HERAPDF

A M Cooper-Sarkar , EPS-HEP-2011 Grenoble
on behalf of ZEUS and H1 collaborations

HERAPDF uses the combined H1 and ZEUS data on:

Inclusive Neutral and Charged Current processes for e^+p and e^-p scattering at 820,920 GeV proton beam energy from HERA-I (HERAPDF1.0) and HERA I+II (HERAPDF1.5)

There are also studies adding data from the lower energy runs at 460, 575 proton beam energy and from adding combined HERA data on F2charm

There are also fits adding separate H1 and ZEUS data on inclusive jet production to the inclusive cross section data (HERAPDF1.6)

Finally HERAPDF1.7 uses ALL of these data sets

Furthermore the HERAPDF uses purely proton data

•No need for deuterium corrections--- arXiv:1102.3686- uncertainties in deuterium corrections can feed through to the gluon PDF in global fits including jet data

•No need for dubious corrections for FL when extracting F2 –arXiv:1101.5261

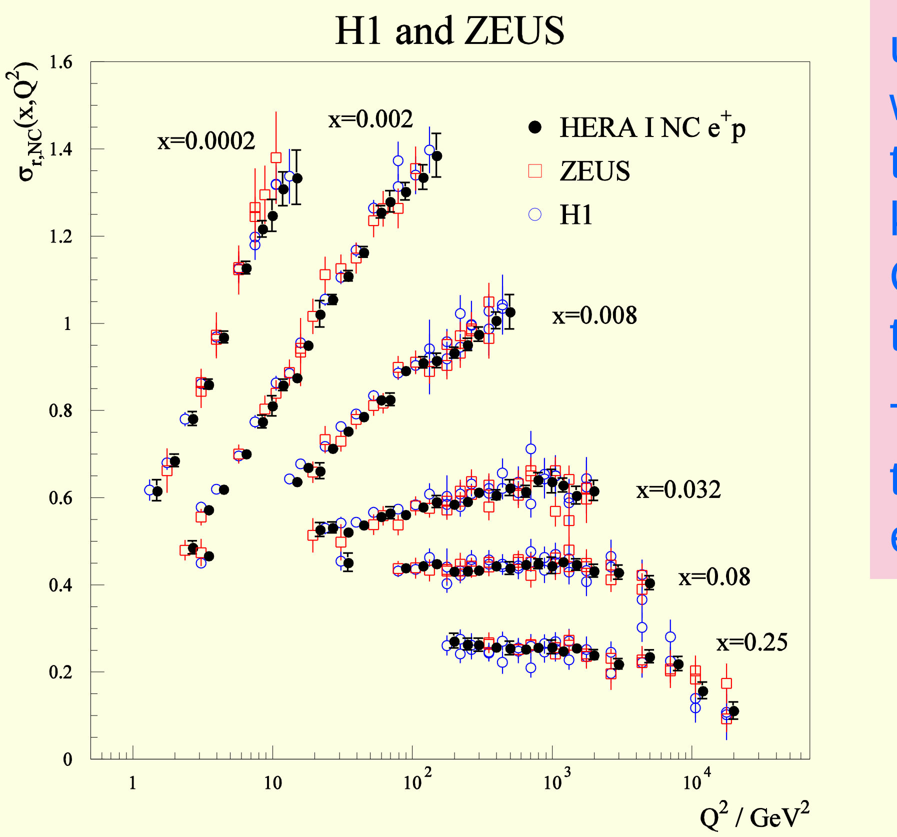
• No need for neutrino data heavy target corrections.

•No assumption on strong isospin needed to get the d-quark

•A very well understood consistent data set JHEP 1001 (2010) 109 +updates

The HERA data combination gives us a well understood ,consistent and accurate data set with systematic errors which are smaller than the statistical errors across most of the kinematic plane. The total errors are ~1% for Q^2 20-100 GeV^2 and less than 2% for most of the rest of kinematic plane.

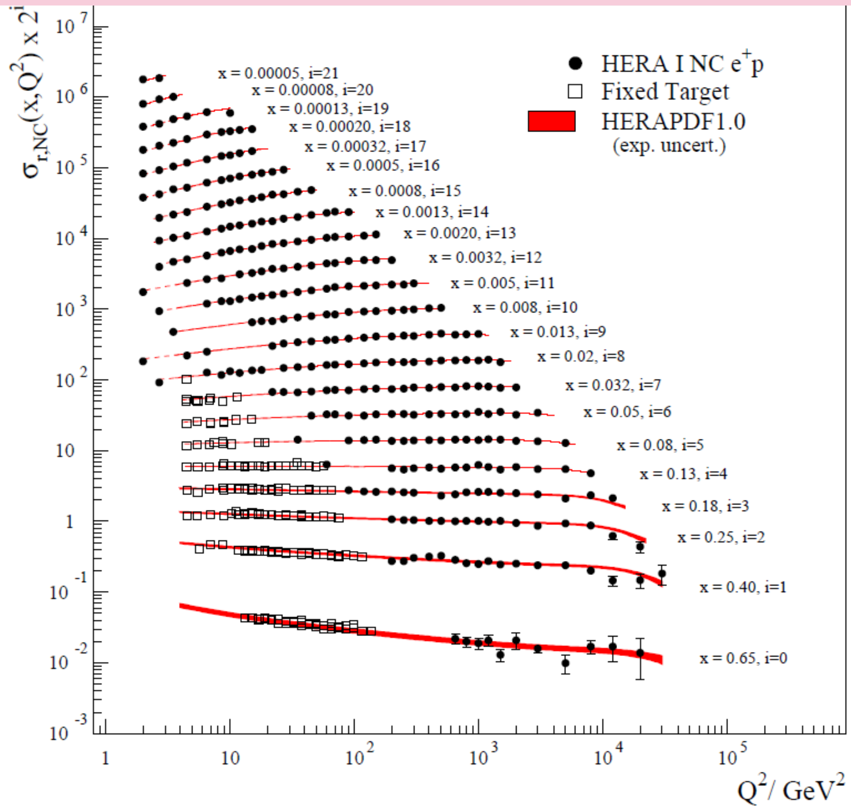
This allows us to use the χ2 tolerance Δχ2 =1 to set 68% limits on the PDFs from experimental sources



This page shows NC e+ combined data

Above : Results of the combination compared to the separate data sets

Right: the full NC e+ data



Where does the information on parton distributions come from?

CC e-p

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

CC e+p

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

•The charged currents give us flavour information for high-x valence PDFs

NC e+ and e-: the F2 term gives the low-x Sea

$$\frac{d^2\sigma(e\pm N)}{dxdy} = \frac{2\pi\alpha^2 s}{Q^4} \quad Y_+ \left[F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2) \pm \frac{Y_-}{Y_+} xF_3(x,Q^2)\right], \quad Y_\pm = 1 \pm (1-y)^2$$

$F_2 = F_2^{\gamma} - v_e P_Z F_2^{\gamma Z} + (v_e^2+a_e^2)P_Z^2 F_2^Z$

$xF_3 = \quad - a_e P_Z xF_3^{\gamma Z} + 2v_e a_e P_Z^2 xF_3^Z$

Where $P_Z^2 = Q^2/(Q^2 + M_Z^2)\ 1/\sin^2\theta_W$, and at LO

$[F_2, F_2^{\gamma Z}, F_2^Z] = \Sigma_i [e_i^2, 2e_i v_i, v_i^2+a_i^2][xq_i(x,Q^2) + x\bar{q}_i(x,Q^2)]$

$[xF_3^{\gamma Z}, xF_3^Z] = \Sigma_i\ 2[e_i a_i, v_i a_i] \quad [xq_i(x,Q^2) - x\bar{q}_i(x,Q^2)]$

So that $xF_3^{\gamma Z} = 2x[e_u a_u u_v + e_d a_d d_v] = x/3\ (2u_v+d_v)$

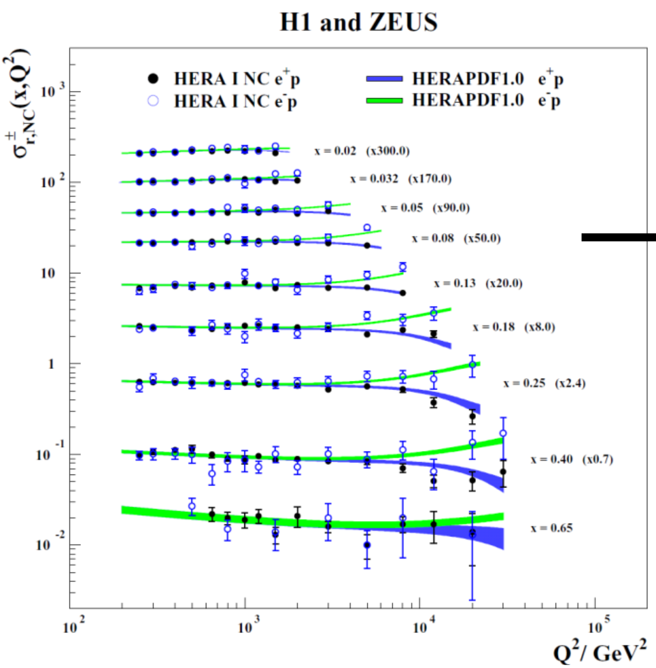
Where $xF_3^{\gamma Z}$ is the dominant term in xF_3

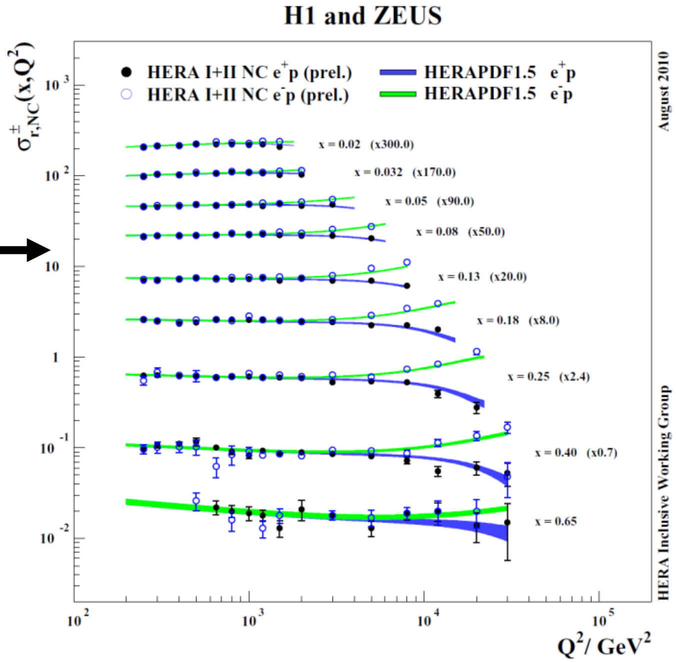
The neutral current F2 gives the low-x Sea

The difference between e- and e+ also gives a valence PDF for x>0.01- not just at high-x

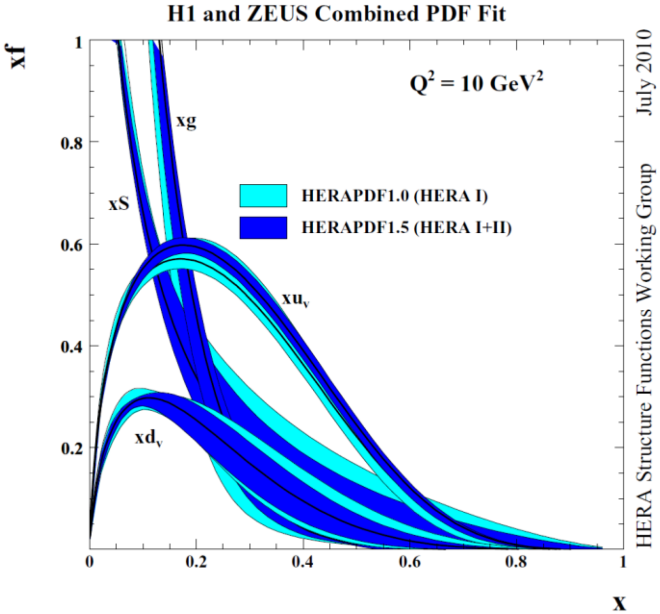
And of course the scaling violations give the gluon PDF

HERAPDF1.0 at NLO is already published (JHEP 1001 -109) now we update to HERAPDF1.5 NLO and NNLO : this is an update of data AND fit





Uses preliminary HERA I+II data combination (ZEUS-prel 10-018, H1prelim-10-042) in addition to the published HERA-1 combined data



Gives increased precision at high-x

Data combinations discussed in the talk of V Shekelyan

HERAPDF1.5 NLO is now on LHAPDF5.8.6

However as we include more data sets and move to NNLO we have extended our parametrisation..

