NNLO QCD fits to HERA jets and extraction of α_s

ZEUS-prel-19-001

H1prelim-19-041

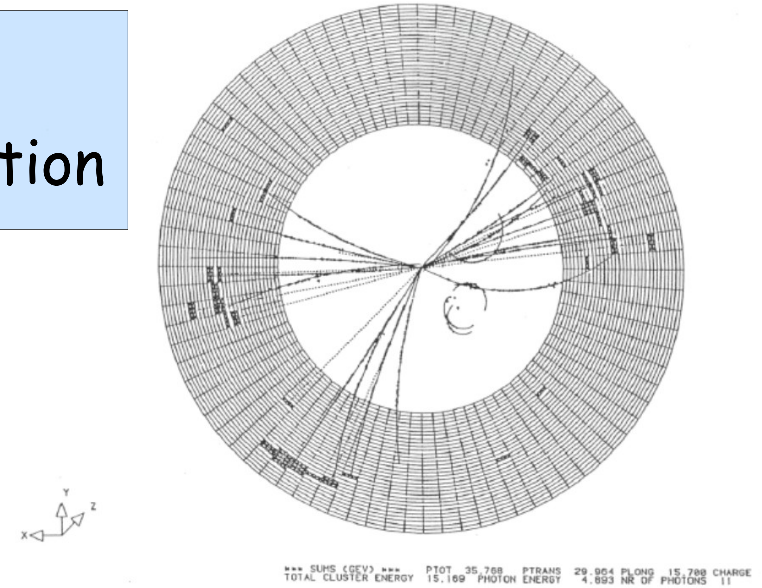
K. Wichmann on behalf of H1 and ZEUS Collaborations

@ Low-x 2019

Nicosia Cyprus

30 years of jet production @ DESY

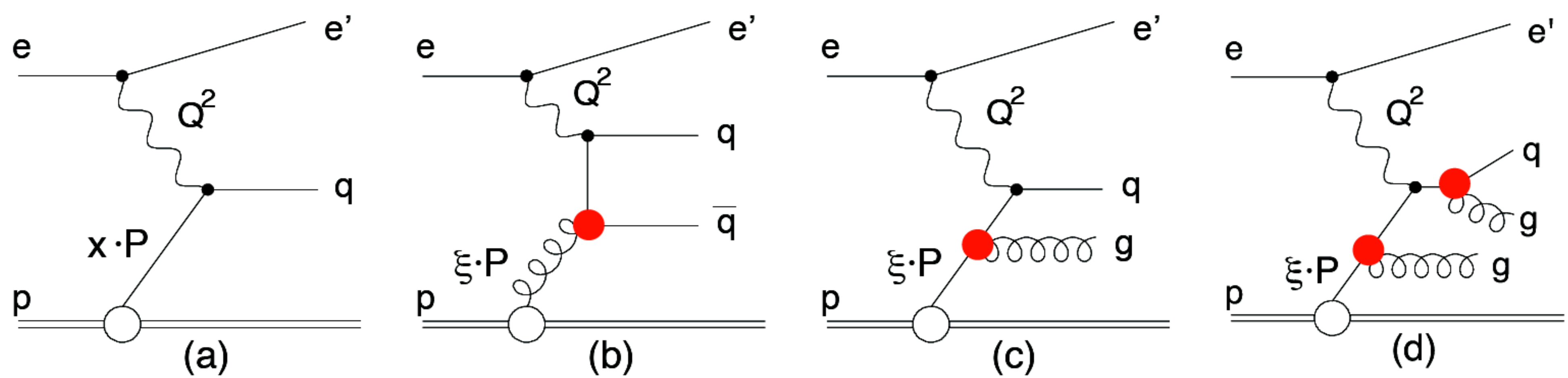
Jets at PETRA, 1979



At HERA direct information on gluon distribution and α_s comes from jet production

→ Possible simultaneous determination of parton densities and α_s

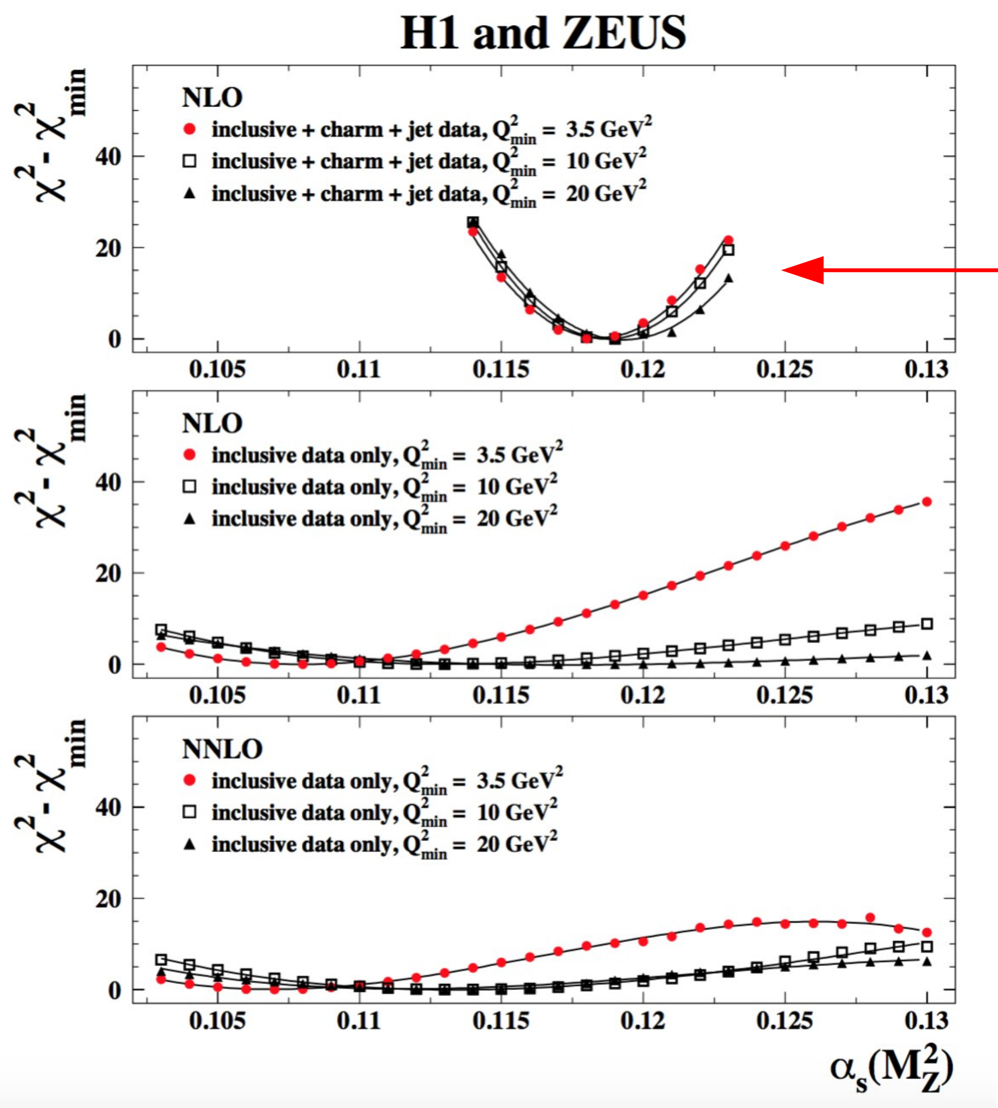
Jets at HERA



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

dijets $\quad$ trijets

Why study jets @ HERA?



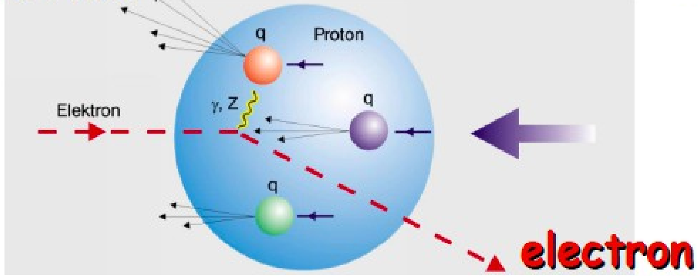
- HERA inclusive data carry little information on α_s
- Jet data sensitive to α_s
- So far NLO available

