HERAPDF2.0 NNLOJets

A M Cooper-Sarkar
on behalf of ZEUS and H1 collaborations
EPS-HEP 2019

Updating HERAPDF2.0Jets with NNLO predictions for jets from NNLOJeT as implemented in the ApplFast system

- New PDFs at NNLO at $\alpha_s(M_Z)$= 0.118 and 0.115
- Because $\alpha_s(M_Z)$ at NNLO is significantly lower than at NLO

- Free $\alpha_s(M_Z)$ fit at NNLO

$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)}{}^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$

Compare the NLO result as published

$\alpha_s(M_Z)=0.1183 \pm 0.0009_{(exp)} \pm 0.0005_{(model/param)} \pm 0.0012_{(had)}{}^{+0.0037}_{-0.0030(scale)}$

Jet Data sets used in the present NNLO analysis

Strong overlap with those used in the NLO analysis

Data Set	published	Q^2[GeV^2] range from	to	$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV	norma-lised	all points	used points
H1 high Q^2 HERA I incl. jets	2007	150	15000	65.4	e^+p	301	yes	24	24
H1 low Q^2 HERA I dijets	2010	5	100	43.5	e^+p	301	no	22	16
H1 high Q^2 HERA II incl. jets	2014	150	15000	351	e^+p/e^-p	319	yes	24	24
H1 high Q^2 HERA II dijets	2014	150	15000	351	e^+p/e^-p	319	yes	24	24
H1 low Q^2 HERA II incl. jets	2016	5	80	290	e^+p/e^-p	319	yes	48	32
H1 low Q^2 HERA II dijets	2016	5	80	290	e^+p/e^-p	319	yes	48	32
ZEUS incl. jets HERA I	2002	125	10000	38.6	e^+p	301	no	30	30
ZEUS dijets HERA I and II	2010	125	20000	374	e^+p/e^-p	318	no	22	16

These data sets are new and were not used in the 2015 NLO analysis

However as well as adding new data sets we have to subtract some data

- Trijets- there are no NNLO predictions
- Data at low scale $\mu = (pt^2 + Q^2) < 13.5$ GeV for which scale variations are large (~25% NLO and ~10% NNLO)
- 6 Dijet data points at low pt for which predictions are unreliable

Further points:

- The new 2016 lowQ^2 jets have some systematic correlations to the older 2014 high Q^2 jets– these are implemented
- All statistical correlation matrices for these jet data sets are implemented by default.

There is a choice of scales to be made for the jets.

Factorisation scale

At NLO we used factorisation scale= Q^2 but this is not a good choice for low Q^2 jets, we have many more low Q^2 jet data points now – from the H1 2016 data- so we move to a choice factorisation scale =(Q^2+pt^2) for all jets- this makes almost no difference to high Q^2 jets

Renormalisation scale

For HERAPDF2.0Jets NLO we chose renormalisation =(Q^2+pt^2)/2

For HERAPDF2.0Jets NNLO jets a choice of renormalisation =(Q^2+pt^2)

Results in a lower χ2, $\Delta\chi$2~ -15

In fact the 'optimal' scale choice for NLO and NNLO is different – if optimal is defined by lower χ2. At NLO $\Delta\chi$2~ -15 for the old scale choice.

We also explore the consequences of scale variation.

The HERAPDF approach uses only HERA combined data

HERAPDF2.0 was based on the new final combination of HERA-I and HERA-II data which supersedes the HERA-I combination and supersedes all previous HERAPDFs

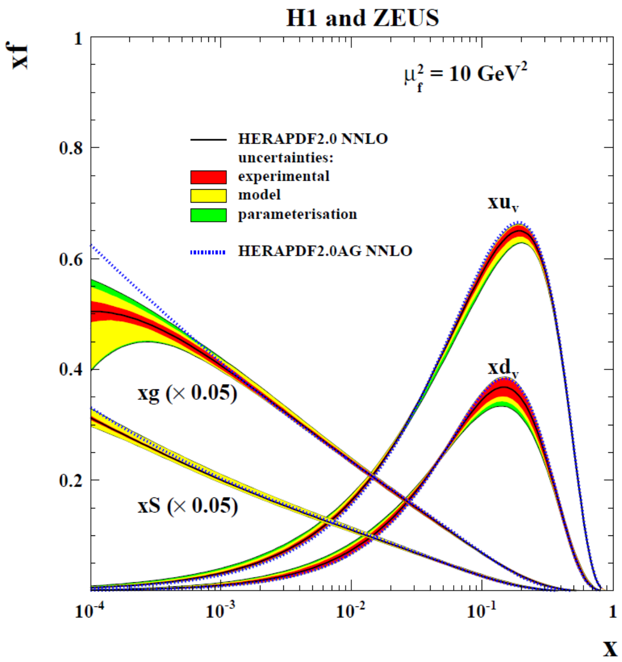
HERAPDF2.0Jets fits add HERA Jet data to this.

All choices of parametrisation, starting scale for evolution, mc, mb, cuts etc are as for the published HERAPDF2.0 (arXIV:1506.06042~)

Experimental
Hessian uncertainties: 14 eigenvector pairs, evaluated with $\Delta\chi 2 = 1$

Model: Variation of input assumptions
Variation of charm mass and beauty mass, Q^2_{min}, strangeness fraction

Parametrisation
Variation of Q^2_0 and addition of 15^{th} parameter(s)



When jets are included we also evaluate a hadronisation uncertainty from offsetting the corrections given for each jet data set

The standard value of $\alpha_s(M_Z)$ for HERAPDF fits is $\alpha_s(M_Z)$ =0.118 but we also perform fits with free $\alpha_s(M_Z)$.
The experimental, model, parametrisation and hadronisation uncertainties are also determined for these fits.
In addition, in fits with free $\alpha_s(M_Z)$ **scale uncertainty** becomes important:

Scale uncertainty is determined from the usual procedure
This was to vary factorisation and renormalisation scales both separately and simultaneously by a factor of two taking the maximal positive and negative deviations. These are assumed to be 50% correlated and 50% uncorrelated.
This gives **scale uncertainty** $^{+0.0026}$ / $_{-0.0027}$ **by far the largest uncertainty.**

To summarise the value of $\alpha_s(M_Z)$ determined from these fits with all uncertainties is:

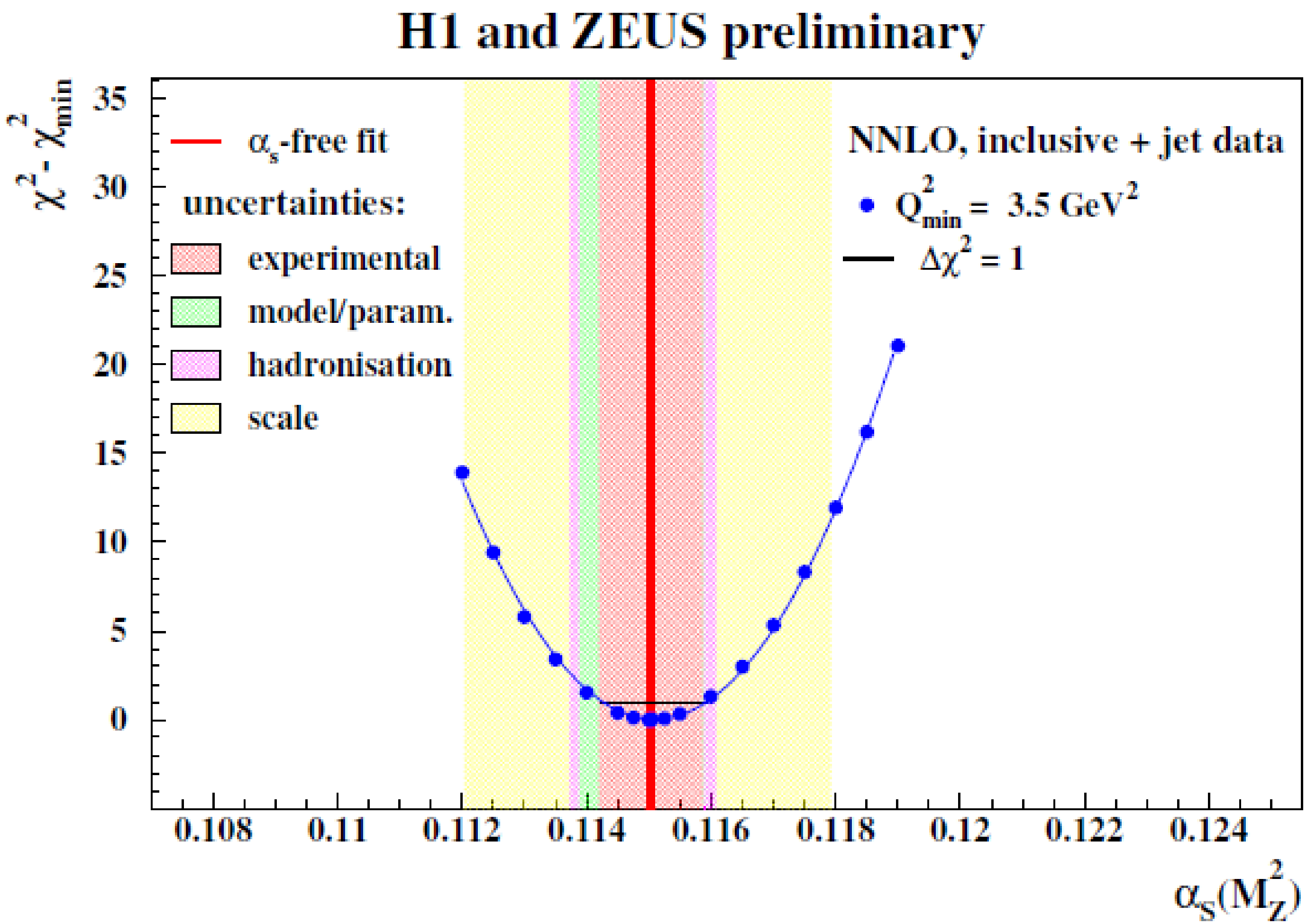
$$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)} \, ^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$$

