Proton Structure from HERA to LHC

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on behalf of H1/ZEUS Collaborations

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Combination of ZEUS and H1 data and PDF fits to these data:

1. Inclusive cross-sections HERA-1 (1992-2000):arxiv:0911.0884 -improved constraints at low-x
2. F2(charm) data (preliminary)- constraints on the charm mass parameter, m_c(model)
3. Low energy runs – FL- 2007- (preliminary) –tension with low x, Q2 data?
4. Inclusive cross-sections HERA-II (2003-2007)- (preliminary) -improved constraints at high-x

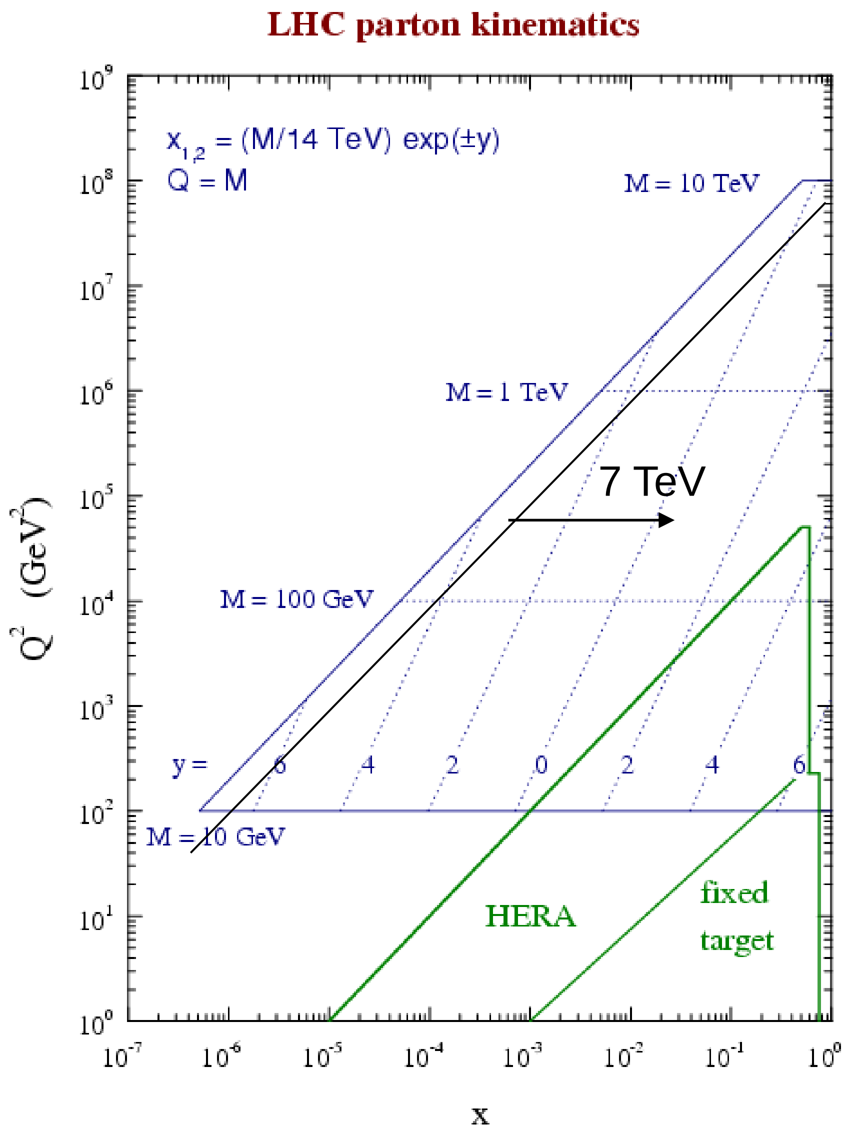
Predictions for LHC cross-sections: W/Z, Higgs, t-tbar

Predictions for Tevatron cross-sections: W/Z, high-ET jets

Why combine ZEUS and H1 data?

At the LHC we collide protons Protons are full of partons. Our knowledge of partons comes from Deep Inelastic Scattering data. HERA dominates these data and is most relevant for the kinematic region of early LHC data

We think we know how to extrapolate in Q^2 using (N)NLO QCD (using the DGLAP equations) but we don't a priori know the shapes of the parton distributions in x. The HERA data is our best guide



$$\frac{dq(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y}\left[P_{qq}(z)q(y,Q^2)+P_{qg}(z)g(y,Q^2)\right]$$

$$\frac{dg(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y}\left[\Sigma_q P_{gq}(z)q(y,Q^2)+P_{gg}(z)g(y,Q^2)\right]$$

DGLAP eqns

A substantial part of the uncertainty on parton distributions comes from the need to use many different input data sets with large systematic errors and questionable levels of consistency

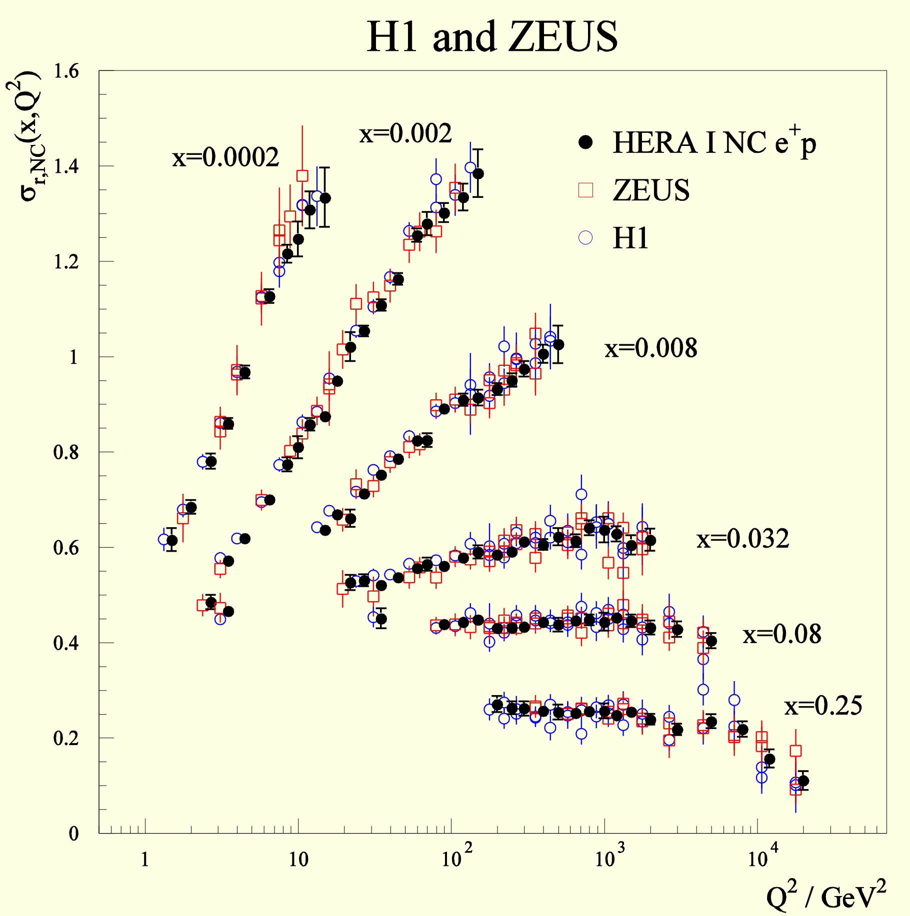
- Averaging H1 and ZEUS data provides a model independent tool to study consistency of the data and to reduce systematic uncertainties:

⇒ Experiments cross calibrate each other JHEP 1001.109 arxiv:0911.0884

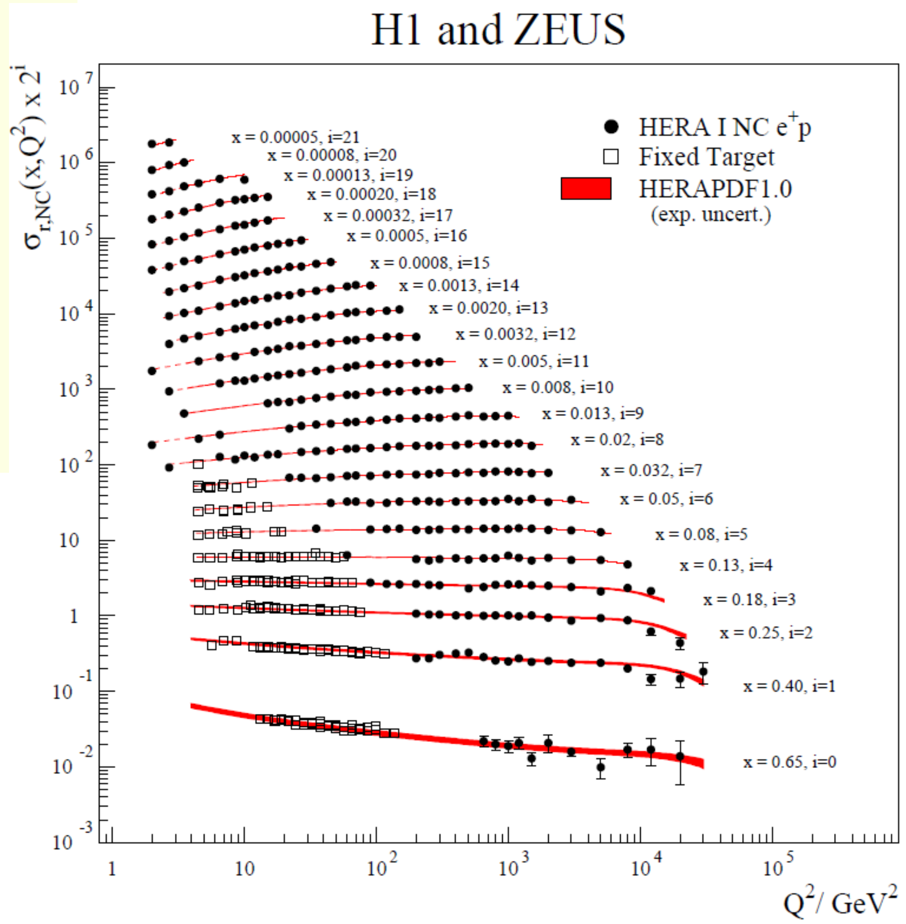
- The combination method includes accounting for full systematic error correlations.

- The resulting combination is much more accurate than expected from the increased statistics of combining two experiments.

- The post-averaging systematic errors are smaller than the statistical across a large part of the kinematic plane



This page shows NC e+ combined data



Results of the combination compared to the separate data sets

These data are used for extracting parton distributions: HERAPDF1.0

Some of the debates about the best way of estimating PDF uncertainties concern the use of many different data sets with varying levels of consistency.

The combination of the HERA data yields a very accurate and consistent data set for 4 different processes: e+p and e-p Neutral and Charged Current reactions.

Whereas the data set does not give information on every possible PDF flavour it does:

•Give information on the low-x Sea (NCe+ data)

•Give information on the low-x Gluon via scaling violations (NCe+ data)

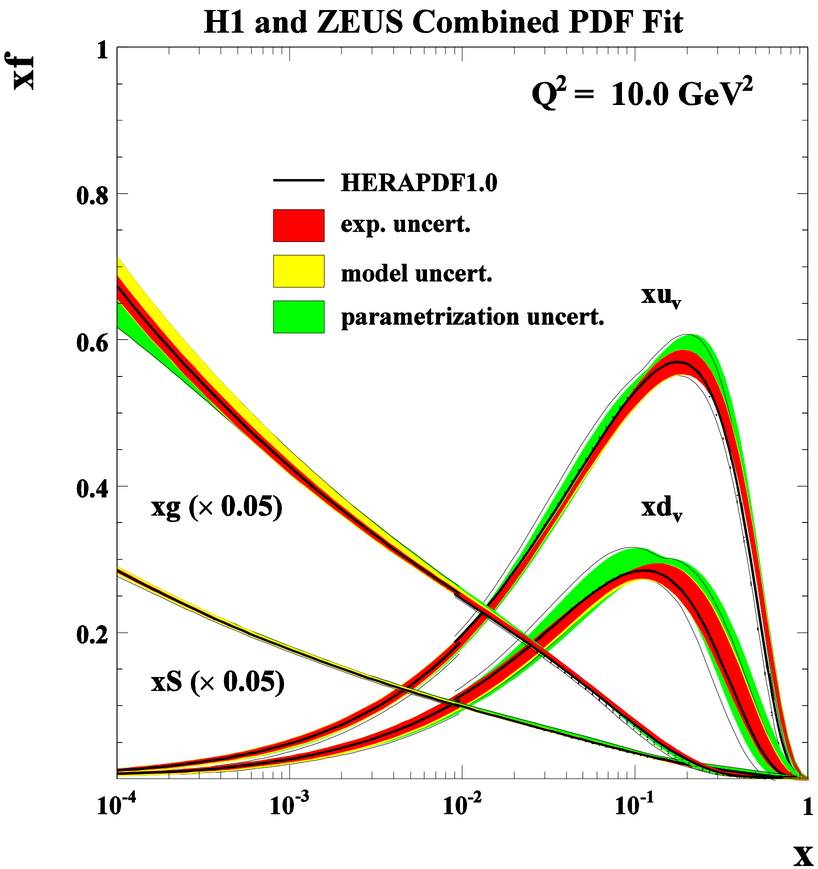
•Give information on high-x u (NCe+/e- and CCe-) and d (CCe+ data) valence PDFs

•Give information on u and d-valence shapes down to x~3 10^{-2} (from the difference between NCe+ and NCe-)

NOTE the use of a pure proton target means d-valence is extracted without need for heavy target/deuterium corrections or strong iso-spin assumptions these are the only PDFs for which this is true

Furthermore, the kinematic coverage at low-x ensures that these are the most crucial data when extrapolating predictions from W, Z and Higgs cross-sections to the LHC

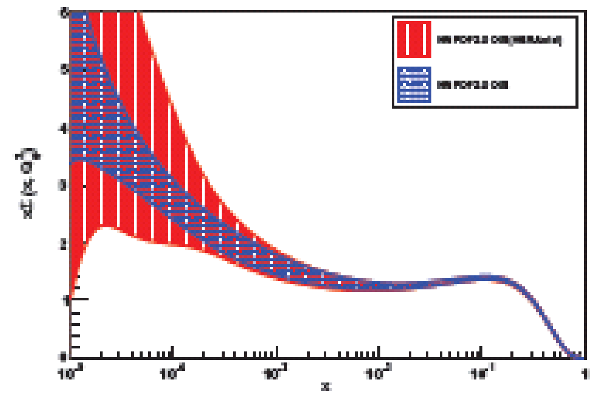
RESULTS for HERAPDF1.0 – arxiv:0911.0884



And here is a summary plot of the HERAPDF results

Experimental uncertainties on PDFs are extracted with $\Delta\chi2=1$, and model and parametrization uncertainties are also evaluated.

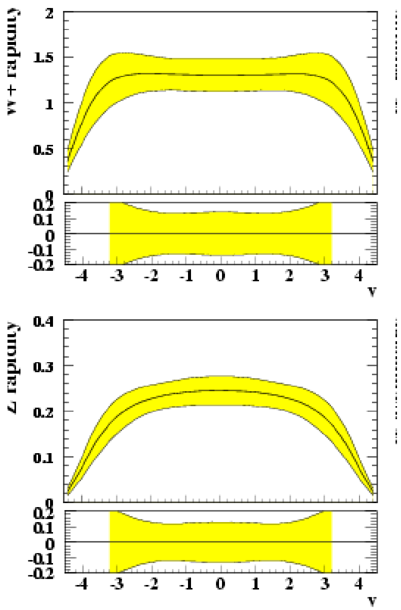
Effect of using HERA combined data on other PDf analyses



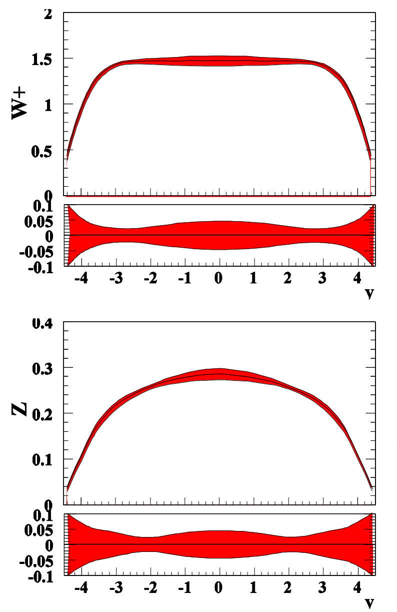
The NNPDF global PDF fitting group have incorporated the combined HERA data into their fit and here is the improvement to the Sea PDF- with uncombined HERA data you get the red- with combined you get the blue

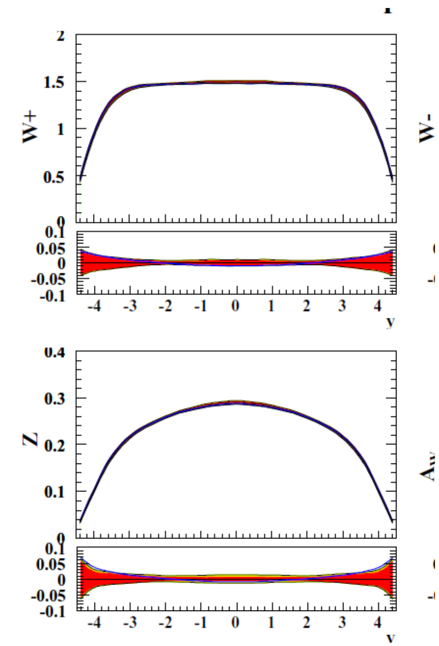
Consequences for W and Z production at the LHC

Look at predictions for W/Z rapidity distributions: Pre- and Post-HERA



Note difference in scale for fractional errors





Just fixed target DIS data ~15% uncertainty

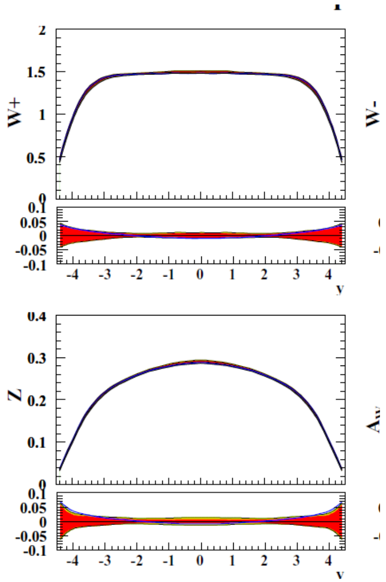
Separate HERA data sets~5% uncertainty

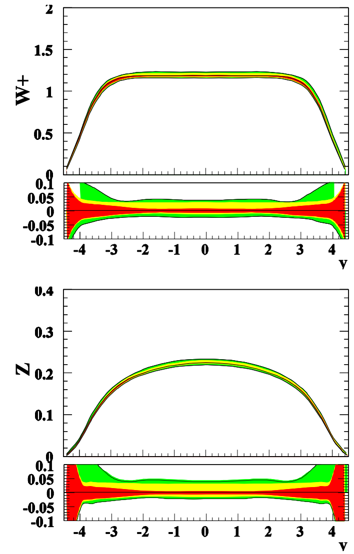
Combined HERA data set~1% uncertainty

Why such an improvement ?