A reminder of the PDF parametrization: u_valence, d_valence, U and D type Sea and the gluon are parametrised by the form

$$xf(x,Q_0^2)=Ax^B(1-x)^C(1+Dx+Ex^2+\varepsilon\sqrt{x})$$

	A	B	C	D	E ε
uv	Sum rule	free	free	free	free var
dv	Sum rule	free	free	var	var var
UBar	=(1-fs)ADbar	=BDbar	free	var	var var
DBar	free	free	free	var	var var
glue	Sum rule	free	free	var	var var

A'g	B'g
free	free

extended gluon parametrisation $Ag\, x^{Bg} (1-x)^{Cg} (1+Dx+Ex^2) - A'g\, x^{B'g} (1-x)^{Cg}$

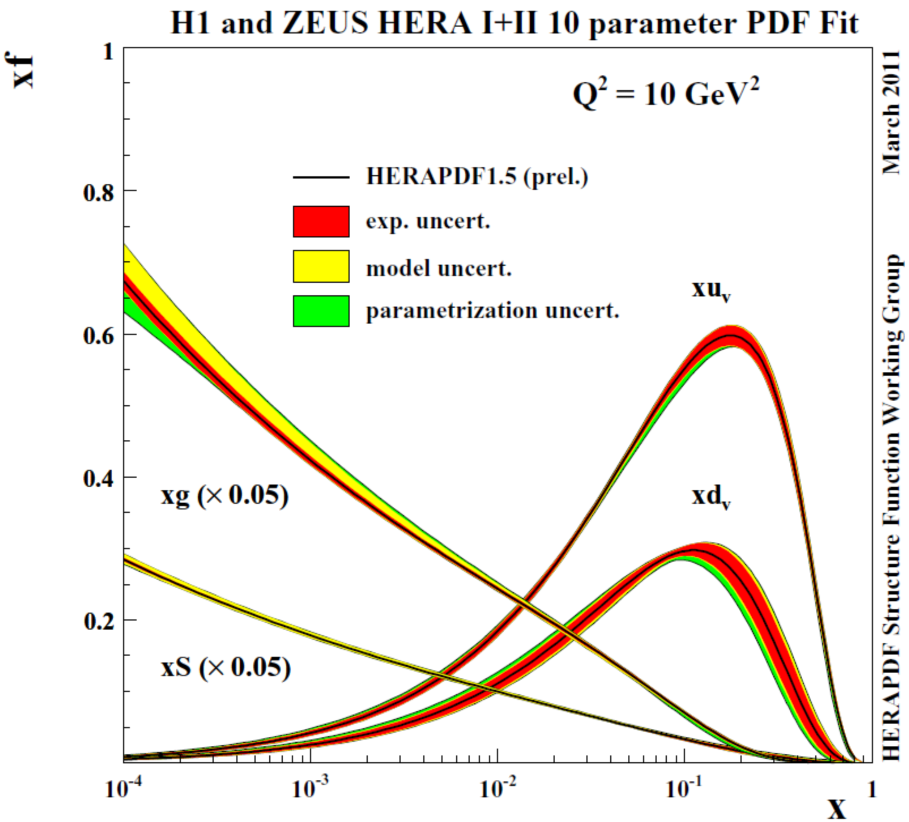
The table summarises our **extended parametrization choices** and the parametrization variations that we consider in our uncertainty estimates (and we also vary the starting scale Q^2_0). **NOTE we have made the gluon more flexible and we have freed low-x d-valence from u-valence**

We also consider model uncertainties on the PDFs by varying m_c, m_b, f_s, Q^2min

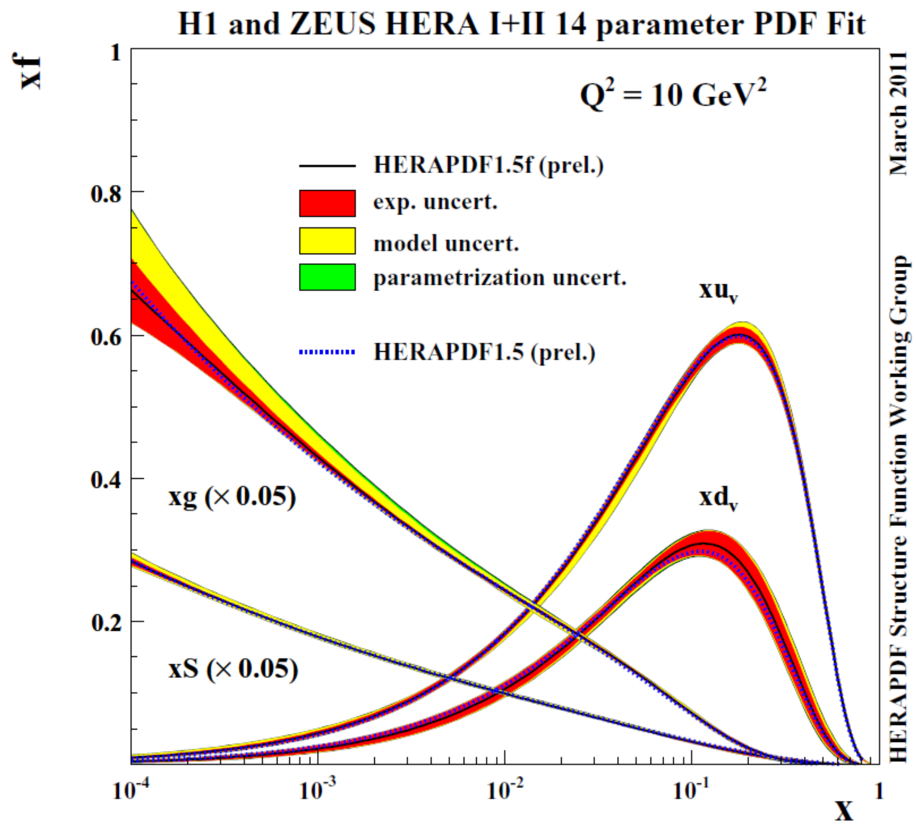
PDFs are also supplied for a range of $\alpha_s(M_Z)$ values

How does the extended parametrisation affect the NLO PDFs?- not much

HERAPDF1.5



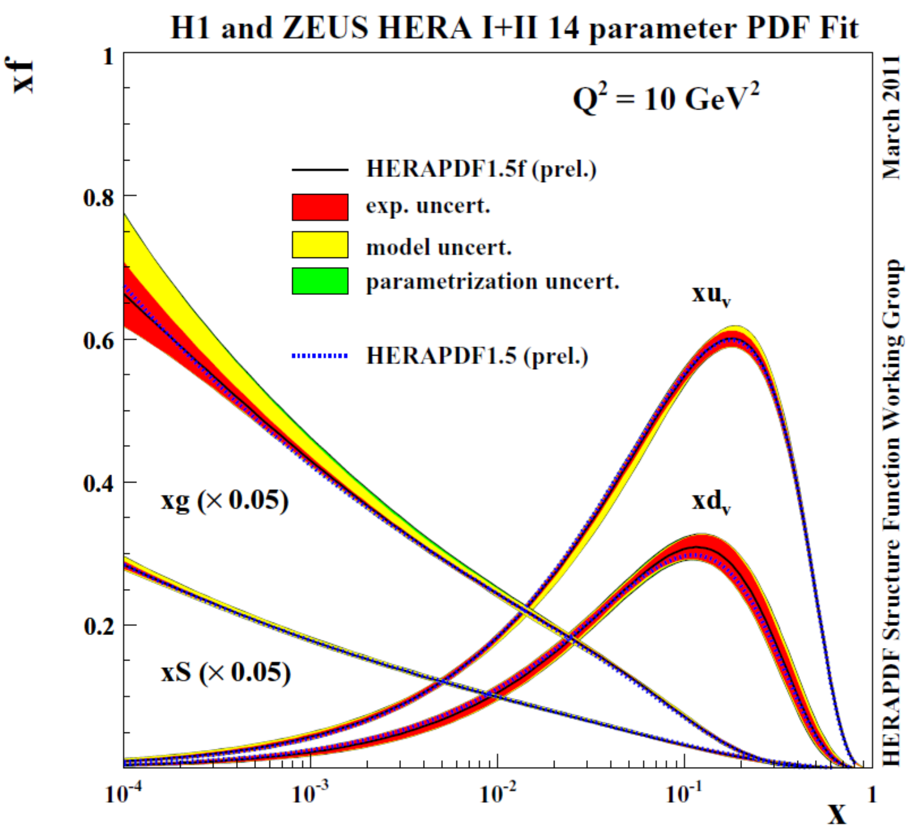
HERAPDF1.5f



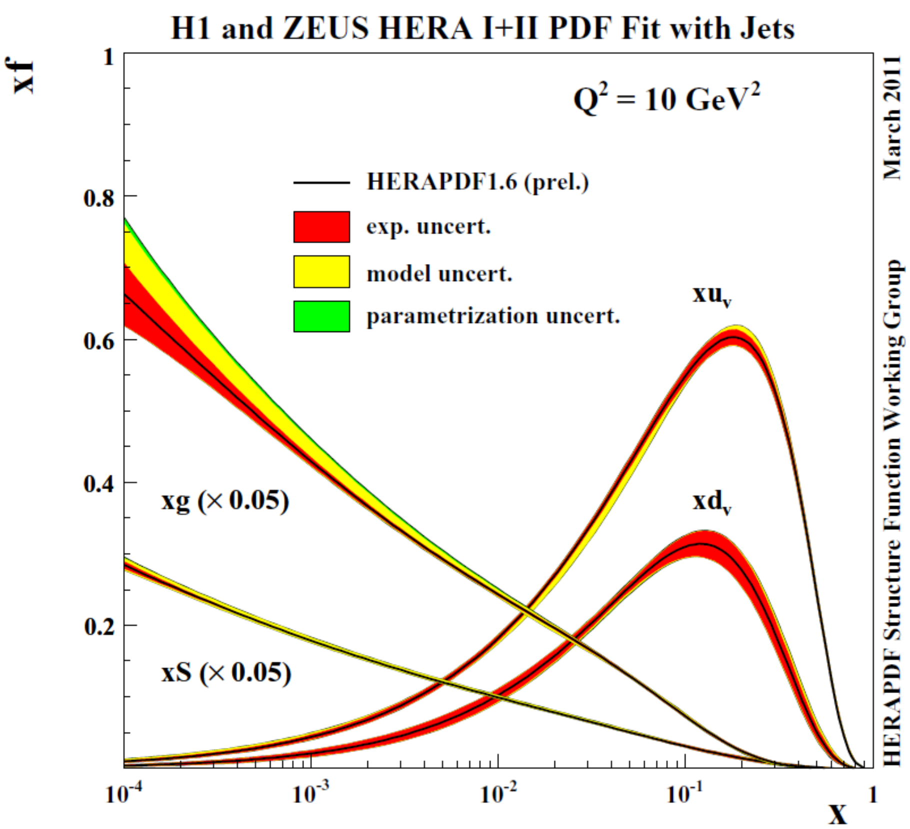
i) The level of total uncertainty is similar- but we swap parametrisation uncertainty for experimental uncertainty- and there is slightly more uncertainty on low-x gluon

ii) The central values have shifted such that the flexible parametrisation has a softer high-x Sea and a suppressed low-x d-valence- but these changes are within our error bands

