HERAPDF1.5 at NNLO
Confronting HERAPDF with Tevatron and LHC data

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PDF4LHC

DESY July 4 2011

The only PDF fit using purely proton data from HERA

•No need for nuclear/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

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

HERAPDF1.5NNLO supercedes HERAPDF1.0NNLO with a thorough investigation of model and parametrisation uncertainties- as well as with new data

Investigate adding other modern collider data with proton (or anti-proton) targets

Where does the information on parton distributions come from?

CC e-p

CC e+p

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

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

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

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

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

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

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

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

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

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

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

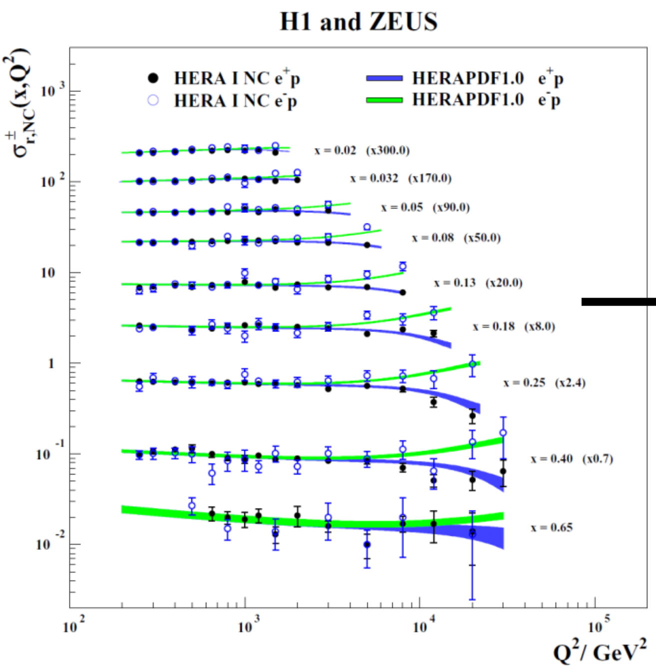
Where $xF_3^{\gamma Z}$ is the dominant term in xF_3

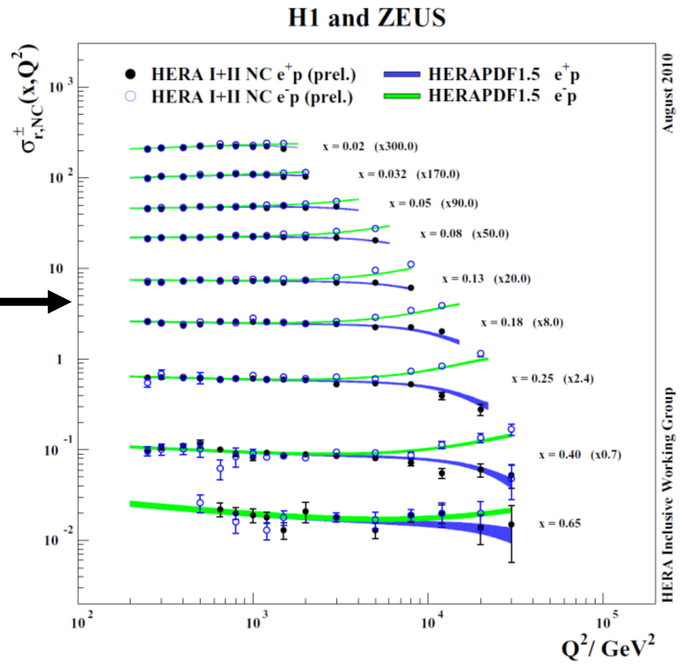
The neutral current F2 gives the low-x Sea

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

Features of the update to HERAPDF1.5 NLO: update of data AND fit

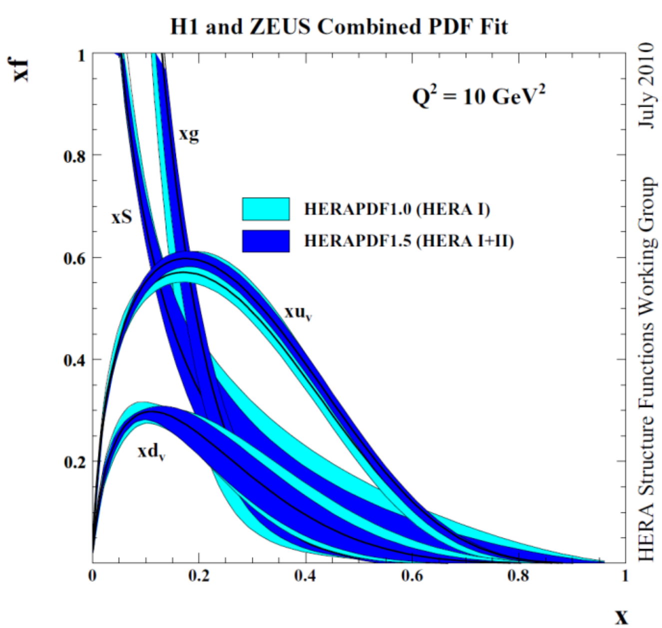




Uses preliminary HERA I+II data combination
ZEUS-prel 10-018
H1prelim-10-042

In addition to the published HERA-I data

ZEUS CC e^-p	175 pb^{-1}	EPJ C 61 (2009) 223-235
ZEUS CC e^+p	132 pb^{-1}	EPJ C 70 (2010) 945-963
ZEUS NC e^-p	170 pb^{-1}	EPJ C 62 (2009) 625-658
H1 CC e^-p	149 pb^{-1}	H1prelim-09-043
H1 CC e^+p	180 pb^{-1}	H1prelim-09-043
H1 NC e^-p	149 pb^{-1}	H1prelim-09-042
H1 NC e^+p	180 pb^{-1}	H1prelim-09-042



Gives increased precision at high-x

HERAPDF1.5 NLO will be on LHAPDF5.8.6

On the way to NNLO fits we extended our PDF parametrisation from 10 to 14 parameters

A reminder of the PDF parametrisation: 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

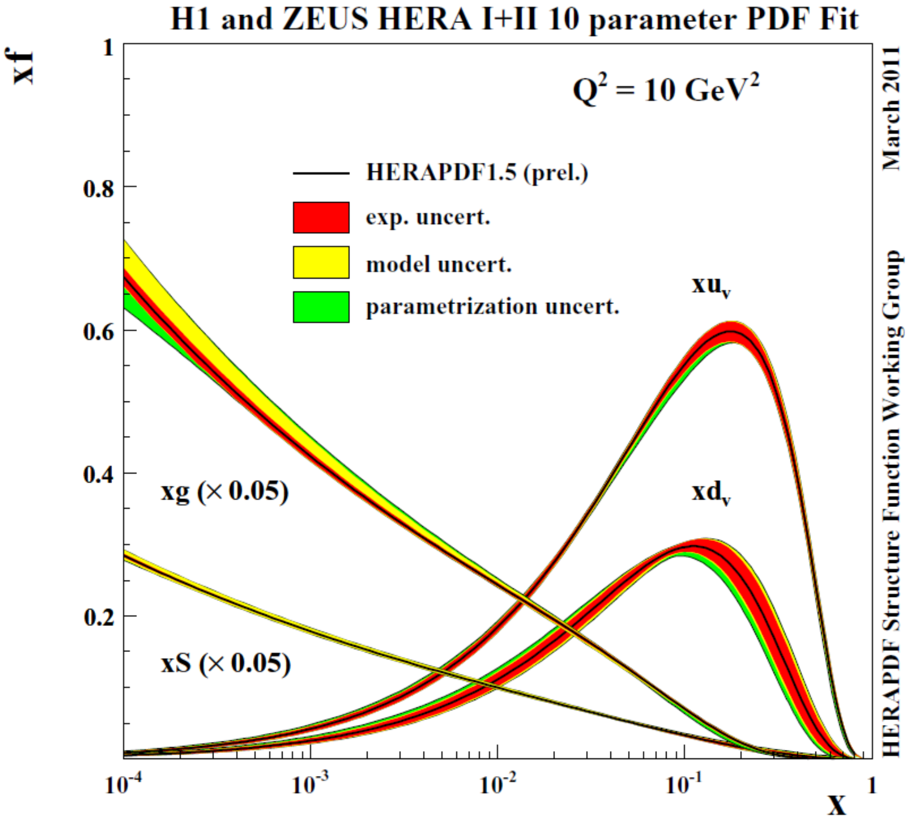
extended gluon parametrisation $Ag\, x^{Bg}\, (1-x)^{Cg}\, (1+Dx+Ex^2) - A'g\, x^{B'g}\, (1-x)^{25}$

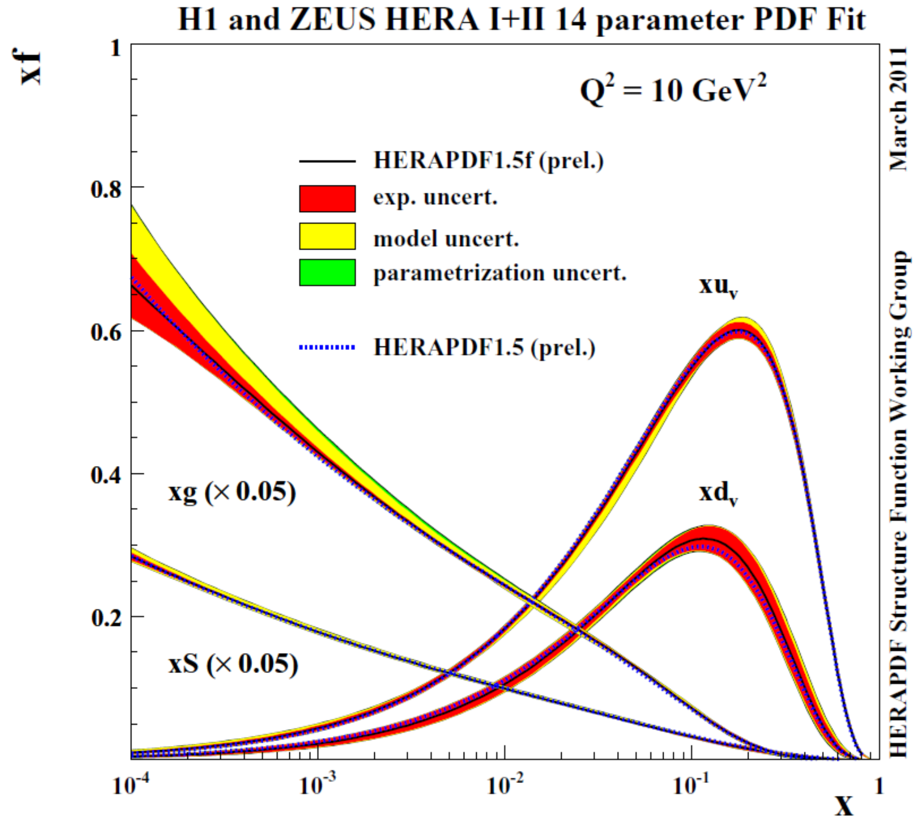
The table summarises our **extended parametrisation choices** and the parametrisation variations that we consider in our uncertainty estimates (and we also vary the starting scale Q^2_0). **NOTE we have made the gluon more flexible and we have freed low-x d-valence from u-valence**

Model uncertainties on m_c, m_b, f_s, Q^2min are also included and 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**

