Inclusive-jet cross sections in photoproduction

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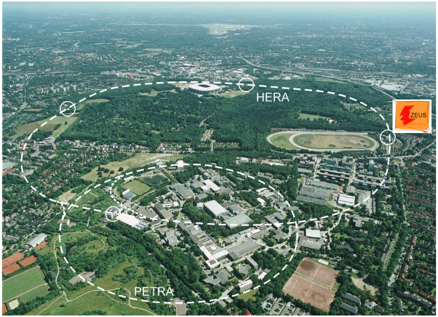
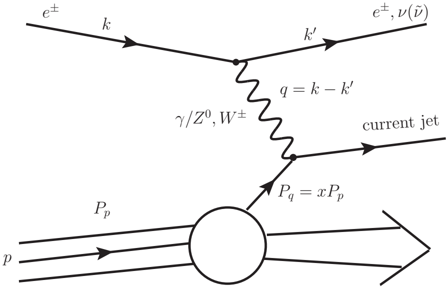
Outline:

1. Jets in photoproduction at HERA
2. Single- and double-differential cross sections
3. Extraction of $\alpha_s(M_Z)$
4. Jet algorithms

HERA collider. ZEUS experiment. Kinematics.



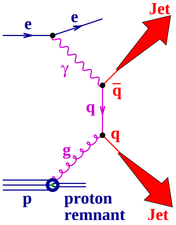


- HERA is a unique $e^{\pm}p$ collider:
  - located at Hamburg, Germany;
  - operated during 1992 — 2007;
  - $\sqrt{s} = 300, 318$ GeV;
- ZEUS collider experiment:
  - 4π geometry;
  - collected ~ 0.5 fb^{-1} of integrated luminosity;

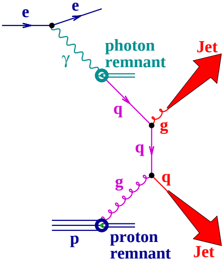
Kinematics:

- momentum transfer: $Q^2 = -q^2 = -(k - k')^2$
  - $Q^2 \approx 0$ GeV^2 — **photoproduction**;
  - $Q^2 \gg \Lambda^2_{QCD}$ — DIS;
- centre-of-mass energy: $s = -(k + p)^2$
- Bjorken scaling variable: $x = \frac{Q^2}{2p \cdot q}$
- inelasticity: $y = \frac{p \cdot q}{p \cdot k}$

Photoproduction is the main source of jets at HERA.
Two processes contribute to the jet cross sections at lowest-order QCD:



Direct photon process



Resolved photon process

In pQCD:

$$d\sigma_{ep}^{jet} = \sum_{a,b=q,\bar{q},g} \int dy\, f_{\gamma/e}\,(y) \iint dx_p\, dx_\gamma\, f_p\,(x_p, \mu_F)\, f_\gamma\,(x_\gamma, \mu_F)\; d\hat{\sigma}_{ab}\,(x_p, x_\gamma, \mu_R)$$

Jet cross sections in photoproduction provide a testing ground for pQCD:

- precise extraction of $\alpha_s\,(M_Z)$ and test of the running of α_s;
- constraints on the proton PDFs: inclusion of jets in photoproduction in ZEUS-jets PDF fit provided constraint of gluon density at medium to high x;
- constraints on the photon PDFs.

Definition of the cross sections and phase space

Phase space

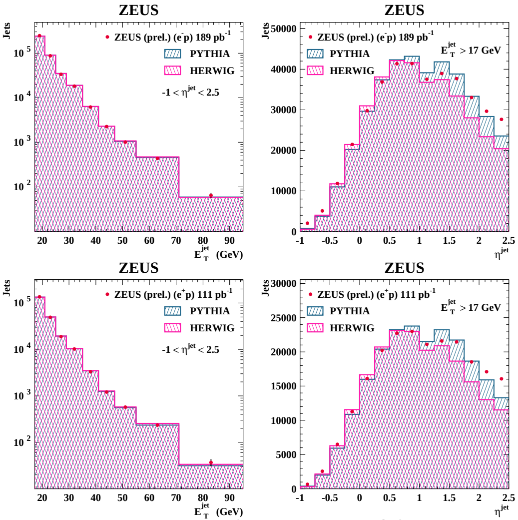
- $Q^2 < 1$ GeV^2 — photon virtuality
- $0.2 < Y < 0.85$ — inelasticity

At least one jet reconstructed with the k_T, anti-k_T or SIScone jet algorithm:

