HERAPDF2.0NNLOJets
March 2020

Some updates to the February talk

- Some model/param variations not quite complete then, now all complete
- Hadronisation uncertainty and
- Scale uncertainty

The plan for work to complete the analysis

- Finish the NNLO analysis much in the way that the DIS19 preliminary was done but with new mc,mb settings accounting for the new c,b combined data
- Using the same data sets, same cuts, same scale choice, same parametrisation ---(all checks done --ie settings and parametrisation choice iterated) –

NO significant change

The extra 6 low pt points of the H1 high Q2 inclusive jet data set have been added.

This does not impact the PDFs for fixed $\alpha_S(M_Z)$

However, it makes our best fit value of $\alpha_S(M_Z)$ ~ 0.116 rather than 0.115

Thus we will show PDFs with full uncertainty analysis for

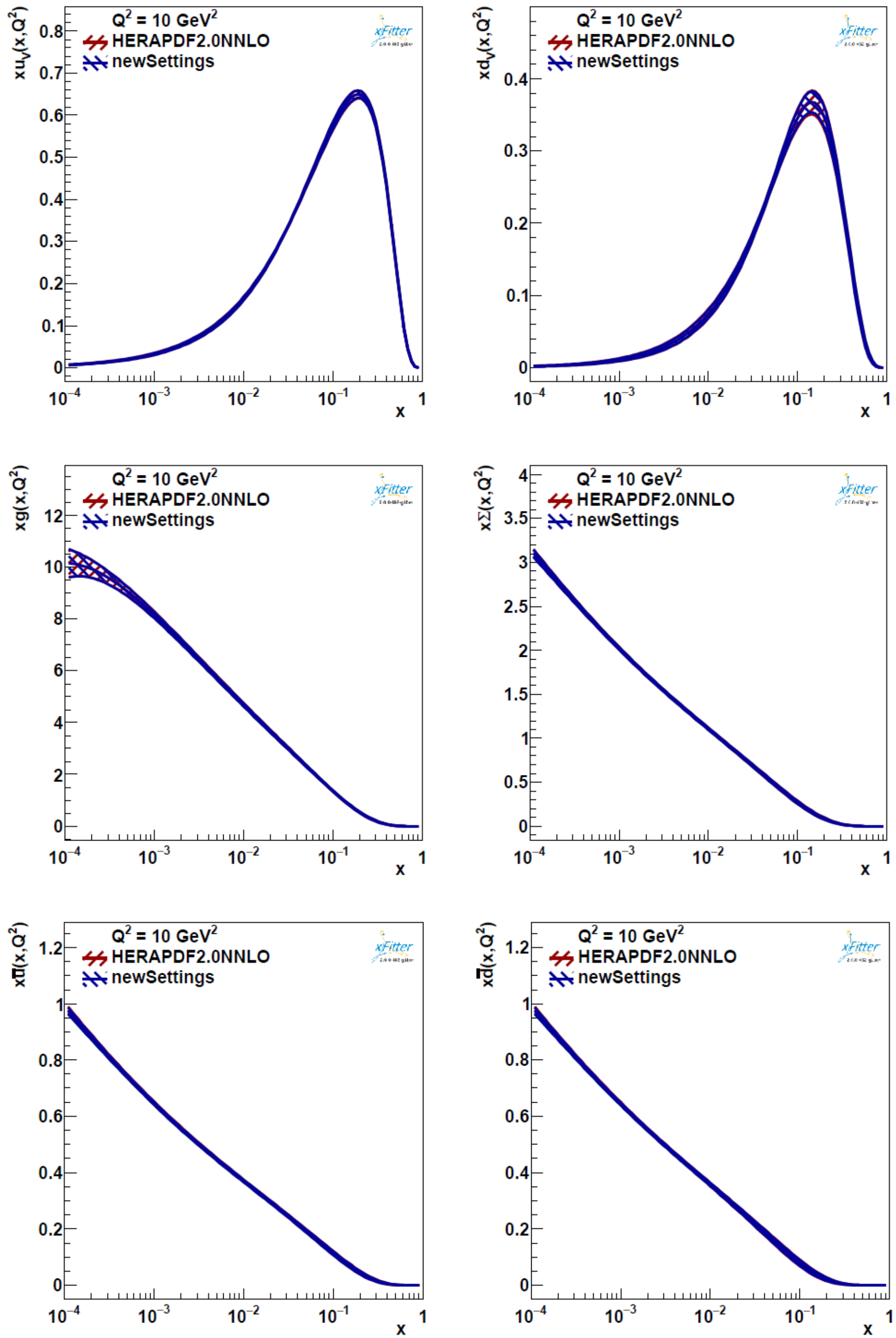
- $\alpha_S(M_Z)$ =0.116
- $\alpha_S(M_Z)$ =0.118
- All model/ parametrisation uncertainties treated as agreed: vary Q^2_0 down ONLY and symmetrise; vary Mc up ONLY and symmetrise

We will also determine the best fit value of $\alpha_S(M_Z)$ for this we also need:

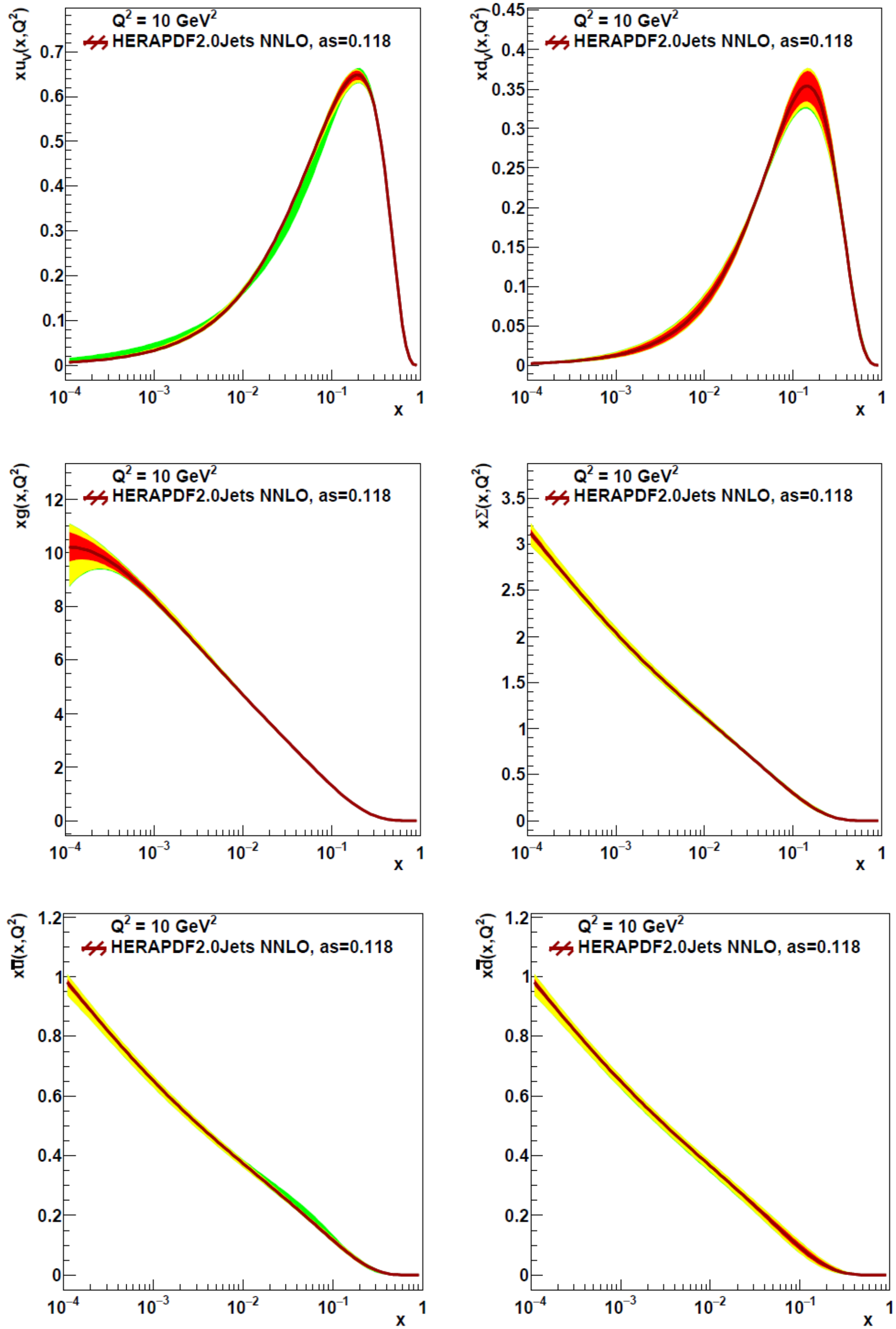
- Hadronisation ---by offset consistently
- Scale uncertainty ---½ correlated , ½ uncorrelated as for HERAPDF2.0NLOJets

- We revisit these decisions today

Compare new and old settings for HERAPDF2.0 without jets



Dataset	HERAPDF2.0NNLO	newSettings
HERA1+2 CCep	45 / 39	45 / 39
HERA1+2 CCem	56 / 42	56 / 42
HERA1+2 NCem	219 / 159	219 / 159
HERA1+2 NCep 820	67 / 70	66 / 70
HERA1+2 NCep 920	445 / 377	442 / 377
HERA1+2 NCep 460	217 / 204	218 / 204
HERA1+2 NCep 575	219 / 254	219 / 254
Correlated χ^2	92	91
Log penalty χ^2	+6.6	+5.8
Total χ^2 / dof	1367 / 1145	1362 / 1131