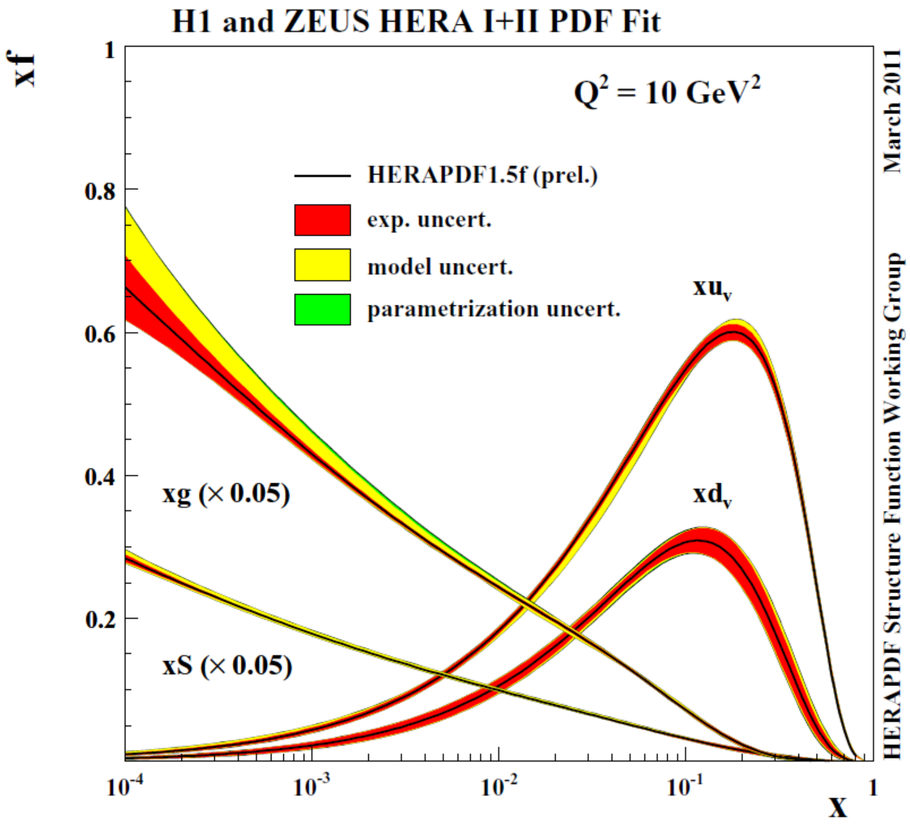




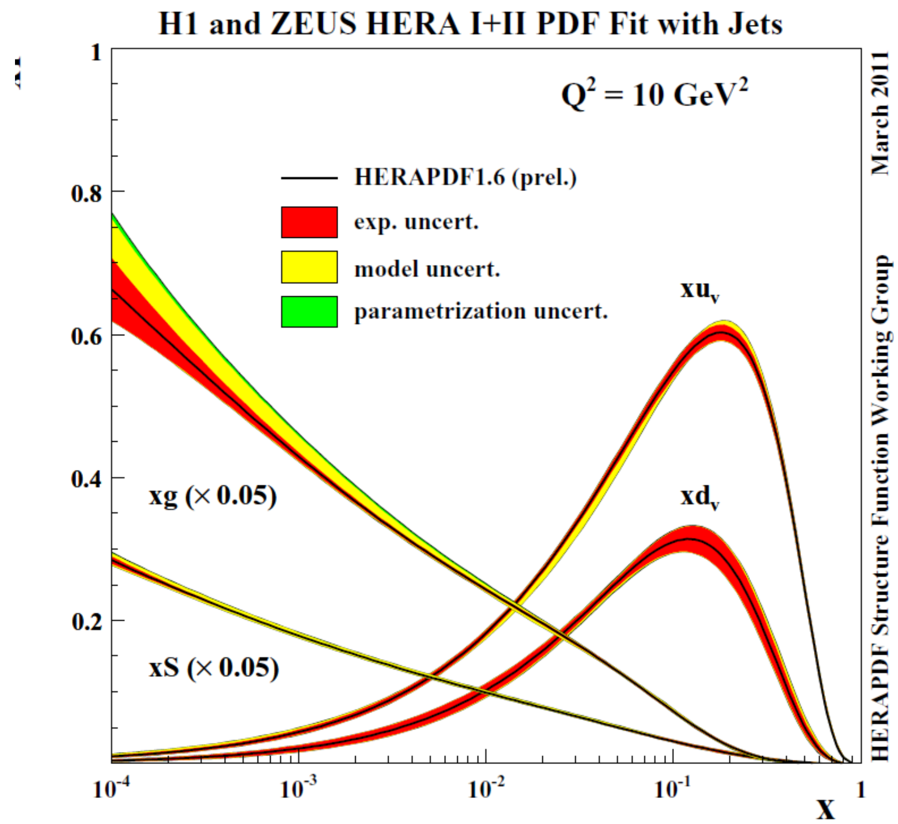
i) The level of total uncertainty is similar- but we swap parametrisation uncertainty for experimental uncertainty

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

We also added HERA jet data (as yet uncombined) to the fit: ZEUS-prel-11-001 H1prelim-11-034



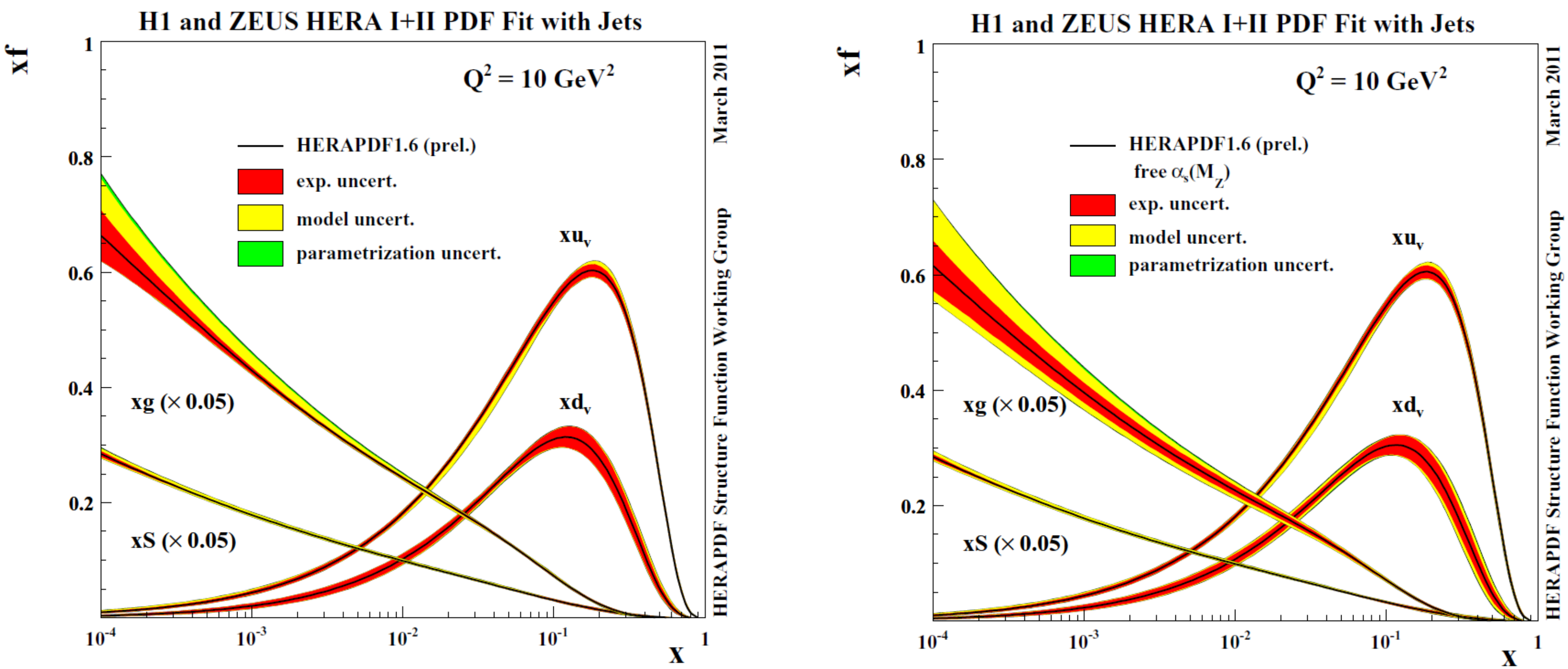
Without jets



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.

And the jet data allow us to free $\alpha_S(M_Z)$



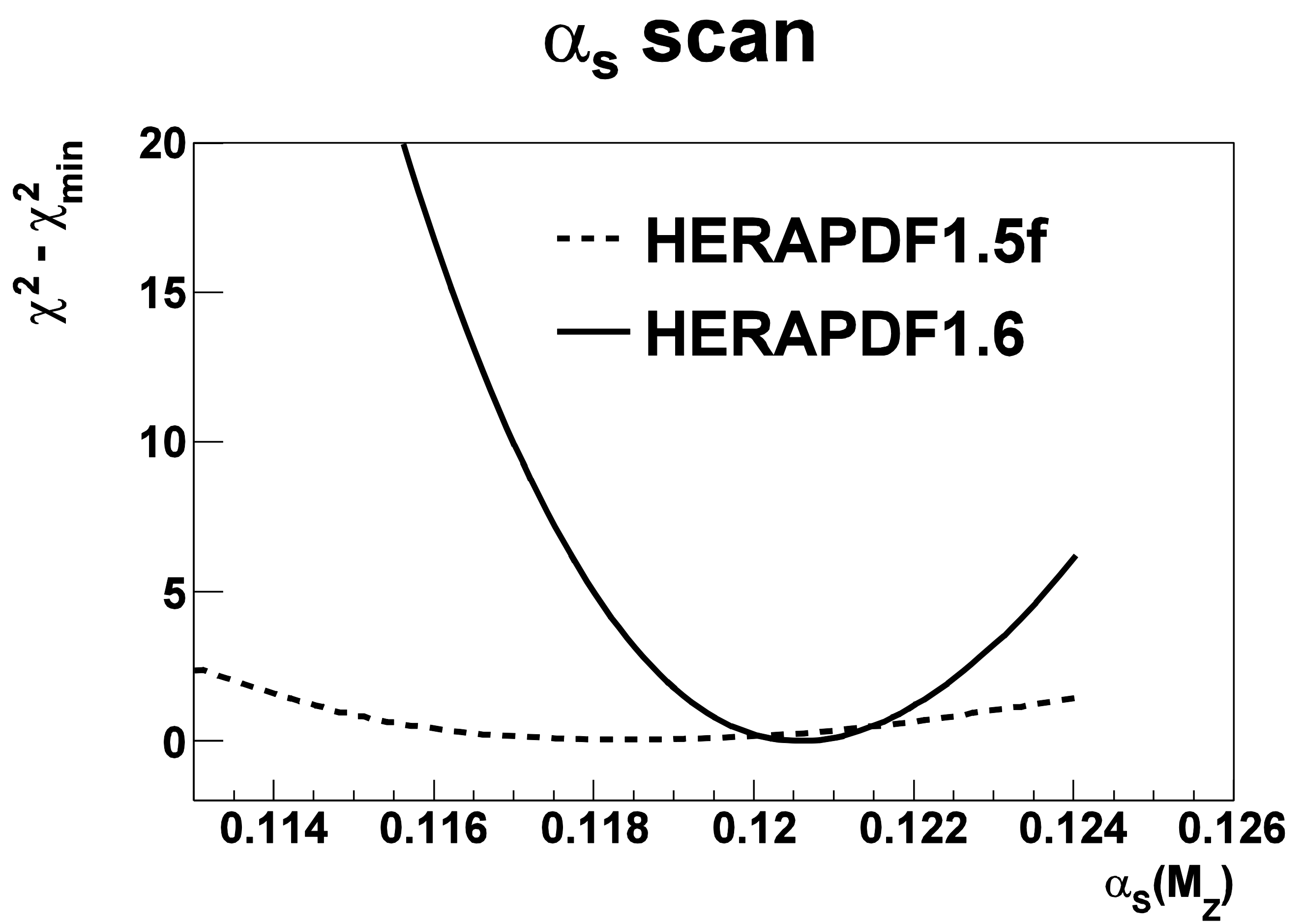
$\alpha_S(M_Z)$ =0.1202 ± 0.0013 (exp) ± 0.0007(model/param) ± 0.0012(hadronisation)

+0.0045/-0.0036 (scale)

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

The dominant contribution to the scale error comes from the renormalisation scales for the jet data.

