HERA@LHC workshop OCT 12th 2004

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1. Comparison of OFFSET and HESSIAN methods for ZEUS data alone.
2. Comparison of ZEUS/H1 public analyses
3. ZEUS/H1 comparison using the SAME analysis
4. Compare using ZEUS+H1 xsecn data to using ZEUS xsecn +ZEUS JETS data
5. Comparison of ZEUS PDF predictions with D0/CDF JET data
6. Further work by Kunihiro Nagano

With thanks to Claire Gwenlan and
all the ZEUS fitting team

1. Comparison of OFFSET and HESSIAN methods

Brief reminder on methods of PDF error estimation

Experimental systematic errors are correlated between data points, so

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

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

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 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

A2

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

Slide 3

A2 Cooper-Sarkar, 15/03/2004

HESSIAN method (smart way- CTEQ hep-ph/0

- **Allow s_λ parameters to vary for the central fit**

1. **The total covariance matrix is then the inverse of a single Hessian matrix expressing the variation of $\chi2$ wrt both theoretical and systematic uncertainty parameters.**

2. **If we believe the theory why not let it calibrate the detector(s)? Effectively the theoretical prediction is not fitted to the central values of published experimental data, but allows these data points to move collectively according to their correlated systematic uncertainties**

3. **The fit determines the optimal settings for correlated systematic shifts such that the most consistent fit to all data sets is obtained. In a global fit the systematic uncertainties of one experiment will correlate to those of another through the fit**

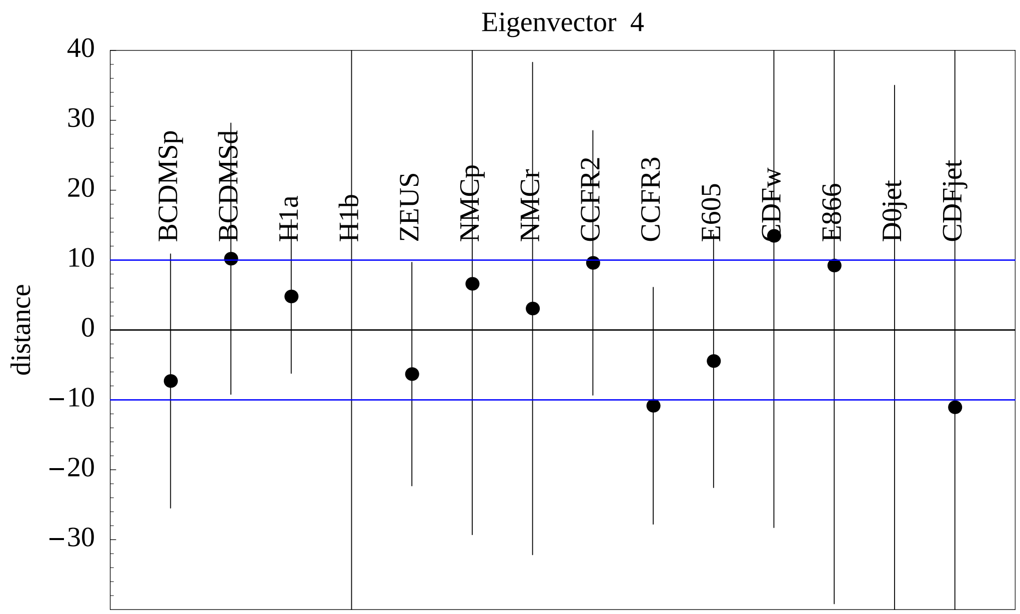
4. **We must be very confident of the theory to trust it for calibration– but more dubiously we must be very confident of the model choices we made in setting boundary conditions to the theory**

CTEQ suggest a modification of the $\chi 2$ tolerance, $\Delta\chi 2 = 1$, with which errors are evaluated such that $\Delta\chi 2 = T^2$, $T = 10$.

Why? Pragmatism

All of the world's data sets must be considered acceptable and compatible at some level, even if strict statistical criteria are not met, since the conditions for the application of strict statistical criteria, namely Gaussian error distributions are also not met.

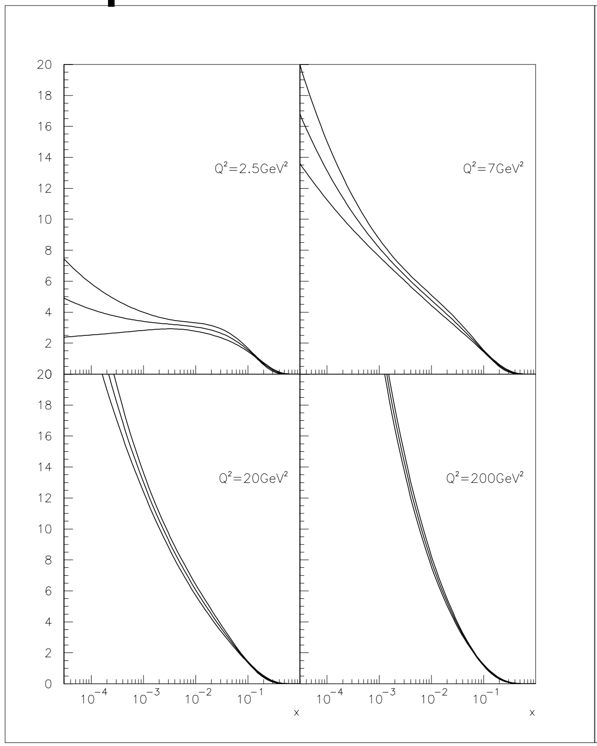
One does not wish to lose constraints on the PDFs by dropping data sets, but the level of inconsistency between data sets must be reflected in the uncertainties on the PDFs.



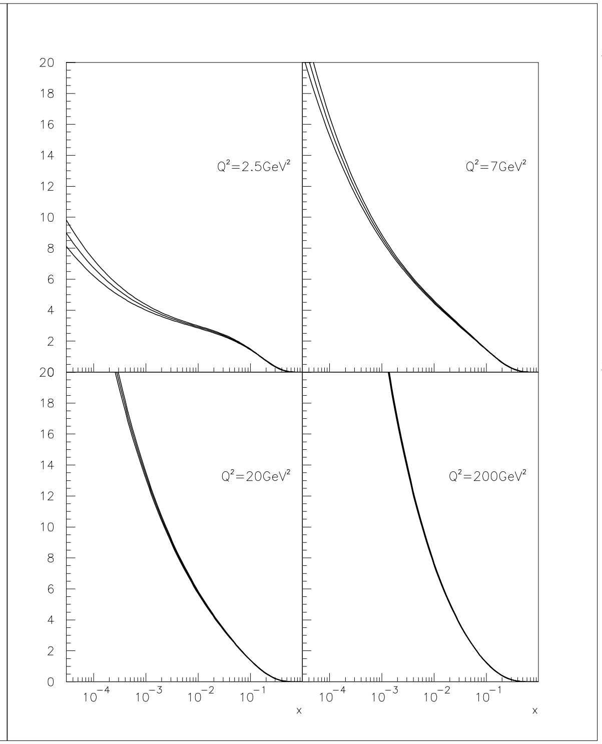
The size of the tolerance T is set by considering the distances from the $\chi 2$ minima of individual data sets from the global minimum for all the parameters of the fit.

MRST have also set larger tolerances (T=5) in recent fits.

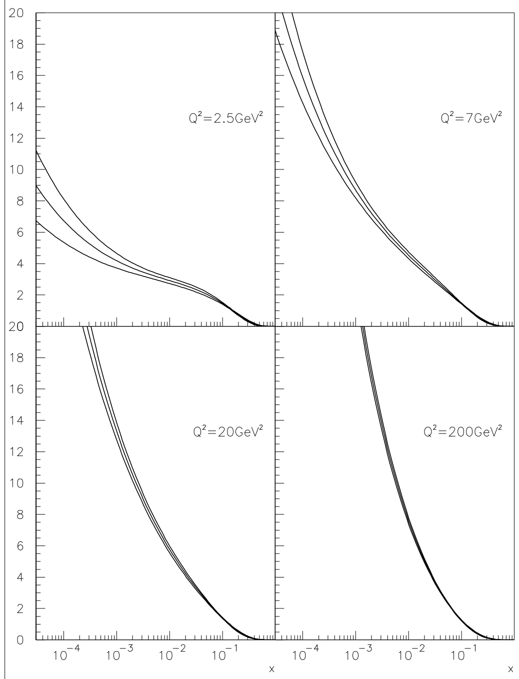
Compare PDFs for Hessian and Offset methods for the ZEUS-global fit analysis



Offset method



Hessian method T=1



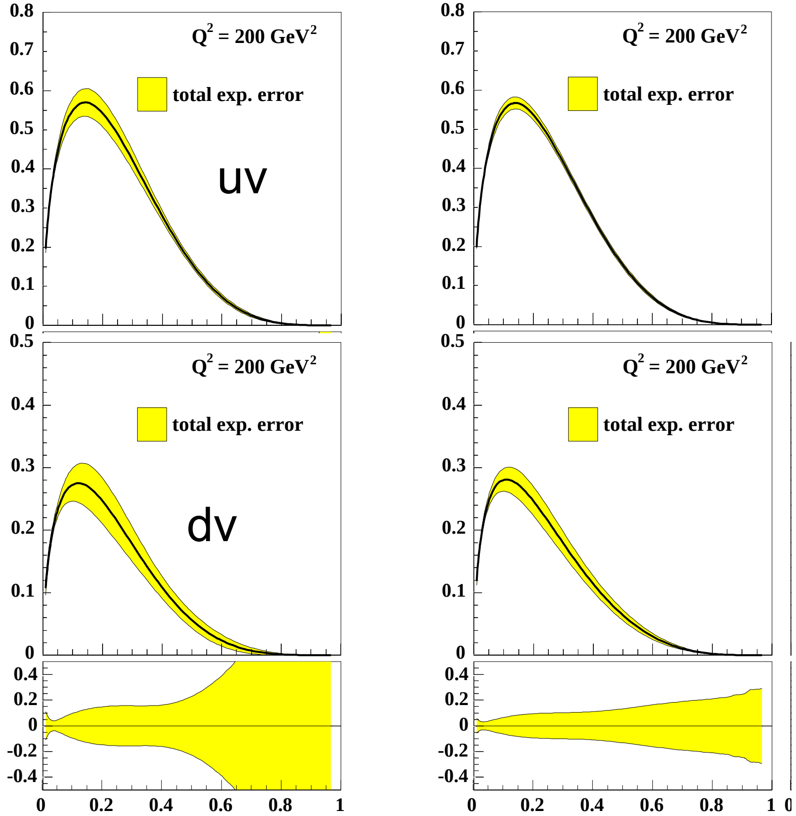
Hessian method T=7

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)

To do better investigate the possibility of using ZEUS data alone..

