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Using dimensional reduction for hadronic collisions

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Abstract

We discuss how to apply regularization by dimensional reduction for computing hadronic cross sections at next-to-leading order. We analyze the infrared singularity structure, demonstrate that there are no problems with factorization, and show how to use dimensional reduction in conjunction with standard parton distribution functions. We clarify that different versions of dimensional reduction with different infrared and factorization behaviour have been used in the literature. Finally, we give transition rules for translating the various parts of next-to-leading order cross sections from dimensional reduction to other regularization schemes.

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1. Introduction

Recently progress on the understanding of regularization by dimensional reduction has been achieved in three directions. First, a mathematically consistent definition avoiding the problem found in Refs. [1,2] was formulated, and a succinct method to check the symmetry properties of dimensional reduction was developed [3], leading to the verification of supersymmetry in important cases at the two-loop level [4]. Second, explicit calculations demonstrated how dimensional reduction can be applied to multiloop calculations and how renormalization has to be carried out in a non-supersymmetric context [5]. This provides the basis of transition rules between various definitions of parameters such as α_s or m_b and is useful to derive the GUT-scale values of these

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parameters from the experimental values [6]. Third, an obstacle in the application of dimensional reduction to hadronic processes was removed [7] by the resolution of the factorization problem of dimensional reduction found in Refs. [8–10].

The purpose of the present article is to further elaborate on the application of dimensional reduction to hadronic processes. In Ref. [7] we restricted ourselves to the case considered in Ref. [8], the real corrections to the process $gg \to t\bar{t}$, and showed that, despite first appearances, in the collinear limit these real corrections factorize into products of splitting functions and leading-order cross sections.

Here we will consider real and virtual NLO QCD corrections to arbitrary hadronic $2 \to (n-2)$ processes with massless or massive partons. We will discuss the infrared singularity structure and the associated regularization-scheme dependence of all these corrections, provide transition rules between the schemes and show that all singularities factorize. In this way we show that the framework of dimensional reduction is completely consistent with factorization, and we show how this scheme can be used to compute hadronic processes in practice.

One of the main points of this article is the distinction of two different versions of dimensional reduction that have been used in the literature. One of the reasons why the factorization problem of Refs. [8–10] has remained unsolved for so long is that these two versions have mainly been applied by two different communities. The version used in Refs. [8–10] is the same as the one defined in Refs. [3,11,12] and is the one mainly used in the context of supersymmetry. The version used in Refs. [13–15], which was denoted by DR and is actually equivalent to the four-dimensional helicity (FDH) scheme [16] at one-loop, is mainly used in the context of QCD. For the latter version, the infrared singularity structure and transition rules have already been derived [13–15]. We denote these two versions by DRED and FDH. They differ in their treatment of external particles, in a way analogous to the difference of the "conventional" and "'t Hooft–Veltman" versions of dimensional regularization, CDR and HV.

In the main part of the present article we will provide results and transition rules for all these four regularization schemes, keeping in mind that the results for the FDH, CDR and HV schemes can already be found in Refs. [13–15], while the results for DRED are new. The results for the infrared singularity structure in CDR, HV, FDH and in DRED are developed in Sections 2 and 3, respectively. The practical application of DRED and transition rules are discussed in Section 4. Appendix A provides explicit results for all relevant splitting functions, and in Appendix B we provide three explicit examples of NLO computations in DRED.

1.1. Elements and scheme dependences of hadronic cross sections

We consider n-parton processes with up to two hadrons in the initial state at next-to-leading (NLO) order in QCD. The partons can be either massless quarks q or gluons g or massive partons such as heavy quarks Q, gluinos, or squarks. In our equations we will restrict ourselves to the most interesting case of two initial-state partons as the simpler cases can be obtained by straightforward modifications. The cross sections of such processes can be written as

$$d\sigma\big(H_1(K_1)H_2(K_2) \to a_3 \dots a_n\big) = \sum_{a_1,a_2} \int_0^1 dx_1\, f_{a_1/H_1}(x_1) \int_0^1 dx_2\, f_{a_2/H_2}(x_2) \times d\hat{\sigma}\big(a_1(x_1K_1)a_2(x_2K_2); a_3 \dots a_n\big), \tag{1}$$

where $H_{1,2}$ are the initial-state hadrons, $K_{1,2}$ their momenta and a_i $(i = 3, \dots, n)$ the final-state partons. The sums run over all possible flavours of the initial-state partons $a_{1,2}$ of the hard