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Probing collinear parton dynamics with groomed jet mass

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Introduction and Observable.

The groomed heavy jet mass is known to next-to-next-to leading logarithmic (NNLL) accuracy ($\mathcal{O}(\alpha_s^n \ln^{n-2} \rho)$) in the small $z_{\rm cut}$ limit, from soft collinear effective theory (SCET) [1], while QCD resummations are so far limited to leading logarithm (LL) accuracy, with full $z_{\rm cut}$ dependence [2].

Logarithms of $\rho = \frac{m_j^2}{p_t^2}$ are of collinear origin, making the collinear limit crucial to understanding the logarithmic structure. The LL structure derives from a series of strongly ordered emissions described by leading order splitting functions. The next to leading logarithms (NLL) should be related to the next to leading order collinear splitting functions, which describe a pair of unordered emissions.

Using the fundamental objects in the collinear limit, the splitting functions, can we understand the NLL structure from a QCD viewpoint? Particularly, what is the link to NLO DGLAP evolution?

(a) Strong Ordering- LL. (b) Unordered- NLL.

We use the $1 \to 3$ collinear splitting functions to calculate the groomed heavy hemisphere mass distribution at $\mathcal{O}(\alpha_s^2)$ [3]. Throughout our calculations we use the e^+e^- definition of heavy hemisphere jet masses, as in [4], that is:

$$\rho = \frac{\max(m_L^2, m_R^2)}{Q^2/4}\,, \qquad (1)$$

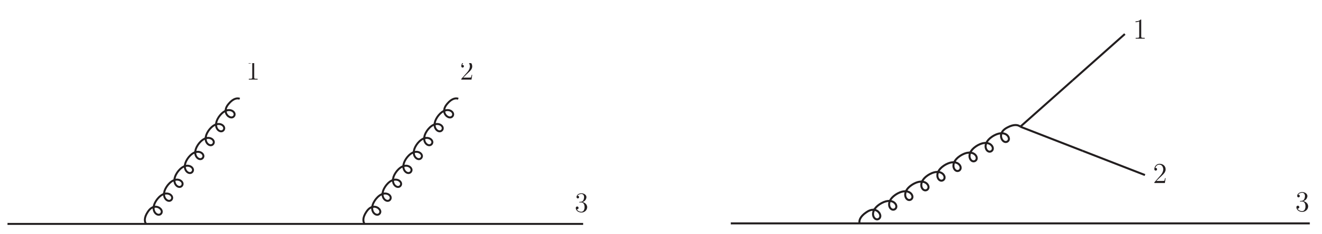
with m_L and m_R the hemisphere masses, after grooming with mMDT[2], or equivalently soft drop ($\beta = 0$) [5]. Although carried out in the small $z_{\rm cut}$ limit, our methods are valid for finite $z_{\rm cut}$.

Approach

We initially use a simplified treatment of the clustering sequence, as shown in figure 2, which we term the inclusive part of our calculation, and compute a correction due to the C/A clustering sequence.

$$\rho\frac{d\Sigma}{d\rho} = \mathcal{F}^{\rm inc.} + \mathcal{F}^{\rm clust.} \qquad (2)$$

The singular structure is completely contained within the inclusive piece. The matrix elements are separated into terms which generate poles and terms which are regular. Regular terms are computed numerically, while the coefficients of poles are computed analytically as a function of ϵ.



(a) The tagger is applied as if partons 2 and 3 are always clustered first.

(b) The tagger is applied as if partons 1 and 2 are always clustered first.

Figure 2: The simplified treatment of clustering used in the inclusive part of the calculation.

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Results of inclusive calculation

It is possible to compute the inclusive contribution from the $T_R n_f$ channel fully analytically. We can identify how the various terms are linked to a QCD resummation:

$$\mathcal{F}^{\rm inc.}_{n_f} = C_F T_R n_f \left(\frac{\alpha_s}{2\pi}\right)^2 \Bigg[\underbrace{\overbrace{-\frac{2}{3}(3 + 4\ln z_{\rm cut})\ln\rho}^{\text{Leading log term.}} - \frac{4}{3}\ln^2 z_{\rm cut}}_{\text{Can be included via } \alpha_s(k_t).} \underbrace{+\frac{40}{9}\ln z_{\rm cut}}_{\text{Can be included via the CMW scheme.}} \underbrace{-2\overbrace{\left(\frac{-1}{6} - \frac{2\pi^2}{9}\right)}^{\gamma_{q,n_f}^{(2)}} - \frac{2}{3}\overbrace{\left(\frac{2\pi^2}{3} - 7\right)}^{b_0 X \text{ term}}}_{\text{Collinear NLL term.}} \Bigg]\,. \qquad (3)$$

Aside from the collinear NLL term, all terms can be found by considering a set of strongly ordered emissions, supplemented with setting the scale of the running coupling to k_t and use of the CMW scheme.

At order α_s^2, the intensity of collinear radiation is related to a coefficient in the quark form factor, generally referred to as $B^{(2)}$. The definition of $B^{(2)}$ depends on the resummation scheme, but always takes the form

$$B^{(2)} = -2\gamma_q^{(2)} + C_F b_0 X\,, \qquad (4)$$

where $\gamma_q^{(2)}$ is the endpoint, $\delta(1-z)$, contribution to the NLO DGLAP splitting functions, and b_0 is the one loop coefficient of the QCD beta function. We find that in all colour channels our inclusive results are consistent with this form, with $X = \frac{2\pi^2}{3} - 7$.

Clustering

We numerically compute $\mathcal{F}^{\rm clust.}$ using $z_{cut} = 10^{-5}$ to suppress power corrections, to find:

$$\mathcal{F}^{\rm clust.} = \left(\frac{\alpha_s}{2\pi}\right)^2 \big(C_F^2(4.246 \pm 0.002) + C_F C_A(-1.161 \pm 0.001) + C_F T_R n_f(-1.754 \pm 0.002)\big)\,. \qquad (5)$$

$\mathcal{F}^{\rm clust.}$ does not form part of $B^{(2)}$ as it violates the form of eq. (4).

We find that the only configurations which contribute to the clustering correction are:

- In the C_F^2 channel, where both gluons would individually fail the z_{cut} condition, leading to a massless jet (inclusive case), but due to clustering, are retained and set a finite jet mass.
- In the $C_F C_A$ and $T_R n_f$ colour channels where the primary emission would pass the z_{cut} condition resulting in a finite jet mass (inclusive case), but due to C/A clustering, it's subsequent daughters are examined individually for the z_{cut} condition and are both removed.

Additionally, the clustering correction in the C_F^2 channel can be evaluated analytically as $\frac{4\pi}{3}{\rm Cl}_2\left(\frac{\pi}{3}\right) \simeq 4.246$.

Conclusions

- We make explicit the link between the next-to-leading collinear logarithms and NLO splitting kernels. This is relevant to the growing interest in including higher order splitting kernels in parton showers.
- This work provides most of the insight needed to compute the NLL groomed jet mass resummation directly in a QCD resummation formalism, as all pieces except the clustering corrections are already included in NNLL QCD resummation of the heavy jet mass [6]. Inclusion of the clustering correction is in progress.
- Our calculation constitutes a powerful cross check on the SCET resummation of the groomed jet mass [4], as we do not rely on any SCET or resummation ingredients.
- Similar methods could be applied to other collinear problems such as soft drop with $\beta \neq 0$ and small R jets.