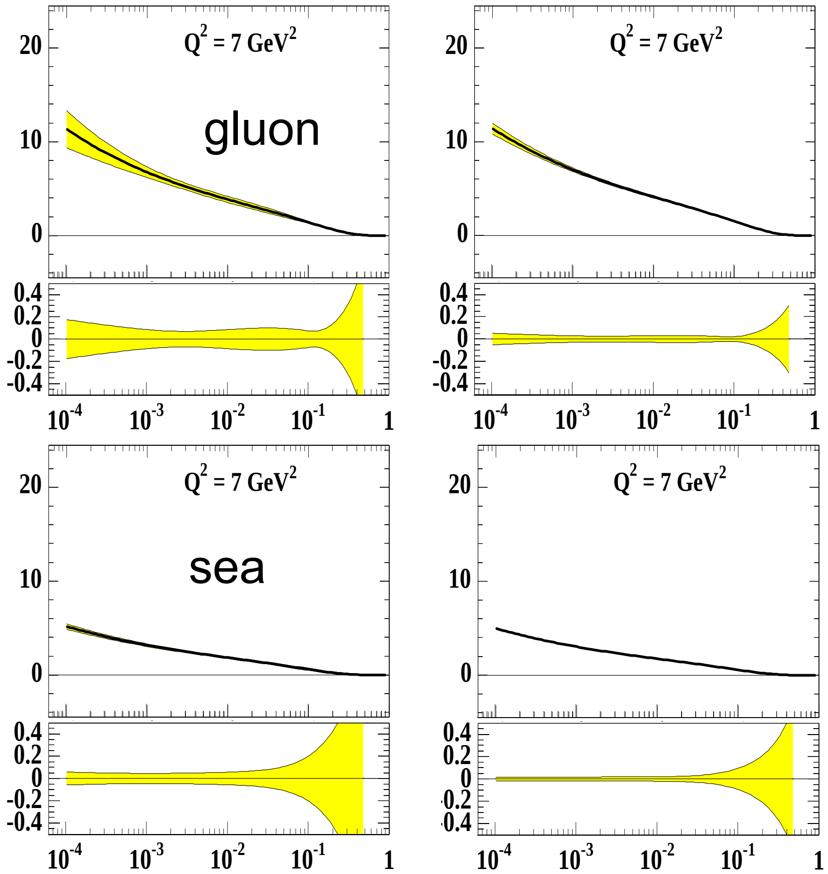
I have done this for the ZEUS-Only 2004 fit……

But the result is not simply encapsulated in a single number for a raised tolerance



Offset method   Hessian method T=1

For the valence distributions the Hessian method gives comparable size of error band as the Offset method, when the tolerance is raised to T ~ 1→ 3, but it depends on x



Offset method   Hessian method T=1

For the gluon and sea distributions the Hessian method still gives a comparable size of error band as the Offset method, when the tolerance is raised to T ~ 7

It depends on the relative size of systematic and statistical error in the data samples which most directly determine the PDF

Now use ALL inclusive cross-section data from HERA-I 112 pb^{-1}

	point to point correlated errors:	normalizations:	data pts
96/97 e+p NC 30 pb^{-1} 2.7 < Q2 < 30000 GeV^2	10	2	242
94-97 e+p CC 33 pb^{-1} 280. < Q2 < 30000 GeV^2	3		26
98/99 e-p NC 16 pb^{-1} 200 < Q2 < 30000 GeV^2	6	1	90
98/99 e-p CC 16 pb^{-1} 200 < Q2 < 30000 GeV^2	3		29
99/00 e+p NC 63 pb^{-1} 200 < Q2 < 30000 GeV^2	8	1	92
99/00 e+p CC 61 pb^{-1} 200 < Q2 < 30000 GeV^2	3		30

The large NC 96/97 sample has correlated systematic errors ~ 3 times larger than statistical errors at low-x → low-x gluon and sea PDFs

The high-Q2 CC samples have larger statistical errors at mid/high-x →mid-x valence PDFs

The interplay of these samples in a PDF fit is complicated

2. Comparison of ZEUS/H1 public analyses

Both ZEUS (2004) and H1 (2003) now make PDF fits to their own data. Where does the information come from in a HERA only fit compared to a global fit ?

	Global	HERA Only
Valence	Predominantly fixed target data (ν-Fe and $\mu D/\mu p$)	High Q^2 NC/CC $e^{\pm}$ cross sections
Sea	Low-x from NC DIS High-x from fixed target Flavour from fixed target	Low-x from NC DIS High-x less precise Flavour ?(need assumptions
Gluon	Low-x from HERA $dF_2/d\ln Q^2$ High-x from momentum sum	Low-x from HERA $dF_2/d\ln Q^2$ High-x from momentum sum

Mostly uv → (Global, Valence: Predominantly fixed target data)

some dv → (HERA Only, Valence: High Q^2 NC/CC $e^{\pm}$ cross sections)

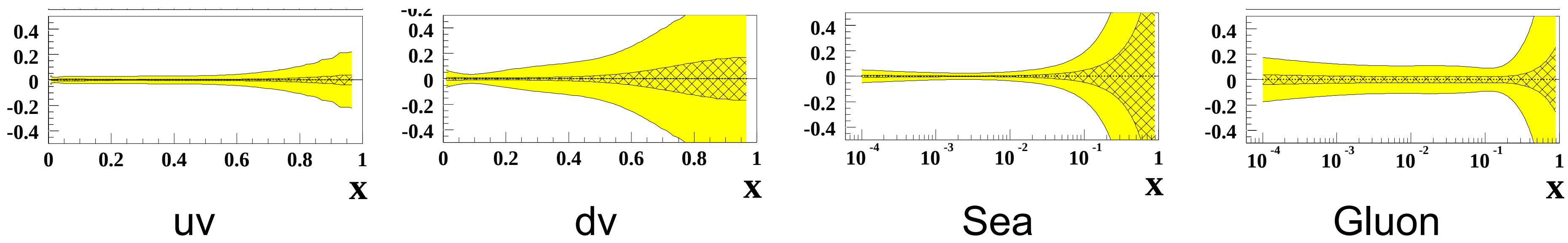
Tevatron jet data? → (Global, Gluon: High-x from momentum sum)

HERA jet data? → (HERA Only, Gluon: High-x from momentum sum)

ANALYSES FROM HERA ONLY …

- Systematics well understood
  - measurements from our own experiments !!!
- No complications from heavy target Fe or D corrections

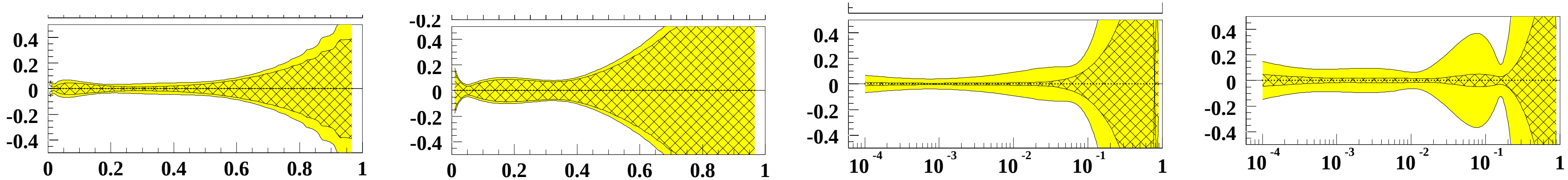
Compare the uncertainties for uv, dv, Sea and glue in a global fit



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 HERA 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 HERA highQ2 data not by fixed target data and precision is comparable- particularly for dv

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

ZEUS PDF 2004 Analysis- OFFSET method used for error estimates

Consider the form of the parametrization at Q^2_0

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

These parameters control the low-x shape

These parameters control the high-x shape

These parameters control the middling-x shape

No χ2 advantage in more terms in the polynomial

No sensitivity to shape of $\Delta = \bar{d} - \bar{u}$
$A\Delta$ fixed consistent with Gottfried sum-rule - shape from E866

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

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

au=ad=av for low-x valence since there is little information to distinguish

→ 12 parameters for the PDF fit

Now consider the high-x Sea and gluon

High-x sea is constrained by simplifying form of parametrization - $c_s=0$ → 11 param

High-x gluon is constrained by adding ZEUS JET data

H1 2003 PDF analysis – HESSIAN method used for error estimates with T=1 (called H1 PDF 2000)

Consider the form of the parametrization at Q^2_0

10 free parameters:

$$xU(x)=A_U x^{b_U}(1-x)^{c_U}(1+e_U x+g_U x^3)$$
$$xD(x)=A_D x^{b_D}(1-x)^{c_D}(1+e_D x)$$
$$x\bar{U}(x)=A_{\bar{U}} x^{b_{\bar{U}}}(1-x)^{c_{\bar{U}}}$$
$$x\bar{D}(x)=A_{\bar{D}} x^{b_{\bar{D}}}(1-x)^{c_{\bar{D}}}$$
$$xg(x)=A_g x^{b_g}(1-x)^{c_g}(1+e_g x)$$

No χ2 advantage in more terms in the polynomial

This looks like 19 parameters BUT

$A_U=A_{\bar{U}}$, $b_U=b_{\bar{U}}$, $A_D=A_{\bar{D}}$, $b_D=b_{\bar{D}} \rightarrow 15$

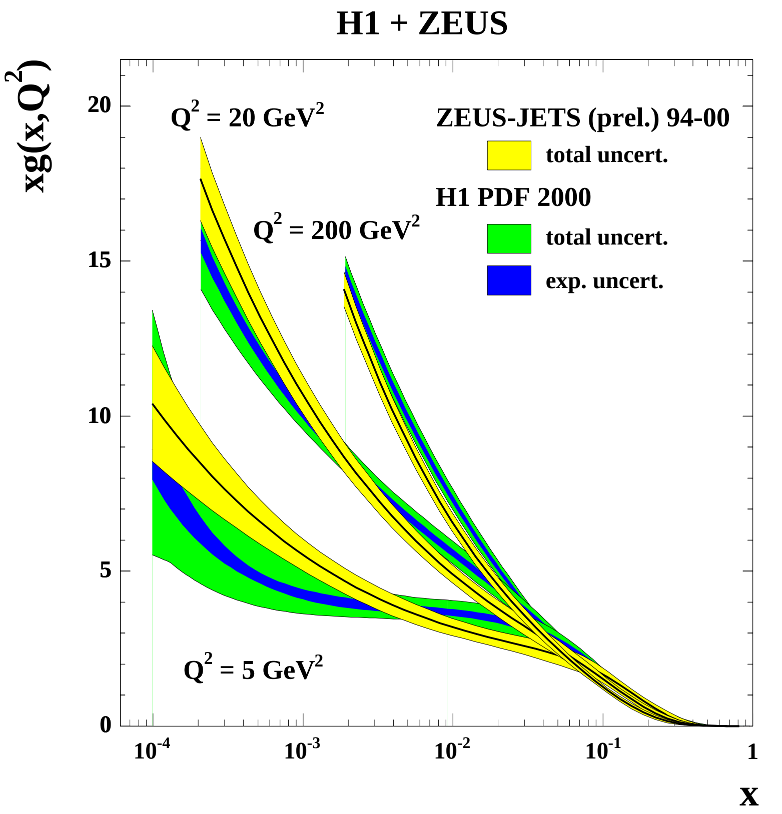
so that U and $\bar{U}$ (and D and $\bar{D}$) are equal as $x \rightarrow 0$ $\rightarrow$strong constraint on shape of low-x valence, where there's little data

