Inclusive jet cross sections at LHeC and prospects for an α_s determination

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Inclusive jet cross sections

Inclusive jet cross sections

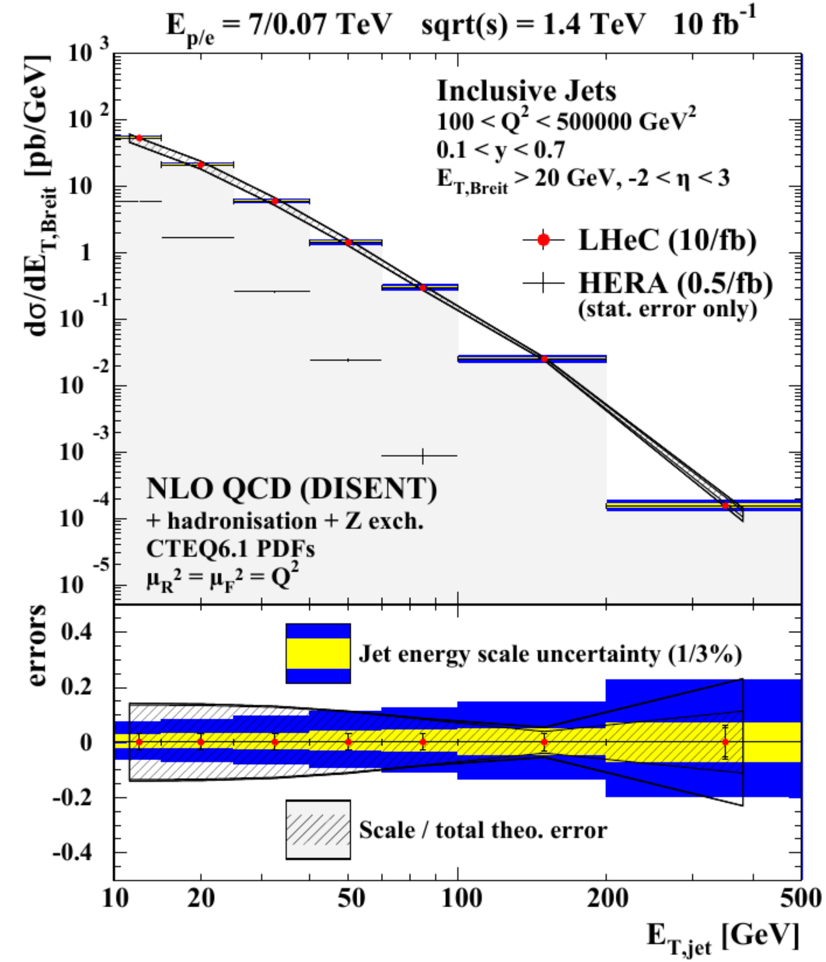
- Measured in Breit frame
- LO proportional to O(α_s)
- Jets are defined as kT jets, R=1.0
  → low hadron. uncertainty

Large cross section
Large kinematic reach

In comparison to HERA

- HERA: 5 < p_T < ~60 GeV
  LHeC: 4 < p_T < ~600 GeV
- HERA: 5.5 < Q^2 < ~15000 GeV^2
  LHeC: 4 < Q^2 < ~600000 GeV^2