- $E_T^{jet} > 17$ GeV
- $-1 < \eta^{jet} < 2.5$

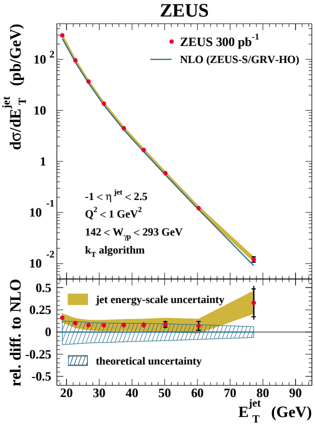
Integrated luminosity $\mathcal{L}$=299.9 $\pm$ 5.4 pb^{-1}

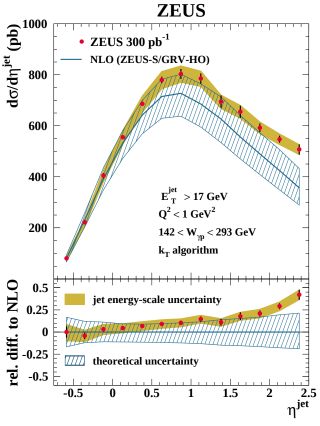
Control plots



Reasonable description of data by both MC for acceptance corrections

Single-differential inclusive-jet photoproduction cross sections as functions of E_T^{jet} and η^{jet}





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Good description of data in shape and normalisation by NLO QCD except at high η^{jet}

$\mapsto$Discrepancies might be due to non-perturbative effects or γPDFs parametrisation

Small experimental uncertainties:

systematic:

- $\pm 4\%$ (low E_T^{jet})
- $\pm 5\%$ ($E_T^{jet} \geq 60$ GeV)

jet-energy scale ($\pm 1\%$):

- $\pm 5\%$ (low E_T^{jet})
- $\pm 10\%$ ($E_T^{jet} \geq 60$ GeV)

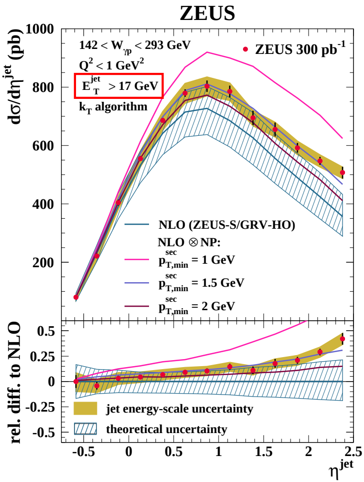
Fixed-order QCD calculations

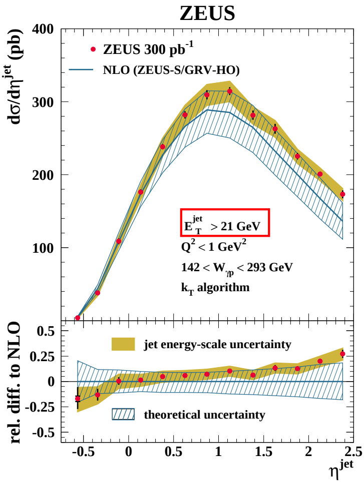
Using program by
M. Klasen, T. Kleinwort, G. Kramer

- pPDFs: ZEUS-S; γPDFs: GRV-HO
- Renormalisation and factorisation scales: $\mu_R = \mu_F = E_T^{jet}$
- Calculations corrected for hadronisation effects

$\longmapsto$Dominant source of the theoretical uncertainty is due to terms beyond NLO

The study of the influence of non-perturbative effects at high η^{jet}





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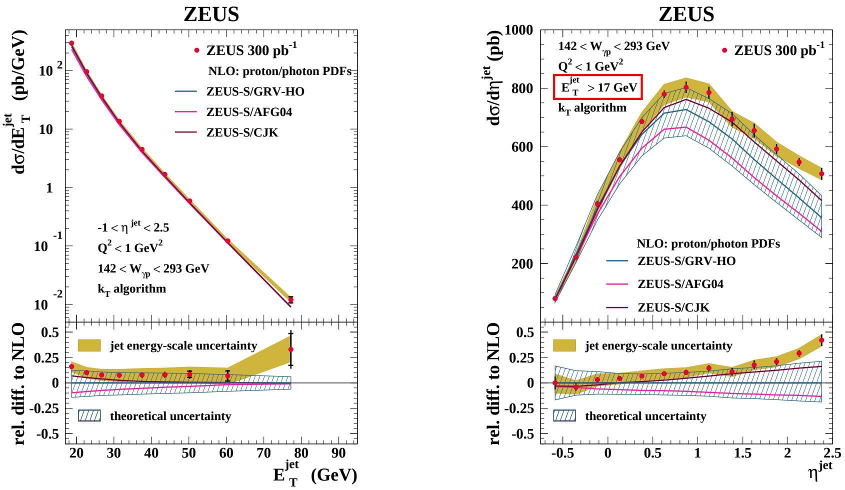
- Non-perturbative contribution increases the jet rate in the regions where discrepancies between data and NLO are observed
- Disagreement between data and NLO decreases when increasing E_T^{jet} threshold to 21 GeV



