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Nuclear Physics B 910 (2016) 568–617

NUCLEAR PHYSICS B

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The complete $O(\alpha_s^2)$ non-singlet heavy flavor corrections to the structure functions $g_{1,2}^{ep}(x, Q^2)$, $F_{1,2,L}^{ep}(x, Q^2)$, $F_{1,2,3}^{\nu(\bar{\nu})}(x, Q^2)$ and the associated sum rules

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Received 18 May 2016; accepted 15 June 2016

Available online 22 June 2016

Editor: Tommy Ohlsson

Abstract

We calculate analytically the flavor non-singlet $O(\alpha_s^2)$ massive Wilson coefficients for the inclusive neutral current non-singlet structure functions $F_{1,2,L}^{ep}(x, Q^2)$ and $g_{1,2}^{ep}(x, Q^2)$ and charged current non-singlet structure functions $F_{1,2,3}^{\nu(\bar{\nu})p}(x, Q^2)$, at general virtualities Q^2 in the deep-inelastic region. Numerical results are presented. We illustrate the transition from low to large virtualities for these observables, which may be contrasted to basic assumptions made in the so-called variable flavor number scheme. We also derive the corresponding results for the Adler sum rule, the unpolarized and polarized Bjorken sum rules and the Gross–Llewellyn Smith sum rule. There are no logarithmic corrections at large scales Q^2 and the effects of the power corrections due to the heavy quark mass are of the size of the known $O(\alpha_s^4)$ corrections in the case of the sum rules. The complete charm and bottom corrections are compared to the approach using asymptotic representations in the region $Q^2 \gg m_{c,b}^2$. We also study the target mass corrections to the above sum rules.

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http://dx.doi.org/10.1016/j.nuclphysb.2016.06.018

1. Introduction

Deep-inelastic scattering provides one of the most direct methods to measure the strong coupling constant from precision data on the scaling violations of the nucleon structure functions [1,2]. The present accuracy of these data also allows to measure the mass of the charm, cf. [3], and bottom quarks due to the heavy flavor contributions. The Wilson coefficients are known to 2-loop order in semi-analytic form [4–6] in the tagged-flavor case,[2] i.e. for the subset in which the hadronic final state contains at least one heavy quark, having been produced in the hard scattering process. The corresponding reduced cross section does not correspond to the notion of structure functions, since those are purely inclusive quantities and terms containing massless final states contribute as well. The heavy flavor contribution to inclusive deep-inelastic structure functions are described by five Wilson coefficients in the case of pure photon exchange [8–10]. In the asymptotic case $Q^2 \gg m^2$, where $Q^2 = -q^2$ denotes the virtuality of the exchanged gauge boson and m the mass of the heavy quark, analytic expressions for the Wilson coefficients have been calculated. A series of Mellin moments has been computed to 3-loop order in [10]. All logarithmic 3-loop corrections [11] as well as all N_F terms are known [12,13]. Four out of five Wilson coefficients contributing to the unpolarized deep inelastic structure functions have been calculated to 3-loop order for general values of Mellin N [12,14,15] in the asymptotic region $Q^2 \gg m^2$. In the flavor non-singlet case also the asymptotic 3-loop contributions to the combinations of the polarized structure functions $g_{1(2)}^{\rm NS}$ [16] and the unpolarized charged current structure function $xF_3^{\bar{\nu}p} + xF_3^{\nu p}$ have been computed [17].

In the present paper, we calculate the complete 2-loop non-singlet heavy flavor corrections to the deep inelastic charged current structure functions $F_{1,2,3}^{\nu p}$ and the neutral current structure functions $F_{1,2}^{ep}$ and g_1^{ep} and a series of sum rules in the deep inelastic region, $Q^2 \gtrsim m_c^2$. In the asymptotic case $Q^2 \gg m^2$ the corresponding Wilson coefficients have been calculated in [11, 16–18] to $O(\alpha_s^2)$ and in [14,16,17] to $O(\alpha_s^3)$. Here the massless Wilson coefficients [19,20] to $O(\alpha_s^3)$ enter. In the tagged flavor case the corresponding corrections to $O(\alpha_s^2)$ have been calculated in [8,21] and in the asymptotic charged current case in [22].[3]

The associated sum rules are the Adler sum rule [23], the unpolarized Bjorken sum rule [24], the polarized Bjorken sum rule [25], and the Gross–Llewellyn Smith sum rule [26]. A central observation in the inclusive case is that there are no logarithmic corrections for the associated sum rules at large Q^2, which are present in the tagged flavor case [27,28], however. The complete massive $O(\alpha_s^2)$ corrections to the structure functions improves the accuracy towards lower values of Q^2. In the case of the sum rules, the corresponding contributions are found to be of the order of the known massless 4-loop corrections. We will also consider the target mass corrections to the sum rules, since they are relevant in the region of low Q^2.

The paper is organized as follows. In Section 2 we present a general outline on the massive Wilson coefficients for the structure functions which will be considered. The $O(\alpha_s^2)$ corrections to the polarized non-singlet neutral current structure functions $g_1^{ep,\rm NS}$ and $g_2^{ep,\rm NS}$ are derived in detail in Section 3 as an example. In Section 4 we discuss the corrections to the neutral current structure functions $F_{1(2)}^{ep,\rm NS}$, and in Section 5 those to the non-singlet charged current structure functions $F_{1,2,3}^{\nu(\bar{\nu})p,\rm NS}$. Detailed numerical results are presented for all the seven non-

[2] For a precise implementation in Mellin space, see [7].

[3] This result has been corrected in Ref. [18].