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Two-loop anomalous dimensions of generic dijet soft functions

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Abstract

We present compact integral representations for the calculation of two-loop anomalous dimensions for a generic class of soft functions that are defined in terms of two light-like Wilson lines. Our results are relevant for the resummation of Sudakov logarithms for e^+e^- event-shape variables and inclusive hadron-collider observables at next-to-next-to-leading logarithmic accuracy within Soft-Collinear Effective Theory (SCET). Our formalism applies to both SCET-1 and SCET-2 soft functions and we clarify the relation between the respective soft anomalous dimension and the collinear anomaly exponent. We confirm existing two-loop results for about a dozen dijet soft functions and obtain new predictions for the angularity event shape and the soft-drop jet-grooming algorithm.

1. Dijet soft functions

Scattering cross sections at large momentum transfer Q are often sensitive to large logarithmic corrections that spoil the convergence of the perturbative expansion in the strong coupling

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$\alpha_s(Q) \ll 1$. By computing corrections of the form $\alpha_s(Q)L \sim 1$ to all orders, where $L \gg 1$ represents the large logarithm, the theoretical predictions can be systematically improved with respect to a fixed-order expansion. This reorganisation of the perturbative series – commonly called *resummation* – can be achieved on the basis of factorisation theorems which disentangle the relevant scales of the scattering process to all orders in perturbation theory.

The factorisation of cross sections in QCD has a long history. Traditionally, factorisation was established via an analysis of Feynman diagrams that incorporates the constraints from gauge invariance using Ward identities (see [1,2] for a review). Alternatively, the problem can be accessed with methods from effective field theory, which separate the effects from the relevant degrees of freedom directly on the level of the Lagrangian. The two approaches have many similarities and yield identical physical results (see e.g. [3] for a detailed comparison). While we use the language of Soft-Collinear Effective Theory (SCET) [4–6] in the present work, we stress that our analysis is also relevant for resummations that are formulated in QCD.

The scattering processes of interest in this work involve two hard, massless and colour-charged partons at the Born level. Whenever the QCD radiation is confined to be low-energetic (soft) or collinear to the directions of the hard partons, the partonic cross section factorises in the schematic form

$$d\hat{\sigma} = H \cdot J_n \otimes J_{\bar{n}} \otimes S\,, \tag{1}$$

where the symbol $\otimes$ denotes a convolution in suitable kinematic variables. The hard function H contains the virtual corrections to the Born process at the scale Q^2, the jet functions J_n and $J_{\bar{n}}$ encode the effects from the collinear emissions in the directions n^μ and $\bar{n}^\mu$ of the hard partons, and the soft function S describes the low-energetic cross talk between the two jets. The characteristic scales associated with the jet and soft functions are typically much smaller than Q^2, but their respective hierarchy depends on the specific observable. In fact, different hierarchies between the jet and soft scales are described by different versions of the effective theory as we will see below.

The individual factors in (1) depend on an unphysical factorisation scale, and by solving the associated renormalisation group equations (RGEs) one can resum the logarithmic corrections to the cross section to all orders. Whereas the fixed-order expansion is organised into leading order (LO) corrections, next-to-leading order (NLO) corrections, and so on, the resummed expressions refer to leading logarithmic (LL) accuracy, next-to-leading logarithmic (NLL) accuracy, etc. As in any effective field theory, the desired accuracy can then be achieved by computing anomalous dimensions and matching corrections to a given order in perturbation theory. For Sudakov problems with a double logarithm per loop order, the appropriate counting scheme is given e.g. in Table 5 of [3].

The purpose of this work is to develop a systematic framework for the computation of two-loop soft anomalous dimensions for a wide class of collider observables. The two-loop soft anomalous dimension is required for NNLL resummation and it often represents the only missing piece at this accuracy, since the two-loop hard anomalous dimension is known for arbitrary processes [7] and the two-loop jet anomalous dimension can then be extracted from the factorisation theorem (1) using RG invariance of the cross section. While one in addition needs the one-loop hard, jet, and soft matching corrections at NNLL, their computation often represents a comparably simple task.

The soft functions that enter the factorisation theorem (1) are given by vacuum matrix elements of a configuration of Wilson lines that reflect the structure of the scattering process at the Born level. More specifically, they can be written in the form