Multijet Production at Low $x_{\rm Bj}$ in Deep Inelastic Scattering at HERA

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Inclusive dijet and trijet production in deep inelastic ep scattering has been measured at ZEUS with an integrated luminosity of 82 pb^{-1} for $10 < Q^2 < 100$ GeV^2 and low Bjorken x, $10^{-4} < x_{\rm Bj} < 10^{-2}$. Measurements of dijet and trijet differential cross sections are presented as functions of Q^2, $x_{\rm Bj}$, jet transverse energy, and jet pseudorapidity. Also presented are correlations in transverse momenta, azimuthal angles, and pseudorapidity. Calculations at $\mathcal{O}(\alpha_s^3)$ generally describe the trijet data well and improve the description of the dijet data compared to the calculation at $\mathcal{O}(\alpha_s^2)$.

1 Introduction

Multijet production in DIS is an ideal environment for investigating different approaches to parton dynamics at low Bjorken-x, $x_{\rm Bj}$. An understanding of this regime is of particular relevance in view of the startup of the LHC, where many of the Standard Model processes such as the production of electroweak gauge bosons or the Higgs particle involve the collision of partons with a low fraction of the proton momentum.

In the usual collinear QCD factorisation approach, the cross sections are obtained as the convolution of perturbative matrix elements and parton densities evolved according to the DGLAP evolution equations. In these equations, all orders proportional to $\alpha_s \ln Q^2$ and the double logarithms $\ln Q^2 \cdot \ln 1/x$, where x is the fraction of the proton momentum carried by a parton, which is equal to $x_{\rm Bj}$ in the quark-parton model, are resummed. In the DGLAP approach, the parton participating in the hard scattering is the result of a partonic cascade ordered in transverse momentum, p_T. The partonic cascade starts from a low-p_T and high-x parton from the incoming proton and ends up, after consecutive branching, in the high-p_T and low-x parton entering in the hard scattering. At low $x_{\rm Bj}$, where the phase space for parton emissions increases, terms proportional to $\alpha_s \ln 1/x$ may become large and spoil the accuracy of the DGLAP approach. In this region the transverse momenta and angular correlations between partons produced in the hard scatter may be sensitive to effects beyond DGLAP dynamics. The information about cross sections, transverse energy, E_T, and angular correlations between the two leading jets in multijet production therefore provides an important testing ground for studying the parton dynamics in the region of small $x_{\rm Bj}$.

In the ZEUS analysis presented, correlations for both azimuthal angles and pseudorapidity, and correlations in jet transverse energy and momenta for dijet and trijet production in the hadronic ($\gamma^* p$) centre-of-mass (HCM) frame are measured with high statistical precision in the kinematic region restricted to $10 < Q^2 < 100$ GeV^2 and $10^{-4} < x_{\rm Bj} < 10^{-2}$ [2]. The results are compared with DGLAP-based pQCD calculations from the NLOJET [3] program at next-to-leading order (NLO).

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2 Single-differential cross sections $d\sigma/dQ^2$, $d\sigma/dx_{\rm Bj}$, $d\sigma/d|\Delta\eta^{\rm jet1,2}_{\rm HCM}$ and trijet to dijet cross section ratios

The single-differential cross-sections $d\sigma/dx_{\rm Bj}$ for dijet and trijet production and the ratio $\sigma_{\rm trijet}/\sigma_{\rm dijet}$ of the trijet cross section to the dijet cross section, as a function $x_{\rm Bj}$ are presented in Fig. 1. The ratio $\sigma_{\rm trijet}/\sigma_{\rm dijet}$ falls steeply with increasing $x_{\rm Bj}$, as shown in Fig. 1. In the cross-section ratios, the experimental and theoretical uncertainties partially cancel, providing a possibility to test the pQCD calculations more precisely than can be done with the individual cross sections. Both the cross sections and the cross-section ratios are well described by the NLOJET calculations, especially at low $x_{\rm Bj}$. The correlations in jet pseudorapidity were examined by measuring $d\sigma/d|\Delta\eta^{\rm jet1,2}_{\rm HCM}|$, where $|\Delta\eta^{\rm jet1,2}_{\rm HCM}|$ is the absolute difference in pseudorapidity of the two jets with highest $E^{\rm jet}_{T,\rm HCM}$. The NLOJET predictions describe the measurements well.