It's due to the improvement in the low-x sea and gluon At the LHC the q-qbar which make the boson are mostly sea-sea partons And at $Q^2 \sim M_Z^2$ **the sea is driven by the gluon**

These illustrations at 14 TeV



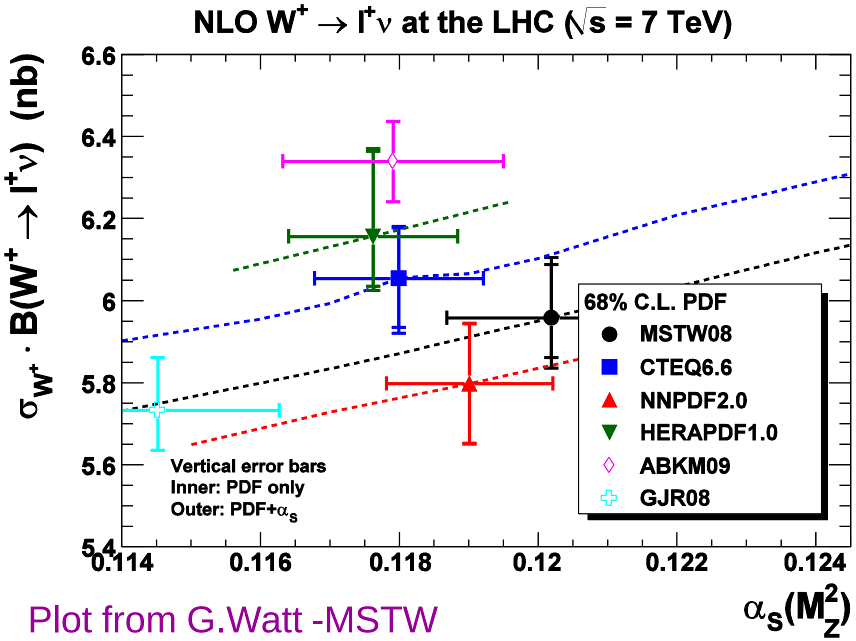


Model errors are the most signficant in the central region: m_c, m_b, fs, Q^2_{min}

m_c =1.35 – 1.65 GeV is the dominant contribution… but this can be improved if F2(charm) data are used…..

However PDF fitting should also include consideration of model errors and parametrisation errors

HERAPDF1.0
experimental plus
model errors plus
parametrisation



Plot from G.Watt -MSTW

Comparisons of W+ cross-section as a function of $\alpha_S(M_Z)$

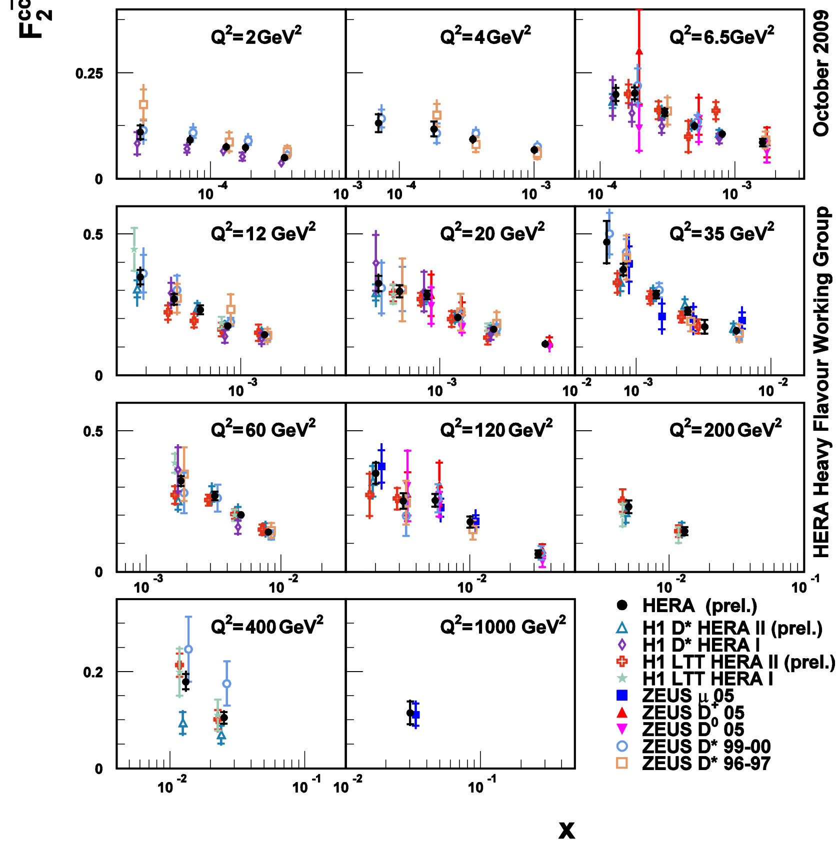
MSTW08
CTEQ66
HERAPDF1.0
NNPDF2.0
ABKM09
GJR08

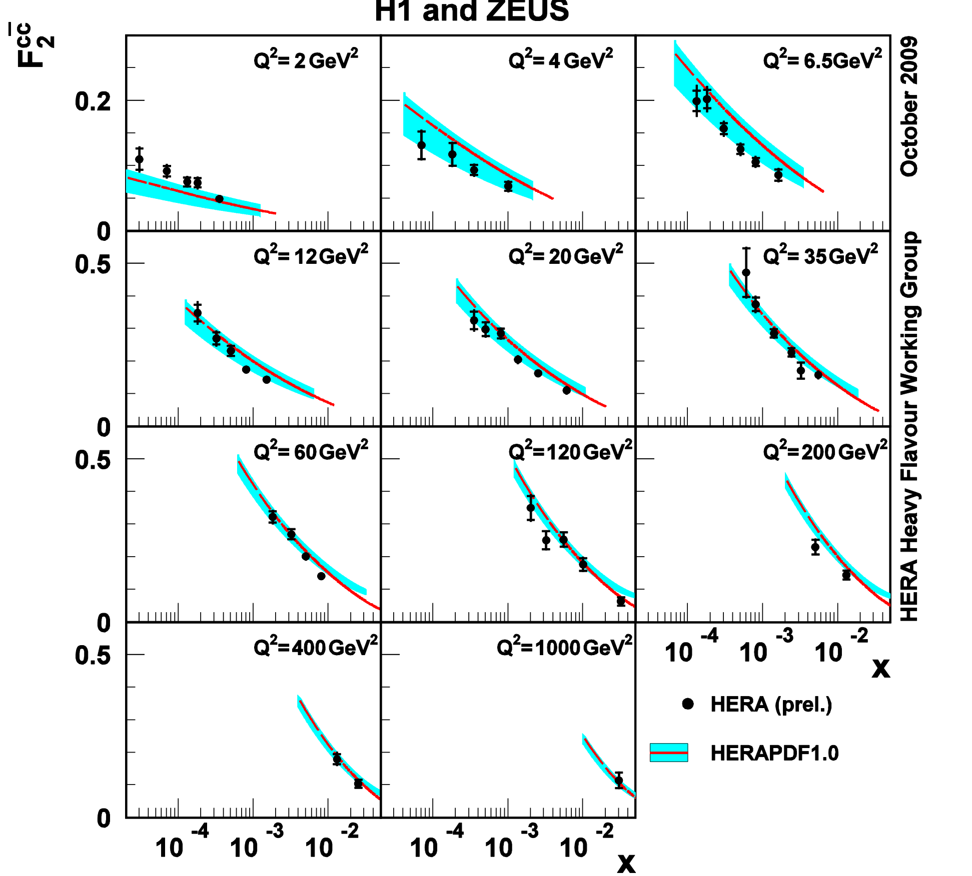
The PDF4LHC group has been considering all these PDFs at NLO

Recently the PDF4LHC group has been considering the role that the uncertainty in the value of $\alpha_S(M_Z)$ plays in the overall uncertainty of predictions

This is not a large effect for W/Z production

But the value of m_c AND the scheme used to account for heavy quark production are..





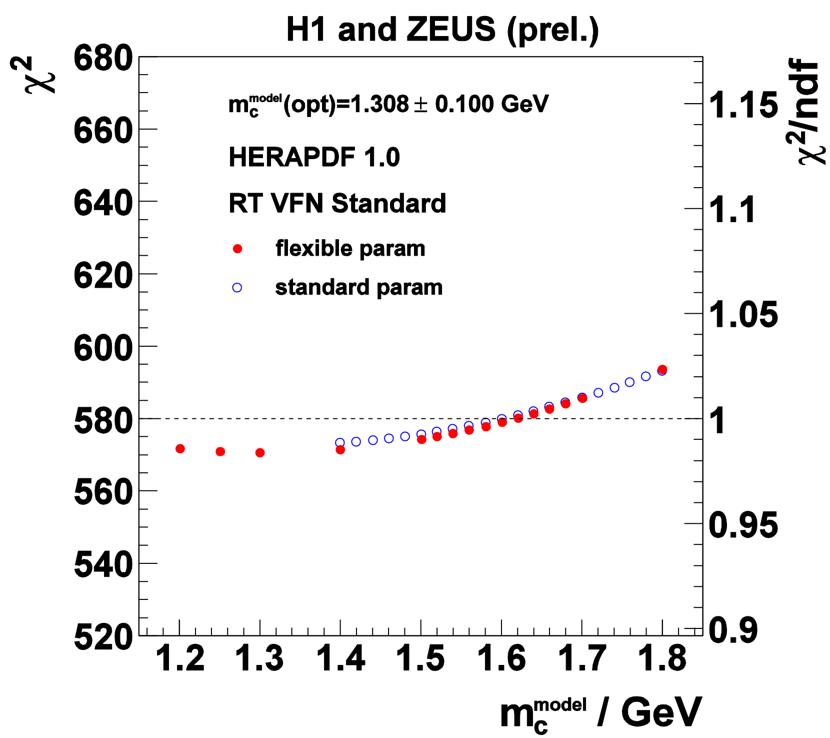
H1 and ZEUS have also combined charm data recently

And the HERAPDF1.0 gives a good description of these data –within its error band-

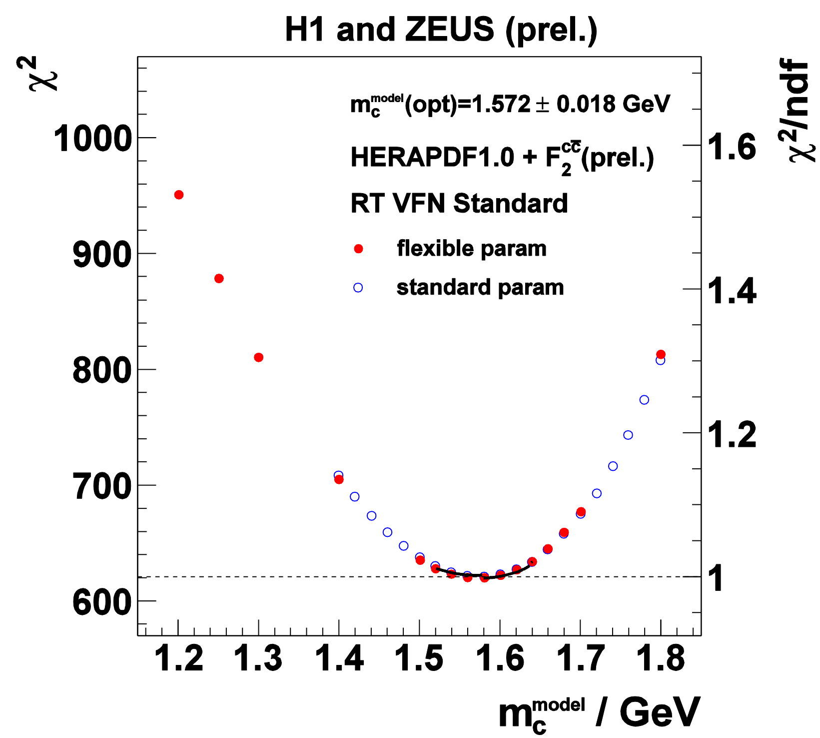
The error band spans m_c=1.35 (high) to m_c=1.65 (low) GeV

The data show some preference for higher charm mass than the standard choice m_c=1.4 GeV

If we input the charm data to the PDF fit it does not change the PDFs significantly BUT

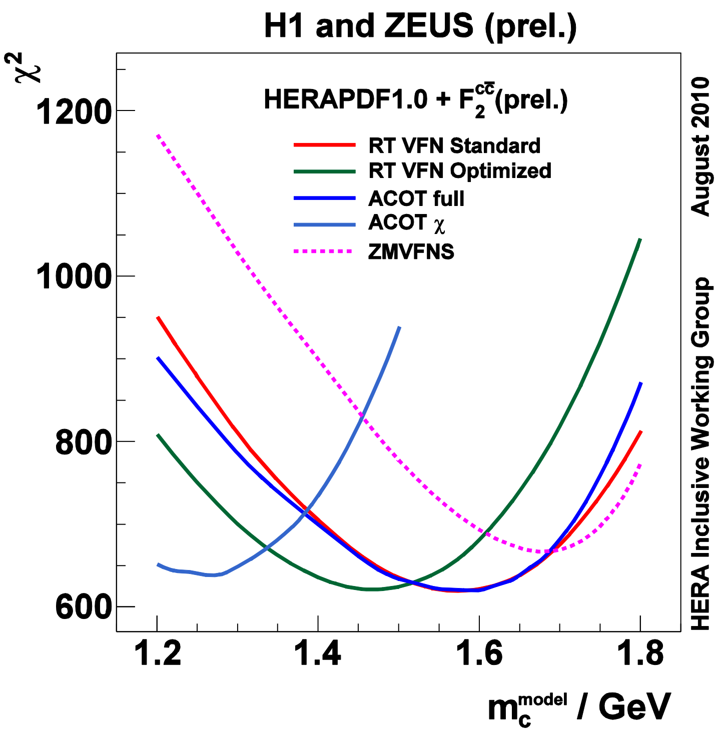


Before charm is input the χ2 profile vs the charm mass parameter is shallow..



After charm is input the χ2 profile vs the charm mass parameter gives

m_c = 1.57 0.02 GeV



But the HERAPDF uses the Thorne General Mass Variable Flavour Number Scheme for heavy quarks as used by MSTW08

This is not the only GMVFN

CTEQ use ACOT- χ

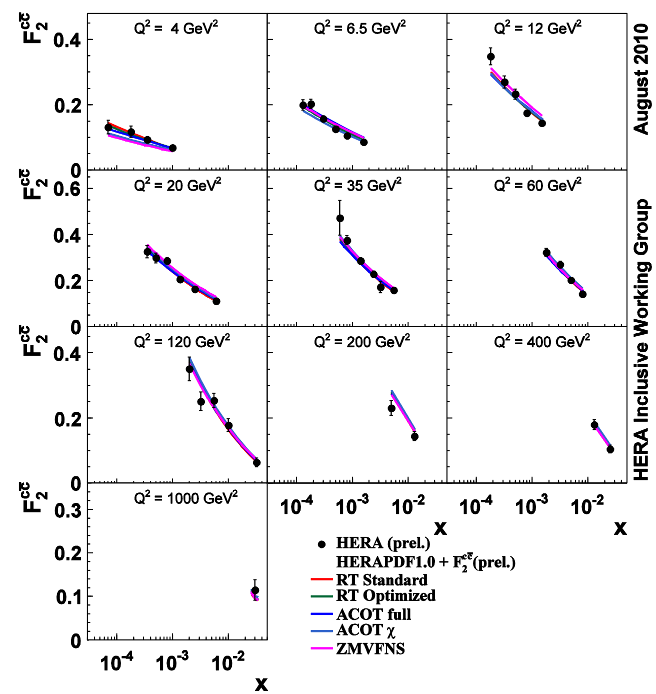
NNPDF2.0 use ZMVFN

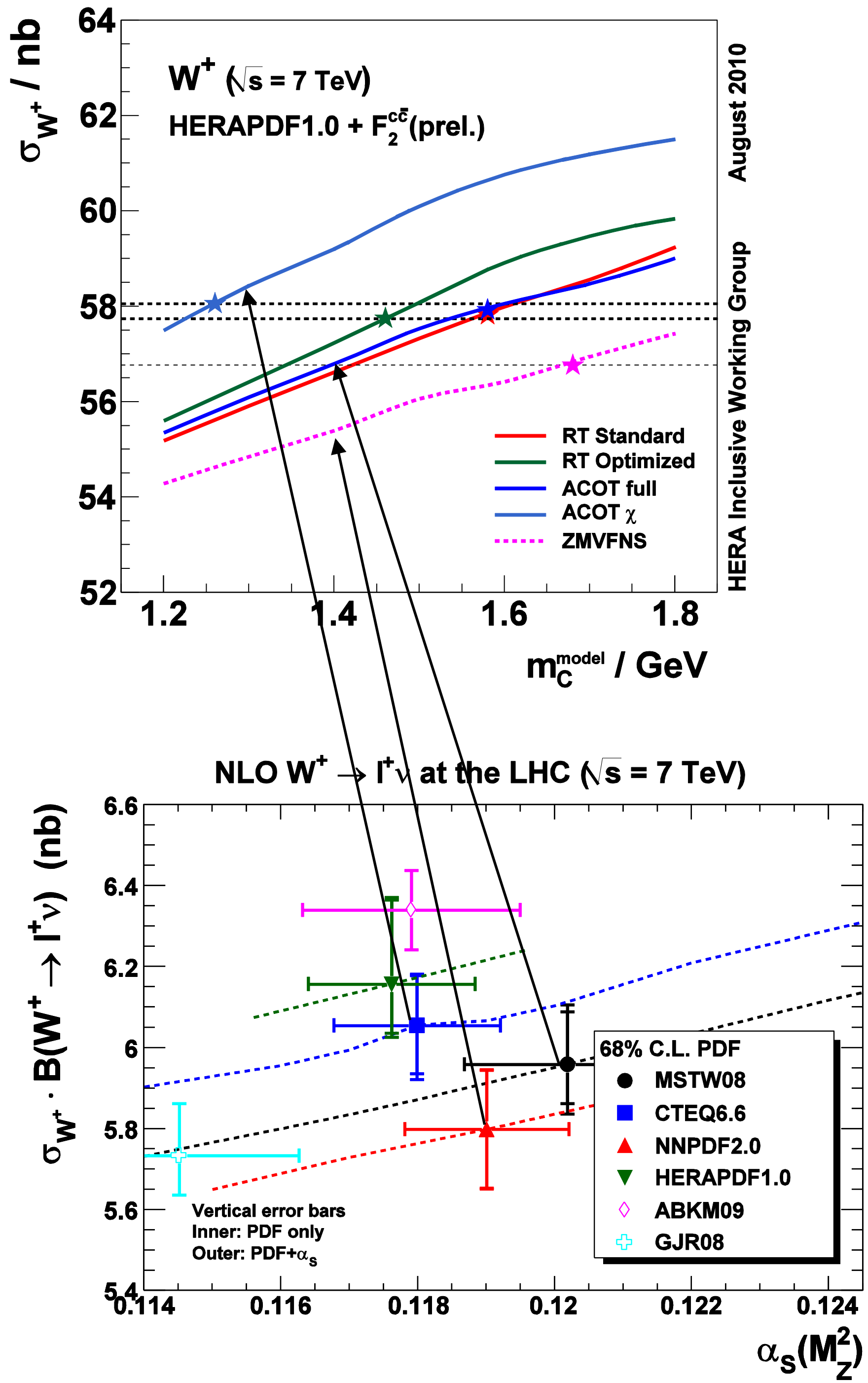
These all have different preferred charm mass parameters, and all fit the data well when used with their own best fit charm mass