χ2=1598.5 for free $\alpha_s(M_Z)$ fit, using1343 data points, 1328 degrees of freedom
χ2/d.o.f =1.203

χ2=1601.3 for fixed $\alpha_s(M_Z)$=0.118 fit, using1343 data points, 1329 degrees of freedom
χ2/d.o.f =1.205

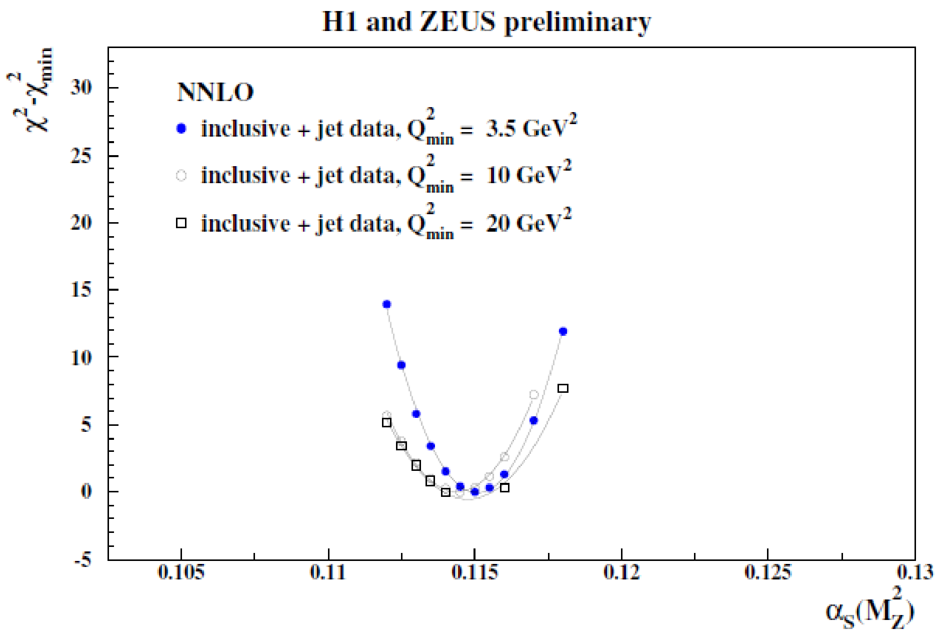
Compare χ2/d.o.f =1.205 for HERAPDF2.0NNLO (with only 1131 degrees of freedom)

The result for $\alpha_s(M_Z)$ from the fit is compared with fits made scanning the $\chi 2$ w.r.t fixed values of $\alpha_s(M_Z)$.



$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)}\ ^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$

Since it is well known that HERA data at low x and Q^2 may be subject to the need for ln(1/x) resummation or higher twist effects we also perform scans with Q^2 cuts



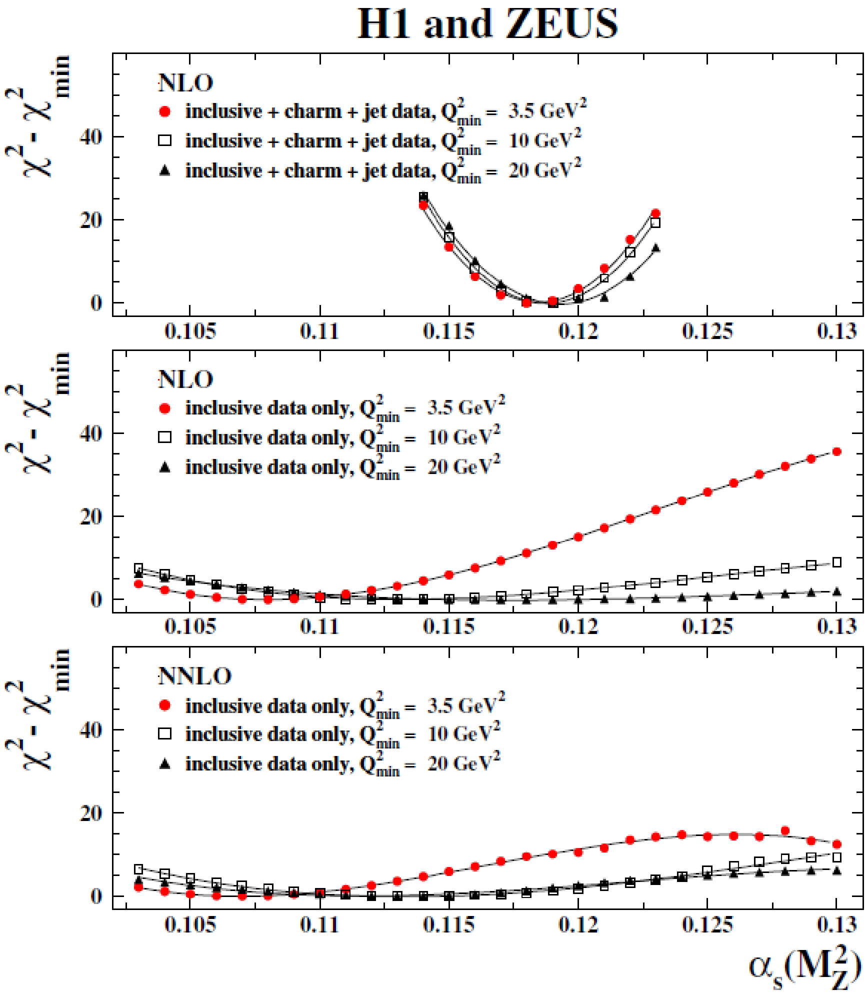
The Q2 cuts do not result in any significant change to the value of $\alpha_s(M_Z)$ that is determined

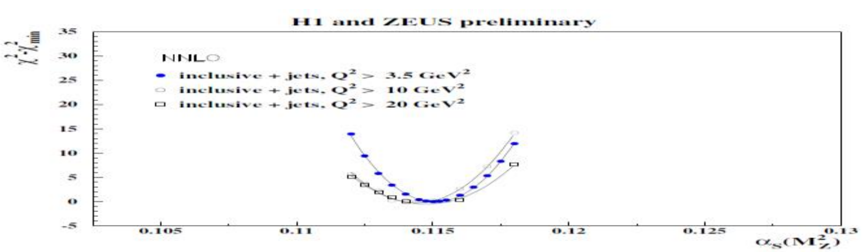
The central values from the three scans are:

$\alpha_s(M_Z) = 0.1150 \pm 0.0008$ Q^2>3.5 GeV^2

$\alpha_s(M_Z) = 0.1144 \pm 0.0010$ Q^2>10 GeV^2

$\alpha_s(M_Z) = 0.1148 \pm 0.0010$ Q^2>20 GeV^2





These scans over the NNLO inclusive +jet data are compared to the published scans done at NLO and to the corresponding scans using only inclusive data.

