Measurement of inclusive jet cross-sections at low Q^2 at HERA[*]

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The single-inclusive cross-section for jet production in deep inelastic e-p scattering (DIS) at HERA is measured for photon virtualities Q^2 between 5 and 100 GeV^2, differentially in Q^2, in transverse jet energy E_T, in E_T^2/Q^2 and in pseudorapidity η_{LAB}. In most of the phase space these data are well described by QCD calculations in next-to-leading order (NLO) using a renormalization scale $\mu_R = E_T$. Significant discrepancies are observed only for jets in the proton beam direction with E_T below 20 GeV and Q^2 below 20 GeV^2.

Jet production in DIS is an ideal testing ground for perturbative QCD (pQCD). Experimental results on (multi) jet production at HERA and elsewhere cover a wide range of Q^2 and have been found to be well described by pQCD in next-to-leading order in the strong coupling constant α_S. The study of inclusive jet production, in particular, gives access to a bigger phase space, and avoids phase space regions where pQCD calculations are infrared sensitive. The data presented here close the gap of inclusive jet production at Q^2 below 100 GeV^2. For details on the experimental measurement and on the theory predictions see [1] and references therein.

Event Selection and Measured Observables

The present analysis is based on a total integrated luminosity of 21.1 pb^{-1} of e$^+$-p collision data collected with the H1 detector [2] in 96 and 97. DIS events are selected by requiring the presence in the electromagnetic calorimeter of an electron with $E > 10\,\mathrm{GeV}$ and with an angle above 156º with respect to the proton beam direction. The kinematic range is then defined by requiring a virtuality Q^2 between 5 and 100 GeV^2 and an inelasticity y between 0.2 and 0.6, as determined from the scattered electron.

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The jet search is performed in the Breit frame where the partons bounce off the virtual photon like from a "brick wall", if one assumes the naive quark parton model. In this frame — as in all reference systems where the γ^* and the proton collide head-on — the transverse parton energy can be considered to stem mainly from QCD radiation.

Jets are searched with the longitudinally invariant, inclusive k_t-algorithm, a clustering algorithm with a transverse-energy-weighted distance measure in the η-ϕ-plane. This algorithm has been demonstrated to be stable against infrared and collinear divergencies and has been extensively used in previous jet analyses at HERA.

For the inclusive cross-section all jets with transverse energy E_T in the Breit-frame above 5 GeV are considered. Furthermore, the pseudo-rapidity η_{LAB} of the jets (when Lorentz-transformed back to the laboratory frame) are required to lie between -1 and 2.8, where electromagnetic and hadronic energy measurement is excellent.

Two sources dominate the systematic error of the measured cross-sections. First, the two Monte-Carlo models used to correct the data for detector effects and QED radiation, RAPGAP and DJANGO/ARIADNE, differ by typically 5–10% in cross-section. Second, a 3% uncertainty in the energy scale of the hadronic liquid argon calorimeter leads to a typical error on the cross-sections of 10–15%.

Perturbative QCD predictions in NLO

The measured jet cross-sections are compared to pQCD predicitions at first (LO) and second (NLO) order in α_S. These calculations are performed using the DISENT program [3] and CTEQ5M/CTEQ5L parton distribution functions. Note that these calculations only take into account the direct photon contribution and neglect any virtual photon structure. The cross-sections have been found to be rather insensitive to even large variations of the factorization scale for which the momentum transfer Q has been used throughout.