'Old' CDR



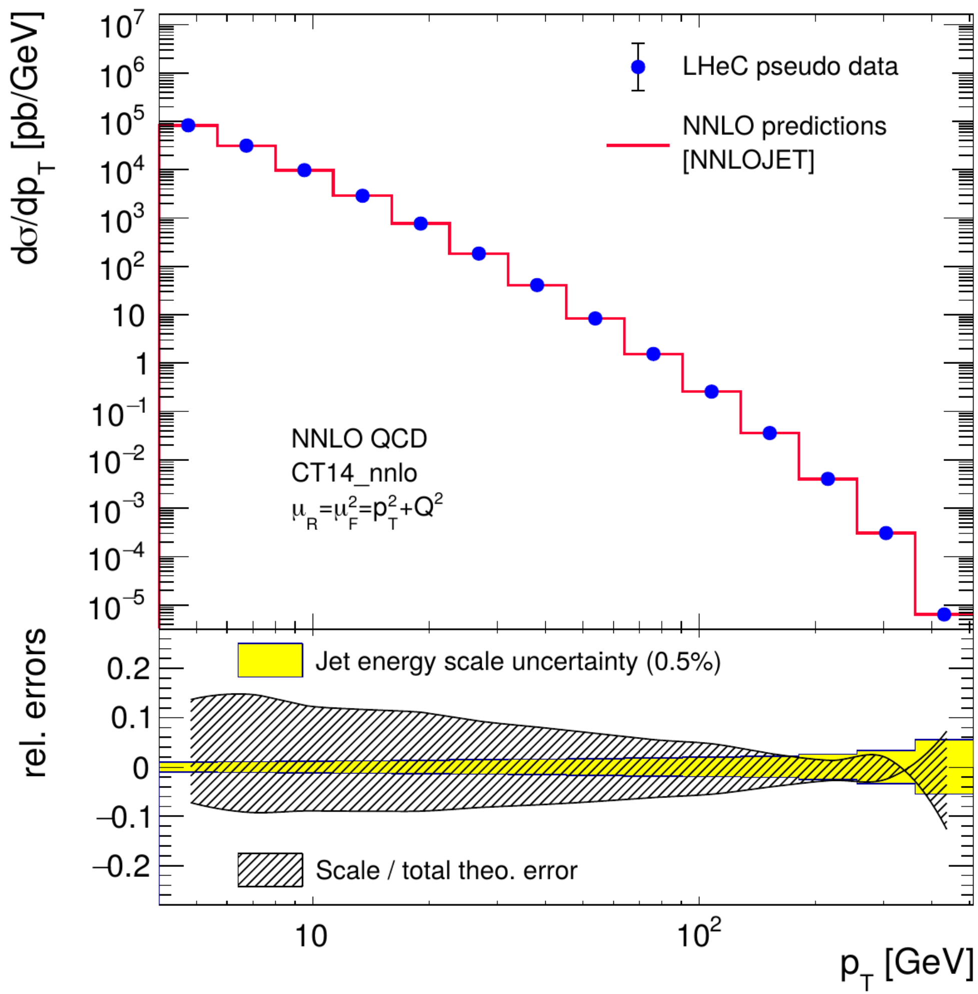
New NNLO predictions

NNLOJET + fastNLO

- NNLOJET predictions (Gehrmann et al.)
- NNPDF31 as PDF
- $x_{min} \sim 0.5 * 10^{-5}$
- Scale: $\mu^2_R = \mu^2_F = Q^2 + p^2_{T,jet}$

- $4 < Q^2 < 524288$ GeV²
- $0.001 < y < 0.95$
- $-5 < \eta_{lab} < 5$
- $p^T_{jet} > 4$ GeV
- electron method for reconstruction of Q² (and x for boost)

- NNLO scale uncertainty: vary scales by 0.5 and 2



Pseudo-data & error summary

Pseudo-data obtained from NNLO predictions

- It was validated, that when using data==prediction, no bias on the error esimate is observed
- [*] stat: at highest-p_T, assume that 2 jets are recorded per event (back-to-back)

Uncertainty	**Shift**	**Size on cross section**
Statistics [*]	min 0.15%	>0.15%, < 5%
Electron energy	0.1 %	0.02 – 0.62%
Polar angle	2mrad	0.02 – 0.48%
Calorimeter noise	+/- 20 MeV (per jet)	0.01 – 0.74%
JES	0.5 % (lab-frame)	0.2 – 4.4%
Uncorrelated		**0.6%**
Normalisation		**1.0%**

- Any further uncertainty (eff., model, unfold, rad.-corr., etc.) has an unknown pT and Q2 shape
  → further uncertainty are represented through **uncorrelated** or **normalisation**

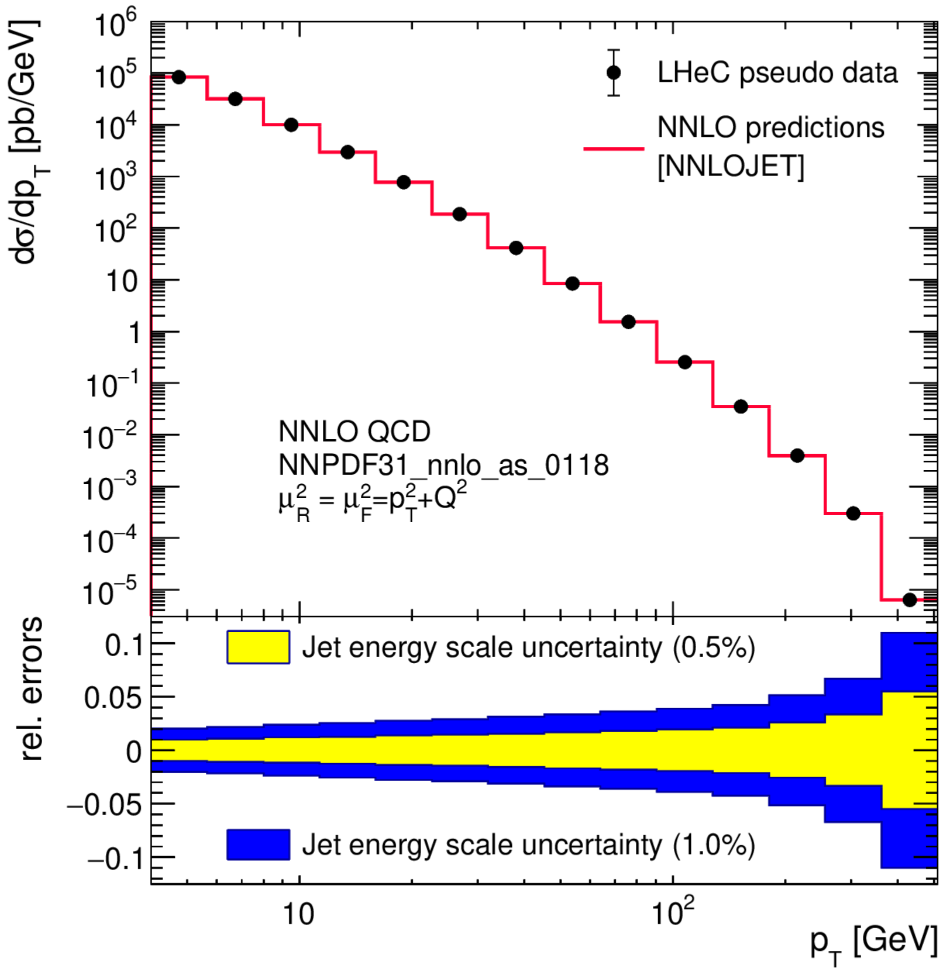
Jet energy scale uncertainty

Jet energy scale uncertainty
- Achieved precision at HERA (H1): 1%

LHeC
- Likely achieve: $\delta_{JES} \sim 0.5\%$

Propagation to cross sections
- JES is defined in lab-frame
- Dedicated simulation performed to

Size of JES uncertainty on cross section
- Similar to values reported by H1
- Very similar with CDR2012



Fit methodology

Fit methology

- similar to EPJ C77 (2017) 791 & EPJ C79 (2019) 68 & arXiv:1906.05303
- NNLO predictions: account for α_s in ME & DGLAP (μ_0~30GeV)
  ME (NNLOJET), P (QCDNUM)

