Jets and α_s measurements at HERA

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On behalf of the H1 and ZEUS collaborations

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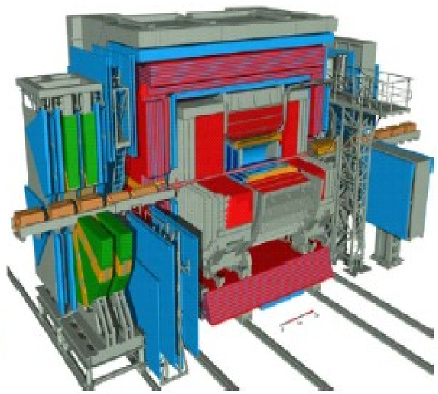
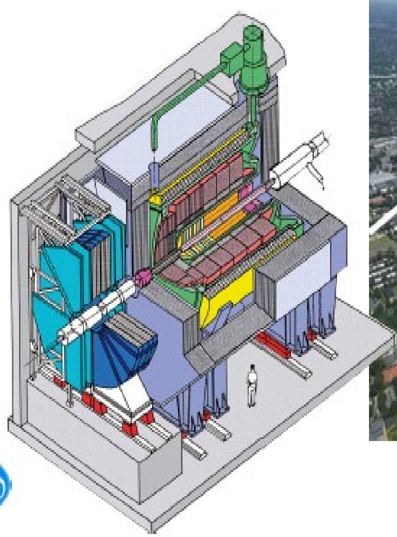
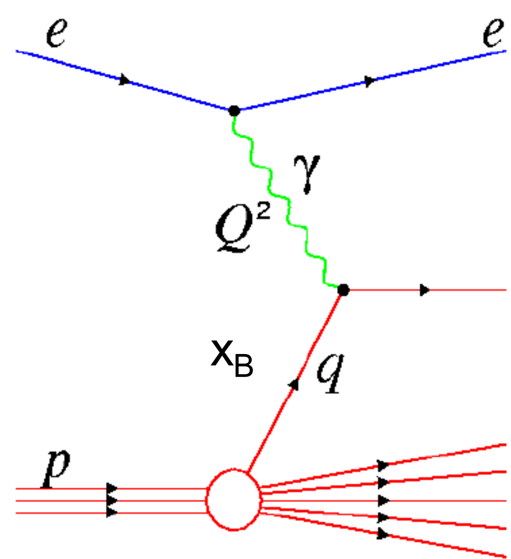
HERA experiments

- ep collider:
- $e^{\pm}$ energy: 27.6 GeV
- p energy: 920 GeV
- Center of mass energy: 319 GeV
- 2 collider experiments: H1 and ZEUS
- Integrated luminosity: ~0.5 fb^{-1} (per experiment)







Q^2 – photon virtuality
x_B – Bjorken scaling variable
y – inelasticity in proton rest frame

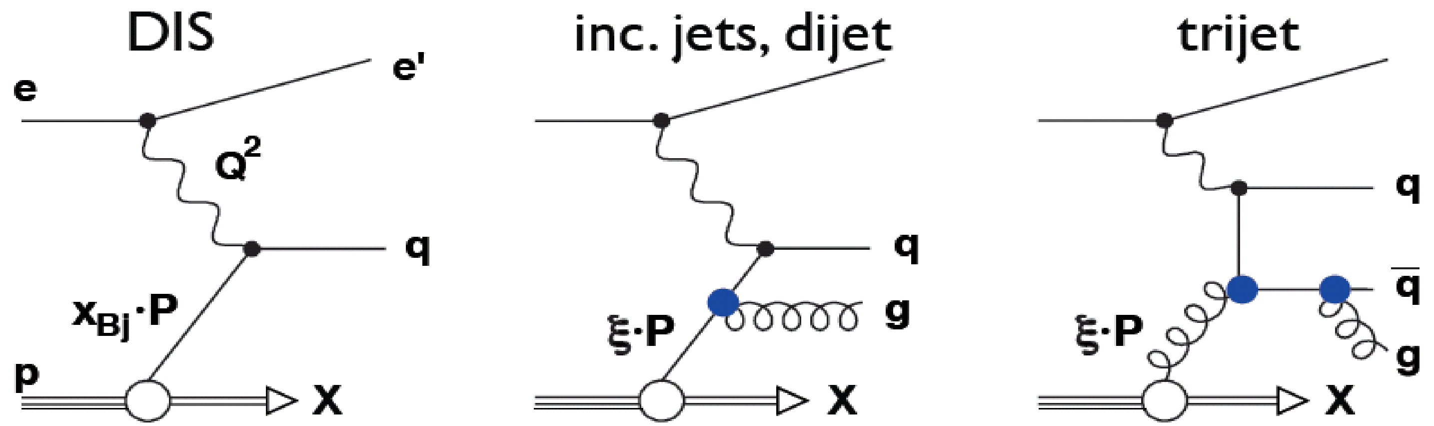
2 kinematics regimes
$Q^2 \approx 0$ GeV^2 – Photoproduction (γp)
$Q^2 > 1$ GeV^2 - DIS

Jet Production

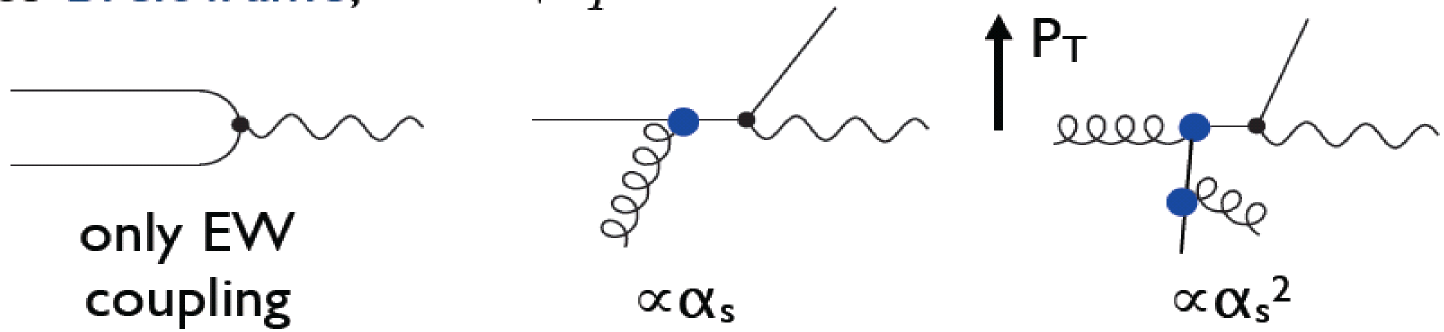
The study of jet production in ep collision at HERA is a testing ground for perturbative QCD (pQCD):

