Impact of jet-production data on the NLO determination of HERAPDF2.0 parton distributions

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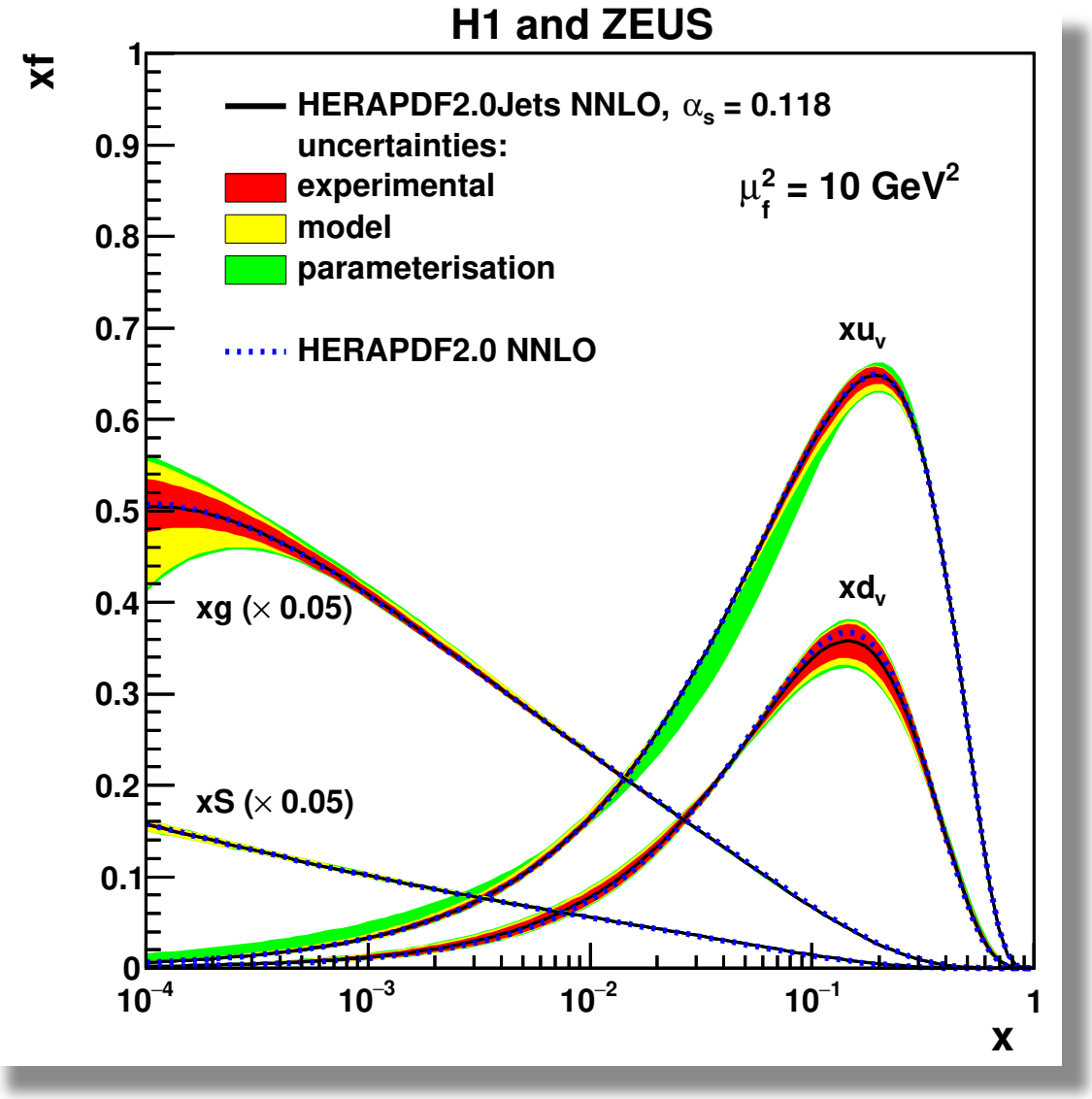
On behalf of the H1 & ZEUS Collaborations

DOE NP contract: DE-SC0013405

Outline

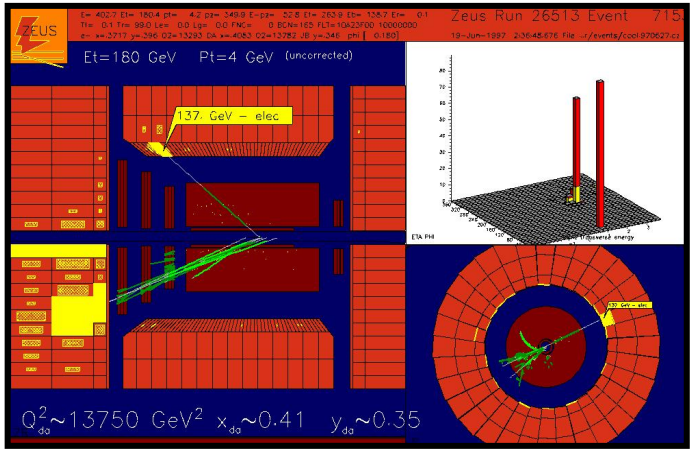
- Introduction
- Details of new HERAPDF2.0
- Results of new HERAPDF2.0
- Summary



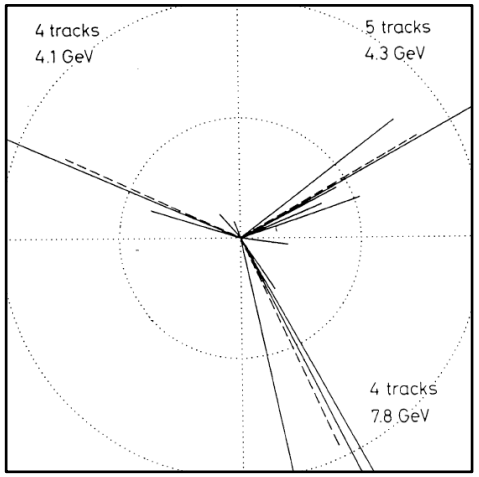
EPJC 82, 243 (2022)

Introduction

- Jet production at DESY for over 40 years
  - At HERA direct information on gluon and α_S from jet production
  - Possible simultaneous determination of parton distribution functions and α_S