Using this extended parametrization we added HERA jet data (as yet uncombined) to the fit (ZEUS-prel-11-001 ,H1prelim-11-034)



Without jets

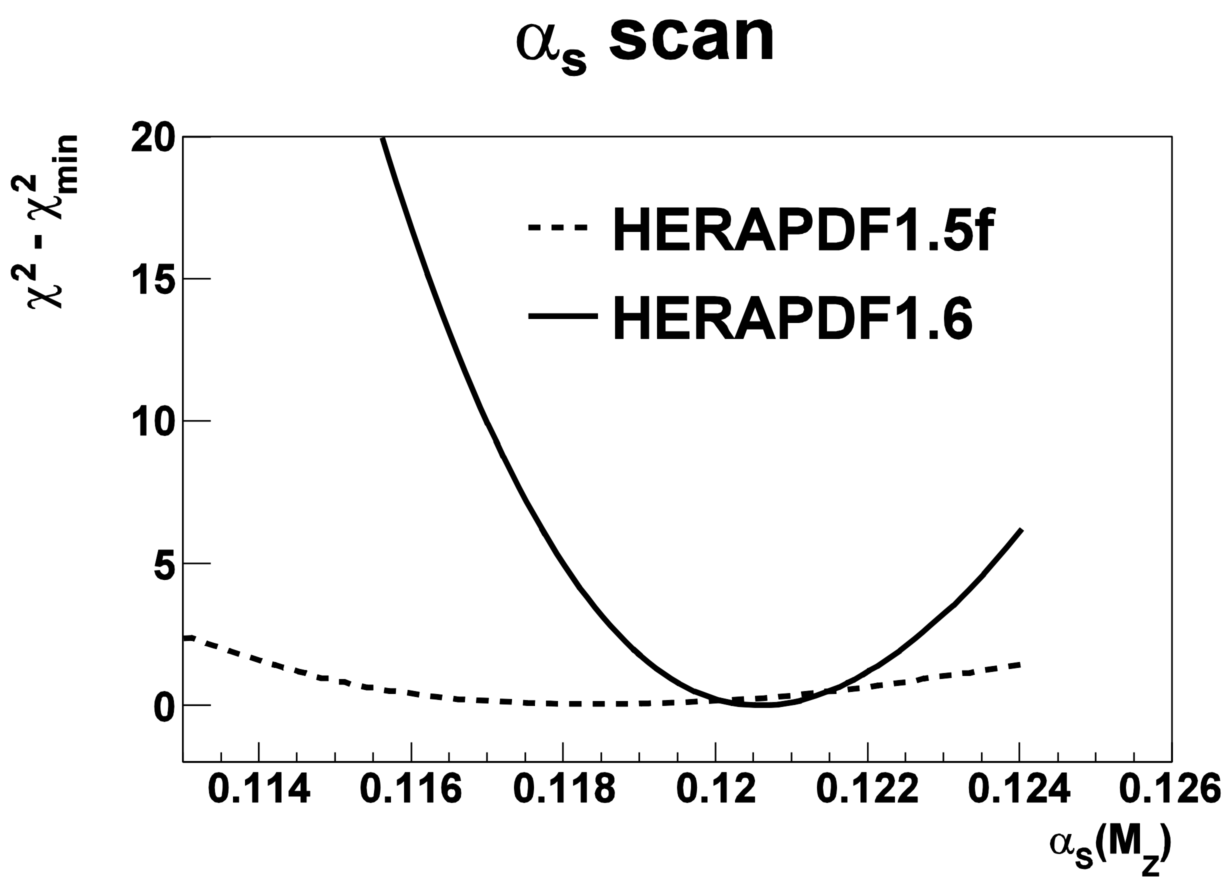


With jets

There is little difference in the size of the uncertainties after adding the jet data –but there is a marginal reduction in high-x gluon uncertainty.

However, the jet data allow us to make a competitive measurement of $\alpha_S(M_Z)$

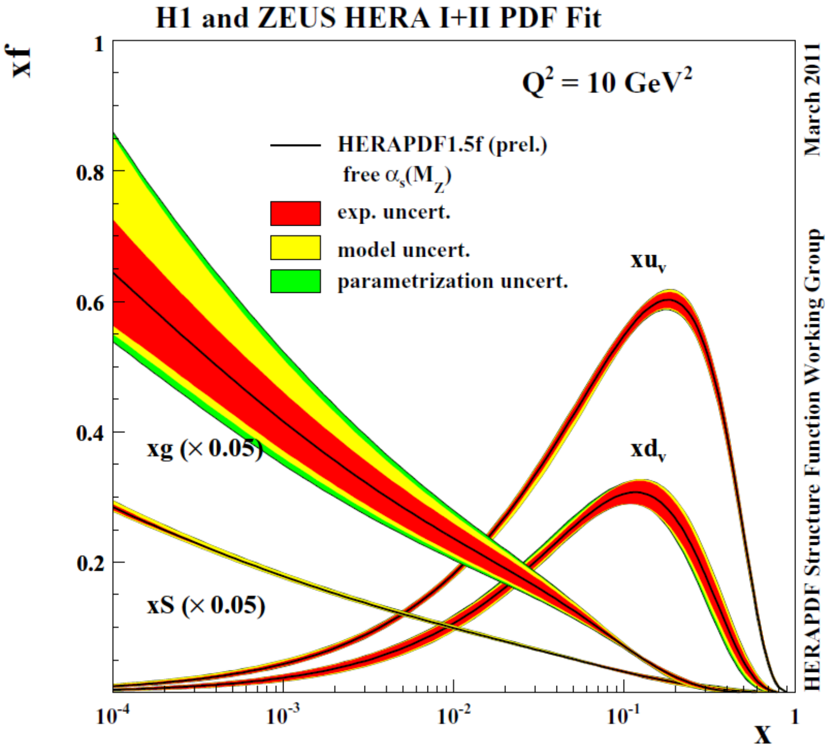
The χ2 scan of HERAPDF1.5f (no jets) and HERAPDF1.6 (with jets) vs $\alpha_S(M_Z)$

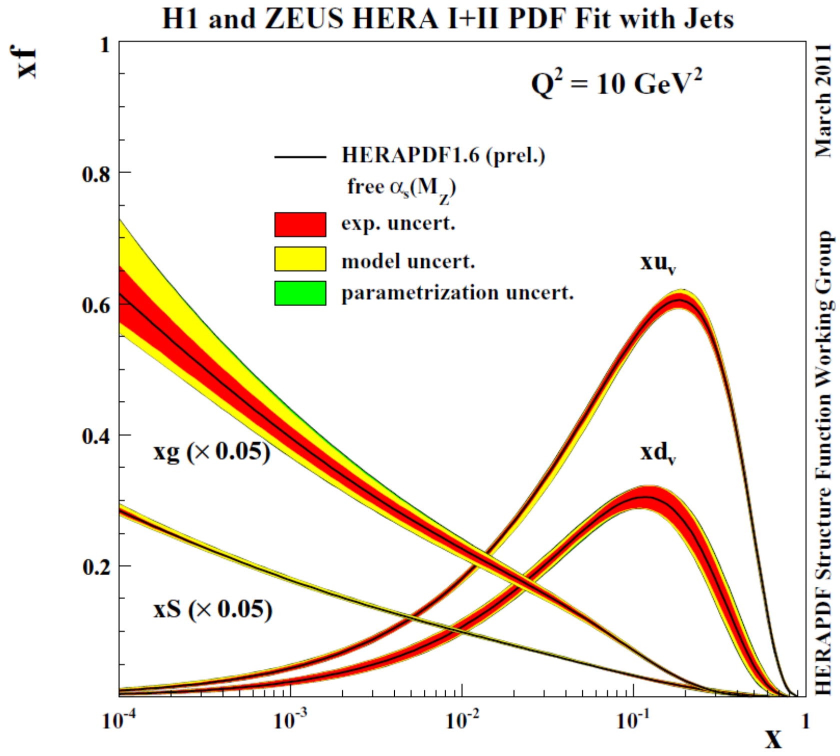


$\alpha_S(M_Z)$ =0.1202 ± 0.0013 (exp) ± 0.0007(model/param) ± 0.0012(hadronisation)

+0.0045/-0.0036 (scale)

$\alpha_S(M_Z)$ = 0.1202 ± 0.0019 ± scale error



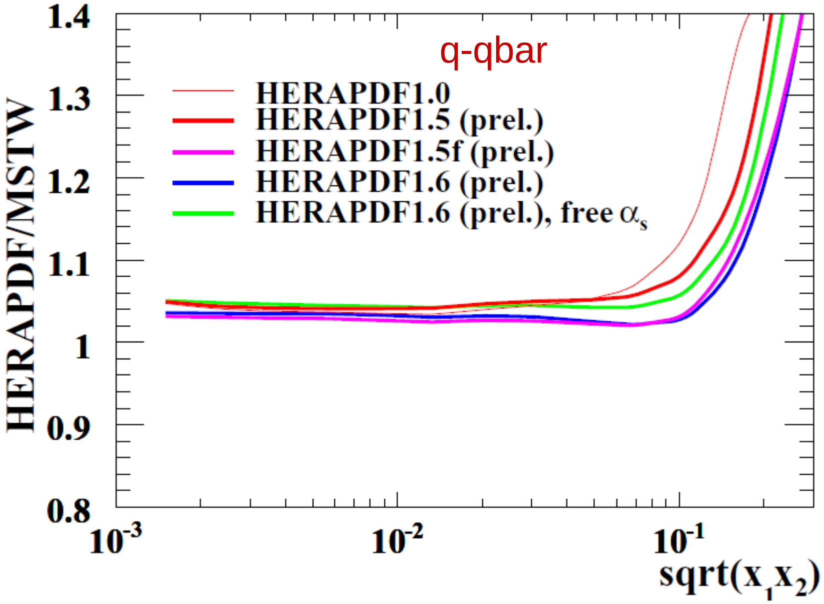


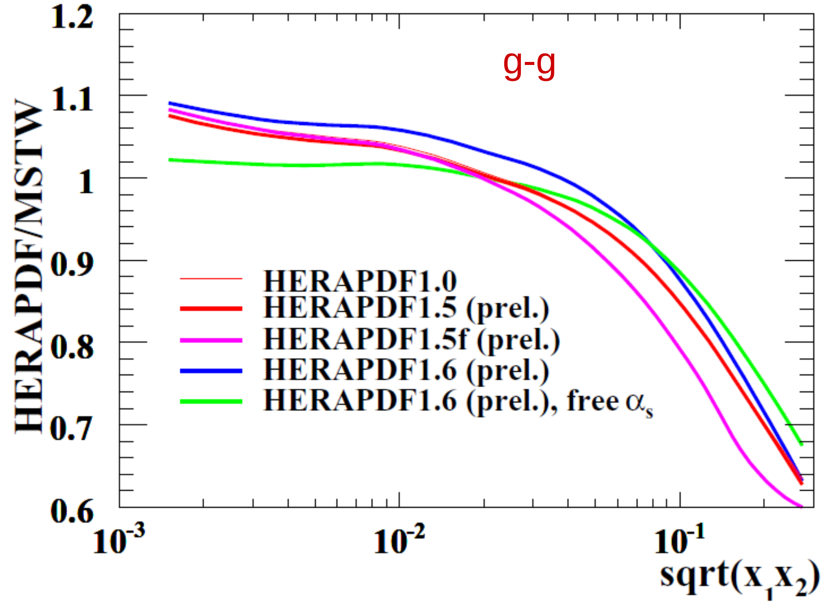
Free $\alpha_S(M_Z)$ no jets

Free $\alpha_S(M_Z)$ with jets

PDFs with free$\alpha_S(M_Z)$ with and without jet data included in the fit
The addition of the jet data ensure that the PDF uncertainty on the gluon due to the uncertainty on **$\alpha_S(M_Z)$ is not very large**

