ZEUS PDF fits

A M Cooper-Sarkar HERA/LHC w/shop March 26 2004

Published GLOBAL ZEUS-S fits to 30 pb^{-1} of ZEUS 96/97 NC e+ differential cross-section data and fixed target DIS structure function data

Phys. Rev. D67,012007(2003) (hep-ex/0208023)

Central PDFs and error analysis available on http://durpdg.dur.ac.uk/hepdata/zeus2002.html

as eigenvector PDF sets in LHAPDF compatible format

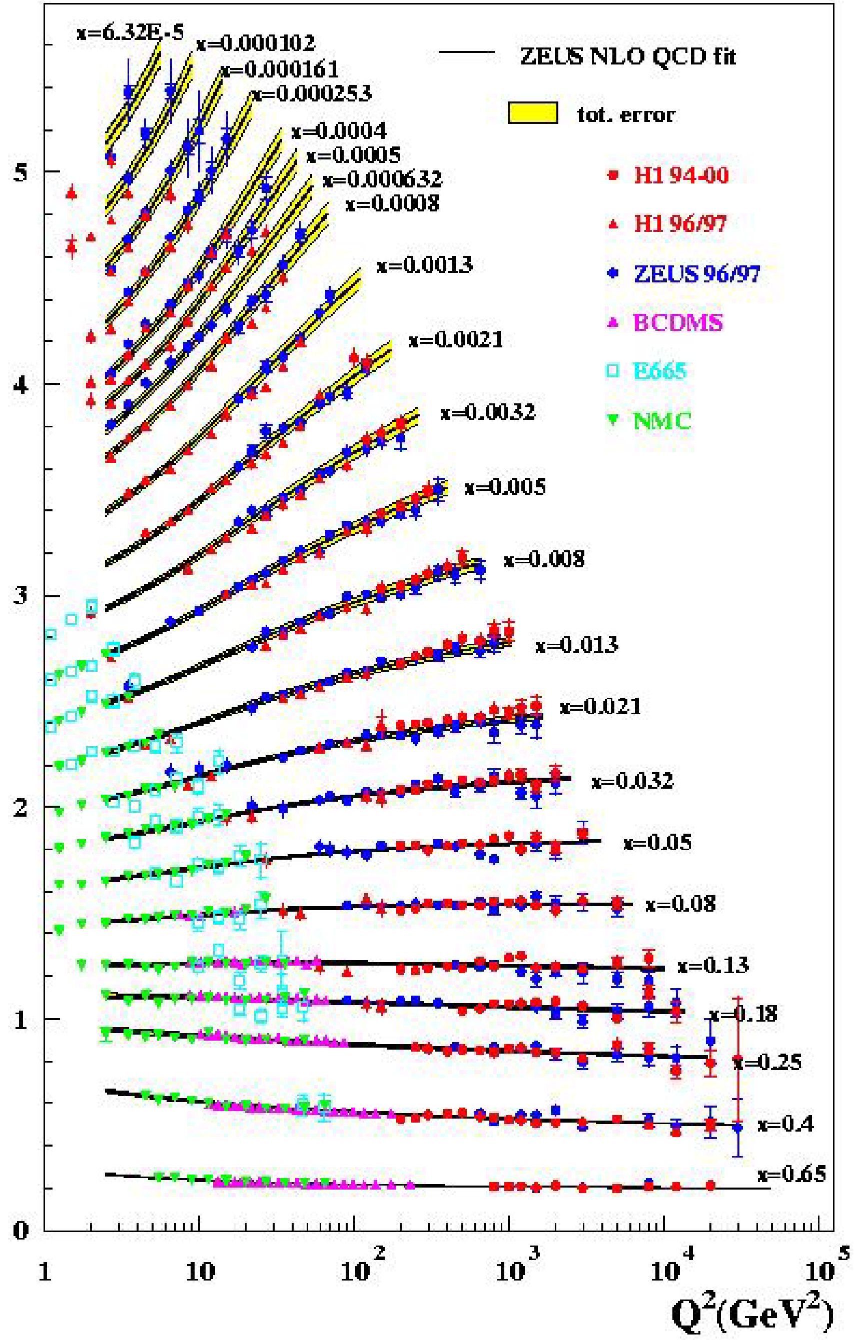
Preliminary ZEUS-Only fits to 109 pb-1 of HERA-I data: 94-97 NC/CC e+/e- inclusive differential cross-section data

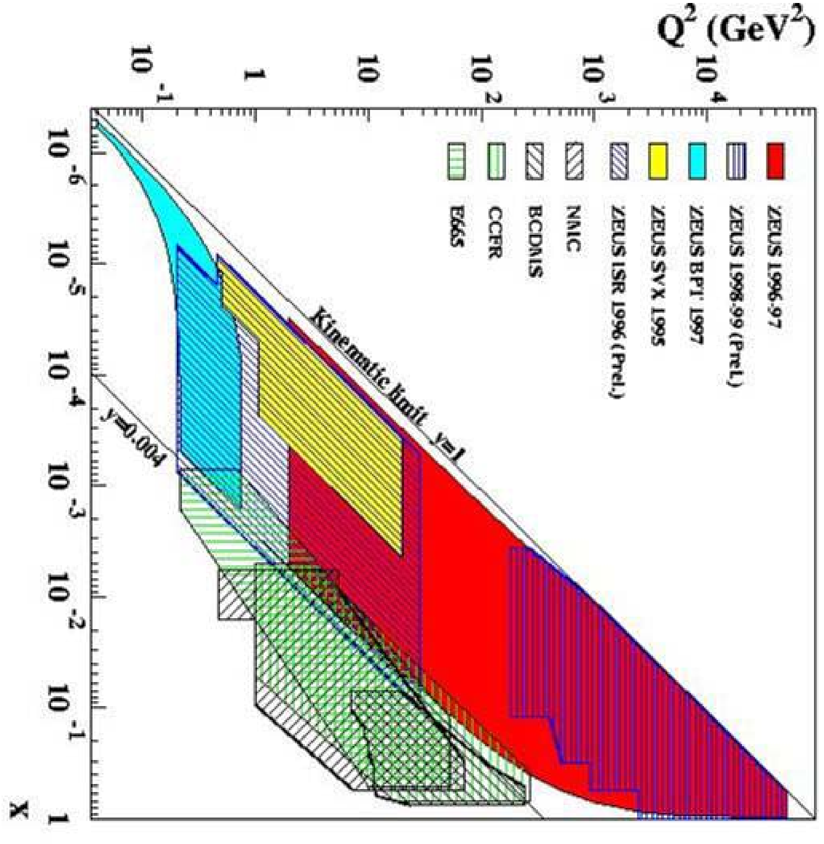
Proton target data from a single experiment

