Update of ZEUS PDF analysis

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DIS2004

- New Analysis of ZEUS data alone using inclusive cross-sections from all of HERA-I data – 112pb^{-1}
- Proton target data –no heavy target or deuterium corrections
- Analysis within one experiment – well understood sytematic errors
- Investigation of use of ZEUS jet data from inclusive jet production in DIS and dijet production from photoproduction

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 from BCDMS, E665, NMC on D and P targets and from CCFR on Fe target

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

as eigenvector PDF sets in LHAPDF compatible format

Where does the information come from in a global PDF fit like ZEUS-S?

Valence: xF3 ~ x(uv +dv) from neutrino-Fe heavy target data
F2n/F2p ~ xdv/xuv at high-x from μ D/p data

Plus F2 l p data at high-x dominantly measure uv

Sea: Low-x from ZEUS F2 e p data
High-x dominantly from fixed target F2 μ p data
Flavour structure from μ D and p

Gluon: Low-x from ZEUS dF2/dlnQ2 e p data
High-x from mom-sum rule only-

Now use ALL inclusive cross-section data from HERA-I 102 pb^{-1}

96/97 e+p NC 30 pb^{-1} 2.7 < Q2 < 30000 GeV^2 242 d.p. 10 corr..err. 2 norms

94-97 e+p CC 33 pb^{-1} 280. < Q2 < 30000 GeV^2 29 d.p. 3 corr. err.

98/99 e-p NC 16 pb^{-1} 200 < Q2 < 30000 GeV^2 92 d.p. 6 corr err. 1 norm

98/99 e-p CC 16 pb^{-1} 200 < Q2 < 30000 GeV^2 26 d.p. 3 corr. err.

99/00 e+p NC 63 pb^{-1} 200 < Q2 < 30000 GeV^2 90 d.p. 8 corr. err. 1 norm

99/00 e+p CC 61 pb^{-1} 200 < Q2 < 30000 GeV^2 29 d.p. 3 corr. err.

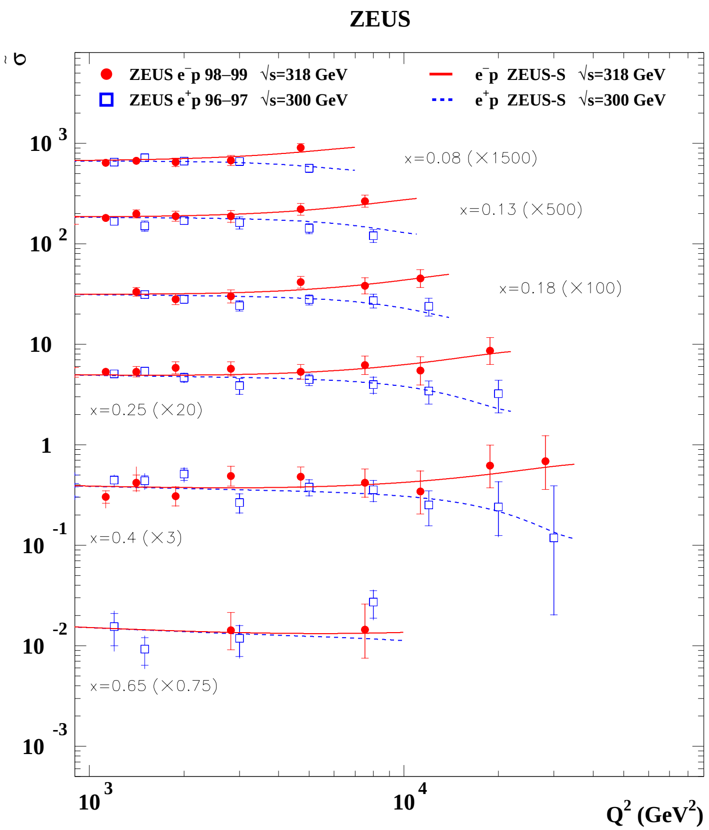
Where does the information come from in a ZEUS-Only fit

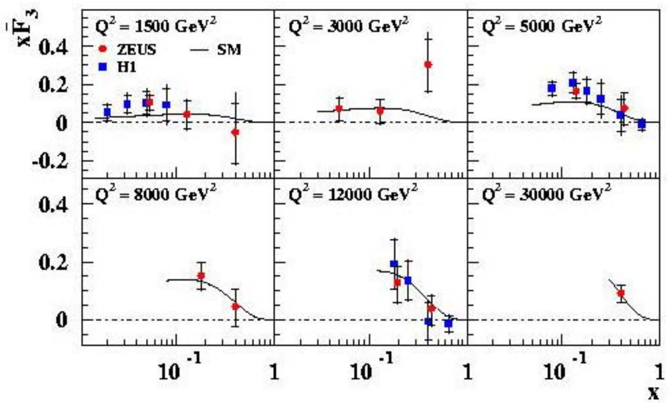
Valence: High-Q2 cross-sections CC/NC e+/-

Sea: Low-x from the ZEUS NC 96/7 `all' Q2 sample.
High x ? Flavour structure?

Gluon: Low-x from ZEUS NC96/7 'all' Q2, dF2/dlnQ2 data.
High-x from mom-sum rule only

On a pure proton target- no heavy target correction or deuterium corrections





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

for NC processes

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

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

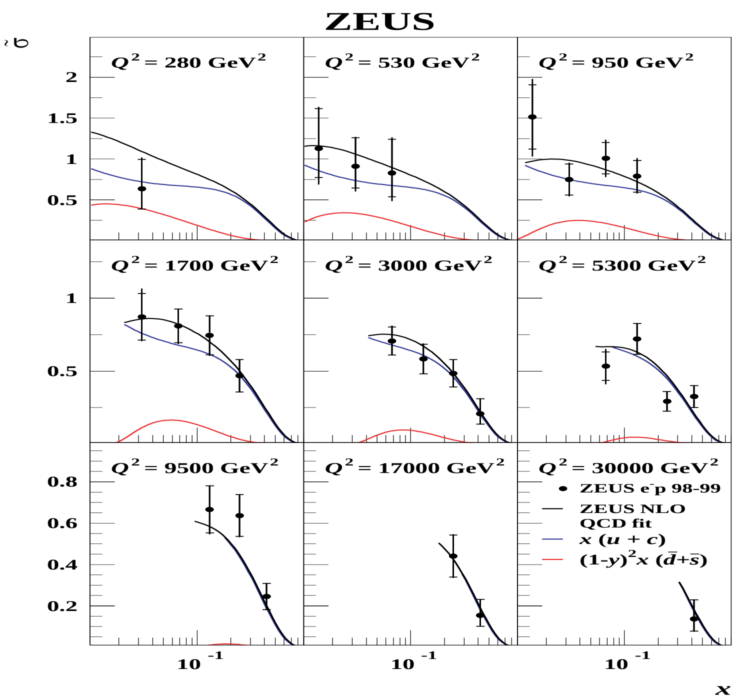
$$A_i(Q^2) = e_i^2 - 2\, e_i\, v_i\, v_e\, P_Z + (v_e^2+a_e^2)(v_i^2+a_i^2)\, P_Z^2$$

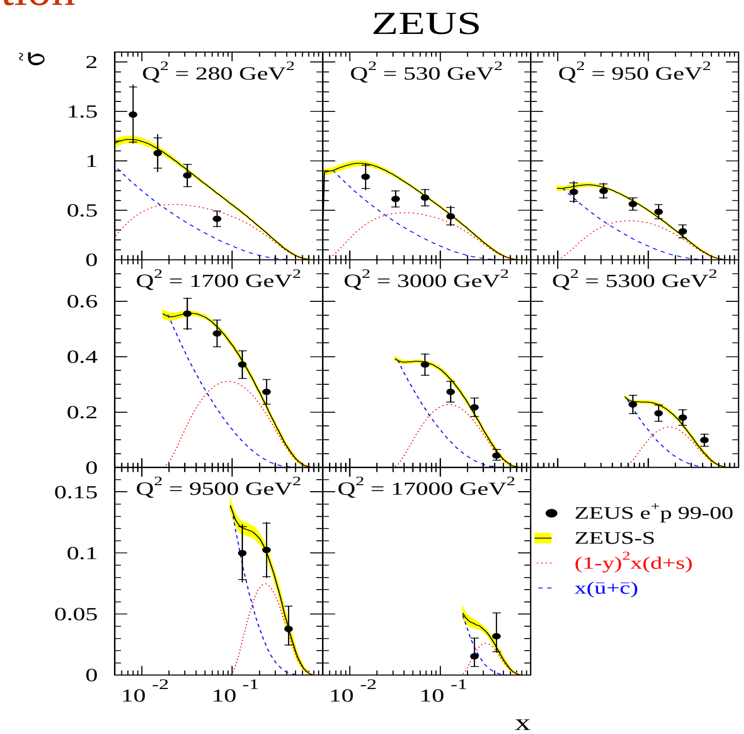
$$B_i(Q^2) = \quad - 2\, e_i\, a_i\, a_e\, P_Z + \quad 4a_i\, a_e\, v_i\, v_e \quad P_Z^2$$

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

$\Rightarrow$ 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





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

u_v at high x

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

d_v at high x

Measurement of high x, d-valence on a pure proton target. NC processes dominantly measure u- valence.

Fixed target measurement of d-valence is from Fe/Deuterium target – needs corrections even for Deuterium

Recap of the method

Parametrize parton distribution functions PDFs at Q^2_0 = 7 Gev^2

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

Evolve in Q^2 using NLO DGLAP (QCDNUM 16.12)

$$\frac{\partial \mathbf{q_i}(\mathbf{x},\mathbf{Q^2})}{\partial \log \mathbf{Q^2}} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{\mathbf{dy}}{\mathbf{y}}\Big\{\mathbf{P}_{q_iq_j}(\mathbf{y},\alpha_S)\ \mathbf{q_j}(\frac{\mathbf{x}}{\mathbf{y}},\mathbf{Q^2}) + \mathbf{P}_{q_ig}(\mathbf{y},\alpha_S)\ \mathbf{g}(\frac{\mathbf{x}}{\mathbf{y}},\mathbf{Q^2})\Big\}$$

$$\frac{\partial \mathbf{g}(\mathbf{x},\mathbf{Q^2})}{\partial \log \mathbf{Q^2}} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{\mathbf{dy}}{\mathbf{y}}\Big\{\mathbf{P}_{gq_j}(\mathbf{y},\alpha_S)\ \mathbf{q_j}(\frac{\mathbf{x}}{\mathbf{y}},\mathbf{Q^2}) + \mathbf{P}_{gg}(\mathbf{y},\alpha_S)\ \mathbf{g}(\frac{\mathbf{x}}{\mathbf{y}},\mathbf{Q^2})\Big\}$$

Convolute PDFs with coefficient functions to give structure functions and hence cross-sections

$$\frac{F_2(x,Q^2)}{x} = \int_0^1 \frac{dy}{y}\left[\Sigma_i C_2(z,\alpha_s)\, q_i(x,Q^2) + C_g(z,\alpha_s)\, g(y,Q^2)\right]$$

Coefficient functions incorporate treatment of Heavy Quarks by Thorne-Roberts Variable Flavour Number

Fit to data under the cuts,

$W^2 > 20\ \mathrm{GeV}^2$ (to remove higher twist),
$30{,}000 > Q^2 > 2.7\ \mathrm{GeV}^2$

$\leftarrow$Use of NLO DGLAP

$x > 6.3\ 10^{-5}$

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

The χ2 includes the contribution of correlated systematic errors

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

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

The statistical errors on the fit parameters, p, are evaluated from **Δχ2 = 1,** s_λ=0

The correlated systematic errors are evaluated by the Offset method –conservative method - s_λ=±1 for each source of systematic error

For the global fit the Offset method gives total errors which are significantly larger than the Hessian method, in which sλ varies for the central fit**.** This reflects tensions between many different data sets (no raise of χ2 tolerance is needed)

It yields an error band which is large enough to encompass the usual variations of model choice (variation of Q^2_0, form of parametrization, kinematic cuts applied)

Now use ZEUS data alone - minimizes data inconsistency (but must consider model dependence carefully)

Using restricted data sets makes us more vulnerable to model dependence

Major source of model dependence is the form of the parametrization at Q^2_0

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

No $\chi 2$ advantage in more terms in the polynomial

No sensitivity to shape of $\Delta = \bar{d} - \bar{u}$

Assume $\bar{s} = (\bar{d}+\bar{u})/4$ consistent with v dimuon data

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

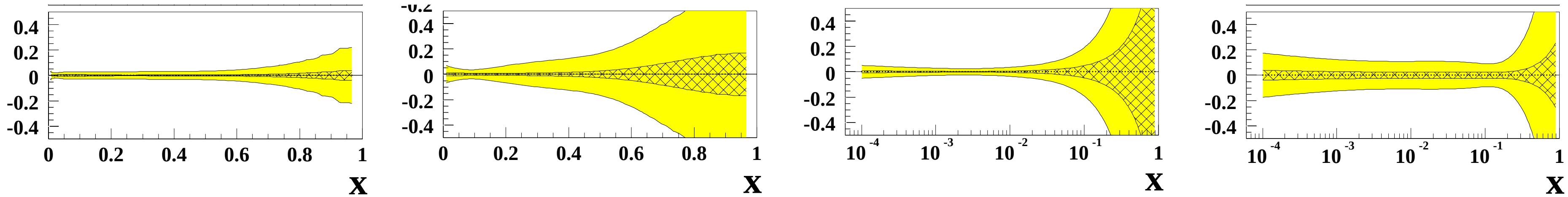
Little low-x valence information to distinguish av for u and d valence

$\rightarrow$ 13 parameters for a global fit

But with ZEUS data alone we lose information/sensitivity to $A\Delta$ – fix to value consistent with Gottfried sum-rule

We also lose information on the high-x Sea and gluon

Compare the uncertainties for uv, dv, Sea and glue in a global fit

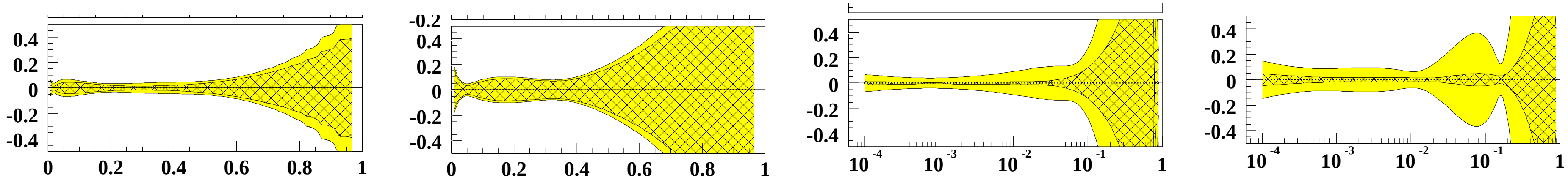


uv dv Sea Gluon

High-x Sea and Gluon are considerably less well determined than high-x valence (note log scales) even in a global fit

