Inclusive-jet cross sections in NC DIS

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On behalf of the ZEUS Collaboration

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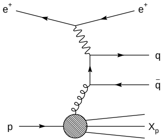
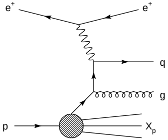
QCD and Hadronic Final States

Jet production in NC DIS at HERA. Kinematics.

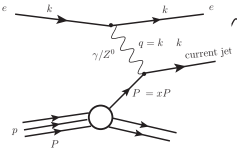
Jet production in neutral current deep inelastic ep scattering at in Breit frame:

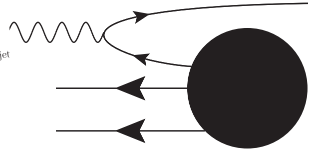


BGF



QCDC





Breit frame

Jet production cross section for NC DIS in pQCD:

$$d\sigma_{ep}^{jet} = \sum_{a,b=q,\bar{q},g} \int dx\, f_a\left(x,\mu_F\right)\, d\hat{\sigma}_a\left(x,\alpha_s\left(\mu_R\right),\mu_R,\mu_F\right)$$

Measurements of jet production in NC DIS at HERA provide a clean hadron-induced reaction and are a powerful tool

- to test perturbative QCD calculations
- to extract $\alpha_s\left(M_Z\right)$
- to determine the energy dependence (running) of $\alpha_s\ (\mu)$
- to constrain the proton PDFs (particularly the gluon)

Kinematics:

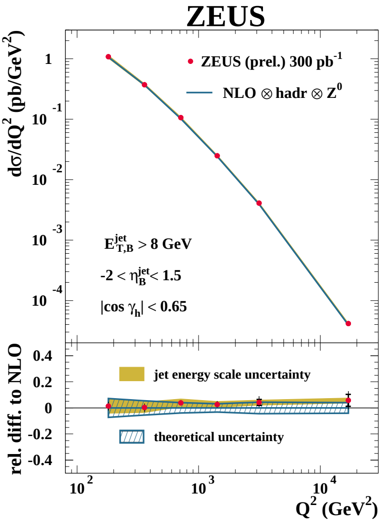
- momentum transfer: $Q^2 = -q^2 = -(k-k')^2$
- Bjorken x: $x = \frac{Q^2}{2 \cdot p \cdot q}$
- hadronic angle: $\cos\gamma_h = \frac{\sum_h (p_x)^2 + \sum_h \left(p_y\right)^2 - \sum_h (E-p_z)^2}{\sum_h (p_x)^2 + \sum_h \left(p_y\right)^2 - \sum_h (E-p_z)^2}$

- Jets searched using the k_T cluster algorithm in Breit frame
- Kinematic region: $Q^2 > 125$ GeV^2 and $|\cos\gamma_h| < 0.65$
- At least one jet with $E^{jet}_{T,B} > 8$ GeV and -2 $< \eta^{jet}_B < 1.5$
- no cuts in LAB frame

Comparison to NLO ($\mathcal{O}(\alpha_s^2)$) predictions (DISENT):

- $\mu_R = E^{jet}_{T,B}, \mu_F = Q$; pPDFs: ZEUS-S; $\alpha_s(M_Z)$ =0.118
- corrected for hadronisation and Z^0 effects

- Inclusive-jet cross sections are very well described by the NLO in the whole measured range
- Inclusive-jet cross sections in NC DIS provide direct sensitivity to $\alpha_s(M_Z)$ with small uncertainties



ZEUS-prel-10-002

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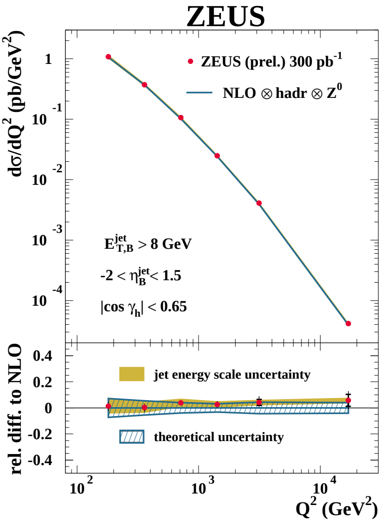
- no cuts in LAB frame

Small experimental uncertainties:

