ZEUS-prel-19-001

H1prelim-19-041

NNLO QCD fits to HERA jets and extraction of α_s

Status report → towards final results

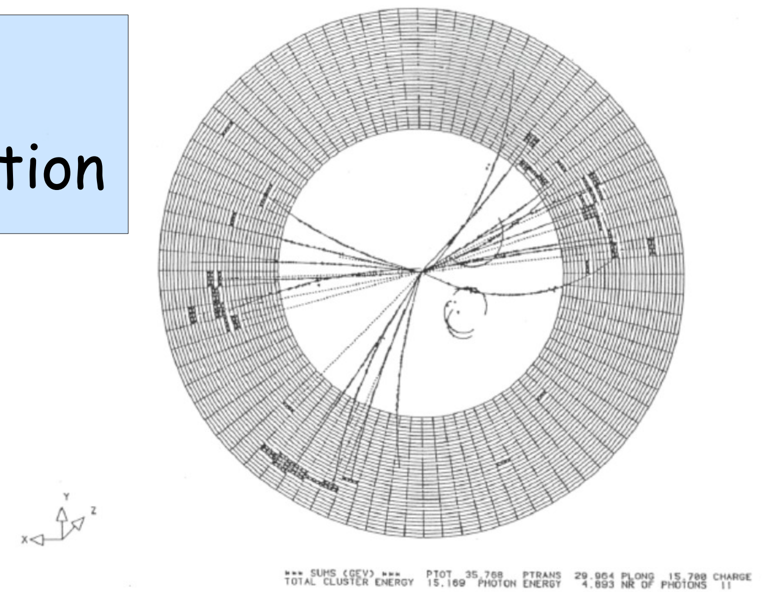
A. Cooper-Sarkar, K. Wichmann

41 years of jet production @ DESY

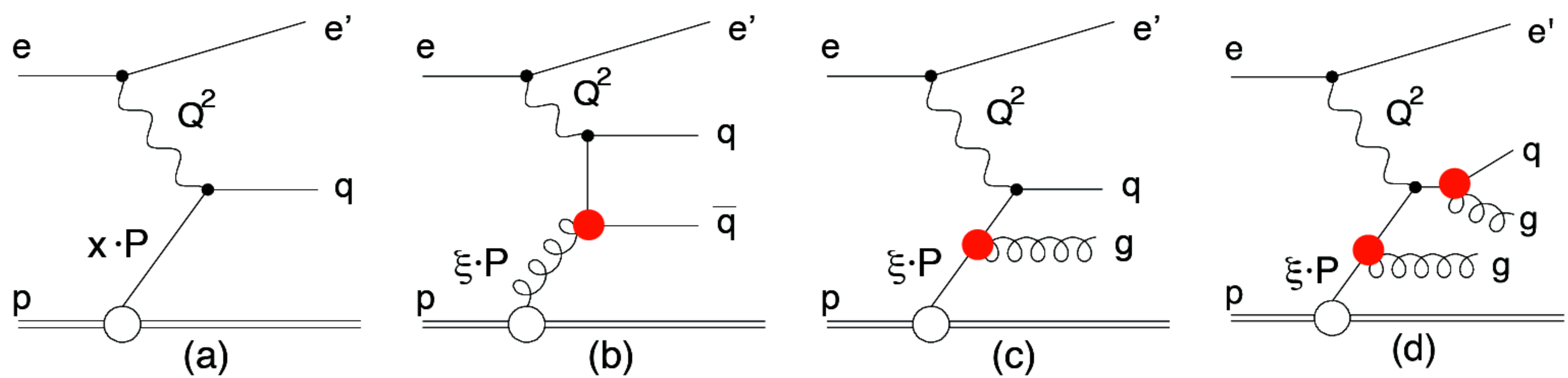
At HERA direct information on gluon distribution and α_s comes from jet production

→ Possible simultaneous determination of parton densities and α_s

Jets at PETRA, 1979



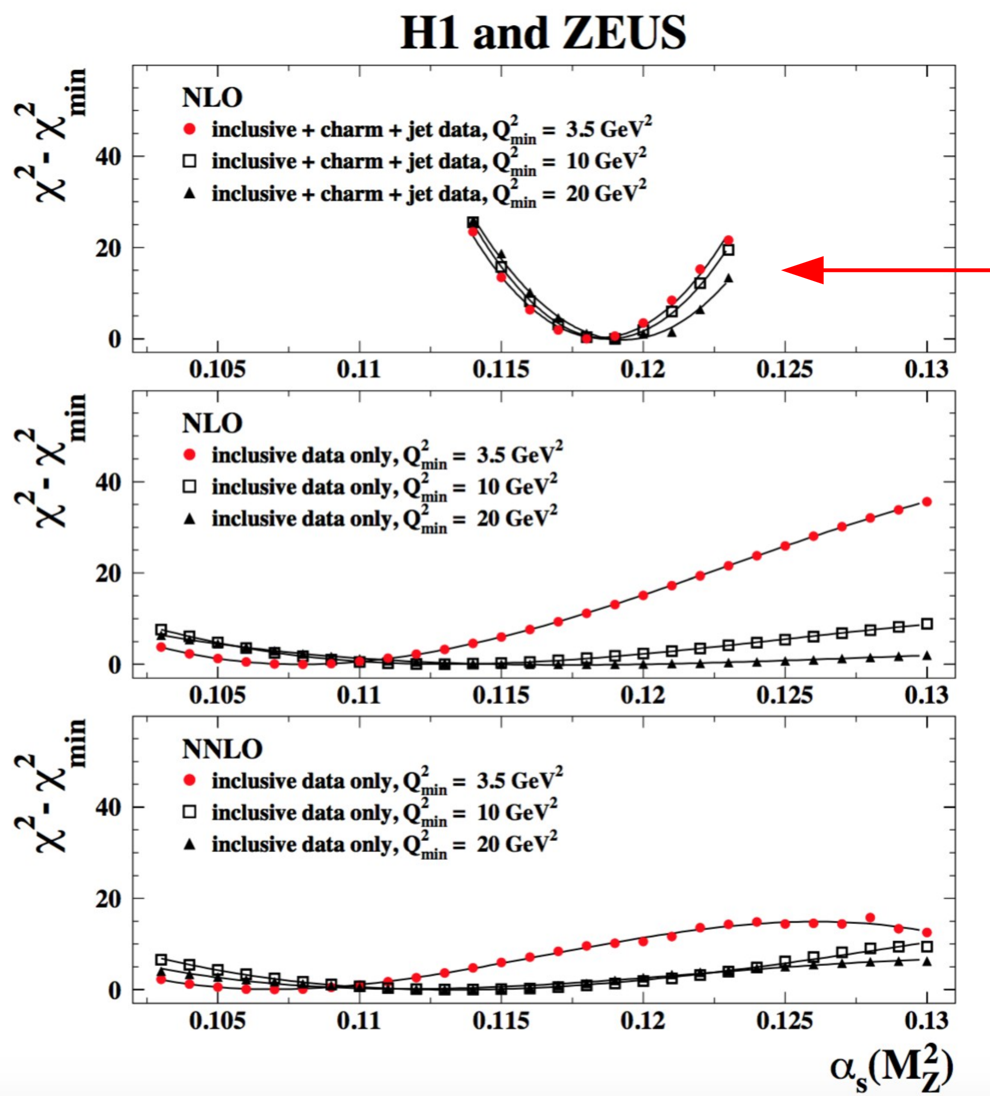
Jets at HERA



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

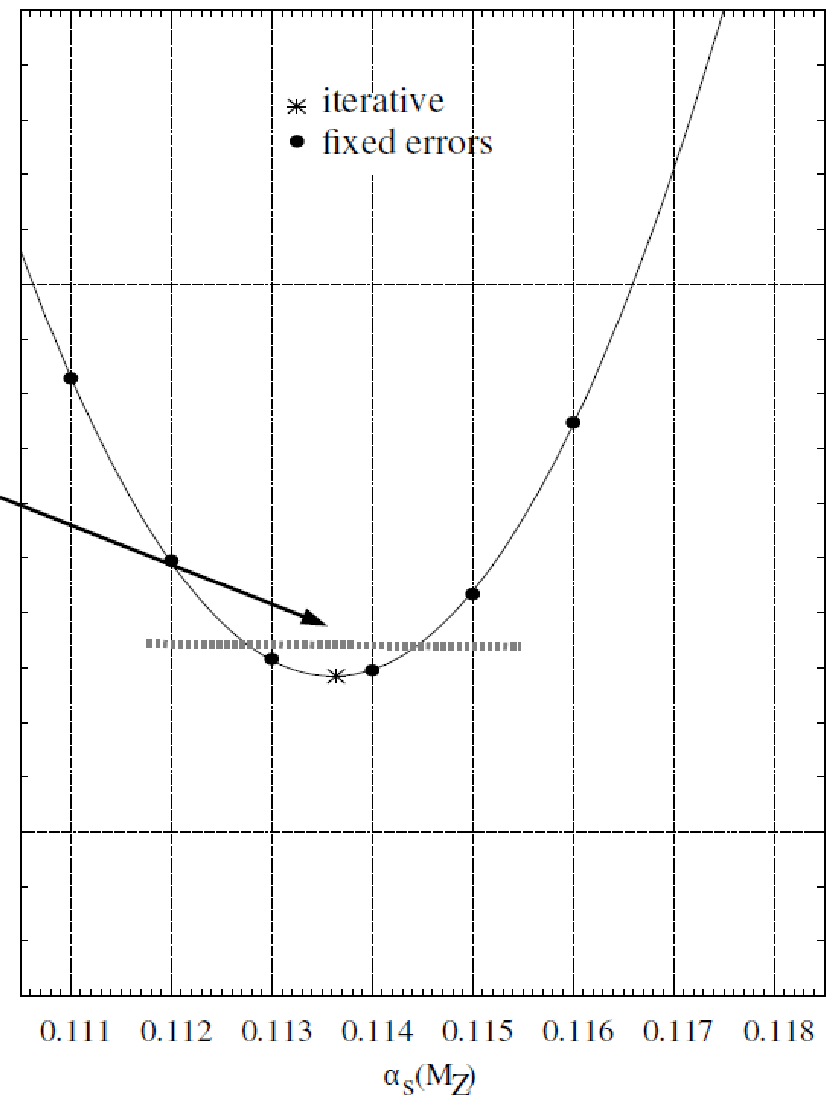
Global analysis of parton distributions

Goal: determination of the ***input distributions*** (for light quarks and gluons):

Method: Parametrizations $xf(x,Q_0^2) = Nx^a(1-x)^b\,\text{function}(x)$

and usual *statistical estimation* (fits):

$$\chi^2(p) = \sum_{i=1}^{N}\left(\frac{\text{data}(i) - \text{theory}(i,p)}{\text{error}(i)}\right)^2$$



Position of minimum gives the value and curvature gives the error (region within a certain “tolerance” $\Delta\chi^2 = 1$)

(Monte Carlo methods can also be used)

Usually the chi-square definition is more sophisticated, experimental correlations are also treated, etc.