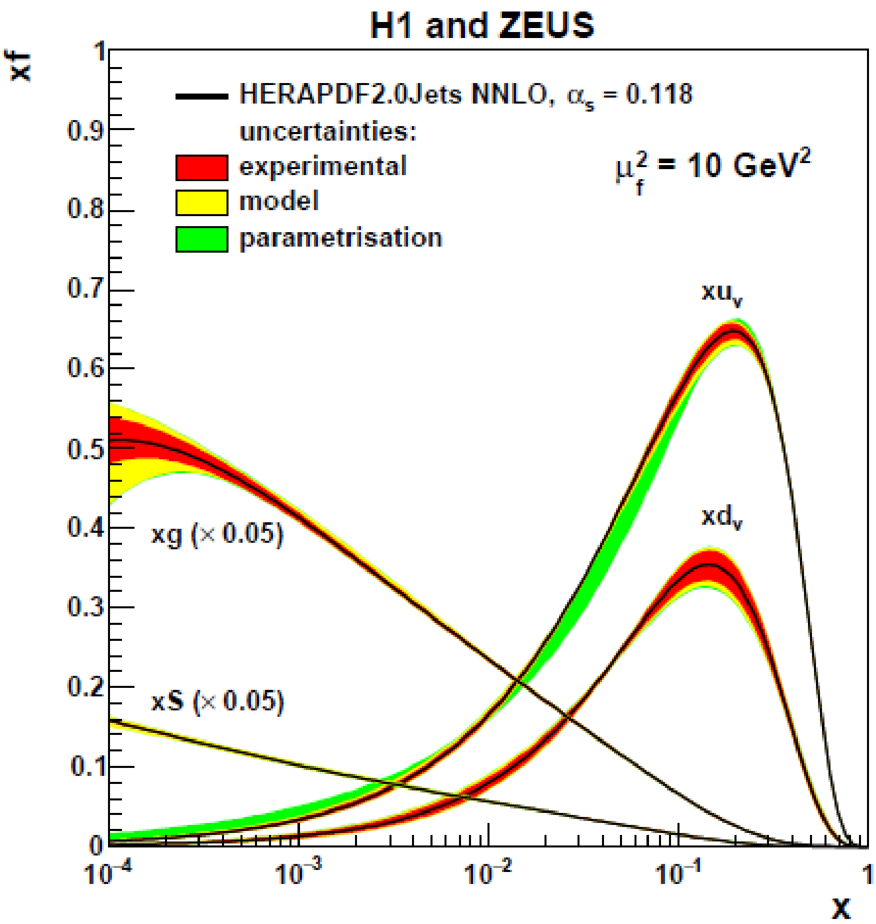
NEW alphas=0.118 NNLOJets fit

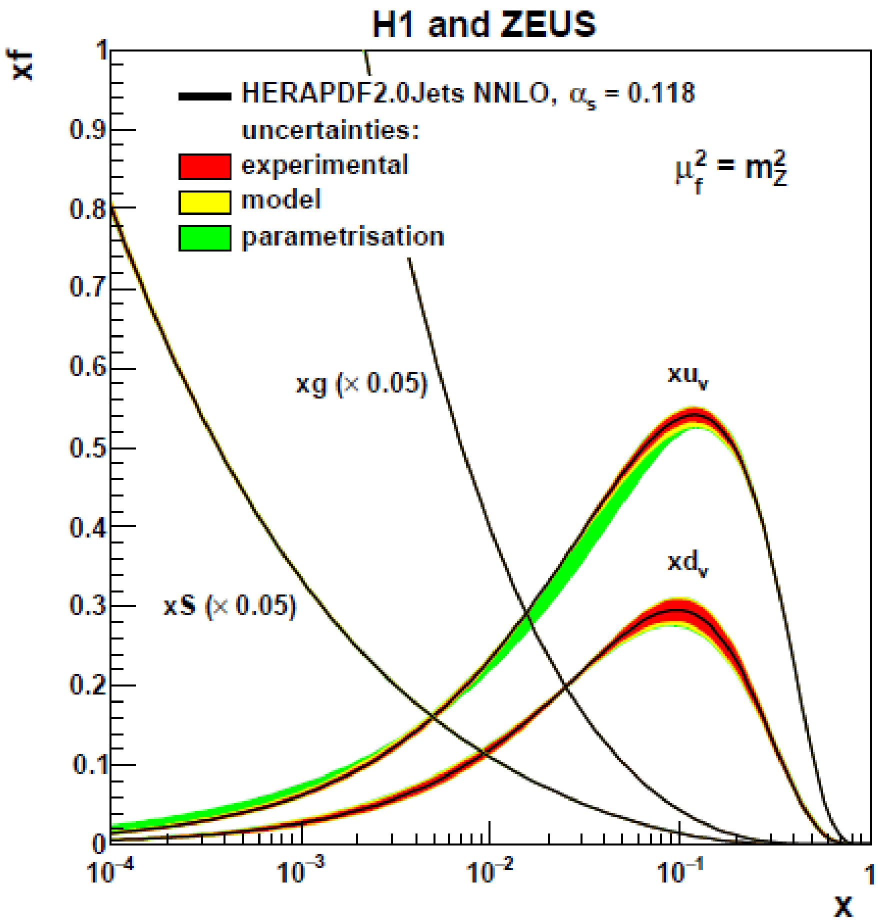
Parameter	HERAPDF2.0Jets NNLO, as=0.118
'Bg'	−0.080 ± 0.043
'Cg'	5.70 ± 0.49
'Aprig'	0.156 ± 0.042
'Bprig'	−0.401 ± 0.028
'Cprig'	25.00
'Buv'	0.801 ± 0.030
'Cuv'	4.858 ± 0.081
'Euv'	10.7 ± 1.5
'Bdv'	0.961 ± 0.095
'Cdv'	4.53 ± 0.41
'CUbar'	7.1 ± 1.3
'DUbar'	1.8 ± 1.6
'ADbar'	0.276 ± 0.011
'BDbar'	−0.1244 ± 0.0050
'CDbar'	7.9 ± 1.4
'alphas'	0.1180

NEW alphas=0.118 NNLOJets fit

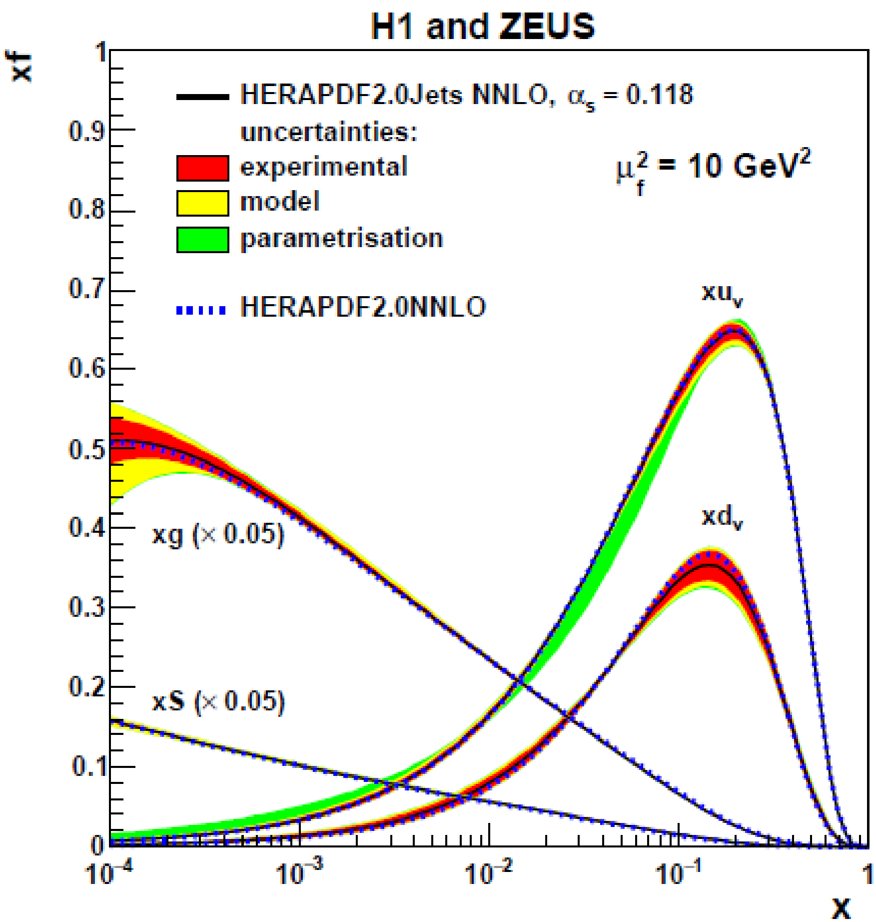
Dataset	HERAPDF2.0J NNLO, as=0.118
H1 normalised inclusive jet 99-00 data 2	1.6 / 4
HERA1+2 CCep	44 / 39
HERA1+2 CCem	57 / 42
HERA1+2 NCem	220 / 159
HERA1+2 NCep 820	64 / 70
HERA1+2 NCep 920	437 / 377
HERA1+2 NCep 460	215 / 204
HERA1+2 NCep 575	216 / 254
H1 normalised inclusive jets with unfolding 1	0 / 5
H1 normalised inclusive jets with unfolding 2	0 / 5
H1 normalised inclusive jets with unfolding 3	0 / 5
H1 normalised inclusive jets with unfolding 4	0 / 5
H1 normalised inclusive jets with unfolding 5	0 / 5
H1 normalised inclusive jets with unfolding 6	0 / 5
H1 normalised dijets with unfolding 1	0 / 4
H1 normalised dijets with unfolding 2	0 / 4
H1 normalised dijets with unfolding 3	0 / 4
H1 normalised dijets with unfolding 4	0 / 4
H1 normalised dijets with unfolding 5	0 / 4
H1 normalised dijets with unfolding 6	0 / 4
ZEUS inclusive dijet 98-00/04-07 data 1	2.3 / 3
ZEUS inclusive dijet 98-00/04-07 data 2	3.3 / 3
ZEUS inclusive dijet 98-00/04-07 data 3	4.5 / 3
ZEUS inclusive dijet 98-00/04-07 data 4	1.7 / 3
ZEUS inclusive dijet 98-00/04-07 data 5	0.84 / 2
ZEUS inclusive dijet 98-00/04-07 data 6	0.61 / 3
H1 low Q2 inclusive jet 99-00 data 1	1.1 / 2
H1 low Q2 inclusive jet 99-00 data 2	0.39 / 2
H1 low Q2 inclusive jet 99-00 data 3	1.4 / 2
H1 low Q2 inclusive jet 99-00 data 4	1.2 / 2
H1 low Q2 inclusive jet 99-00 data 5	0.23 / 2
H1 low Q2 inclusive jet 99-00 data 6	0.81 / 3
H1 low Q2 inclusive jet 99-00 data 7	6.8 / 3
H1 normalised inclusive jet 99-00 data 1	4.8 / 4
H1 normalised inclusive jet 99-00 data 3	0.98 / 4
H1 normalised inclusive jet 99-00 data 4	4.2 / 4
H1 normalised inclusive jet 99-00 data 5	6.7 / 4
H1 normalised inclusive jet 99-00 data 6	8.2 / 4
ZEUS inclusive jet 96-97 data 1	3.8 / 5
ZEUS inclusive jet 96-97 data 2	5.7 / 5
ZEUS inclusive jet 96-97 data 3	5.7 / 5
ZEUS inclusive jet 96-97 data 4	9.4 / 5
ZEUS inclusive jet 96-97 data 5	3.0 / 5
ZEUS inclusive jet 96-97 data 6	4.2 / 5
H1 low Q2 inclusive jets normalised 1	0 / 4
H1 low Q2 inclusive jets normalised 2	0 / 4
H1 low Q2 inclusive jets normalised 3	0 / 4
H1 low Q2 inclusive jets normalised 4	0 / 4
H1 low Q2 inclusive jets normalised 5	0 / 4
H1 low Q2 inclusive jets normalised 6	0 / 4
H1 low Q2 inclusive jets normalised 7	0 / 4
H1 low Q2 inclusive jets normalised 8	0 / 4
H1 low Q2 dijets normalised 1	0 / 4
H1 low Q2 dijets normalised 2	0 / 4
H1 low Q2 dijets normalised 3	0 / 4
H1 low Q2 dijets normalised 4	0 / 4
H1 low Q2 dijets normalised 5	0 / 4
H1 low Q2 dijets normalised 6	0 / 4
H1 low Q2 dijets normalised 7	0 / 4
H1 low Q2 dijets normalised 8	0 / 4
Correlated χ^2	120
Log penalty χ^2	+27
Total χ^2 / dof	1618 / 1336

