THREE-JET PRODUCTION IN DEEP-INELASTIC SCATTERING AND PHOTOPRODUCTION AT HERA

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The production of three-jet events has been measured in e-P scattering at HERA. These events are perfectly adapted for testing perturbative QCD and to look for new physics signals. The data of various measurements are compared to perturbative QCD calculations to order α_s^2.

1 Introduction

Events containing one or two jets have been studied at HERA in great detail by the H1 and ZEUS collaborations. This contribution summarizes some recent measurements of three-jet final states. The data contain events taken up to the year 1997 by colliding 27.5 GeV positrons on 820 GeV protons. Final states containing three or more jets provide an excellent testing ground of perturbative QCD. These events are also important as a possible background to various new physics signals. It is therefore important to compare the data with predictions of QCD and to search for deviations.
The hadronic three-jet cross section can be calculated in perturbative QCD according to the factorization theorem. The cross section can be written as the convolution of the partonic cross sections of pointlike particles with parton momentum distributions of the proton and the photon. For high virtualities of the exchanged photon, Q^2, only the pointlike γP interaction has to be taken into account. For low photon virtualities, resolved contributions have also to be considered. The partonic cross section can be expanded as a perturbative series in powers of α_s. For three-jet production only the leading-order term is available, which is of order α_s^2. Since next-to-leading order cross sections have not been calculated yet, the theoretical predictions lead to large renormalization and factorization-scale uncertainties.

In all recent analyses, jets are defined by the inclusive k_T jetalgorithm which is theoretically and experimentally preferred. The pseudorapidity region is matched to the angular coverage of the main calorimeters.

2 Comparison of data and QCD predictions

The H1 experiment has measured three-jet cross sections [1] in deep inelastic scattering from Q^2 of 5 GeV^2 up to 5000 GeV^2. Jets are defined in the Breit

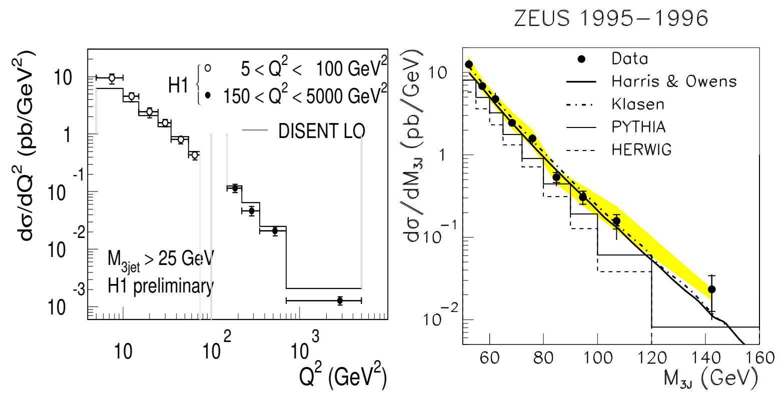

Figure 1: Three-jet cross sections for Q^2 between 5 and 5000 GeV^2 as a function of Q^2 (left). Three-jet cross sections in photoproduction as a function of the three-jet invariant mass (right).

frame, where the transverse momentum, E_T, of a jet has to fulfill $E_T > 5$ GeV. The data are shown in figure 1 (left plot) as circles and are compared with LO predictions calculated using DISENT [2] where the mean E_T of the jets has been chosen as renormalization and factorization scale. Hadronization corrections would lower the QCD calculations by 20-40 percent. When they are applied, leading-order QCD calculations describe the data for $Q^2 > 40\text{GeV}^2$. At lower Q^2, the result of the calculation is below the data.

Since three-jet events are preferentially produced in photoproduction, it is interesting to look at the invariant mass spectra of the three-jet system in this kinematic region. The ZEUS and H1 experiments have measured the three-jet cross section as a function of the invariant mass of all three jets.

The ZEUS analysis [3] defines jets by demanding $E_T > 6$ GeV for the two leading jets and $E_T > 5$ GeV for the third jet. The inelasticity y is required to be between 0.2 and 0.8. The data are shown in figure 1 (right plot) as points and are compared to LO perturbative QCD predictions by two groups [4] [5] which agree within 10 percent. The leading-order QCD predictions describe the data up to the highest masses. However, the uncertainty due to the choice of the renormalization and factorization scale is large (up to 100 percent [4]). The parton shower models PYTHIA and HERWIG describe the shape but fail in describing the normalization of the measured cross section.