We have re-analysed the HERAPDF+F2c data using several different heavy quark schemes

	m_c^{thr} (opt) / GeV	stat	syst	
RT stand	1.57	±0.02	+0.01	-0.03
RT optim	1.47	±0.02	+0.01	-0.03
ACOT full	1.58	±0.02	+0.02	-0.04
ACOT χ	1.25	±0.02	+0.02	-0.04
ZMVFNS	1.67	±0.02	+0.06	-0.06

Model and param.
Errors included





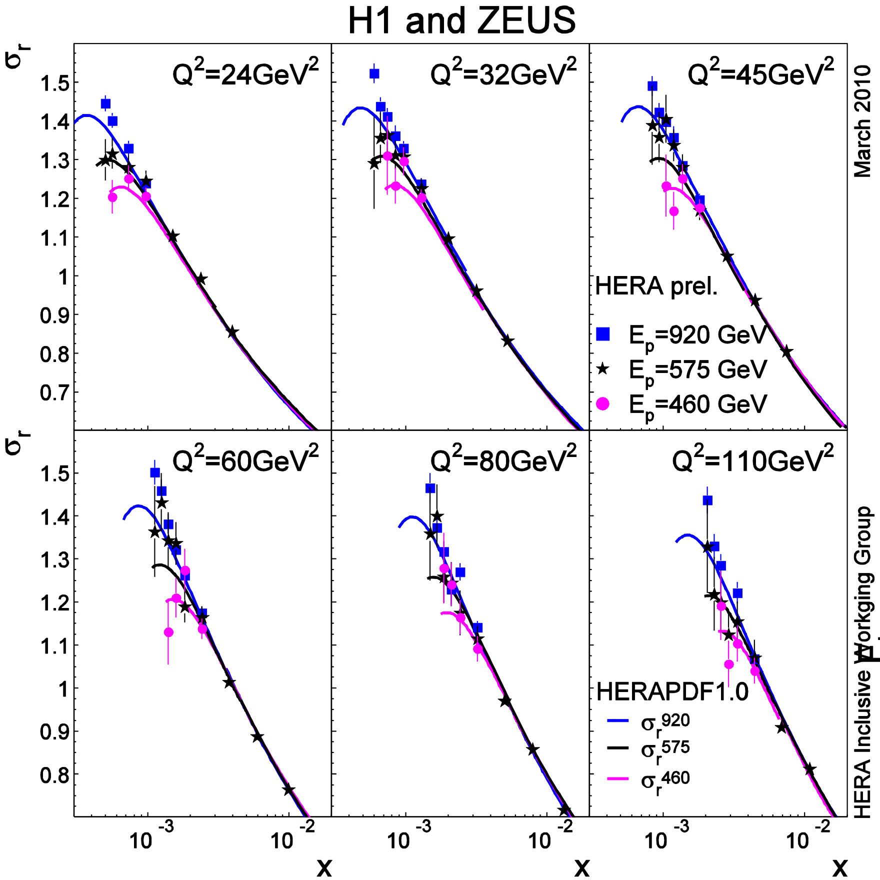
We then use each of these schemes to predict W and Z cross-sections at the LHC (at 7 TeV) as a function of charm mass parameter

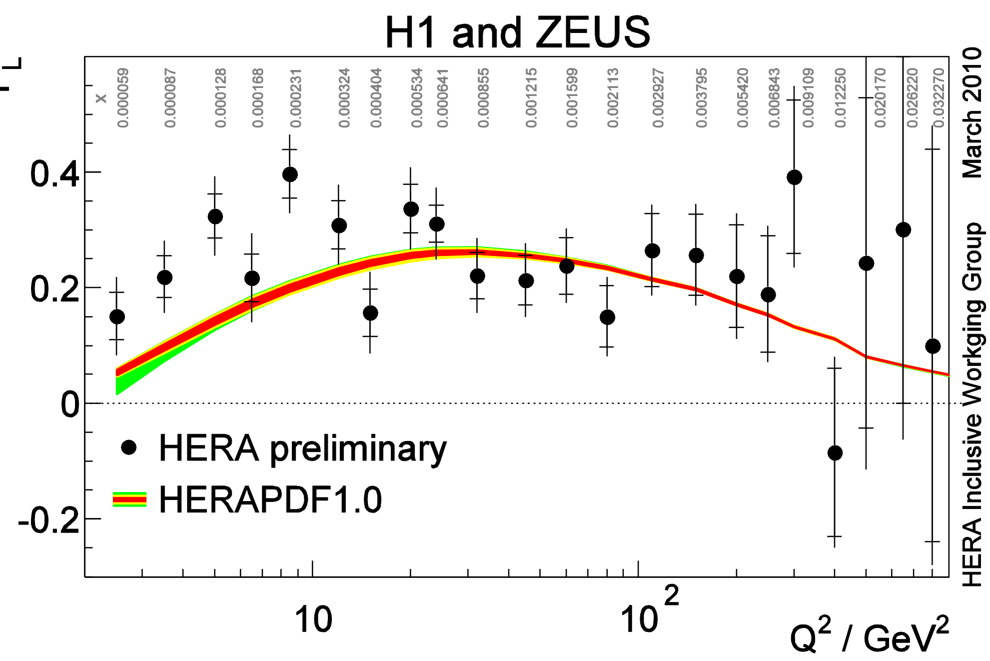
If a fixed value of mc is used then the spread is considerable (~7%)- but if each prediction is taken at its own optimal mass value the spread is dramatically reduced (~2%) even when a Zero-Mass (ZMVFN) approximation has been used

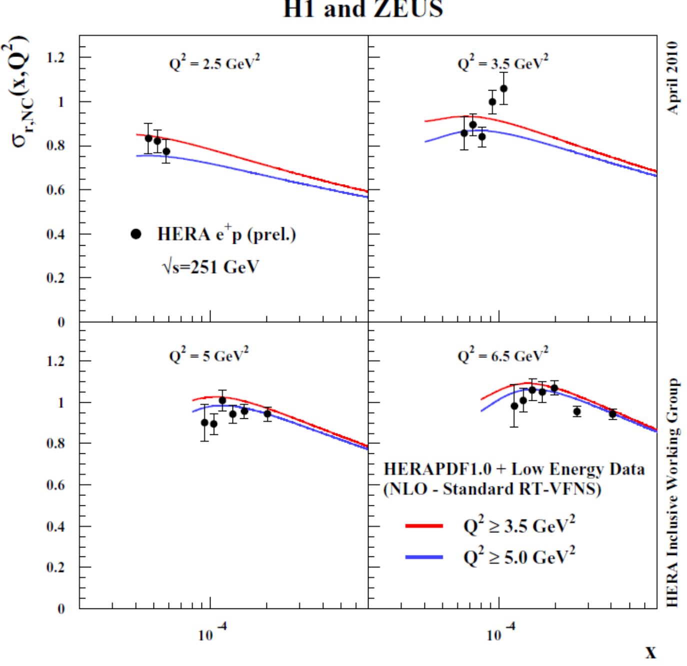
scheme	m_c^{model}(opt)	χ^2/dof	χ^2/ndp	σ_Z(nb)	σ_{W^+}(nb)	σ_{W^-}(nb)
RT Standard	$1.58^{+0.02}_{-0.03}$	620.3/621	42.0/41	$29.27^{+0.07}_{-0.11}$	$57.82^{+0.14}_{-0.22}$	$40.22^{+0.10}_{-0.15}$
RT Optimized	$1.46^{+0.02}_{-0.04}$	621.6/621	46.5/41	$29.17^{+0.07}_{-0.13}$	$57.75^{+0.14}_{-0.26}$	$40.15^{+0.10}_{-0.18}$
ACOT full	$1.58^{+0.03}_{-0.04}$	621.2/621	59.9/41	$29.28^{+0.10}_{-0.13}$	$57.93^{+0.18}_{-0.24}$	$40.16^{+0.12}_{-0.16}$
S-ACOT-χ	$1.26^{+0.02}_{-0.04}$	639.7/621	68.5/41	$29.37^{+0.08}_{-0.15}$	$58.06^{+0.16}_{-0.30}$	$40.23^{+0.11}_{-0.21}$
ZMVFNS	$1.68^{+0.06}_{-0.07}$	667.4/621	88.1/41	$28.71^{+0.19}_{-0.20}$	$56.77^{+0.33}_{-0.34}$	$39.46^{+0.24}_{-0.25}$
			differences	0.7% 2.3%	0.5% 2.3%	0.2% 2.0%

The PDFs MSTW08, CTEQ6.6, NNPDF2.0 do NOT use charm mass parameters at the optimal values- and this may explain their differing predictions.

H1 and ZEUS have also combined the e+p NC inclusive data from the lower proton beam energy runs (P_P = 460 and 575) and produced a common FL measurement

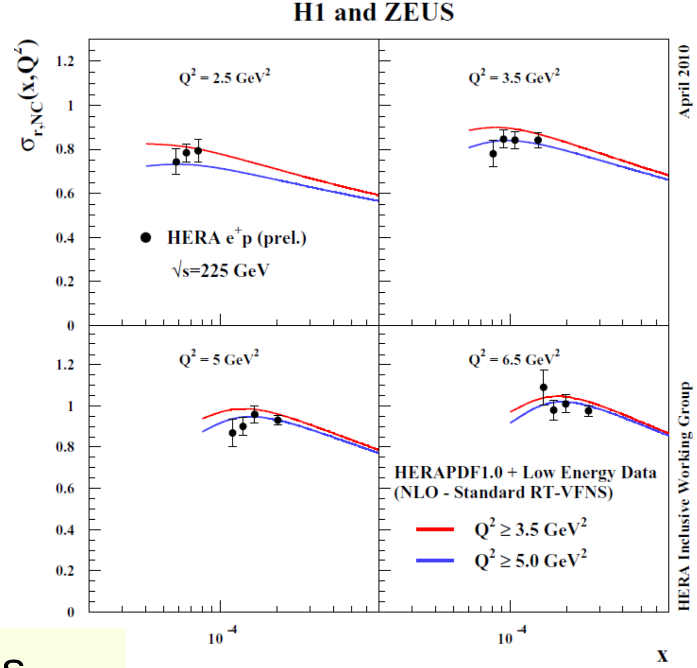


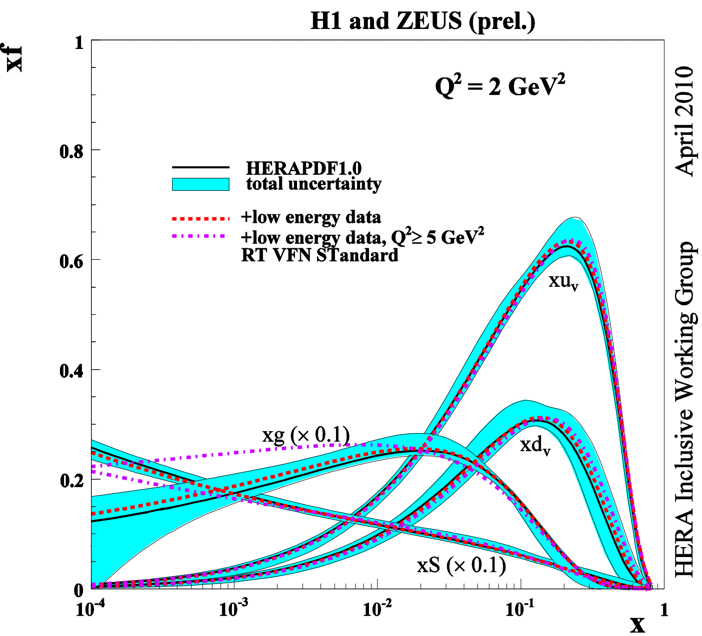




When the low energy data are input to the HERAPDF fit it becomes evident that the low Q^2/low-x data are not well fit –

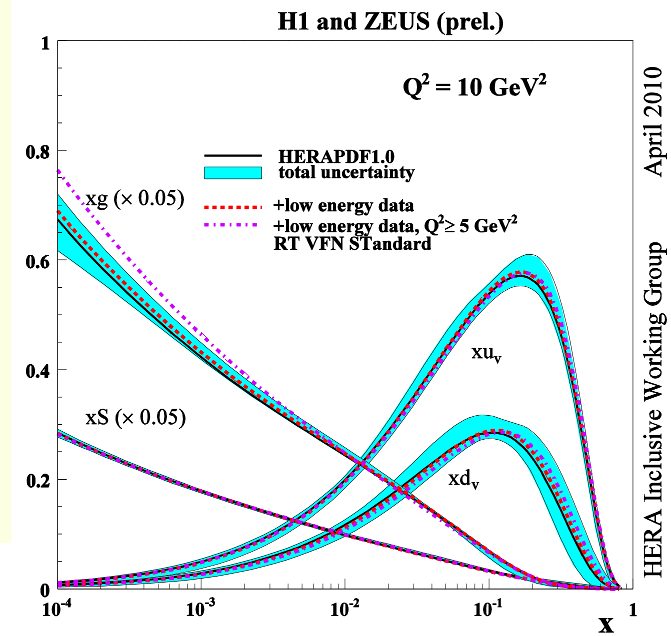
Imposing a harder Q^2 cut $Q^2 > 5$ improves the situation





The resulting PDFs have a somewhat different shape- less valence-like gluon at low Q^2… steeper gluon at higher Q^2

This is also true if you make an x cut
$x > 5\ 10^{-4}$
or a combined cut
$Q^2 > 0.5\ x^{-0.3}$

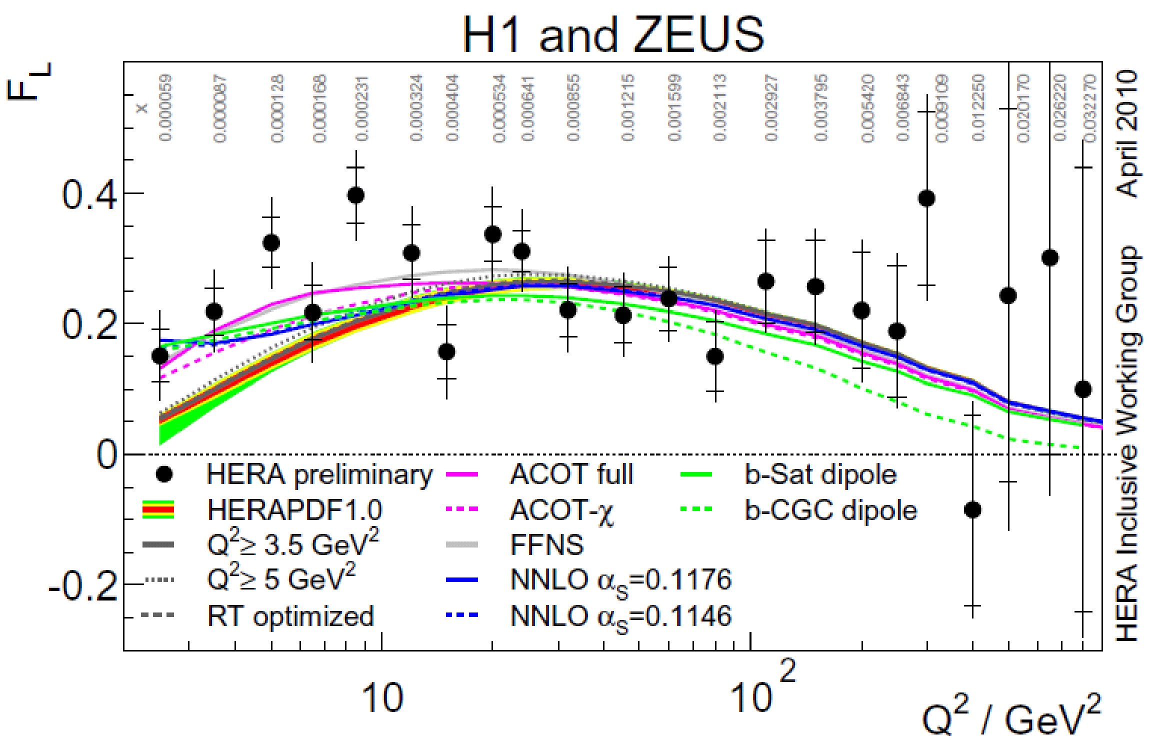


BUT NOTE there is no improvement from cutting high y. These x,Q^2 cuts do NOT have a big effect on the description of FL.

