Progress in the Understanding of Dijet Production in DIS

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Recent results on dijet production in deep-inelastic scattering from the H1 experiment at the ep-collider HERA are presented. Internal jet structure has been studied in terms of jet shapes and subjet multiplicities in the Breit frame. Both observables are seen to be well described by QCD models. We observe a broadening of the jets towards the proton direction and at lower transverse jet energies. Dijet rates and dijet cross sections have been measured over a wide range of four momentum transfers ($5 < Q^2 < 5000$ GeV^2) and transverse jet energies ($25 < E^2_{t,\mathrm{Breit}} \lesssim 1200$ GeV^2) with different jet algorithms. Perturbative QCD calculations in next-to-leading order in the strong coupling constant give a good description of the data.

1 Introduction

The production of jets with high transverse energies in the Breit frame in deep-inelastic scattering is directly sensitive to the dynamics of the strong interaction. Perturbative calculations in next-to-leading order in the strong coupling constant are expected to be able to describe this process. In this contribution we present various measurements of dijet production in deep-inelastic scattering. We report on extensions of measurements of dijet rates shown at the previous DIS workshop [1] in a slightly modified phase space. We have also performed new measurements of dijet cross sections at higher transverse jet energies in the Breit frame with different jet algorithms. Jet shapes and subjet multiplicities in dijet production in the Breit frame are used to study the internal structure of jets. All measurements presented here have been corrected for detector effects (corresponding to the level of stable hadrons).

2 Internal Jet Structure

The understanding of the internal structure of jets is an important prerequisite for the understanding of the production rates of jets. Furthermore it also allows a deeper insight into the mechanism of how hard partons evolve into jets of hadrons. In the present analysis we have studied two observables using cone and k_t jet algorithms: subjet multiplicities and jet shapes.

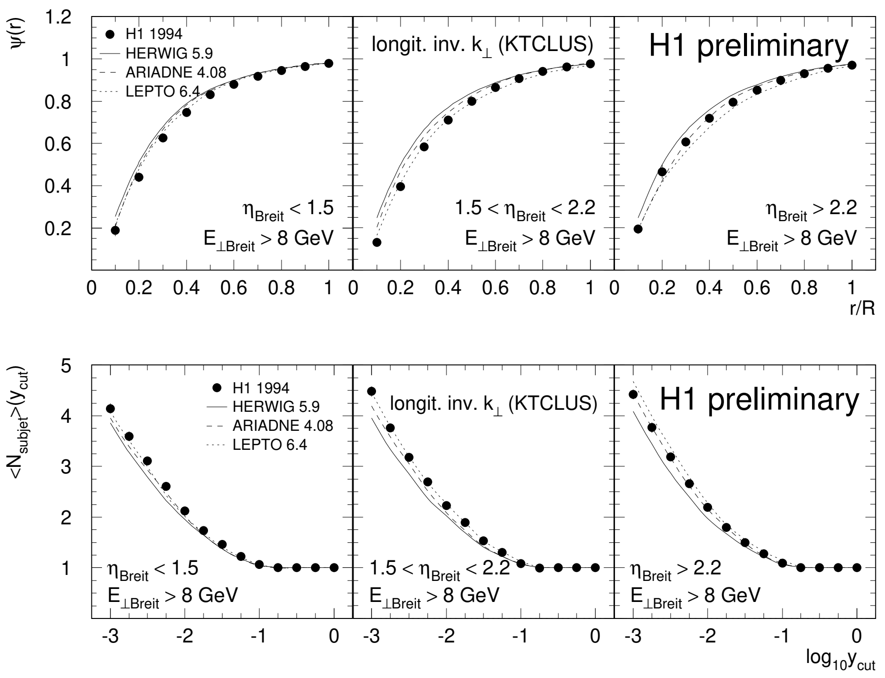

Figure 1: Observables of internal jet structure for the k_t cluster algorithm as a function of the jet pseudorapidity in the Breit frame for jets with transverse energies of $E_{t,\text{jet, Breit}} > 8\,\text{GeV}$. Jet shapes (top) as a function of the radius r relative to the jet radius R and subjet multiplicities (bottom) as a function of the resolution parameter y_{cut} (as explained in the text) are compared to the prediction of QCD models. Positive pseudorapidities are towards the proton direction.

The jet shape $\psi(r)$ is defined as the average fractional transverse energy of the jet inside a subcone of radius r concentric around the jet axis. Only particles assigned to the jet are considered [2]. The measurements have been performed using a k_t [3] and a cone [4] jet algorithm.

Subjet multiplicities are a natural way of studying internal jet structure for clustering algorithms. The clustering procedure is repeated for all particles assigned to a given jet. The clustering is stopped when the distances d_{ij} between all particles i, j are above some cutoff y_{cut}

$$d_{ij} \;=\; \min(E_{t,i}^2, E_{t,j}^2)\,/\,E_{t,\text{jet}}^2 \;\cdot\; (\Delta\eta_{ij}^2 + \Delta\varphi_{ij}^2) \;>\; y_{\text{cut}}\;.$$

The remaining (pseudo-)particles are called subjets. The observable studied in this analysis is the average number of subjets at a given value of $y_{\rm cut}$ in the range $10^{-3} \leq y_{\rm cut} \leq 1$ for the k_t algorithm.