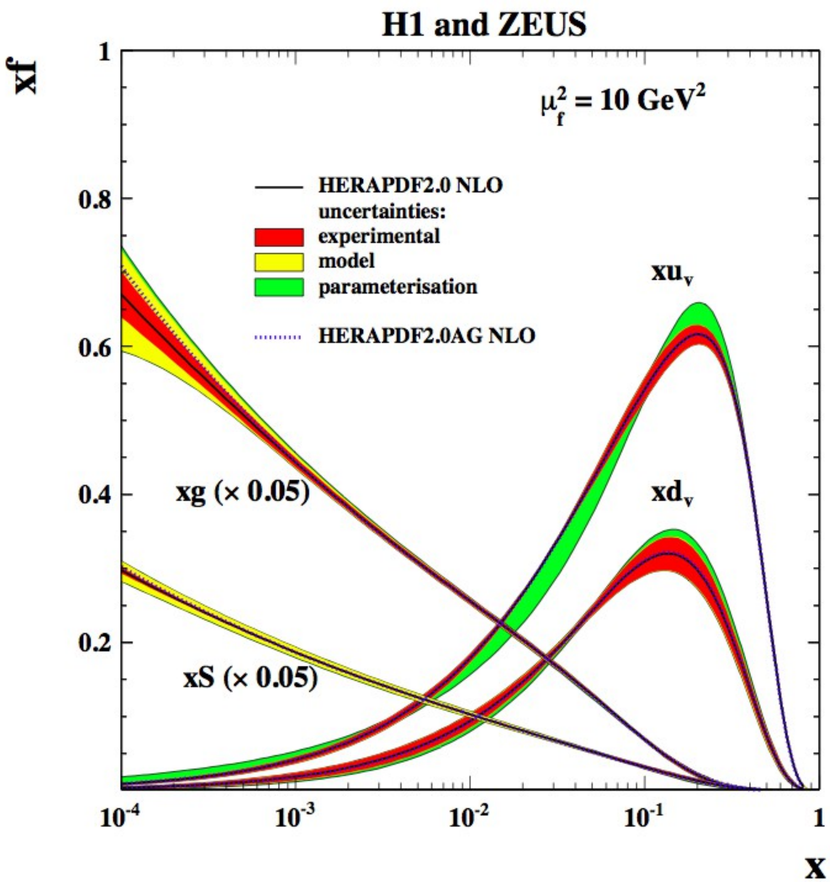
HERAPDF2.0 parameterisation

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

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

- Additional 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_{f_0} [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

The plan for work to complete the analysis is outlined in the talk from November 29th: IN SUMMARY

- Finish the NNLO analysis much in the way that the DIS19 preliminary was done but with new mc,mb settings accounting for the new c,b combined data
- Using the same data sets, same cuts, same scale choice, same parametrisation ---(all checks done --ie settings and parametrisation choice iterated) – done

FOR:

- $\alpha_S(M_Z)$ =0.115
- $\alpha_S(M_Z)$ =0.118
- Free alphas

- All model/ parametrisation uncertainties treated as agreed: vary Q^2_0 down ONLY and symmetrise; vary Mc up ONLY and symmetrise done

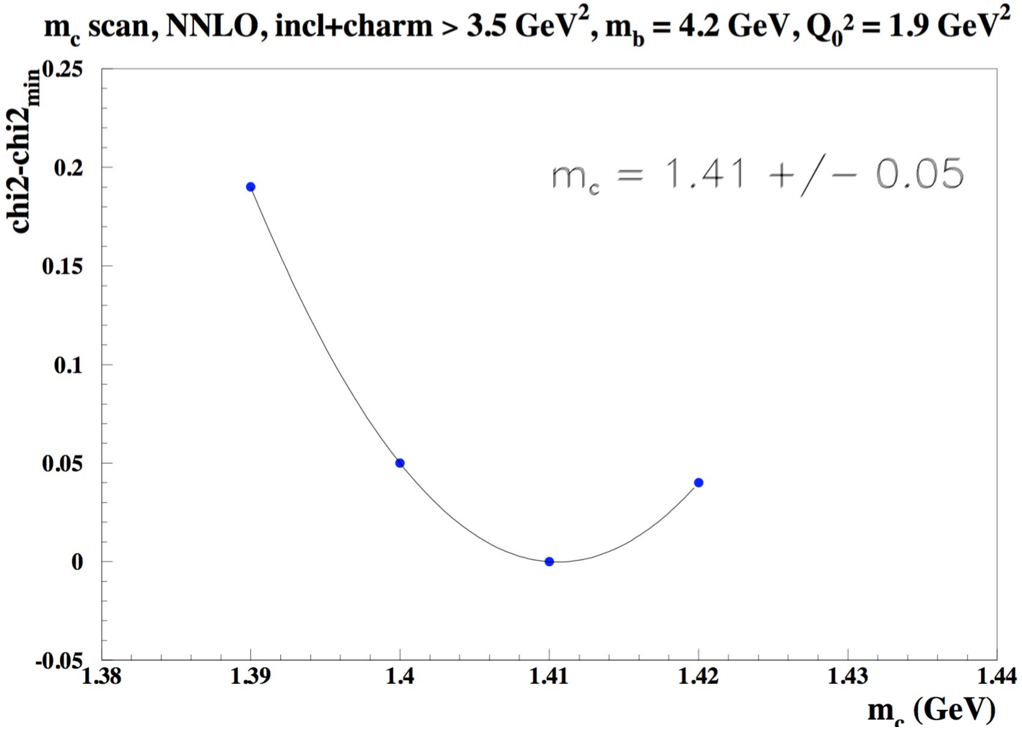
- Hadronisation by offset consistently ie set hadronisation uncertainty of H1 2016 low Q2 jets=zero for central job (it was the 13th systematic uncertainty) in progress

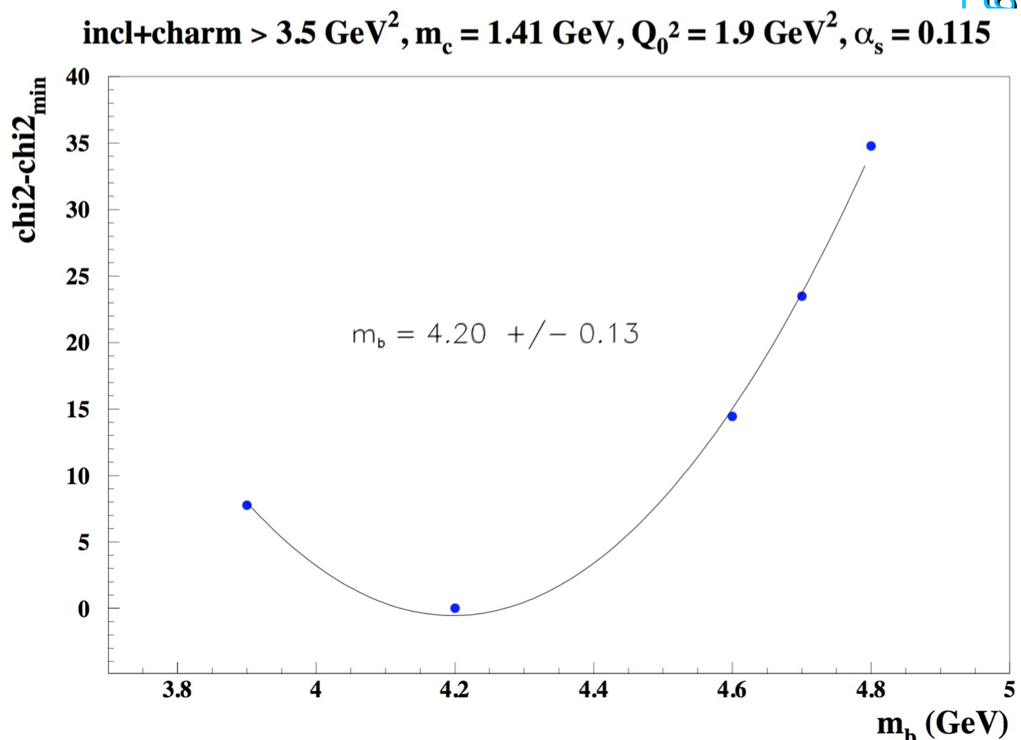
- Scale uncertainty ½ correlated , ½ uncorrelated as for HERAPDF2.0NLOJets in progress

- Do not revisit NLO other than to say that the current scale choice would have resulted in $\alpha_S(M_Z)$ =0.121 rather than 0.118
- Maybe also say not revisiting it because the most significant new data set—H1 low Q2 jets 2016 is not well fitted at NLO

Updates for final results

- New charm and beauty masses
  → from final H1/ZEUS beauty results Eur. Phys. J C 78 (2018) 473
  - Charm mass m_c = 1.41 +/- 0.05
  - Beauty mass m_b = 4.20 +/- 0.13





Updates for final results

- Other settings stay the same
  → parameter scan done using new settings → as before: 14 params
  → α_s repeated with new parameters → very small differences compared to preliminary results (both studies already presented in H1/ZEUS meetings)

- New points in jet data (5 points) → see next slide
  - Studies shown by Mandy on jan. 22nd

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^-	norma-lised	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

- 6 data points added
  → H1 normalised inclusive jets at high Q^2
    → for each Q^2 bin low-p_t point added

