Treatment of heavy quarks in ZEUS PDF fits

NOT an official ZEUS talk

HERA-LHC workshop 2007

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Once upon a time, a long time ago

There was the ZEUS-S global fit to fixed target DIS data plus ZEUS 96/97 NC data

Phys Rev D67(2003)012007

This did not fit heavy quark production data explicitly but since heavy quarks are part of inclusive production F2c and F2b are contributions to the total F2

So we had to chose a scheme to deal with heavy quark production

There were three available at the time

Fixed Flavour Number –FFN- always 3 fixed flavours

Zero-Mass Variable Flavour Number- ZMVFN

General Mass Variable Flavour Number- GMVFN –Thorne/Roberts

(But note this has evolved over the years)

We chose GMVFN for our main fit

But we had always looked at the others…….

EXPLAIN FFN ZMVFN GMVFN briefly…….

FFN

No heavy quark parton densities- charm (and beauty) generated by Boson Gluon Fusion

Threshold region correctly treated – but large $\ln(Q^2/m_c^2)$ logs at high Q^2 are not resummed.

ZMVFN

Charm parton densities are zero for $Q^2 < \sim m_c^2$, charm parton density is then turned on but treated as massless in the DGLAP equations.

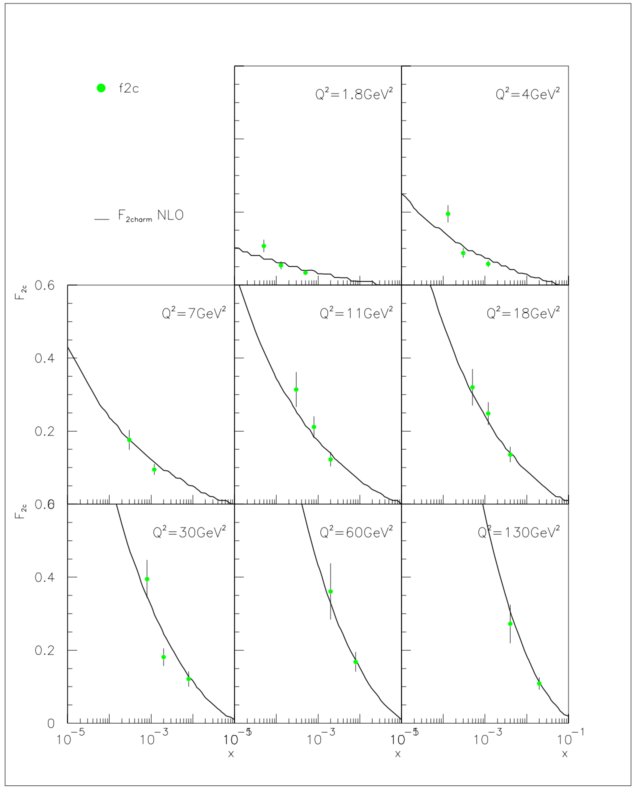
Threshold region $W^2 > 4m_c^2$ is not correctly treated, but high Q^2 large logs are resummed

GMVFN

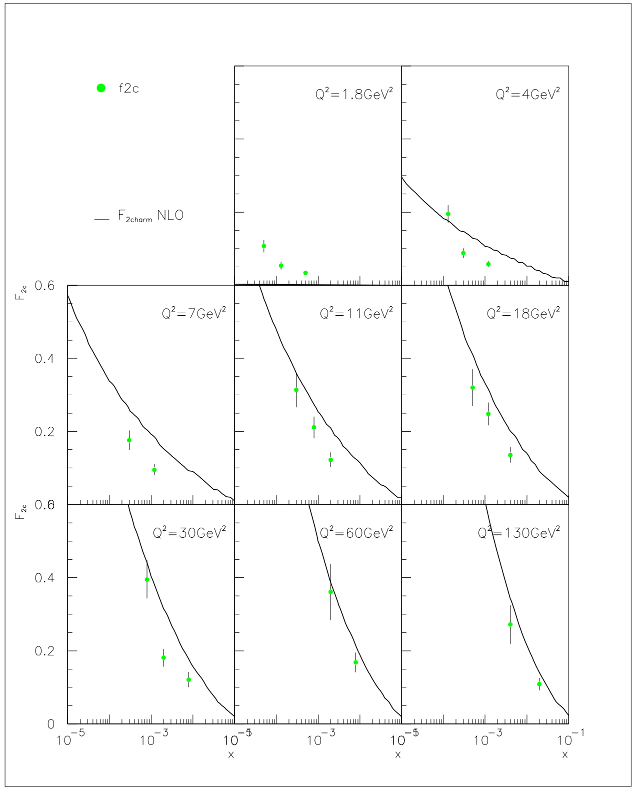
Combine the correct features of FFN at thresholds and ZMVFN at high Q^2

But what about the treatment of running $\alpha_s(Q^2)$?- see later

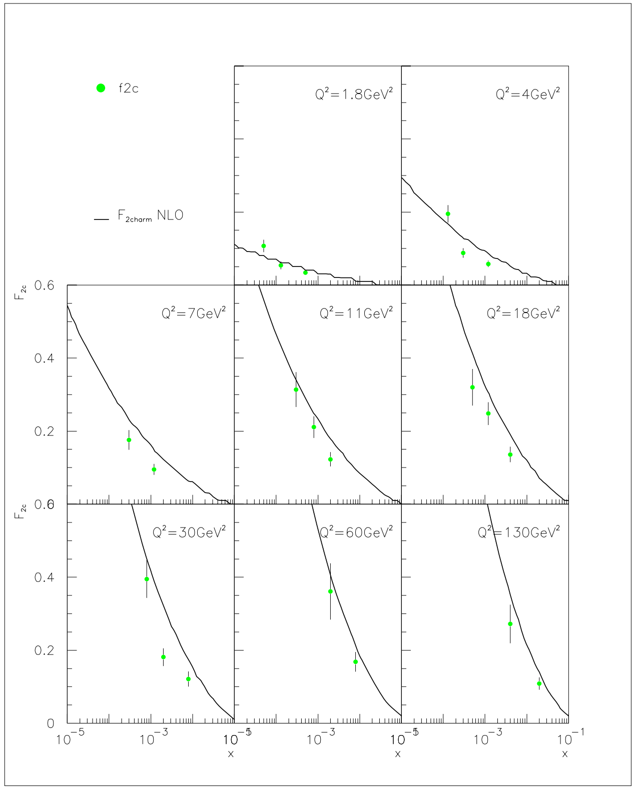
Here's the predictions of the three different schemes for F2c – all using the same PDF parameters – these happen to be the parameters for the FFN fit



FFN



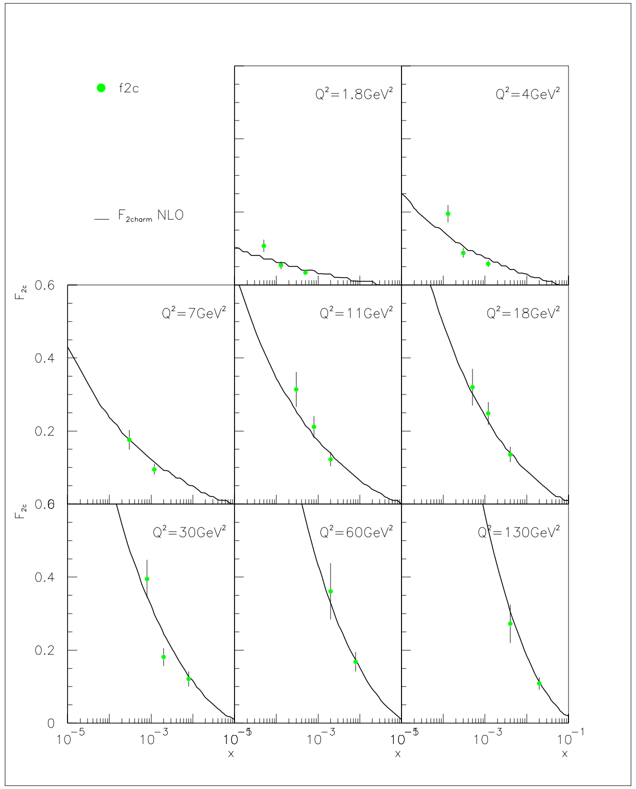
ZM-VFN



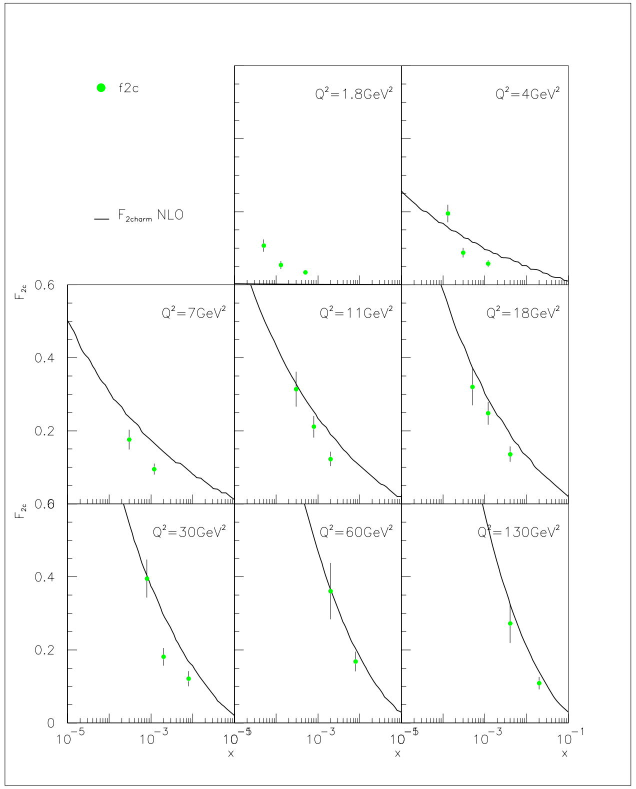
GM-VFN

The data points are old ZEUS F2c data

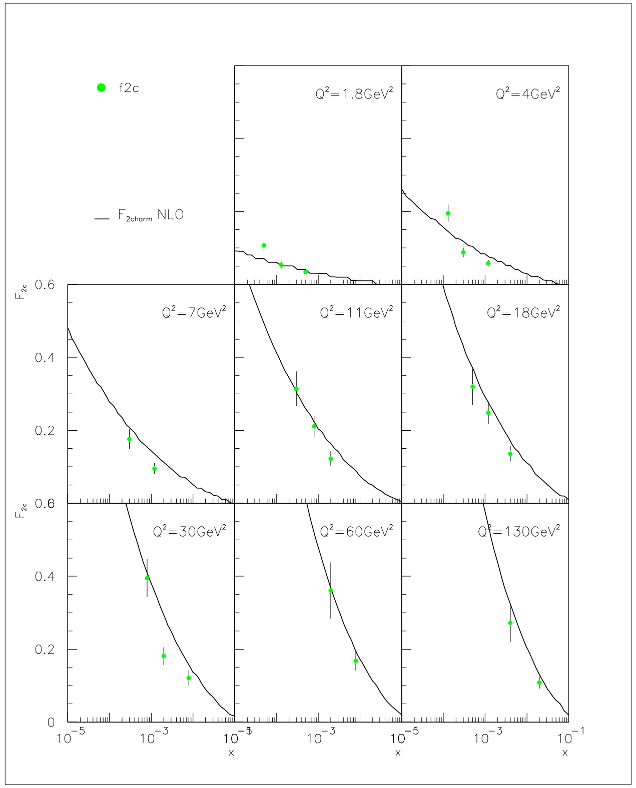
But we should really re-fit the PDF parameters for each scheme



