Precision Tests of QCD Using Final State Jets and Particles

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Abstract.
The data from the HERA experiments H1 and ZEUS allows a precise extraction of the strong coupling constant α_S with the highest experimental precision (sub 1%). A review of recent measurements of jet cross sections in neutral current deep inelastic scattering (NC DIS) at HERA is presented and compared with theoretical NLO QCD predictions. The latest determinations of α_S in a large range of Q^2 are shown.

1. Introduction

In $e^{\pm}p$ collisions at HERA, according to the virtuality Q^2 of the exchanged boson we distinguish two processes, DIS and photoproduction. In DIS process ($Q^2 > 1$ GeV^2) a highly virtual boson interacts with a parton carrying a momentum fraction of the proton. Among the spray of particles emerging from a high-energy reaction we can recognize collimated subsystems of hadrons, so called jets. Jets in DIS at HERA result from the scattered quark and from additional QCD radiation either in the initial or the final state. For quantitaive measurements we need to define jets using a jet algoritam which prescribes how to combine object (partons, hadrons, energy deposit, ..) close in phase space to jets. In the analyses presented here jets are defined using the k_T clustering algorithm applied in the Breit frame. The associated cross sections are collinear and infrared safe and therefore well suited for comparison with predictions from fixed order QCD calculations. Jet production in $e^{\pm}p$ 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, siginificant transverse momenta (E_T) are produced at leading order (LO) in α_S by the boson-gluon fusion and QCD Compton processes. In the pQCD, the jet cross section depends on the strong coupling constant α_S as the expansion parameter for the perturbation series and on the parton densities in the proton (PDFs). In regions where the PDFs are well constrained, the jet data allow a test of 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. This contribution presents the latest jet production studies made by the H1 and ZEUS Collaborations and the resulting determinations of α_S. Such determinations allow a stringent test of the running of α_S predicted by pQCD.

2. Jet Measurements in DIS

Jet measurements in DIS were recently performed by the H1 Collaboration in two kinematic regimes. The low Q^2 data [1] corresponding to $5 < Q^2 < 100$ GeV^2 use a HERA-I sample of 44 pb^{-1}, whereas the high Q^2 data [2], corresponding to $150 < Q^2 < 15000$ GeV^2, are based on nearly the full H1 data sample of about 400 pb^{-1}. The inclusive jet cross sections are measured in the low Q^2 regime by requiring $E_T > 5$ GeV and $-1.0 < \eta^{\rm Lab} < 2.5$. Comparison of inclusive jet cross sections, 2-jet cross sections and 3-jet cross sections for the low Q^2 regime with NLO QCD predictions are shown on Figure 1.

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 $-0.8 < \eta^{\rm Lab} < 2.0$. 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 a function of Q^2 are shown in Figure 2. One of the main sources of experimental uncertainties remains to be the uncertainty on the absolute calibration of the hadronic energy scale, which results in an uncertainty 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%. Differential inclusive-jet cross sections have been measured in NC DIS *ep* for boson virtuality $Q^2 > 125$ GeV^2 with ZEUS detector at HERA [3]. The measurement of the differential cross section and relative difference between the measurement and NLO QCD calculation are shown on Figure 3.