There is a similar level of accuracy at NNLo and NLO and $\alpha_s(M_Z)$ clearly moves lower at NNLO –

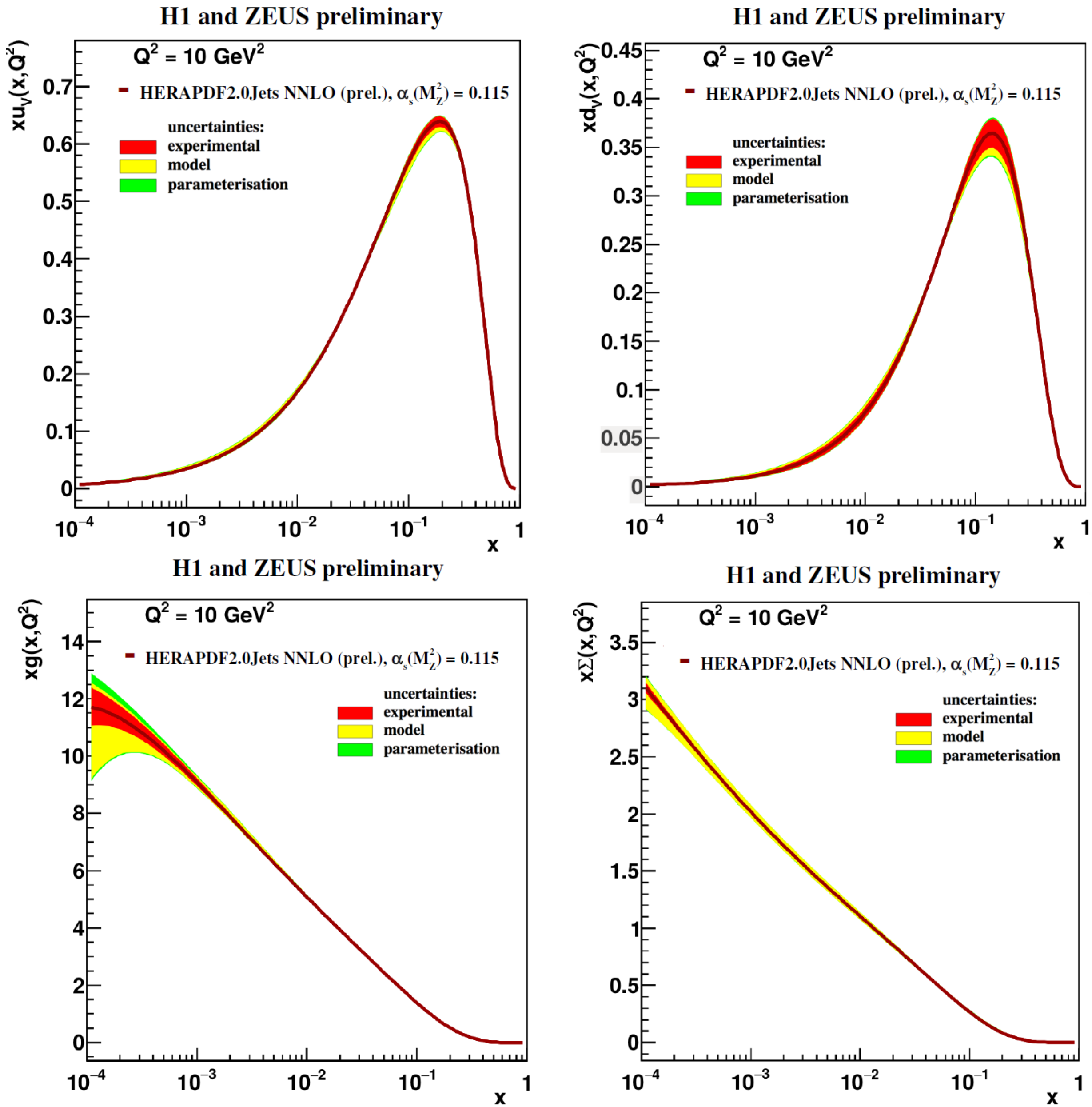
But note we are using a different scale now– our scale uncertainty studies show that with the old scale choice used at NLO the NNLO result would be even lower ~ $\alpha_s(M_Z)$ =0.1135.
So this is a systematic shift.

The NNLO result is:
$\alpha_s(M_Z)$=0.1150 ± 0.0008$_{(exp)}$ $^{+0.0002}_{-0.0005}$$_{(model/param)}$ ± 0.0006 $_{(had)}$ ± 0.0027 $_{(scale)}$

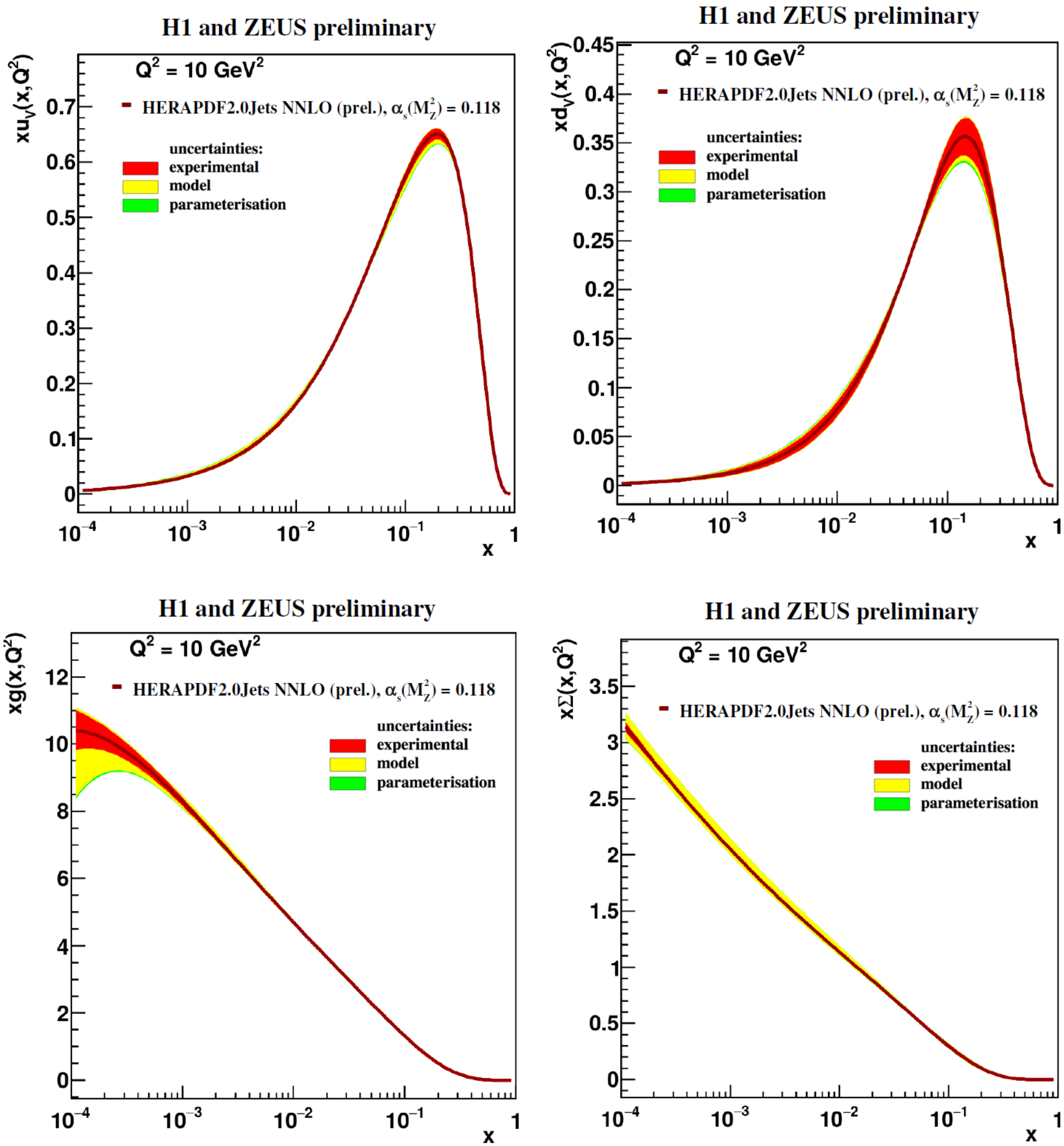
Compare the NLO result
$\alpha_s(M_Z)$=0.1183 ± 0.0009$_{(exp)}$± 0.0005 $_{(model/param)}$ ± 0.0012 $_{(had)}$ $^{+0.0037}_{-0.0030}$$_{(scale)}$

