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Wilson coefficients of dimension 6 gluon operators with spin indices in the heavy quark current correlation functions

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Abstract

We calculate the Wilson coefficients of dimension 6 gluon operators with spin indices in the two point correlation function of the heavy scalar, pseudoscalar, and axialvector currents. Our result completes the list of all Wilson coefficients of gluon operators up to dimension 6 for the correlation functions between heavy quark currents without derivatives. We then use the result to investigate the stability of the QCD sum rule results for the η_c, J/Ψ, χ_{c0}, and χ_{c1} mesons near T_c. While the inclusion of the dimension 6 operators increases the stability of the sum rules for all currents, all of them break down slightly above T_c with that for the J/ψ persisting to relatively highest temperature.
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1. Introduction

Ever since the seminal work by Matsui and Satz [1] that the J/ψ suppression in heavy ion collisions could serve as a signature for the formation of the quark–gluon plasma, a great deal of works have been devoted to the subject [2]. On the other hand, the question of whether the charmonium states disappears at T_c or at higher temperature is still controversial up to this date [3]. While it is generally accepted that J/ψ is composed dominantly of $c\bar{c}$ quark pair interacting

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within a non-relativistic confining potential at zero temperature, it is not clear what effective potential should be used to analyze the property at finite temperature [4,5].

A robust non-perturbative method to calculate the properties of charmonium at zero temperature is based on the QCD sum rule approach [6,7]. The method has been found to work well in reproducing the masses of the ground state charmonium states, the electromagnetic decay width of the J/ψ, and even the mass difference between η_c and J/ψ even before experiment. In a constituent quark model, the mass difference between the η_c and J/ψ is due to the color–spin interaction, which phenomenologically is inversely proportional to the masses of the quark and antiquark. However, it is well known that a naive generalization of the formula fitted to the light quark system and the light heavy quark system underestimates the mass splittings between heavy–heavy quark systems by a factor of 4 [8]. The fact that QCD sum rule fits the mass difference indicates that the method captures well the detailed non-perturbative effects involved in the masses of the charmonium states. Therefore, if one is able to systematically investigate the temperature modification of the operator product expansion (OPE) starting from the vacuum, one can hope to learn about the modification as well as the disappearance of the charmonium states above the critical temperature.

In a previous set of works [9–11], it was shown that one can indeed study the gradual change of the OPE at finite temperature as well as the abrupt change near T_c. This was due to the fact that the temperature dependence of dimension 4 operators, the gluon condensate, and the twist-2 gluon operator that newly appears at finite temperature, could be well extracted from the lattice calculation of the energy density and pressure at finite temperature. On the other hand, when the temperature dependencies of the OPE were used in the charmonium sum rules, it was found to break down at $T > 1.04T_c$ for the J/ψ and at $T > 1.03T_c$ for the P-wave states, respectively [12].

It is not clear if the breakdown of the sum rules is due to the melting of the charmonium states or the breakdown of the OPE. To shed light into the problem, we have recently studied the effect of including the dimension 6 operators to the moment sum rules for J/ψ at finite temperature. It was found that their contribution indeed improved the stability to slightly higher temperature [13]. In this work, we calculate the Wilson coefficients of dimension 6 gluon operators with spin indices in the two point correlation function of the heavy scalar, pseudoscalar, and axialvector currents. Our result completes the list of all Wilson coefficients of gluon operators up to dimension 6 for heavy quark currents without derivatives. We then use the result to investigate the stability of both the moment and Borel QCD sum rule result for the η_c, J/ψ, χ_{c0}, and χ_{c1} mesons near T_c. While the inclusion of the dimension 6 operators increases the stability, the sum rules for all currents break down slightly above T_c with that for the J/ψ persisting to relatively highest temperature.

The paper is organized as follows. In section 2, we give a summary of the independent dimension 6 gluon operators. Section 3 shows the calculation for the Wilson coefficients of gluon operator with spin indices up to dimension 6 for each currents. In section 4, we discuss the temperature dependence and the stability for the moment and Borel sum rules for charmonium states near T_c. Section 4 is devoted to the summary and a possible interpretation of our result. We list moments and Borel transformed Wilson coefficients in Appendix A and Appendix B respectively. Appendix C summarizes the forms for the continuum contribution.

2. Independent dimension 6 gluon operators

Here, we summarize the different representations of the dimension 4 and dimension 6 operators with spin 0 and spin 2 [13].

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