LHC at 7 TeV parton-parton luminosity plots for HERAPDF1.5 in ratio to MSTW2008





The q-qbar luminosity at NLO

HERAPDF1.5 is softer than 1.0 at high-x and 1.5f is even softer

Adding the jets to make it 1.6 makes very little difference

Letting alphas be free so that $\alpha_S(M_Z)$=0.1202 rather than 0.1176 hardens the high-x quark distribution marginally

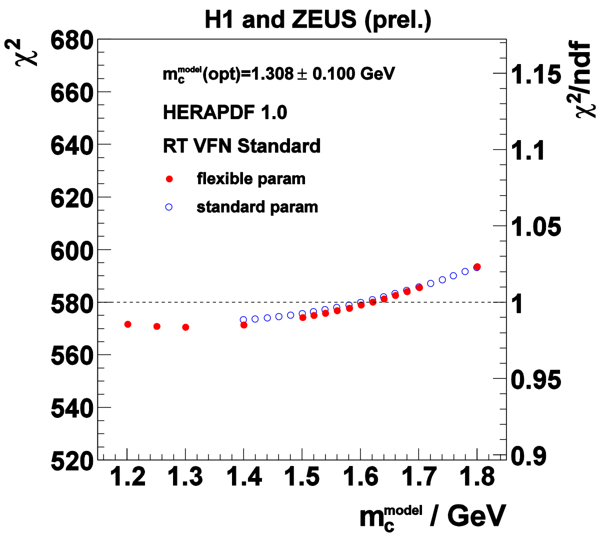
The g-g luminosity at NLO

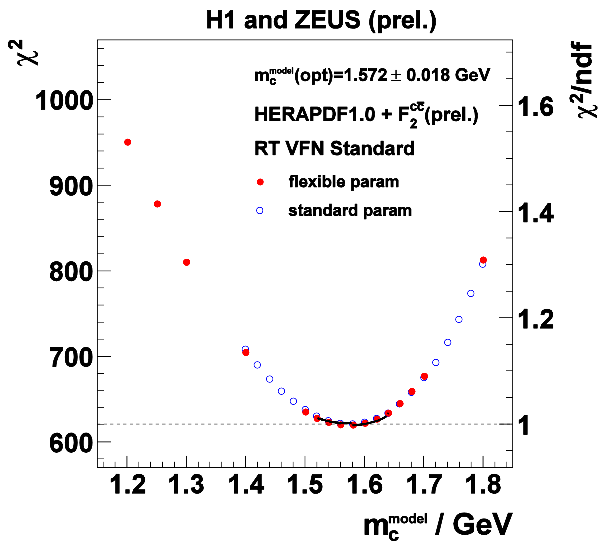
HERAPDF1.5 is on top of 1.0 and 1.5f is slightly softer

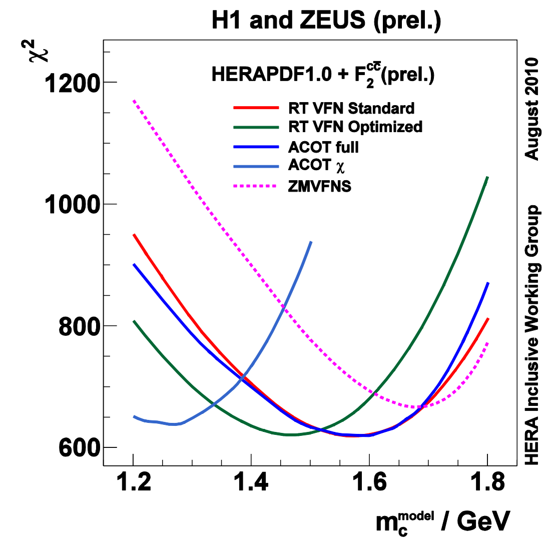
Adding the jets to make it 1.6 hardens the high-x gluon

Letting alphas be free so that $\alpha_S(M_Z)$=0.1202 rather than 0.1176 also reduces the low-x gluon

We have also made specific studies of the addition of the HERA combined F2charm data (ZEUS prel 10- 009,H1prelim 10 -045)



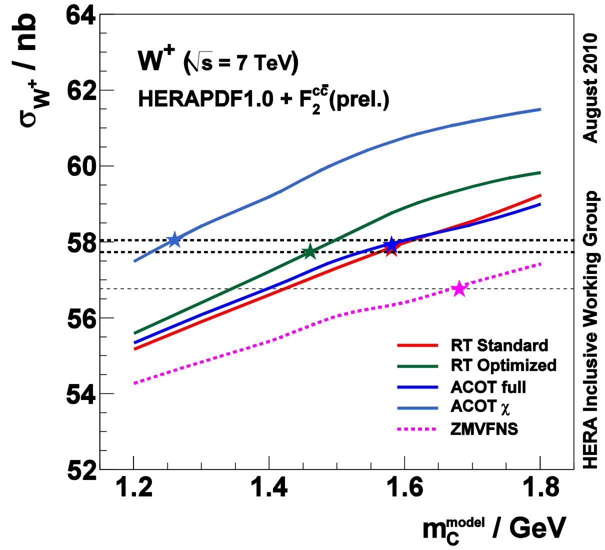




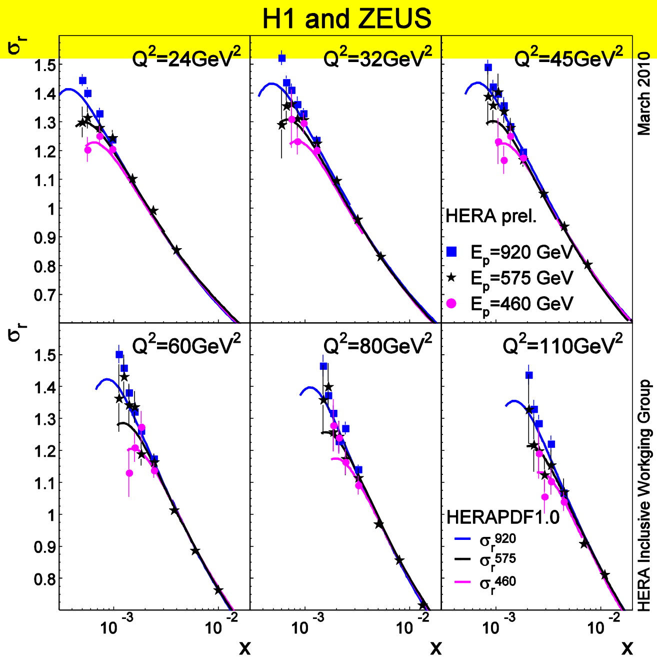
In HERAPDF1.0,1.5 we present a model uncertainty of mc 1.35 to 1.65 GeV on the charm mass . The inclusive data have no sensitivity to mc (left). The combined charm data do (middle). However the value depends on the scheme chosen to calculate the heavy quark contributions (right). All schemes bar the Zero Mass Variable Flavour Number have equally acceptable χ2

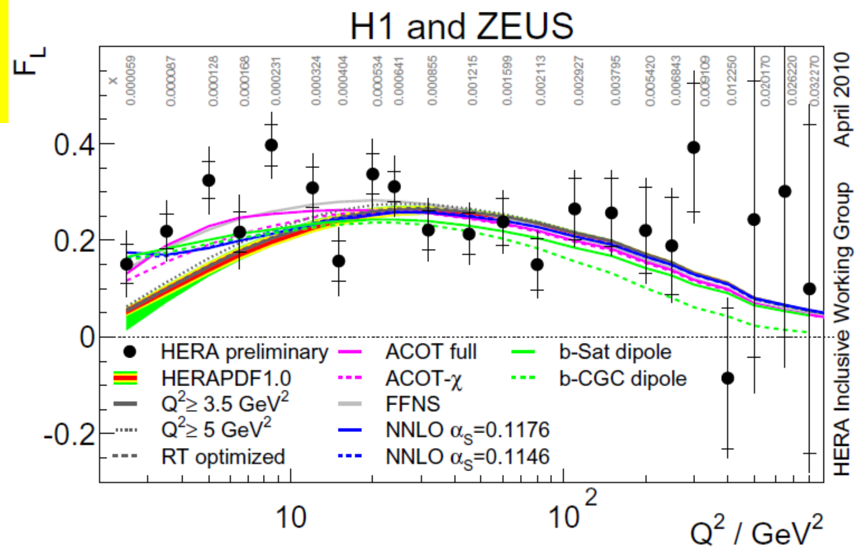
The use of the optimal charm mass for the chosen scheme has consequences for the predictions of LHC W, Z cross sections.

