Measurements of Jets and α_s at HERA

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Abstract. Jet production in electron-proton scattering at HERA provides an important testing ground for Quantum Chromodynamics and allows improved determinations of the strong coupling, α_S. A review of recent measurements of jet cross sections in photoproduction and neutral current DIS (NC DIS) at HERA is presented, and the latest determinations of α_S are shown.

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INTRODUCTION

The strong coupling, α_s, is the fundamental parameter of perturbative QCD (pQCD). The running of α_s is predicted by the pQCD but not the absolute normalisation, which must be determined by experiment. This contribution presents the latest jet production studies made by the H1 and ZEUS Collaborations and the resulting determinations of α_s, which result in an unprecedented level of precision at HERA. Furthermore, these determinations allow a stringent test of the running of α_s predicted by pQCD.

In *ep* collisions at HERA one distinguishes two processes, according to the virtuality Q^2 of the exchanged boson, DIS and photoproduction. In DIS a highly virtual boson ($Q^2 > 1$ GeV^2) interacts with a parton carrying a momentum fraction of the proton. In photoproduction the quasi-real photon ($Q^2 < 1$ GeV^2) interacts with a parton from the proton either *directly*, or it via its constituent (*resolved photoproduction*).

In the pQCD, a jet cross section is expressed as the convolution of the parton distribution functions (PDFs) with the matrix elements. In regions where the PDFs are well constrained, the jet data allow to test the general aspects of pQCD. In regions where the PDFs are not so well constrained, jet cross sections can be incorporated into global QCD fits to help further constrain them.

Jet production in *ep* collisions proceeds via the Born, boson-gluon fusion and QCD Compton processes. In the Breit frame, where the virtual boson and the proton collide head on, the siginificant transverse momenta (E_T) are produced at leading order (LO) in α_s by the boson-gluon fusion and QCD Compton processes. Jet production with E_T in the Breit frame is thus directly sensitive to α_s and to the PDFs of the proton. In the analyses presented here jets are defined using the k_T clustering algorithm. The associated cross sections are collinear and infrared safe and therefore well suited for comparison with predictions from fixed order QCD calculations. For DIS, the jet algorithm is applied in the Breit frame, and for photoproduction in the photon-proton collinear frame.

JET CROSS SECTIONS IN PHOTOPRODUCTION

ZEUS Collaboration presented the analyses of dijet and inclusive jet photoproduction [1, 2]. For dijet cross sections at least two jets are required with E_T above 20 GeV for the first and 15 GeV for the second jet, whereas the inclusive jets are selected with E_T above 17 GeV. The jet pseudorapidity is required to fulfill $-1.0 < \eta^{\rm Lab} < 2.5$. The data sampes correspond to integrated luminosity of 82 pb^{-1}. The overall experimental systematic uncertainty of typically 10 to 15% is dominated by the uncertainty on the absolute energy scale of the hadronic calorimeters.In the left side of Figure 1 the dijet cross sections are shown as a function of the mean E_T of the two jets together with the NLO QCD calculations [3] corrected for hadronisation and using different parameterisations of photon PDF. In the right side of Figure 1 the inclusive jet cross section is shown as function of E_T^{jet} together with the NLO QCD calculations of [4]. There is a good general agreement with the predictions. The direct-dominated ($x_\gamma > 0.75$) cross section is well described. Some discrepancy is observed for resolved photon ($x_\gamma < 0.75$) distribution, suggesting that this data can be used to adjust the photon PDF.

