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Jet production at HERA and determination of α_s with the H1 experiment

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Inclusive jet, dijet and trijet differential and double differential cross sections as a function of the virtuality Q^2 of the exchanged boson, the jet transverse momentum P_T as well as the incident parton momentum fraction ξ have been measured in neutral current deep-inelastic ep scattering with the H1 detector at HERA. Trijet to dijet cross section ratios have been measured as well, with significantly reduced uncertainties. The measurements are used to determine the value of the strong coupling $\alpha_s(M_Z)$.

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1. Multijet production in deep-inelastic scattering

In contrast to deep-inelastic scattering (DIS) the jet production in the Breit frame is already in leading order (LO) proportional to the strong coupling α_s through QCD Compton and boson-gluon fusion processes. Thus, it provides a good opportunity for an accurate determination of $\alpha_s(M_Z)$. The presented data were taken with the H1 detector at electron/positron and proton beam energies of 27.6 GeV and 920 GeV respectively. Two data samples were analysed: one covering the region of low virtuality of the exchanged boson, $5 < Q^2 < 100$ GeV^2 (low Q^2) [1], corresponding to an integrated luminosity of 43.5 pb^{-1}, and one with $150 < Q^2 < 15000$ GeV^2 (high Q^2) and corresponding to an integrated luminosity of 351.6 pb^{-1}. The inelasticity y of the interaction is

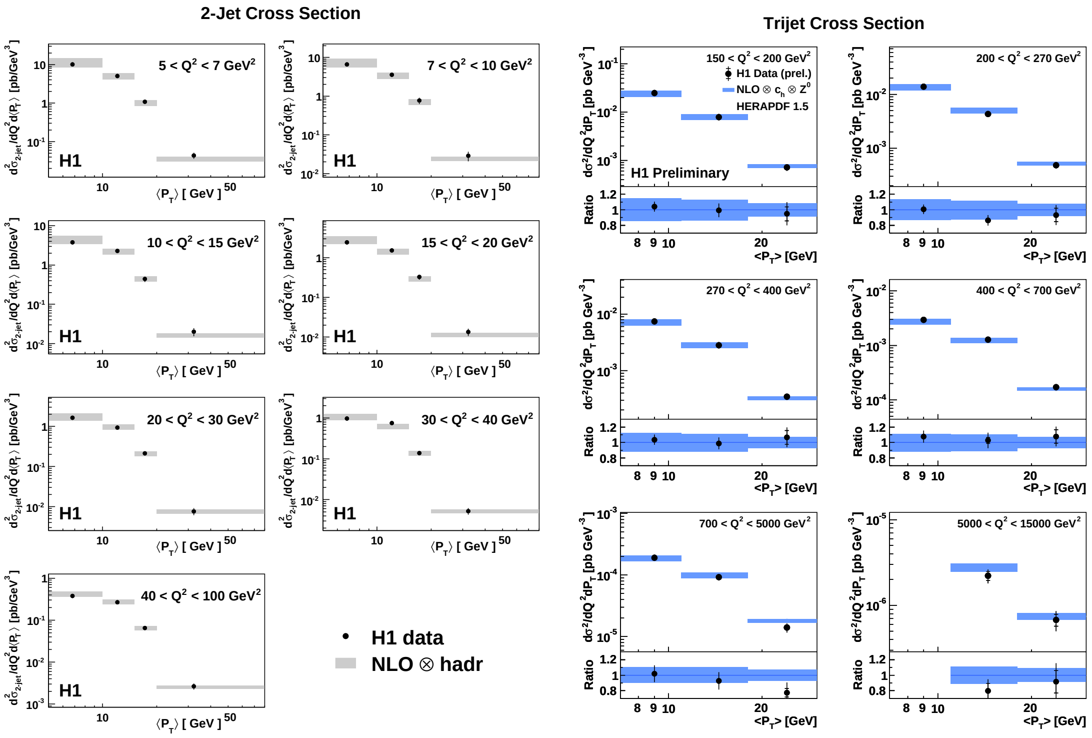

Figure 1: Double differential dijet (left) and trijet (right) cross sections as functions of Q^2 and $< P_T >$ compared with NLO QCD predictions corrected for hadronisation and Z boson exchange effects.

restricted to the range $0.2 < y < 0.7$. Jets with transverse momentum $P_T > 5$ GeV in the Breit frame are reconstructed with the inclusive k_t algorithm. Cuts on the jet pseudorapidity in the laboratory frame, $-1.0 < \eta_{\mathrm{Lab}} < 2.5$, are applied to ensure that the jets are well contained within the acceptance of the calorimeter. To ensure the reliability of the QCD predictions for the dijet and trijet sample [2] an additional cut on the invariant mass of the two leading jets $M_{12} > 16$ GeV (for high Q^2) and $M_{12} > 18$ GeV (for low Q^2) is applied. Measurements of the inclusive jet, dijet and trijet cross sections as well as the ratio of trijet to dijet cross sections are presented as a function of Q^2 and the jet transverse momenta P_T in the Breit frame, for inclusive jet, and the average transverse momentum of the two (three) leading jets $< P_T >$ in the Breit frame for dijets (trijets), and ξ. Experimental uncertainties are about 10% at low Q^2 and 6% at high Q^2 and dominated by the hadronic energy scale and model uncertainties. The dijet and trijet cross sections as a function of Q^2 and $< P_T >$ are presented in Fig. 1. The data are compared to NLO QCD [3] predictions, performed in the $\overline{\mathrm{MS}}$ scheme for five massless quark flavors. The parton level calculations are corrected for hadronisation and Z boson exchange effects at the highest Q^2 values. The PDFs of the proton are taken from the CTEQ6.5M set (for low Q^2) and from the HERAPDF1.5 set (for high Q^2) with $\alpha_s(M_Z) = 0.118$. The factorisation and renormalisation scales are chosen as $\mu_f = \mu_r = \sqrt{(Q^2+P_T^2)/2}$. To estimate the effects of higher orders, the scales μ_f and μ_r are varied independently by factors of $1/2$ and 2. Scale uncertainties up to about 10% for low Q^2 and 7% for high Q^2 are observed for the NLO predictions. They are the dominant theory uncertainties. The total theory uncertainties, which include also the hadronisation uncertainty are indicated in Fig. 1 as grey and blue bands. The data are well described by the theoretical prediction in the whole phase space. The theoretical uncertainties, which are dominated by possible effects from higher orders estimated by scale variations, exceed the total experimental uncertainties in almost all the bins.