Discussion of ways of treating correlated systematic errors

Use of jet data as well as inclusive xsecns

Note strong rise at small x

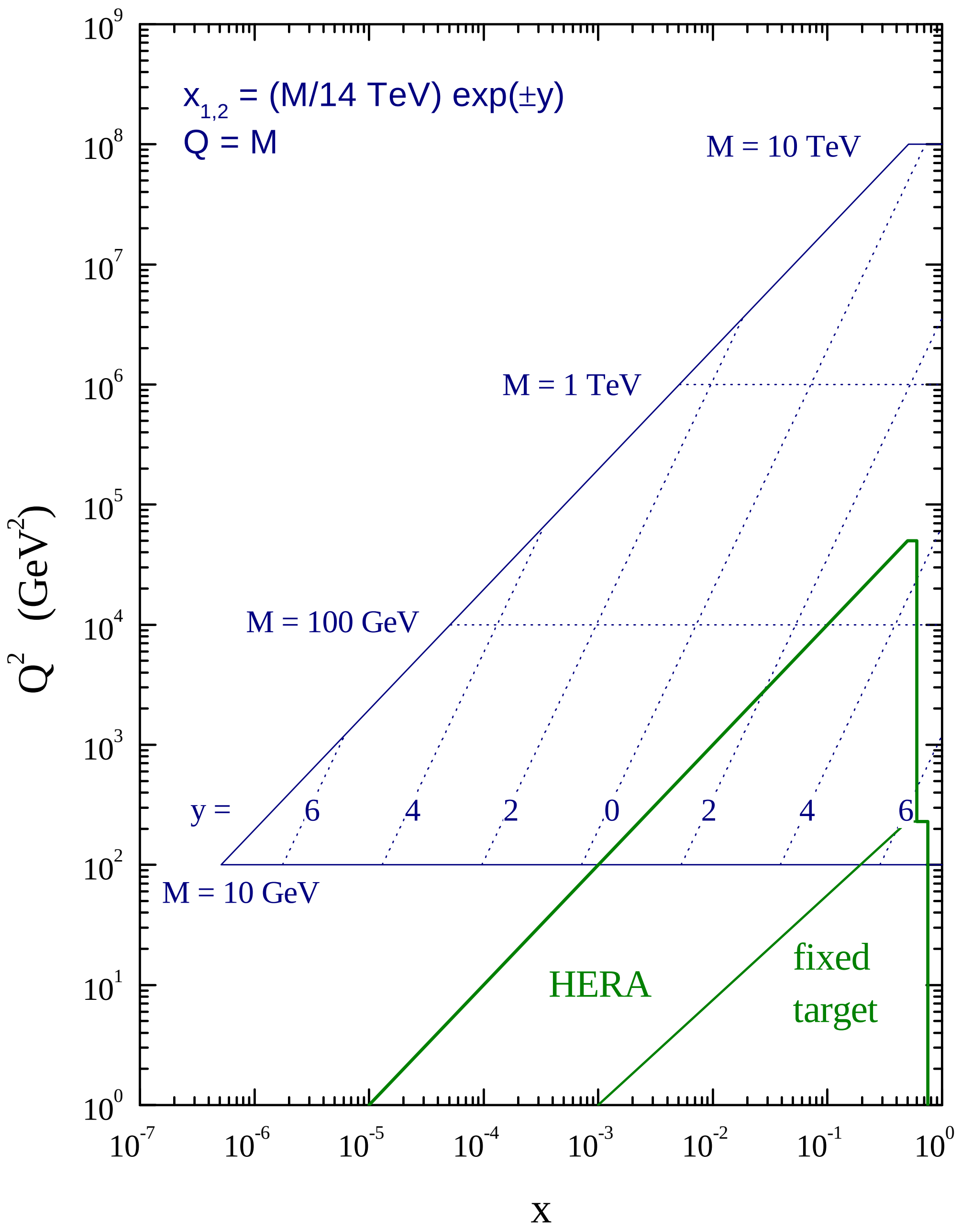


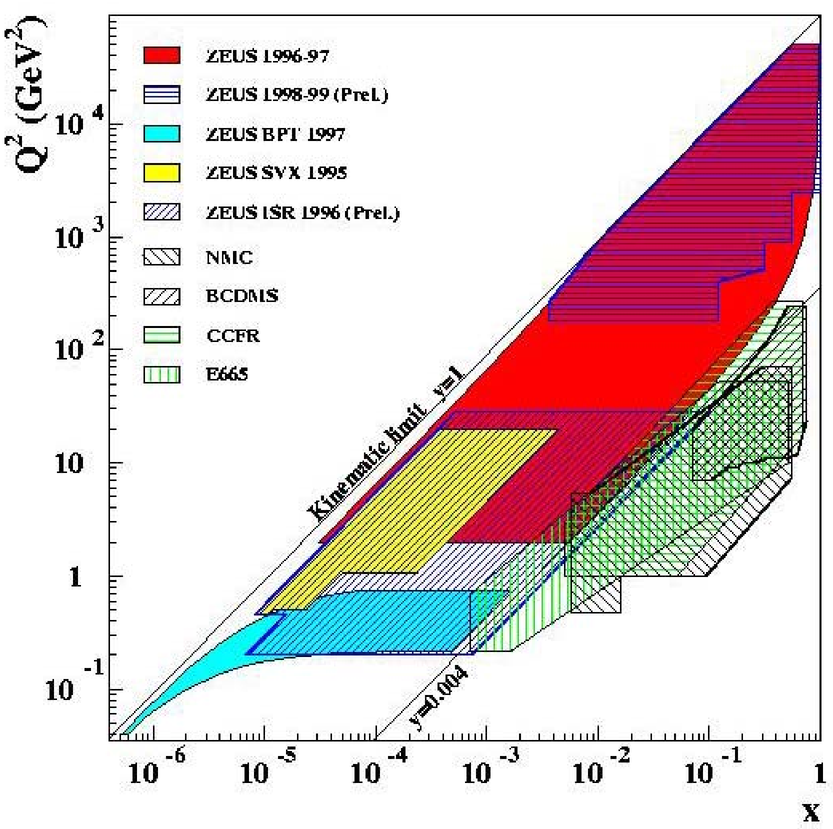


Terrific expansion in measured range across the x, Q^2 plane due to HERA data

Pre HERA fixed target $\overline{\mu}$p,μD NMC,BDCMS, E665 and ν,ν Fe CCFR

LHC parton kinematics





Parametrize parton distributions at Q^2_0

Evolve in Q^2 using NLO DGLAP (QCDNUM)

Convolute with coefficient functions ⇒ structure functions ⇒ cross-sections

Treatment of Heavy Quarks by Thorne-Roberts Variable Flavour Number

Cuts, $W^2 > 20$ (to remove higher twist), $30{,}000 > Q2 > 2.7$, $x > 6.3\ 10^{-5}$

$\chi 2$ fit to 1263 data points ⇒ errors on params ⇒ errors on extracted PDF shapes, predicted structure functions and cross-sections

Accounting for correlated systematic errors by Offset method

- $$\begin{aligned} xuv(x) &= Au\ x^{av}\ (1-x)^{bu}\ (1 + c_u\ x) \\ xdv(x) &= Ad\ x^{av}\ (1-x)^{bd}\ (1 + c_d\ x) \\ xS(x) &= As\ x^{as}\ (1-x)^{bs}\ (1 + c_s\ x) \\ xg(x) &= Ag\ x^{ag}\ (1-x)^{bg}\ (1 + c_g\ x) \\ x\Delta(x) &= A\Delta\ x^{av}\ (1-x)^{bs+2} \end{aligned}$$

⇐ Model choices ⇒Form of parametrization at Q^2_0, value of Q^2_{0},, flavour structure of sea, cuts applied, heavy flavour scheme

These parameters control the low-x shape

These parameters control the high-x shape

These parameters control the middling-x shape

Au, Ad, Ag are fixed by the number and momentum sum-rules

Treatment of correlated systematic errors

$$\chi 2 = \sum_i \left[\frac{F_i^{QCD}(p) - F_i^{MEAS}]^2}{(\sigma_i^{STAT})^2 + (\Delta_i^{SYS})^2} \right.$$

Errors on the fit parameters, p, evaluated from $\Delta\chi 2 = 1$,

THIS IS NOT GOOD ENOUGH if experimental systematic errors are correlated between data points- e.g. **Normalisations**

BUT there are more subtle cases- e.g. **Calorimeter energy scale/angular resolutions** can move events between x,Q^2 bins and thus **change the shape** of experimental distributions

$$\chi^2 = \sum_i \sum_j [F_i^{QCD}(p) - F_i^{MEAS}] V_{ij}^{-1} [F_j^{QCD}(p) - F_j^{MEAS}]$$

$$V_{ij} = \delta_{ij}(\sigma_i^{STAT})^2 + \Sigma_\lambda \Delta_{i\lambda}^{SYS} \Delta_{j\lambda}^{SYS}$$

Where $\Delta_{i\lambda}^{SYS}$ is the correlated error on point **i** due to systematic error source **λ**

It can be established that this is equivalent to

$$\chi^2 = \sum_i \frac{[F_i^{QCD}(p) - \sum_\lambda s_\lambda \Delta_{i\lambda}^{SYS} - F_i^{MEAS}]^2}{(\sigma_i^{STAT})^2} + \sum s_\lambda^2$$

