FIRST STUDIES OF THREE-JET PRODUCTION IN DEEP-INELASTIC SCATTERING

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Three-jet production in deep-inelastic scattering is studied with the H1 detector at HERA over a large range of four-momentum transfers $5 < Q^2 < 5000\,\mathrm{GeV}^2$ and invariant three-jet masses $25 < M_{\mathrm{3jet}} < 140\,\mathrm{GeV}$. For the first time differential distributions of the three-jet cross section and angular distributions of the jets are used to test the predictions of perturbative QCD in next-to-leading order in α_s.

1 Introduction

Jet production at large transverse energies E_T in high energy particle collisions has been proven to be useful for studying the dynamics of the interaction between the particles and to gain insight into their inner structure. Studies of jet production in deep-inelastic lepton-proton scattering (DIS) have so far been limited to processes in which the final state of the reaction contains either one or two hadronic jets in addition to the scattered lepton and the remnant of the incident proton. The H1 collaboration has recently measured the inclusive jet and the dijet cross sections in DIS in the Breit frame to determine the strong coupling constant α_s and the gluon density in the proton [1]. All differential distributions of the inclusive jet and the dijet cross sections are well described by the predictions of perturbative QCD (pQCD) in next-to-leading order (NLO) in α_s and the results for $\alpha_s(M_Z)$ and the gluon density agree well with results from other processes. This demonstrates a very good understanding of hard processes in DIS in terms of pQCD at order $\mathcal{O}(\alpha_s)$.

How can this understanding can be extended to processes of higher orders in α_s? A natural observable to study hard processes in DIS beyond order $\mathcal{O}(\alpha_s)$ is the three-jet cross section for which only recently a NLO calculation has become available [2]. The three-jet cross section in DIS is already at leading order proportional to α_s^2 and therefore more sensitive to the value of $\alpha_s(M_Z)$ than the inclusive jet or the dijet cross sections. In addition, the larger number of degrees of freedom in the three-jet final state allows to test the pQCD predictions in greater detail. A new observable can be defined by the ratio $R_{3/2}$ of the three-jet and the dijet cross sections. While in $R_{3/2}$ some experimental and theoretical uncertainties cancel, it is still proportional to α_s and thus well suited for quantitative tests of QCD.

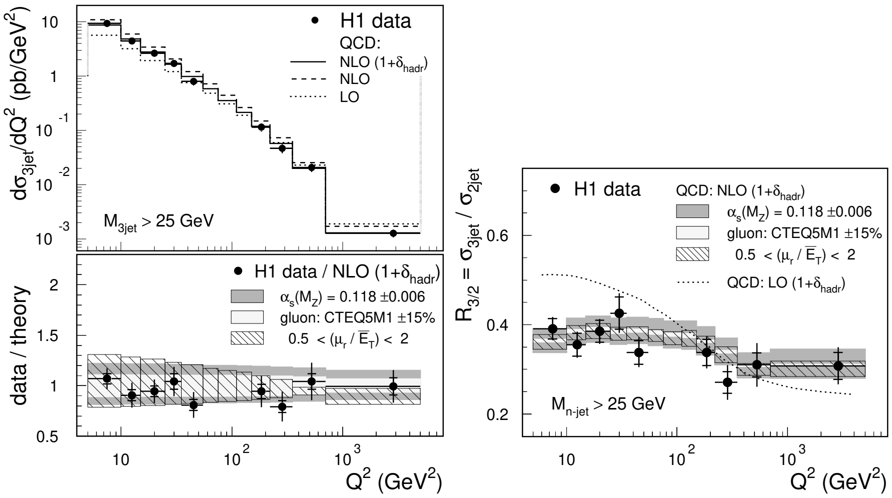

Figure 1. The three-jet cross section (left) and the ratio $R_{3/2}$ of the three-jet and the dijet cross sections (right), both measured as a function of Q^2.

2 Results

The measurement has been carried out using data collected in positron-proton collisions in the years 1995-1997 with the H1 detector at HERA at a center-of-mass energy $\sqrt{s} = 300\,\mathrm{GeV}$. The kinematic range of the analysis covers three orders of magnitude in the four-momentum transfer squared $5 < Q^2 < 5000\,\mathrm{GeV}^2$ and a range of $0.2 < y < 0.6$ in the inelasticity variable y. Jets are defined in the Breit frame by the inclusive $k_\perp$ algorithm [3]. The inclusive three-jet (dijet) event sample consists of all events with at least three (two) jets in the pseudorapidity range $-1 < \eta_{\mathrm{lab}} < 2.5$ with transverse energies in the Breit frame of $E_T > 5\,\mathrm{GeV}$ and an invariant mass of $M_{3\mathrm{j}}(M_{2\mathrm{j}}) > 25\,\mathrm{GeV}$ for the three (two) jets of highest E_T.