Changes of heavy quark scheme to ACOT, FFN

or a change from NLO to NNLO have a bigger effect on FL

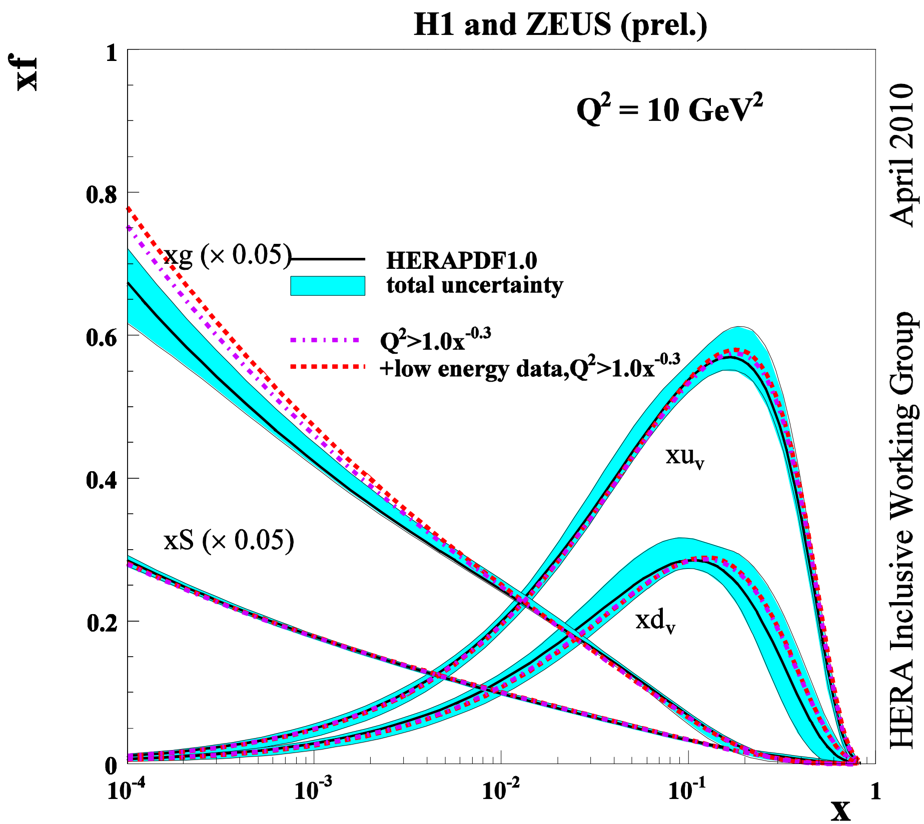
Whereas such changes do not improve the description of the low x,Q^2 cross-section data significantly

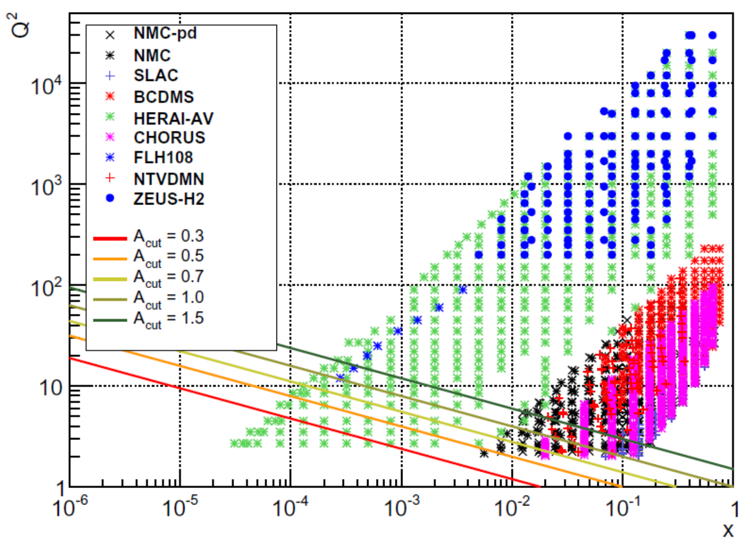


How hard do we need to cut such that analysis of just Ep=920 data

And analysis of lower energy data is once more in good agreement?

$Q^2 > 1.0\ x^{-0.3}$

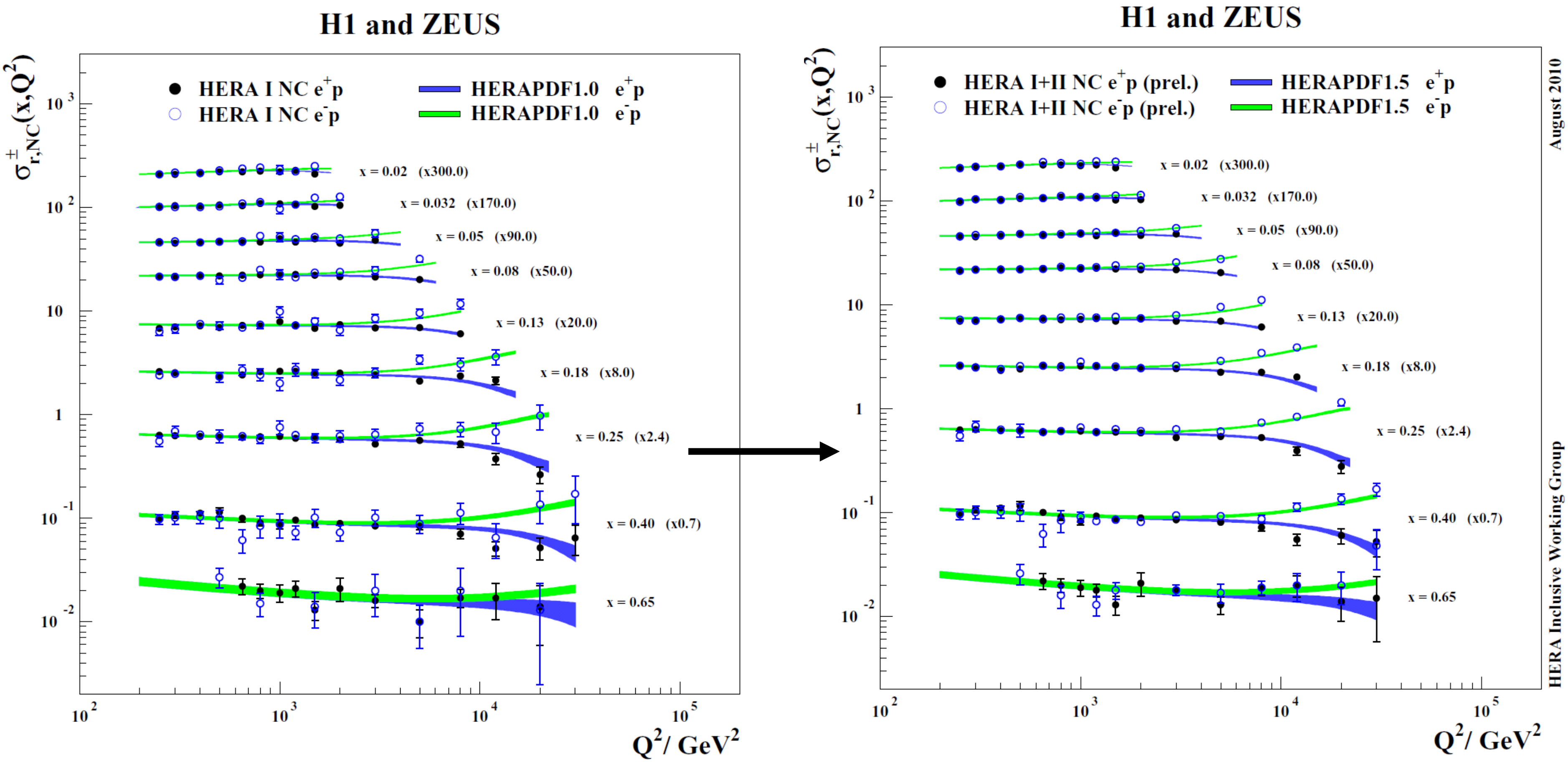




This implies that the 'true' gluon could be a little bit steeper than the HERAPDF1.0 gluon- or indeed CTEQ6.6 or MSTW08 gluons

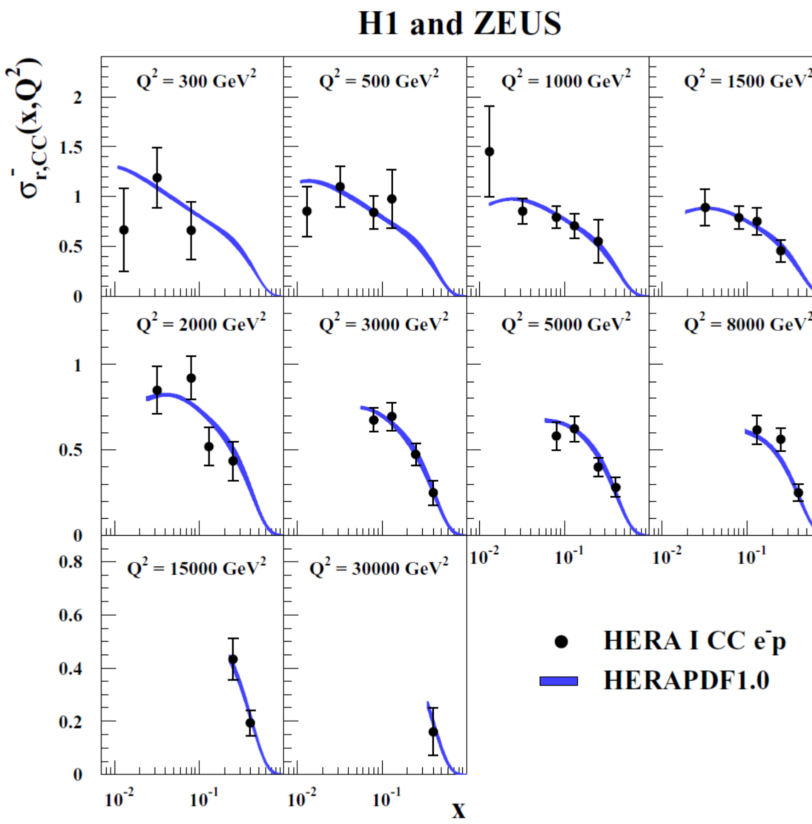
However this effect only starts to become important for $x < 10^{-3}$ so W/Z cross-sections at the LHC are only marginally affected- 1-1.5% up at 7 TeV

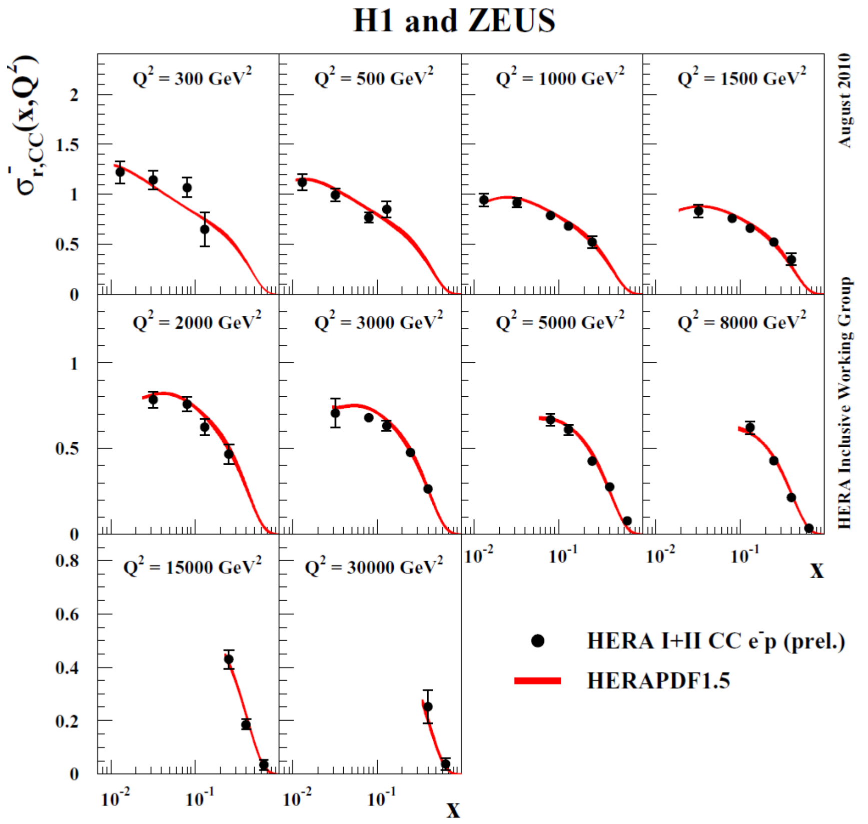
H1 and ZEUS have also combined preliminary high Q^2 HERA-II data along with the HERA-I data and HERAPDF1.0 has recently been updated to HERAPDF1.5 by including these data



The data on the left has been updated to the data on the right

The HERAPDF1.0 fit on the left has been updated to the HERAPDF1.5 fit on the right





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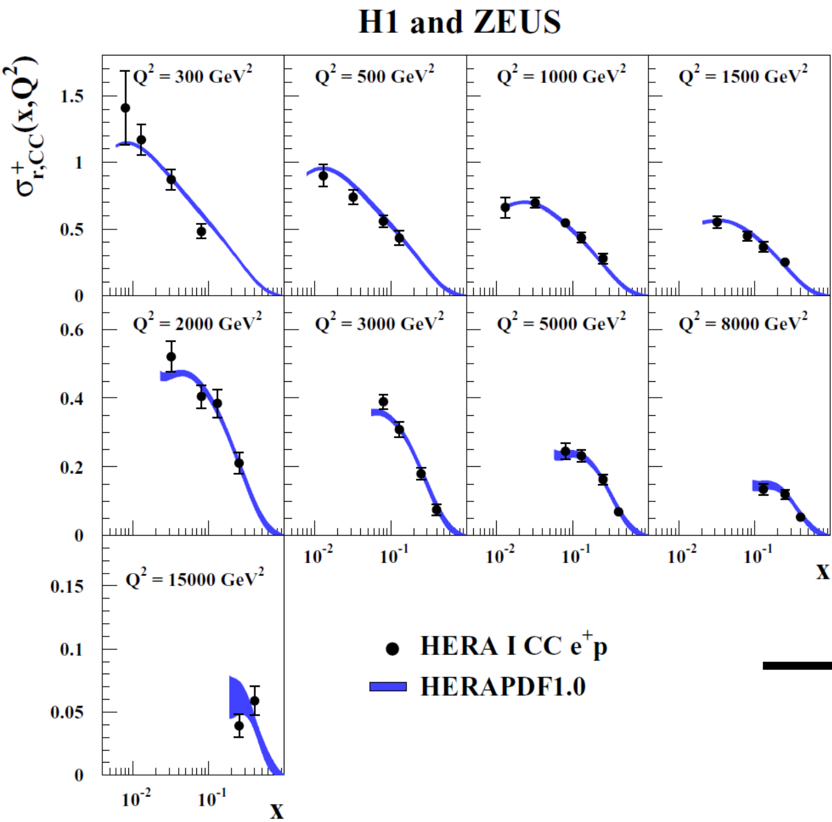