Only $f_{\mu 0}$ is taken from NNPDF31

$$\sigma = f_{\mu_0} \otimes P_{\mu_0 \rightarrow \mu_F}(\alpha_s(M_Z)) \otimes \hat{\sigma}(\alpha_s(M_Z), \mu)$$

- α_s dependence in P is almost negligible

Minimisation with Minuit

- Consider all uncertainties as 'relative' in χ^2
  → No 'error-rescaling' needed.
  → No dependence on actual size of cross section in fit

$$\chi^2 = \sum_{ij} \log \frac{s_i}{\tilde{\sigma}_i} V_{ij}^{-1} \log \frac{s_j}{\tilde{\sigma}_j}$$

Consider 2D pseudo-data

- use 509 data points (H1 had 78 in HERA-II)
- pT binning gauged with CMS and H1 binning
- Q2 binning gauged with HERA (H1) NC DIS binning

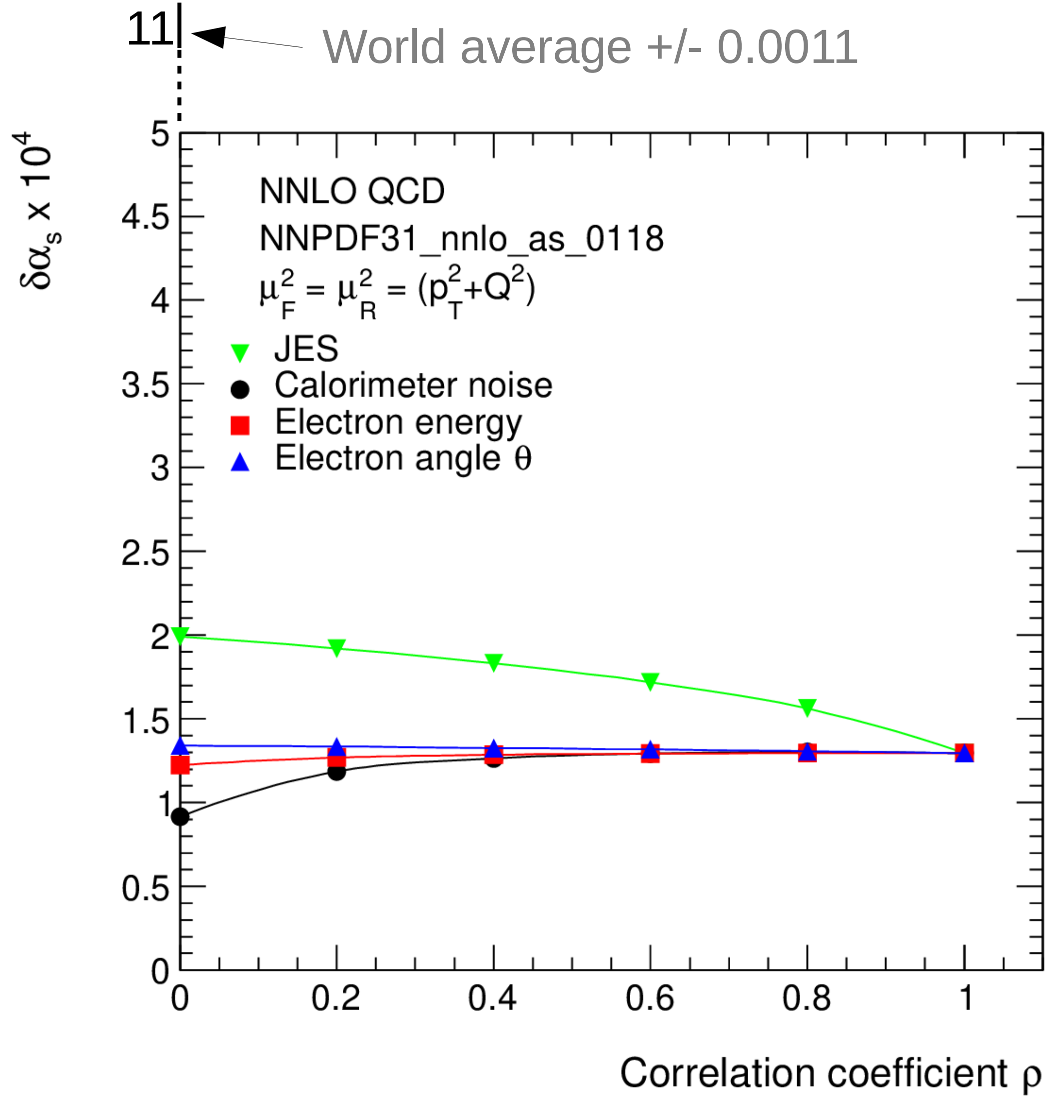
α_s uncertainty vs. 'correlation model'

Systematic uncertainties are considered as 'fully' correlated

- This may not be overoptimistic
- A full calibration could come with many smaller (correlated) error sources

Vary the correlation of a single syst. uncertainty

- Electron uncertainties are altogether fairly negligible
- Calorimeter noise decreases $\delta\alpha_s$ when considered uncorrelated
- JES increases $\delta\alpha_s$ when 'decorrelating' it



Size of jet-energy scale (JES)

