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Studies of dijet and trijet production in ep interactions at HERA

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Abstract. Measurements of dijet and trijet production in photoproduction, deep inelastic scattering and in the transition region between them, performed with the H1 and ZEUS detector at HERA are presented. The predictions of next-to-leading-order perturbative QCD are compared to the measured cross sections and found to be compatible with the data over a wide kinematic range.

PACS. 12.38.Qk Experimental test – 13.60.Hb Total and inclusive cross sections

1 Introduction

Jet production in ep collisons at HERA can be studied over a wide range of the photon virtuality, Q^2. Depending on the Q^2, and the transverse energy of the jet, E_T, three different regions can be distinguished: photoproduction with $E_T^2 >> Q^2 \sim 0$, low Q^2 transition region with $E_T^2 > Q^2 > 0$ and deep inelastic scattering (DIS) with $Q^2 >> m_p^2$. As the virtuality of the photon increases, the photon begins to lack the time to develop a complex hadronic structure.

At high E_T both experimental and theoretical uncertainties are small, this allows precise tests of perturbative QCD and further constraints of both existing proton and photon parton distribution functions (PDFs). Extensive dijet studies provide a rich laboratory background for multijet study, where some experimental and theoretical uncertainties are cancelled.

Dijet cross sections in photoproduction and DIS, as well as trijet cross sections in DIS have been measured with the H1 and ZEUS detector at HERA over the whole Q^2 spectrum. Next-to-leading-order(NLO) QCD calculations have been found to be compatible with the measurements.

2 Dijet production in photoproduction

In QCD, the photoproduction of dijets with high transverse energy can be split into direct and resolved processes. The calculation of the resolved processes can be approximated by ascribing parton densities to the photon, which depend on a factorization scale and x_γ, the longitudinal momentum fraction of the photon taken by the interacting parton. The limiting case of direct interactions is given by $x_\gamma = 1$. The H1 collaboration has measured

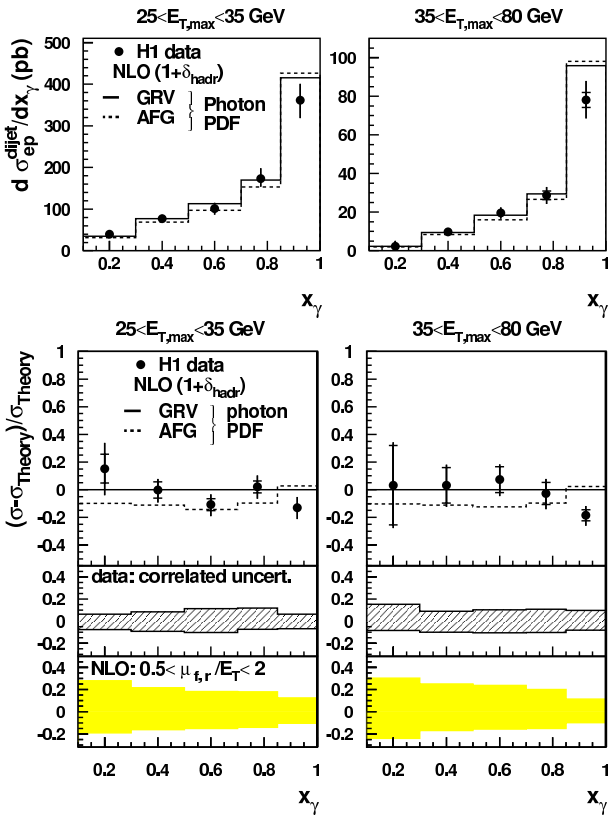

Fig. 1. Differential dijet cross section $d\sigma/dx_\gamma$ as a function of x_γ in different $E_{T,max}$ regions and using different photon PDFs. *Shallow bands* indicate NLO scale uncertainties

the dijet cross sections as a function of the invariant mass of the dijet system, $\overline{E_T}$ (mean E_T of the two highest energetic jets), and x_γ [1]. Figure 1 displays the differential cross sections $d\sigma/dx_\gamma$ as a function of x_γ for two regions of

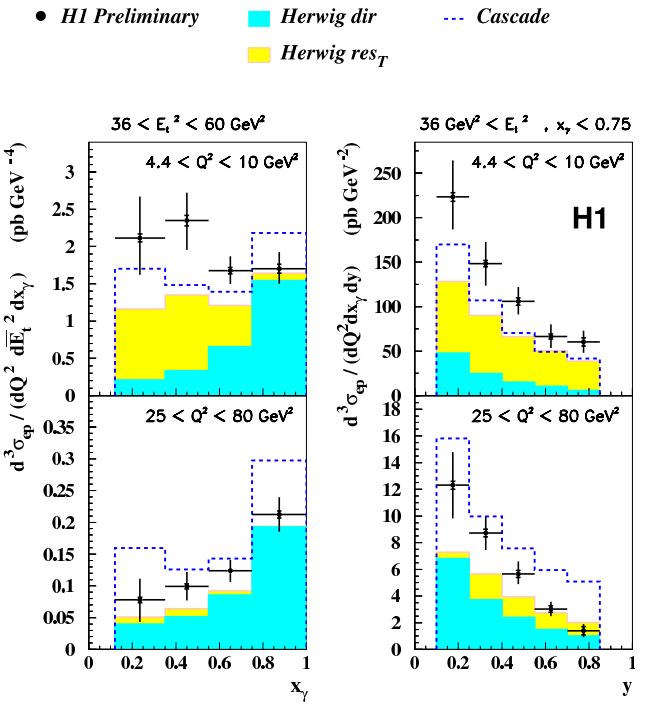

Fig. 2. Threefold differential dijet cross section $d\sigma^3/dQ^2 d\overline{E_T}^2 dx_\gamma$, for the H1 data depicted by *points* is compared to predictions of HERWIG [8] and CASCADE MC programs [7]