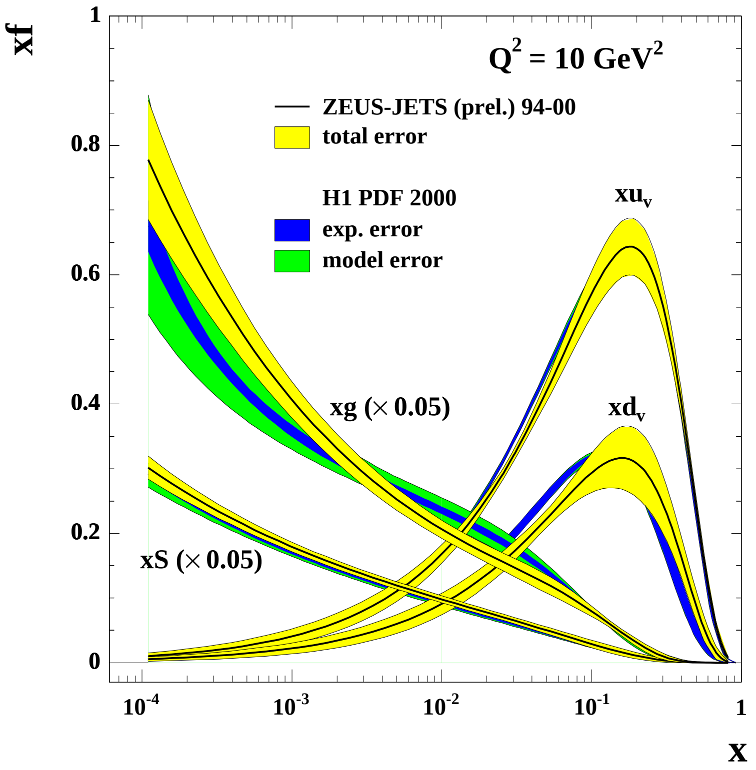
and $b_{\bar{U}}=b_{\bar{D}} \rightarrow 14$, since there's no information on the difference of $\bar{U}$ and $\bar{D}$

Then the valence number sum rules and the momentum sum rule determine A_g, A_U, A_D $\rightarrow$ 11 $\rightarrow$also constrains sea A's

Finally $A_{\bar{U}}=A_{\bar{D}}(1-f_s)/(1-f_c) \rightarrow 10$, constrains the amount of U and D in the sea, fs=0.33, fc=0.15

Comparison of ZEUS 2004 and H1 2003 analyses



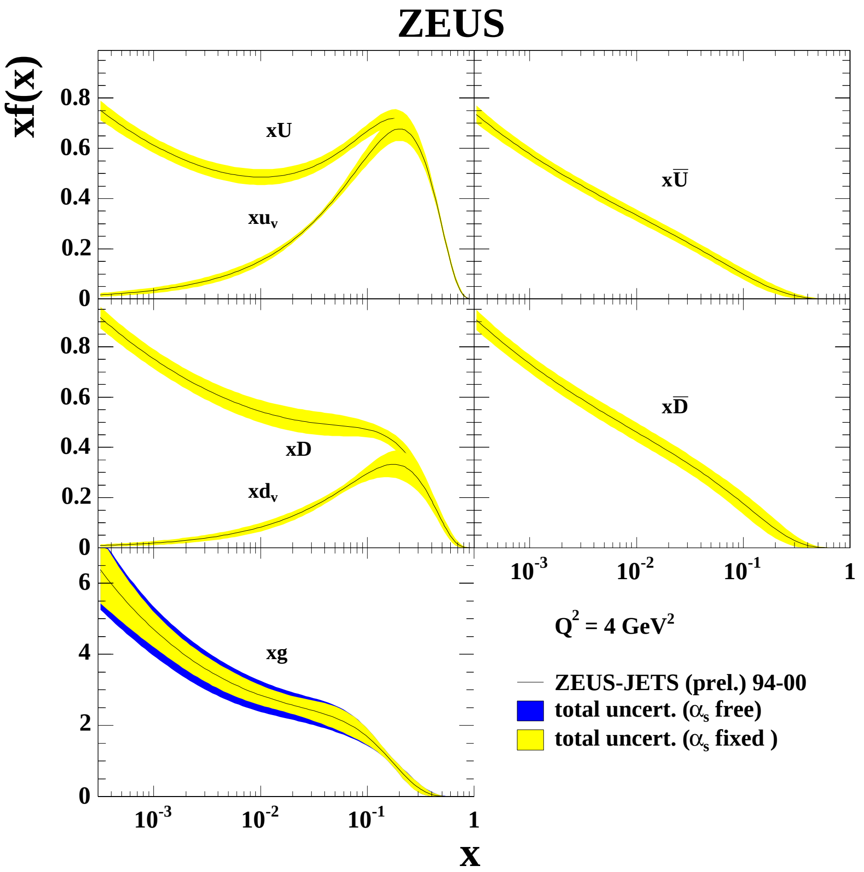


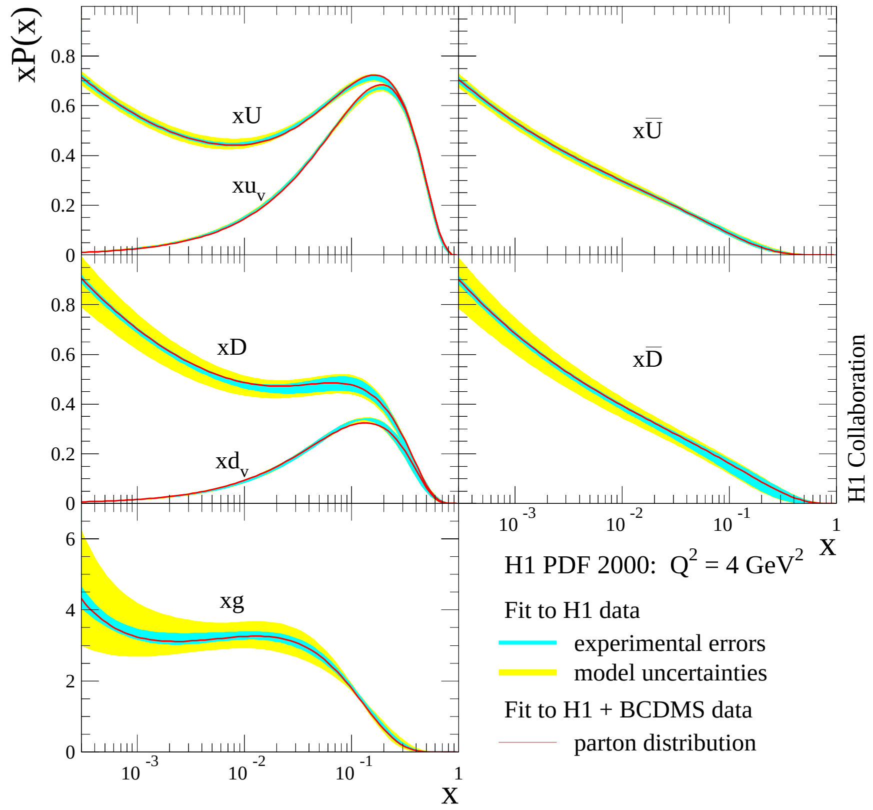
Both collaborations include model errors – variations on assumptions at $Q^2{}_0$. These are large compared to the HESSIAN exp. errors of H1, and small compared to the OFFSET exp. errors of ZEUS. Comparison with model errors included gives similar size of errors

But valence PDFs cannot really be compared this way because H1 do not fit in terms of valence PDFs and model errors cannot be easily evaluated- recall that the H1 parametrization puts a strong constraint on the shape of the valence PDF

ZEUS-JETS 2004

H1 2003





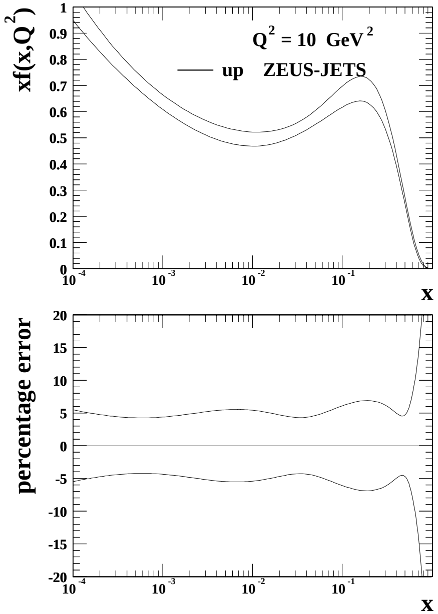
Instead compare interms of U= u+c=u_v+u_{sea}+c, D=d+s(+b)=d_v+d_{sea}+s(+b) and the corresponding Ubar Dbar distributions

Note that in these comparisons model uncertainty is also included

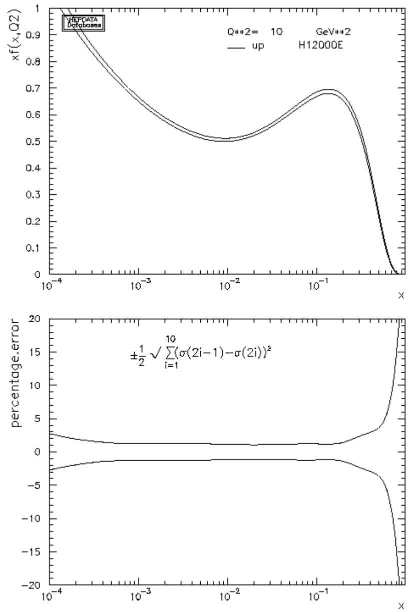
Compare HERA PDFs to CTEQ using Durham data base

u = uv+usea

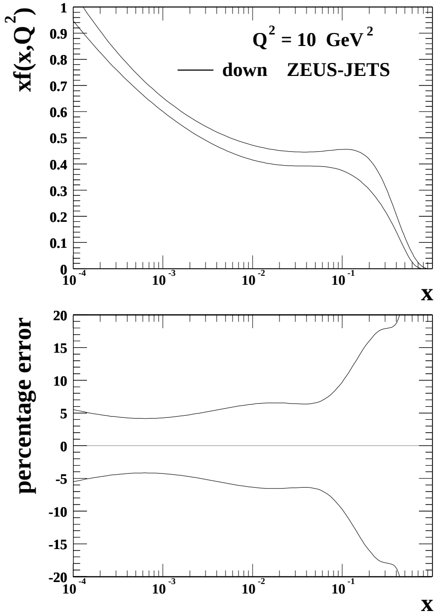
d = dv+dsea



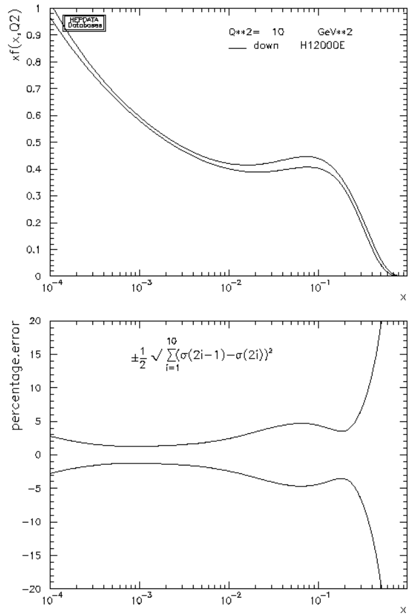
ZEUS-JETS



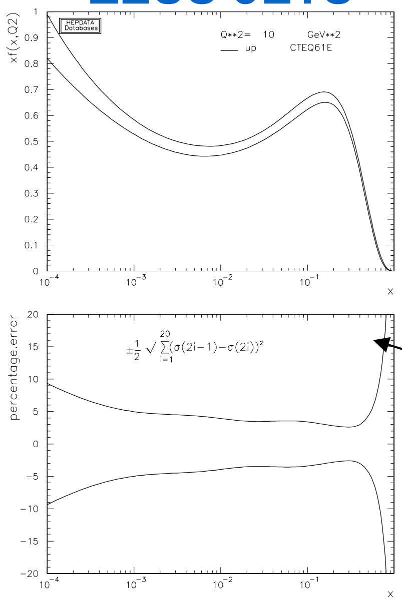
H1 2003



ZEUS-JETS



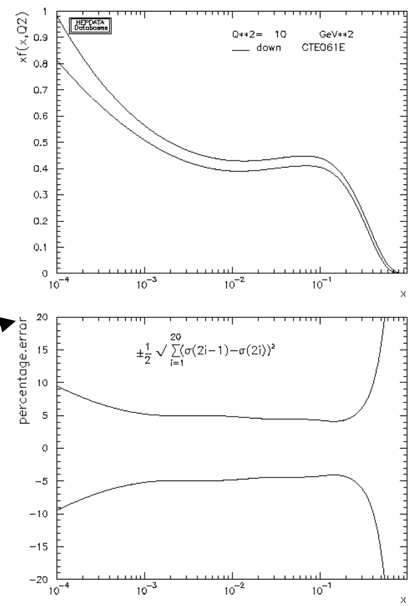
H1 2003



Smaller H1 errors due to use of the Hessian method with T=1 AND due to strong constraints on the low-x parametrization (no model dependence here)