FFN



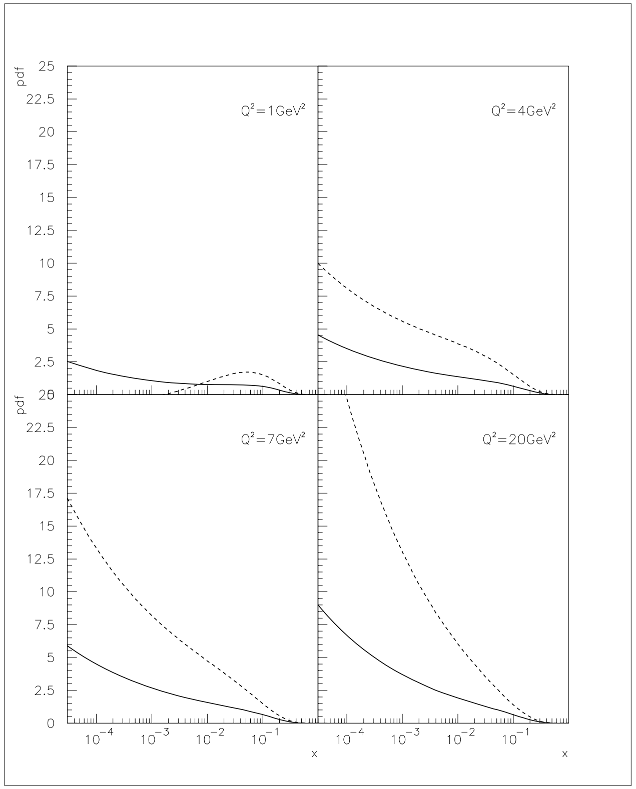
ZM-VFN



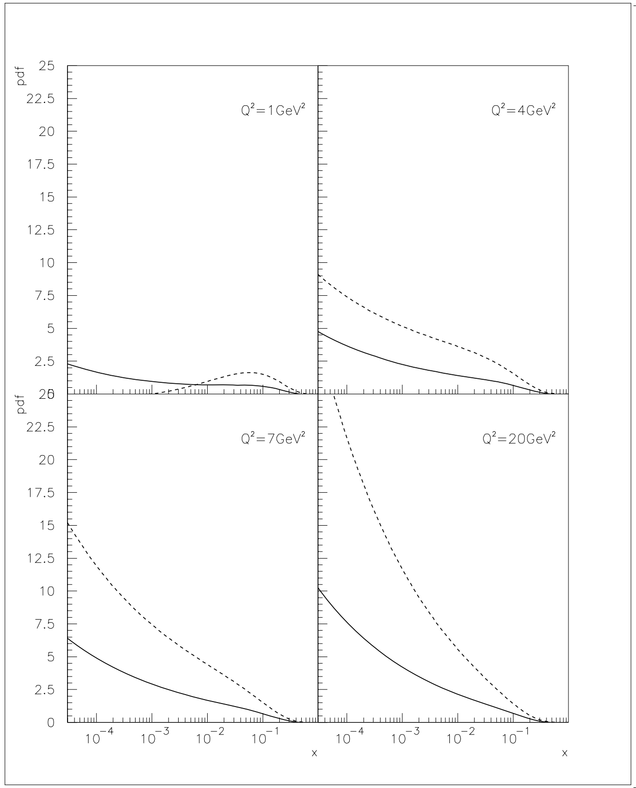
GM-VFN

And this is the fit we finally chose

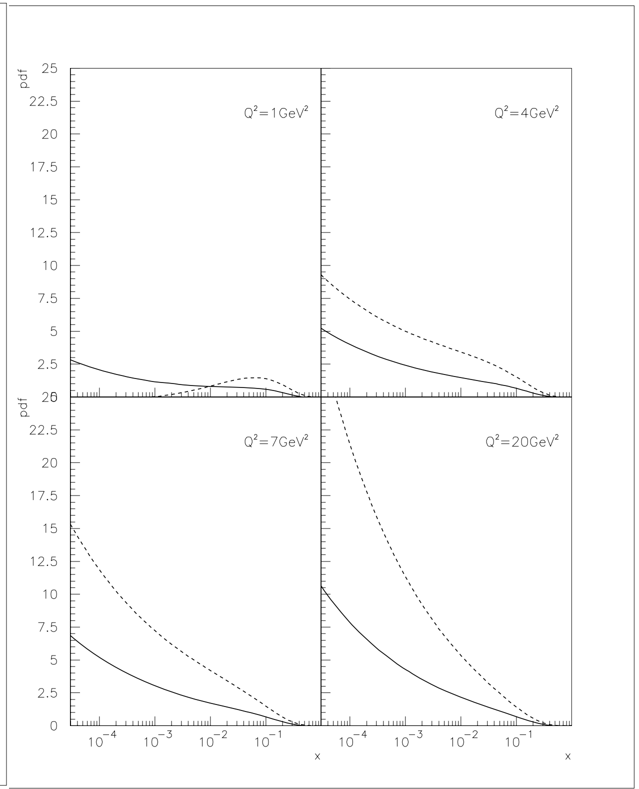
The PDFs differ slighlty with the choice of scheme



Glue and sea FFN

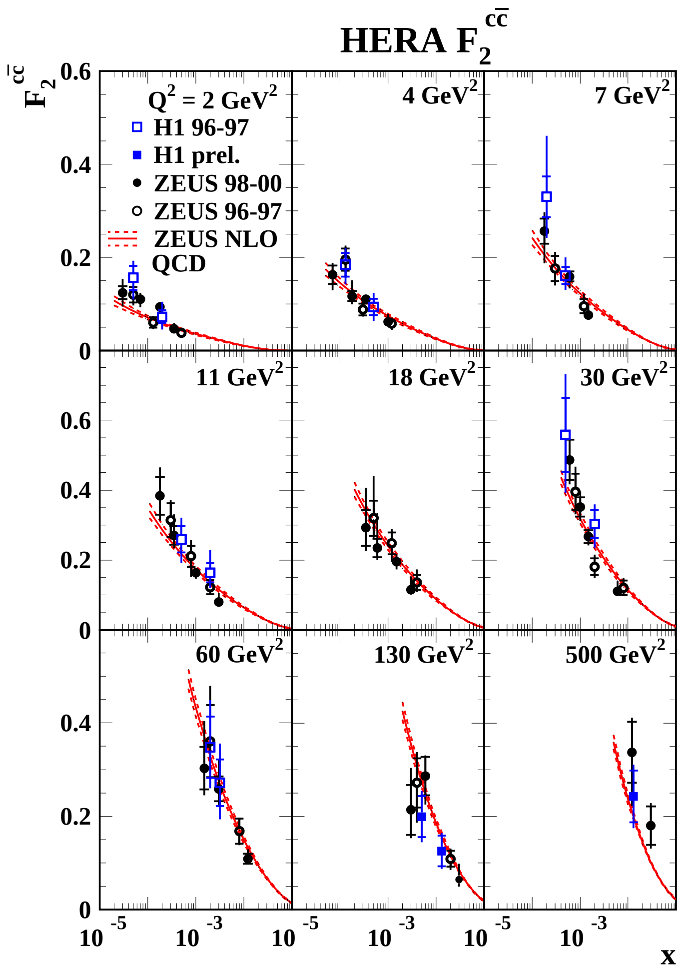


Glue and sea ZMVFN



Glue and sea GMVFN

Now look at our predictions for the ZEUS HERA-I charm data published in DESY-03-115



In fact the predictions shown here are not for GMVFN but for FFN Why?

Because the F2c we published was extracted using the HQVDIS programme which is only compatible with an FFN treatment.

Also- the factorisation scale for the charm quark was $Q^2+4m_c^2$ for HQVDIS

The renormalisation scale and the factorisation scale for light or heavy quarks were all set equal to Q^2 in our previous plots but we changed the heavy quark scale for this plot

We also varied the value of the charm quark mass in the range mc = 1.35±0.15- very small effect

The ZEUS-S global fit to fixed target DIS data plus ZEUS 96/97 NC data

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- **PDFs parameterisation**
  - **$xf(x) = p_1 x^{p2}(1-x)^{p3}(1+p_5 x)$**