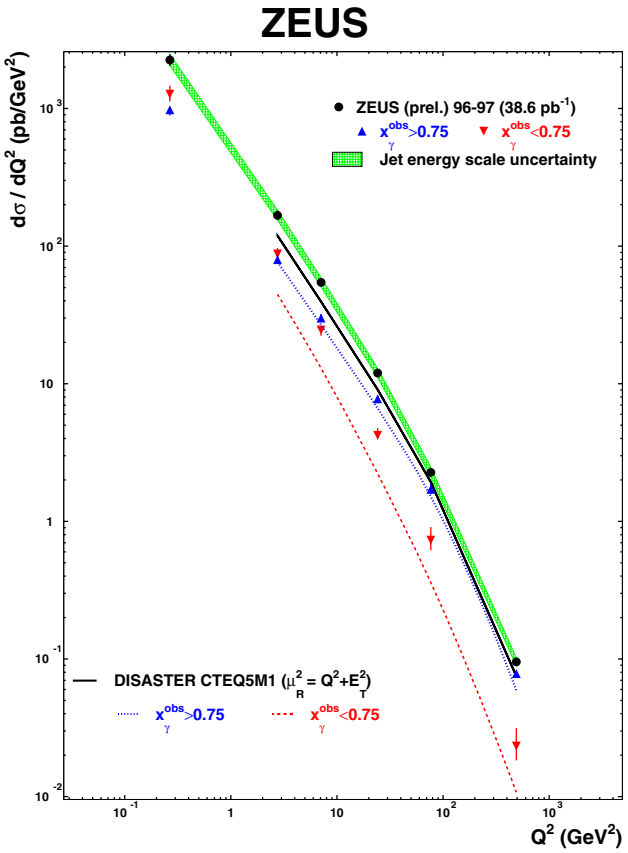

Fig. 3. Measured dijet cross sections $d\sigma/dQ^2$ for $x_\gamma^{obs} > 0.75$, $d\sigma/dQ^2$ for $x_\gamma^{obs} > 0.75$ and $d\sigma/dQ^2$ for whole x_γ^{obs} region, compared to the DISASTER++ calculations

the scale $E_{T,max}$. The NLO calculations [2] corrected for hadronization effects describe the data well within the uncertainties, which suggests a picture of a universal photon structure.

3 Dijet production in the low Q^2 transition region and in the DIS

There are three different theoretical approaches to explore the low Q^2 transition region: a) LO direct and resolved interactions based on the DGLAP evolution equations and parton showers allow the effects of transverally and longitudinally polarized resolved photon interactions to be studied [3,4]; b) QCD cascades based on the BFKL or CCFM evolution [5]; c) NLO calculations with and without concept of the resolved photon.

Figure 2 presents the dijet cross sections measured as a function of Q^2, $\overline{E_T}^2$, x_γ and y with the H1 detector [6]. LO MC programs HERWIG 5.9 [8] based on the DGLAP evolution scheme and CASCADE 1.0 [7] based on the CCFM evolution scheme are chosen for comparisons with the data. In the DGLAP evolution, the importance of γ_T^* resolved photon interaction is clearly demonstrated in the region where $\overline{E_T}^2 > Q^2$. In the CCFM scheme, CASCADE gives a qualitative description of the measured differential cross sections. A third approach has been investigated by studying hadronic structure of the virtual photon by means of dijet cross sections differential with respect to Q^2, E_T^{jet} and η^{jet} [9]. The x_γ^{obs} variable [10] is used to separate the two processes since resolved (direct) processes dominate at low (high) x_γ^{obs} values. Figure 3 shows precise measurements over a wide range of photon virtualities, including the transition region from photoproduction to DIS. The cross section for $x_\gamma^{obs} > 0.75$ is well described by the calculation. A possible explanation of the discrepancy at low x_γ^{obs} is the lack of hadronic photon structure in the DISASTER++ NLO [11] calculations.

4 Dijet and trijet production in DIS

Investigations requiring large inter-jet separations of the hadronic final state have shown that QCD is able to describe highly energetic dijet events [12,13]. The H1 Collaboration has tested the ability of the fixed order perturbative QCD to describe the hadronic final state in DIS even where jet separations are small [14].

Figure 4 presents the predictions of the DISENT NLO program [15] and LO MC program RAPGAP [16] compared with the dijet cross sections as a function of the jet separation variable y_2 [14]. The perturbative QCD preditions agree well with data when jet separations $y_2 > 0.001$.