New NNLO calculations for HERA ep jet production available now

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

→ Possible simultaneous determination of parton densities and α_s at NNLO

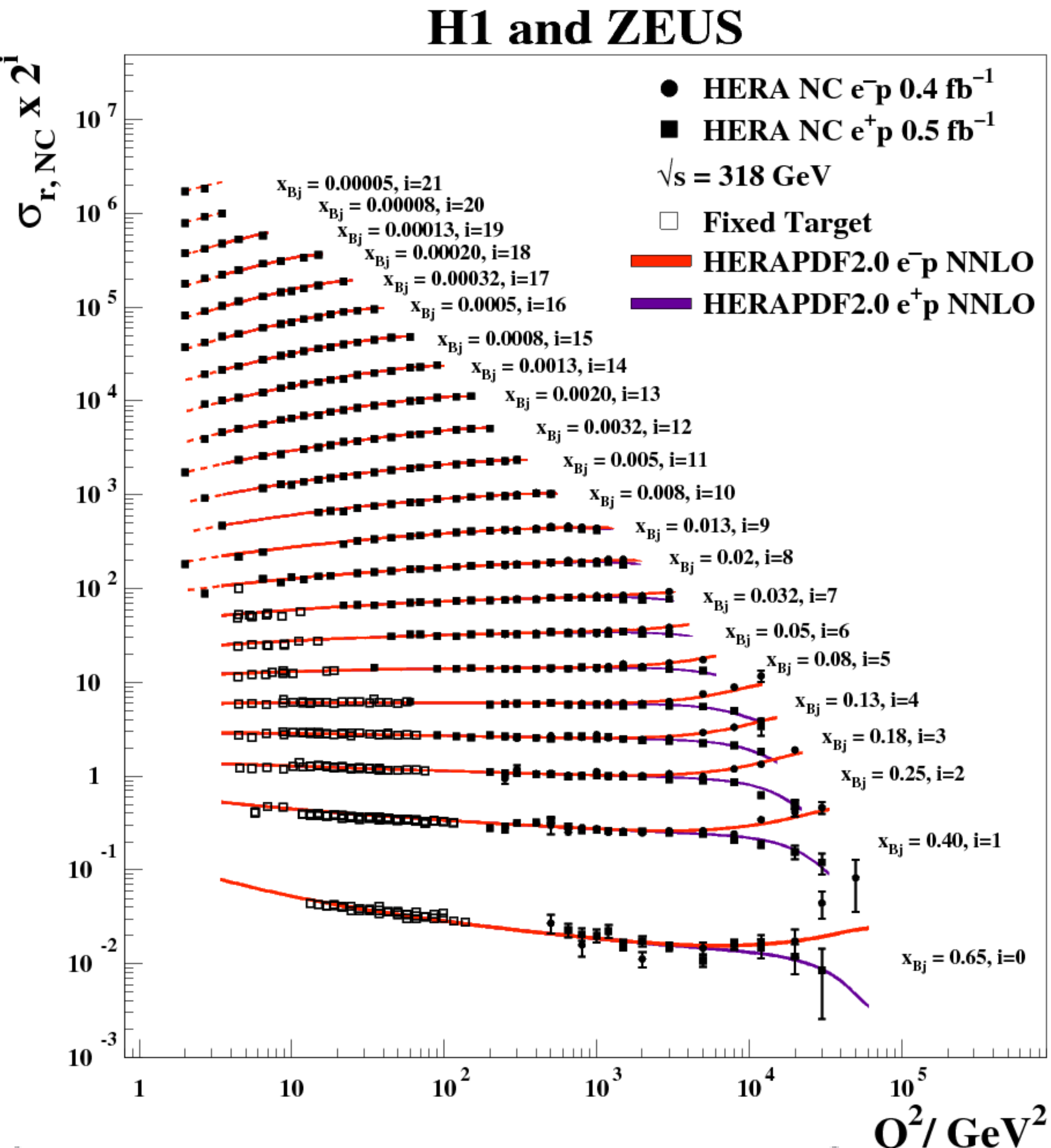
HERA combined inclusive DIS



<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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HERA jet data used in PDF fit

- 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^-	normalised	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

- Possibilities for PDF fit with jet data
  - With fixed α_s
  - With free α_s or doing α_s scan → α_s value

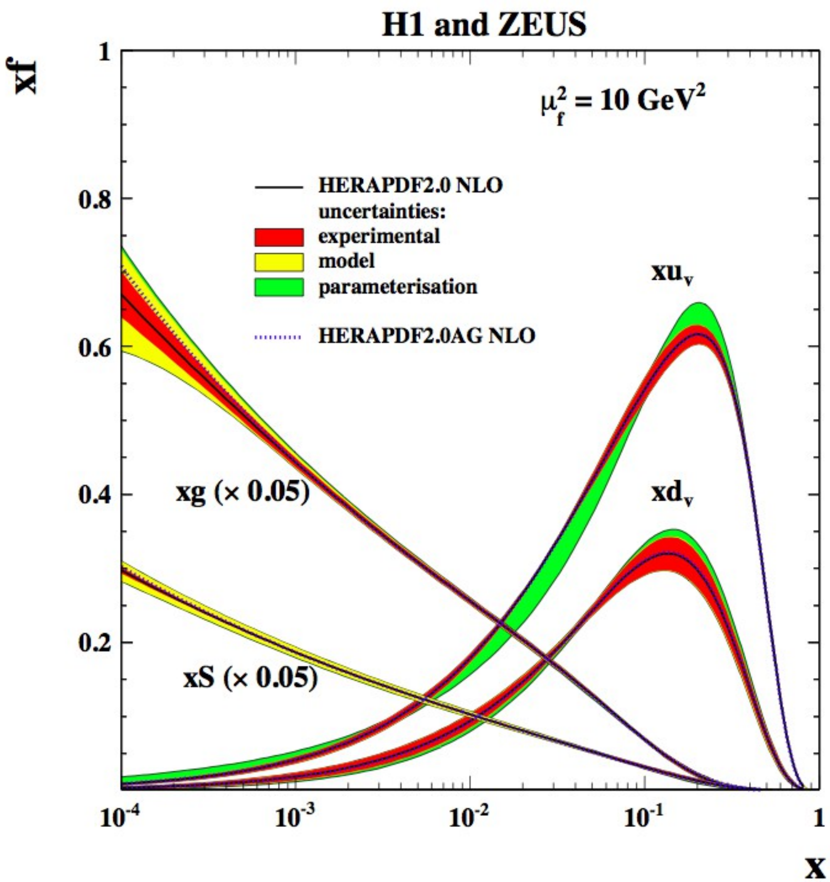
HERAPDF2.0 parameterisation

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

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

- 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

xFitter



PDF uncertainties

HERAPDF experimental, model and parameterisation uncertainties

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

Variation	Standard Value	Lower Limit	Upper Limit
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_{min} [GeV^2] HiQ2	10.0	7.5	12.5
M_c(NLO) [GeV]	1.47	1.41	1.53
M_c (NNLO) [GeV]	1.43	1.37	1.49
M_b [GeV]	4.5	4.25	4.75
f_s	0.4	0.3	0.5
μ_{f0} [GeV]	1.9	1.6	2.2

Adding D and E parameters to each PDF

- **Model uncertainties**
  - variations added in quadrature

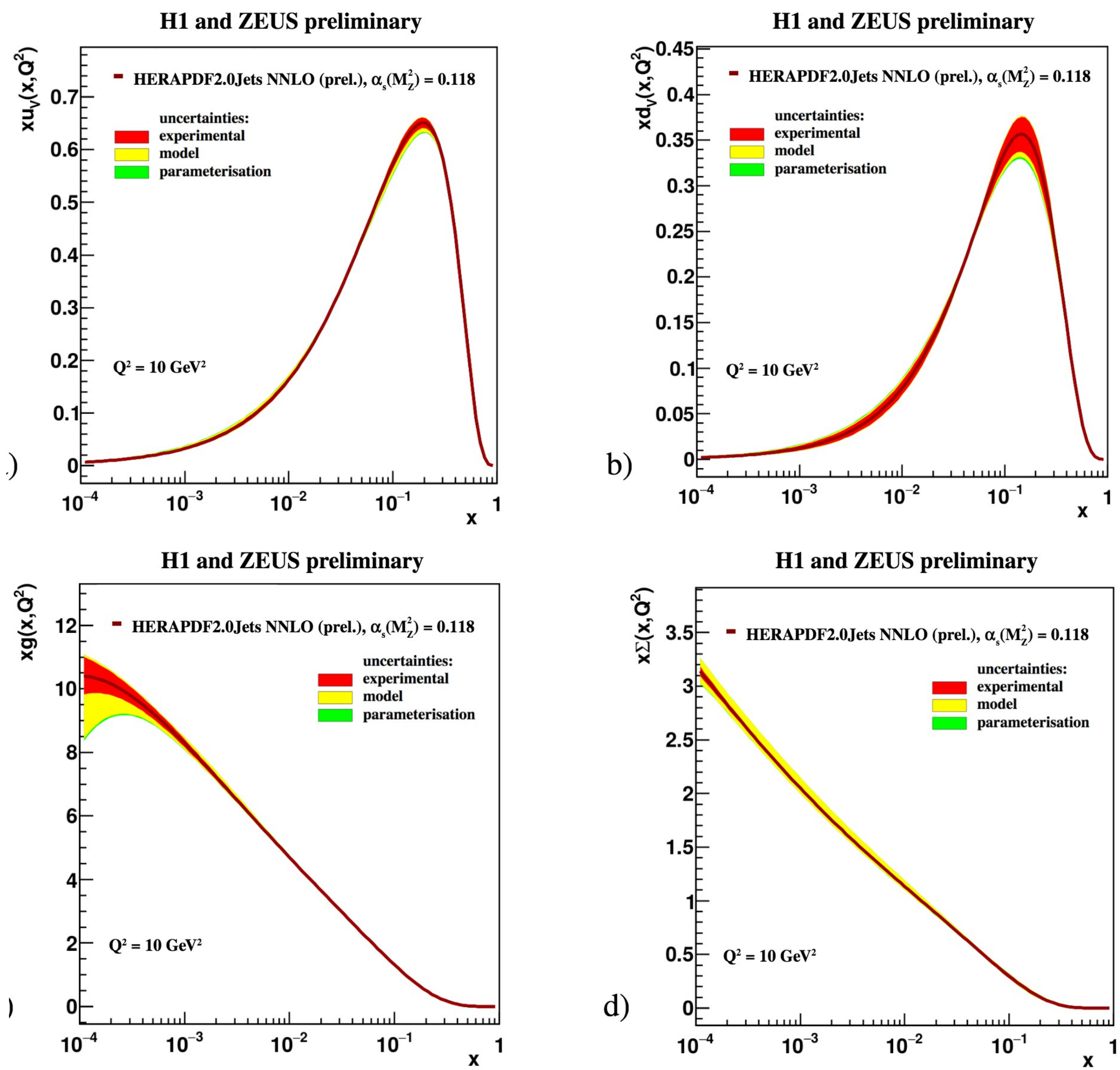
- **Parametrisation uncertainties**
  - largest deviation

