Jet Production at HERA

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2009-01/37

Abstract

Precise jet measurements at HERA are used to extract α_s value in the regions where the theoretical predictions and data are less affected by uncertainties and to explore regions where the theoretical calculations deviate from the data.

1 Jet measurements and extraction of α_s

Jet production in neutral current (NC) deep-inelastic scattering (DIS) and photoproduction (PHP) at HERA provides an important testing ground for QCD. The strong coupling constant α_s is one of the fundamental parameters of the QCD. High precision in the determination of α_s and consistency in the α_s values obtained in different experiments are achieved by using best available theoretical calculations with experimentally precise measurements in the regions where both are less affected by uncertainties. The HERA combined $\alpha_s(M_Z)$ value [1] is shown in Fig. 1 together with the values obtained by H1 and ZEUS collaborations separately, the 2004 HERA average value, 2006 world average and recent LEP values. The combined value $\alpha_s(M_Z) = 0.1198 \pm 0.0019(exp.) \pm 0.0026(th.)$ was obtained by making a simultaneous fit to H1 and ZEUS data sets, instead of just combining $\alpha_s(M_Z)$ values as it was done for the HERA 2004 average value.

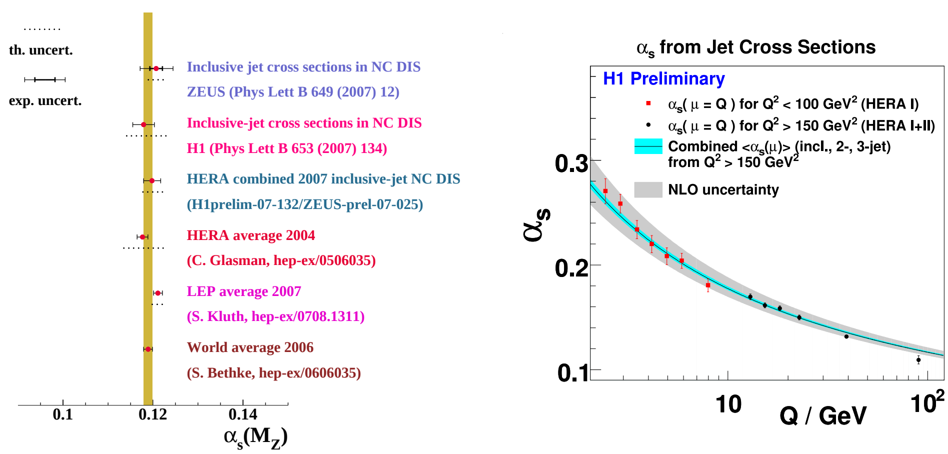

Fig. 1: Measurements of $\alpha_s(M_Z)$ and $\alpha_s(Q)$ at HERA.

A comparison of the combined HERA value to the most recent value of $\alpha_s(M_Z)$ from LEP shows that the central values are compatible within the experimental uncertainty and that the HERA uncertainty is very competitive with the LEP, which includes an average of many precise determinations.

The precision of the cross-section measurement is directly reflected in the precision of the α_s extraction and can be improved if instead of cross sections the ratios of them are used, since in the cross-section ratios the experimental and theoretical uncertainties partially cancel. Recent H1 measurements in the phase-space region $150 < Q^2 < 15000$ GeV^2 and $0.2 < y < 0.7$, where Q^2 is the virtuality of exchanged boson and y is the inelasticity of the interaction, used most of the data collected by HERA [2]. The data sample corresponds to an integrated luminosity of 395 pb^{-1}. The ratios of the differential inclusive, 2-jet and 3-jet cross sections to the differential NC DIS cross sections were measured. The QCD predictions were calculated using the NLOJET++ program [3]. The predictions were found to describe the data well and all the ratios were fitted simultaneously in order to extract the $\alpha_s(M_Z)$ value, which was found to be $0.1182 \pm 0.0008(exp.)^{+0.0041}_{-0.0031}(scale) \pm 0.0018(PDF)$. The values of α_s as function of Q are shown in Fig. 1. The same plot shows the fitted values of α_s from the recent low-Q^2 measurements (red points, [4]). The error bar denotes the experimental uncertainty of each data point. The solid curve shows the results of evolving $\alpha_s(M_Z)$ only at high $Q^2 (Q^2 > 150 \text{ GeV}^2)$, with the inner blue band denoting the correlated experimental uncertainties and the grey band denoting the theoretical uncertainties associated with the renormalisation and factorisation scales, PDF uncertainty and uncertainty in the hadronisation corrections.

A successful extraction of the α_s value in the jet measurements at HERA in a wide kinematic region, including PHP and low-Q^2 DIS, confirms the quality of existing theoretical calculations and their ability to describe the HERA data.

2 Resolved Photoproduction

In PHP at HERA, a quasi-real photon emmitted from the incoming positron or electron can directly take part in the hard interaction, direct PHP, or can act as a source of quarks and gluons with only a fraction of its momentum, x_γ, participating in the hard scatter, resolved PHP. Since x_γ is not directly measurable, a variable x_γ^{obs} is used to differentiate between direct- and resolved-photon enriched events.

