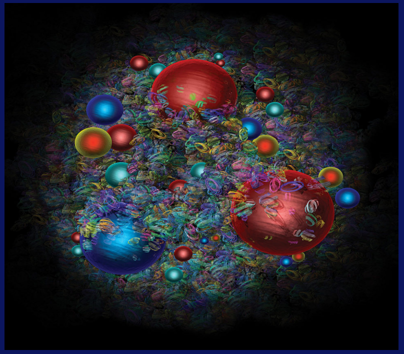
Moriond QCD

La Thuile

19 – 26 March 2022



Impact of jet-production data on the NNLO HERAPDF2.0 proton PDFs, and extraction of αs(MZ)

EPJ C 82, 243 (2022)

Claire Gwenlan, Oxford

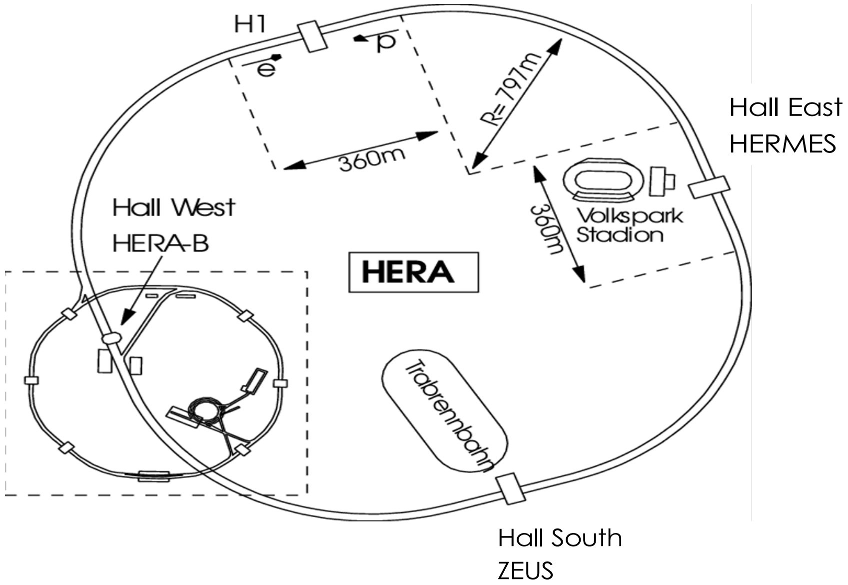
on behalf of the H1, ZEUS, NNLOJet and APPLfast collaborations

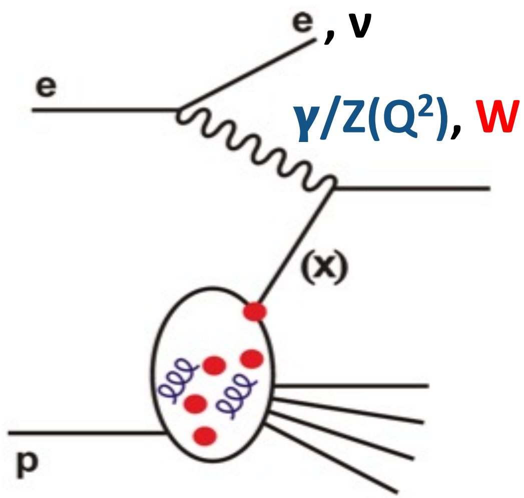
HERA (1992 – 2007)

- **HERA**: the world's first and, to date, only, **ep collider**, situated at DESY, Hamburg

$e^{\pm}$ **27.5 GeV** → ← **820 – 920 GeV** p

$\sqrt{s}$ = 320 GeV





Q^2: virtuality of exchanged boson

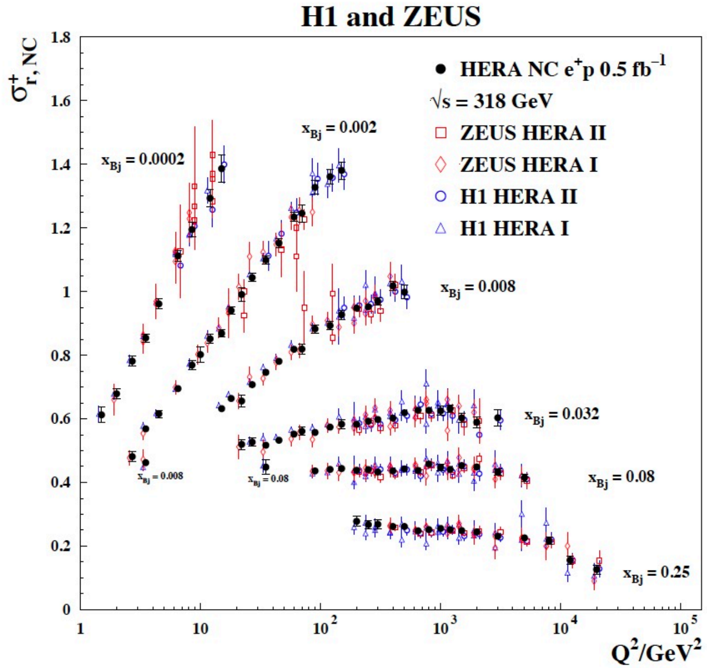
x: longitudinal proton momentum fraction carried by struck parton

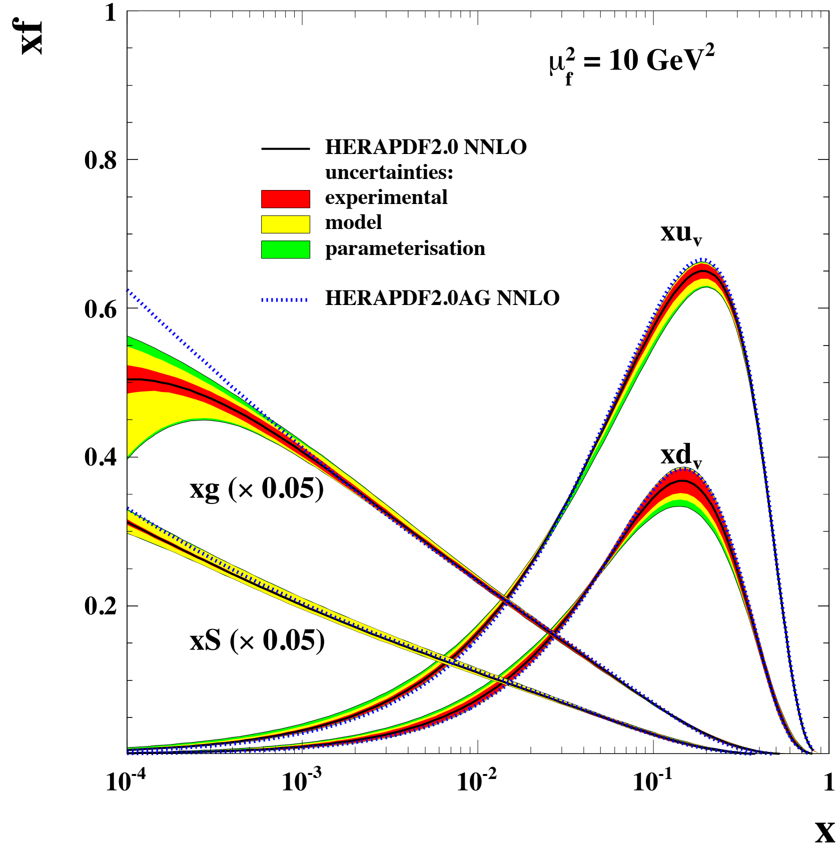
NC: $ep \to e'X$ CC: $ep \to \nu_e X$

- **two general-purpose experiments: H1 and ZEUS**
- **DIS at HERA: cleanest and highest resolution microscope for probing proton up to very high Q^2 and very low x**

HERA legacy

arXiv:1506.06042





- **HERA I+II (H1+ZEUS combined) inclusive DIS dataset is most important input to any modern proton PDF** (just small subset shown here)

- **HERAPDF2.0 – uses only HERA inclusive DIS**

- **HERA,** a success story: established detailed structure of proton, including strong rise of gluon (and much more besides: large contribution from diffraction, jets, **γ** structure, **αs**, c, b, BSM limits, …)

outline of this talk

EPJ C 82, 243 (2022)
arXiv:2112.01120

- completion of **HERAPDF2.0** family of **PDFs**
- previously produced (arXiv:1506.06042): HERAPDF2.0 LO, NLO and NNLO PDFs;
- **HERAPDF2.0Jets** was only at **NLO** – since no NNLO DIS jet predictions at that time

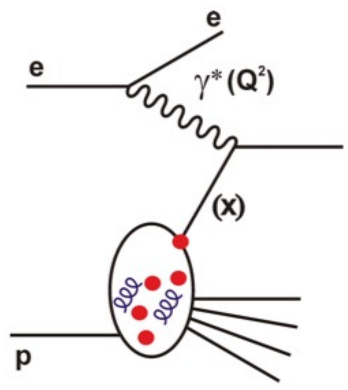
- NEW **HERAPDF2.0Jets NNLO** presented here
- NNLO QCD DIS jet predictions from NNLOJET, interfaced to APPLfast for fast theoretical predictions

- simultaneous fit of **PDFs + αs(MZ)**
- inclusion of jet data allows constrained **αs**:

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

- **NEW** PDFs at NNLO QCD for fixed **αs(MZ)=0.118** and **0.1155**

why jet data?

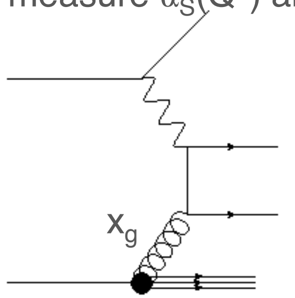


- HERA inclusive DIS gives information on **quark PDFs** via NC and CC cross sections, and **gluon** via **scaling violations**
- HERA inclusive DIS alone cannot give precise **α_s** determination since shape of **gluon** and **α_s** are coupled through DGLAP equation

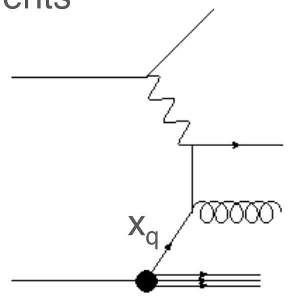
- considering also **HERA jet data**, which depend on **α_s** and **gluon in a different way**, helps break correlation, and gives improved constraints on both

Jet studies in the Hadron Final state gives us more information (from A. Cooper-Sarkar)

- You can measure $\alpha_S(Q^2)$ and $xg(x,Q^2)$ from 2+1 jet events



BGF

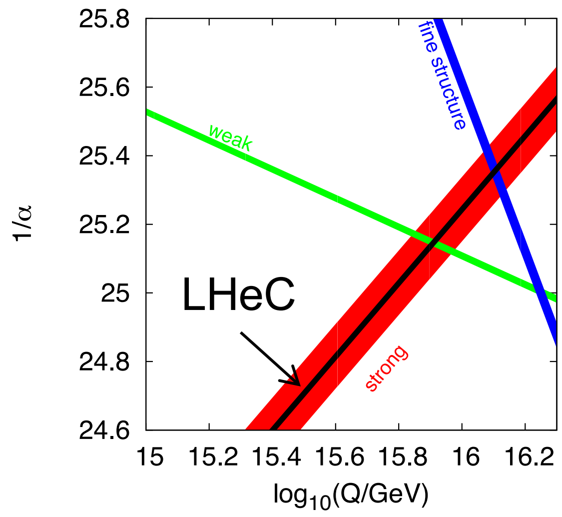


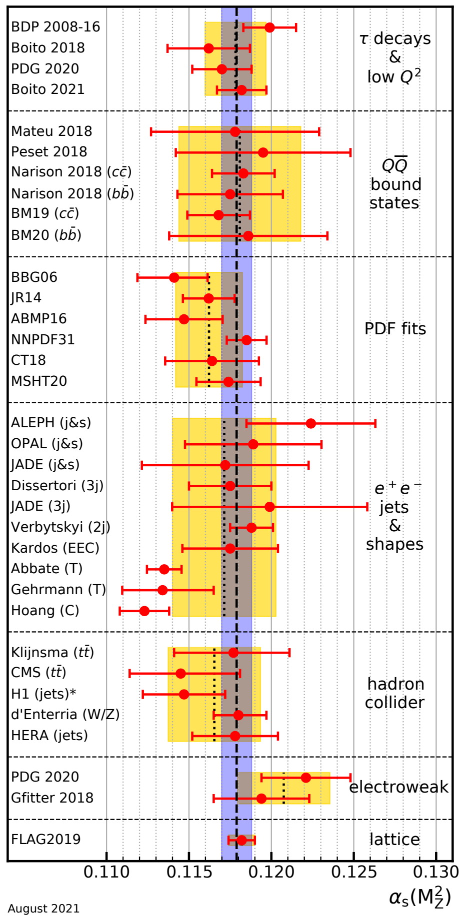
QCDC

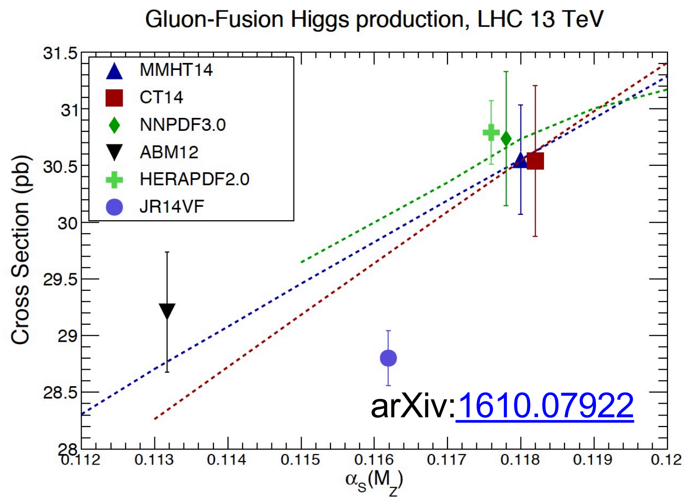
+1 means proton remnant

$$\sigma_{2+1} \sim \alpha_s\left[A\, x_g\, g(x_g, Q^2) + B\, x_q\, q(x_q, Q^2)\right]$$

motivation and impact at LHC







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

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

  …

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

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

- what is true **αs** central value and uncertainty?

  new precise determinations have important role to play

HERAPDF approach

- **HERAPDF uses only HERA data**

- HERAPDF2.0 based on FINAL combination of HERA I+II inclusive DIS data
- combination yields very precise and consistent dataset for 4 different processes: **e+p** and **e-p** neutral (**NC**) and charged (**CC**) current reactions (also e+p NC @ 4 beam energies)

- single, consistent dataset → conventional X^2 tolerance, $\Delta X^2=1$, when setting 68% CL experimental uncertainties

- HERAPDF evaluates model and parameterisation uncertainties as well as experimental

- HERAPDF2.0Jets adds HERA inclusive- and di-jet data over wide Q^2 range

- **HERA** – other advantages:
- pure proton target, no need for heavy target/deuterium corrections
- d-valence from CC e+p without need for strong isospin symmetry assumption
- negligible higher twist effects (data at high hadronic mass, W > 15 GeV)

HERA NNLO QCD analysis: jet datasets

- strong overlap with those used in previous NLO analysis (arXiv:1506.06042)