originally 11 parameters

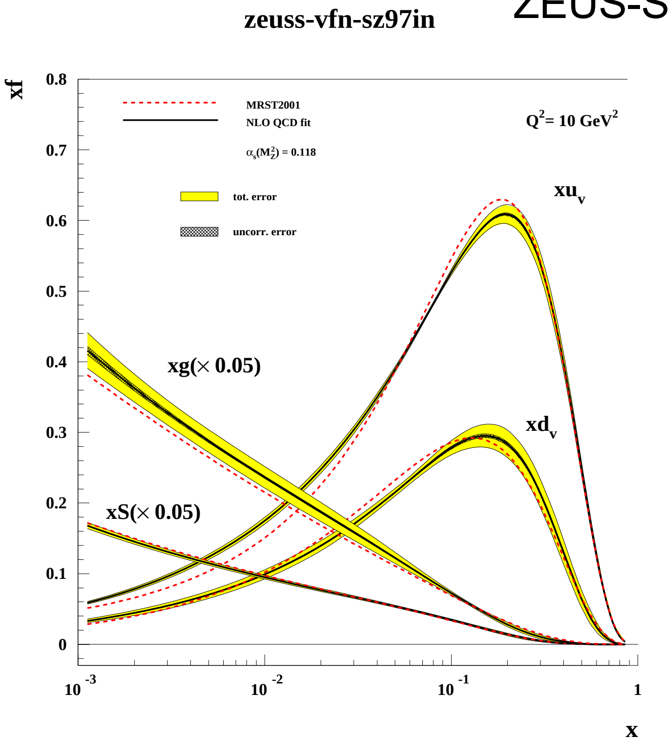
- **xu_v, xd_v, xS (sea), xg**

has been updated to included newer ZEUS data 98-00

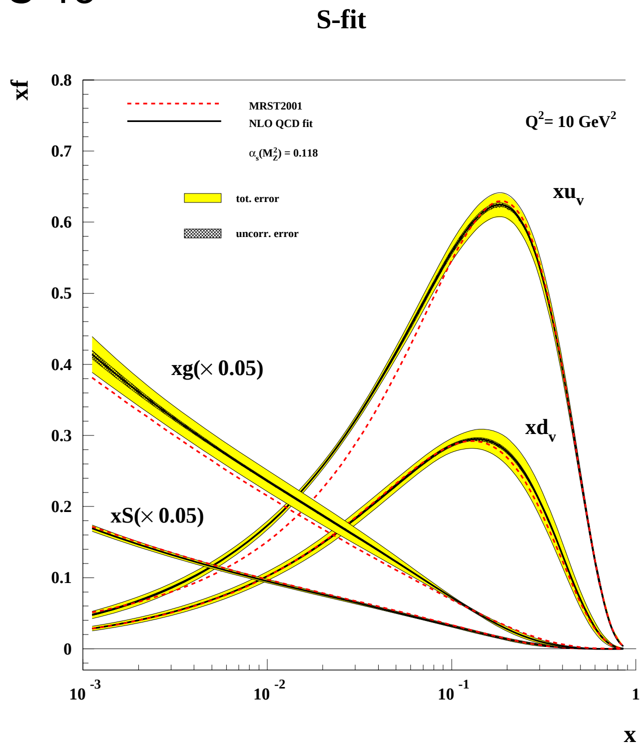
And now has 13 parameters

Most relevantly p5g is freed

ZEUS-S



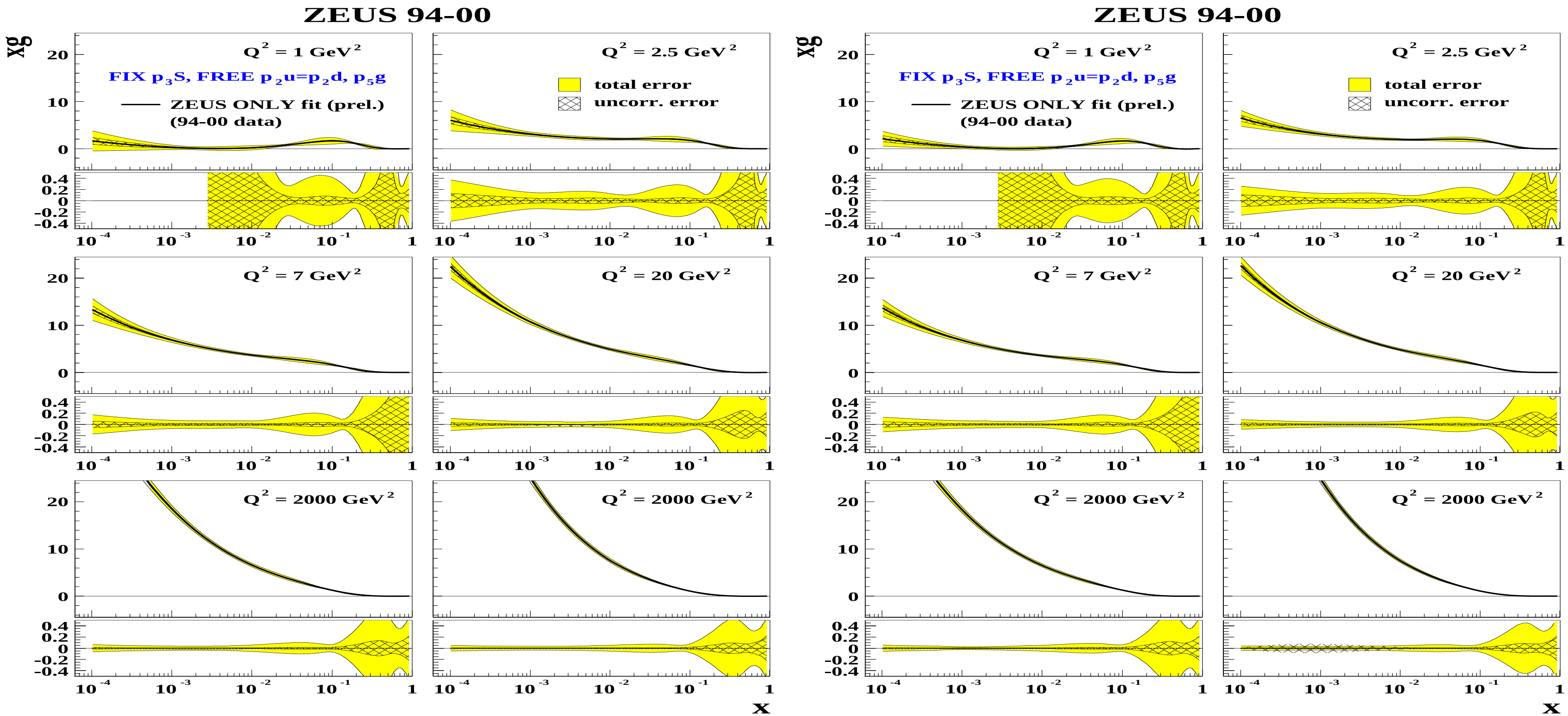
ZEUS-S-13



Obviously we also asked ourselves what would happen if we put these charm data into our fit ? Would it help to constrain our gluon distribution? g →c cbar

This was done for a GMVFN fit to ONLY ZEUS-DATA 94-00 with ZEUS-S-13 parameters

F_2^{charm} ADDED ↓



- For model with $p_{5}g$ free (more free gluon params.) improvement is more significant compared to equivalent model without F_2^{charm}

→ WITHOUT : $p_{2}g = -0.290 \pm 0.020 \pm 0.065$, $p_{3}g = 10.65 \pm 0.89 \pm 4.72$, $p_{5}g = 18.9 \pm 5.7 \pm 26.5$

→ WITH : $p_{2}g = -0.300 \pm 0.020 \pm 0.040$, $p_{3}g = 10.35 \pm 0.80 \pm 3.63$, $p_{5}g = 20.6 \pm 5.6 \pm 20.8$

But are we really doing the best thing by fitting F2c?

It is measured via D* production cross-sections

And we now have the technology to include any NLO cross-sections in the fit using the same grid technique as used for the ZEUS-JETS fit

Eur Phys J C42 (2005) 1

— Unlike F_2^{charm}, cross sections are directly measured and not affected by extrapolation to full phase space

→ more promising than F_2^{charm} ?

The Charm Cross Section Data

- 98-00 charm differential cross sections (DESY-03-115)

<u>kinematic region:</u>

$1.5 < Q^2 < 1000\ GeV^2$, $0.02 < y < 0.7$

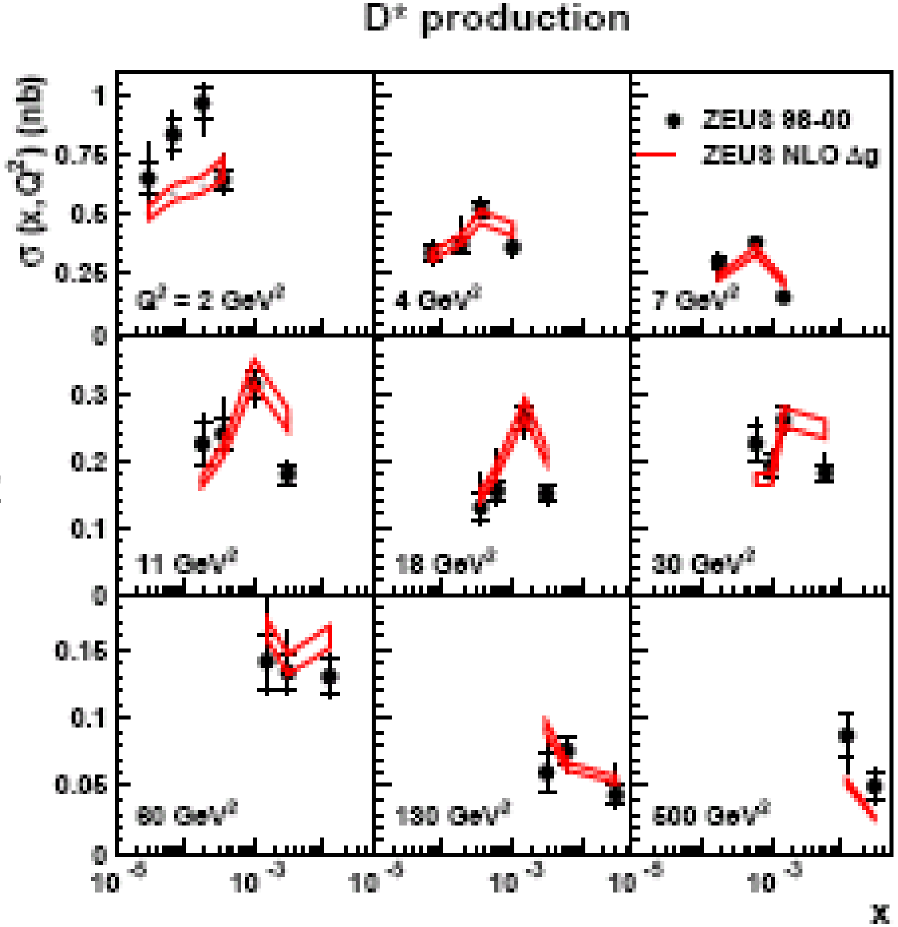
$1.5 < p_T(D^*) < 15\ GeV$, $|\eta(D^*)| < 1.5$

→ 13 cross sections available:

differential in Q^2, x, $p_T(D^*)$, $\eta(D^*)$

and <u>double differential in Q2 and y</u>

Only the 9 double differential cross sections in Q^2 and y have been used, to avoid correlations between cross sections



Inclusion of Charm: The Method

<u>GRIDS PRODUCED BY E.Tassi, J.Terron</u>

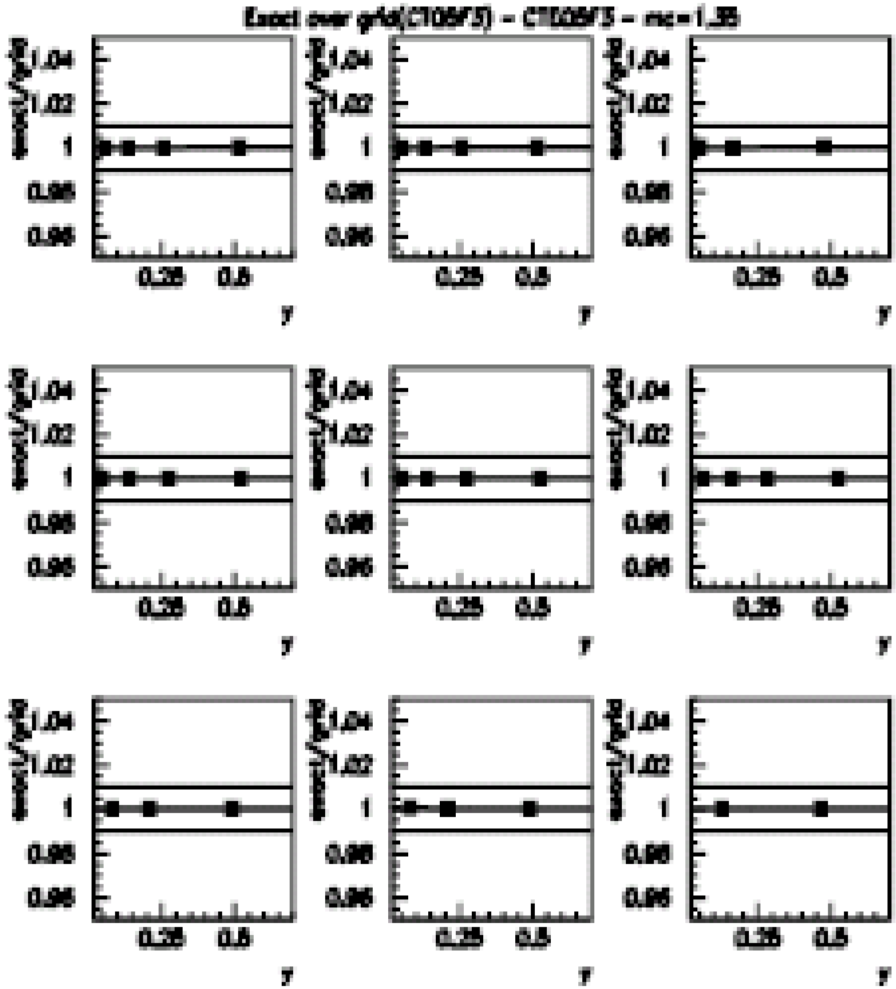
Method analagous to that used for inclusion of jet data