- When jets included – also hadronisation uncertainty

  → offsetting corrections given for each jet data set

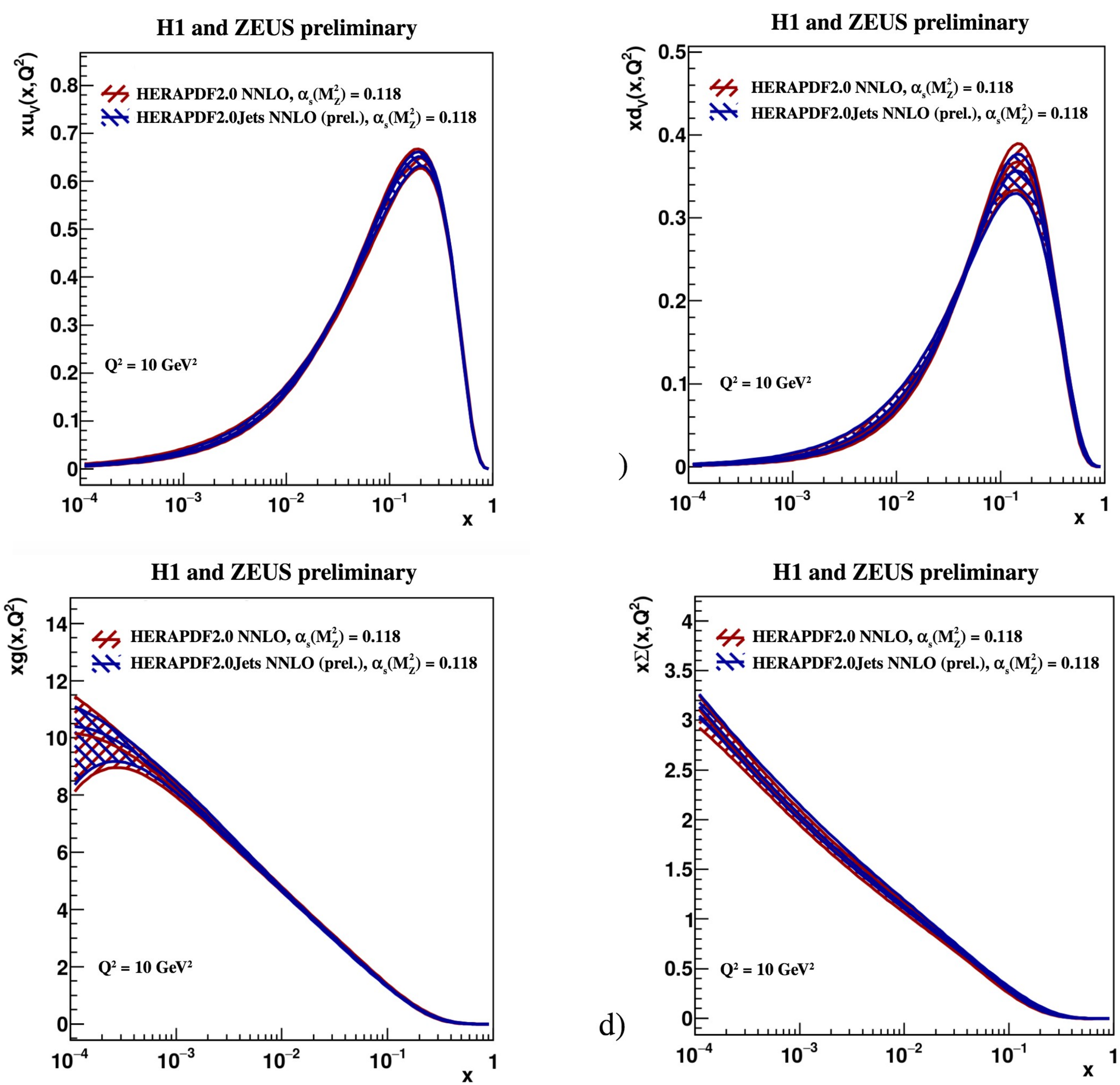
Let's first look at PDFs with α_s = 0.118, as for HERAPDF2.0

HERAPDF2.0Jets NNLO (prel.), $\alpha_s(M_Z)$ = 0.118



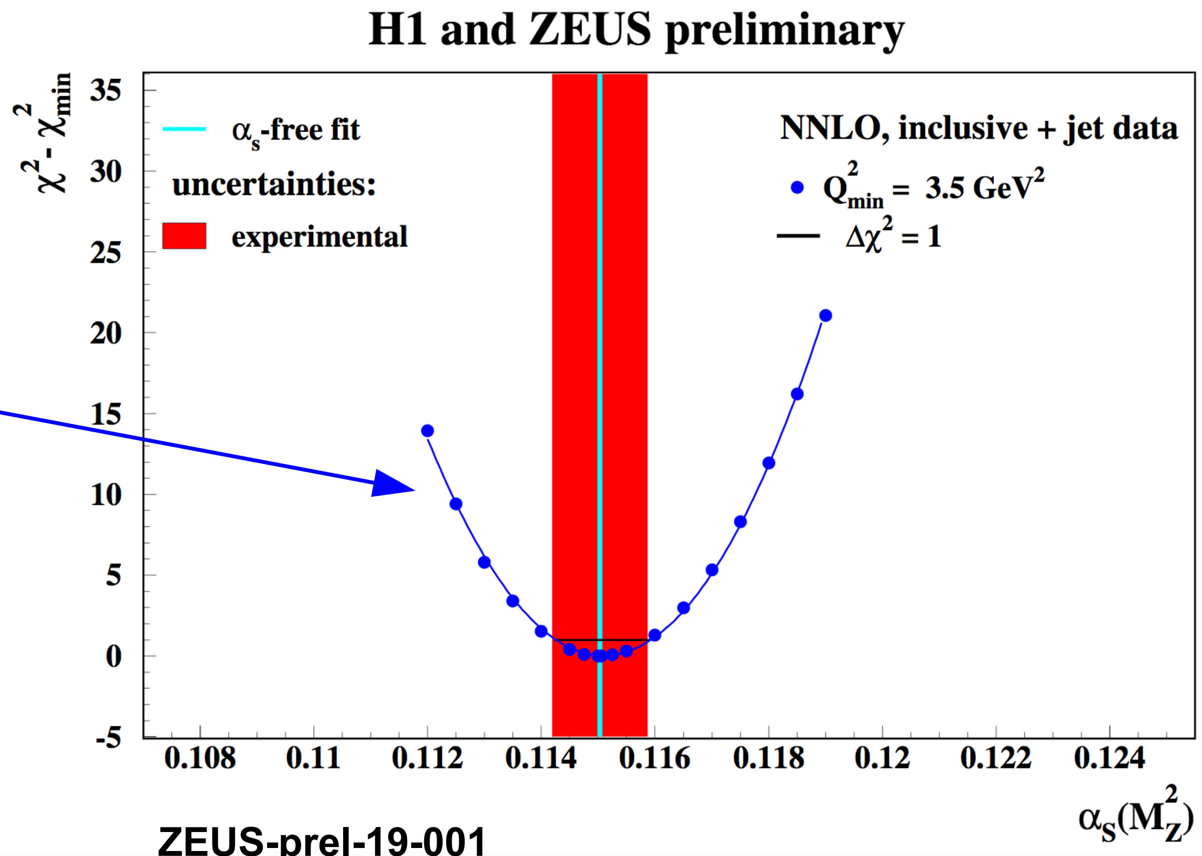
How does it compare to HERAPDF2.0? Well!

HERAPDF2.0Jets NNLO (prel.), $\alpha_s(M_Z) = 0.118$



α_s @ NNLO from HERA jets

- 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

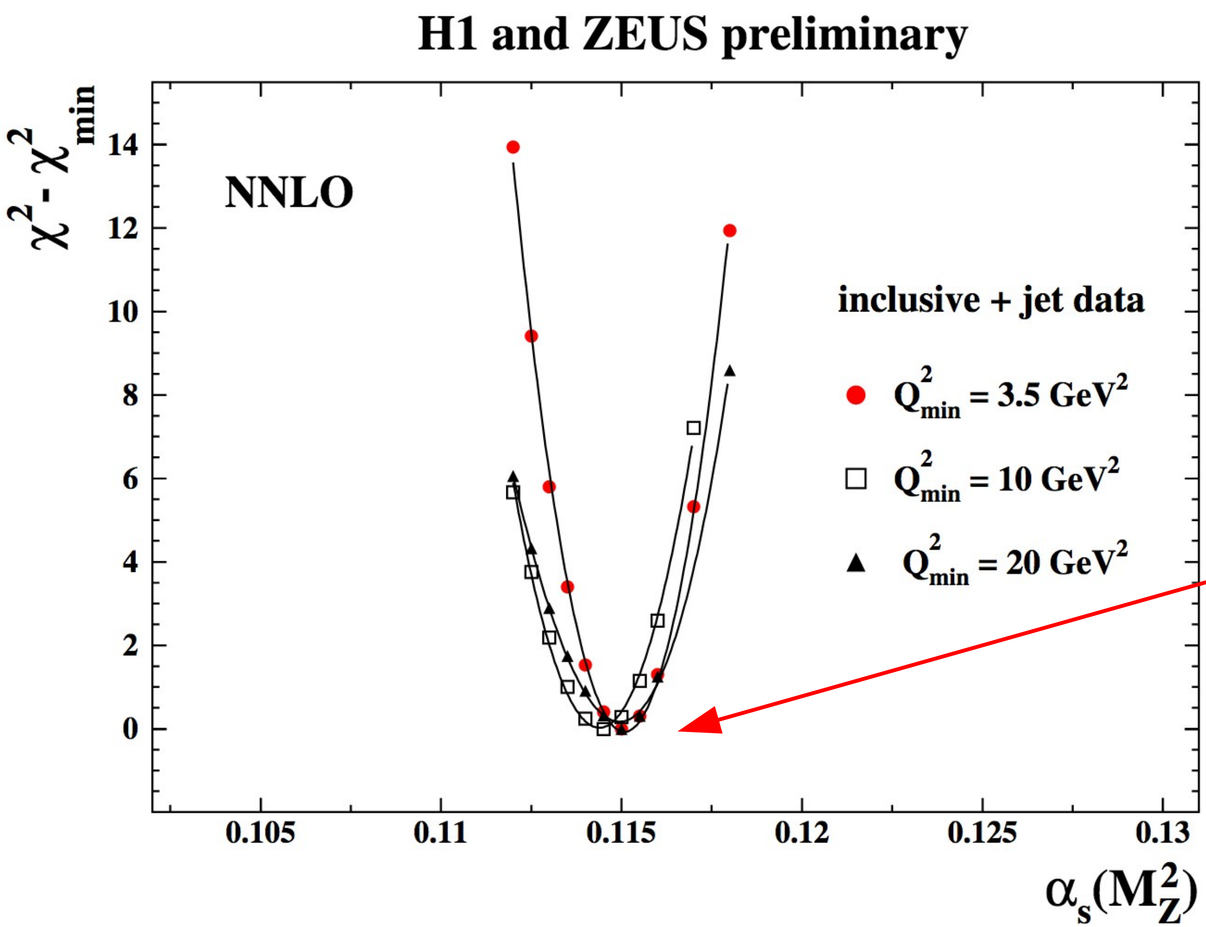


$$\alpha_s(M_Z^2) = 0.1150 \pm 0.0008(\text{exp})$$

Scans with harder Q^2 cuts

• HERA data at low x and Q^2 may be subject to need for ln(1/x) resummation or higher twist effects