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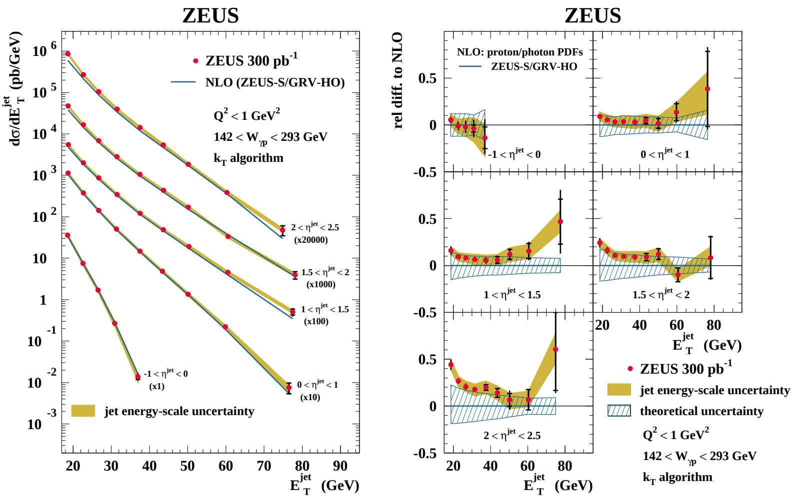
- CJK (AFG04) gives higher (lower) prediction than GRV-HO at high η^{jet}



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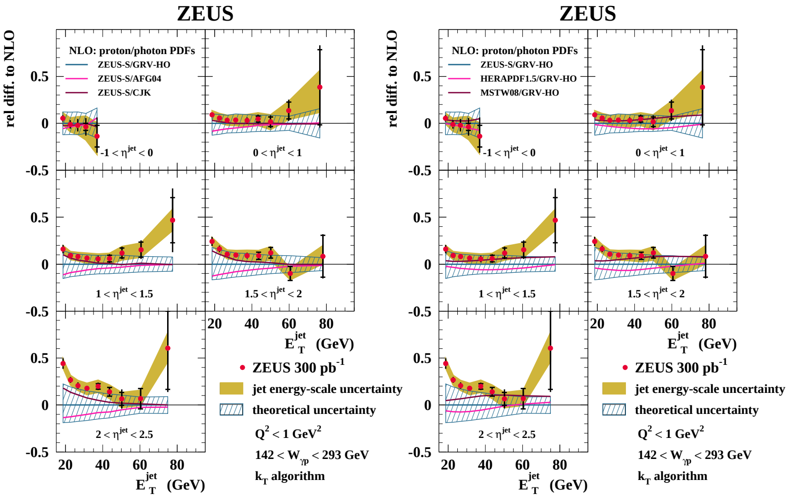
- Good description of data in shape and normalisation by NLO QCD except low E_T^{jet} and high η^{jet}



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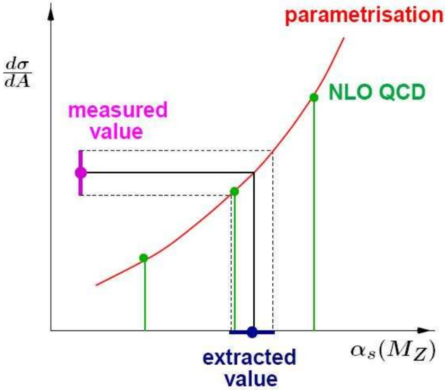
- These precise measurements have the potential to constrain the PDFs of the proton and the photon

The method to determine α_s from jet observables

- NLO calculations based on different pPDFs using in the matrix elements the $\alpha_s(M_Z)$ value assumed in each PDF set
- Parametrisation of the α_s dependence of the prediction: $\frac{d\sigma^i}{dE_T^{jet}}(\alpha_s) = A_1^i \alpha_s + A_2^i \alpha_s^2$
- α_s determined from the measured value using this parametrisation
- This procedure handles correctly the correlation between $\alpha_s(M_Z)$ and the PDFs in the NLO calculations



