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DIJET RATES WITH SYMMETRIC CUTS

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We show that a resummation of infrared logarithms is needed to obtain a sensible theoretical description of dijet rates when symmetric cuts are applied to the transverse energies of both jets. We also present the next-to-leading logarithmic (NLL) resummation we carried out for DIS production of two jets selected with the cone algorithm.

1 Introduction

It was observed some time ago [1,2] that next-to-leading order (NLO) QCD calculations are not able to describe dijet rates measured experimentally in the whole of the dijet phase space [3,4]. In particular in [2] a study was performed of the cross section $\sigma(\Delta)$ for producing two jets with transverse energies $E_{t1} > E_{t2}$, $E_{t2} > E_{\min}$ and $E_{t1} > E_{\min} + \Delta$. There it was observed that $\sigma(\Delta)$ at NLO was finite for $\Delta = 0$ (symmetric cuts), but in the vicinity of that point the slope $\sigma'(\Delta)$ became unphysically positive and infinite. This pathological behaviour can be attributed to the fact that incomplete real-virtual cancellations give rise to large logarithms $\ln Q/\Delta$ (with Q the hard scale of the process) at all orders in the perturbative expansion for $\sigma'(\Delta)$. However, an all-order resummation of such logarithms restores the correct physical behaviour for the slope, as will be discussed in the following.

2 Resummation of the jet transverse energy difference

To understand the physical origin of the divergent behaviour of $\sigma'(\Delta)$ we first observe that this quantity can be related to the differential cross section in the transverse energy of the highest E_t jet:

$$\sigma'(\Delta) = -\frac{d\sigma}{dE_{t1}}(E_{t1} = E_{\min} + \Delta)\,. \tag{1}$$

Being the opposite of a physical cross section, the slope has to be always negative, as is observed experimentally [3,4].

However, if we emit an arbitrary number of soft gluons k_i, and define $E_{t,\mathrm{jet}} = |\sum_{i\in\mathrm{jet}} \vec{k}_{ti}|$, in a recombination scheme that adds transverse momenta vectorially, we have, from momentum conservation,

$$E_{t1} - E_{t2} = |\sum_{i\notin\mathrm{jets}} k_{xi}|\,, \tag{2}$$

where k_x is the component of $\vec{k}_t$ parallel to the jet axis (which can be taken as the direction of any of the two hard jets). The definition in eq. (1) implicitly imposes the constraint $|\sum_{i\notin\text{jets}} k_{xi}| < \Delta$ on emitted particle transverse momenta. Such a veto on soft radiation is known to give rise to terms $\alpha_s^n \ln^m Q/\Delta$, which for $\Delta \ll Q$ diverge making $\sigma'(\Delta)$ become infinite, as was first observed in [2].

We then consider the probability $S(q_x)$ of producing an arbitrary number of soft/collinear (SC) partons such that $q_x = \sum_{i\notin\text{jets}} k_{xi}$. For $\Delta \ll Q$, SC emissions factorise from the leading order value for the slope $\sigma_0'(\Delta)$ as follows:

$$\sigma'(\Delta) \simeq \sigma_0'(\Delta)\cdot\Sigma(\Delta)\,, \qquad \Sigma(\Delta) \equiv \int dq_x\, S(q_x)\,\Theta(\Delta - |q_x|)\,. \tag{3}$$

Assuming that multiple SC emissions are distributed according to a 'random walk' [5] around $q_x = 0$ leads to $\Sigma(\Delta) \sim \Delta/Q$ for small Δ. The resulting slope is finite and negative defined as expected. QCD radiation is a particular form of random walk, giving rise to the following expression for $\Sigma(\Delta)$ (see [6]):

$$\Sigma(\Delta) = \frac{2}{\pi}\int_0^\infty \frac{db}{b}\sin(b\Delta)e^{-R(b)}\,, \tag{4}$$

where the positive defined 'radiator' $R(b)$ acts as an effective cutoff on the b integral. Its *perturbative* expansion can be reorganised as follows:

$$-R(b) = Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \dots\,, \qquad L = \ln b\,, \tag{5}$$

where $Lg_1(\alpha_s L)$ resums leading logarithms ($\alpha_s^n L^{n+1}$, LL), $g_2(\alpha_s L)$ resums next-to-leading logarithms ($\alpha_s^n L^n$, NLL) and so on. The NLL expression for $R(b)$ reads

$$R(b) = R_{\text{inc}}(b) + R_{\text{soft}}(b) + R_{\text{jet}}(b) + R_{\text{ng}}(b)\,. \tag{6}$$