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	15,000	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	15,000	351	e^+p/e^-p	319	Yes	30	30
H1 normalised dijets at high Q^2	2003–2007	150	15,000	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	10,000	38.6	e^+p	301	No	30	30
ZEUS dijets	1998–2000 and 2004–2007	125	20,000	374	e^+p/e^-p	318	No	22	16

low Q^2 H1 datasets added (published **2016**) that were not used in the previous NLO analysis

- … plus, some data removed cf. NLO analysis:
- trijets; no NNLO QCD calculations available
- low scale data $\mu = \sqrt{(Q^2 + pt^2)} < \mathbf{10}$ GeV; keeps NNLO scale uncertainties below **10%**
- 6 ZEUS dijet data points at low pt, for which predictions are not truly NNLO

- all systematic and statistical correlations implemented

HERAPDF parameterisation and uncertainties

- generic form as for HERAPDF2.0 NNLO (full details in extras);
- parameterise: **xg**, **xuv**, **xdv**, **xUbar=xubar**, **xDbar=x(dbar+sbar)** at scale $\mu_{f0}^2 = 1.9\,\mathrm{GeV}^2$

Regge theory inspired

f(1)=0

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

(extra negative term for gluon $-A'_g x^{B'_g}(1-x)^{C'_g}$)

QCD sum rules constrain: **Ag**, **Auv**, **Adv**

$$x\bar{s} = f_s x\bar{D}$$

$$A_{\bar{U}} = A_{\bar{D}}(1-f_s),\ B_{\bar{U}} = B_{\bar{D}} \quad (x\bar{u} \to x\bar{d} \text{ as } x \to 0)$$

D,E parameters only if favoured by χ^2

14 parameter central fit

- PDF uncertainties:

experimental uncertainties treated using Hessian method, evaluated with **$\Delta\chi^2$=1**

- Model:

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*

Parameter:

+ addition of 15th D,E parameter(s)

† range of variation for Mc and Mb restricted using HERA charm and beauty data (see extras)

HERAPDF specification updates

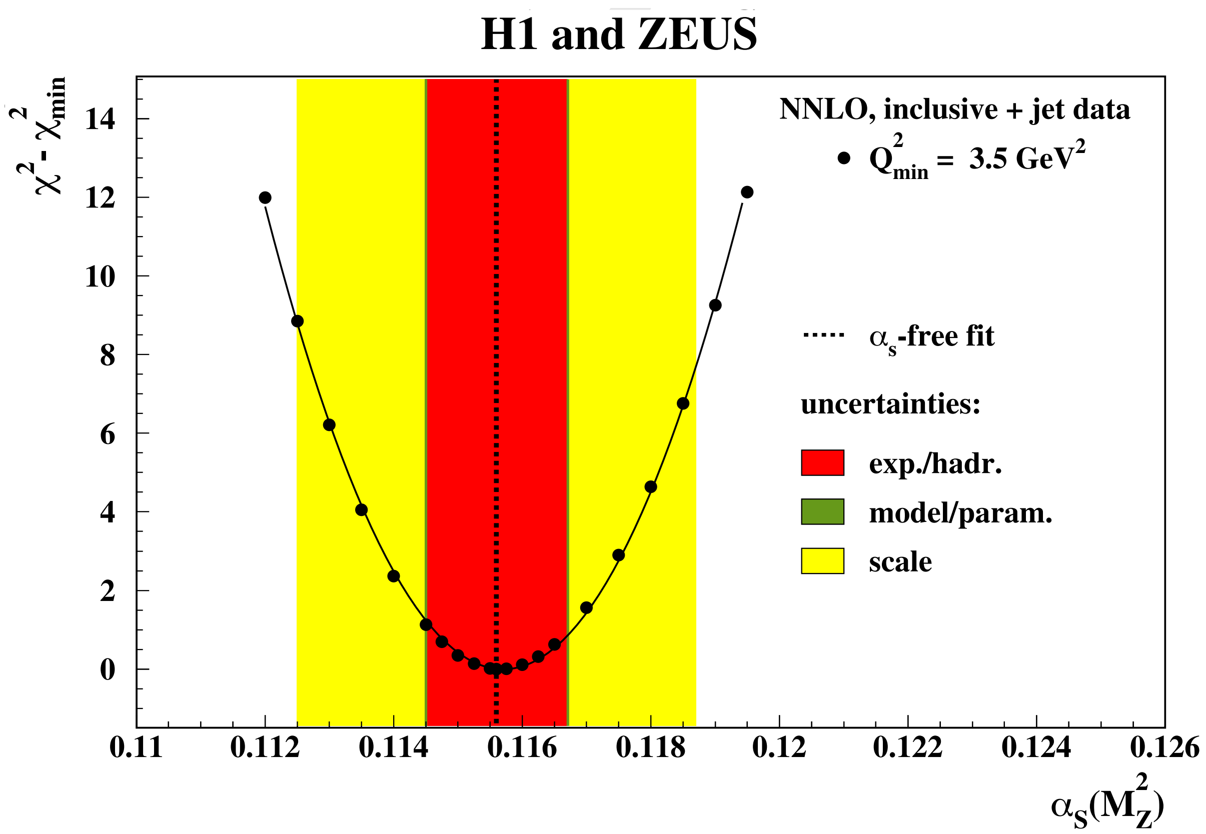
- factorisation and renormalisation **scale** choices: $\mu_F^2 = \mu_R^2 = (Q^2 + pt^2)$
- **scale uncertainties treated as completely correlated between bins and datasets**

- cf. previous NLO analysis:
- $\mu_F^2 = Q^2$; updated since not a good choice for low Q^2 jet data; change makes almost no difference for high Q^2
- $\mu_R^2 = (Q^2 + pt^2)/2$; NNLO fit with $\mu_R^2 = (Q^2 + pt^2)$ gives $\Delta\chi^2 = $ **–15** cf. $\mu_R^2 = (Q^2 + pt^2)/2$ and vice versa for NLO
- scale uncertainties previously treated as ½ correlated and ½ uncorrelated

† 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 experimental systematics**; treated as ½ correlated, ½ uncorrelated between bins and datasets, c.f. previously treated using offset method
- (small) uncertainties on theory predictions included

HERAPDF2.0Jets NNLO α_s determination

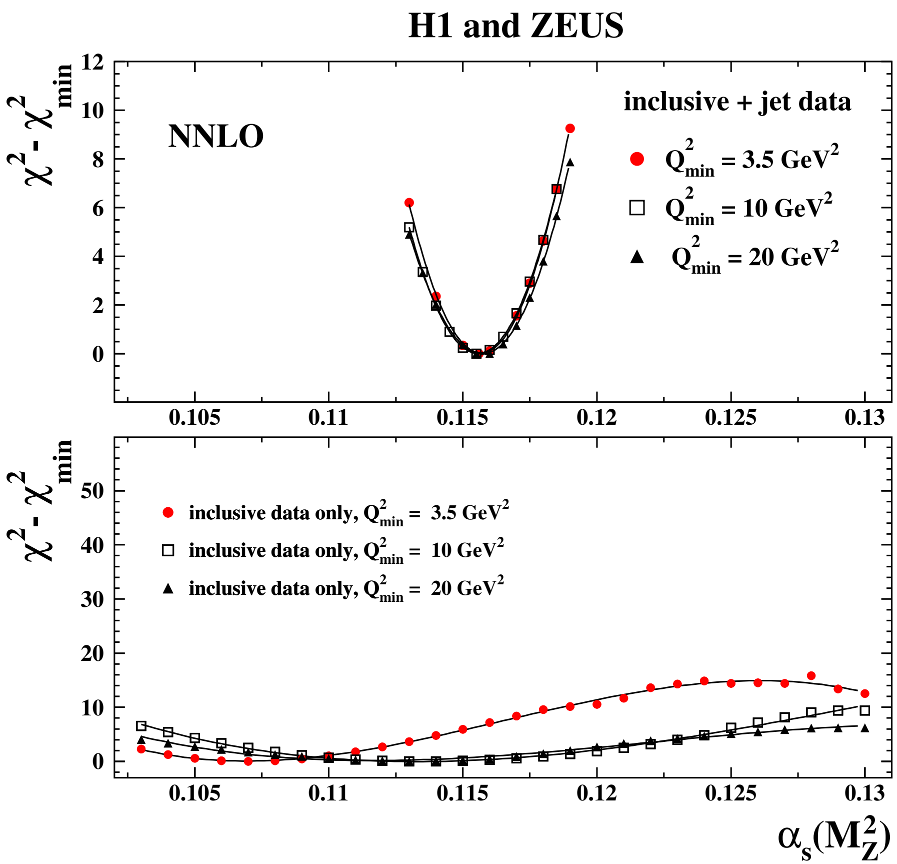


X^2/dof=**1.197**

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

NB, scale uncertainty dominates, μR, μF varied by factor of 2 avoiding cases with μR/μF =4 or ¼, and treated fully correlated between bins and datasets; (exp) uncertainty includes hadronisation correction uncertainties

α_S sensitivity to cut and parameterisation choices



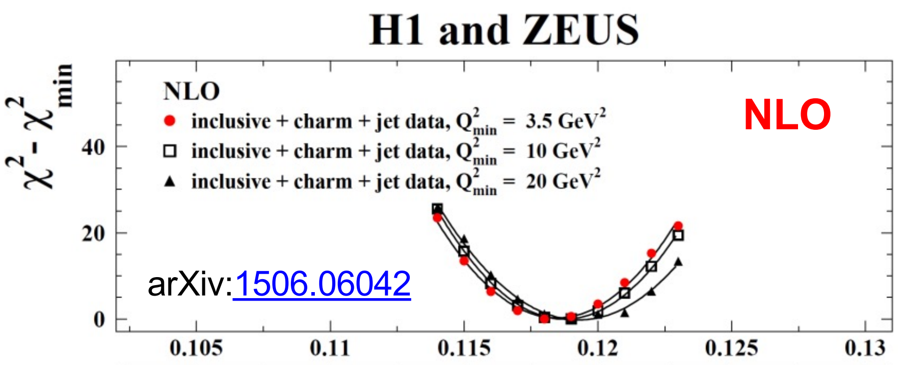
- HERA data at small x, Q^2 may be subject to need for ln(1/x) resummation or higher twist effects (EG, arXiv:1506.06042, 1710.05935)
- X^2 scans performed with various minimum Q^2 cuts to assess sensitivity; no significant change to extracted α_S(Mz)
- inclusive DIS data alone unable to sufficiently constrain α_S(Mz)

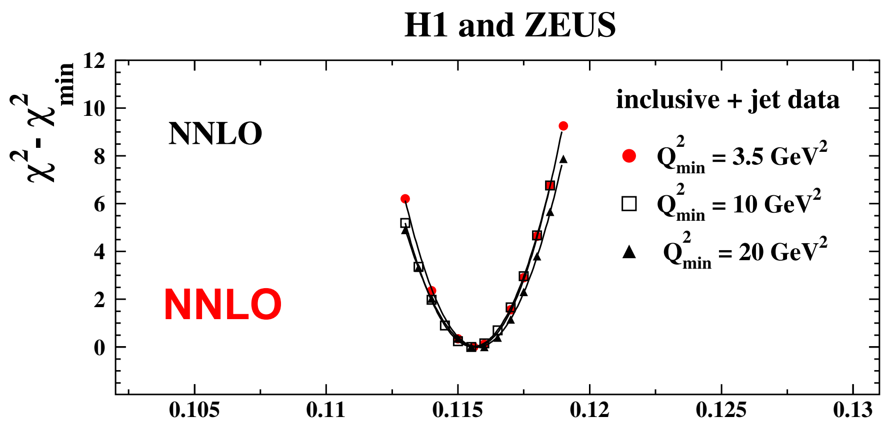
- in addition, alternative parameterisation checked, with negative gluon term removed (Ag'=0) :
- NB, adding a multiplicative (1+Dg.x) does not change this result

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

consistent with central result

comparison to NLO αs result





NNLO X^2 scans from new fit with HERA jet data, compared to previously published scans at NLO

similar level of precision at NLO and NNLO

smaller value of αs(Mz) preferred at NNLO

NB, however, these results not directly comparable, since different scale choice and slightly different jet datasets

with choices harmonised, result is in fact an **increased** difference between **NLO** and **NNLO**:

αs(Mz) = 0.1186 ± 0.0014 (exp) **NLO**

αs(Mz) = 0.1144 ± 0.0013 (exp) **NNLO**

← change from preferred value of 0.1156 mainly from exclusion of the H1 low Q^2 data, and low-pt points at high Q^2 (more detail in extras)

comparison to NLO α_s result

- in previous NLO analysis, scale uncertainties were applied as ½ correlated and ½ uncorrelated between bins and data sets, due to inclusion of HQ and trijet data

NOW using that previous procedure, our present NNLO result becomes:

$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\ (\mathrm{exp})\ {}^{+0.0001}_{-0.0002}\ (\mathrm{model + parameterisation})\ \boxed{\pm 0.0022}\ (\mathrm{scale})$$

↑ (includes hadronisation uncertainties)

c.f. published NLO result:

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

→ considerable reduction in scale uncertainty from NLO to NNLO

comparison to other HERA DIS jet results

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

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

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

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

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

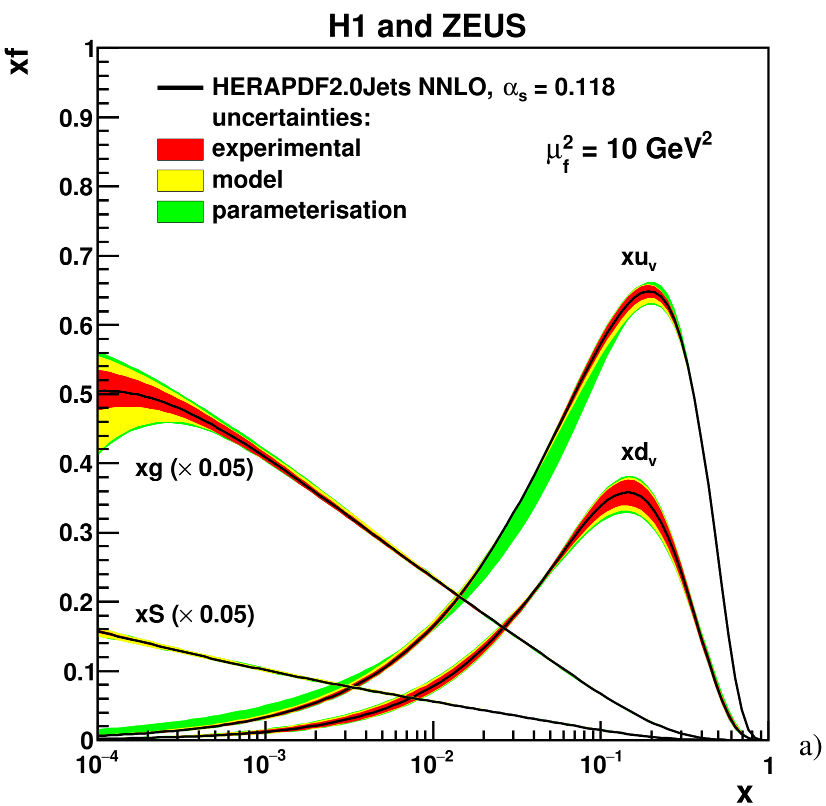
$$0.1147\ (11)_{\mathrm{exp,NP,PDF}}\ (2)_{\mathrm{mod}}\ (3)_{\mathrm{par}}\ (23)_{\mathrm{scale}}$$