The measurements have been performed in a region of four momentum transfers $10 < Q^2 \lesssim 120\,{\rm GeV}^2$ and values of the inelasticity variable of $0.15 < y < 0.6$. The jet algorithms are applied in the Breit frame. Events with at least two jets with transverse energies of $E_{t,{\rm jet,Breit}} > 5\,{\rm GeV}$ inside the pseudorapidity region in the laboratory frame $-1 < \eta_{\rm lab} < 2$ are selected.

Both the jet shapes and the average number of subjets are presented as a function of the transverse energy $E_{t,{\rm jet,Breit}}$ and the pseudorapidity $\eta_{\rm jet,Breit}$ of the jets in the Breit frame[a]. The results for the k_t and for the cone algorithm are well described by QCD models (in Fig. 1 we show some results for the k_t algorithm; see also [5]). We observe a dependence of the jet broadness and the average number of subjets on the transverse energy and the pseudorapidity of the jets in the Breit frame. With increasing transverse jet energies and decreasing pseudorapidities the jets are more collimated. Furthermore the jets defined by the k_t algorithm turn out to be narrower than jets defined by the cone algorithm.

3 Dijet Rates

At the previous DIS workshop we have presented measurements of dijet rates [1] (i.e. the fraction of dijet events in all DIS events) for a cone algorithm at four momentum transfers $5 < Q^2 < 100\,{\rm GeV}^2$ and transverse jet energies $E_{t,{\rm jet,Breit}} > 5\,{\rm GeV}$. The predictions of next-to-leading order (NLO) calculations [6] were significantly lower (up to factors of 0.5) than the data.

In the meantime it has been argued [7] that the phase space chosen in that analysis contained infrared sensitive regions where fixed order calculations are not predictive. This mainly concerns the selection cut on the transverse jet energies $E_{t,{\rm min,Breit}} = 5\,{\rm GeV}$ which is applied for both jets. For this selection cut the cross section receives large contributions from the threshold region where both jets have similar transverse energies $E_{t,1} \simeq E_{t,2} \simeq E_{t,{\rm min,Breit}}$. The emission of a soft gluon can reduce the transverse energy of one of the jets such that it falls below the threshold. In fixed order calculations this results in an incomplete cancelation between real and virtual corrections at the threshold region, thereby making them unpredictive.

The infrared sensitive regions can e.g. be avoided by asymmetric E_t cuts ($E_{t,{\rm min}} > 5\,{\rm GeV}$ and $E_{t,{\rm max}} > 7\,{\rm GeV}$) or by applying an additional harder

[a]Positive pseudorapidities are along the positive z-axis which is defined as the direction of the incoming proton in both, the Breit and the laboratory frame.

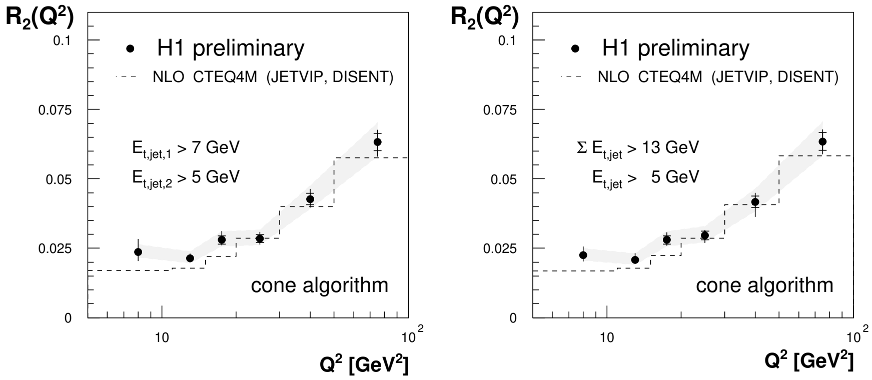

Figure 2: The Q^2 dependence of the dijet rates for transverse jet energy cuts that avoid infrared sensitive phase space regions. The data are compared to NLO predictions with the renormalization and the factorization scale set to $\mu_r^2 = \mu_f^2 = Q^2 + \langle E_t \rangle^2$.

cut on the sum of the transverse jet energies ($E_{t,\min} > 5\,\text{GeV}$ and $\sum_{1,2} E_{t,i} > 13\,\text{GeV}$). We have repeated the analysis for both of these scenarios, using the same selection cuts as in the previous analysis otherwise [1].

The results are displayed in Fig. 2 where the data are compared to NLO predictions[b] [6] [8]. It is noticeable that the data are equally well described by the NLO calculations in both cases, so that it does not seem to play a role how in detail the infrared sensitive regions are avoided. Further discussion on these data can be found in [8].

4 Dijet Cross Sections

The last analysis that we present here has been performed with different jet clustering algorithms: the longitudinally invariant k_t algorithm (originally proposed for hadron collisions [3]), the k_t algorithm that was originally proposed for DIS [10], and the recently proposed Cambridge algorithm [11] (which we have modified for DIS to treat the proton remnant according to the prescription used in the k_t algorithm for DIS).