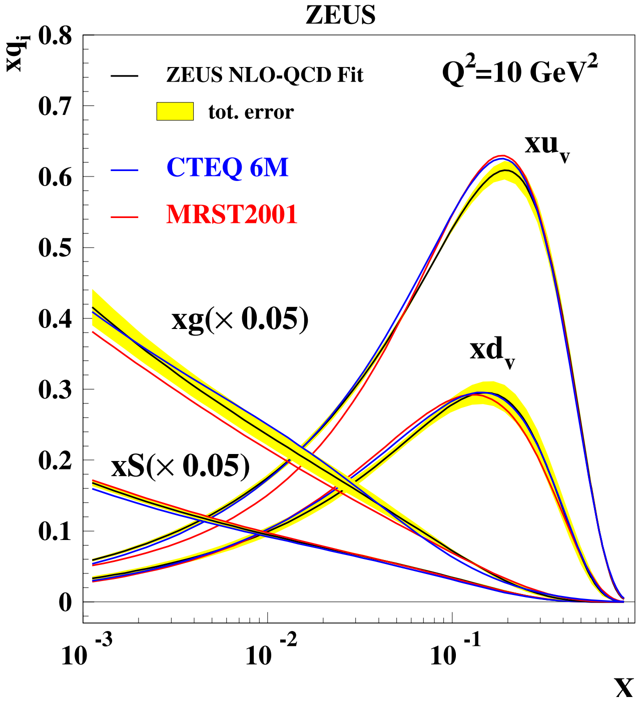
Where s_λ are systematic uncertainty fit parameters of zero mean and unit variance

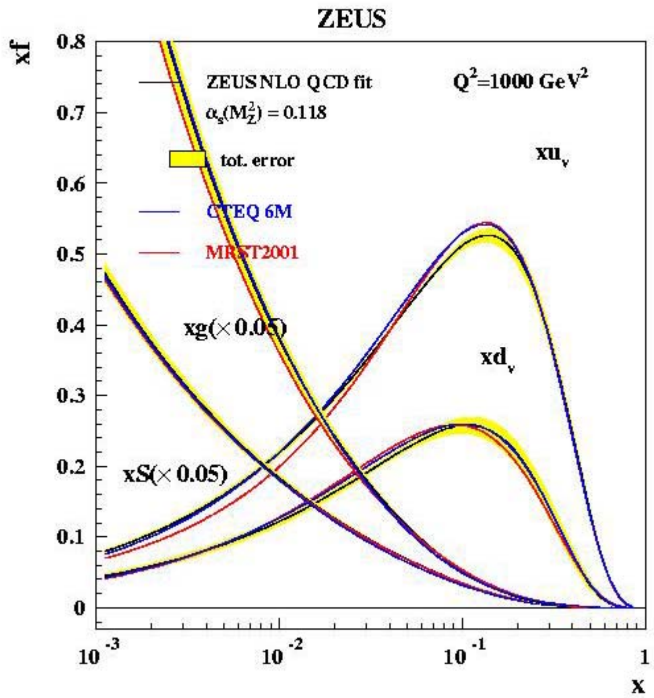
This has modified the fit prediction by each source of systematic uncertainty

How do experimentalists usually proceed: OFFSET method

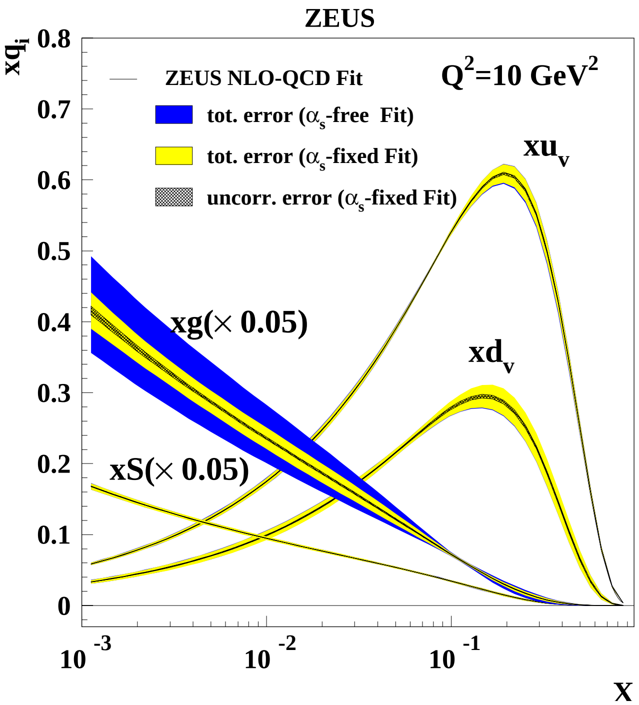
1. Perform fit without correlated errors ($s_\lambda = 0$) for central fit
2. Shift measurement to upper limit of one of its systematic uncertainties ($s_\lambda = +1$)
3. Redo fit, record differences of parameters from those of step 1
4. Go back to 2, shift measurement to lower limit ($s_\lambda = -1$)
5. Go back to 2, repeat 2-4 for next source of systematic uncertainty
6. Add all deviations from central fit in quadrature (positive and negative deviations added in quadrature separately)
7. This method does not assume that correlated systematic uncertainties are Gaussian distributed

Fortunately, there are smart ways to do this (Pascaud and Zomer LAL-95-05, Botje hep-ph-0110123)





Evolve in $Q^2 \Rightarrow$ low-x uncertainties of sea/gluon decrease



Value of α_s and shape of gluon are correlated in DGLAP evolution

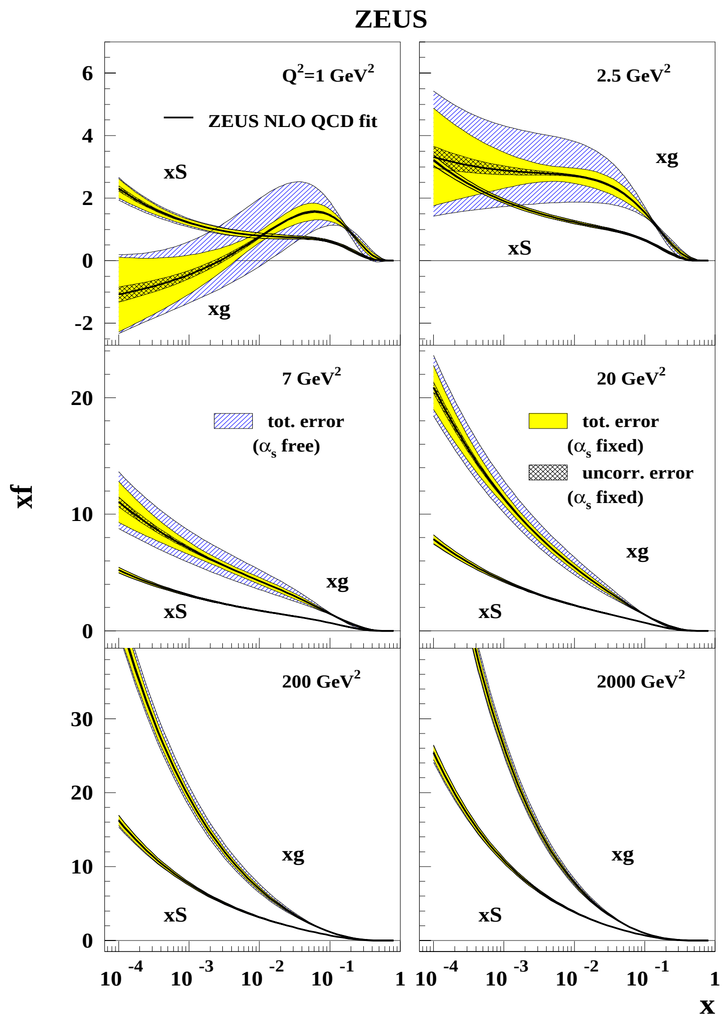
α_s increases $\Rightarrow$ harder gluon

