HERAPDF2.0Jets and estimation of $\alpha_s(M_Z)$ @ NNLO

EPJ C 82, 243 (2022)
arXiv:2112.01120

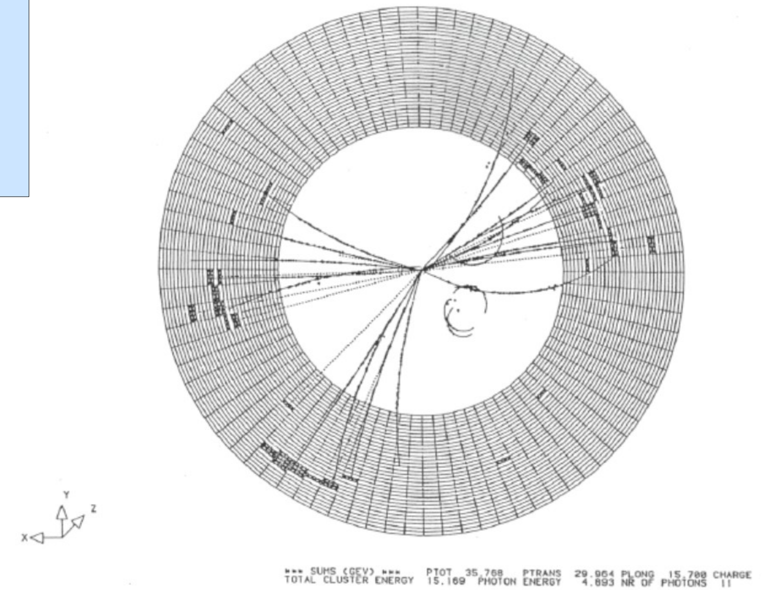
K. Wichmann @REF22

Jets produced @ DESY for over 40 years

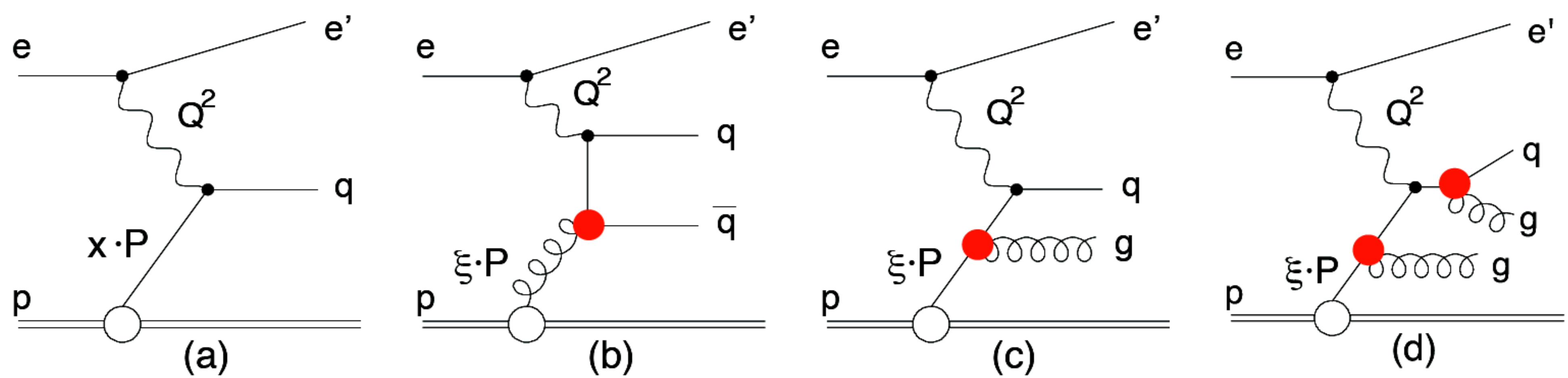
At HERA direct information on gluon and $\alpha_s(M_Z)$ comes from jet production

→ Possible simultaneous determination of parton densities and $\alpha_s(M_Z)$

Jets at PETRA, 1979



Jets at HERA

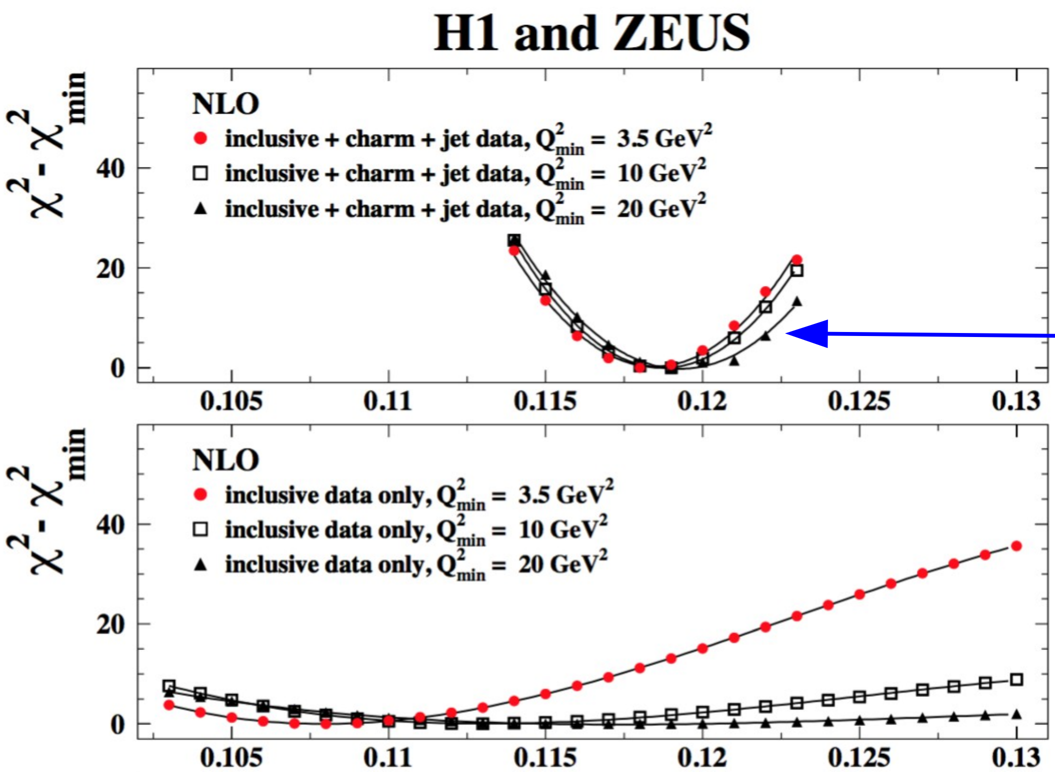


elweak coupling $\propto \alpha_S$ $\propto \alpha_S$ $\propto \alpha_S^2$

dijets trijets

K. Wichmann @ REF22 NNLO jets @ HERA

Why study jets @ HERA?



- HERA inclusive data carry little information on $\alpha_s(M_Z)$
- Jet data sensitive to $\alpha_s(M_Z)$

New NNLO calculations for HERA ep jet production available now

- Implemented in FastNLO and APPLEGRID → fast cross section calculation possible

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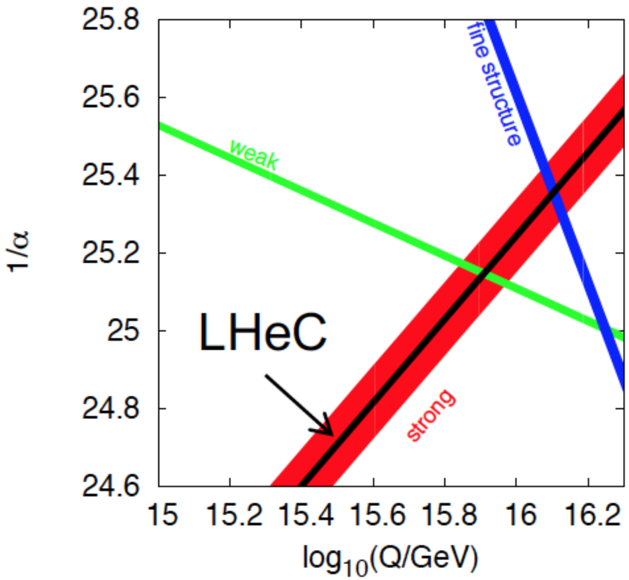
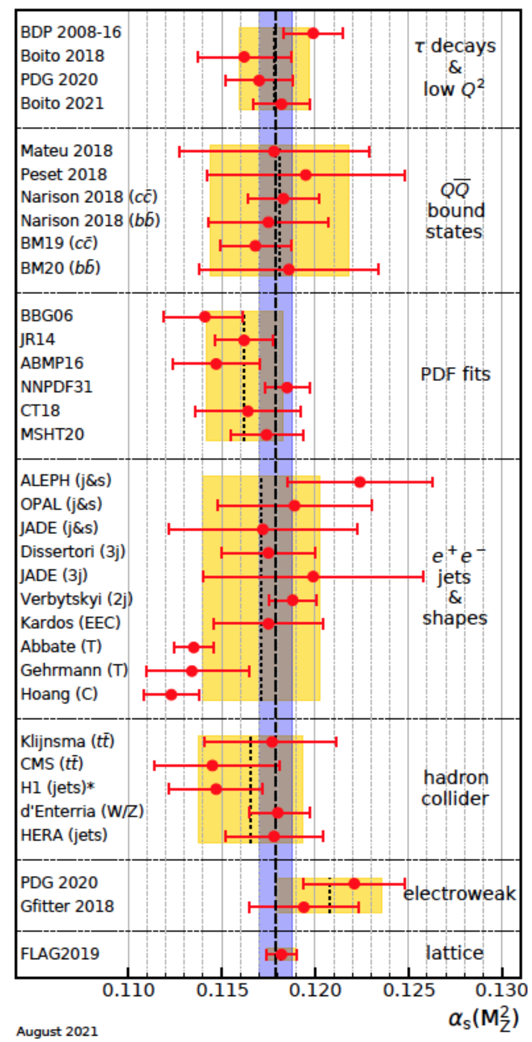
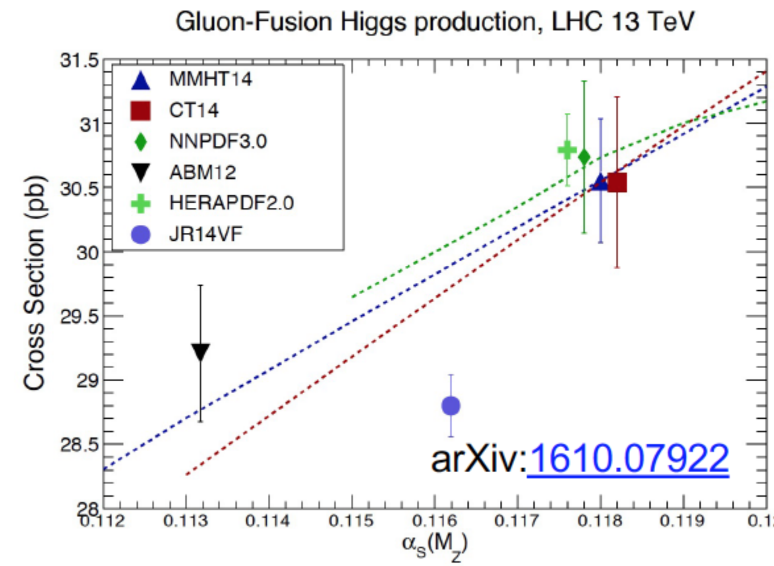
→ Possible simultaneous determination of PDFs and $\alpha_s(M_Z)$ at NNLO

motivation and impact at LHC







- **α_s** is least known coupling constant;

  needed to constrain GUT scenarios; cross section predictions, including Higgs; …

- **PDFs** and/or **α_s** limit: precision SM and Higgs measurements, BSM searches, …

PDG21: α_s = 0.1175 ± 0.0010 (w/o lattice)

- what is true α_s central value and uncertainty?

  new precise determinations have important role to play

HERAPDF2.0 parameterisation

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

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

- 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

Updates in the procedure

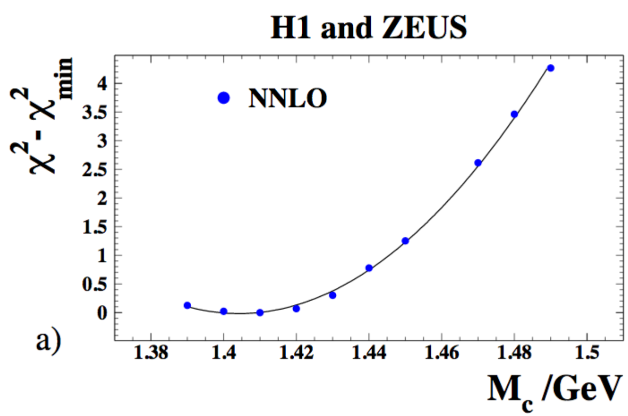
- scale choice changes:
- factorisation: $\mu F^2=(Q^2+pt^2)$
- cf. $\mu F^2=Q^2$ in previous NLO analysis; updated since not a good choice for low Q^2 jet data; change makes almost no difference for high Q^2 jets
- renormalisation: $\mu R^2=(Q^2+pt^2)$
- cf. $\mu R^2=(Q^2+pt^2)/2$ in previous NLO analysis
- NNLO fit with $\mu R^2=(Q^2+pt^2)$ gives $\Delta X^2=$ **–15** cf. $\mu R^2=(Q^2+pt^2)/2$ and vice versa for NLO fit
- scale uncertainties treated as completely correlated between bins and datasets

† pt denotes pt^{jet} in the case of inclusive jet cross sections and <pt> for dijets

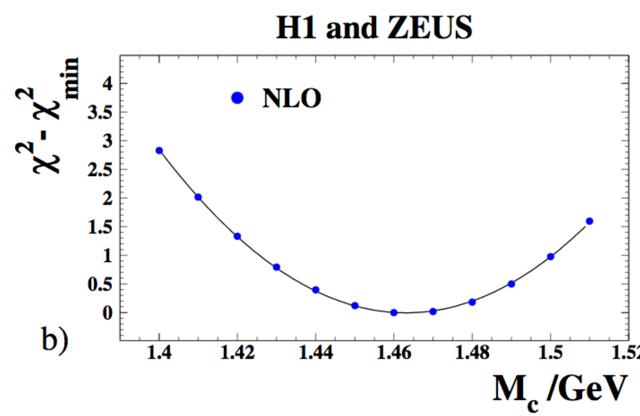
- improved treatment of hadronisation uncertainties; NOW included together with exp. systematics; treated as ½ correlated, ½ uncorrelated between bins and datasets
- (small) uncertainties on theory predictions included

Estimation of charm & beauty masses

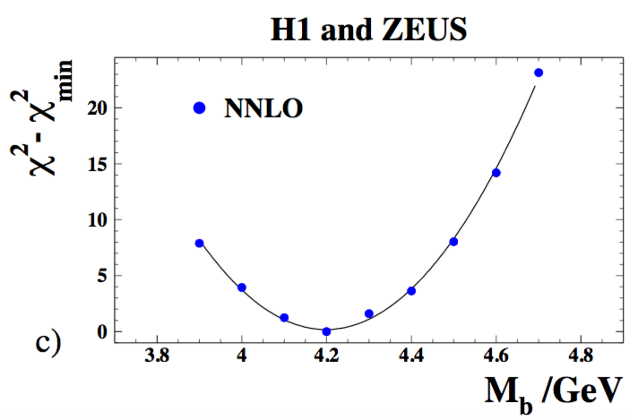
- new HERA combined charm and beauty data: EPJ C78 (2018), 473
  → updated estimation of M_c and M_b
  → Heavy Quark (HQ) coefficient functions evaluated using Thorne-Roberts Optimised Variable Flavour Number Scheme



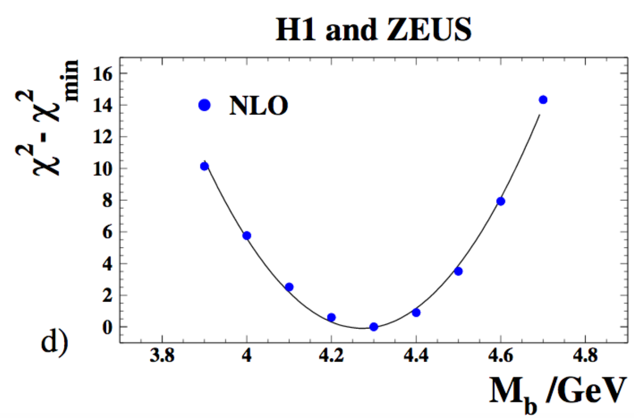
M_c = 1.41 +- 0.04



M_c = 1.46 +- 0.04



M_b = 4.2 +- 0.1



M_b = 4.3 +- 0.1

HERA jet data used in PDF fit

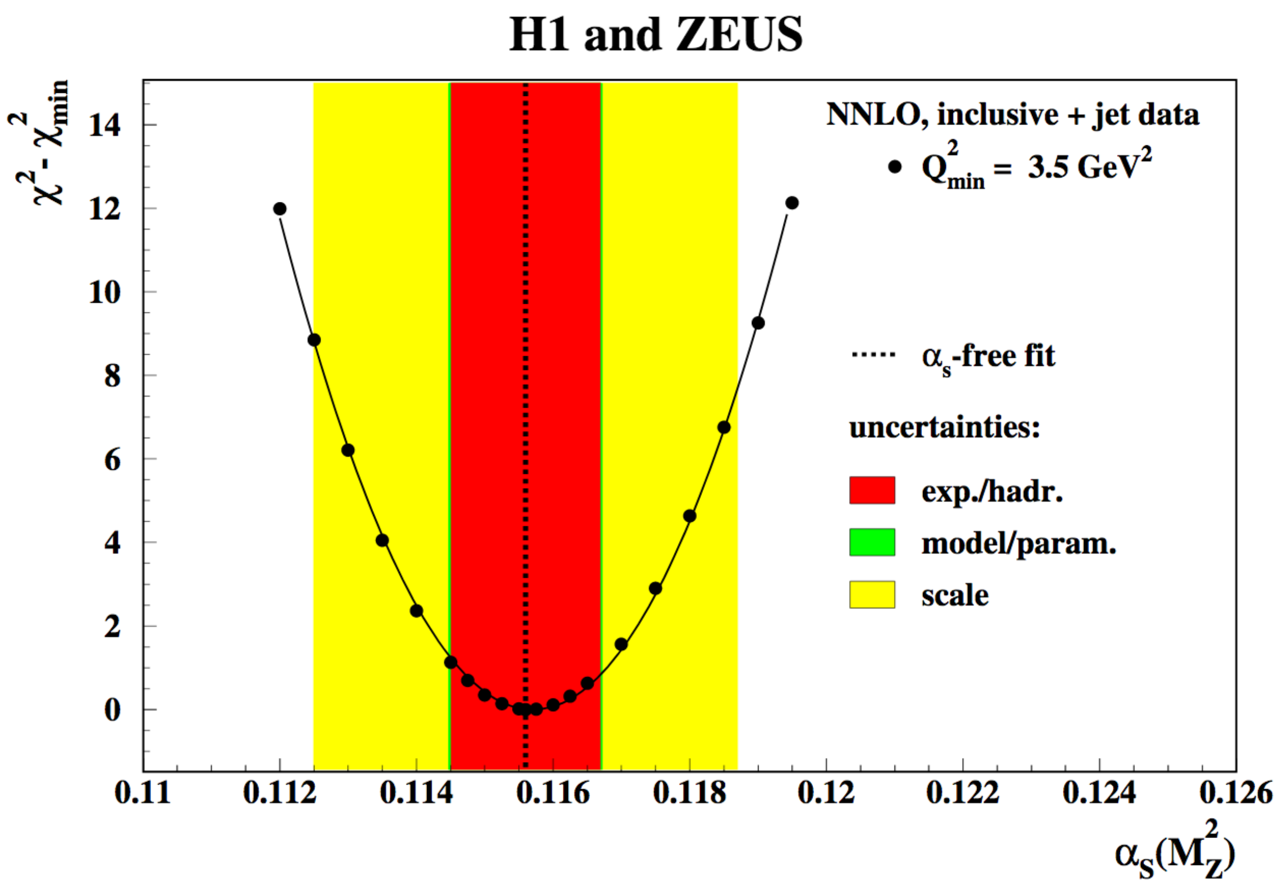
- Inclusive jets and dijets icluded
- Trijets from HERAPDF2Jets NLO excluded → no NNLO predictions
- H1 low Q^2 data added – particularly sensitive to $\alpha_s(M_Z)$
- Some data points excluded due theory limitations
  - Data at low scale μ = (pt2 +Q2) < 10 GeV → scale variations are large (~25% NLO and ~10% NNLO)
  - 6 ZEUS Dijet data points at low ptfor which predictions are not truly NNLO