Compare also CTEQ6.1

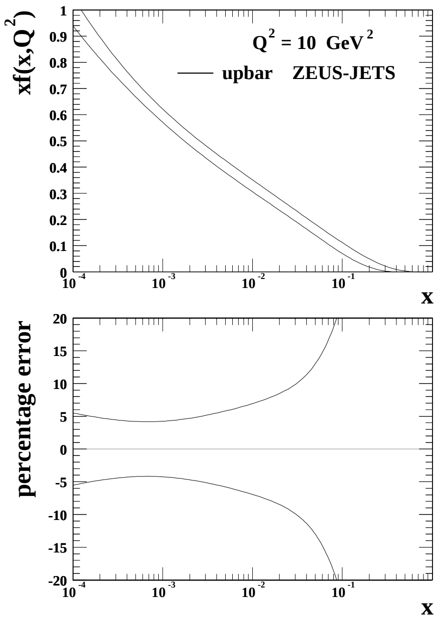
Global fit, Hessian method T=10



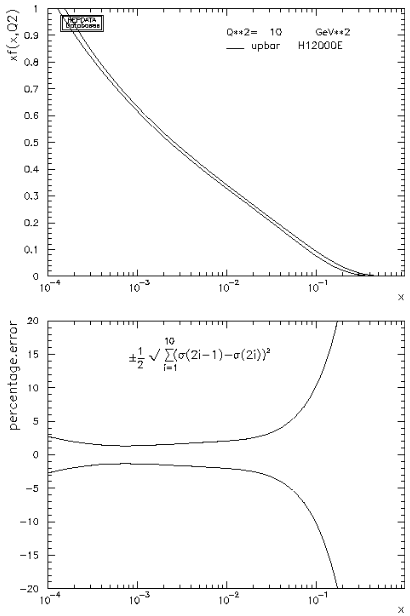
Compare HERA PDFs to CTEQ using Durham data base

u-bar

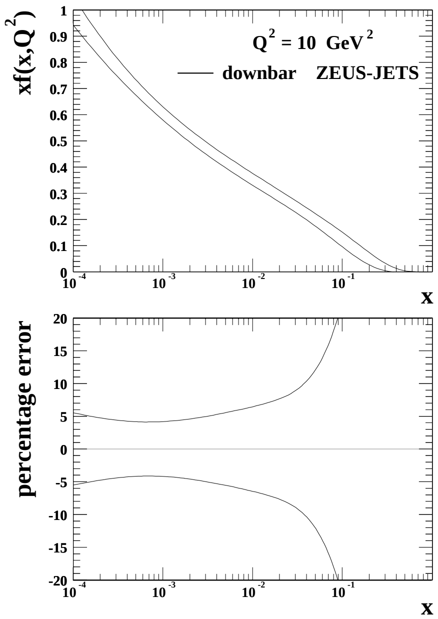
d-bar



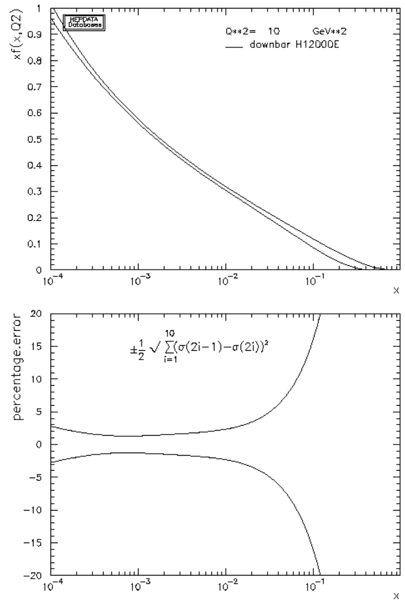
ZEUS-JETS



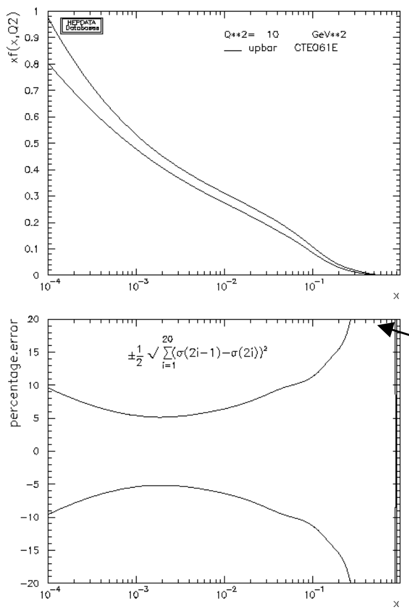
H1 2003



ZEUS-JETS

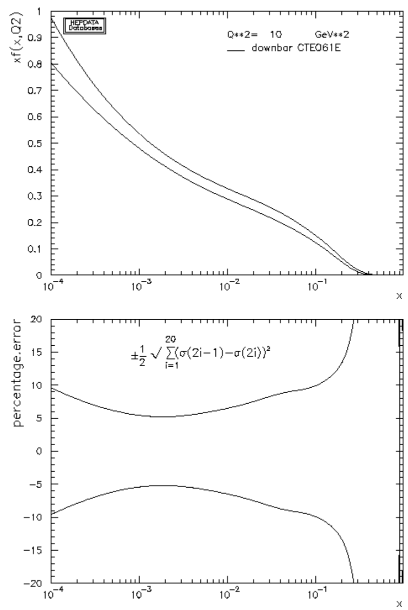


H1 2003

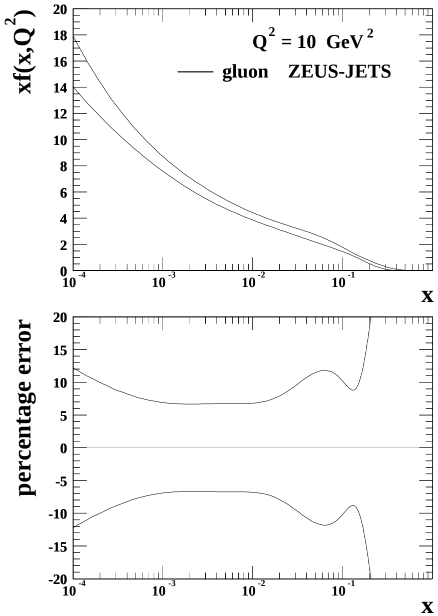


Smaller H1 errors due to use of the Hessian method with T=1 AND due to strong constraints on the low-x parametrization (no model dependence here)

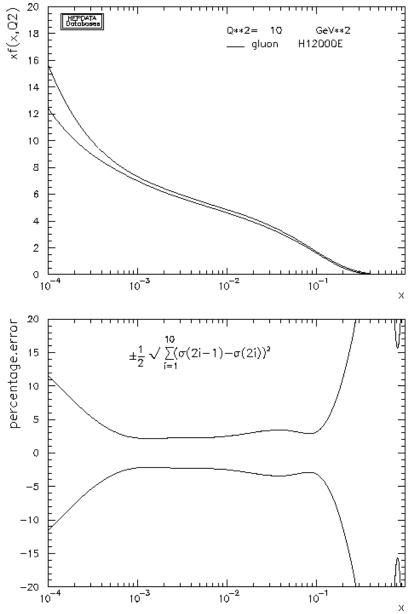
Compare also CTEQ6.1



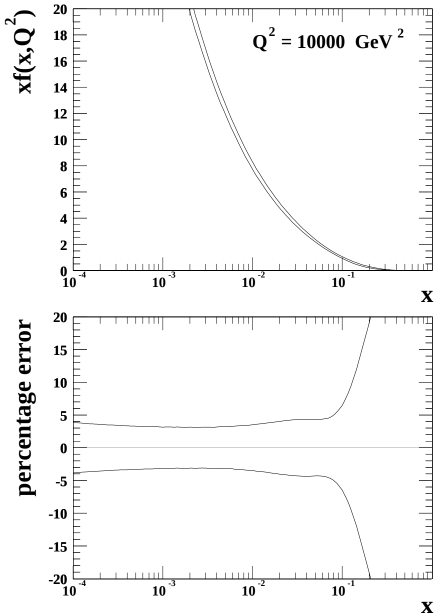
Compare HERA PDFs to CTEQ using Durham data base



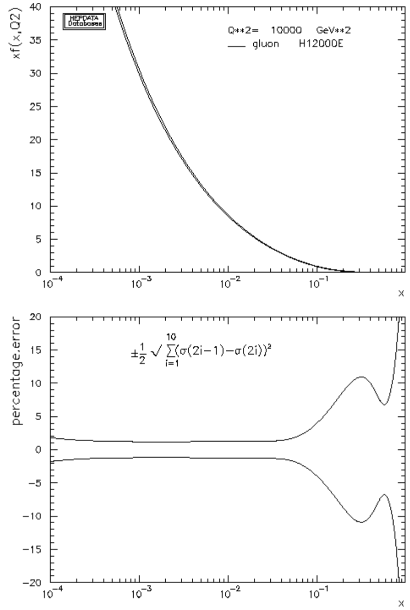
ZEUS-JETS



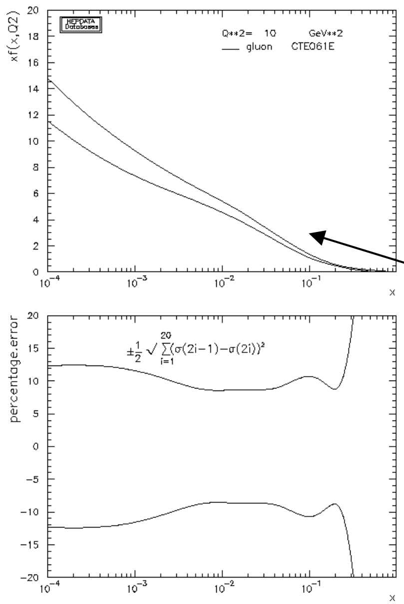
H1 2003



ZEUS-JETS



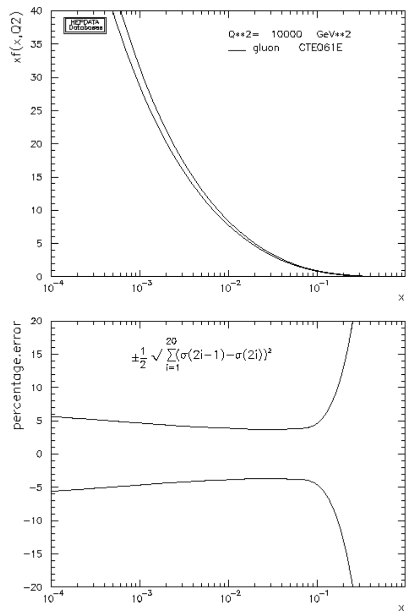
H1 2003



Q2=10 **gluon comparison** Q2=10000

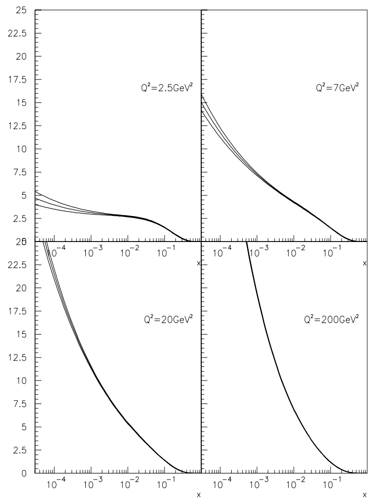
Smaller H1 errors due to use of the Hessian method with T=1 (no model dependence here)