- this gets worse when fitting ZEUS data alone

Compare the uncertainties for uv, dv, Sea and glue in a fit to ZEUS data alone



uv and dv are now determined by the ZEUS highQ2 data not by fixed target data and precision is comparable- particularly for dv

Sea and gluon at low-x are determined by ZEUS data with comparable precision for both fits – but at mid/high-x precision is much worse

STRATEGY A: Constrain high-x Sea and gluon parameters

$xf(x) = A\ x^a (1-x)^b\ (1 + c\, x)$

The fit is not able to reliably determine both b and c parameters for the Sea and the gluon – these parameters are highly correlated

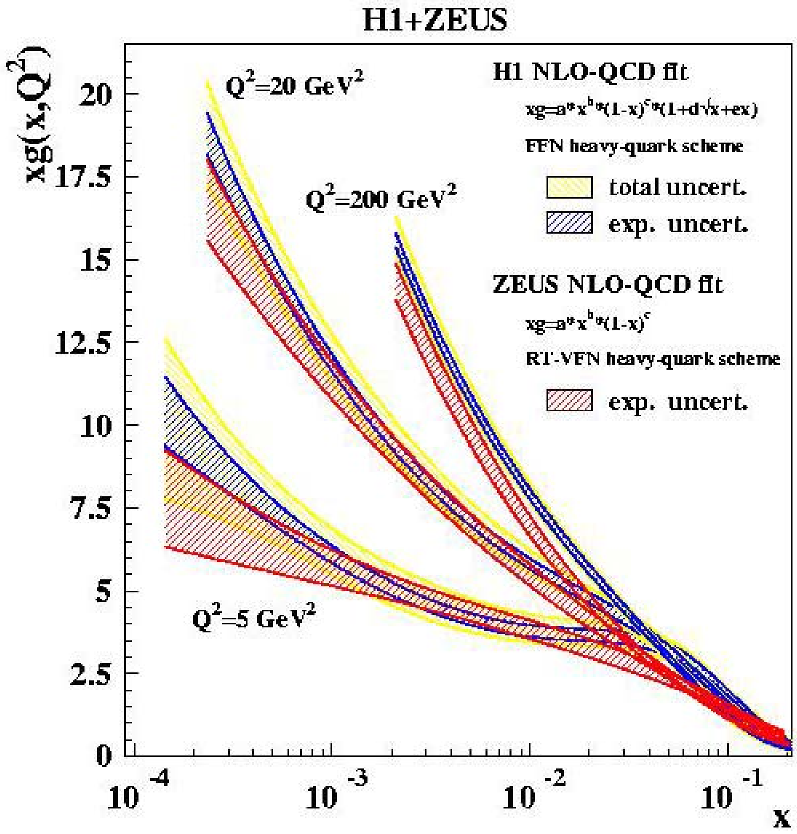
We could either

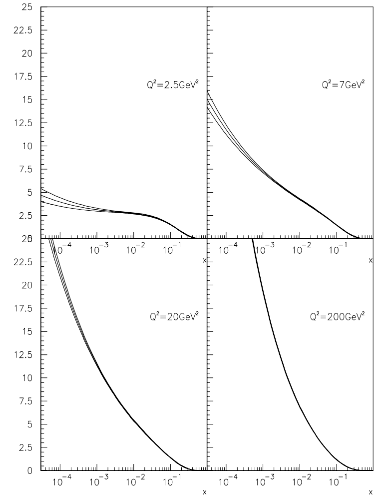
1. Choose a simpler parametrization: $xf(x) = A\ x^a (1-x)^b$
2. Fix parameter b to the value from the ZEUS-S global fit, and vary this value between the one σ errors determined in that fit $xf(x) = A\ x^a (1-x)^{b \pm \Delta b} (1+cx)$

Choice 1. would not allow structure in the mid x Sea/gluon distributions even in principle (recall the difference in H1 and ZEUS published gluons)

Thus choice 2 is made for the central 10 parameter ZEUS – Only fit

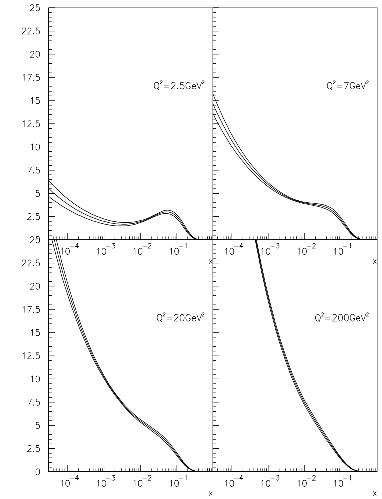
In practice choice 1. and 2. give very similar results





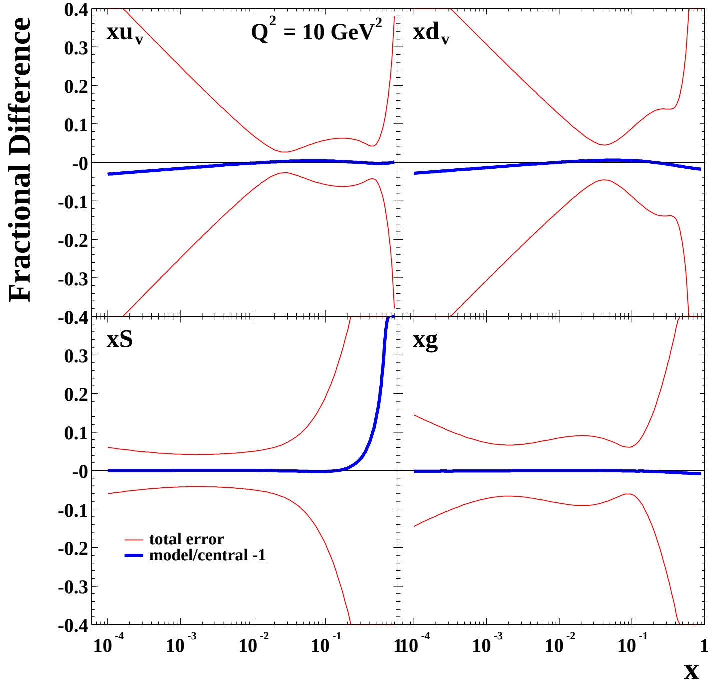
Zeus-Only

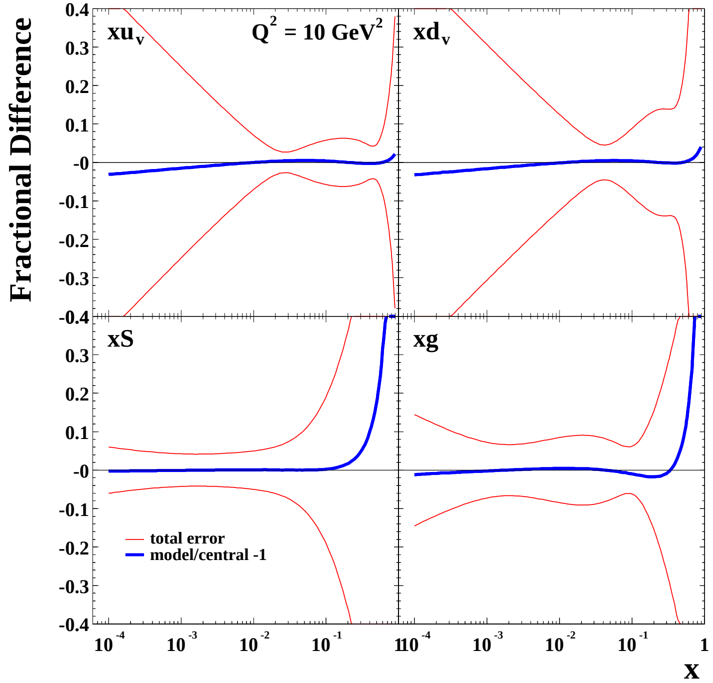
Zeus and H1 gluons are rather different even when these data are used in the same analysis - AMCS



H1-Only

Model errors: Percentage difference in choice 1 and choice 2 vs uncertainties on central fit





Percentage difference

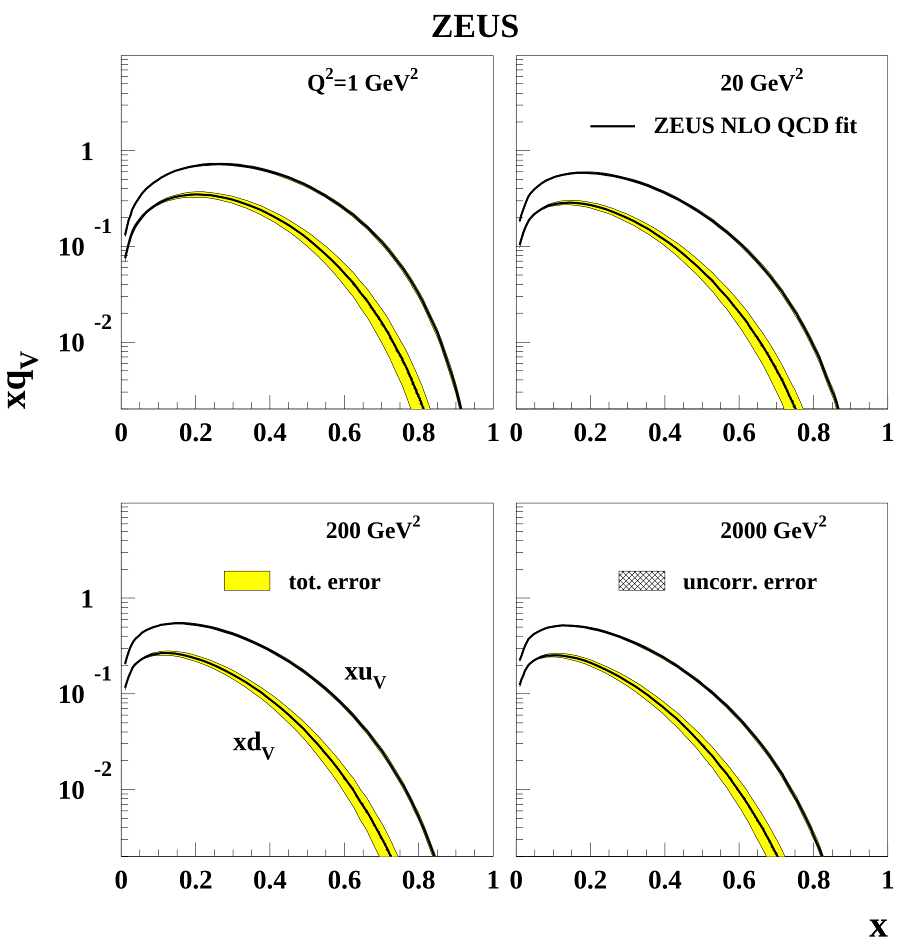
Sea choice 1 + gluon choice 2.

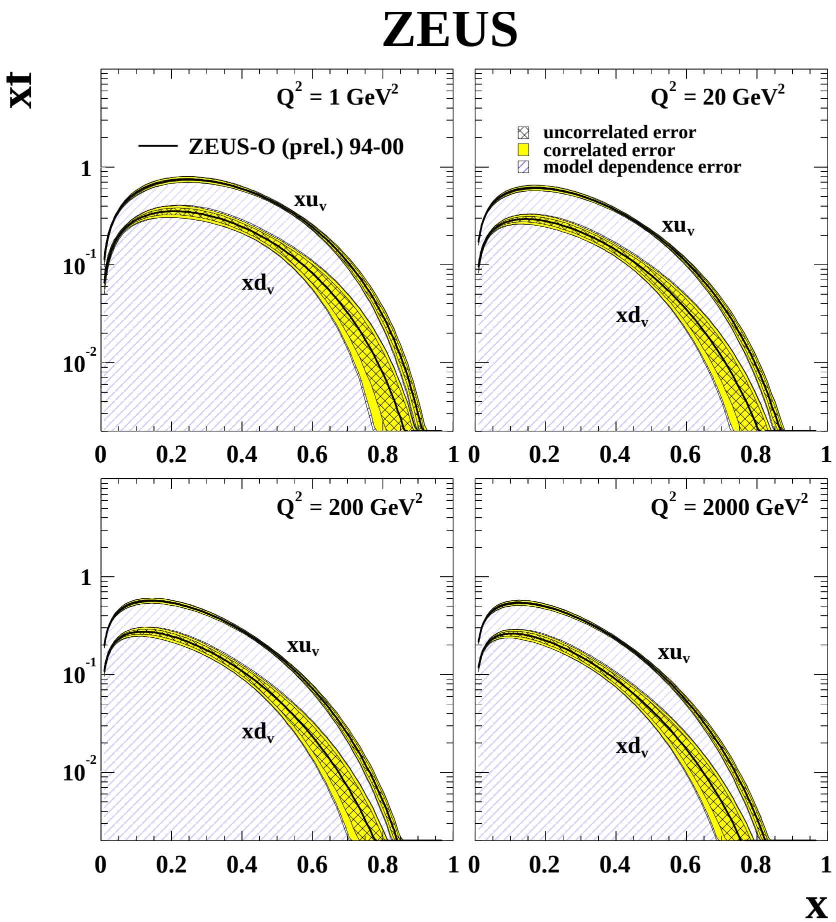
to Sea choice 2 + gluon choice 2

Percentage difference

Sea choice 1 + gluon choice 1.