Data set	taken from – to	Q^2[GeV^2] range from	to	$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV	Normalised	All points	Used points
H1 HERA I normalised jets	1999 – 2000	150	15000	65.4	e^+p	319	yes	24	24
H1 HERA I jets at low Q^2	1999 – 2000	5	100	43.5	e^+p	319	no	28	20
H1 normalised inclusive jets at high Q^2	2003 – 2007	150	15000	351	e^+p/e^-p	319	yes	30	30
H1 normalised dijets at high Q^2	2003 – 2007	150	15000	351	e^+p/e^-p	319	yes	24	24
H1 normalised inclusive jets at low Q^2	2005 – 2007	5.5	80	290	e^+p/e^-p	319	yes	48	37
H1 normalised dijets at low Q^2	2005 – 2007	5.5	80	290	e^+p/e^-p	319	yes	48	37
ZEUS inclusive jets	1996 – 1997	125	10000	38.6	e^+p	301	no	30	30
ZEUS dijets 1998 –2000 &	2004 – 2007	125	20000	374	e^+p/e^-p	318	no	22	16

- Possibilities for PDF fit with jet data
  - With fixed $\alpha_s(M_Z)$
  - With free $\alpha_s(M_Z)$ or doing $\alpha_s(M_Z)$ scan → $\alpha_s(M_Z)$ value

α_s @ NNLO from HERA jets

- $\alpha_s(M_Z)$ determined with experimental, model, param. and hadr. uncertainties
- In fits with free $\alpha_s(M_Z)$ scale uncertainty important → calculated as 100% correlated between bins and data sets

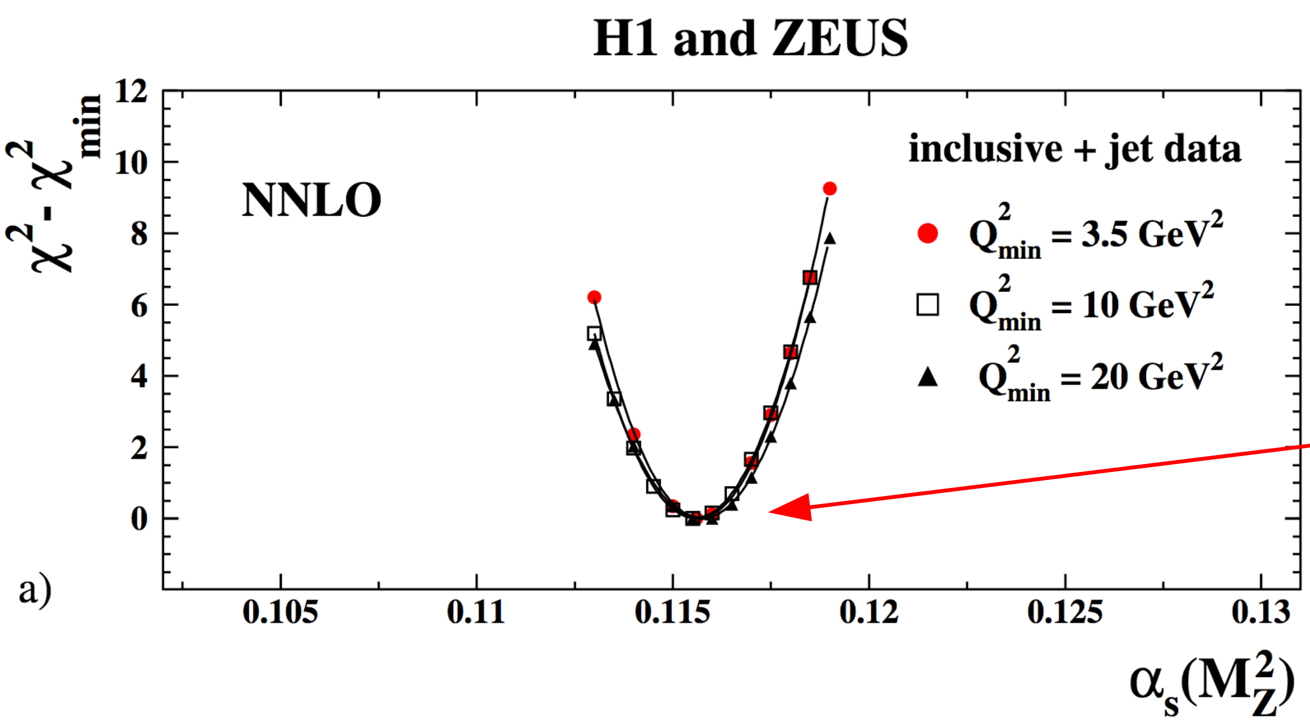


$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\,(\text{exp})\ ^{+0.0001}_{-0.0002}\,(\text{model + parameterisation}) \pm 0.0029\,(\text{scale})$$

Checking robustness of results

- HERA data at low x and Q^2 may be subject to need for ln(1/x) resummation or higher twist effects (eg arXiv:1506.06042, 1710.05935)

→ χ^2 scans performed with harder Q^2 cuts

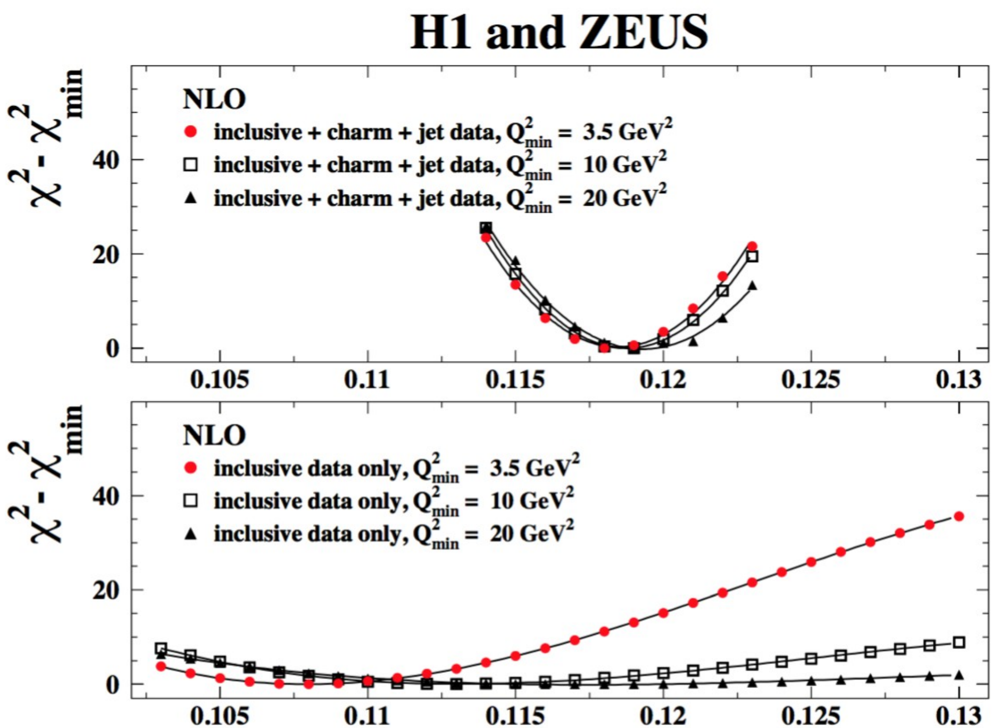


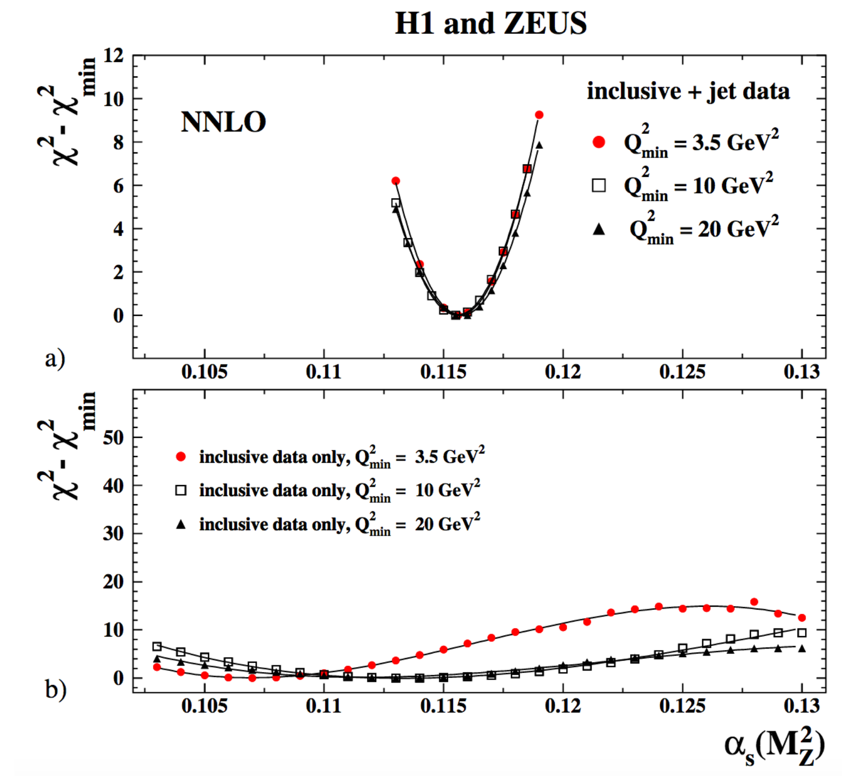
Q^2 cuts do not result in any significant change to the value of $\alpha_s(M_Z)$

- Alternative parameterisations checked
  - No negative gluon term and no NG but additional Dg parameter
    → both give the same result
    → consistent with nominal

$$\alpha_s(M_Z^2) = 0.1151 \pm 0.0010\ (\text{exp})$$

Completing NLO picture





- Similar behavior and level of precision at NLO and NNLO
- However direct comparison of 2015 and 2022 results not possible
  → different scale choice and slightly different jet data sets

- After unifying (details in backup)

αs(Mz) = 0.1186 ± 0.0014 (exp) **NLO**
αs(Mz) = 0.1144 ± 0.0013 (exp) **NNLO**

Comparison to other HERAPDF2.0 fits

- For previous NLO results scale uncertainty applied as 50% correlated and 50% uncorrelated between bins and data sets (due to inclusion of HQ and trijet data)
- Using the precious procedure at NNLO:

NNLO

$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\,(\text{exp})\ {}^{+0.0001}_{-0.0002}\,(\text{model + parameterisation})$$

$$\pm 0.0022$$

HERAPDF2.0Jets NLO

$$\alpha_s(M_Z^2) = 0.1183 \pm 0.0009(\text{exp}) \pm 0.0005(\text{model/parameterisation}) \pm 0.0012(\text{hadronisation})\ {}^{+0.0037}_{-0.0030}(\text{scale})\,.$$

Scale uncertainties reduced
→ as expected for NNLO calculations

comparison to other HERA DIS results

1. **H1** NNLO jet study using fixed PDFs, includes H1 inclusive-jet and di-jet:

H1 jets	$\mu > 2m_b$	$0.1170\ (9)_{\rm exp}\ (7)_{\rm had}\ (5)_{\rm PDF}\ (4)_{{\rm PDF}\alpha_s}\ (2)_{\rm PDFset}\ (38)_{\rm scale}$

with similar breakup of uncertainties and similar μ, new HERA result:

$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\,(\text{exp+had+PDF})\ ^{+0.0001}_{-0.0002}\,(\text{model + parameterisation})\ \pm 0.0029\,(\text{scale})$$

H1 also provided a **PDF+αs** fit to H1 inclusive and jet data

$$0.1147\,(11)_{\rm exp,NP,PDF}\ (2)_{\rm mod}\ (3)_{\rm par}\ (23)_{\rm scale}$$

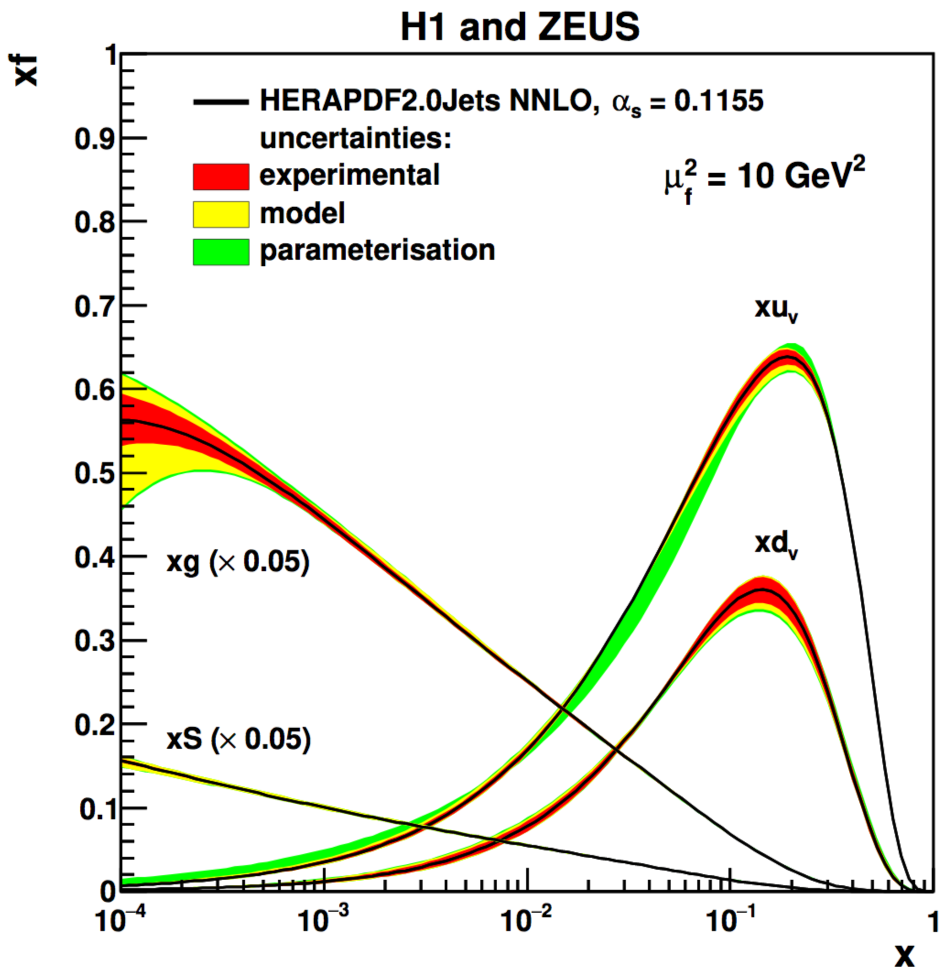
analysis required $Q^2 >$ **10**GeV^2; NEW HERA result re-evaluated with this cut (rather than >**3.5**GeV^2), is:

$$\alpha_s(M_Z^2) = \boxed{0.1156} \pm 0.0011\,(\text{exp}) \pm 0.0002\,(\text{model + parameterisation}) \pm \boxed{0.0021\,(\text{scale})}$$

2. **NNLOJet+APPLfast** using fixed PDFs, includes H1+ZEUS inclusive-jet:

HERA inclusive jets	$\mu > 2m_b$	$0.1171\ (9)_{\rm exp}\ (5)_{\rm had}\ (4)_{\rm PDF}\ (3)_{{\rm PDF}\alpha_s}\ (2)_{\rm PDFset}\ (33)_{\rm scale}$

Fit with fixed α_s = 0.1155



- **Experimental uncertainties:**
  - Hessian method
  - Conventional $\Delta\chi^2 = 1 \rightarrow 68\%$ CL