What we have as preliminary and how it compares to new results

→ not everything finished yet

PDF fits for

$\alpha_s = 0.118$

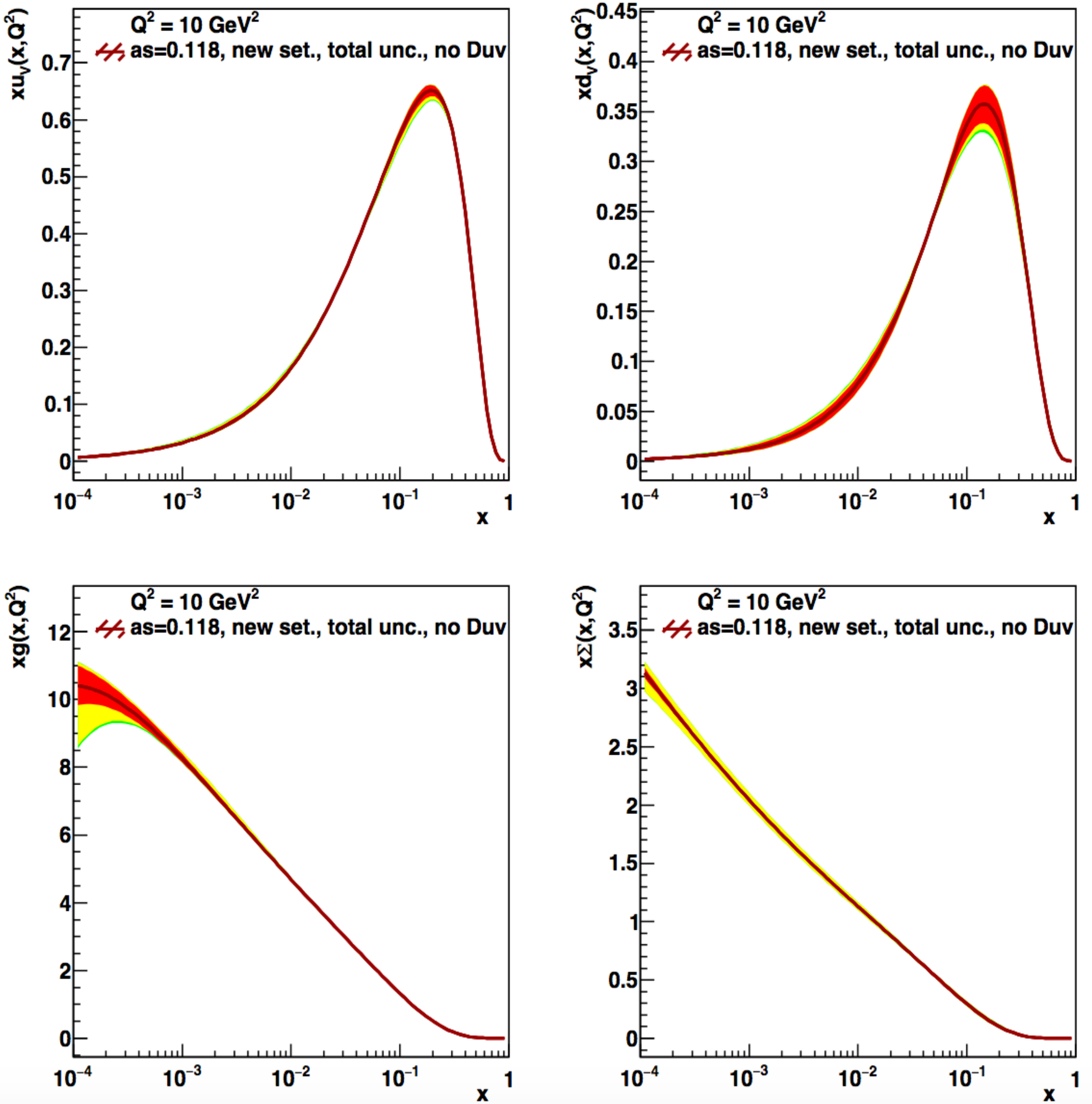
Caution: not done yet

- For parameterisation uncertainty
  - Adding Duv paramter → 15 parameters

→ very difficult fits, problems with convergence, work in progress

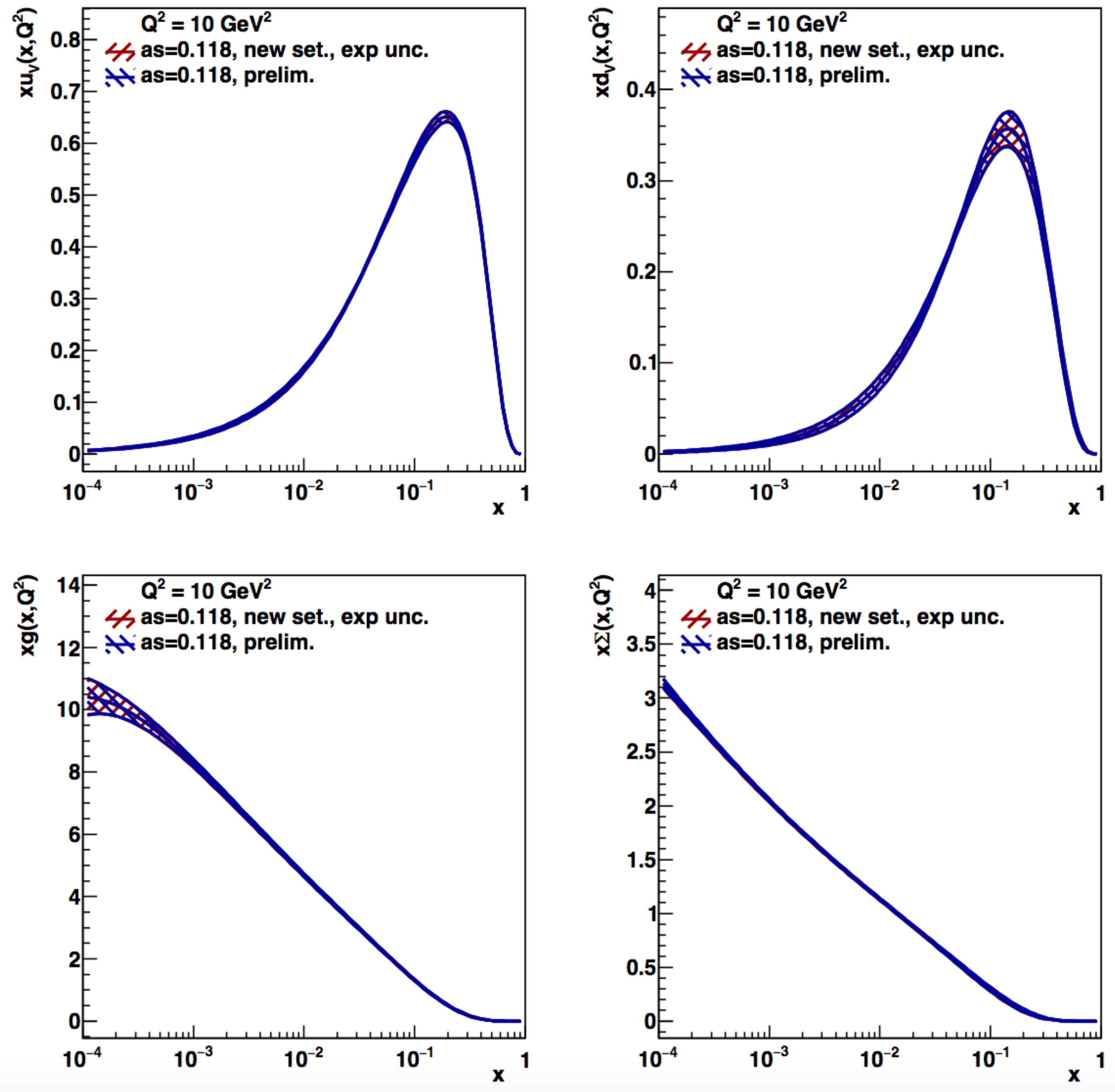
→ affects mostly valence quarks distributions