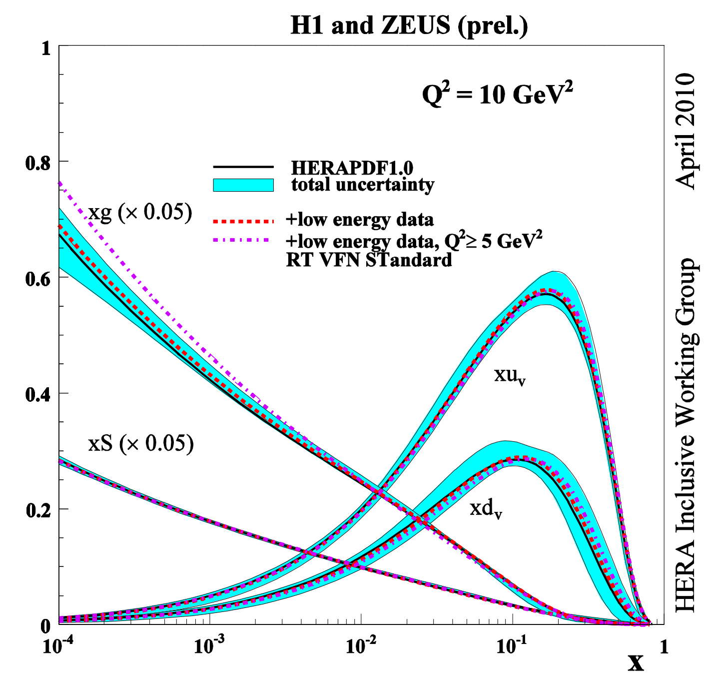
The charm data will help to reduce uncertainties



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 (ZEUS prel 10-001 , H1prelim 10-043)







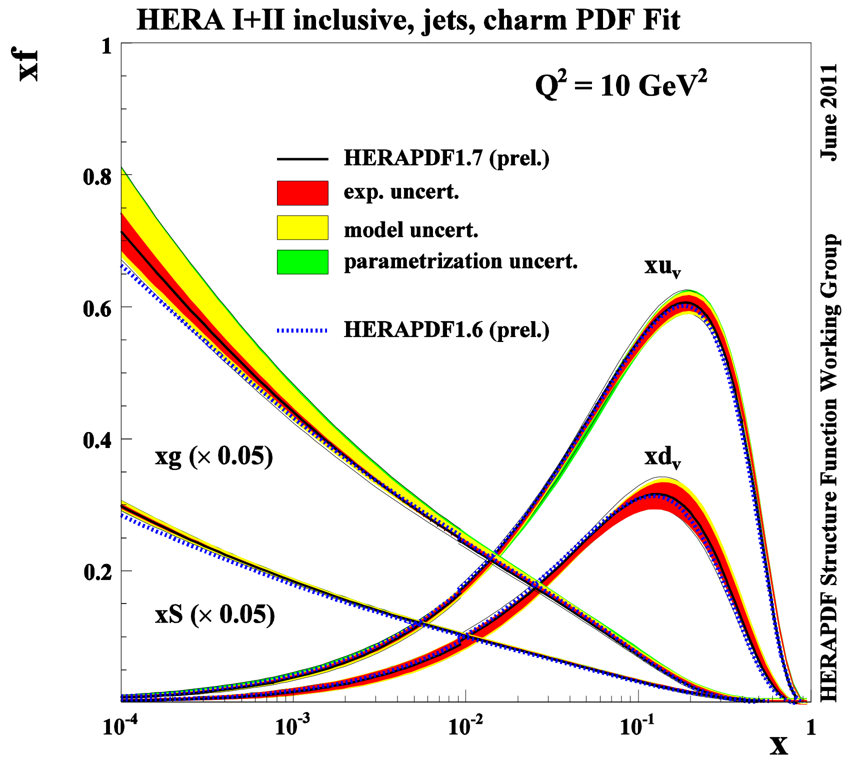
In HERAPDF1.0,1.5 we also present a model uncertainty from the variation of the minimum Q^2 cut on the data The low energy data are more sensitive to this cut.

If low Q^2 -and hence low x - data are cut -the resulting gluon is somewhat steeper.
This level of uncertainty is now covered by the extended parametrization

We have now put together all the data sets:
HERA –I +II high energy inclusive, HERA-II low energy inclusive , F2charm and the separate H1 and ZEUS jet data to make HERAPDF1.7 NLO using the extended parametrization.(ZEUS prel-11-010)

All the data sets are very compatible and

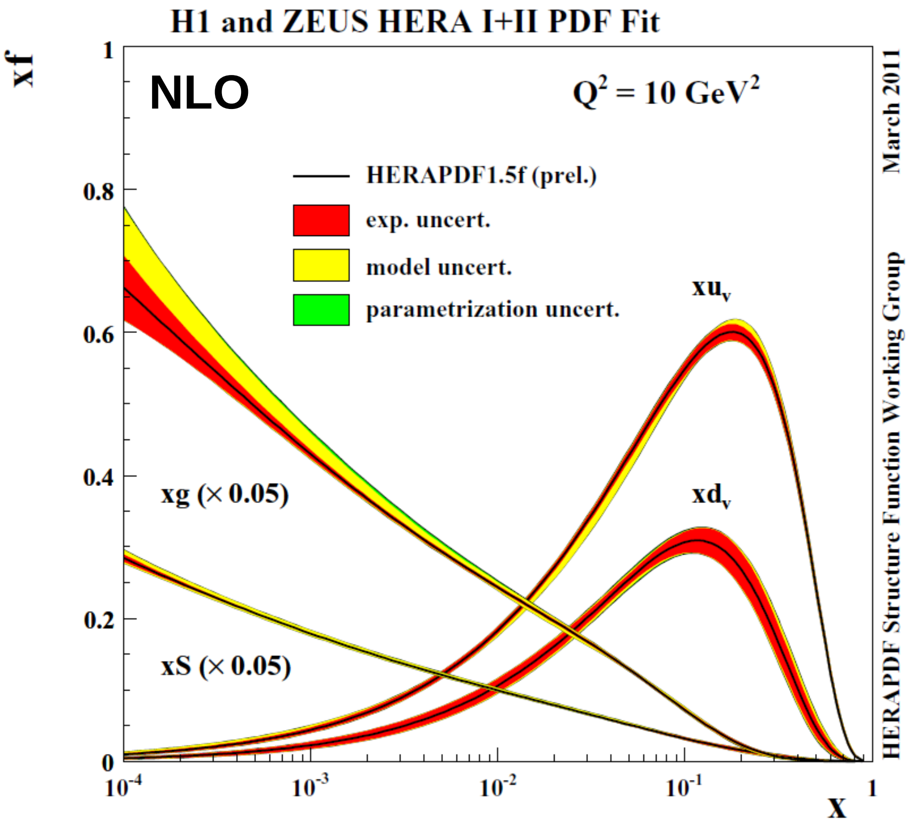
- the addition of charm motivates us to change our standard VFN to the RT optimised version, with its preferred value of the charm mass parameterr mc=1.5 GeV,
- whereas the jet data motivate us to raise our standard NLO $\alpha_S(M_Z)$ value to $\alpha_S(M_Z) = 0.119$

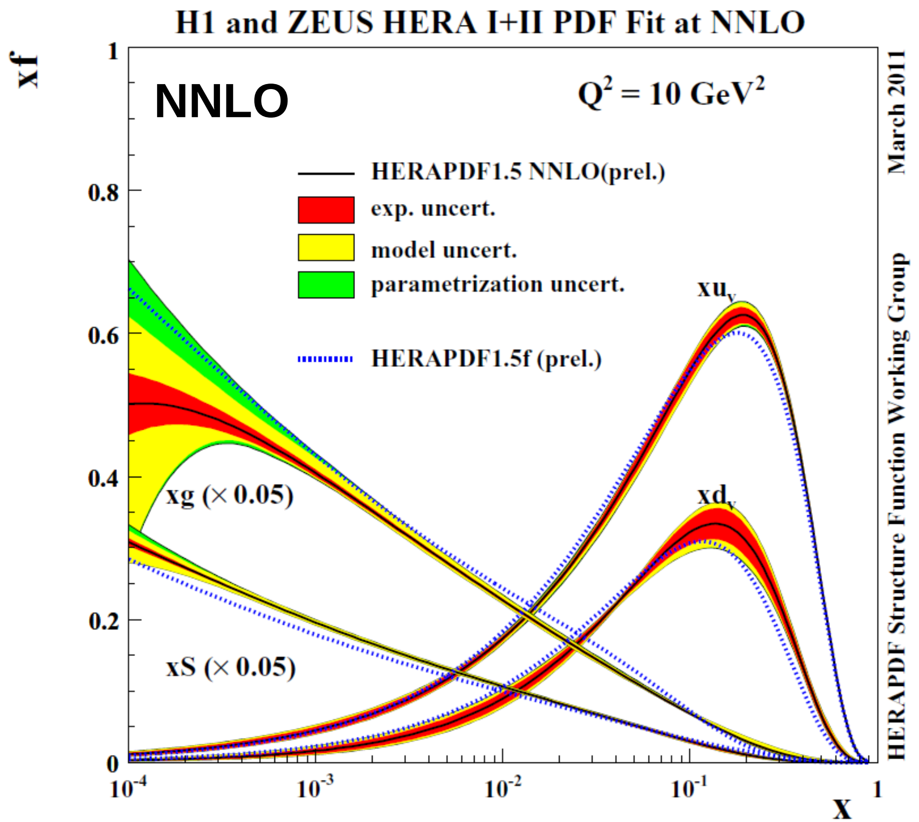


In view of the larger value of $\alpha_S(M_Z)$ at NLO we now recommend the larger value $\alpha_S(M_Z) = 0.1176$ for the central value for HERAPDF1.5 NNLO.
For HERAPDF1.0 NNLO we had used both 0.1145 and 0.1176

And so to NNLO: **ZEUS-prel-11-002/H1prelim-11-042. For these fits only HERA I+II high energy inclusive data are used (jets cannot be fits at NNLO)**

First compare HERAPDF1.5 NLO and NNLO both with extended parametrization





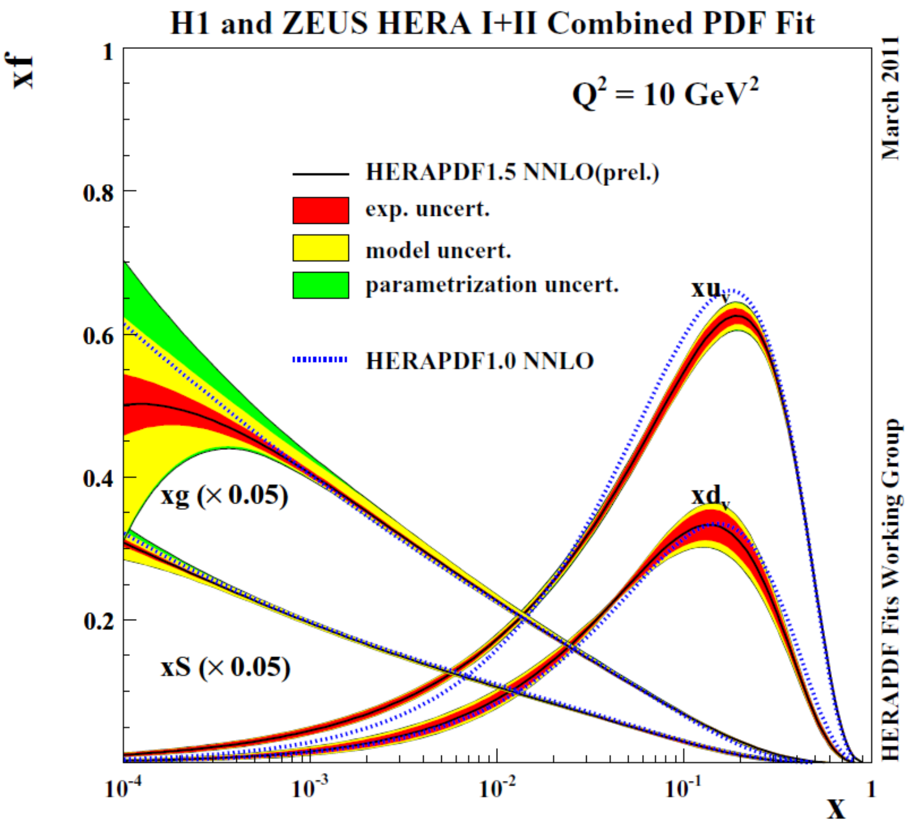
What are the differences?