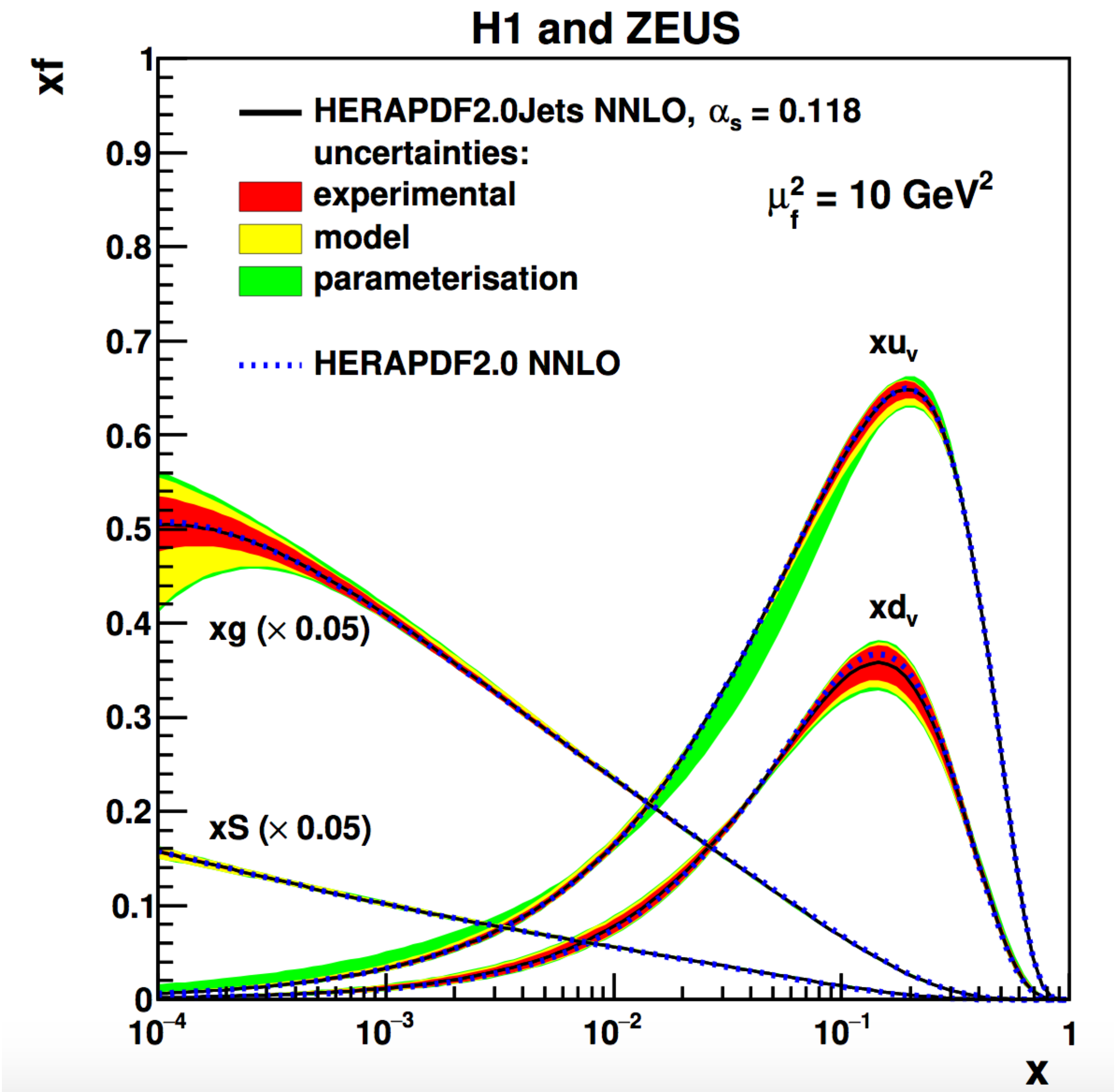
Parameter	Central value	Downwards variation	Upwards variation
Q^2_{min} [GeV^2]	3.5	2.5	5.0
f_s	0.4	0.3	0.5
M_c [GeV]	1.41	1.37*	1.45
M_b [GeV]	4.20	4.10	4.30
μ^2_{f0} [GeV^2]	1.9	1.6	2.2*

Adding D and E parameters to each PDF

- **Parametrisation uncertainties**
  - largest deviation
- **Model uncertainties**
  - all variations added in quadrature

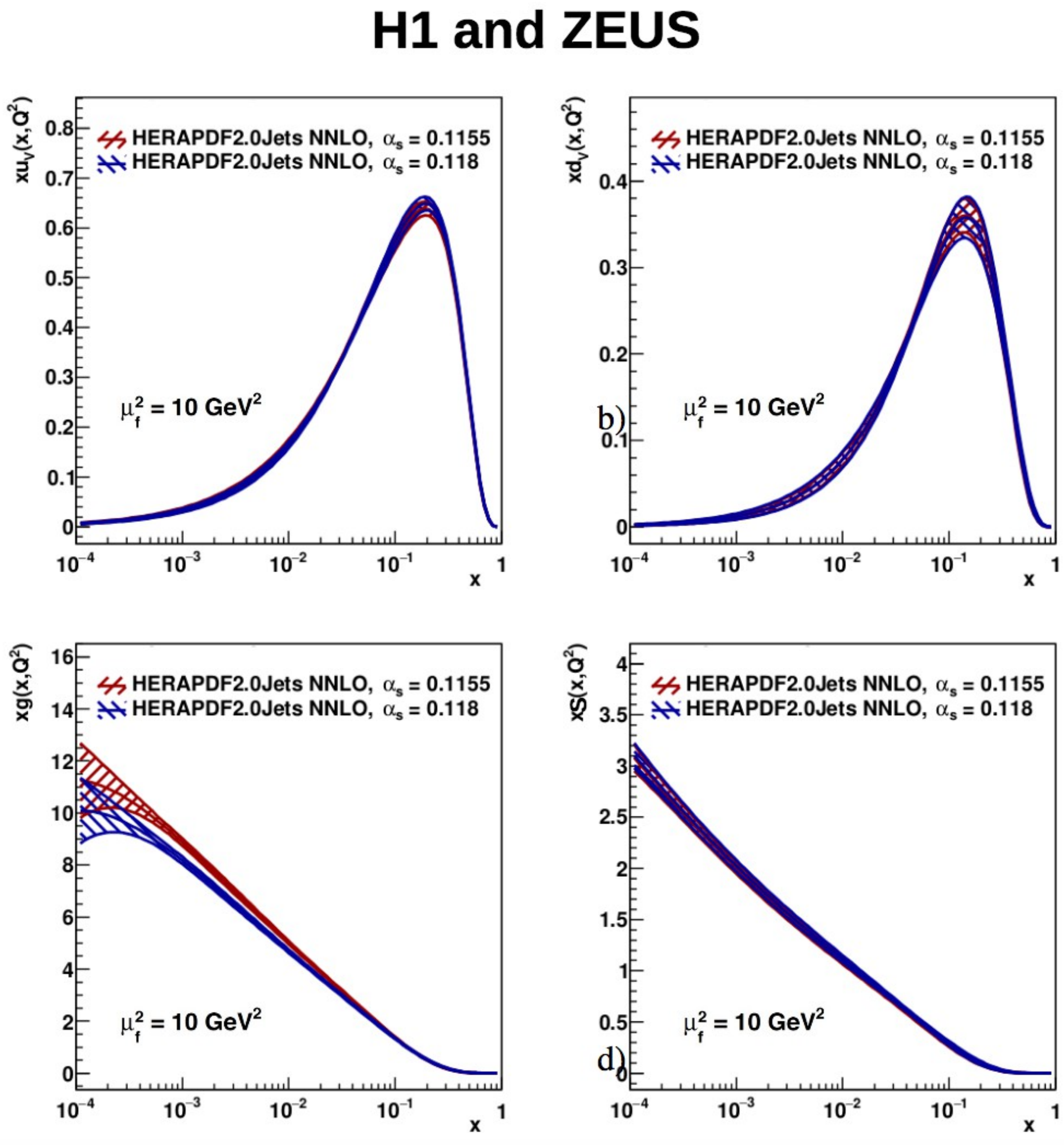
Fit with fixed $\alpha_s = 0.118$

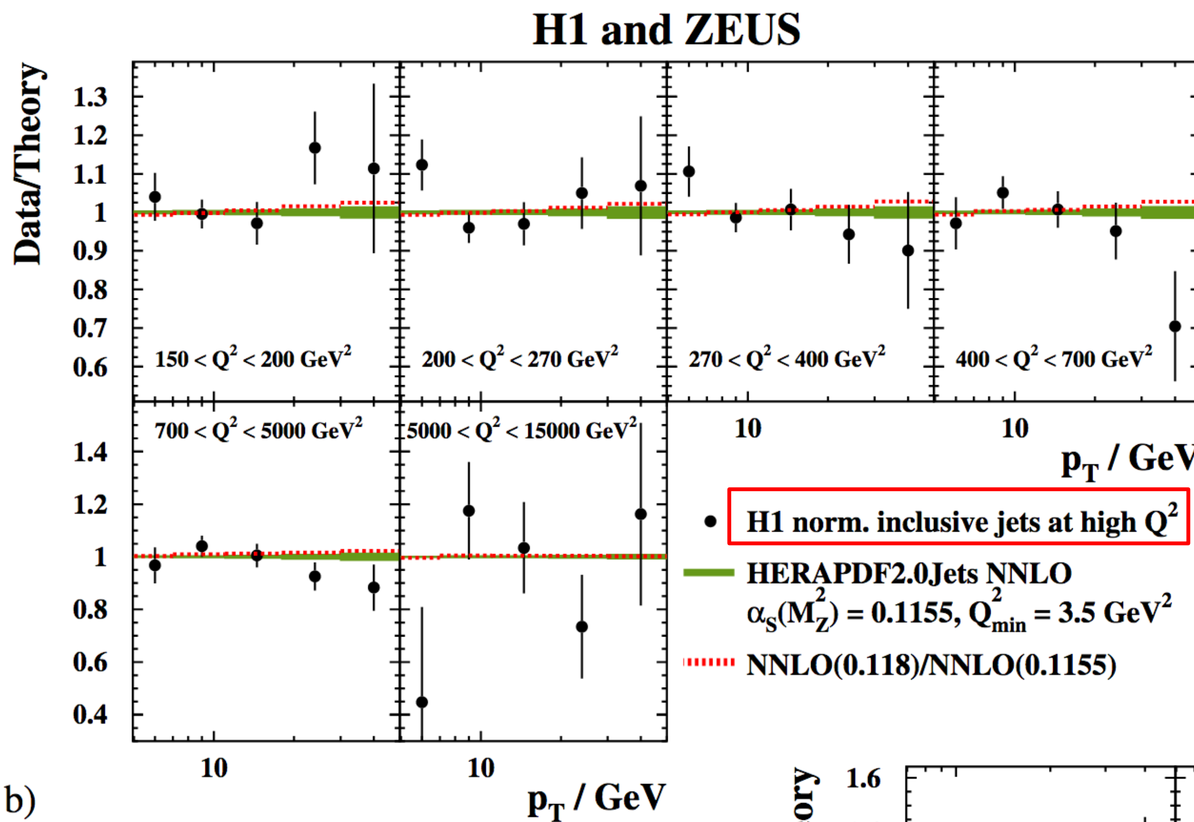
How does it compare to HERAPDF2.0? Well!



K. Wichmann @ REF22 NNLO jets @ HERA

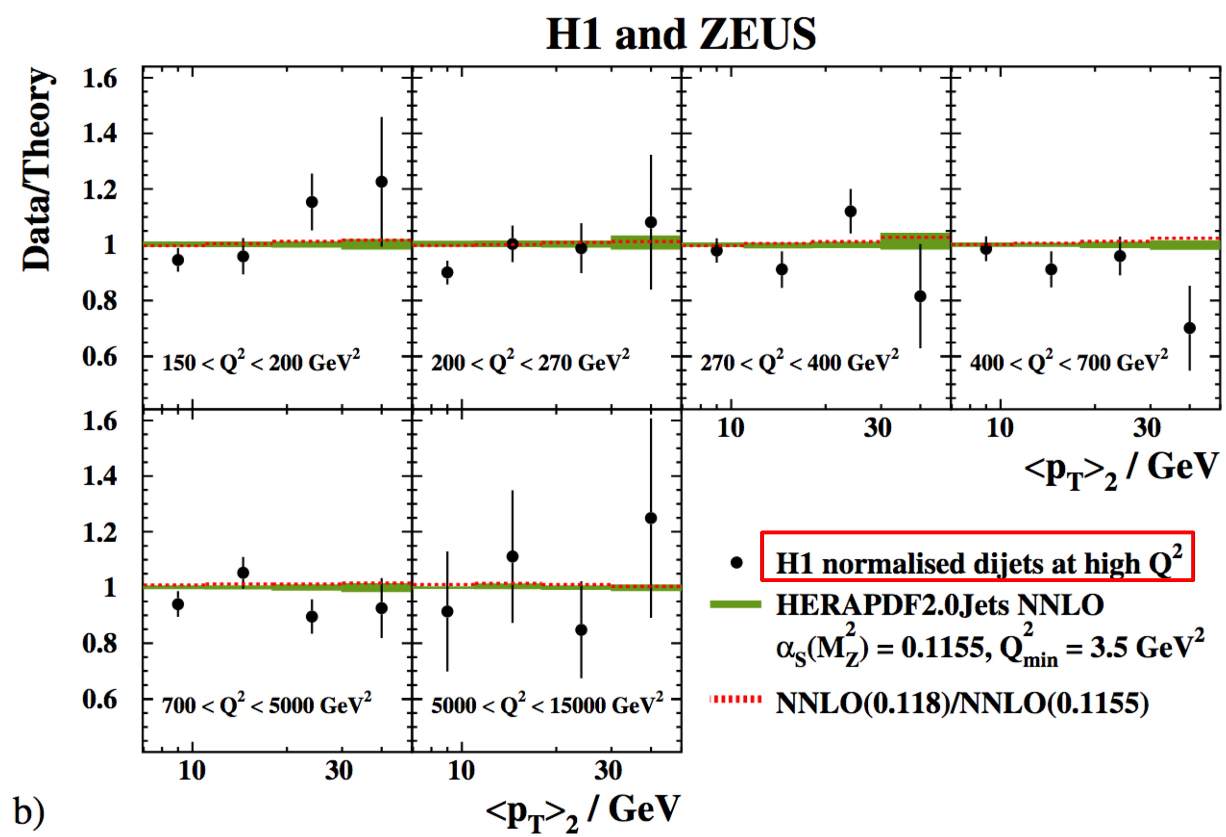
… and how it compares to α_s = 0.1155





Comparison of theory predictions to H1 HERA II normalised jets @ high Q^2

→ good agreement for all data used in PDF fits



Message to take away

- HERAPDF2.0 family completed
  → NNLO fit including jet data performed
- Two new PDF sets
  → HERAPDF2.0Jets NNLO $\alpha_s(M_Z)$ = 0.118 → PDG
  → HERAPDF2.0Jets NNLO $\alpha_s(M_Z)$ = 0.1155 → value favored by our fit
- Jet data allow us to constrain $\alpha_s(M_Z)$

$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\ (\mathrm{exp})\ {}^{+0.0001}_{-0.0002}\ (\mathrm{model} + \mathrm{parameterisation})\ \pm 0.0029\ (\mathrm{scale})$$

- Comparing to NLO at the same footing

NNLO $$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\ (\mathrm{exp})\ {}^{+0.0001}_{-0.0002}\ (\mathrm{model} + \mathrm{parameterisation})$$

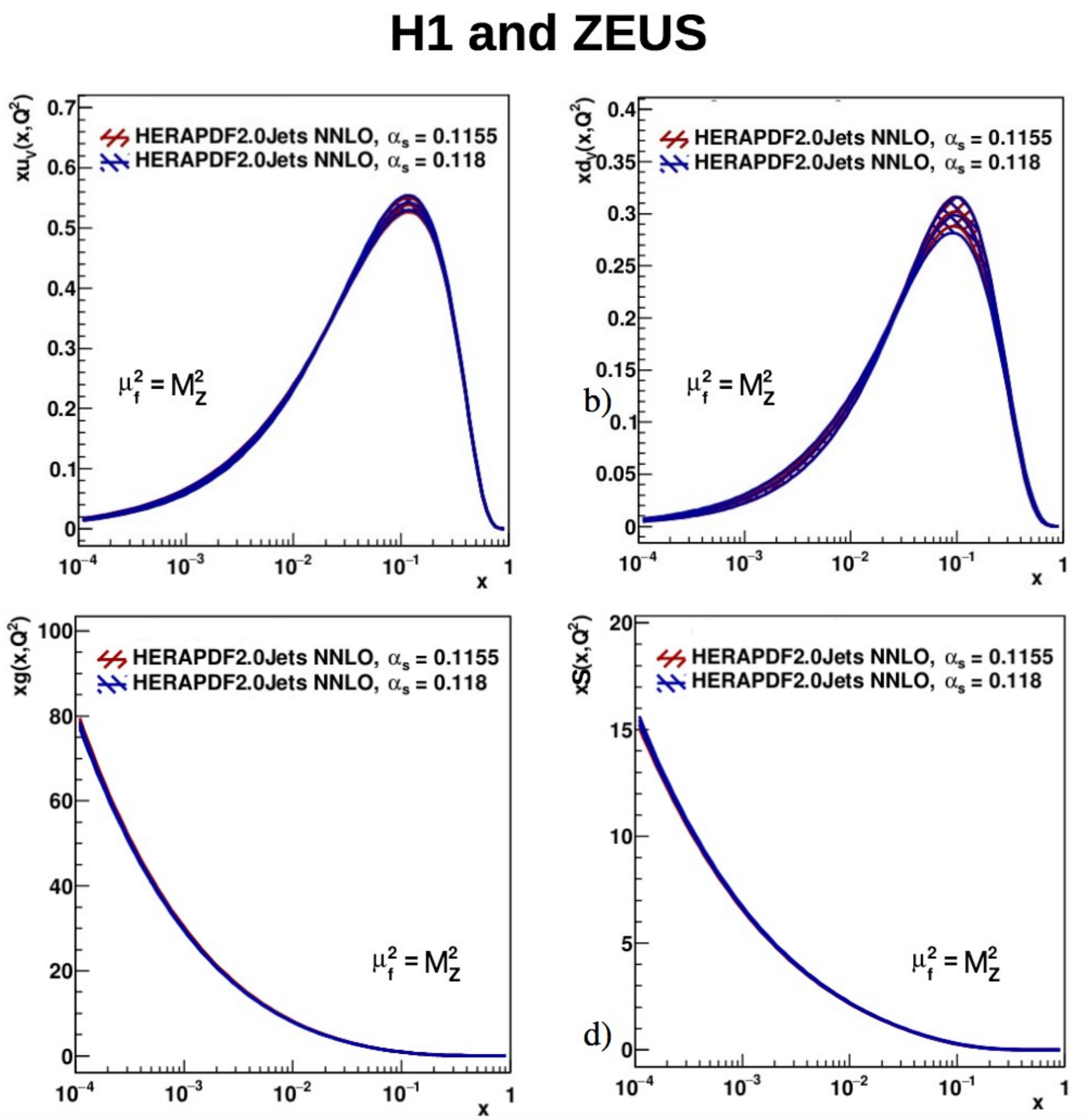
$$\pm 0.0022$$

NLO $$\alpha_s(M_Z^2) = 0.1183 \pm 0.0009(\mathrm{exp}) \pm 0.0005(\mathrm{model/parameterisation}) \pm 0.0012(\mathrm{hadronisation})\ {}^{+0.0037}_{-0.0030}(\mathrm{scale})\ .$$

Systematic shift downwards at NNLO and reduction of scale uncertainty

Additional slides

… and how it compares to α_s = 0.1155



Some remarks on NLO to NNLO comparison- (not in the paper)

Our present NNLO result using ½ correlated and ½ uncorrelated scale uncertainty

$\alpha_s(M_Z) = 0.1156 \pm 0.0011(\text{exp})\ ^{+0.0001}_{-0.0002}(\text{model+parametrisation}) \pm 0.0022(\text{scale})$

where "exp" denotes the experimental uncertainty which is taken as the fit uncertainty, including the contribution from hadronisation uncertainties.

