Dijet Azimuthal Correlations in QCD Hard Processes

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We study the azimuthal correlation distribution for dijet production in QCD hard processes. This observable is sensitive to soft and/or collinear emissions in the back-to-back region, giving rise to single and double logarithms. We provide resummed predictions to NLL accuracy for both DIS at HERA and hadronic collisions at Tevatron and perform a NLO matching to NLOJET++ results in the DIS case.

1 Introduction

Studies of soft gluon radiation and non-perturbative effects in QCD observables are of vital importance. These studies help us better understand the dynamics of QCD and enhance the accuracy of theoretical predictions for measured quantities. In several instances precision in QCD is limited not just by what powers of α_s are controlled, but also by the lack of better understanding of QCD dynamics such as the all-orders behaviour (embodied in the resummation of large logarithms) and inevitably the process of hadronisation.

Successful examples of such studies are manifested in event-shape variables at LEP and HERA. Resummed estimates for these observables, combined with NLO predictions and corrected for non-perturbative effects, have been very successful in describing the data [2, 3]. Parameters such as the strong coupling and the effective non-perturbative coupling [4] can then be consistently extracted by studying distributions and mean values of such observables (see for instance Ref. [5] for a recent review).

Going beyond the case of two hard partons is more challenging in terms of theory but is also a more stringent test of our understanding of QCD dynamics. Multi-jet event-shape variables have been studied (see Refs. [6, 7]). However for jet-defined quantities, e.g. several dijet distributions, there are currently very few resummed predictions because of the lack of theoretical insight to all orders in the presence of a jet algorithm. Many measurements are already established (see e.g. [8, 9]) and await comparison to theoretical estimates.

Effort has recently been devoted to improve the understanding of the effect of jet algorithms on QCD resummation [10, 11, 12, 13]. A clustering algorithm has an impact on the resummation of observables which are defined in a limited region of the phase-space (such as energy flow outside jets), known as "non-global" observables [14, 15]. These receive single logs which could only be resummed numerically in the large N_c limit for processes involving only two hard partons. It was shown in Ref. [10] that employing a k_t algorithm on the final-state particles reduces these logarithms in the case where only two hard partons are present. However the resummation of jet-defined quantities proved to be non-trivial [12] and the full impact of clustering algorithms on resummation has been explained more recently in Ref. [13].

With the technique of resummation using a clustering algorithm one can proceed with studying jet-defined quantities. In the present work we focus on the dijet azimuthal correlation distribution. We consider the process of production of two hard jets in DIS or hadronic

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collisions. We study the azimuthal correlation defined by the azimuthal angle between the leading hard jets in the final state.

The azimuthal angle of a jet is defined by:

$$\phi_{\rm jet} = \frac{\sum_{i\in{\rm jet}} E_{t,i}\phi_i}{\sum_{i\in{\rm jet}} E_{t,i}}\,, \tag{1}$$

where the sum runs over all particles inside the jet. The observable we study has the following approximation in the soft and/or collinear regime:

$$\begin{aligned} \Delta\phi &= \left|\pi - \delta\phi_{\rm jets}\right|, \\ &= \left|\sum_i \frac{k_{t,i}}{p_t}\left(\sin\phi_i - \theta_{i1}\phi_i - \theta_{i2}(\pi-\phi_i)\right)\right|, \end{aligned} \tag{2}$$

where p_t is the transverse momentum of the outgoing hard partons, which we assumed to be at azimuths $\phi_1 = 0$ and $\phi_2 = \pi$. Here $\theta_{ij} = 1$ if particle i is clustered to jet j and is zero otherwise.

The above definition implies that the observable in question is global. This means that no non-global component is present and the resummed result to next-to-leading log (NLL) accuracy has no dependence on the jet algorithm. This is the recombination scheme used by the H1 collaboration at HERA to measure this observable [8]. However if one employs a recombination scheme in which the four-momentum of the jet is defined by the addition of four-momenta of particles in the jet, then our observable becomes non-global. In this case one would need to calculate the additional non-global component as well as the dependence on the jet algorithm. The DØ collaboration at Tevatron employed the latter recombination scheme to measure the observable [9, 16].

We note that in the soft and/or collinear region, i.e. close to the Born configuration in which the outgoing jets are back-to-back ($\Delta\phi \sim 0$), the distribution receives large logarithms. This region is also strongly affected by non-perturbative effects. In the present study we shall report the resummed predictions for these logarithms to NLL accuracy both in DIS and hadronic collisions and provide a matching to NLO results obtained from NLOJET++ [17] in the DIS case.

2 Resummation and matching

The resummed result for the integrated distribution for events with $\Delta\phi < \Delta$ is given by:

$$\sigma(\Delta) = \int d\mathcal{B}\frac{2}{\pi}\int_0^{+\infty}\frac{db}{b}\sin(\Delta b)\sigma_{\mathcal{B}}(b)e^{-R(b)}\,, \tag{3}$$

where we reported the result for the DIS case assuming the azimuths of the jets are recombined using Eq. (1). In Eq. (3) $\sigma_{\mathcal{B}}(b)$ is the Born cross-section for the production of two hard jets in DIS, containing parton distribution functions (pdfs) evolved to μ_f^2/b^2, with μ_f being the factorisation scale, and $d\mathcal{B}$ is the corresponding phase-space. The function $R(b)$ is the radiator which contains the resummed leading and next-to-leading logs.