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

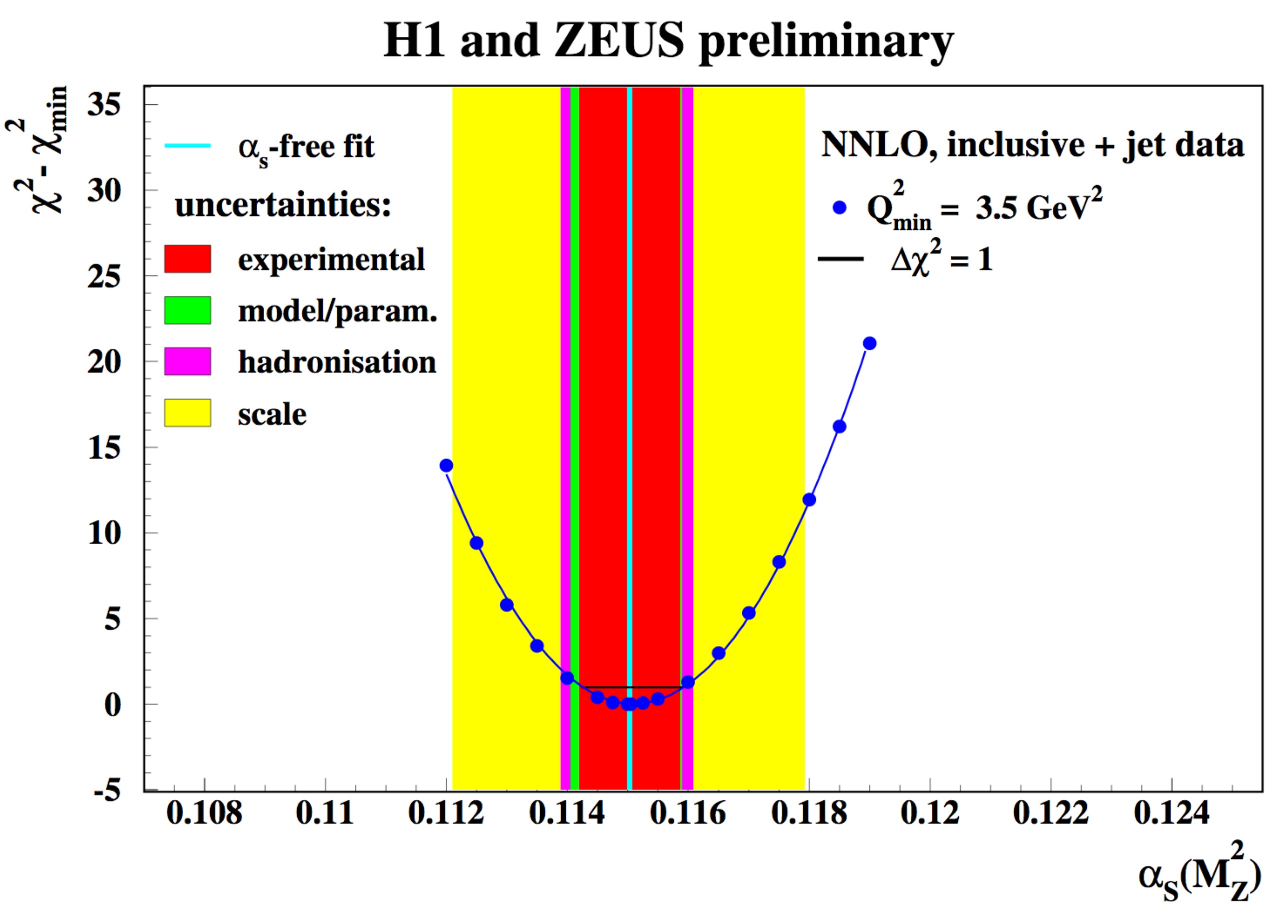


Q^2 cuts do not result in any significant change to the value of $\alpha_s(M_Z)$

Full uncertainties

- Experimental, model, parametrisation and hadronisation uncertainties
- In fits with free $\alpha_s(M_Z)$ scale uncertainty important

→ factorisation and renormalisation scales varied both separately and simultaneously by a factor of two and taking maximal positive and negative deviations (assumed to be 50% correlated and 50% uncorrelated)



Comparison to other HERAPDF2.0 fits

- NNLO fits with and without jets of similar quality
  - χ^2/d.o.f = 1.203 for free $\alpha_s(M_Z)$ fit with 1328 degrees of freedom
  - χ^2/d.o.f = 1.205 for HERAPDF2.0NNLO with only 1131 degrees of freedom
- NLO and NNLO results for $\alpha_s(M_Z)$ consistent within experimental uncertainties
  - Scale uncertainties reduced

    → as expected for NNLO calculations

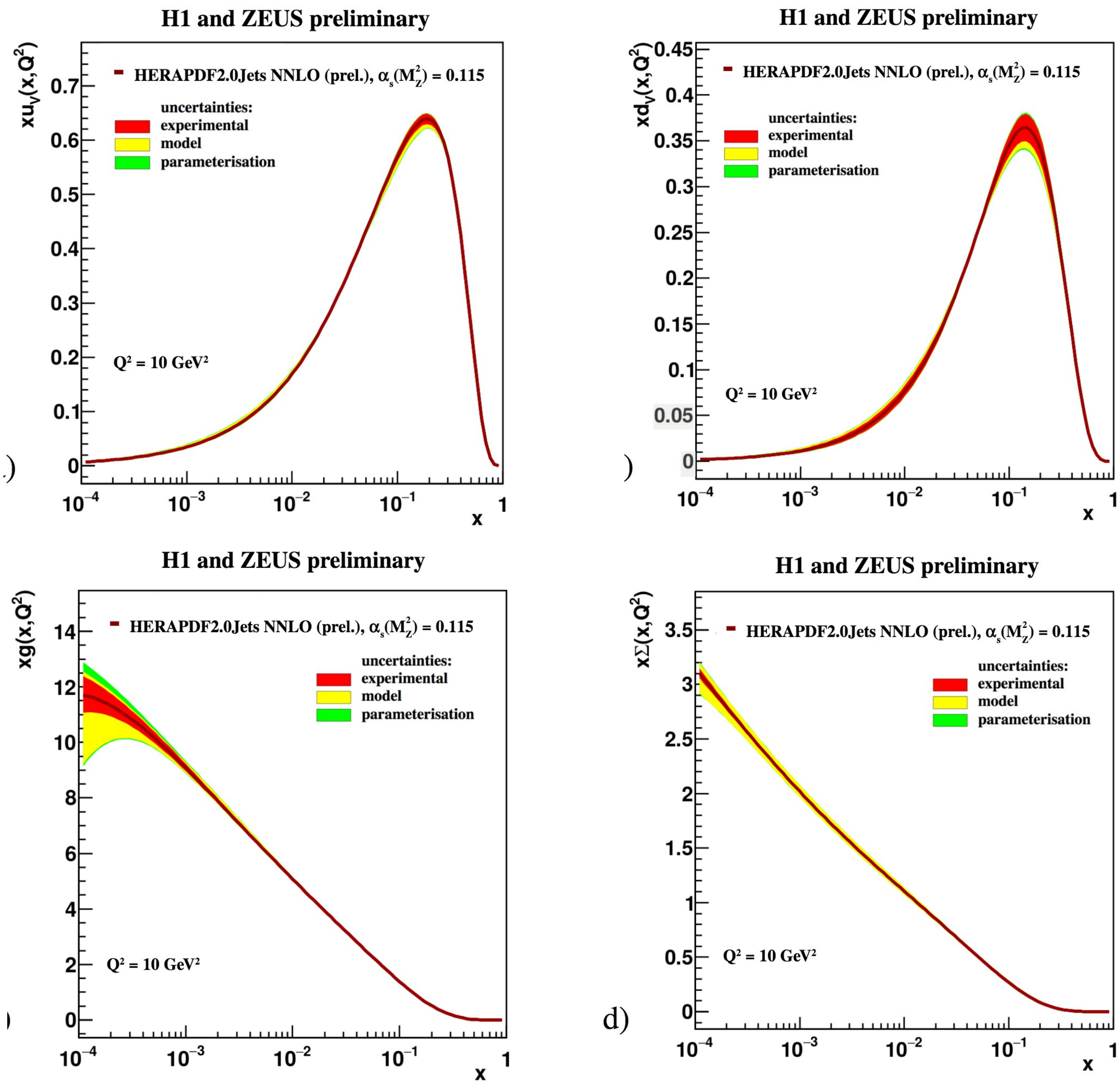
HERAPDF2.0Jets NNLO (prel.), free $\alpha_s(M_Z)$

$$\alpha_s(M_Z^2) = 0.1150 \pm 0.0008(\mathrm{exp})^{+0.0002}_{-0.0005}(\mathrm{model/parameterisation}) \pm 0.0006(\mathrm{hadronisation}) \pm 0.0027(\mathrm{scale}) .$$

HERAPDF2.0Jets NLO

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

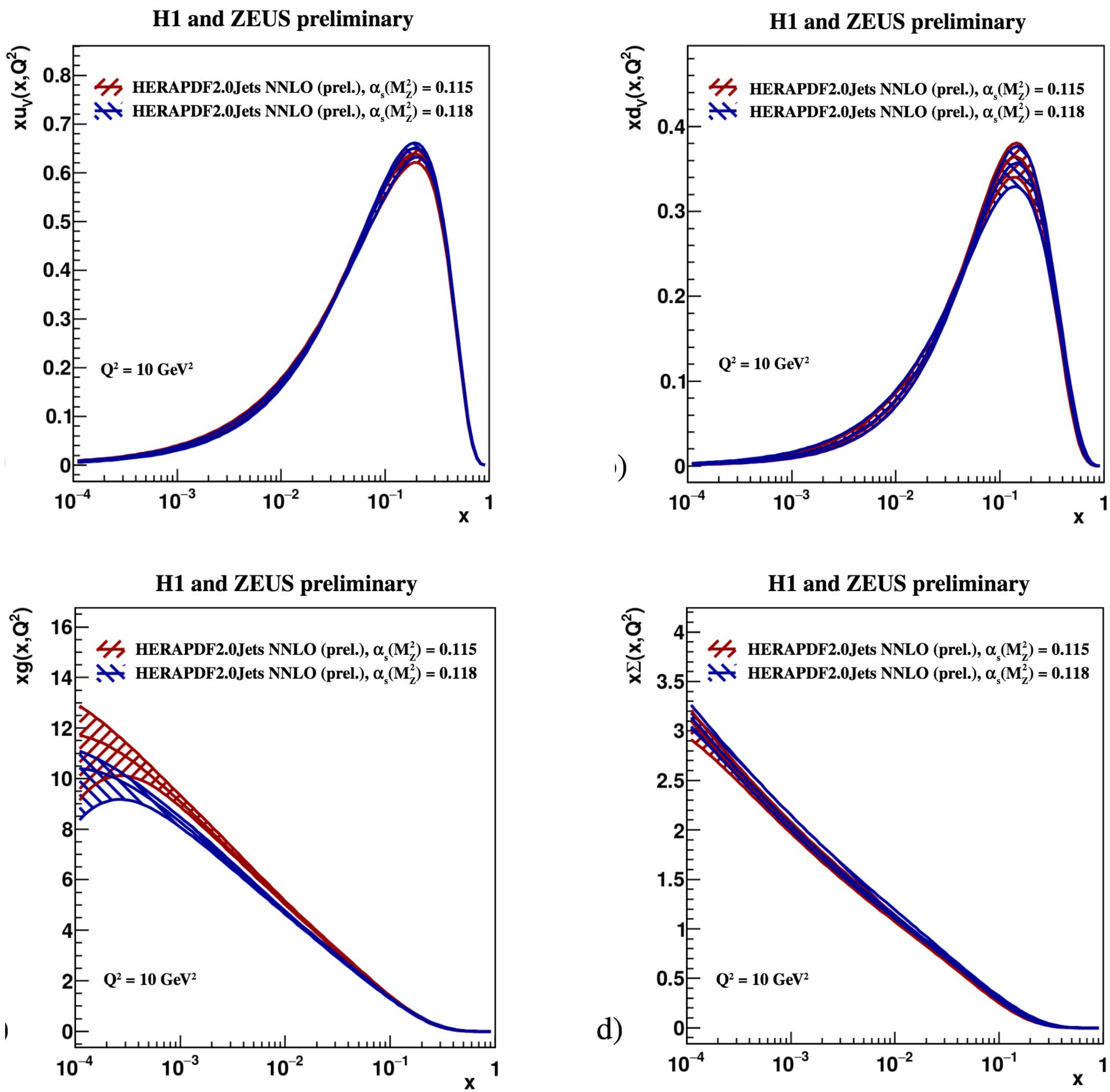
Let's look at PDF with $\alpha_s = 0.118$