2. Extraction of the strong coupling $\alpha_s(M_Z)$

Fits of the jet cross sections in bins of Q^2 and P_T to the NLO predictions are performed, in order to extract $\alpha_s(M_Z)$. The experimental uncertainties and their correlations are taken into account using the Hessian method [4]. The fits yield the following values for the strong couplings:

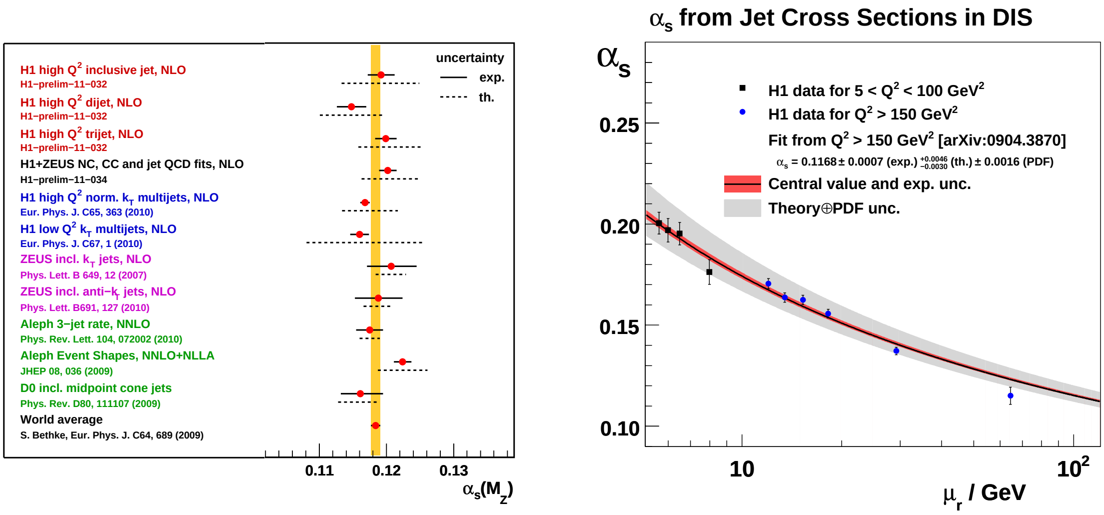

Figure 2: Values of $\alpha_s(M_Z)$ from jets and world average (left). Comparison of $\alpha_s(\mu_r)$ values obtained by a fit of low Q^2 (squares) and high Q^2 (circles) jet data to NLO QCD predictions.

$$\begin{array}{ll}
\text{low } Q^2\text{, multijets} & \alpha_s(M_Z) = 0.1160 \pm 0.0014(\mathrm{exp}) \pm 0.0016(\mathrm{pdf}), \\
\text{high } Q^2\text{, inclusive jet} & \alpha_s(M_Z) = 0.1190 \pm 0.0021(\mathrm{exp}) \pm 0.0020(\mathrm{pdf}), \\
\text{high } Q^2\text{, dijet} & \alpha_s(M_Z) = 0.1146 \pm 0.0022(\mathrm{exp}) \pm 0.0021(\mathrm{pdf}), \\
\text{high } Q^2\text{, trijet} & \alpha_s(M_Z) = 0.1196 \pm 0.0016(\mathrm{exp}) \pm 0.0010(\mathrm{pdf}).
\end{array}$$

The values of $\alpha_s(M_Z)$ agree with each other and with the world average as shown in Fig. 2 (left). The running of α_s as a function of the renormalisation scale as extracted from low Q^2 [1] and published high Q^2 [5] is displayed in Fig. 2, right. The $\alpha_s(M_Z)$ value and uncertainties from the high Q^2 extraction are used to extrapolate to the four points (squared) at low μ_r from the low Q^2

data, using the two-loop renormalisation group equation. The values and experimental uncertainties of α_s in the low Q^2 region are found to be in very good agreement with the QCD expectation. The total experimental uncertainties are considerably smaller than the theory uncertainties, hence setting a challenge for providing improved theoretical calculations.

3. Summary

Measurements of the inclusive jet, dijet and trijet cross sections as well as the ratio of trijet to dijet cross sections in the Breit frame in neutral current DIS at low Q^2 and high Q^2 are presented. NLO QCD calculations, corrected for hadronisation and Z boson exchange effects, provide a good description of the single and double differential cross sections as a function of the boson virtuality Q^2, the jet transverse momentum P_T as well as the parton momentum fraction ξ in the whole phase space. Fits of the jet cross sections in bins of Q^2 and P_T to the NLO predictions are performed. The value of $\alpha_s(M_Z)$, extracted from the trijet cross sections at high Q^2, shows the smallest uncertainties. All four extracted values of $\alpha_s(M_Z)$ agree with each other and with the world average, dominated by theoretical uncertainty.

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