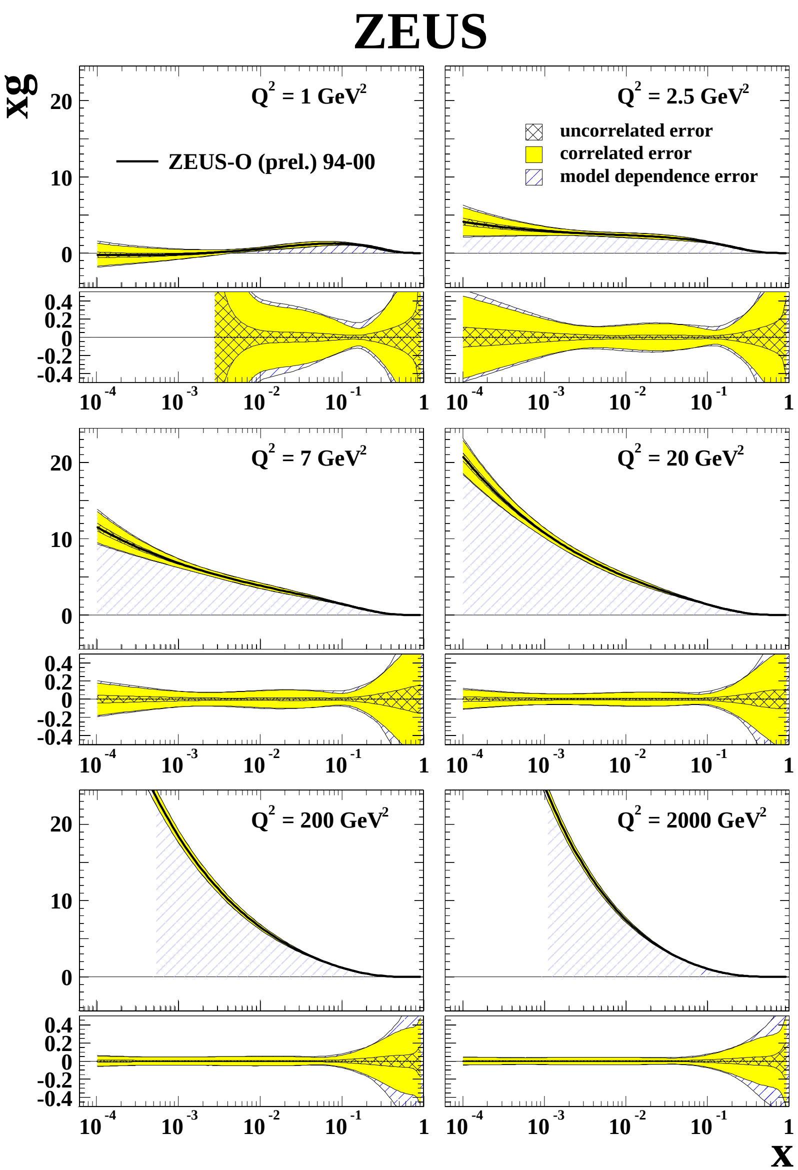
to Sea choice 2 + gluon choice 2

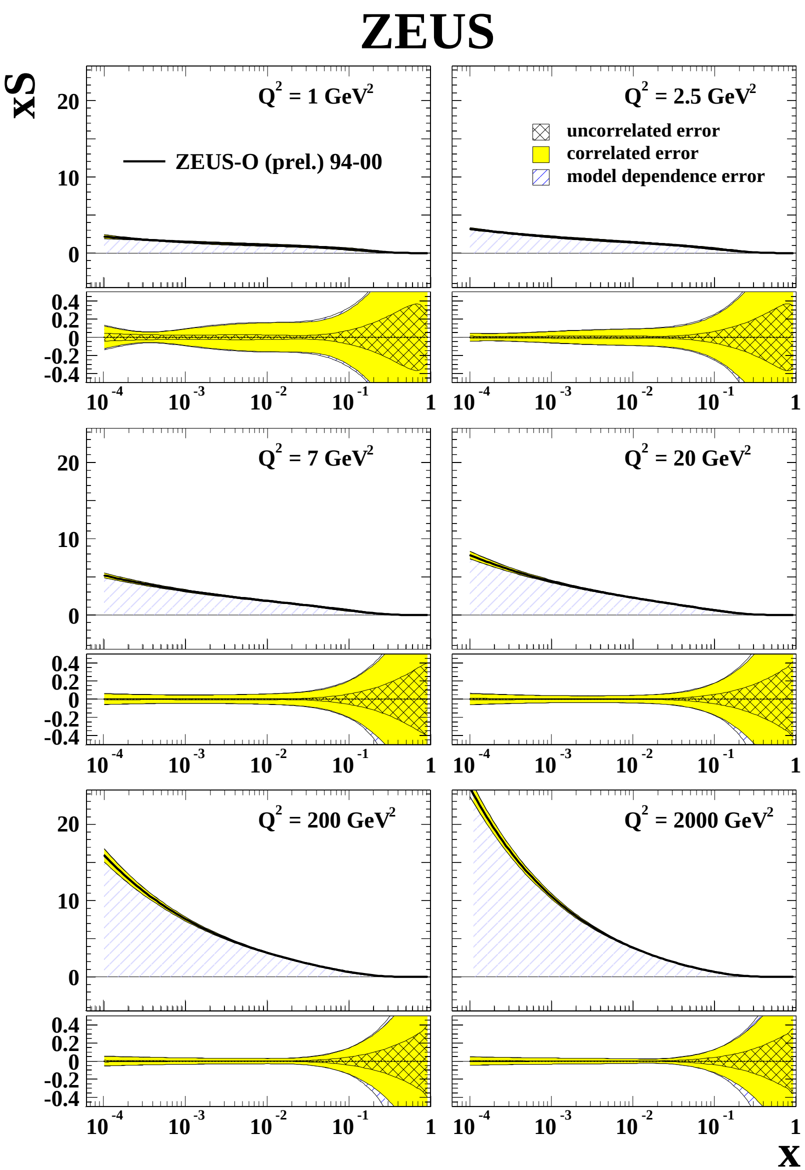




Compare valence partons for ZEUS-S global fit and ZEUS-Only fit

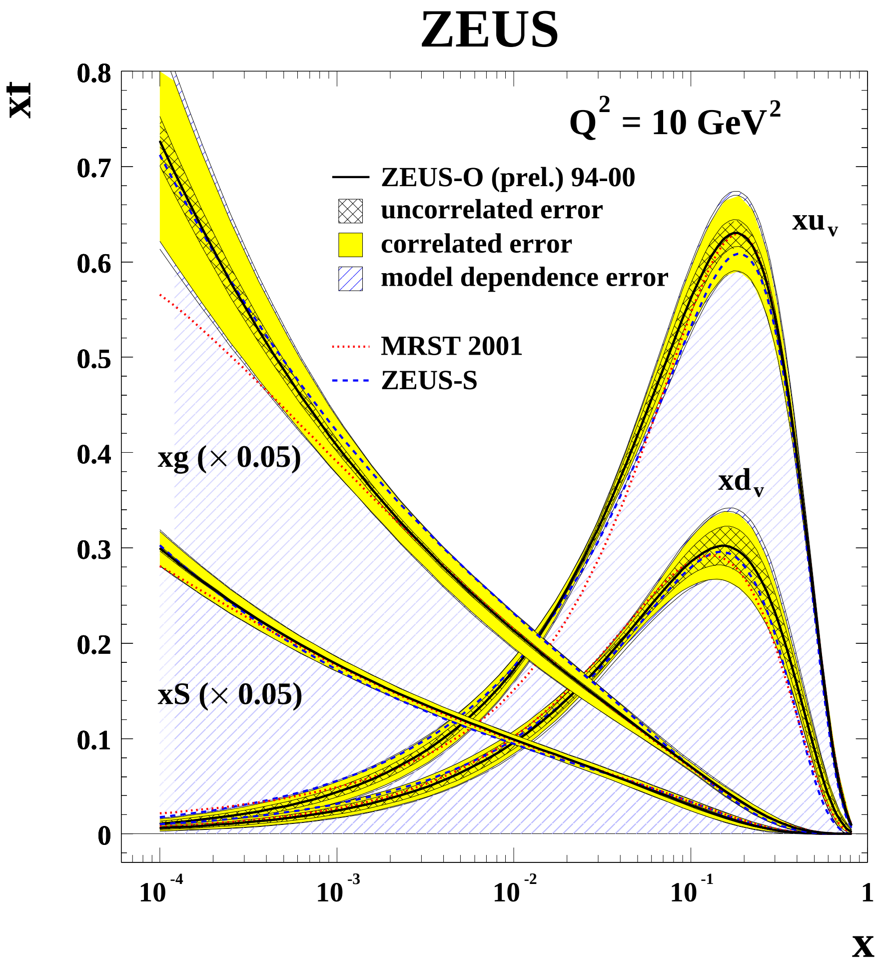
1. Global fit uncertainty is systematics dominated whereas ZEUS-Only fit is statistics dominated- much improvement expected from HERA-II, particularly if there is lower energy running to access higher-x
2. ZEUS-Only fit uses proton target data only- particularly important for dv



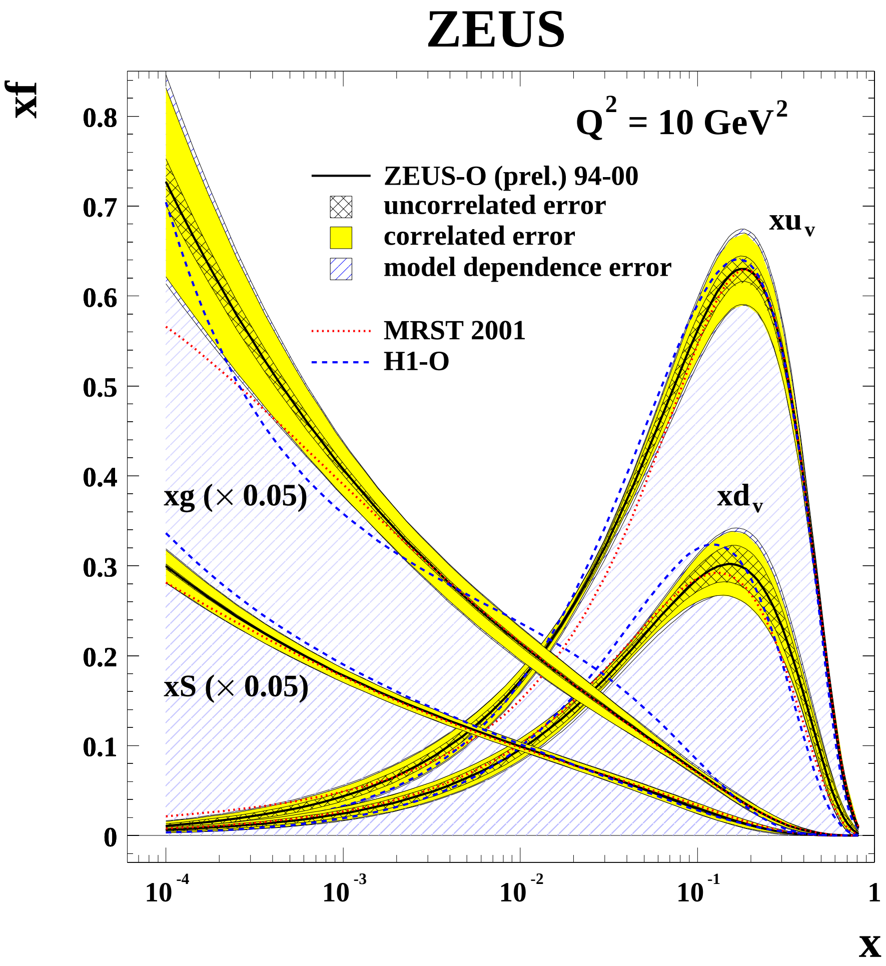


Gluon and Sea are similar to the global fit – same information at low-x

-- by construction at higher-x



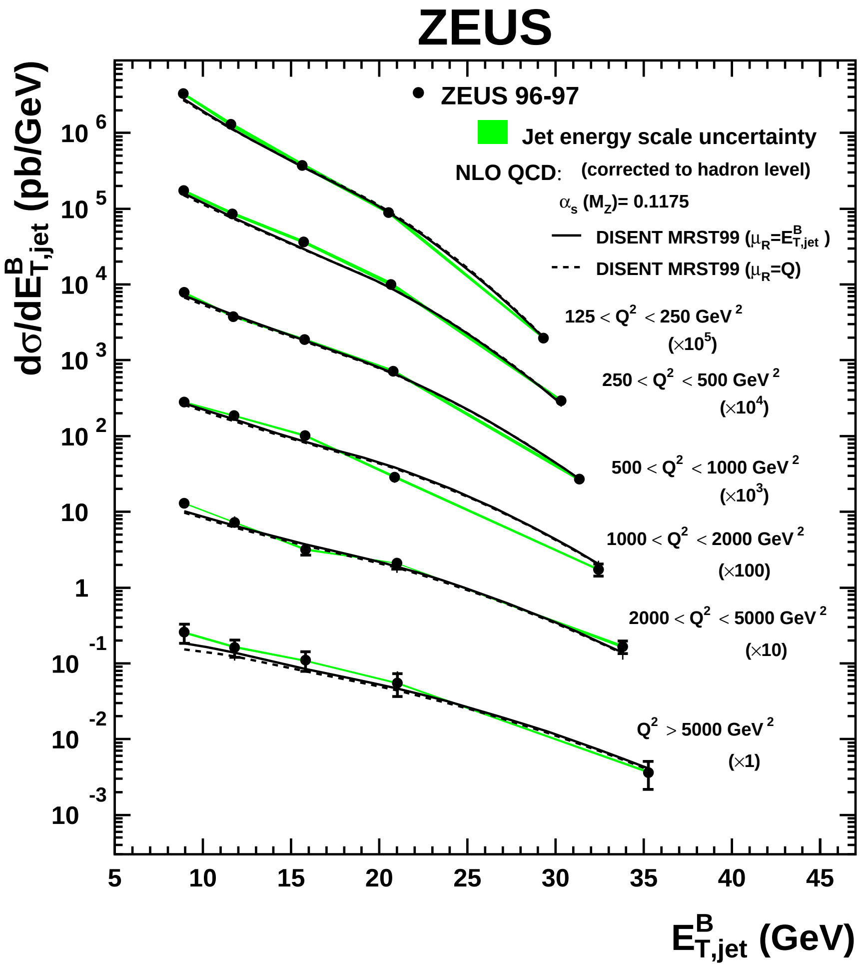
Compare ZEUS-Only fit to ZEUS-S global fit and to MRST-2001

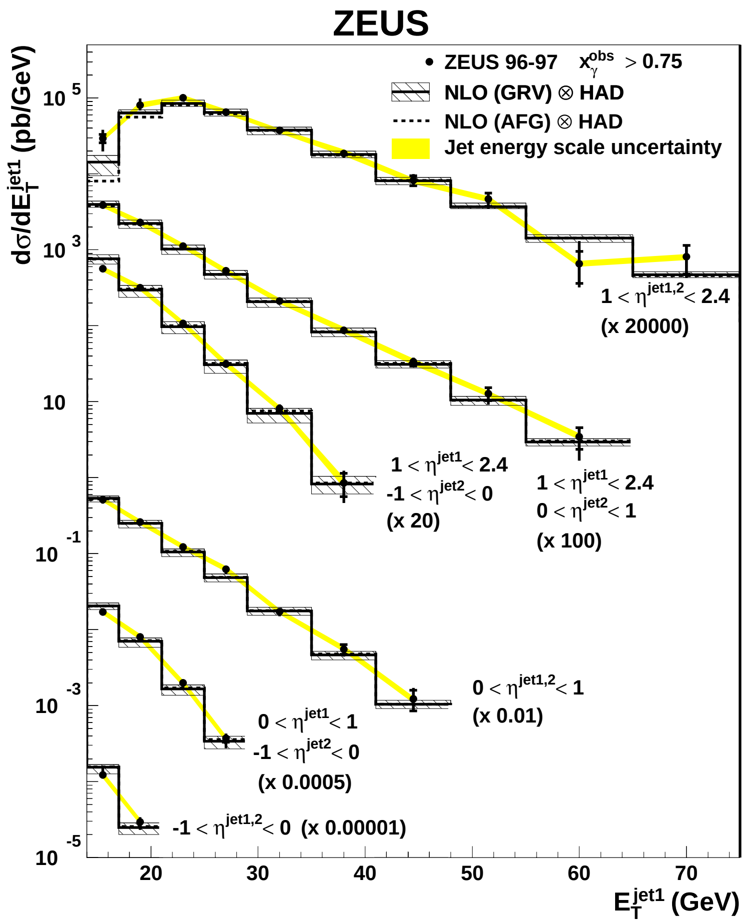


Compare ZEUS-Only fit to H1-Only fit

STRATEGY B: Use more data to tie down the high-x gluon

What data? Published Jet production data from 96/97 30 pb^{-1}





Inclusive jet cross-sections vs E_T(Breit) for DIS in bins of Q^2

Di-jet photoproduction cross-sections vs E_T(lab) in bins of rapidity for direct photons (x_γ > 0.75)

How?