- Jet observables (normalised and non-normalised inclusive jet, dijet and trijet in electro- and photoproduction) used to test pQCD
- Jet cross sections provide a precise determinations of $\alpha_s(M_Z)$
- Jet production is sensitive to gluon PDFs
- Jet production in photoproduction is also directly sensitive to photon PDFs

Jet Production in DIS



Boost to Breit frame, $2xP + q = 0$



Momentum fraction of struck parton (in LO): $\xi = x\left(1 + \frac{M_{12}^2}{Q^2}\right)$

Jet production at large P_T in Breit is sensitive to α_S directly

Jet Measurements in DIS at HERA

Differential and double differential cross sections and normalised to DIS cross sections are measured at:

H1-Prelim-11-032

H1-Prelim-12-031

- photon virtuality $150 < Q^2 < 15000$ GeV^2
- inelasticity $0.2<y<0.7$
- jet transverse momentum $P_T > 7$ GeV (inclusive) and $P_T > 5$ GeV (dijet and trijet).

High Statistics:

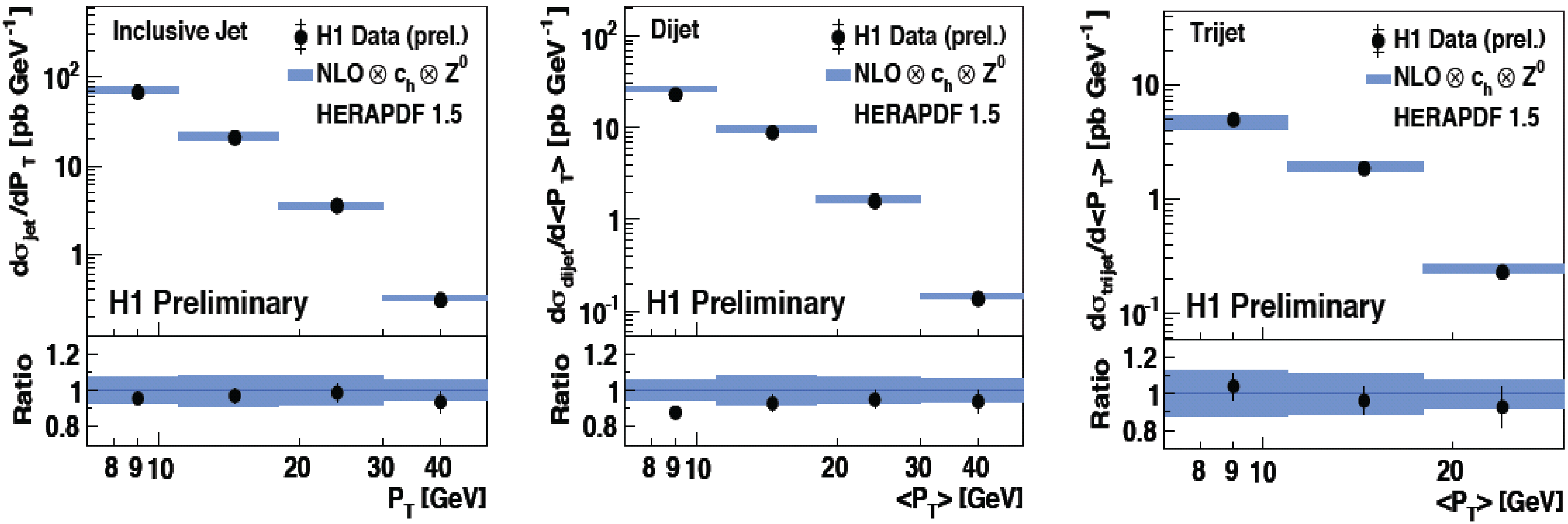
$L \sim 300 pb^{-1}$ (small statistical uncertainties even at large Q^2 and P_T)

Excellent control of systematic uncertainties:

electron energy scale 0.5-1%, effect on cross sections <2%
jet energy scale 1%, effect on cross sections 3-10%
acceptance correction: 4-5% uncertainty

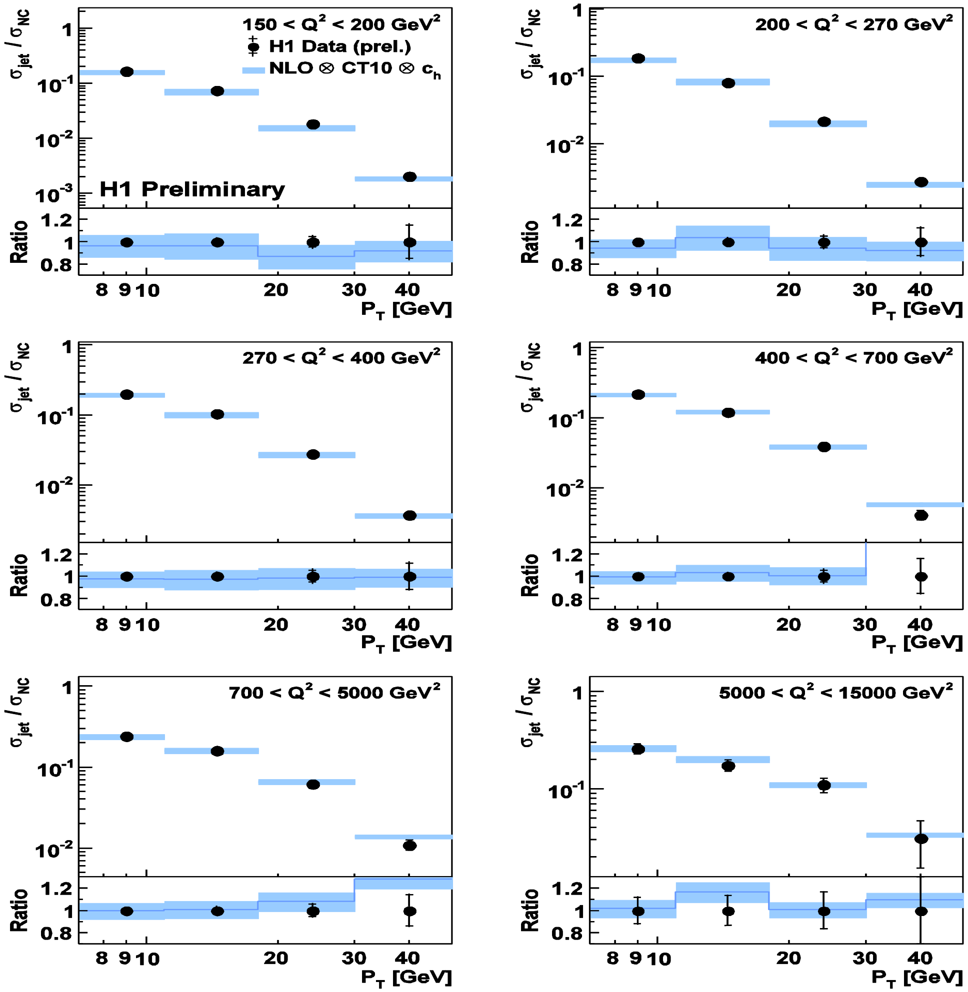
Triggers: *1-2% normalization uncertainty*
Luminosity: *2-2.5% normalization uncertainty*