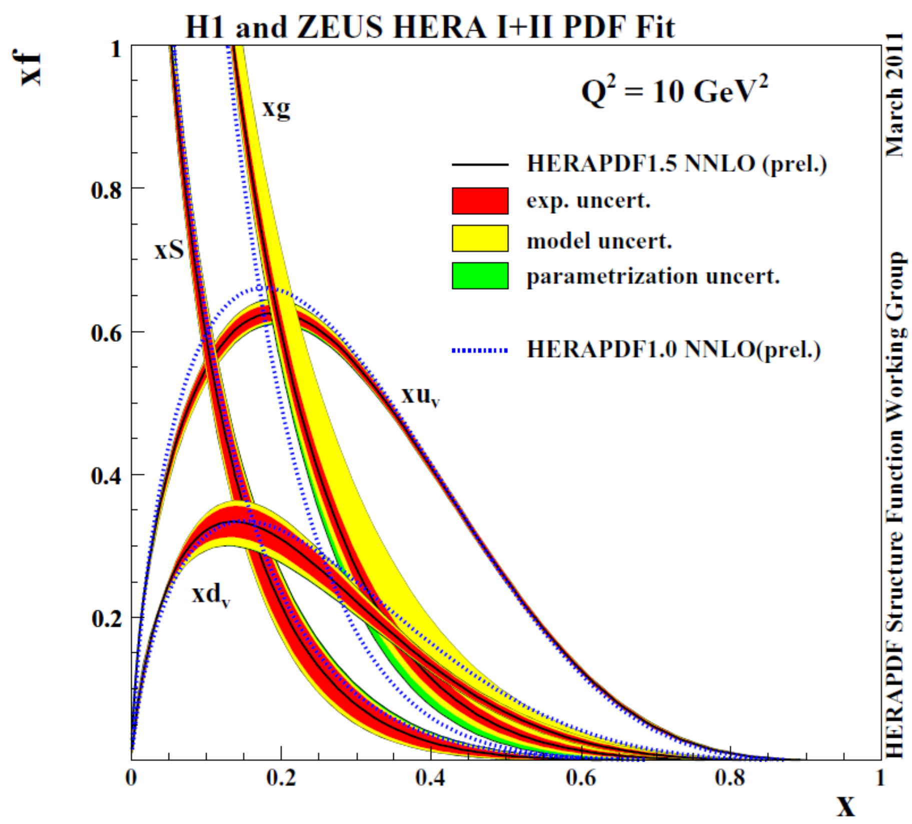
- Valence not much
- Sea a little steeper
- Gluon more valence like

On these plots both NLO and NNLO have $\alpha_s(M_Z)$ =0.1176

The low-x gluon has greater uncertainty NNLO DGLAP is NOT a better fit than NLO to low-x,Q^2 data

Now compare HERAPDF1.5NNLO to HERAPDF1.0 NNLO



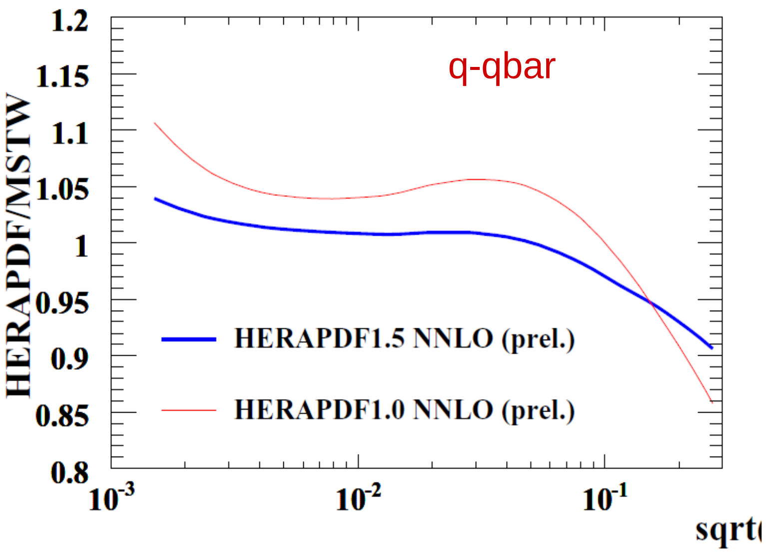


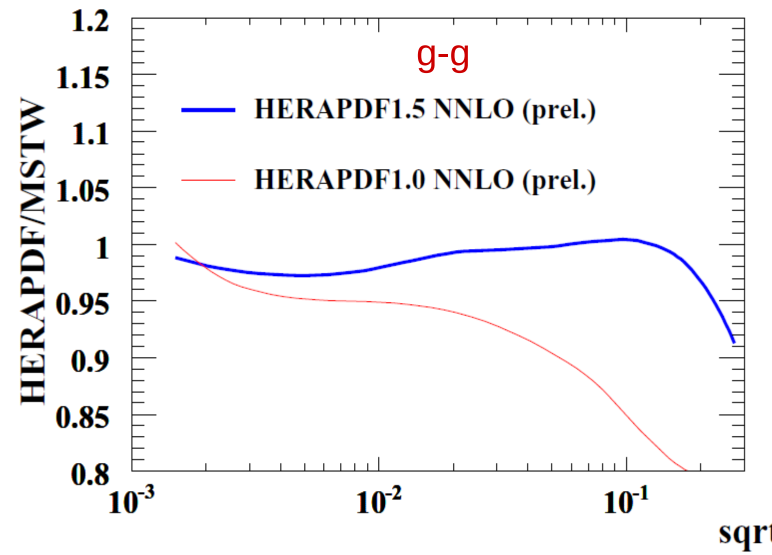
Previously we did not issue an error band on the 1.0 NNLO fits – the errors were in fact asymmetric and this is what led us to the extended parametrisation. Here we compare at $\alpha_S(M_Z)$=0.1176, which is our recommended central value for NNLO

The HERAPDF1.5 NNLO is available for a series of $\alpha_S(M_Z)$ values and with model and parametrisation uncertainties on LHAPDF5.8.6

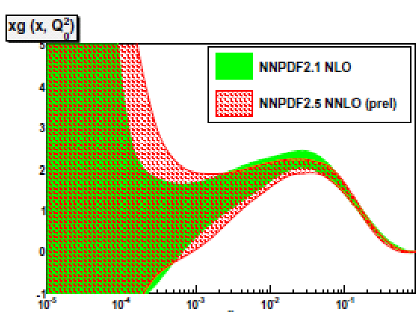
HERAPDF1.5 NNL0 has a harder high-x gluon than HERAPDF1.0.

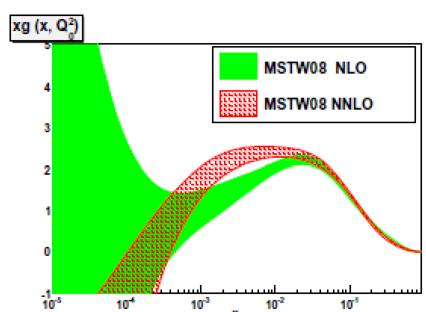
LHC at 7 TeV parton-parton luminosity plots for HERAPDF1.0/1.5 in ratio to MSTW2008 at NNLO

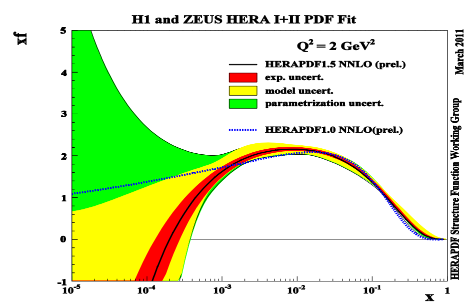




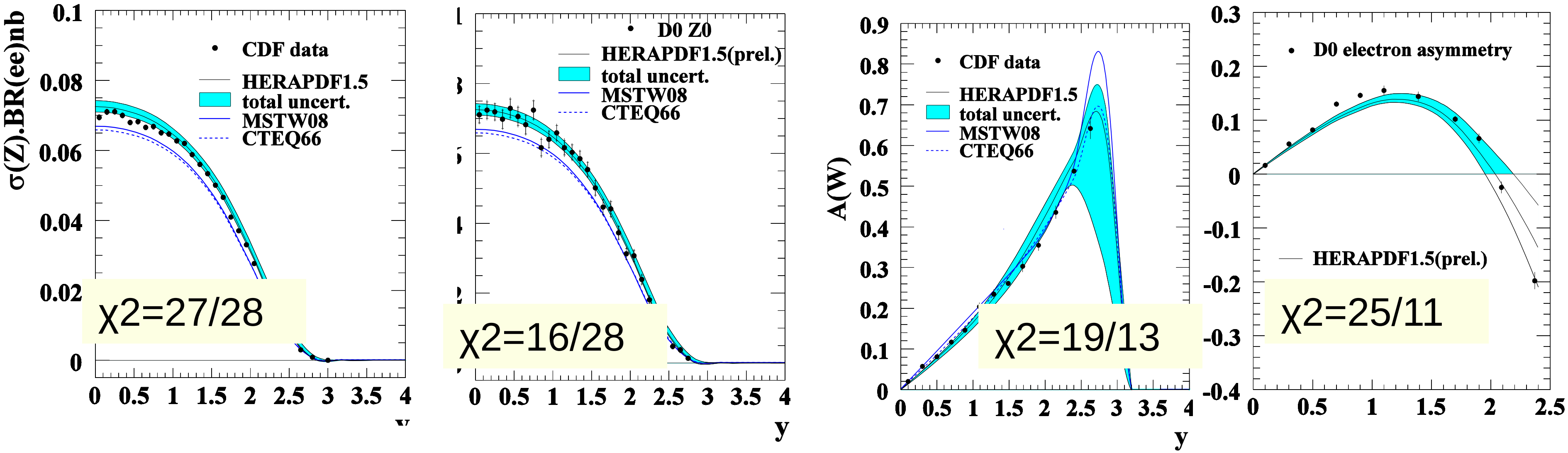
NNLO -- NNPDF2.1 Compare MSTW Compare HERAPDF1.5



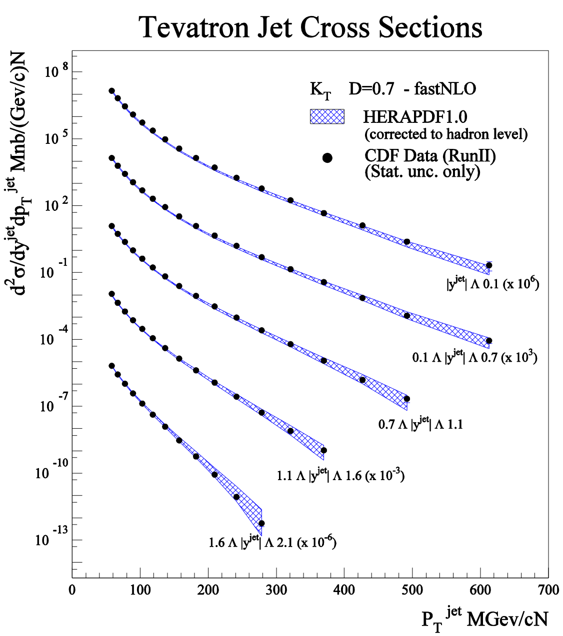




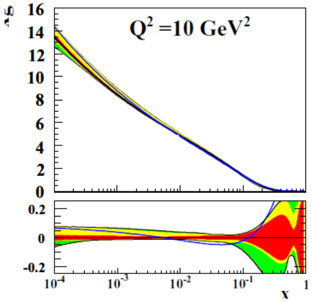
FInally how does HERAPDF measure up to Tevatron and LHC data