NLO QCD predictions for jet production: DISENT for DIS jets, FRIXIONE and RIDOLFI for photoproduced di-jets are too slow to be used every iteration of a fit. Thus these codes are used to produce grids in (x, μ_F^2), for each cross-section bin and each flavour of parton (gluon, up-type, down-type).

$$\mathrm{d}\sigma_{\mathrm{jet}} = \Sigma_{a=q,\bar{q},g} \int \mathrm{d}x\, f_a(x,\mu_F^2)\,\mathrm{d}\hat{\sigma}_a(x,\alpha_s(\mu_R),\mu_F^2) \times (1+\delta_{had})$$

$\rightarrow$ where $\hat{\sigma}_a(x,\alpha_s(\mu_R),\mu_F^2)$ is the weight

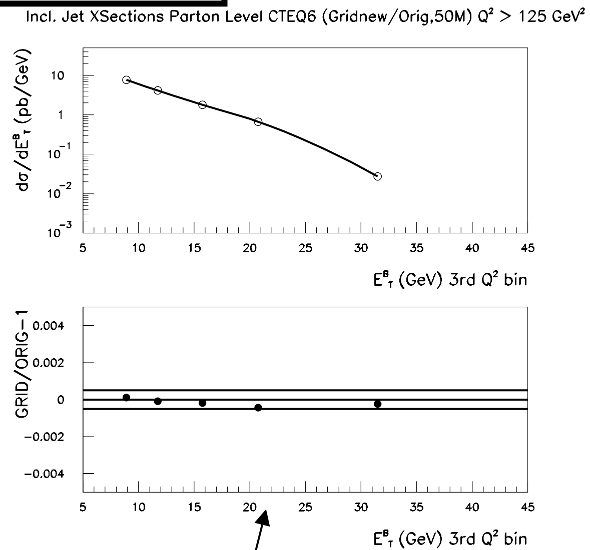
$\rightarrow$ where $f_a(x,\mu_F^2)$ is the PDF for parton a at x and scale μ_F

The predictions must also be multiplied by hadronization corrections and Z_O corrections

The calorimeter energy scale and the luminosity are treated as correlated systematic errors

μ_F= Q for the DIS jets, μ_R=Q or ET as a cross-check

μ_R= μ_F = E_T/2 for the γ di-jets (E_T is summed E_T of final state partons), the AFG photon PDF is used but only direct photon events are used to minimize senstivity



This is how well the grids reproduce the predictions – to 0.05%

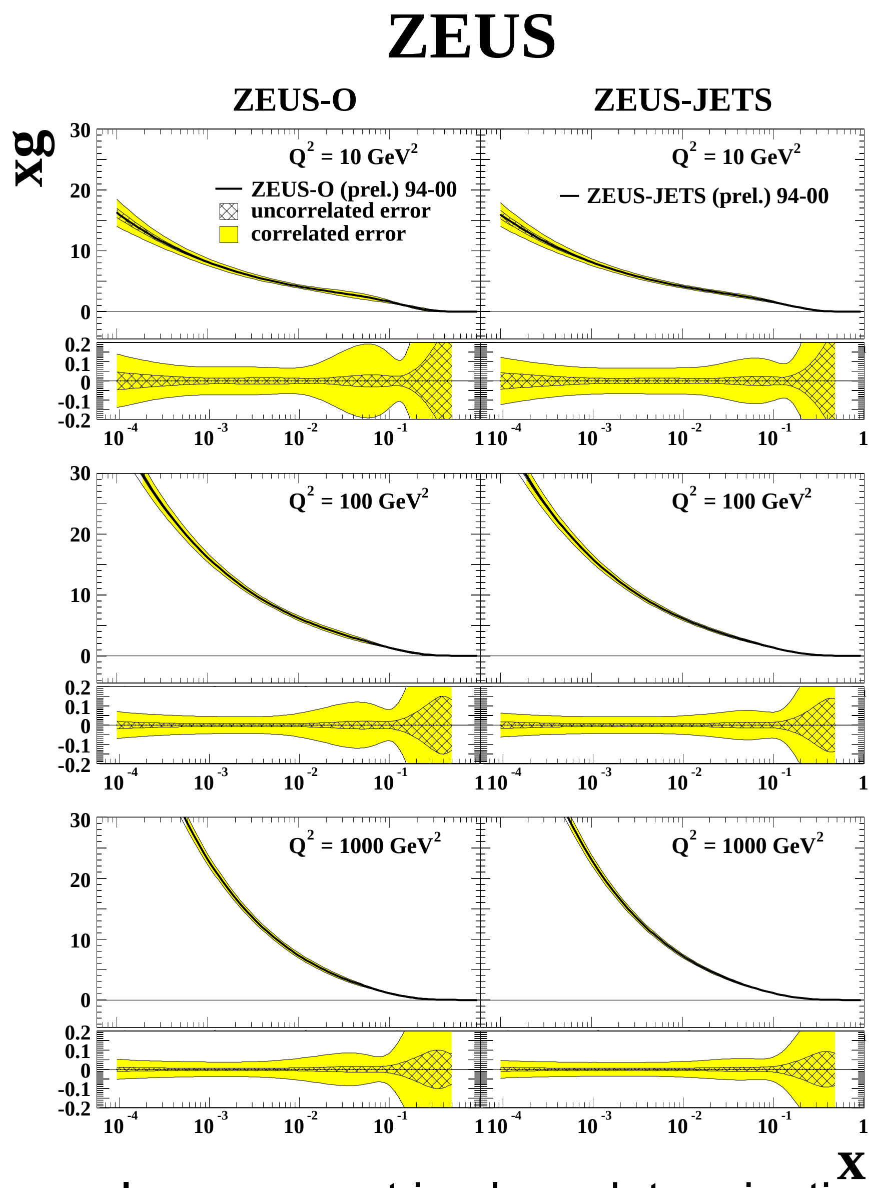
•Retain a, b, c all free in gluon param.
•$xg(x) = A_g \; x^{a_g} (1-x)^{b_g} \; (1 + c_g \, x)$
→11 parameter fit

The improvement in the determination of the gluon distribution at moderate to high-x is quite striking

Although the jet data mostly affect 0.01<x<0.1 (region of visible difference in the H1/ZEUS gluons) the momentum sum-rule transfers some of this improvement to higher-x

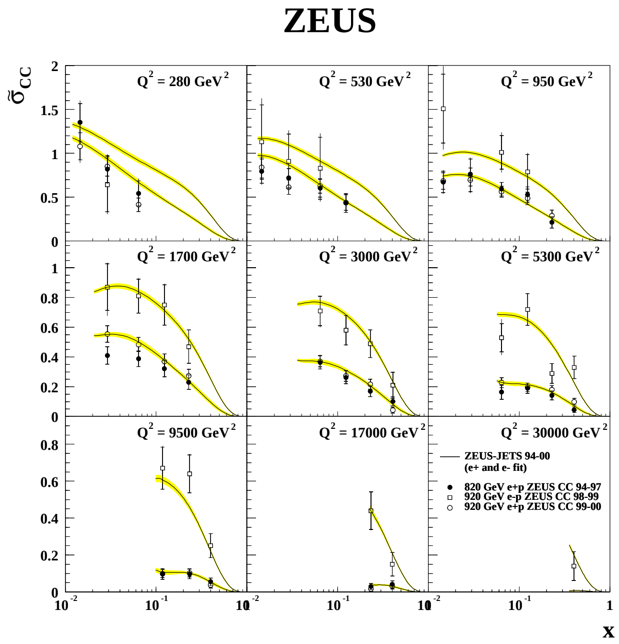
The Sea distribution is not significantly improved and we maintain our previous strategy of constraining a high-x sea parameter (choices 1 or 2 are very similar)

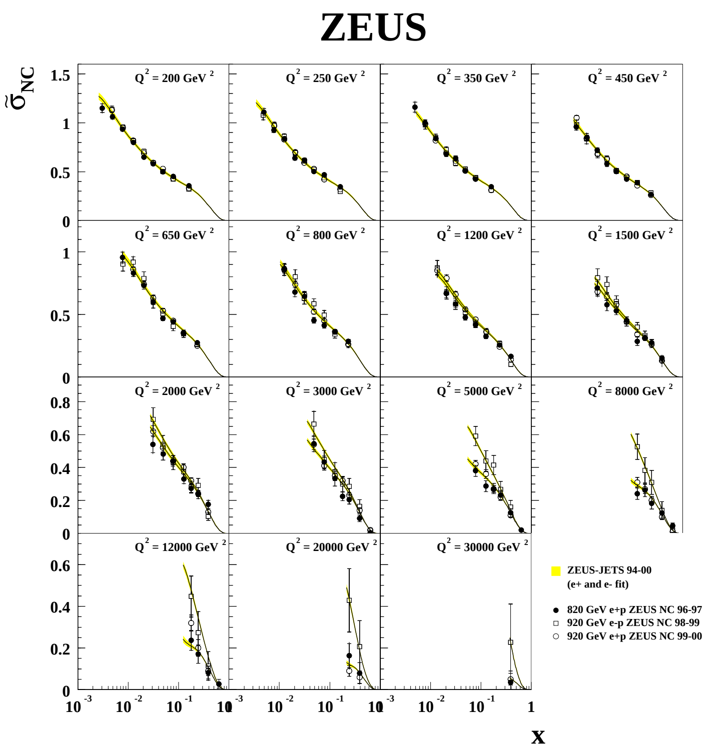
For a better high-x Sea determination we await HERA-II (and low energy running?)