- NLO program: HVQDIS

→ Peterson fragmentation function

→ charm mass: m_c = 1.35 GeV

→ $\mu_F = \mu_R = Q^2 + 4m_c^2$



<u>Grid reproduction of HVQDIS</u>

Actual predictions of HVQDIS well reproduced to within 1% using grid method

Complications to the Inclusion of Charm

- HVQDIS (and all current NLO programs for charm production!) is based on the Fixed Flavour Number (FFN) Scheme
  - → only u, d, s included in proton as active partons obeying DGLAP
  - → $c\bar{c}$ produced via Boson-Gluon-Fusion
- <u>But</u> standard ZEUS fits use Robert-Thorne Variable Flavour Number (RTVFN) Scheme
  - → not consistent with weights from HVQDIS

<u>OUR PROCEDURE (FOR THE MOMENT !!!):</u>

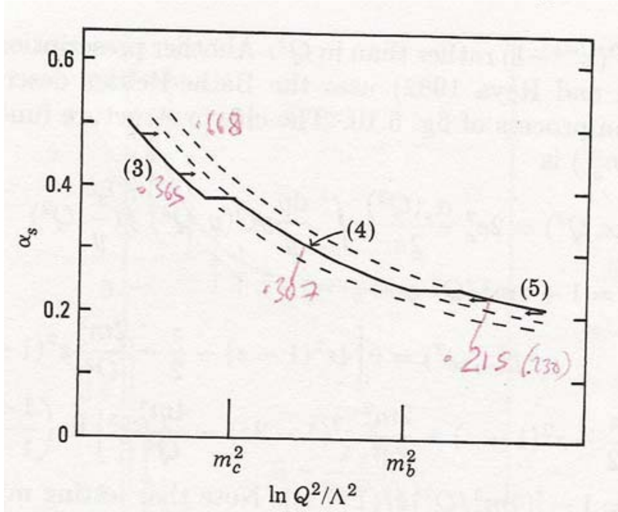
- *Assess effect of charm by performing <u>independent fit</u> in FFN*
  - → Evolve α_s for three flavours only — →This needs more explanation
  - → FFN not applicable at high Q^2, so apply cut $Q^2 < 3000$ GeV^2
  - → With upper Q^2 cut, not enough information from only ZEUS data
    - need fixed target data to help constrain PDFs

Use ZEUS-S as basis for the charm fit ...

What about the treatment of running $\alpha_s(Q^2)$?

NLO $\alpha_s(Q^2)$ depends on the QCD β function

There are no mass terms in this but it contains n_f and thus changes as flavour thresholds are crossed



Thus α_s as a function of Q^2 follows a different curve according to whether n_f =3,4,5..

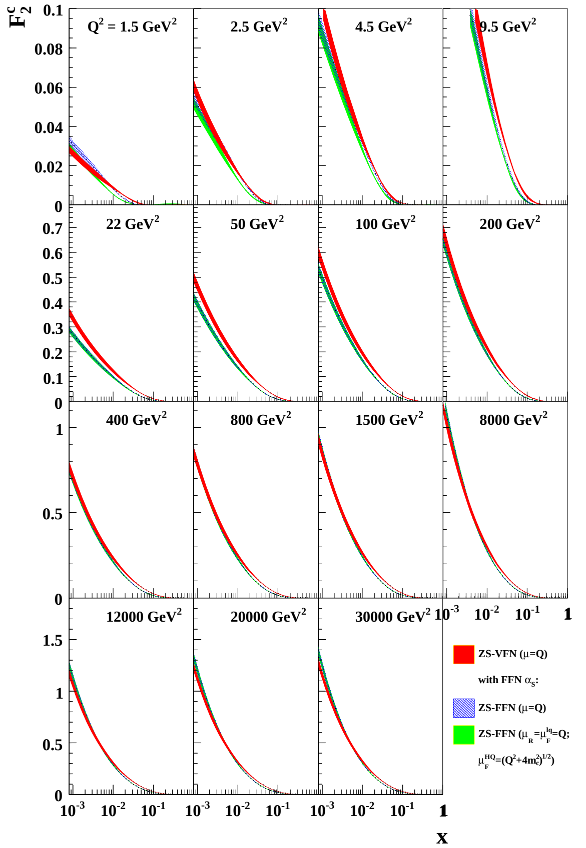
To make $\alpha_s(Q^2)$ continuous a matching prescription is needed. Marciano's prescription shifts the curves horizontally to match at $Q^2 = m_c^2$ and $Q^2 = m_b^2$

This has been widely used in MRST PDF fits (except hep-ph/0603143) and CTEQ fits (except CTEQ5FF3/4) and is used in QCDNUM. I will call it VFN $\alpha_s(Q^2)$

But it is not used in HQVDIS –in this $\alpha_s(Q^2)$ remains a 3-flavour function-
We finally realised that in FFN we never had been completely compatible with HVQDIS which has a fixed 3-flavour $\alpha_s(Q^2)$ as well as fixed flavour coefficient functions.
We had always used a VFN $\alpha_s(Q^2)$

And note that if you use a 3-flavour $\alpha_s(Q^2)$ it needs an equivalent value of $\alpha_s(M_Z)$~0.105 in order to be consistent with the VFN $\alpha_s(M_Z)$~0.118 at low Q^2.

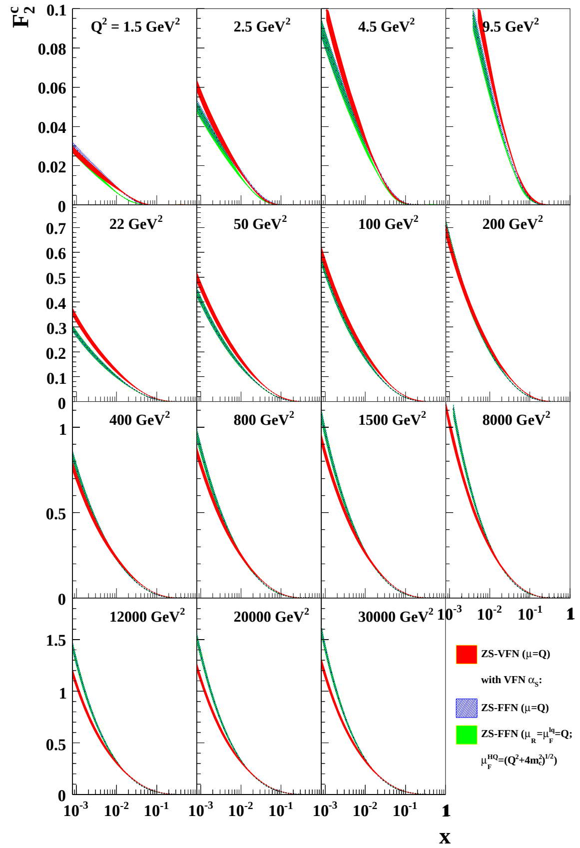
And here is what difference it makes to predictions for F2c



FFN with all scales =Q2

FFN with heavy quark factorisation scale =Q2+4mc2

And GMVFN



FFN predictions with 3-flavour αs(Q2)

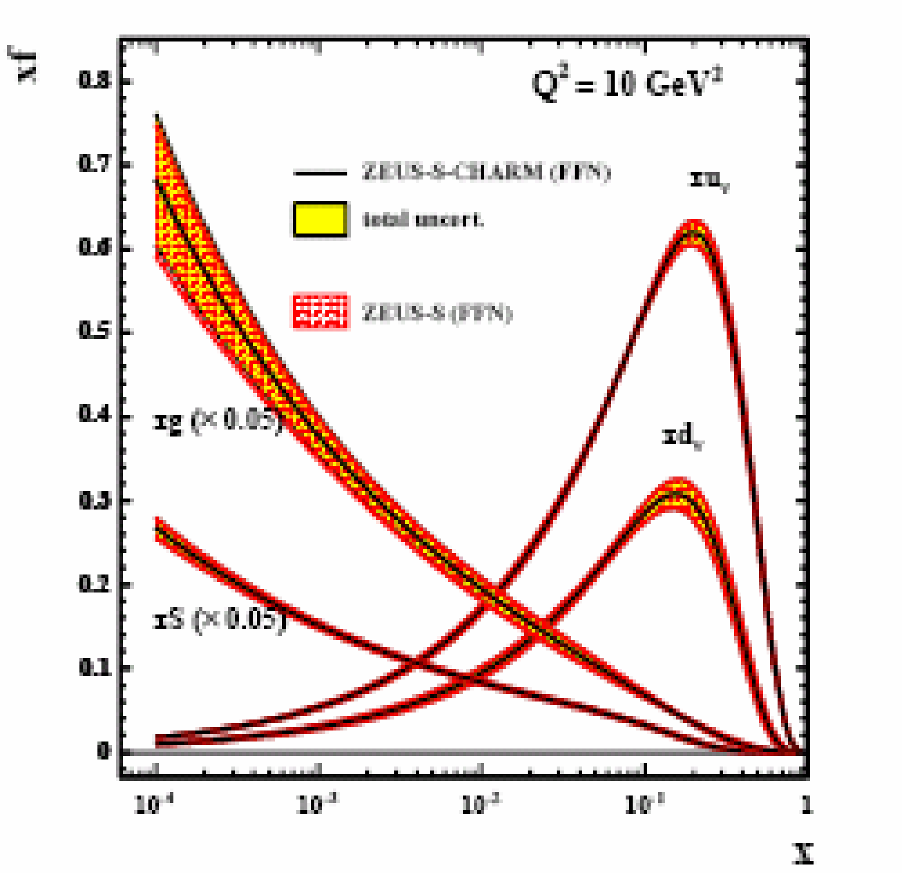
FFN predictions with VFN αs(Q2)

FFN predictions are then more compatible with GMVFN at higher Q2

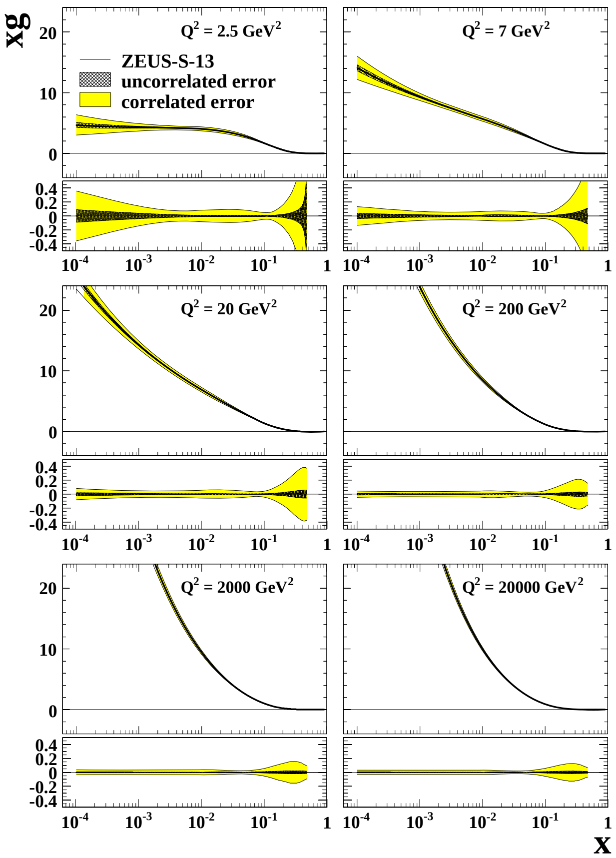
Return to results of fitting D* cross-sections