The $\chi 2$ scan of HERAPDF1.5f (no jets) and HERAPDF1.6 (with jets) vs $\alpha_S(M_Z)$

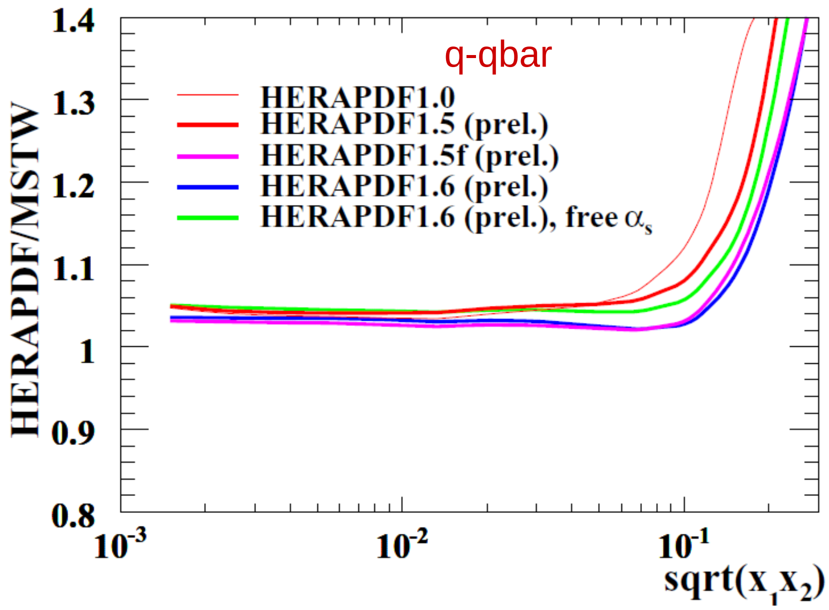


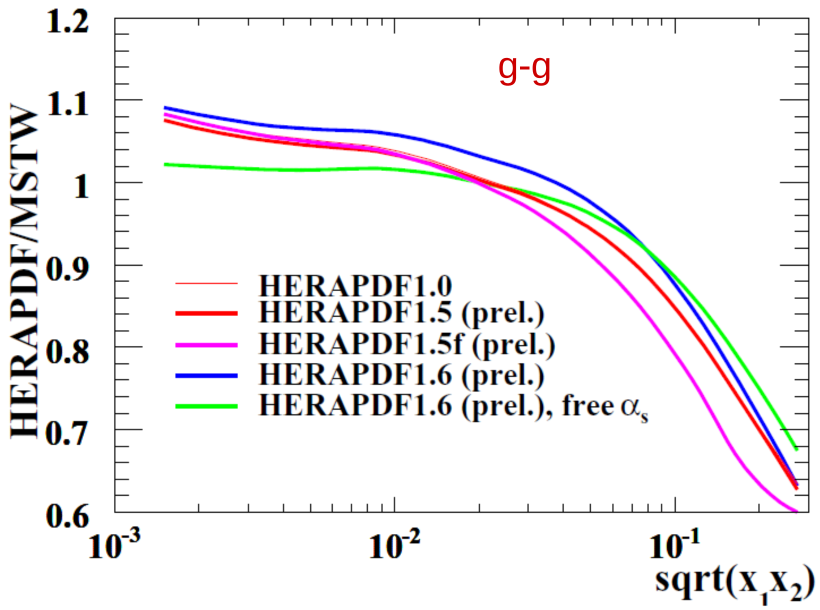
We do not put these jet data into our NNLO fit since we do not have an NNLO calculation.

However, since we now have a relatively large central value for $\alpha_S(M_Z)$ at NLO, we have decided to use the central value $\alpha_S(M_Z)$ =0.1176 at NNLO

However, our NNLO PDFS are also available for a range of αS(MZ) values

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

Finally at NLO

A ‘global’ HERA fit: HERAPDF1.7

Which has

1. the combined inclusive HERA I + II data at high energy
2. And the combined low eneregy run data from 2010
3. And the combined F2c data from 2010
4. AND H1 and ZEUS jet data

5. X2=1097.5 for 1045 data points

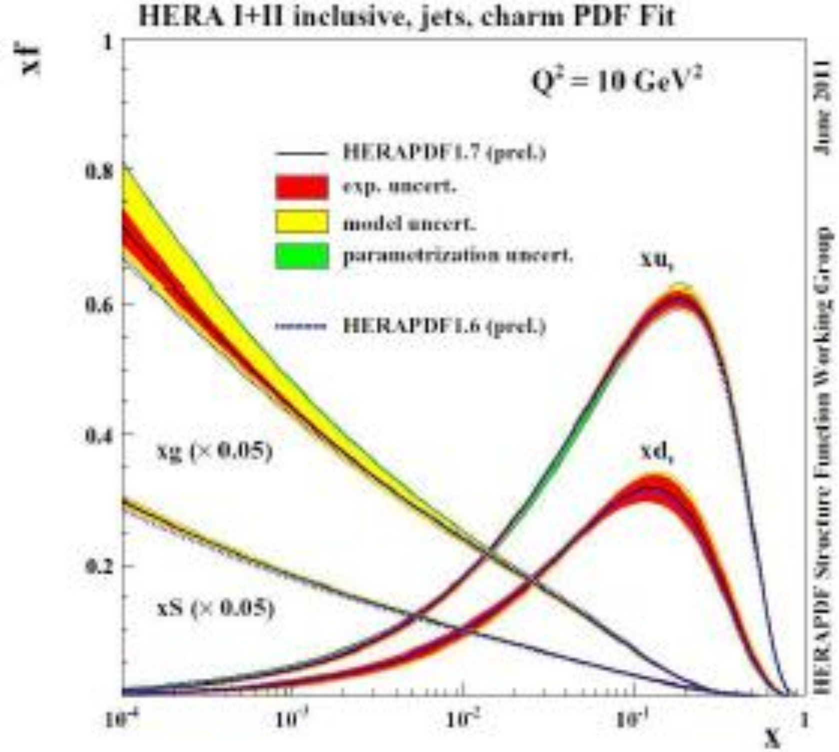
All data compatible all previous conclusions stand

But we would now recommend

1. a central value of $\alpha_S(M_Z)$ ~ 0.119 at NLO
2. Use of the RT optimized VFN scheme
3. mc=1.5 GeV central value

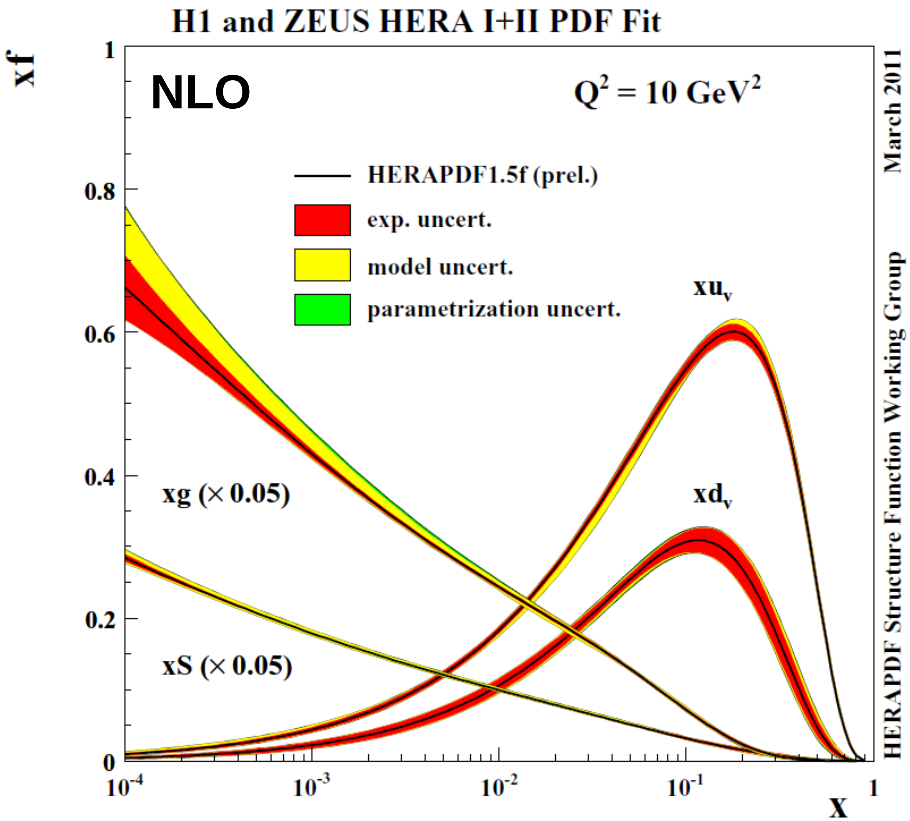
The fit shown adopts these changes

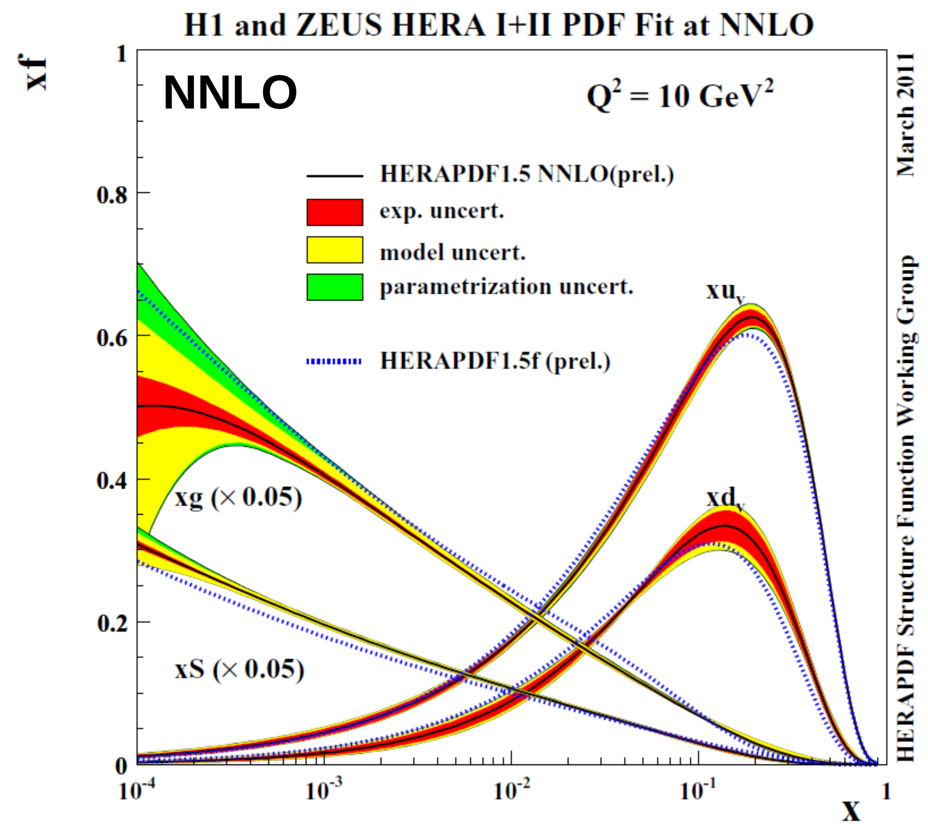
However this is all ‘work in progress’ our recommended NLO PDF is HERAPDF1.5



And so to NNLO: ZEUS-prel-11-002/H1prelim-11-042

We use the more flexible form of the parametrisation and we use Thorne's NNLO VFN scheme. **First compare NLO and NNLO**