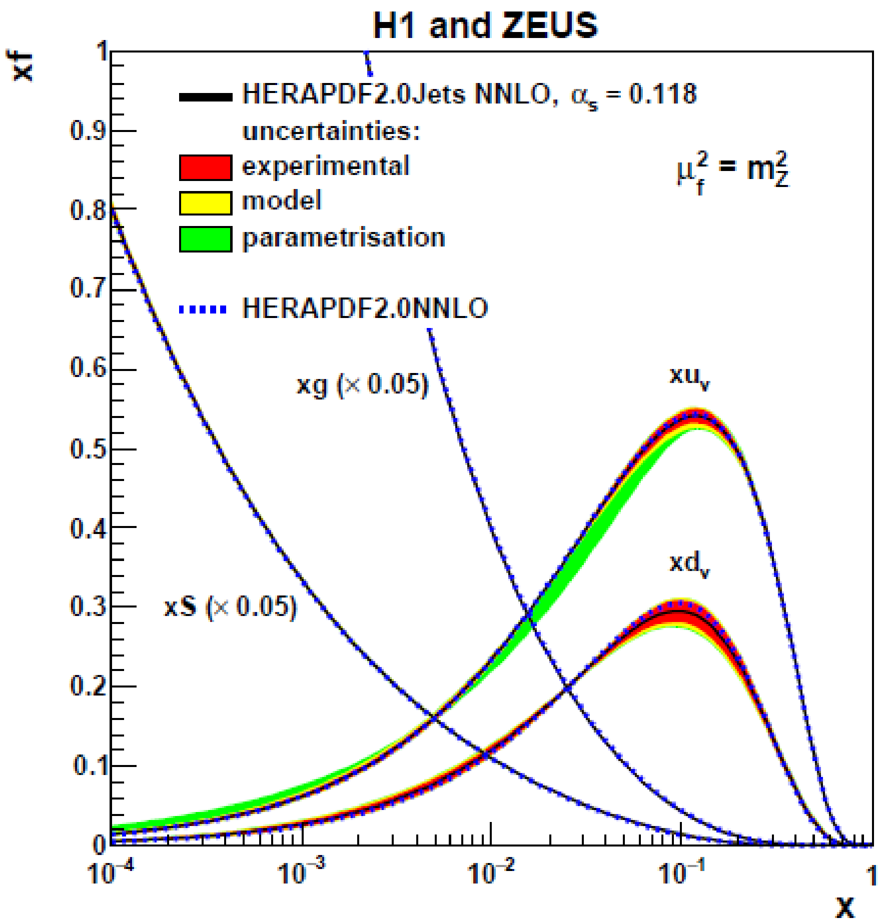
NEW alphas=0.118 NNLOJets fit - SUMMARY PLOTS



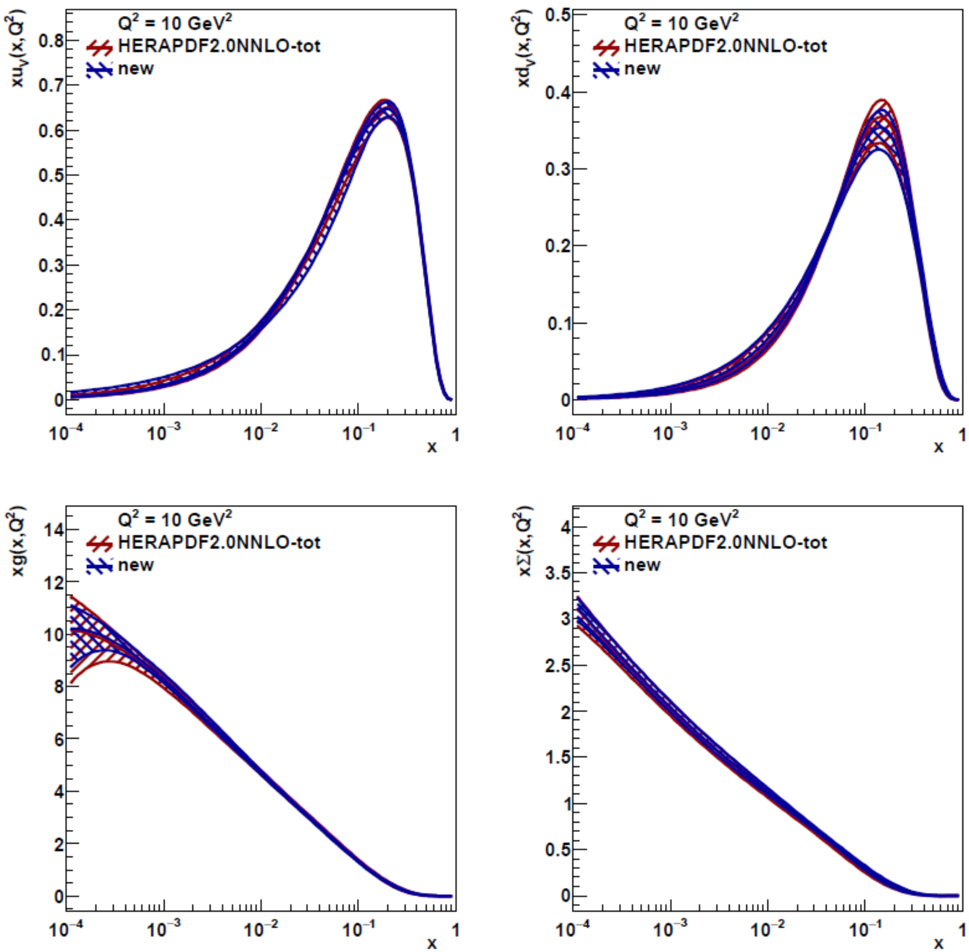


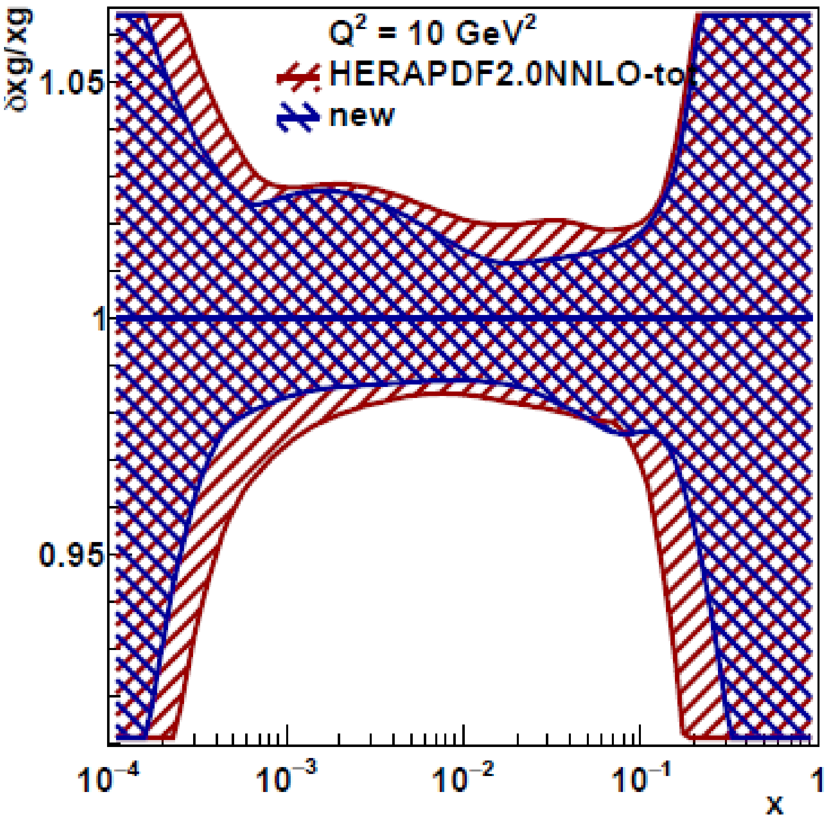
NEW alphas=0.118 NNLOJets fit - SUMMARY PLOTS
HERAPDF2.0NNLOJets compared to HERAPDF2.0NNLO