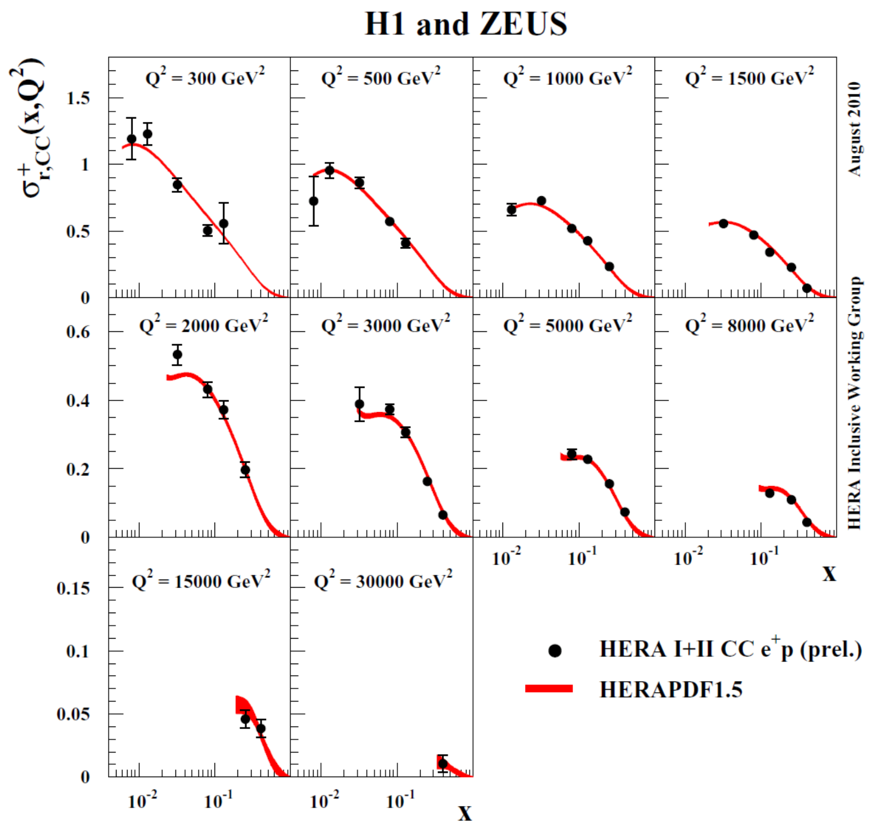

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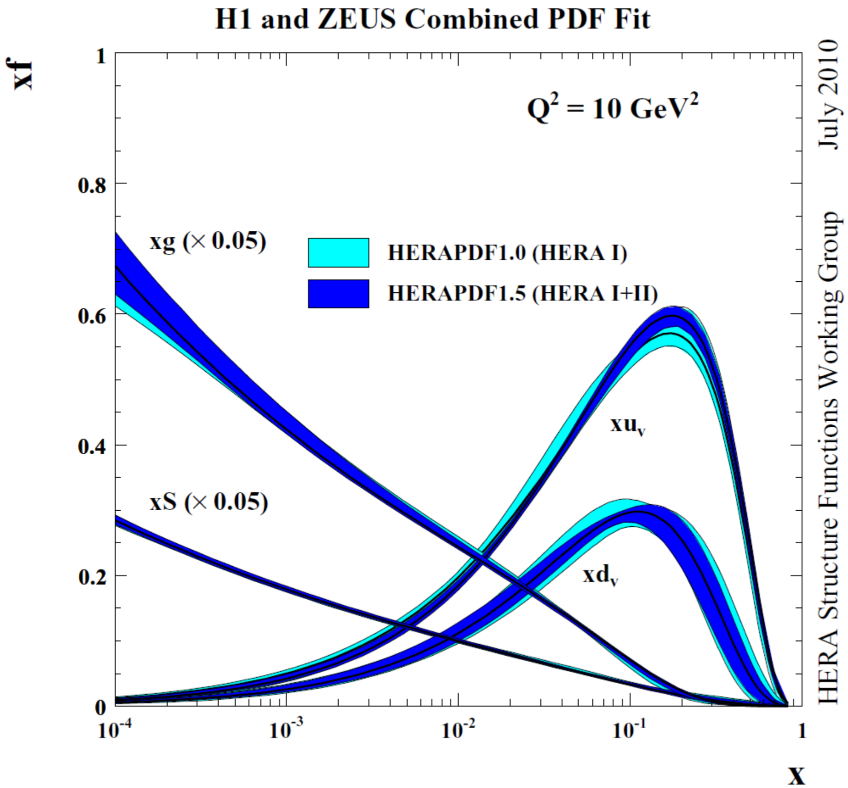
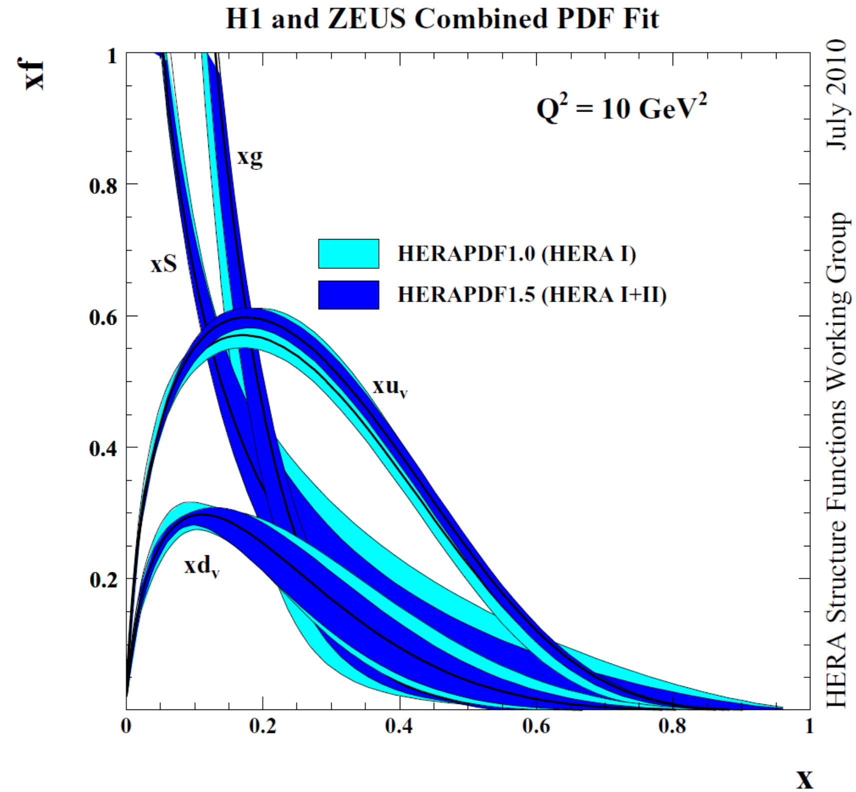
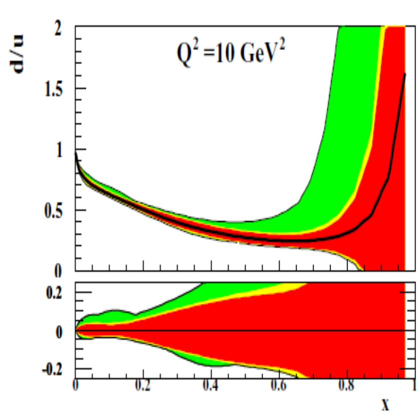




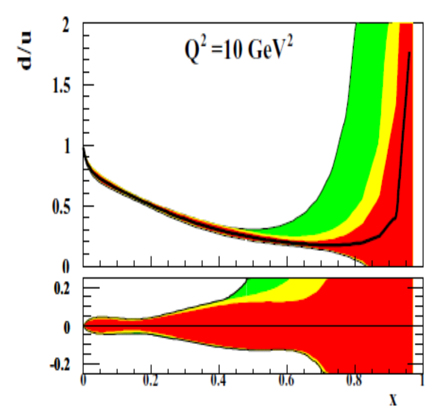
The PDF uncertainties have been reduced at high-x

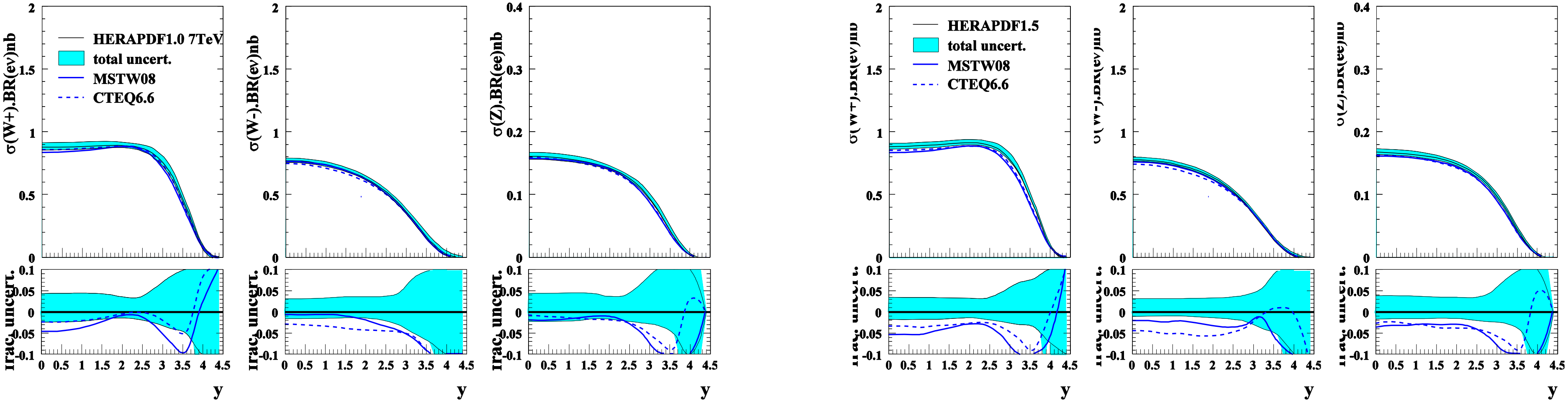
These plots show total uncertainties (model and parametrization included)

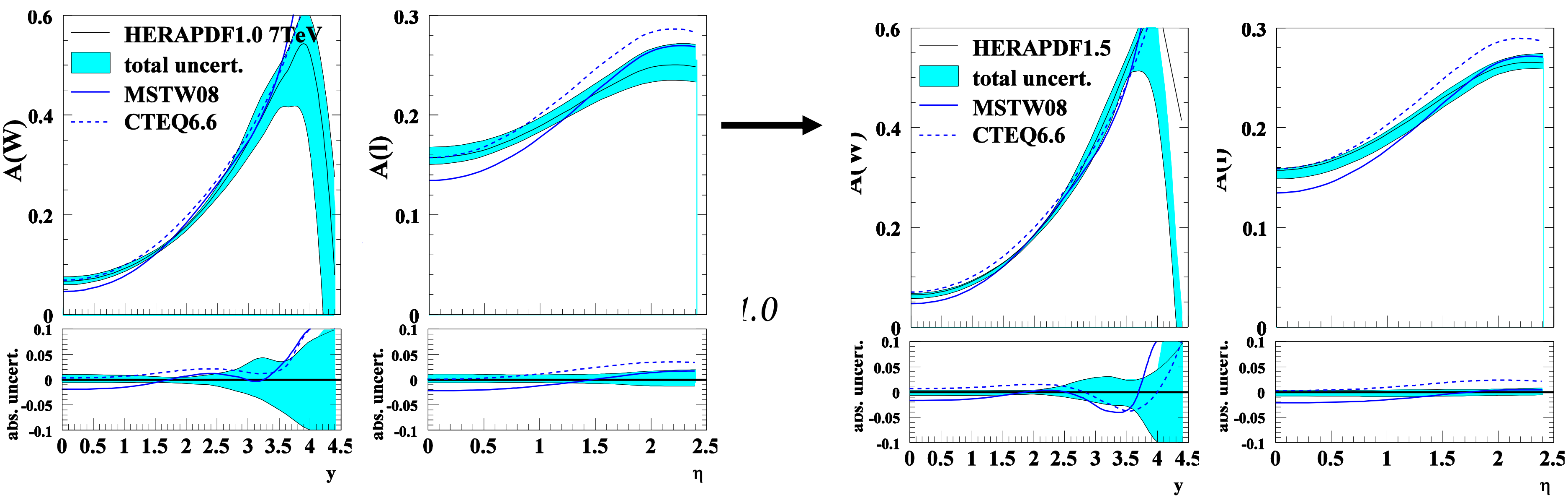


Improved determination of the d/u ratio at high-x.

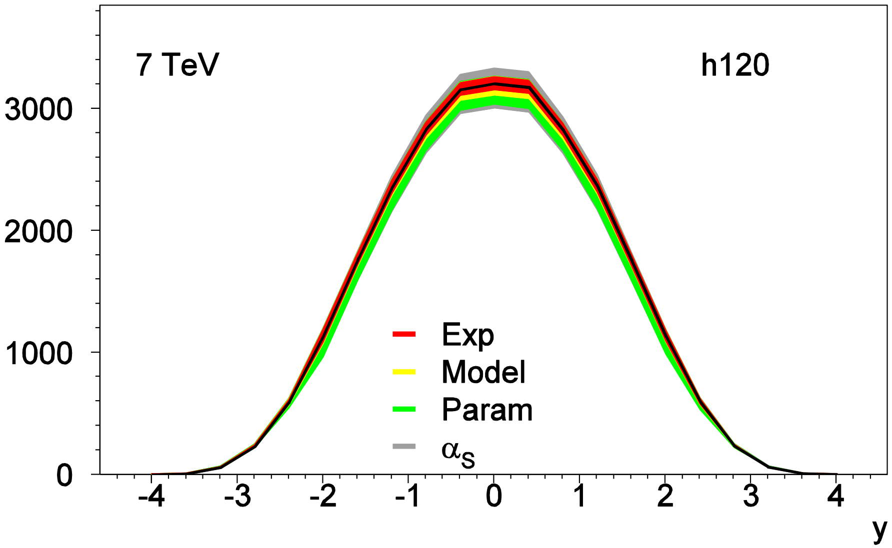
The only PDF which measures d in a proton rather than an isoscalar target

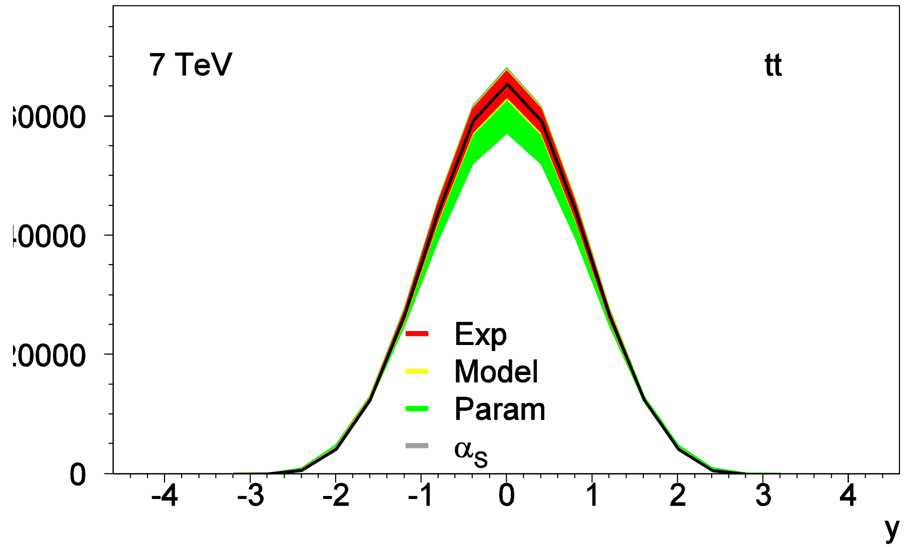




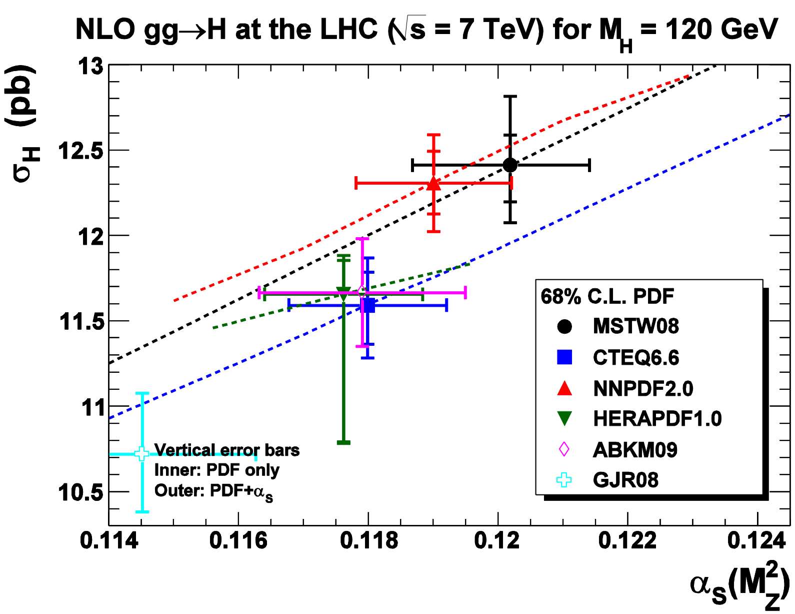


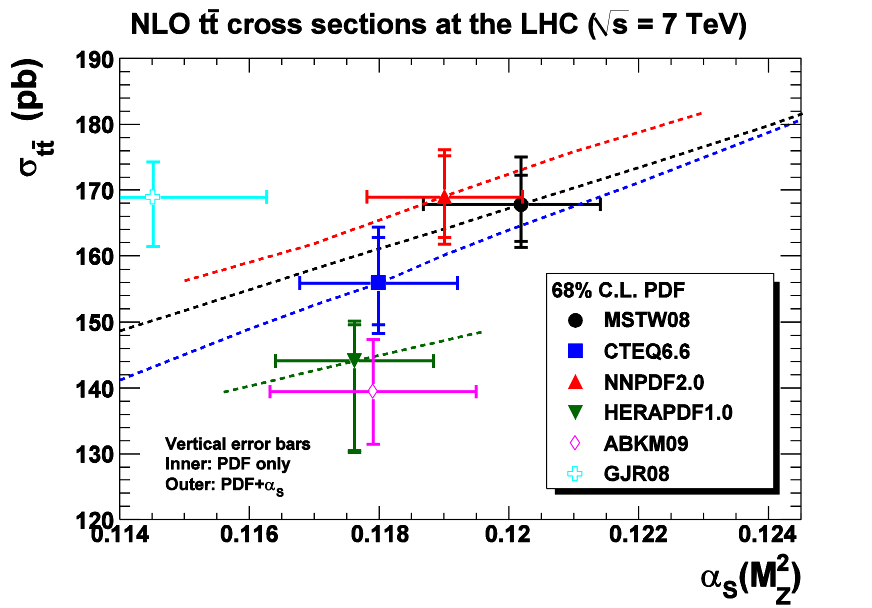
This reduced high-x error results in a reduced error at high rapidity for W/Z production at the LHC

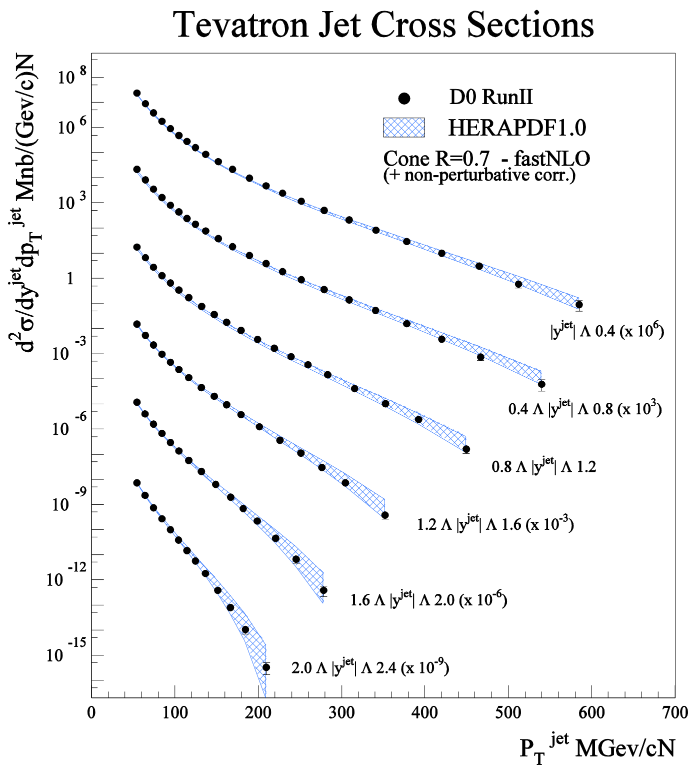


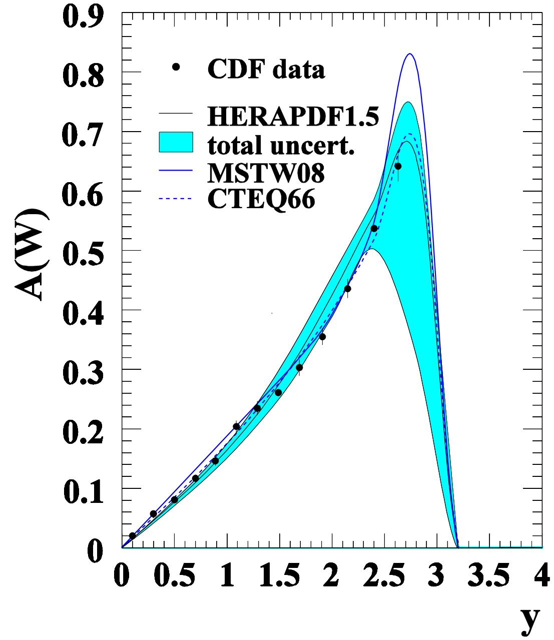


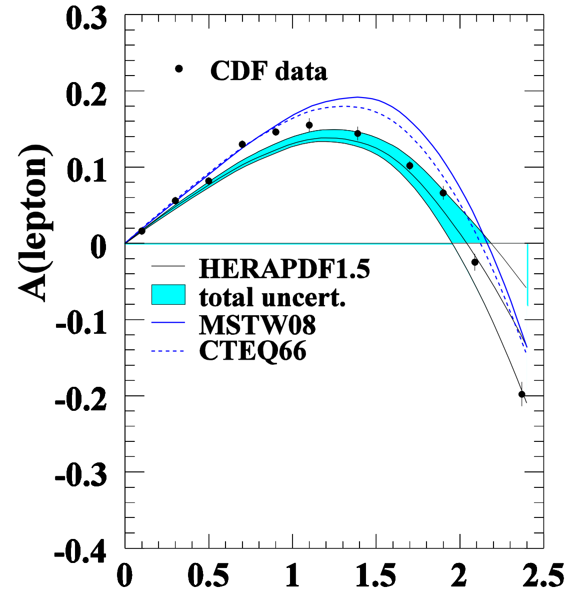
HERAPDF can also be used to predict gluon-gluon dependent cross-sections such as Higgs and t-tbar