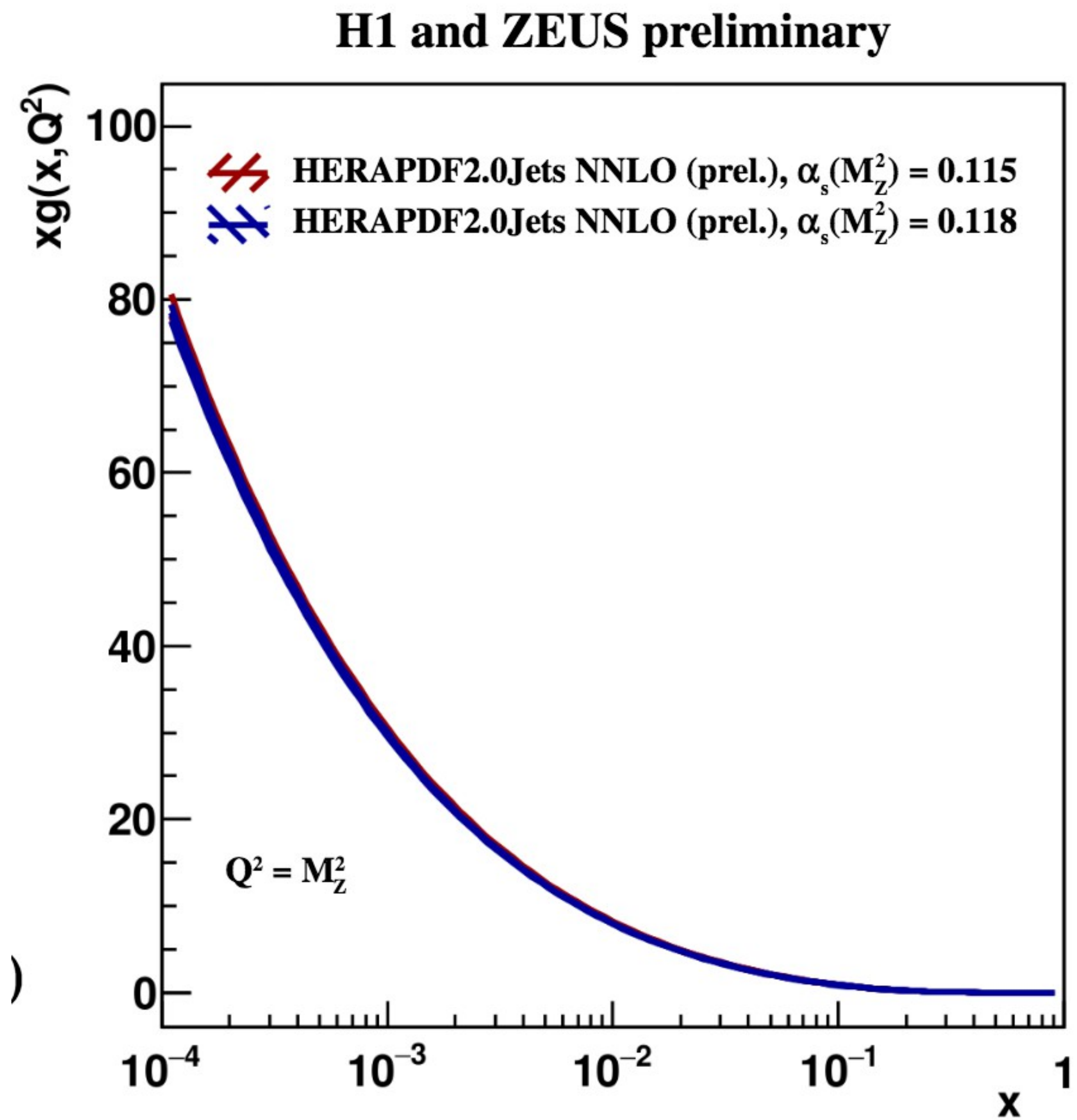
K. Wichmann @ Low-x19

NNLO jets @ HERA

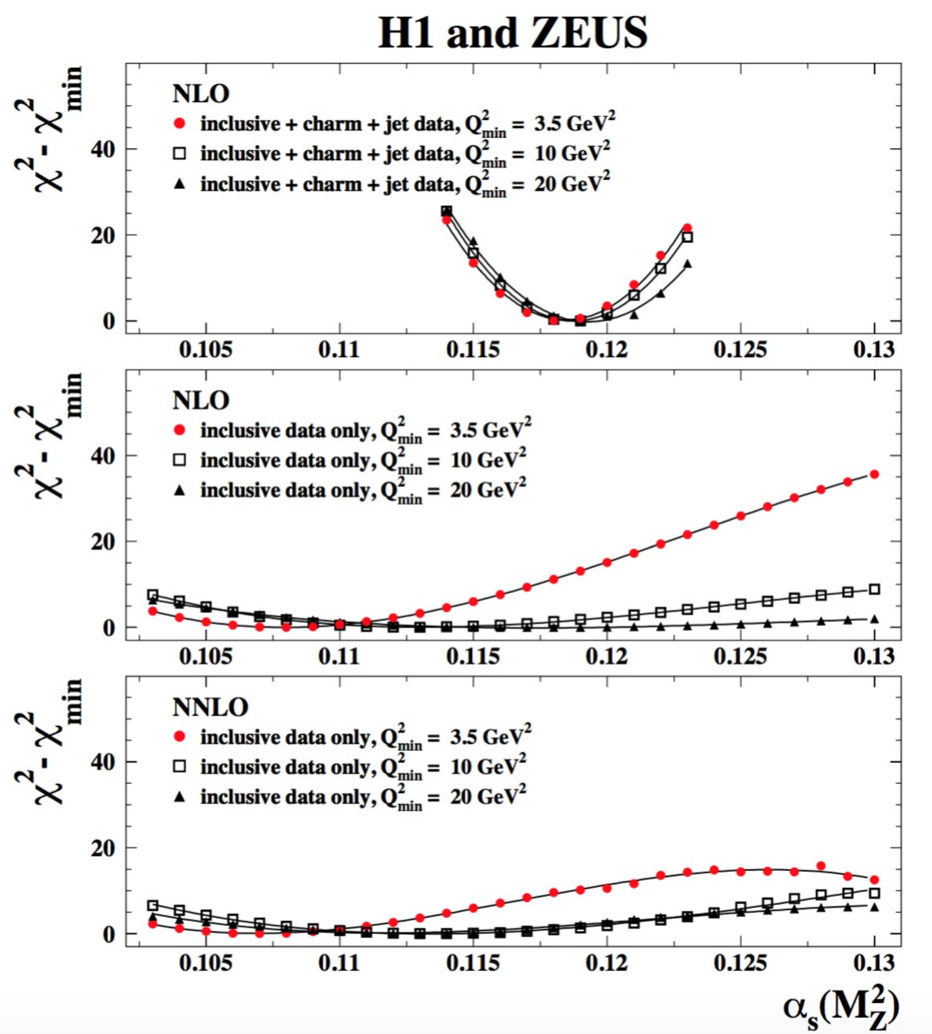
… and how they compare to α_s = 0.118

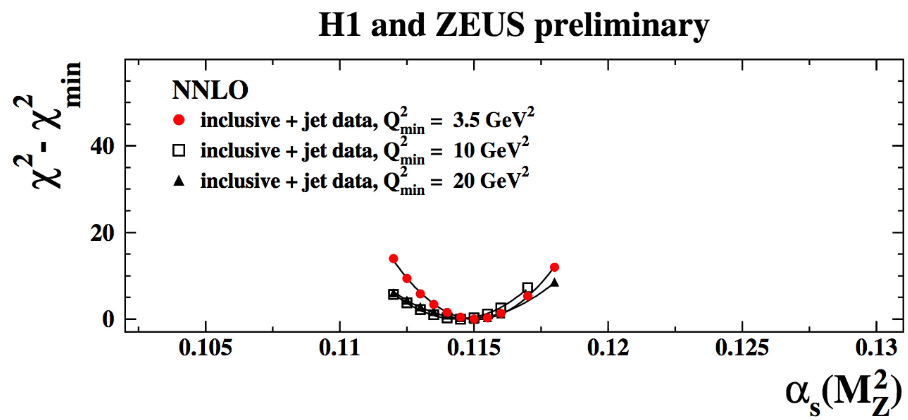


Gluon at scale of M_Z^2 very similar

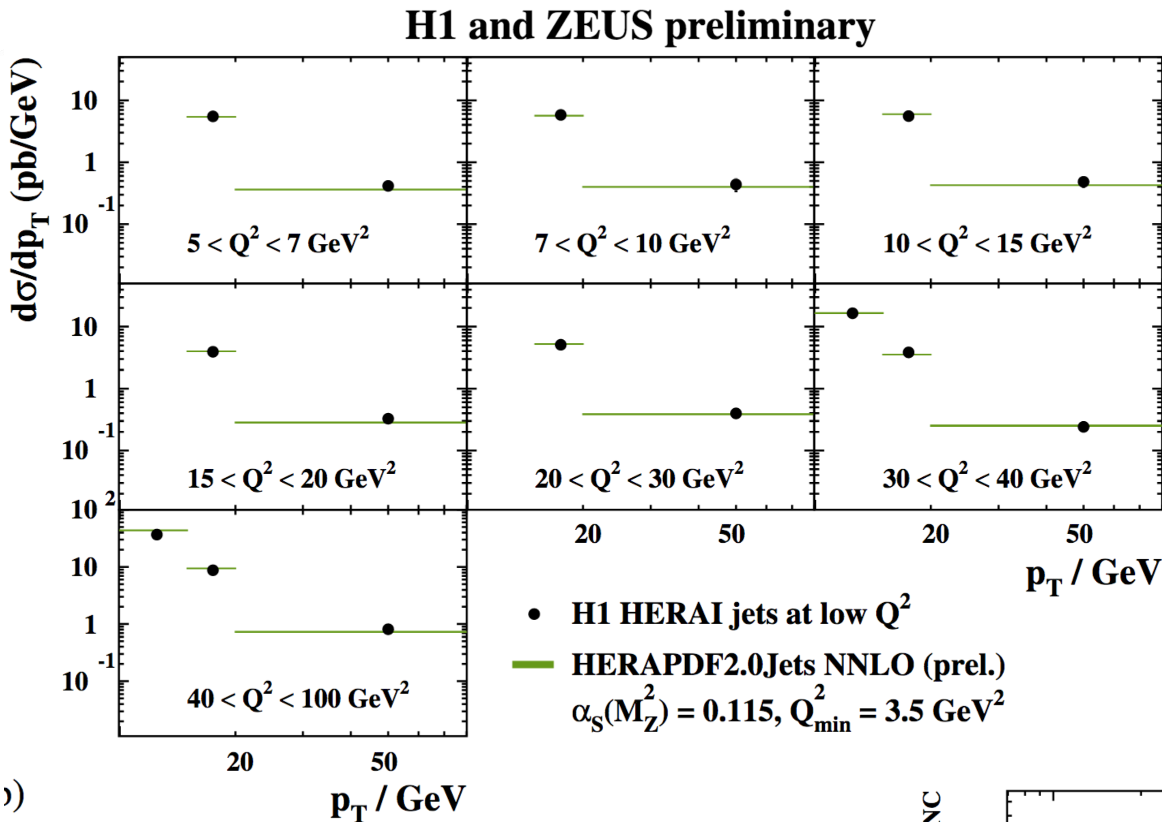