Single Differential Cross Sections at High Q^2



NLO QCD with $\mu_r = \sqrt{(Q^2 + P_T^2)/2}$ and HERAPDF 1.5 describes well inclusive jet, dijet and trijet single differential cross sections

Normalised Double Differential Inclusive Jet Cross Sections



Benefit:

partial cancellation of experimental and theoretical uncertainties

Comparison with

NLOJet++ and QCDNUM corrected to hadronisation effects

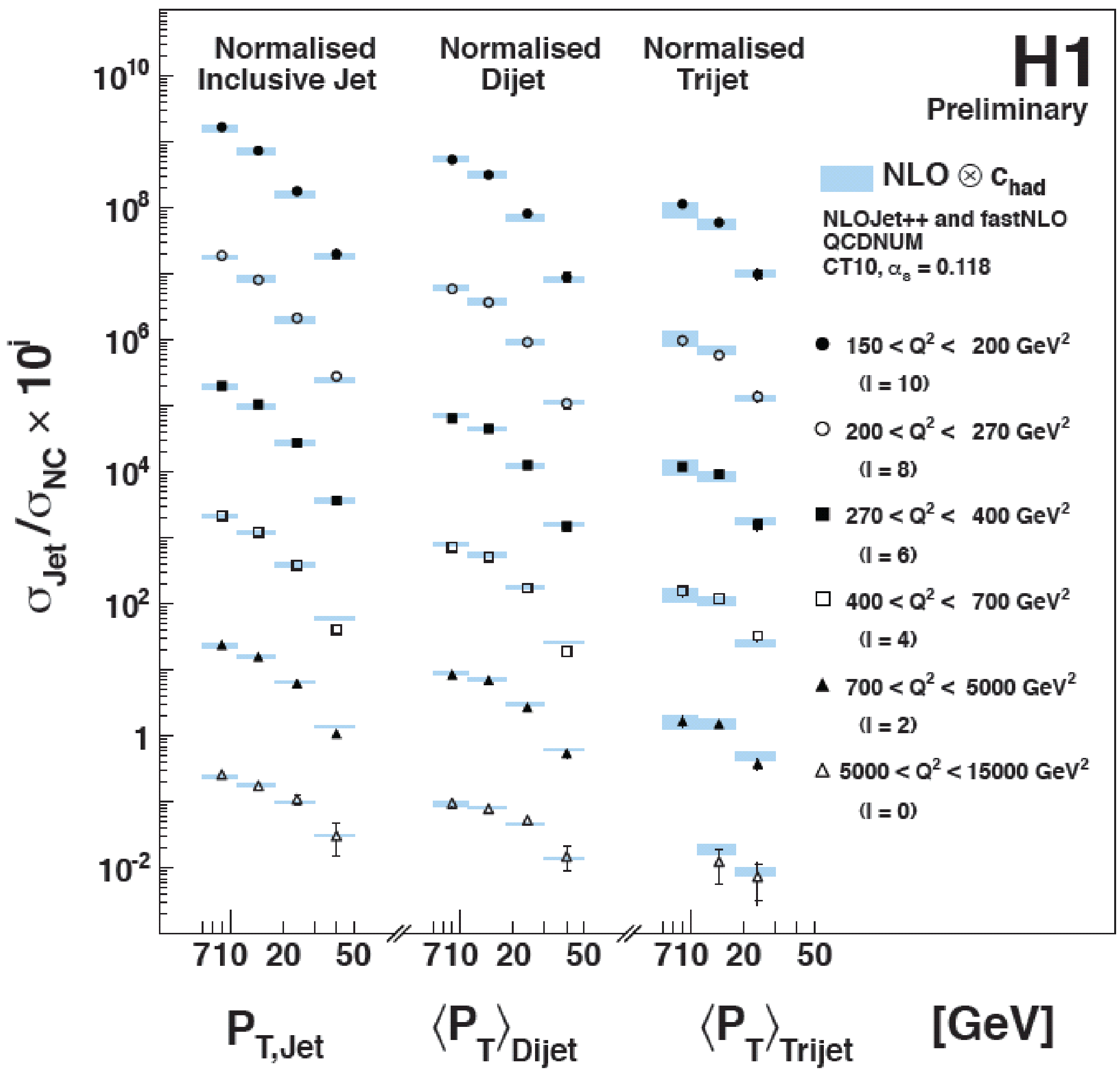
Scale choice:

$\mu^2_f = Q^2$,

$\mu^2_r = (Q^2+P_T^2)/2$

In all bins (besides the highest Q^2 and highest P_T) the experimental uncertainties are essentially smaller than the theoretical uncertainties

Normalised Multijet Cross Sections at High Q^2



NLO Calculation:

NLOJet++ and QCDNUM corrected for hadronisation effects

Scale Choice:

$\mu_f^2 = Q^2$

$\mu_r^2 = (Q^2 + P_T^2)/2$

- Small experimental uncertainties
- Good NLO description of the data

$\alpha_s(M_z)$ Combined Fit

Largest benefit is from a combined fit

simultaneous fit to normalised inclusive jet, dijet and trijet cross sections (all correlations are included)

Sensitive to higher orders

Theoretical uncertainties estimated by variation of scale, k-factor ($k = \sigma_{NLO}/\sigma_{LO}$) – an estimator of higher order contributions reaches values up to 1.45