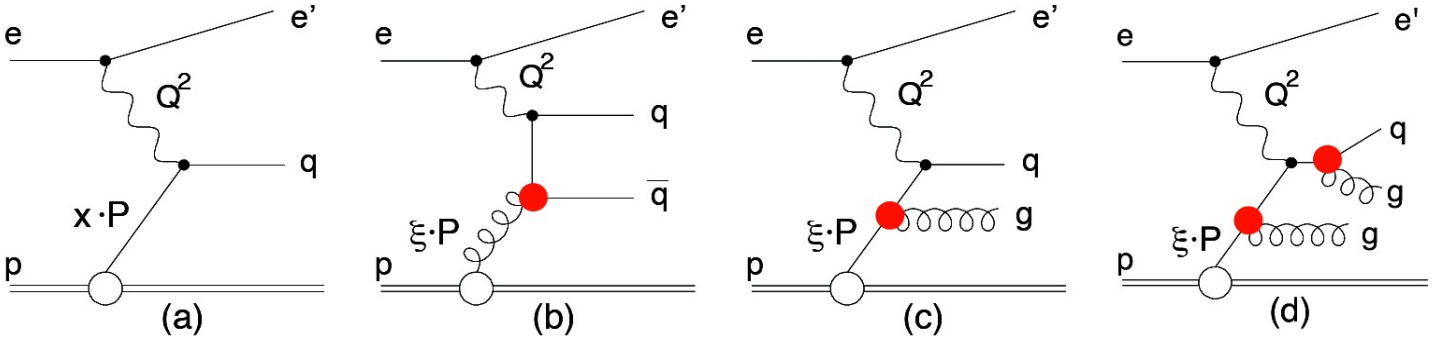


Jet production at HERA



Jet production at PETRA

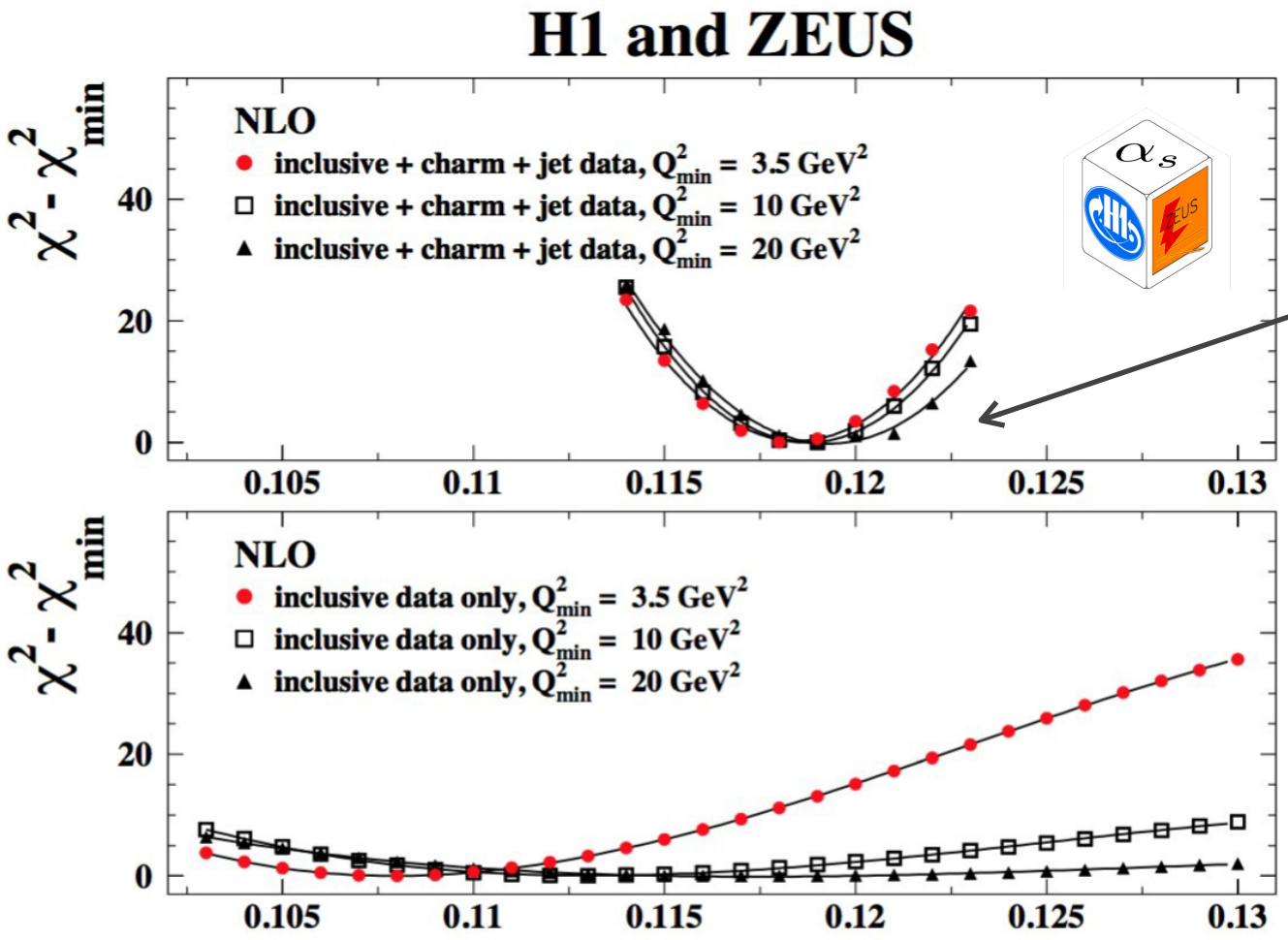
TASSO Collaboration, R. Brandelik et al., Phys. Lett. B 86 (1979) 243.



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

Introduction

- Motivation for jet production

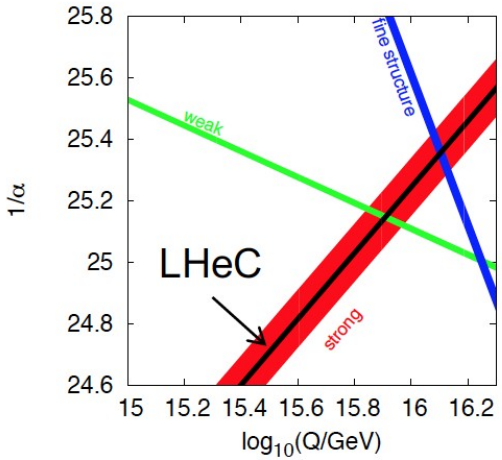


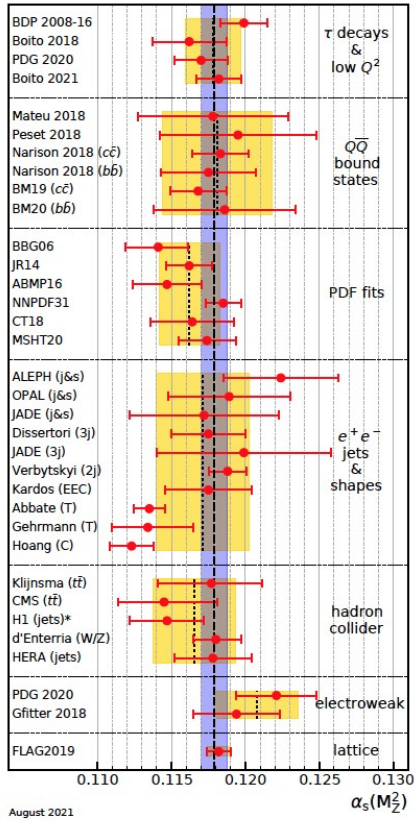
- At HERA inclusive data carry little information on α_S
- Jet data sensitive to α_S
- New NNLO calculations for HERA ep jet production available now: Implemented in FastNLO and APPLEGRID, allowing for fast cross-section calculations

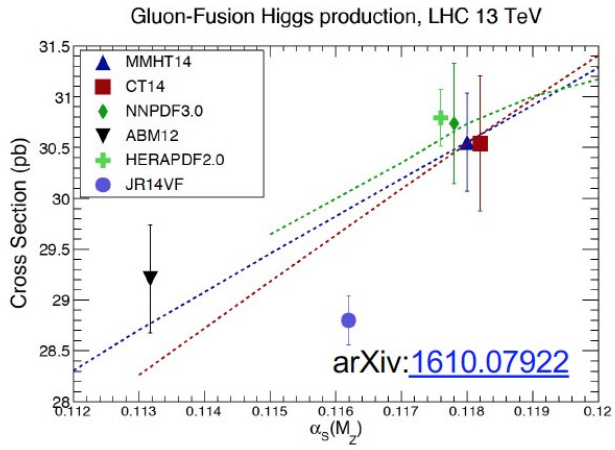
Introduction

Impact for LHC program

Claire Gwenlan, Moriond 2022







- αs is least known coupling constant;

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

  …

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

  …

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

- what is true αs central value and uncertainty?