Extraction of $\alpha_s\,(M_Z)$

From the measured $\frac{d\sigma}{dE_T^{jet}}$ for 21 GeV $< E_T^{jet} <$ 71 GeV a value of $\alpha_s\,(M_Z)$ was extracted:

$$\alpha_S\,(M_Z) = 0.1206 \;\; {}^{+0.0023}_{-0.0022}\,(exp.) \;\; {}^{+0.0042}_{-0.0035}\,(theo.)$$

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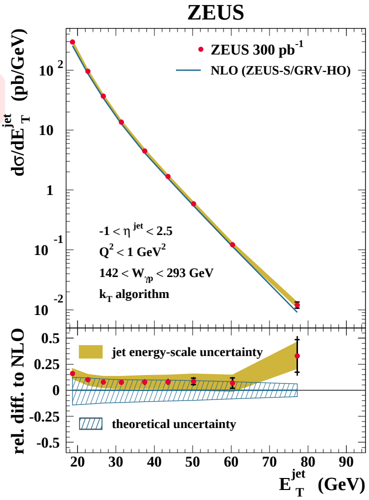
Experimental uncertainties:

- dominated by jet energy-scale uncertainty: ${}^{+1.8\%}_{-1.7\%}$

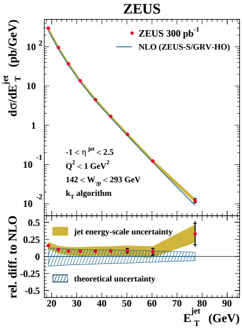
Theoretical uncertainties:

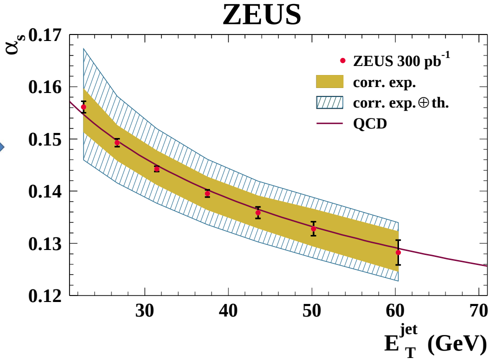
- terms beyond NLO: ${}^{+2.4\%}_{-2.5\%}$
- uncertainties from pPDF: $\pm1.0\%$
- uncertainties from γPDF: ${}^{+2.3\%}_{-0.9\%}$
- hadronisation: $\pm0.4\%$



Precise value of $\alpha_s\,(M_Z)$ from inclusive-jet photoproduction, in agreement with the world average and other determinations

The QCD prediction for the energy-scale dependence of the coupling was determined by extracting α_s from the measured $\frac{d\sigma}{dE_T^{jet}}$ at different E_T^{jet} values:



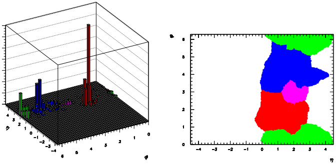


The results are in good agreement with the predicted running of α_s over a wide range in E_T^{jet} from a single experiment

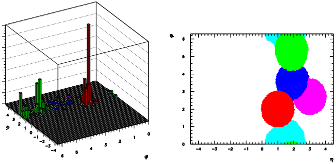
New infrared- and collinear-safe jet algorithms:
$\longrightarrow$ anti-k_T (M Cacciari, G Salam, G Soyez) and SIScone (G Salam, G Soyez)

- Cluster algorithms:
  $\longrightarrow d_{ij} = min[(E_T^i)^{2p}, (E_T^j)^{2p}] \cdot \Delta R^2/R^2$
  with p=1 (-1) for k_T (anti-k_T)
  $\longrightarrow$ anti-k_T keeps infrared and collinear safety and provides $\approx$ circular jets (experimentally desirable)
- Cone algorithms:
  $\longrightarrow$ seedless cone algorithm produces also jets with well-defined area and is infrared and collinear safe (theoretically desirable)