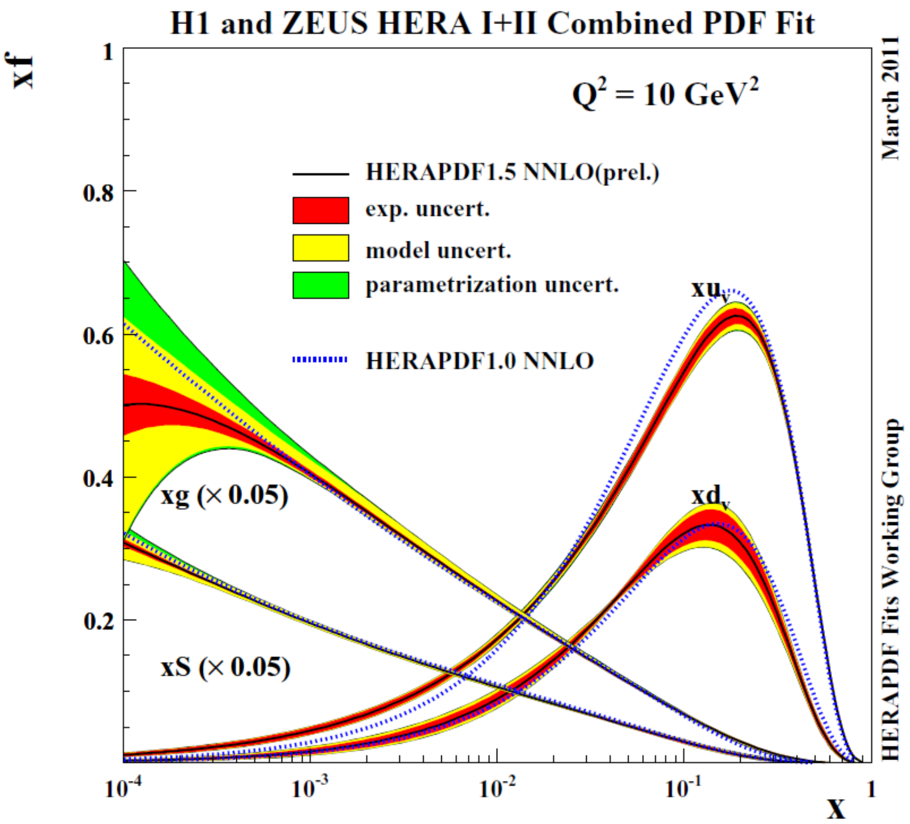
What are the differences?

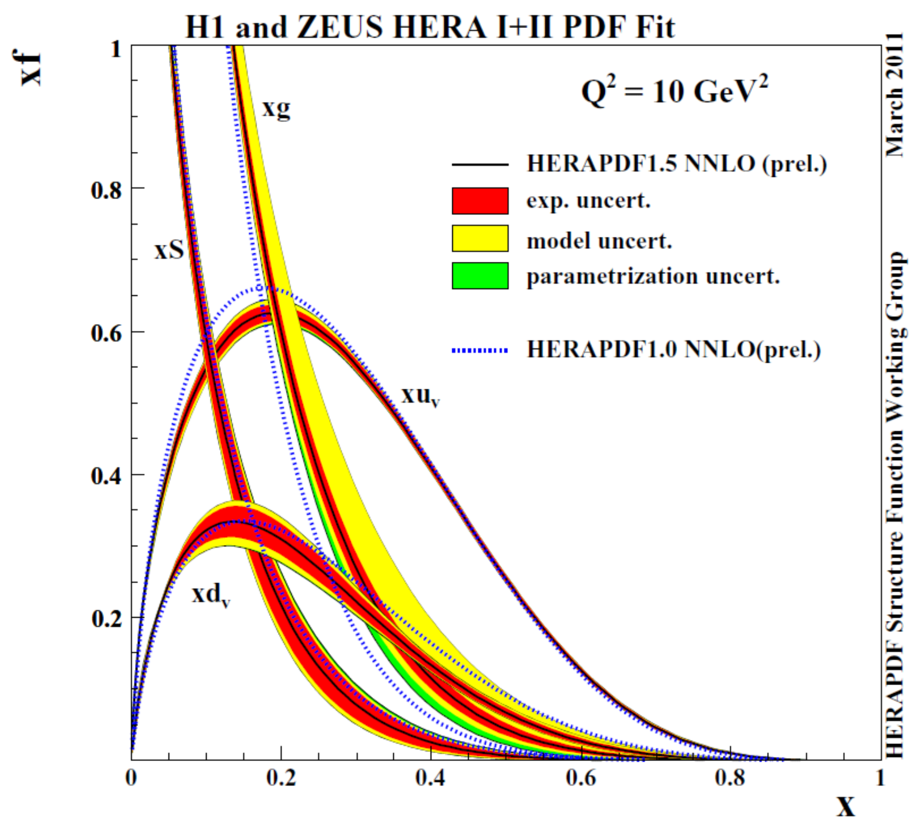
- Valence not much
- Sea a little steeper
- Gluon more valence like

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

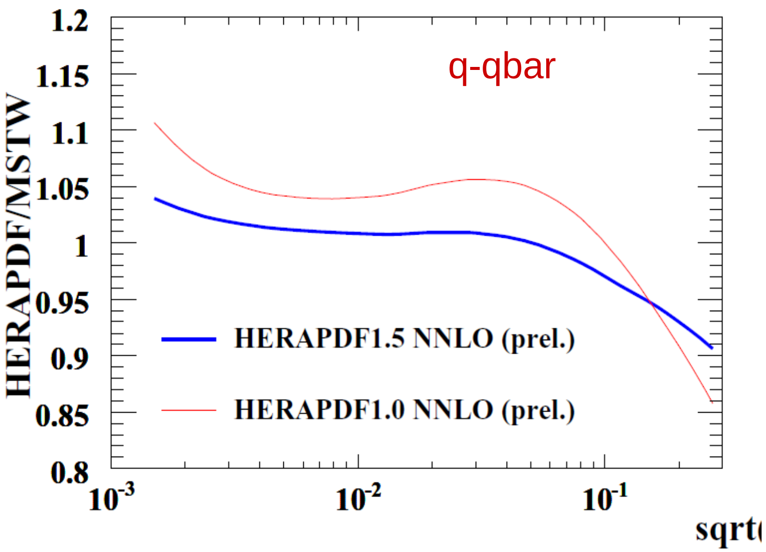


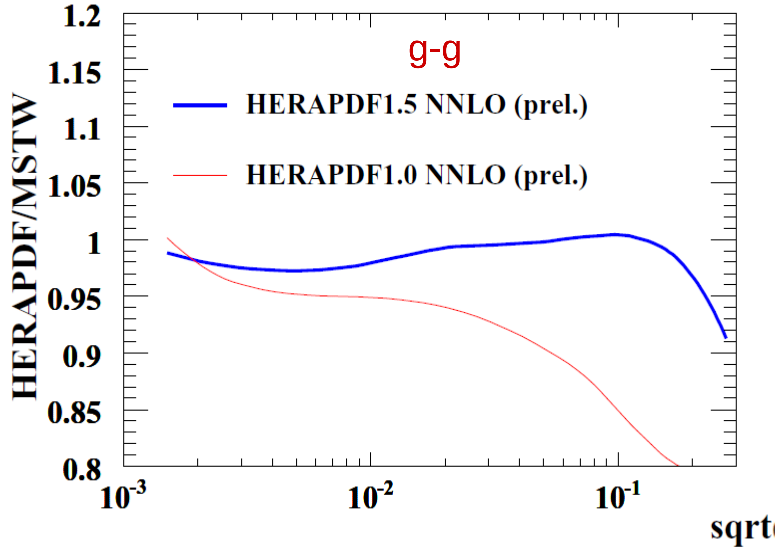


Previously we did not issue an error band on the 1.0 NNLO fits – the errors were in fact asymmetric and this is what led us to the extended parametrisation. Here we compare at $\alpha_S(M_Z)$=0.1176

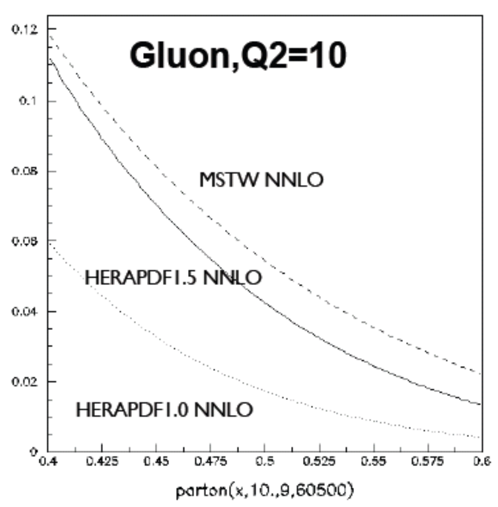
HERAPDF1.5 NNL0 has a harder high-x gluon than HERAPDF1.0

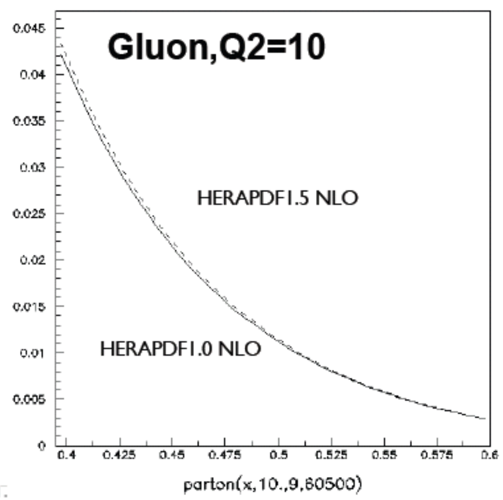
LHC at 7 TeV parton-parton luminosity plots for HERAPDF1.0/1.5 in ratio to MSTW2008 at NNLO





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

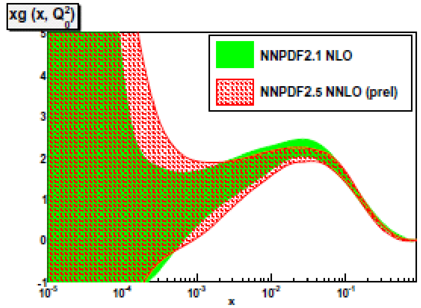


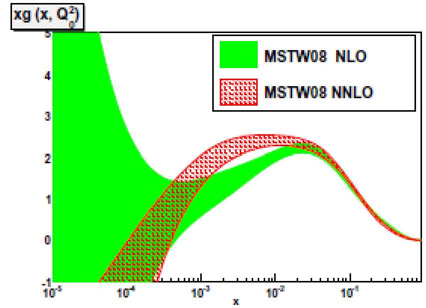


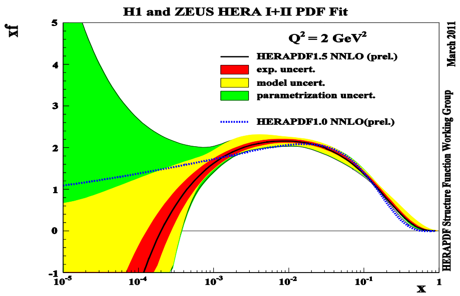
NNLO -- NNPDF2.5

Compare MSTW

Compare HERAPDF1.5







HERAPDF1.5NNLO central values resemble MSTW NNLO.

But Uncertainties on HERAPDF1.5NNLO resemble those of NNPDF2.5, largest contributors are the Q^2_{min}>5 GeV^2 cut and the Q^2_0 = 2.5 GeV^2 variation

The first HERA NNLO analysis with accounting for PDF uncertainties is ready
HERAPDF1.5NNLO will be on LHAPDF5.8.6 (beta release already there)

Fits using only HERA and Tevatron and LHC data?

Motivation- using only proton data, using data with well understood systematic errors and with information on correlations.