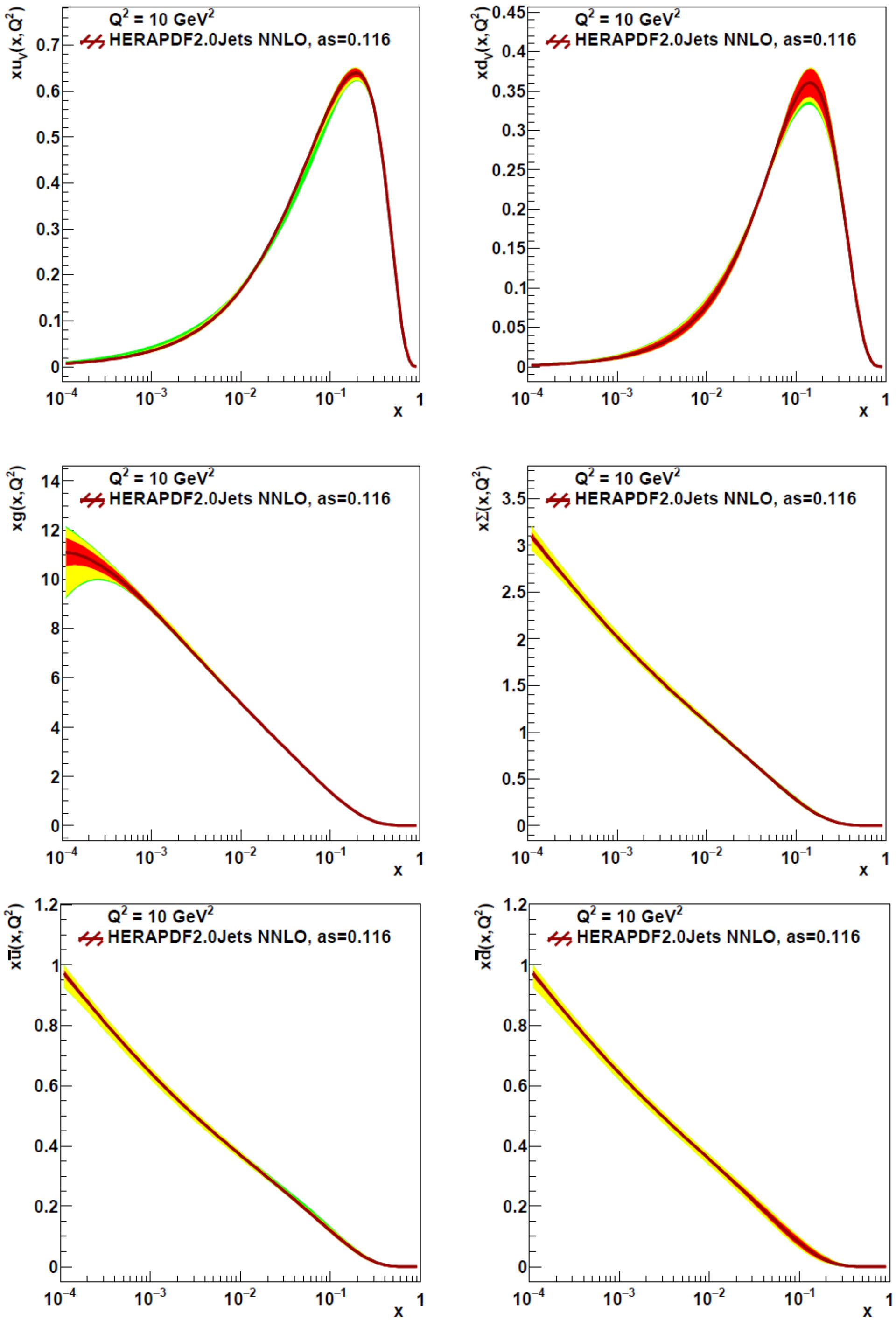


Decrease in total uncertainties from NNLO to NNLO+jet
—similar to NLO and to preliminary NNLO





A closer look at the gluon



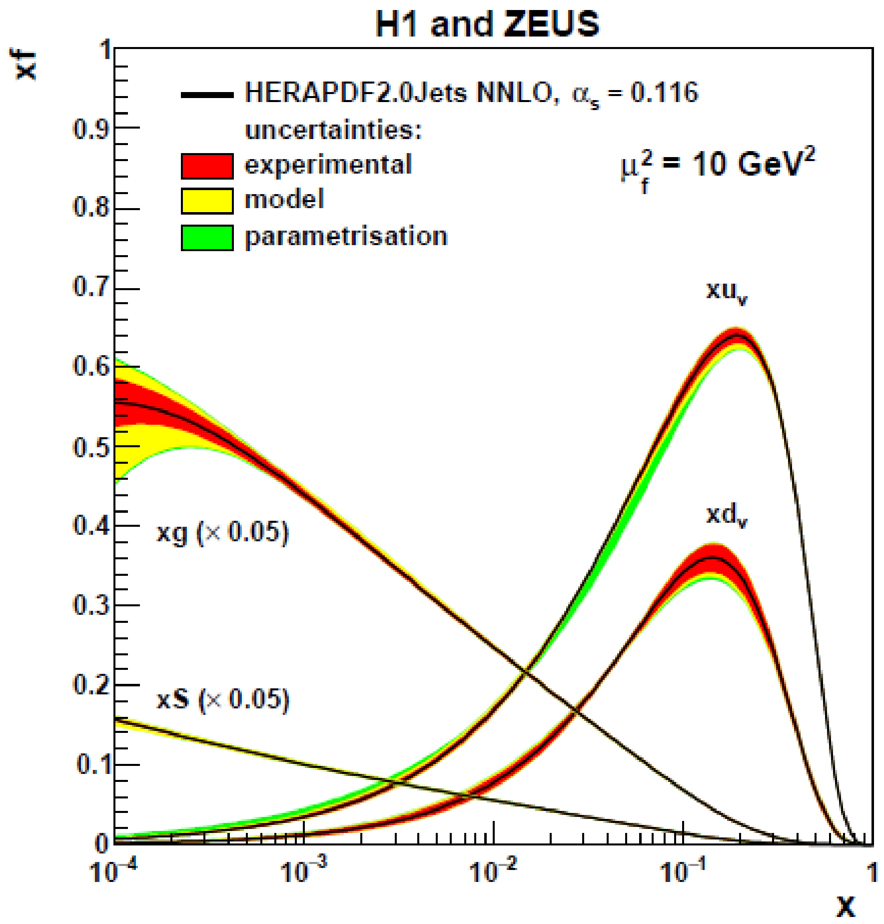
NEW alphas=0.116 NNLOJets fit

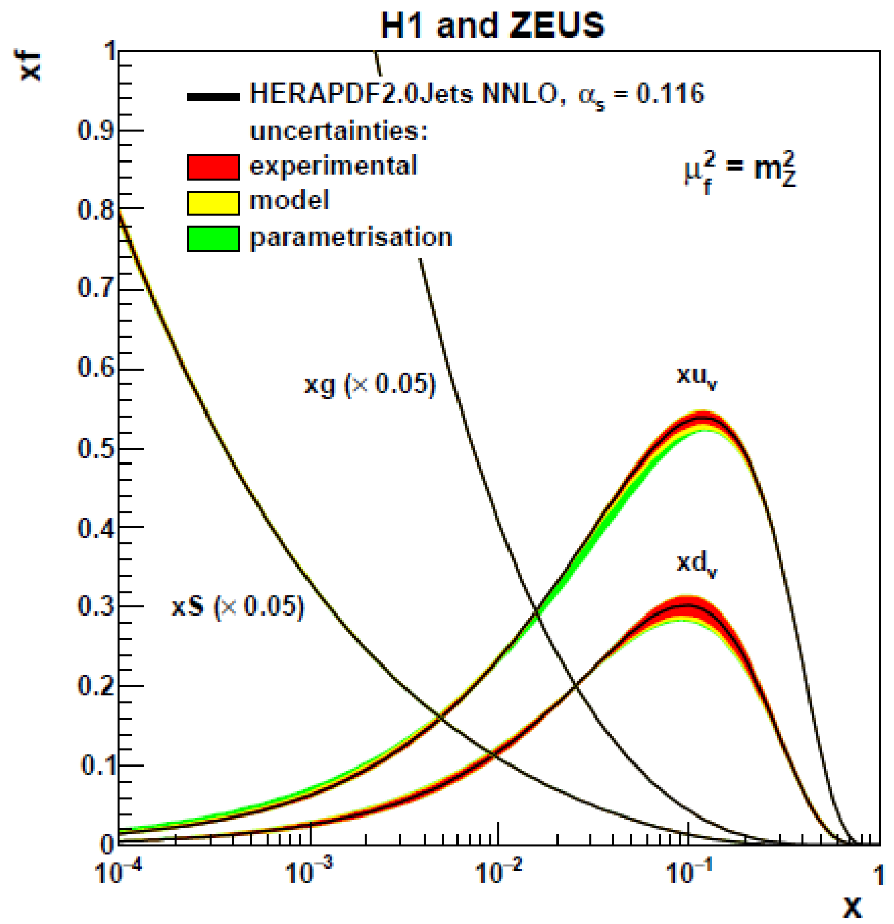
Parameter	HERAPDF2.0Jets NNLO, as=0.116
'Bg'	−0.090 ± 0.039
'Cg'	5.98 ± 0.48
'Aprig'	0.144 ± 0.040
'Bprig'	−0.414 ± 0.028
'Cprig'	25.00
'Buv'	0.783 ± 0.026
'Cuv'	4.875 ± 0.081
'Euv'	10.5 ± 1.4
'Bdv'	0.987 ± 0.088
'Cdv'	4.80 ± 0.39
'CUbar'	7.1 ± 1.3
'DUbar'	2.1 ± 1.7
'ADbar'	0.268 ± 0.011
'BDbar'	−0.1269 ± 0.0049
'CDbar'	9.5 ± 1.9
'alphas'	0.1160