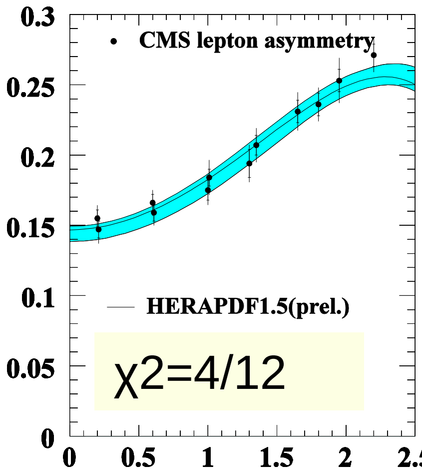
Pretty well for Tevatron W and Z data – even before fitting –and if these data are fit (χ2 given after fit) the resulting PDFs lie within the HERAPDF1.5 error bands

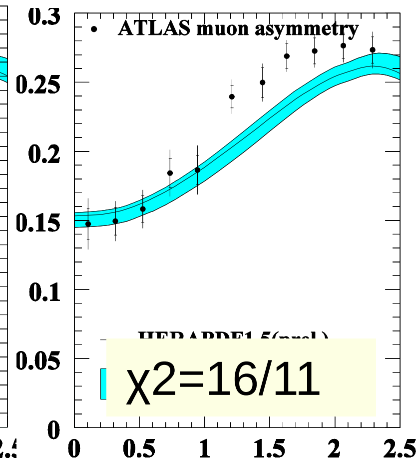


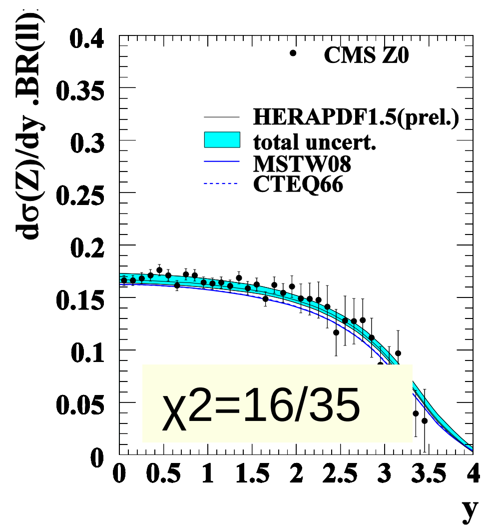
The description of Tevatron jet data before fitting (ie to the HERAPDF1.5 central values) is not so great BUT if these data are fitted the χ2 are acceptable (χ2=113/76) and the resulting PDFs are within the HERAPDF1.5 errors bands..although tending to the edge.

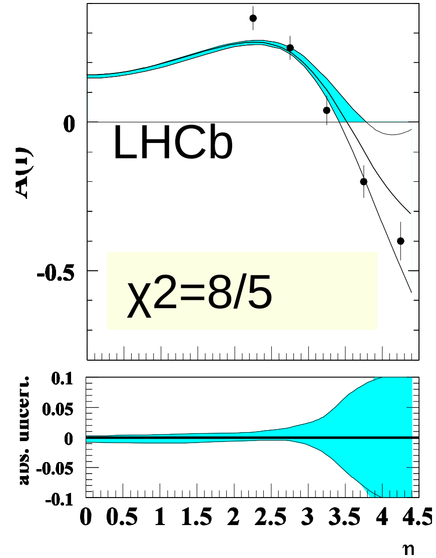


How does HERAPDf measure up to LHC data?



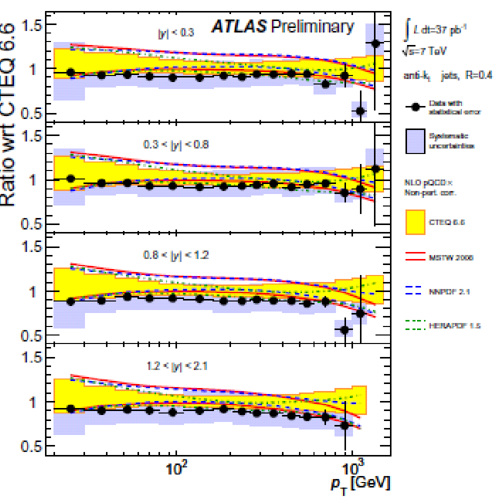


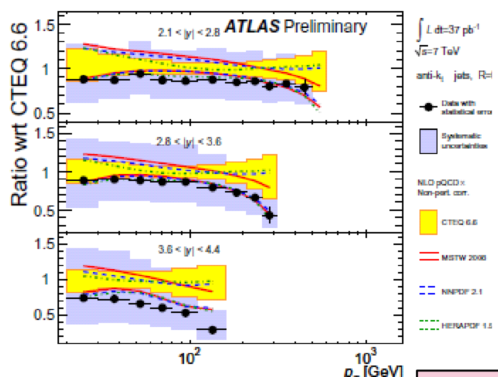




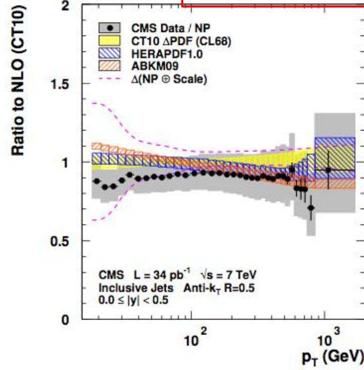
Early ATLAS W and Z data are described fairlly well and if these data are fit ($\chi 2$ given after fit) the resulting PDFs lie within the HERAPDF1.5 error bands

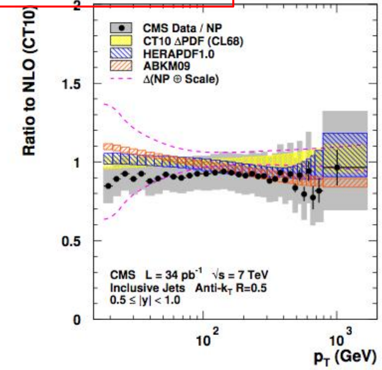
And for ATLAS jet data





CMS jet data





Fitting the jet data and the latest W, Z data, shown in this session, is work in progress

Interim Conclusions

The HERA inclusive data provide precision for the low-x Sea and gluon PDFs, the u-valence is also well measured, and the d-valence is measured without assumptions about nuclear corrections or strong isospin.

Adding HERA jet data allows a measurement of $\alpha_S(M_Z)$ and the high-x gluon

Adding charm data will allow a reduction in model uncertainties concerning the charm mass and scheme.

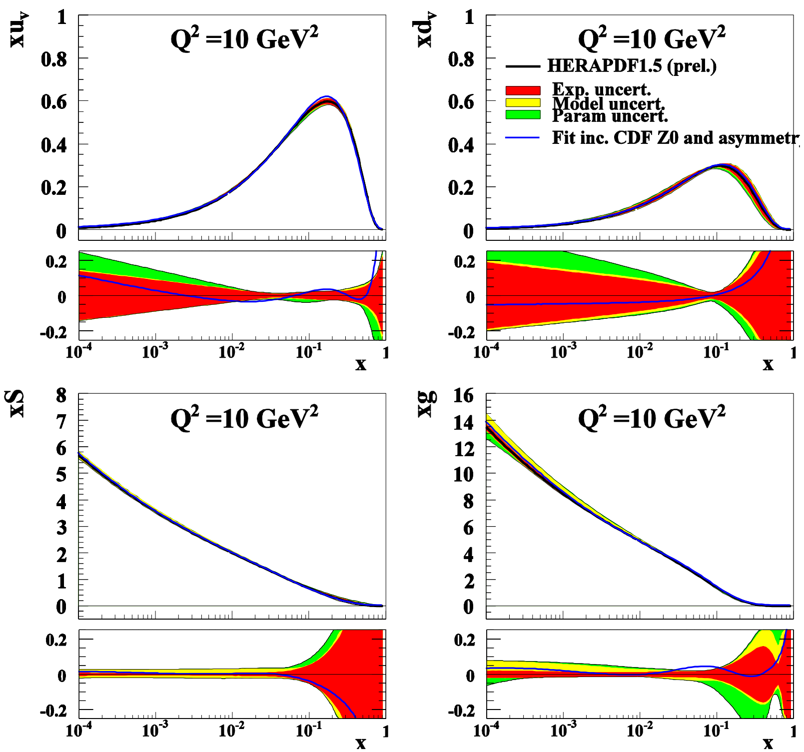
Adding low energy data will allow us to investigate non-DGLAP behaviour at low x,Q^2

HERAPDF gives a good description of Tevatron W, Z data and jet data (within its error bands) and a good description of LHC W ,Z and jet data

Work is ongoing to incorporate these data into the fits

extras

It does not really make sense to add these LHC data just to the HERA data alone we need to see what improvement LHC data make in addition to the Tevatron data.



We add CDF Z0 AND W-asymmetry- data to the HERAPDF 1.5 fit.

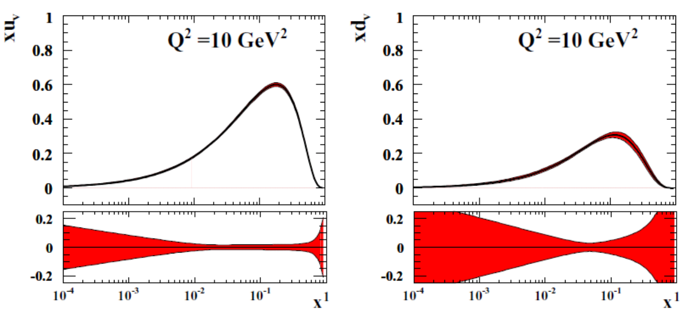
It is reasonable to proceed just with these CDF data because

1. D0 Z0 has the same trend as CDF Z0 data but is less constraining and
2. D0 lepton asymmetry data has a similar trend as CDF W-asymmetry data and is similarly constraining

The result of adding both CDF data sets is quite similar to just adding the W-asymmetry: χ^2/ndp =18.1/13 (asymmetry) and 26/28 (Z0)

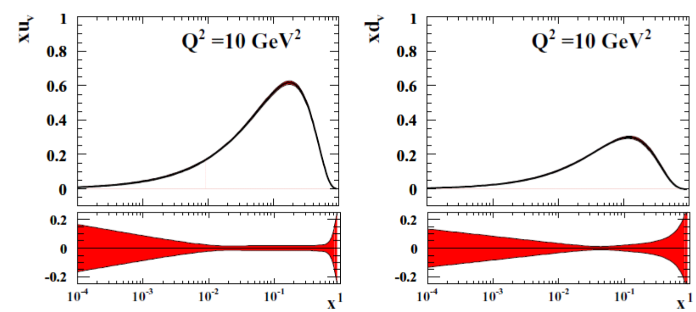
(tendency of Z0 rapidity data to make d-valence softer at high-x is counteracted by the tendency of the asymmetry to make it harder)