Finally a full picture of jets@HERA



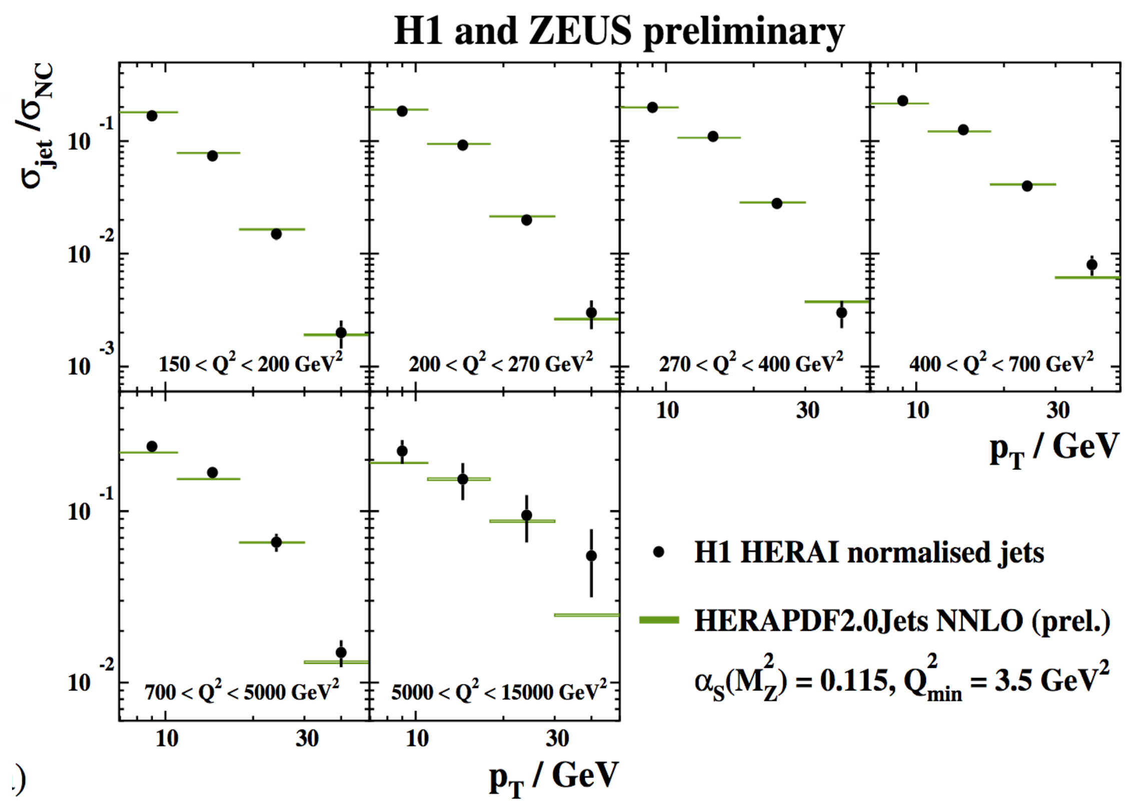


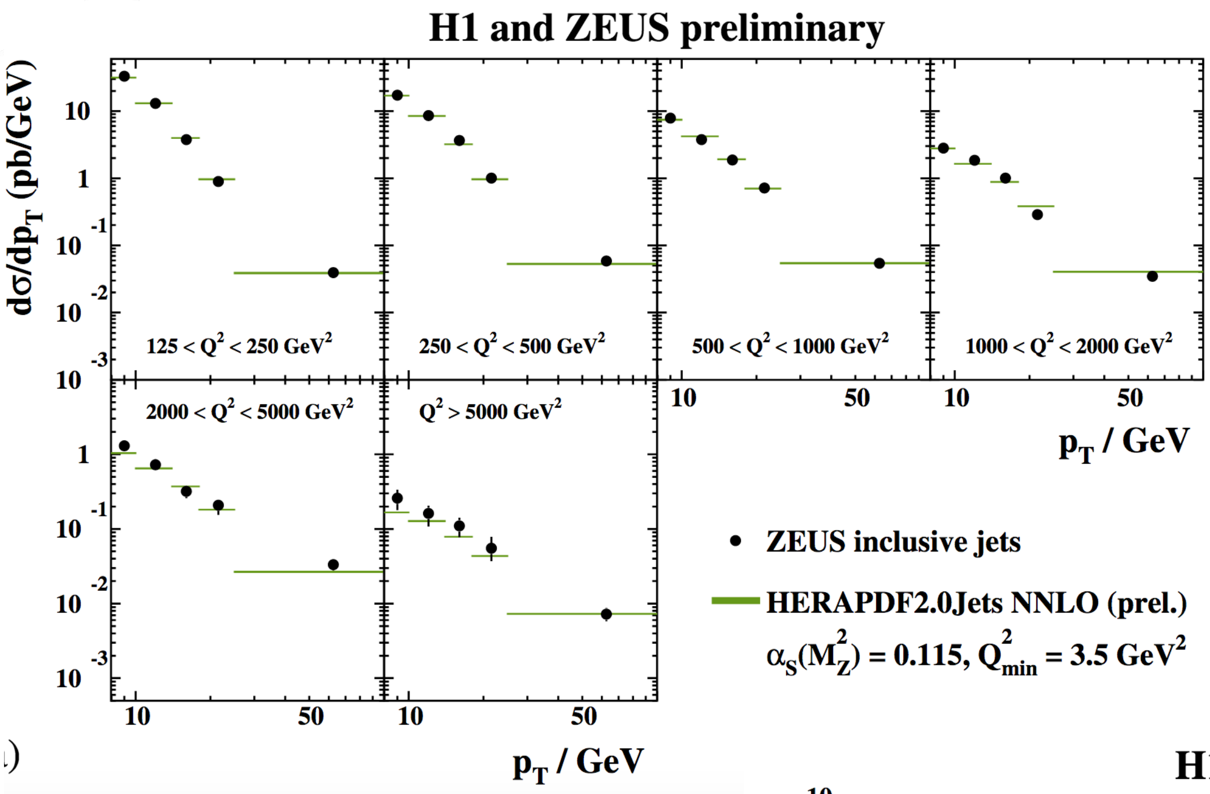
- Just as at NLO the jet data constrain $\alpha_s(M_Z)$
- Similar level of accuracy at NNLO and NLO
- $\alpha_s(M_Z)$ clearly lower at NNLO