α_s = 0.118

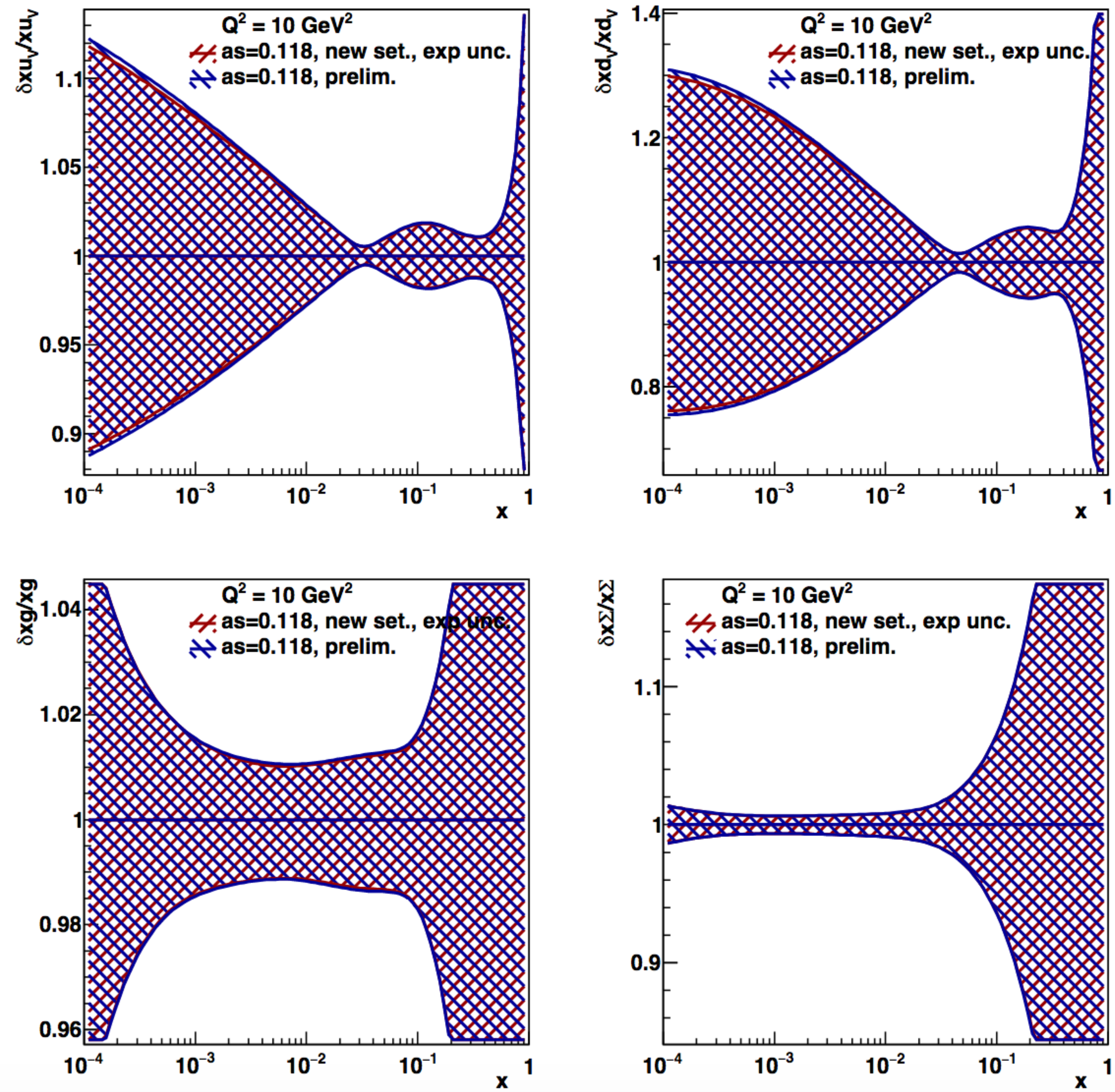


Q^2 = 10 GeV^2
as=0.118, new set., total unc., no Duv
$xu_v(x,Q^2)$
$xd_v(x,Q^2)$
$xg(x,Q^2)$
$x\Sigma(x,Q^2)$
x

Comparison with preliminary fit

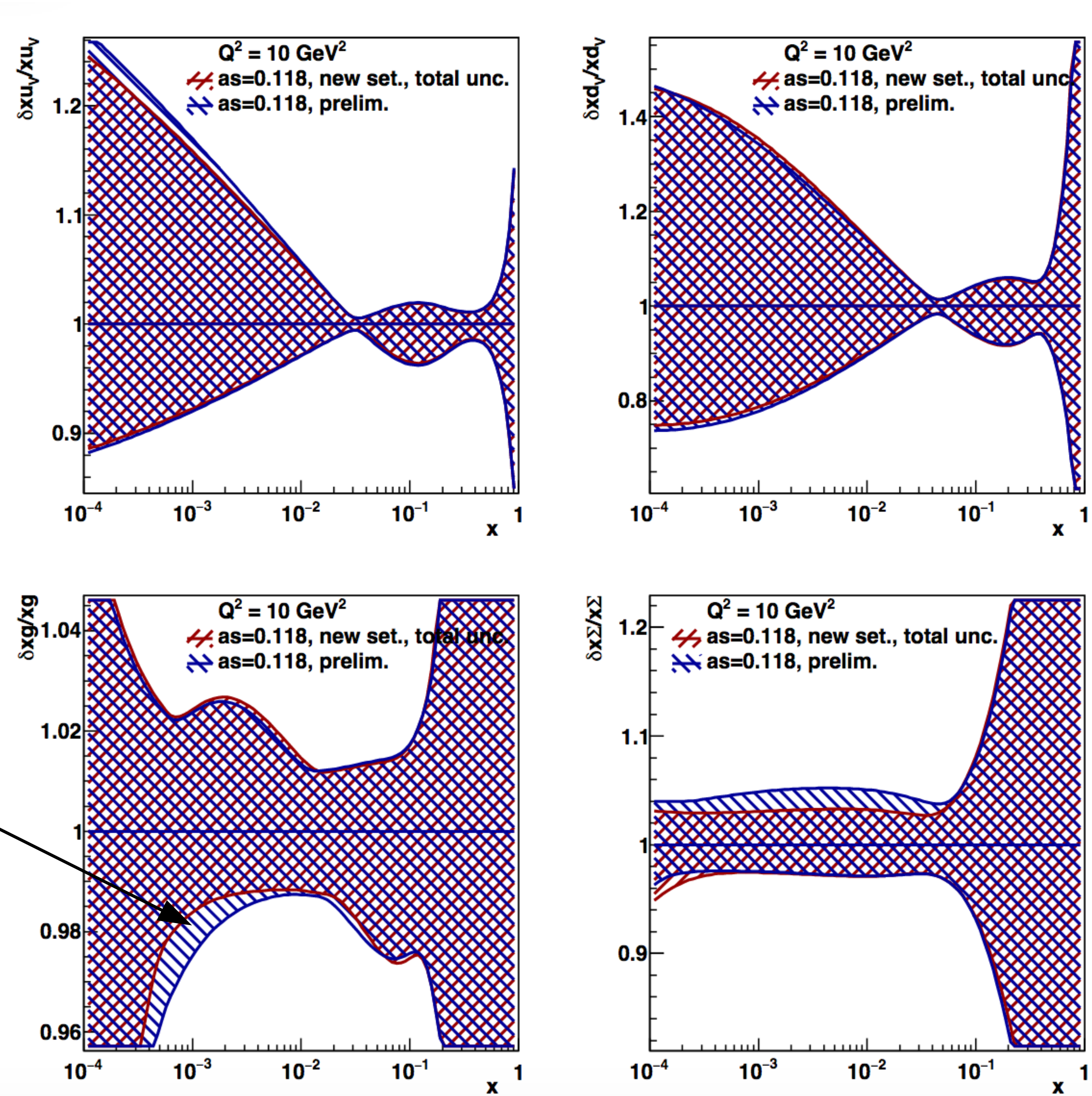


Experimental uncertainties



Total uncertainties

Double counting in preliminary results from varying m_c and Q_0^2 variations simultaneously



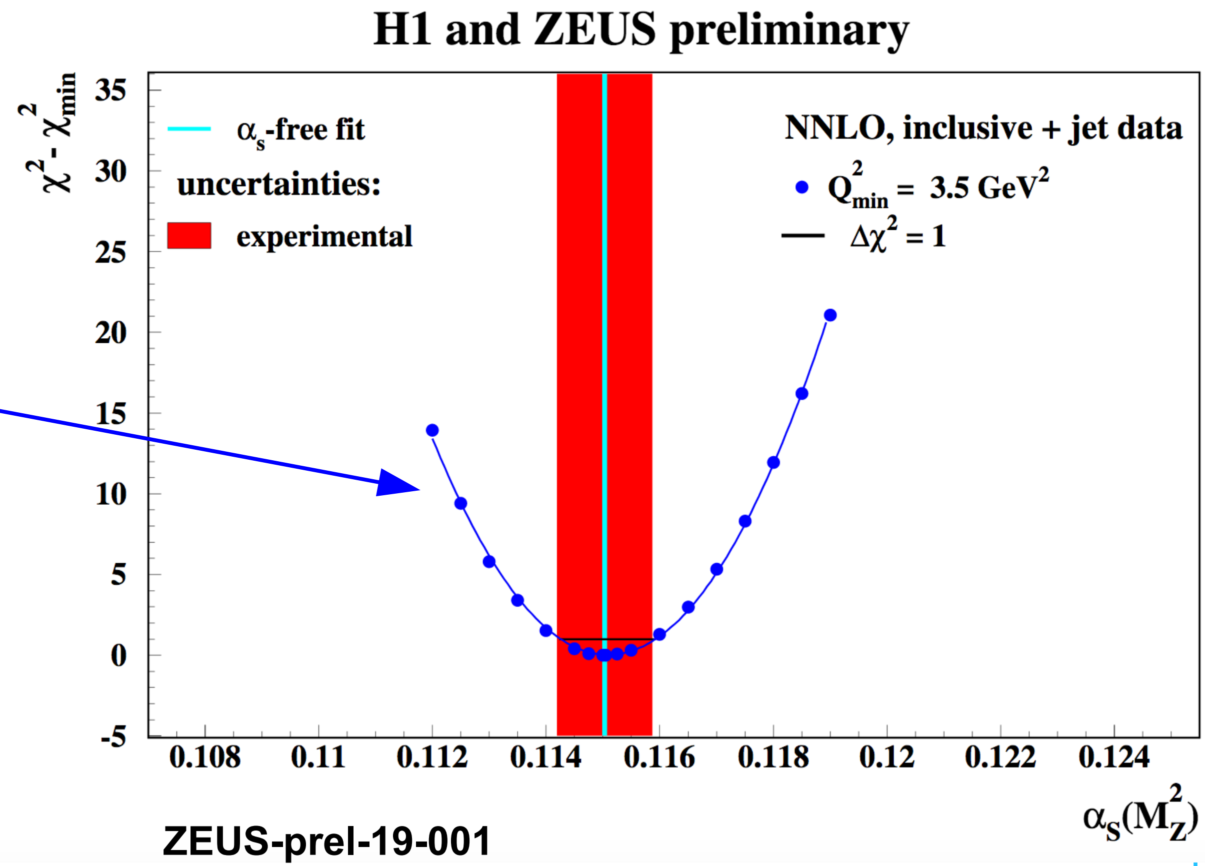
What we have as preliminary and how it compares to new results