- uncorrelated: $\sim\pm3(7)\%$ at low (high) $Q^2/E_{T,B}^{jet}$
- correlated(energy scale $\pm1\%$ for $E_T^{jet} > 10$ GeV): $\sim\pm5(2)\%$ at low (high) $Q^2/E_{T,B}^{jet}$

Small theoretical uncertainties:

- higher orders (below $\pm5\%$ for $Q^2 > 250$ GeV^2)
- proton PDFs (below $\pm3\%$)
- $\alpha_s(M_Z)$ (below $\pm1(2)\%$ at low (high) $Q^2/E_{T,B}^{jet}$
- parton-to-hadron corrections (below $\pm2\%$)



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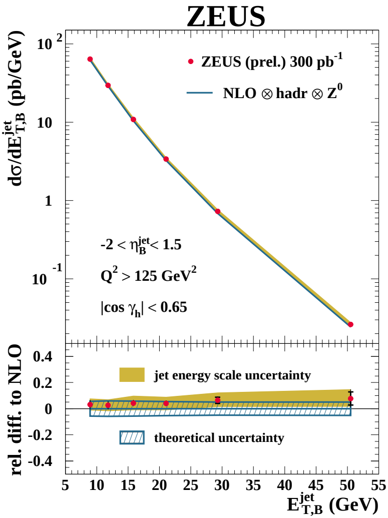

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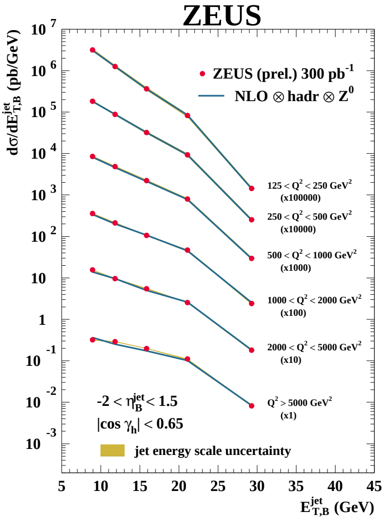

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- High precision inclusive-jet data have the potential to constrain further the pPDFs in regions of phase space relevant for new physics searches at LHC

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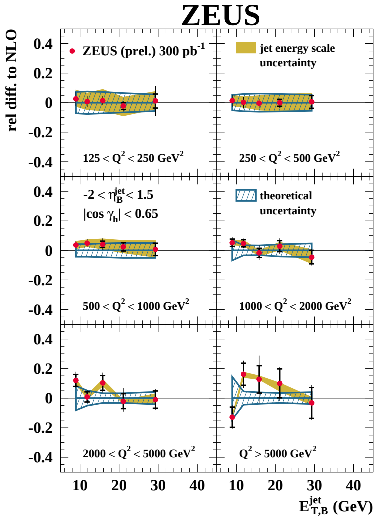

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From the measured $\frac{d\sigma}{dQ^2}$ for $Q^2 > 500$ GeV^2 a value of $\alpha_s(M_Z)$ has been extracted:
(assuming predicted running of α_s)

$$\alpha_S(M_Z) = 0.1208 \ ^{+0.0032}_{-0.0037}(exp.) \ ^{+0.0022}_{-0.0022}(theo.)$$

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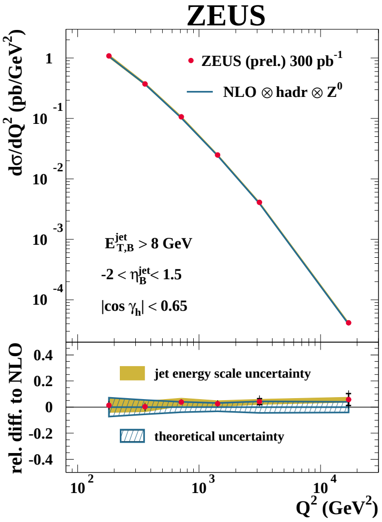
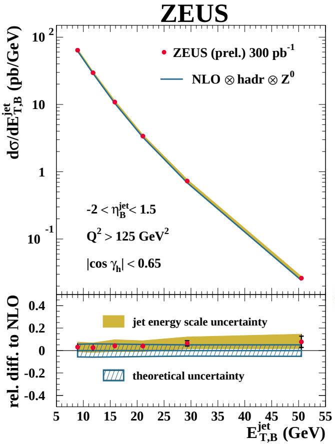
- Experimental uncertainties:
  $\longrightarrow$ dominated by jet energy scale uncertainty:
  $\Delta\alpha_s / \alpha_s = \pm 1.9\%$
- Theoretical uncertainties:
  $\longrightarrow$ terms beyond NLO: $\Delta\alpha_s / \alpha_s = \pm 1.5\%$
  $\longrightarrow$ uncertainties from pPDFs: $\Delta\alpha_s / \alpha_s = \pm 0.7\%$
  $\longrightarrow$ hadronisation corrections: $\Delta\alpha_s / \alpha_s = \pm 0.8\%$
  $\longrightarrow$ μ_F uncertainty: negligible