Maybe compared with the NLO result

$\alpha_S(M_Z) = 0.1183 \pm 0.0008(\text{exp}) \pm 0.0012(\text{had})\ ^{+0.0003}_{/-0.0005}(\text{mod/param})\ ^{+0.0037}_{/-0.003}(\text{scale})$

BUT

- the choice of scale was different;
- the NLO result did not include the recently published H1 low-Q^2 inclusive and dijet data [28];
- the NLO result did not include the newly published low p_T points from the H1 high-Q^2 inclusive data;
- the NNLO result does not include trijet data;
- the NNLO result does not include the low p_T points from the ZEUS dijet data;
- the NNLO analysis imposes a stronger kinematic cut $\mu > 10$ GeV
- the treatment of hadronisation uncertainty differs.

All these changes with respect to the NLO analysis had to be made to create a consistent environment for a fit at NNLO. at the same time, an NLO fit cannot be done under exactly the same conditions as the NNLO fit since the H1 low Q^2 data cannot be well fitted at NLO. However, an NLO and an NNLO fit can be done under the common conditions:

(from A. Cooper-Sarkar, alpha-s 2022 workshop)

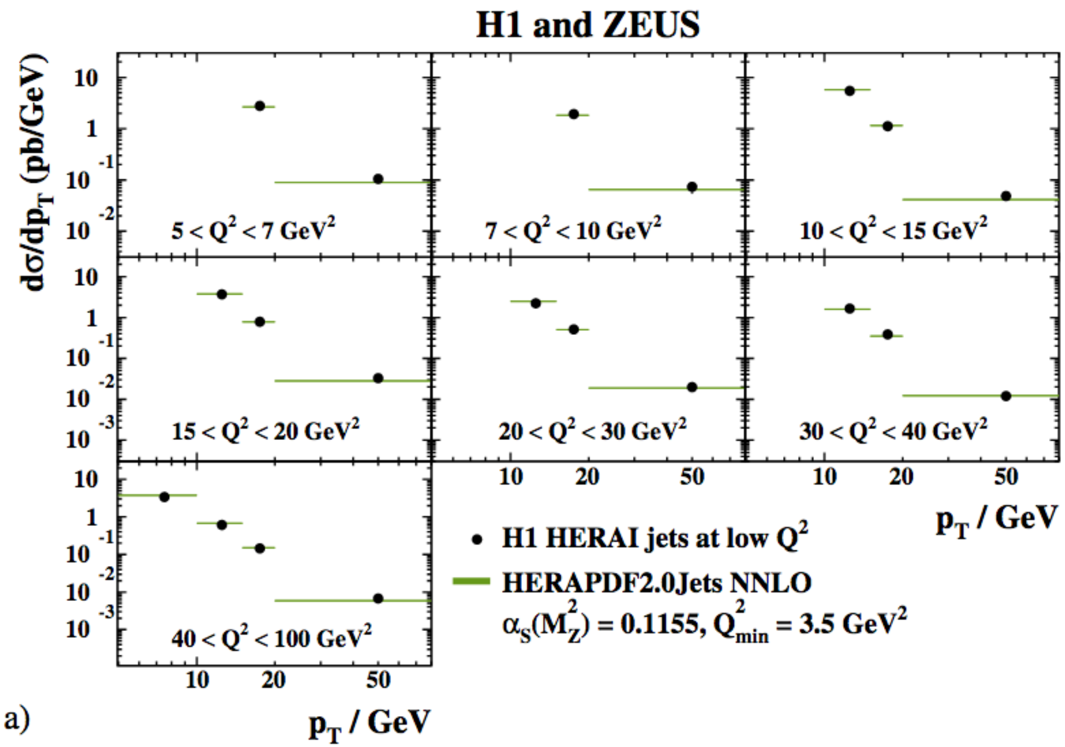
An NLO and an NNLO fit can be done under the common conditions:

- choice of scale, $\mu_f^2 = \mu_r^2 = Q^2 + p_T^2$;
- exclusion of the H1 low-Q^2 inclusive and dijet data;
- exclusion of the low-p_T points from the H1 high-Q^2 inclusive jet data;
- exclusion of trijet data;
- exclusion of low-p_T points from the ZEUS dijet data;
- exclusion of data with $\mu < 10$ GeV
- hadronisation uncertainties treated as correlated systematic uncertainties as done in the NNLO analysis.

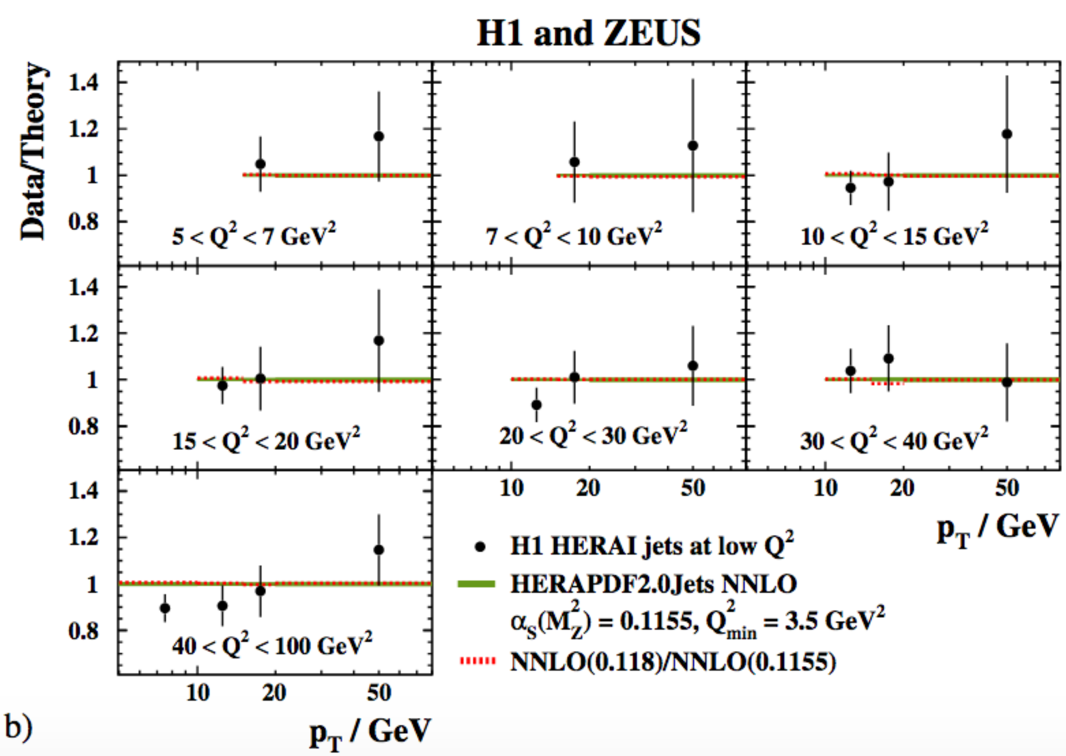
The values of $\alpha_S(M_Z)$ obtained for these conditions are:
0.1186 ± 0.0014(exp) NLO and 0.1144 ± 0.0013(exp) NNLO.
The change of the NNLO value from the preferred value of 0.1156 is mostly due to the exclusion of the H1 lowQ^2 data and the low-p_T points at high Q^2

What do we mean when we say the H1 low Q^2 jets cannot be well fitted at NLO?
Simply this, that at NNLO the increase in overall $\chi 2$ of the fit when the 74 data pts of these data are added is ~80 (exact value depends on $\alpha_S(M_Z)$ and on scale choice)
Whereas at NLO the increase in overall $\chi 2$ of the fit when the 74 data pts of these data are added is ~180.

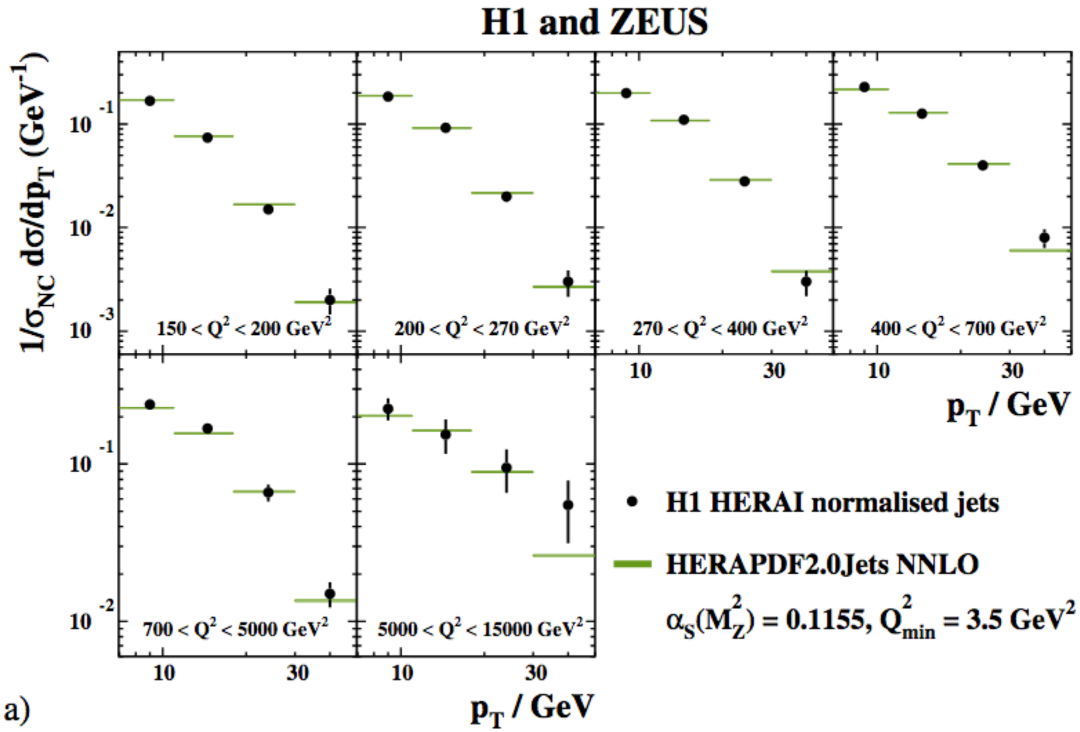
(from A. Cooper-Sarkar, alpha-s 2022 workshop)


H1 and ZEUS
dσ/dp_T (pb/GeV)
5 < Q² < 7 GeV²
7 < Q² < 10 GeV²
10 < Q² < 15 GeV²
15 < Q² < 20 GeV²
20 < Q² < 30 GeV²
30 < Q² < 40 GeV²
40 < Q² < 100 GeV²
p_T / GeV
H1 HERAI jets at low Q²
HERAPDF2.0Jets NNLO
α_S(M_Z²) = 0.1155, Q²_min = 3.5 GeV²

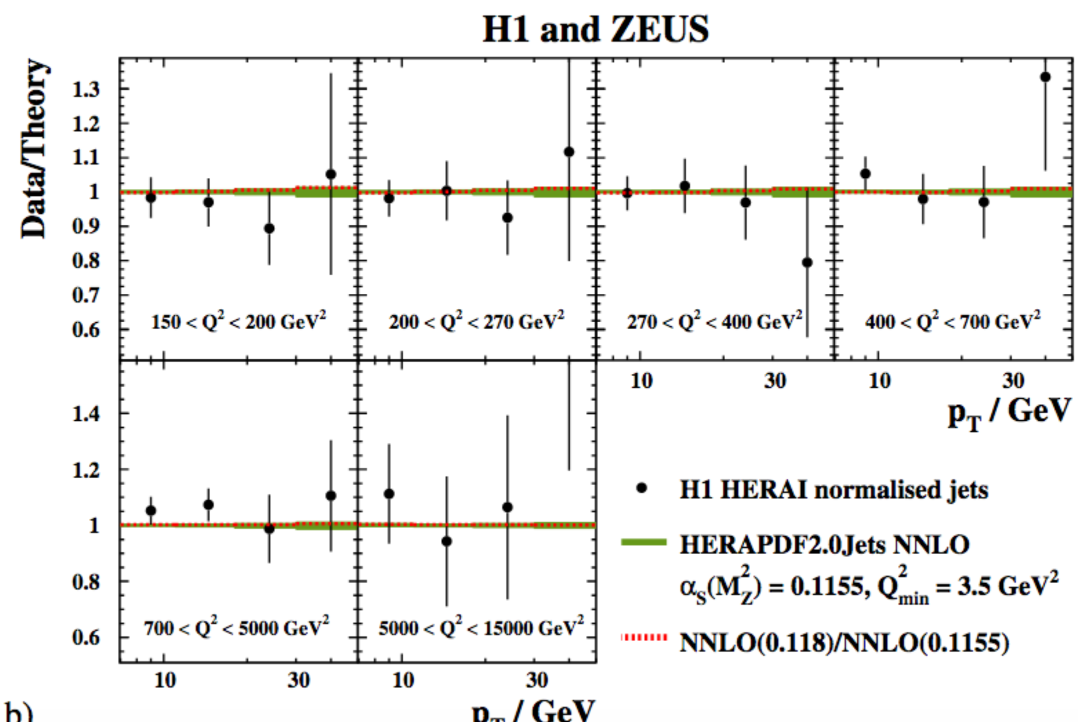
a)


H1 and ZEUS
Data/Theory
5 < Q² < 7 GeV²
7 < Q² < 10 GeV²
10 < Q² < 15 GeV²
15 < Q² < 20 GeV²
20 < Q² < 30 GeV²
30 < Q² < 40 GeV²
40 < Q² < 100 GeV²
p_T / GeV
H1 HERAI jets at low Q²
HERAPDF2.0Jets NNLO
α_S(M_Z²) = 0.1155, Q²_min = 3.5 GeV²
NNLO(0.118)/NNLO(0.1155)

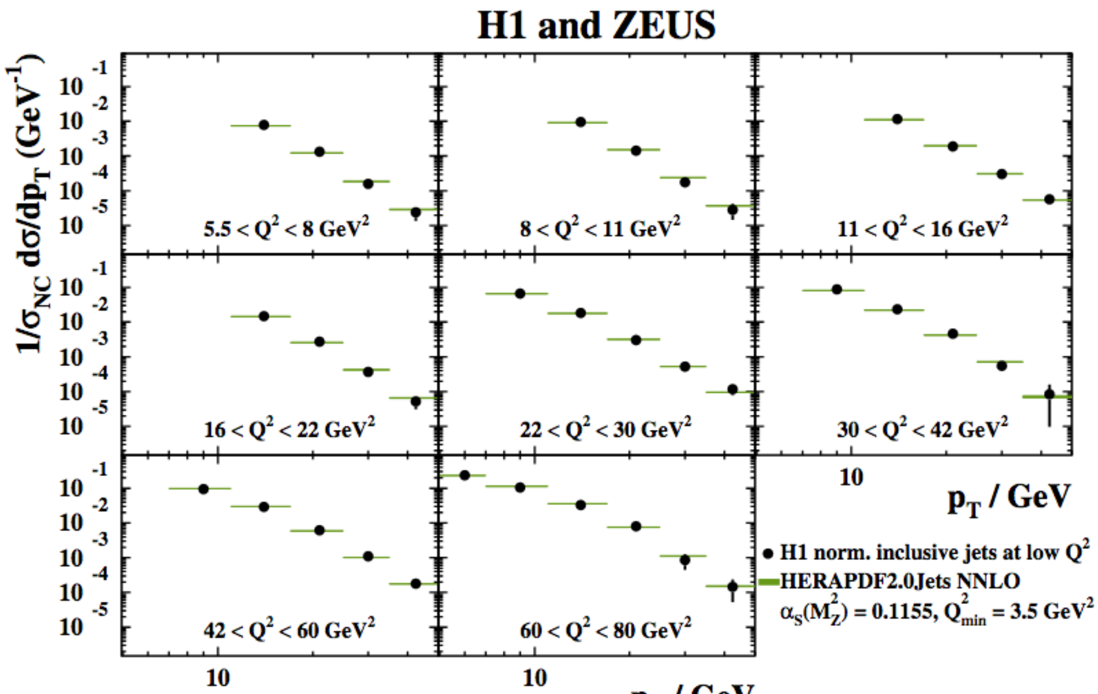
b)


H1 and ZEUS
1/σ_NC dσ/dp_T (GeV^-1)
150 < Q^2 < 200 GeV^2
200 < Q^2 < 270 GeV^2
270 < Q^2 < 400 GeV^2
400 < Q^2 < 700 GeV^2
700 < Q^2 < 5000 GeV^2
5000 < Q^2 < 15000 GeV^2
p_T / GeV
H1 HERAI normalised jets
HERAPDF2.0Jets NNLO
α_S(M_Z^2) = 0.1155, Q^2_min = 3.5 GeV^2

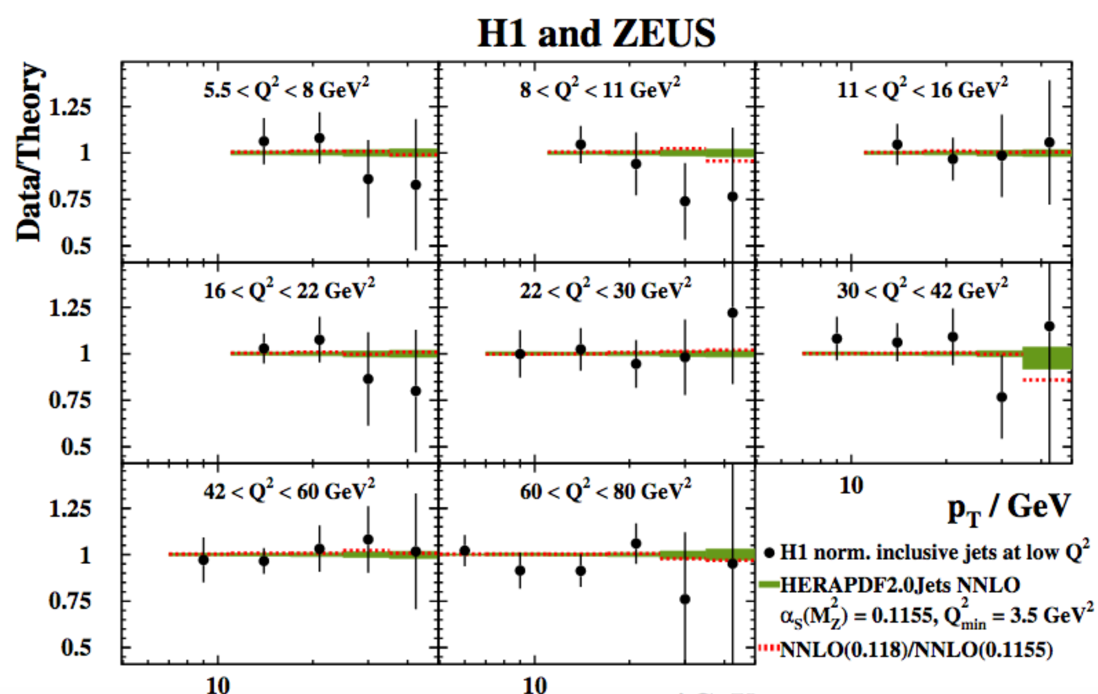
a)