Restrict analysis to k < 1.3

faster convergence of perturbative series

trade-off between number of data points and smaller theoretical uncertainties

Normalised Multijets with k < 1.3

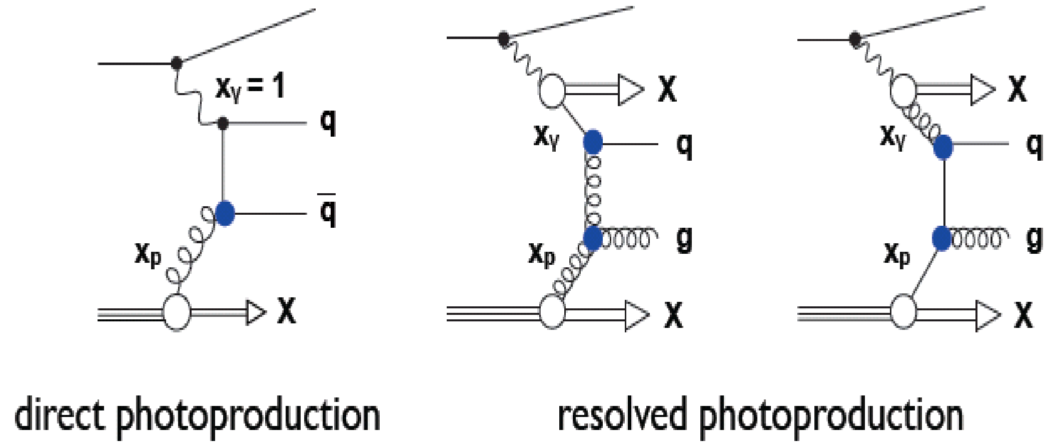
χ^2/ndf: 53.2/41 = 1.30

$$\alpha_s = 0.1163 \pm 0.0011\,(\text{exp}) \;\pm 0.0014\,(\text{PDF}) \;\pm 0.0008\,(\text{had}) \;\pm 0.0039\,(\text{theo})$$

Consistent with other $\alpha_s(M_Z)$ measurements
Small experimental uncertainties
Theoretical uncertainties are larger than the experimental

Jet Production in Photoproduction

- Direct sensitive to α_s, gluon and photon PDFs
- Large statistics
- Single hard scale - E^{jet}_T
- Multiparton interactions



Single and double differential inclusive jet cross sections are measured as functions of jet transverse energy E_T^{jet} and pseudorapidity η^{jet} for

$Q^2 < 1$ GeV^2

γp centre-of-mass energies $142 < W_{\gamma p} < 293$ GeV

and jets with

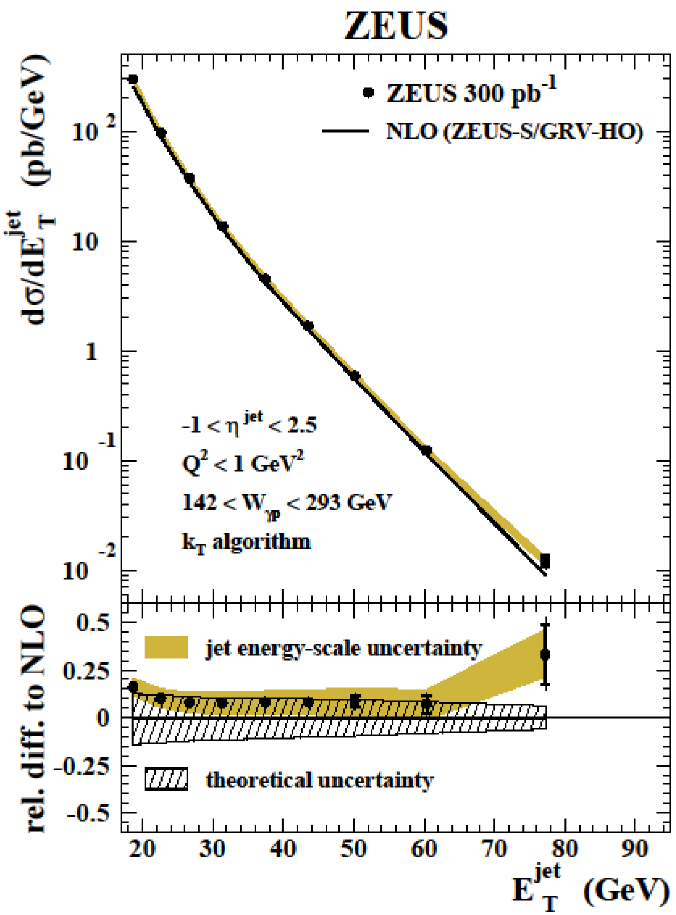
$E_T^{jet} > 17$ GeV

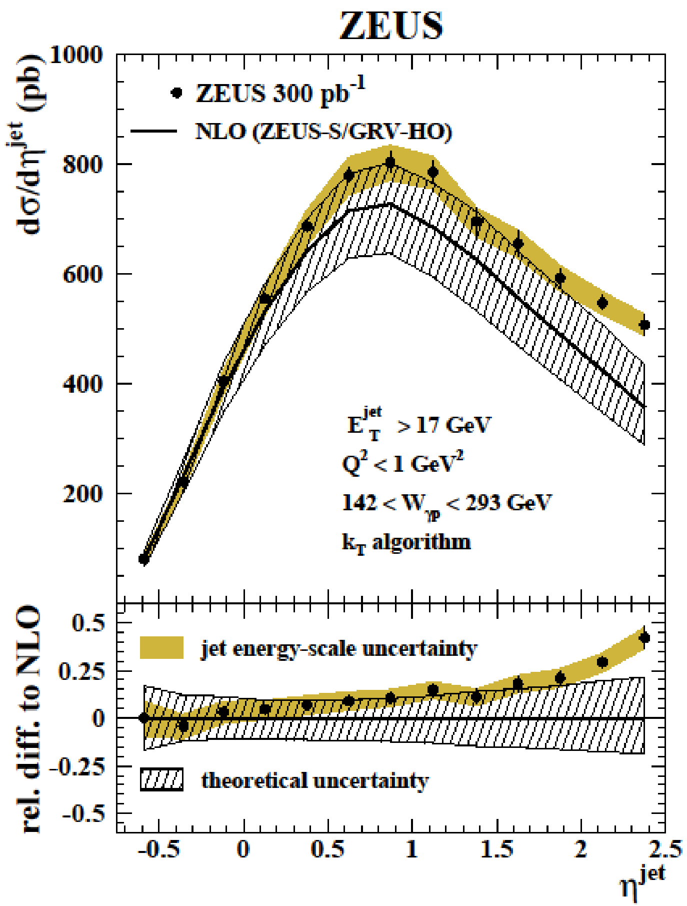
$-1 < \eta^{jet} < 2.5$

ZEUS. Nucl. Phys. B864 (2012), pp. 1-37

Jets were identified using the k_T, anti-k_T and SIScone jet algorithms in laboratory frame.