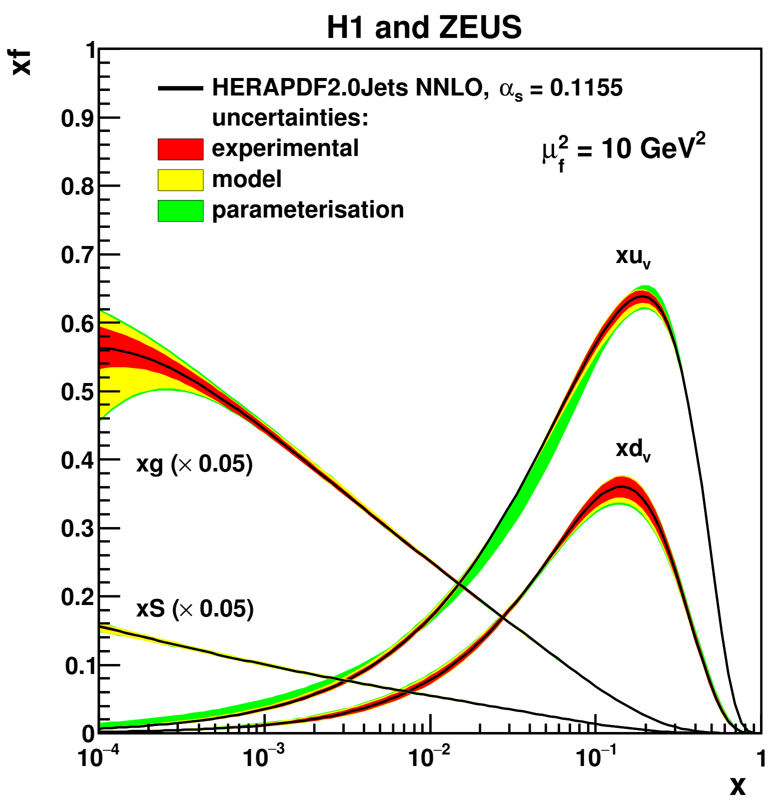
analysis required $Q^2 >$ **10** GeV^2; NEW HERA result re-evaluated with this cut (rather than >**3.5** GeV^2), is:

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

† balance between experimental uncertainty and scale can be changed with choice of μ cut

HERAPDF2.0 Jets NNLO PDFs

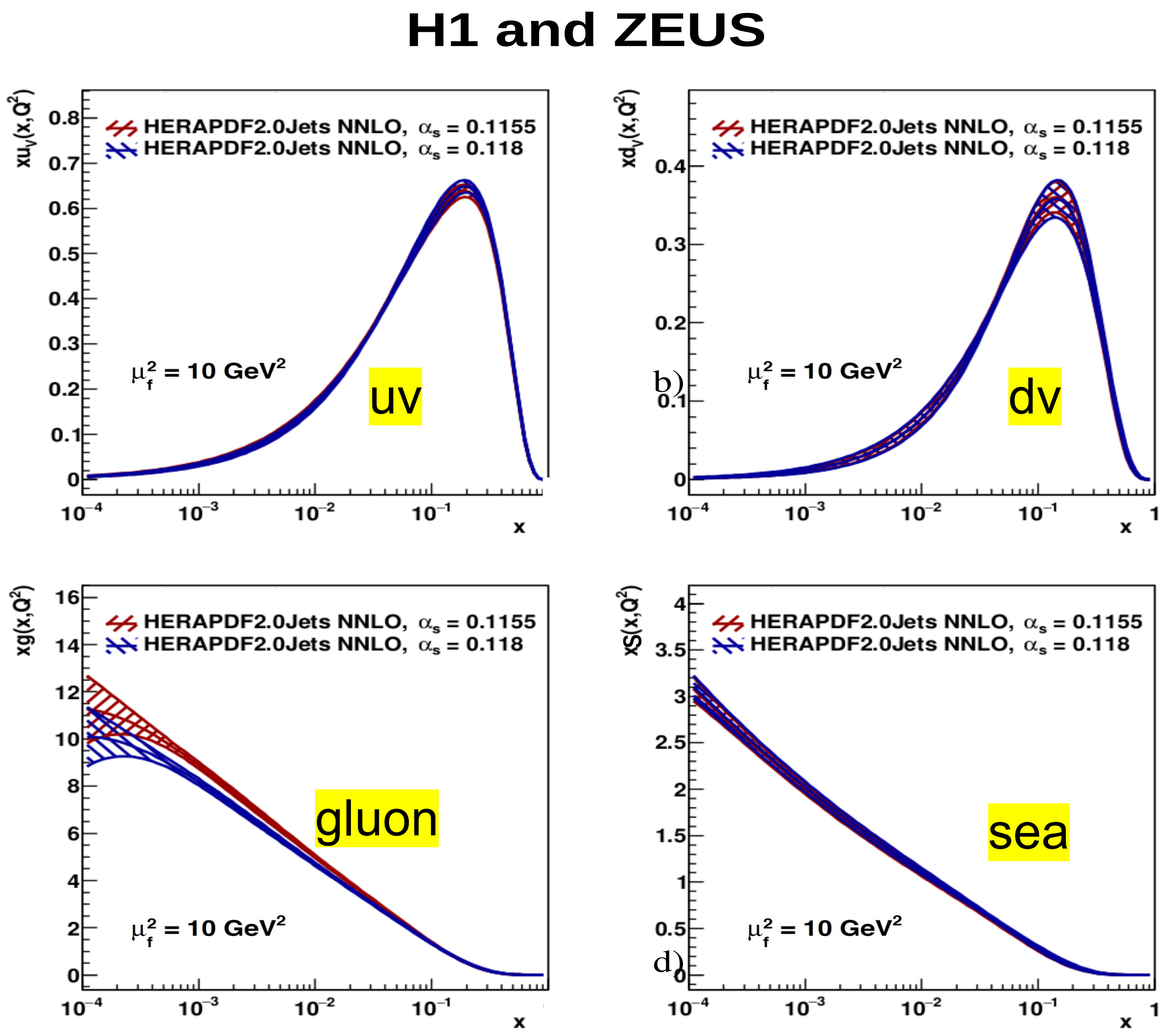




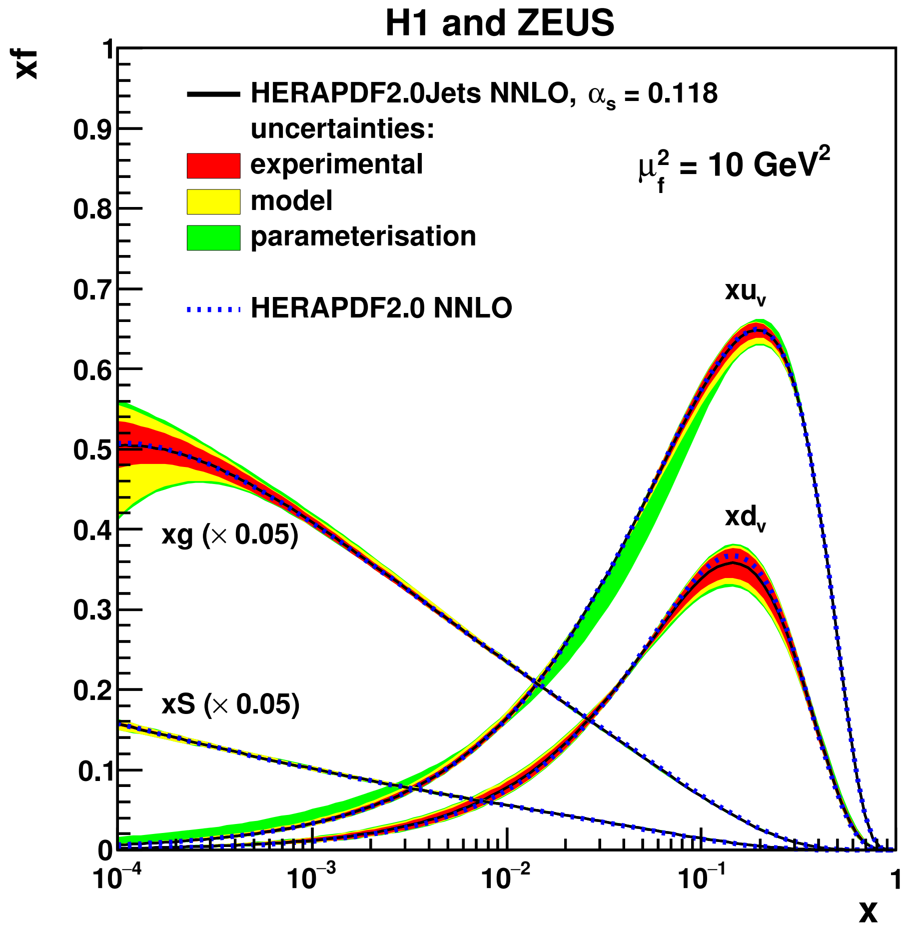
$\alpha_s(M_Z)=0.118$ $\alpha_s(M_Z)=0.1155$

NEW set of PDFs also determined, **HERAPDF2.0Jets NNLO**

comparison of $\alpha_s(M_Z)$=0.1155 and 0.118



HERAPDF2.0 vs. HERAPDF2.0Jets NNLO

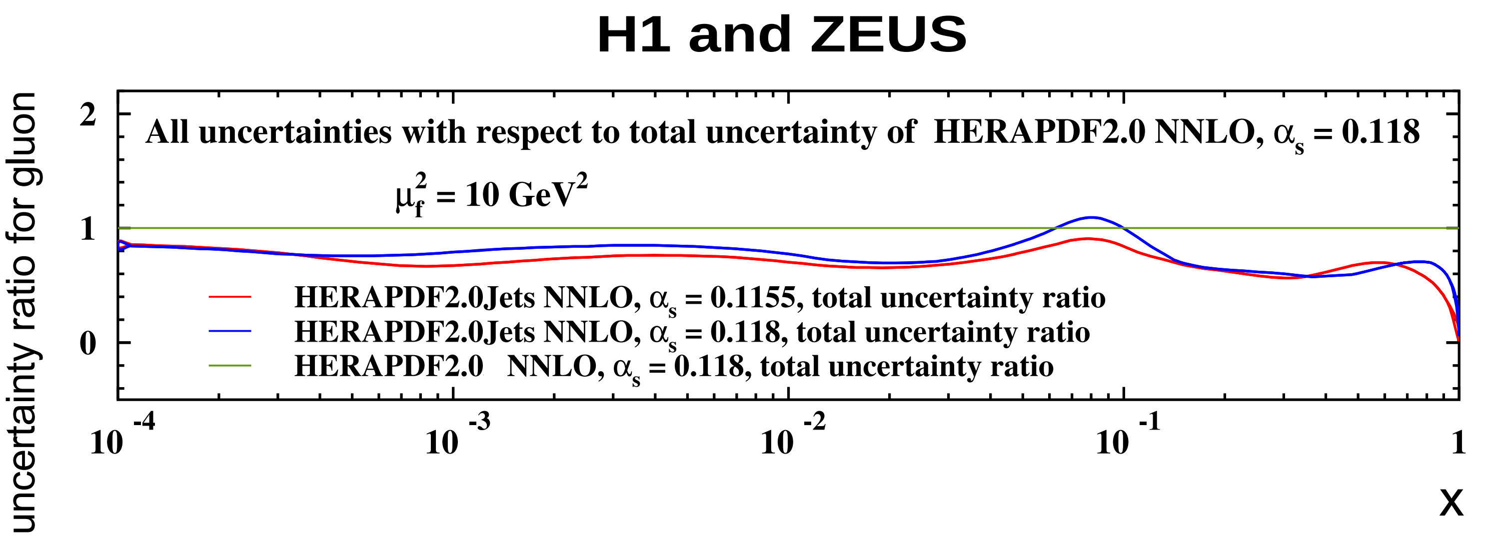


HERAPDF2.0Jets NNLO
αs =0.118
X^2/dof=**1.199**

HERAPDF2.0 NNLO
X^2/dof=**1.205**

comparison with **HERAPDF2.0 NNLO**, with fixed **αs(Mz)=0.118**
(arXiv:1506.06042)

Gluon PDF uncertainties



comparison of uncertainties of new NNLO **jets fits** with **inclusive-only** fit

- large-x gluon uncertainties reduced due to jet data
- small-x uncertainties reduced due to reduced model uncertainties in Mc and μ_{f0}^2

summary

- HERAPDF2.0 family of PDFs completed by performing an **NNLO QCD fit including HERA DIS inclusive-jet and di-jet data**
- possible due to **theoretical** (NNLOJet) and **fast interpolation grid technology** developments (APPLfast)

- jet data allows constraint of **αs(MZ)** – new **HERA NNLO PDF+αs** result:

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

with scale uncerts. evaluated in same way as previous NLO result: ± 0.0022

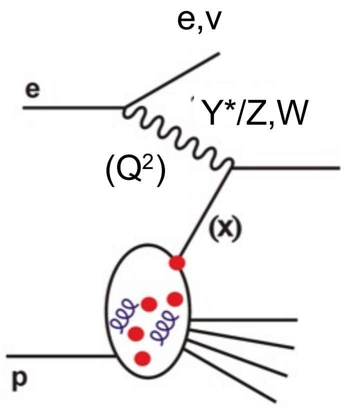
cf. NLO value: $\alpha_s(M_Z^2) = 0.1183 \pm 0.0009\,(\mathrm{exp}) \pm 0.0005\,(\mathrm{model/par.}) \pm 0.0012\,(\mathrm{had})^{+0.0037}_{-0.0030}\,(\mathrm{scale})$

shift downwards at NNLO and reduction in scale uncertainties

- two new PDF sets, to appear in LHAPDF:
- HERAPDF2.0Jets NNLO αs(MZ)=0.1180 (PDG value)
- HERAPDF2.0Jets NNLO αs(MZ)=0.1155 (value favoured by new fits)

extras

DIS – the best tool to probe proton structure



- Kinematic variables:

$Q^2 = -q^2 = -(k - k')^2$ Virtuality of the exchanged boson

$x = \frac{Q^2}{2p \cdot q}$ Bjorken scaling parameter

$y = \frac{p \cdot q}{p \cdot k}$ Inelasticity parameter

$s = (k+p)^2 = \frac{Q^2}{xy}$ Invariant c.o.m.