H1 and ZEUS
Data/Theory
150 < Q^2 < 200 GeV^2
200 < Q^2 < 270 GeV^2
270 < Q^2 < 400 GeV^2
400 < Q^2 < 700 GeV^2
700 < Q^2 < 5000 GeV^2
5000 < Q^2 < 15000 GeV^2
p_T / GeV
H1 HERAI normalised jets
HERAPDF2.0Jets NNLO
α_S(M_Z^2) = 0.1155, Q^2_min = 3.5 GeV^2
NNLO(0.118)/NNLO(0.1155)

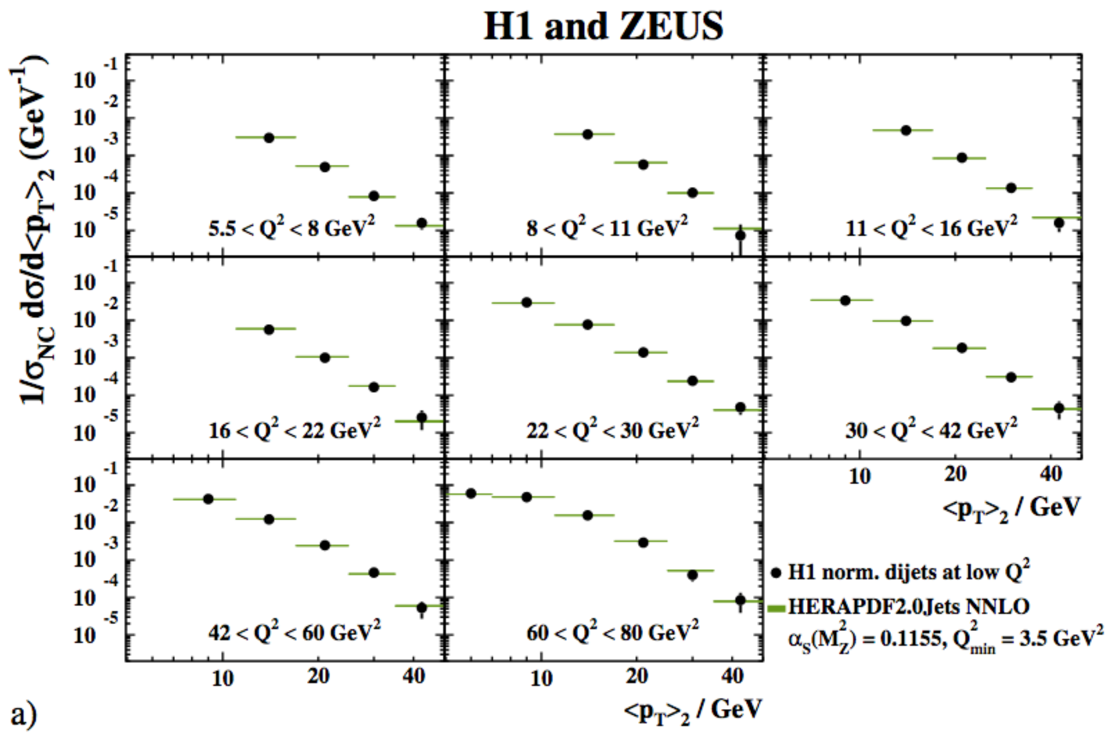
b)

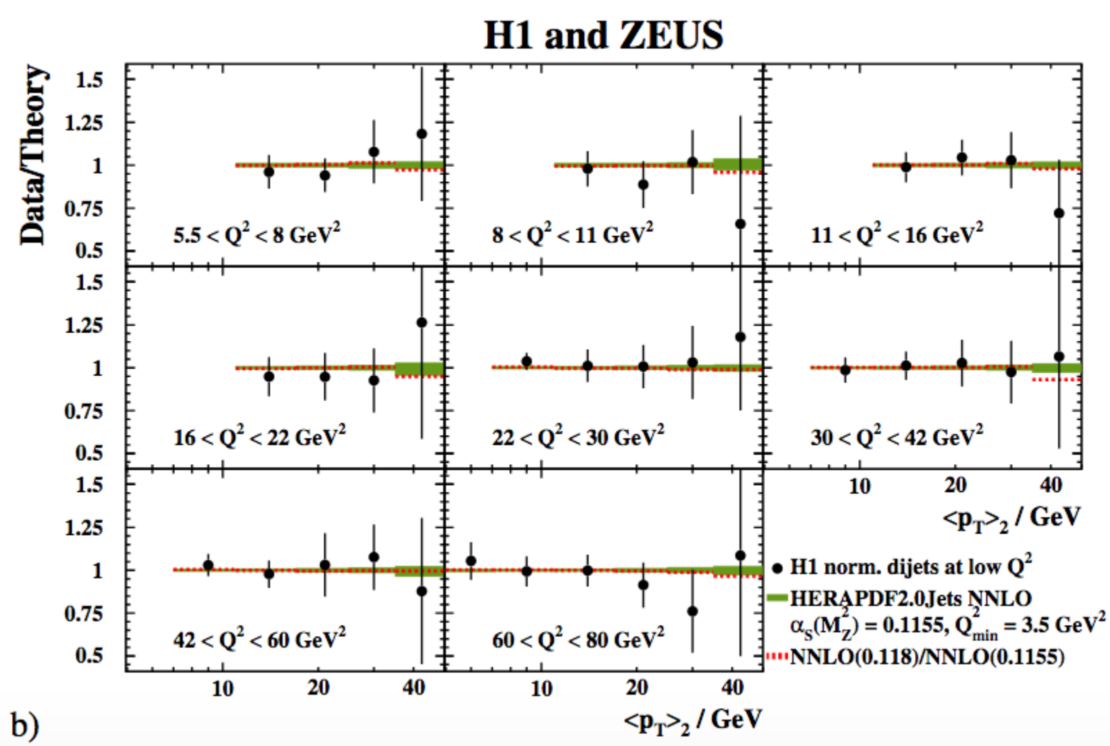

H1 and ZEUS
1/σ_NC dσ/dp_T (GeV^-1)
5.5 < Q^2 < 8 GeV^2
8 < Q^2 < 11 GeV^2
11 < Q^2 < 16 GeV^2
16 < Q^2 < 22 GeV^2
22 < Q^2 < 30 GeV^2
30 < Q^2 < 42 GeV^2
42 < Q^2 < 60 GeV^2
60 < Q^2 < 80 GeV^2
p_T / GeV
H1 norm. inclusive jets at low Q^2
HERAPDF2.0Jets NNLO
α_S(M_Z^2) = 0.1155, Q^2_min = 3.5 GeV^2

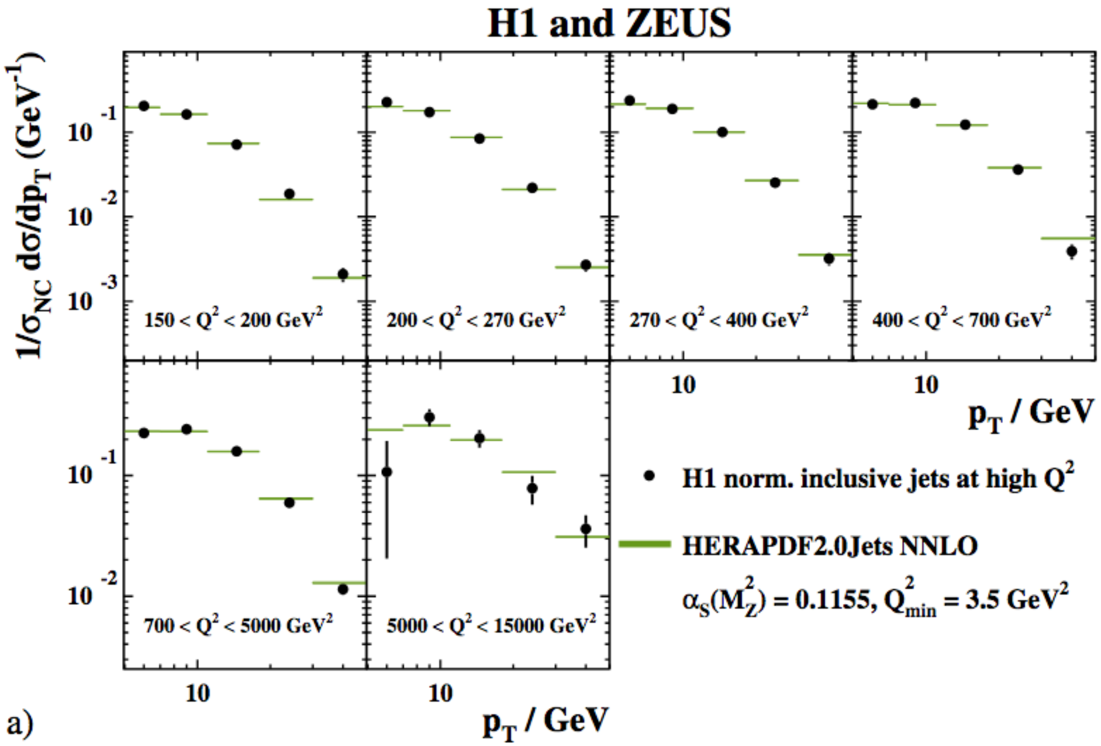
a)


H1 and ZEUS
Data/Theory
5.5 < Q^2 < 8 GeV^2
8 < Q^2 < 11 GeV^2
11 < Q^2 < 16 GeV^2
16 < Q^2 < 22 GeV^2
22 < Q^2 < 30 GeV^2
30 < Q^2 < 42 GeV^2
42 < Q^2 < 60 GeV^2
60 < Q^2 < 80 GeV^2
p_T / GeV
H1 norm. inclusive jets at low Q^2
HERAPDF2.0Jets NNLO
α_S(M_Z^2) = 0.1155, Q^2_min = 3.5 GeV^2
NNLO(0.118)/NNLO(0.1155)

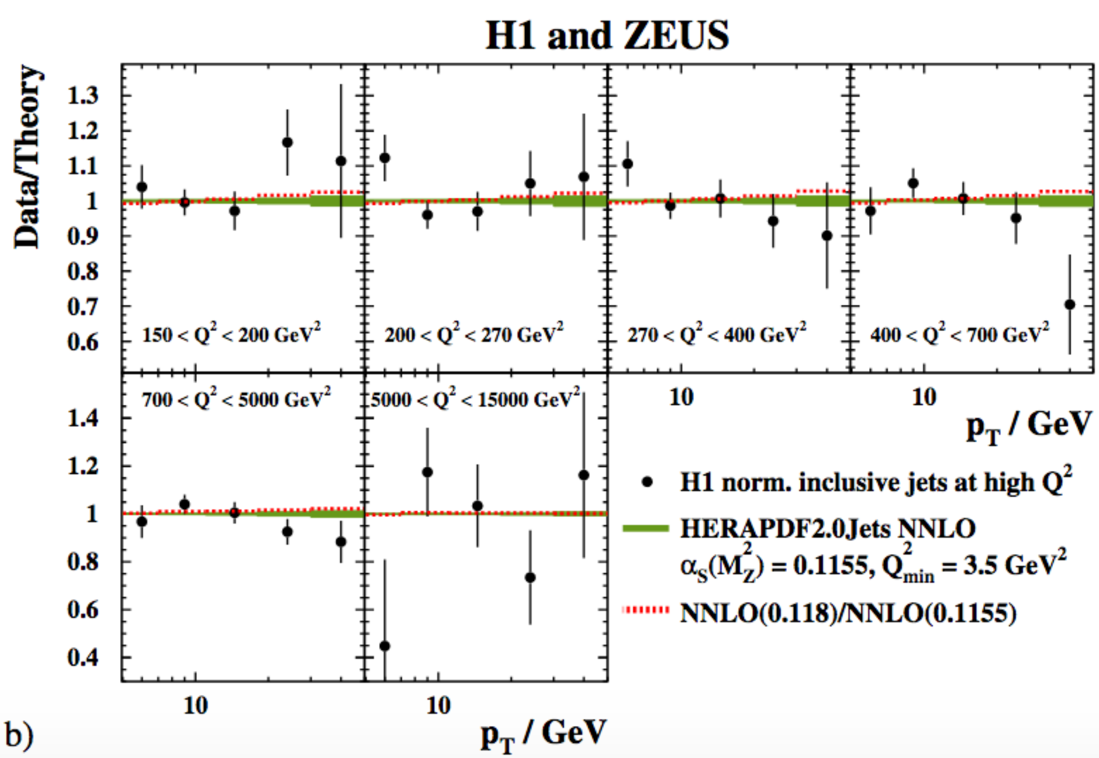
b)


H1 and ZEUS
$1/\sigma_{NC}\ d\sigma/d\langle p_T\rangle_2\ (GeV^{-1})$
$5.5 < Q^2 < 8\ GeV^2$
$8 < Q^2 < 11\ GeV^2$
$11 < Q^2 < 16\ GeV^2$
$16 < Q^2 < 22\ GeV^2$
$22 < Q^2 < 30\ GeV^2$
$30 < Q^2 < 42\ GeV^2$
$42 < Q^2 < 60\ GeV^2$
$60 < Q^2 < 80\ GeV^2$
$\langle p_T\rangle_2$ / GeV
H1 norm. dijets at low Q^2
HERAPDF2.0Jets NNLO
$\alpha_s(M_Z^2) = 0.1155$, $Q^2_{min} = 3.5\ GeV^2$
a)

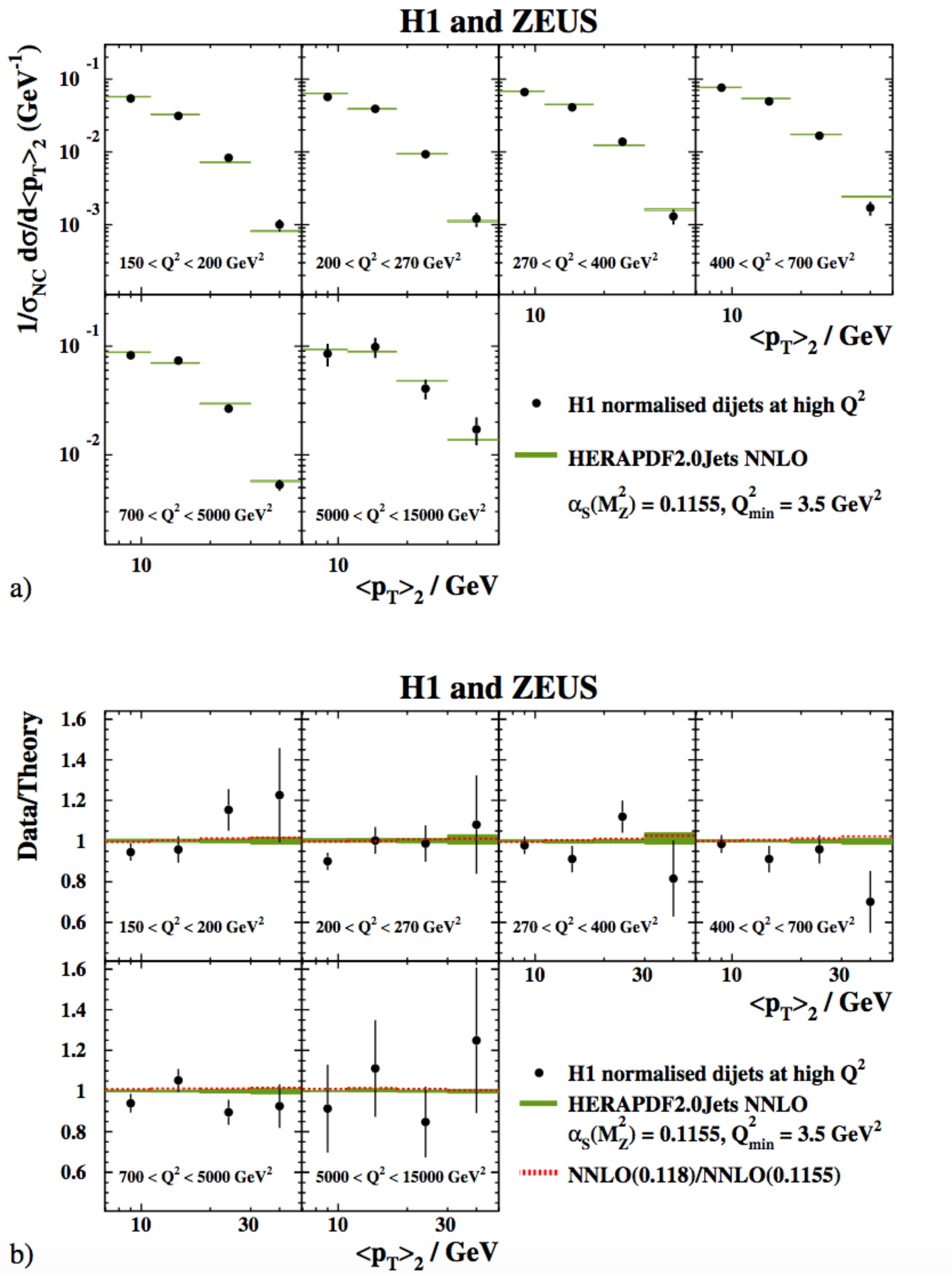

H1 and ZEUS
Data/Theory
$5.5 < Q^2 < 8\ GeV^2$
$8 < Q^2 < 11\ GeV^2$
$11 < Q^2 < 16\ GeV^2$
$16 < Q^2 < 22\ GeV^2$
$22 < Q^2 < 30\ GeV^2$
$30 < Q^2 < 42\ GeV^2$
$42 < Q^2 < 60\ GeV^2$
$60 < Q^2 < 80\ GeV^2$
$\langle p_T\rangle_2$ / GeV
H1 norm. dijets at low Q^2
HERAPDF2.0Jets NNLO
$\alpha_s(M_Z^2) = 0.1155$, $Q^2_{min} = 3.5\ GeV^2$
NNLO(0.118)/NNLO(0.1155)
b)