Inclusive Jet Photoproduction



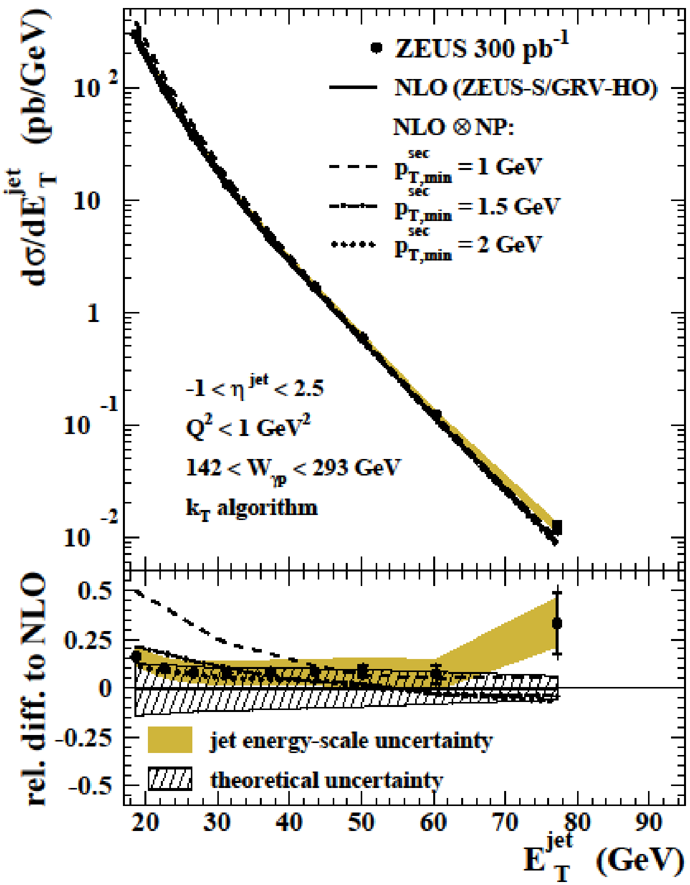


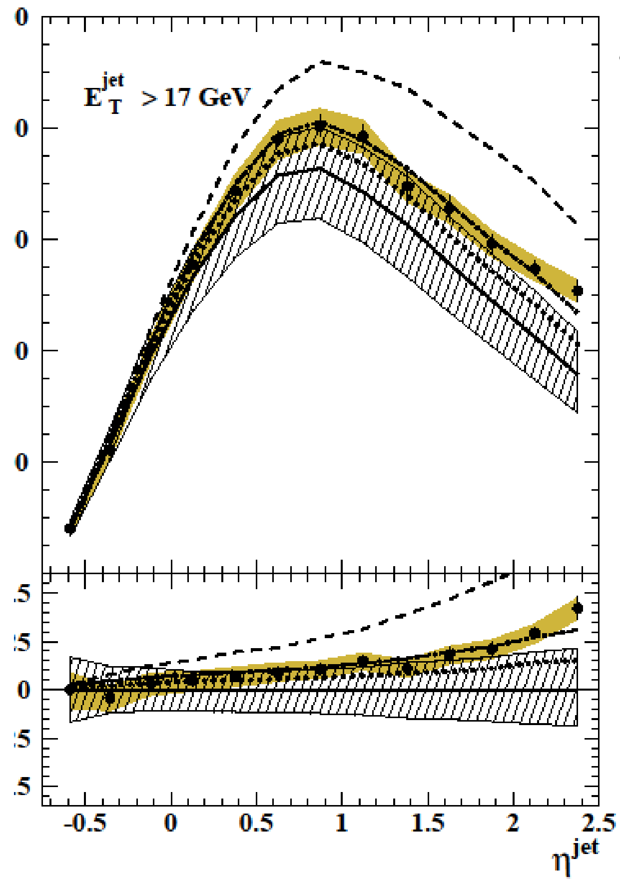
Data compared to NLO QCD ($O(\alpha_s^2)$):

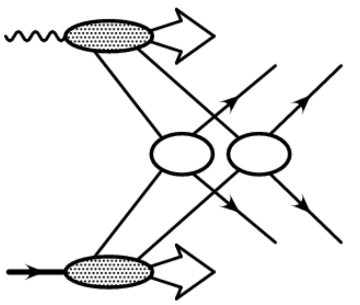
- $\mu_R = \mu_F = \mu = E_T^{jet}$
- PDFs: proton PDF -ZEUS-s, photon PDF – GRV-HO, $\alpha_s = 0.118$

The NLO QCD calculation reproduce $d\sigma/dE_T^{jet}$ well, $d\sigma/d\eta^{jet}$ is well described for $\eta^{jet} < 2$