Now for the PDFs

$\alpha_s(M_Z) = 0.115$

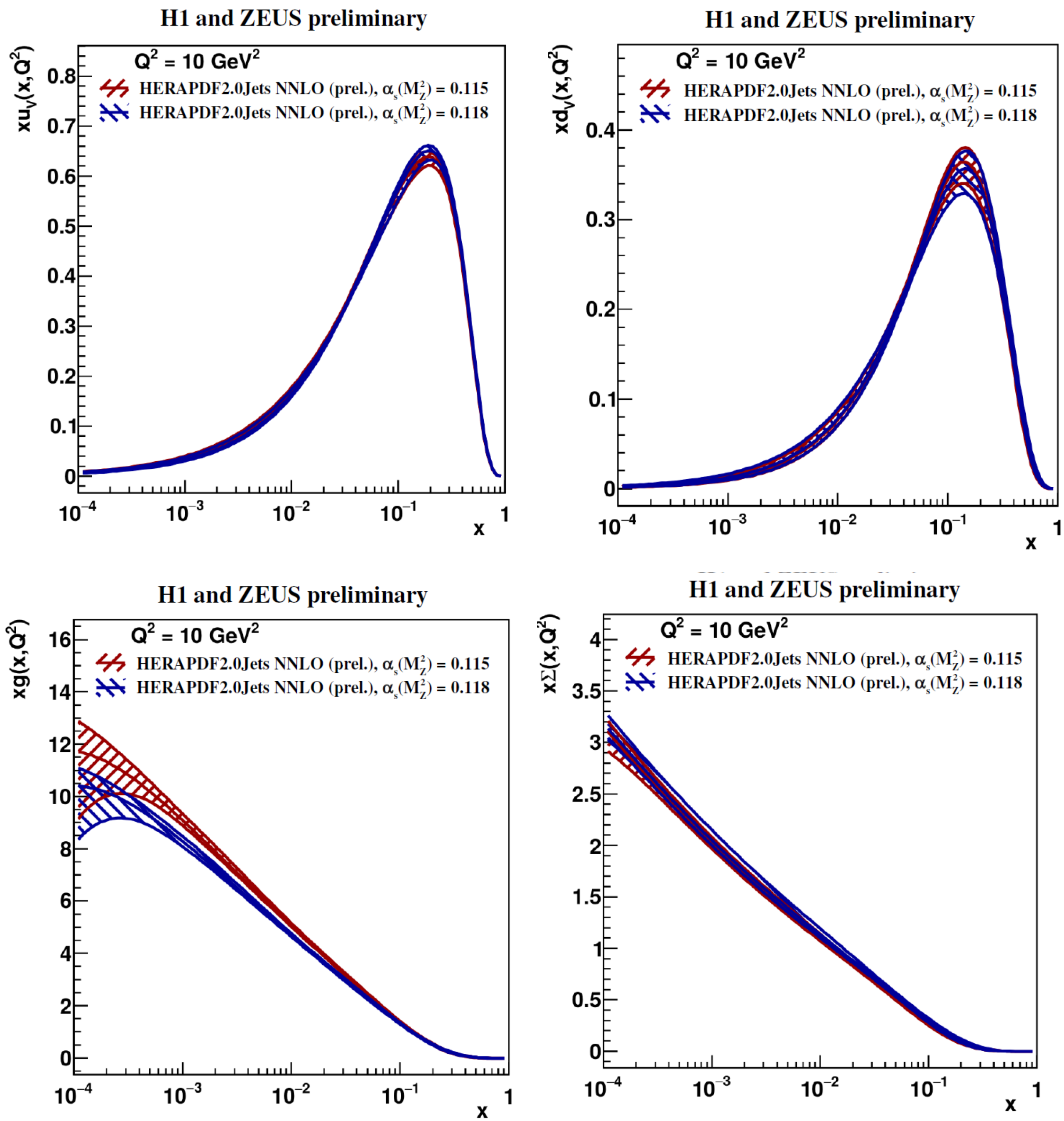


$\alpha_s(M_Z)$ =0.118

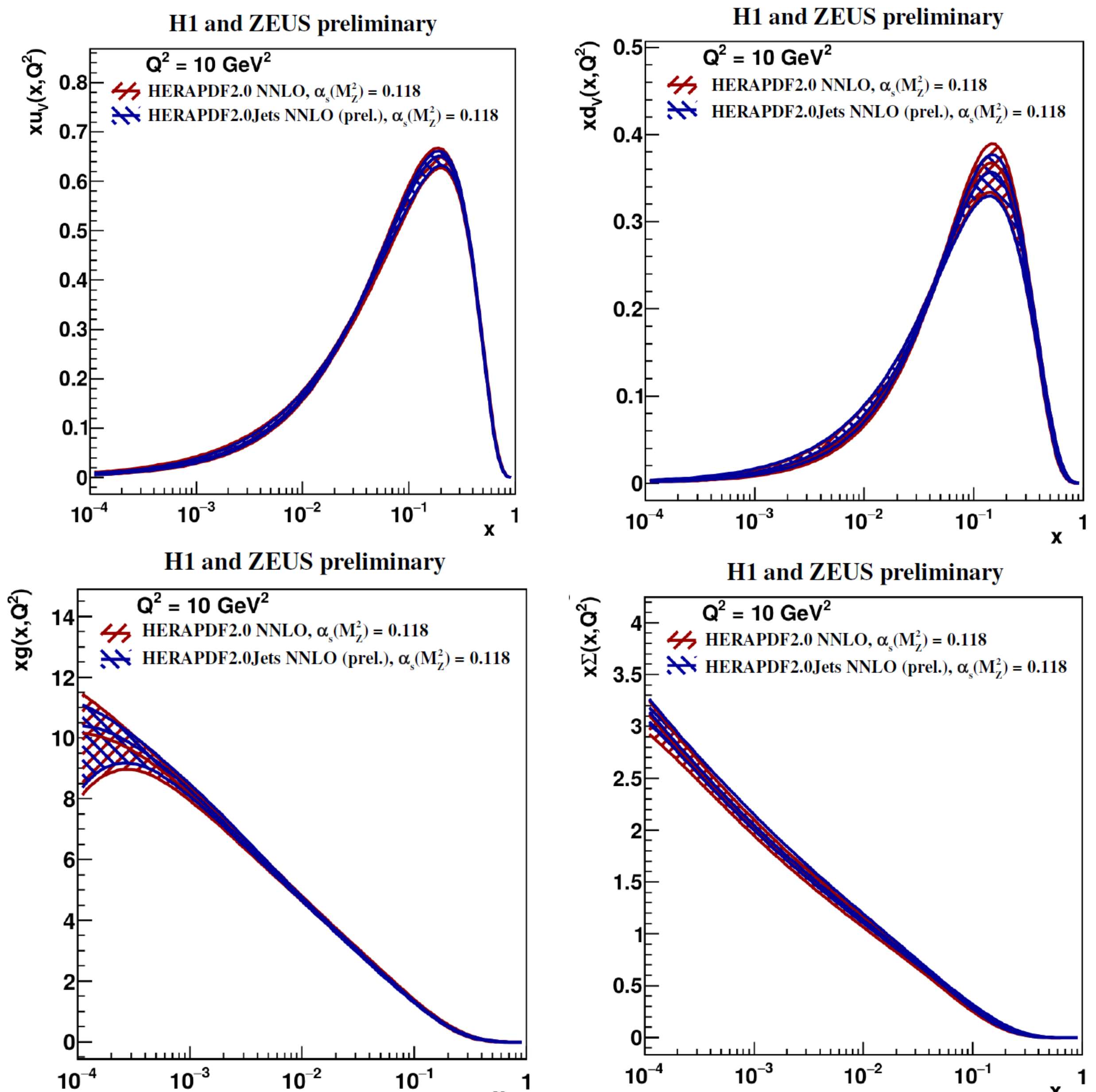


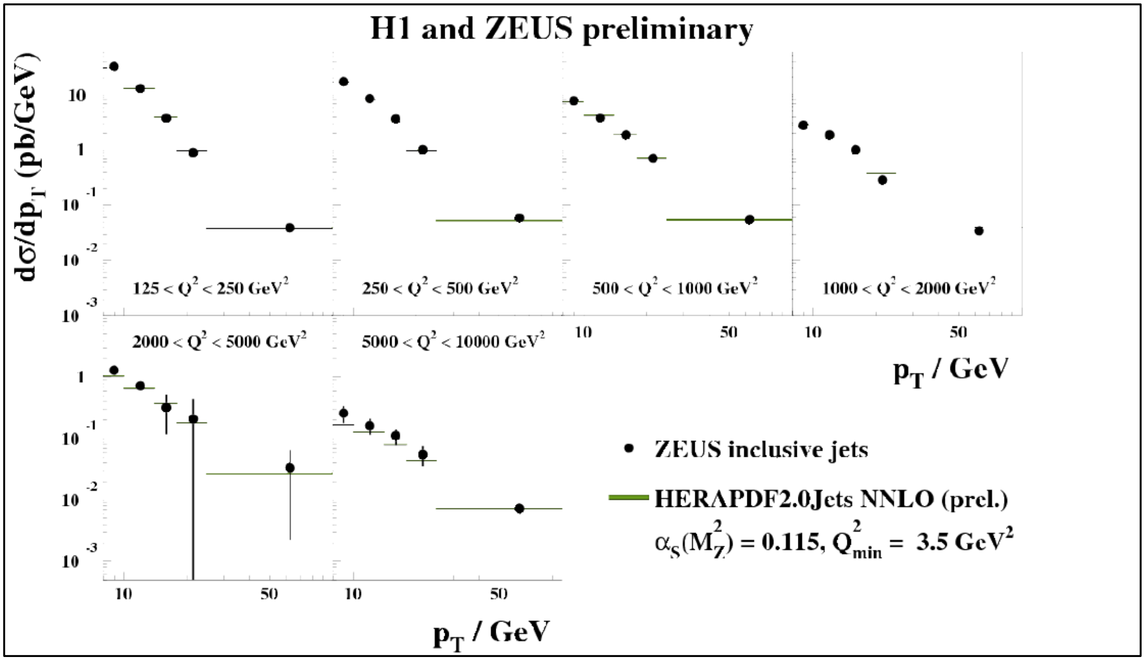
NOW compare PDFs for

$\alpha_s(M_Z)$ =0.115 and