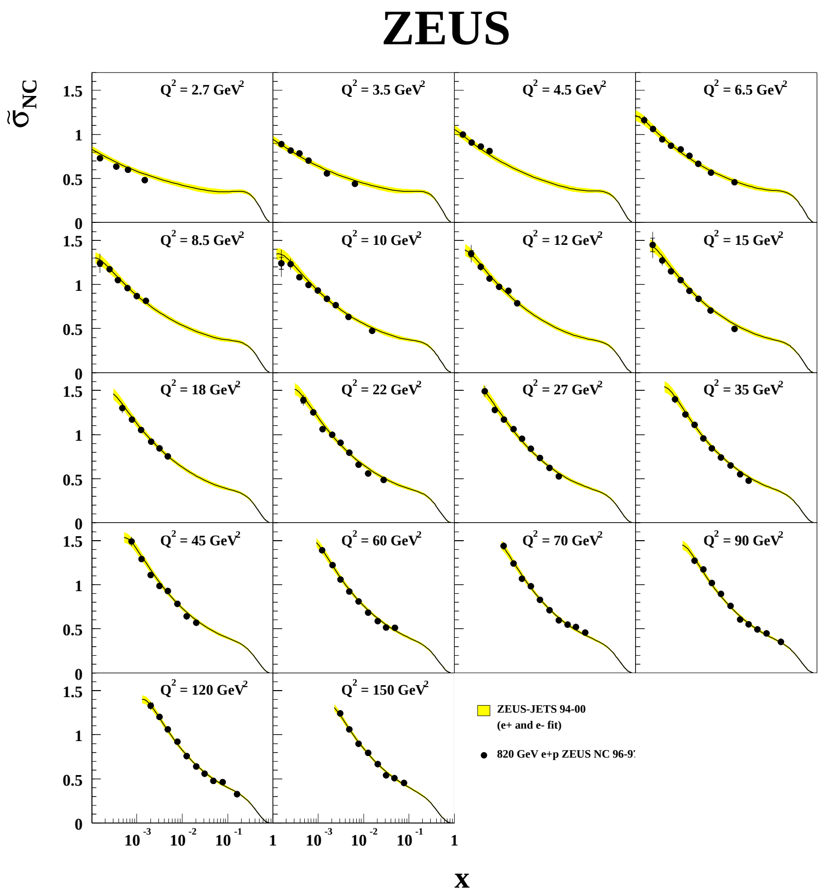


Improvement in gluon determination
without jets → with jets

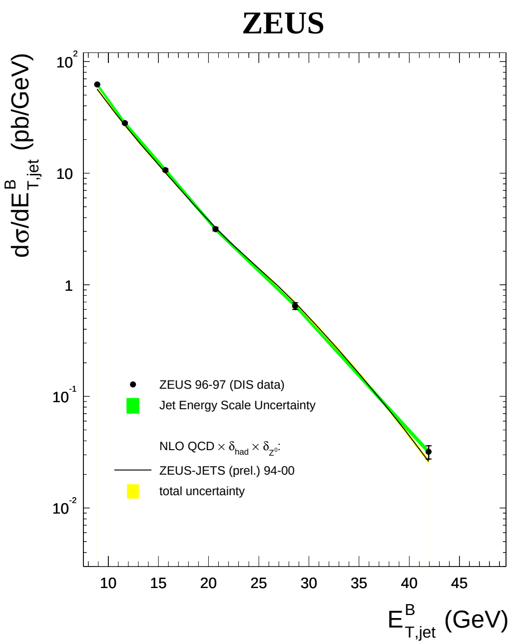
11 parameter fits

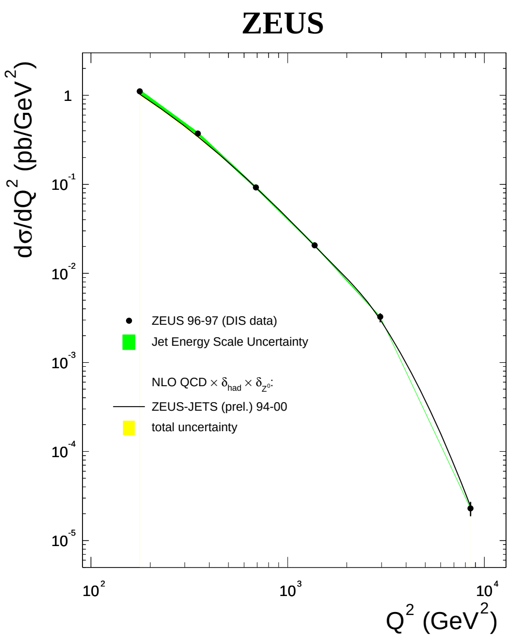


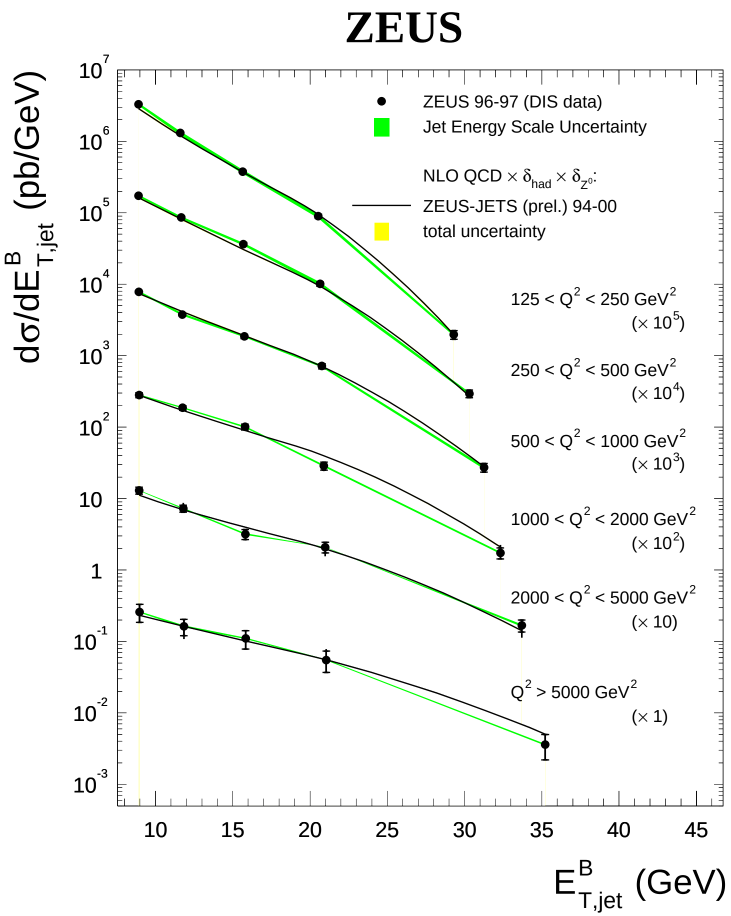


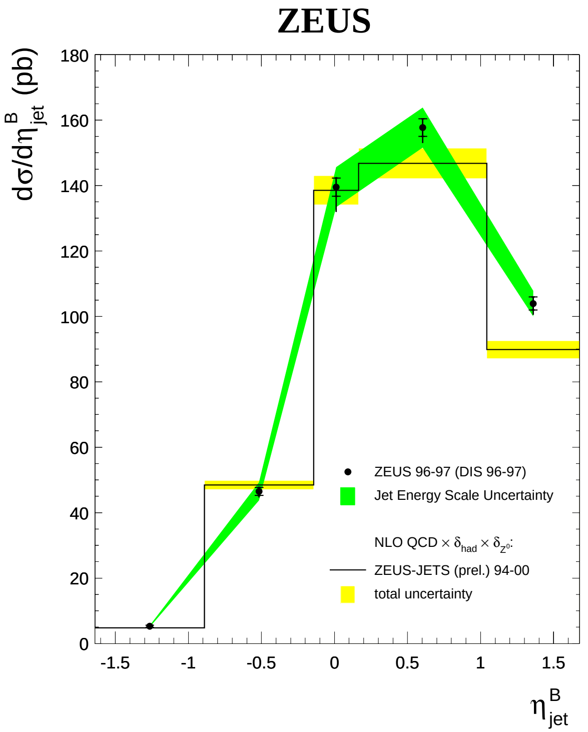


The ZEUS-Only fit including jet data compared to the inclusive cross-section data

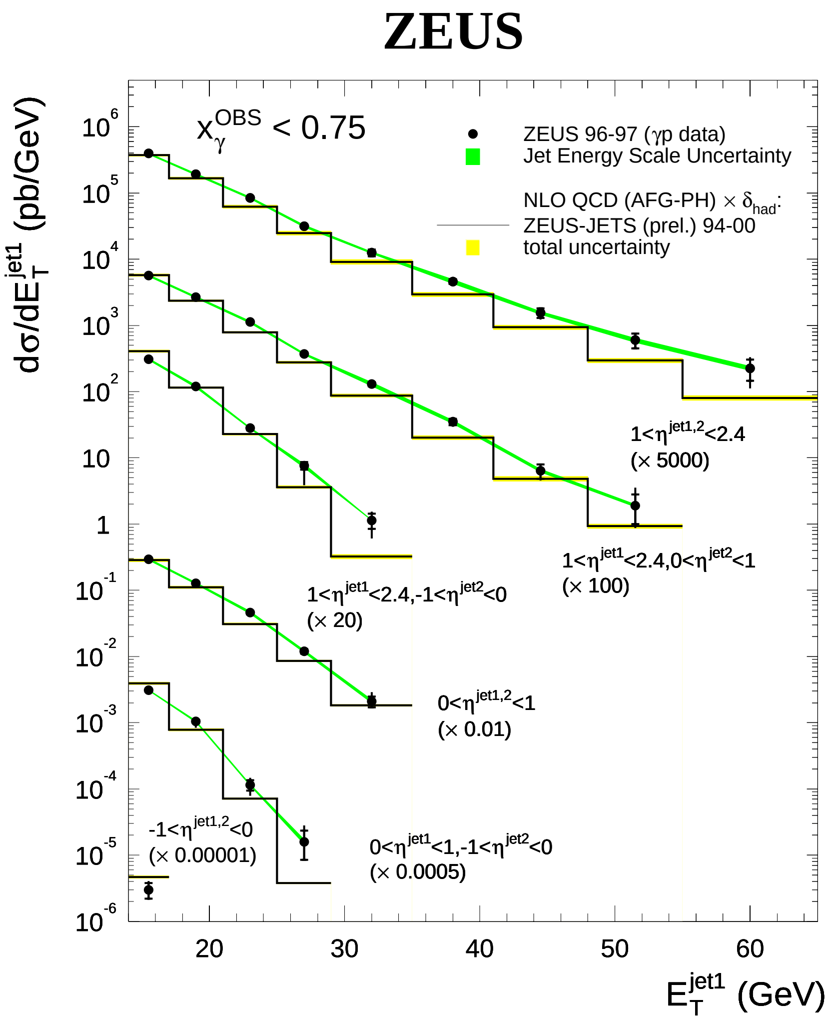


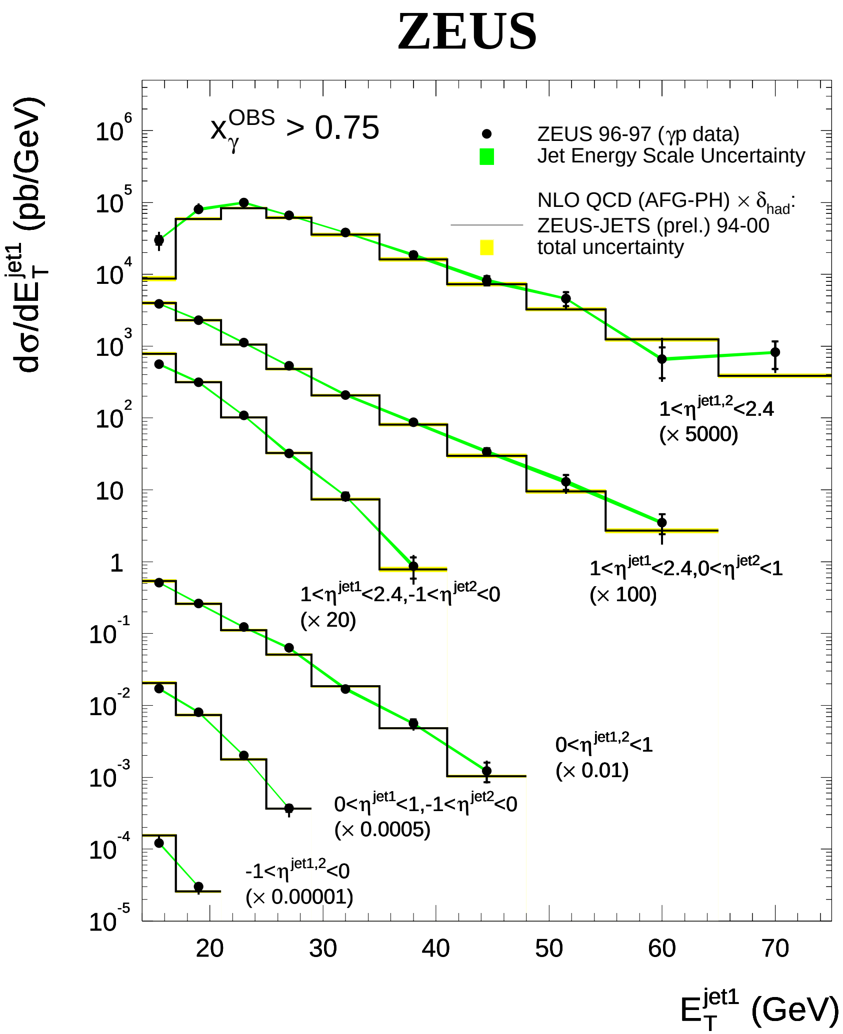






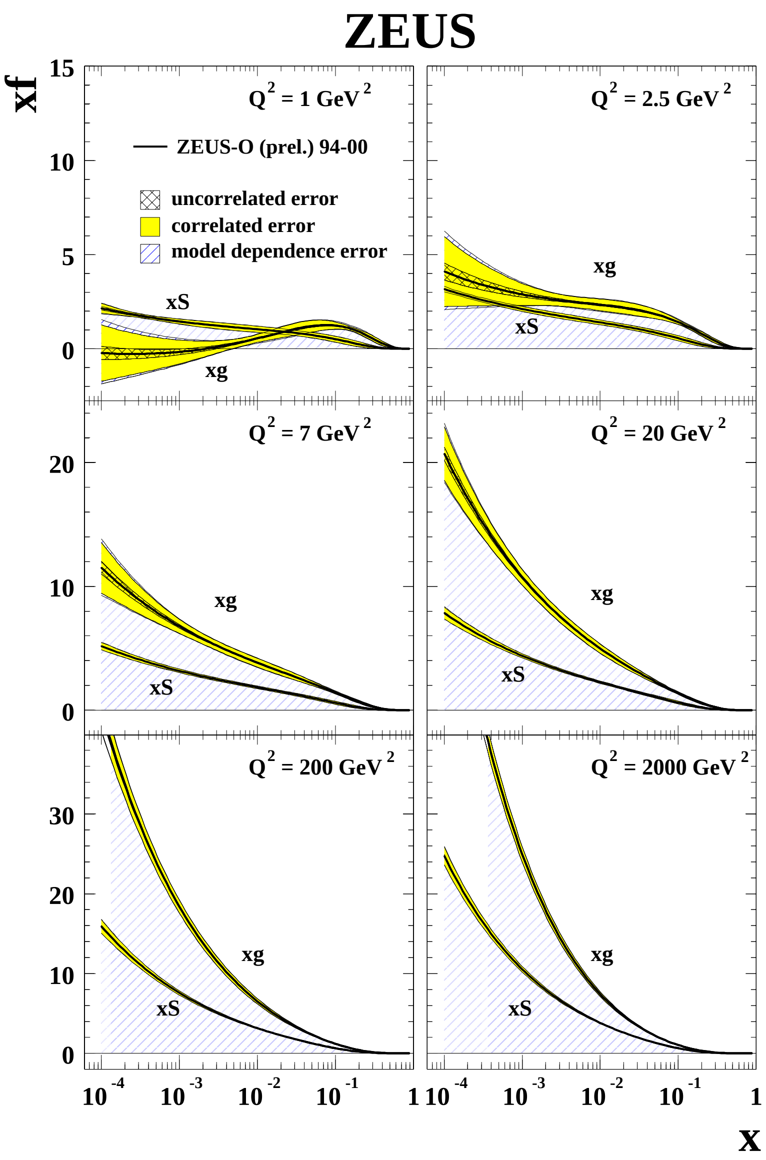
The ZEUS-Only fit with Jets compared to DIS inclusive jet data