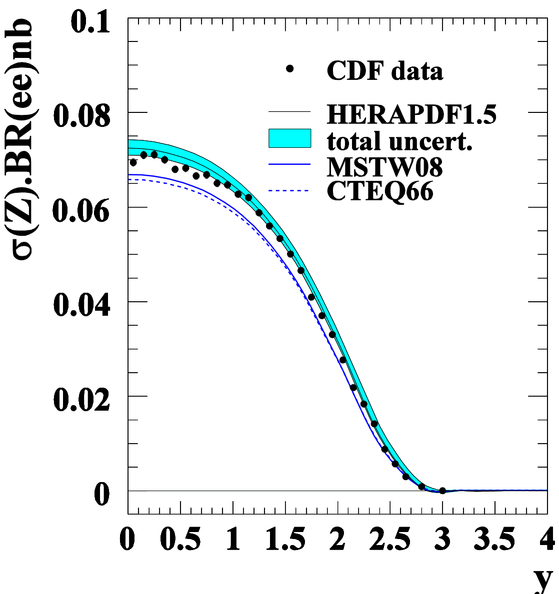












Lastly let's not forget the Tevatron

SUMMARY

Combination of ZEUS and H1 data and PDF fits to these data:

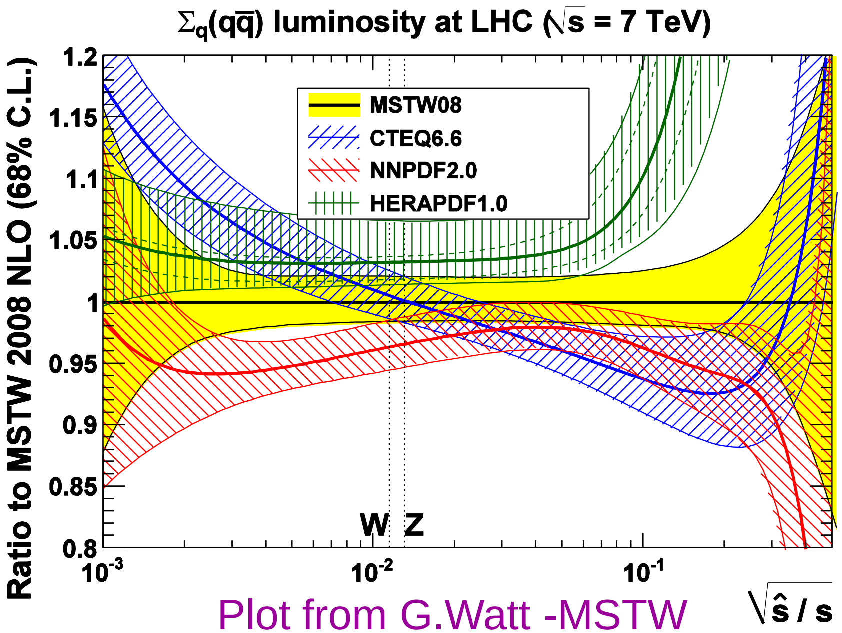
1. Inclusive cross-sections HERA-1 (1992-2000):arxiv:0911.0884 -improved constraints at low-x
2. F2(charm) data (preliminary)- constraints on the charm mass parameter, m_c(model)
3. Low energy runs – FL- 2007- (preliminary) –tension with low x, Q2 data?
4. Inclusive cross-sections HERA-II (2003-2007)- (preliminary) -improved constraints at high-x

Predictions for LHC cross-sections: W/Z, Higgs, t-tbar

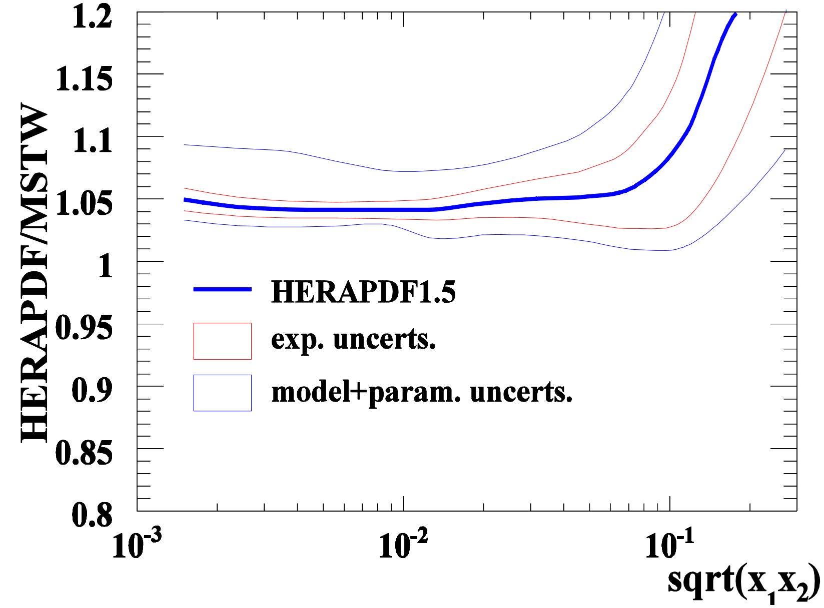
Predictions for Tevatron cross-sections: W/Z, high-ET jets

extras

The PDF4LHC group has been comparing PDFs at the level of parton-parton lumiosities



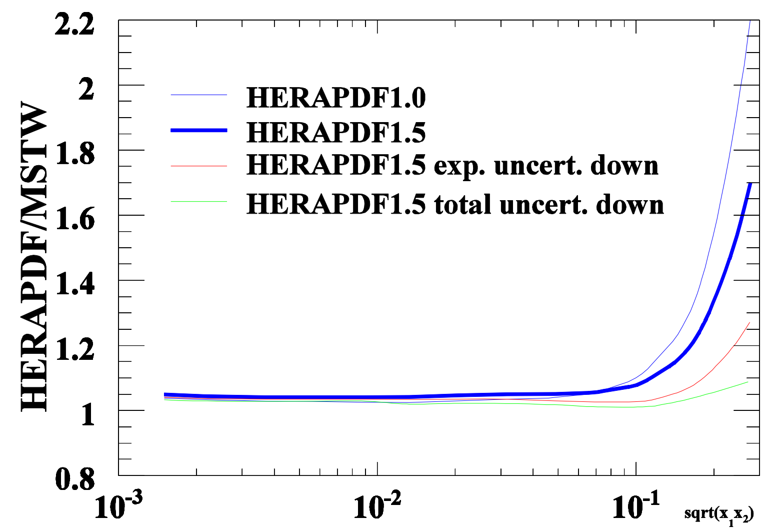
Plot from G.Watt -MSTW

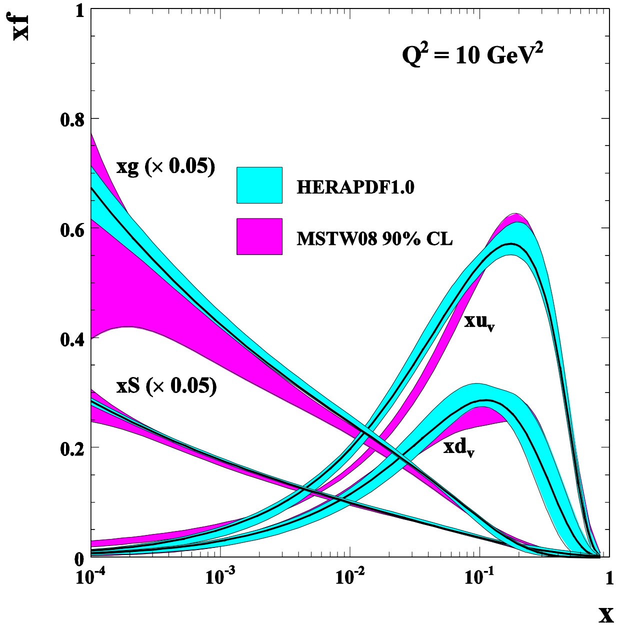


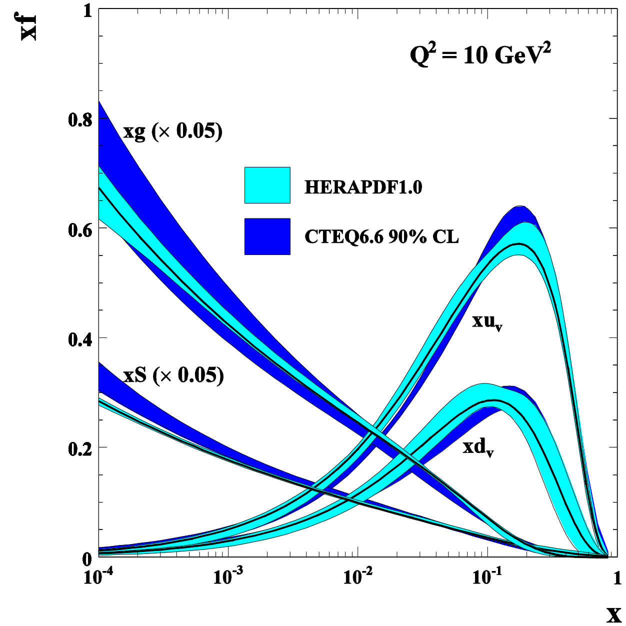
HERAPDF1.0 has a rather high q-qbar luminosity at high scale.

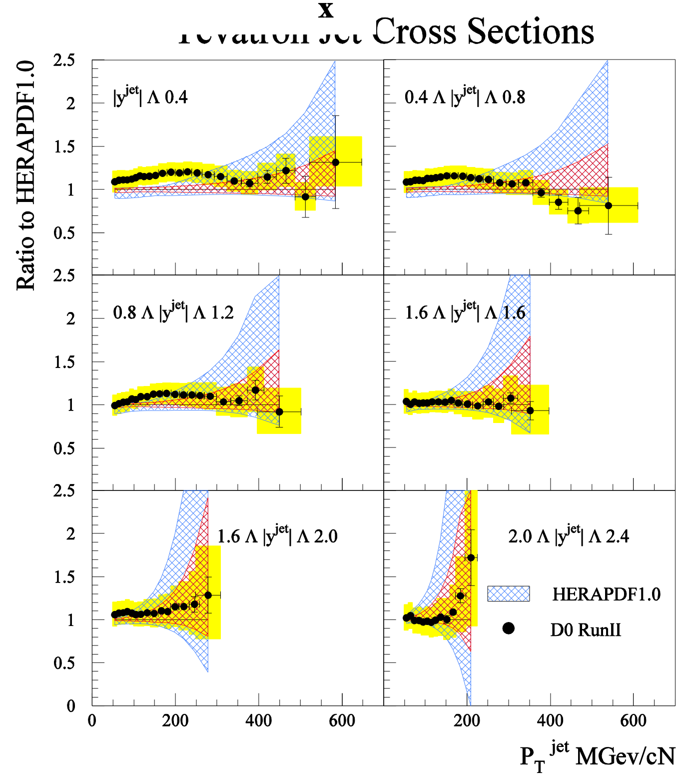
This is reduced in HERAPDF1.5

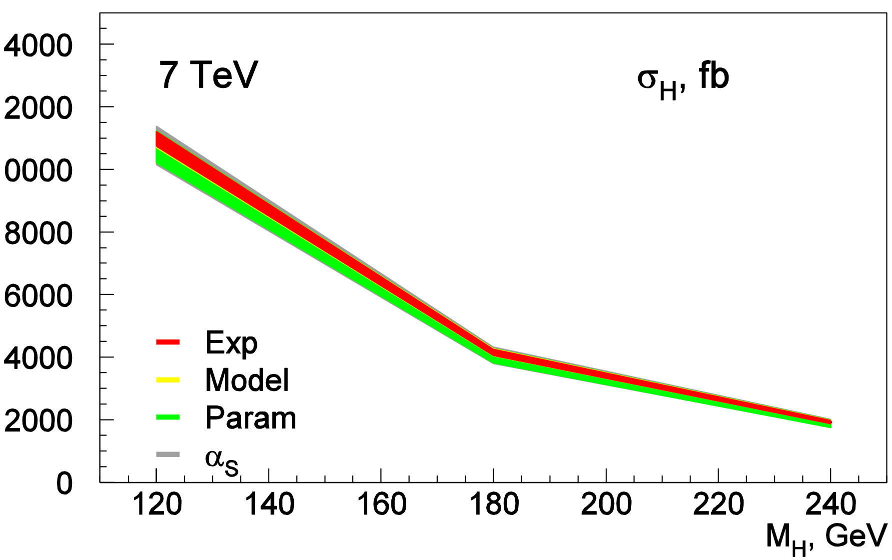
It is now closer to MSTW within uncertainties




xf
$Q^2 = 10\ GeV^2$
xg (× 0.05)
HERAPDF1.0
MSTW08 90% CL
xu_v
xS (× 0.05)
xd_v
x


xf
$Q^2 = 10\ GeV^2$
xg (× 0.05)
HERAPDF1.0
CTEQ6.6 90% CL
xu_v
xS (× 0.05)
xd_v
x

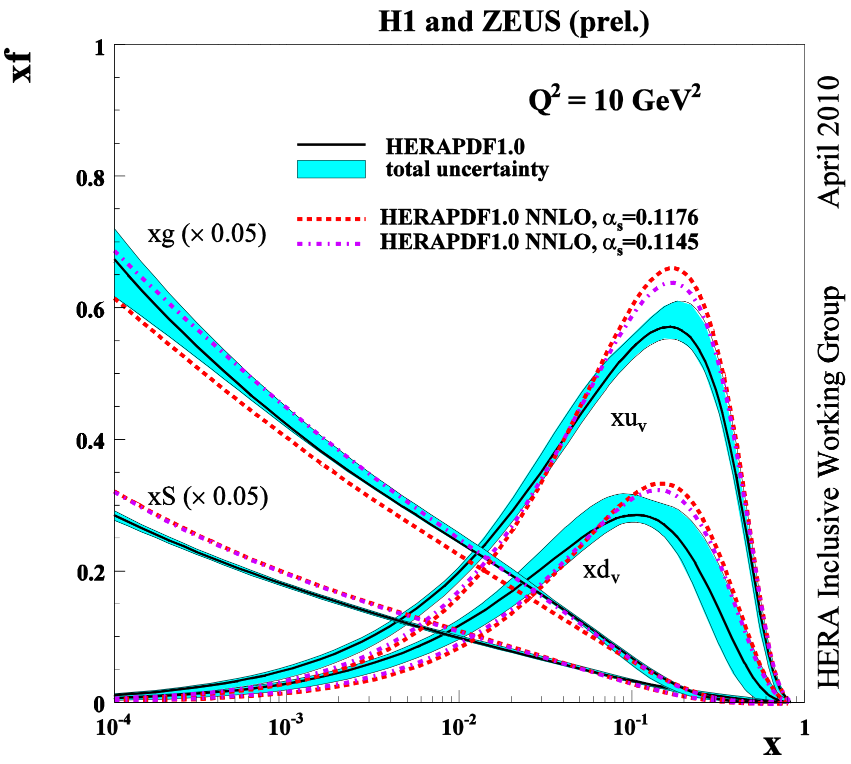

Cross Sections
Ratio to HERAPDF1.0
|y^jet| Λ 0.4
0.4 Λ |y^jet| Λ 0.8
0.8 Λ |y^jet| Λ 1.2
1.6 Λ |y^jet| Λ 1.6
1.6 Λ |y^jet| Λ 2.0
2.0 Λ |y^jet| Λ 2.4
HERAPDF1.0
D0 RunII
P_T jet MGev/cN


7 TeV
σ_H, fb
Exp
Model
Param
α_S
M_H, GeV

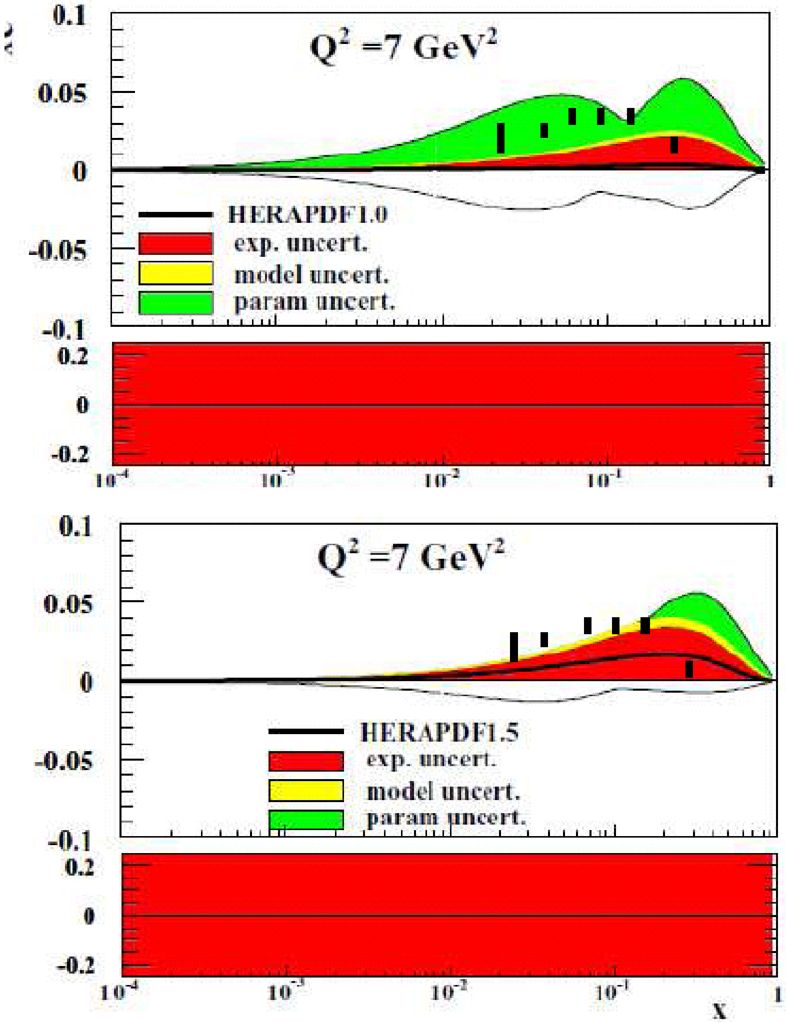
HERAPDF1.0 is also available at NNLO for two values of $\alpha_S(M_Z)$ (since many analyses indicate that alphas seems to be smaller at NNLO than at NLO)

This is important for precision studies of cross-section uncertainties.