NEW alphas=0.116 NNLOJets fit

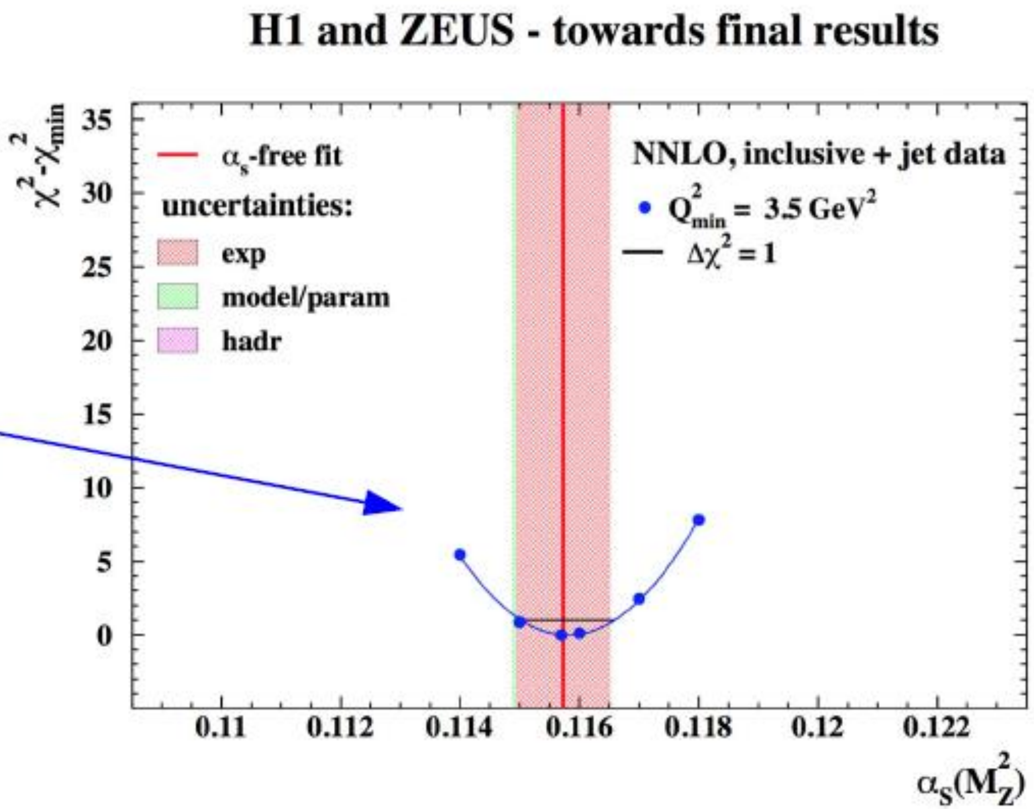
Dataset	HERAPDF2.0Jets NNLO, as=0.116
H1 normalised inclusive jet 99-00 data 2	1.5 / 4
HERA1+2 CCep	46 / 39
HERA1+2 CCem	55 / 42
HERA1+2 NCem	220 / 159
HERA1+2 NCep 820	65 / 70
HERA1+2 NCep 920	442 / 377
HERA1+2 NCep 460	217 / 204
HERA1+2 NCep 575	218 / 254
H1 normalised inclusive jets with unfolding 1	0 / 5
H1 normalised inclusive jets with unfolding 2	0 / 5
H1 normalised inclusive jets with unfolding 3	0 / 5
H1 normalised inclusive jets with unfolding 4	0 / 5
H1 normalised inclusive jets with unfolding 5	0 / 5
H1 normalised inclusive jets with unfolding 6	0 / 5
H1 normalised dijets with unfolding 1	0 / 4
H1 normalised dijets with unfolding 2	0 / 4
H1 normalised dijets with unfolding 3	0 / 4
H1 normalised dijets with unfolding 4	0 / 4
H1 normalised dijets with unfolding 5	0 / 4
H1 normalised dijets with unfolding 6	0 / 4
ZEUS inclusive dijet 98-00/04-07 data 1	2.7 / 3
ZEUS inclusive dijet 98-00/04-07 data 2	3.4 / 3
ZEUS inclusive dijet 98-00/04-07 data 3	4.6 / 3
ZEUS inclusive dijet 98-00/04-07 data 4	1.8 / 3
ZEUS inclusive dijet 98-00/04-07 data 5	0.69 / 2
ZEUS inclusive dijet 98-00/04-07 data 6	0.60 / 3
H1 low Q2 inclusive jet 99-00 data 1	1.3 / 2
H1 low Q2 inclusive jet 99-00 data 2	0.35 / 2
H1 low Q2 inclusive jet 99-00 data 3	1.4 / 2
H1 low Q2 inclusive jet 99-00 data 4	1.2 / 2
H1 low Q2 inclusive jet 99-00 data 5	0.19 / 2
H1 low Q2 inclusive jet 99-00 data 6	0.85 / 3
H1 low Q2 inclusive jet 99-00 data 7	6.9 / 3
H1 normalised inclusive jet 99-00 data 1	4.4 / 4
H1 normalised inclusive jet 99-00 data 3	0.95 / 4
H1 normalised inclusive jet 99-00 data 4	4.7 / 4
H1 normalised inclusive jet 99-00 data 5	8.2 / 4
H1 normalised inclusive jet 99-00 data 6	8.5 / 4
ZEUS inclusive jet 96-97 data 1	3.9 / 5
ZEUS inclusive jet 96-97 data 2	6.4 / 5
ZEUS inclusive jet 96-97 data 3	5.7 / 5
ZEUS inclusive jet 96-97 data 4	9.5 / 5
ZEUS inclusive jet 96-97 data 5	3.5 / 5
ZEUS inclusive jet 96-97 data 6	4.7 / 5
H1 low Q2 inclusive jets normalised 1	0 / 4
H1 low Q2 inclusive jets normalised 2	0 / 4
H1 low Q2 inclusive jets normalised 3	0 / 4
H1 low Q2 inclusive jets normalised 4	0 / 4
H1 low Q2 inclusive jets normalised 5	0 / 4
H1 low Q2 inclusive jets normalised 6	0 / 4
H1 low Q2 inclusive jets normalised 7	0 / 4
H1 low Q2 inclusive jets normalised 8	0 / 4
H1 low Q2 dijets normalised 1	0 / 4
H1 low Q2 dijets normalised 2	0 / 4
H1 low Q2 dijets normalised 3	0 / 4
H1 low Q2 dijets normalised 4	0 / 4
H1 low Q2 dijets normalised 5	0 / 4
H1 low Q2 dijets normalised 6	0 / 4
H1 low Q2 dijets normalised 7	0 / 4
H1 low Q2 dijets normalised 8	0 / 4
Correlated χ^2	112
Log penalty χ^2	+11
Total χ^2 / dof	1612 / 1336

NEW alphas=0.116 NNLOJets fit SUMMARY PLOTS





New α_s



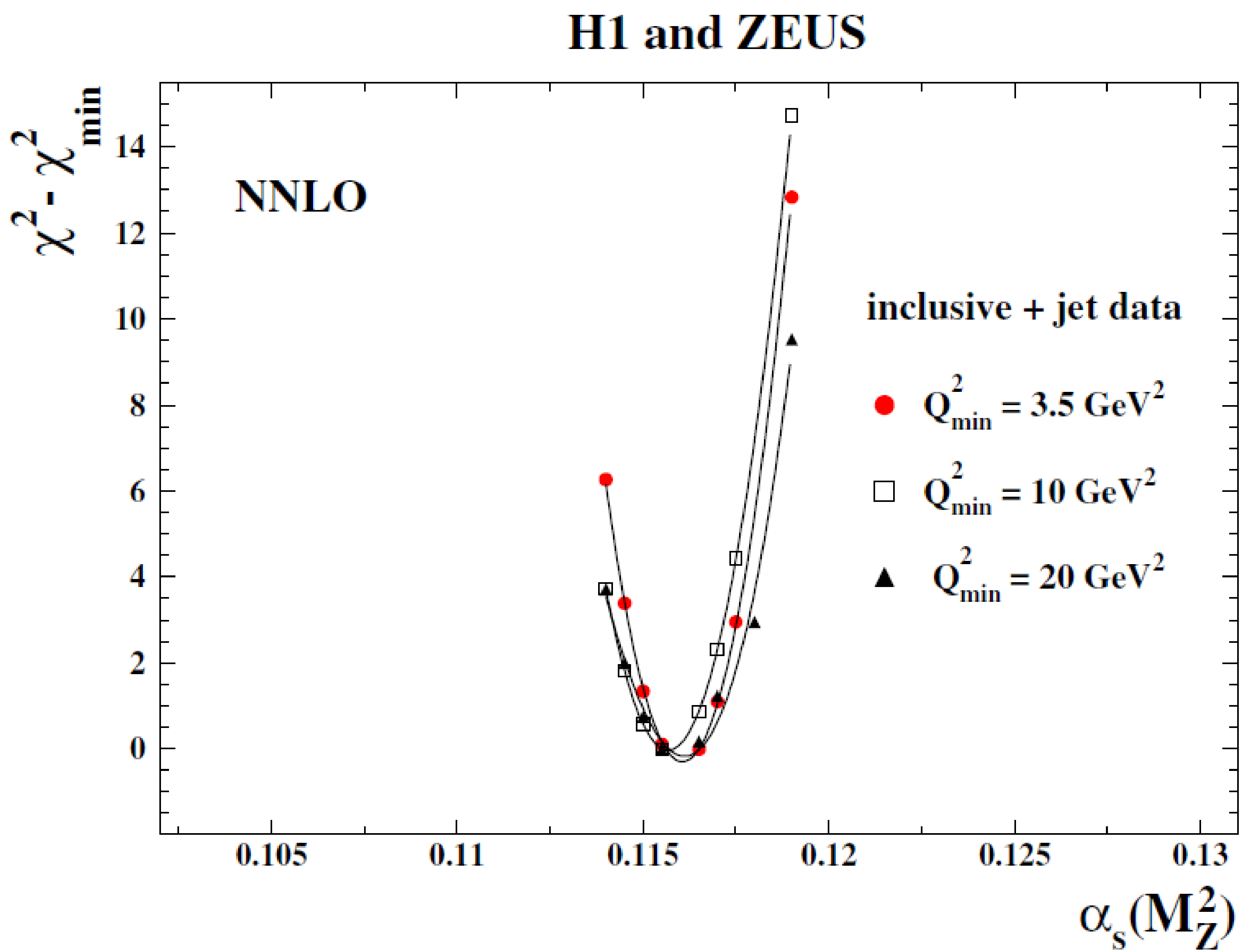
- Two ways of estimating α_s @NNLO using HERA jet data
  - → α_s-scan
  - → simultaneous fit of PDFs and α_s
- Both methods give the same result

- Fit:

$$\alpha_s(M_Z^2) = 0.1157 \pm 0.0008(\text{exp})$$

- α_s-scan: α_s = 0.1158 +- 0.0008

- Model/parameterisation uncertainty +0.0001 -0.0003



H1 and ZEUS
NNLO
inclusive + jet data
Q^2_{min} = 3.5 GeV^2
Q^2_{min} = 10 GeV^2
Q^2_{min} = 20 GeV^2
$\chi^2 - \chi^2_{min}$
$\alpha_s(M_Z^2)$
14
12
10
8
6
4
2
0
0.105
0.11
0.115
0.12
0.125
0.13

In February we had not yet revisited the hadronisation uncertainty on $\alpha_S(M_Z)$
First by Hessian method

For preliminary hadronisation had been treated somewhat inconsistently as a mixture of the offset method and the Hessian method. We wish to be consistent.
The treatment of hadronisation in the H1 HERA-II low Q2 jet data sets was recommended as ½ correlated and ½ uncorrelated.
I had made a mistake with this and taken it as literally ½ when it should have been $1/\sqrt{2}$!
When correcting this mistake we thought it would be most consistent to apply this treatment to ALL the jet data sets (indeed this is done for H1 jets in their alphas determinations).

