Progress in inputting heavy quark structure functions and cross-section measurements in ZEUS PDF fits

NOT an official ZEUS talk

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Michiel Botje

Inputting some of the new heavy flavour data into ZEUS-PDF fits

Technical difficulties

Comparison of fits to data

Impact of HQ data on PDFs

Expectations for more data

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

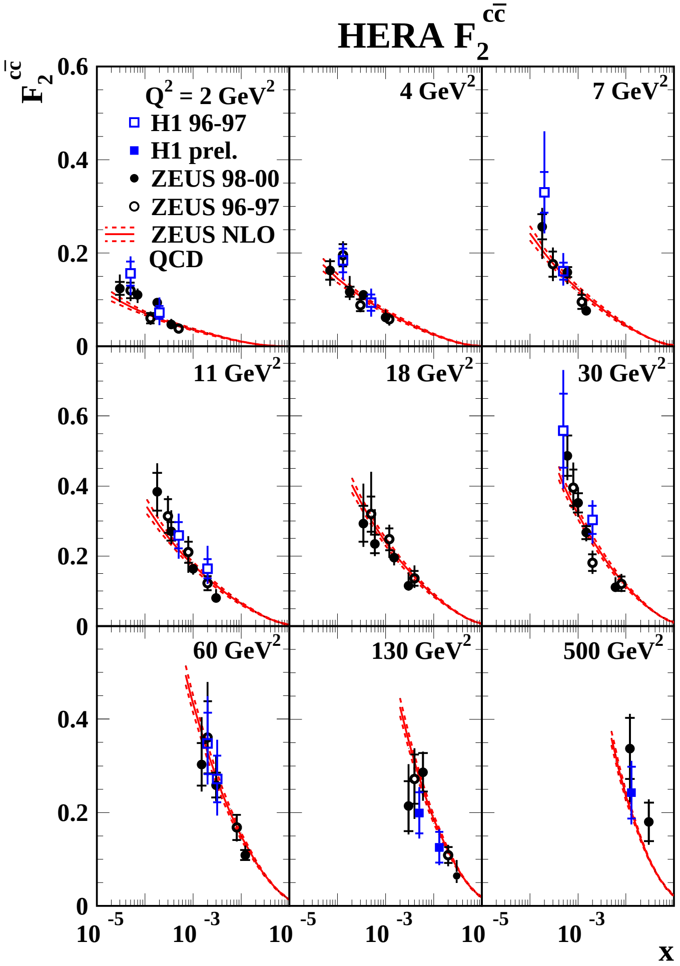
GMVFN

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

Also considert the treatment of running $\alpha_s(Q^2)$

Predictions for published ZEUS HERA-I charm data: F2c from 82pb-1 of data 1998-2000

Phys Rev D69, 012004, 2004



The predictions shown here are 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

We also varied the value of the charm quark mass in the range mc = 1.35±0.05- very small effect

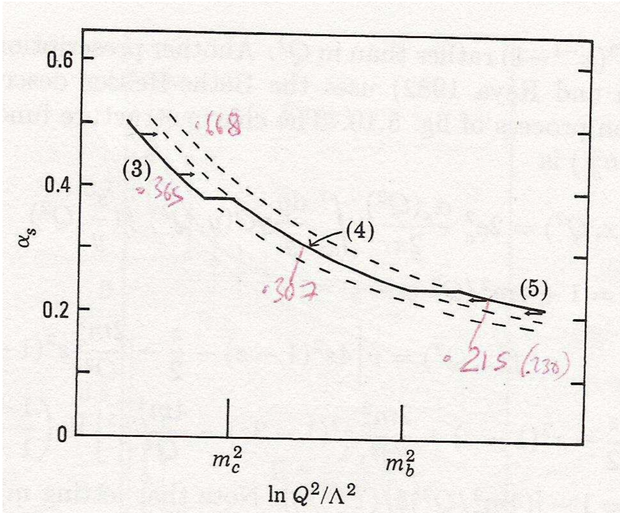
But what about the treatment of running $\alpha_s(Q^2)$?

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 $Q^2 = m_b^2$

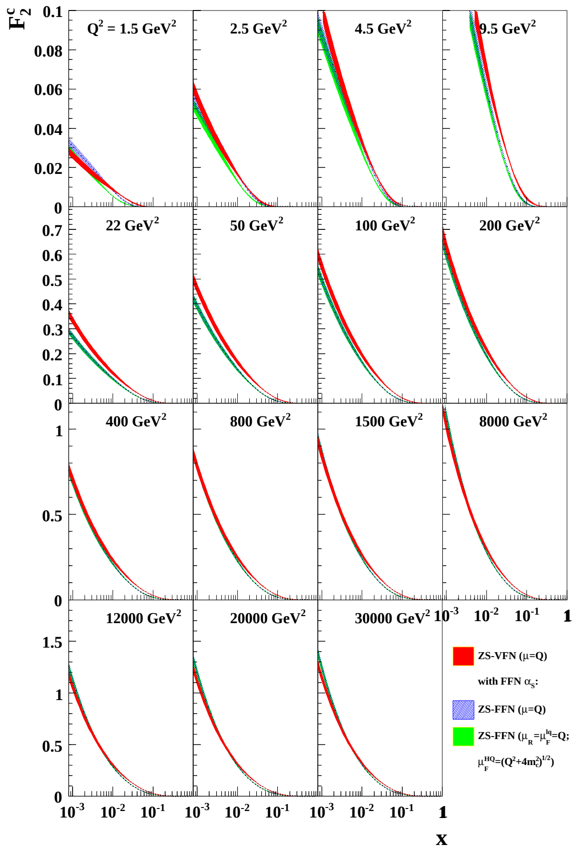


This has been widely used in MRST PDF fits (except hep-ph/0603143) and CTEQ fits (except CTEQ5FF3/4) and is used in QCDNUM. I will call it VFN $\alpha_s(Q^2)$

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.
Previously we used a VFN $\alpha_s(Q^2)$

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.

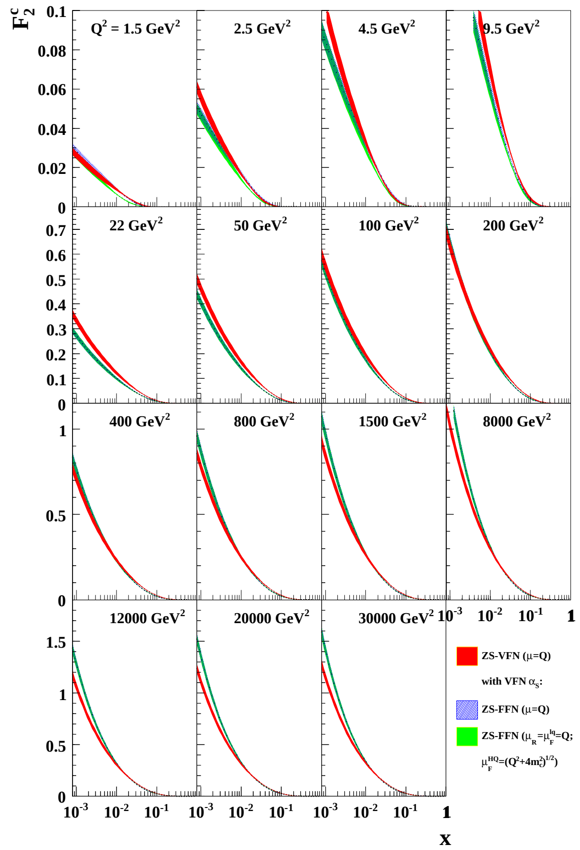
And here is what difference it makes to predictions for F2c



FFN with all scales =Q2

FFN with heavy quark factorisation scale =Q2+4mc2

And GMVFN (Thorne 2007)