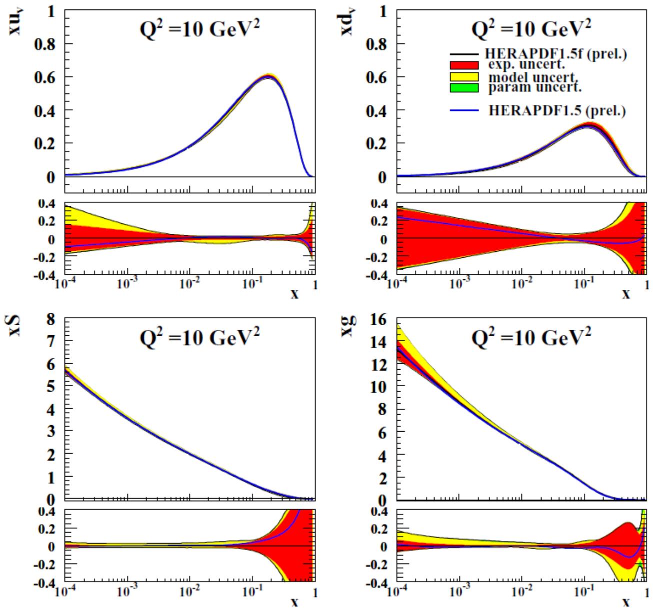
HERAPDF1.5f



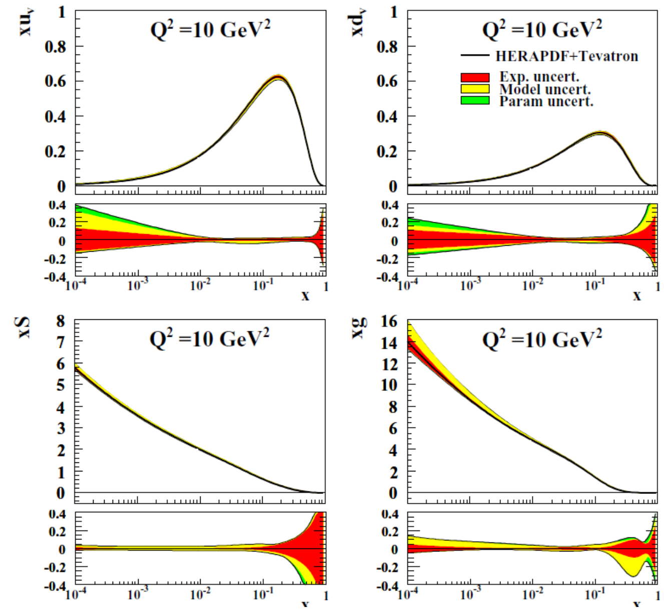
Improvement in experimental uncertainties →

HERAPDF1.5f +Tevatron

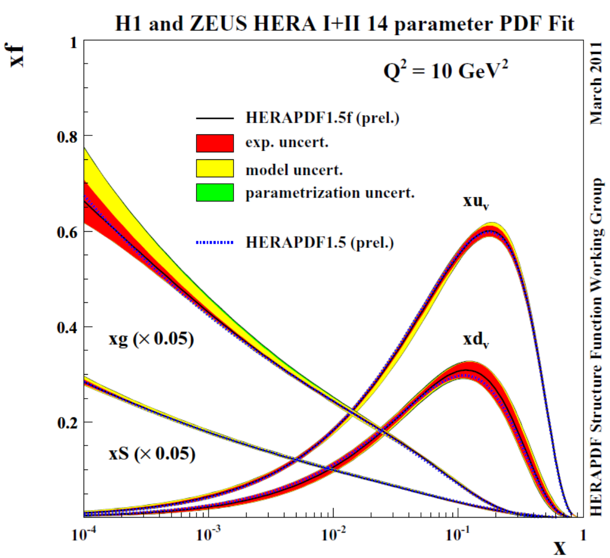




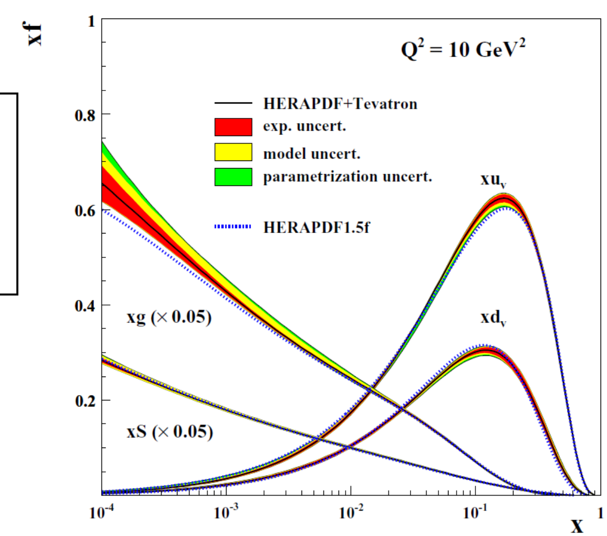
The improvement in experimental uncertainties is not washed out by model and parametrisation uncertainty.



Comparison of HERAPDF1.5f with a fit to the same HERA data plus CDF Z0 and W-asymmetry data with a preliminary estimate of model and parametrisation uncertainty included



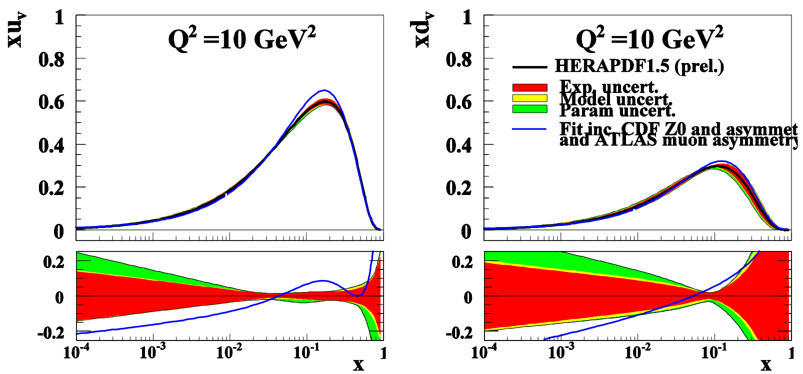
The shapes of the PDFs are very similar

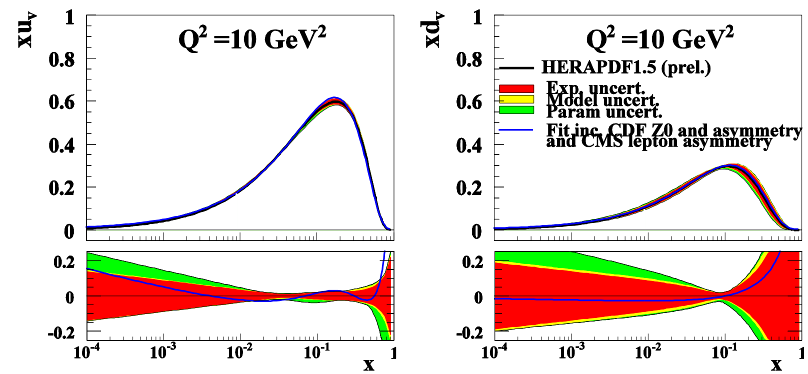


Once these Tevatron data are added there is no further improvement in experimental uncertainties and no significant shifts in the PDFs from adding:

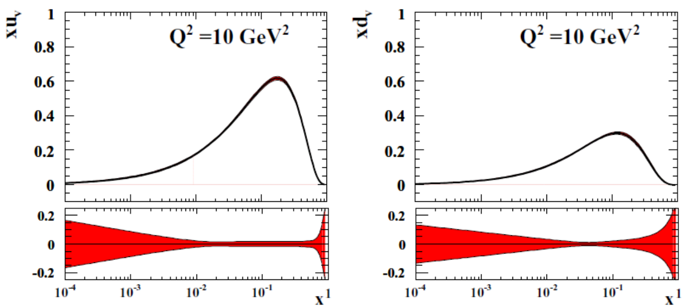
- LHCb asymmetry data –the high-x d-valence is already so much improved by Tevatron data that LHCb data adds nothing
- CMS Z0 data (added little even before Tevatron data were added)

However the CMS and ATLAS asymmetry data are still interesting since they shift the data in opposite ways I expect this to be resolved once more LHC data are analysed

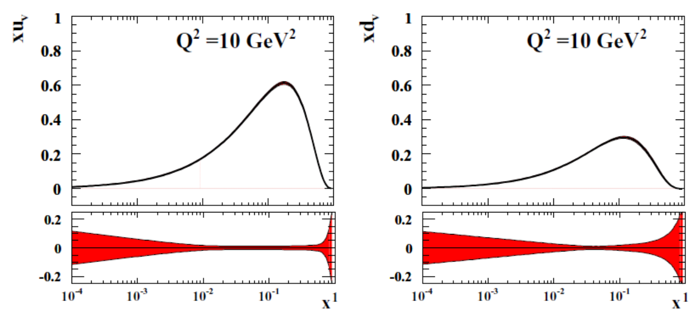


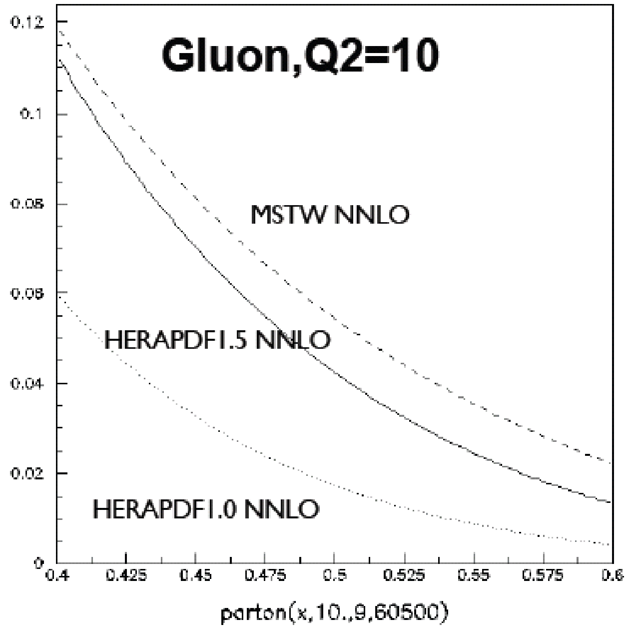


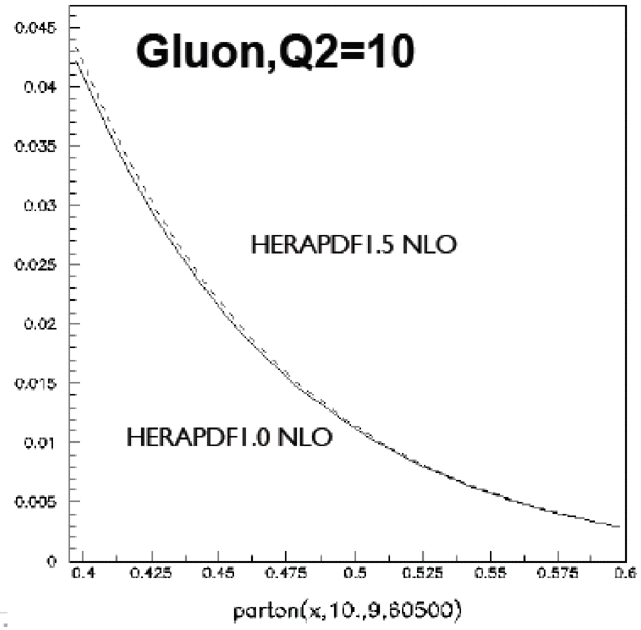
The CMS data also lead to a small improvement in the valence uncertainties at low-x, the LHC data reaches kinematic regions that the Tevatron could not reach



Improvement in experimental uncertainties







And a comparison of gluon shapes HERAPDF/MSTW at NNLO and NLO