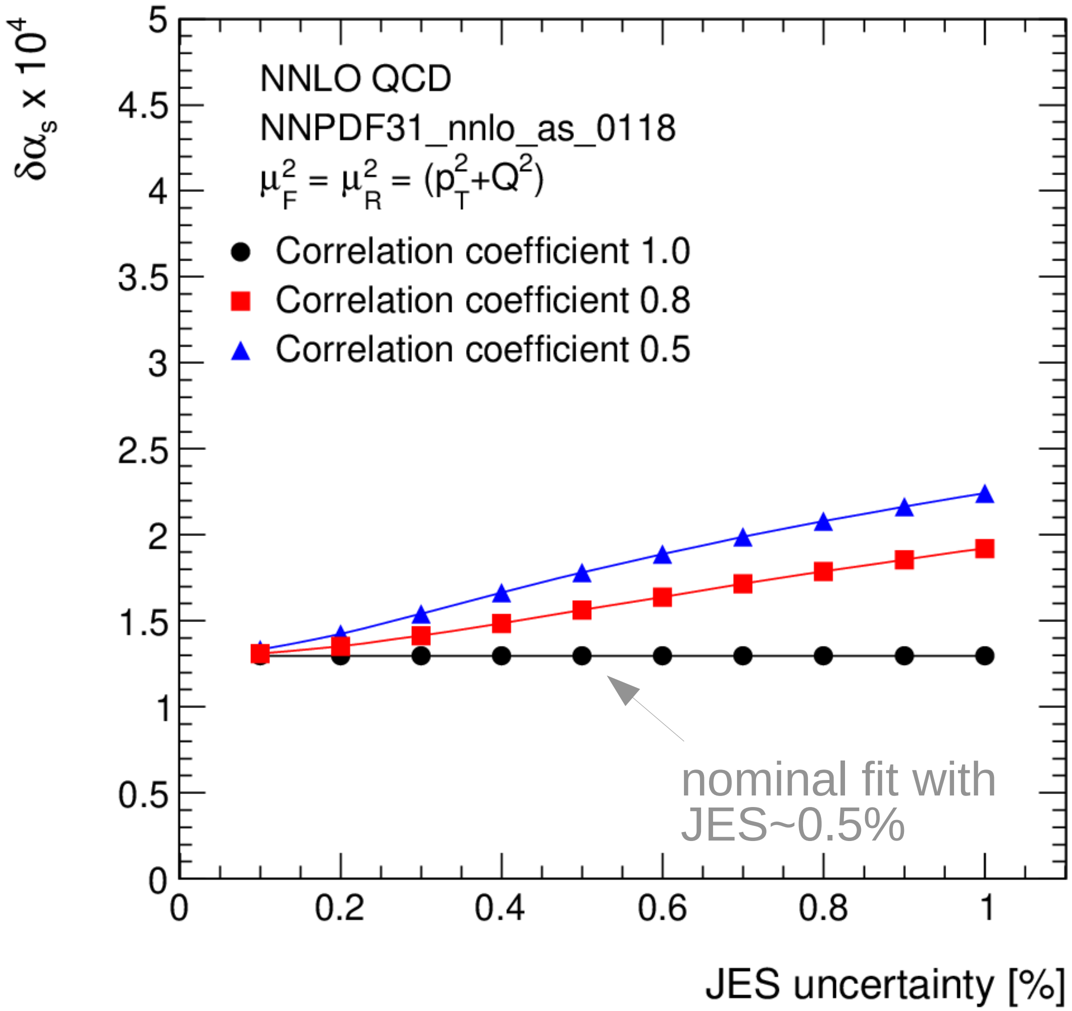
Jet energy scale (JES)

- JES is expected to be 0.5% at detector-level
- H1 achieved 1%
- ATLAS/CMS ~1% (but pile-up, and difficult in-situ calibration!)

- Maybe even 0.3% is achievable ?!

Increase JES

- 0.1% up to 1.0%
- For fully correlated JES, size of JES irrelevant (but shape matters)
- moderate de-correlation:
  → moderate increase of $\delta\alpha_s$



Size of normalisation and uncorr. uncert.

Study size of

- normalisation uncertainty
- uncorrelated uncertainty

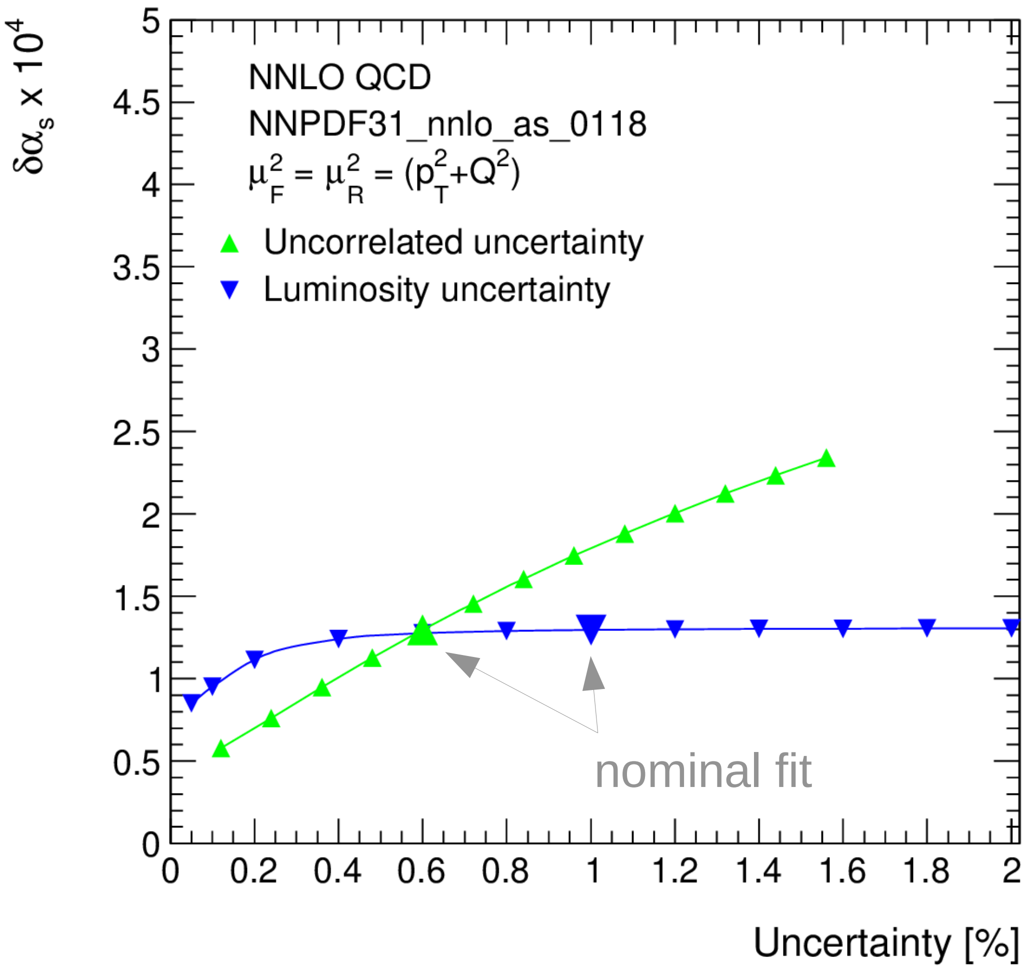
These two errors collect all sources with unknown p_T and Q^2 dependence