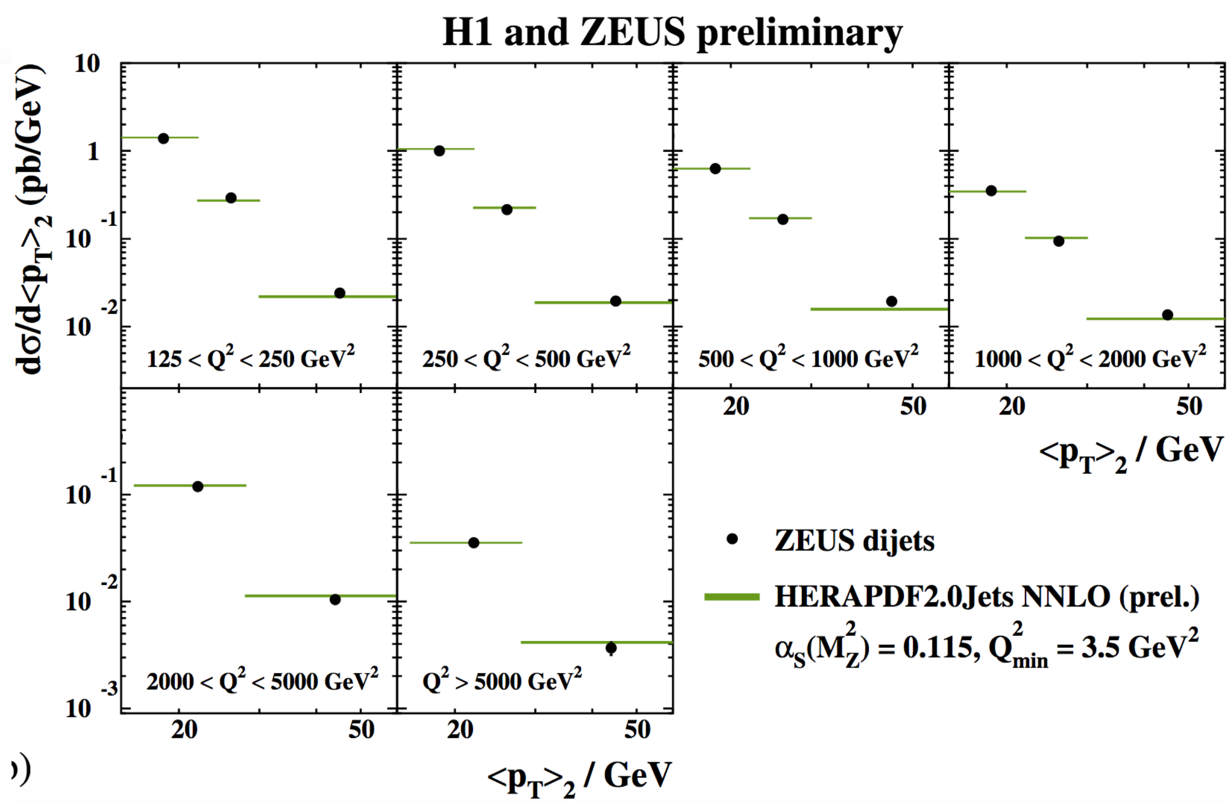
Comparison of theory predictions to H1 HERA I inclusive jets @ low and high Q^2

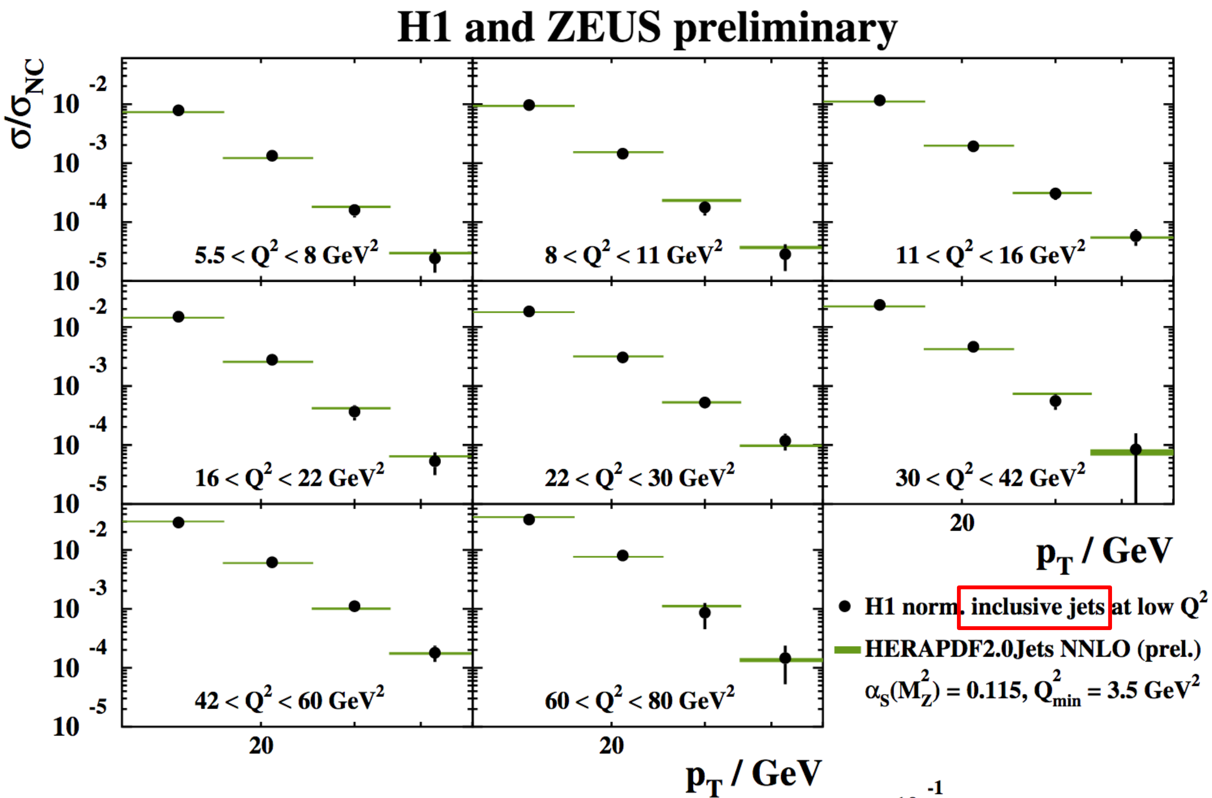
→ good agreement





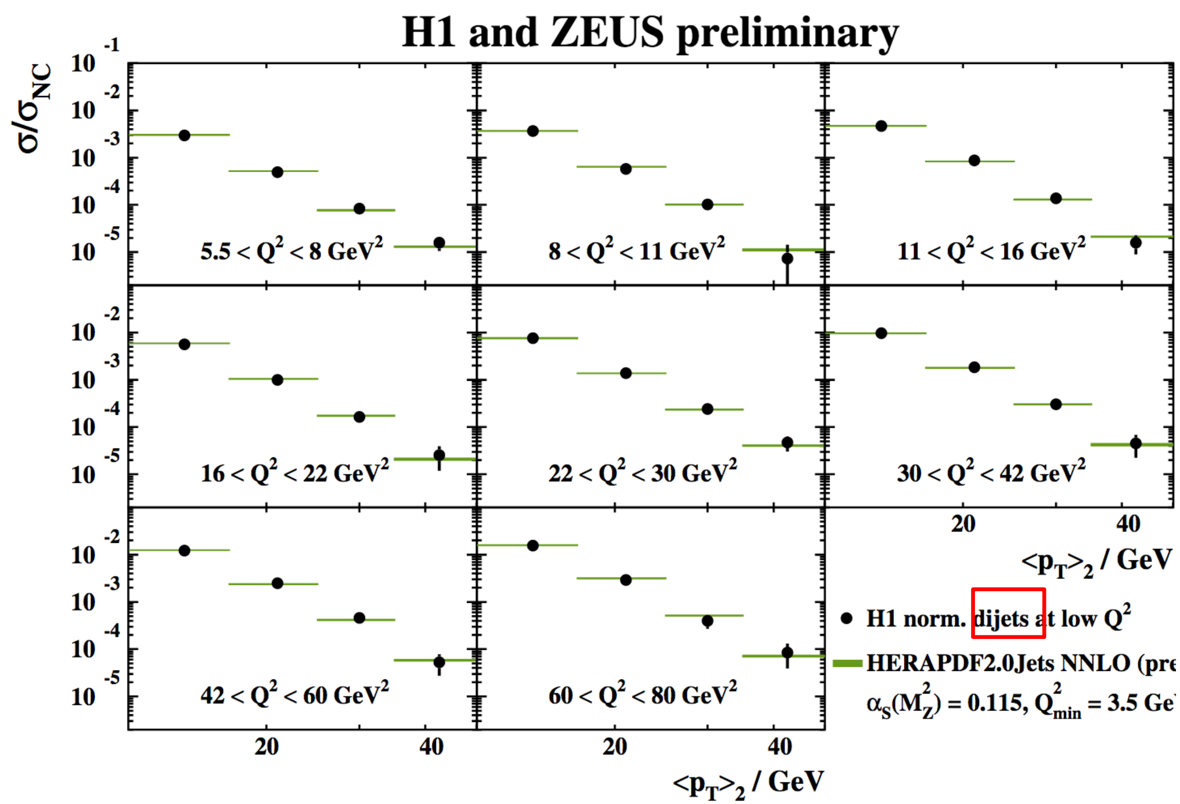
Comparison of theory predictions to ZEUS HERA I inclusive jets and dijets
→ good agreement





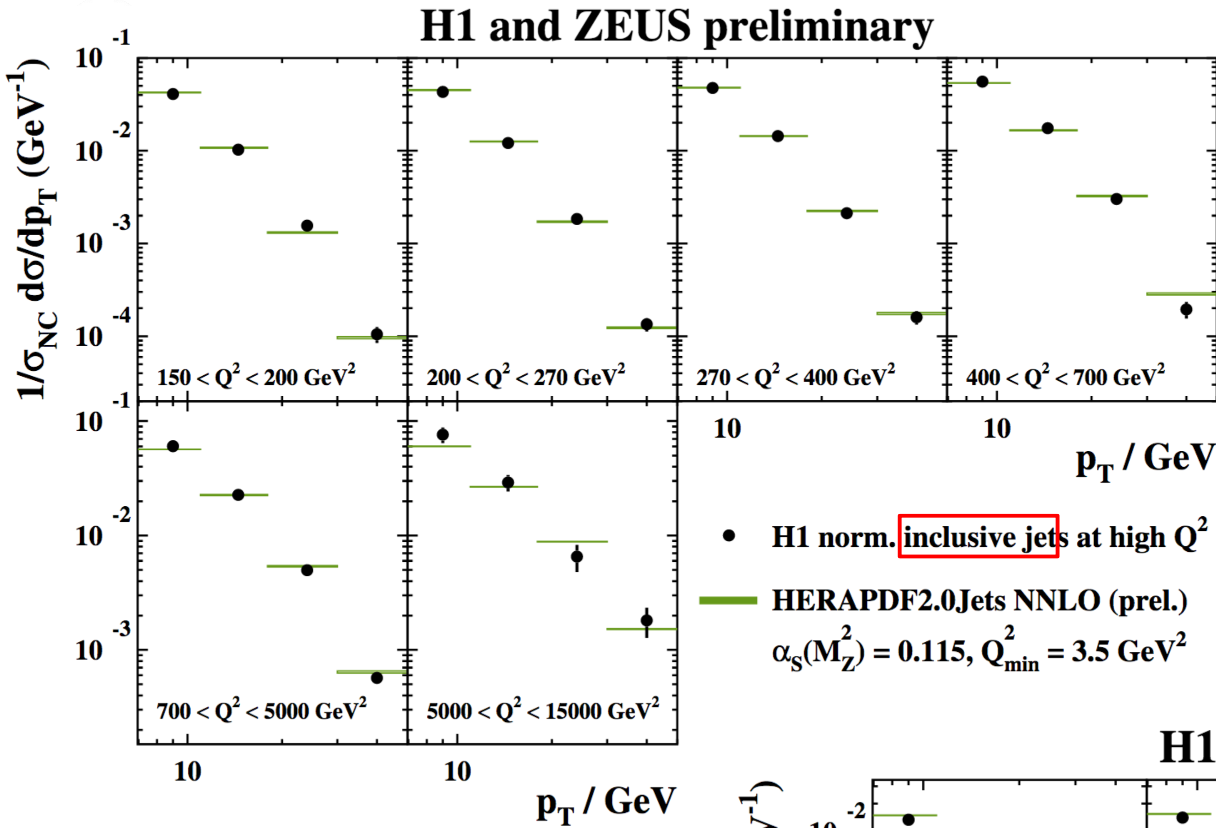
Comparison of theory predictions to H1 HERA II normalised jets @ low Q^2