  new precise determinations have important role to play

Details of new HERAPDF2.0 global fit

- PDF parameterization

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

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

Additional constraints:

- A_{u_v}, A_{d_v}, A_g, constrained by quark-number and momentum sum rules
- $B_{\bar{U}} = B_{\bar{D}}$
- Strange-quark distribution, $x\bar{s}$, expressed as an x-dependent fraction, f_s, of the d-type sea, $x\bar{s} = f_s x\bar{D}$

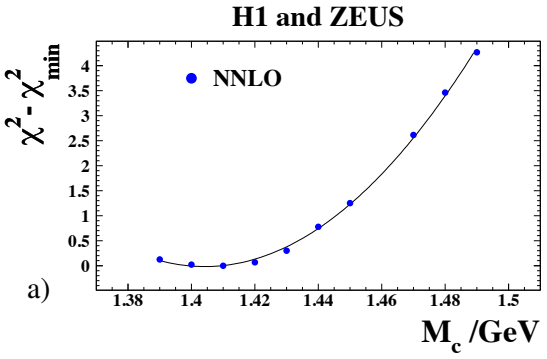
Details of new HERAPDF2.0 global fit

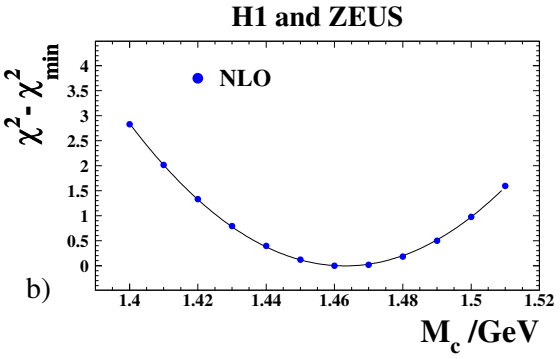
- Updates on global fit procedure
  - At NLO, the factorizations scale was chosen as $\mu_f^2 = Q^2$, for the inclusive data, while the renormalization scale was linked to the transverse momenta, p_T, of the jets as $\mu_r^2 = (Q^2 + p_T^2)/2$.
  - At NNLO, the factorizations/renormalization scales were chosen as $\mu_f^2 = \mu_r^2 = Q^2 + p_T^2$ for inclusive jets and $\mu_f^2 = \mu_r^2 = (Q^2 + p_T^2)/2$ for dijets.
  - Changes resulted in improved χ^2 values for the fits!
  - In general, scale variations are used to estimate uncertainties due to missing higher-order contributions.
  - Model and parameterization uncertainties on the PDFs were evaluated by using fits with modified input assumptions.
  - For jet-data analysis, the effect of the uncertainties from hadronization corrections were taken into account: No significant difference to any of the results presented!

Details of new HERAPDF2.0 global fit

- Estimation of charm & beauty mass parameters
  - Roberts-Thorne Optimal (RTOPT) heavy-quark scheme used to evaluate predictions for the inclusive data requiring charm/beauty mass parameters: m_c, m_b
  - Optimized mass parameters: m_c, m_b

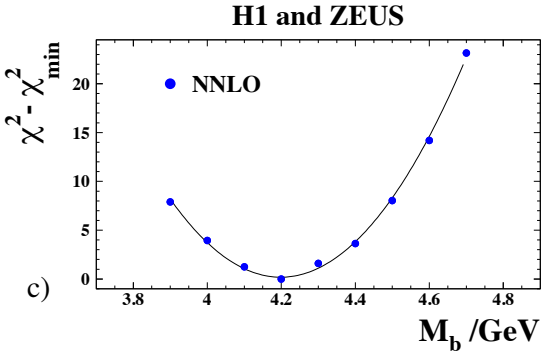
$M_c = 1.41 \pm 0.04\,\text{GeV}$

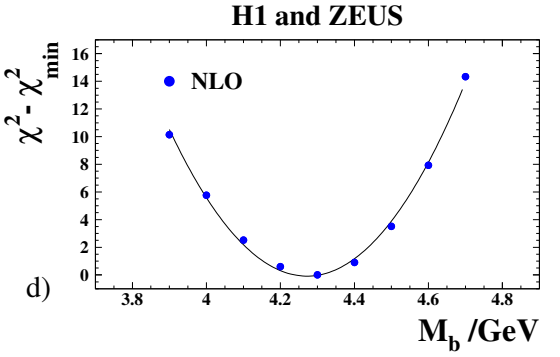




$M_c = 1.46 \pm 0.04\,\text{GeV}$

$M_b = 4.20 \pm 0.10\,\text{GeV}$





$M_b = 4.30 \pm 0.10\,\text{GeV}$

Details of new HERAPDF2.0 global fit

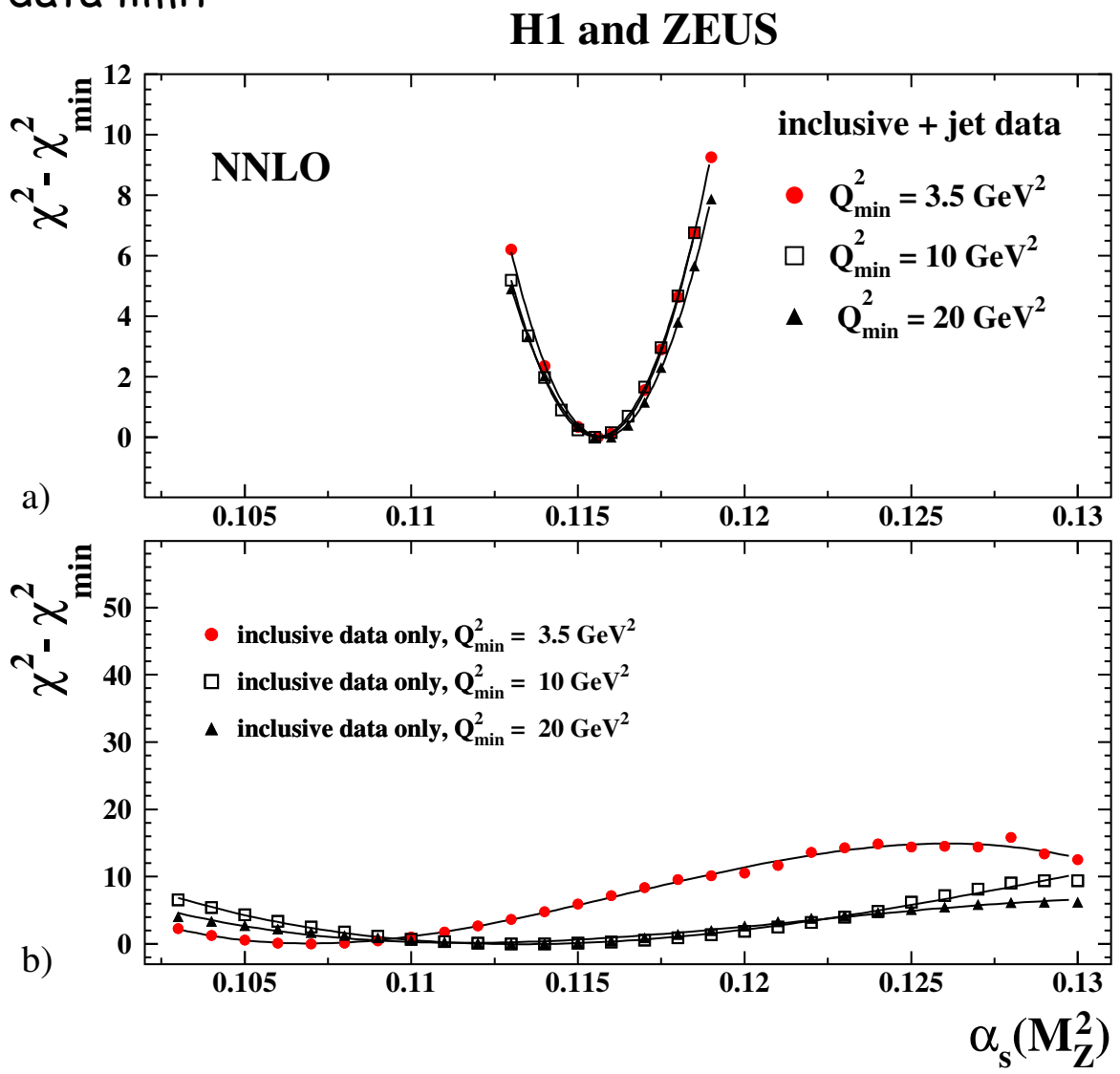
- HERA global analysis data set
  - Data taken by H1 and ZEUS from 1993 - 2007 were combined for inclusive HERA ep DIS cross-sections taking all systematic uncertainties into account (Previously used for HERAPDF2.0!).
  - HERAPDF2.0Jets analysis at NNLO, use selected data of inclusive jet and dijet production from H1 and ZEUS, adding new low Q^2 data from H1.
  - Jet reconstruction: Massless jets identified with k_T algorithm, with R=1.