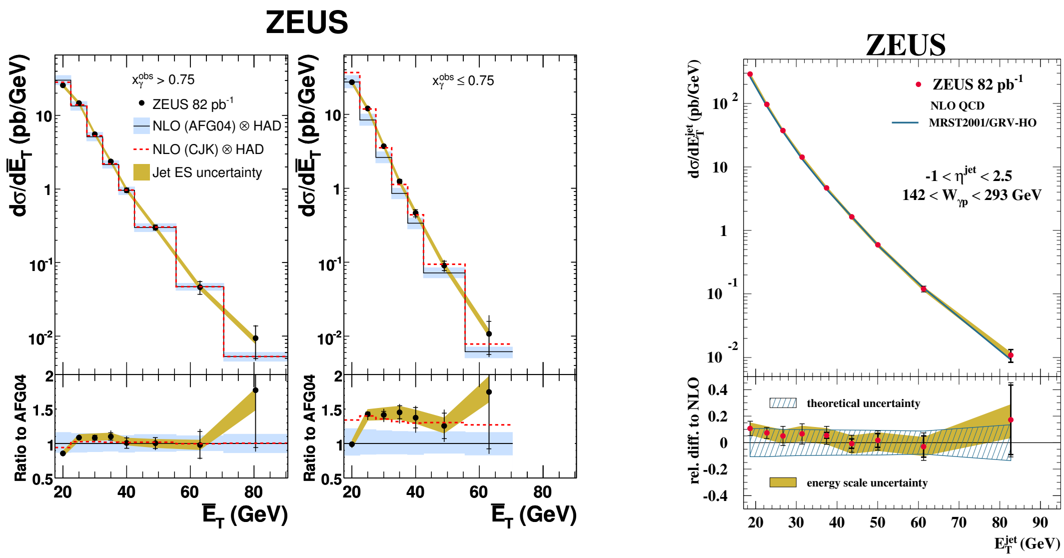

FIGURE 1. The photoproduction dijet cross section $d\sigma/d\bar{E}_T$ for $x_\gamma > 0.75$ and $x_\gamma < 0.75$ compared with NLO QCD predictions using different photon PDFs and the inclusive jet cross section as a function of E_T^{jet}. The data are shown with experimental uncertainties (error bars) along with the jet energy scale uncertainty (shaded band). The discrete bands indicate the uncertainty on the NLO predictions. The ratios to the predictions are shown at the bottom of the figures.

The measured inclusive jet cross section is used to extract strong coupling α_s with a minimal χ^2 fit procedure where the value of the α_s at the Z boson mass, $\alpha_s(M_Z)$, is taken to be the only free parameter of the theory. The experimental uncertainty is estimated by the *offset method* adding in quadrature the deviation of α_s from the central value when the fit is repeated with independent variations of various experimental sources. The obtained value of α_s at the scale M_Z is [5]

$$\alpha_s(M_Z) = 0.1223 \pm 0.0001\ (stat.)^{+0.0023}_{-0.0021}\ (exp.)^{+0.0029}_{-0.0030}\ (th.)$$

The theoretical uncertainty contains a dominating part coming from terms beyond NLO estimated using the band method [6], added in quadrature to the uncertainties on the hadronisation corrections and to the uncertainties on the proton and photon PDFs parameterisation. The total theoretical uncertainty amounts to 2.5%.

JET MEASUREMENTS IN DIS

Jet measurements in DIS were recently performed by the H1 collaboration in two kinematic regimes. The low Q^2 data [7] corresponding to $5 < Q^2 < 100\,\mathrm{GeV}^2$ use a HERA-1 sample of 44 pb^{-1}, whereas the high Q^2 data [8], corresponding to $150 < Q^2 < 15000\,\mathrm{GeV}^2$, are based on nearly the full H1 data sample of about 400 pb^{-1}. The inclusive jet cross sections are measured in low Q^2 regime by requiring $E_T > 5$ GeV and $-1.0 < \eta^{\mathrm{Lab}} < 2.5$. At high Q^2 the cross sections are measured for inclusive jets with $7 < E_T < 50$ GeV and for 2-jet and 3-jet events containing jets with $5 < E_T < 50$ GeV and $-0.8 < \eta^{\mathrm{Lab}} < 2.0$. The jet cross sections at high Q^2 are normalised to the inclusive DIS cross sections in order to reduce the sensitivity to the absolute normalisation uncertainties. The normalised jet cross sections as function of Q^2 are shown on Figure 2. One of the main sources of experimental uncertainties remains the uncertainty on the absolute calibration of the hadronic energy scale with an impact on the cross sections of about 1 to 5%. The detector correction factors show an uncertainty due to the MC model dependence which amounts typically to 1 to 10%.

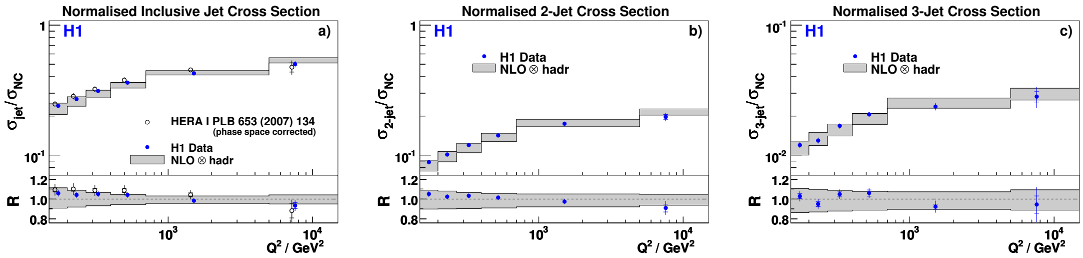

FIGURE 2. Normalised inclusive, 2-jet and 3-jet cross sections in NC DIS measured as a function of Q^2.