•First compare HERAPDF1.5 with Tevatron data

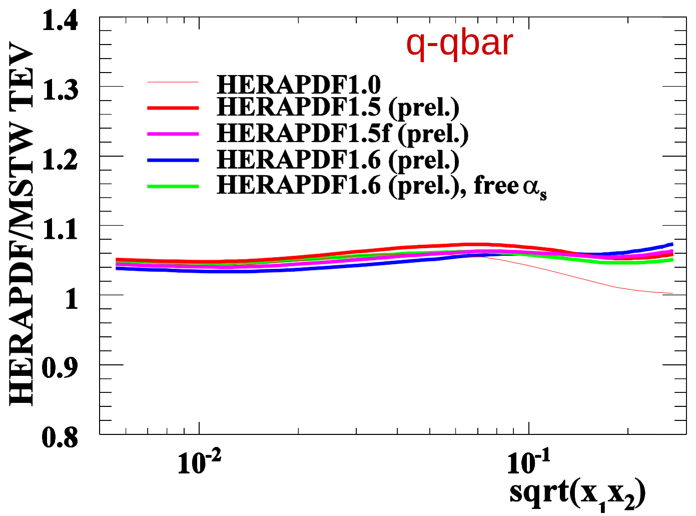
•Then fit HERA+Tevatron data

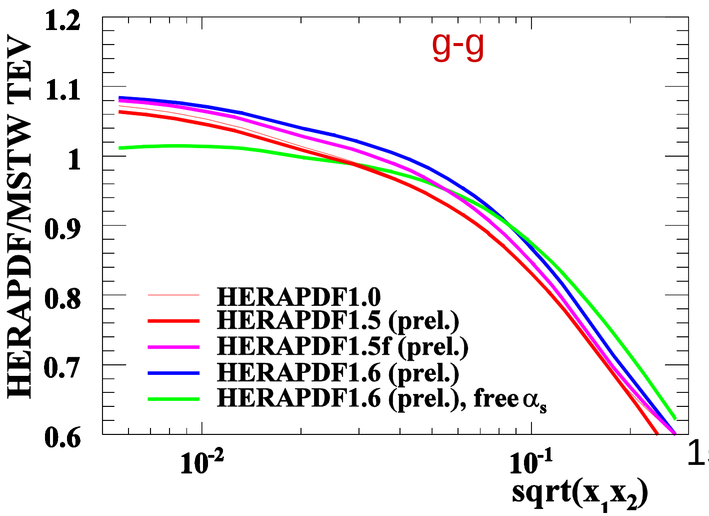
•Then compare HERAPDF1.5 with LHC data

•Then fit HERA+Tevatron+LHC data

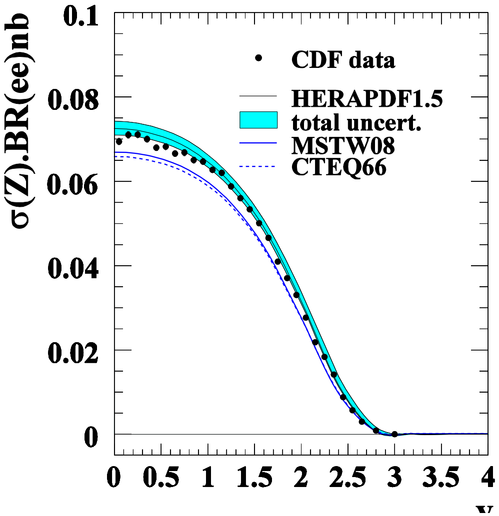
What information is missing?

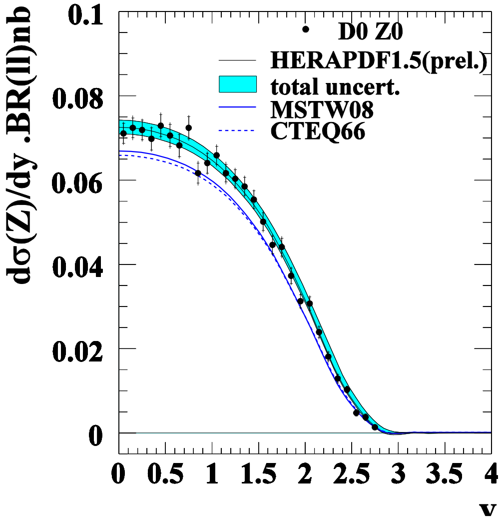
TEVATRON parton-parton luminosity plots for HERAPDF1.5 in ratio to MSTW2008 NLO





First Z0 rapidity data from both CDF and D0 is well described even before it is fitted





The description improves after fitting

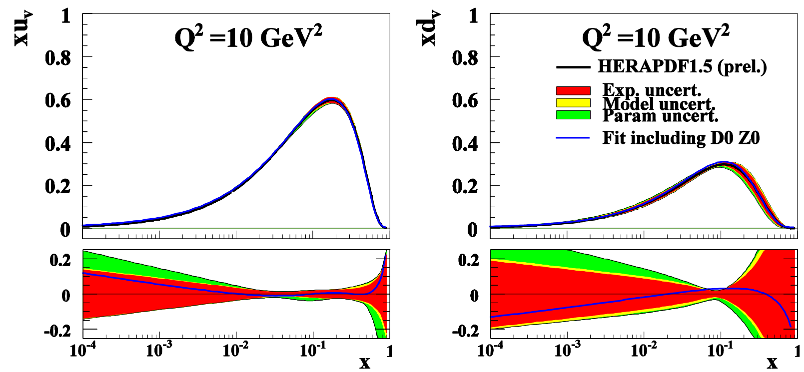
X2/ndp= 36/28 →27/28 for CDF and 23/28 → 16/28 for D0

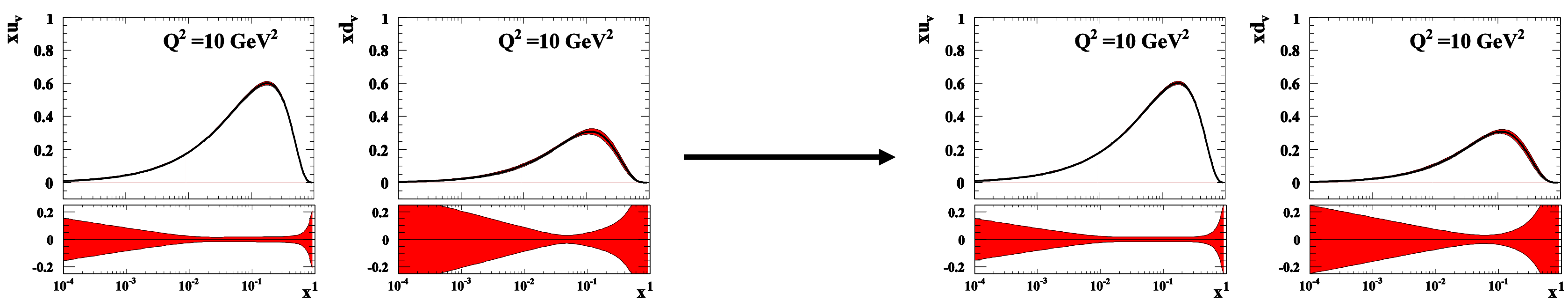
The CDF data are more constraining so are used for further illustrations

The fit does not move the PDFs outside the HERAPDF1.5 error bands.

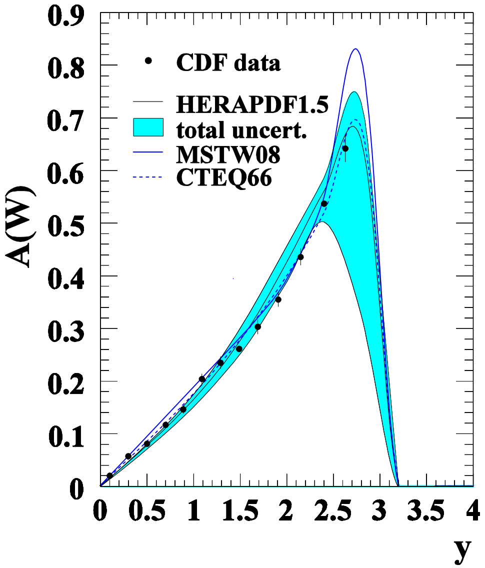
However it DOES improve the uncertainties on the d-valence distribution

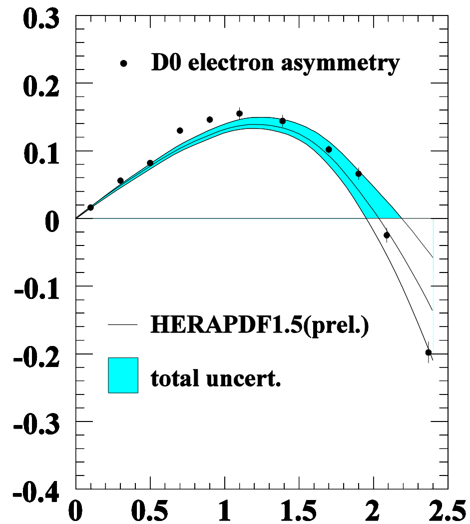
Illustrated here for using the experimental errors only for the flexible parametrisation





NEXT W-asymmetry data from CDF and lepton asymmetry data from D0

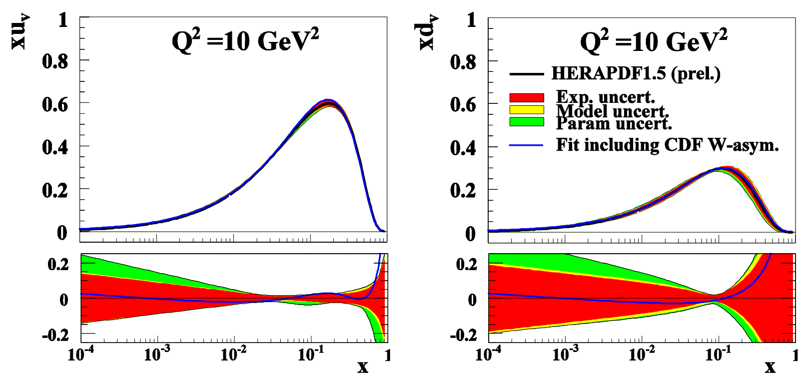




after fitting

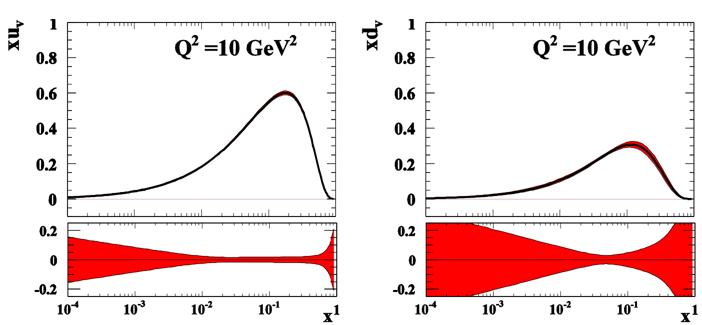
X2/ndp= 19/13 for CDF and
χ2/ndp= 25/11 for D0

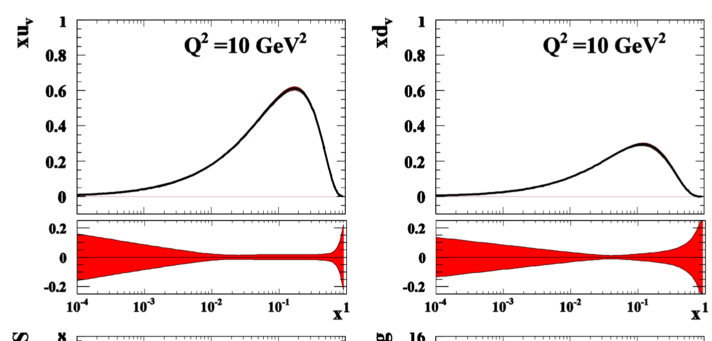
Using the most inclusive data as recommended by Schellman