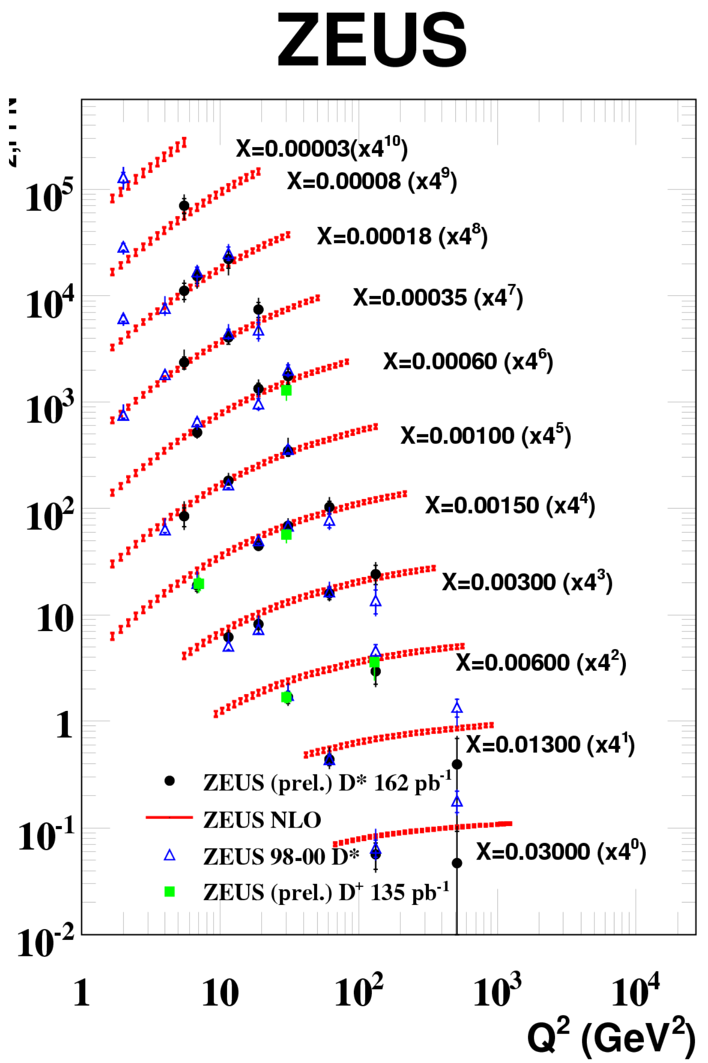


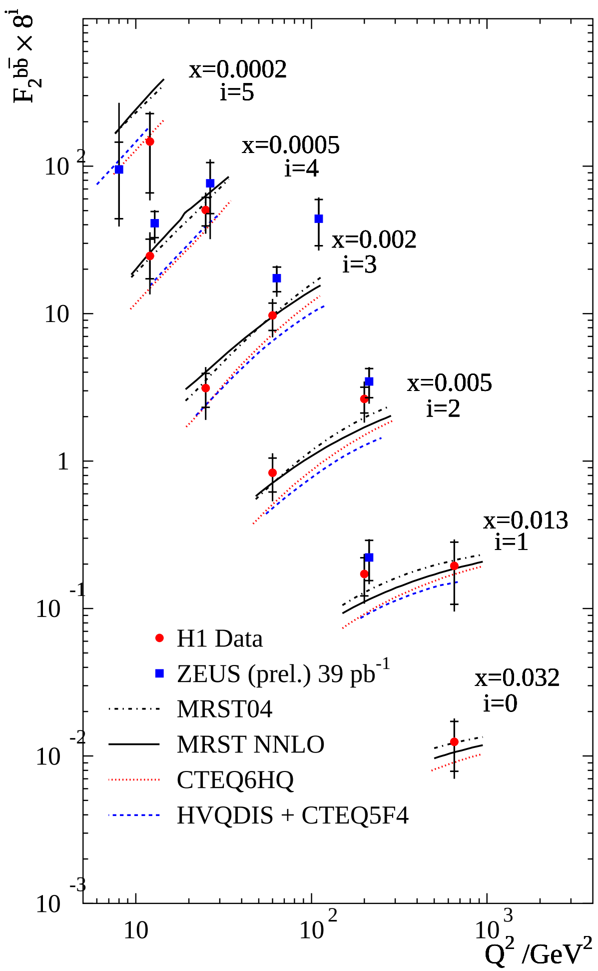
FFN predictions with 3-flavour αs(Q2)

FFN predictions with VFN αs(Q2)

FFN predictions are then more compatible with GMVFN at higher Q2

What are the new/old data sets we can add in?





F2c from 162 pb-1 of D* data e±p from 2003-2005

F2c from 135pb-1 of D+ data e-p from 2004-2005

F2c from 82pb-1 of D* data from e+p 1998-2000

F2b from 39pb-1 of μ +jet data from 2003-2004

Note differences in heavy quark predictions from different groups

Will show FFN and GMVFN fits to ZEUS data alone using ZEUS PDF fit formalism

Data included are NC and CC e± p inclusive cross-sections and jet cross-sections from HERA-I and NC and CC e- p inclusive cross-sections from HERA-II as specified for the ZEUS-pol. Fit (see talk of Kunihiro Nagano in SF+EW session). Compare using just these data, to using these data plus F2c and F2b measurements.

HEALTH WARNING

Should not pursue an FFN fit to very high Q2. Does not resum $\ln(Q^2/mh^2)$

In practice χ2 for high Q^2 (Q2 > 3000 GeV2) NC data is not bad

CC data is another matter

At HERA it is all high Q2 such that we are above the charm threshold for

W+s →c

But what about NLO BGF in the FFN scheme?

W+g →c+sbar

Need heavy quark coefficient functions for this, they are not in QCDNUM

In practice χ2 for CC data is not so bad

MOST RESULTS QUOTED FOR GMVFN

The PDF parametrization

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

p1u,p1d,p1g are fixed by sum rules, p2u=p2d, and p5s=0.

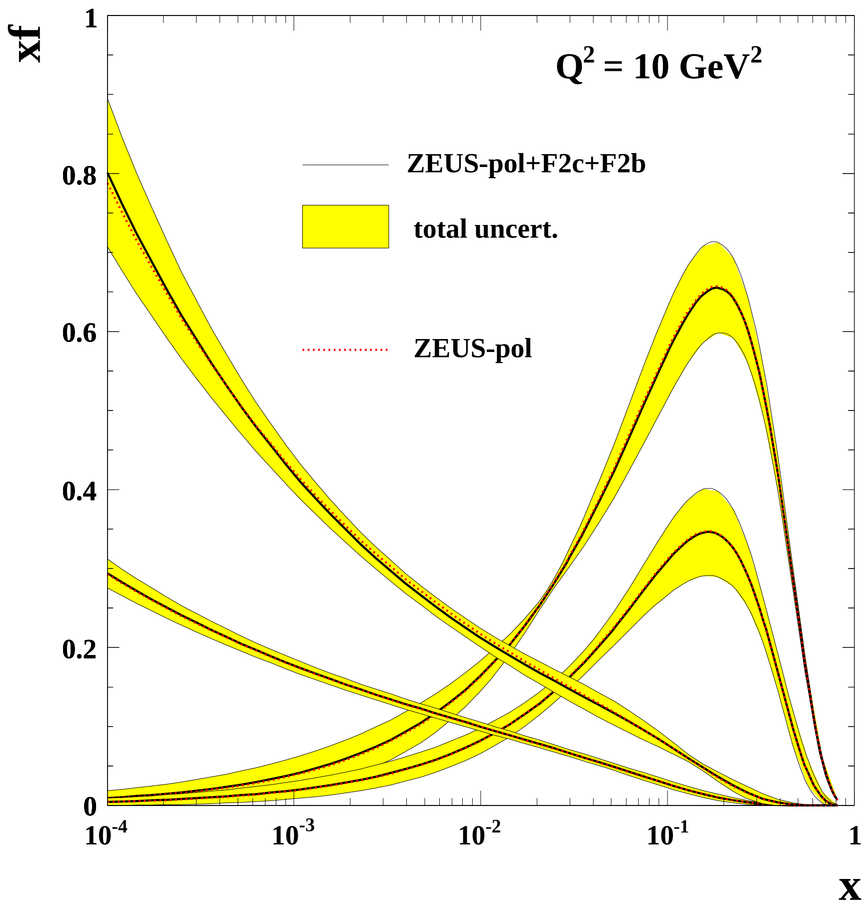
Standard fit is done using GMVFN scheme of Thorne 2007

Adding the heavy flavour data has very little influence on the central values of the fit.

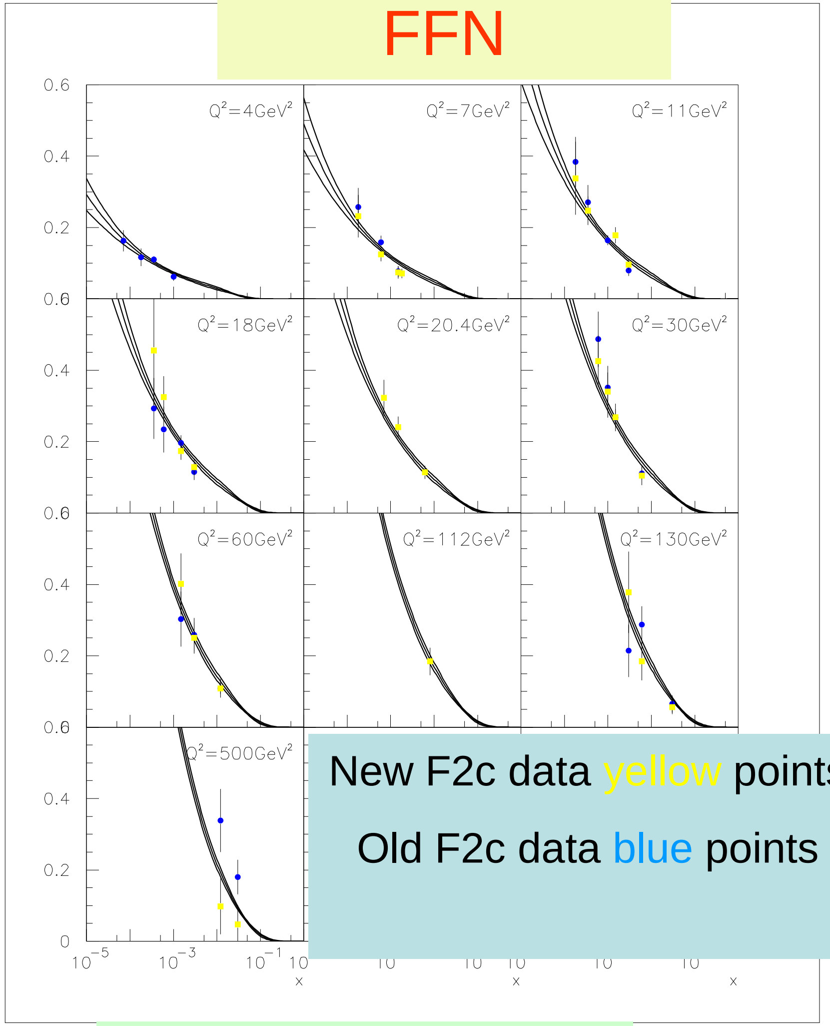
Heavy flavour data is well fit, but fit χ2 depends on charm mass, prefers values mc = 1.4-1.5 GeV