Figure 2 represents the cross section $d\sigma/d\overline{\eta}$ for direct- and resolved-enriched samples of the dijet photoproduction events measured by the ZEUS experiment [5]. The mean pseudorapidity, $\overline{\eta}$, was calculated for two leading jets with transverse energy, E_T, $E_T^{\text{jet1}} > 20$ and $E_T^{\text{jet2}} > 15$ GeV.

The next-to-leading-order (NLO) QCD predictions, corrected for hadronisation and using two different photon parton density functions (PDFs) are compared to the data. For, $x_\gamma^{\text{obs}} > 0.75$, the NLO QCD predictions describe the data well, with CJK photon PDF better reproducing the shape of the data. At low x_γ^{obs} the description is not satisfactory. In this regime the calculations are much more sensitive to the photon PDF, than in the direct photoproduction, but none of the PDFs gives an adequate description of the resolved-enriched data sample. Another issue, which becomes important at low x_γ^{obs}, is the high-order effects, which will be discussed in details in the next two sections.

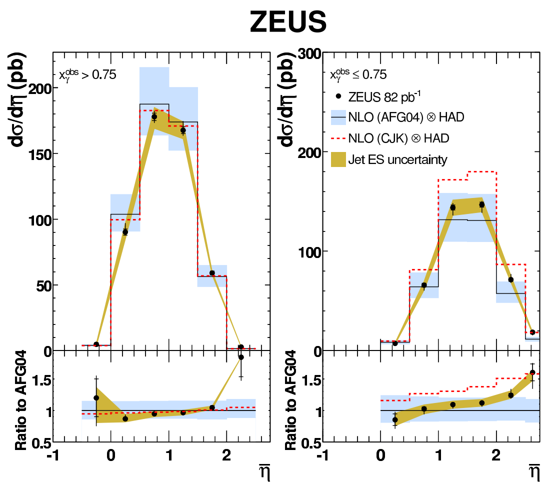

Fig. 2: Measured dijet PHP cross section $d\sigma/d\overline{\eta}$ in direct- and resolved-photon enriched regions, compared to theoretical predictions using different photon PDFs .

3 Forward jets in DIS

A comparison of data on jets produced near the proton direction, forward jets, with NLO QCD calculations has revealed a clear deficit of gluons with sizable transverse momentum, emmitted in these direction. The ZEUS collaboration recently extended the pseudorapidity range of the jets up to 4.3 and performed a measurement in the phase space $0.04 < y < 0.7$, $20 < Q^2 < 100\ \mathrm{GeV}^2$ and $0.0004 < x_{Bj} < 0.005$ [6].

The measured differential forward-jet cross sections as function of Q^2 and x_{Bj} are shown in Fig. 3a) and b), where they are compared to predictions of the NLOJET++ calculations. The calculations predict lower cross sections than obtained from the data, however they have a large theoretical uncertainty. The leading-order (LO) calculation is also shown, indicating that the contribution of the NLO terms is significant. The difference between data and calculations increases with decreasing x, where the difference between LO and NLO is also increasing. The large contribution of the NLO corrections and the size of the theoretical uncertainty indicate that in this phase-space region the higher-order contributions are important.

The H1 measurement at low-x [7] was performed in region $0.1 < y < 0.7$, $5 < Q^2 < 80\ \mathrm{GeV}^2$ and $0.0001 < x_{Bj} < 0.01$. The forward jet had to be found in the pseudorapidity range $1.73 < \eta_{jet} < 2.5$ and the "central jet" in the region $-1 < \eta_{jet} < 1$. The cross section as a function of x is presented in Fig. 3 for events which contain two forward and one central jet, where the second forward jet is required to have $\eta_{jet} > 1$. The calculation fails to describe the data at low-x, where the difference between LO and NLO calculations is most pronounced. The data excess provides a strong hint for missing higher-order QCD corrections, i.e. beyond $\mathcal{O}(\alpha_s^3)$, in this forward gluon-radiation-dominated phase space. However, for the process with two radiated gluons, the $\mathcal{O}(\alpha_s^3)$ calculation can only provide a leading order perturbative estimate.