Events with trijets can be seen as dijet processes with an additional gluon radiation or splitting of a gluon into a

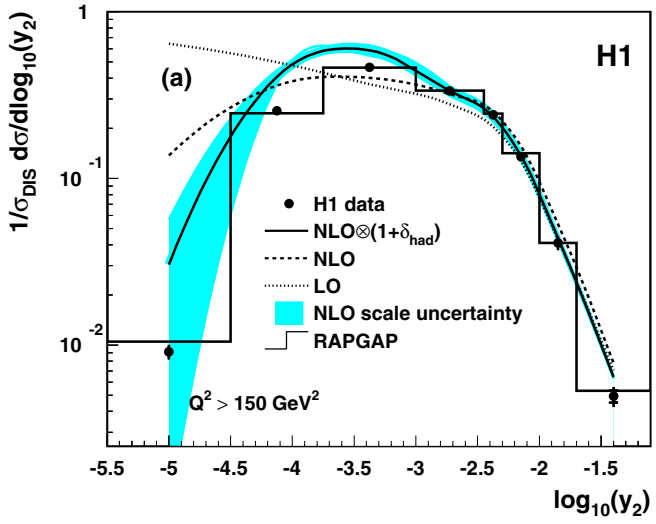

Fig. 4. Distribution of y_2, determined with modified Durham algorithm [17], compared to the perturbative calculations in LO, NLO and QCD model RAPGAP [16]

quark-antiquark pair, which are directly sensitive to $\mathcal{O}(\alpha_s^2)$ QCD effects. Recent ZEUS measurements have measured the inclusive dijet and trijet cross sections in neutral current DIS with high precision as a function of Q^2, E_T and η [18]. In Fig. 5, the upper plot presents that the predictions of NLO perturbative QCD describe both the dijet and trijet cross sections well over the whole range of Q^2; the lower plot presents that NLO perturbative QCD calculations also give a good description of trijet to dijet cross section ratio $R_{3/2}$ over the whole Q^2 range.

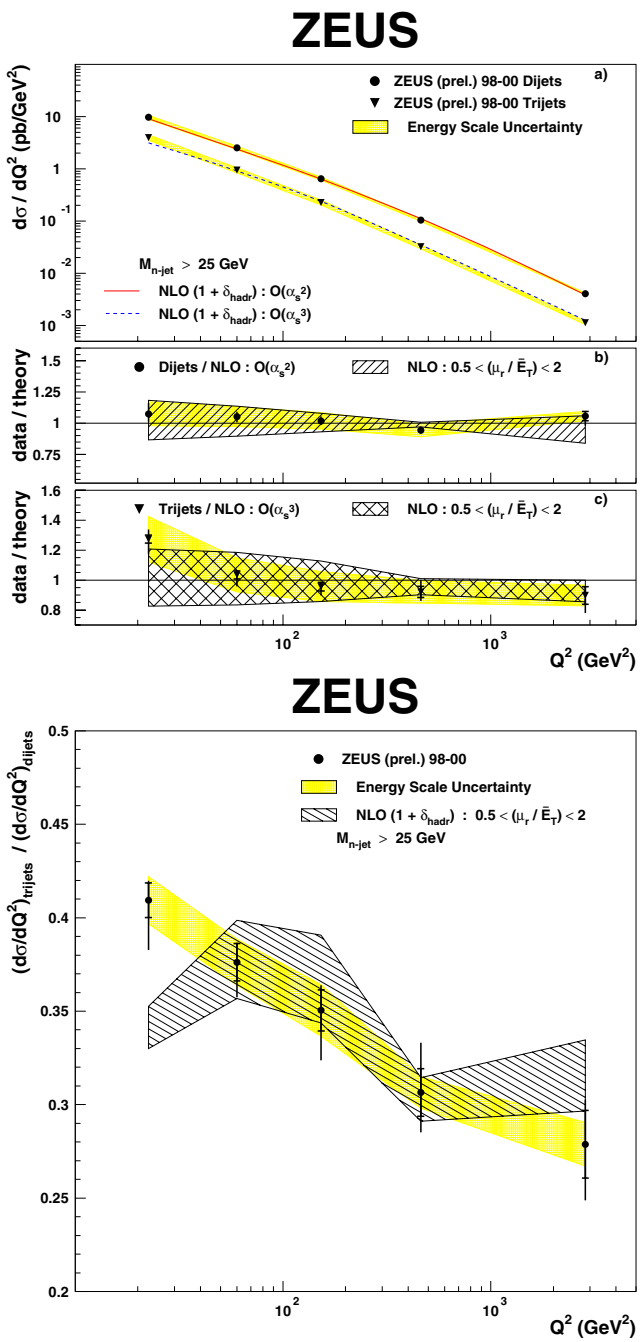

Fig. 5. The inclusive dijet and trijet cross sections as a function of Q^2 (*upper plot*). The ratios of inclusive trijet over dijet cross sections as a function of Q^2 (*lower plot*). The predictions of the next-to-leading order QCD calculation NLOJET [19] are compared to the data

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