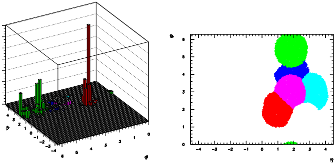
k_T passive area



anti-k_T

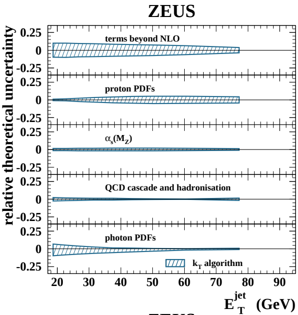


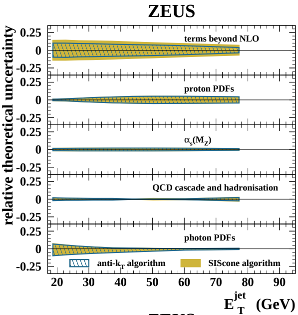
SIScone

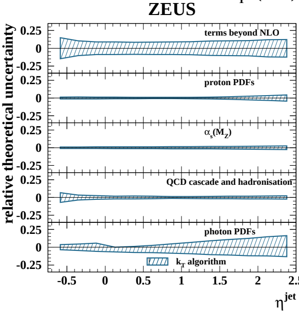


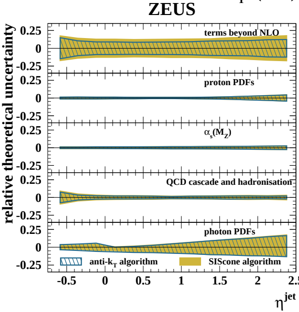
Theoretical uncertainties:

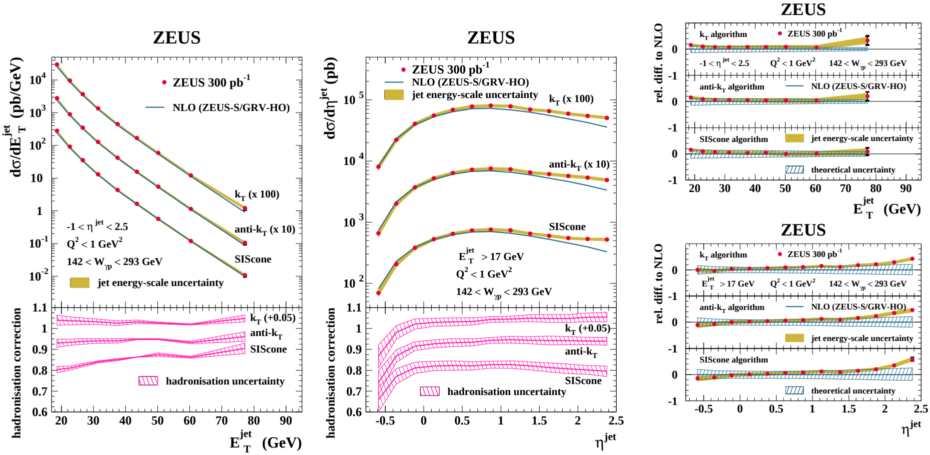
- PDFs and value of $\alpha_s(M_Z)$:
  $\longrightarrow$ very similar for all three jet algorithms
- terms beyond NLO and hadronisation modelling:
  $\longrightarrow$ very similar for k_T and anti-k_T ; somewhat larger for SIScone











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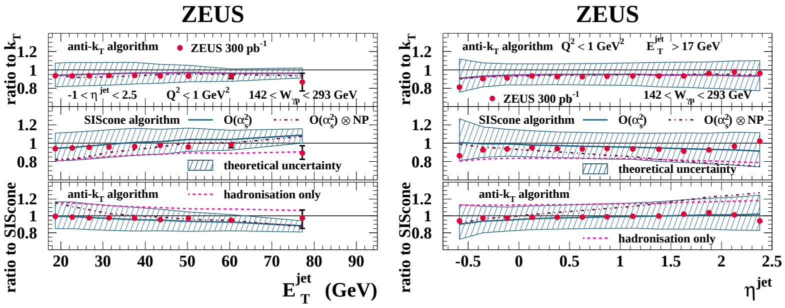
- Good description of data in shape and normalisation by NLO QCD
- Bigger hadronisation corrections for SIScone than anti-k_T (similar to k_T)
- Similar shape and normalisation in data and theory for the three jet algorithms
- Experimental uncertainties are similar for the three jet algorithms

Ratio of cross sections based on different jet algorithms

- $\frac{\text{anti-}k_T}{k_T}$
- $\frac{\text{SIScone}}{k_T}$
- $\frac{\text{anti-}k_T}{\text{SIScone}}$



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$\longrightarrow$ anti-k_T has same shape and is $\approx 6\%$ smaller than k_T