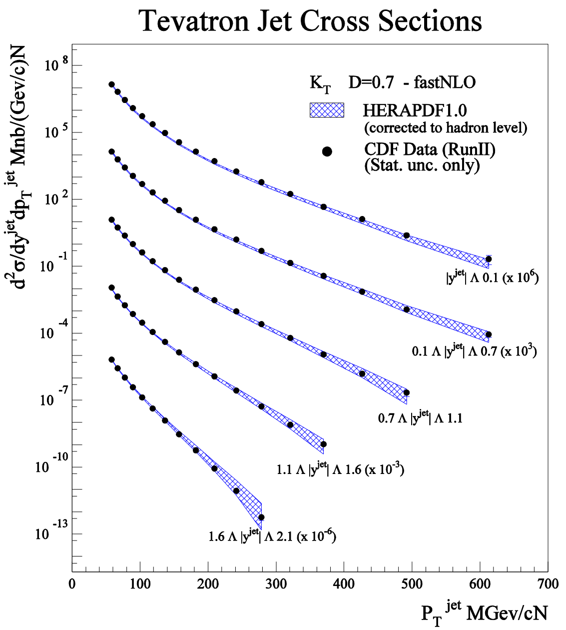
Again the fit does not move the PDFs outside the HERAPDF1.5 error bands. Both D0 and CDF data give a somewhat harder high-x d-valence

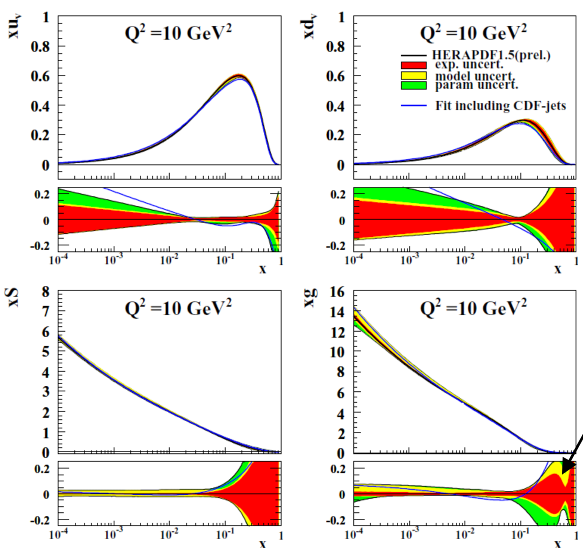
And both lead to a dramatic improvement of he uncertainties on the d-valence distribution





How well are Tevatron jet data described HERAPDF1.5



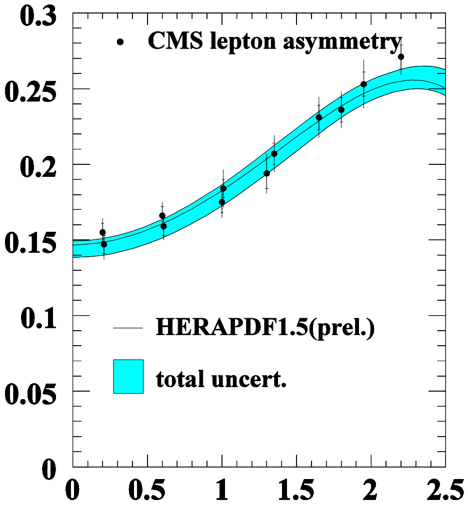


HERAPDF1.5 χ2/dp = 176/76 for CDF and 245/110 for D0 for the central PDF- not great BUT this ignores the error band of the PDF fit. If these data are included in an NLO fit we get χ2/dp = 113/76 and 157/110 respectively

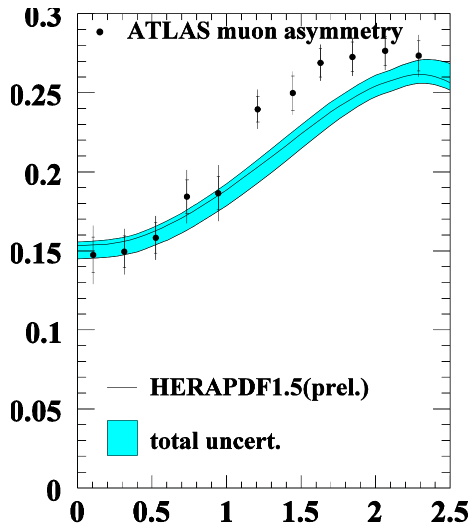
The resulting PDF is near the edge of HERAPDF1.5 (68%CL) error bands

However, if we use HERAPDF1.5 NNLO PDFs to fit these jets data the description is MUCH better χ2/dp=72/76 for CDF even for the central PDF

Next W asymmetry data from CMS and ATLAS



Pt lepton > 25 GeV
Etmiss > 0 GeV



Pt lepton > 20 GeV
Etmiss > 25 GeV

The description of the asymmetries LOOKS OK for CMS not so great for ATLAS – the description improves after fitting

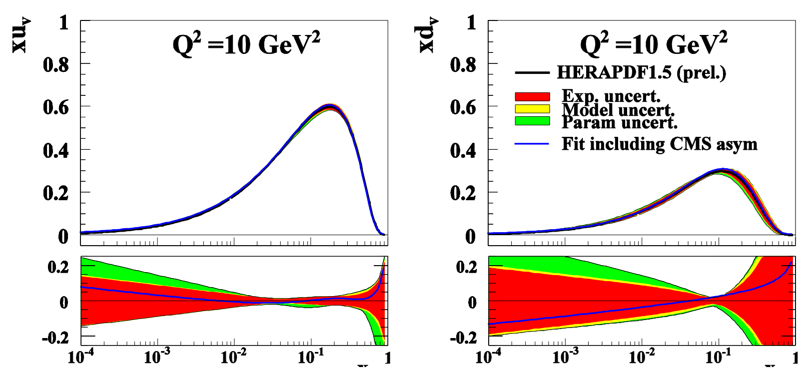
X2/ndp=6.5/12 →3.7/12 for CMS
χ2/ndp= 30/11→ 16/11 for ATLAS

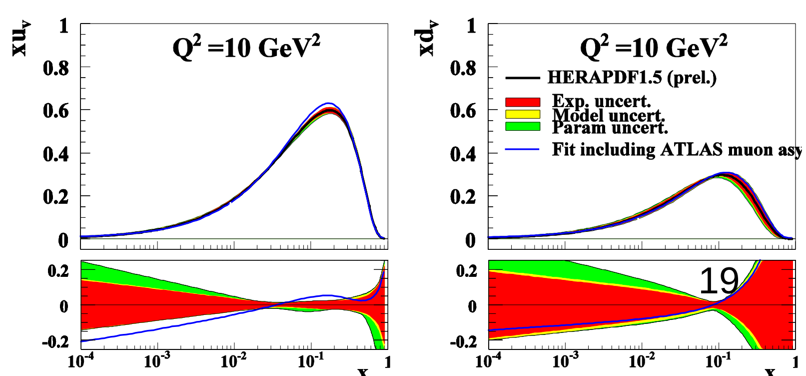
But these χ2 do NOT account for the error band of the HERAPDF fit

•The fit does not move the PDFs much outside the HERAPDF1.5 error bands.

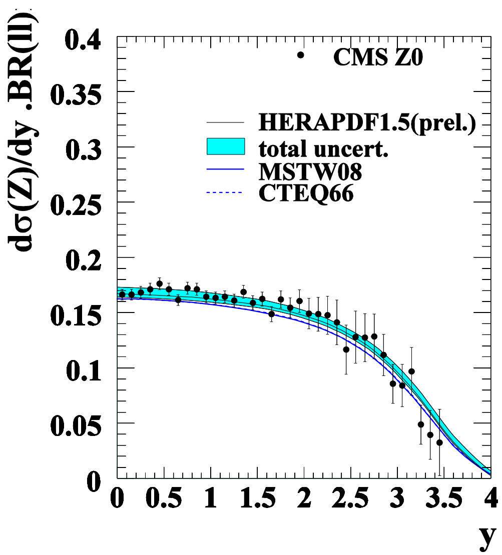
•The shifts are similar to those for the TeV W-asymmetry at high-x.
•Comparing ATLAS to CMS the low-x shifts of the u-valence are opposite!

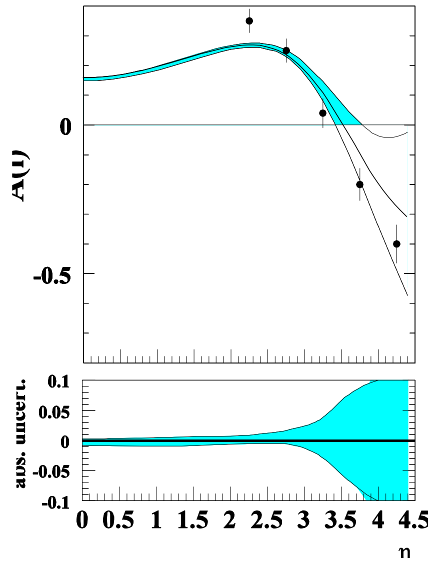
•The CMS data also give some improvement in uncertainty for the low-x valence BUT this should be considered in a fit which also has Tevatron data included





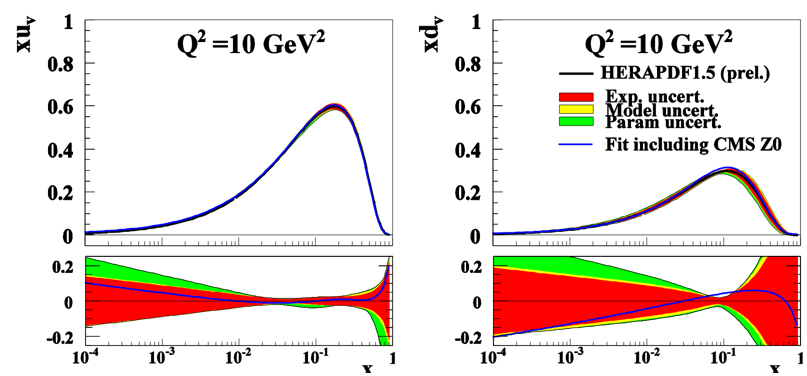
There is also CMS Z0 rapidity spectrum and LHCb W-asymmetry





These data are well described both before and after fitting

X2/ndp=9.1/5 →7.8/5for LHCb
χ2/ndp= 35/35→ 16/35 for CMS

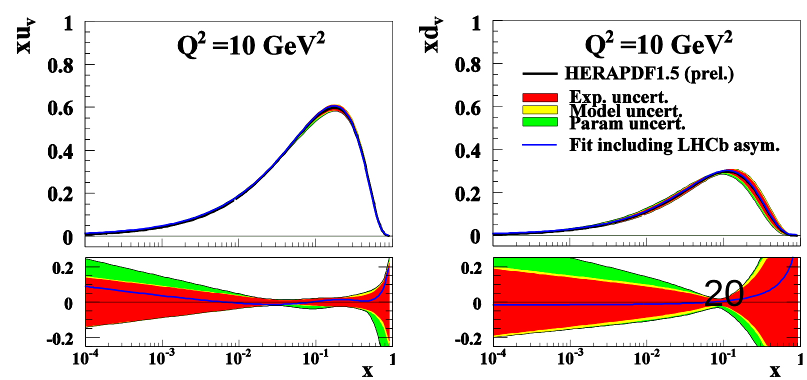


•The fit does not move the PDFs outside the HERAPDF1.5 error bands.