Non-perturbative Effects





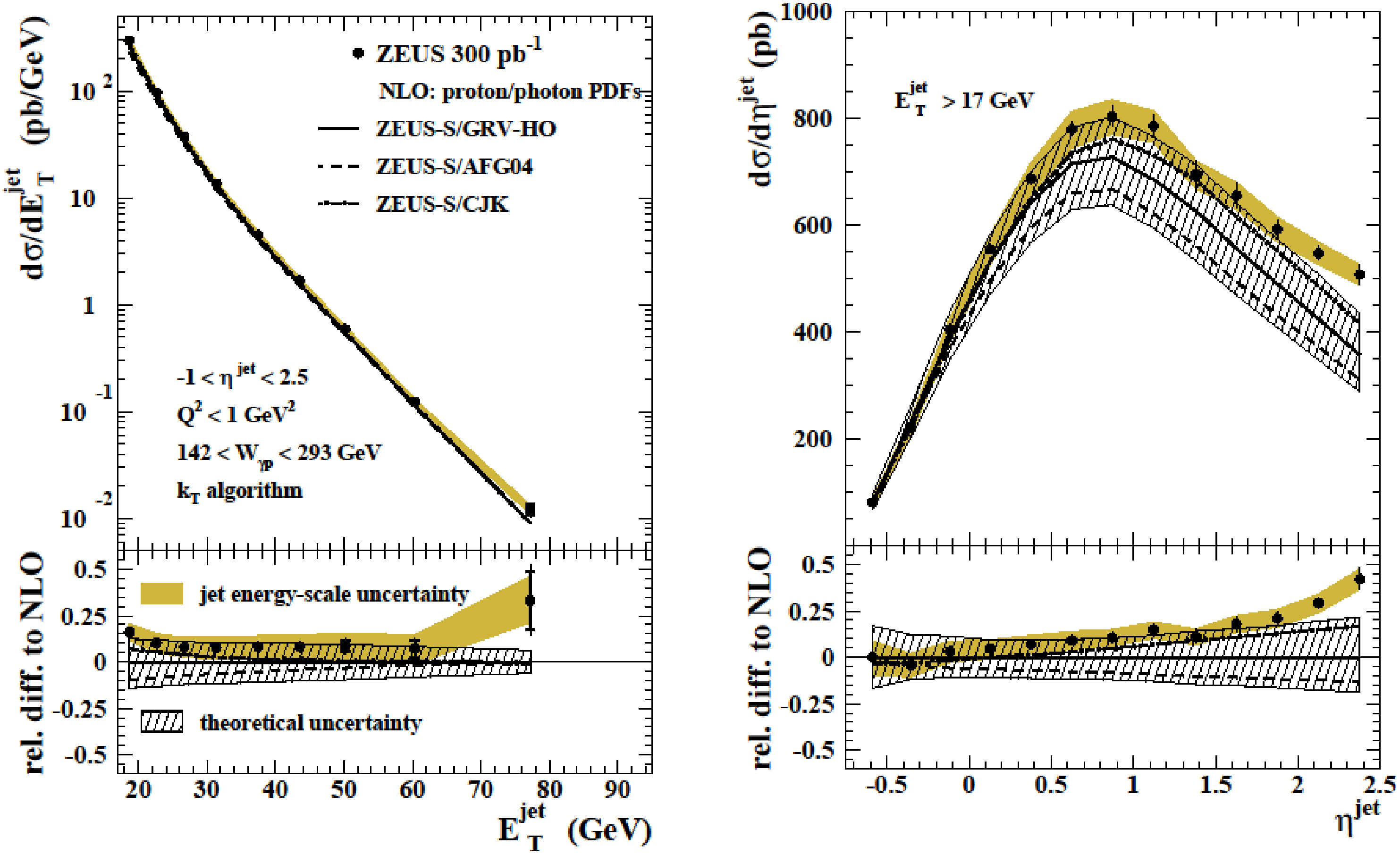


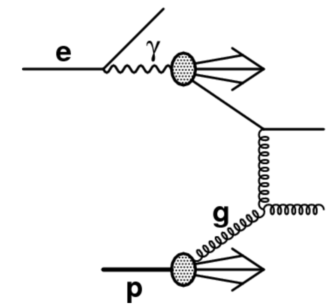
Not includeed in NLO calculation

Data comparison to the NLO QCD calculation including an estimation of non-perturbative effects not related to hadronisation

Possible presence of effects in the data, which are not included in the NLO QCD calculation

Dependence on photon PDFs

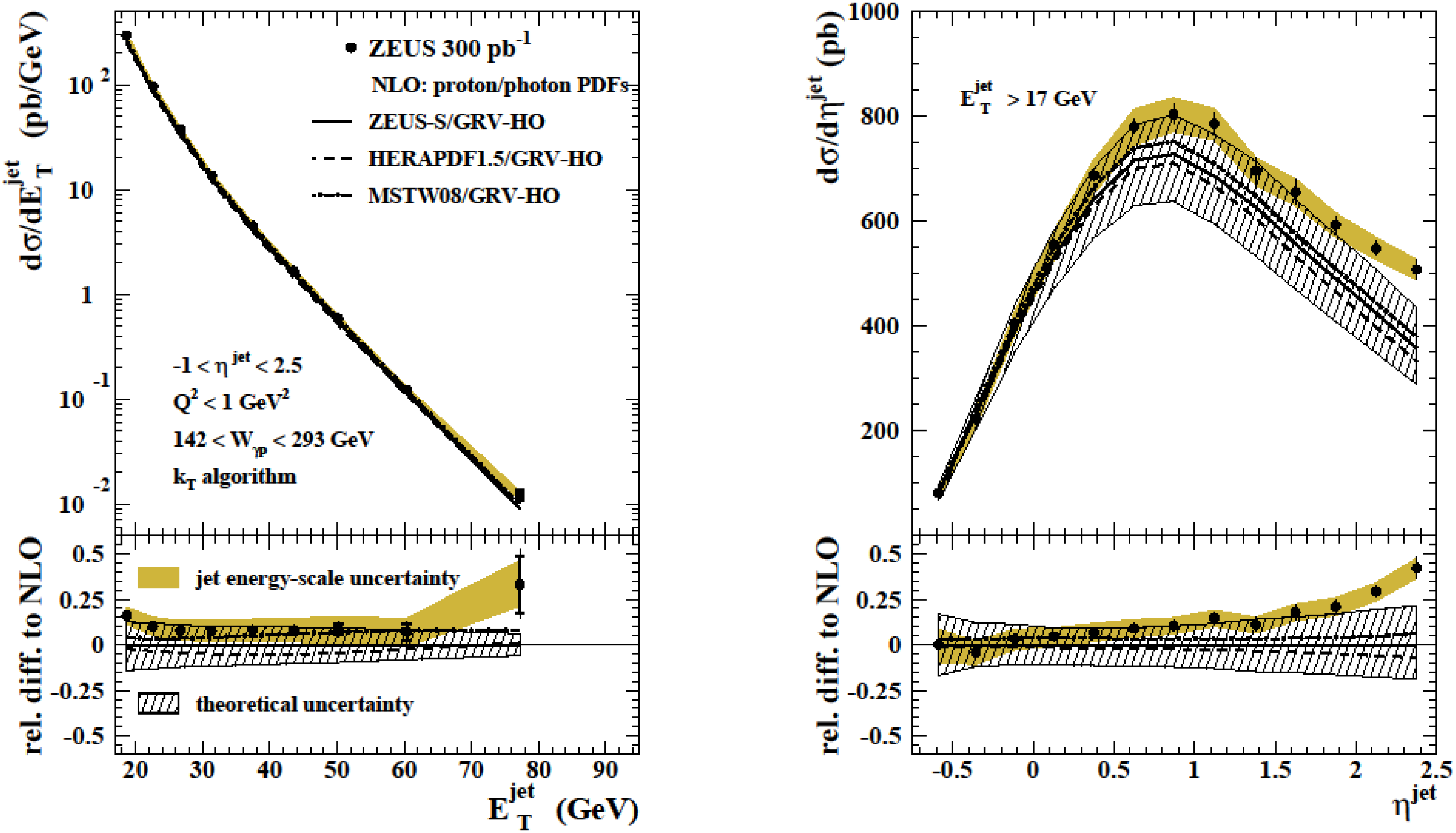




Some difference between three predictions, especially at low E^{jet}_T and high η^{jet}