So fit α_s and PDF parameters simultaneously

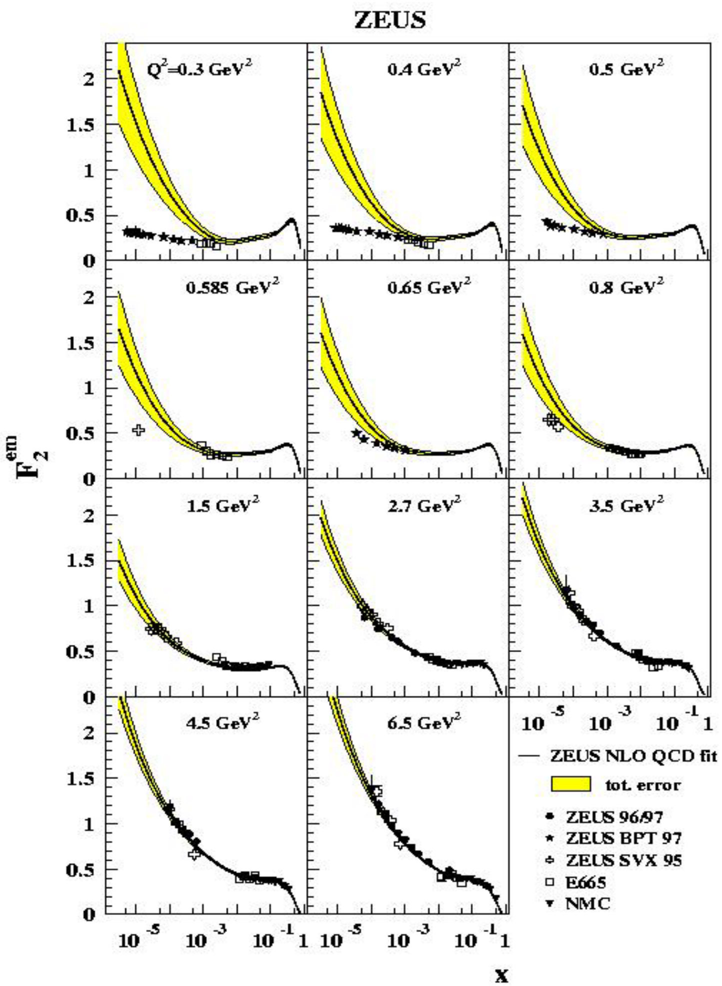
Uncertainty on gluon increases

$$\alpha_s = 0.1166 \pm \underset{\text{stat.}}{0.0008} \pm \underset{\text{sys.}}{0.0032} \pm \underset{\text{norms.}}{0.0036} \pm \underset{\text{model}}{0.0018}$$

Look more closely at small-x



BUT below $Q^2 \sim 5\ GeV^2$ the gluon is no longer steep at small x – in fact its becoming valence-like, and then negative!



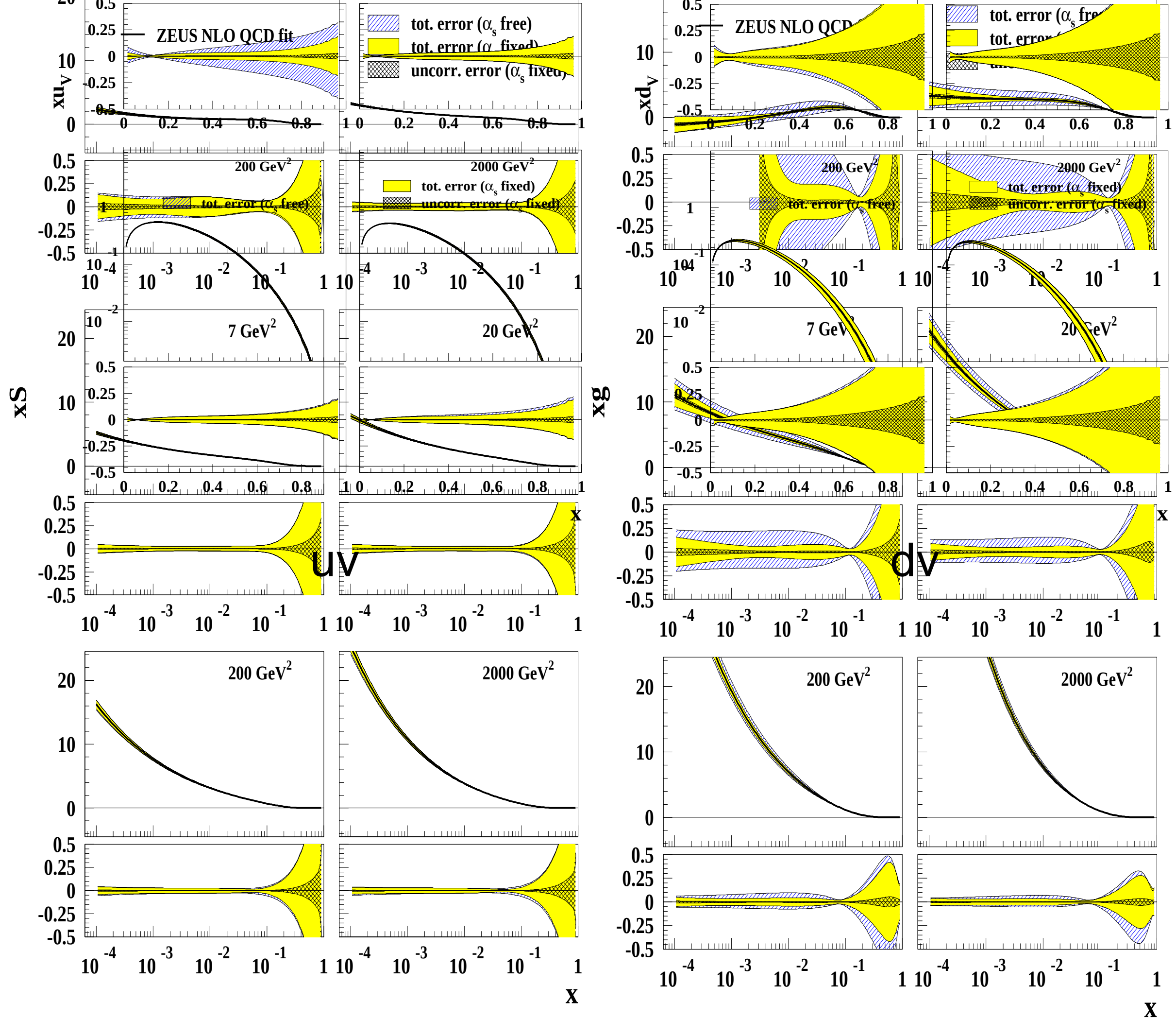
It was a surprise to see F_2 still steep at small x - even for $Q^2 \sim 1\ GeV^2$ should perturbative QCD work? α_s is becoming large

Look more closely at high-x

uv much better measured than dv

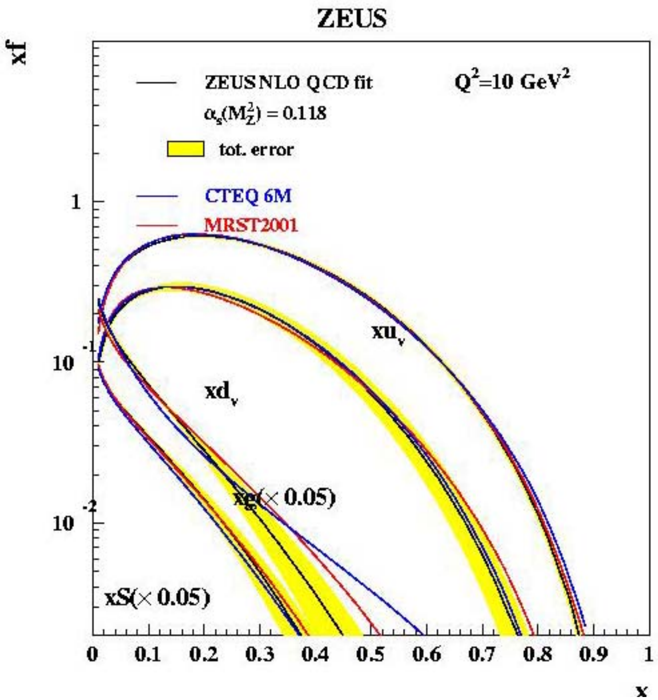
Valence much better measured than sea/gluon

Uncertainties at high-x do not decrease so much with Q2 evolution



Sea

Gluon



Compare PDFs at high-x

High-x gluon ⇒High ET jet production at Tevatron/LHC

There are other ways to treat correlated systematic errors- HESSIAN method (covariance method)

Allow $s\lambda$ parameters to vary for the central fit –there are smart ways to do this CTEQ hep-ph/0101032

If we believe the theory why not let it calibrate the detector(s)? The fit determines the optimal settings for correlated systematic shifts.