So this has been applied but there are choices on the degree of correlation

1. One could correlate all the correlated hadronisation uncertainties to each other $\alpha_S(M_Z) = 0.1161 \pm 0.0010$
2. One could correlate all H1 and all ZEUS separately $\alpha_S(M_Z) = 0.1150 \pm 0.0010$
3. One could correlate only within each data set (where inclusive and dijets from the same set remain correlated) $\alpha_S(M_Z)$ 0.1157 ± 0.0009- this is closest what we were doing (inconsistently) so far

Each of these three choices give slightly different answers

Choice 1: correlating ALL hadronisation uncertainties is the closest to spirit of the OFFSET method we have used for HERAPDF in the past –but it is not the same..

Suppose we made choice 1 $\alpha_S(M_Z)$ =0.1161 ± 0.0010(exp,had,PDF)
Then to evaluate the contribution of hadronisation to the uncertainty one can compare this to the result when hadronisation uncertainty is not applied at all –when we obtain
$\alpha_S(M_Z)$ =0.1160 ± 0.0008
the increase from 0.0008 to 0.0010 represents a hadronisation uncertainty of 0.0006 (co
So we could quote $\alpha_S(M_Z)$ = 0.1160 ± 0.0008(exp) ± 0.0006(had.)

However we SAID we were going to do Hadronisation by OFFSET not Hessian
We had not applied this consistently for preliminary since we retained the ½ n ½ correlated treatment of hadronisation for the low Q2 jets and we also offset ½ of it (except with a mistake using ½ not 1/√2)

There are two choices to be consistent with the offset method
(NOTE: When offsetting we always do this correlated between all data samples)

1) Remove the 1/√2 of the uncertainty from the correlated uncertainties (while retaining the uncorrelated 1/√2) and then offset this correlated 1/√2 part, this gives
$\alpha_S(M_Z)$ = 0.1160± 0.0009(exp) ± 0.0009(offset)
2) Remove ALL the hadronisation uncertainty and offset the full uncertainty for all data sets— this is most akin to the HERAPDF2.0NLOjet treatment—
$\alpha_S(M_Z)$ = 0.1160± 0.0008(exp) ± 0.0012(offset)

I also think that an uncertainty of ~0.001 is most reasonable given the variation in values under hadronisation treatment

Treatment of scale uncertainty

This can be treated as ½ correlated and ½ uncorrelated (yes it is actually $1/\sqrt{2}$)
--- as suggested in the H1 HERA_II high Q2 paper
Or as fully correlated as in more recent H1 publications.

The full scale uncertainty for all the current choices of cuts is ± 0.0036
If this is applied as ½ correlated and ½ uncorrelated instead then it is ± 0.0026

It seems to me that both these estimates could be given in the paper as follows.

'We first compare the present NNLO result for alphas with that obtained in the NLO HERAPDF2.0Jets study:

NLO

$\alpha_S(M_Z)$ = 0.1183 ± 0.0009(exp) ± 0.0005(mod/par) ± 0.0012(had) ± 0.0034(scale)

NNLO

$\alpha_S(M_Z)$ = 0.1160 ± 0.0008(exp) ± 0.0003(mod/par) ± 0.0012(had) ± 0.0026(scale)

Where all sources of uncertainty have been treated similarly.

We note that

- *had the NLO evaluation been done using the present choice of central scale the result would have bee 0.1210 \pm 0.0009 and that*
- *if the NNLO evaluation had been done without HERA-II H1 low Q2 jets (as the NLO evaluation was done) it would have been 0.1154 \pm 0.0009.*

Thus the change from NLO to NNLO represents a decrease in the value $\alpha_S(M_Z)$ and a decrease in the scale uncertainties…….

‘However, the result may also be compared to the recent NNLO $\alpha_S(M_Z)$ determinations from H1, which use some of the same jet data sets and which make a study of the trade off between the increase in experimental uncertainty and the decrease in scale uncertainty resulting from various cuts on the kinematic variable μ. The most comparable result to the present result is that for μ > 2mb, since we use μ > 13.5

H1 jets	μ >	$2m_b$	$0.1143\,(9)_{\rm exp}\,(6)_{\rm had}\,(5)_{\rm PDF}\,(5)_{{\rm PDF}\alpha_s}\,(4)_{\rm PDFset}\,(42)_{\rm scale}$
H1 jets		28 GeV	$0.1157\,(20)_{\rm exp}\,(6)_{\rm had}\,(3)_{\rm PDF}\,(2)_{{\rm PDF}\alpha_s}\,(3)_{\rm PDFset}\,(27)_{\rm scale}$
H1 jets		42 GeV	$0.1168\,(22)_{\rm exp}\,(7)_{\rm had}\,(2)_{\rm PDF}\,(2)_{{\rm PDF}\alpha_s}\,(5)_{\rm PDFset}\,(17)_{\rm scale}$

Note that the H1 result uses full scale uncertainties, but the hadronisation uncertainties are treated in the Hessian rather than offset method so our most comparable result IS $\alpha_S(M_Z)$ =0.1160 ± 0.0008(exp) ± 0.0006(had) ± 0.0003(mod/par) ± 0.0036(scale)

Another comparable result is that of the ApplFAST study using just HERA inclusive jets

HERA inclusive jets		
HERA inclusive jets	$2m_b$	$0.1149\,(9)_{\rm exp}\,(5)_{\rm had}\,(4)_{\rm PDF}\,(3)_{{\rm PDF}\alpha_s}\,(2)_{\rm PDFset}\,(37)_{\rm scale}$
HERA inclusive jets	28 GeV	$0.1170\,(15)_{\rm exp}\,(7)_{\rm had}\,(3)_{\rm PDF}\,(2)_{{\rm PDF}\alpha_s}\,(3)_{\rm PDFset}\,(24)_{\rm scale}$

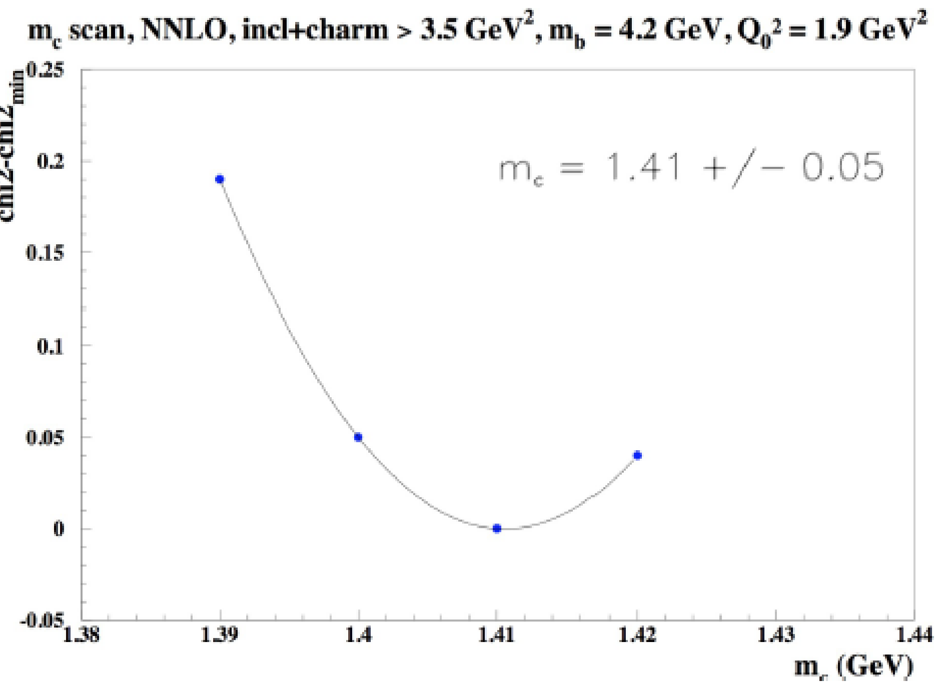
But note both the H1 results and the Applfast use fixed PDFs (recently criticised**)
Alternatively we may compare to the H1 result making a simultaneous PDF and $\alpha_S(M_Z)$ fit to just H1 inclusive and jet data

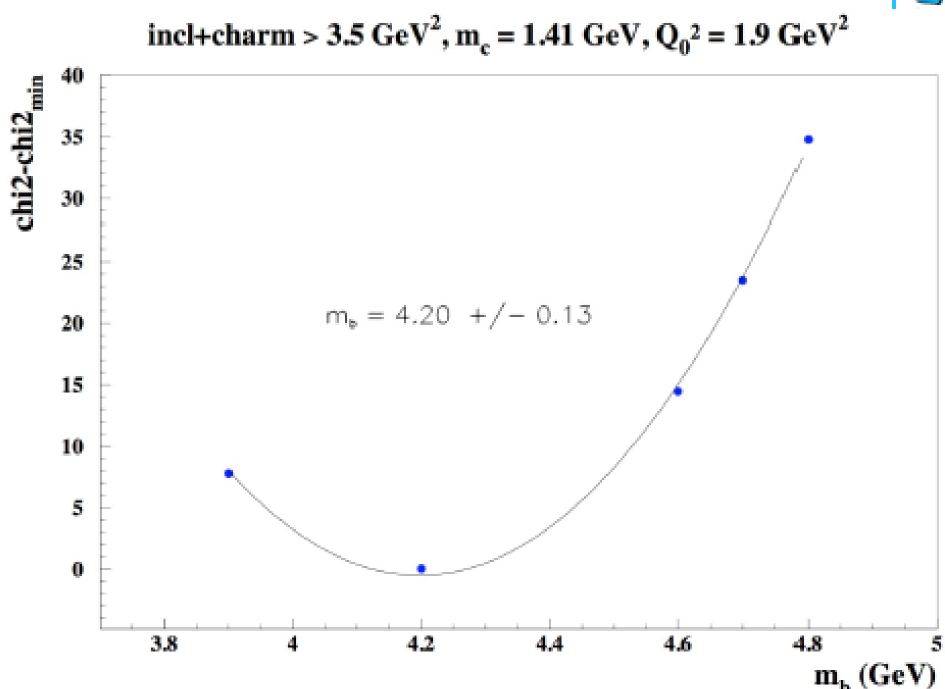
$$\alpha_s(m_Z) = 0.1142\,(11)_{\rm exp,had,PDF}\,(2)_{\rm mod}\,(2)_{\rm par}\,(26)_{\rm scale}\,.$$

For which our comparable result is
$\alpha_S(M_Z)$ =0.1160 ± 0.0010(exp,had,PDF) ± 0.0003(mod/par) ± 0.0036(scale)’

Back-up of slides shown
at previous meeting

- New charm and beauty masses
  → from final H1/ZEUS beauty results Eur. Phys. J C 78 (2018) 473
    - Charm mass m_c = 1.41 +/- 0.05 (before 1.43 +/- 0.06)
    - Beauty mass m_b = 4.20 +/- 0.13 (before 4.5 +/- 0.25)