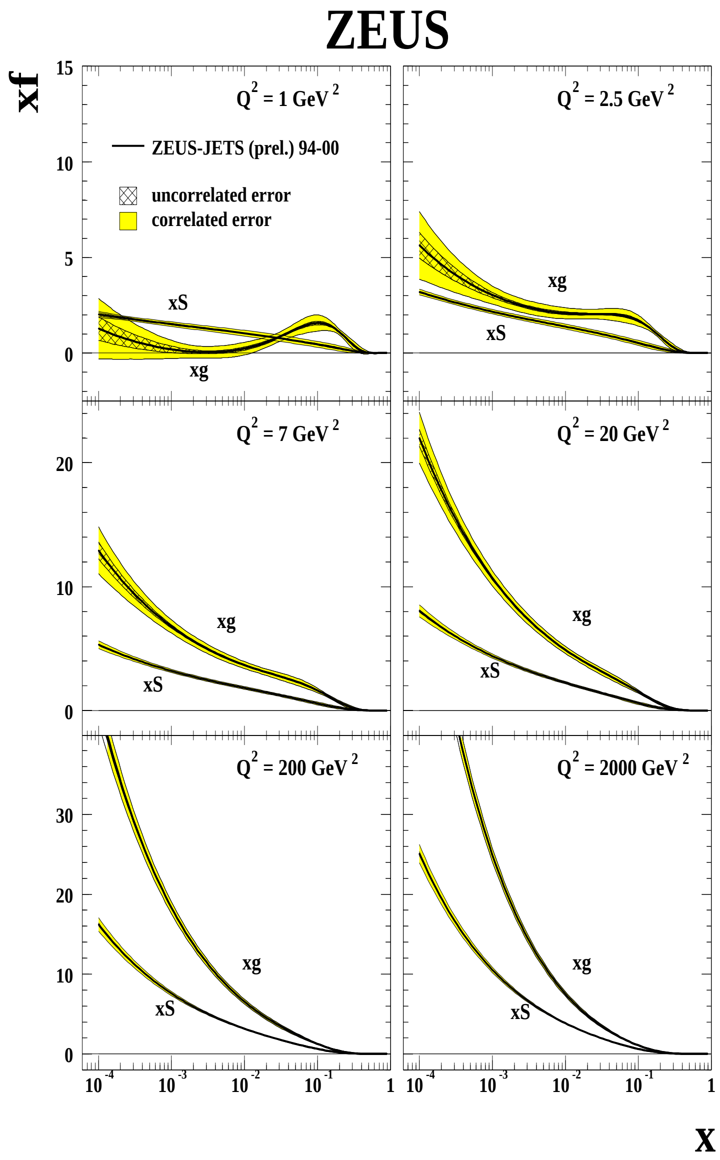


The ZEUS-Only fit with jets compared to di-jet photoproduction data

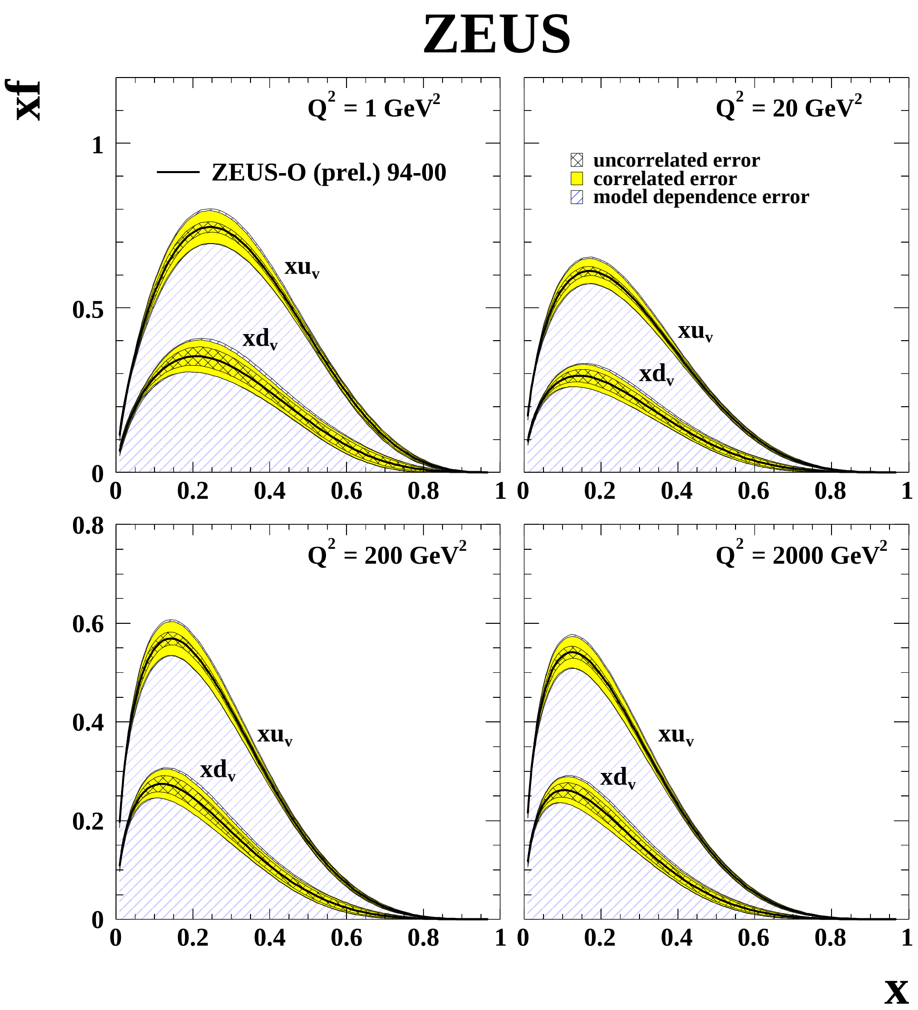
Less good NLOQCD description of data at the lowest ET → hence a cross-check removing the lowest ET bin from both DIS and Photoproduction Jet data was made



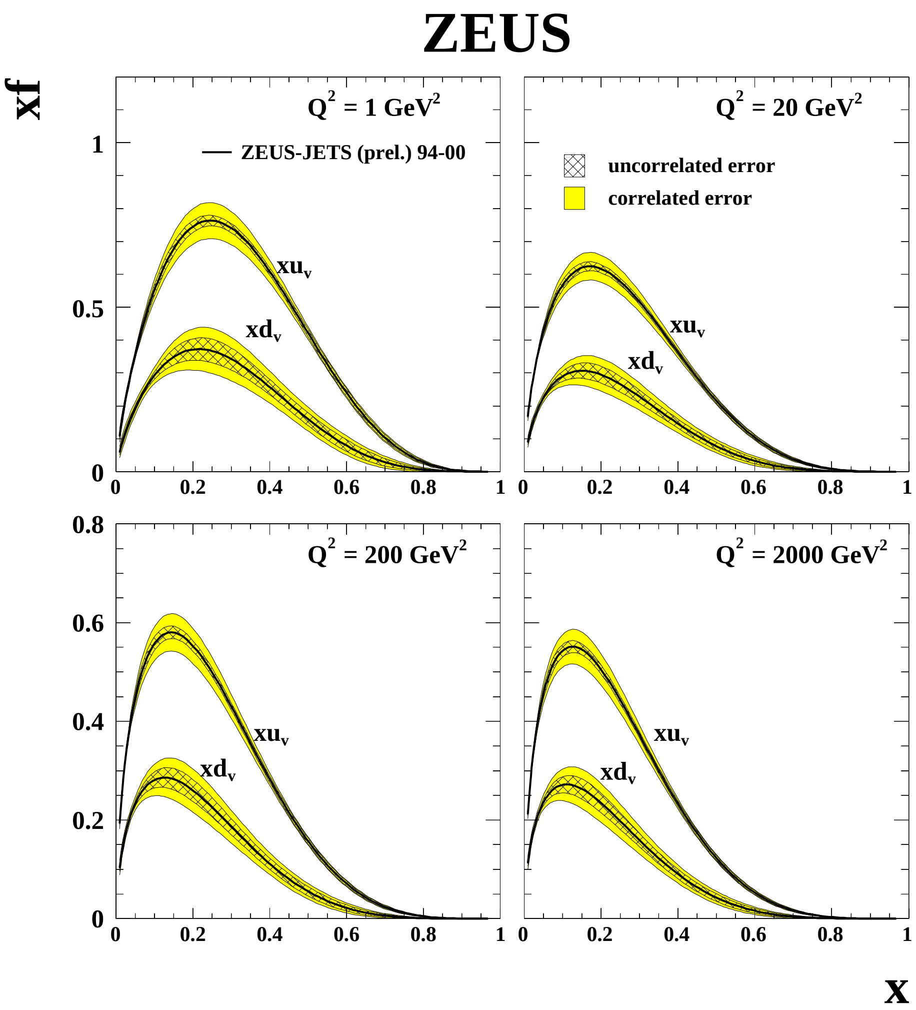
Sea/gluon STRATEGY A



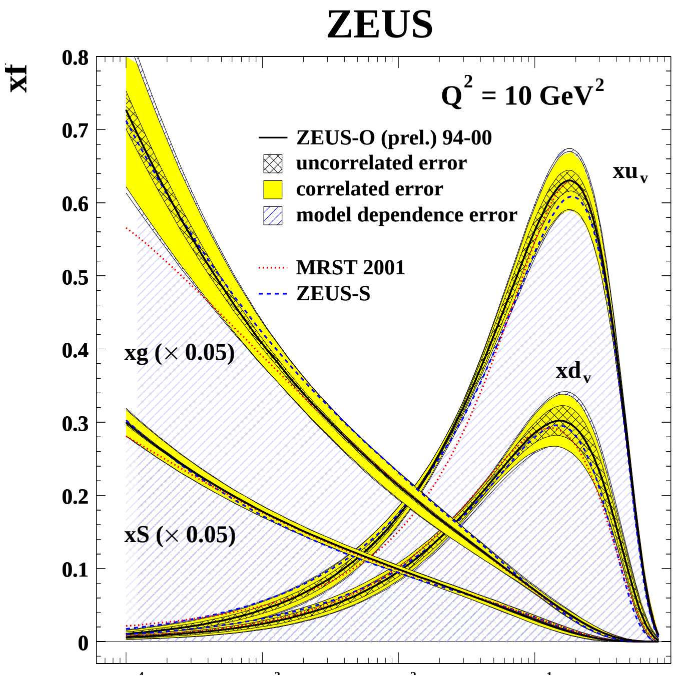
Sea/gluon STRATEGY B



Valence STRATEGY A

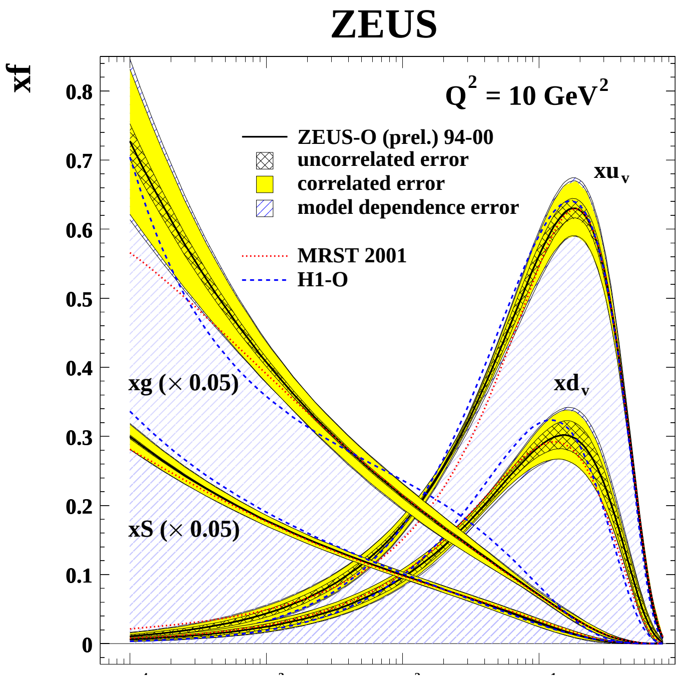


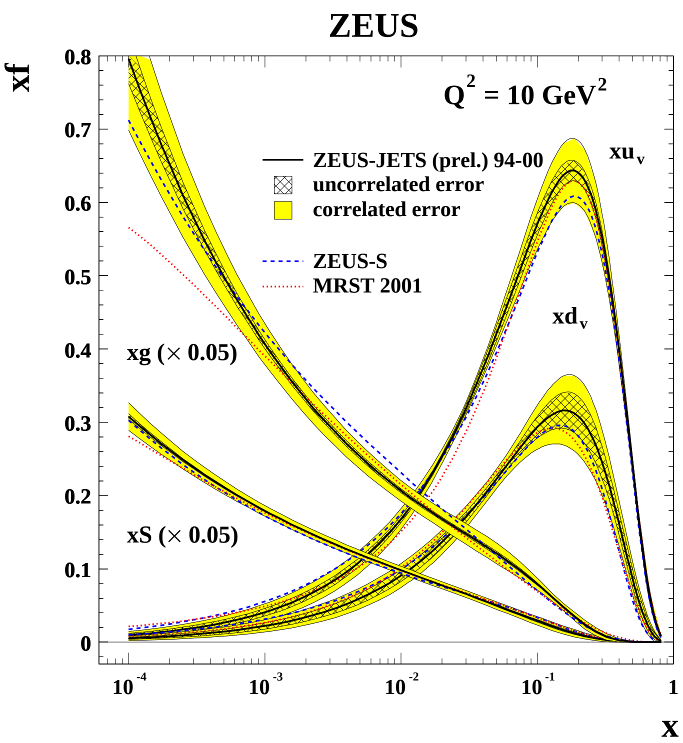
Valence STRATEGY B



Strategy A

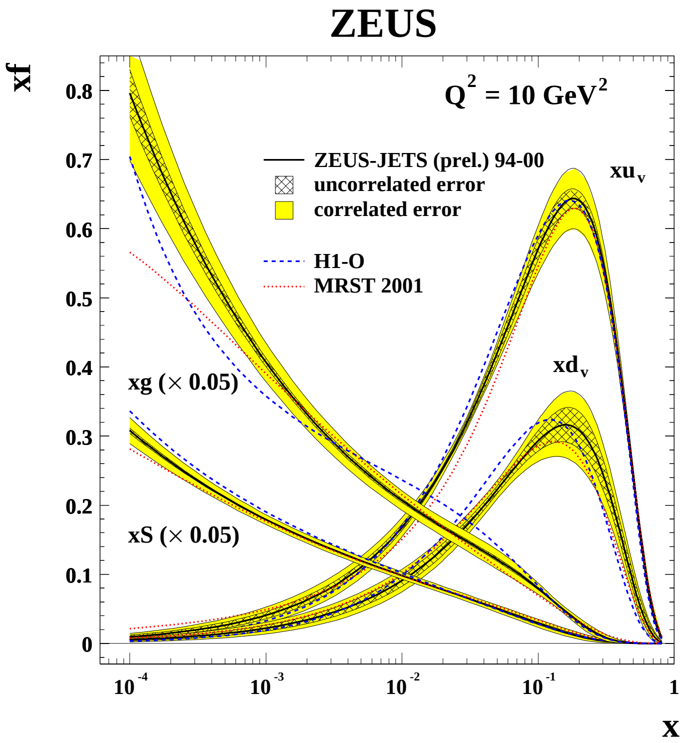
(constrain high-x Sea/Gluon)





Strategy B

(use jet data to determine high-x gluon)



SUMMARY AND CONCLUSION

- PDF Analysis of ZEUS data alone reduces the uncertainty involved in the combination of correlated systematic errors from many different experiments with possible incompatibilities
- Using ZEUS data alone also avoids uncertainty due to heavy target corrections for Fe and Deuterium– particularly important for d valence
- ZEUS data now cover a large range in the x,Q2 kinematic plane

→ Valence is well measured → low-x Sea/gluon are well measured

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Adding jet data gives a significant constraint on the mid/higher x gluon

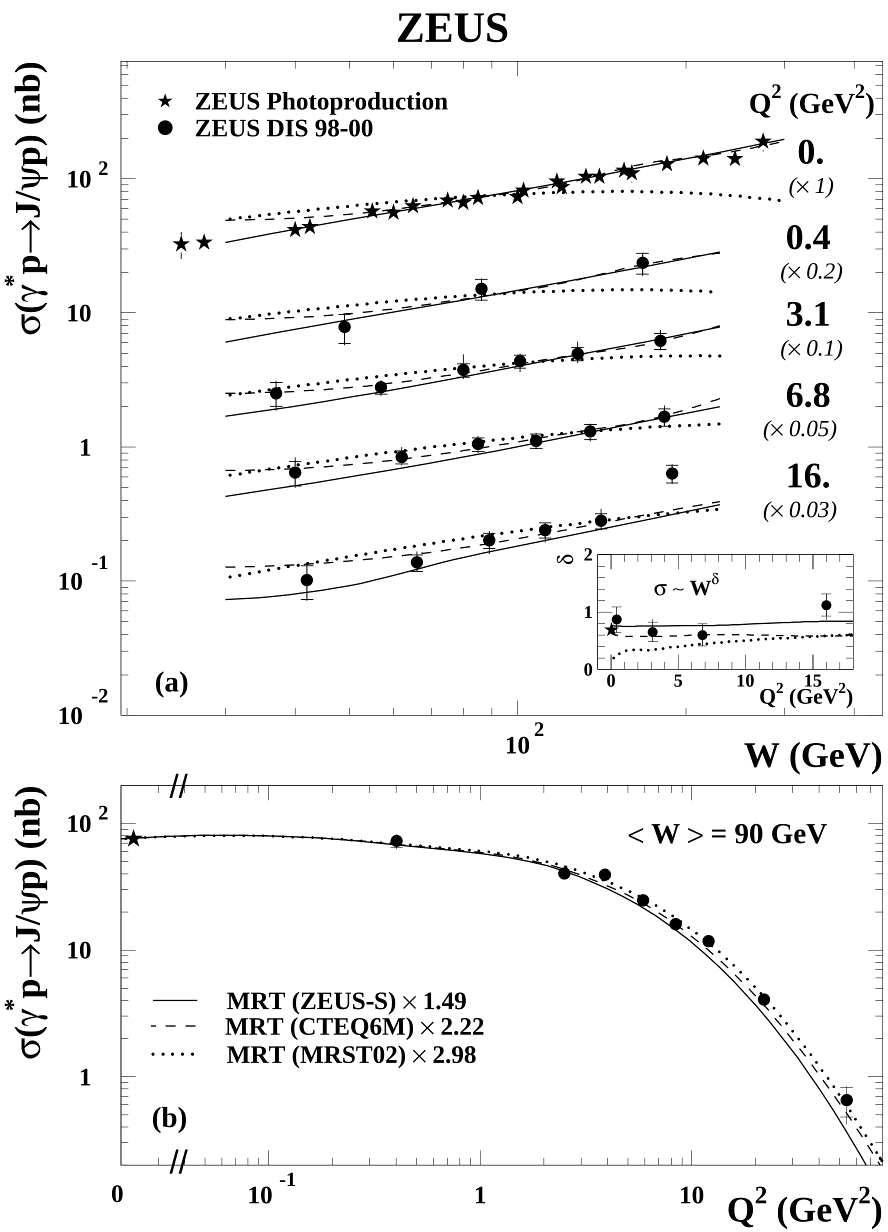
→ There's a lot more that could be done – Use more jet cross-sections