Compare also CTEQ6.1

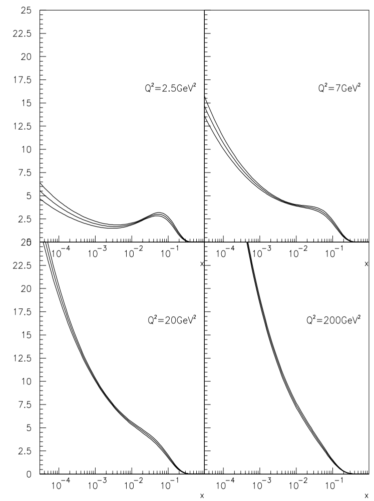


Note that errors decrease as we evolve up in Q2- and shapes become much more similar

3. ZEUS/H1 comparison using the SAME analysis



Zeus-Only



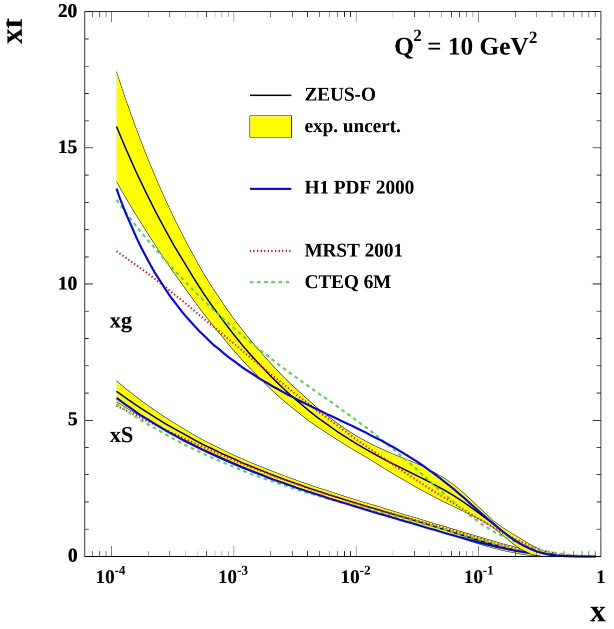
H1-Only

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

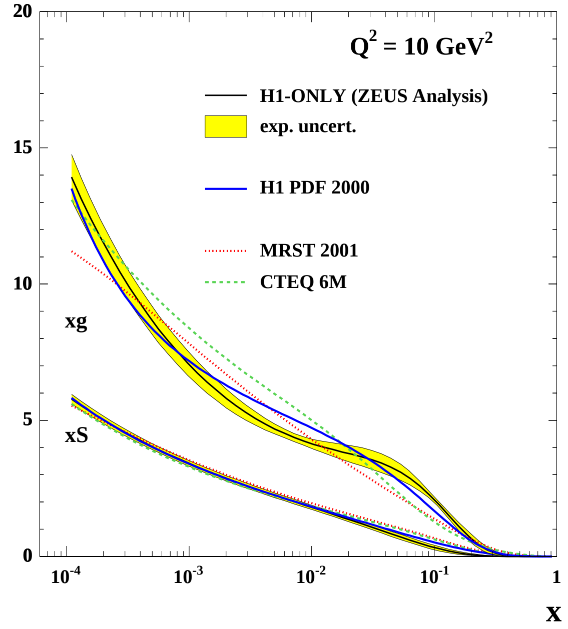
BUT now let's update this old comparison to include all the HERA-I data

Use the ZEUS ONLY 2004 analysis WITHOUT JETS

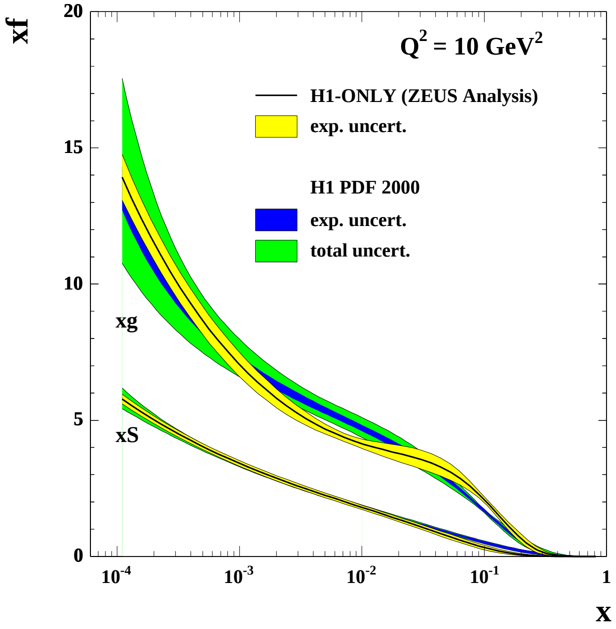
(note exp, error only NO model errors)



ZEUS analysis/ZEUS data



ZEUS analysis/H1 data



ZEUS analysis/H1 data compared to

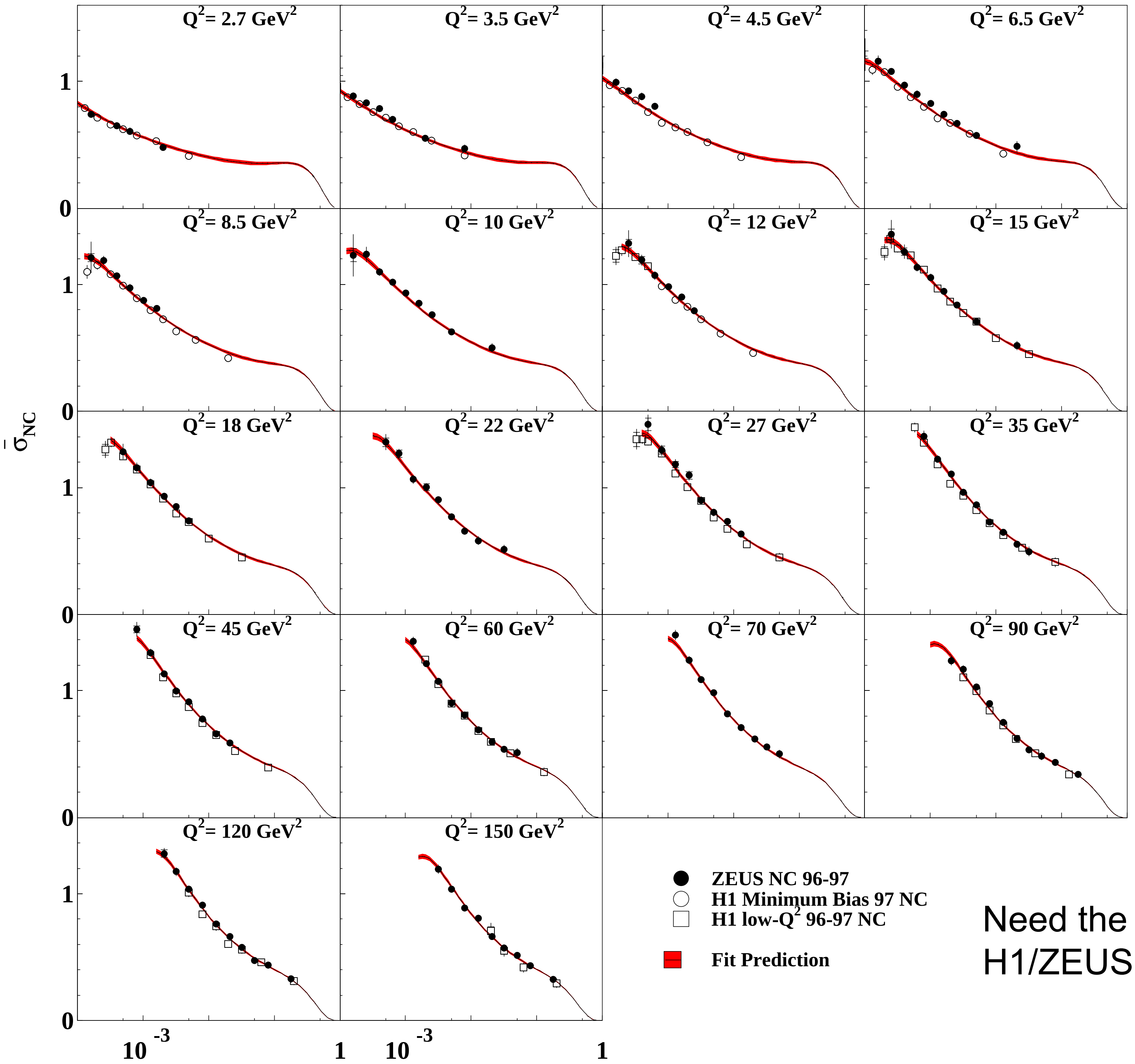
H1 analysis/H1 data

Here we see the effect of differences in the data, recall that the gluon is not directly measured (no jets)

The data differences are most notable in the large 96/97 NC samples at low-Q2 The data are NOT incompatible, but seem to 'pull against each other'

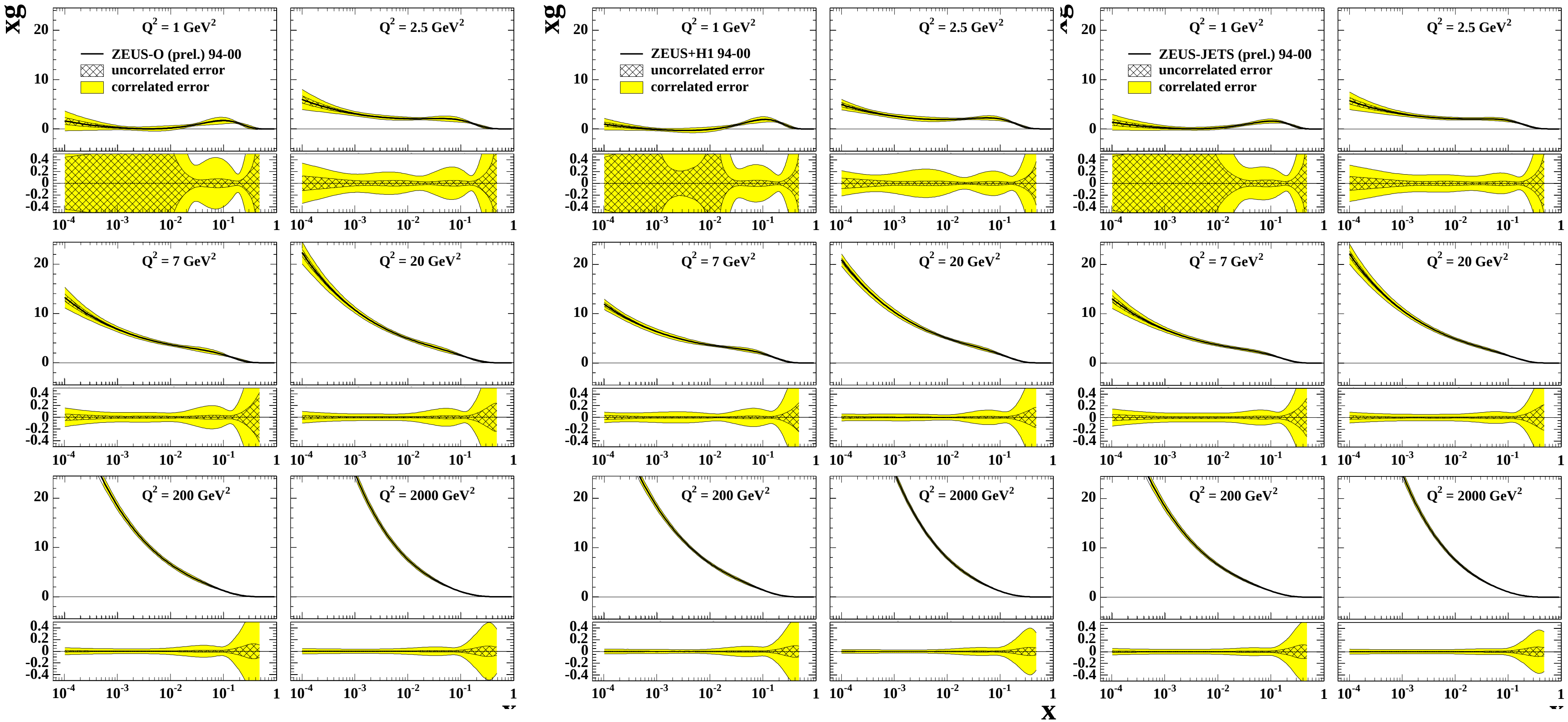
IF a fit is done to ZEUS and H1 together the $\chi2$ for both these data sets rise compared to when they are fitted separately………..