Neutral Current:

LO expressions

$$\frac{d^2\sigma^{\pm}_{NC}}{dx dQ^2} = \frac{2\alpha\pi^2}{xQ^4}\left(Y_+ F_2 \mp Y_- xF_3 - y^2 F_L\right)$$

$F_2 \sim \sum_i e_i^2 (xq_i + x\bar{q}_i)$ $xF_3 \sim \sum_i (xq_i - x\bar{q}_i)$ $F_L \sim \alpha_s \times g$

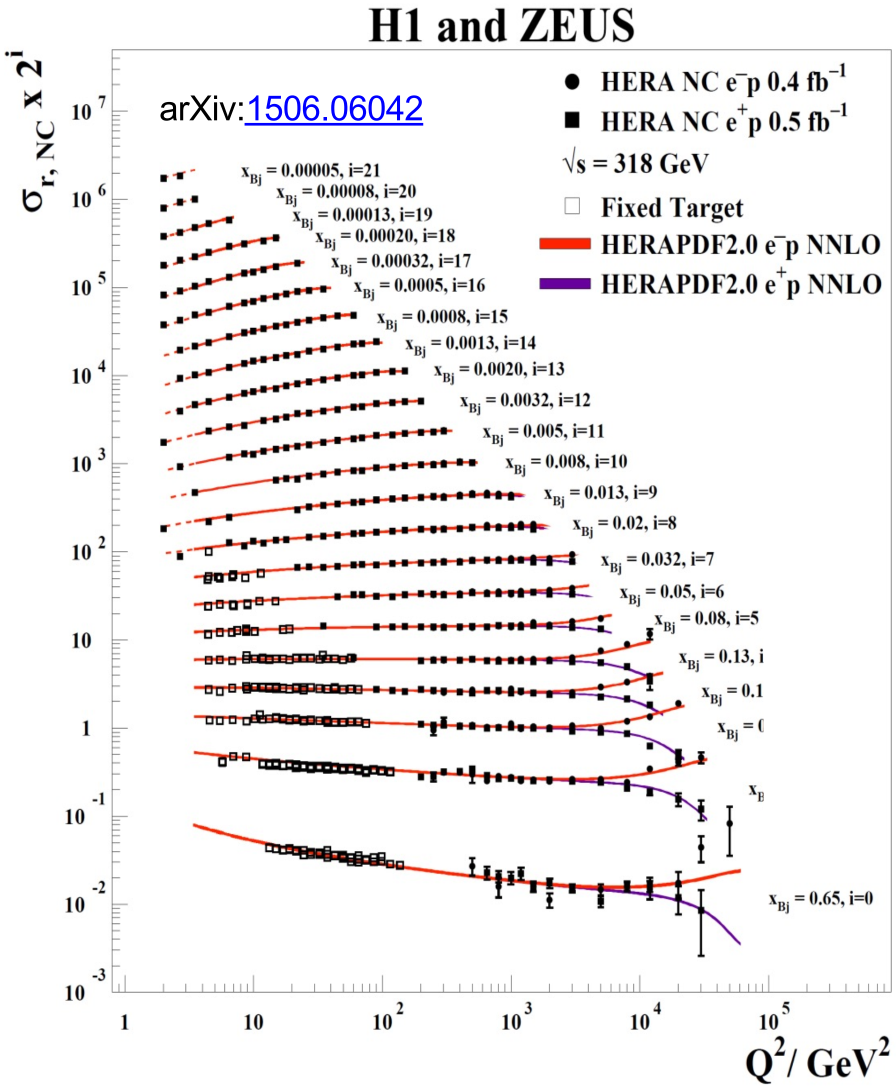
quarks pdfs — valence quarks — gluon via $\mathcal{O}(\alpha s)$

Charged Current:

$$\frac{d^2\sigma^{-}_{CC}}{dx dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2 + Q^2}\left(u + c + (1-y^2)(\bar{d} + \bar{s})\right)$$

$$\frac{d^2\sigma^{+}_{CC}}{dx dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2 + Q^2}\left(\bar{u} + \bar{c} + (1-y^2)(d + s)\right)$$

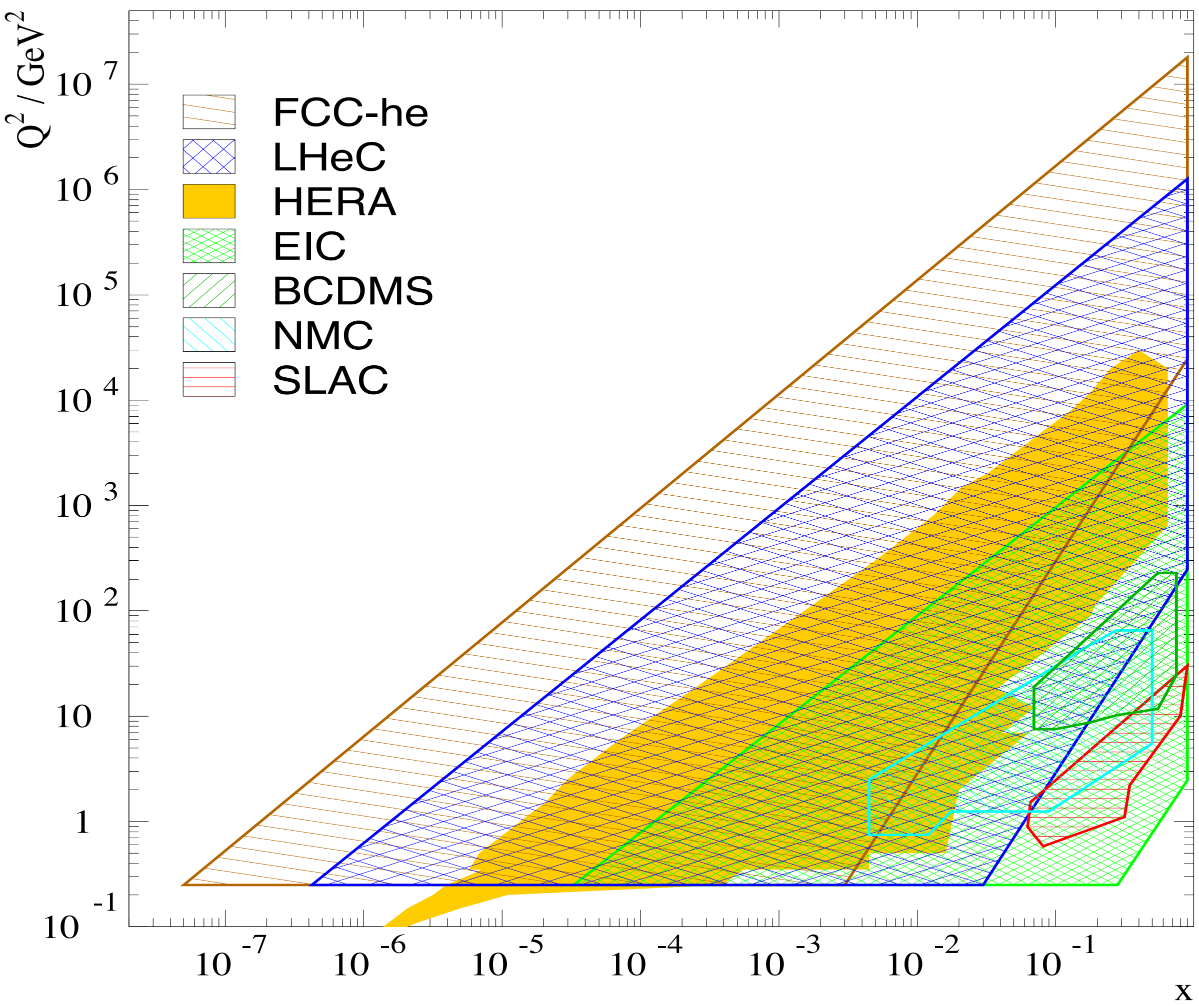
flavour decomposition



gluon from scaling violations:

$$\frac{\partial F}{\partial \ln Q^2} \sim x\, g(x, Q^2)$$

(x,Q2) plane



FCC-he
LHeC
HERA
EIC
BCDMS
NMC
SLAC
Q^2 / GeV^2
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x

HERAPDF parameterisation

- generic form as for HERAPDF2.0 NNLO;
- parameterise: **xg**, **xuv**, **xdv**, **xUbar=xubar**, **xDbar=x(dbar+sbar)** at scale $\mu_{f0}^2 = 1.9\,\mathrm{GeV}^2$

Regge theory inspired

f(1)=0

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

(extra negative term for gluon $-A_g' x^{B_g'}(1-x)^{C_g'}$)

QCD sum rules constrain: **Ag**, **Auv**, **Adv**

$x\bar{s} = f_s x\bar{D}$

$A_{\bar{U}} = A_{\bar{D}}(1-f_s), B_{\bar{U}} = B_{\bar{D}}$ $(x\bar{u} \to x\bar{d}$ as $x \to 0)$

D,E parameters only if favoured by X^2

14 parameter central fit

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A_g' x^{B_g'}(1-x)^{C_g'},$$

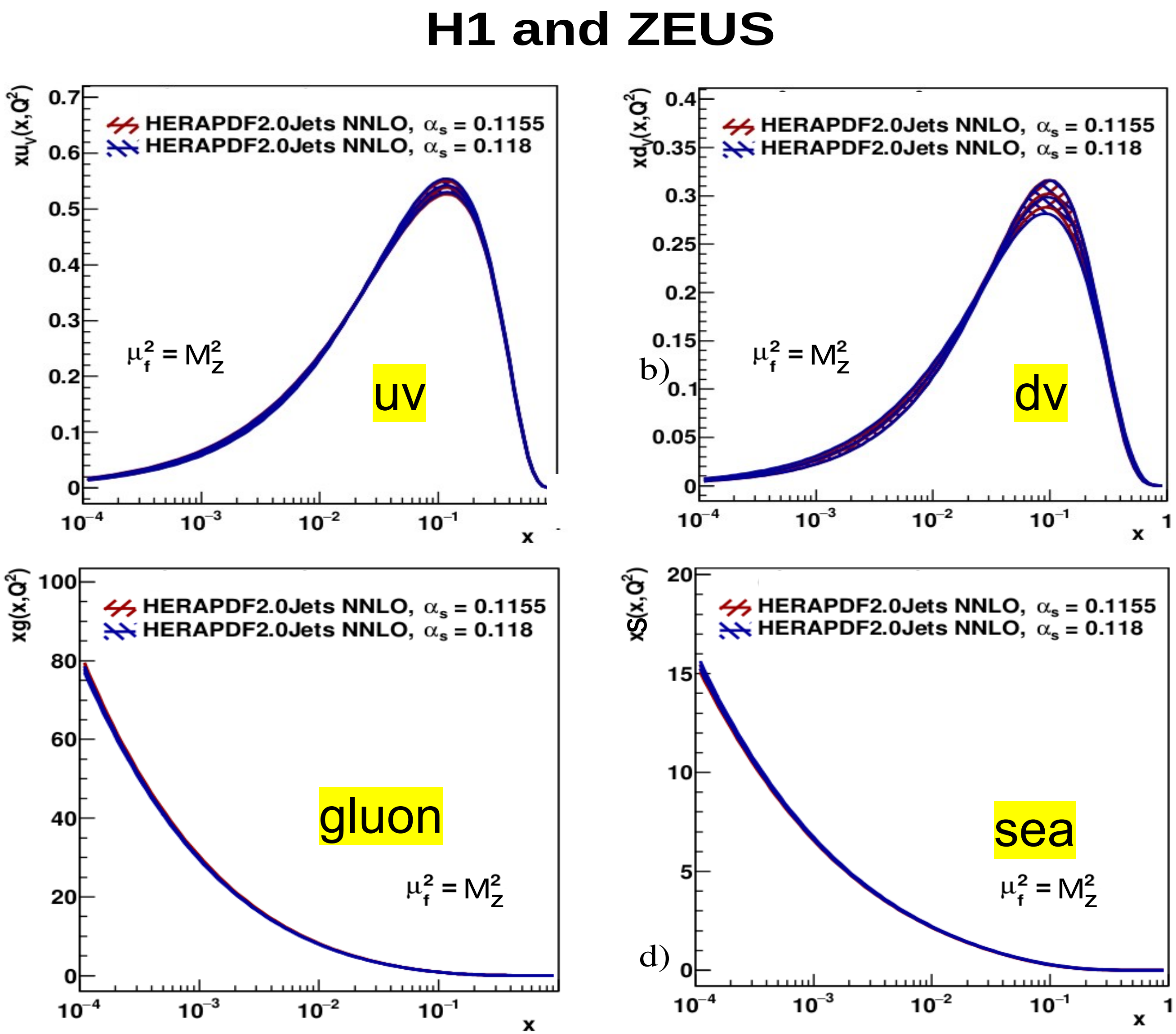
$$xu_v(x) = A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right),$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}},$$

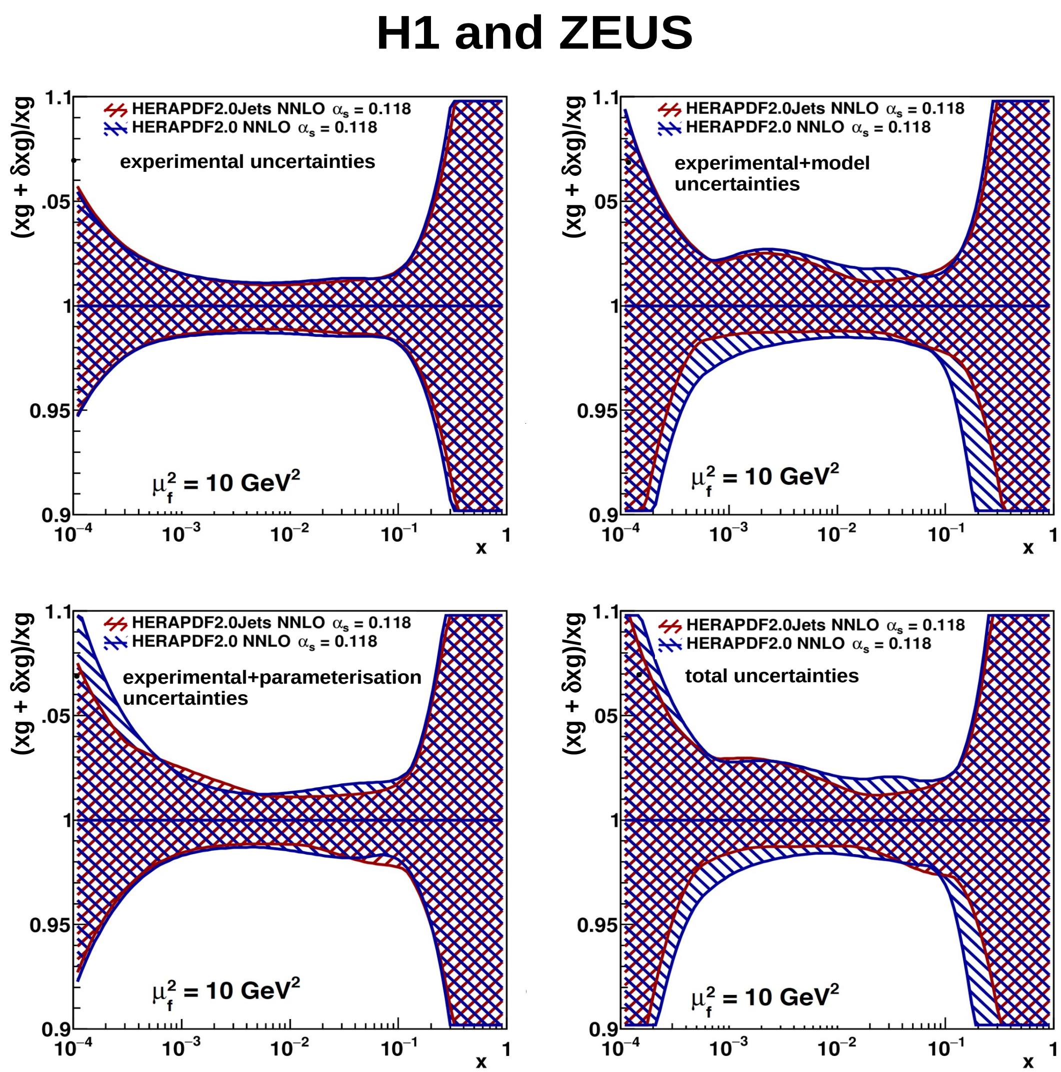
$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}\left(1+D_{\bar{U}}x\right),$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.$$