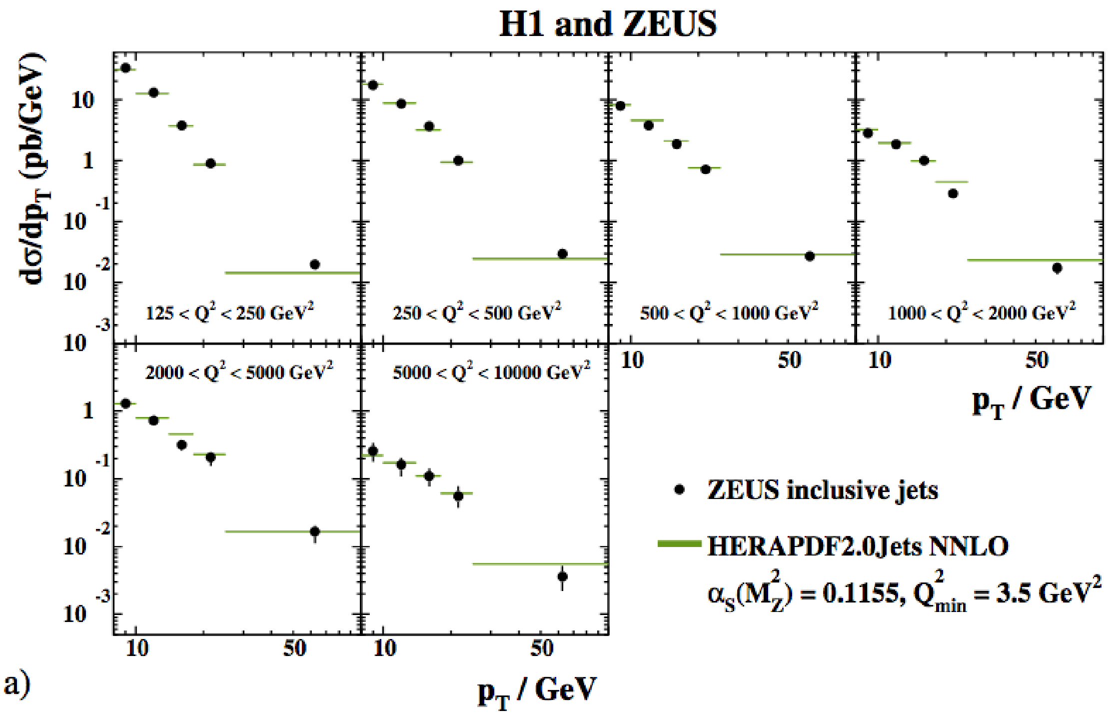

H1 and ZEUS
1/σNC dσ/dpT (GeV-1)
150 < Q2 < 200 GeV2
200 < Q2 < 270 GeV2
270 < Q2 < 400 GeV2
400 < Q2 < 700 GeV2
700 < Q2 < 5000 GeV2
5000 < Q2 < 15000 GeV2
pT / GeV
H1 norm. inclusive jets at high Q2
HERAPDF2.0Jets NNLO
αS(MZ2) = 0.1155, Q2min = 3.5 GeV2

a)

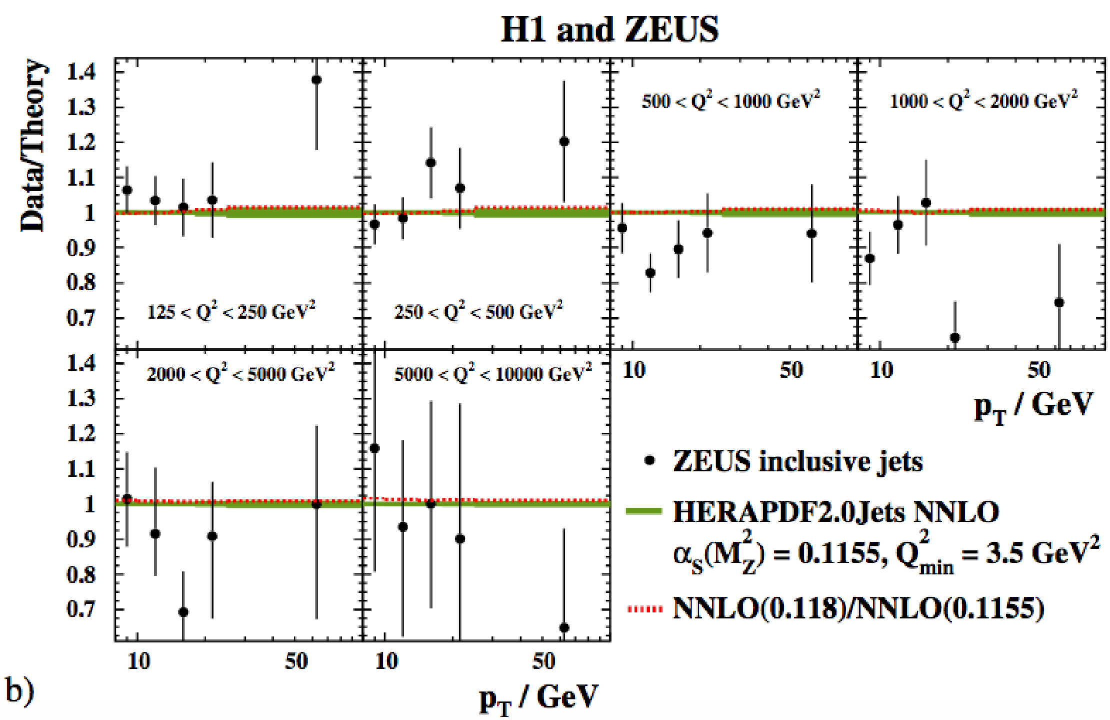

H1 and ZEUS
Data/Theory
150 < Q2 < 200 GeV2
200 < Q2 < 270 GeV2
270 < Q2 < 400 GeV2
400 < Q2 < 700 GeV2
700 < Q2 < 5000 GeV2
5000 < Q2 < 15000 GeV2
pT / GeV
H1 norm. inclusive jets at high Q2
HERAPDF2.0Jets NNLO
αS(MZ2) = 0.1155, Q2min = 3.5 GeV2
NNLO(0.118)/NNLO(0.1155)

b)

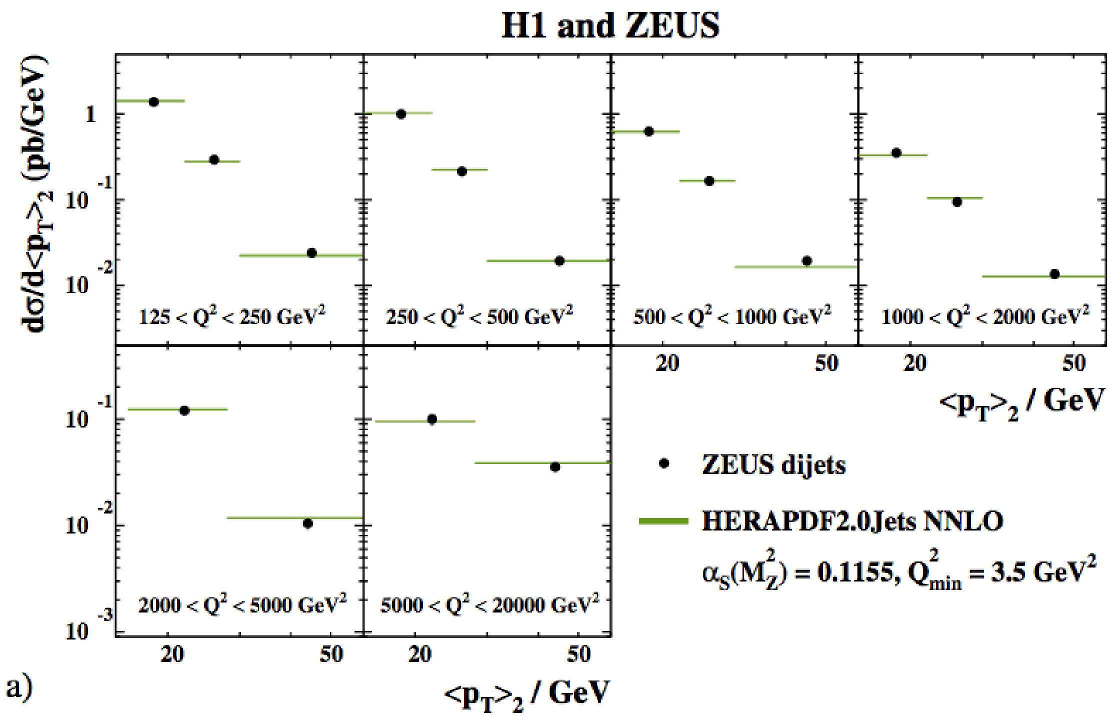

H1 and ZEUS
$1/\sigma_{NC}\, d\sigma/d\langle p_T\rangle_2$ (GeV^{-1})
150 < Q^2 < 200 GeV^2
200 < Q^2 < 270 GeV^2
270 < Q^2 < 400 GeV^2
400 < Q^2 < 700 GeV^2
700 < Q^2 < 5000 GeV^2
5000 < Q^2 < 15000 GeV^2
$\langle p_T\rangle_2$ / GeV
H1 normalised dijets at high Q^2
HERAPDF2.0Jets NNLO
$\alpha_S(M_Z^2) = 0.1155$, $Q^2_{min} = 3.5$ GeV^2
a)
H1 and ZEUS
Data/Theory
150 < Q^2 < 200 GeV^2
200 < Q^2 < 270 GeV^2
270 < Q^2 < 400 GeV^2
400 < Q^2 < 700 GeV^2
700 < Q^2 < 5000 GeV^2
5000 < Q^2 < 15000 GeV^2
$\langle p_T\rangle_2$ / GeV
H1 normalised dijets at high Q^2
HERAPDF2.0Jets NNLO
$\alpha_S(M_Z^2) = 0.1155$, $Q^2_{min} = 3.5$ GeV^2
NNLO(0.118)/NNLO(0.1155)
b)

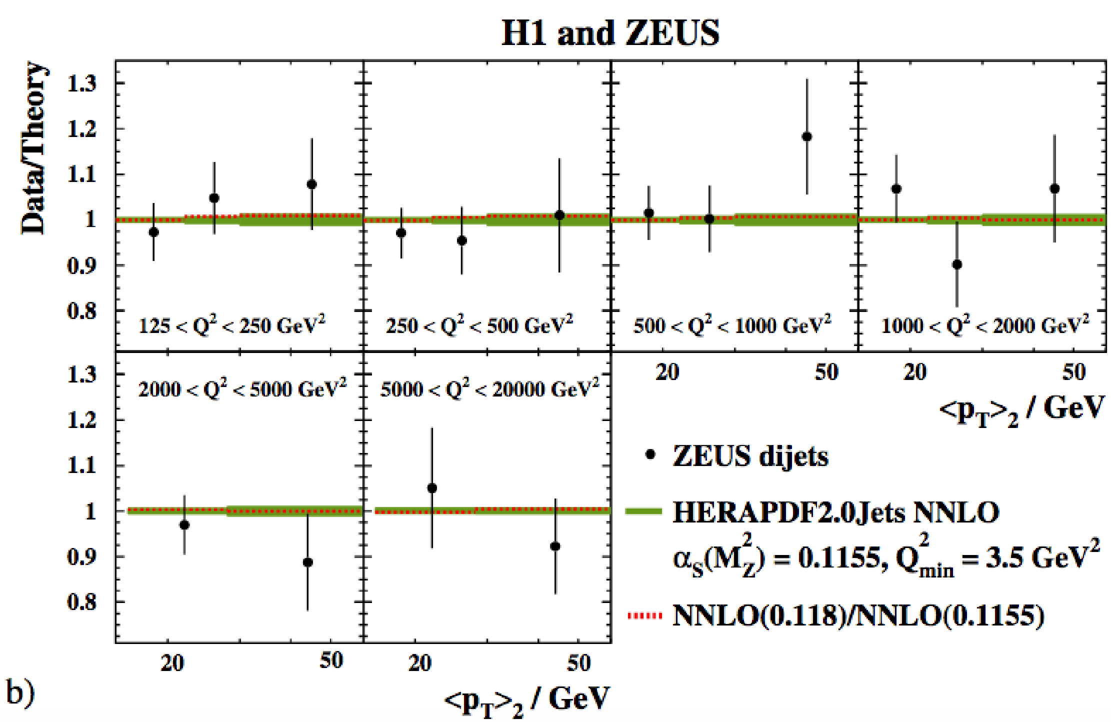

H1 and ZEUS
dσ/dp_T (pb/GeV)
125 < Q² < 250 GeV²
250 < Q² < 500 GeV²
500 < Q² < 1000 GeV²
1000 < Q² < 2000 GeV²
2000 < Q² < 5000 GeV²
5000 < Q² < 10000 GeV²
p_T / GeV
ZEUS inclusive jets
HERAPDF2.0Jets NNLO
α_S(M_Z²) = 0.1155, Q²_min = 3.5 GeV²

a)


H1 and ZEUS
Data/Theory
125 < Q² < 250 GeV²
250 < Q² < 500 GeV²
500 < Q² < 1000 GeV²
1000 < Q² < 2000 GeV²
2000 < Q² < 5000 GeV²
5000 < Q² < 10000 GeV²
p_T / GeV
ZEUS inclusive jets
HERAPDF2.0Jets NNLO
α_S(M_Z²) = 0.1155, Q²_min = 3.5 GeV²
NNLO(0.118)/NNLO(0.155)

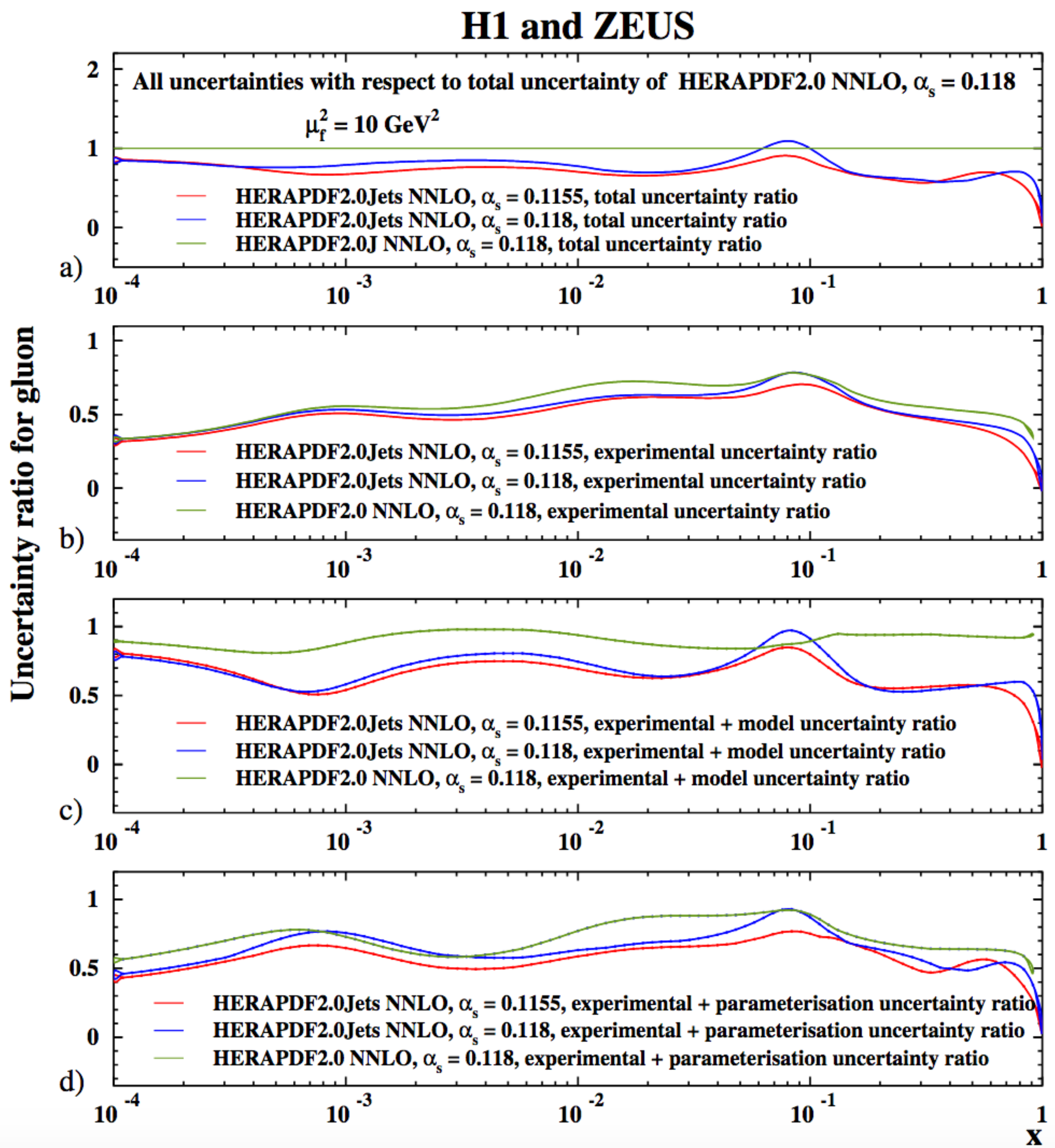
b)


H1 and ZEUS
dσ/d<p_T>_2 (pb/GeV)
125 < Q² < 250 GeV²
250 < Q² < 500 GeV²
500 < Q² < 1000 GeV²
1000 < Q² < 2000 GeV²
2000 < Q² < 5000 GeV²
5000 < Q² < 20000 GeV²
<p_T>_2 / GeV
ZEUS dijets
HERAPDF2.0Jets NNLO
α_S(M_Z²) = 0.1155, Q²_min = 3.5 GeV²
a)