The dijet analysis covers a kinematical range of four momentum transfers $200 < Q^2 < 5000\,\text{GeV}^2$ (for the longitudinally invariant k_t the range was extended down to $Q^2 = 10\,\text{GeV}^2$) and $0.2 < y < 0.6$. For the longitudinally in-

[b] Hadronization corrections are not included in the comparison. Their size has been estimated by QCD models to be in the order of 10 % (i.e. the partonic dijet cross section is 10 % higher as compared to the hadronic dijet cross section).

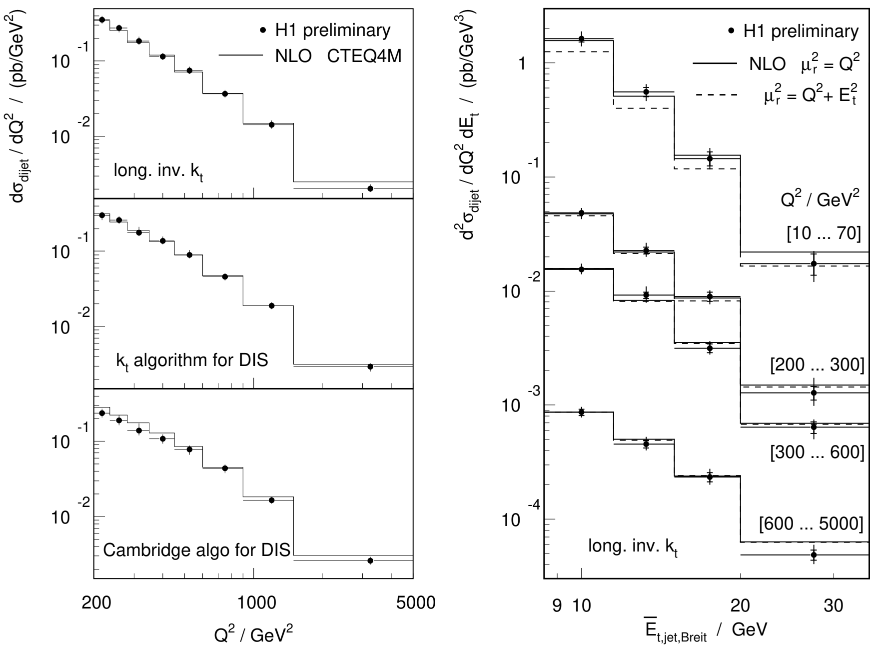

Figure 3: The Q^2 dependence of the dijet cross sections for different jet algorithms (left) and the average transverse jet energy distribution of the two jets with highest transverse energies for the longitudinally invariant k_t algorithm (right) compared to NLO predictions.

variant k_t algorithm we required $E_{t,\mathrm{min,\ Breit}} > 5\,\mathrm{GeV}$ and $\sum_{1,2} E_{t,i} > 17\,\mathrm{GeV}$, while the k_t for DIS and the Cambridge algorithm were used with a reference scale of $100\,\mathrm{GeV}^2$ and $y_{\mathrm{cut}} = 1$ (these values were chosen to obtain dijet cross sections of similar size for all algorithms). Events with at least two jets in $-1 < \eta_{\mathrm{lab}} < 2.5$ are selected.

The results are presented in Fig. 3 where the data are compared to the NLO predictions. Hadronization corrections are not considered in the comparison[c]. For all algorithms we observe good agreement between data and theory. However, at lower Q^2 ($Q^2 \lesssim 100\,\mathrm{GeV}^2$) the agreement depends strongly on the choice of the renormalization scale in the NLO calculation. The choice of $\mu_r^2 = Q^2$ gives a perfect description of the data (which is also seen in other

[c] QCD models predict hadronization corrections of 7 % (longitudinally invariant k_t), and on average 15 % (k_t for DIS) and 18 %(Cambridge); the corrections for the latter algorithms show a stronger Q^2 dependence.

dijet distributions not shown here). Although a scale of $\mu_r^2 = Q^2 + E_t^2$ is more reasonable (it gives a smooth interpolation between $\mu_r^2 = E_t^2$ in the limit $Q^2 \to 0$ and $\mu_r^2 = Q^2$ in the limit $E_t^2 \to 0$), this choice leads to NLO cross sections up to 30 % below the data.

5 Summary and Outlook

Within the last year we have significantly improved our understanding of dijet production in deep-inelastic scattering. Measurements of internal jet structure are very well described by QCD models. We have learned that the applicability of perturbative calculations in fixed order can be heavily restricted in badly chosen (i.e. infrared sensitive) regions of phase space. Considering such limitations and avoiding infrared sensitive phase space regions, we have shown that NLO calculations can give a very good description of our dijet data over a very large kinematical range of four momentum transfers $10 < Q^2 < 5000\,\mathrm{GeV}^2$ and transverse jet energies $25 < E_{t,\mathrm{Breit}}^2 \lesssim 1200\,\mathrm{GeV}^2$, for various jet definitions.

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