Normalisation uncertainty

- Fit uncertainty largely <u>independent</u> on size of normalisation uncertainty

Uncorrelated uncertainty

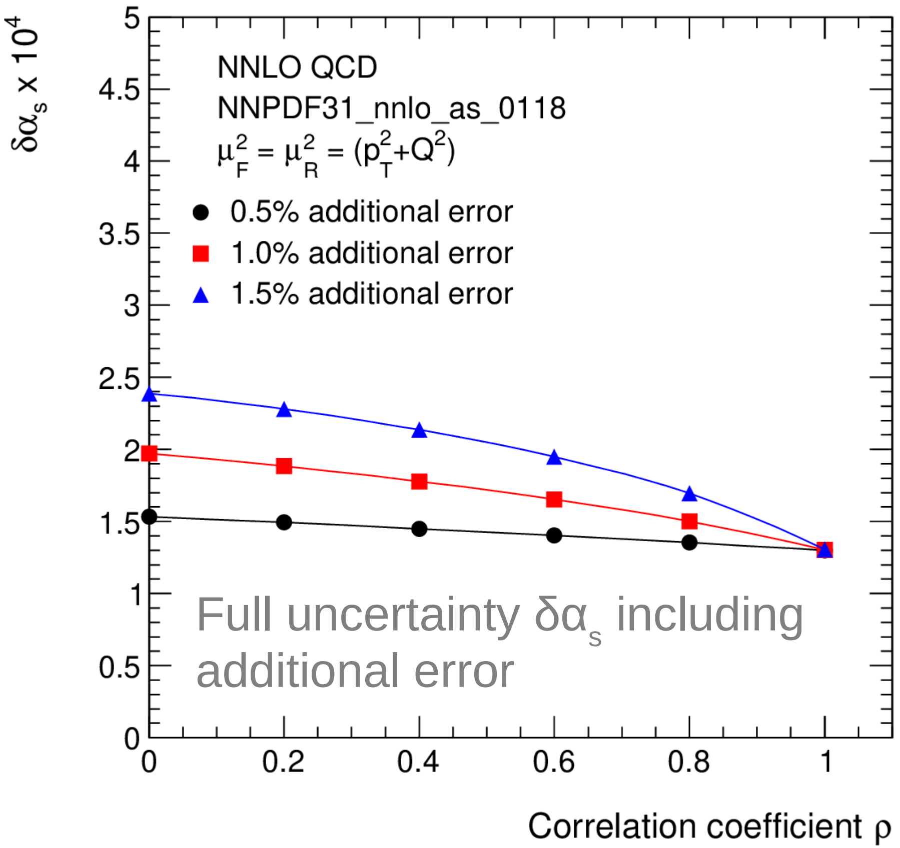
- Fit uncertainty <u>largely dependent</u> on size of uncorr. uncertainty
- Dominant uncertainty
- Difficult to estimate & correlates with number of data points