Central values of fit with and without charm cross-sections are very similar

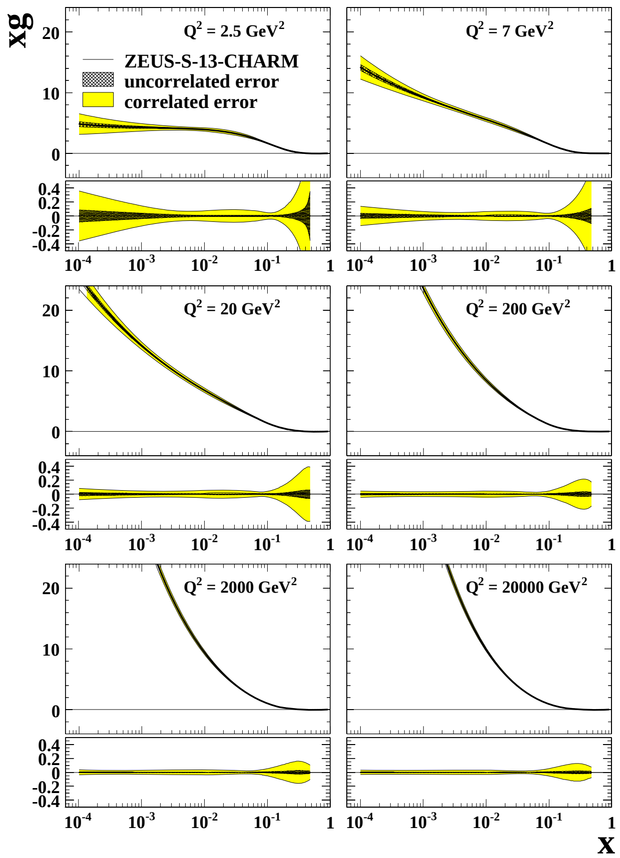
χ2/d.p. also similar for inclusive cross-sections- but not all the charm cross-sections are well fit



Without D* cross-sections



With D* cross-sections



$$xg(x) = p_1g\ x^{\ p2g}\ (1-x)^{p3g}\ (1+p_5g\ x)$$

WITHOUT: p2g=-0.176±0.008±0.038 p3g=9.75±0.22±1.50 p5g=0.18±0.03±0.10

WITH: p2g=-0.182±0.008±0.038 p3g=9.37±0.22±1.42 p5g = 0.19±0.03±0.09

Not a striking improvement

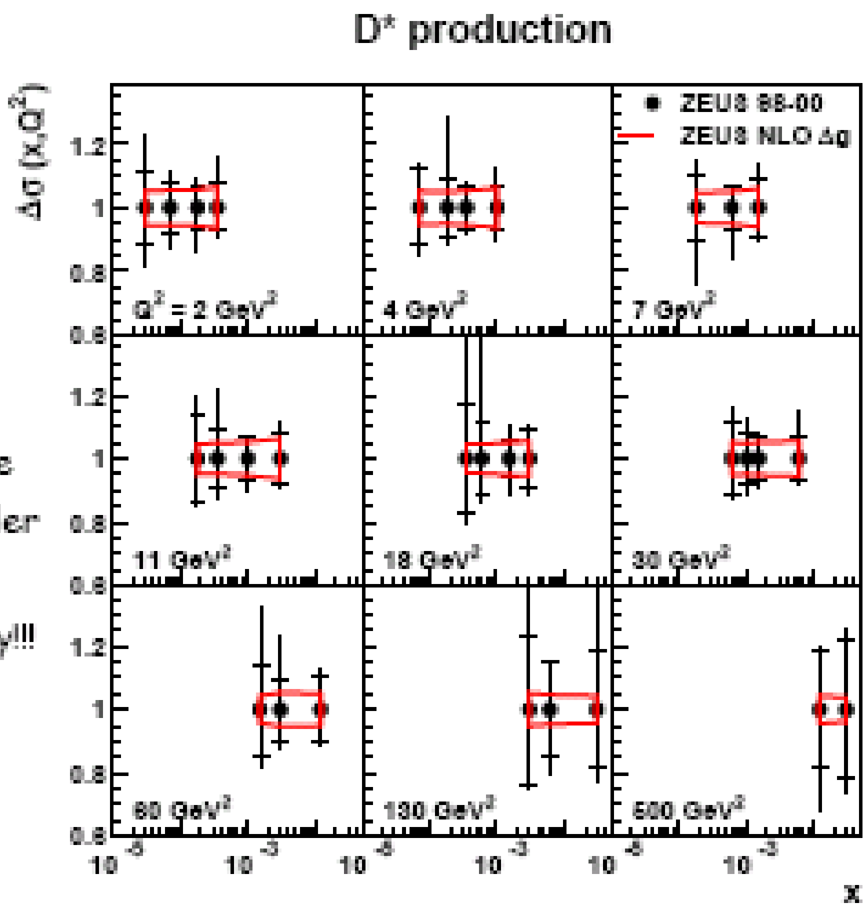
Should we expect a significant improvement?

Plot from Matthew Wing

Points: fractional uncertainty on data
Band: fractional uncertainty on gluon (which dominates PDF uncertainty for charm) from published ZEUS-S fit

- also, from the fractional uncertainties on data and theory it is clear that there are no points where the data have smaller uncertainties than the theory
  → need more data to better constrain theory!!!

BUT HERA-II data with 5 times the statistics is coming



Other theoretical uncertainties

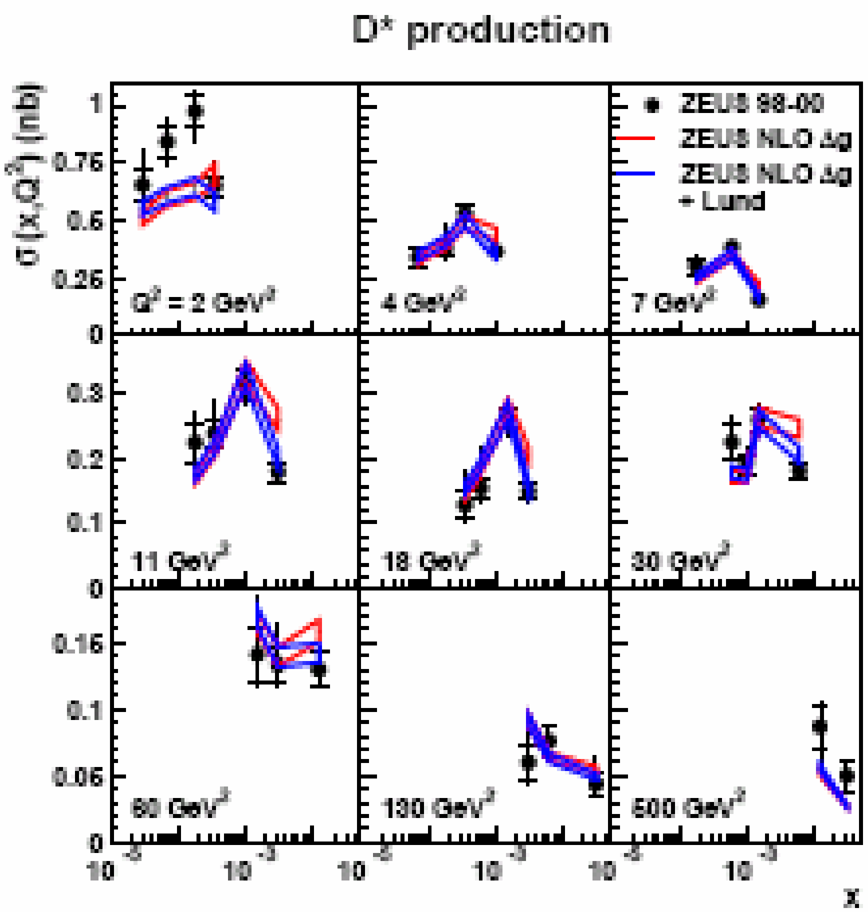
What if we had used an alternative fragmentation function when producing the NLO grid predictions?

Petersen was used

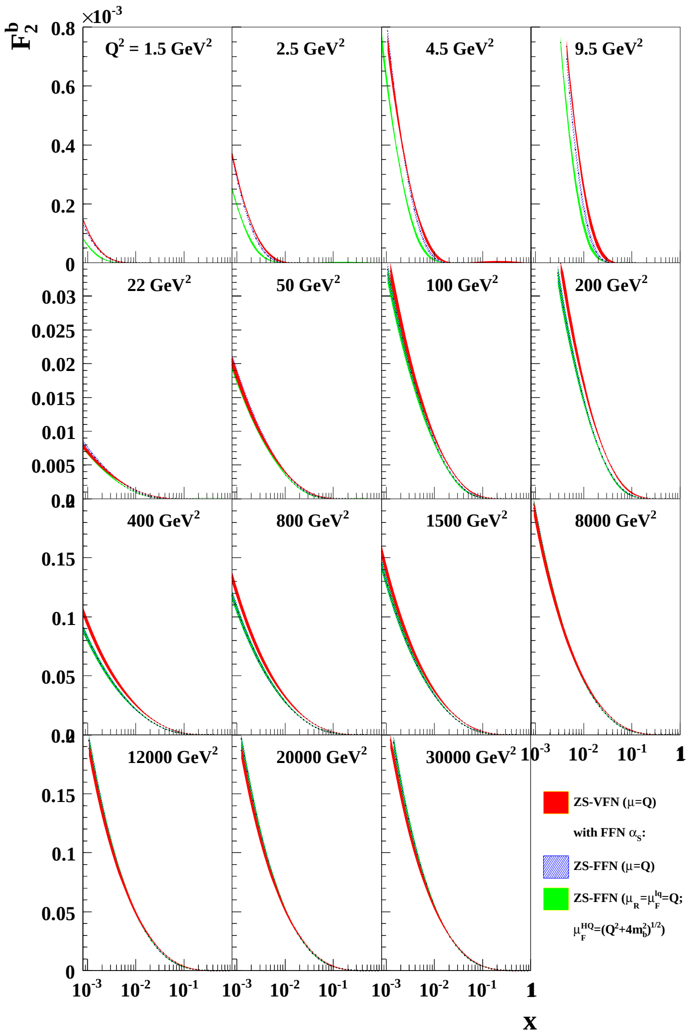
But we could have used Lund

Which seems to give a somewhat better description of the data

This was not pursued…but it could be



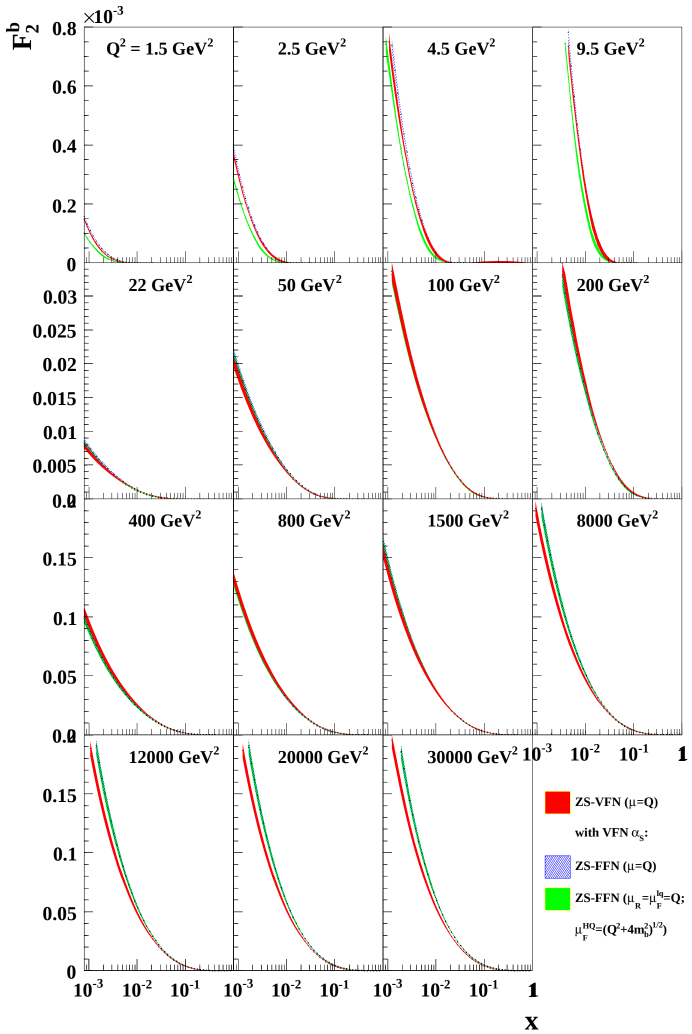
And now we have F2b data coming so we re-visIted this



FFN with all scales =Q2

FFN with heavy quark factorisation scale =Q2+4mc2

And GMVFN



FFN predictions with 3-flavour αs(Q2)

FFN predictions with VFN αs(Q2)

And actually FFN predictions are then more compatible with the GMVFN to higher Q2…

Whither the future?