Compare FFN fit which prefers mc=1.3-1.4 GeV

No sensitivity to beauty mass



FFN



New F2c data yellow points

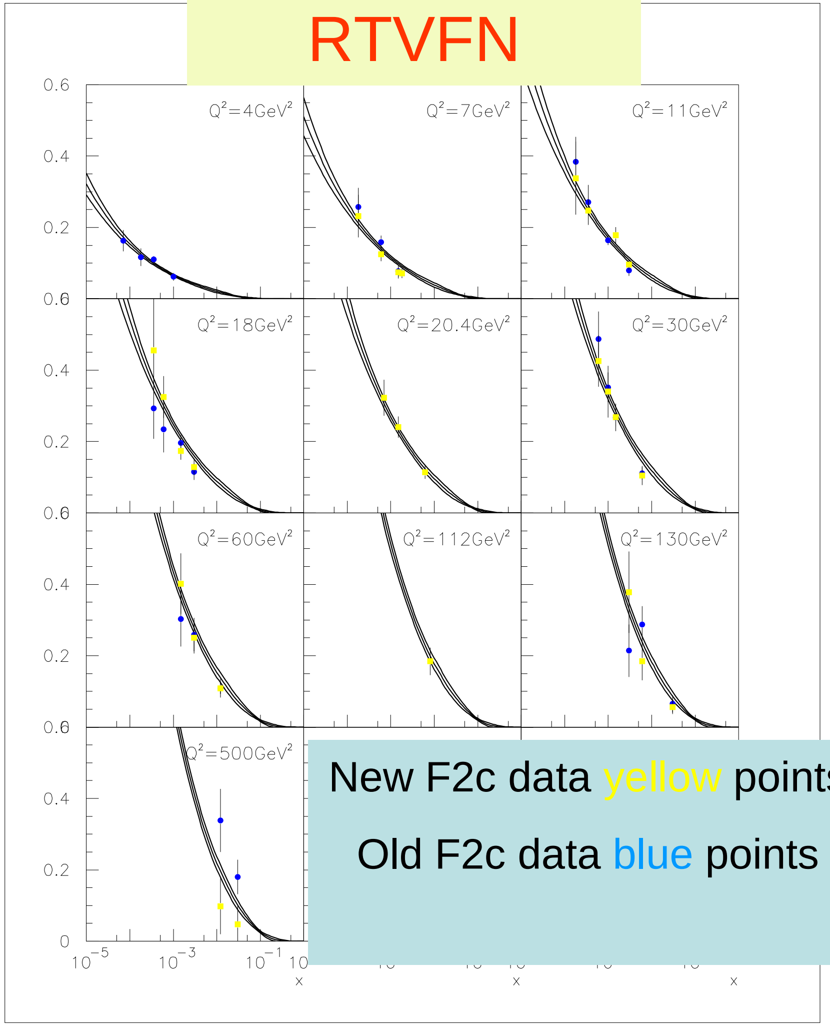
Old F2c data blue points

Predictions for F2c from an FFN fit with both F2c and F2b

χ2 /ndp =0.87 for F2c 03-05
χ2 /ndp =1.32 for F2c 98-00

mc = 1.35 GeV

RTVFN



New F2c data yellow points

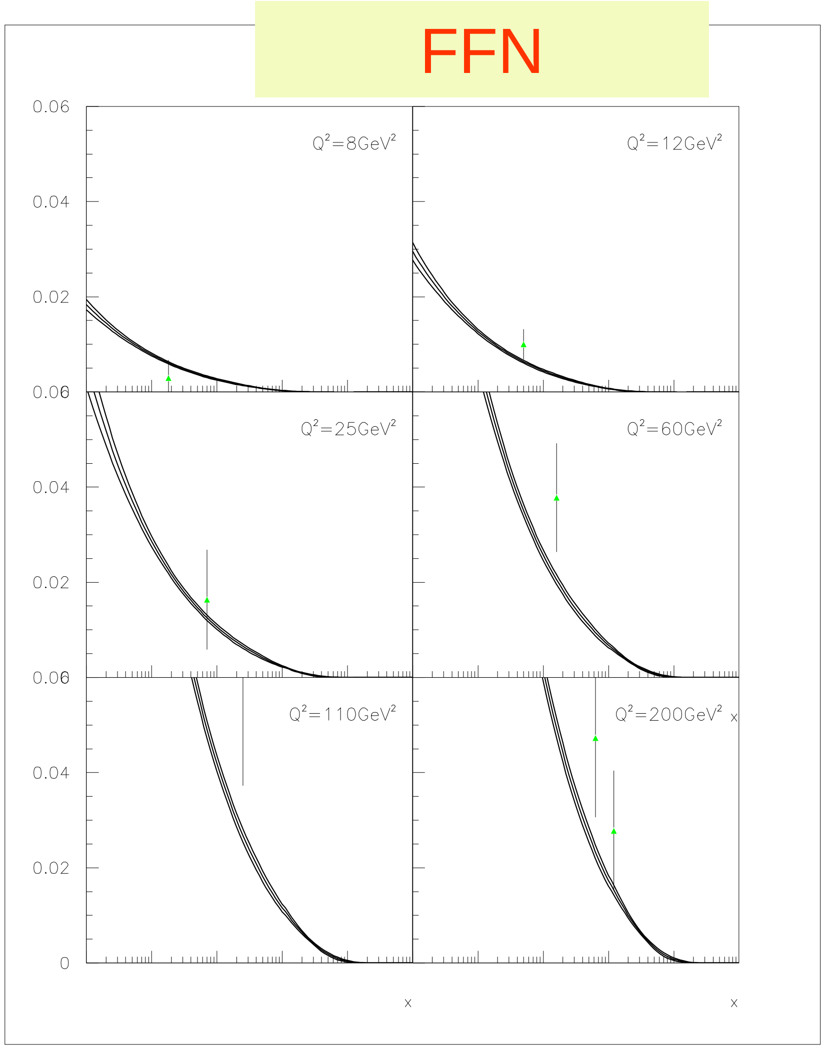
Old F2c data blue points

Predictions for F2c from an GMVFN Thorne 2007 fit with both F2c and F2b

χ2 /ndp =0.87 for F2c 03-05
χ2 /ndp =1.42 for F2c 98-00

mc = 1.45 GeV

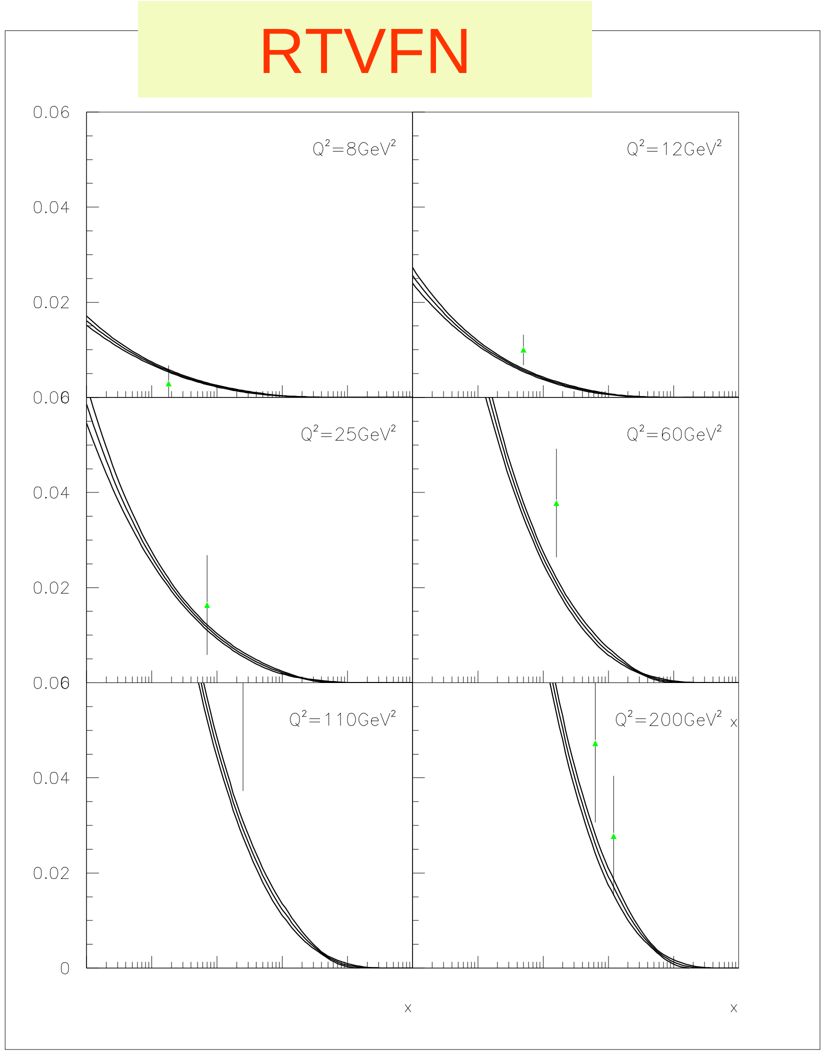
NOTE difference in charm mass



Predictions for F2b from an FFN fit with both F2c and F2b

$\chi2$ /ndp = 1.29 for F2b

mb=4.3

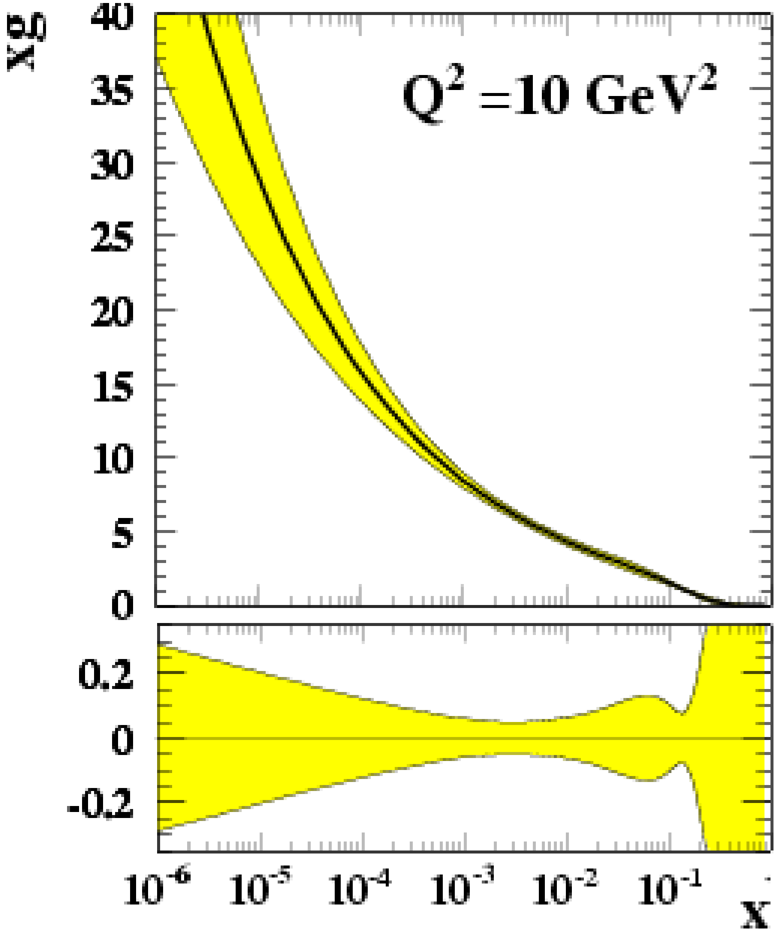


Predictions for F2b from an GMVFN Thorne 2007 fit with both F2c and F2b