Potential to constrain photon PDFs

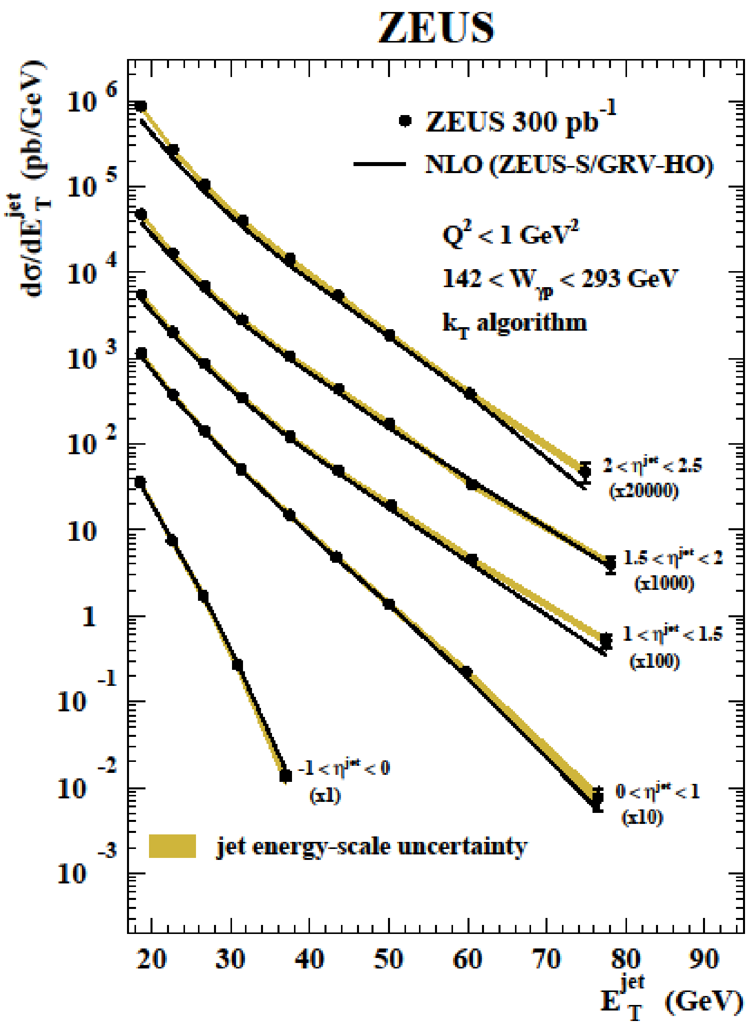
Dependence on proton PDFs



Small difference between three predictions.

Low sensitivity to proton PDFs

Inclusive Jet Photoproduction

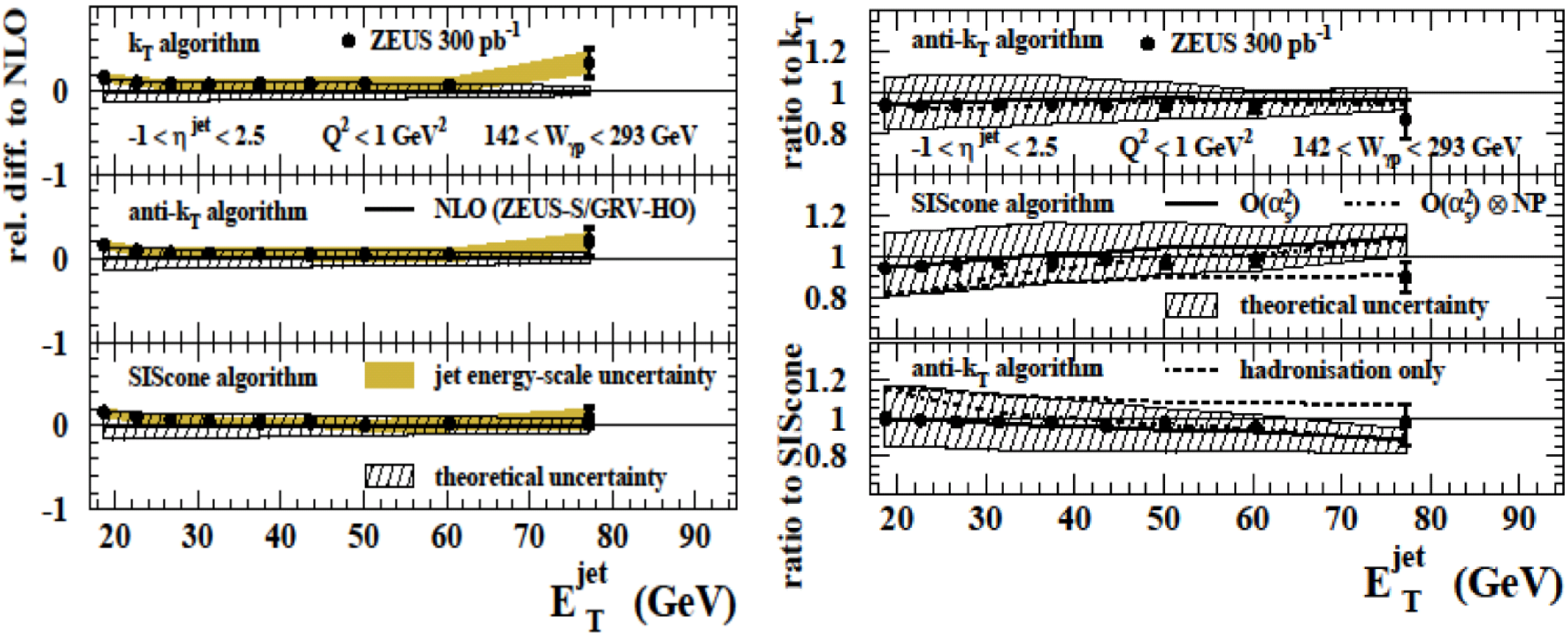


Differential cross section based on k_T jet algorithm for inclusive jet photoproduction with $E^{jet}{}_T$ >17 GeV in different η^{jet} regions.