Here we see the effect of differences of analysis choice - form of parametrization at Q2_0 etc



Need the joint
H1/ZEUS data set?

4. Compare the effect of adding H1 data to the ZEUS data in the ZEUS-ONLY 2004 analysis (without jets) to the effect of adding ZEUS JET data



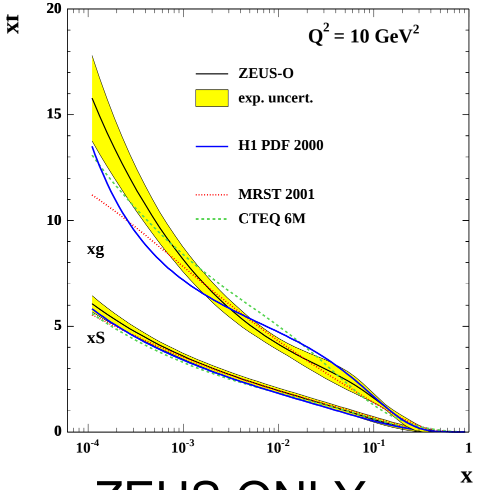
ZEUS ONLY

ZEUS+H1

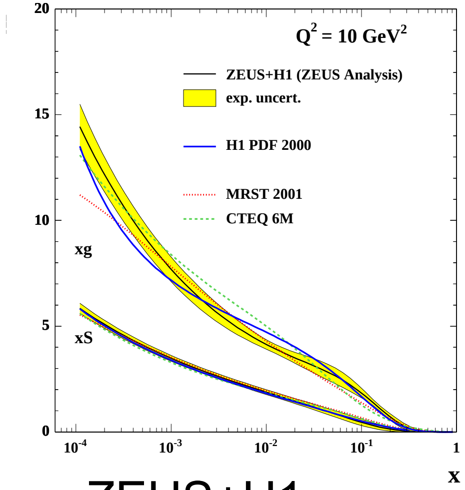
ZEUS_JETS

Adding H1 data does NOT significantly improve errors on the gluon - statistical uncertainty improves - but systematic uncertainty does not -χ2 for each data set increases

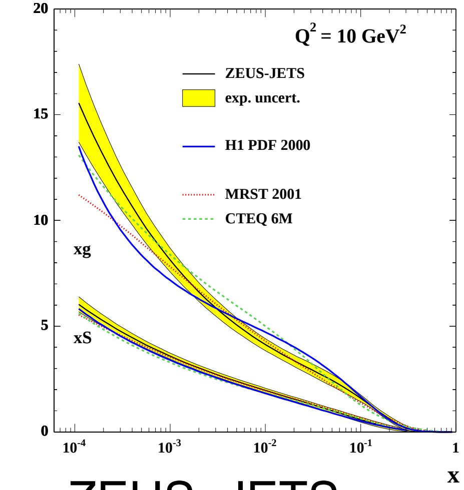
Adding JET data does improve the errors on the gluon – ZEUS JET data is compatible with ZEUS cross-secn data- χ2 for these data does NOT increase



ZEUS ONLY

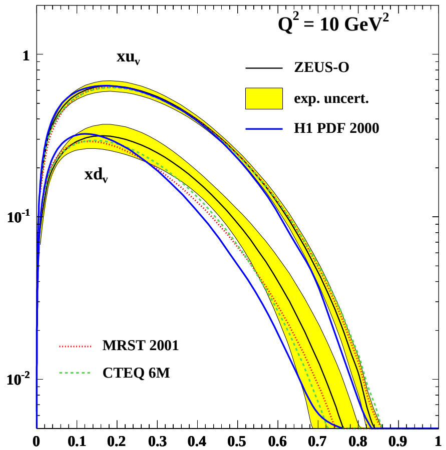


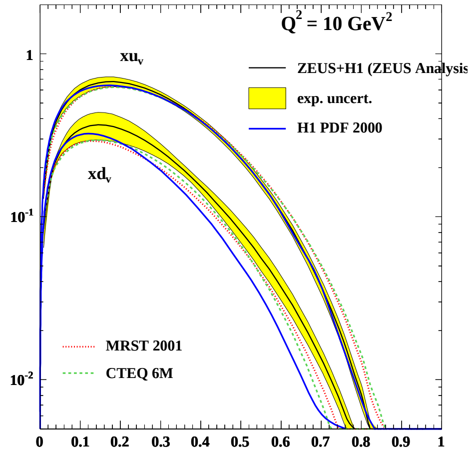
ZEUS+H1

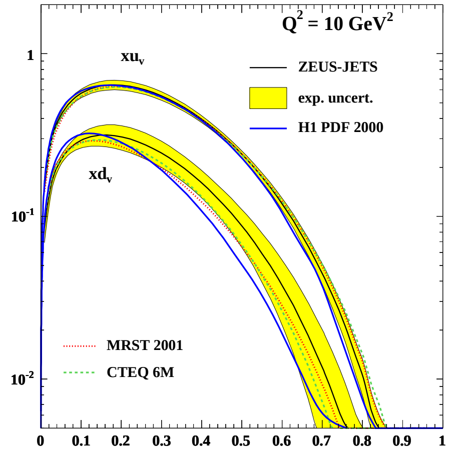


ZEUS_JETS

Whereas adding H1 to ZEUS data brings no significant improvement for the low/mid-x sea and glue determination, where systematic uncertainties already dominate statistical uncertainties, it does bring improvement to the high-x valence distributions where statistical uncertainties dominate

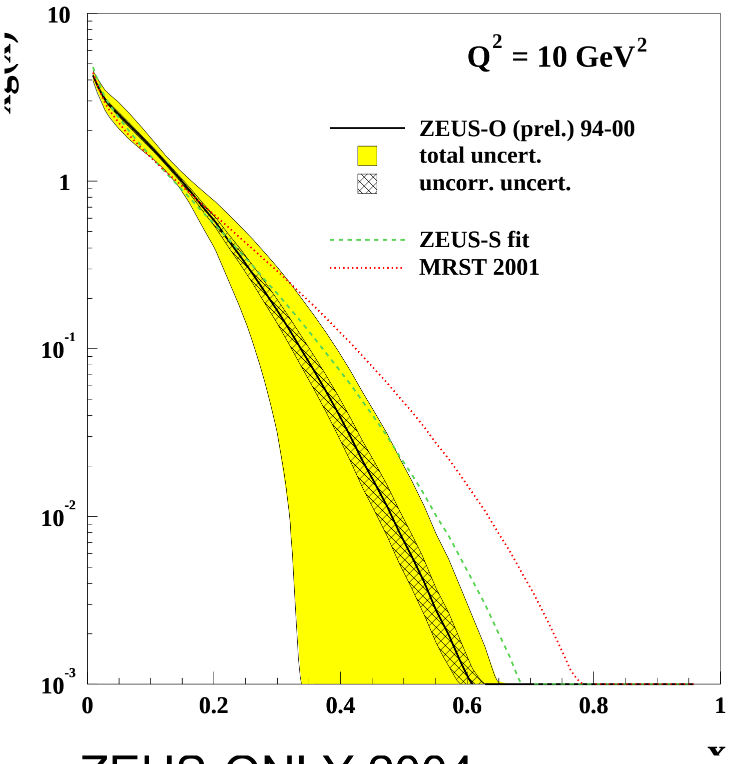




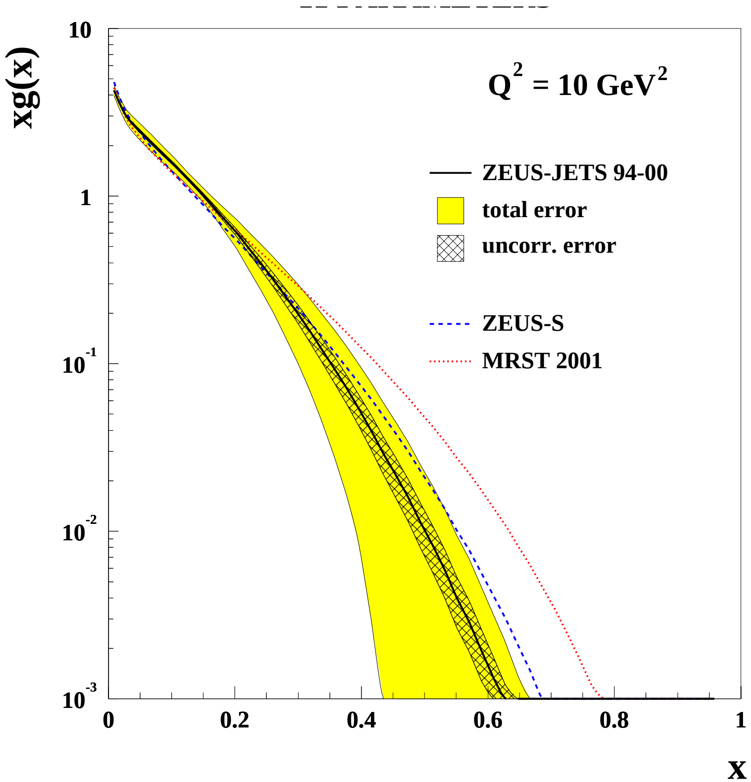


The ZEUS and H1 high-Q2 data are also more compatible –again need the joint H1/ZEUS data set?

5. Comparison of ZEUS PDF predictions with D0/CDF JET data. It can be interesting to look at the gluon very high-x



ZEUS-ONLY 2004
without JETS



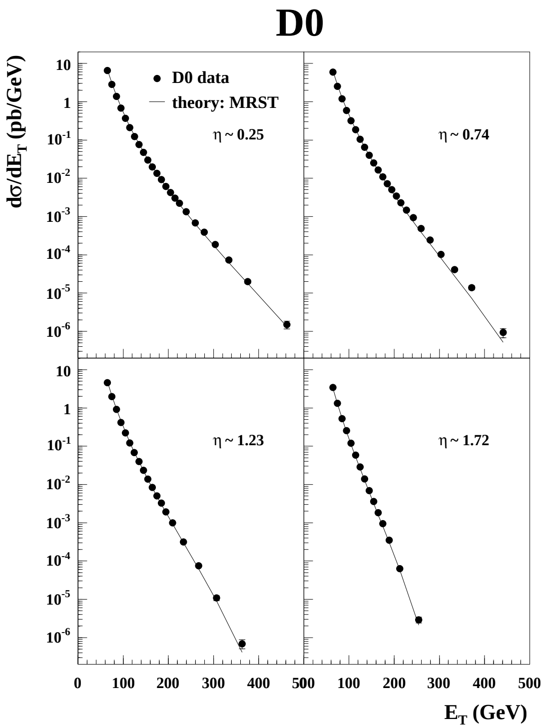
ZEUS-JETS 2004

It has often been suggested that fits to DIS data alone, without input of Tevatron jets data cannot give a hard enough gluon at high-x to fit these data.