→ not everything finished yet

we revisit α_s now

Preliminary α_s

- 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

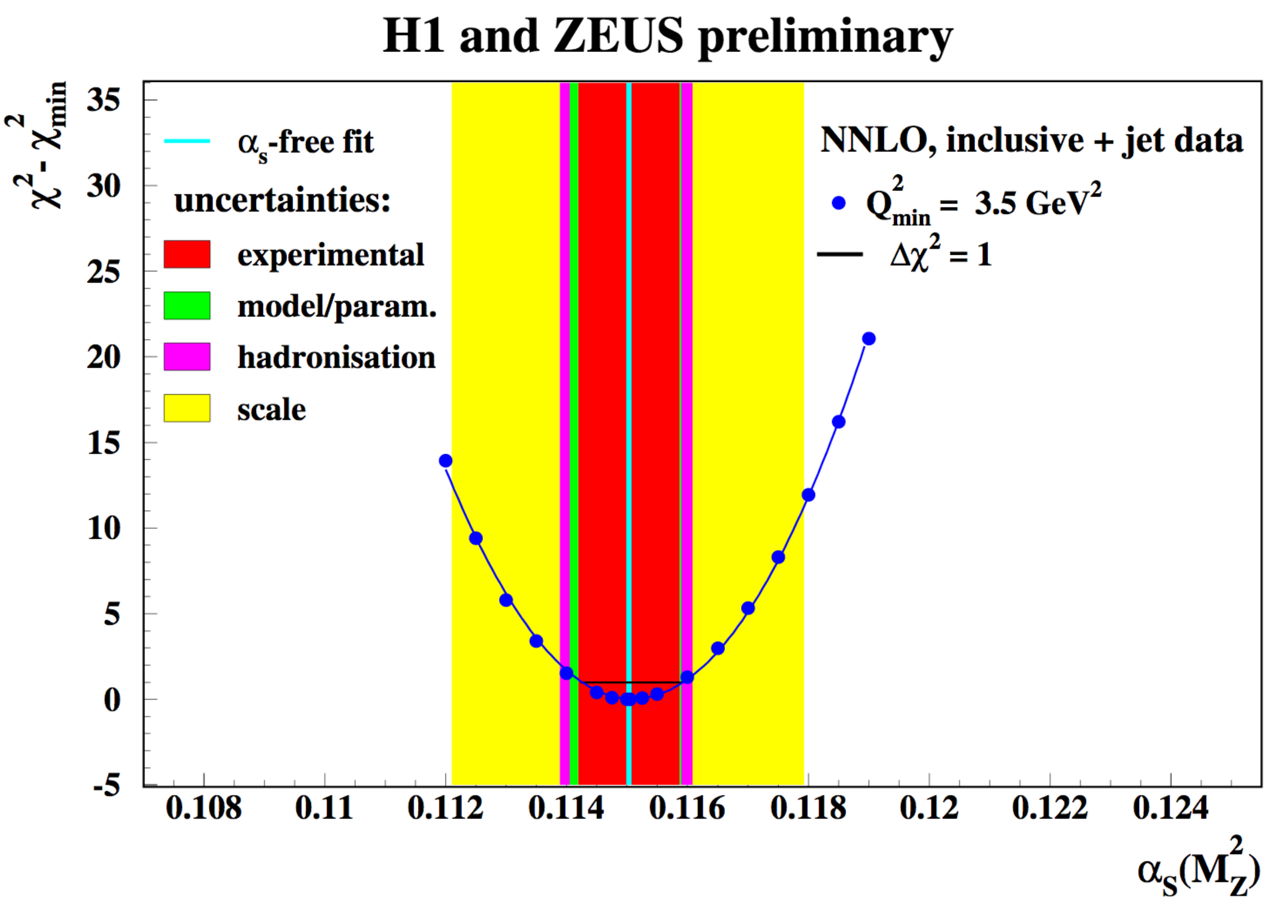


$$\alpha_s(M_Z^2) = 0.1150 \pm 0.0008(\text{exp})$$

Preliminary α_s with full uncertainties

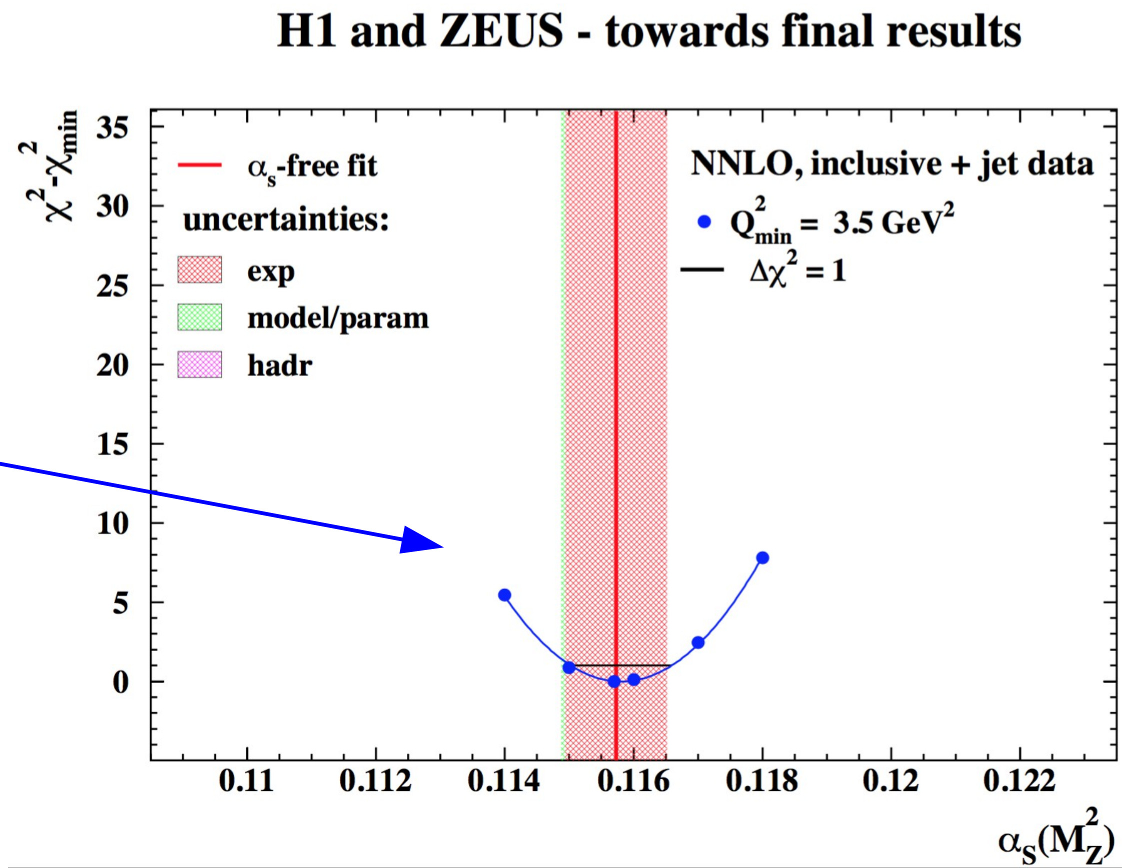
- Experimental, model, parametrisation and hadronisation uncertainties
- In fits with free $\alpha_s(M_Z)$ scale uncertainty important

→ 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)



New α_s

- 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



- Fit: $$\alpha_s(M_Z^2) = 0.1157 \pm 0.0008(\text{exp})$$

- α_s-scan: α_s = 0.1158 +- 0.0008

New α_s

$$\alpha_s(M_Z^2) = 0.1157 \pm 0.0008(\text{exp})$$

- Compared to

  0.1150 +/- 0.0008 → preliminary

  0.1151 +/- 0.0008 → new settings, no low-p_T jet points

- Model/parameterisation uncertainty

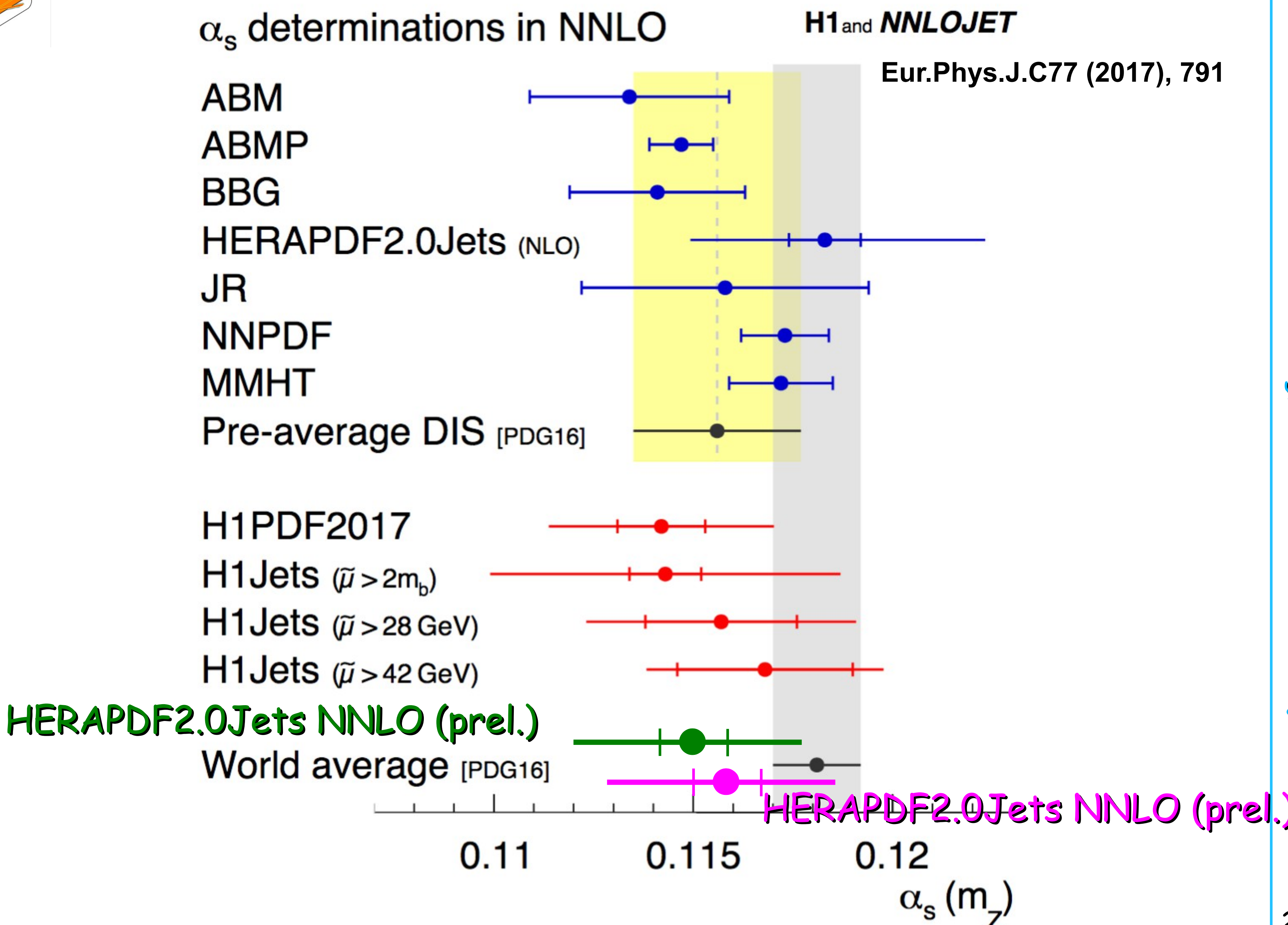
  +0.0001 -0.0003

- Compared to

  +0.0002 -0.0005 → preliminary

- Difference for positive uncertainty comes from double counting mentioned before
- Difference for negative uncertainty comes from large difference for added EUbar parameter (more stable fit now?)
- In any case → scale uncertainty dominates