comparison of $\alpha_s(M_Z)$=0.1155 and 0.118

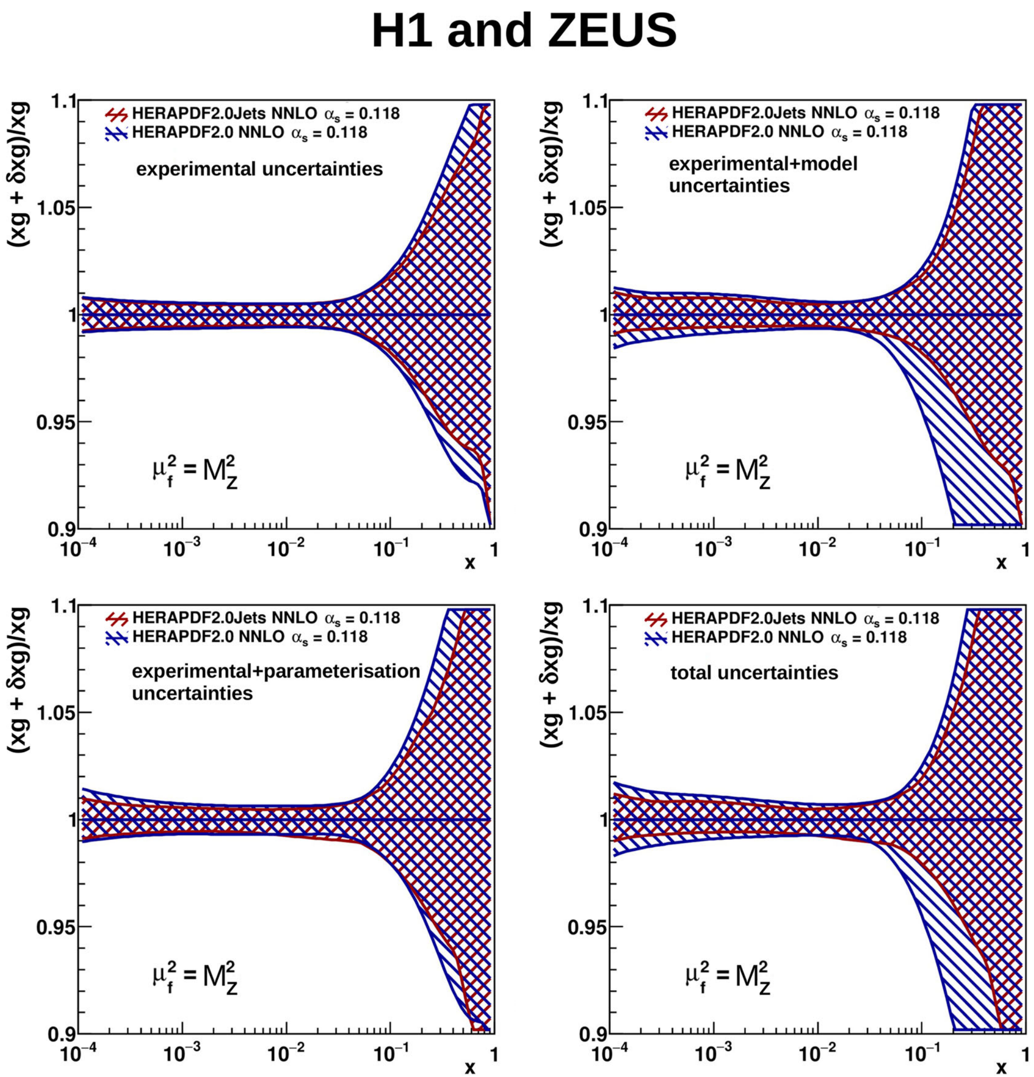


Gluon PDF uncertainties



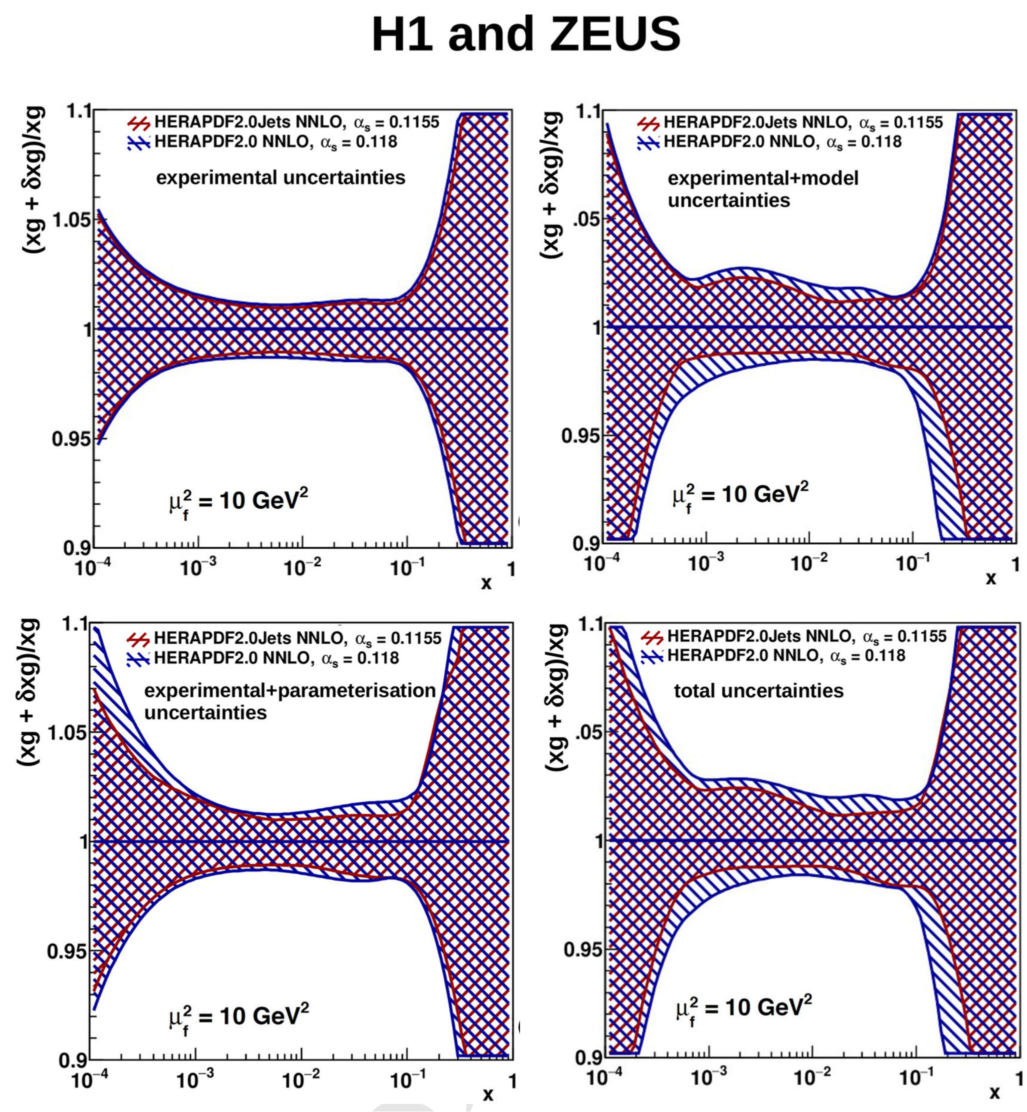
comparison of uncertainties of new NNLO **jets fit** with **inclusive-only** fit

Gluon PDF uncertainties



comparison of uncertainties of new NNLO **jets fit** with **inclusive-only** fit

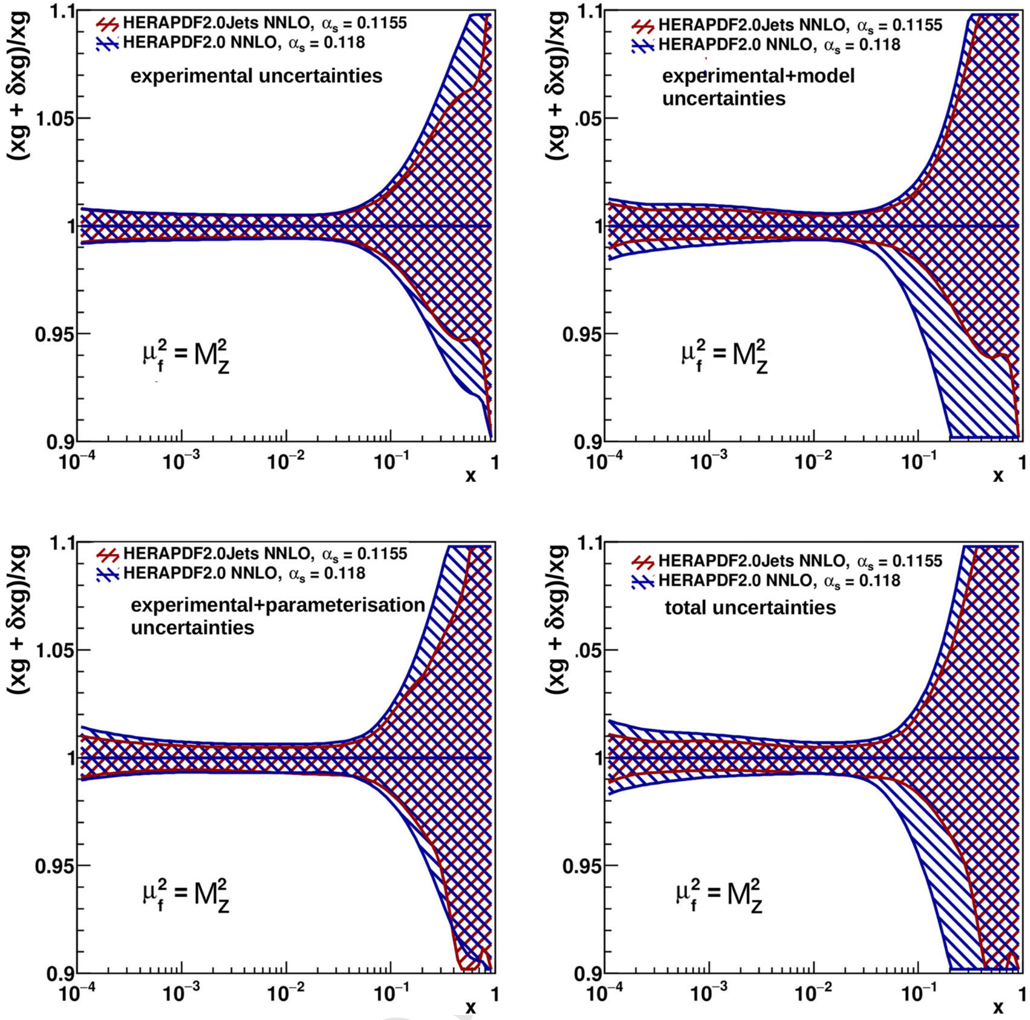
Gluon PDF uncertainties



new NNLO **jets fit** at **αs(Mz)=0.1155** vs HERAPDF2.0 NNLO with **αs(Mz)=0.118**

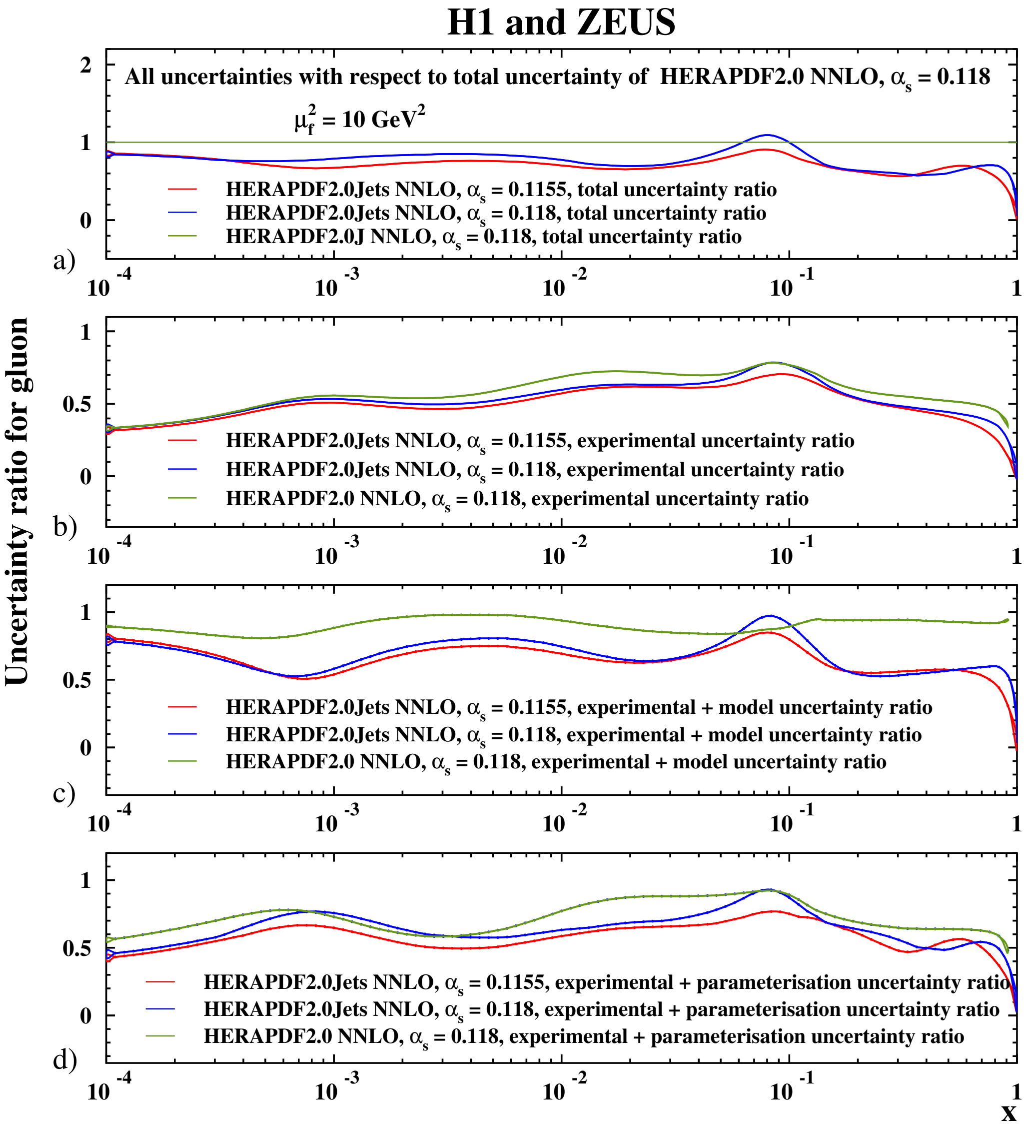
Gluon PDF uncertainties

H1 and ZEUS



new NNLO **jets fit** at **αs(Mz)=0.1155** vs HERAPDF2.0 NNLO with **αs(Mz)=0.118**