Difference between data and NLO at large η^{jet} and low $E^{jet}{}_T$ could be from photon PDFs or non-repturbative effects

The NLO QCD predictions give a good description of the data , except at low $E_T{}^{jet}$ and high $d\eta^{jet}$

NLO QCD and Jet Algorithms Comparison



- the agreement of the data to the NLO prediction is the same for all three jet algorithms
- no sensitivity of the result on the choice of the jet algorithm used

Determination of $\alpha_s(M_z)$

The measured single differential cross sections based on the three jet algorithms were used to determine $\alpha_s(M_Z)$ values.

To minimise the effects of a non-perturbative contributions and reduce uncertainties coming from proton PDFs only the measurements for $21 < E^{jet}_T < 71$ GeV were used in the fit.

The values of $\alpha_s(M_Z)$ obtained from presented data are:

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

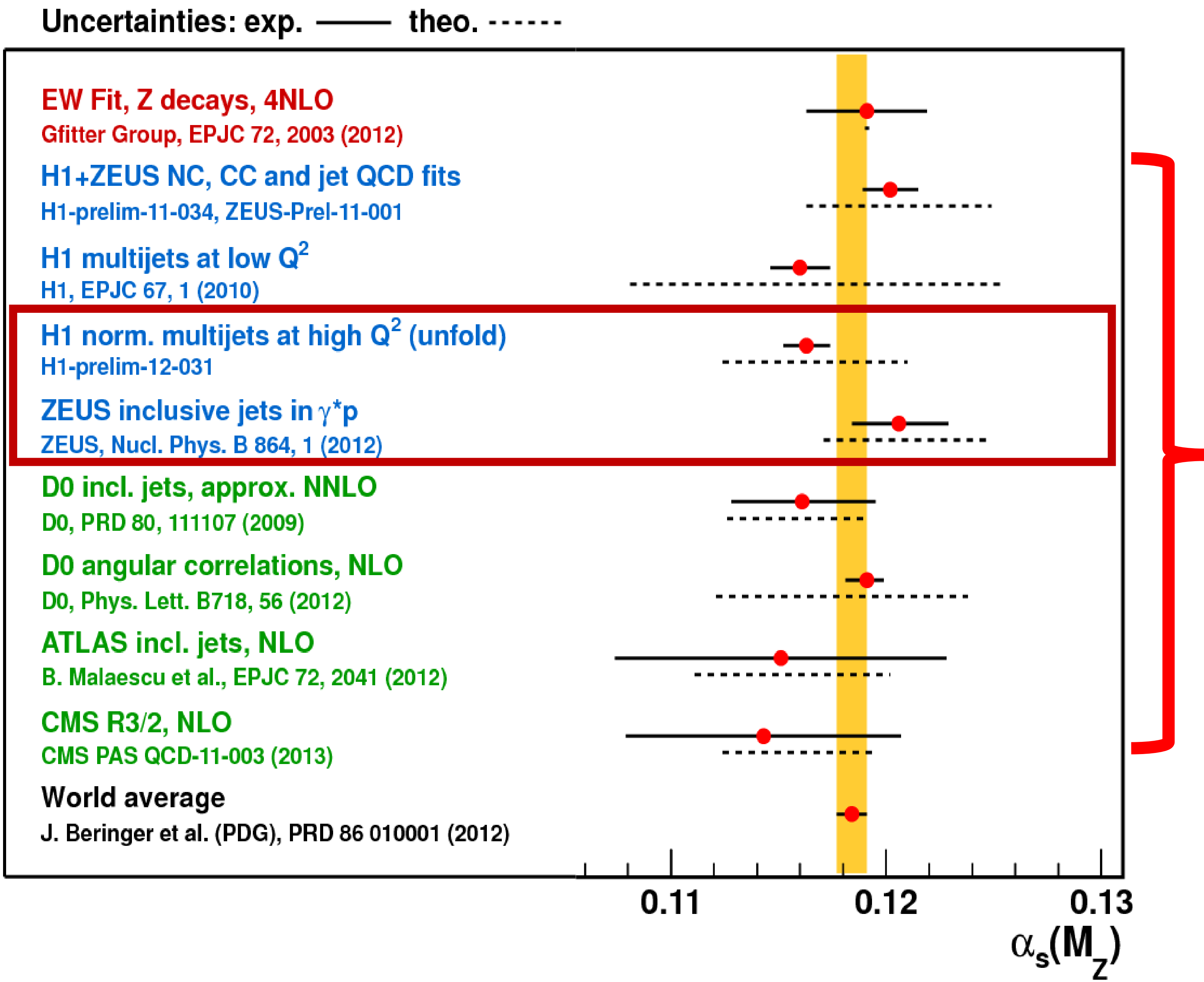
$$\alpha_s(M_Z)|_{\text{anti-}k_T} = 0.1198\,^{+0.0023}_{-0.0022}\,(\text{exp.})\,^{+0.0041}_{-0.0034}\,(\text{th.}),$$

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

The value of $\alpha_s(M_Z)$ determined from the k_T, anti-k_T and SIScone measurements are nicely agreeing

These determinations are consistent with previous determinations of $\alpha_s(M_Z)$ and have a precision comparable to those obtained from e^+e^- experiments

Comparison of $\alpha_s(M_Z)$ Values



Theory uncertainty dominate, NNLO needed

Summary

Experimental Data

- HERA jet data among the most precise data for precision test of QCD
- pQCD calculations in general describe the data
  - ***Precision Measurement of Jet Production in DIS***
    - *absolute and normalised single and double differential cross sections*
    - *multi-dimentional unfolding of various measurements simultaneously*
  - ***Precision Measurement of Jet Production in Photoproduction***
    - *absolute and normalised single and double differential cross sections based on the three jet algorithms (k_T , anti- k_T, SIScone)*
    - *The three jet algorithms give very similar results*

Extraction of $\alpha_s(M_z)$

- Both measurements are used to extract $\alpha_s(M_z)$ yielding values consistent with the world average and having an experimental precision competitive with other extraction methods

Theory

- Missing higher orders often the dominated source of uncertainty