Comparison to other NNLO results



What we have as preliminary and how it compares to new results

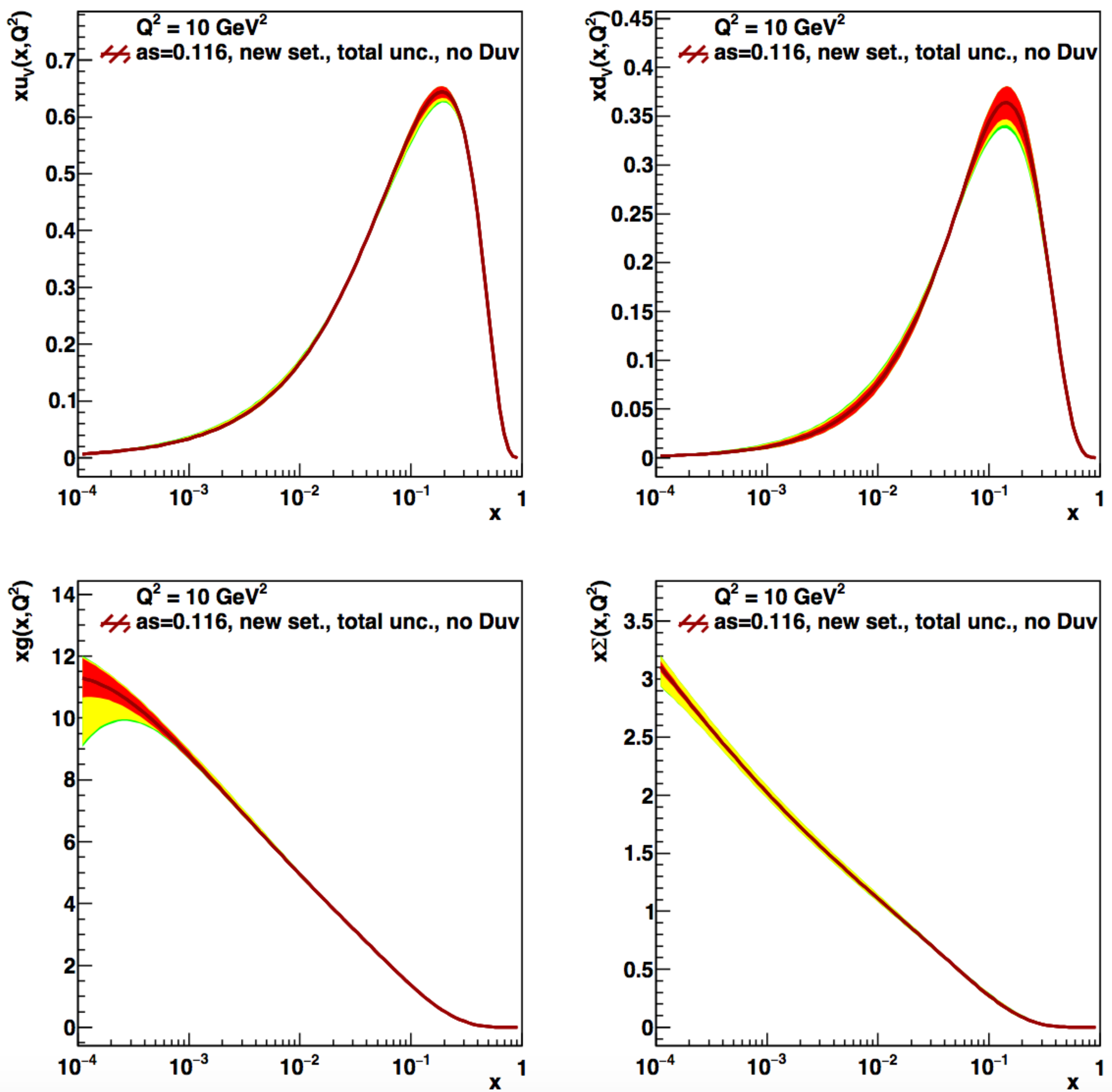
→ not everything finished yet

PDF fits for

nominal $\alpha_s = 0.116$

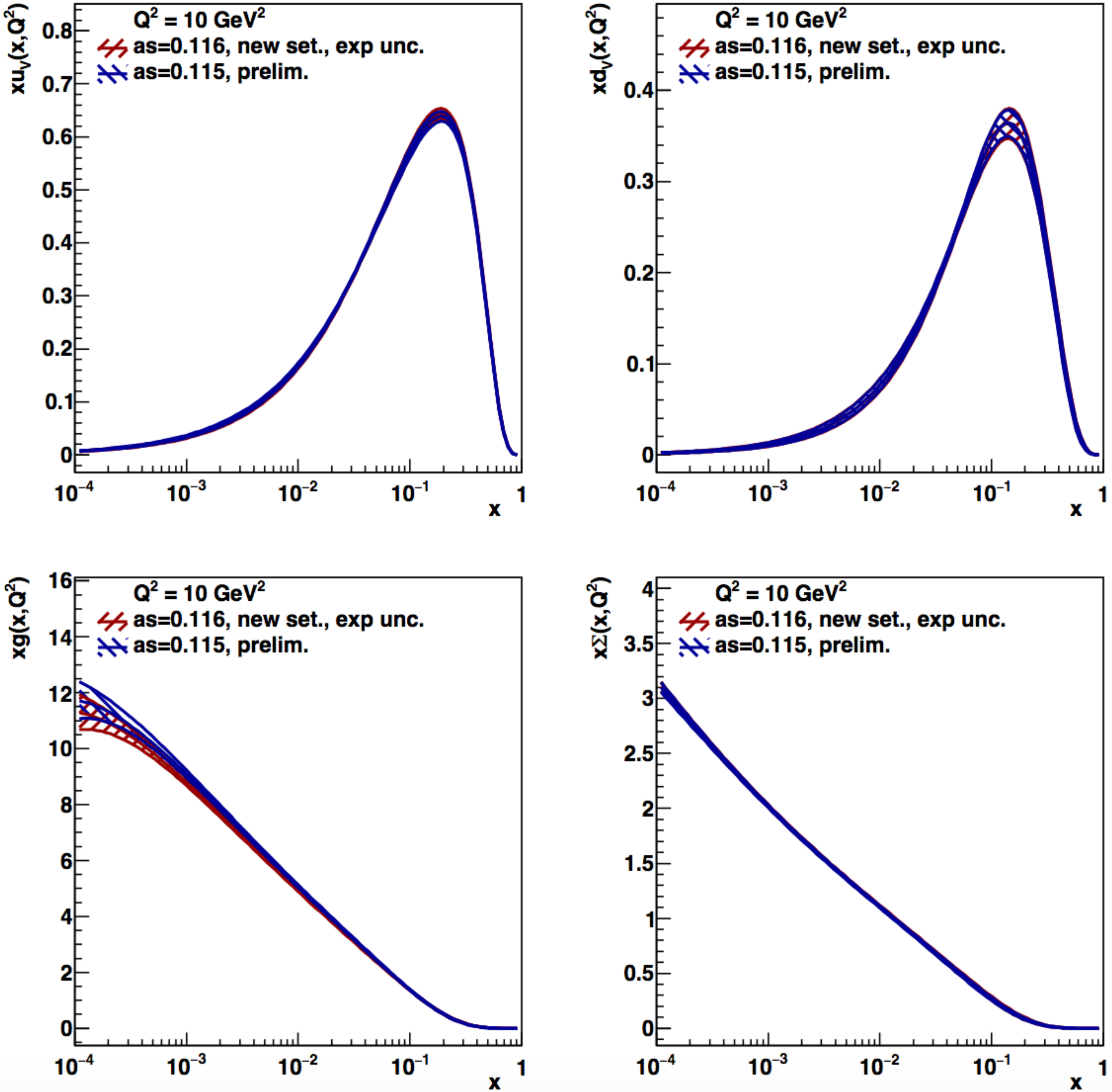
(used to be 0.115 for preliminary)