Gluon PDF uncertainties



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 ± 0.0011(exp) $^{+0.0001}_{-0.0002}$(model+parametrisation ± 0.0022(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 ± 0.0008(exp)±0.0012(had$)^{+0.0003}/_{-0.0005}$(mod/param) $^{+0.0037}/_{-0.003}$(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 μ > 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:

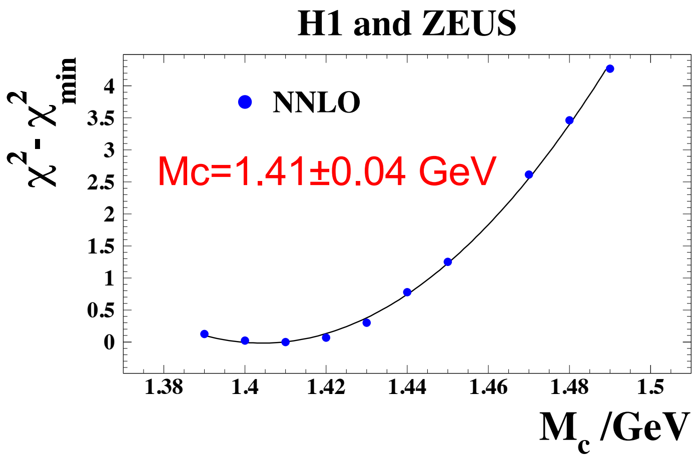
- choice of scale, $\mu_f^2 = \mu_r^2 = Q^2 + p_T^2$;
- exclusion of the H1 low-Q^2 inclusive and dijet data;
- exclusion of the low-p_T points from the H1 high-Q^2 inclusive jet data;
- exclusion of trijet data;
- exclusion of low-p_T points from the ZEUS dijet data;
- exclusion of data with $\mu <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

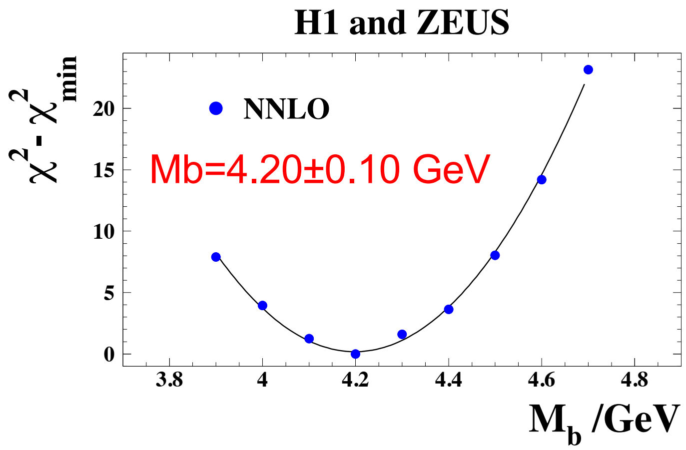
The values of $\alpha_S(M_Z)$ obtained for these conditions are:
0.1186 ± 0.0014(exp) NLO and 0.1144 ± 0.0013(exp) NNLO.
The change of the NNLO value from the preferred value of 0.1156 is mostly due to the exclusion of the H1 lowQ^2 data and the low-p_T points at high Q^2

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 $\chi2$ 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 $\chi2$ of the fit when the 74 data pts of these data are added is ~180.

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

Mc and Mb

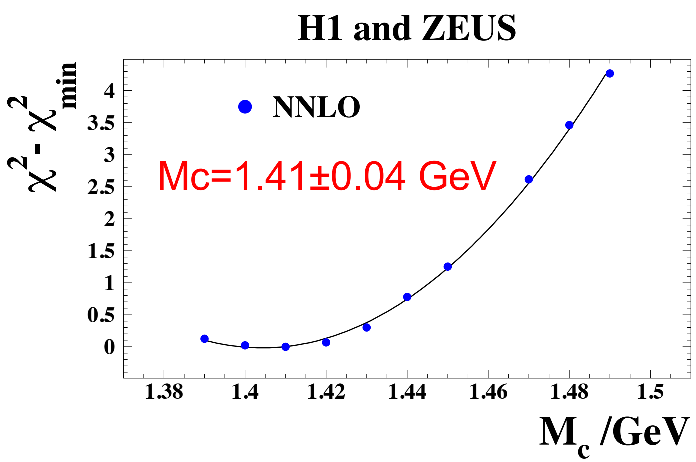


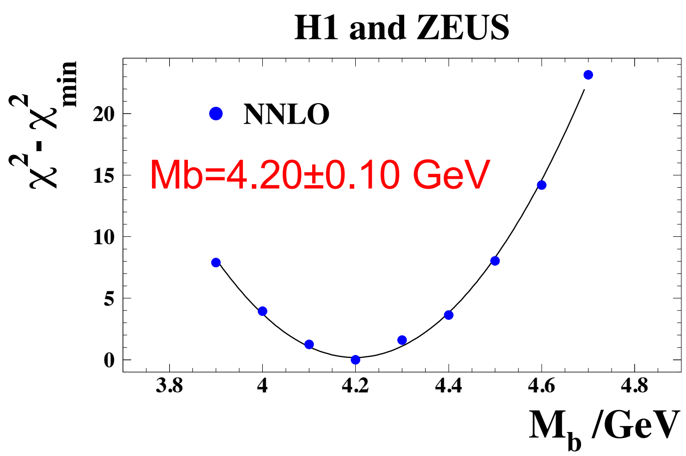


- since publication of HERAPDF2.0, new HERA combined charm and beauty data published, EPJ C78 (2018), 473 – affects evaluation of optimal **Mc** and **Mb**
- Heavy Quark (HQ) coefficient functions evaluated using Thorne-Roberts Optimised Variable Flavour Number Scheme

- optimal **Mc** and **Mb** values for current study chosen from X^2 scans performed using inclusive and HQ data (iterative procedure; further details in next slide)

Mc and Mb optimisation

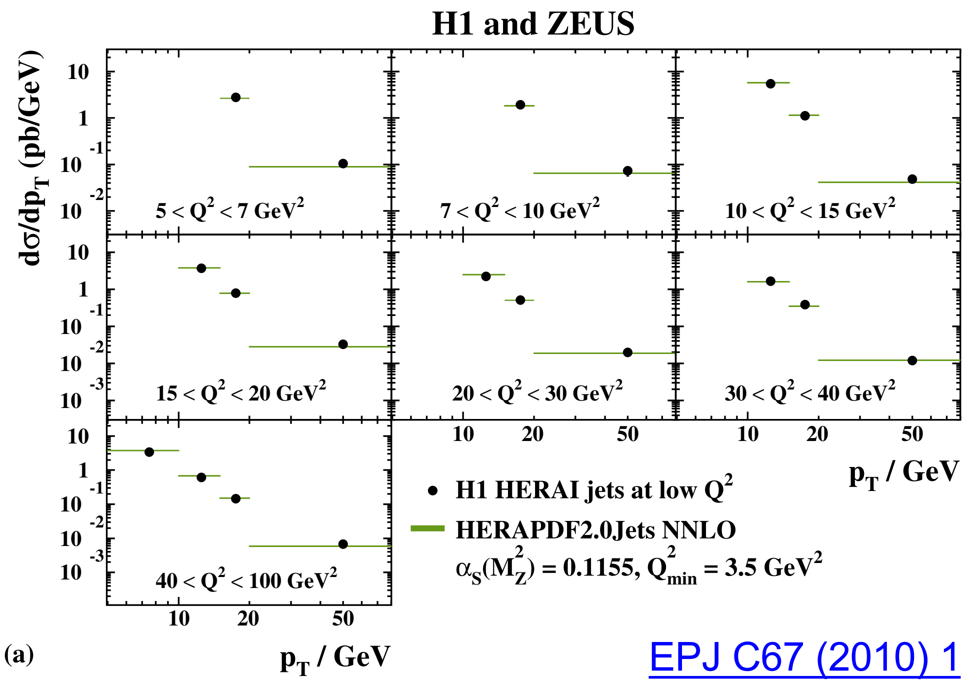




- X2 scans performed versus Mc and Mb using inclusive and heavy quark data
- start with **αs(MZ)=0.118** and the usual HERAPDF2.0 parameterisation; perform scan and adopt resulting values of Mc and Mb
- then fit for **αs(MZ)** including jet data
- Since new value (**αs(MZ)=0.1156**) is obtained (see slide 10), scans are revisited obtaining very slightly different Mc and Mb values
- then refit for **αs(MZ)** using these new Mc and Mb values – **αs(MZ)=0.1156** is unchanged
- then recheck parameterisation with new Mc, Mb, **αs(MZ)=0.1156** AND jet data added
- previous parameterisation confirmed – no further iteration needed!

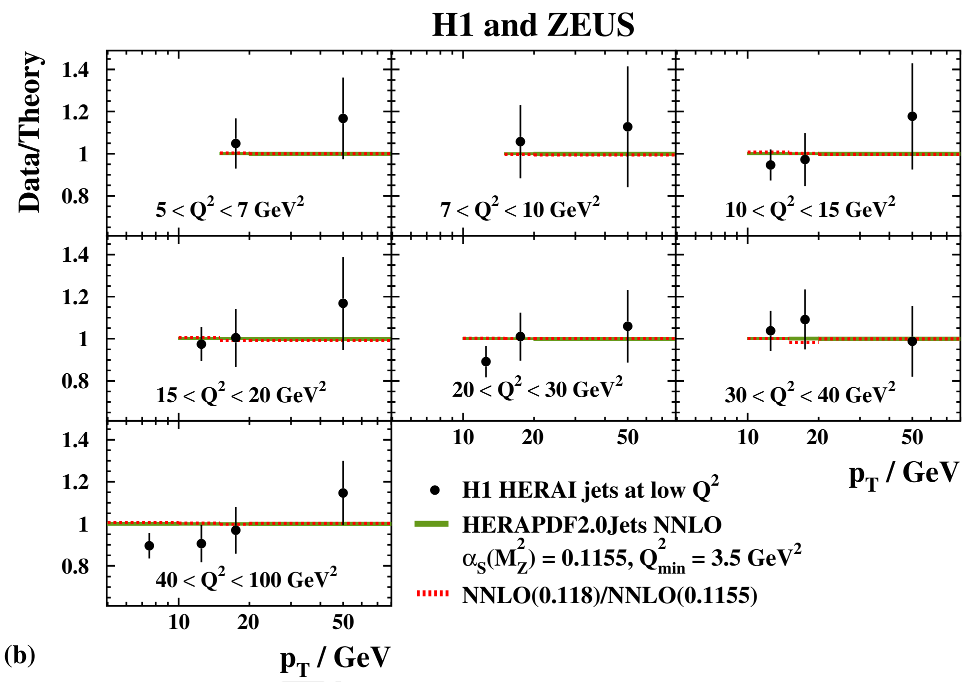
(from A. Cooper-Sarkar)

cf. HERA jet data



(a)

EPJ C67 (2010) 1

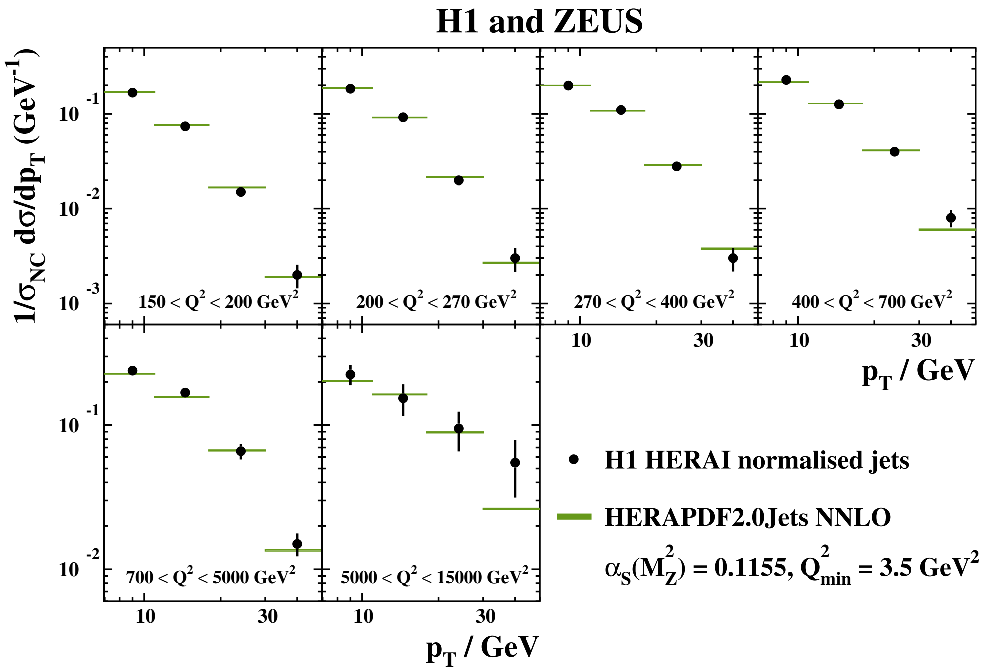


(b)