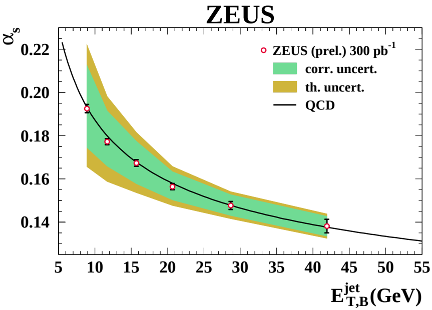


$\alpha_s(M_Z)$ from inclusive jet cross sections: precise determination at HERA
$\longrightarrow$ (total uncertainty: $\sim^{+3.5}_{-3.2}$ %; theoretical uncertainty: $\sim 1.9\%$)

Determination of the energy-scale dependence of α_s $\mathcal{L}$=300pb^{-1}

The energy-scale dependence of the coupling was determined by extracting α_s from the measured $\frac{d\sigma}{dE^{jet}_{T,B}}$ at different $E^{jet}_{T,B}$ values:





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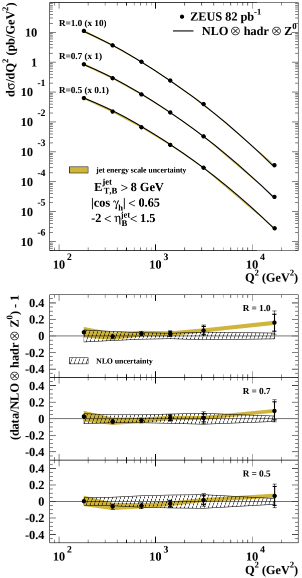
The results are in good agreement with the predicted running of α_s over a large range in $E^{jet}_{T,B}$

- Tests of pQCD with jets require infrared- and collinear-safe jet algorithms:
  $\longrightarrow$ k_T cluster algorithm in the longitudinally invariant inclusive mode
- Performance of k_T algorithm tested extensively
  $\longrightarrow$ stringent tests of pQCD
  $\longrightarrow$ good performance of k_T algorithm
- New jet algorithms being used at LHC
  $\longrightarrow$ need validation
- NEW STUDIES AT ZEUS:
  $\longrightarrow$ test of performance of anti-k_T and SIScone in a hadron-induced but well-understood reaction:
  - comparison to measurements based on k_T
  - comparison of measurements and NLO QCD calculations



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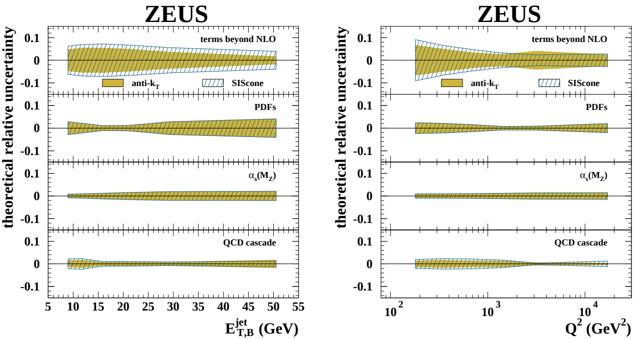

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Theoretical uncertainties:

⟶ proton PDFs and value of $\alpha_s(M_Z)$

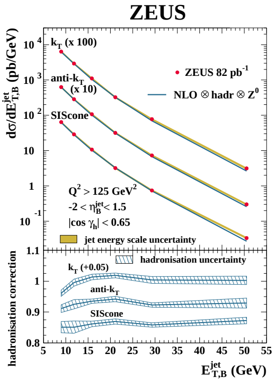
- very similar for all three jet algorithms