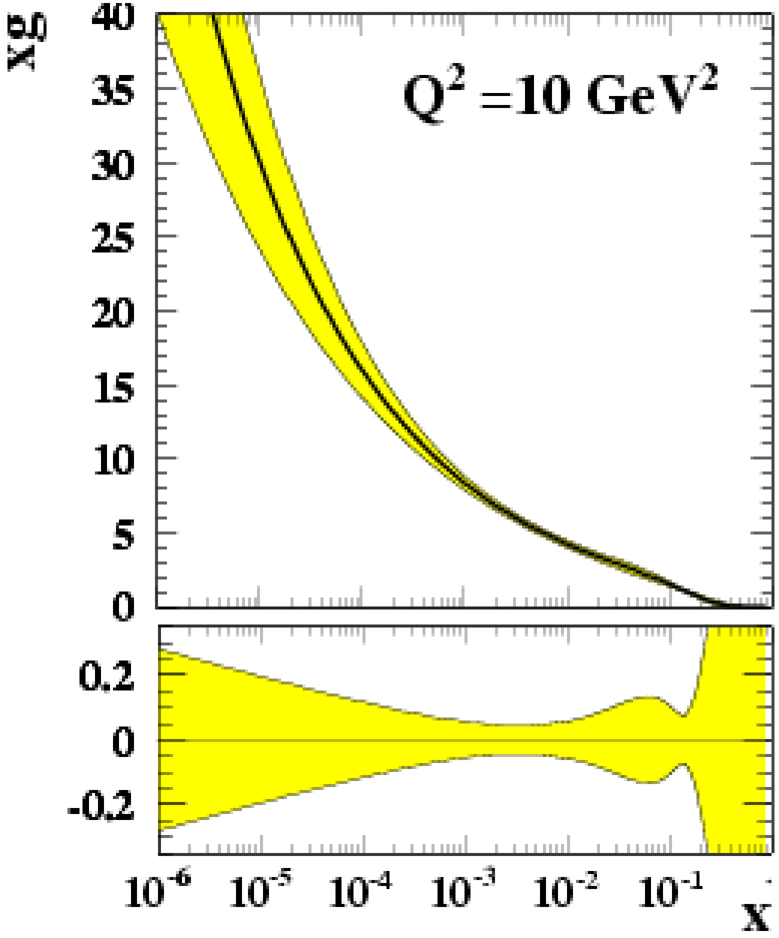
$\chi2$ /ndp = 1.20 for F2b

mb=4.3

Impact of HQ structure function data



PDFs without HQ data GMVFN Thorne 2007

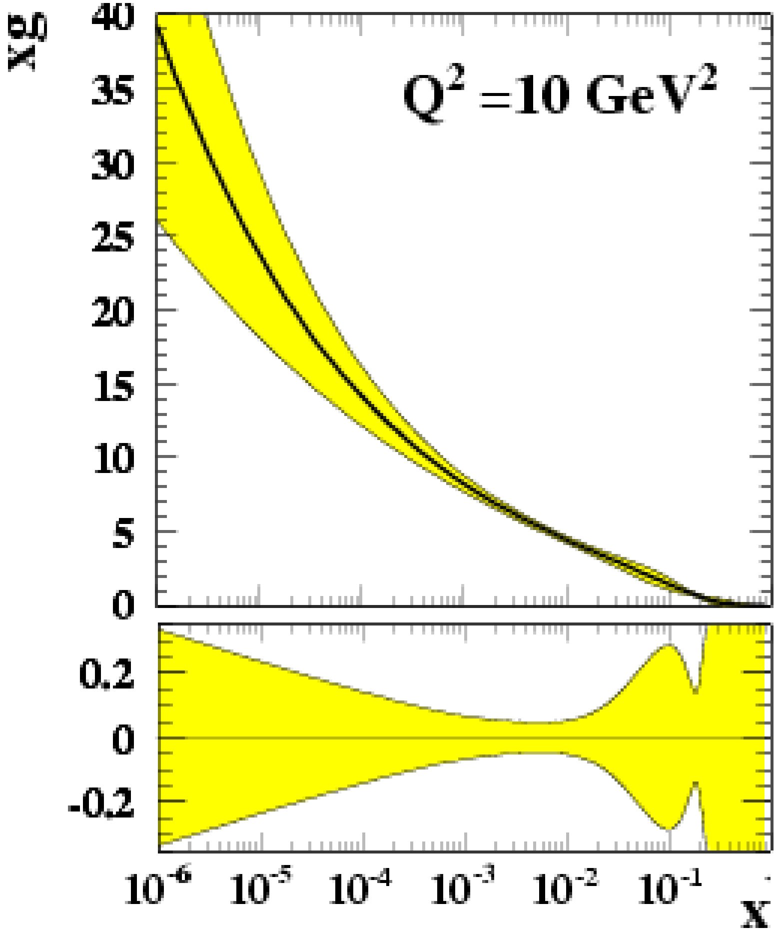


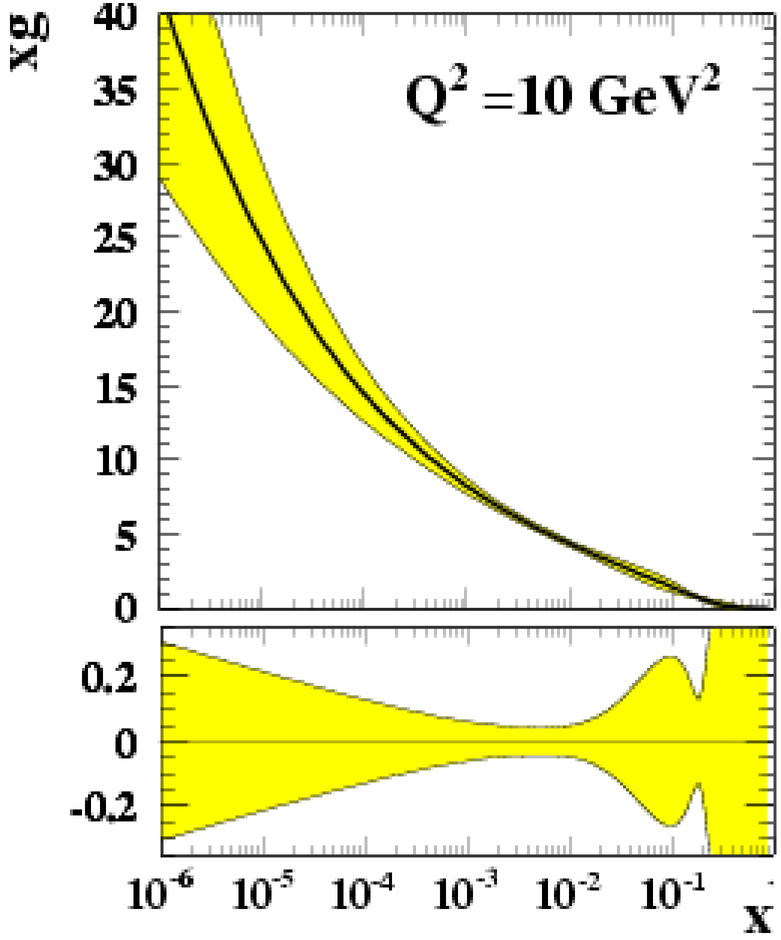
PDFs with F2c F2b GMVFN Thorne 2007

Effect of adding in heavy flavour data is mostly seen in the gluon PDFs

Those with good eyesight can see it at very low-x

Impact of HQ structure function data



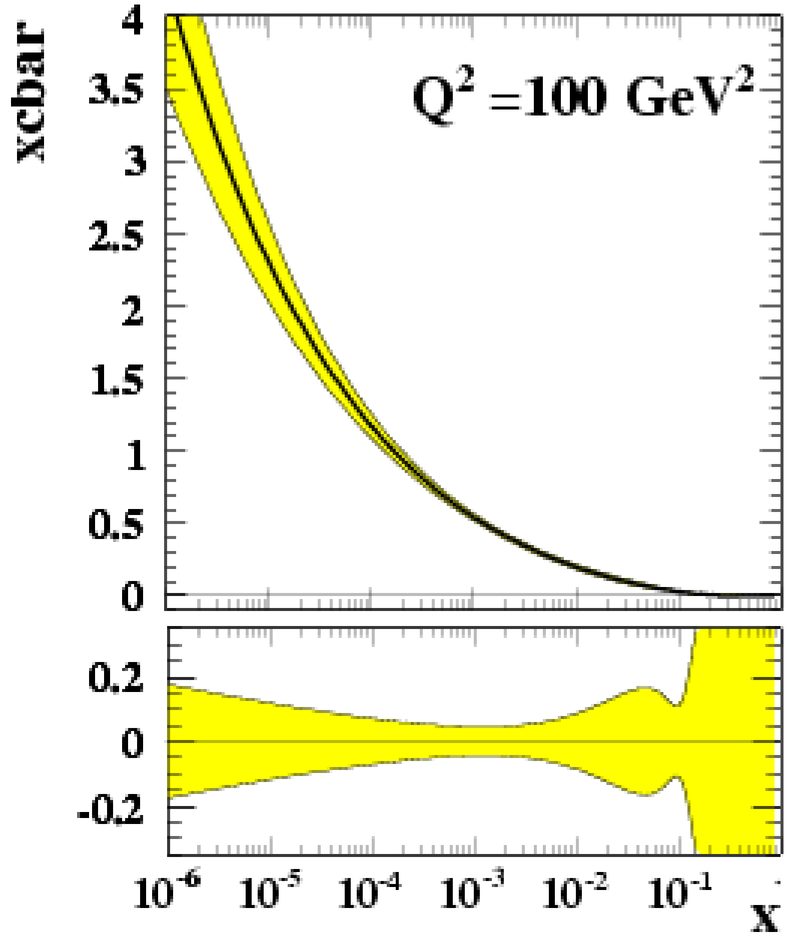


PDFs without HQ data and without jets

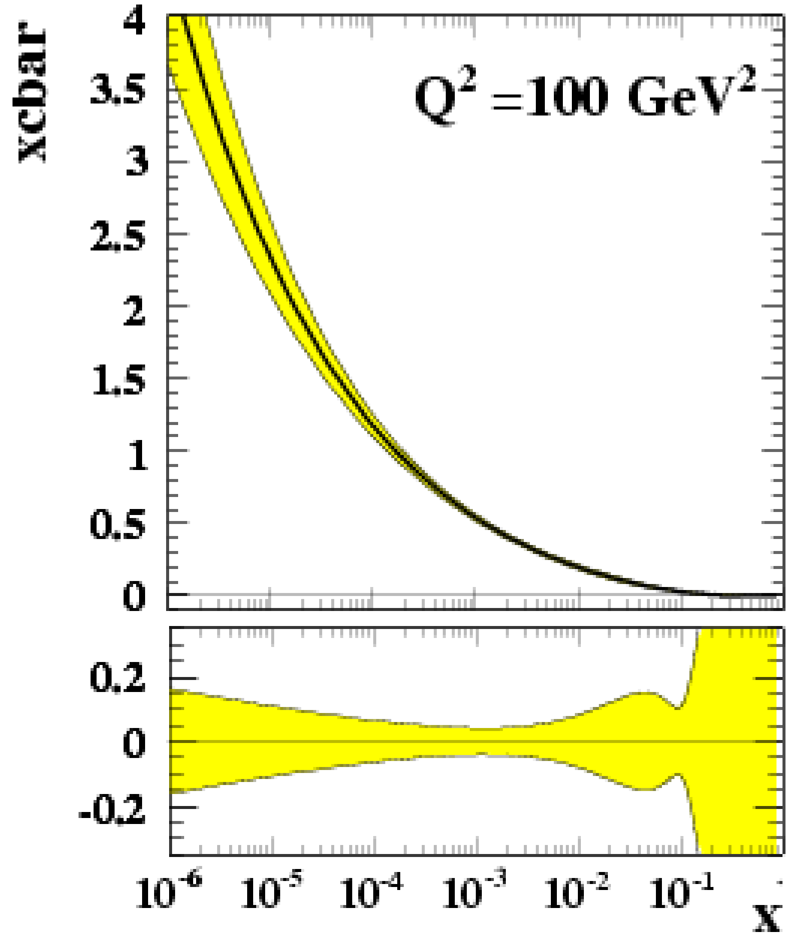
GMVFN Thorne 2007

The effect is more visible if we do not use the JET data in the fits There is a visible effect on the low-x gluon AND on the high-x gluon- from the momentum sum-rule

Impact of HQ structure function data