Data set	taken from	to	Q^2[GeV^2] range from	to	$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV	Norma-lised	All points	Used points	Ref.
H1 HERA I normalised jets	1999	2000	150	15000	65.4	e^+p	319	yes	24	24	[9]
H1 HERA I jets at low Q^2	1999	2000	5	100	43.5	e^+p	319	no	28	20	[10]
H1 normalised inclusive jets at high Q^2	2003	2007	150	15000	351	e^+p/e^-p	319	yes	30	30	[13,14]
H1 normalised dijets at high Q^2	2003	2007	150	15000	351	e^+p/e^-p	319	yes	24	24	[13]
H1 normalised inclusive jets at low Q^2	2005	2007	5.5	80	290	e^+p/e^-p	319	yes	48	37	[14]
H1 normalised dijets at low Q^2	2005	2007	5.5	80	290	e^+p/e^-p	319	yes	48	37	[14]
ZEUS inclusive jets	1996	1997	125	10000	38.6	e^+p	301	no	30	30	[11]
ZEUS dijets 1998 –2000 &	2004	2007	125	20000	374	e^+p/e^-p	318	no	22	16	[12]

EPJC 82, 243 (2022)

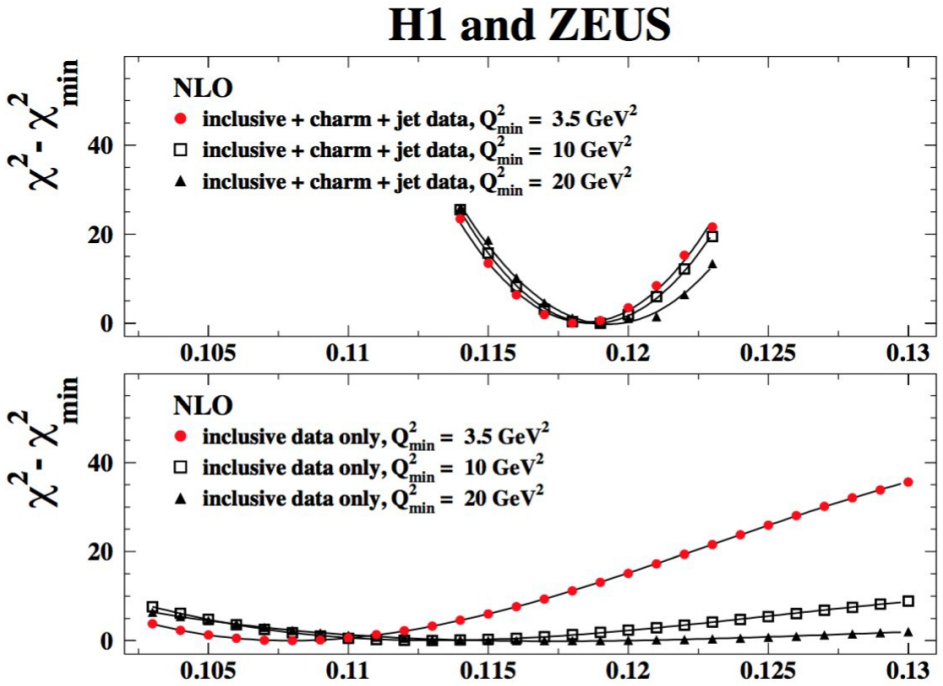
Details of new HERAPDF2.0 global fit

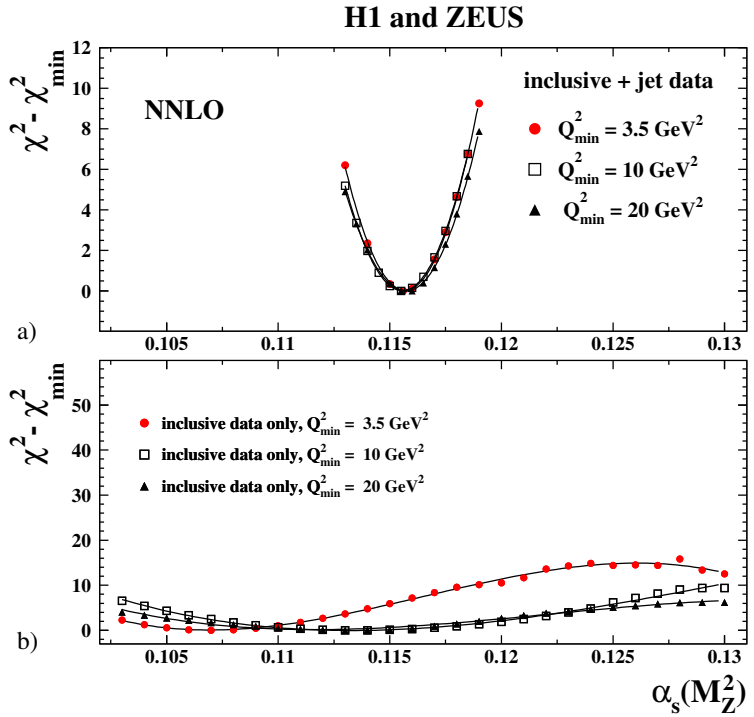
- Robustness of global fit - Low Q^2 data limit
  - HERA data at low x and Q2 may be subject to need for ln(1/x) corrections or higher twist effects!
  - Data with $Q^2 \geq Q^2_{min}$ were taken into account. Variation of Q^2_{min} does not result in any significant changes to the value of α_S.



Details of new HERAPDF2.0 global fit

- Robustness of global fit - NLO/NNLO comparison





- Jet data crucial for enhancing sensitivity to α_S
- Similar behavior and level of precision at NLO and NNLO. However direct comparison of 2015 and 2022 results not possible due to different scale choices and slightly different jet data sets!