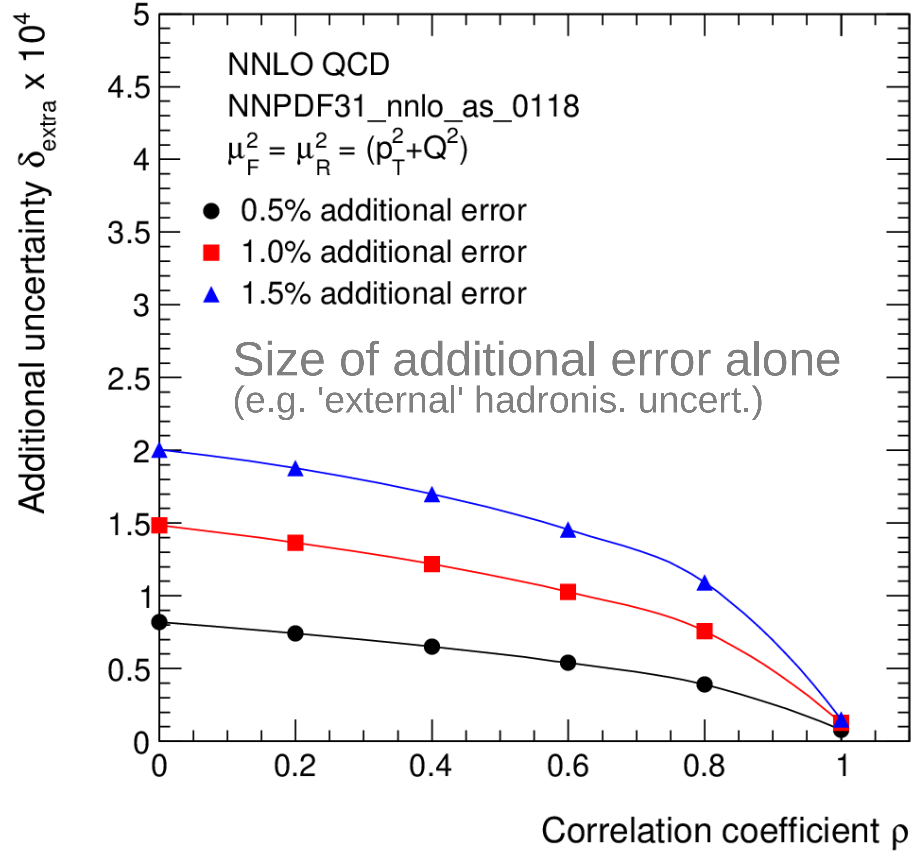


Consider an additional error

One additional error of same size for all points

- Study different sizes (0.5, 1.0, 1.5%) vs. its correlation
- Moderate increase in uncertainty





Error budget

Estimate size of individual uncertainty

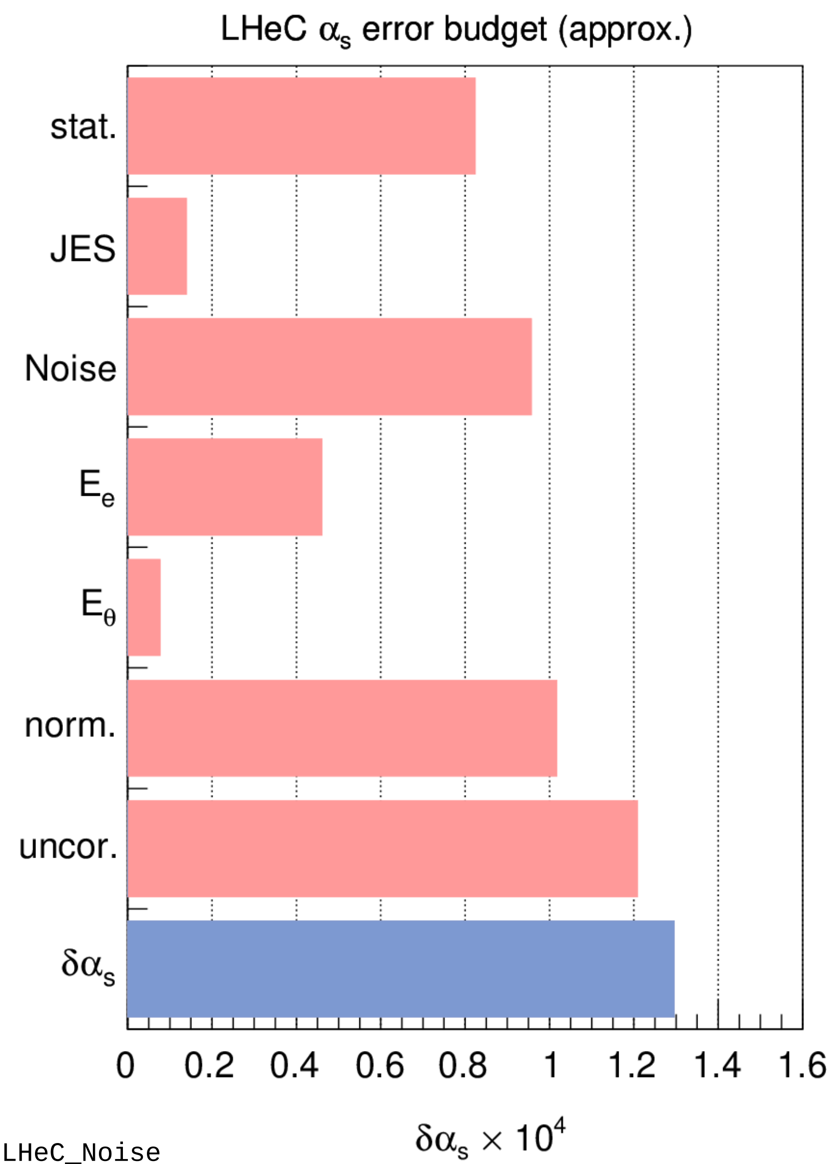
- Repeat fit with a single source excluded
- Calculate quadratic 'difference' to nominal fit uncertainty

→ (only) an approximate estimate

(quadratic sum of all sources overestimates total uncertainty)

Reasonable estimate

- Uncor. dominant
- stat. not negligible (min 0.15%)
- Calo-Noise more important than JES
  - → shape more similar to α_s dependence
  - → more important at lower p_T
- Electron uncertainties negligible
- Normalisation uncertainty important albeit it is finally constraint by fit
- PDF uncert (NNPDF31) ~ 0.0002 [not shown]



Correlations	AlphasMz	LHeC_ElEn	LHeC_ElTh	LHeC_JES5	LHeC_Lumi	LHeC_Noise
AlphasMz	1	0.25549	0.15361	-0.30176	-0.82283	-0.86228

NNLO scale uncertainty

Scale uncertainty

- Vary scale(s) by 0.5 and 2

Or alternatively:

- Estimate derivate w.r.t. μ_R, μ_F and get scale uncertainty as linear error propagation