The three-jet cross section (Fig. 1, left) and the ratio $R_{3/2}$ of the three-jet and the dijet cross sections (Fig. 1, right) are measured as a function of Q^2 (further differential distributions can be found in ref. [4]). Over the whole range of Q^2 the data are well described by the predictions of pQCD in NLO using a recent parameterization of the proton's parton density functions (CTEQ5M1 [5]) and the world average value of $\alpha_s(M_Z) = 0.118$ [6] (hadronization corrections are applied to the NLO calculation as described in ref. [4]). The theoretical predictions for both distributions are only weakly affected

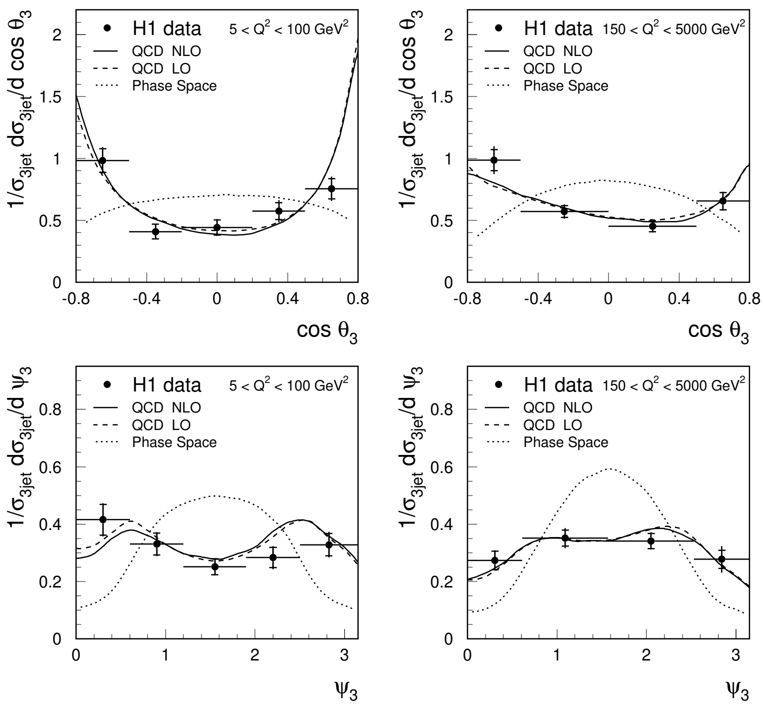

Figure 2. Normalized angular distributions of the three-jet events in the regions of low Q^2 (left) and high Q^2 (right).

by an overall change of the gluon density by $\pm 15\%$. A variation of $\alpha_s(M_Z)$ by ± 0.006, however, leads to large variations of the predictions which are larger than the renormalization scale dependence of the NLO calculation (except for $\sigma_{3\text{jet}}(Q^2)$ at low Q^2). The pQCD predictions describe the data only for values of $\alpha_s(M_Z)$ close to the world average while for variations of $\Delta\alpha_s(M_Z) = \pm 0.006$ the predictions are apparently not consistent with the present measurement.

A further test of the pQCD predictions is made, based on angular distributions of the three-jet system in its center-of-mass frame. Measured are the angle θ_3 of the highest energetic jet with respect to the proton beam direction and the angle ψ_3 between the plane spanned by the highest energy jet and the proton beam and the plane containing the three jets. The normalized angular distributions are displayed in Fig. 2 separately for the regions of low and high

Q^2 in comparison to the pQCD predictions in LO and in NLO. Also shown in the Figures is the underlying three-jet phase space which differs qualitatively from the pQCD curves. The latter exhibit the typical properties expected from the Bremsstrahlung nature of the process and give a good description of the measured distributions.

3 Summary and Outlook

The new measurements of the three-jet cross section, the ratio $R_{3/2}$ and angular jet distributions extend previous studies of jet production in deep-inelastic scattering to higher jet multiplicities. A recent NLO pQCD calculation describes the size of the three-jet cross section and its Q^2 dependence in the range $5 < Q^2 < 5000\,\mathrm{GeV}^2$ as well as the shapes of angular jet distributions. A comparison of the pQCD predictions with the three-jet cross section and the the ratio $R_{3/2}$ confirms the world average value of $\alpha_s(M_Z)$.

Due to limited statistics, this first detailed analysis of three-jet production in deep-inelastic scattering had to be carried out at relatively small transverse jet energies ($E_T > 5\,\mathrm{GeV}$) and small three-jet masses ($M_{3\mathrm{jet}} > 25\,\mathrm{GeV}$). In this kinematic region the three-jet cross section is still subject to hadronization corrections above 20%, as estimated by hadronization models matched to parton showers (and not to NLO). These large non-perturbative corrections (for which uncertainties can hardly be determined) limit any quantitative pQCD analysis, including a determination of α_s. The luminosity upgrade at HERA, however, will allow to measure the three-jet cross section at higher E_T and $M_{3\mathrm{jet}}$ where hadronization corrections are smaller and the perturbative predictions become more reliable. These data will offer good prospects for a precise determination of $\alpha_s(M_Z)$.

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