α_s = 0.116

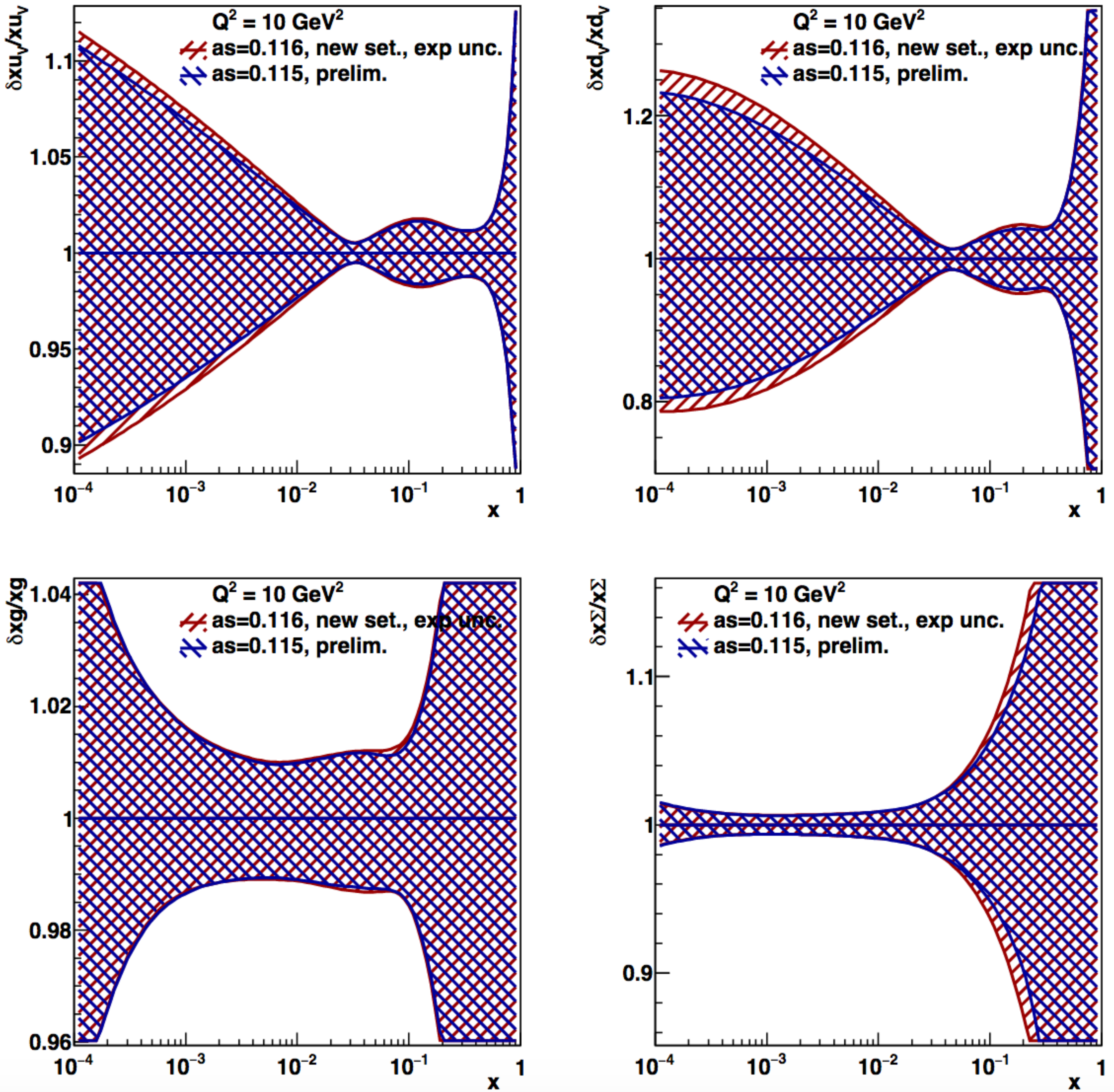


Q^2 = 10 GeV^2
as=0.116, new set., total unc., no Duv
$xu_v(x,Q^2)$
x
Q^2 = 10 GeV^2
as=0.116, new set., total unc., no Duv
$xd_v(x,Q^2)$
x
Q^2 = 10 GeV^2
as=0.116, new set., total unc., no Duv
$xg(x,Q^2)$
x
Q^2 = 10 GeV^2
as=0.116, new set., total unc., no Duv
$x\Sigma(x,Q^2)$
x

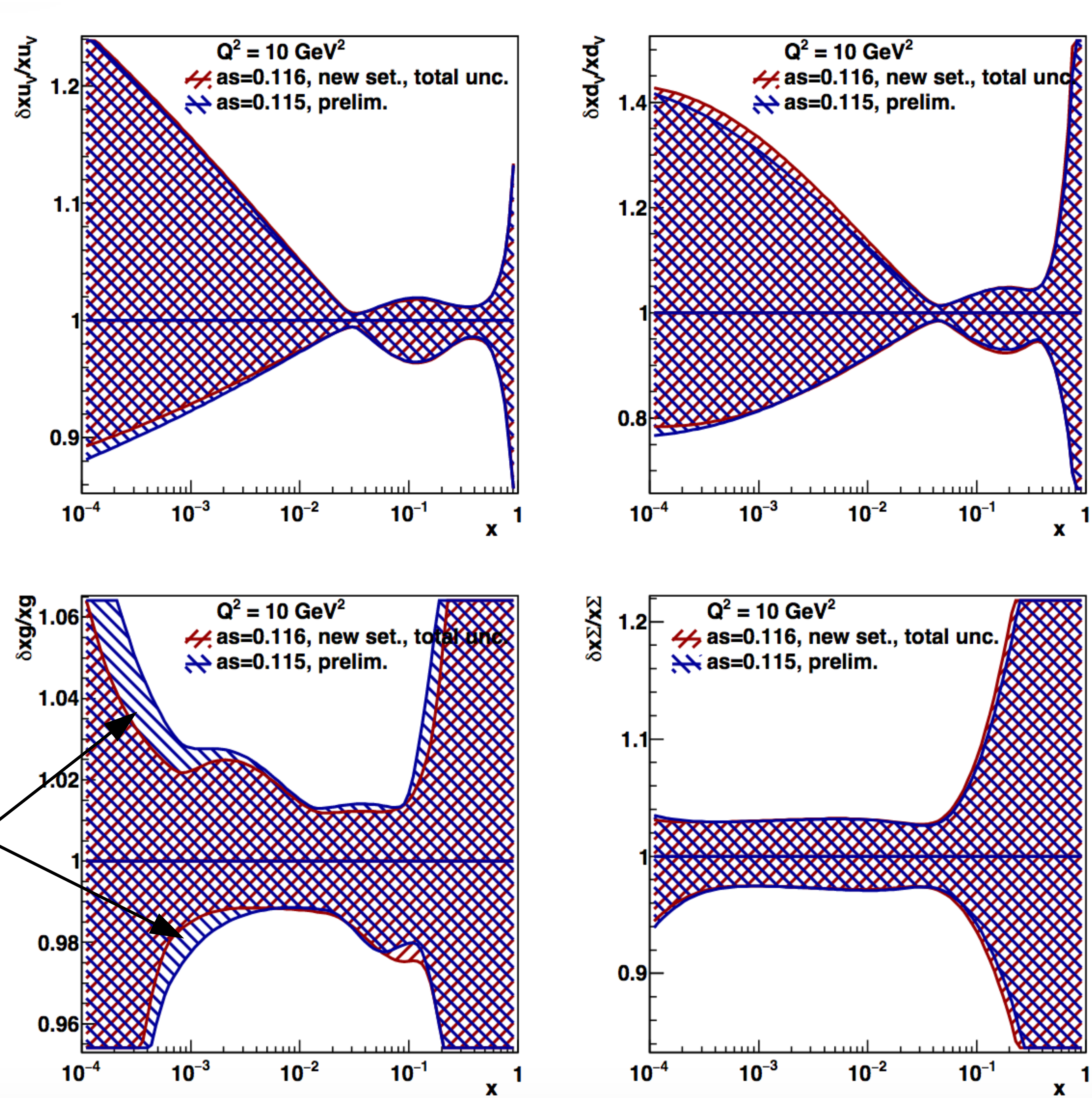
Experimental uncertainties



Experimental uncertainties



Total uncertainties



Double counting in preliminary results from varying m_c and Q_0^2 variations simultaneously