$\alpha_s(M_Z)$ =0.118



Now compare HERAPDF2.0 NNLO and HERAPDF2.0Jets NNLO both with $\alpha_s(M_Z)$ =0.118

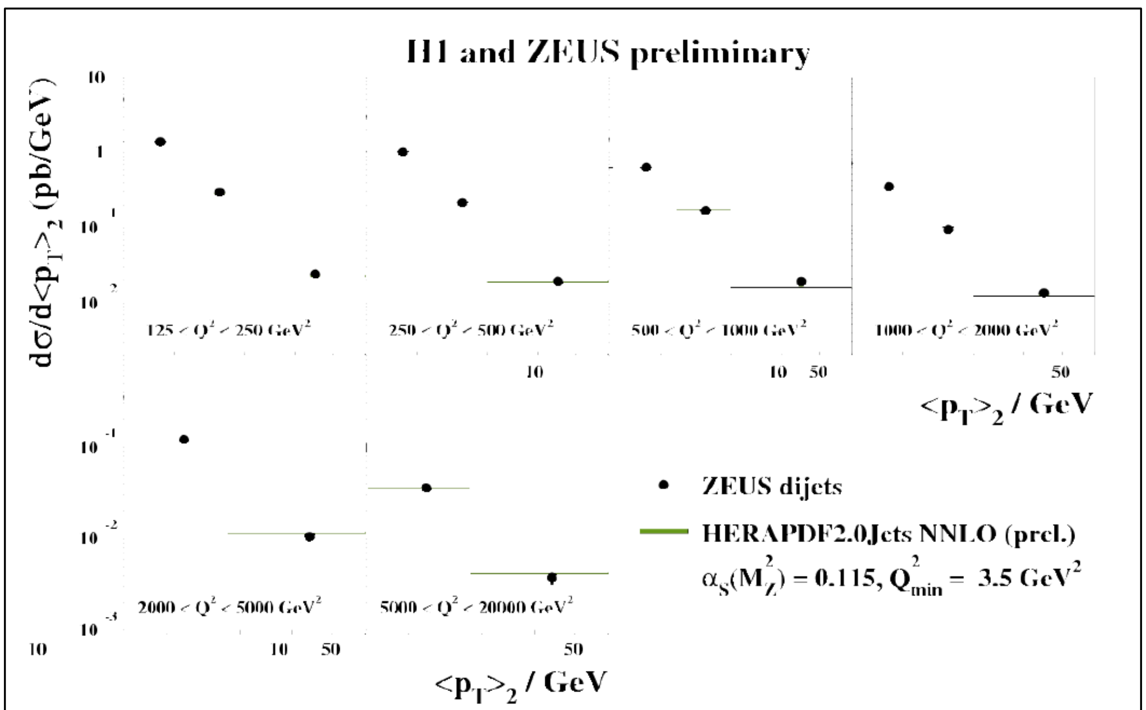




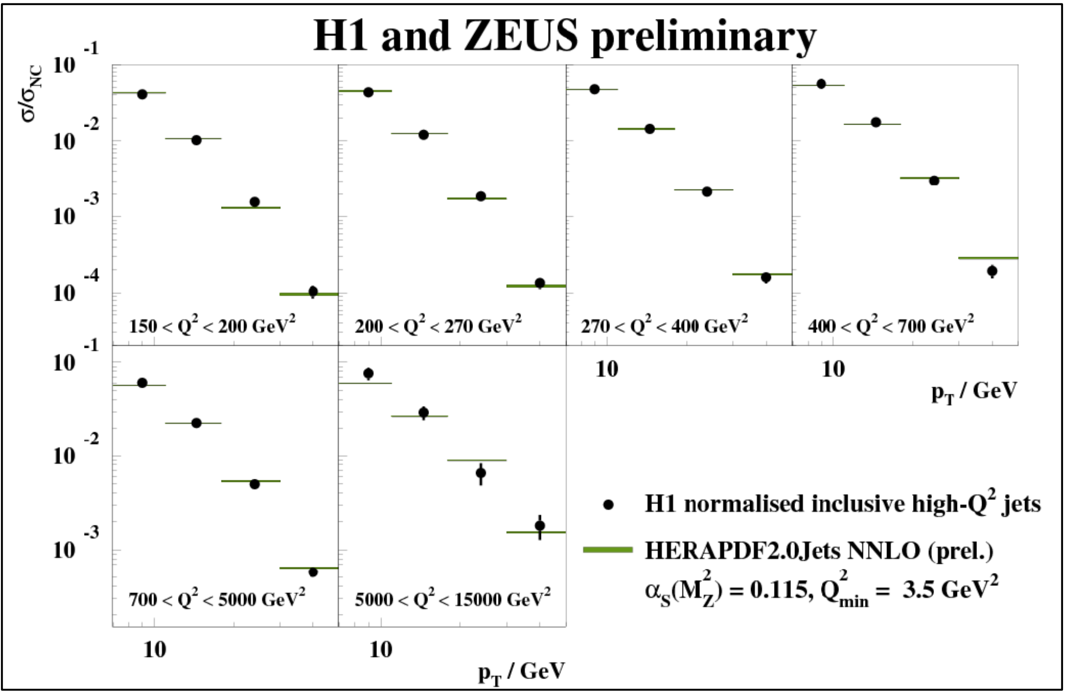
Now compare the NNLO fit with $\alpha_s(M_Z)$=0.115 to the jet data