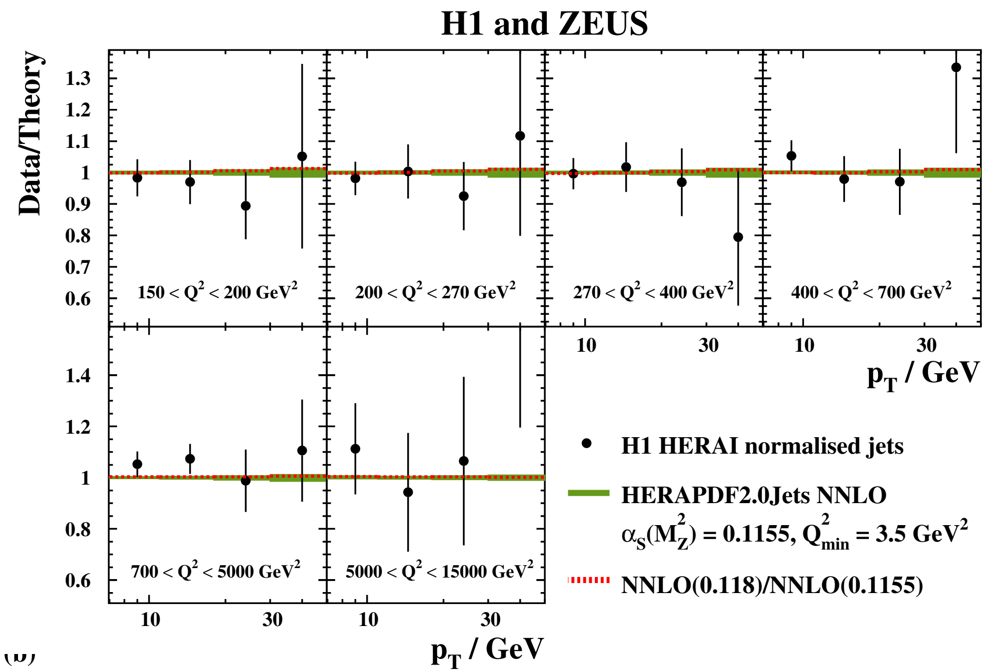
HERAPDF2.0JetsNLO

$\alpha_s(M_Z)=0.1155$

cf. HERA jet data



PLB 653 (2007) 134



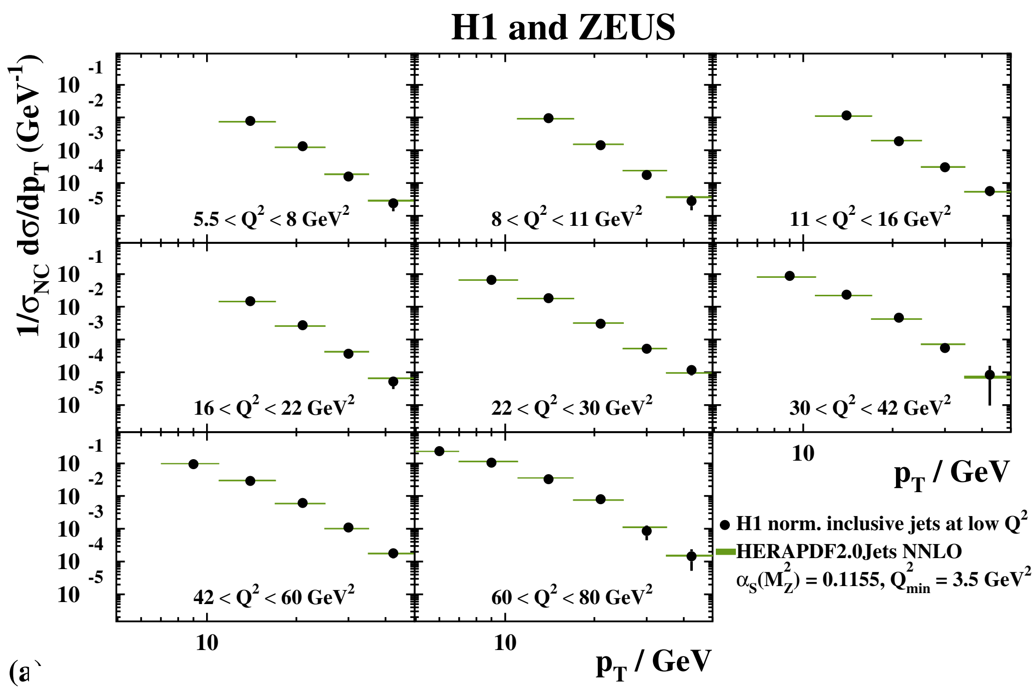
HERAPDF2.0JetsNLO

$\alpha_s(M_Z)=0.1155$

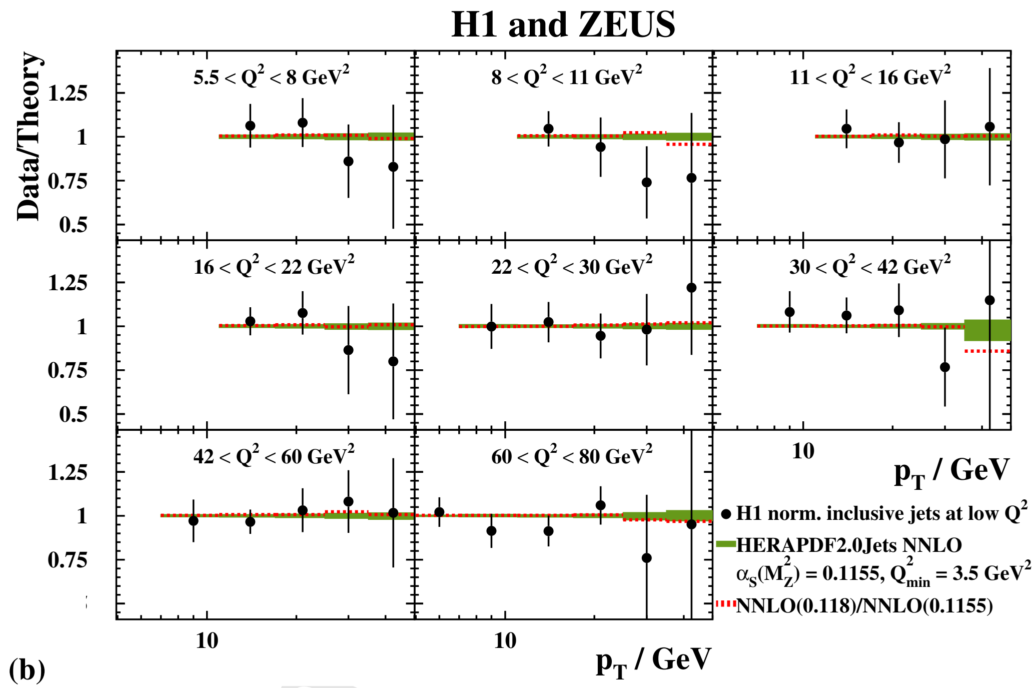
cf. HERA jet data

HERAPDF2.0JetsNLO

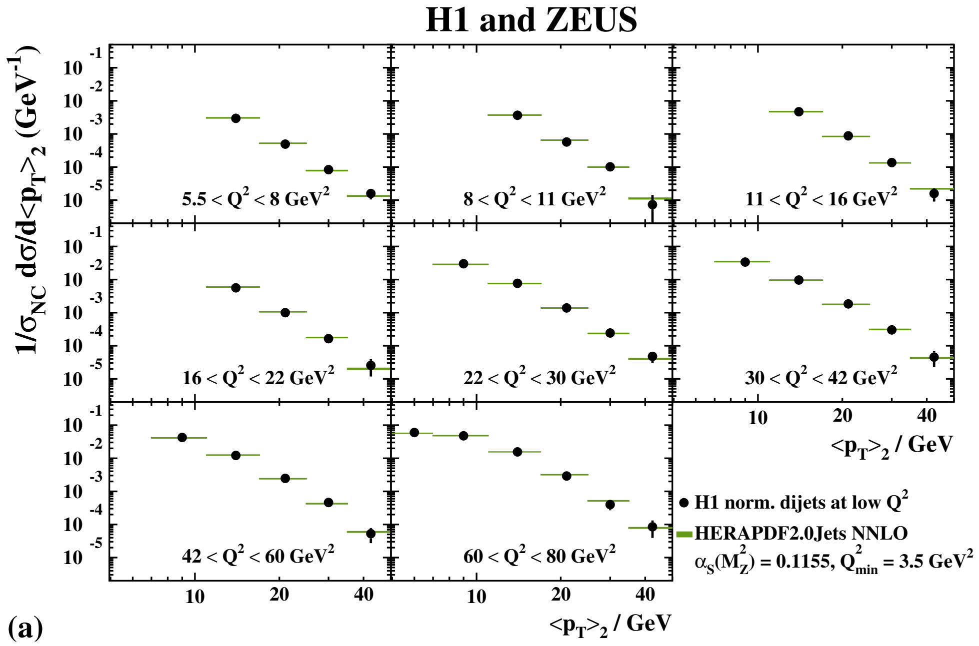
$\alpha_s(M_Z)$=0.1155



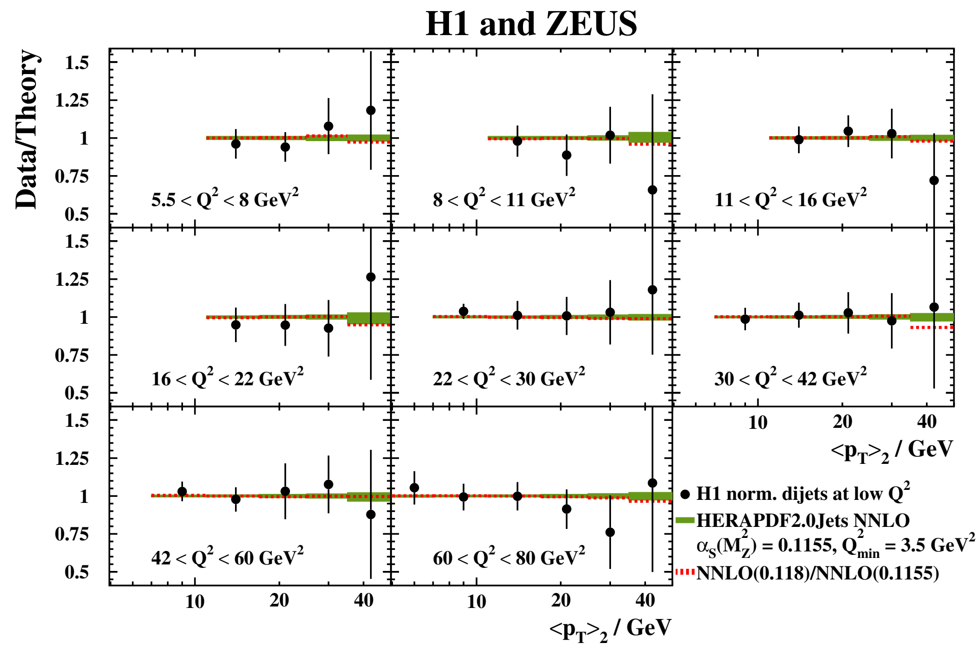
EPJ C77 (2017) 215



cf. HERA jet data



EPJ C77 (2017) 215



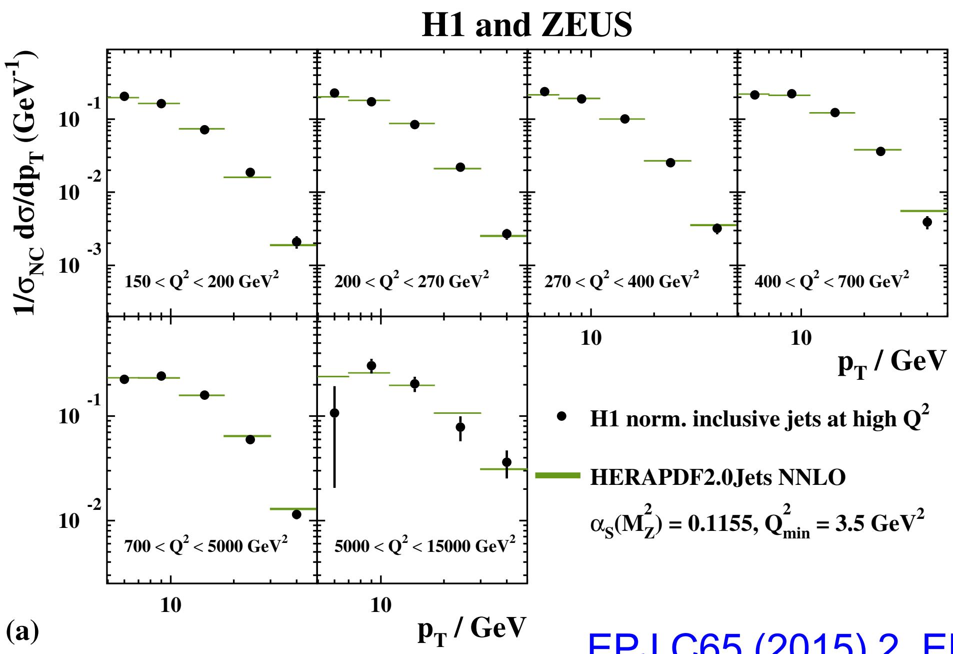
HERAPDF2.0JetsNLO

$\alpha_s(M_Z)=0.1155$

cf. HERA jet data

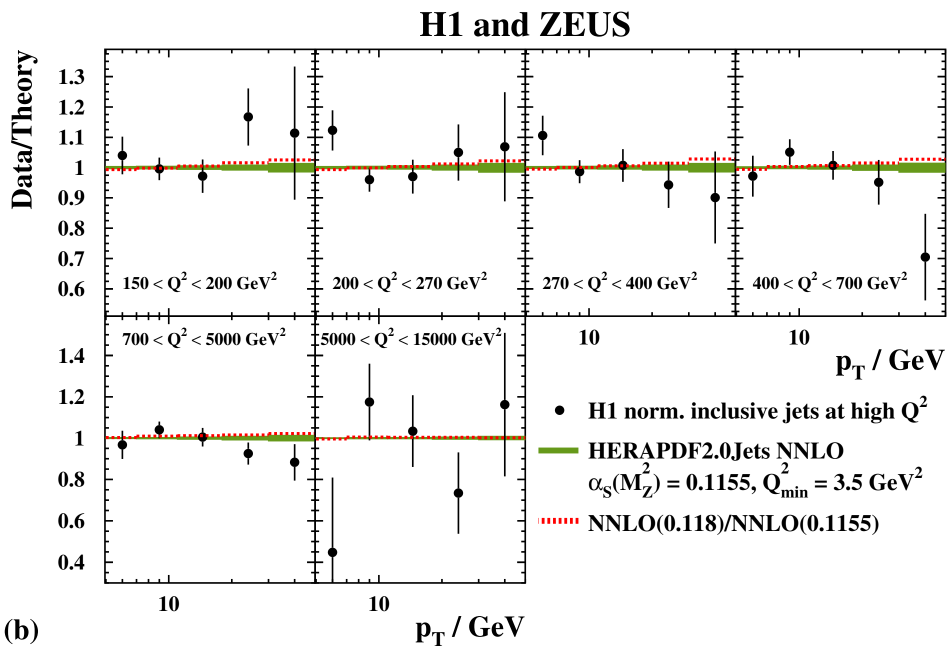
HERAPDF2.0JetsNLO

$\alpha_s(M_Z)=0.1155$



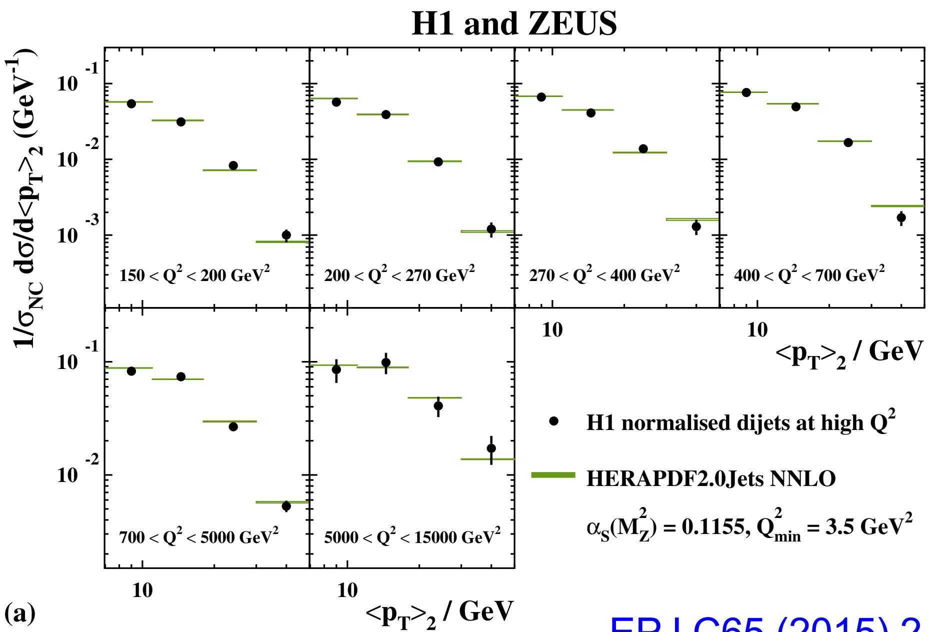
(a)