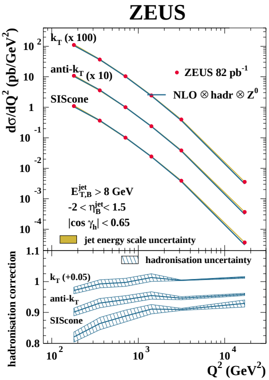
⟶ terms beyond NLO and parton-shower modelling:

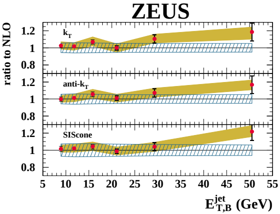
- very similar for k_T and anti-k_T
- somewhat larger for SIScone

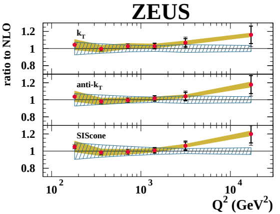
Inclusive-jet cross sections: k_T vs anti-k_T vs SIScone $\mathcal{L}$=82pb^{-1}

Inclusive-jet cross sections as functions of $E^{jet}_{T,B}$ and Q^2 for k_T , anti-k_T and 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
- The jet algorithms have similar experimental uncertainties

- Inclusive-jet cross sections can be calculated only up to $\mathcal{O}(\alpha_s)$ (DISENT or NLOJET++)
- Differences of cross sections using different algorithms can be calculated up to $\mathcal{O}(\alpha_s^3)$ with NLOJET++

- Ratios of cross sections for different algorithms can be calculated using the differences up to $\mathcal{O}(\alpha_s^3)$ as:

$$\frac{d\sigma_{\text{SIScone}}/dX}{d\sigma_{k_T}/dX} = 1 + \frac{d\sigma_{\text{SIScone}}/dX - d\sigma_{k_T}/dX}{d\sigma_{k_T}/dX} \cong 1 + \frac{D\cdot\alpha_s^2 + E\cdot\alpha_s^3}{A\cdot\alpha_s + B\cdot\alpha_s^2}$$

$$\frac{d\sigma_{\text{anti-}k_T}/dX}{d\sigma_{k_T}/dX} = 1 + \frac{d\sigma_{\text{anti-}k_T}/dX - d\sigma_{k_T}/dX}{d\sigma_{k_T}/dX} \cong 1 + \frac{C\cdot\alpha_s^3}{A\cdot\alpha_s + B\cdot\alpha_s^2}$$

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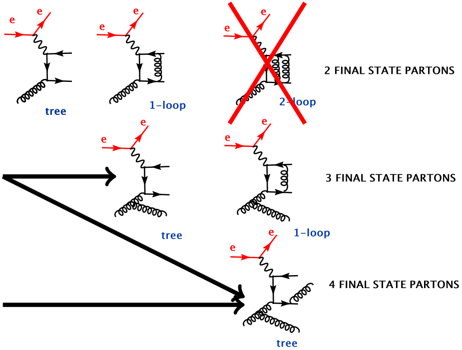
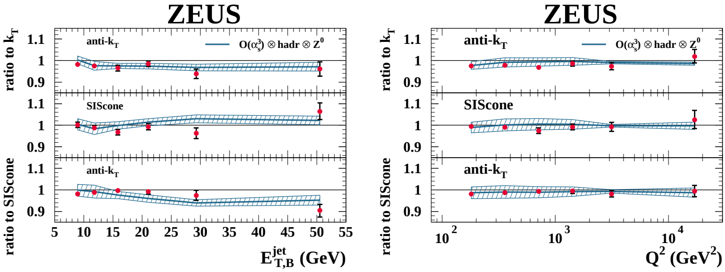


Ratio of cross sections based on different jet algorithms:

anti-k_T/k_T

SIScone$/k_T$

anti-k_T/SIScone



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- the measured cross sections with the three jet algorithms are similar:
  $\longrightarrow < 3.2\%$ for Q^2 and $< 3.6\%$ for $E_{T,B}^{jet}$(except at high $E_{T,B}^{jet}$: 10%)
- the uncertainty due to higher orders in the $\mathcal{O}\left(\alpha_s^3\right)$ calculation is reduced:
  $\longrightarrow$ theoretical uncertainty now dominated by that on the QCD-cascade modelling

pQCD calculations with up to four partons in the final state account adequately for the differences between jet algorithms

Inclusive-jet cross sections: extraction of $\alpha_s(M_Z)$ $\mathcal{L}$=82pb^{-1}

