New Insights into N-jettiness Computations

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Perturbative QCD has been remarkably successful in describing high-energy scattering processes at colliders with high precision. A central challenge in such calculations is the treatment of infrared divergences, which arise from soft and collinear emissions. *Subtraction* and *slicing* schemes provide systematic strategies to handle these divergences and obtain finite predictions. In subtraction methods, local counterterms cancel singularities point by point, while slicing methods divide phase space using a resolution variable. N-jettiness slicing is a popular slicing scheme as it is the most effective in computing jet cross sections. The phase space is sliced in the following manner:

$$\sigma = \int_0^{\tau_{\text{cut}}} d\tau \frac{d\sigma}{d\tau} + \int_{\tau_{\text{cut}}} d\tau \frac{d\sigma}{d\tau} \tag{1}$$

N-jettiness Soft Function at NNLO

For values of the slicing variable below the cutoff, $\tau < \tau_{\text{cut}}$, the cross section develops infrared singularities. A finite result can nevertheless be obtained using the SCET factorization theorem, which organizes the calculation into universal building blocks: the hard function $\mathcal{H}$ the beam functions $\mathcal{B}$, the jet functions $\mathcal{J}$ and the soft function $\mathcal{S}$. In schematic form, the factorized cross section reads

$$\int_0^{\tau_o} d\tau \frac{d\sigma}{d\tau} = \int B_\tau \otimes B_\tau \otimes S_\tau \otimes H_\tau \otimes \prod^N J_{i,\tau} + \mathcal{O}(\tau_o) \tag{2}$$

Among these ingredients, the soft function encodes the dynamics of low-energy radiation from final-state colored particles and can be formulated in a process-independent way. Currently, the state of the art for soft functions extends to next-to-next-to-leading order (NNLO), with explicit results known for 0-jettiness, 1-jettiness, and 2-jettiness. The first part of this thesis advances this frontier by presenting the calculation of the renormalized N-jettiness soft function at NNLO for a generic N. This novel approach demonstrates the link between subtraction methods and modern slicing schemes by using soft and collinear subtractions to calculate the N-jettiness Soft function.

0-jettiness Power Corrections to Color Singlet production at NLO

The use of slicing methods, one of such described above, is still hindered by very large numerical cancellations caused by the need to take the slicing parameter to be very small, to ensure the independence of the final result on its value. To overcome this challenge, one needs to compute the *unresolved* contribution more accurately. To achieve this, a description of real-emission amplitudes and cross sections beyond leading soft and collinear limits is required.

Such power-suppressed contributions have been calculated for simple processes at NLO, however no calculation for arbitrary processes has been done for a generic collider observable. The second part of my thesis comprises of calculating power corrections for the processes comprising of arbitrary color-singlet production $q\bar{q} \to X$ in the context of the N-jettiness slicing scheme at NLO QCD.

Power Corrections to prompt-photon + jet production at NLO

It is important to extend our discussion of power corrections to the N-jettiness cross section at NLO to processes with jets in the final state. This significantly increases the complexity of the calculation, since one must account not only for final-state collinear singularities but also for the action of a jet clustering algorithm. Because these effects are not yet well understood, we study a simplified toy model: the production of a prompt photon in association with a jet,

$$q\bar{q} \to \gamma g, \tag{3}$$

to understand the power corrections to jet cross sections.