Since this is a short talk these comparisons are only shown for a subset of data

Here the ZEUS inclusive and dijet data

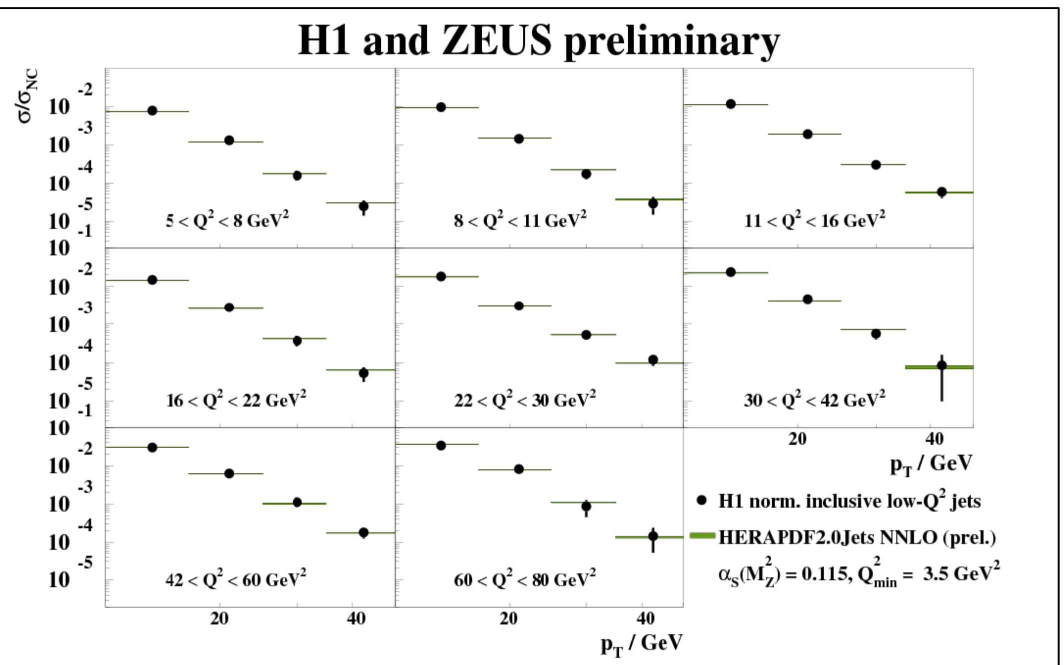


Now compare the NNLO fit with $\alpha_s(M_Z)$=0.115 to the jet data



Here the H1 inclusive normalised high Q2 jets from HERA-II
And the H1 inclusive normalised low Q2 jets from HERA-II

Other jet data sets in back-up



Conclusions

We have completed the HERAPDF2.0 family by performing an NNLO fit including jet data

This results in two new PDF sets:

HERAPDF2.0JetsNNLO $\alpha_s(M_Z)$ =0.118 – the PDG value

HERAPDF2.0JetsNNLO $\alpha_s(M_Z)$ =0.115 – The value favoured by our own fit

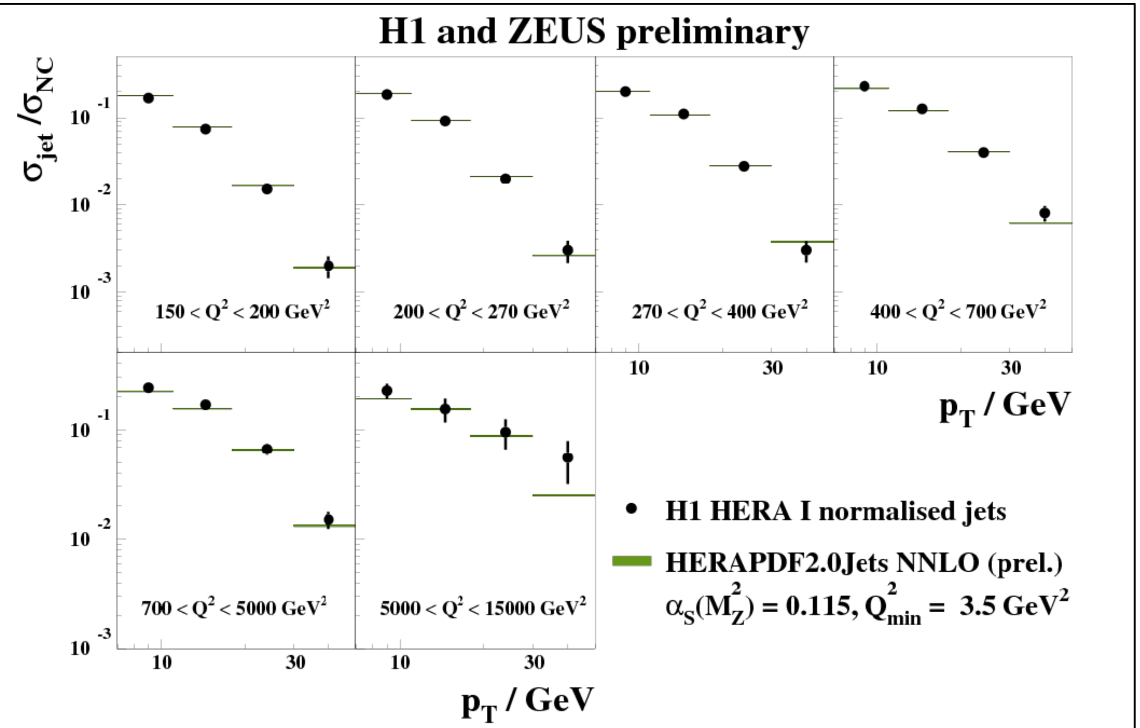
The NNLO value is

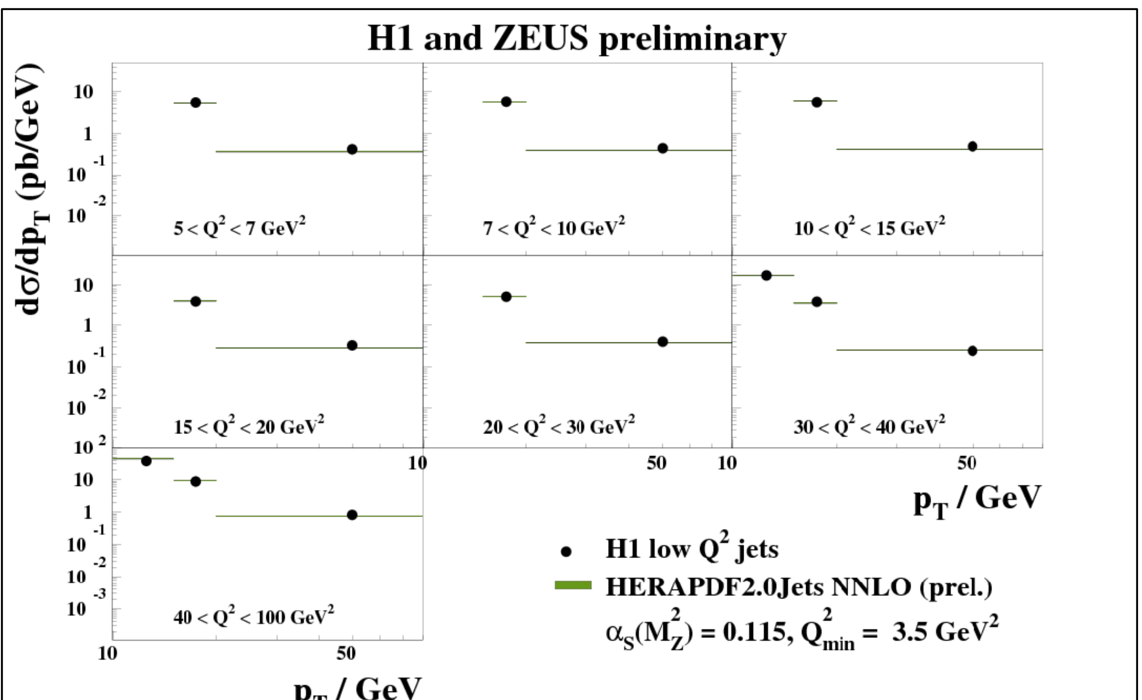
$$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)}\,{}^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$$