The resummed result needs to be corrected to include pieces which are not captured by the resummation. Many techniques have been developed to match resummed predictions

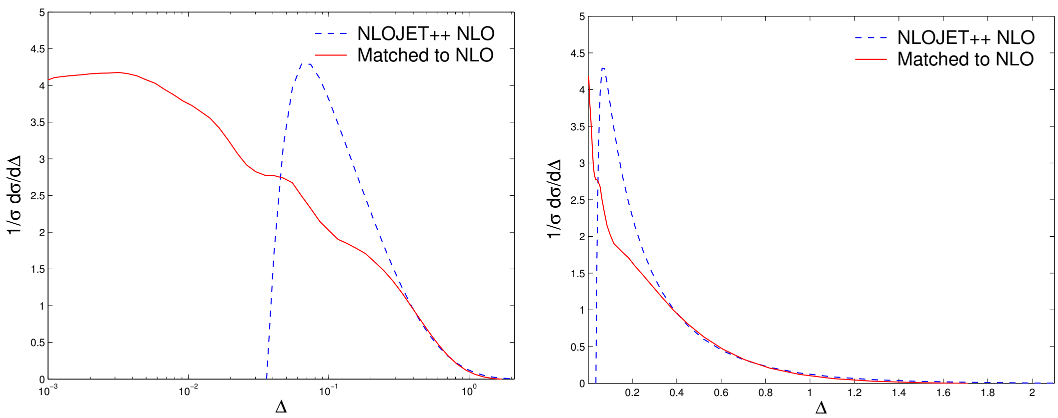

Figure 1: The Dijet azimuthal correlation distribution in DIS. A comparison between the NLO and matched results is shown. The NLO result diverges when $\Delta \to 0$, while the matched result tends to a constant. The effect of matching is to bring the distribution to NLOJET++ [17] curve at large Δ (where we expect the NLO result to hold) and to correct the resummed result at small Δ by a constant factor, not accounted for in the resummation.

with NLO results. Below we report the matching formula we use here:

$$\sigma_{\text{mat}} = \sigma(\Delta)\left[1 + \left(\sigma_e^{(1)} - \sigma_r^{(1)}\right)/\sigma_0\right] + \left(\sigma_e^{(2)} - \sigma_r^{(2)}\right)\exp\left(-R_{\text{DL}}\right), \tag{4}$$

where $\sigma(\Delta)$ is the resummed result, $\sigma_r^{(1)}$ and $\sigma_r^{(2)}$ are the expansion of the resummed result to $\mathcal{O}(\alpha_s)$ and $\mathcal{O}(\alpha_s^2)$ respectively and σ_0 is the Born cross section. Here σ_e denotes the integrated distributions given by NLOJET++ [17], with the superscripts indicating the order, and R_{DL} is the double logarithmic piece of the radiator obtained by replacing $b \to e^{-\gamma_E}/\Delta$, where γ_E is the Euler constant. We present the results in Fig. 1.

3 Hadronic collisions case

We report below the result for the dijet azimuthal correlation distribution in hadronic collisions. This has been measured at DØ using the jet recombination scheme in which the four-momentum of a jet is obtained by the sum over the four-momenta of particles in the jet. Here we only report the result which exploits Eq. (1) although similar results can be obtained for the other scheme. The resummed result is given by:

$$\sigma(\Delta) = \int d\mathcal{B}\frac{2}{\pi}\int_0^\infty \frac{db}{b}\sigma_{\mathcal{B}}(b)\sin(b\Delta)e^{-R(b)} \times S\,, \tag{5}$$

where

$$S = \text{Tr}(He^{-SL(b)\Gamma^\dagger/2}Me^{-SL(b)\Gamma/2})/\text{Tr}(HM)\,, \tag{6}$$

with H, Γ and M being the hard, anomalous dimension and soft matrices. These depend on the kinematics of the process and appear in various places (e.g. [18, 19, 20]). The single logarithmic function $SL(b)$ accounts for soft wide-angle emissions. Here $\sigma_{\mathcal{B}}(b)$ is the Born cross-section for the production of two jets in hadronic collisions, which also contains pdfs from both incoming legs evolved to μ_f^2/b^2, and $d\mathcal{B}$ is the corresponding phase-space for the production of a dijet system in hadronic collisions. Note that the radiator in this case has a slightly different form than in the DIS case.

4 Future directions

Having performed an NLL resummation (and NLO matching in the DIS case) we can now compare our predictions with data and other approaches (e.g. that of Ref. [21] which implements unintegrated pdfs).

We can further our study by looking at the hadronic collisions case using the same jet definitions as those used by the DØ collaboration. The current indication is that the size of the non-global component and the impact of the jet algorithm on the "global" piece may not be significant [13, 22], particularly since these pieces contain only single logarithms while the distribution is dominated by double logarithms.

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