I have used the MRST programme to predict inclusive jet differential cross-sections as a function of ET in η bins- for the Tevatron Run-I data.

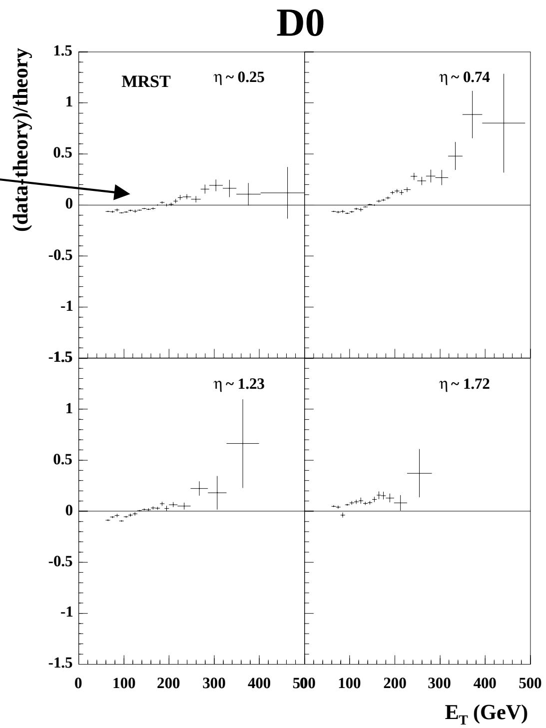
Note the predictions are done as if all the data were at precise values of η and ET, i.e these are not MC calculations which are binned

Can reproduce MRST results - the **χ2** for the **MRST2002** prediction to this data is **85 for 82** D0 data points

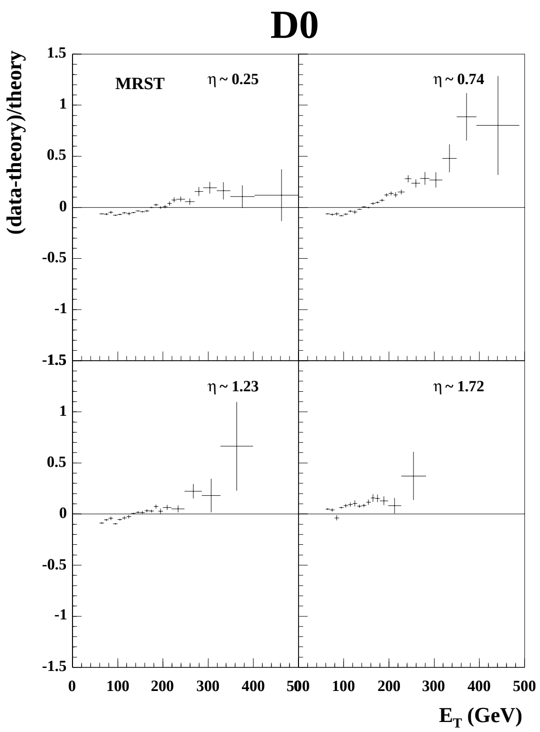


This figure shows (data-theory)/theory

And the lines represent the size of the experimental error



Now use the MRST prediction programme with **ZEUS-S 2002 central PDFs** to compare to these data and the **χ2 is 109 for 82 data points-** not SO much worse than MRST2002



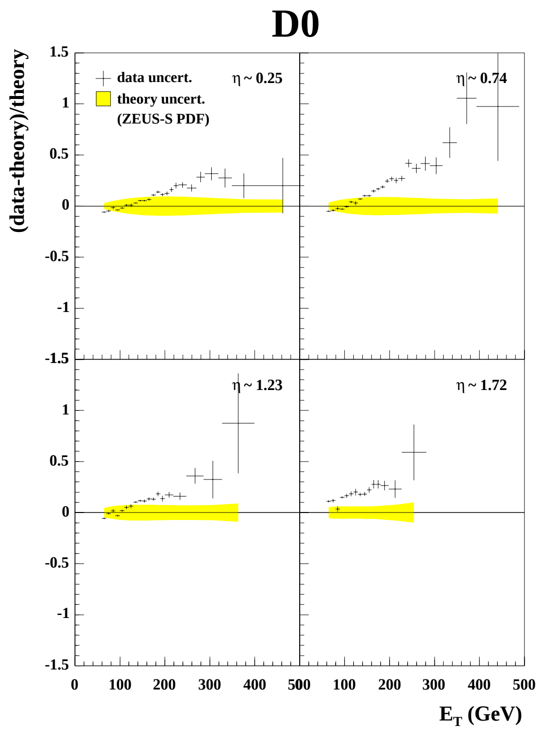
MRST2002

This figure shows (data-theory)/theory

And the error bars represent the size of the experimental error

Whereas the shaded area represents the PDF error- larger than exp. error -except at high ET.

Furthermore the PDF error can be included in the χ2 – in this case we get χ2 =58 for 82 data points



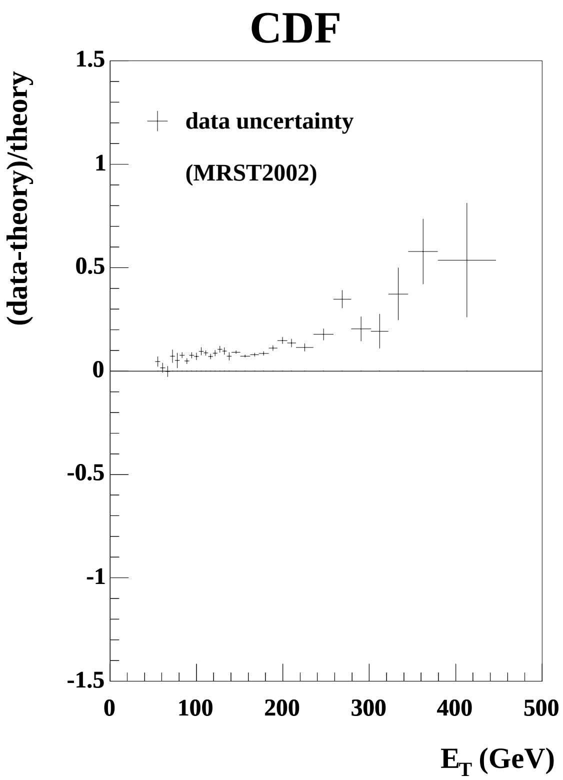
ZEUS-S 2002

I have also made predictions for CDF jet data

-And I obtain **χ2 of 63 for 31** data points for **MRST2002** PDFs

-Whereas I obtain **χ2 of 51 for 31** data points for **ZEUS-S 2002 central PDFs**

I,e we are actually BETTER at predicting CDF jets!



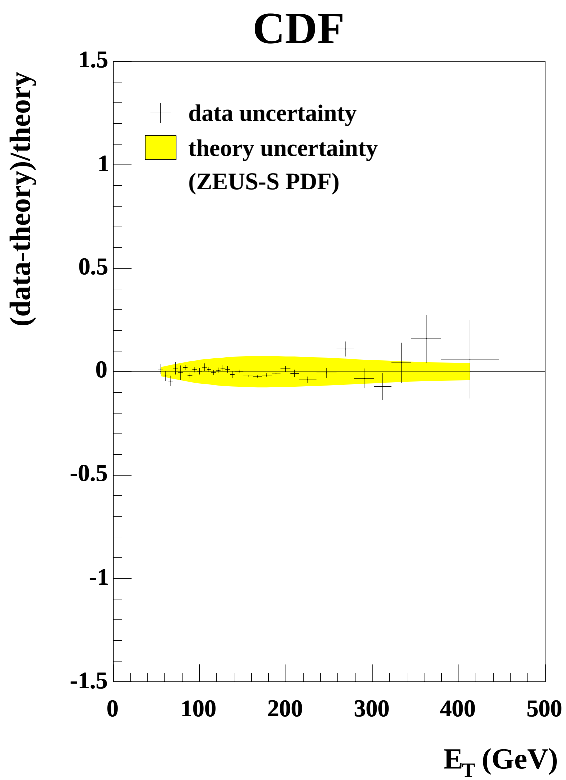
MRST2002

This figure shows (data-theory)/theory

And the error bars represent the size of the experimental error

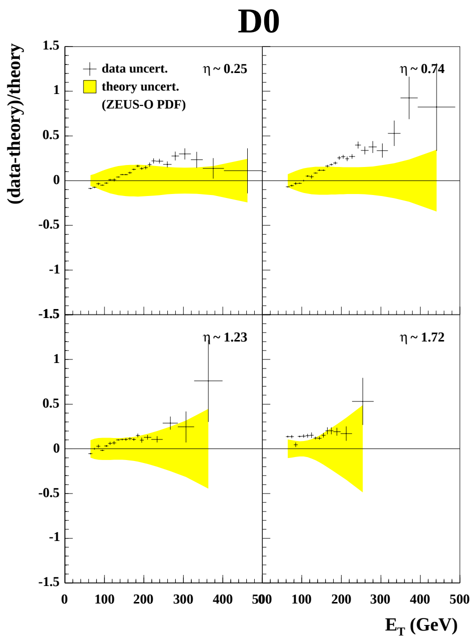
Whereas the shaded area represents the PDF error-larger than exp error until high ET

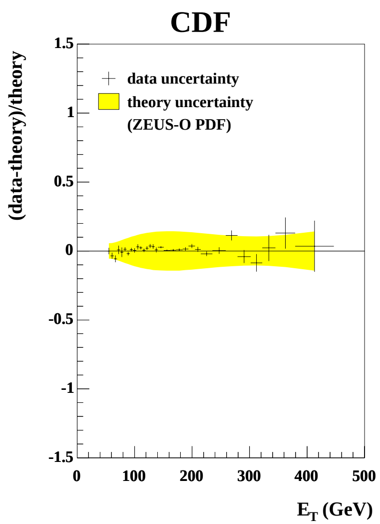
IF the PDF error is included in the χ2 we get χ2 = 13 for 31 d.p.