Compare the NLO result

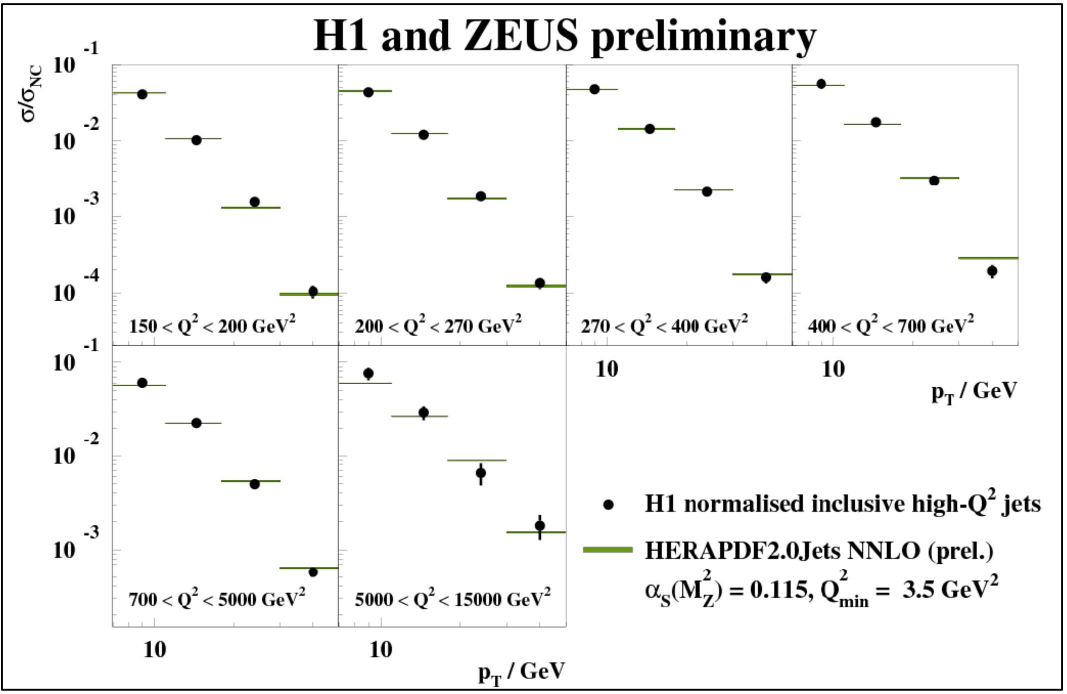
$$\alpha_s(M_Z)=0.1183 \pm 0.0009_{(exp)} \pm 0.0005_{(model/param)} \pm 0.0012_{(had)}\,{}^{+0.0037}_{-0.0030(scale)}$$

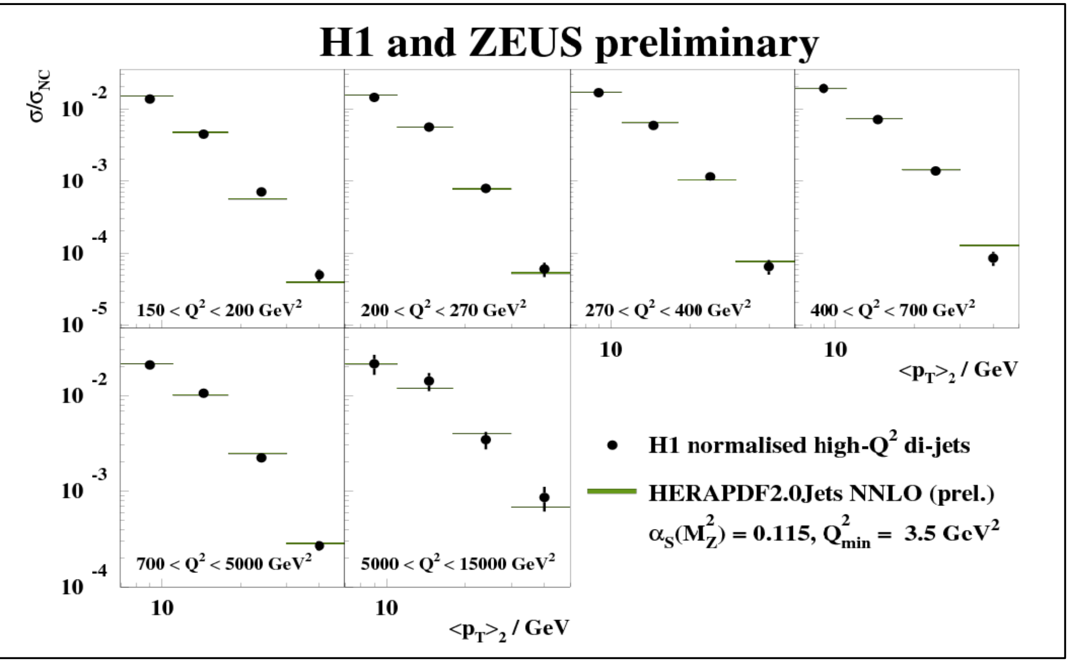
There is a systematic shift downwards at NNLO even taking scale variation into account





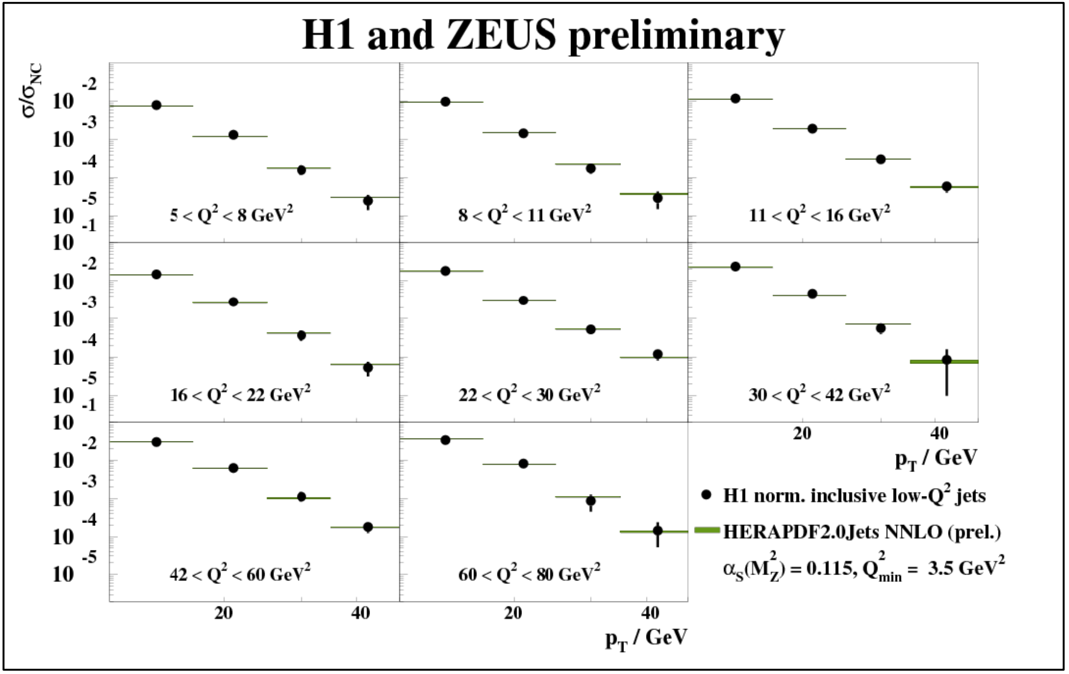
Now compare the NNLO fit with $\alpha_s(M_Z)$=0.115 to the jet data