•The CMS Z0 data shift the fit similarly to the TeV Z0 data

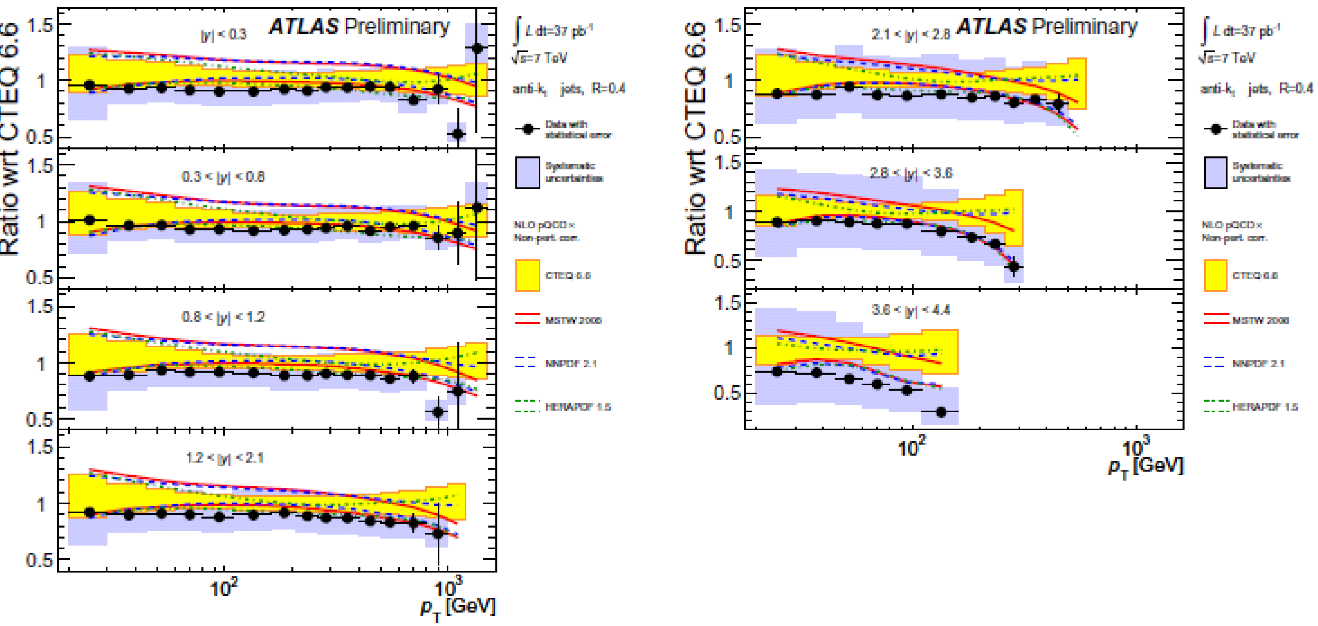
•The LHCb asymmetry data shifts the fit similarly to the TeV asymmetry data

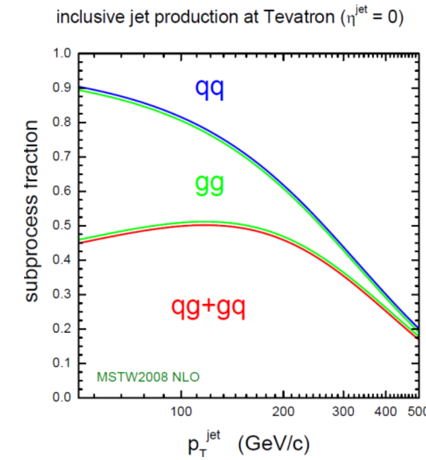
•The LHCb data would reduce uncertainties in the high-x d-valence quark BUT this should be considered in a fit which also has Tevatron data included

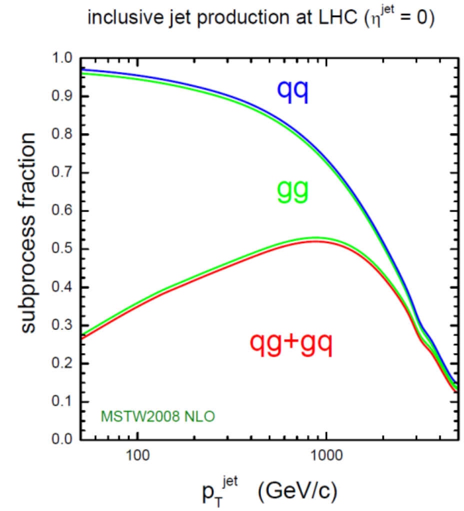


There is also ATLAS jet data yet to be input to the fits

ATLAS jet data





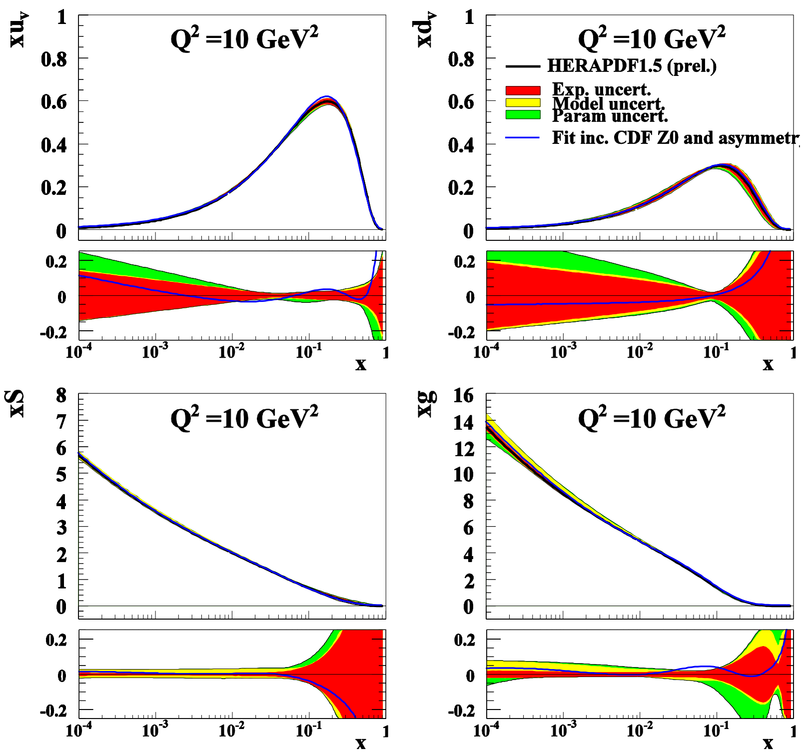


Jet data will also soon be discriminating for PDFs

The PDFs that fit the Tevatron jets best are not necessarily those that fit the LHC jets best. The mixture of q-q, q-g, g-g induced jets is different.

HERAPDF1.5 is doing a good job at LHC

It does not really make sense to add these LHC data just to the HERAPDF, 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.

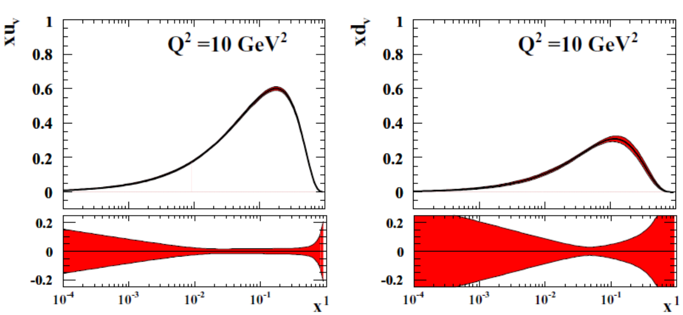
It is reasonable to proceed just with these CDF data because

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: χ2/ndp =18.1/13 (asymmetry) and 26/28 (Z0)

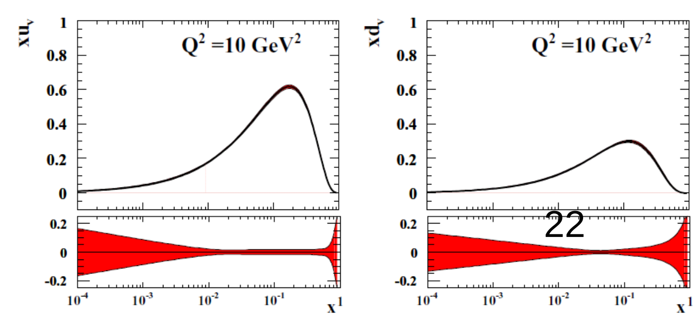
(tendency of Z0 rapidity data to make d-valence softer at high-x is counteracted by the tendency of the asymmetry to make it harder)

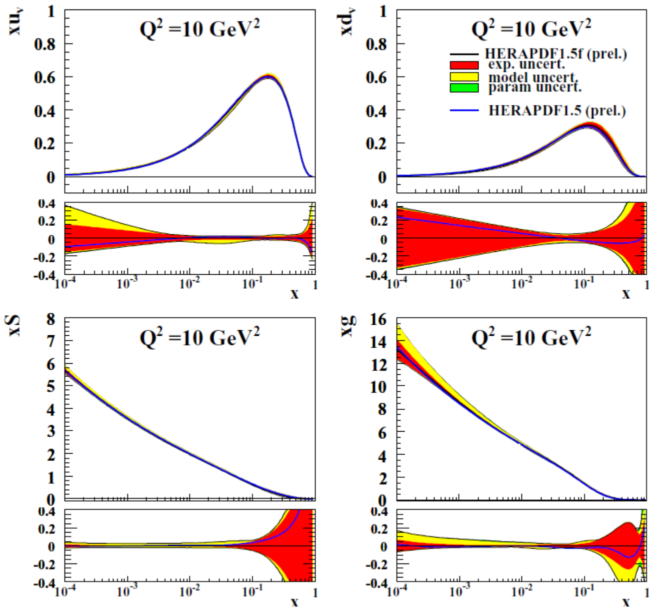
HERAPDF1.5f

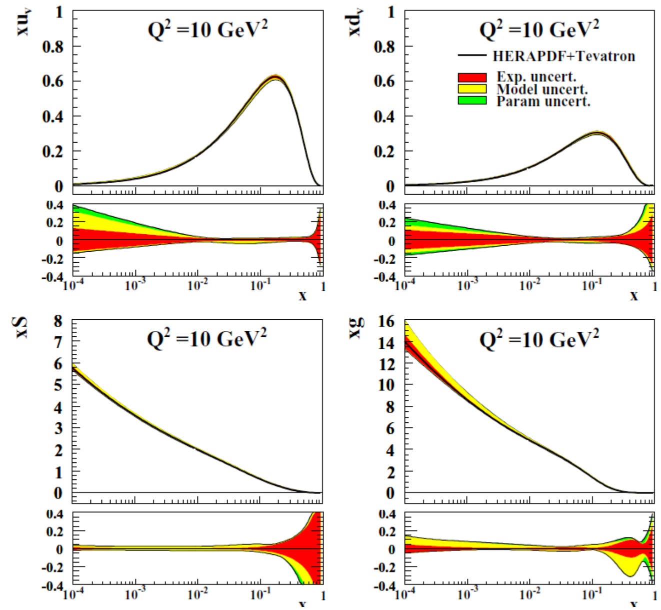


Improvement in experimental uncertainties

HERAPDF1.5f +Tevatron

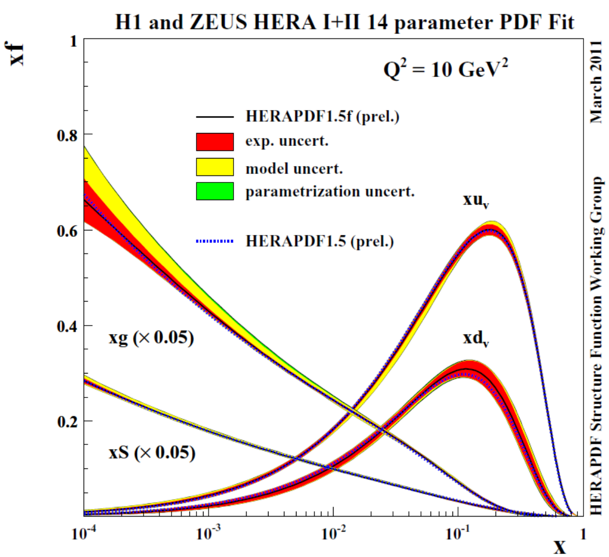




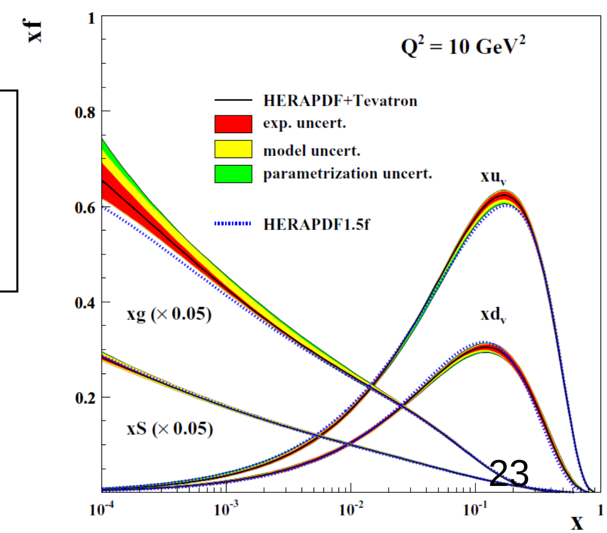


The improvement in experimental uncertainties is not washed out by model and parametrisation uncertainty.