PDFs without HQ data and without jets
GMVFN Thorne 2007



PDFs with F2c F2b and without jets
GMVFN Thorne 2007

You can also see the reduction in uncertainty on the charm quark distribution itself!

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} ?

To be consistent with the method of extraction of the data use FFN fit

→ Evolve α_s for three flavours only

→ FFN not applicable at high Q^2, so apply cut $Q^2 < 3000$ GeV^2

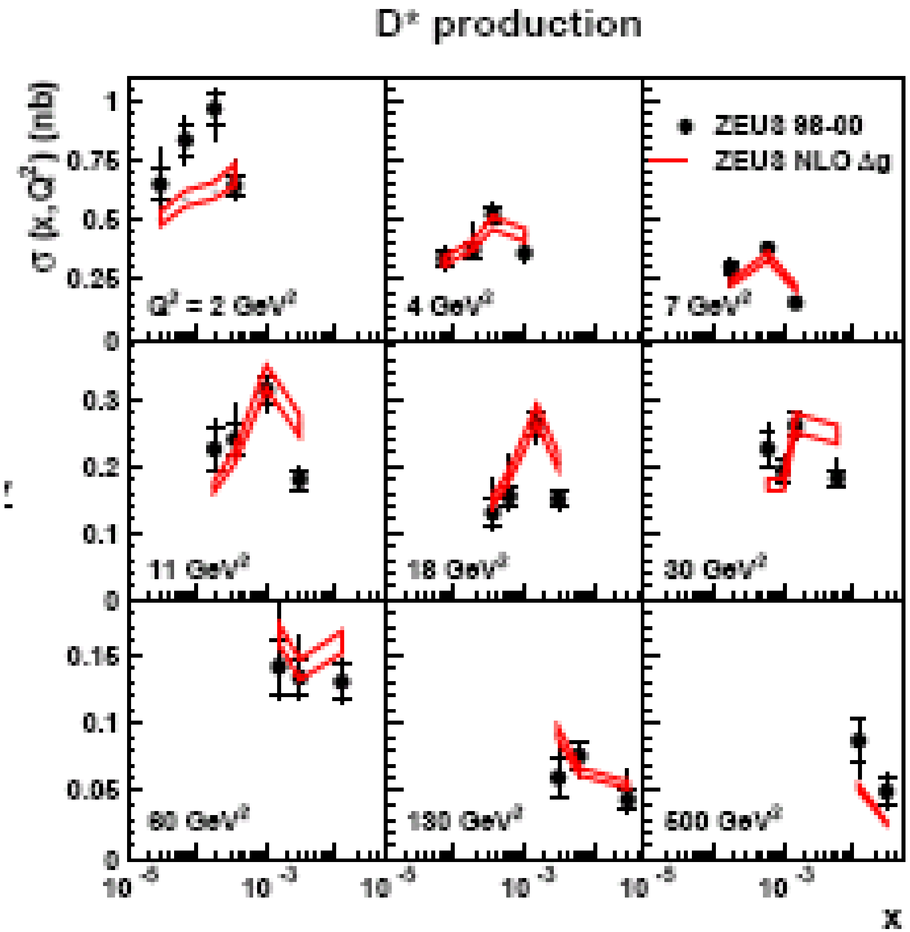
→ With upper Q^2 cut, not enough information from only ZEUS data

- need fixed target data to help constrain PDFs

Use ZEUS-S global fit (Phys Rev D67, 012007,2003) as basis for D*fit

D*cross-sections from

Phys Rev D69,012004,2004



kinematic region:

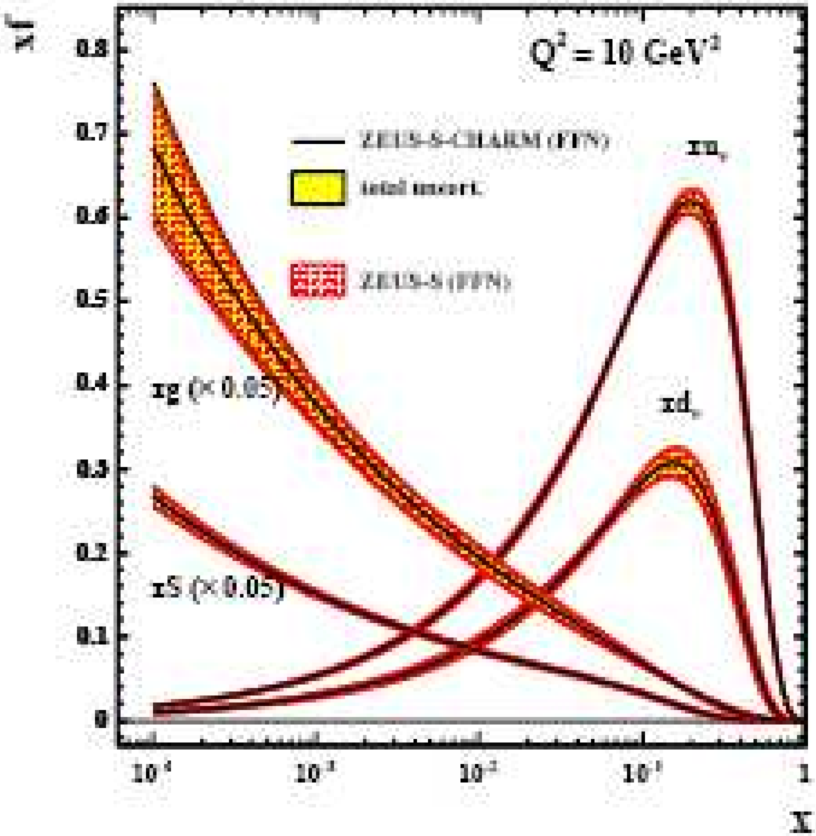
$1.5 < Q^2 < 1000\ GeV^2,\ 0.02 < y < 0.7$