Because the perturbation series is truncated, fixed order QCD calculations exhibit an explicit dependence on the renormalization scale μ_R. Among the two possible hard scales in DIS jet events, Q and jet transverse energy E_T, the latter has been mainly chosen for μ_R, but the alternate choice $\mu_R = Q$ has been studied as well (see below). In order to assess the sensitivity of the theory prediction to the value of the renormalization scale, μ_R has been raised (lowered) by a factor of 2 (0.5).
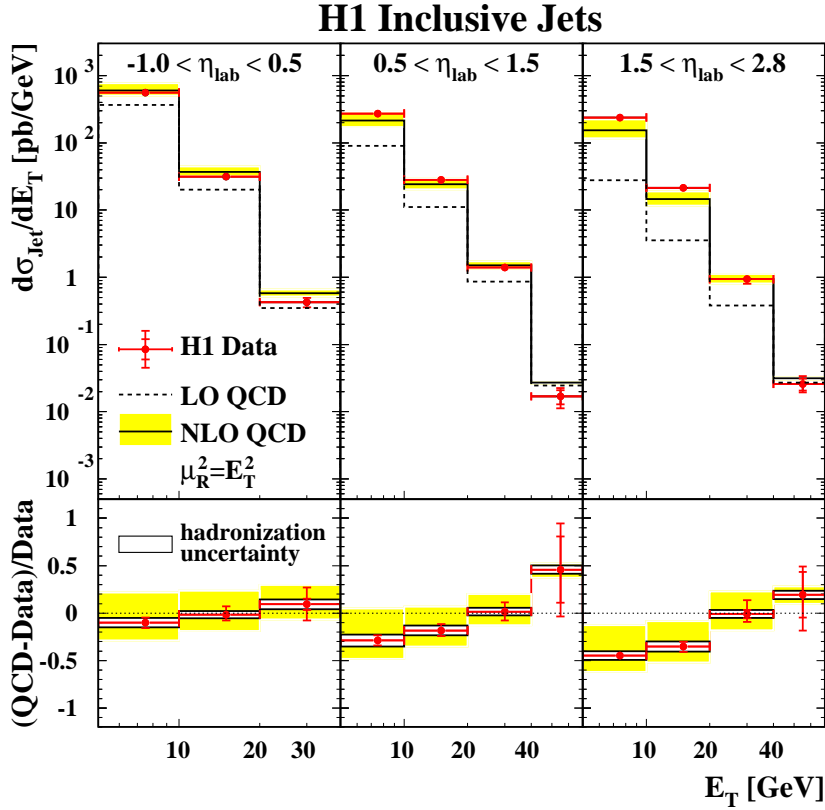
Figure 1: E_T dependence in backward, central, and forward regions

Furthermore, for a detailed comparison of the parton-level QCD calculations to the measured data a hadronization correction has been applied to the former. The Lund string model of hadronization together with two different models of soft gluon emission (CDM and ME+PS) are used. In the kinematic range under study here, hadronization is found to decrease the cross-section typically by 5–15%.

Experimental Results

In figure 1 the E_T-dependence of the inclusive jet cross-section is compared to QCD predictions in three ranges of pseudorapidity, here called backward ($-1.0 < \eta_{\mathrm{LAB}} < 0.5$), central ($0.5 < \eta_{\mathrm{LAB}} < 1.5$), and forward ($1.5 < \eta_{\mathrm{LAB}} < 2.8$). In the upper part of these (and all following plots) the data are com-
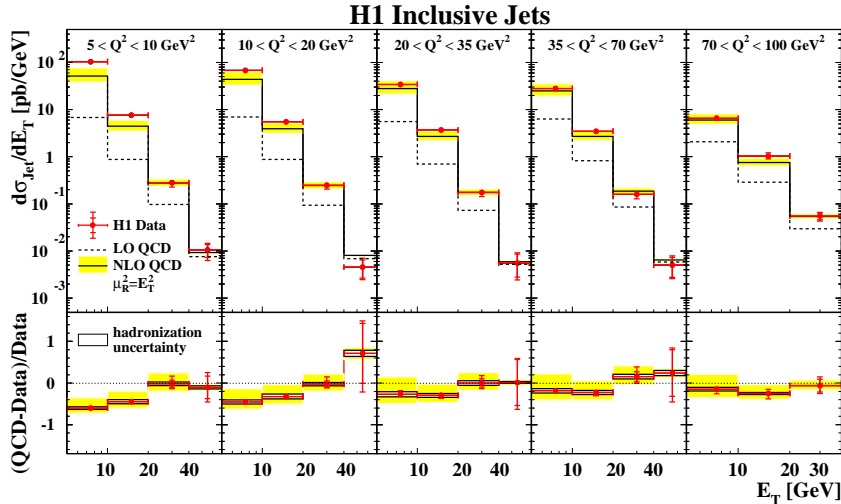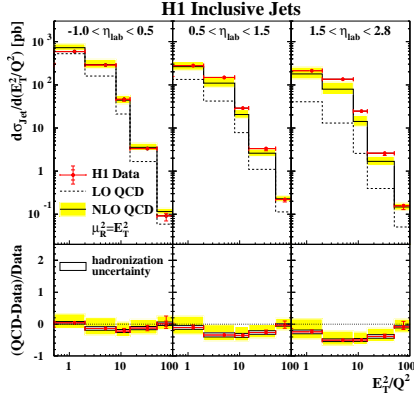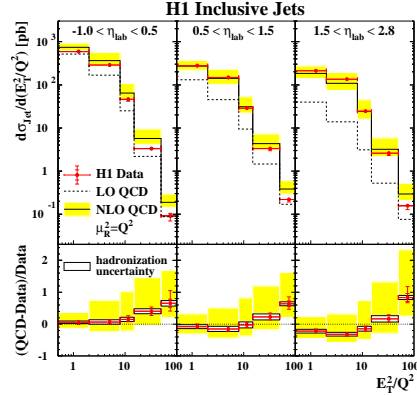
Figure 2: Q^2 dependence $\mathrm{d}\sigma_{\mathrm{Jet}}/\mathrm{d}E_T(E_T)$ in the forward region.