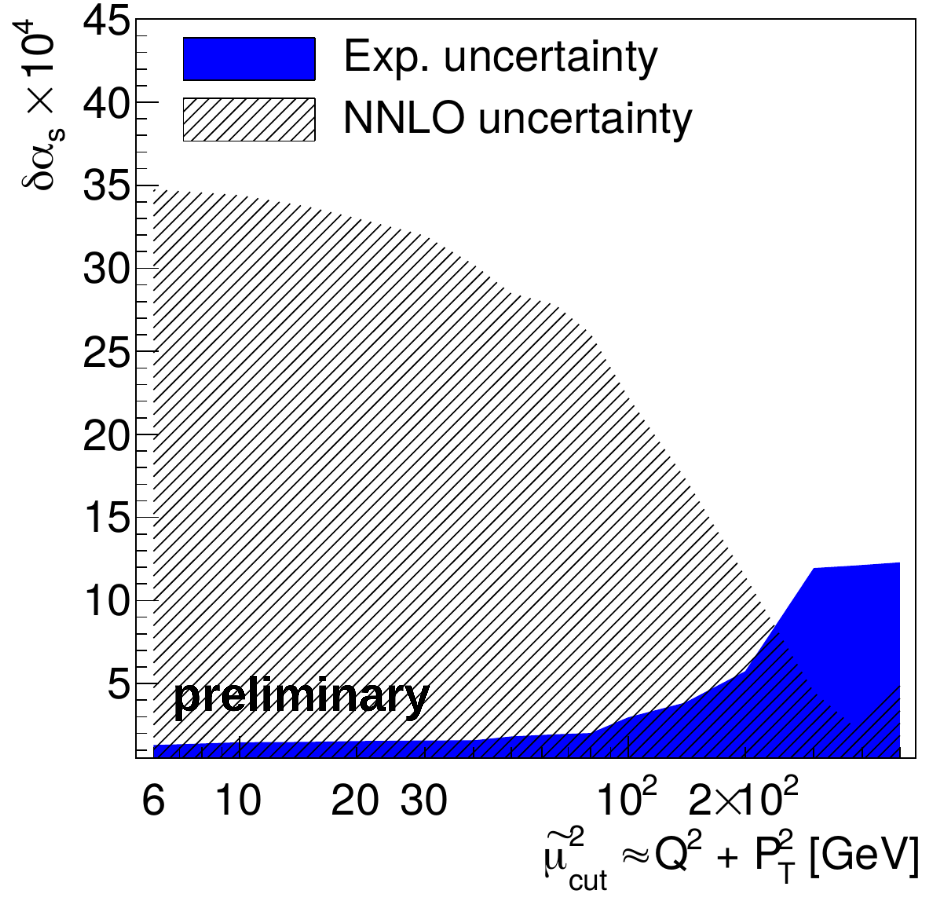
Scale uncertainty full fit

- about: +/- 0.0035

→ fairly large

Restrict data to higher scales

- define a lower cut: $\mu^2 \sim Q^2 + p_T^2$
- Cut lower scales: expect reduction of scale uncertaint



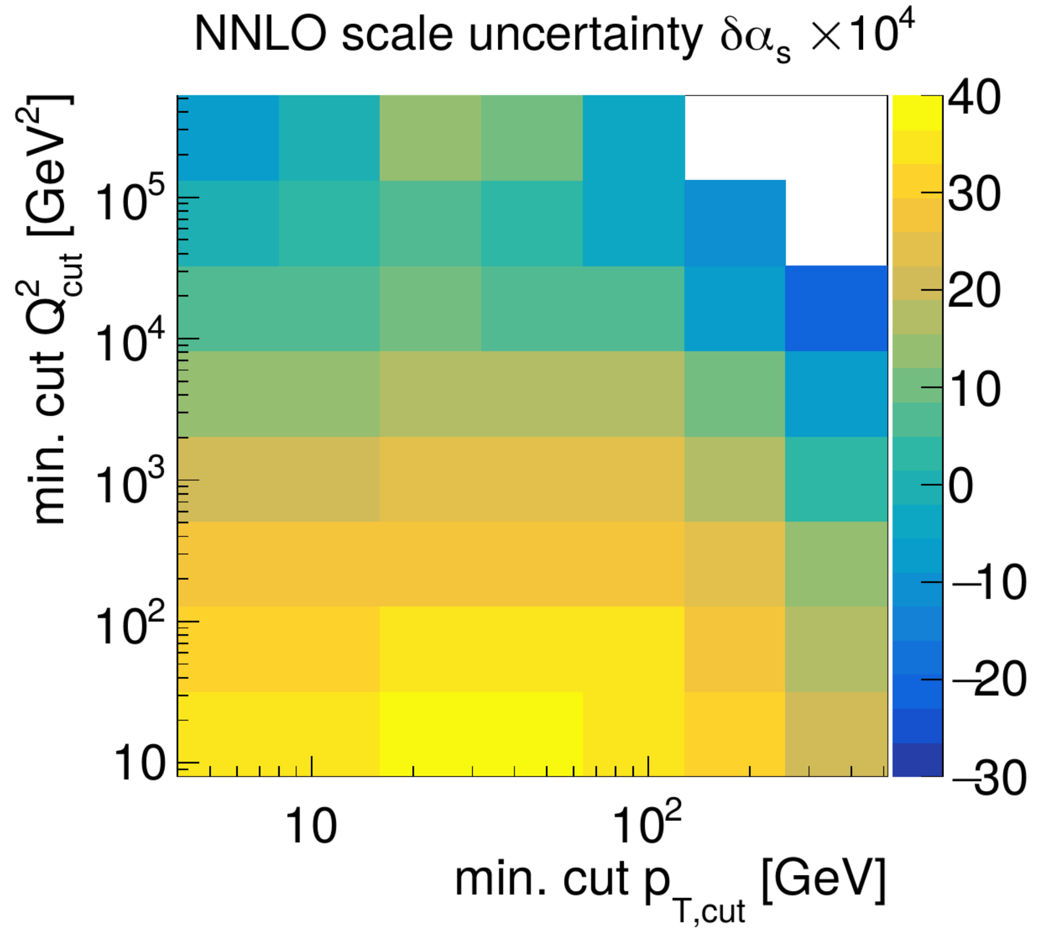
NNLO scale uncertainty

Evaluate NNLO scale uncertainty

- Cut lower values p_T and Q^2

NNLO scale uncertainty

- Exclusion of low-pT bins does not reduce scale uncertainty
- Exclusion of low-Q2 bins reduces scale uncertainty
- For Q^2>2000 GeV^2 $\delta\alpha_s^{scale}$ ~ 0.0015
- For Q^2>8000 GeV^2 $\delta\alpha_s^{scale}$ ~ 0.001