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

Results of fitting D* cross-sections

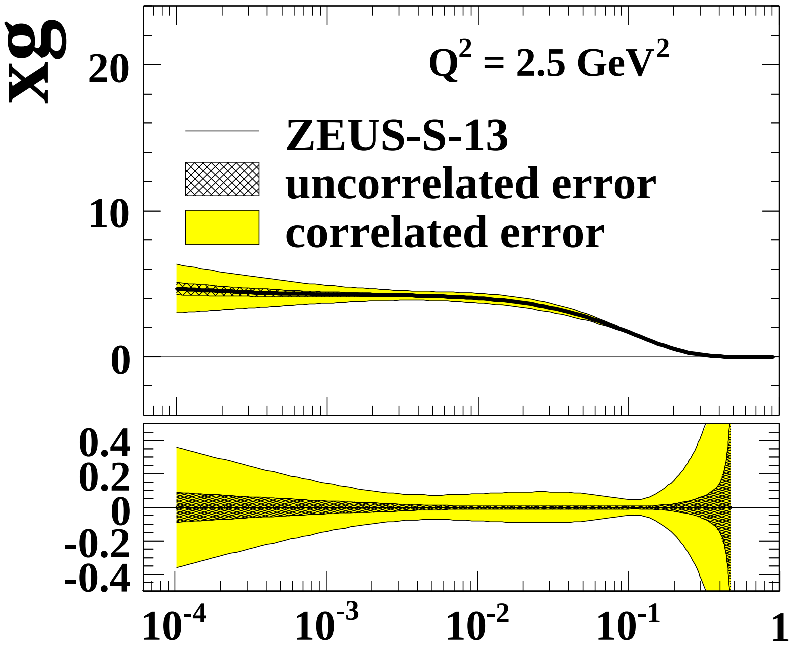
Central values of fit with and without charm cross-sections are very similar

Consistency of approach

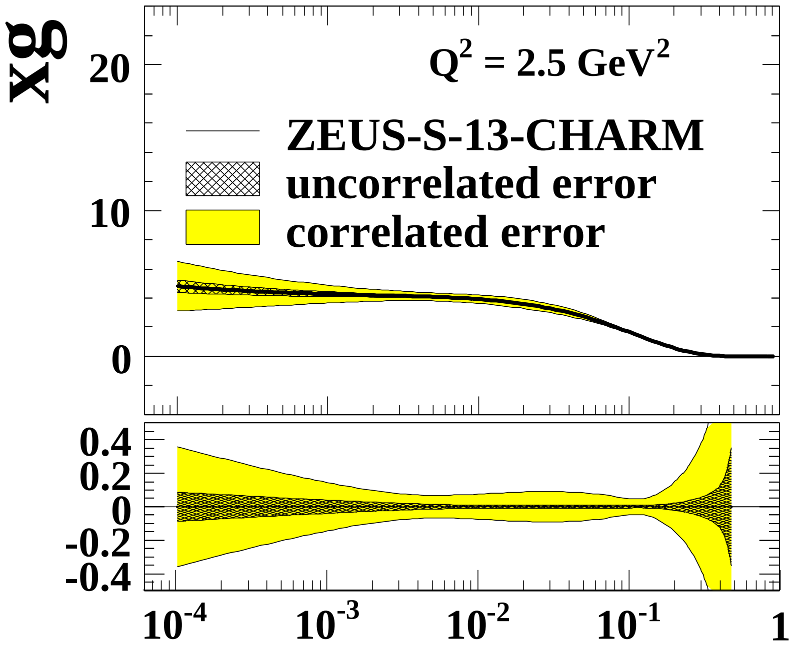


Impact of HQ cross-section data

Without D* cross-sections



With D* cross-sections



No striking improvement but consistency of D* data with the PDF fit formalism

Summary

Including heavy flavour data in the PDF fits shows consistency with the GMVFN formalism within NLO DGLAP

There is also a marginal improvement in the gluon and charm PDFs

FFN fits also fit heavy flavour data but to use this scheme the coefficient functions for CC W+g →c +sbar must be input to QCDNUM

There are further reservations about its use at high Q2

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

Use double differential D* cross-sections rather than extrapolate to F2c?

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

F2c from 162 pb-1 of D* data to become ~360 pb-1 -

F2c from 135pb-1 of D+ data to become ~180pb-1

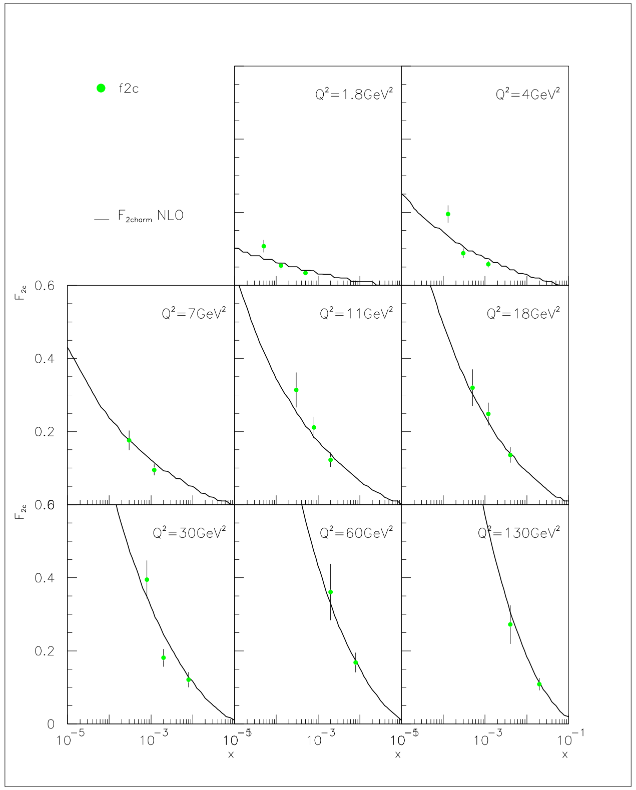
F2b from 39pb-1 of μ +jet data to become ~360pb-1

Not only improved statistics but improved technique (impact parameter) will improve precision.

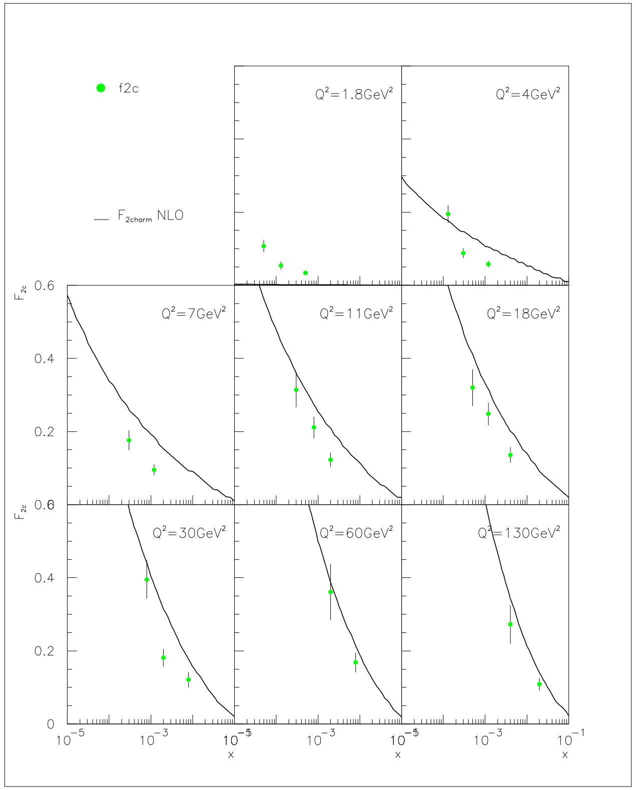
What about combining ZEUS and H1 heavy flavour data?

Extras

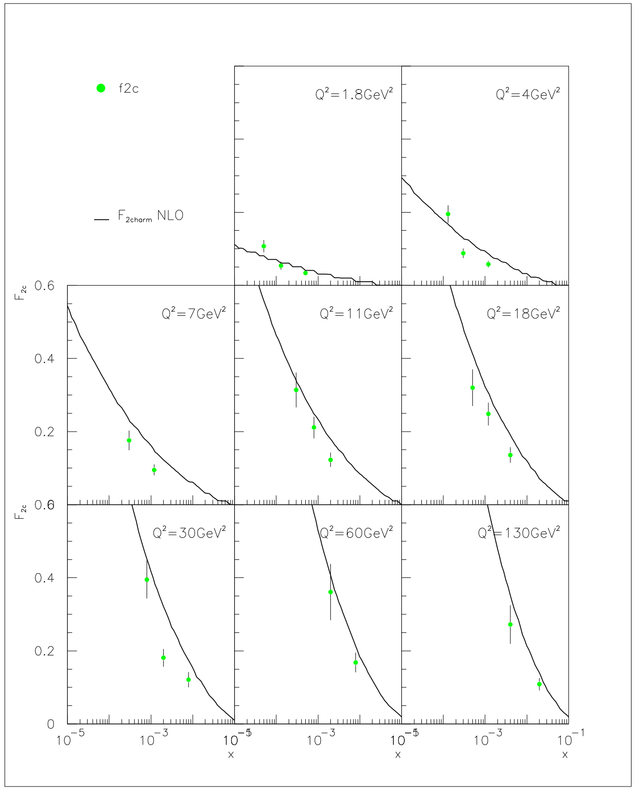
Here's the predictions of the three different schemes for F2c – all using the same PDF parameters