The H1 jet cross sections at low and high Q^2 are used to extract α_s. The experimental uncertainty of α_s is defined by that change in α_s which increases the minimal χ^2 by one unit. The α_s is extracted individually from the inclusive jets at low Q^2 and from the inclusive, 2-jet and 3-jet at high Q^2. The experimentally most precise determination of $\alpha_s(M_Z)$ is derived from the combined fit to all three observables at high Q^2:

$$\alpha_s(M_Z) = 0.1168 \pm 0.0007\,(exp.)^{+0.0046}_{-0.0030}\,(th.) \pm 0.0016\,(PDF).$$

The theory uncertainty is estimated by the *offset method* adding in quadrature the deviations due to various choices of scales and hadronisation corrections. The largest contribution is the theoretical uncertainty arising from terms beyond NLO which amounts to 3%. The PDF uncertainty, estimated using CTEQ6.5, amounts to 1.5%. The value extracted at low Q^2, $\alpha_s(M_Z) = 0.1186\ \pm 0.0014\ (exp.)^{+0.0132}_{-0.0101}\ (th.) \pm 0.0021\ (PDF)$ is compatible with high Q^2, but the uncertainty arising from the renormalisation scales variation reach 10%. The measurement of the strong coupling in a large Q^2 range allows to test the $\alpha_s(Q)$ running between 2 and 100 GeV as shown on the Figure 3.

ZEUS Collaboration has determined α_s from the inclusive jet cross section in DIS. The analysis is based on the HERA-2 data sample corresponding to integrated luminosity of 188.3 pb^{-1}. In order to reduce the theory uncertainty on α_s, only the data at $Q^2 > 500$ GeV^2 are used in the fit, resulting to value of

$$\alpha_s(M_Z) = 0.1192 \pm 0.0009\ (stat.)^{+0.0035}_{-0.0032}\ (exp.)^{+0.0020}_{-0.0021}\ (th.).$$

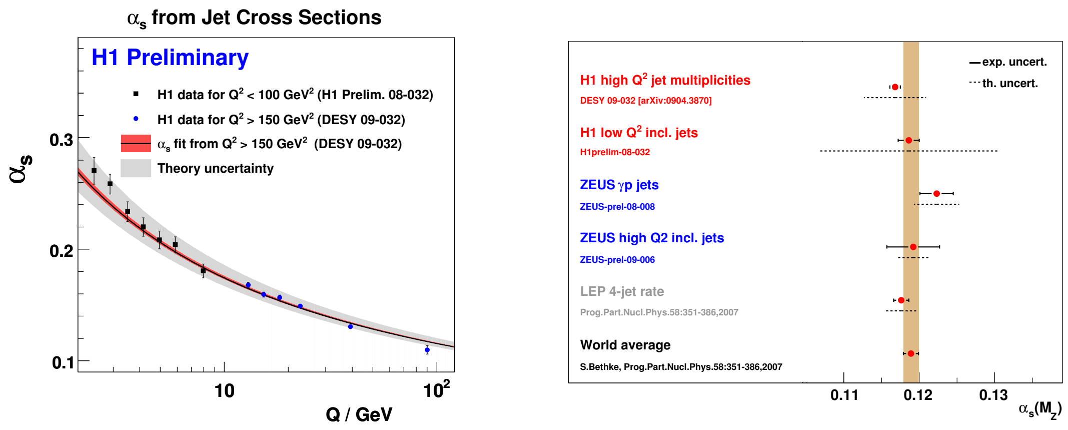

FIGURE 3. The running of $\alpha_s(Q)$ (left) and different recent determinations of $\alpha_s(M_Z)$ from HERA, compared with a LEP measurement and the world average (right).

CONCLUSIONS

Numerous measurements of jet production in DIS have been made over a wide kinematic range at HERA. In this overview only few recent results could be given. In general, the data are well described by NLO QCD predictions, and the small experimental uncertainty in the high Q^2 regime allows to extract values of α_s with high experimental precision, which is not yet matched by the theory error. The results for jets at HERA are precise and competitive with those from e^+e^- data [9] and are in good agreement with world averages [9, 10].

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