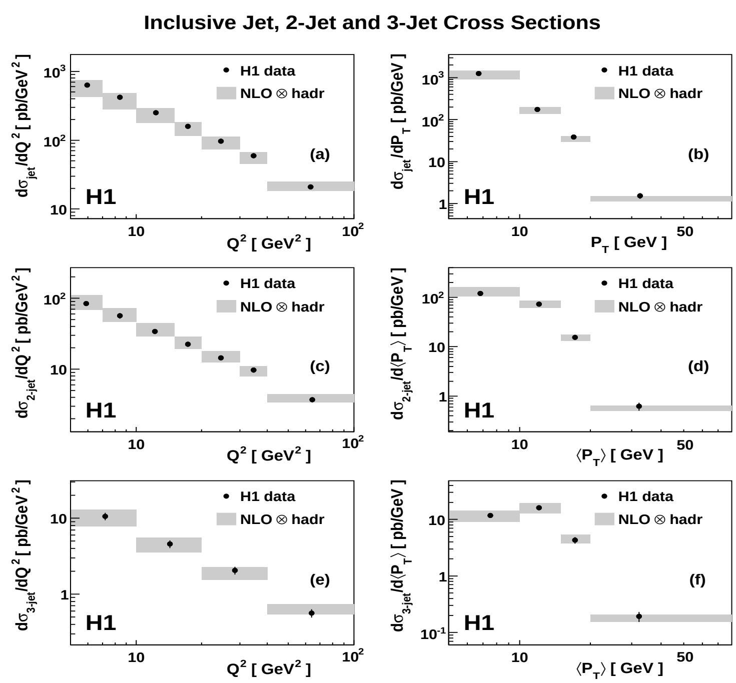

Figure 1. Inclusive jet cross sections $d\sigma_{jet}/dQ^2$ (a) and $d\sigma_{jet}/dP_T$ (b), 2-jet cross sections $d\sigma_{2-jet}/dQ^2$ (c) and $d\sigma_{2-jet}/d\langle P_T\rangle$ (d) and 3-jet cross sections $d\sigma_{3-jet}/dQ^2$ (e) and $d\sigma_{3-jet}/d\langle P_T\rangle$ (f), compared with NLO QCD predictions corrected for hadronisation. The error bars show the total experimental uncertainty, formed as the quadratic sum of the statistical and systematic uncertainties. The points are shown at the average values of Q^2, P_T or $\langle P_T\rangle$ within each bin. The NLO QCD predictions are shown together with the theoretical uncertainties associated with the scale uncertainties and the hadronisation (grey band).

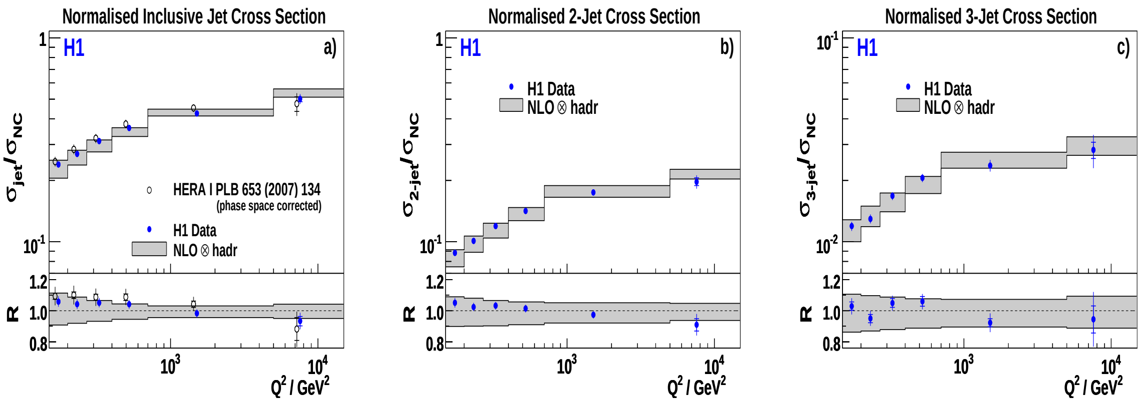

Figure 2. Normalised inclusive (a), 2-jet (b) and 3-jet (c) cross sections in NC DIS for high Q^2 regime, measured as a function of Q^2. The points are shown at the average value of Q^2 within each bin.