FFN



ZM-VFN



GM-VFN

The data points are old ZEUS F2c data

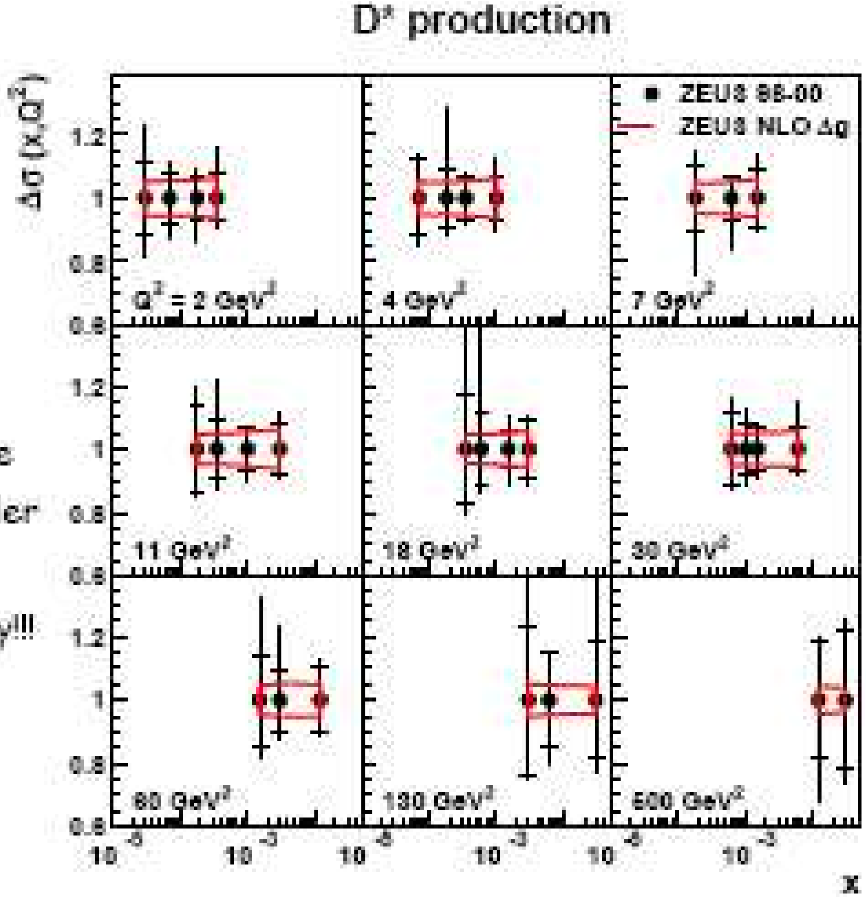
Should we expect a significant improvement?

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

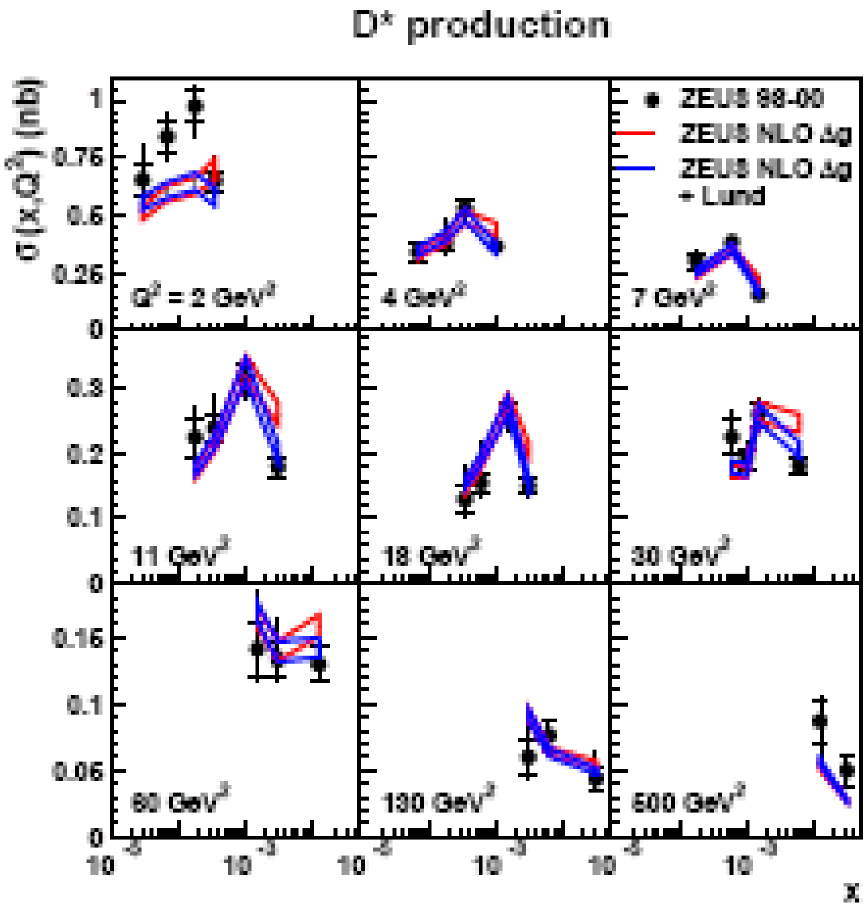
What if we had used an alternative fragmentation function when producing the NLO grid predictions?

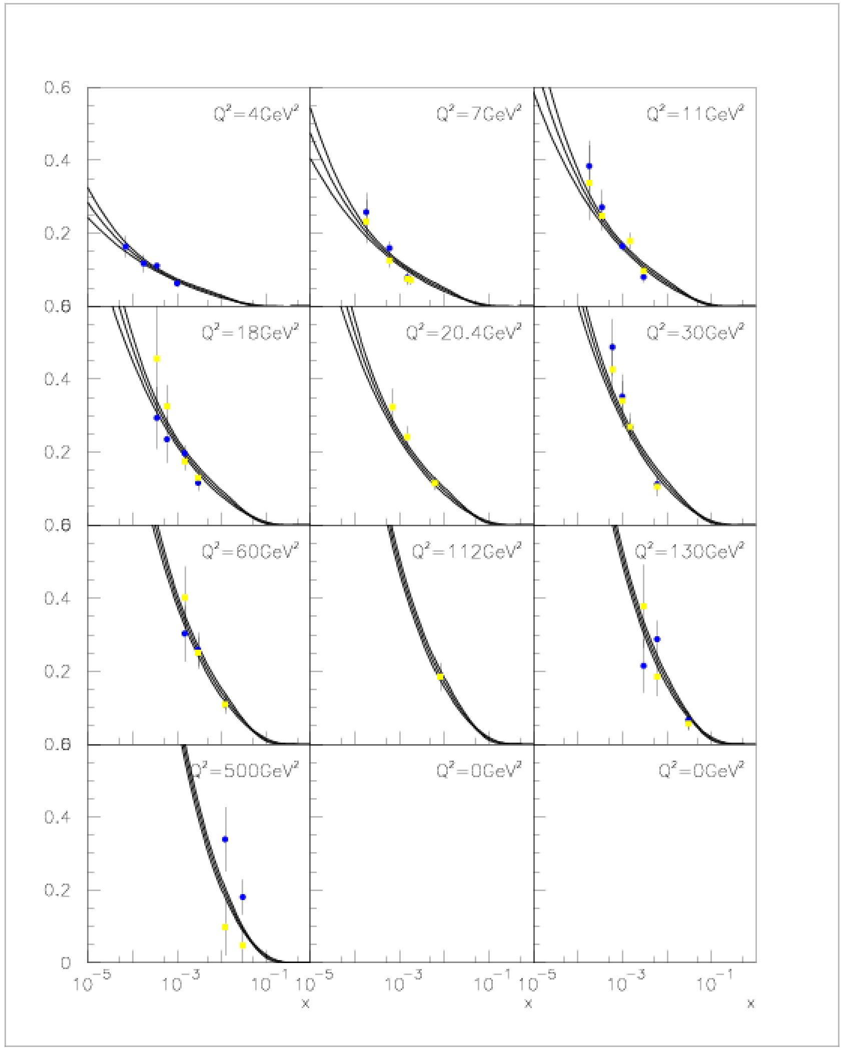
Petersen was used

But we could have used Lund

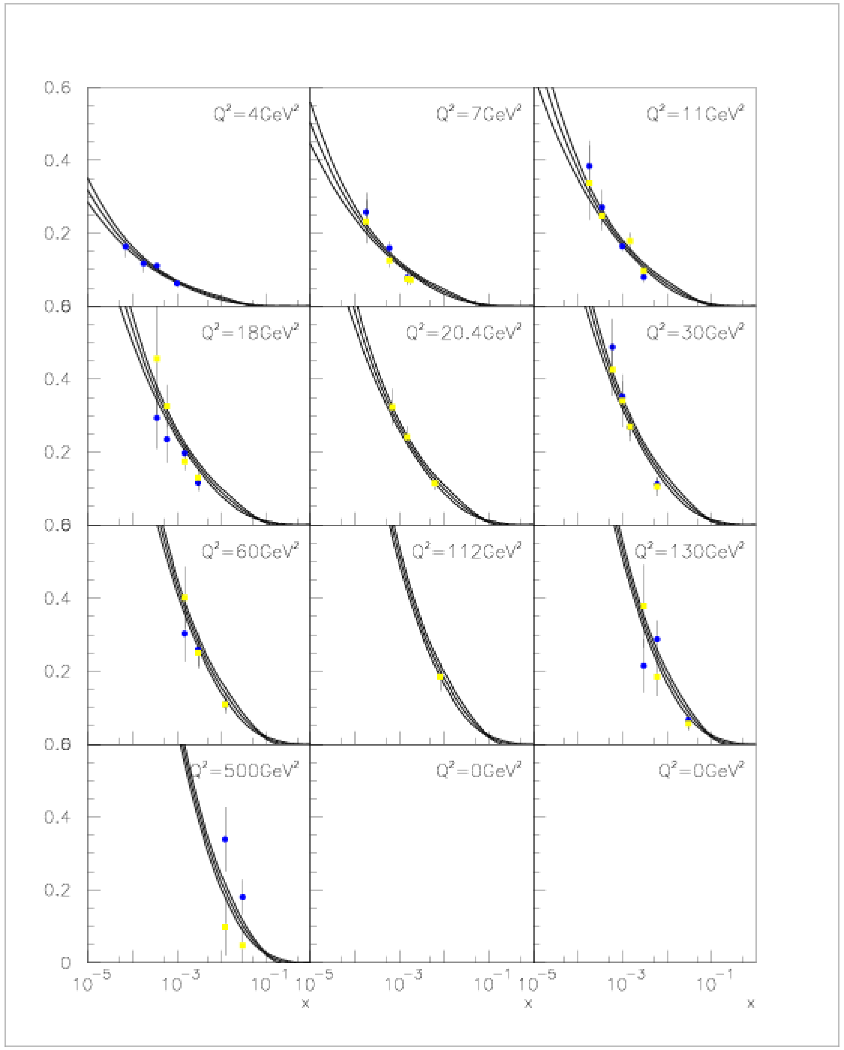
Which seems to give a somewhat better description of the data