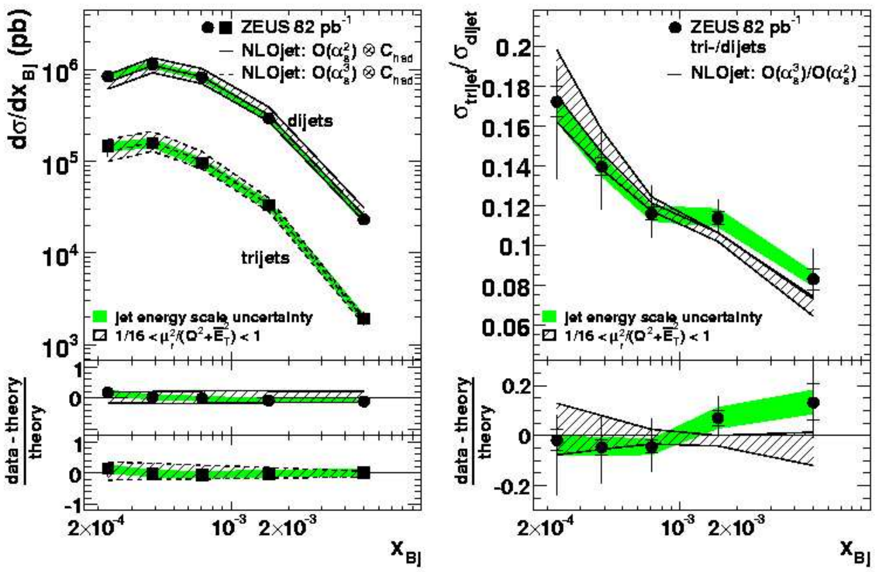

Figure 1: Dijet and trijet cross sections, and the ratio $\sigma_{trijet}/\sigma_{dijet}$, as a function of $x_{\rm Bj}$ compared to predictions from NLOJET.

3 Jet momentum correlations

In addition to correlations in jet pseudorapidity ($|\Delta\eta^{\rm jet1,2}_{\rm HCM}|$), correlations of the jet tranverse momenta have also been investigated. The correlations in jet transverse momenta were examined by measuring two sets of double-differential cross sections: $d^2\sigma/dx_{\rm Bj}d|\Sigma\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|$ and $d^2\sigma/dx_{\rm Bj}d(|\Delta\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|/(2E^{\rm jet1}_{T,\rm HCM}))$. The variable $|\Sigma\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|$ is the transverse component of the vector sum of the jet momenta of the two jets with the highest $E^{\rm jet}_{T,\rm HCM}$. For events with only two jets $|\Sigma\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}| = 0$, and additional QCD radiation increases this value. The variable $|\Delta\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|/(2E^{\rm jet1}_{T,\rm HCM})$ is the magnitude of the vector difference of the transverse momenta of the two jets with the highest $E^{\rm jet}_{T,\rm HCM}$ scaled by twice the transverse energy of the hardest jet. For events with only two jets $|\Delta\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|/(2E^{\rm jet1}_{T,\rm HCM}) = 1$, and additional QCD radiation decreases this value. Figure 2 shows the cross-sections $d^2\sigma/dx_{\rm Bj}d|\Sigma\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|$ in bins of $x_{\rm Bj}$ for the dijet sample.

At low $x_{\rm Bj}$, the NLOJET calculations at $\mathcal{O}(\alpha_s^2)$ underestimate the dijet cross sections at high values of $|\Sigma\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|$ and low values of $|\Delta\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|/(2E^{\rm jet1}_{T,\rm HCM})$. The description of the data by the NLOJET calculations at $\mathcal{O}(\alpha_s^2)$ improves at higher values of $x_{\rm Bj}$. A higher-order calculation with NLOJET at $\mathcal{O}(\alpha_s^3)$ for the dijet sample has been obtained for the region $|\Sigma\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}| > 4$ GeV, which is compared to the data in Fig. 2; and for the region $|\Delta\vec{p}^{\,\rm jet1,2}_{T,\rm HCM}|/(2E^{\rm jet1}_{T,\rm HCM}) < 0.85$. With the inclusion of the next term in the perturbative series in α_s, the NLOJET calculations describe the data well. The NLOJET calculations at $\mathcal{O}(\alpha_s^3)$ for trijet production are consistent with the measurements.

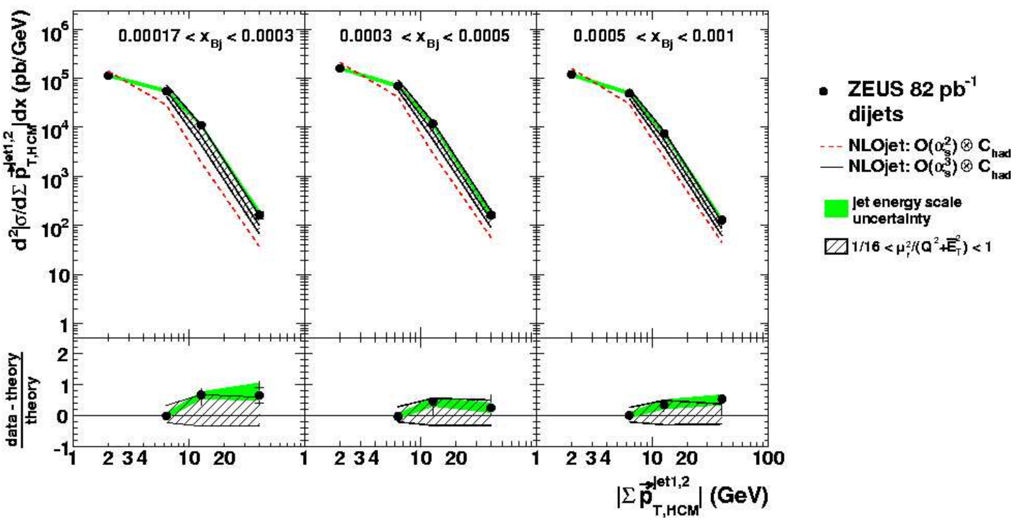

Figure 2: Dijet cross sections as a function of $|\Sigma p^{\rm jet1,2}_{T,\rm HCM}|$ compared to predictions from NLOJET at $\mathcal{O}(\alpha_s)^2$ and $\mathcal{O}(\alpha_s)^3$.