Sort out correct theoretical approach- differences in GMVFN schemes for inclusive F2c/b fits?

Use double differential D* cross-sections- need to use FFN? -is HVQDIS the only tool?

What about fragmentation functions?

New data coming from HERA-II on both charm and beauty

-now is the time to do this.

Extras

Extend ZEUS-S (ZEUS+fixed target data) fits 11 to 13 parameters

!

- $xuv(x) = p1u\, x^{p2u}\, (1-x)^{p3u}\, (1 + p5u\, x)$
  $xdv(x) = p1d\, x^{p2d}\, (1-x)^{p3d}\, (1 + p5d\, x)$
  $xS(x) = p1s\, x^{p2s}\, (1-x)^{p3s}\, (1 + p5s\, x)$
  $xg(x) = p1g\, x^{p2g}\, (1-x)^{p3g}\, (1 + p5g\, x)$

These parameters control the low-x shape

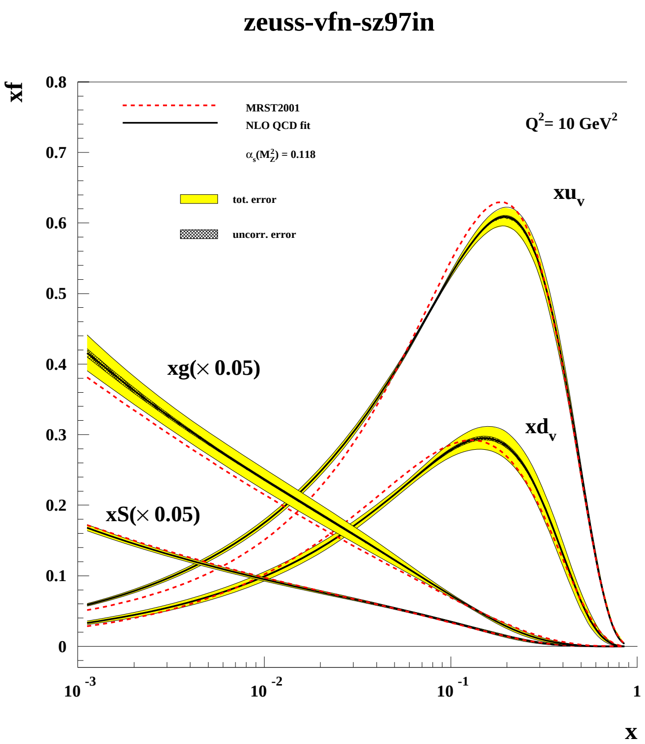
These parameters control the high-x shape

These parameters control the middling-x shape

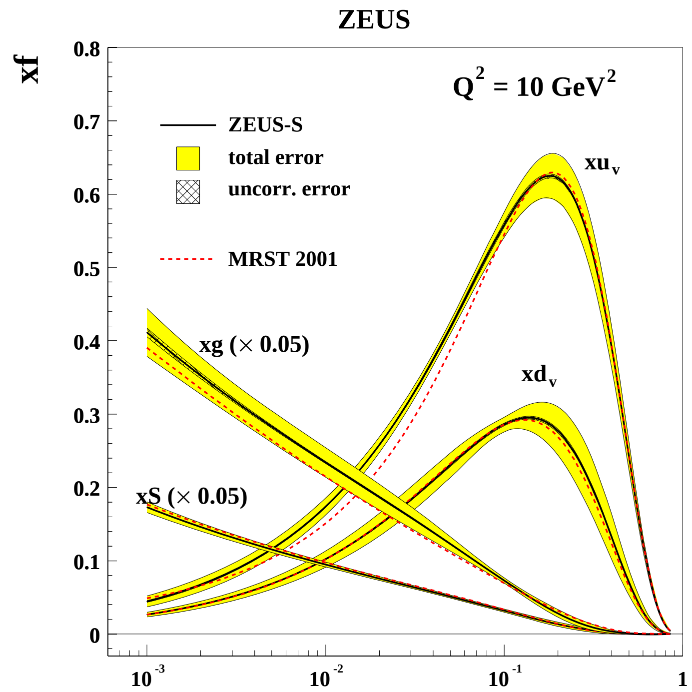
In the published ZEUS-S fit p1u,p1d,p1g are fixed by sum rules, p2u=p2d=0.5 is fixed, and p5g is fixed. We also free the normalisation of $x\Delta = x(\bar{d}-\bar{u})$, but its shape is taken from the Sea shape. This makes 11 parameters.

Freeing p2u =p2d and freeing p5g makes NO significant change to ZEUS-S PDFs

11-parameters

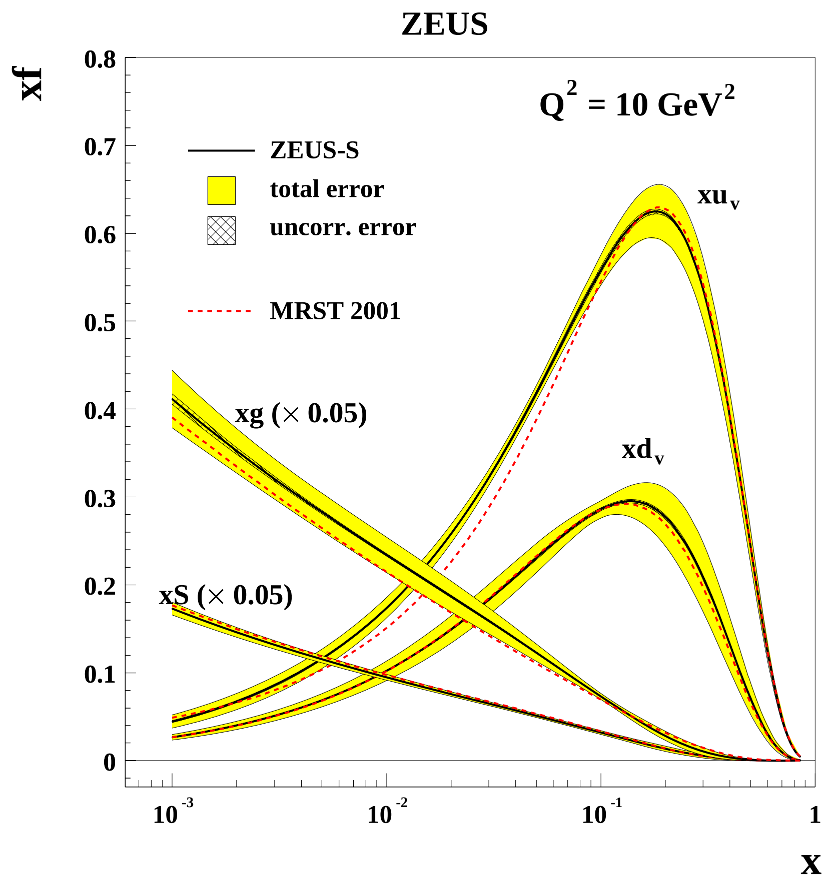


13 parameters



The Obvious thing to do next is to update these extended ZEUS-S fits to include the high-Q2 cross-section data, which was not included in the published ZEUS-S fits

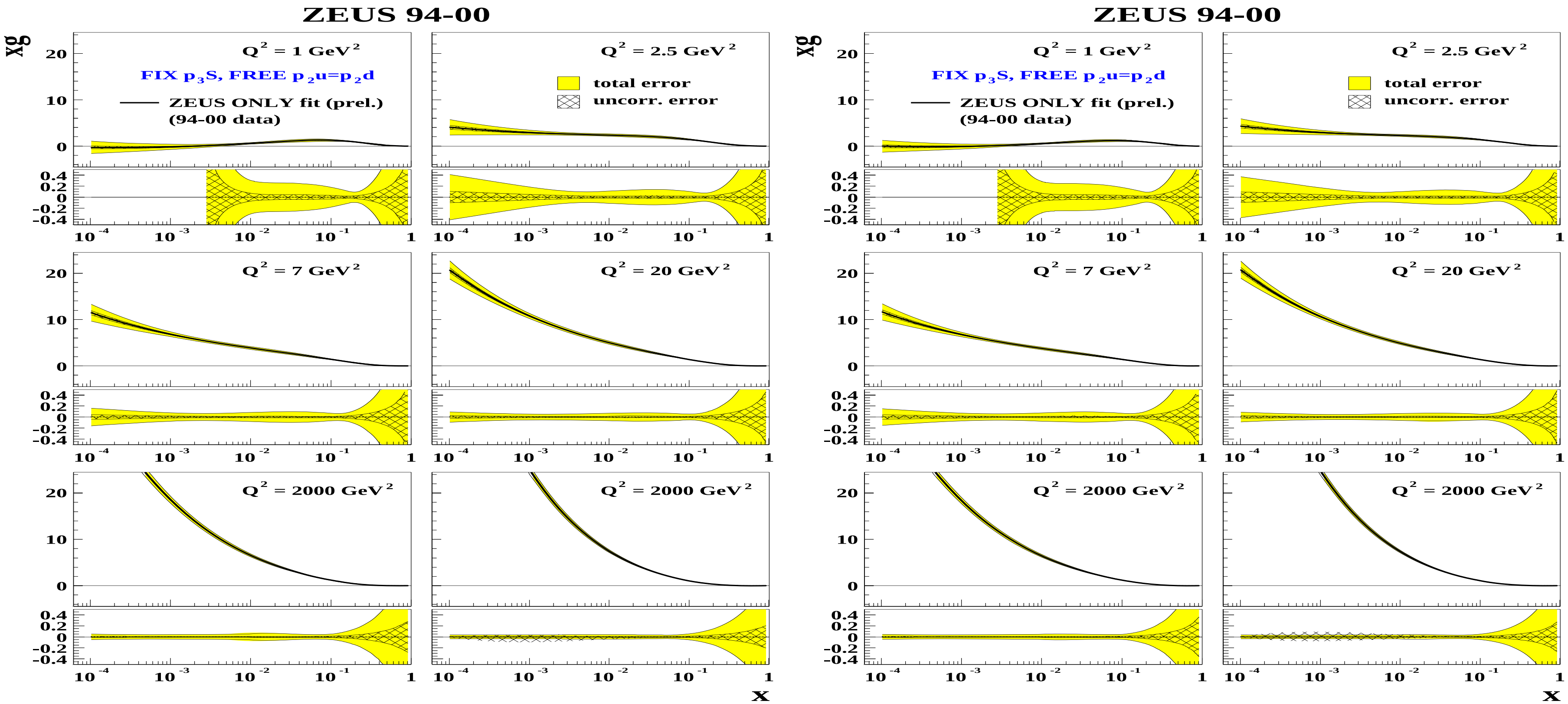
CC 94-97, NC+CC 98/99 and NC+CC 99/00 data