Details of new HERAPDF2.0 global fit

- Comparison to other HERAPDF2.0 fits
  - For previous NLO results scale uncertainty applied as 50% correlated and 50% uncorrelated between bins and data sets.
  - Using the same procedure, our present NNLO result becomes:

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

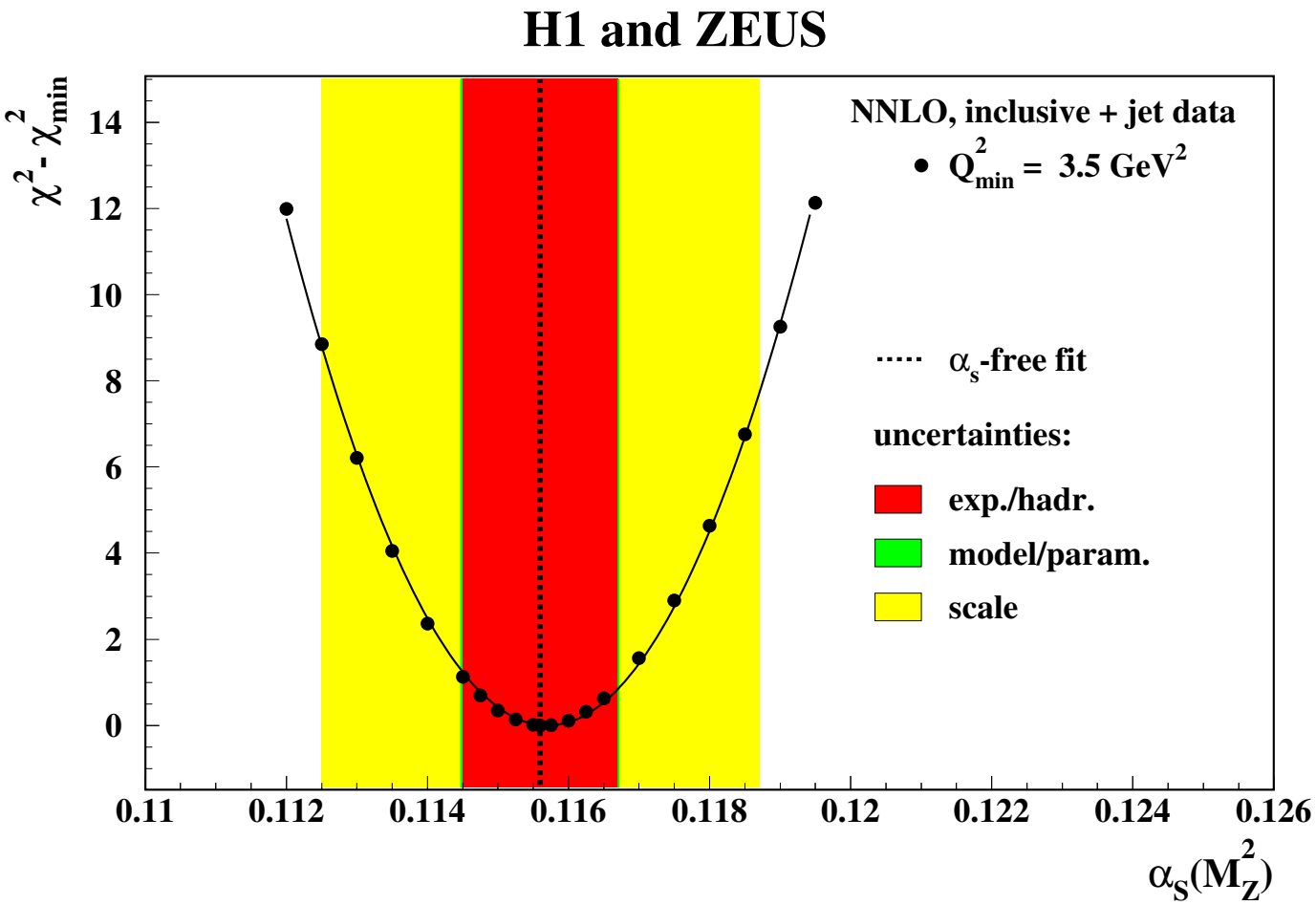
At NLO:

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

  - Scale uncertainties reduced as expected for NNLO calculations!

Results of new HERAPDF2.0 global fit

- α_S from HERA jets



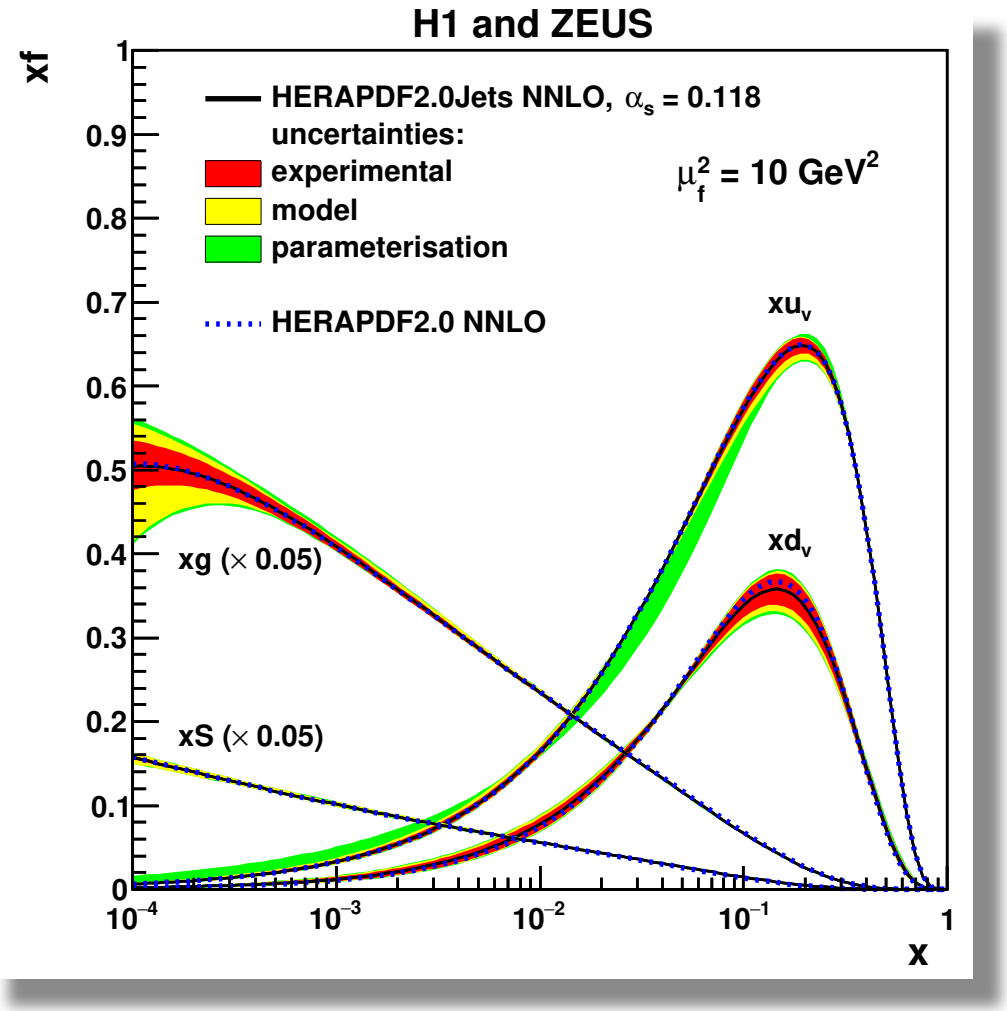
$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\ (\text{exp})\ {}^{+0.0001}_{-0.0002}\ (\text{model + parameterisation})\ \pm 0.0029\ (\text{scale})$$

Results of new HERAPDF2.0 global fit

- Comparison to other HERAPDF2.0 fits
  - Experimental uncertainties: Hessian method
  - Model uncertainties all added in quadrature
  - Parametrization uncertainties largest deviation