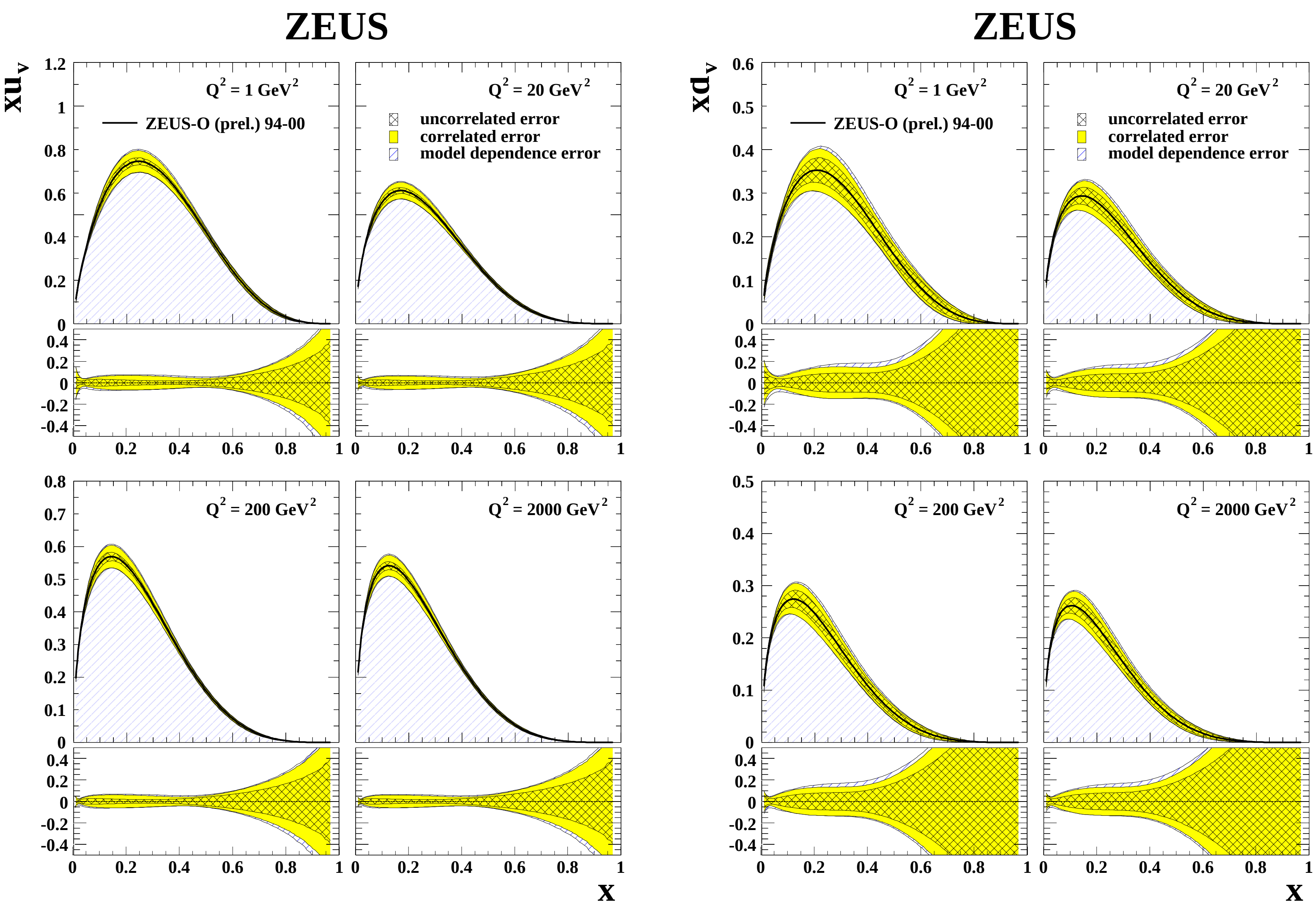
1. Add jet data from 1998/2000 → α_s measurement
2. Add charm differential cross-sections in ET and rapidity
3. Add resolved photon xsecns (if can control the photon PDF uncertainty)

Add HERA-II data for: more accurate valence (xF3 from NC/ flavours from CC)
: more accurate high-x Sea

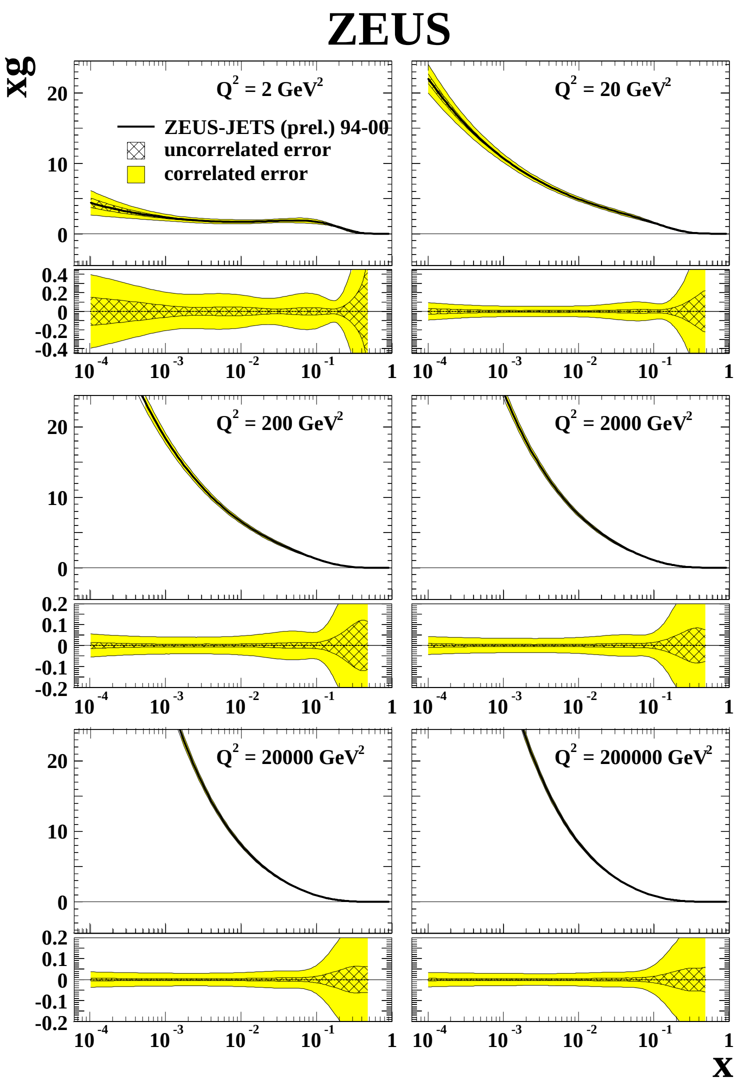
Low energy running at HERA-II → for higher x and for FL → Gluon

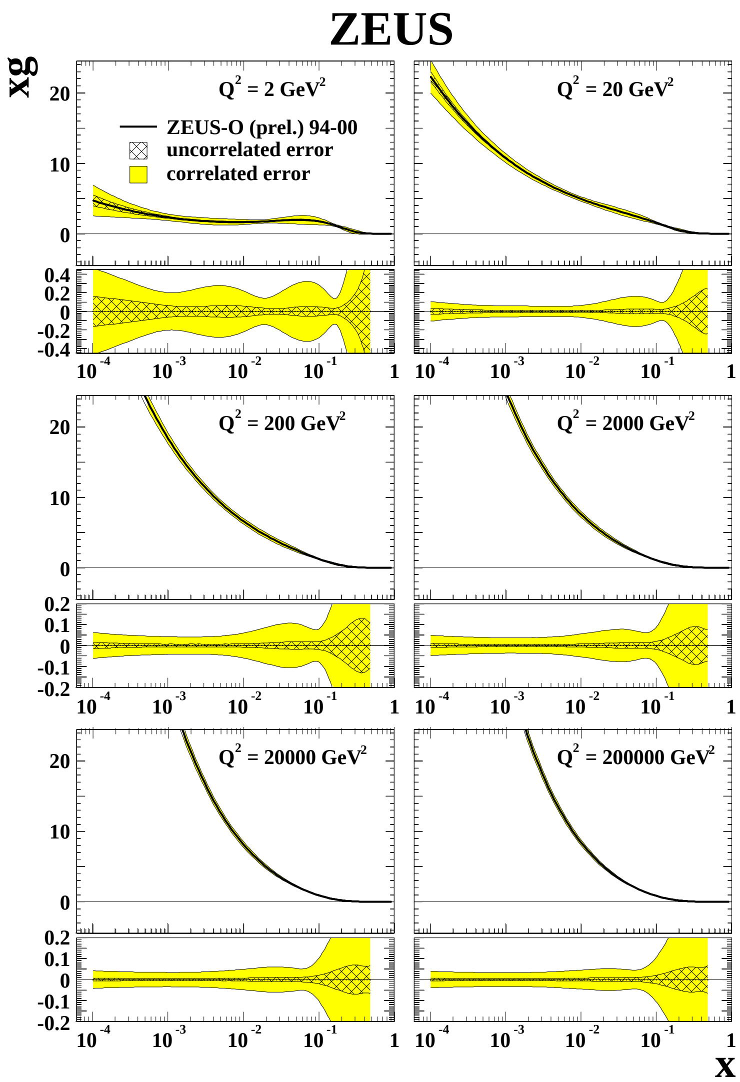
Extras after here


ZEUS
ZEUS Photoproduction
ZEUS DIS 98-00
Q^2 (GeV^2)
0. (× 1)
0.4 (× 0.2)
3.1 (× 0.1)
6.8 (× 0.05)
16. (× 0.03)
σ(γ* p→J/ψp) (nb)
σ ~ W^δ
δ
Q^2 (GeV^2)
(a)
W (GeV)
< W > = 90 GeV
MRT (ZEUS-S) × 1.49
MRT (CTEQ6M) × 2.22
MRT (MRST02) × 2.98
(b)
Q^2 (GeV^2)

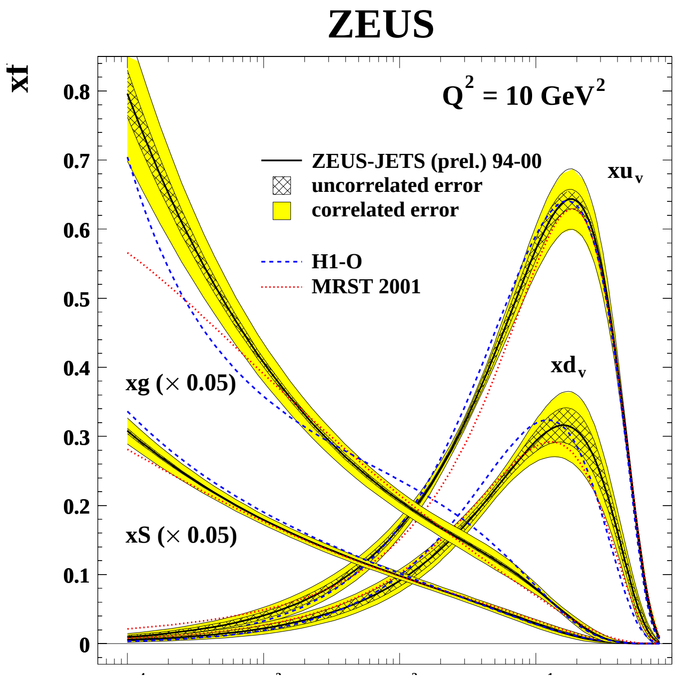


uv and dv from 10 parameter STRATEGY A



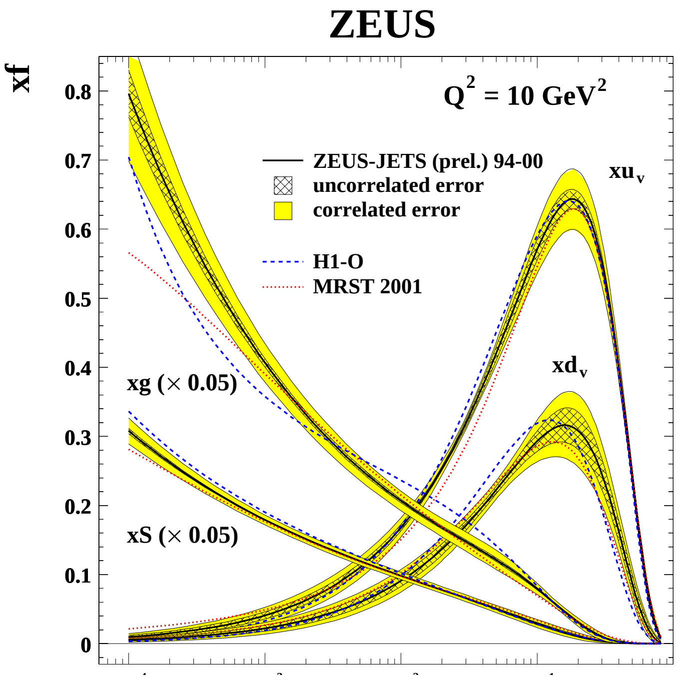


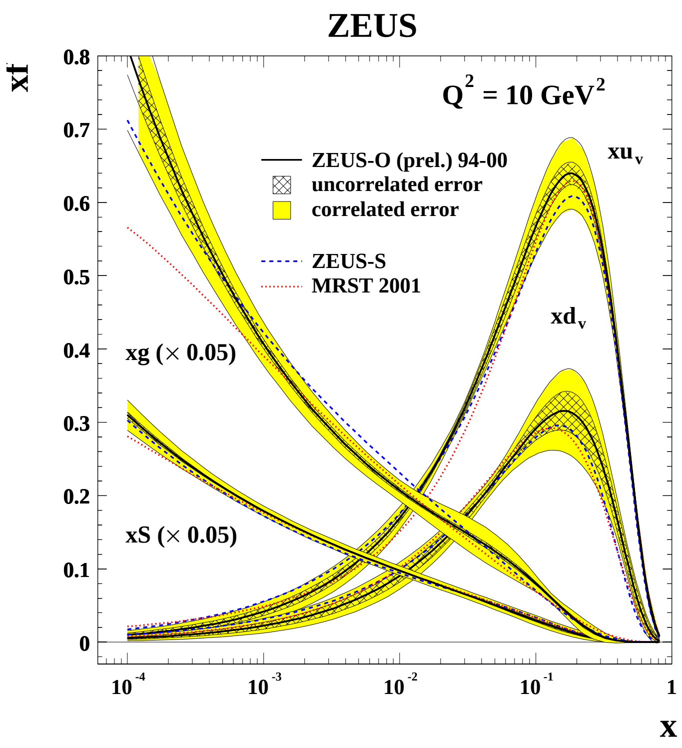
Gluon with and without jets STRATEGY-B summary