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

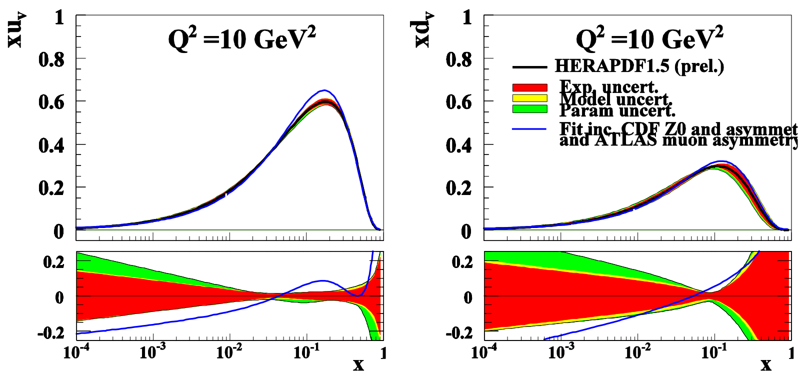


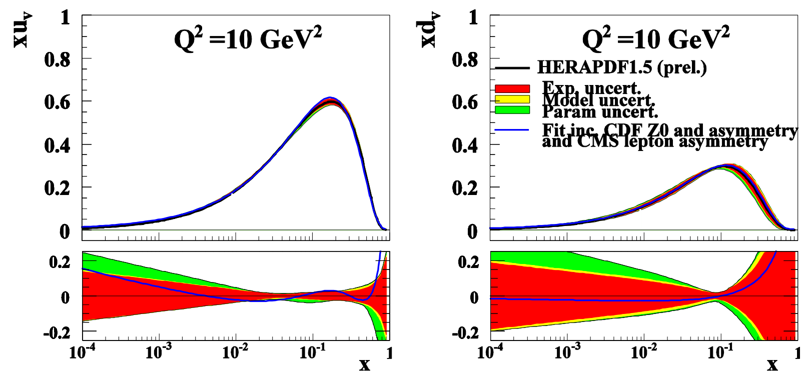
Once these Tevatron data are added there is no further improvement in experimental uncertainties and no significant shifts in the PDFs from adding:

•LHCb asymmetry data –the high-x d-valence is already so much improved by Tevatron data that LHCb data adds nothing

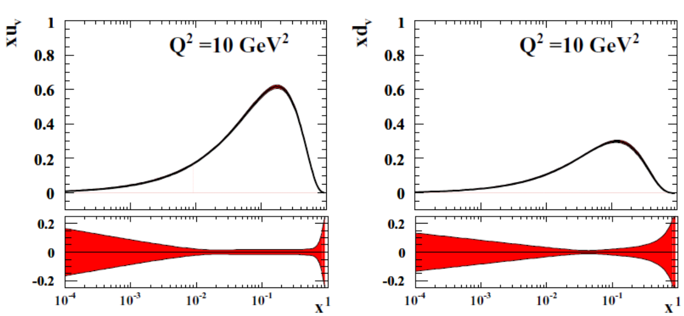
•CMS Z0 data (added little even before Tevatron data were added)

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

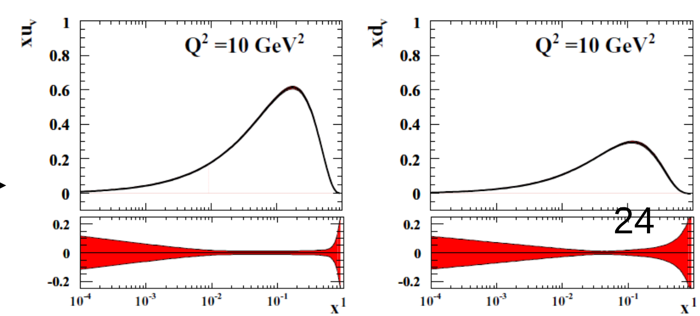




The CMS data also lead to a small improvement in the valence uncertainties at low-x, the LHC data reaches kinematic regions that the Tevatron could not reach



Improvement in experimental uncertainties



Interim Conclusions

The HERAPDF describes Tevatron and LHC W,Z data very well .

HERAPDF also describes Tevatron and LHC jet data within its uncertainties

This emphasizes that HERA data are the backbone of PDF fits

The HERA inclusive data provide precision for the low-x Sea and gluon PDFs, the u-valence is also well measured. The d-valence from CCe+p is reasonably well measured

Adding HERA jet data allows a competitive measurement of $\alpha_S(M_Z)$.

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

Adding the final low energy run data will allow studies beyond DGLAP

The Tevatron W,Z data improve the precision of the d-valence PDF mostly at high-x.

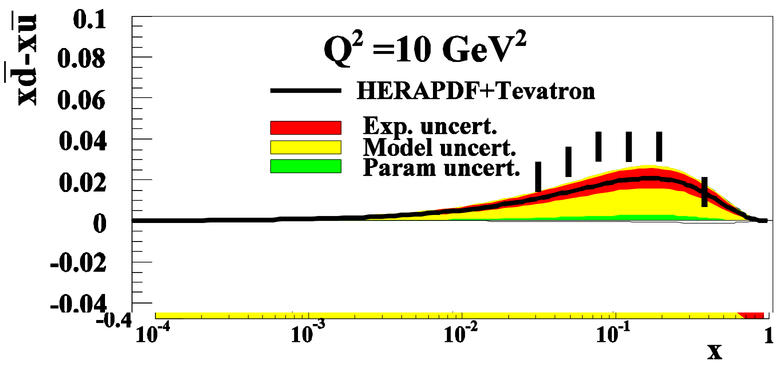
The LHC W,Z data will improve the low-x valence PDF precision

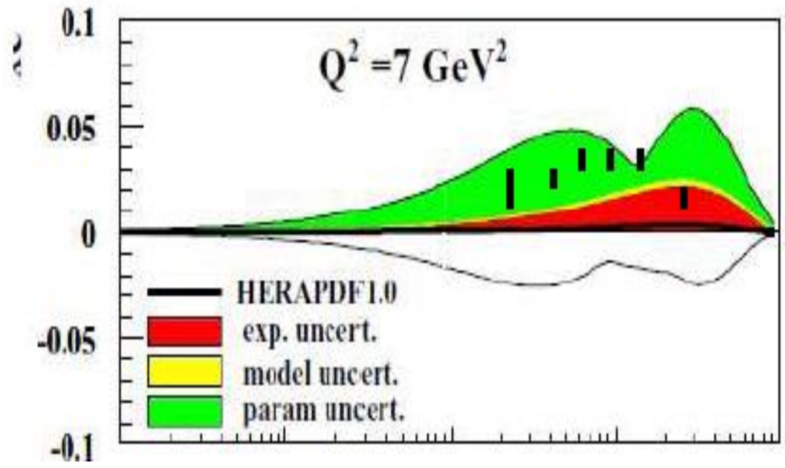
The LHC and Tevatron jet data should further improve the high-x parton PDF precision

But what is missing? Flavour information in the Sea.

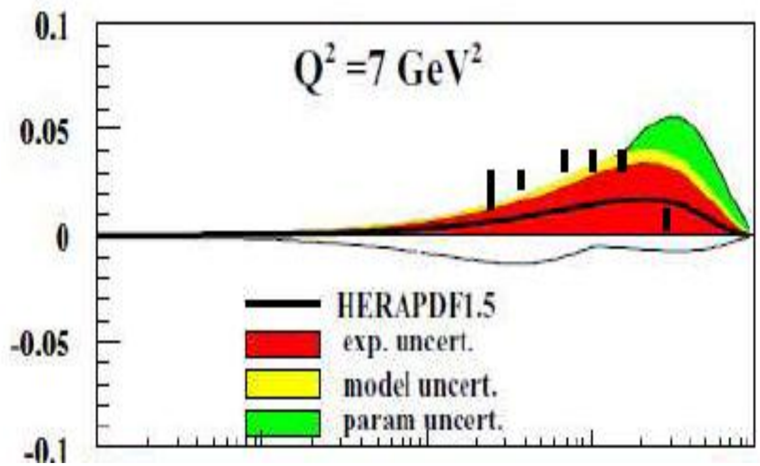
To come from LHC processes? E.g W+charm can give the strange sea

How about dbar-ubar?





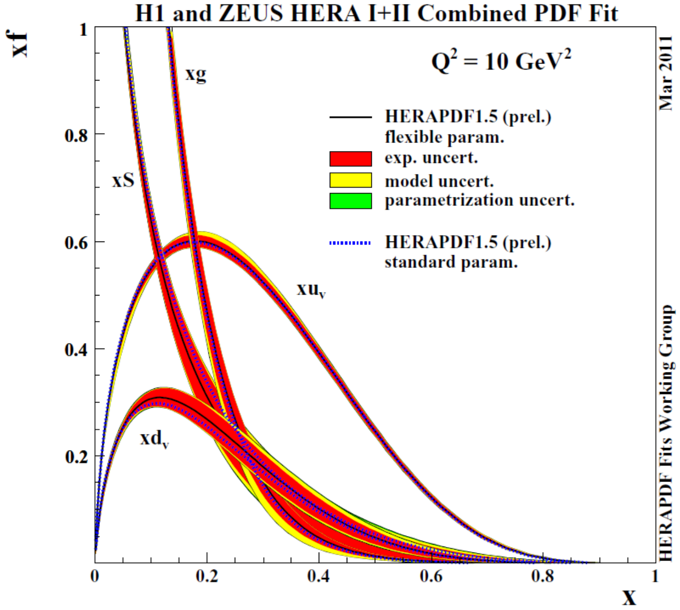
X value	E866 x(dbar-ubar)
0.026	0.022± 0.013
0.038	0.029± 0.005
0.067	0.036± 0.005
0.097	0.038± 0.005
0.142	0.036± 0.005
0.236	0.01 ± 0.005

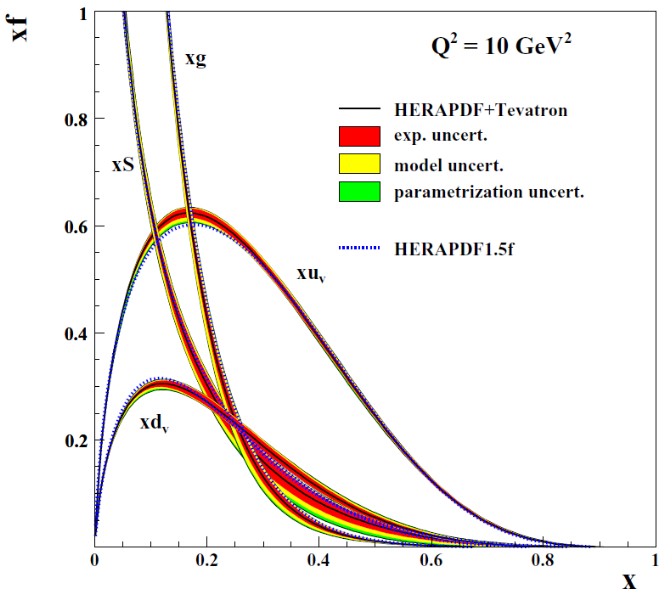


Input of the E866 data could add information to the fit.

Do we trust these data?- they do involve deuterium!

extras





Comparison of HERAPDF1.5f to HERAPDf+Tevatron.

High-x uncertainties reduce