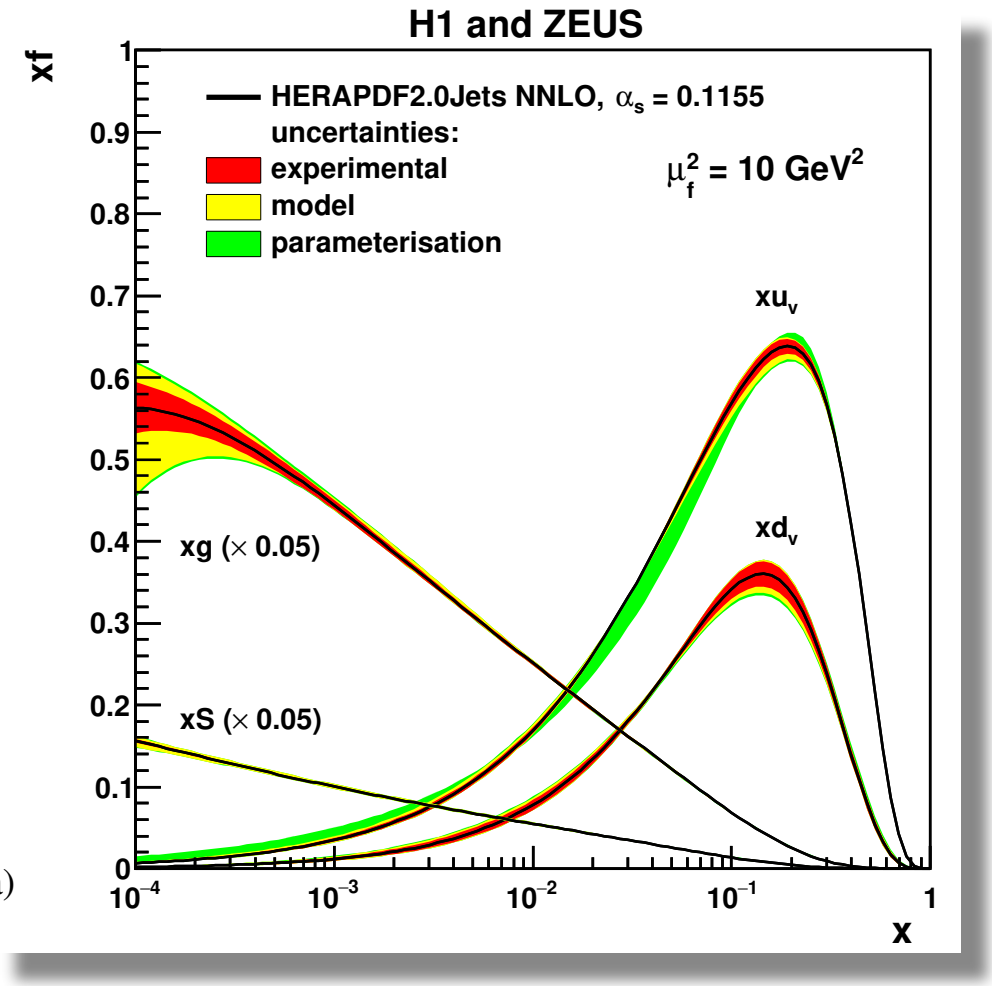
Parameter	Central value	Downwards variation	Upwards variation
$Q^2_{\min}$ [GeV^2]	3.5	2.5	5.0
f_s	0.4	0.3	0.5
M_c [GeV]	1.41	1.37*	1.45
M_b [GeV]	4.20	4.10	4.30
μ^2_{f0} [GeV^2]	1.9	1.6	2.2*

  - HERAPDF2.0Jets NNLO fit: 1363 data points with $\chi^2/\mathrm{ndf} = 1614/1348 = 1.197$ compared to $\chi^2/\mathrm{ndf} = 1363/1131 = 1.205$ based in incl. data only!
  - Jet data do not introduce any additional tension into the fit and are fully consistent with inclusive data!