EPJ C65 (2015) 2, EPJ C77 (2017) 215



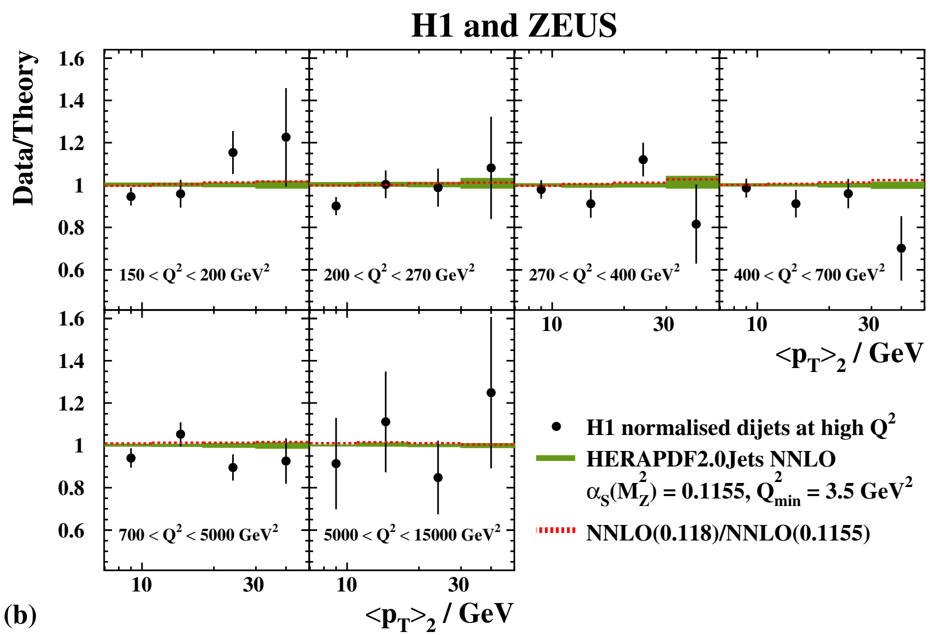
(b)

cf. HERA jet data



(a)

[EPJ C65 (2015) 2]



(b)

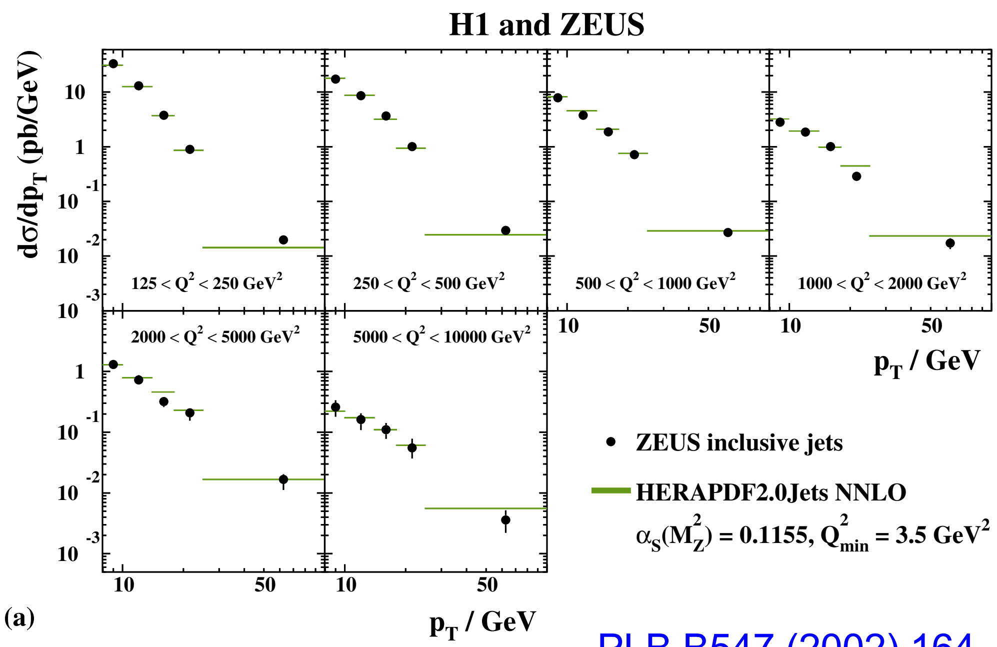
HERAPDF2.0JetsNLO

$\alpha_s(M_Z)=0.1155$

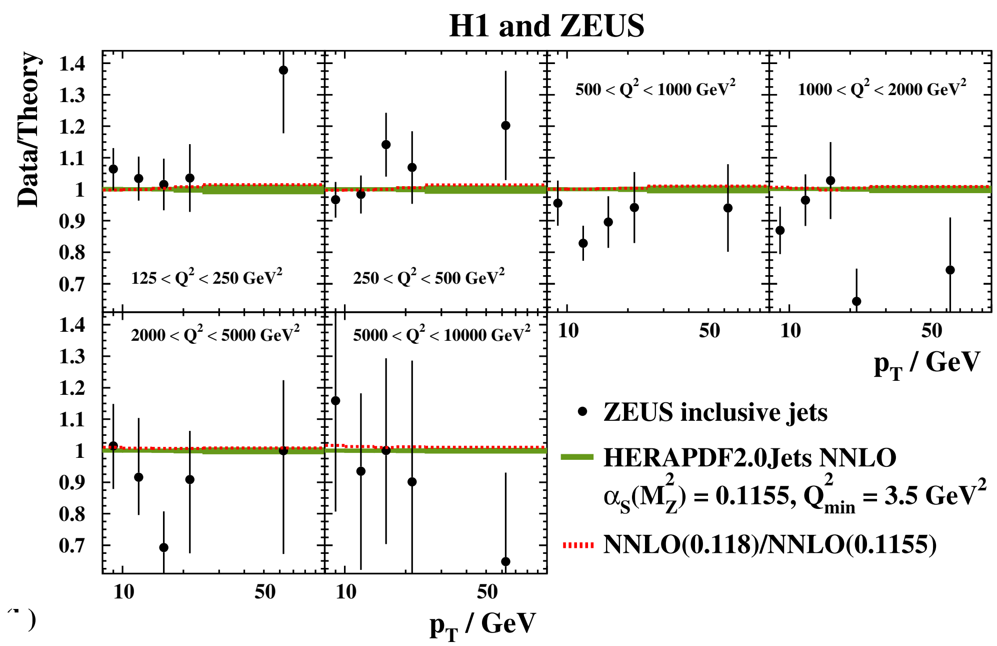
cf. HERA jet data

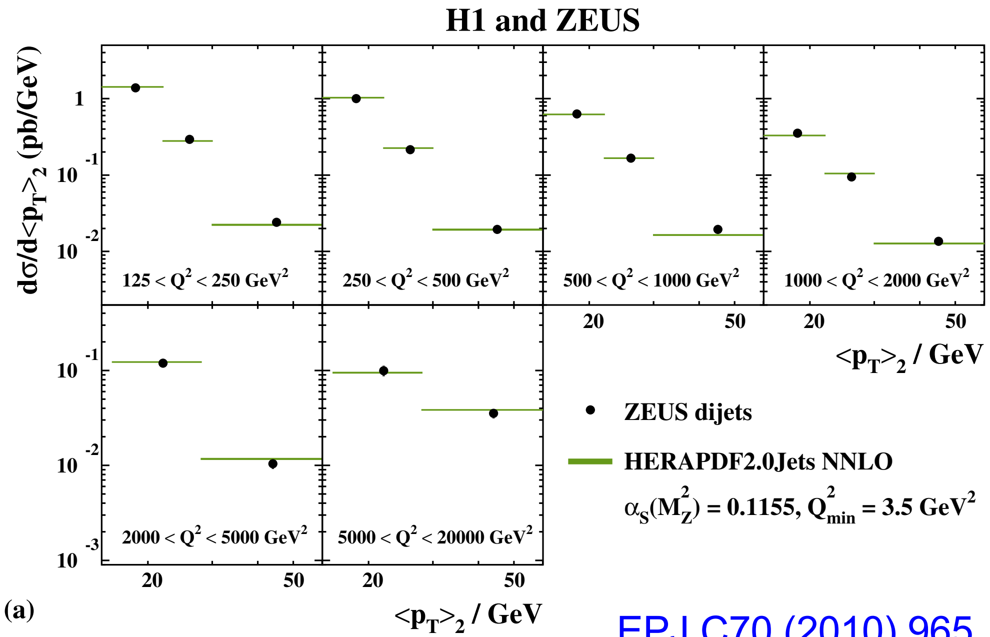
HERAPDF2.0JetsNLO

$\alpha_s(M_Z)=0.1155$



[PLB B547 (2002) 164]



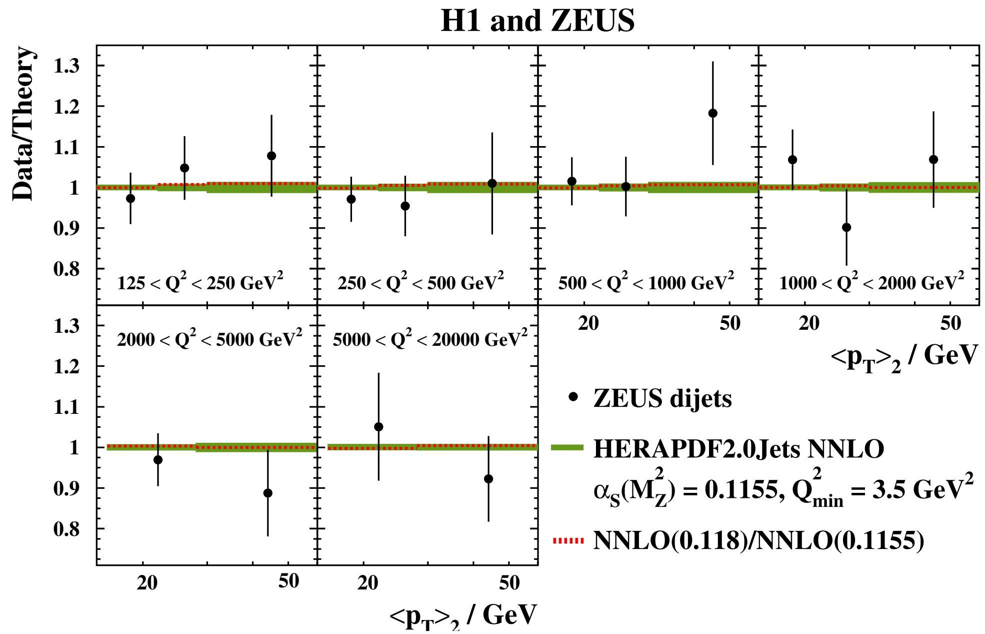


cf. HERA jet data

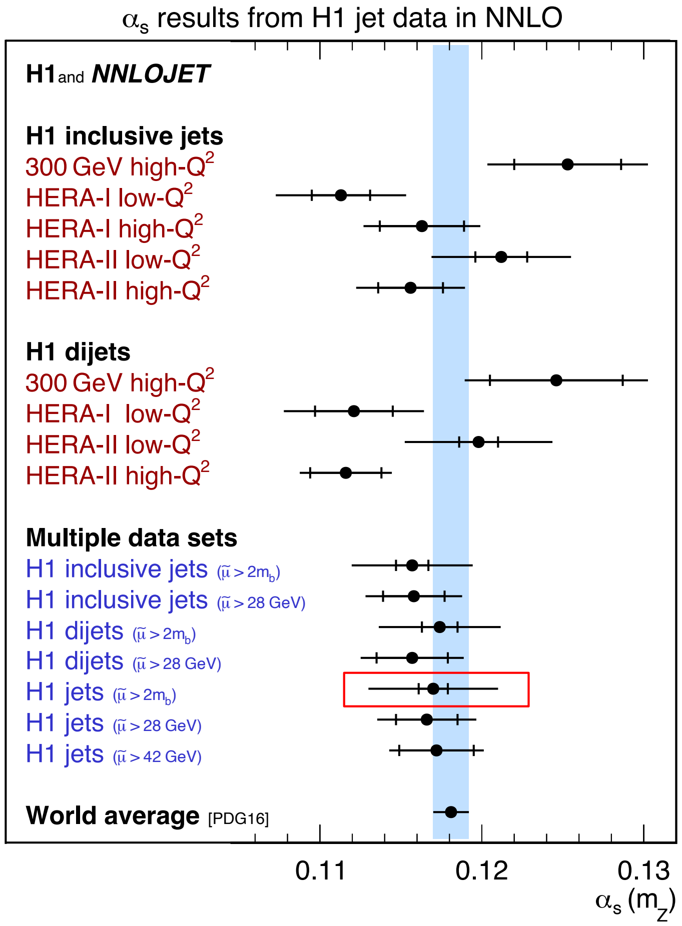
HERAPDF2.0JetsNLO

$\alpha_s(M_Z)=0.1155$

EPJ C70 (2010) 965

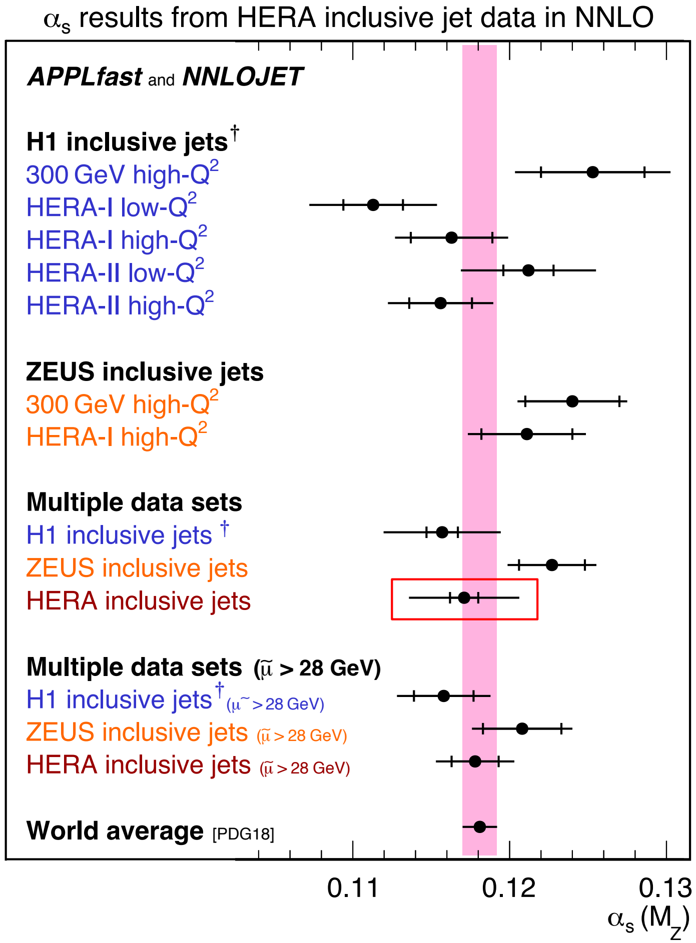


cf. other NNLO results using HERA jets



H1 jets, arXiv:1709.07251

see also, arXiv:2203.08271



H1+ZEUS inclusive jets, arXiv:1906.05303