In the H1 analysis [6] the three-jet invariant mass region is analyzed up to 180 GeV for the last bin center by increasing the upper y cut to 0.9 and by

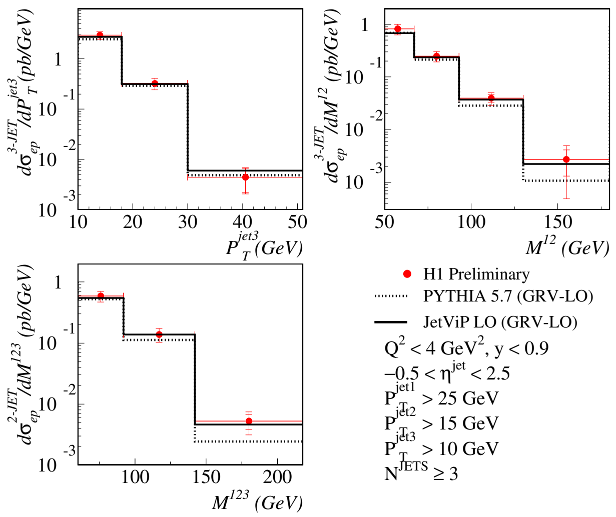

Figure 2: Cross sections for 3-jet production as function of the jet transverse momentum of the third highest jet P_T^{Jet3} (top left); as function of the invariant mass of the two leading jets M^{12} (top right) and as function of the invariant mass of all three jets M^{123} (lower left).

analyzing a higher integrated luminosity. The data are shown in figure 2 (lower left plot) and are compared to PYTHIA and LO perturbative QCD predictions using JetViP [7]. The E_T of the leading jet is chosen as renormalization and factorization scale. In addition, the cross section has been measured as a function of the E_T of the third jet (upper left plot) and as a function of the invariant mass of the two leading jets. All distributions are described by the QCD calculations up to masses of 180 GeV.

Topological variables defined in the three-jet CMS frame can also be used as a test of QCD predictions. Five variables fully characterize the three-jet properties for the process 1+2 $\rightarrow$ 3+4+5. The jets are numbered in order of decreasing energy, e.g. jet 3 is the most energetic.

ZEUS [3] has measured the two energy fractions $X_3 = \frac{2E_3}{M_{123}}$ and $X_4 = \frac{2E_4}{M_{123}}$ and two angles which specify the Jet orientation, $\cos\theta_3 = \frac{\vec{P_B}\vec{P_3}}{|\vec{P_B}||\vec{P_3}|}$ and $\cos\psi_3 = \frac{(\vec{P_3}\times\vec{P_B})(\vec{P_4}\times\vec{P_5})}{|\vec{P_3}\times\vec{P_B}||\vec{P_4}\times\vec{P_5}|}$. $\vec{P_B}$ is the momentum vector of the proton beam. θ_3 is sensitive to the orientation of the highest energetic jet and to the spin of the exchanged particle. ψ_3 and θ_3 are influenced by the orientation of the least energetic jet.

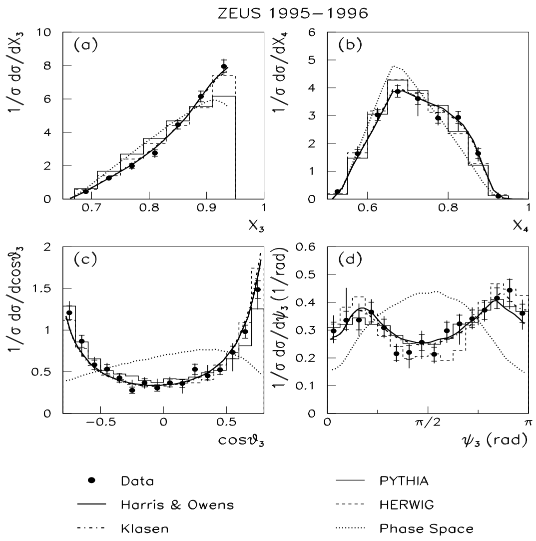

Figure 3: Area normalized distributions of a) X_3 , b) X_4 ,c) $\cos\theta_3$ and d) ψ_3.

The distributions are shown in figure 3 where the data are again compared with pQCD calculations by two groups and the QCD Monte Carlos PYTHIA and HERWIG. A pure phase space distribution is shown as a dotted line. The data show a clear sensitivity to QCD and the area normalized distributions are described by all models.

References

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