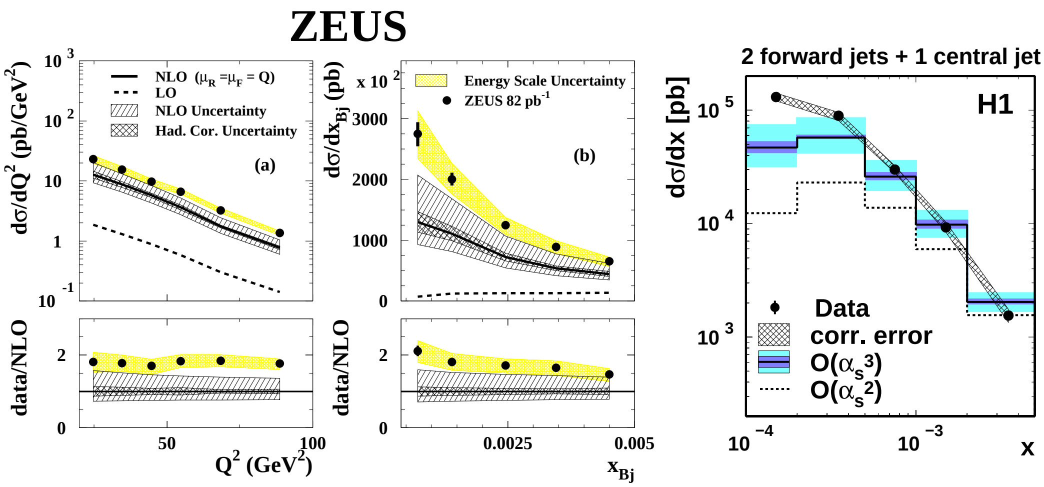

Fig. 3: Forward jets production in DIS.

4 Correlations in multijets at low x_{Bj} in DIS

Inclusive dijet and trijet production in DIS has been measured by the ZEUS collaboration for $10 < Q^2 < 100\ \text{GeV}^2$ and $10^{-4} < x_{Bj} < 10^{-2}$ [8]. Cross sections, cross section ratios and correlations between the two leading jets provide an important testing ground for studying the parton dynamics in the region of small x_{Bj}.

The dijet and trijet cross sections for events with azimuthal separation between two leading jets, $|\Delta\phi^{jet1,2}_{HCM}|$, less than $2\pi/3$ are presented in Fig. 4. The restriction on the azimuthal separation in dijet sample implicitly requires the presence of at least one other jet, which may or may not be observed in the detector. From the QCD calculation point of view it means that the NLO dijet predictions, at $\mathcal{O}(\alpha_s^2)$, become essentially only LO. Therefore the NLO trijet calculations at $\mathcal{O}(\alpha_s^3)$ were used for comparison with the dijet data sample. An implicit third jet requirement led the trijet NLO calculation to converge even if only two jets are defined. For the trijet data sample the standard trijet NLO procedure was used.

The NLOJET++ calculations at $\mathcal{O}(\alpha_s^2)$ for dijet production underestimate the data, the difference increasing towards low x_{Bj}. The NLOJET++ calculations at $\mathcal{O}(\alpha_s^3)$ are up to about an order of magnitude larger than the $\mathcal{O}(\alpha_s^2)$ calculations and are consistent with the data, thus demonstrating the importance of higher-order corrections in the low-x_{Bj} region. For the trijet sample the calculation works well, since it still provides a proper next-to-leading-order perturbative estimate.

5 Conclusions

The precise study of jet production at HERA demonstrates, that the theoretical predictions are able to successfully describe the data in the regions, where the NLO estimate is available. High-order effects become important in the regions, which are dominated by gluon radiation. The precision in the extraction of α_s at HERA is competitive with those from e^+e^- experiments.

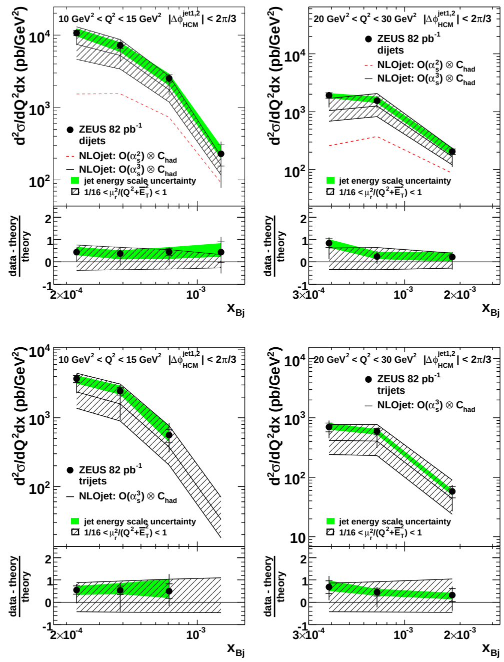

Fig. 4: The dijet and trijet cross sections for events with $|\Delta\phi^{\rm jet1,2}_{\rm HCM}| < 2\pi/3$ as a function of x_{Bj} in two Q^2-bins.

References

[1] H1 Collaboration, H1prelim-07-132 (2007);
ZEUS Collaboration, ZEUS-prel-07-025 (2007).

[2] H1 Collaboration, H1prelim-08-031 (2008).

[3] Z. Nagy and Z. Trocsanyi, Phys. Rev. Lett. **87**, 082001 (2001). `hep-ph/0104315`.

[4] H1 Collaboration, H1prelim-08-032 (2008).

[5] ZEUS Collaboration, S. Chekanov *et al.*, Phys. Rev. **D76**, 072011 (2007).

[6] ZEUS Collaboration, S. Chekanov *et al.*, Eur. Phys. J. **C52**, 515 (2007).

[7] H1 Collaboration, F. D. Aaron *et al.*, Eur. Phys. J. **C54**, 389 (2008).

[8] ZEUS Collaboration, S. Chekanov *et al.*, Nucl. Phys. **B786**, 152 (2007).