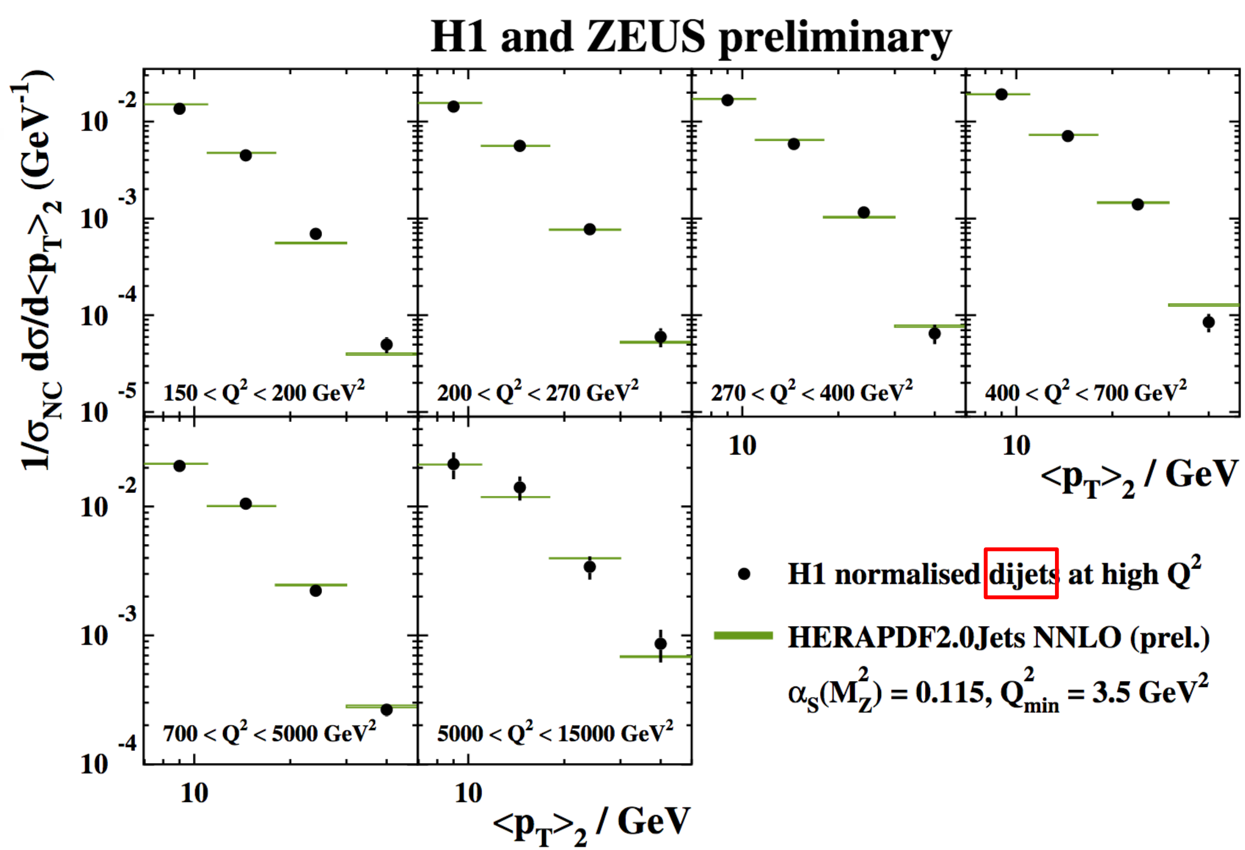
→ good agreement



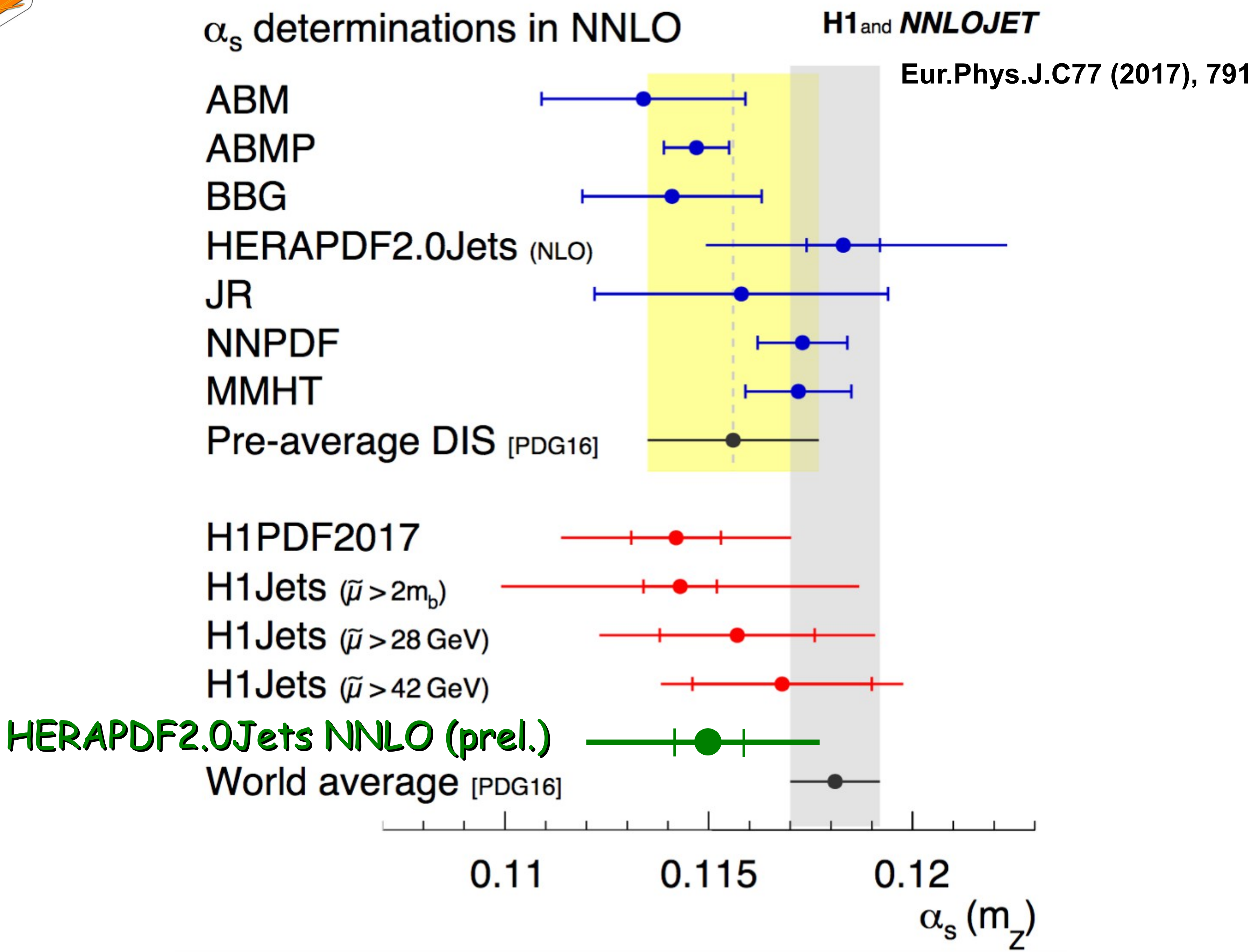
Comparison of theory predictions to H1 HERA II normalised jets @ high Q^2

→ good agreement

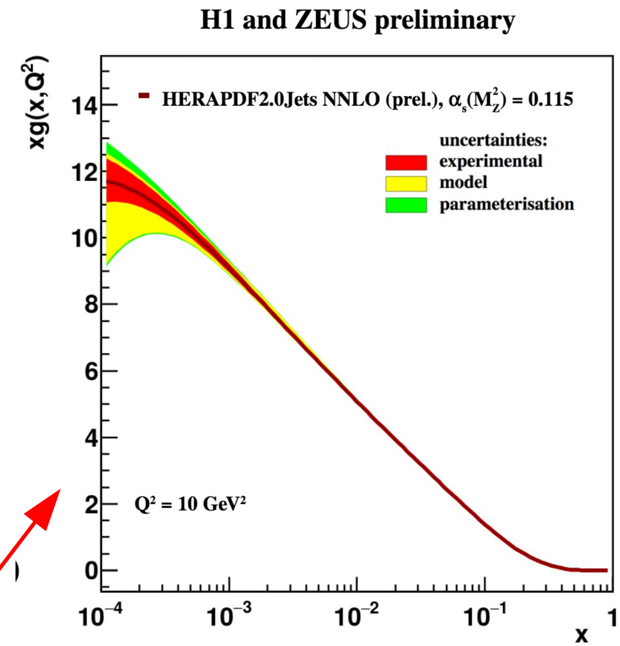




Comparison to other NNLO results



Summary & conclusions



- 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 (prel.), $\alpha_s(M_Z)$ = 0.115 → value favoured by our fit
- Jet data allow us to constrain $\alpha_s(M_Z)$

$$\alpha_s(M_Z^2) = 0.1150 \pm 0.0008(\text{exp})^{+0.0002}_{-0.0005}(\text{model/parameterisation}) \pm 0.0006(\text{hadronisation}) \pm 0.0027(\text{scale}) .$$

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

Systematic shift downwards at NNLO and reduction of scale uncertainty