in chi2 minimisation

$Q^2 > 2.5$ GeV^2, $W^2 > 20$GeV^2, RT-VFNS, $b_{uv} = b_{dv} = 0.5$

fit α_s, xg, uv, dv, sea, $\bar{d} - \bar{u}$ (MRST)

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if fixed flavour scheme is used: +0.0010

HERA Determinations of α_s From Inclusive Data

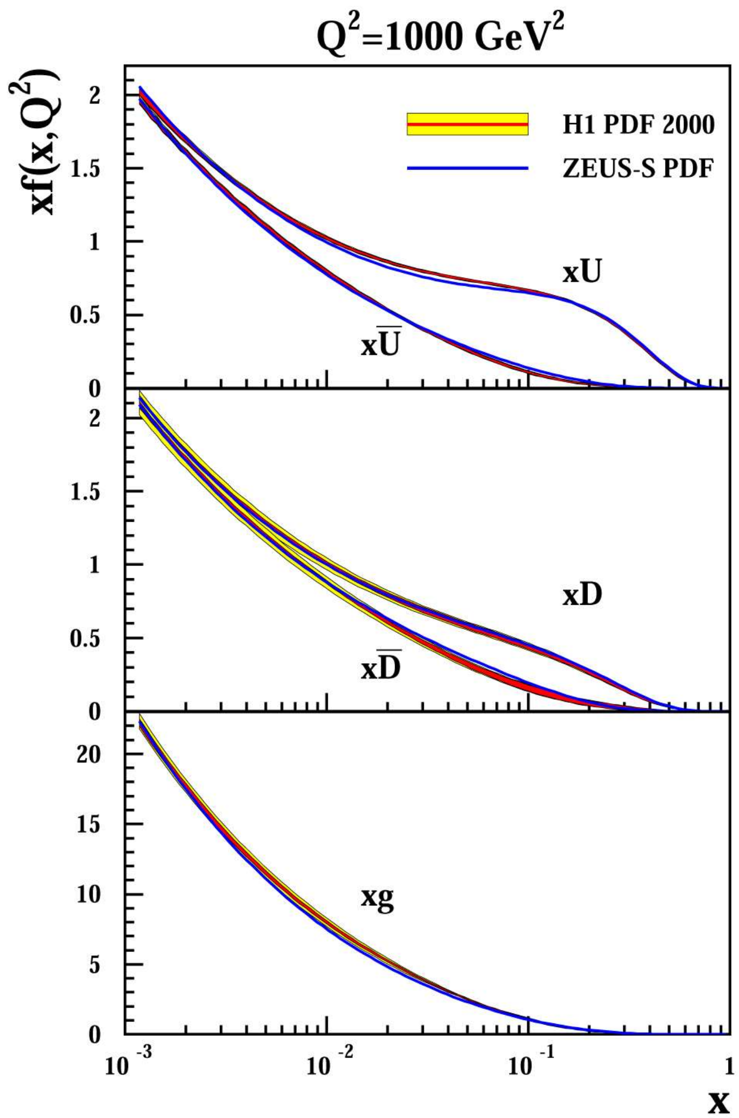
Large χ^2 variations if renormalisation scale is varied: ±20 units !

→ (¼ .. 4) : ± 0.005 (H1)

→ (½ .. 2) : ± 0.004 (ZEUS)

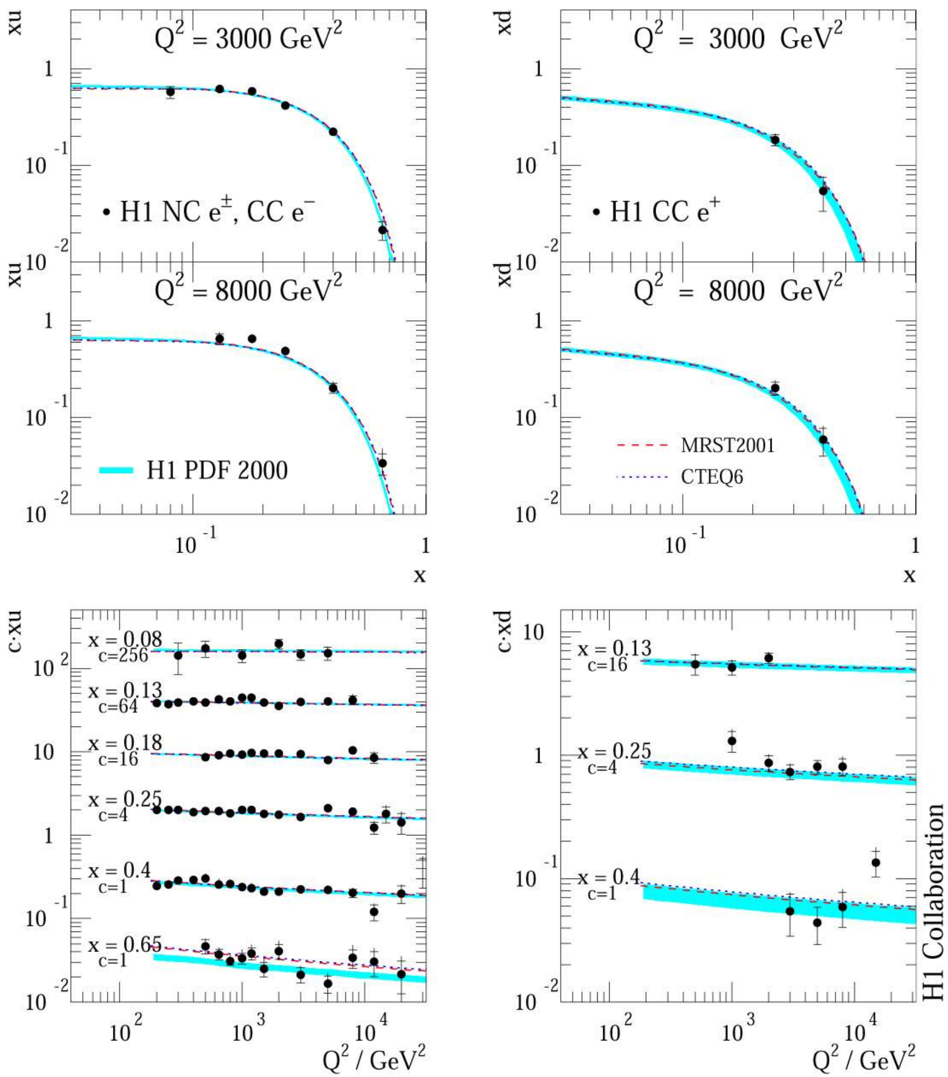
- **Variations of factors 2 or 4 are ad hoc**
- **Largest single uncertainty in determination of α_s**
- **Expected to be reduced in a NNLO analysis**

QCD Analyses of HERA Structure Function Data



- HERA data now able to constrain PDFs alone
- At high Q^2 (LHC region) QCD evolution washes out differences
- PDF extractions should consider parameterisation uncertainty
- α_s extracted from DIS data - competetive with world average
- NNLO analysis could yield most precise determination of α_s

H1 PDFs



Can compare fit result with local extraction method:

Use cross section measurements at high x dominated (>70%) by xu or xd

Apply correction to measurements based on QCD expectation

Assumptions in expectation largely cancel

Insensitive to QCD evolution effects

Complementary to QCD fit

Description of CC Data

Good description of CC data

CC cross sections sensitive to d_v at high