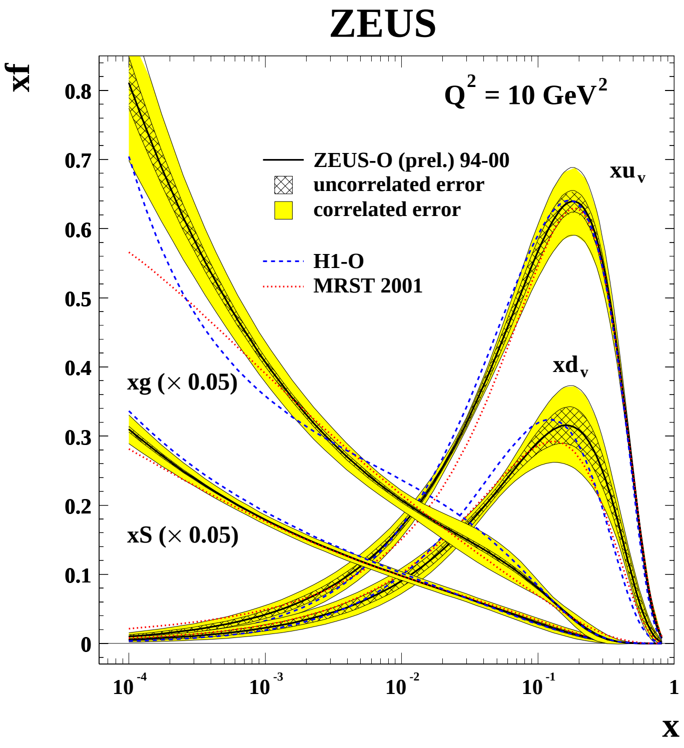
ZEUS with jets

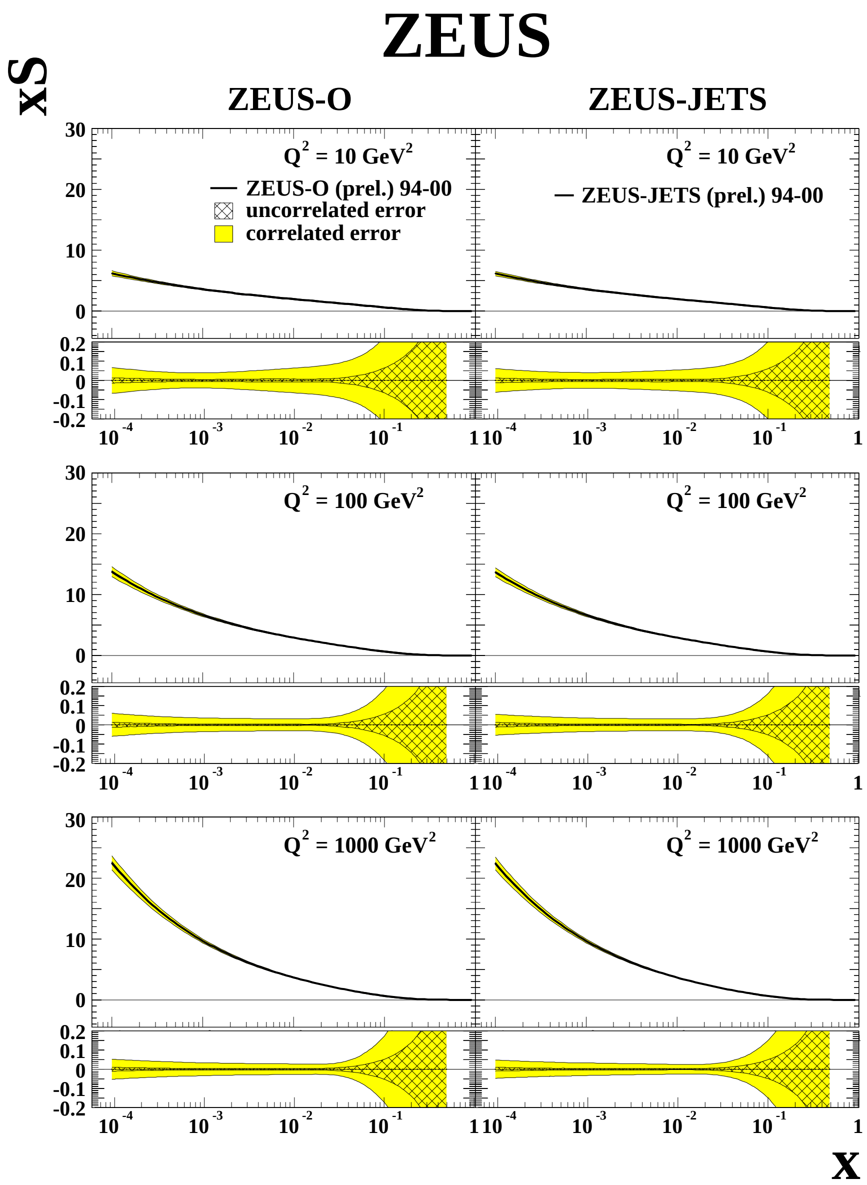
STRATEGY-B





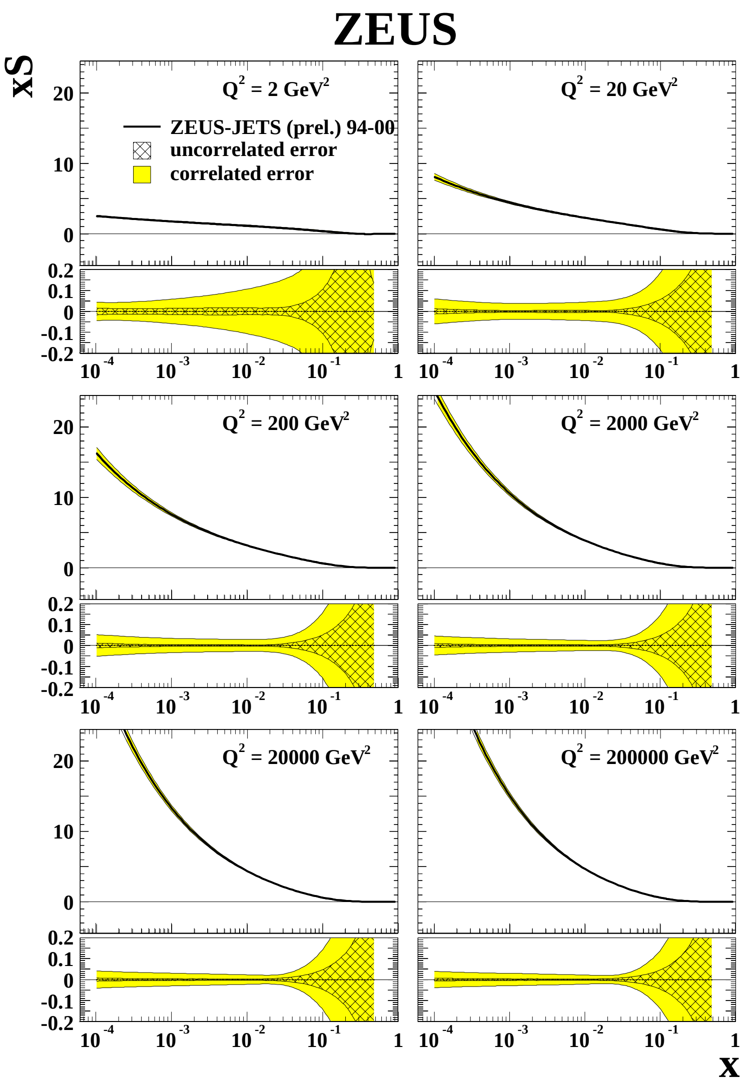
ZEUS Without jets

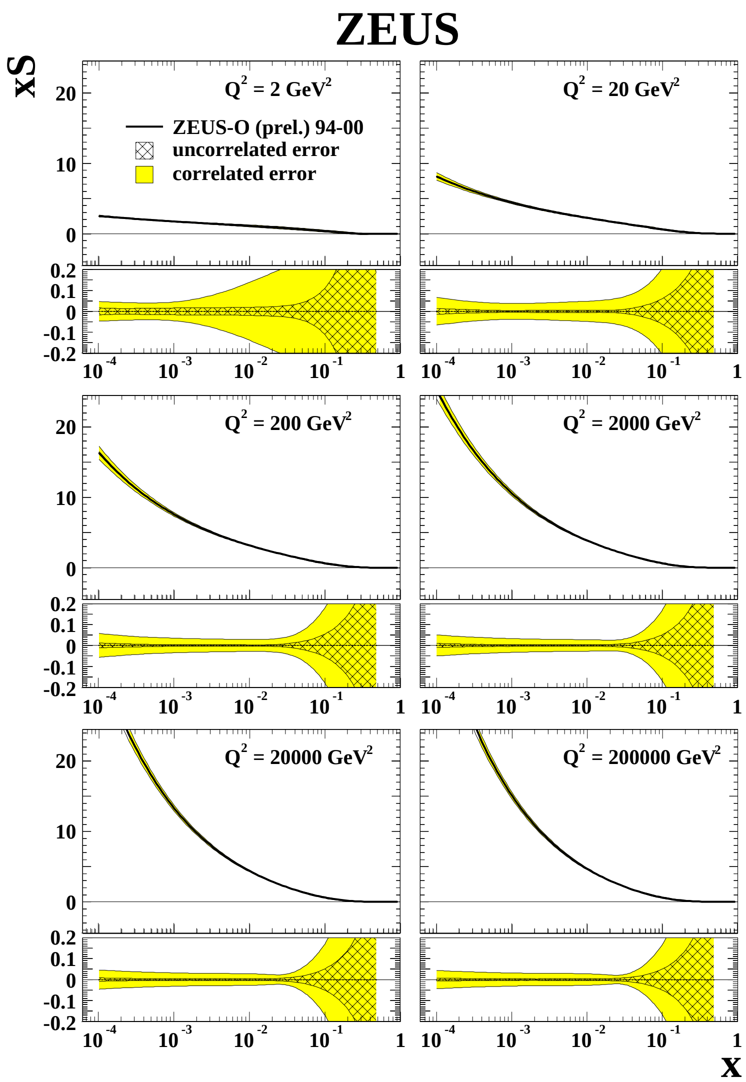




Improvement in sea determination
without jets → with jets

11 parameter fits STRATEGY-B





Sea with and without jets STRATEGY-B summary

The χ2 includes the contribution of correlated systematic errors

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

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

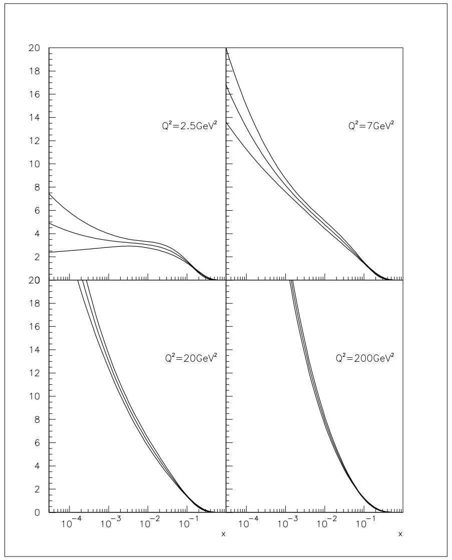
The statistical errors on the fit parameters, p, are evaluated from **Δχ2 = 1**

The correlated systematic errors are evaluated by the Offset method –conservative method

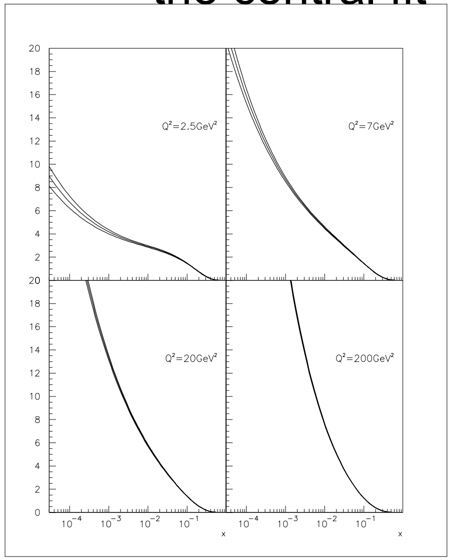
1. Perform fit without correlated errors (sλ = 0) for central fit
2. Shift measurement to upper limit of one of its systematic uncertainties (sλ = +1)
3. Redo fit, record differences of parameters from those of step 1
4. Repeat 2-3 for lower limit (sλ = -1)
5. Repeat 2-4 for next source of systematic uncertainty
6. Add all deviations from central fit in quadrature (positive and negative deviations added in quadrature separately)

- Does not assume that correlated systematic uncertainties are Gaussian distributed

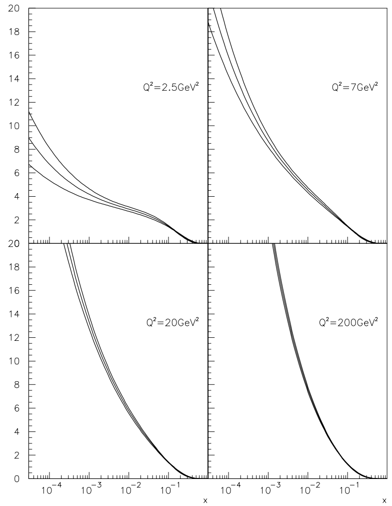
Offset method gives smaller errors than the Hessian method in which s_λ varies for the central fit



Offset method



Hessian method T=1



Hessian method T=7

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

Note this makes the Offset method 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 $N \pm \sqrt{2N}$, where N is the number of degrees of freedom. For the ZEUS-S global fit $\sqrt{2N}$=50.

Using ZEUS data alone - consistency of data sets - mimimizes difference between Hessian and Offset method errors – study indicates T ~ 2 (and most of it is norms.)