pared with LO and NLO QCD calculations at parton level, whereas in the lower part the relative difference between data and NLO QCD prediction after applying the hadronization correction is shown. The uncertainty of the NLO QCD prediction due to the variation of μ_R is indicated by a shaded band.

The remarkably good description of the experimental data by NLO QCD in the backward and central region is due to the substantial NLO/LO corrections. In the forward region where these are highest, however, the QCD prediction falls short of the data by about 40% for E_T below 20 GeV.

Figure 2 takes a closer look at the Q^2 dependence of $\mathrm{d}\sigma_{\mathrm{Jet}}/\mathrm{d}E_T$ in the forward region. For Q^2 above 20 GeV^2 the data are well described by the QCD prediction, again owing to the large NLO/LO corrections which reach up to a factor of 4. For $Q^2 < 20\,\mathrm{GeV}^2$, in contrast, the theoretical prediction falls short of the data by up to 50% for E_T below 20 GeV where NLO/LO corrections are largest.

In order to study the interplay of the two possible scales in DIS jet production, figure 3 shows the inclusive jet cross-section differentially in the scale ratio E_T^2/Q^2, in the three η_{LAB} ranges. Only the backward region is well described by NLO QCD, whereas in the central and forward region the theory prediction lies 30–50% below the measured data for $2 < E_T^2/Q^2 < 50\,\mathrm{GeV}^2$. This medium range of the scale ratio is dominated by small values of E_T^2 and Q^2.

Figure 3: $\mu_R = E_T$ Figure 4: $\mu_R = Q$

Inclusive jet cross-section measured differentially in the scale ratio E_T^2/Q^2 and comparison to pQCD calculations with two alternative choices of μ_R

So far, E_T has been used as the renormalization scale in the NLO calculation. Switching to $\mu_R = Q$ changes the situation as can be seen from figure 4. Here, the strongest discrepancies occur for very high values of the scale ratio, i.e. where Q^2 is small, irrespective of η_{LAB}. This suggests that Q^2 is not an appropriate choice for μ_R when E_T^2 is much higher than Q^2. It should be noted that this choice of μ_R strongly increases the scale uncertainties, making the QCD calculations less predictive.

Summary

The single-inclusive jet cross-section in DIS has been measured double differentially for Q^2 below 100 GeV^2 with the H1 detector at HERA. With E_T as the renormalization scale, the data are well described by NLO QCD calculations except when both Q^2 and E_T are relatively small. The correlation of large NLO/LO corrections and high sensitivity to μ_R variations with poor agreement between data and theory strongly suggests that the inclusion of higher order (e.g. NNLO) terms in the QCD calculations is necessary in order to describe the data.

References

[1] C. Adloff *et al.*, Phys. Lett. **B542** (2002) 193

[2] I. Abt *et al.*, Nucl. Instrum. Meth. **A386** (1997) 310

[3] S. Catani and M. H. Seymour, Nucl. Phys. **B 485** (1997) 291