There are far fewer NNLO PDFS: MSTW08, ABKM

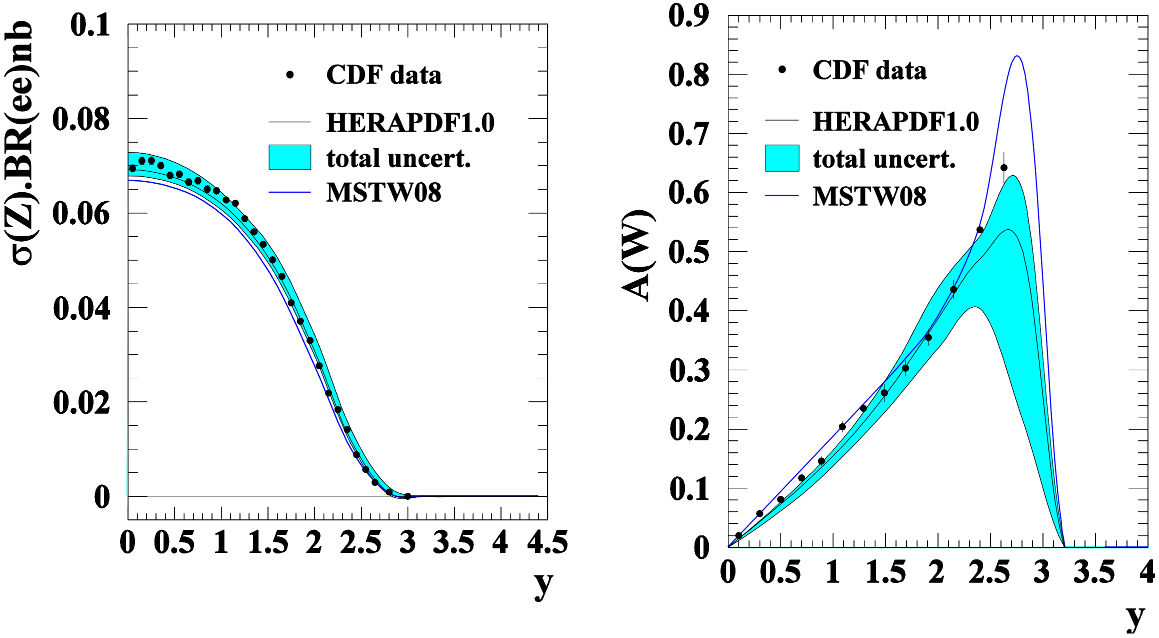


Compare x(dbar-ubar) for HERAPDF1.0 and 1.5



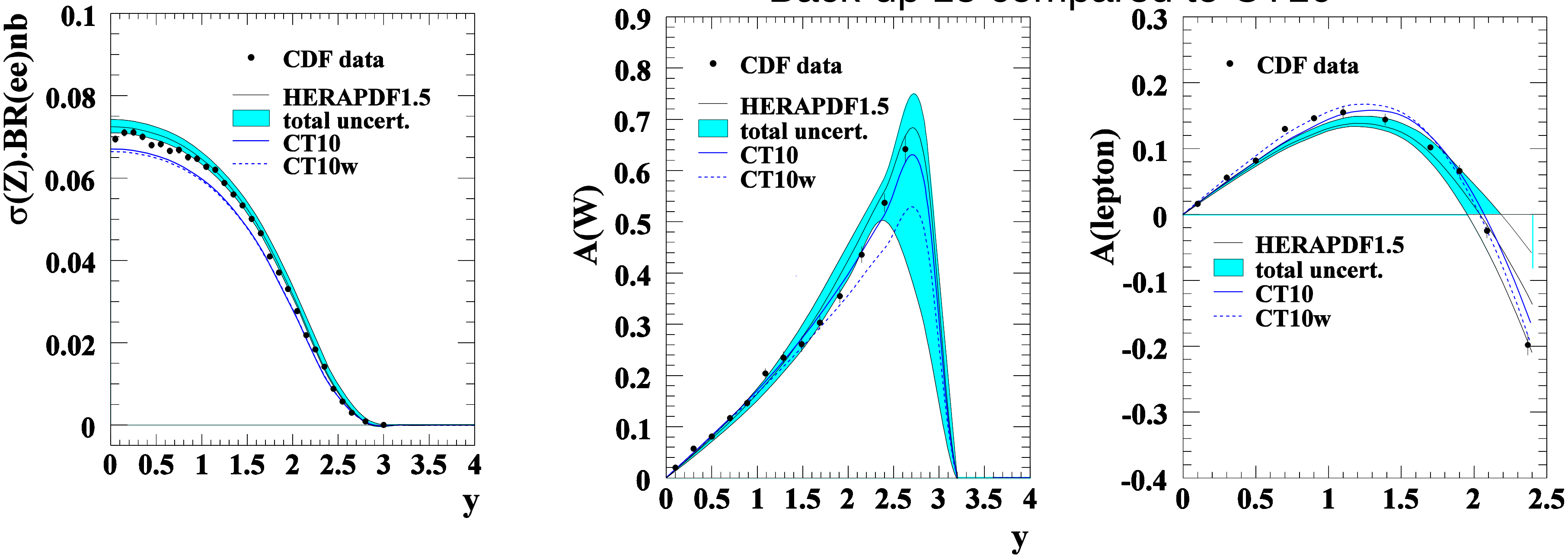
X value	E866 x(dbar-ubar)
0.026	0.022± 0.013
0.038	0.029± 0.005
0.067	0.036± 0.005
0.097	0.038± 0.005
0.142	0.036± 0.005
0.236	0.01 ± 0.005

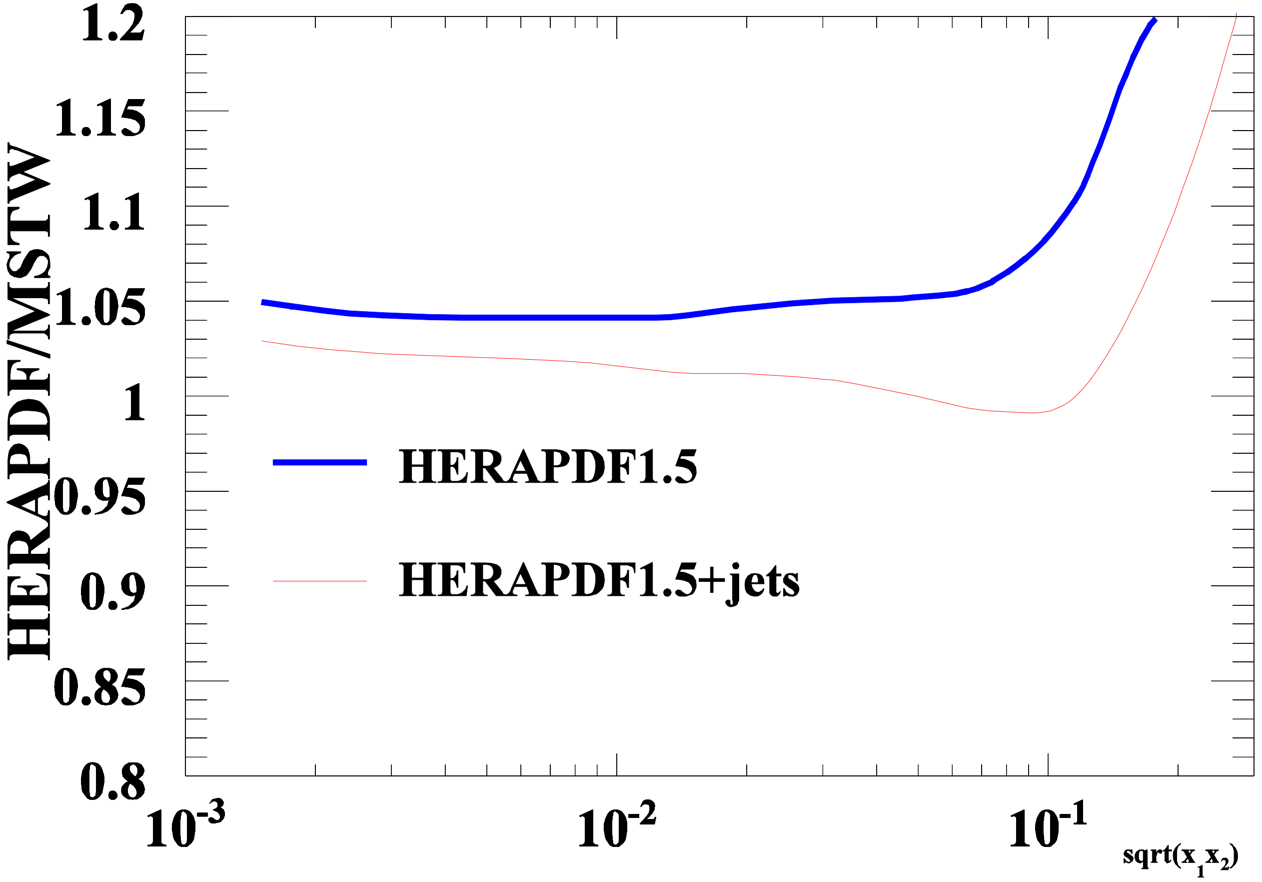
The black lines represent the E866 data, which are described by these PDFs – though not perfectly!



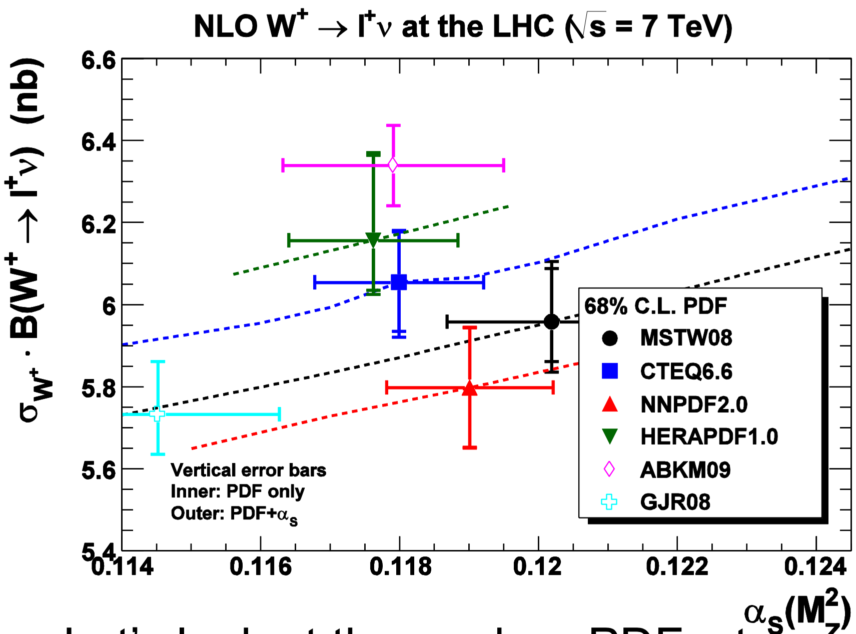
Back up HERAPDF1.0

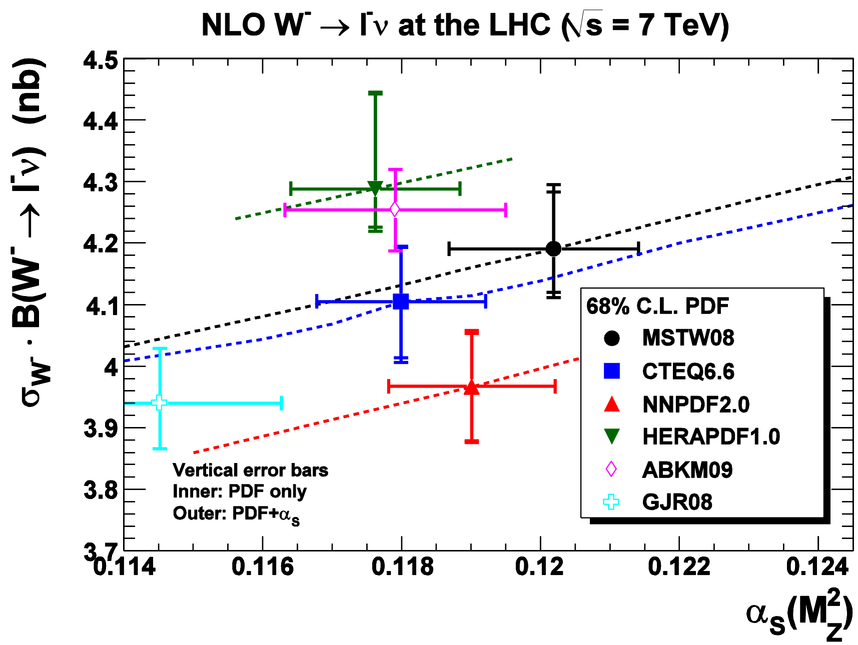
Back-up 15 compared to CT10





HERAPDF/MSTW
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
HERAPDF1.5
HERAPDF1.5+jets
10^{-3}
10^{-2}
10^{-1}
sqrt(x_1x_2)



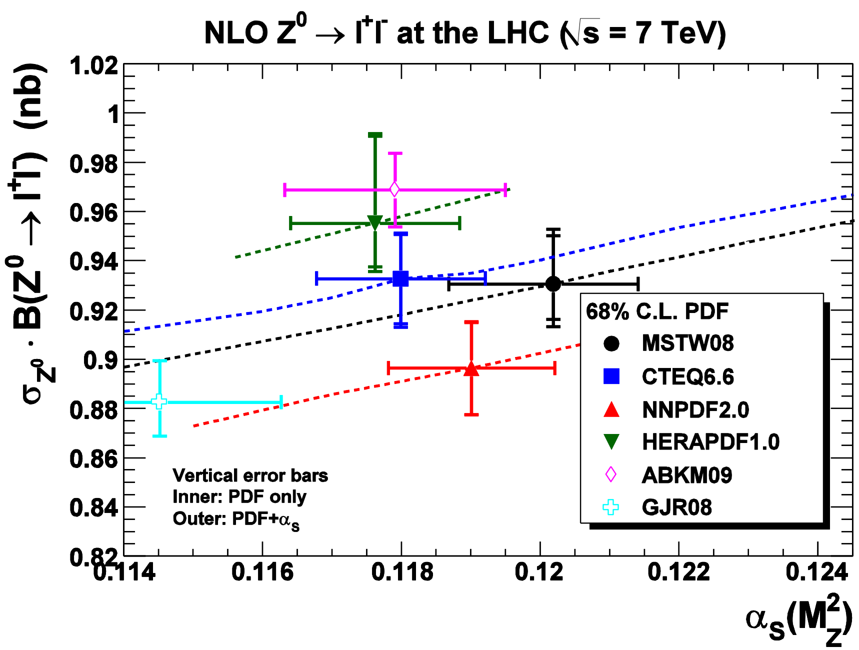


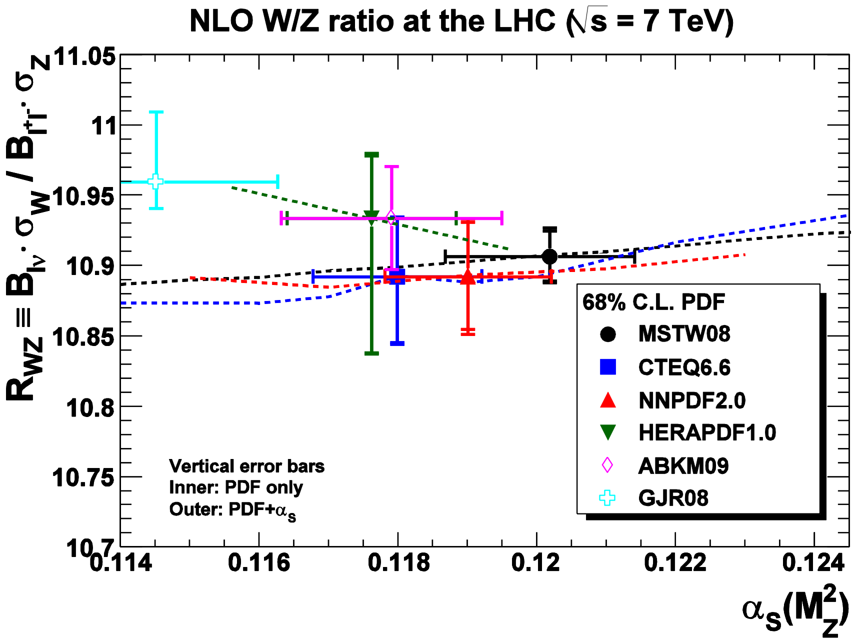
Let’s look at the modern PDFsets
MSTW08
CTEQ66
HERAPDF1.0
NNPDF2.0
ABKM09
GJR08

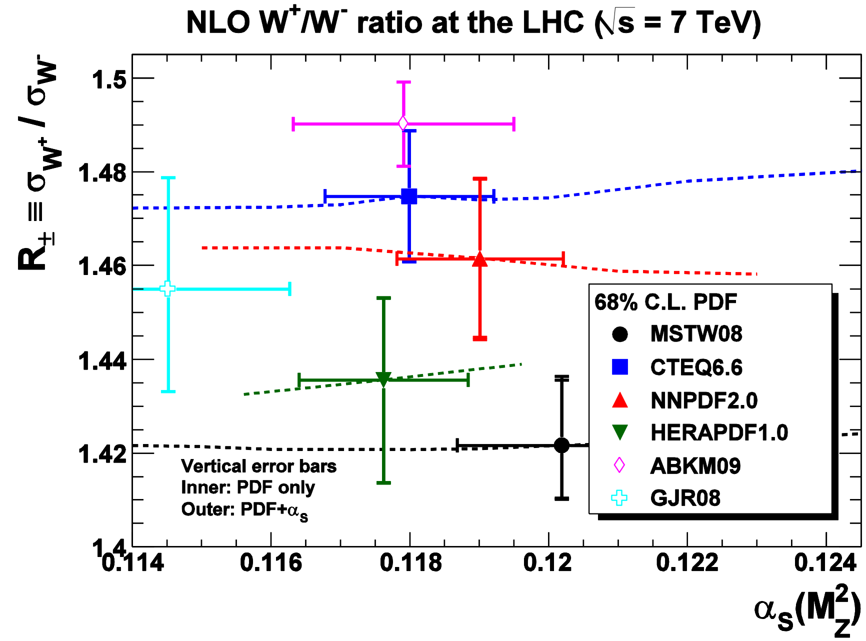
Overall disagreement ~8% in W, Z cross-sections

The PDF4LHC recommendation is to take the envelope of the NNPDF, MSTW, CTEQ predictions --even this may not be enough!