The resulting estimate of PDF errors is much smaller than for the Offset method for $\Delta\chi 2 = 1$

We must be very confident of the theory – but more dubiously **we must be very confident of the model choices** we made in setting boundary conditions

In a global fit the best fit parameters can be far from those which would be acceptable for some of the individual experiments- **data inconsistencies**?

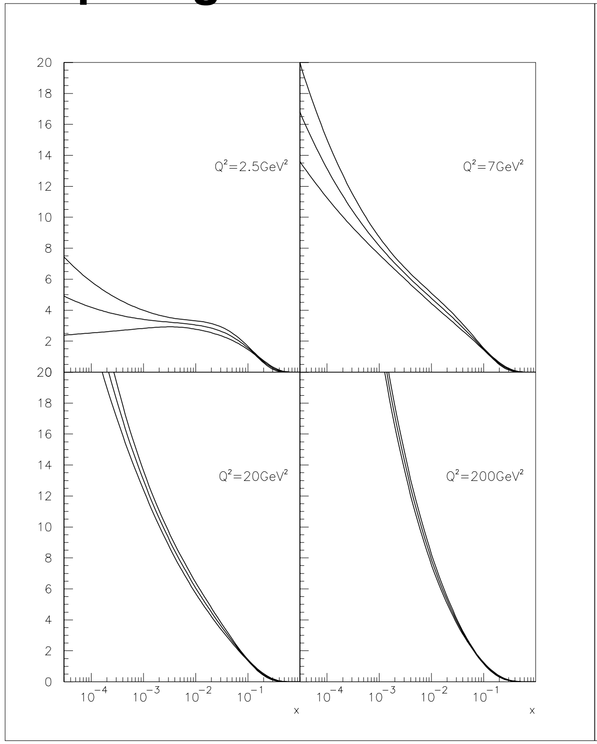
One could **restrict the data sets** to those which are sufficiently consistent that these problems do not arise – (e.g.Giele, Keller, Kosover,FNAL)

But one **loses information** since partons need constraints from many different data sets – no single experiment has sufficient kinematic range / flavour info.

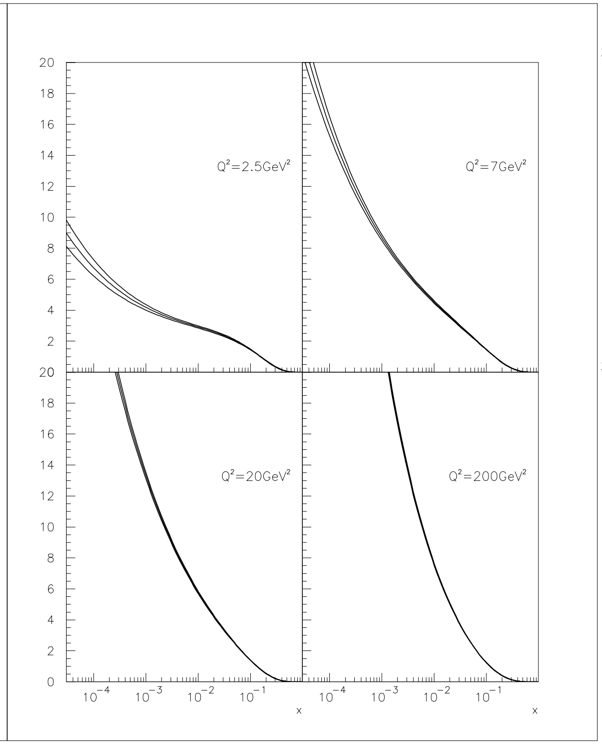
CTEQ use an increased $\chi 2$ tolerance, $\Delta\chi 2 = T^2$, $T = 10$ to make an estimate of the PDF error which allows for this level of inconsistency in the data

MRST have also used increased tolerances in recent fits

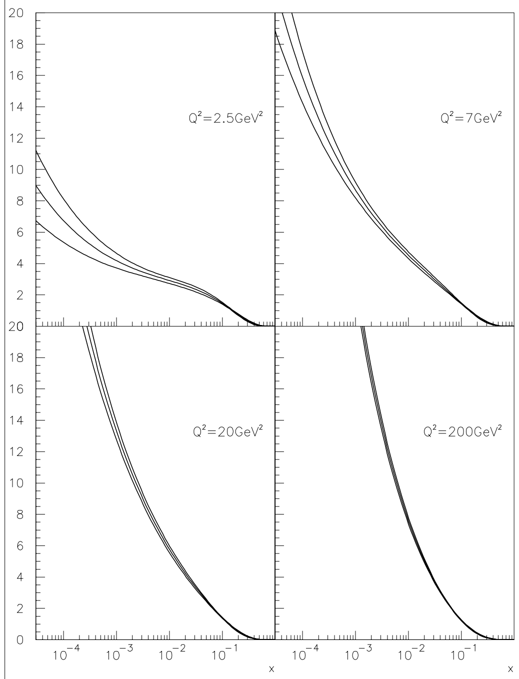
Compare gluon PDFs for Hessian and Offset methods for the ZEUS fit analysis



Offset method



Hessian method T=1



Hessian method T=7

The Hessian method gives comparable size of error band as the Offset method, when the tolerance is raised to T ~ 7 – (similar ball park to CTEQ, T=10)

Note this makes the error band large enough to encompass reasonable variations of model choice since the criterion for acceptability of an alternative hypothesis, or model, is that $\chi2$ lie in the range N ± $\sqrt{2N}$, where N is the number of degrees of freedom. For the ZEUS global fit $\sqrt{2N}$=50.

To do better investigate the possibility of using ZEUS data alone

Where does the information come from in a global PDF fit to DIS data?

Valence: from fixed target data – CCFR ν Fe xF3, NMC D/p ratio at high-x – HEAVY target corrections

Sea: Low-x from HERA F2 data

High-x from fixed target F2 data

Gluon: Low-x from HERA dF2/dlnQ2 data

High-x from mom-sum rule only- (UNLESS we put in JET DATA!)

Where does the information come from in a ZEUS-Only fit ?

Valence: HERA High-Q2 cross-sections CC/NC e+/-

Sea: Low-x from HERA F2 data

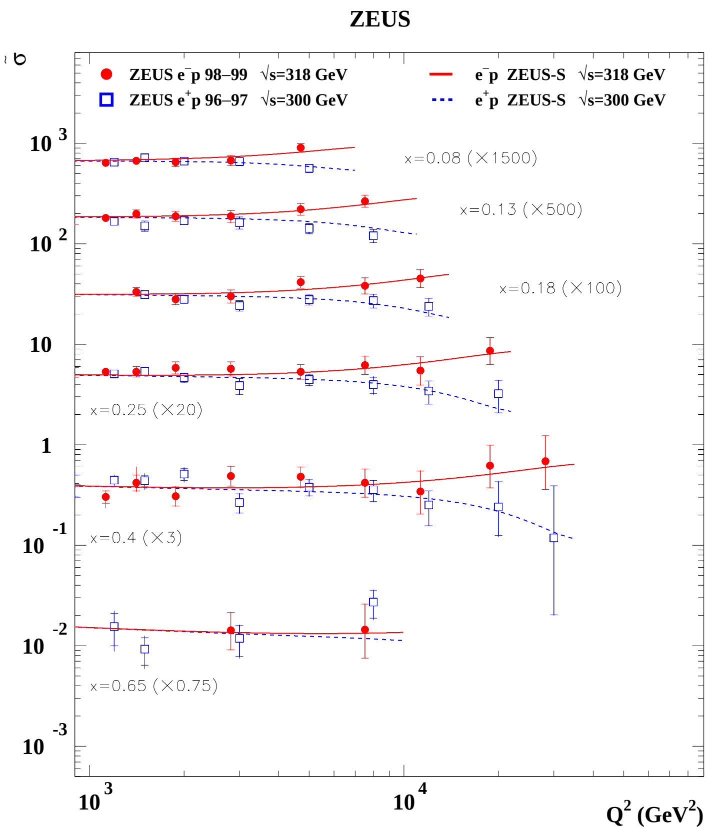
Gluon: Low-x from HERA dF2/dlnQ2 data

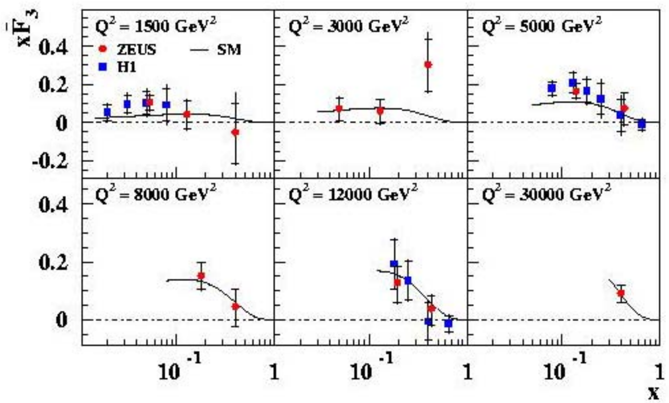
High-x from mom-sum rule only- (UNLESS we put in JET DATA!)