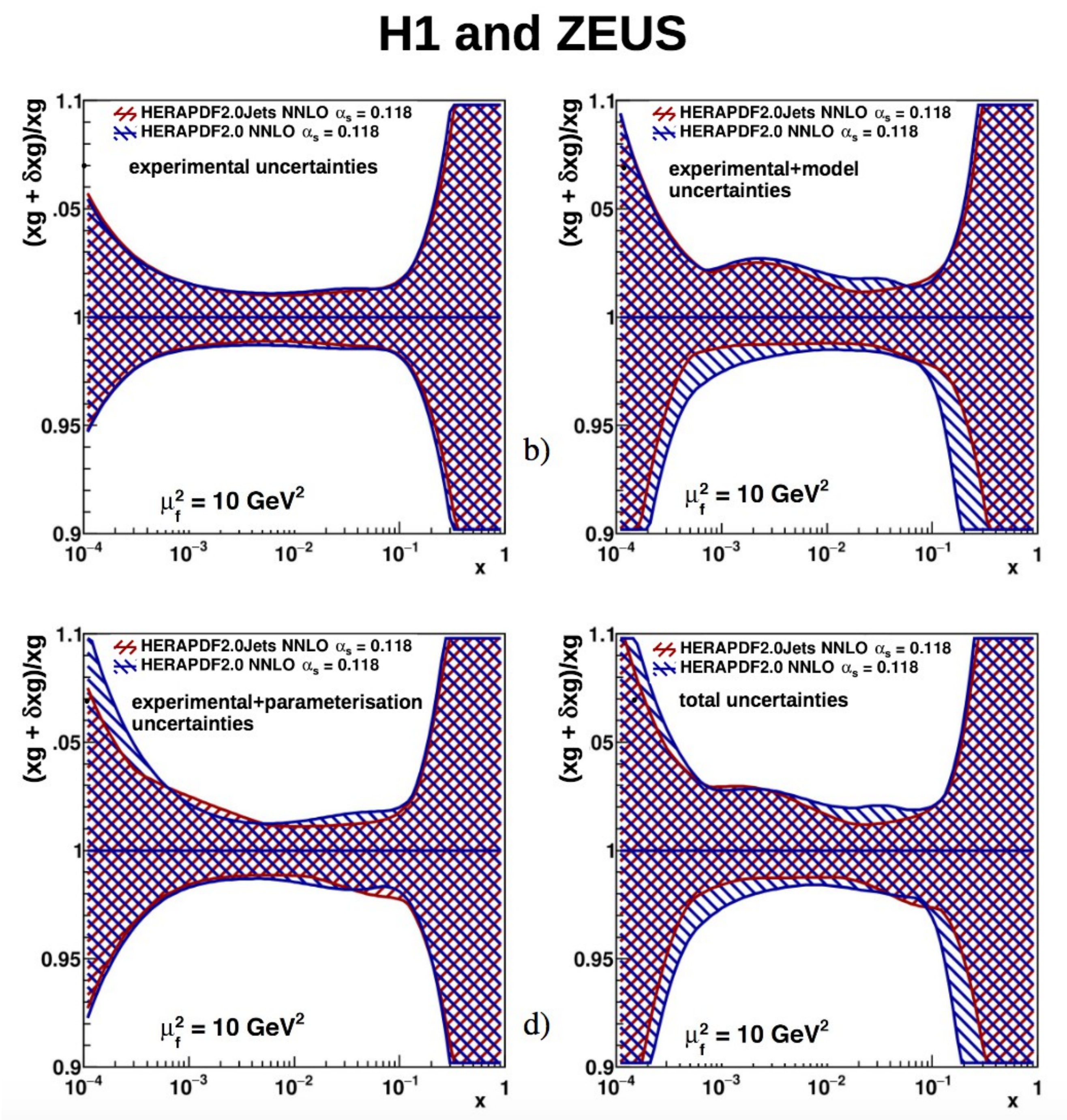

H1 and ZEUS
Data/Theory
125 < Q² < 250 GeV²
250 < Q² < 500 GeV²
500 < Q² < 1000 GeV²
1000 < Q² < 2000 GeV²
2000 < Q² < 5000 GeV²
5000 < Q² < 20000 GeV²
<p_T>_2 / GeV
ZEUS dijets
HERAPDF2.0Jets NNLO
α_S(M_Z²) = 0.1155, Q²_min = 3.5 GeV²
NNLO(0.118)/NNLO(0.1155)
b)

Uncertainties

- Reduction of low-x gluon ($x < 10^{-3}$) uncertainties due to reduced model/param uncertainties in variations of M_c and μ_f^2
- Reduction of high-x gluon ($x > 10^{-3}$) uncertainties due to reduced model/param/exp uncertainties
- The same for other scales