Parameterisation scan repeated -> stays the same

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

$$\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1+D_{\bar{U}}x), \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}$$

- Additional constrains
  - A_{u_v}, A_{d_v}, A_g: constrained by the quark-number sum rules and momentum sum rule
  - $B_{\bar{U}} = B_{\bar{D}}$;
  - $x\bar{s} = f_s x\bar{D}$ at starting scale, $f_s = 0.4$

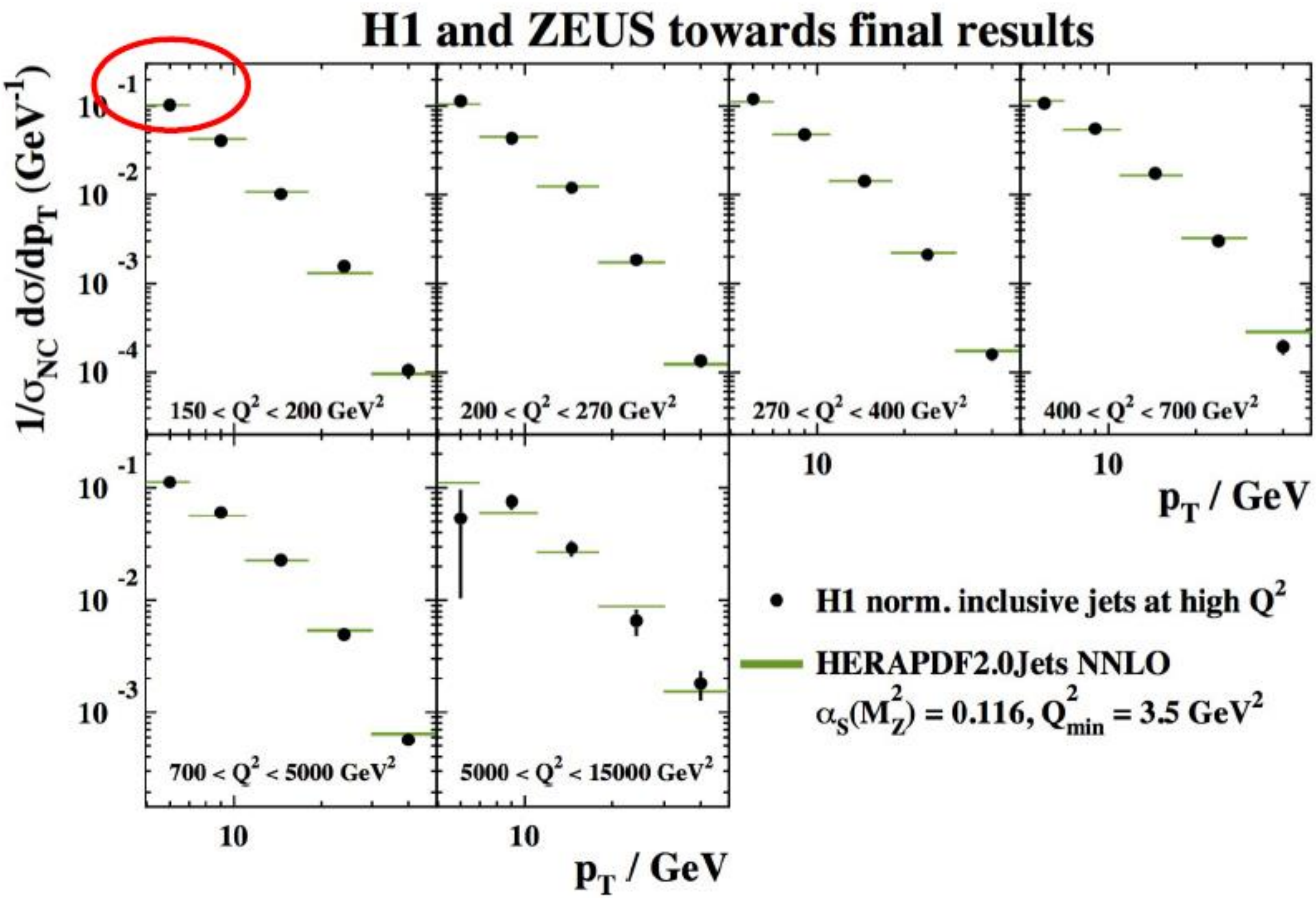
- Inclusive jets and dijets
- Some data points excluded due theory limitations
- Absolute and normalised cross sections
- Low-Q^2 and high-Q^2 production
- HERAI and HERAII

Data Set	taken from – to	Q^2[GeV^2] range from	to	$\mathcal{L}$ pb^{-1}	e^+/e^-	norma-lised	all points	used points
H1 HERA I normalised jets	1999 – 2000	150	15000	65.4	e^+p	yes	24	24
H1 HERA I jets at low Q^2	1999 – 2000	5	100	43.5	e^+p	no	28	16
H1 normalised inclusive jets at high Q^2	2003 – 2007	150	15000	351	e^+p/e^-p	yes	30	24
H1 normalised dijets at high Q^2	2003 – 2007	150	15000	351	e^+p/e^-p	yes	24	24
H1 normalised inclusive jets at low Q^2	2005 – 2007	5.5	80	290	e^+p/e^-p	yes	48	32
H1 normalised dijets at low Q^2	2005 – 2007	5.5	80	290	e^+p/e^-p	yes	48	32
ZEUS inclusive jets	1996 – 1997	125	10000	38.6	e^+p	no	30	30
ZEUS dijets	1998 –2000 & 2004 – 2007	125	20000	374	e^+p/e^-p	no	22	16

- 6 data points added
  → H1 normalised inclusive jets at high Q^2
  → for each Q^2 bin low-p_t point added

Comparison of new data points to predictions

- Data - full uncertainty, predictions - experimental only
- All looks fine



New α_s

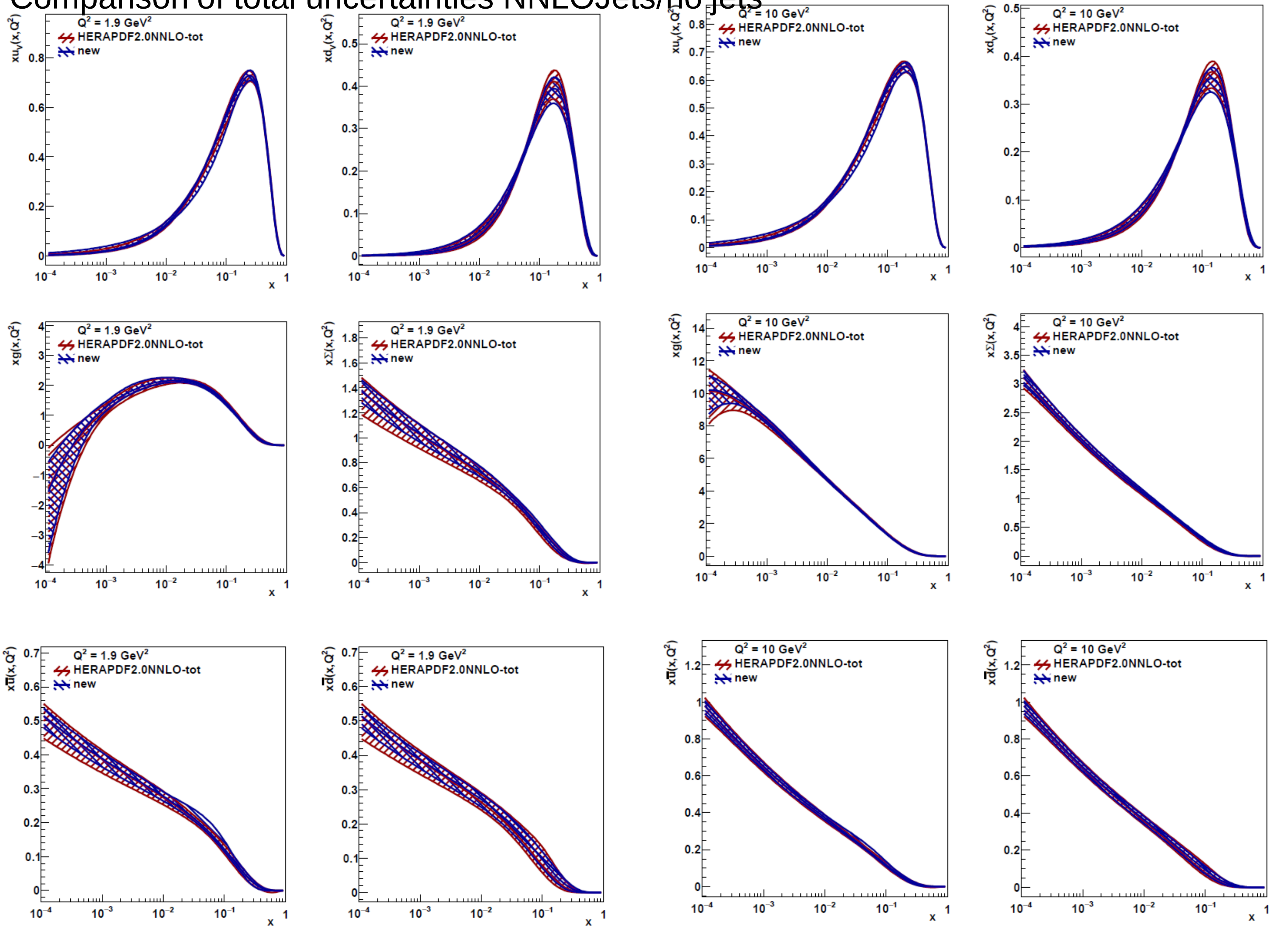
$$\alpha_s(M_Z^2) = 0.1157 \pm 0.0008(\text{exp})$$

- Compared to
  - 0.1150 +/- 0.0008 → preliminary
  - 0.1151 +/- 0.0008 → new settings, no low-p_T jet points
  - <u>Scale uncertainties from preliminary</u>: +- 0.0027