$R_{\text{inc}}(b)$ collects contributions from radiation that is soft and collinear to the incoming parton(s). Its expression is analogous to the well-known Sudakov exponent in Drell-Yan transverse momentum distribution [7]. The term $R_{\text{soft}}(b)$ accounts for coherence of QCD radiation arising from interference among soft gluons at large angles. Both $R_{\text{inc}}(b)$ and $R_{\text{soft}}(b)$ are *universal*, in the sense that they do not depend on the details of the jet algorithm. However, $R_{\text{soft}}(b)$ should be corrected by taking into account the fact that not all soft gluons contribute to $E_{t1} - E_{t2}$, but only those outside the jets. The correction is provided by the additional terms $R_{\text{jet}}(b)$ and $R_{\text{ng}}(b)$, both of which depend on the jet algorithm. $R_{\text{jet}}(b)$, as well as $R_{\text{inc}}(b)$ and $R_{\text{soft}}(b)$, can be computed by simply considering the emission of a single SC gluon (including its multiple SC splittings) and exponentiating the result. However, NL logarithms arise also when soft gluons inside the jets emit coherently a relatively softer gluon outside. Such contributions are typical of non-global observables [8] like $E_{t1} - E_{t2}$, and are embodied in $R_{\text{ng}}(b)$. Their resummed expression, known only in the large-N_c limit, has been already computed for two outgoing jets in e^+e^- annihilation, both in the cone algorithm [9] and in the inclusive k_t algorithm [10].

We now discuss the phenomenological impact of such a resummation for dijet production in DIS. The explicit expression for $R(b)$ in this specific case can be found in [6]. Here we present numerical results corresponding to $Q = 20\text{GeV}$, $x_B = 0.01$, where $-Q^2$ is the virtuality of the photon and x_B the usual Bjorken variable. Jets are selected with the variant of the cone algorithm proposed in [11] with an opening angle $\delta = 0.3$, minimum transverse energy $E_{\text{min}} = 10\text{GeV}$ and rapidity

$|\eta| < 1$ in the Breit frame. In fig. 1 we plot the ratio $D(\Delta) \equiv \sigma'(\Delta)/\sigma_0'(\Delta)$, with the slope $\sigma'(\Delta)$ computed at NLO in the SC approximation (lower curve) and NLL resummed (upper curve). As can be seen, while the NLO curve diverges for $\Delta \ll Q$, the resummed curve stays finite, vanishing as Δ/Q. The numerical analysis of [6]

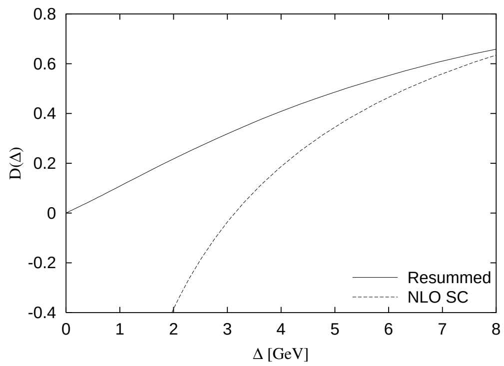

Figure 1. The ratio $D(\Delta) = \sigma'(\Delta)/\sigma_0'(\Delta)$. See [6] for details.

shows also that the impact of the non-global piece $R_{\rm ng}(b)$ turns out to be negligible in the whole range of Δ values considered. This is consoling in view of the fact that its expression is known only in the large-N_c limit.

3 Obtaining the total dijet rate

After a resummation for the slope $\sigma'(\Delta)$ has been computed, and after matching to fixed order calculations, one could obtain the total dijet rate $\sigma(0)$ by simply integrating $\sigma'(\Delta)$ from the maximum kinematically allowed value $\Delta_{\rm max}$ back to $\Delta = 0$. However, resumming the distribution in the transverse energy difference is not the only way to compute $\sigma(0)$. One can envisage the possibility of studying other observables, which we will discuss shortly.

First of all one can observe that in the massless E_0 recombination scheme $E_{t1} - E_{t2}$ takes contribution also from the invariant masses of the two outgoing jets. This makes the observable global, and therefore within the scope of the automated resummation program CAESAR [12]. However, one should be aware of the fact that, since a mechanism that keeps $E_{t1} - E_{t2}$ small is transverse momentum cancellation (see eq. (2)), one should expect a divergence in the resummed distribution provided by CAESAR at a critical value Δ_c (see [12] for a discussion on this point).

Another possibility would be to consider any observable V that vanishes in the limit of two outgoing partons ($E_{t1} - E_{t2}$ is only an example of such an observable). One could then resum the differential distribution $d\sigma(V)/dV$ and integrate it from $V_{\rm max}$ to $V = 0$, thus obtaining again the total dijet rate. This has been observed already in [2] for the case of the azimuthal angle ϕ between the jets, where $V = \pi - \phi$ was the quantity to be resummed.

4 Outlook

What we have done so far [6] shows that we have a clear understanding of the physics underlying dijet rates with symmetric E_t cuts. As a mandatory test of our ideas, we plan to extend our calculation in DIS to the k_t algorithm [13], so that we can compare our predictions with existing data [3,4]. Since the data have very small errors, such a comparison would also offer a test of QCD predictions in a three-jet environment, complementary to the event-shape measurements proposed for instance in [14], and, as we believe, less affected by non-perturbative hadronisation corrections. Further developments should include the extension of our results to other hard processes. In particular a study of dijet rates in photoproduction could be exploited to better constrain the gluon distribution $g(x)$ at moderately large x, which should be important for the LHC [15].

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