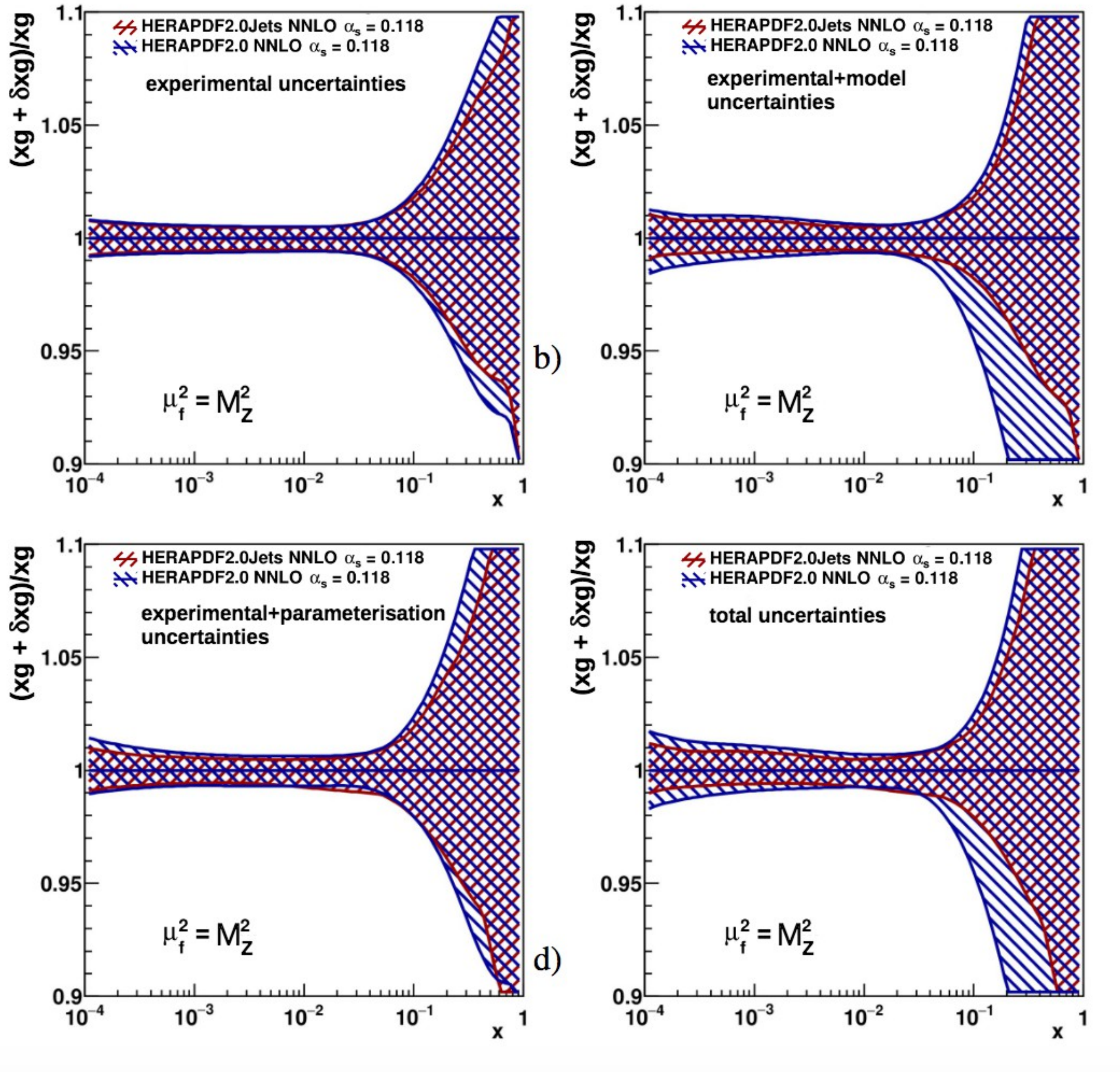


Uncertainties



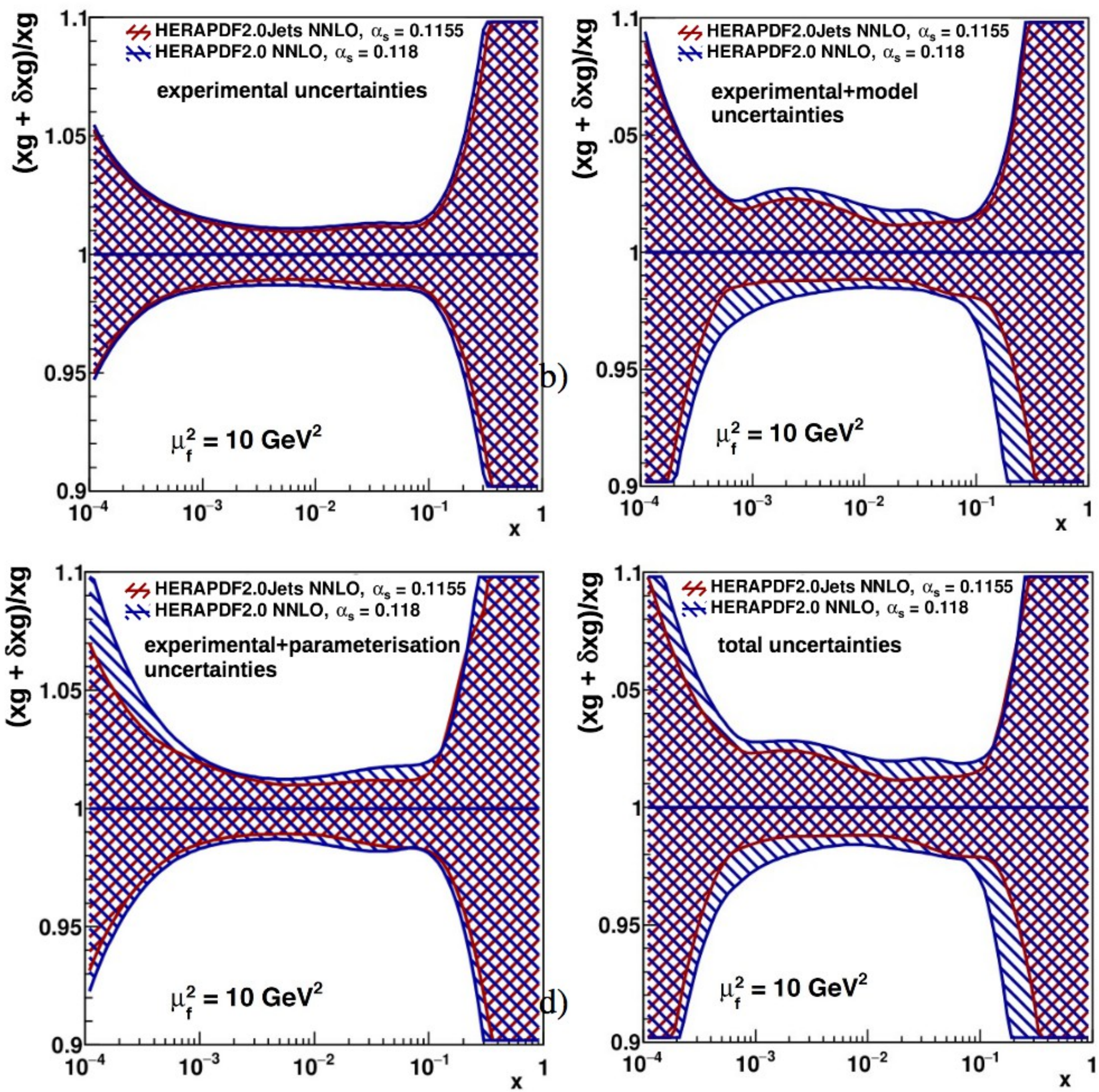
Uncertainties

H1 and ZEUS



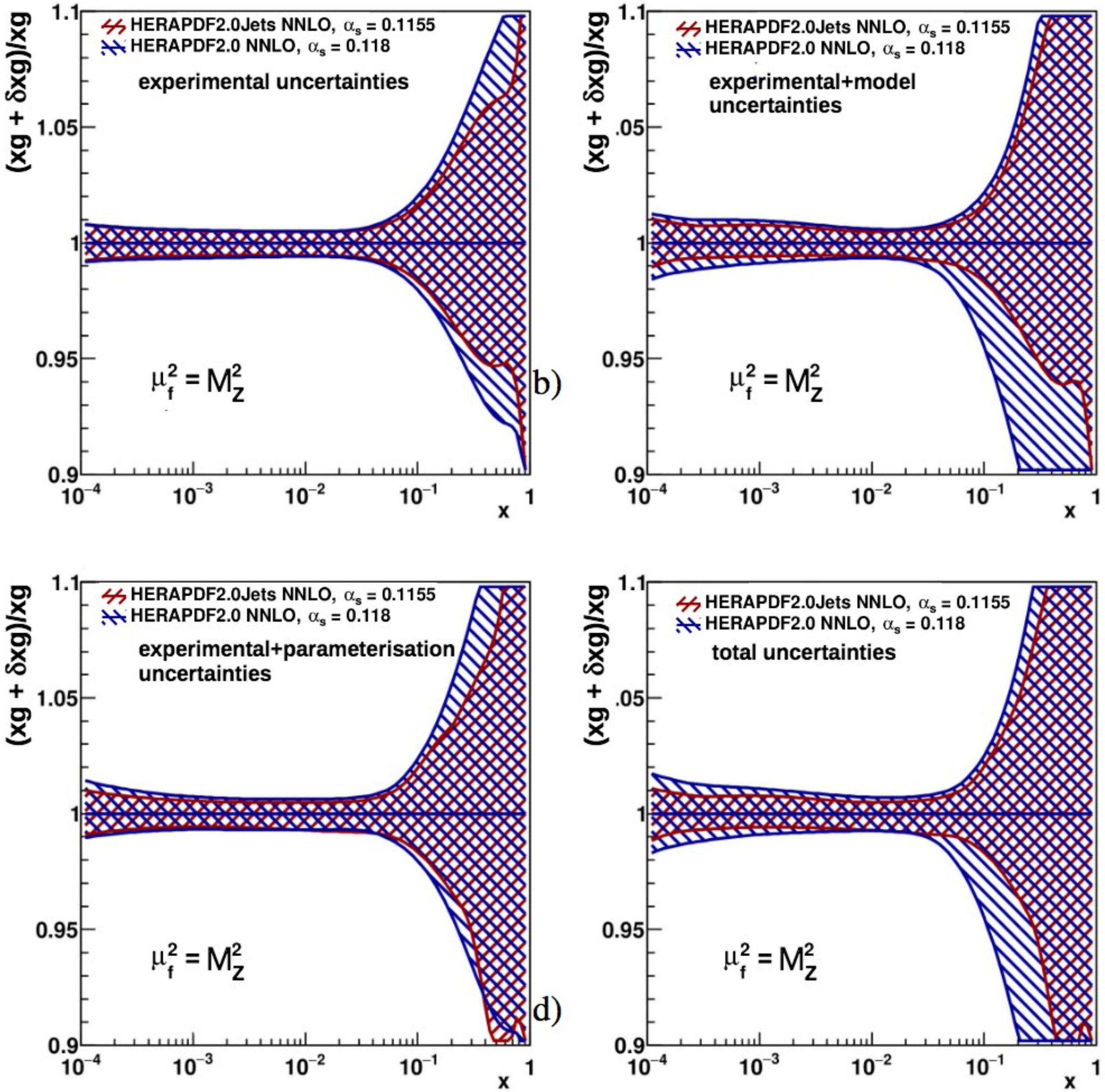
Uncertainties

H1 and ZEUS

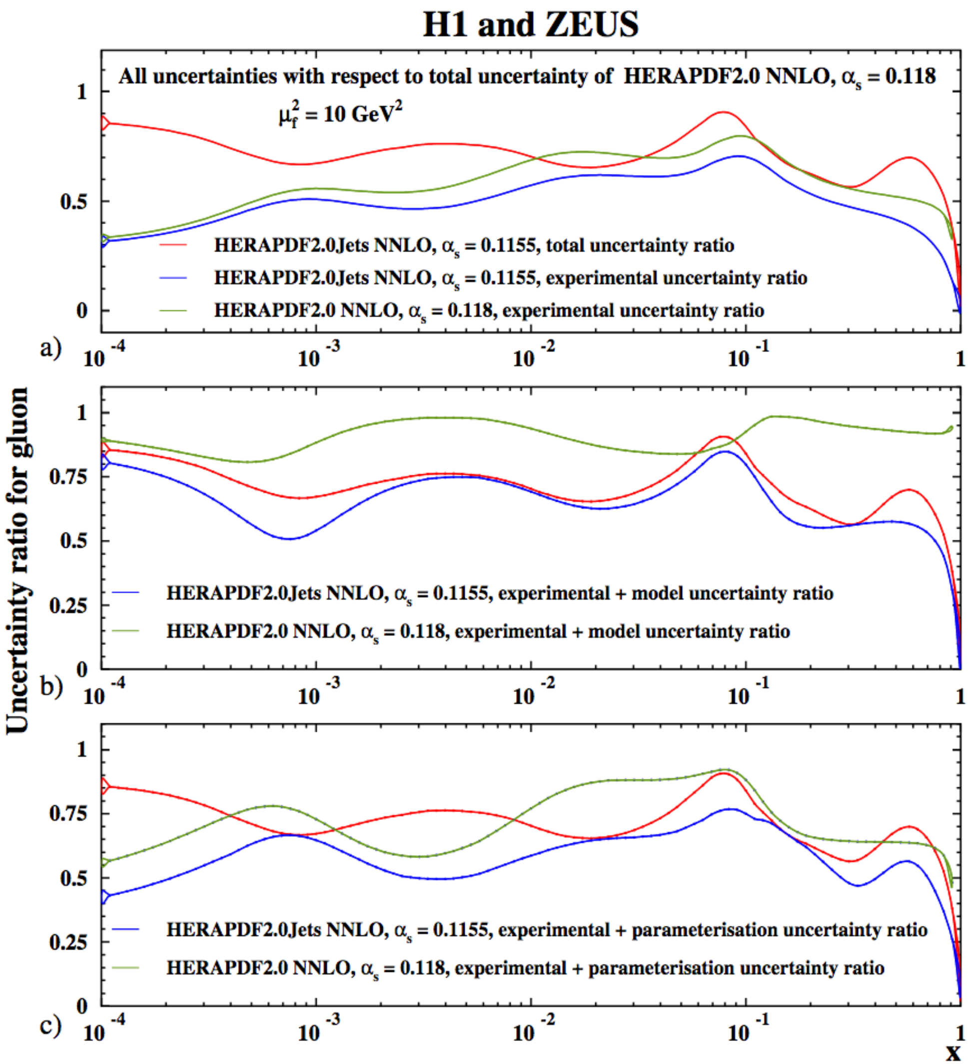


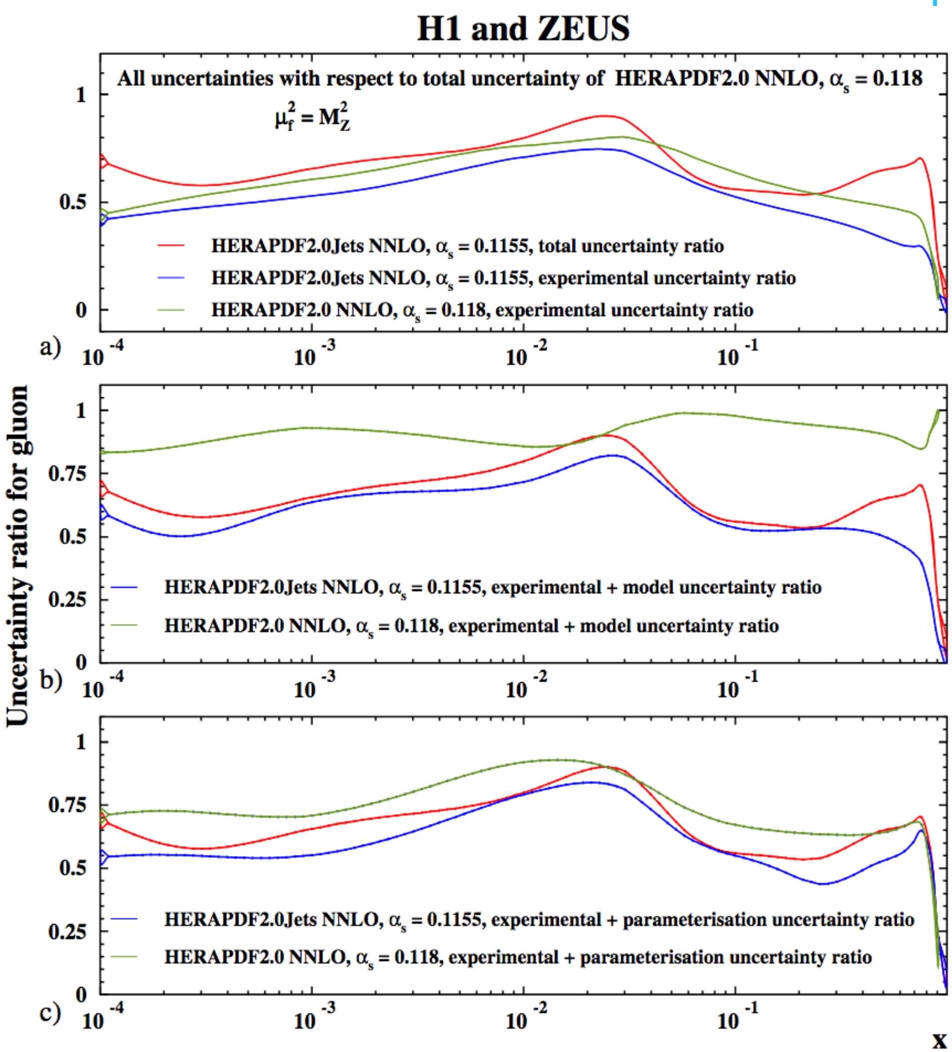
Uncertainties

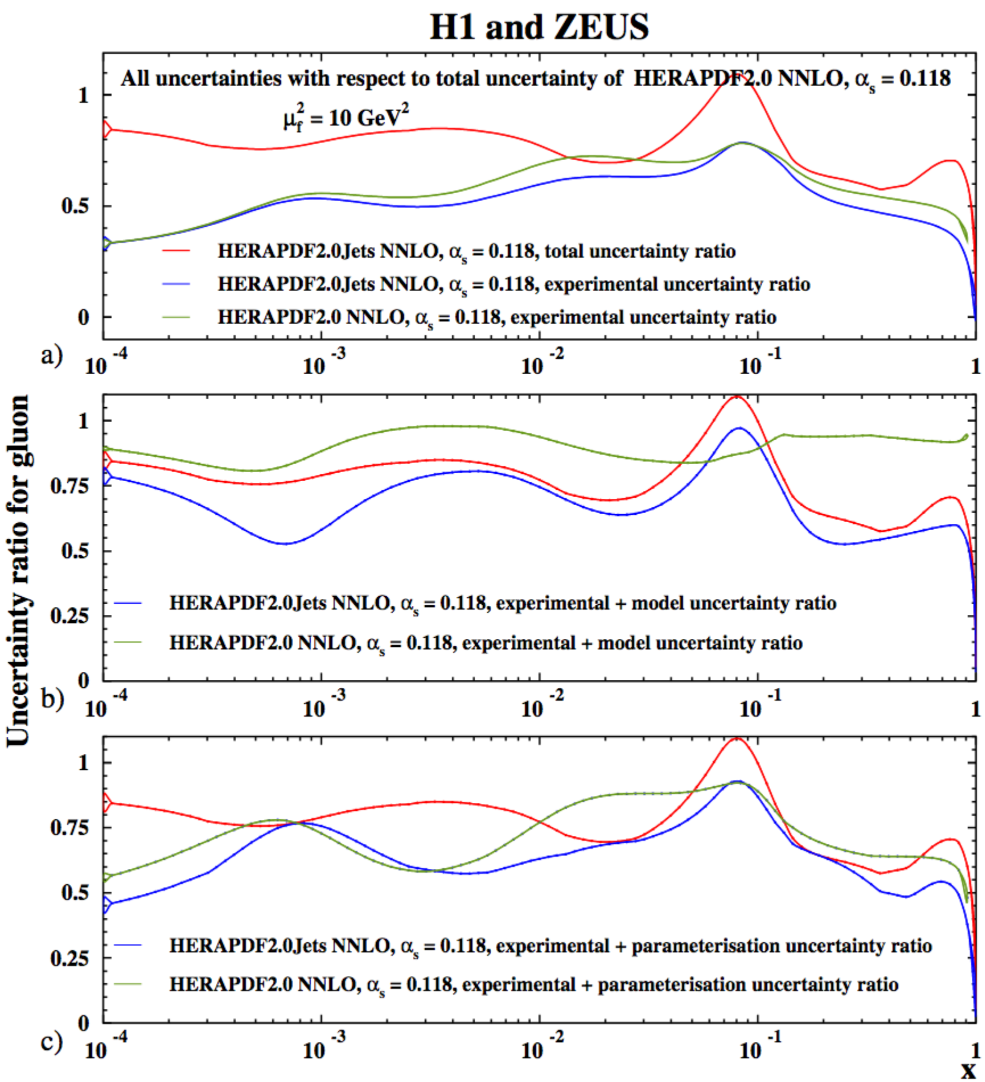
H1 and ZEUS

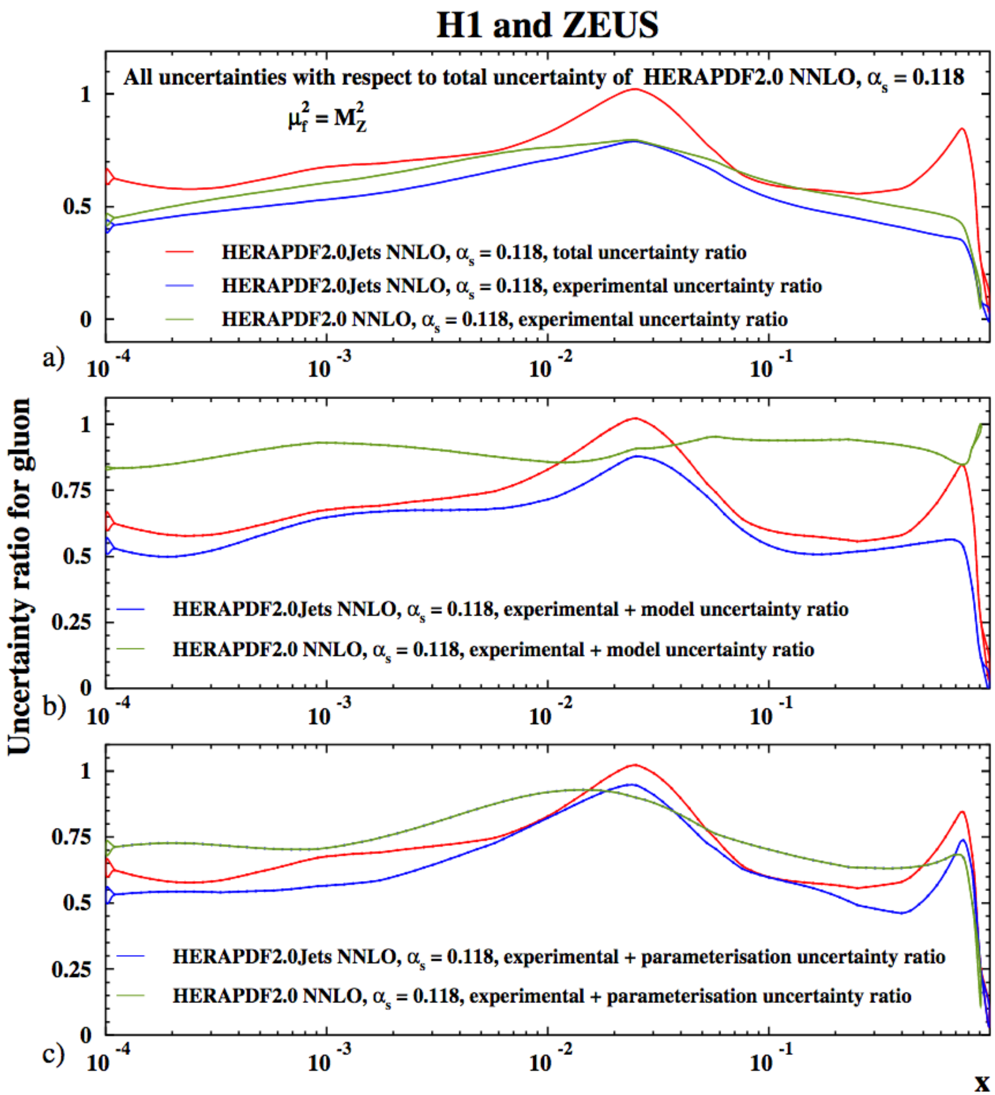


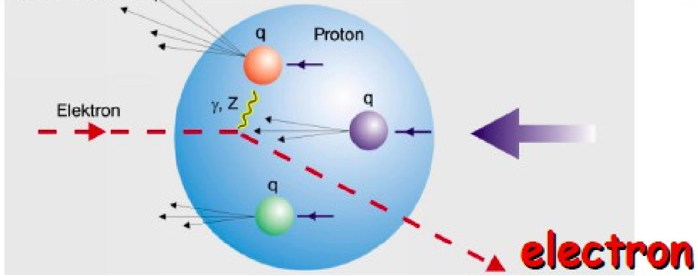
K. Wichmann @ REF22 NNLO jets @ HERA


H1 and ZEUS
All uncertainties with respect to total uncertainty of HERAPDF2.0 NNLO, αs = 0.118
μf² = 10 GeV²
HERAPDF2.0Jets NNLO, αs = 0.1155, total uncertainty ratio
HERAPDF2.0Jets NNLO, αs = 0.1155, experimental uncertainty ratio
HERAPDF2.0 NNLO, αs = 0.118, experimental uncertainty ratio
HERAPDF2.0Jets NNLO, αs = 0.1155, experimental + model uncertainty ratio
HERAPDF2.0 NNLO, αs = 0.118, experimental + model uncertainty ratio
HERAPDF2.0Jets NNLO, αs = 0.1155, experimental + parameterisation uncertainty ratio
HERAPDF2.0 NNLO, αs = 0.118, experimental + parameterisation uncertainty ratio
Uncertainty ratio for gluon
a)
b)
c)
x

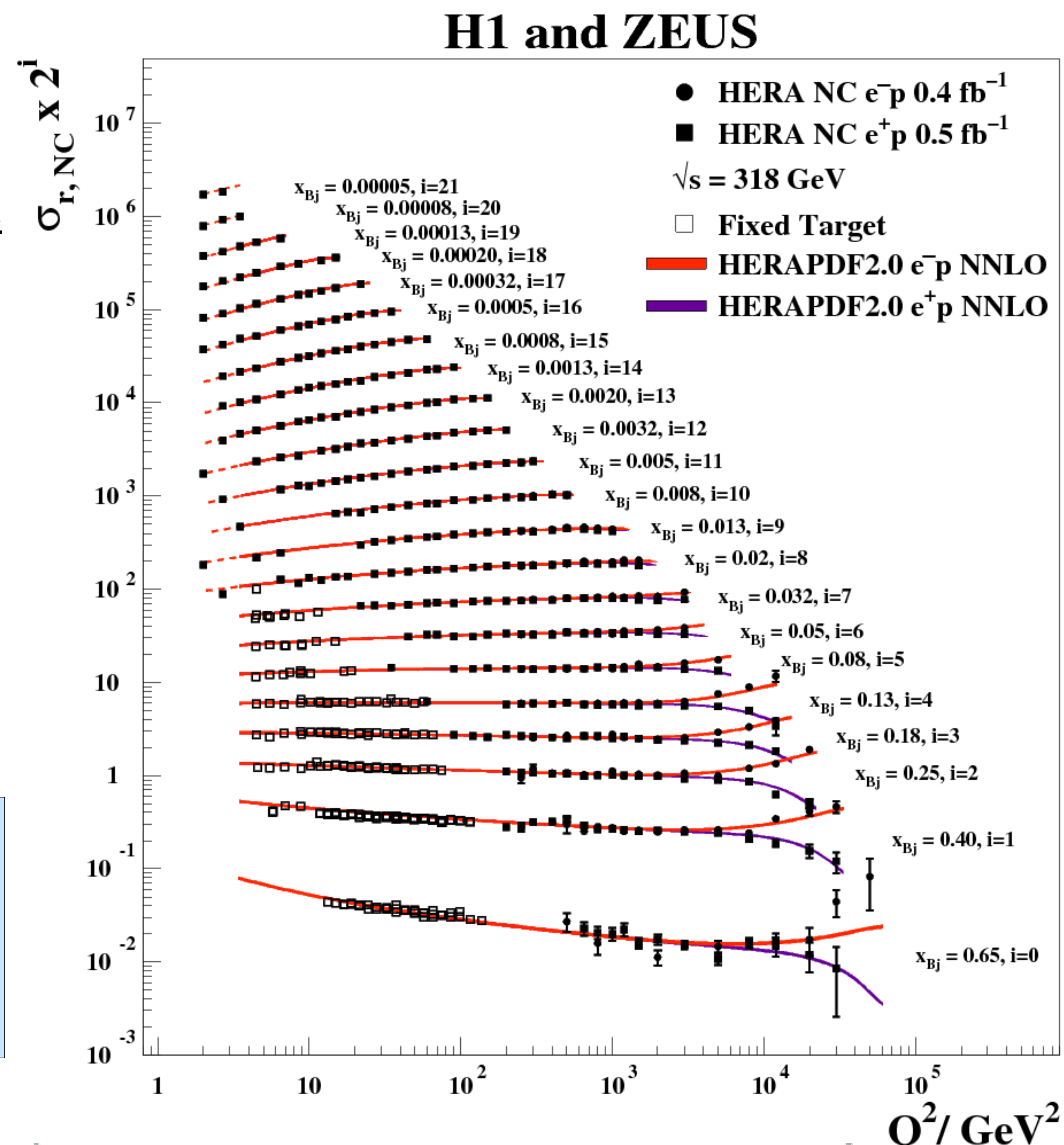

H1 and ZEUS
All uncertainties with respect to total uncertainty of HERAPDF2.0 NNLO, αs = 0.118
μf² = MZ²
HERAPDF2.0Jets NNLO, αs = 0.1155, total uncertainty ratio
HERAPDF2.0Jets NNLO, αs = 0.1155, experimental uncertainty ratio
HERAPDF2.0 NNLO, αs = 0.118, experimental uncertainty ratio
HERAPDF2.0Jets NNLO, αs = 0.1155, experimental + model uncertainty ratio
HERAPDF2.0 NNLO, αs = 0.118, experimental + model uncertainty ratio
HERAPDF2.0Jets NNLO, αs = 0.1155, experimental + parameterisation uncertainty ratio
HERAPDF2.0 NNLO, αs = 0.118, experimental + parameterisation uncertainty ratio
Uncertainty ratio for gluon
a)
b)
c)
x


H1 and ZEUS
All uncertainties with respect to total uncertainty of HERAPDF2.0 NNLO, α_s = 0.118
$\mu_f^2 = 10\ GeV^2$
HERAPDF2.0Jets NNLO, α_s = 0.118, total uncertainty ratio
HERAPDF2.0Jets NNLO, α_s = 0.118, experimental uncertainty ratio
HERAPDF2.0 NNLO, α_s = 0.118, experimental uncertainty ratio
HERAPDF2.0Jets NNLO, α_s = 0.118, experimental + model uncertainty ratio
HERAPDF2.0 NNLO, α_s = 0.118, experimental + model uncertainty ratio
HERAPDF2.0Jets NNLO, α_s = 0.118, experimental + parameterisation uncertainty ratio
HERAPDF2.0 NNLO, α_s = 0.118, experimental + parameterisation uncertainty ratio
Uncertainty ratio for gluon
a)
b)
c)
x


H1 and ZEUS
All uncertainties with respect to total uncertainty of HERAPDF2.0 NNLO, α_s = 0.118
$\mu_f^2 = M_Z^2$
HERAPDF2.0Jets NNLO, α_s = 0.118, total uncertainty ratio
HERAPDF2.0Jets NNLO, α_s = 0.118, experimental uncertainty ratio
HERAPDF2.0 NNLO, α_s = 0.118, experimental uncertainty ratio
HERAPDF2.0Jets NNLO, α_s = 0.118, experimental + model uncertainty ratio
HERAPDF2.0 NNLO, α_s = 0.118, experimental + model uncertainty ratio
HERAPDF2.0Jets NNLO, α_s = 0.118, experimental + parameterisation uncertainty ratio
HERAPDF2.0 NNLO, α_s = 0.118, experimental + parameterisation uncertainty ratio
Uncertainty ratio for gluon
a)
b)
c)
x



HERA combined inclusive DIS



<u>HERA combined DIS data are core of every modern PDF extraction</u>

- 2927 data points combined to 1307
- impressive precision

HERAPDF approach uses ONLY HERA data in global QCD fit

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