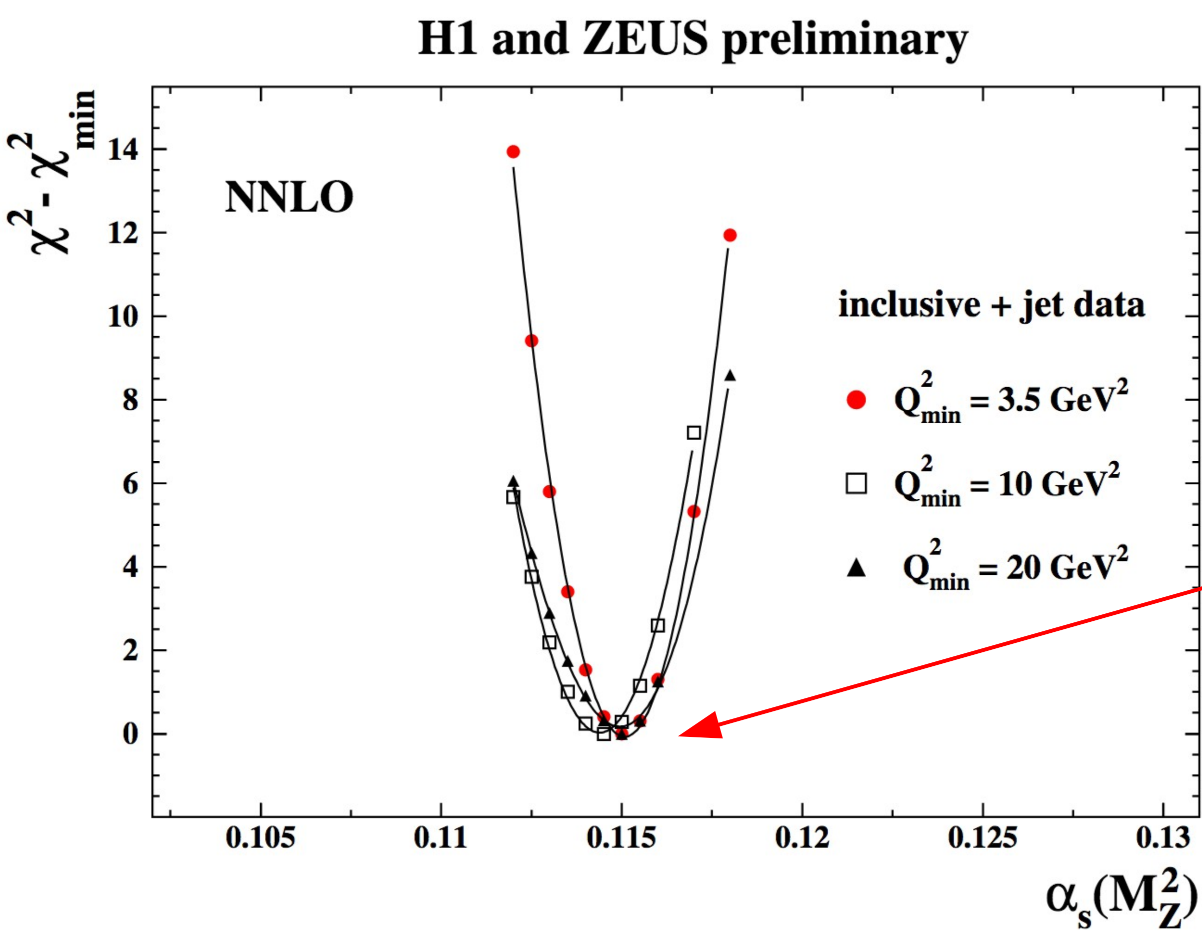
- Missing incl variation

Scans with harder Q^2 cuts

Preliminary: 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

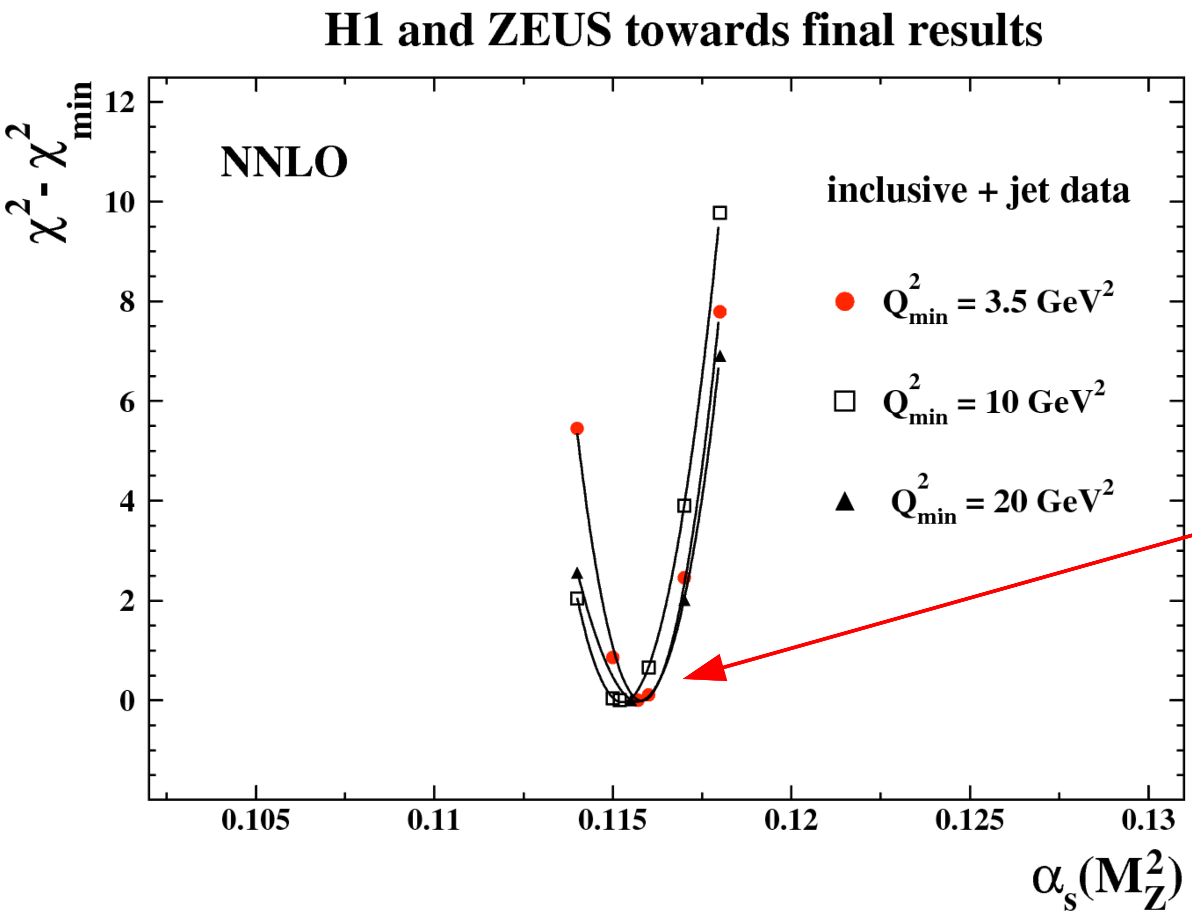
→ χ^2 scans performed with harder Q^2 cuts



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

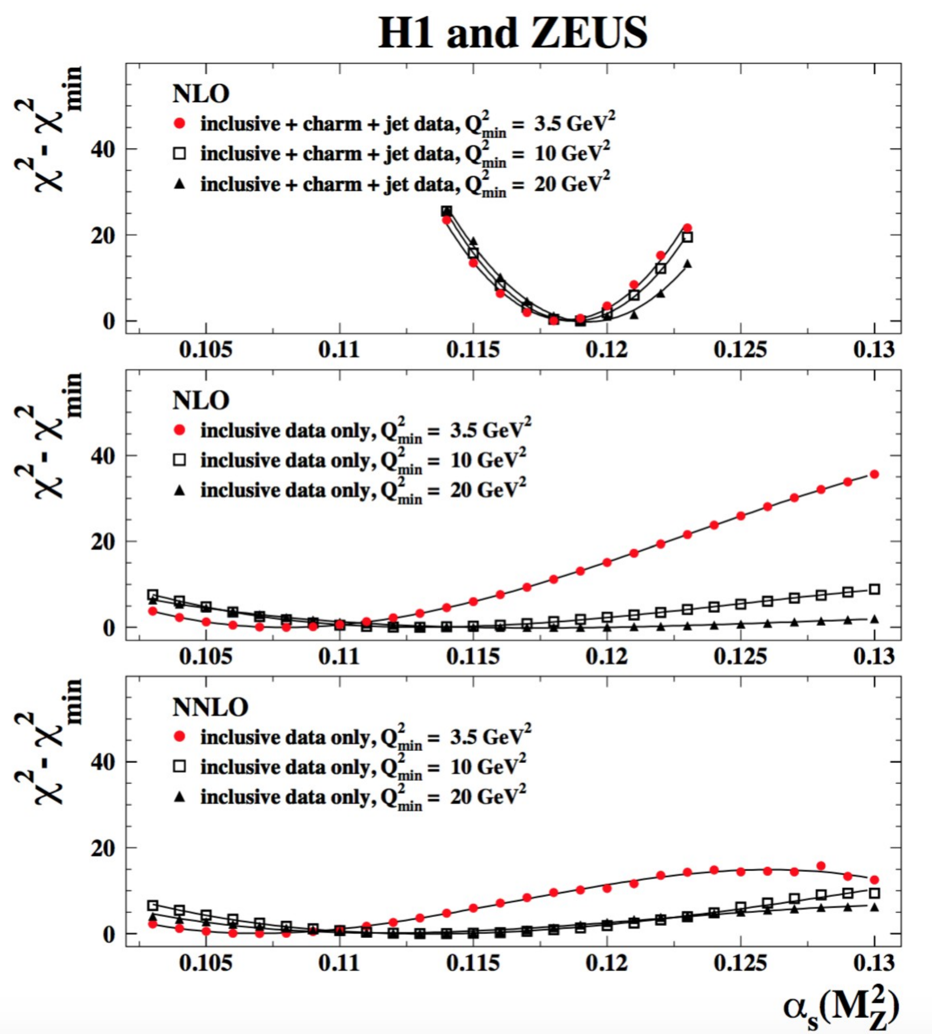
Preliminary: scans with harder Q^2 cuts

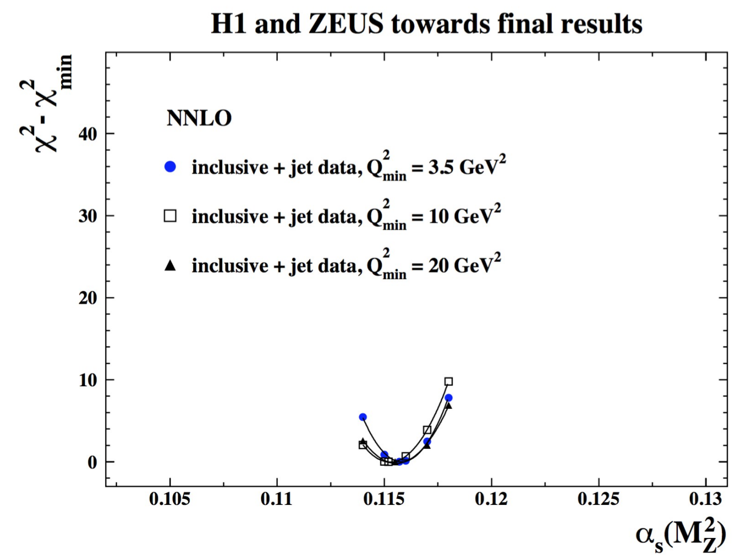
- Results with new settings and low-p_T data, same Q^2 cuts
  - $Q^2 > 10$ GeV^2: scan: α_s = 0.1153 +- 0.0009; α_s-free fit: α_s = 0.1152 +- 0.0008
  - $Q^2 > 20$ GeV^2: scan: α_s = 0.1155 +- 0.0010; α_s-free fit: α_s = 0.1155 +- 0.0008



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

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

Summary & conclusions
→ no real change since preliminary

- HERAPDF2.0 family completed
  → new settings and low-p_T points added, analysis repeated
  → some things still need to be done:
  - Handronisation and scale uncertainties (we do not expect them to change)
  - Some model/param uncertainties to be added (Duv, one inclusive cut)
- Jet data allow us to constrain $\alpha_s(M_Z)$

PRELIMINARY

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

NEW

- Compared to new

$$\alpha_s(M_Z^2) = 0.1150 \pm 0.0008(\text{exp})^{+0.0001}_{-0.0003}(\text{model/parameterisation})$$

- 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

Outlook

- Next steps are rather clear

  → finish missing parts of analysis

  → show these results tomorrow at H1/ZEUS meeting; ask for their "approval" (so lack of trouble ...)

  → paper draft v0 in place

  → would like to start official publishing procedure in april

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 $\alpha_s(M_Z)$

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

HERAPDF2.0Jets NLO

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