Obviously we also asked ourselves what would happen if we put these charm data into our fit ? Would it help to constrain our gluon distribution? g →c cbar

This was first done for a GMVFN fit to ONLY ZEUS-DATA 94-00 with ZEUS-S parameters

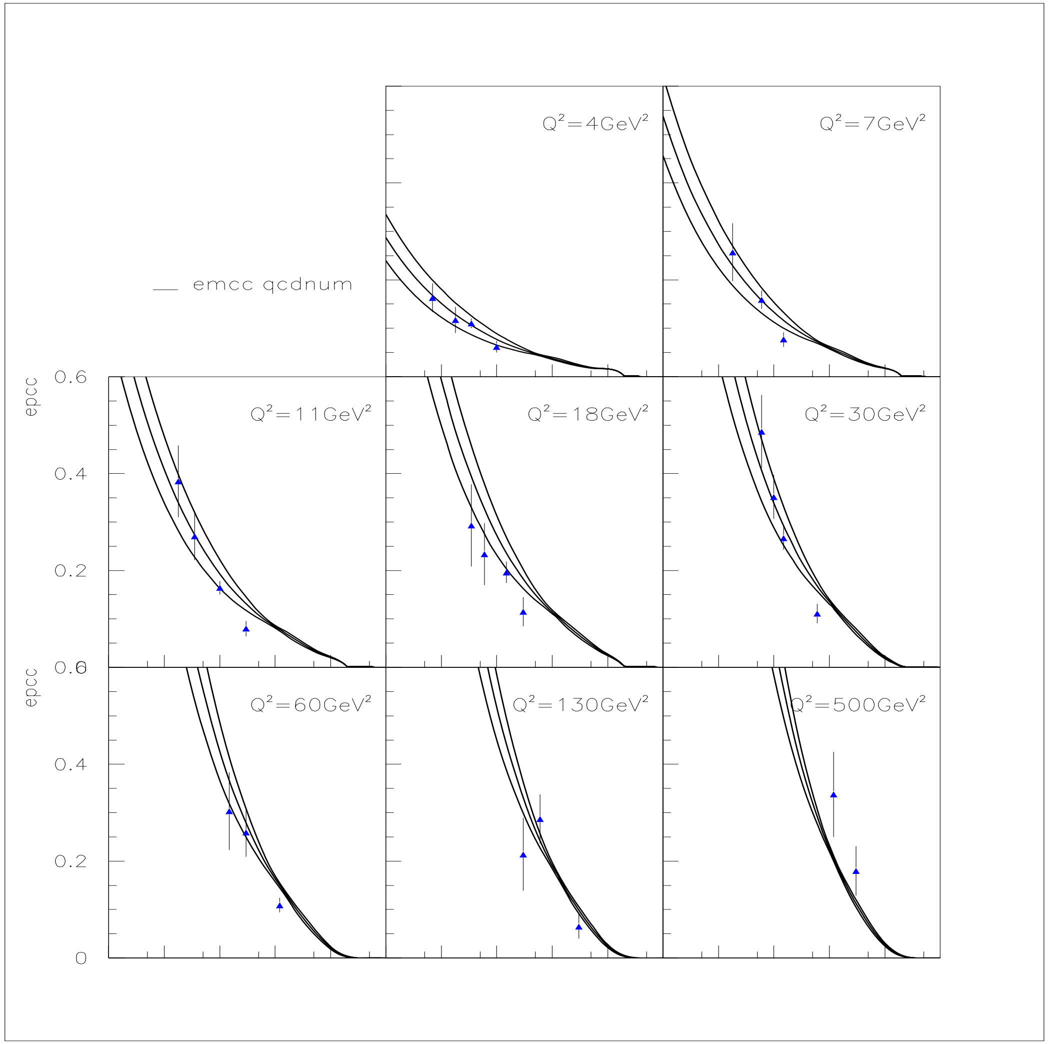
F_2^{charm} ADDED ↓



- Inclusion of F_2^{charm} does provide some improvement in determination of gluon
  - → WITHOUT : $p_{2g} = -0.226 \pm 0.010 \pm 0.045$, $p_{3g} = 5.09 \pm 0.29 \pm 1.33$
  - → WITH : $p_{2g} = -0.240 \pm 0.010 \pm 0.040$, $p_{3g} = 4.69 \pm 0.27 \pm 1.17$

→ not very significant, but at least it goes the right way!

For the record the description of F2c when charm was input to the fit is similar to that before it is input to the fit



With p_{5g} also FREE:

- Reasonable description of F_2^{charm} itself...

Inputting data to a PDF fit needs a prediction for the cross-section which can be easily obtained analytically –true for DIS inclusive cross-section. But many NLO cross-sections can only be computed by MC and can take 1-2 CPU days to compute. This cannot be done for every iteration of a PDF fit.

Recently grid techniques have been developed

Separating PDFs From The Integral

- A NLO Cross-Section for DIS is normally calculated using MC by:

$$W = \sum_{m=1}^{N} w_m \left(\frac{\alpha_s(Q_m^2)}{2\pi} \right)^{p_m} q(x_m, Q_m^2)$$

For events m=1….N, (w_m is an MC weight, $q(x,Q^2)$ a PDF).

- Can instead define a weight grid in (x,Q^2), which is updated for each event m:

$$W_{i,j}^{(p)} = W_{i,j}^{(p)} + w_m$$

Where i, j define a discrete point in x,Q^2 space relating to the event.

- A PDF grid is also defined in x,Q^2 as $q_{i,j}$.

- Cross-Section can be reproduced by combining the PDF and weight grids *after* the Monte-Carlo run:

$$W = \sum_i \sum_j W_{i,j}^{(p)} \left(\frac{\alpha_s(Q^2)}{2\pi} \right)^{p} q_{i,j}$$

4

Should we expect a significant improvement?

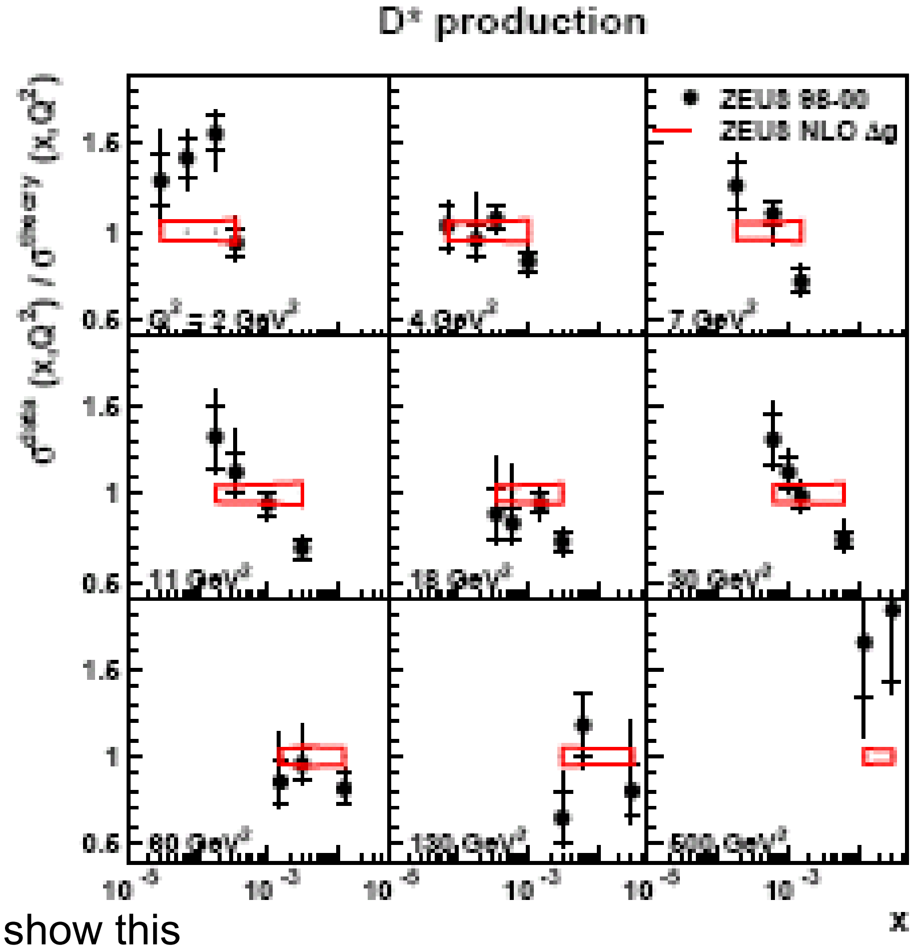
Plot from Matthew Wing

Points: data/theory

Band: theory over theory

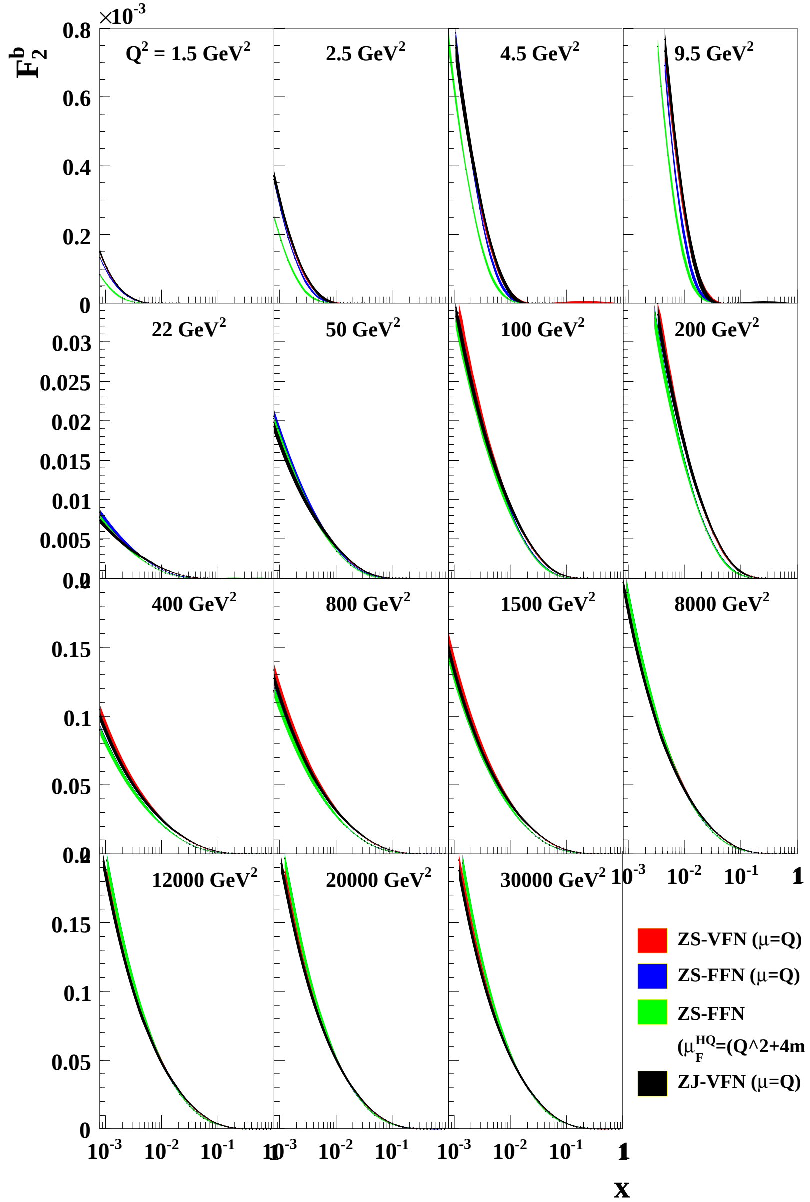
N.B. width of band represents uncertainty on gluon (which dominates PDF uncertainty for charm) from the published ZEUS-S fit