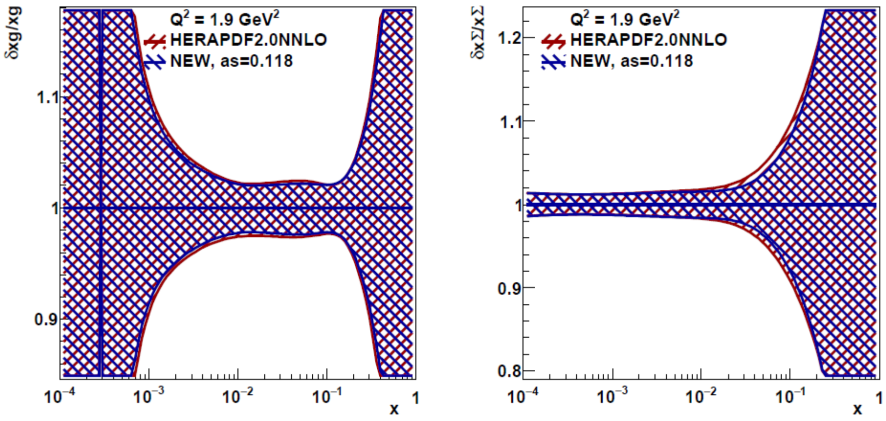
- Model/parameterisation uncertainty
  - +0.0001 -0.0003
- Compared to
  - +0.0002 -0.0005 → preliminary

- Difference for positive uncertainty comes from double counting mentioned before
- Difference for negative uncertainty comes from large difference for added EUbar parameter (more stable fit now?)
- In any case → scale uncertainty dominates

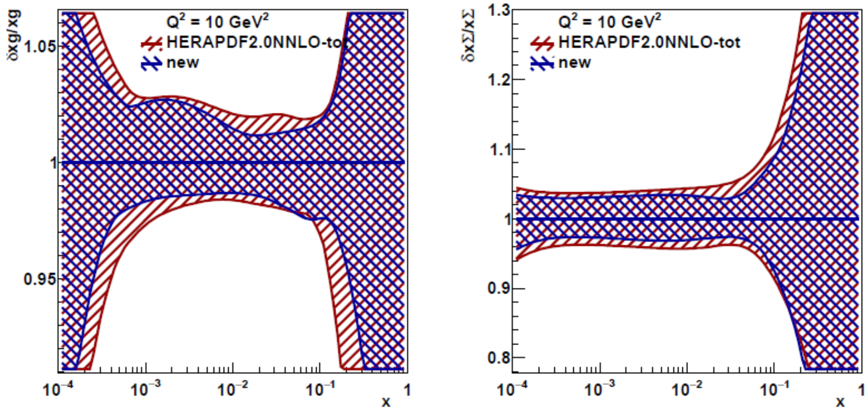
Comparison of total uncertainties NNLOJets/no jets



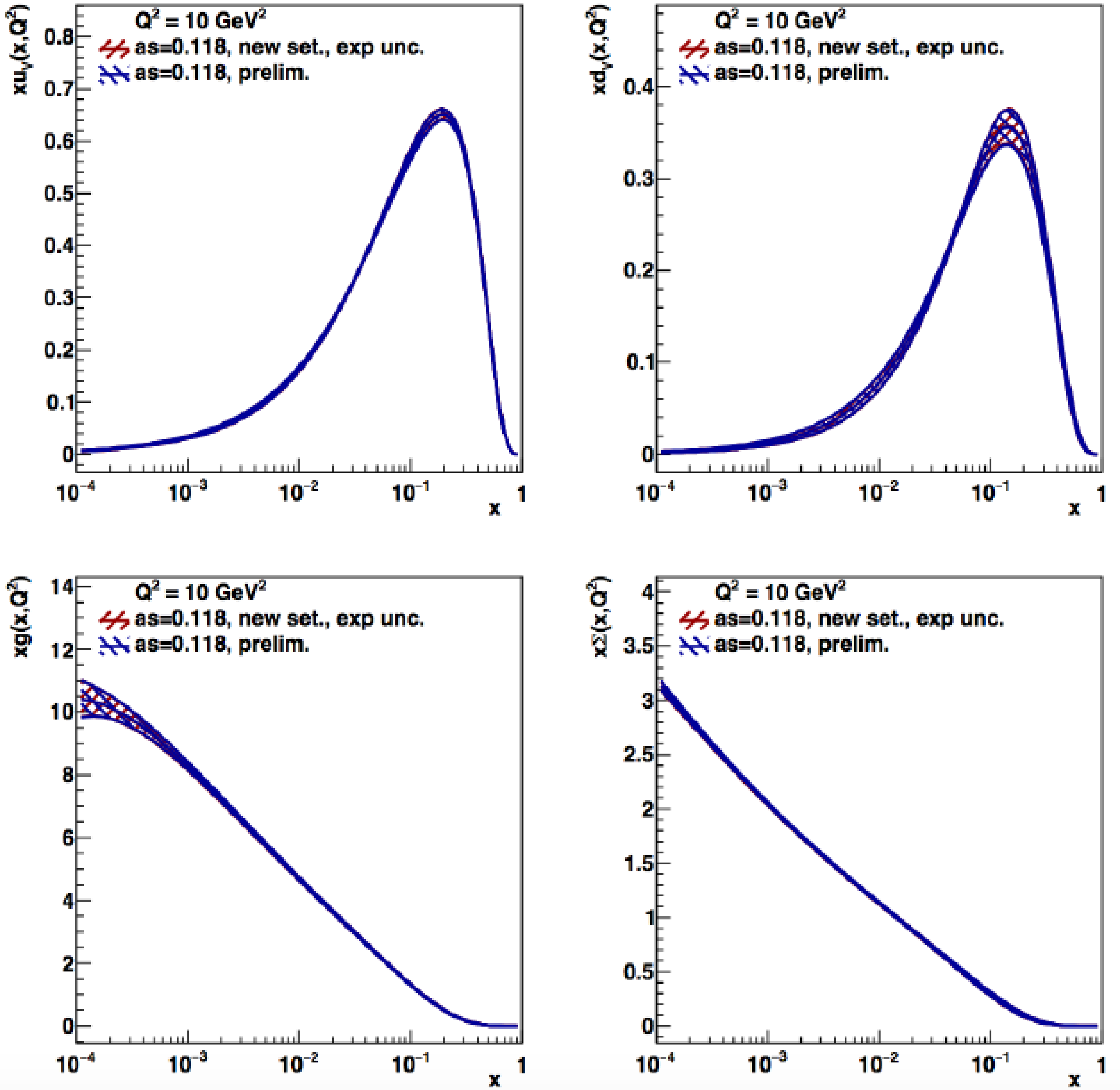
Decrease just in experimental uncertainties NNLO to NNLOJet (at Q2=1.9)



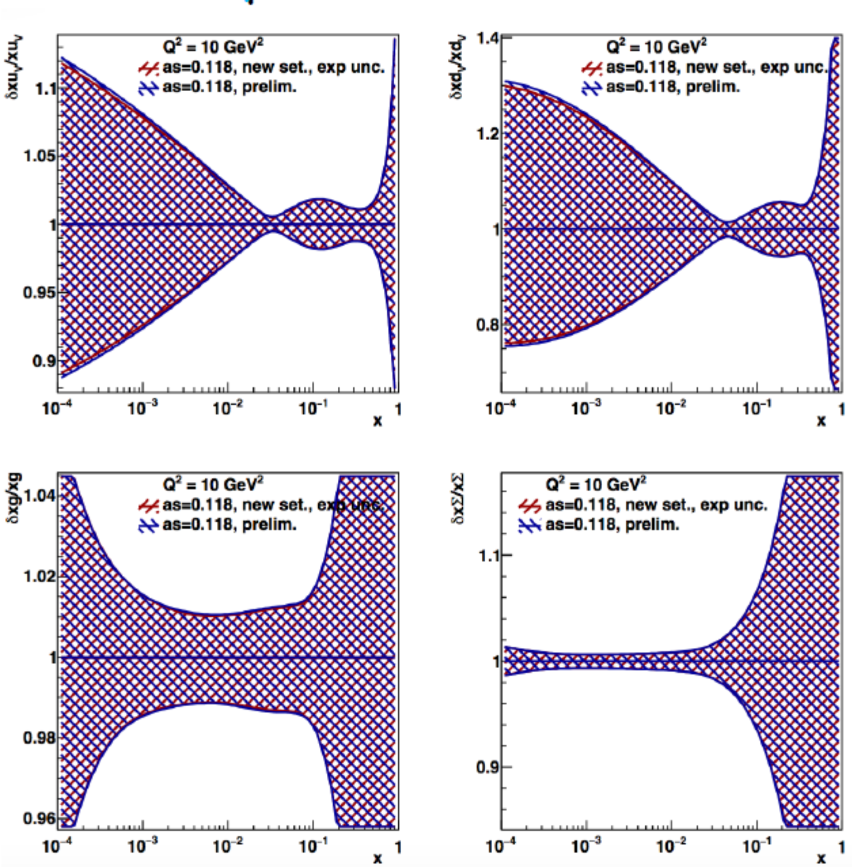
Decrease in total unceratinties NNLO to NNLOjet at Q2=10 (also have it for Q2=1.9 but relative change is not much different



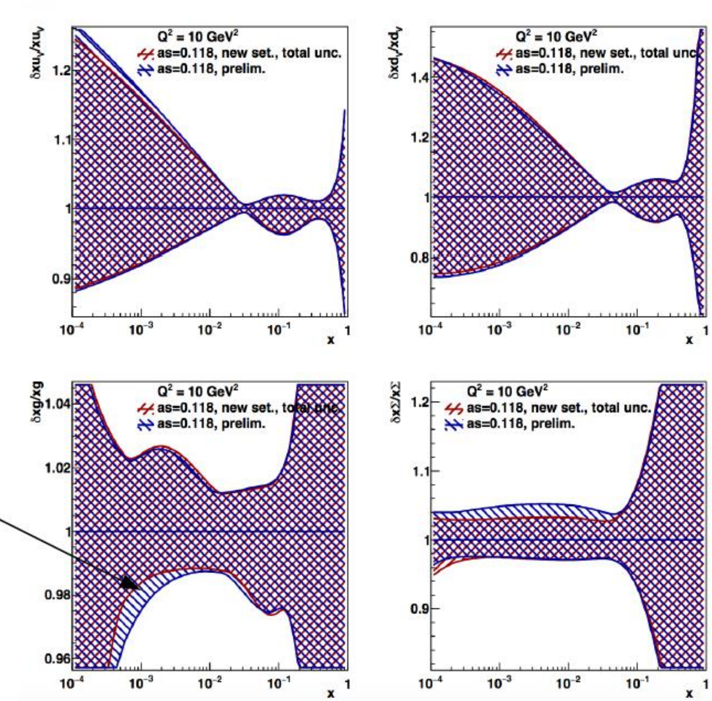
Comparison with preliminary fit



Experimental uncertainties



Total uncertainties



Double counting in preliminary results from varying m_c and Q_0^2 variations simultaneously