Advantages:

Pure proton target- no heavy target correction or deuterium corrections

Single experiment - correlated systematic errors well understood





Use ALL HERA-I data on NC/CC e+/e- high-Q^2 differential cross-sections ~ $109 pb^{-1}$, 509 data points

HERA at high $Q^2 \Rightarrow Z^0$ and $W^{+/-}$ exchanges become important

for NC processes

$$F_2 = \sum_i A_i(Q^2)\,[xq_i(x,Q^2) + x\bar{q}_i(x,Q^2)]$$

$$xF_3 = \sum_i B_i(Q^2)\,[xq_i(x,Q^2) - x\bar{q}_i(x,Q^2)]$$

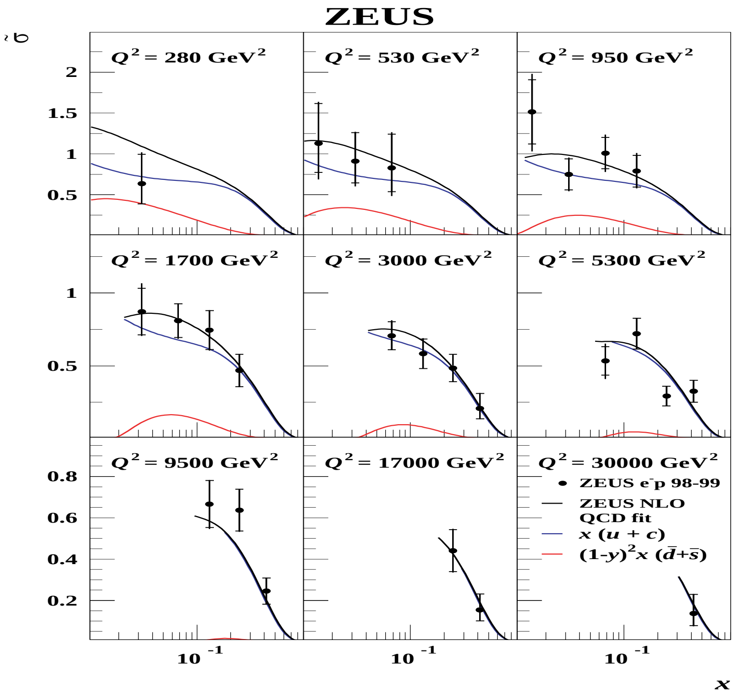
$$A_i(Q^2) = e_i^2 - 2\,e_i\,v_i\,v_e\,P_Z + (v_e^2+a_e^2)(v_i^2+a_i^2)\,P_Z^2$$

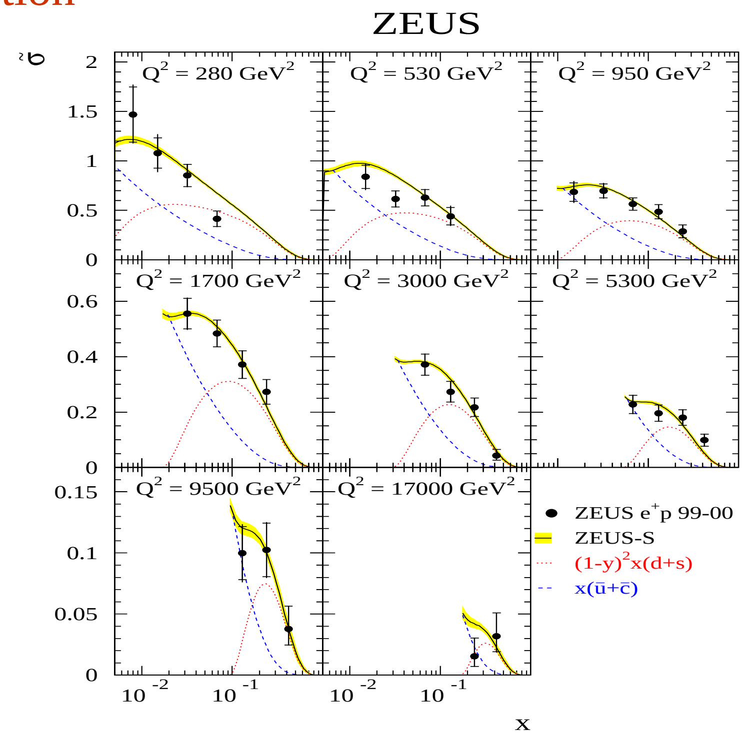
$$B_i(Q^2) = \quad - 2\,e_i\,a_i\,a_e\,P_Z + \quad 4a_i\,a_e\,v_i\,v_e \quad P_Z^2$$

$$P_Z^2 = Q^2/(Q^2 + M^2_Z)\;1/\sin^2\theta_W$$

$\Rightarrow$ Z exchange gives a new valence structure function xF_3 measurable from low to high x- on a pure proton target

CC processes give
flavour information





$$\frac{d^2\sigma(e^-p)}{dxdy} = \frac{G_F^2\, M^4_W}{2\pi x(Q^2+M^2_W)^2}\left[x\,(u+c) + (1-y)^2 x\,(\bar{d}+\bar{s})\right]$$

$$\frac{d^2\sigma(e^+p)}{dxdy} = \frac{G_F^2\, M^4_W}{2\pi x(Q^2+M^2_W)^2}\left[x\,(\bar{u}+\bar{c}) + (1-y)^2 x\,(d+s)\right]$$

M_W information

u_v at high x

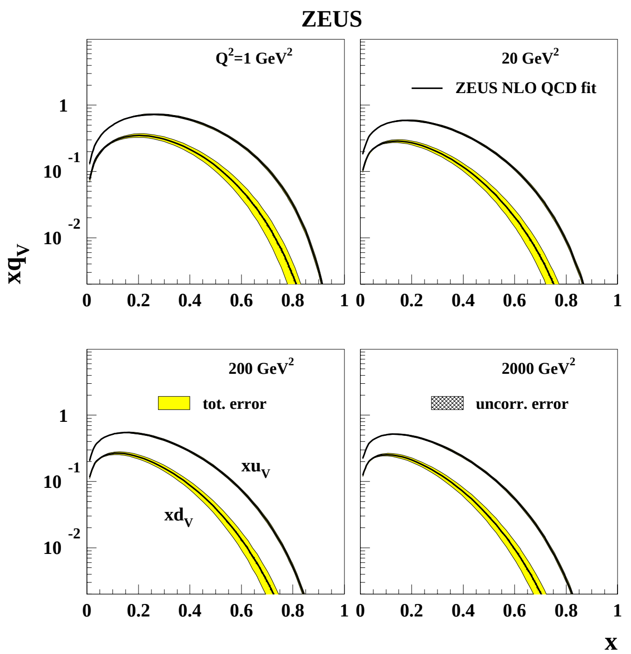
d_v at high x

Measurement of high x, d-valence on a pure proton target. Most processes dominantly measure u- valence, only νFe xF3 and μD/p give d-valence info.