From the measured $\frac{d\sigma}{dQ^2}$ for $Q^2 > 500$ GeV^2 values of $\alpha_s(M_Z)$ were extracted:

$$\alpha_s(M_Z) = 0.1188 \;{}^{+0.0036}_{-0.0035}(\text{exp.}) \;{}^{+0.0022}_{-0.0022}(\text{th.}) \quad \text{anti-}k_T$$

$$\alpha_s(M_Z) = 0.1186 \;{}^{+0.0037}_{-0.0035}(\text{exp.}) \;{}^{+0.0026}_{-0.0026}(\text{th.}) \quad \text{SIScone}$$

$$\alpha_s(M_Z) = 0.1207 \;{}^{+0.0038}_{-0.0036}(\text{exp.}) \;{}^{+0.0022}_{-0.0023}(\text{th.}) \quad k_T$$

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Experimental uncertainties:

dominated by jet energy scale uncertainty:
$\Delta\alpha_s/\alpha_s = \pm 1.9\%(\text{anti-}k_T)$ $\pm 1.9\%(\text{SIScone})$ $\pm 2.0\%(k_T)$

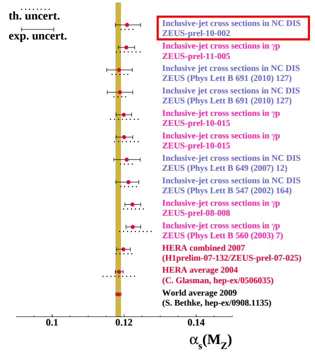
Theoretical uncertainties:

		anti-k_T	SIScone	k_T
terms beyond NLO:	$\Delta\alpha_s/\alpha_s =$	${}^{+1.4\%}_{-1.5\%}$	${}^{+1.6\%}_{-1.7\%}$	${}^{+1.5\%}_{-1.5\%}$
uncertainties from pPDFs:	$\Delta\alpha_s/\alpha_s =$	$\pm 0.8\%$	$\pm 0.8\%$	$\pm 0.7\%$
hadronisation corrections	$\Delta\alpha_s/\alpha_s =$	$\pm 0.9\%$	$\pm 1.3\%$	$\pm 0.8\%$

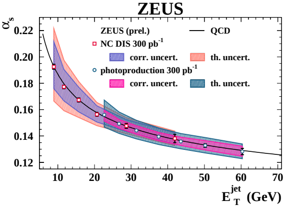
$\alpha_s(M_Z)$ from inclusive-jet cross sections in NC DIS:

precise determination using:	anti-k_T	SIScone	k_T
total uncertainty (%):	~ 3.5	3.7	3.3
theoretical uncertainty (%):	~ 1.9	2.2	1.9

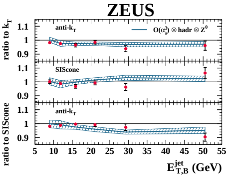
ZEUS latest $\alpha_s(M_Z)$ values and running of α_s from inclusive-jet cross sections in NC DIS and photoproduction:

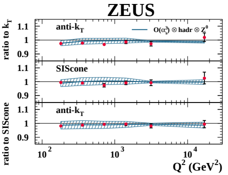


Measurements consistent with each other and the world average



Measurements consistent with the predicted running of α_s over a wide range of E_T^{jet}

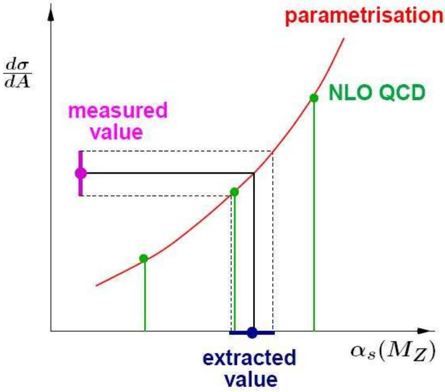




Precise test of the performance of the k_T , anti-k_T and SIScone algorithms

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: $\frac{d\sigma^i}{dA}(\alpha_s) = A_1^i \alpha_s + A_2^i \alpha_s^2$
- 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



k_T vs anti-k_T vs SIScone

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

- Cluster algorithms:
  $\longrightarrow d_{ij} = min[(E^{i}_{T,B})^{2p}, (E^{j}_{T,B})^{2p}] \cdot \Delta R^2/R^2$
  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)