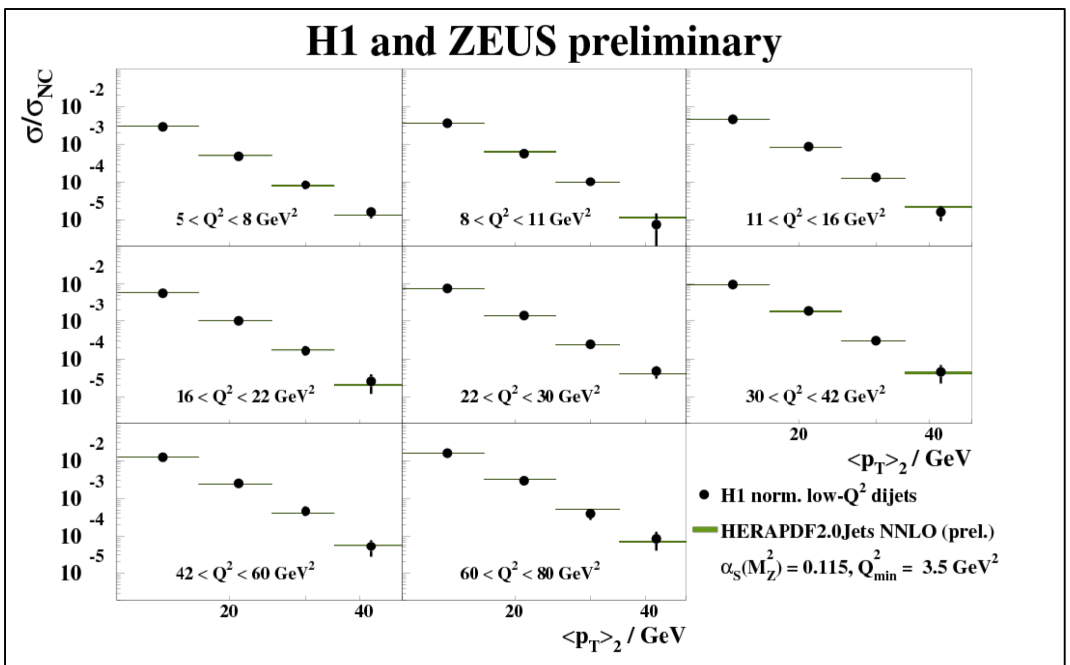


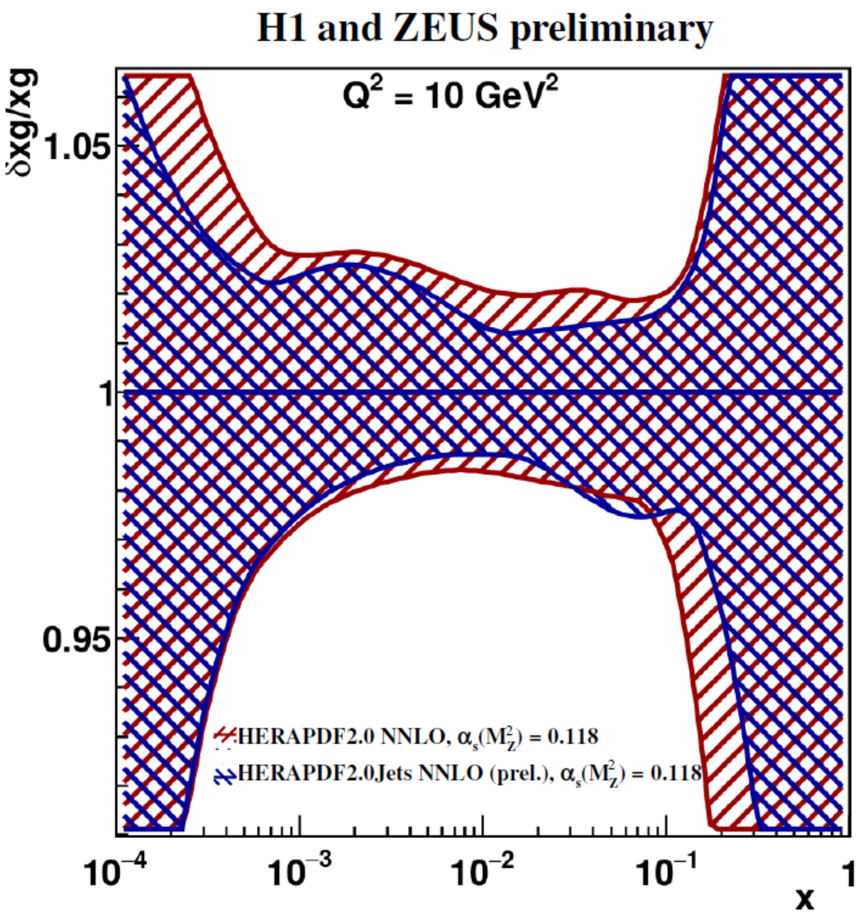


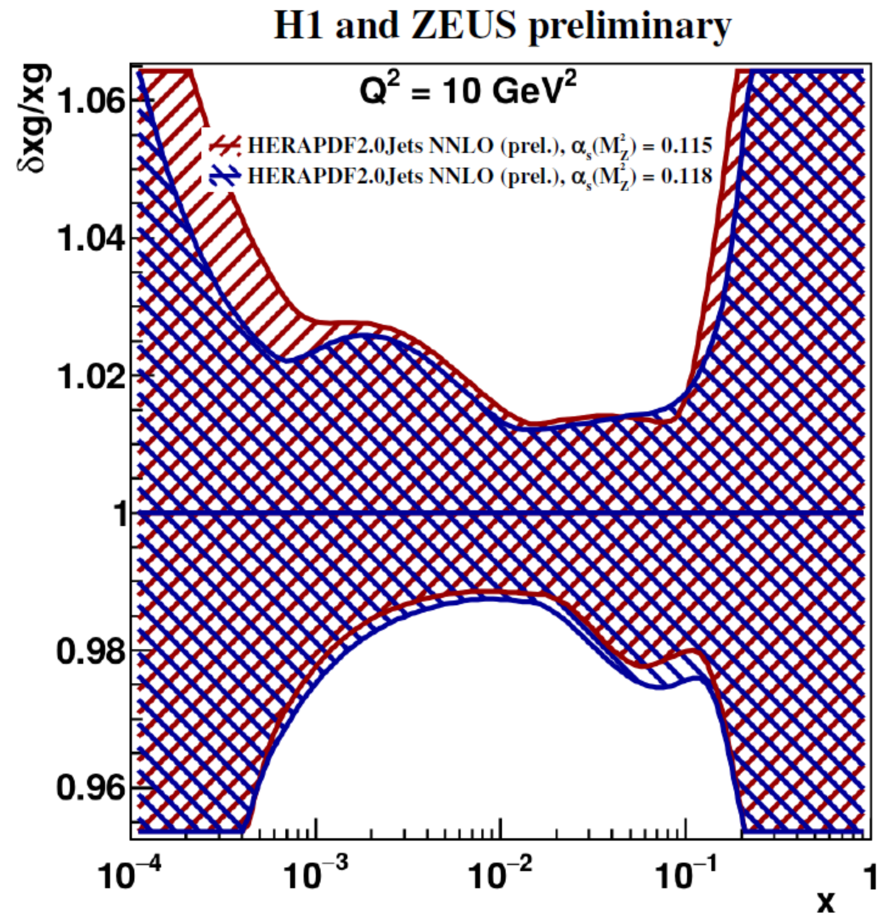
Now compare the NNLO fit with $\alpha_s(M_Z)$=0.115 to the jet data

Now compare the NNLO fit with $\alpha_s(M_Z)$=0.115 to the jet data






H1 and ZEUS preliminary
Q^2 = 10 GeV^2
δxg/xg
1.05
1
0.95
HERAPDF2.0 NNLO, $\alpha_s(M_Z^2)$ = 0.118
HERAPDF2.0Jets NNLO (prel.), $\alpha_s(M_Z^2)$ = 0.118
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x


H1 and ZEUS preliminary
Q^2 = 10 GeV^2
δxg/xg
1.06
1.04
1.02
1
0.98
0.96
HERAPDF2.0Jets NNLO (prel.), $\alpha_s(M_Z^2)$ = 0.115
HERAPDF2.0Jets NNLO (prel.), $\alpha_s(M_Z^2)$ = 0.118
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x