4 Azimuthal distributions of the jets

Measurements of the double-differential cross-section $d^2\sigma/dx_{\rm Bj}d|\Delta\phi^{\rm jet1,2}_{\rm HCM}|$, where $|\Delta\phi^{\rm jet1,2}_{\rm HCM}|$ is the azimuthal separation of the two jets with the largest $E^{\rm jet}_{T,\rm HCM}$, were measured for dijet and trijet production in all bins of $x_{\rm Bj}$. For both dijet and trijet production the cross section falls with $|\Delta\phi^{\rm jet1,2}_{\rm HCM}|$. The NLOJET calculations at $\mathcal{O}(\alpha_S^2)$ for dijet production decrease more rapidly with $|\Delta\phi^{\rm jet1,2}_{\rm HCM}|$ than the data and the calculations disagree with the data at low $|\Delta\phi^{\rm jet1,2}_{\rm HCM}|$. A higher-order NLOJET calculation at $\mathcal{O}(\alpha_S^3)$ for the dijet sample has been obtained for the region $|\Delta\phi^{\rm jet1,2}_{\rm HCM}| < 3\pi/4$ and describes the data well. The measurements for trijet production are reasonably well described by the NLOJET calculations at $\mathcal{O}(\alpha_S^3)$, with the description improving somewhat at higher $x_{\rm Bj}$.

A further investigation into the azimuthal correlations has been performed by measuring the cross-section $d^2\sigma/dQ^2dx_{\rm Bj}$ for dijet (trijet) events with $|\Delta\phi^{\rm jet1,2}_{\rm HCM}| < 2\pi/3$ as a function of $x_{\rm Bj}$. For the two-jet final states, the presence of two leading jets with $|\Delta\phi^{\rm jet1,2}_{\rm HCM}| < 2\pi/3$ can indicate another high-E_T jet or set of high-E_T jets outside the measured η range. One of these measured cross sections is presented in Fig. 3. The NLOJET calculations at $\mathcal{O}(\alpha_S^2)$ for dijet production underestimate the data, the difference increasing towards low $x_{\rm Bj}$. The NLOJET calculations at $\mathcal{O}(\alpha_S^3)$ are up to about one order of magnitude larger than the $\mathcal{O}(\alpha_S^2)$ calculations and are consistent with the data, demonstrating the importance of the higher-order terms in the description of the data especially at low $x_{\rm Bj}$. The NLOJET calculations at $\mathcal{O}(\alpha_S^3)$ describe the trijet data within the renormalisation-scale uncertainties.

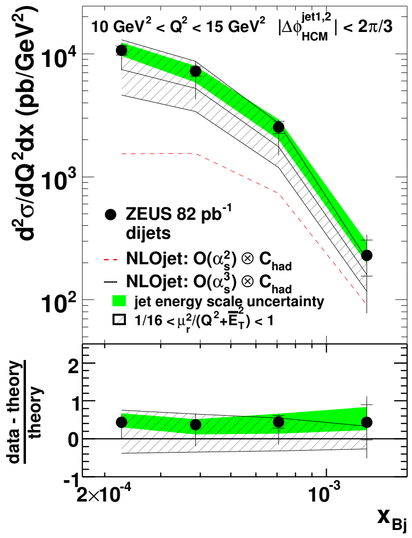

Figure 3: Dijet cross sections in $x_{\rm Bj}$ and Q^2 as a function of $x_{\rm Bj}$ with $\Delta\phi^{\rm jet1,2}_{HCM} < 120°$

5 Summary

Multijet production in deep inelastic *ep* scattering has been measured in the phase space region $10 < Q^2 < 100$ GeV^2 and $10^{-4} < x_{\rm Bj} < 10^{-2}$ using an integrated luminosity of 82 pb^{-1} collected by the ZEUS experiment. The high statistics have made possible detailed studies of multijet production at low $x_{\rm Bj}$. The dependence of dijet and trijet production on the kinematic variables Q^2 and $x_{\rm Bj}$ and on the jet variables $E^{\rm jet}_{T,\rm HCM}$ and $\eta^{\rm jet}_{\rm LAB}$ is well described by perturbative QCD calculations which include NLO corrections. At low $x_{\rm Bj}$, measurements of dijet production with low azimuthal separation are reproduced by the perturbative QCD calculations provided that higher-order terms ($\mathcal{O}(\alpha_s^3)$) are accounted for. Such terms increase the predictions of pQCD calculations by up to one order of magnitude when the two jets with the highest $E^{\rm jet1,2}_{T,\rm HCM}$ are not balanced in transverse momentum. This demonstrates the importance of higher-order corrections in the low-$x_{\rm Bj}$ region.

References

[1] Slides:
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