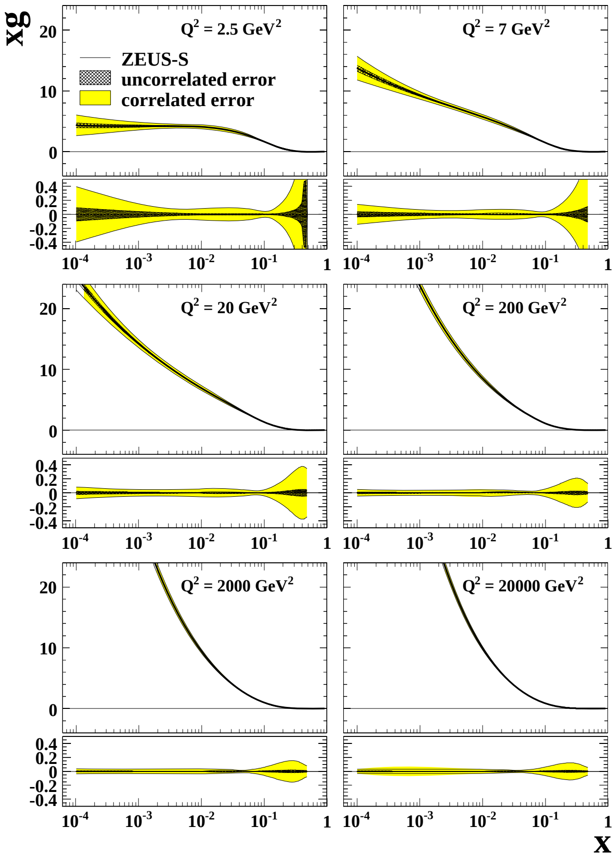
- There are differences between data and theory
  → we could expect some "pull" from data, but differences could be due to other things e.g. fragmentation model, and not just the PDF (see in a minute!)



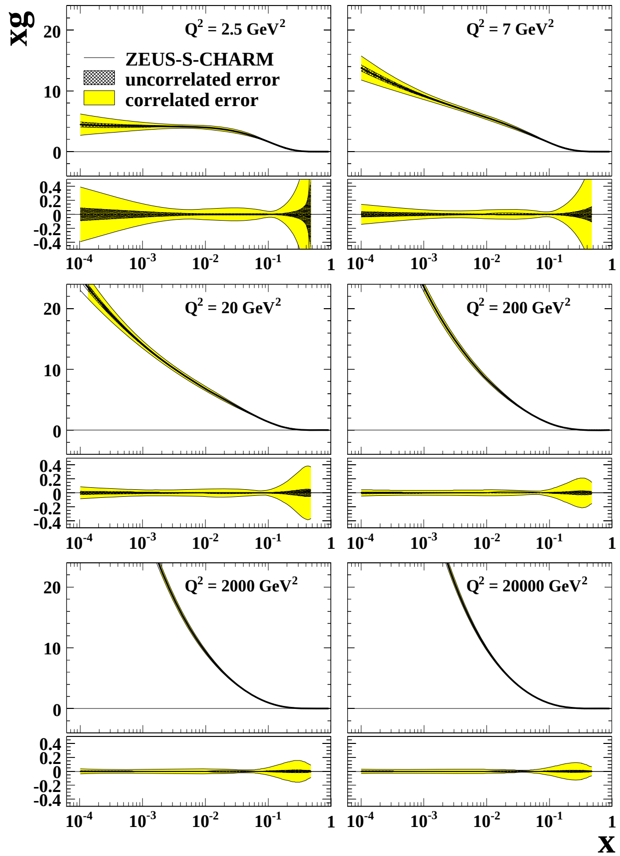
Probably don't show this

Proof that it doesn't matter much if we did use ZEUS-JETS parametrisation rather than ZEUS-S

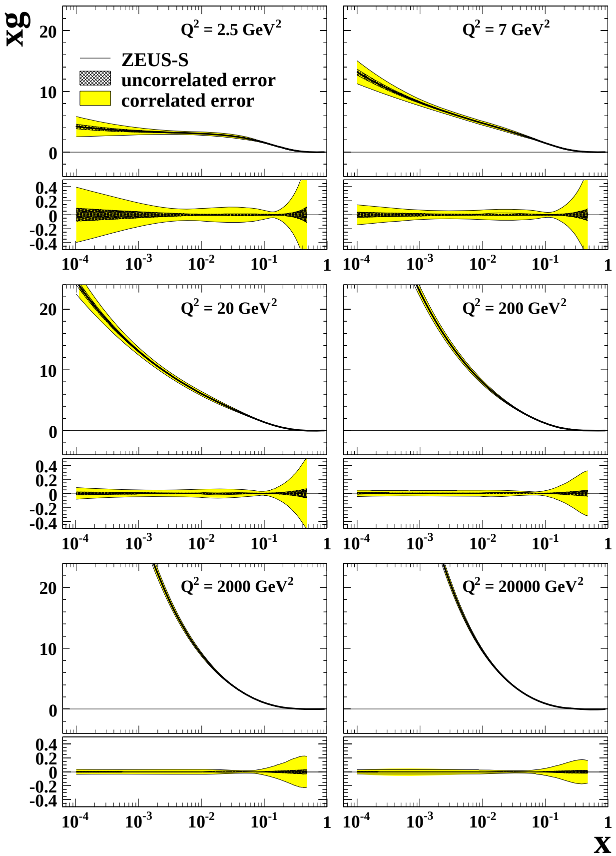




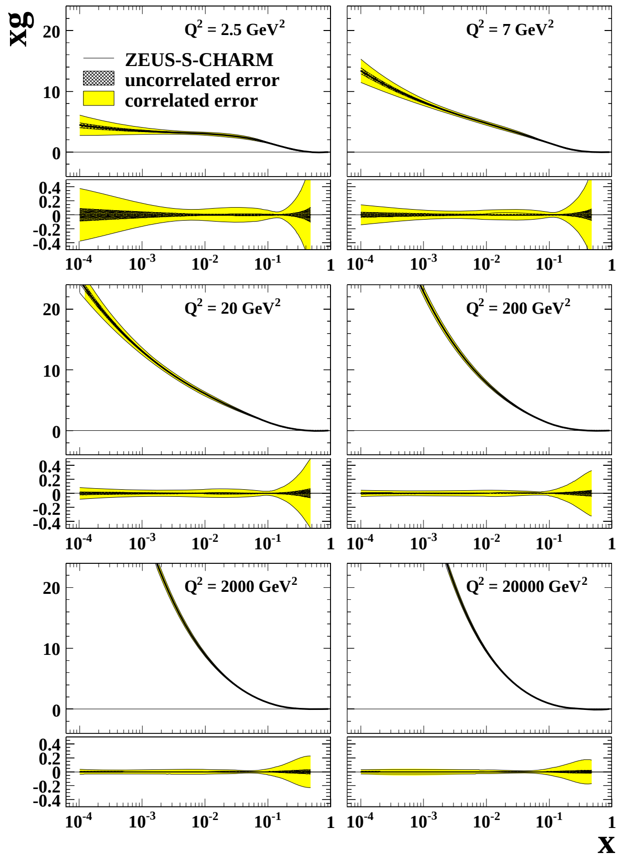
ZEUS-S without charm



ZEUS-S with charm

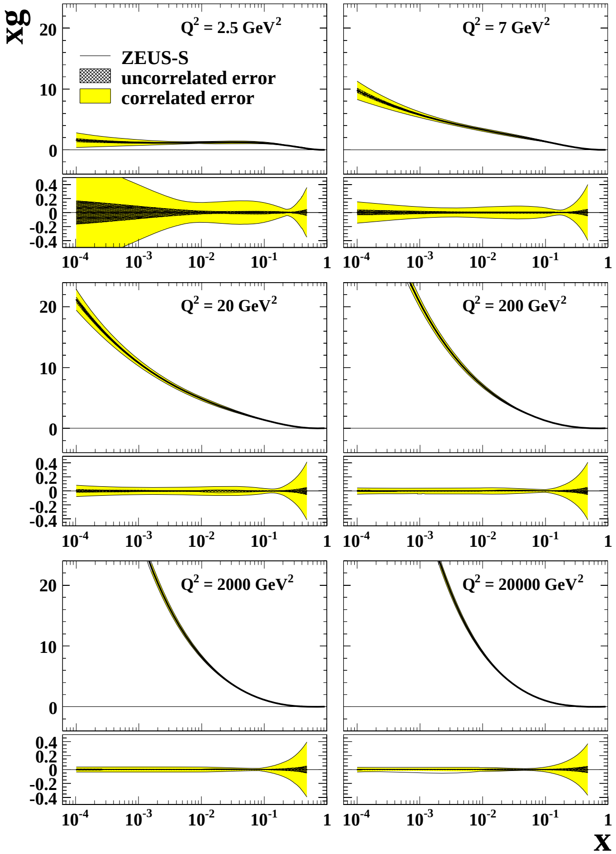


ZEUS-S without charm

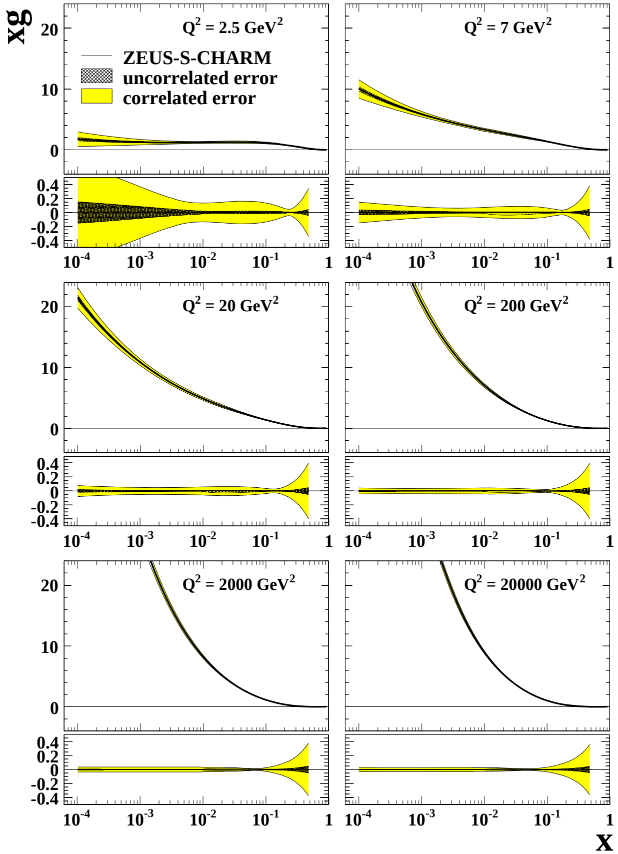


ZEUS-S with charm

Both of these have VFN alphas



ZEUS-S without charm



ZEUS-S with charm

Both of these have FFN alphas HYBRID 0.118