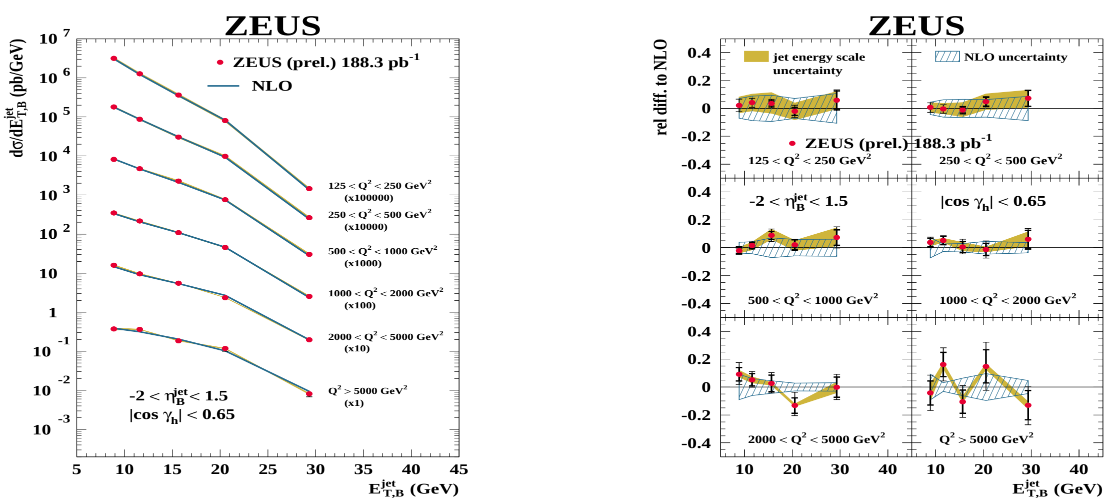

Figure 3. The measured differential cross-section $d\sigma/dE^{jet}_{T,B}$ for inclusive-jet production in different regions of Q^2 (left). The relative difference between the measured differential cross-sections $d\sigma/dE^{jet}_{T,B}$ and NLO QCD calculation (right).

The H1 jet cross sections at low and high Q^2 are used to extract α_S [1]. 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 measurement 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:

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

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, $\alpha_S(M_Z) = 0.1160\ \pm 0.0014\ (\text{exp.})^{+0.0093}_{-0.0077}\ (\text{th.}) \pm 0.0016\ (\text{PDF})$ is compatible with high the Q^2 value, but the uncertainty arising from the renormalisation scale variation reach 10%. The measurement of the strong coupling in a large Q^2 range allows to test the value $\alpha_S(\mu_r)$ where $\mu_r = \sqrt{(Q^2 + P^2_{T,pbs})/2}$ is renormalisation scale running between 6 and 70 GeV as shown in Figure 4.

The ZEUS Collaboration has determined α_S from the inclusive jet cross section in DIS. The analysis is based on the HERA-II data sample corresponding to an integrated luminosity of 188.3 pb^{-1}. In order to reduce the theory uncertainty on α_S [4], only the data at $Q^2 > 500 GeV^2$ are used in the fit, resulting to value of:

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

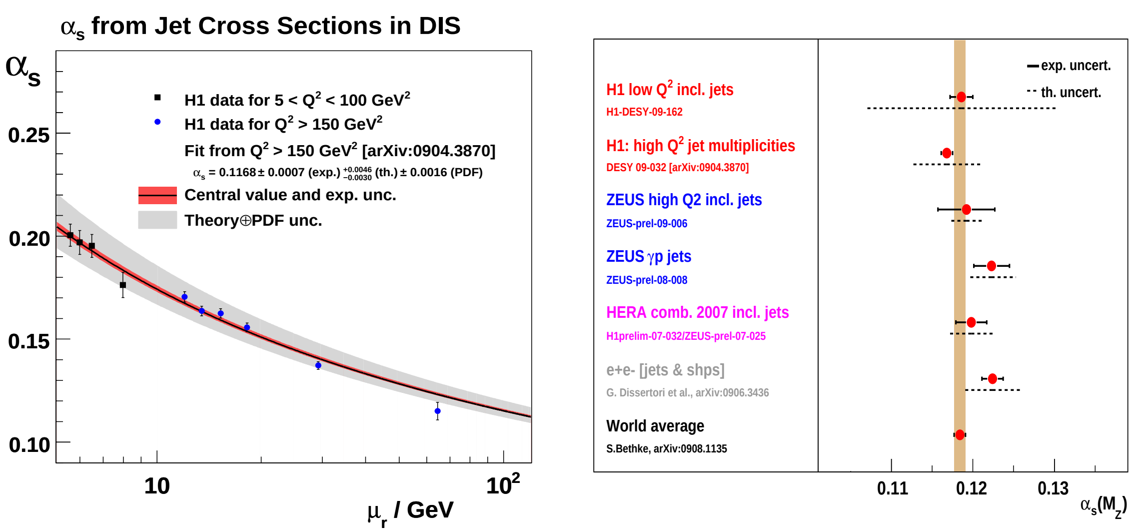

Figure 4. The running of $\alpha_S(Q)$ (left) and different recent determinations of $\alpha_S(M_Z)$ from HERA, compared with a LEP measurement and the world average (right).

3. Conclusions

Numerous measurements of jet production in DIS have been made over a wide kinematic range at HERA. In this overview only a 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 the exctraction of 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 [5] and are in good agreement with world averages [5, 6].

References

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