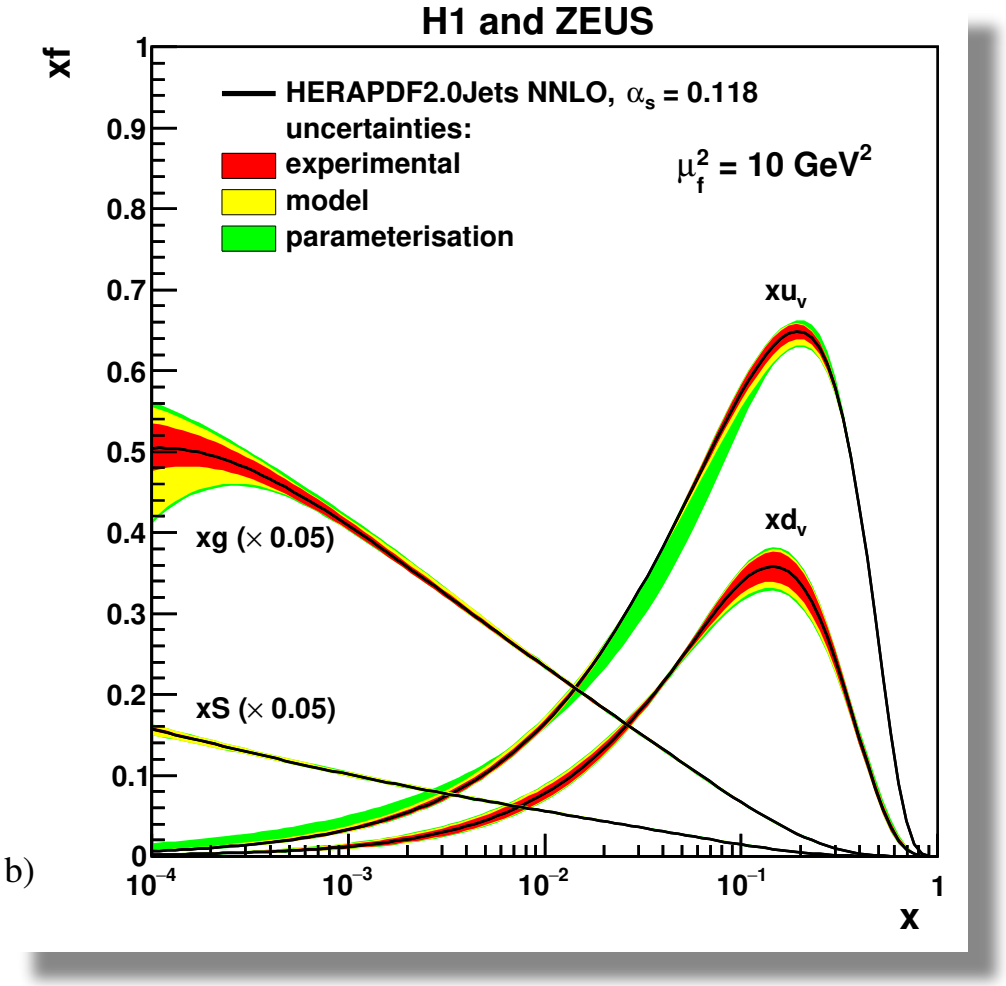


Results of new HERAPDF2.0 global fit

- New HERAPDF2.0 fit



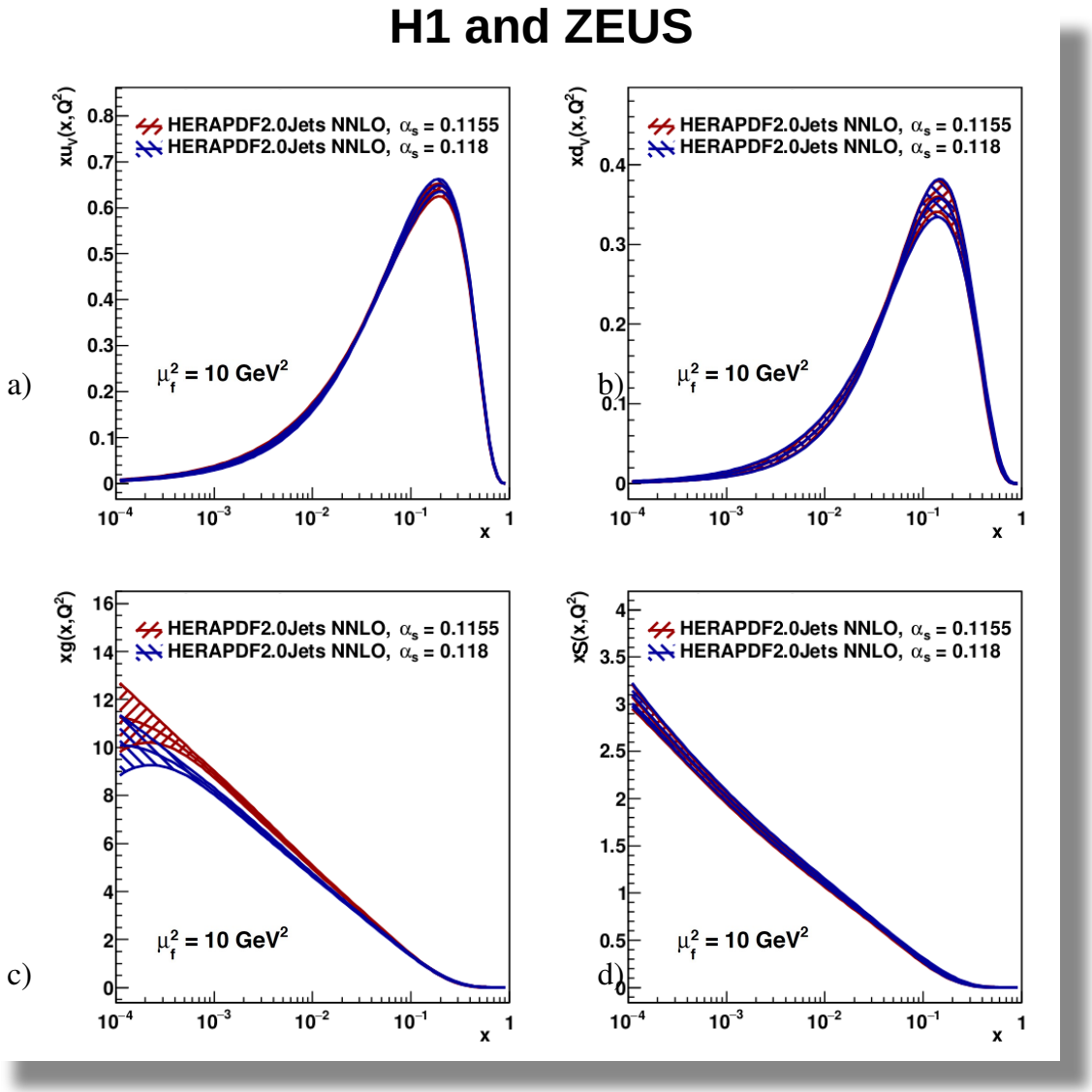
a)



b)