This was not pursued…but it could be

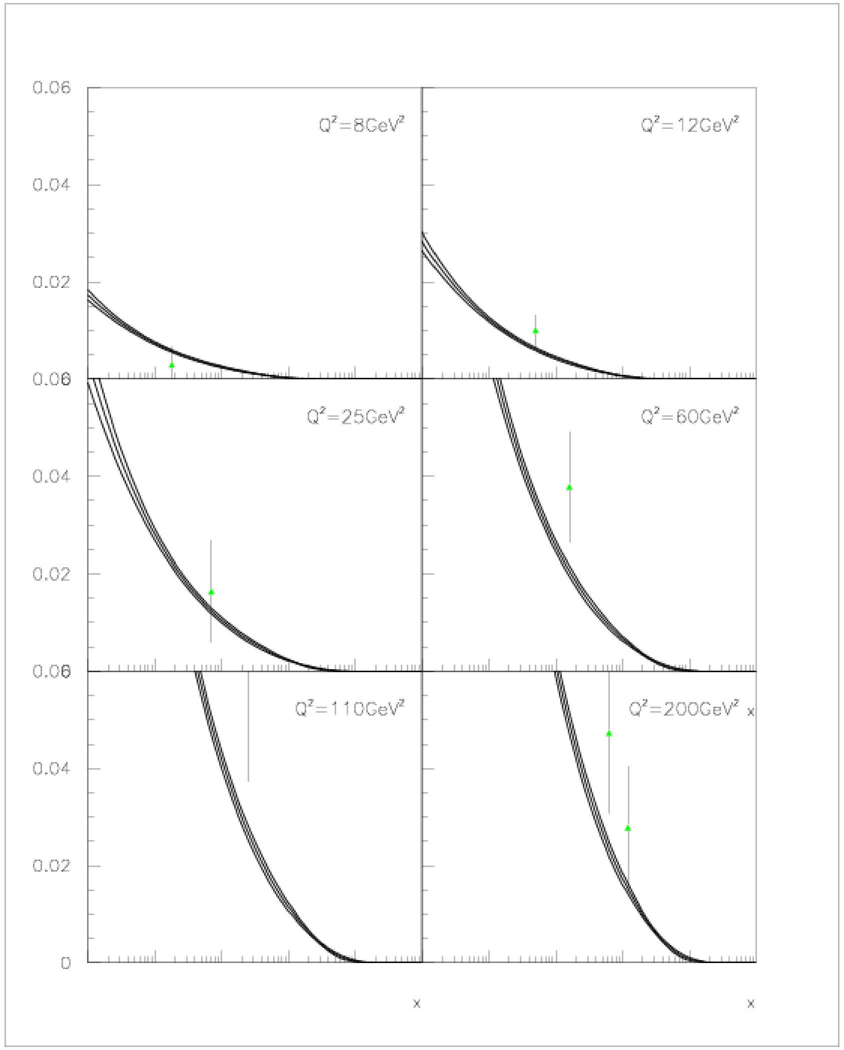




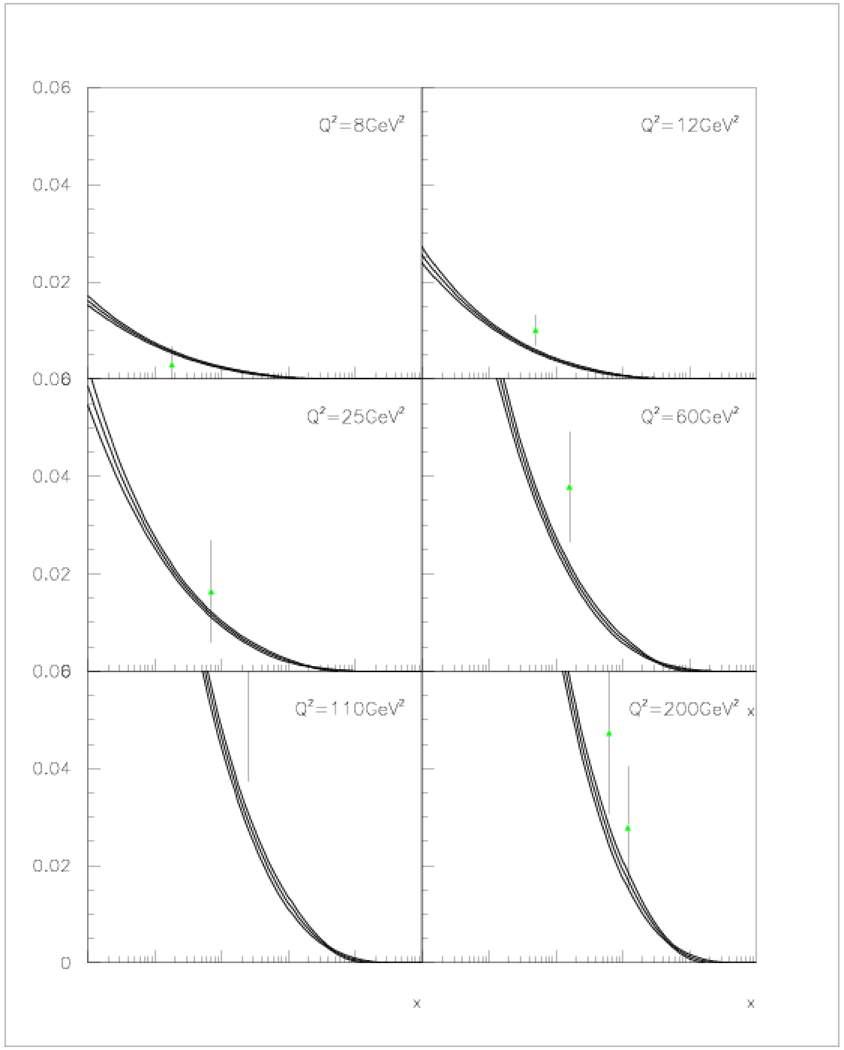
Predictions for F2c using FFN but F2c is Not in the fit



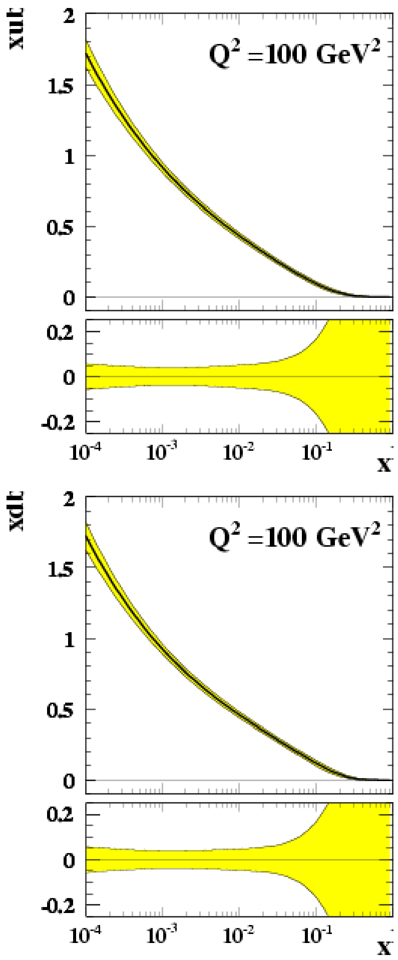
Predictions for F2c using RTVFN 2007 but F2c is Not in the fit



Predictions for F2b using FFN but F2b is Not in the fit

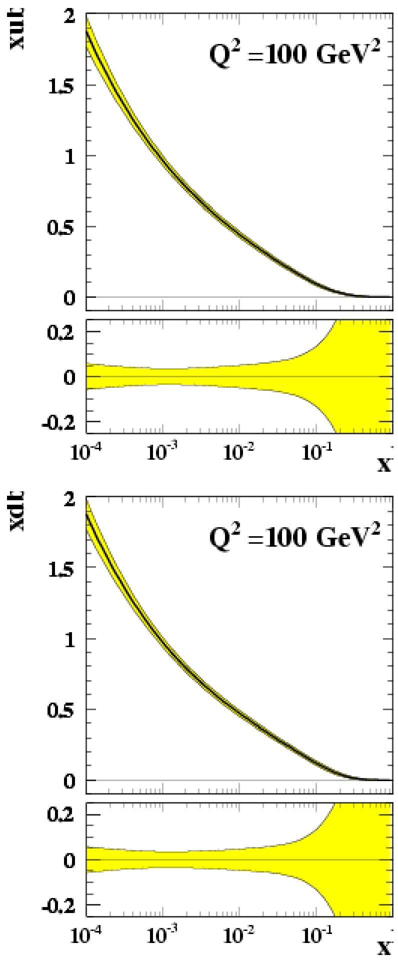


Predictions for F2b using RTVFN 2007 but F2b is Not in the fit



PDFs with F2c F2b

GMVFN Thorne 2007



PDFs with F2c F2b
FFN