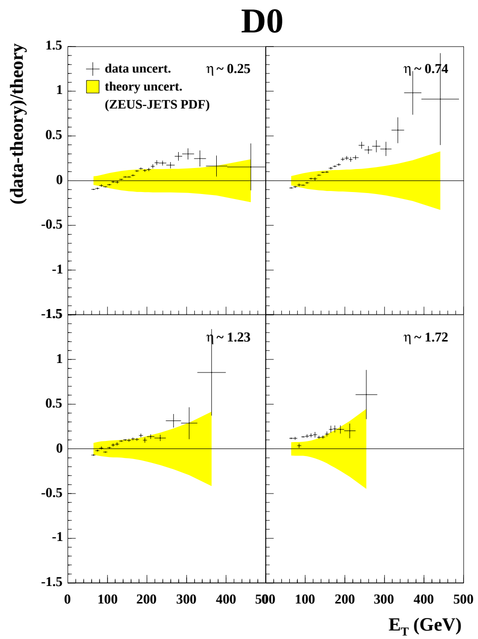


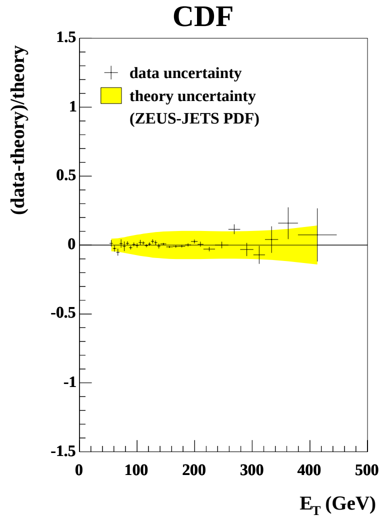
ZEUS-S 2002

We would also like to investigate these things for the ZEUS PDFs 2004 both the ZEUS-ONLY (no jets) PDFs and the ZEUS-JETS PDFS









ZEUS-ONLY nojets $\chi2$=122 for central PDF $\chi2$=26 if PDF error accounted

ZEUS-ONLY nojets $\chi2$=49 for central PDF $\chi2$=8 if PDF error accounted

ZEUS-JETS $\chi2$=118 for central PDF $\chi2$=34 if PDF error accounted

ZEUS-JETS $\chi2$=49 for central PDF $\chi2$=10 if PDF error accounted

So one cannot say that ZEUS PDFS do not agree with Tevatron jet data

BUT putting such data into the fit could improve the knowledge of the high-x gluon

Why do I say the high-x gluon and not any other PDF?

Because there is more that one can do:-

Instead of adding up the errors for all the eigenvector PDF sets to get a new χ2 including PDF error, one can look at each of these PDFs in turn to see which one(s) give the greatest improvement (change) in χ2 (e.g. CTEQ do this for their PDFs in hep-ph/0303013**)**

e.g. for D0 data – 82 data points

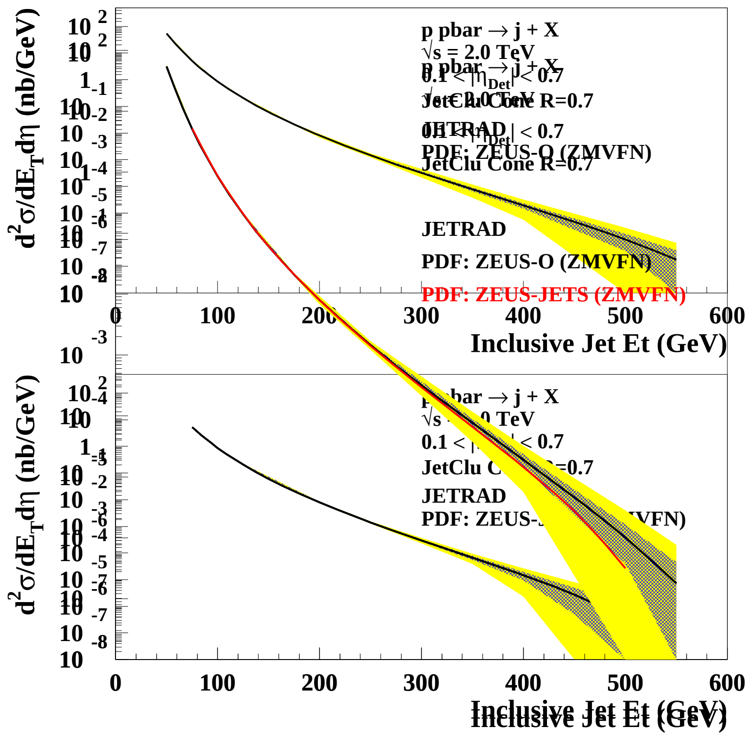
For the ZEUS-S 2002 PDF sets **the greatest change happens along the 9th eigenvector:** the **χ2 changes from 89.5 to 123.8 (central value 109)** as we move up and down this eigenvector. **This is the eigenvector which is dominated by the high-x gluon power $(1-x)^{bg}$.**

For the ZEUS-JETS eigenvector PDF sets: **the greatest changes in χ2 are 87 to 156** (central value 121) **for the 11th eigenvector**, which relates to the **(1+γg.x) term in the gluon parametrisation**

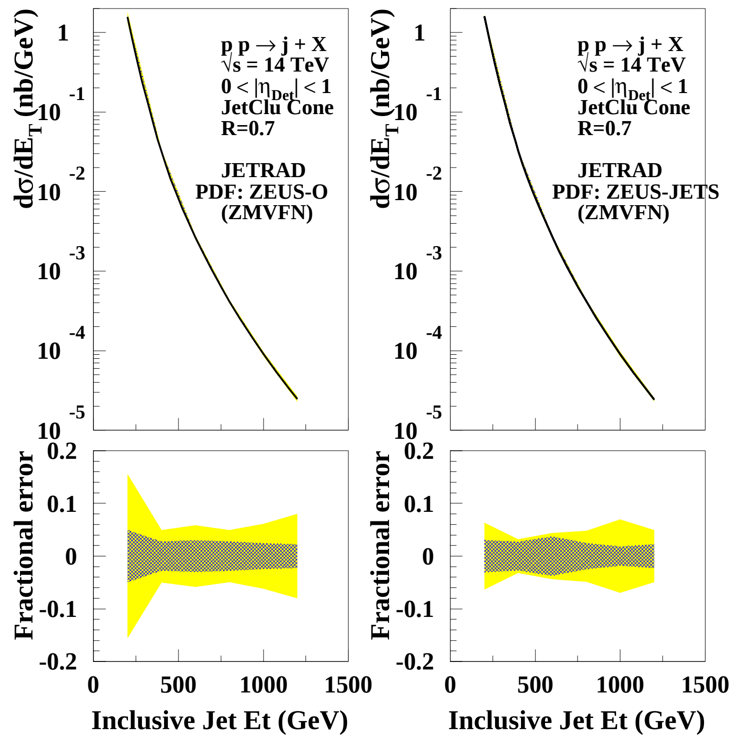
Summary and Conclusions

1. Comparison of OFFSET and HESSIAN methods for ZEUS data alone- OFFSET method always gives larger errors. How much larger depends on relative size of systematic and statistical uncertainties on data.
2. Comparison of ZEUS/H1 public analyses – 'disagreement' in the shape of the gluon, but also very different PDF uncertainty estimates –always use model error
3. ZEUS/H1 comparison using the SAME analysis- gluon shapes remain different even when same analysis is used
4. Compare using ZEUS+H1 xsecn data to using ZEUS xsecn +ZEUS JETS data – marginal compatibility of ZEUS/H1 96/97 NC data sets means that there is less improvement in combining the data-sets than one might hope for! Need to combine with compatible data (like ZEUS JETS). But ZEUS+H1 data still important to improve statistics at high-x (see Glazov)
5. Comparison of ZEUS PDF predictions with D0/CDF JET data- ZEUS PDFs are compatible with Tevatron jet data
6. Further work by Kunihiro Nagano

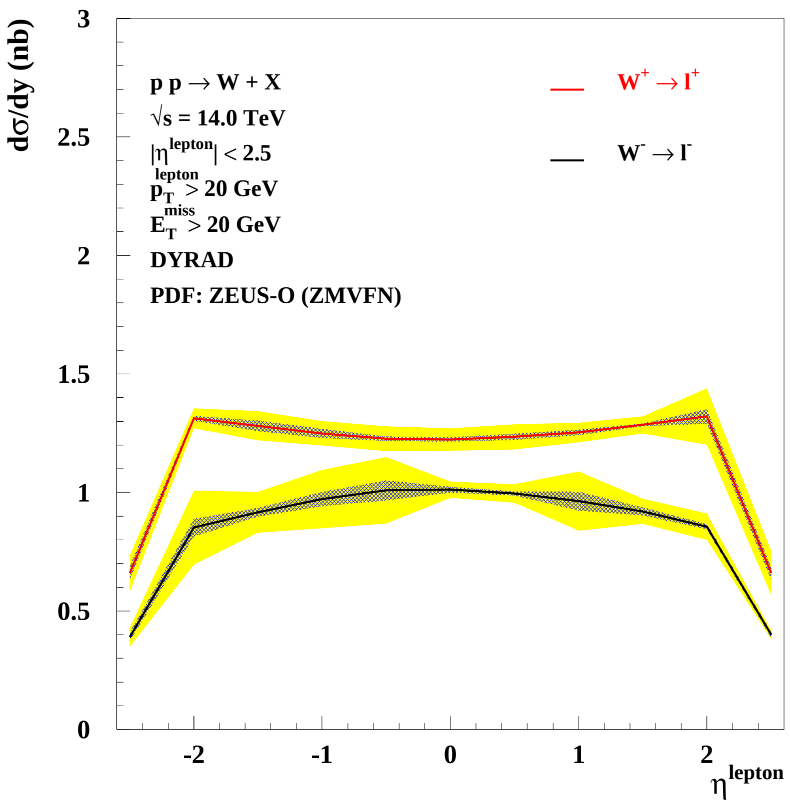
Further work by Kunihiro Nagano

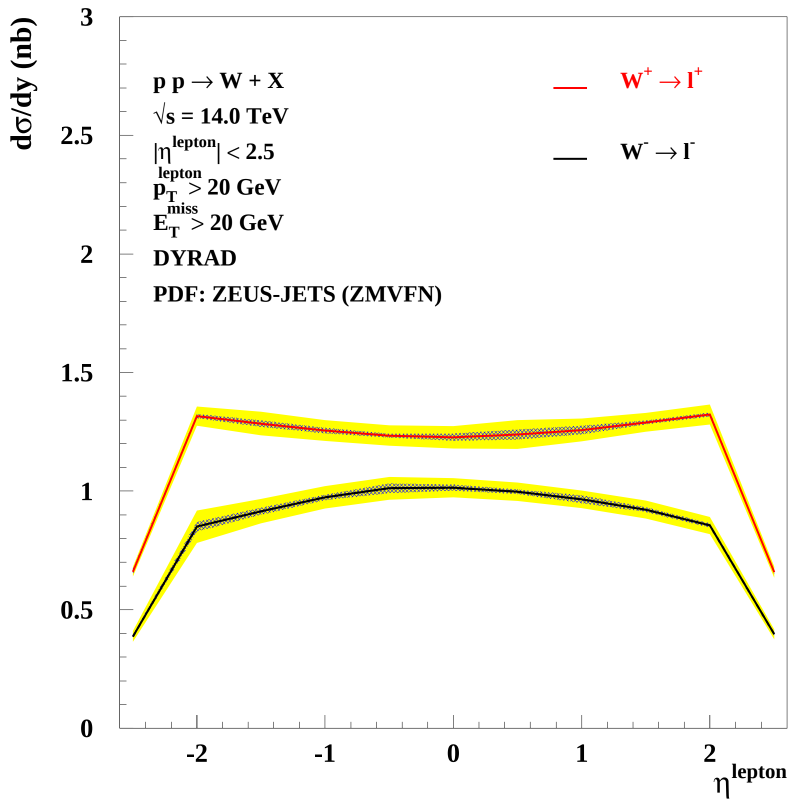


Prediction for Run-II Tevatron Inclusive jet production using ZEUS-ONLY 2004 and ZEUS-JETS 2004 PDFS in the JETRAD programme



Prediction for LHC Inclusive jet production using ZEUS-ONLY 2004 and ZEUS-JETS 2004 PDFS in the JETRAD programme- uncertainties in the prediction are smaller using the PDFs which include HERA jet infromation





Prediction for Run-II Tevatron Inclusive $W^{\pm}$ production using ZEUS-ONLY 2004 and ZEUS-JETS 2004 PDFS in the DYRAD programme again uncertainties are smaller using the PDFs which include HERA jet information

extras

Old ZEUS/H1 gluon comparison