α_s determination at different μ_R intervals

α_s determination at different μ_r intervals

→ 'running'

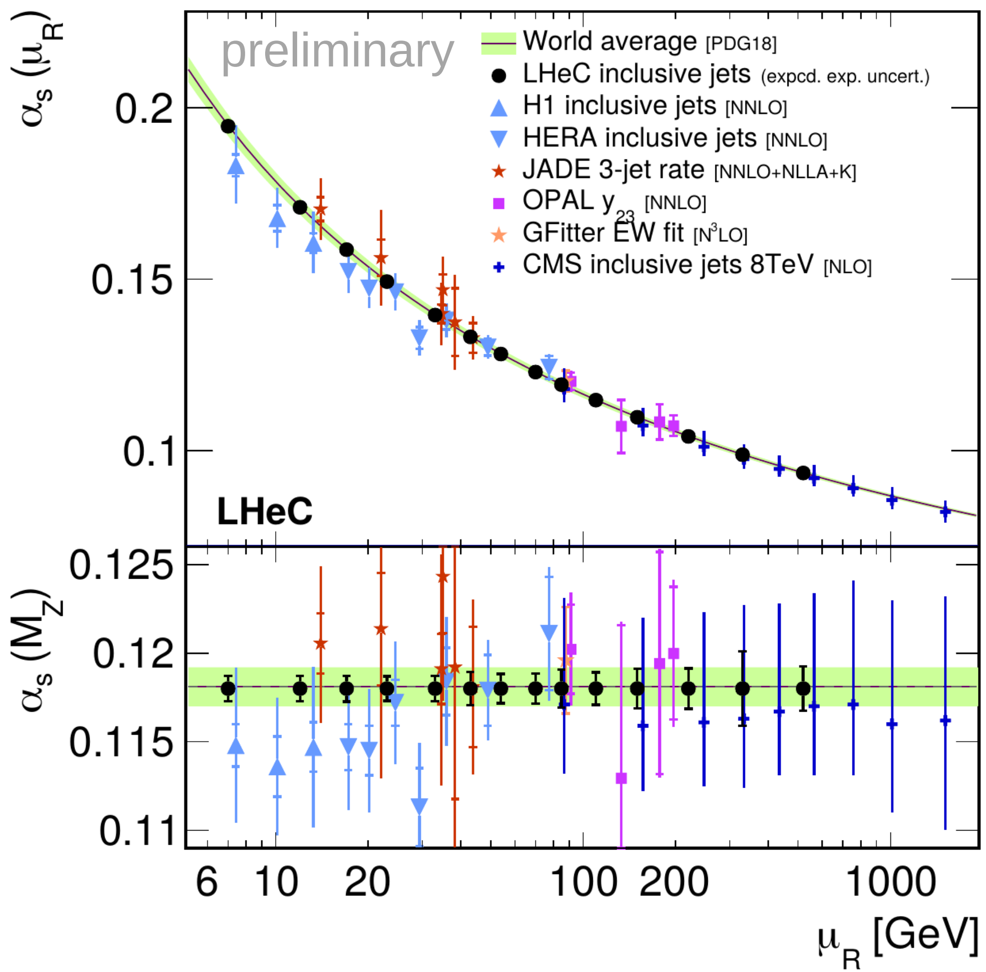
Use: $\mu_R^2 = Q^2 + p_T^2$

High exp. sensitivity over large kinematic range

- $6 < \mu_R < 600$ GeV

- Exp. uncertainty typically $\delta\alpha_s \sim 0.0007$–$0.0011$ for all studied intervals

Great improvement over other (jet-based) measurements



α_s from inclusive NC/CC DIS cross sections

Perform α_s-fit together with PDFs

- 'standard' HERA-like parameterisation
- Validate that different gluon param. do not alter the α_s uncertainty significantly

NC+CC DIS @ 60 x 7000 GeV

- $\delta\alpha_s \sim 0.00029$

NC+CC DIS @ 50 x 7000 GeV

- $\delta\alpha_s \sim 0.00038$
- $Q^2 > 20$ GeV^2: $\delta\alpha_s \sim 0.00044$

+ inclusive jets

- NC/CC + incl. jets: fit does not yield reliable uncertainties (yet)

Snowmass 2013

case	cut [Q^2 in GeV^2]	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.26

DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h > 5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

(prel.) conclusion
In such a 'combined' PDF+α_s fit I do not see much impact of the inclusive jet pseudo-data

Summary and conclusions

Inclusive jets @ LHeC

- new NNLO calculations performed
- pseudo-data estimated

α_s estimate

- α_s uncertainty estimated from inclusive jet pseudo-data
- Exp. uncertainty: **$\delta\alpha_s$ ~ 0.00013**
  → Improvement w.r.t. current world average by factor ~8
- NNLO scale uncertainty remains
  → Reduction feasible with restricted kinematic range (remove parts with large log(pT/Q))
  → Reduction possible with improved predictions (resumm.)
  → Other processes with possibly less scale dependence (e.g. di-jets)
- αs from inclusive DIS
  - E_e = 60 GeV: $\delta\alpha_s$ ~ 0.0003
  - E_e = 50 GeV: $\delta\alpha_s$ ~ 0.0004