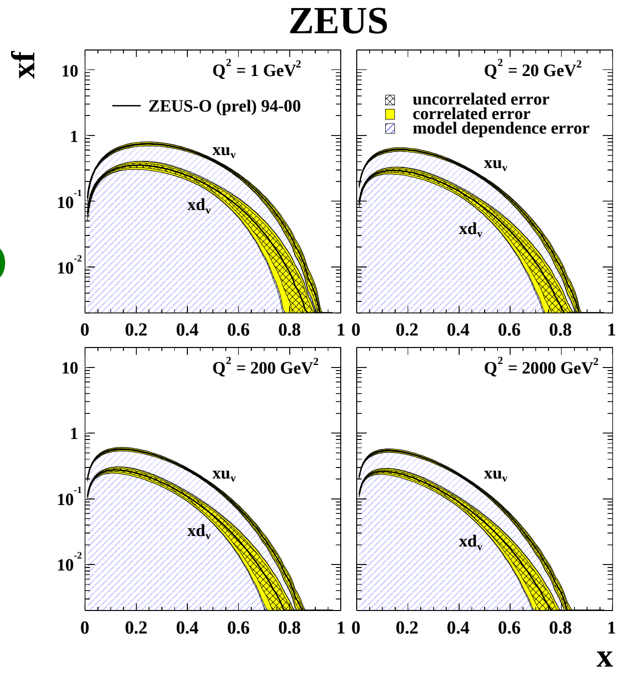
And these are heavy target - even Deuterium needs corrections, does $d_v/u_v \rightarrow 0$, as $x \rightarrow 1$?

Compare valence PDFs for ZEUS-Only and ZEUS-S global fits

ZEUS-S global



ZEUS-O proton target only

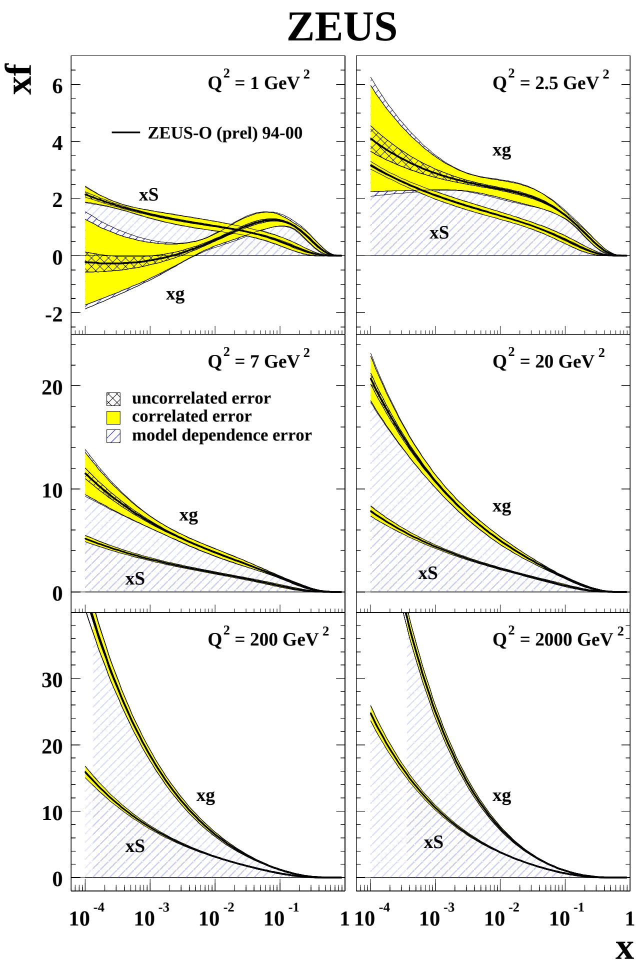


ZEUS-O fit precision is becoming competitive – and is on a proton target- statistical precision will improve with HERA-II data. ZEUS-S global fit precision is already systematics dominated

The precision on d_v is much worse than for u_v because most cross-sections measure u_v,but HERA high Q2 CC e+ measures d_v on a proton target

In HERA-II things can only get better! – more high Q2 CC plus NC xF3 data

Compare sea and gluon PDFs for ZEUS-Only and ZEUS-S global fits



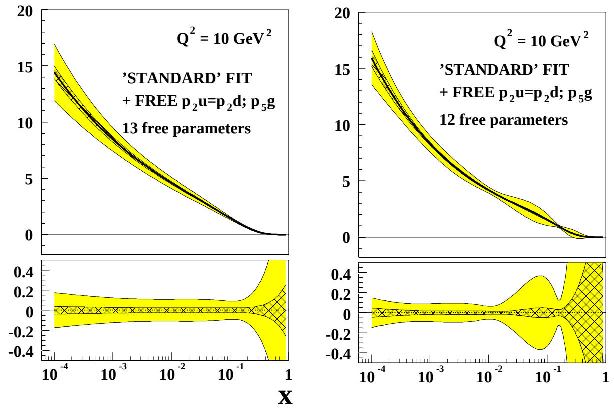
Low-x precision is comparable – info. In global fit came from ZEUS data
High-x precision is worse.

Interim solution: simplify sea/glue high-x param.
Eigenvector procedure gives information on fit stability and parameter correlations- tells you which params are constrained best/which you need

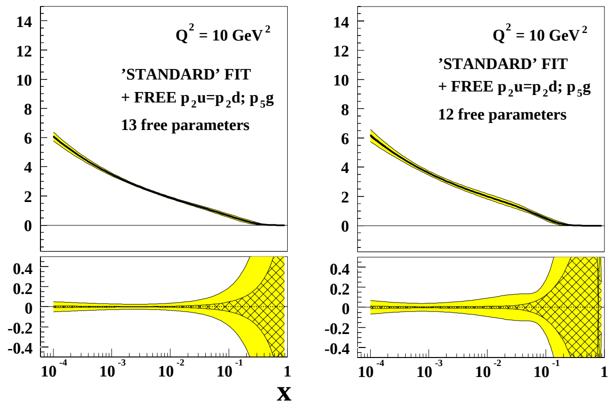
Long term solution: HERA-II data

Medium term solution: use ZEUS jet data from HERA-I ⇒ impacts on gluon 0.01 < x < 0.1⇒ via momentum sum-rule on higher-x gluon