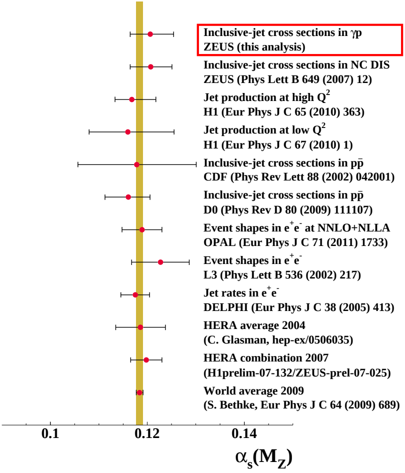
$\longrightarrow$ SIScone has slightly different shape than k_T and anti-k_T

- The pQCD calculations with up to three partons in the final state describe the measured ratios
- Theoretical uncertainties are dominated by higher-order terms

Summary and conclusions

- What has been presented:
  - new precise measurements of single- and double-differential inclusive-jet photoproduction cross sections using different jet algorithms
  - precise determinations of $\alpha_s(M_Z)$
  - precise determination of the running of α_s

    in a wide range of E_T^{jet}
- Inclusive-jet cross sections are well described by NLO calculations except at low E_T^{jet} and high η^{jet}
- Excess in the high-η^{jet} and low-E_T^{jet} regions might be explained by a possible presence of non-perturbative effects or poorly constrained γPDF
- New $\alpha_s(M_Z)$ determinations are consistent with others from ZEUS and the world average



Fixed-order QCD calculations

- Jet cross sections were calculated at NLO using M. Klasen, T. Kleinwort and G. Kramer [Eur.Ph.J. Direct C 1, 1 (1998)] program:
  - pPDFs: ZEUS-S; γPDFs: GRV-HO; (default)
  - pPDFs: MSTW08; γPDFs: CJK, AFG04; (for the comparison to the data)
  - Renormalisation and factorisation scales:$\mu_R = \mu_F = E_T^{jet}$;
  - calculations corrected for hadronisation effects.
- Contribution to the theoretical uncertainty in the cross sections considered:
  - terms beyond NLO: variation of μ_R by factors 2 and 1/2;
  - pPDFs: using error analysis from ZEUS-S sets;
  - value of $\alpha_s\,(M_Z)$;
  - modelling of parton shower and hadronisation: PYTHIA vs HERWIG;
  - γPDFs: AFG04 sets.

Inclusive-jet cross sections: extraction of $\alpha_s(M_Z)$

From the measured $\frac{d\sigma}{dE_T^{jet}}$ for 21 GeV $< E_T^{jet} <$ 71 GeV values of $\alpha_s(M_Z)$ were extracted:

$$\alpha_s(M_Z) = 0.1206 \,^{+0.0023}_{-0.0022}(\text{exp.}) \,^{+0.0042}_{-0.0035}(\text{th.}) \quad k_T$$

$$\alpha_s(M_Z) = 0.1198 \,^{+0.0023}_{-0.0022}(\text{exp.}) \,^{+0.0041}_{-0.0034}(\text{th.}) \quad \textbf{anti-}k_T$$

$$\alpha_s(M_Z) = 0.1196 \,^{+0.0022}_{-0.0021}(\text{exp.}) \,^{+0.0046}_{-0.0043}(\text{th.}) \quad \textbf{SIScone}$$

Experimental uncertainties:

dominated by jet energy scale uncertainty:
$\Delta\alpha_s/\alpha_s = ^{+1.8\%}_{-1.7\%}(k_T) \; ^{+1.8\%}_{-1.8\%}(\text{anti-}k_T) \; ^{+1.7\%}_{-1.6\%}\%(\text{SIScone})$

Theoretical uncertainties:

		k_T	anti-k_T	SIScone
terms beyond NLO:	$\Delta\alpha_s/\alpha_s =$	$^{+2.4\%}_{-2.5\%}$	$^{+2.3\%}_{-2.4\%}$	$^{+3.2\%}_{-3.3\%}$
uncertainties from pPDFs:	$\Delta\alpha_s/\alpha_s =$	$\pm1.0\%$	$\pm1.0\%$	$\pm1.0\%$
uncertainties from γPDFs:	$\Delta\alpha_s/\alpha_s =$	$^{+2.3\%}_{-0.9\%}$	$^{+2.2\%}_{-0.9\%}$	$^{+1.9\%}_{-0.9\%}$
hadronisation corrections	$\Delta\alpha_s/\alpha_s =$	$\pm0.4\%$	$\pm0.4\%$	$\pm0.2\%$

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These values are consistent with each other and have similar precision