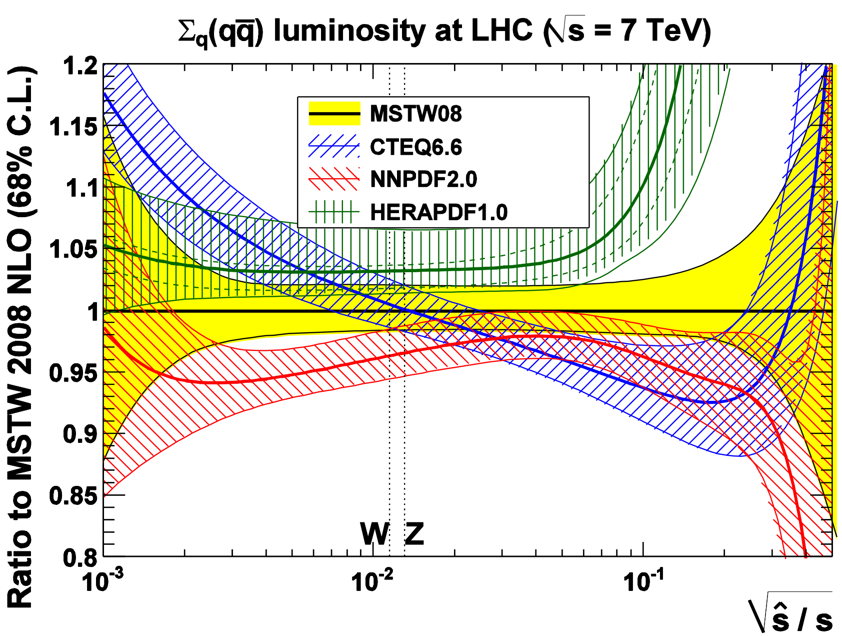
Plots from G.Watt -MSTW

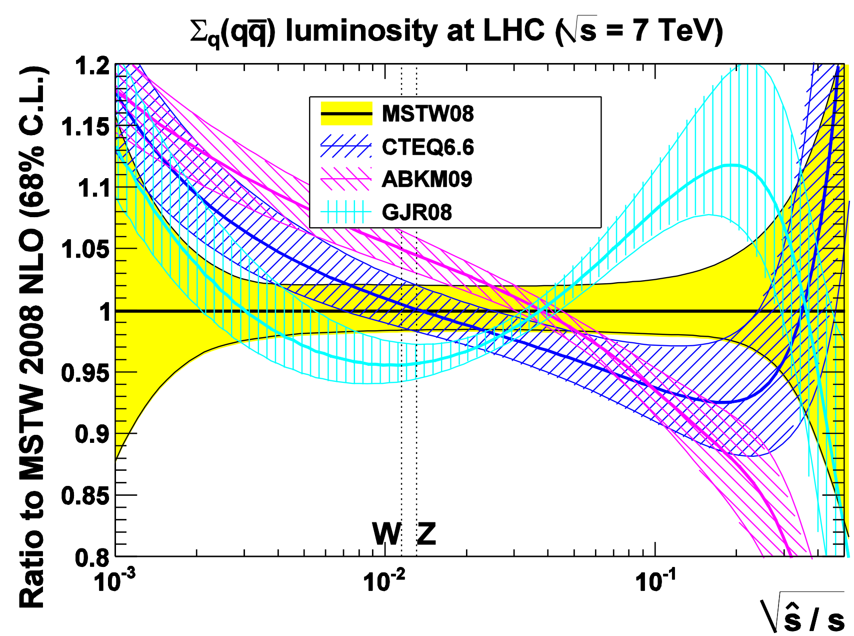


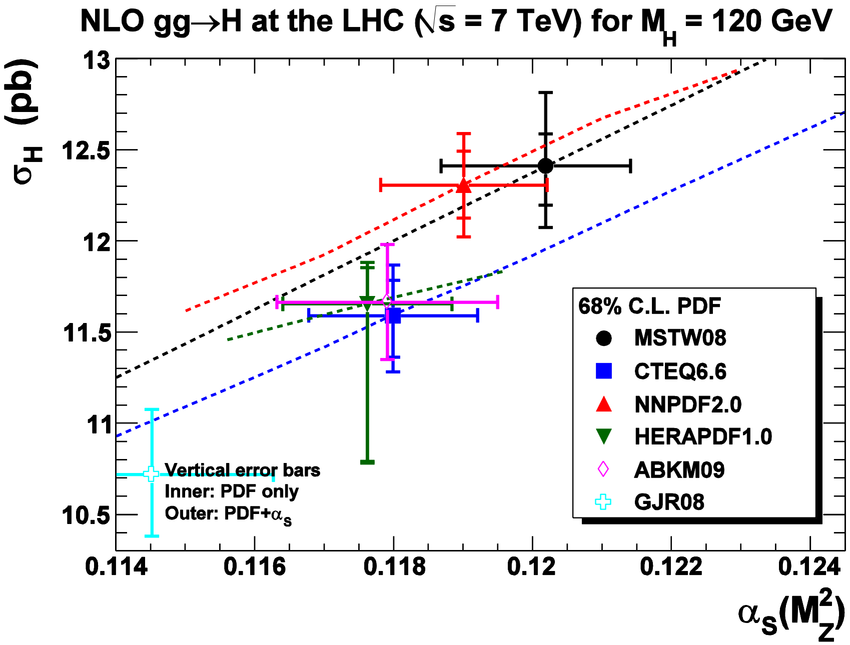


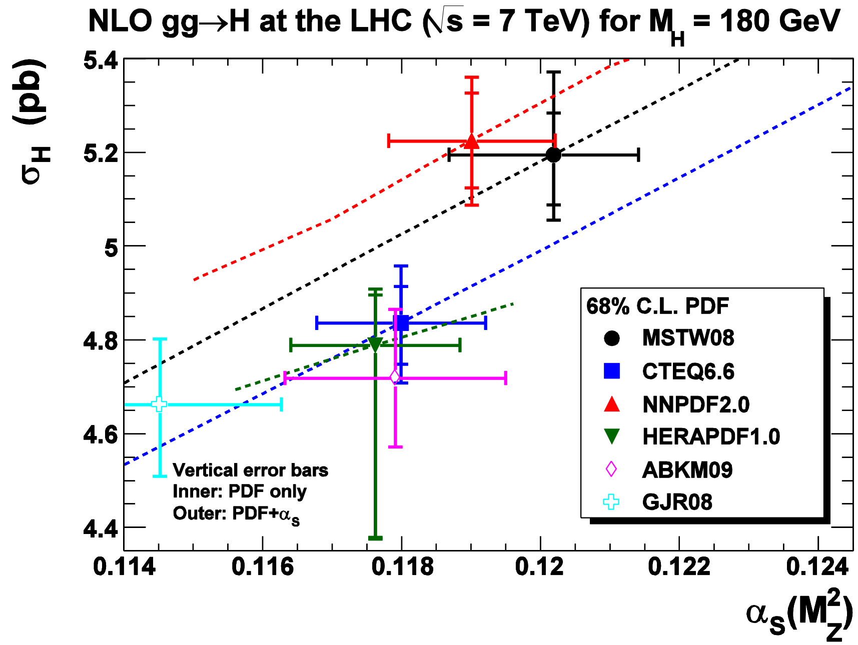


Plots from G.Watt -MSTW



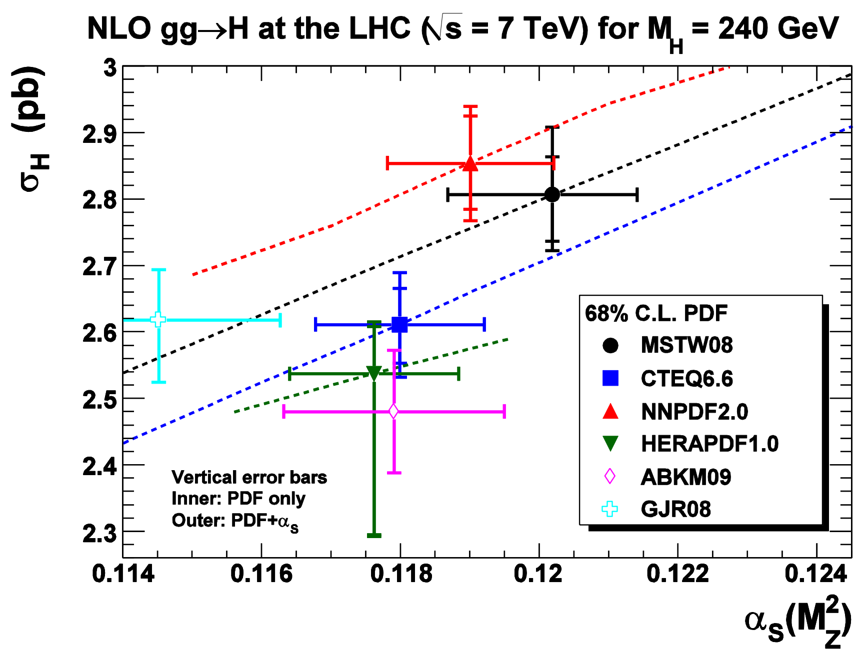


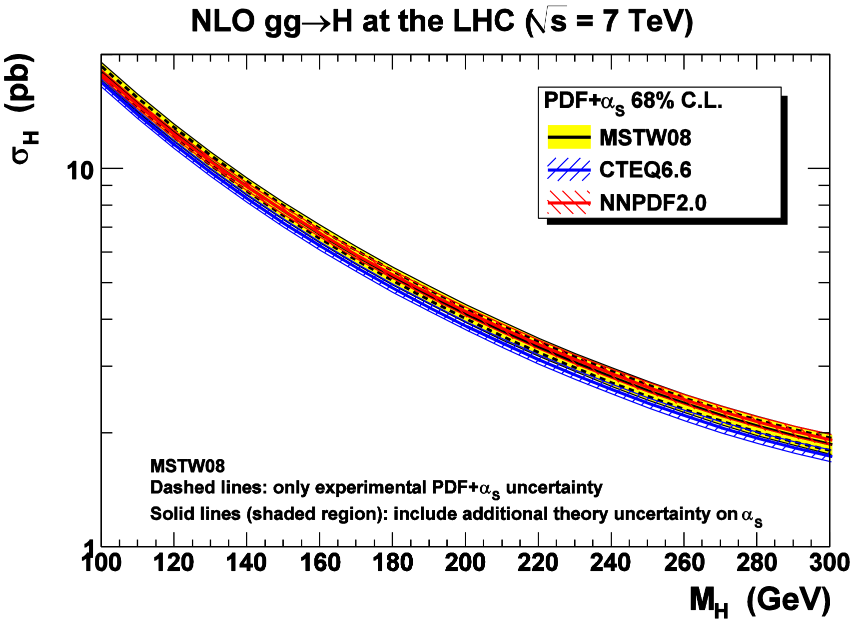


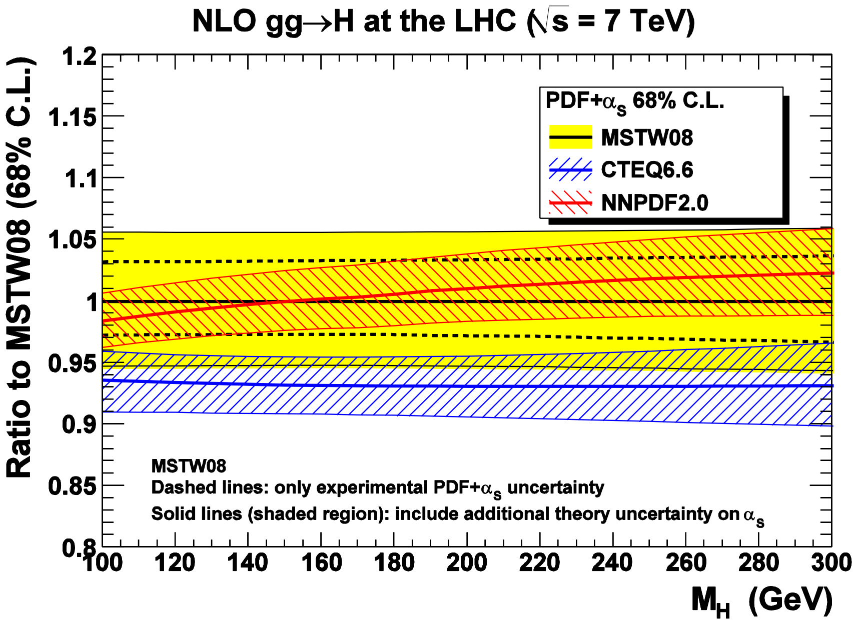


Plots from G.Watt -MSTW

Spread in Higgs production cross-sections is now > 15%
Dependence on alphas is also increased

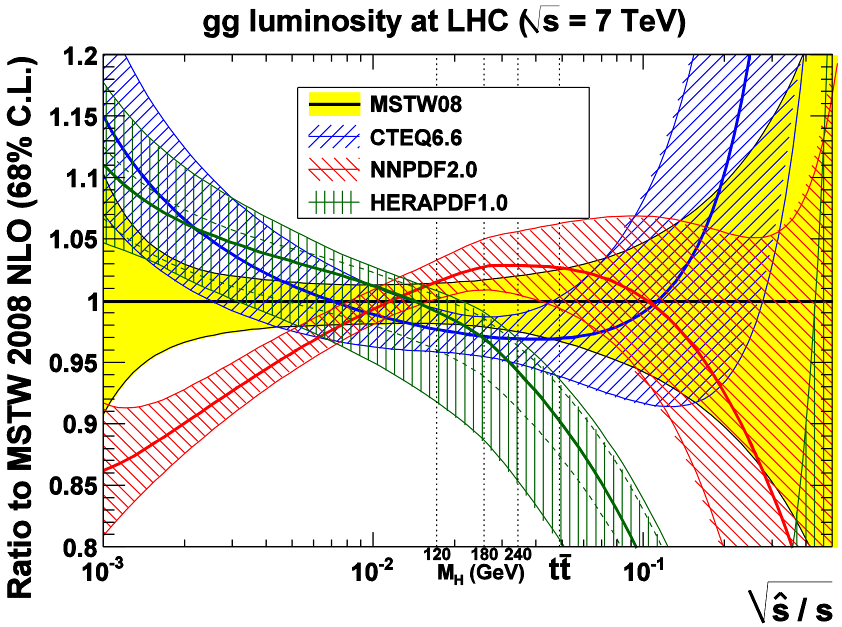


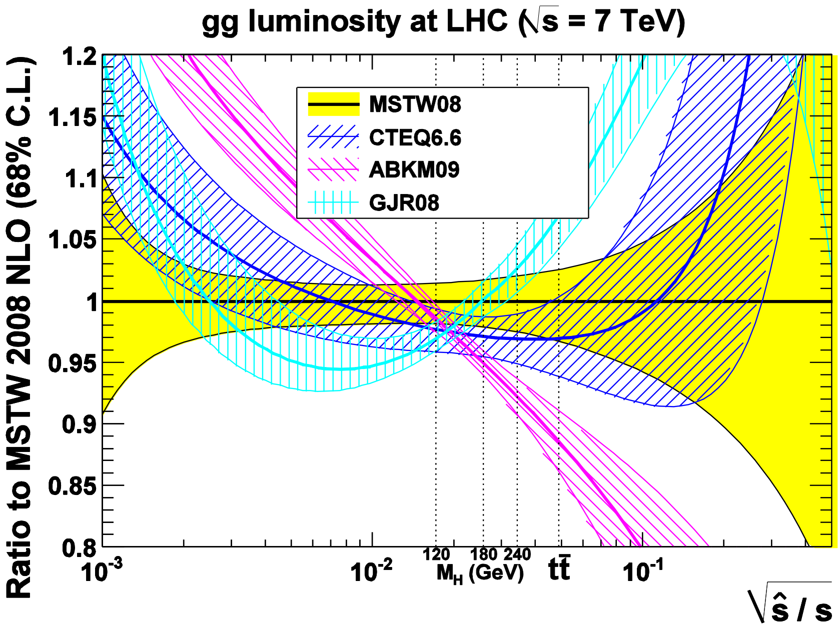


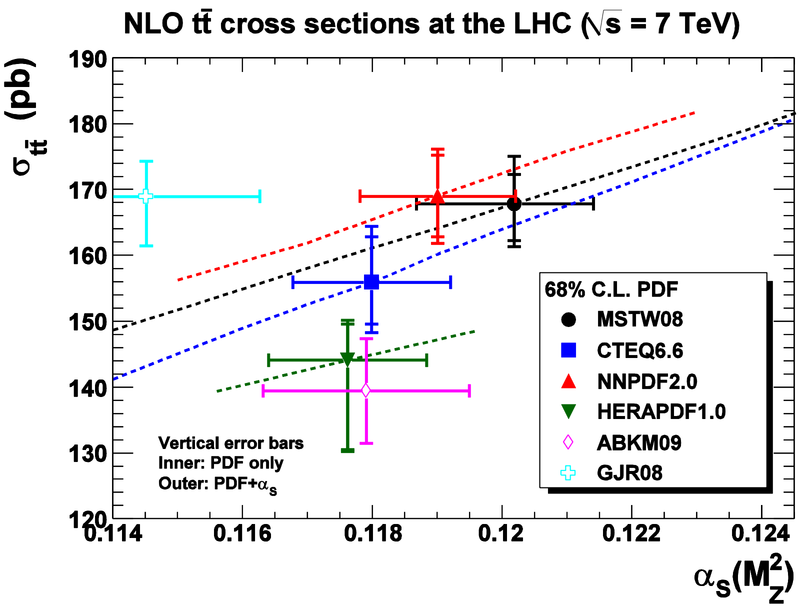


Plots from G.Watt -MSTW

Illustration of uncertainty band for MSTW due to PDFs alone within the dotted lines and total uncertainty due to PDFs +alphas is the full yellow band







Plots from G.Watt -MSTW