ZEUS-S ZEUS-O

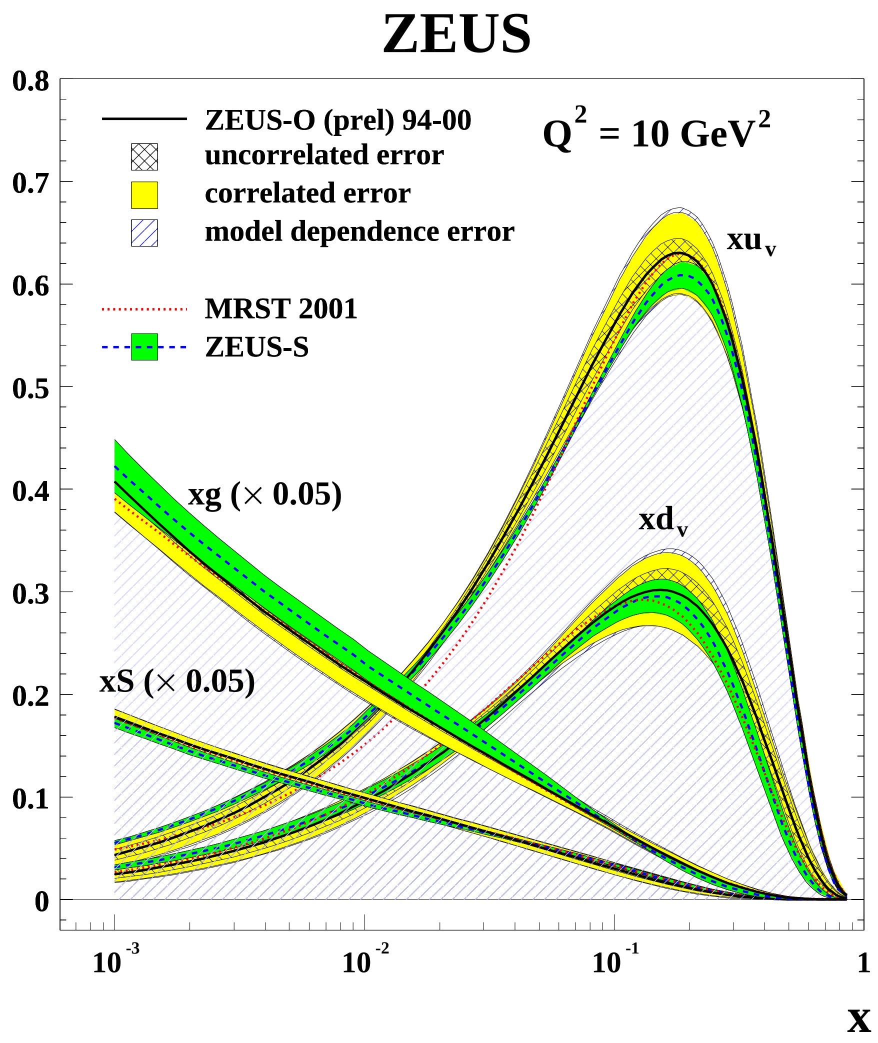


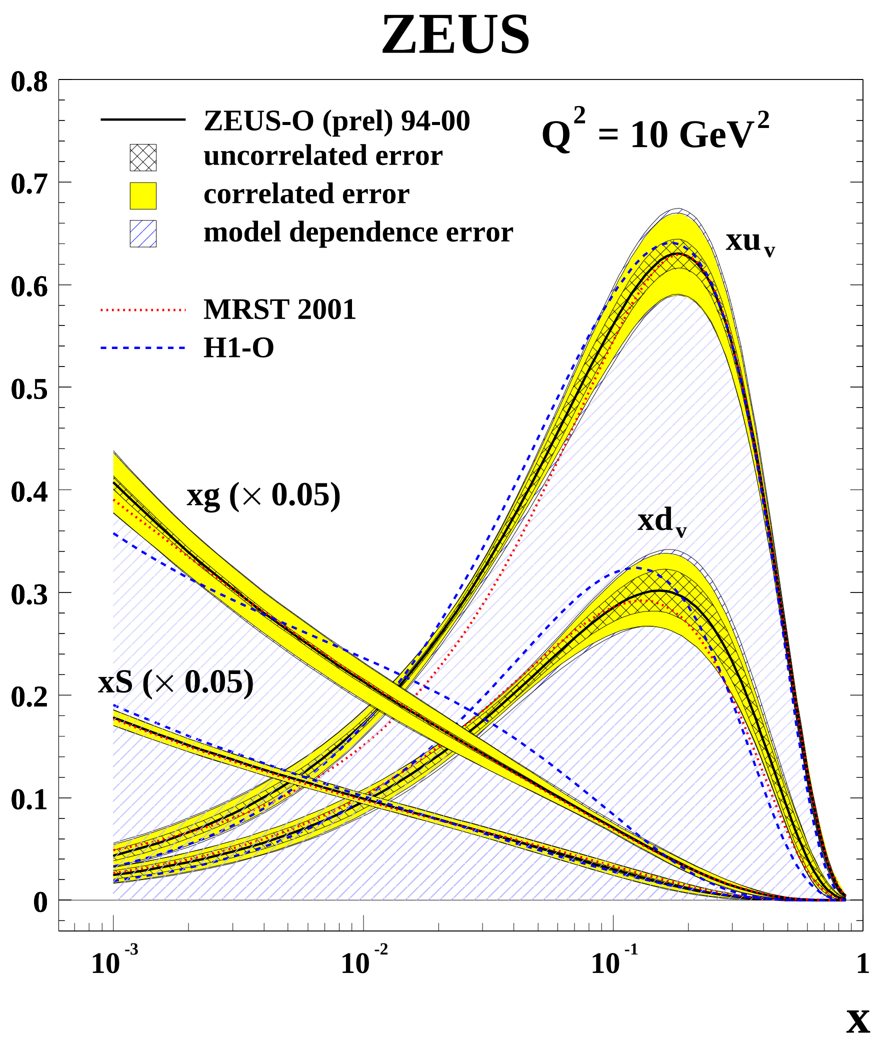
Glue



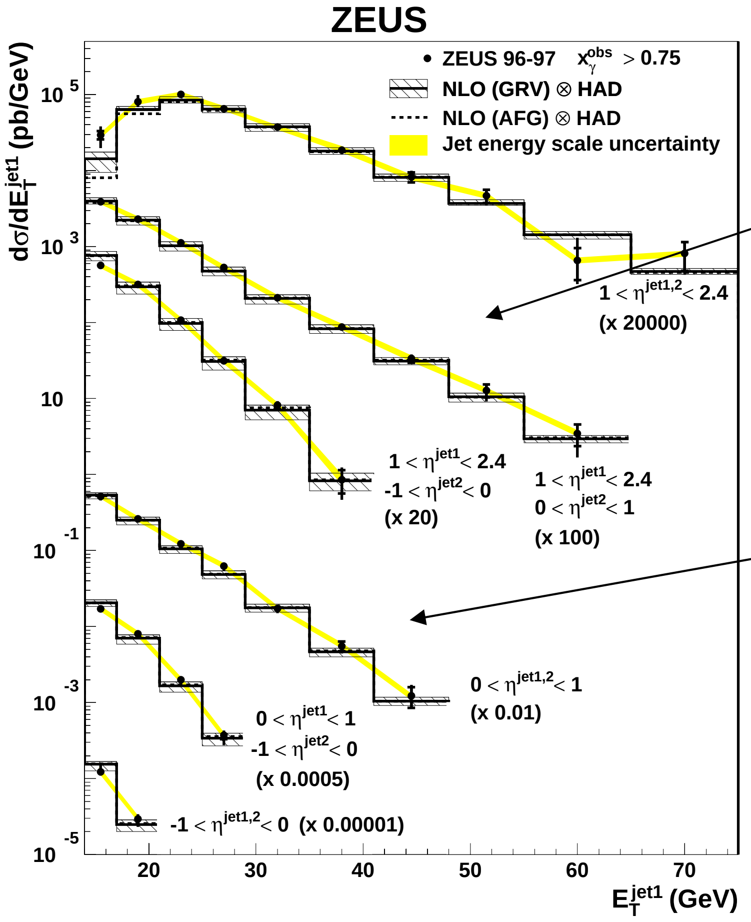
Sea

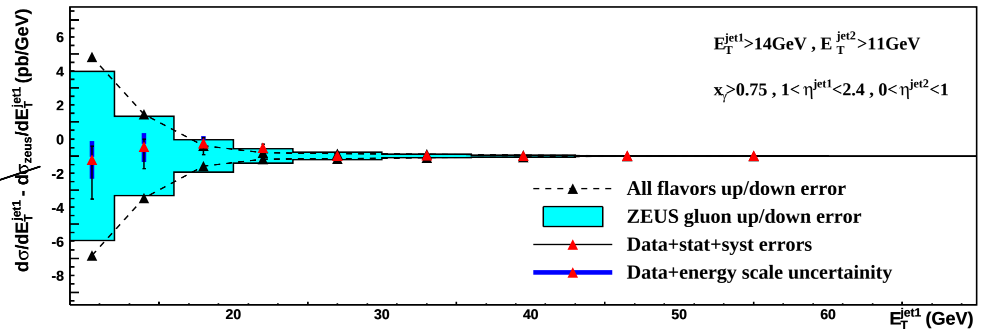
Interim solution: Compare HERA-I ZEUS-Only PDFs extracted from inclusive cross-section data to published ZEUS-S Global PDFs, and to MRST and H1 PDFS

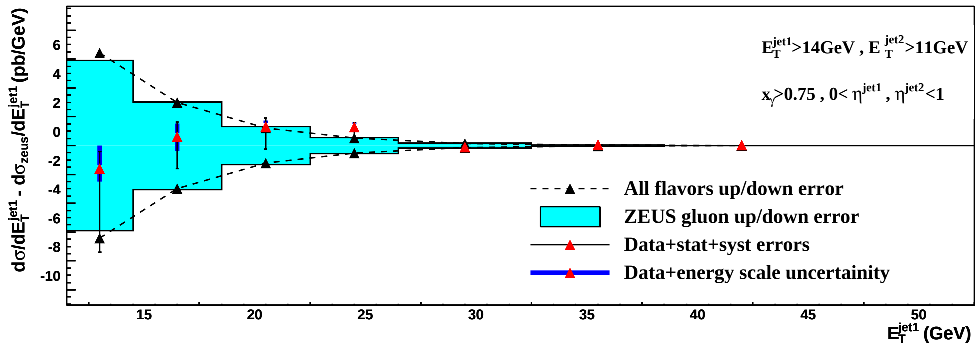




Mid term solution







Have significant impact on the uncertainties of the ZEUS-Only fit

Photproduction dijet cross-sections vs ET

Many jet cross-sections can be exploited to improve gluon measurement pre-LHC