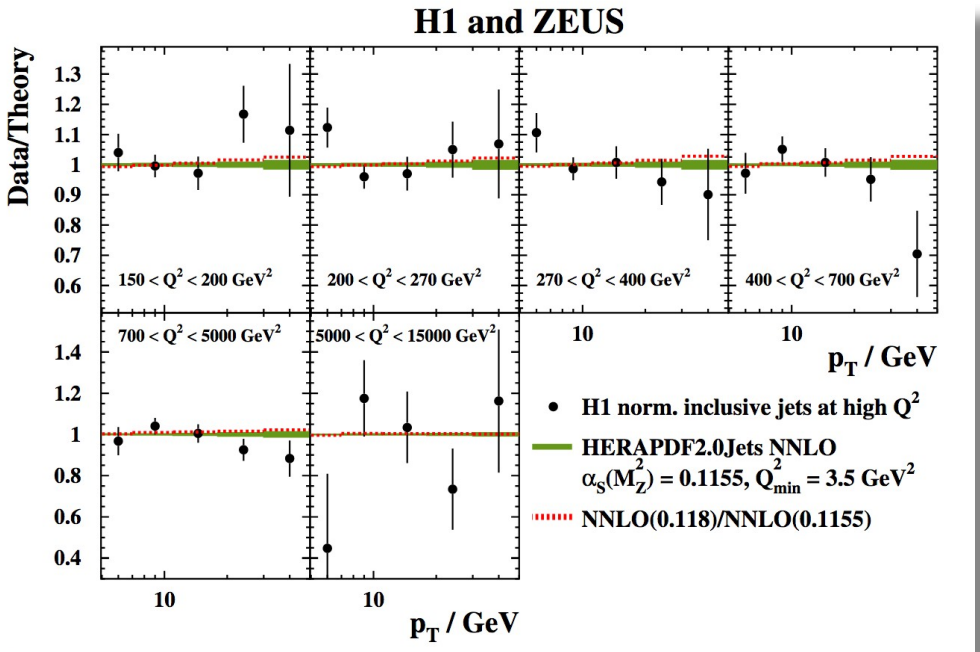
Results of new HERAPDF2.0 global fit

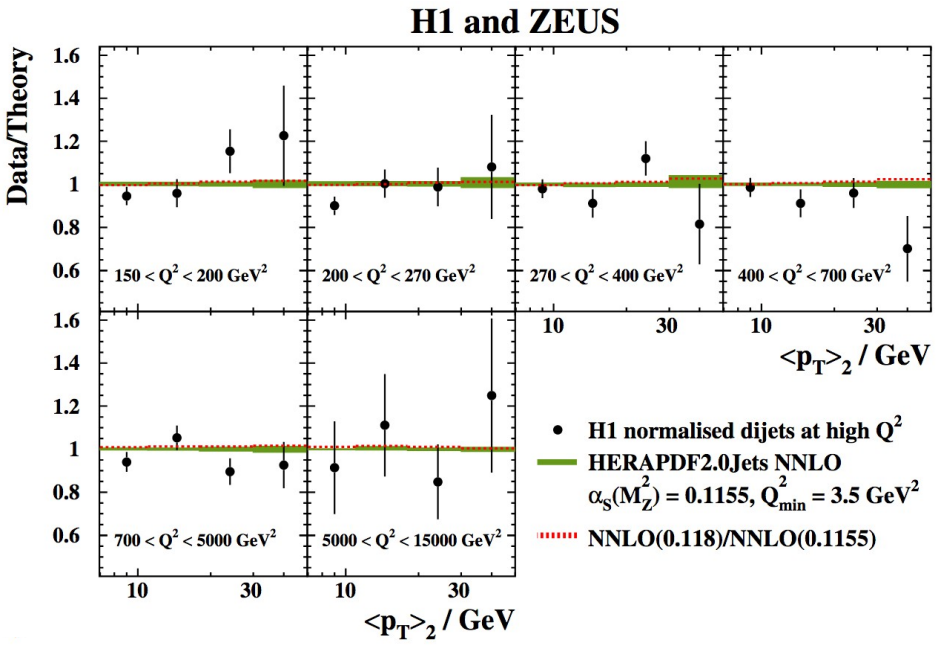
- Comparison to $\alpha_S = 0.1155$



Results of new HERAPDF2.0 global fit

- Comparison of theory predictions to H1 norm. inclusive jets at high Q^2

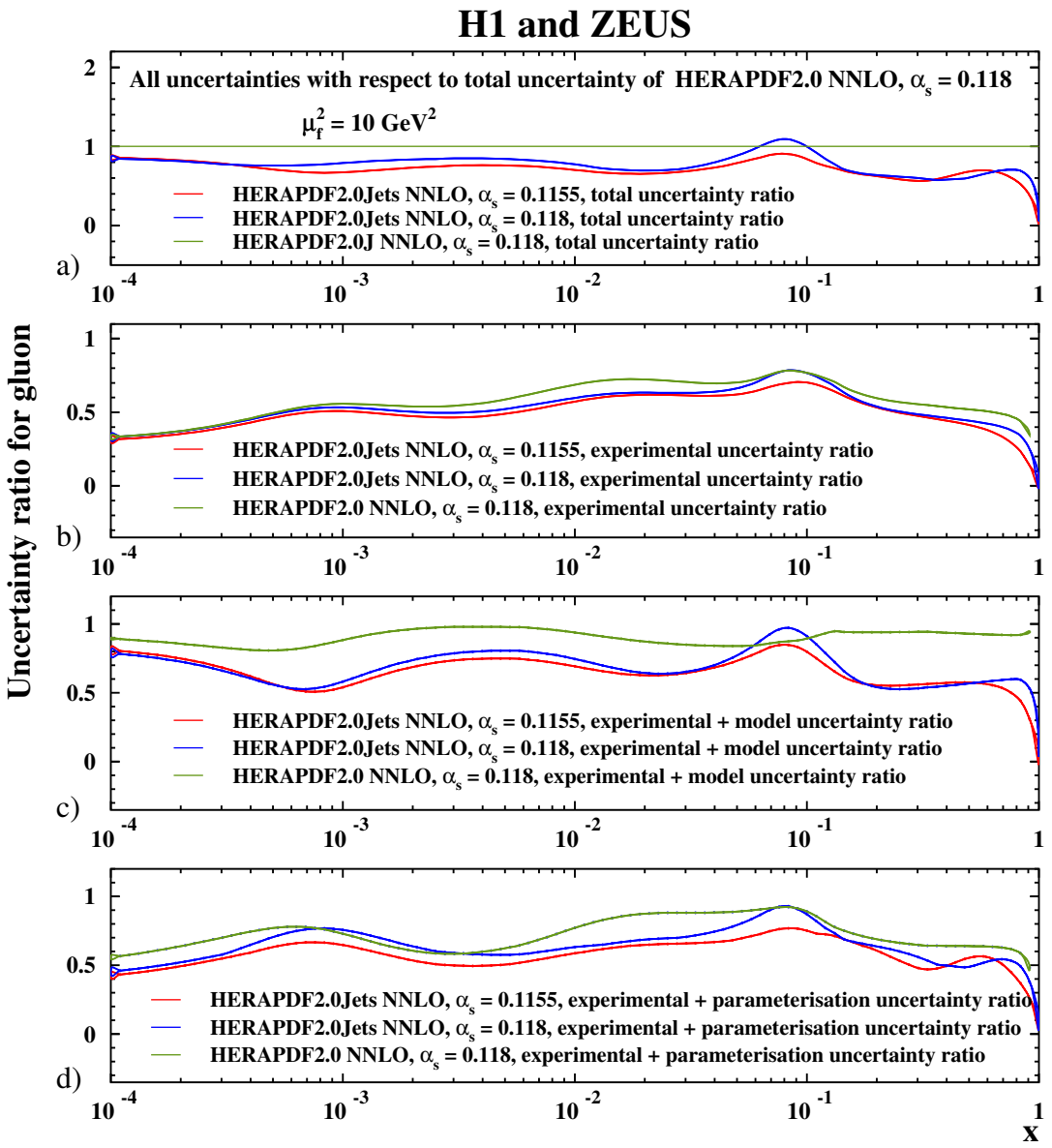




- Comparison of theory predictions to H1 HERA II normalized jets @ high Q^2
- Good agreement for all data used in PDF fits

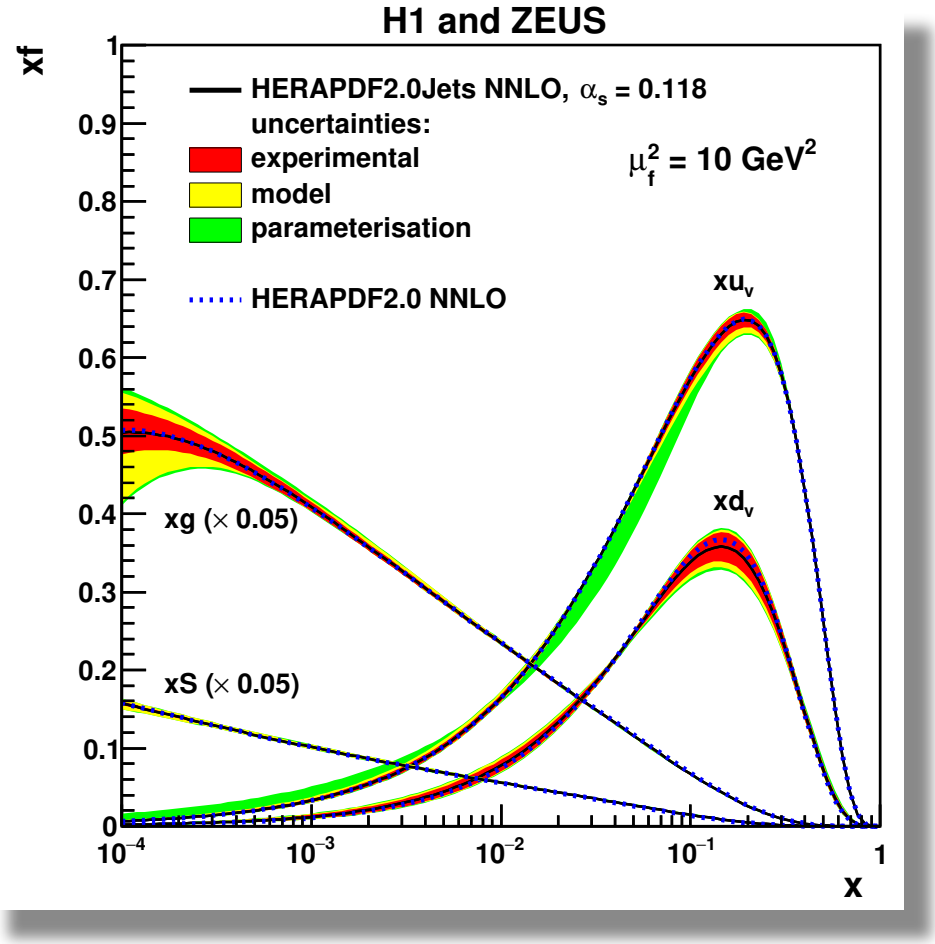
Results of new HERAPDF2.0 global fit

- Impact on uncertainties
  - Reduction of low-x gluon ($x < 10^{-3}$) uncertainties due to reduced model/param. uncertainties
  - Reduction of high-x gluon ($x > 10^{-3}$) uncertainties due to reduced model/param./exp. uncertainties



Summary

- HERAPDF2.0 family of PDFs completed by performing an NNLO QCD fit including HERA DIS inclusive-jet and di-jet data with α_S and PDFs fitted simultaneously!
- Critical: Theoretical (NNLOJet) and fast interpolation grid technology development (APPLfast)
- Jet data sensitive to α_S :



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

Thank you!

Thank you!

Katarzyna Wichmann (DESY)

and

Amanda Cooper-Sarkar (Oxford University) /

Claire Gwenlan (Oxford University)