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Mass spectra of 0^{+-}, 1^{-+}, and 2^{+-} exotic glueballs

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Abstract

With appropriate interpolating currents the mass spectra of 0^{+-}, 1^{-+}, and 2^{+-} oddballs are studied in the framework of QCD sum rules (QCDSR). We find there exits one stable 0^{+-} oddball with mass of 4.57 ± 0.13 GeV, and one stable 2^{+-} oddball with mass of 6.06 ± 0.13 GeV, whereas, no stable 1^{-+} oddball shows up. The possible production and decay modes of these glueballs with unconventional quantum numbers are analyzed, which are hopefully measurable in either BELLEII, PANDA, Super-B or LHCb experiments.

1. Introduction

Quantum chromodynamics (QCD) is the underlying theory of hadronic interaction. In the high energy regime, it has been tested up to the 1% level due to asymptotic freedom [1]. However, the nonperturbative aspect related to the hadron spectrum is difficult to be calculated from first principles because of the confinement [2]. A unique attempt in understanding the nonperturbative aspect of QCD is to study the glueball (gg, ggg, $\cdots$), where the gauge field plays a more

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important dynamical role than in ordinary hadrons. This has created much interest in theory and experiment for quite a long time.

In the literature, many theoretical investigations on glueball were made through various techniques, including lattice QCD [3–7], the flux tube model [8], the MIT bag model [9,10], the Coulomb gauge model [11], the holographic model [12–15], and QCD sum rules (QCDSR) [16–24]. Of these techniques, the QCDSR, developed more than 30 years ago by Shifman, Vainshtein, and Zakharov (SVZ) [16], has some peculiar advantages in the study of hadron phenomenology. Its starting point in evaluating the properties of the ground-state hadron is to construct the current, which possesses the foremost information about the concerned hadron, like quantum numbers and the constituent quark or gluon. By using the current, one can then construct the two-point correlation function, which has two representations: the QCD representation and the phenomenological representation. Equating these two representations, the QCDSR will be formally established.

In the framework of QCDSR, the two-gluon glueballs with conventional quantum numbers of 0^{++} [18–20] and 0^{-+} [20,21] have been studied extensively. Note that even the trigluon components of these glueballs were considered [22–24], which is enlightening for the research of this work.

Although the glueball has been searched for for many years in experiments, so far there has been no definite conclusion about it, mainly due to the mixing effect between glueballs and quark states, and lack of the knowledge about glueball production scheme and decay properties. Of these difficulties, from the experimental point of view, the most outstanding obstacle is how to disentangle the glueball from the mixed quarkonium states ($q\bar{q}$). Fortunately, there is a class of glueballs, the unconventional glueballs, which with quantum numbers unaccessible by quark–antiquark bound states can avoid such problems. The quantum numbers of those glueballs include $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}$, and so on. Note, according to C-parity conservation, glueballs with negative C parity cannot be reached by two gluons, but have to be composed of at least three gluons. It should be noted that the 1^{-+} glueballs also have to be made of at least three gluons, since the coupling of two transverse particles forbids the existence of $J = 1$ states. This fact is known as Yang's theorem [25]. In the literature the term oddball has been used to describe glueballs having unconventional quantum numbers [26] as well as 3 gluon glueballs with odd J, P, C having conventional quantum numbers [11]. In this paper, we adopt the definition of oddball in [27] to unify and avoid confusion.

Among various oddballs, special attention ought be paid to the 0^{--} ones, since they possess the lowest spin and their quantum number enables their production in the decays of vector quarkonium or quarkoniumlike states relatively easier. Ref. [27] studied the 0^{--} oddballs via QCD Sum Rules, and found there exit two stable 0^{--} oddballs with masses of 3.81 ± 0.12 GeV and 4.33 ± 0.13 GeV. The aim of this paper is to evaluate the other unconventional oddballs which have to be composed of at least three gluons (i.e., $J^{PC} = 0^{+-}, 1^{-+}$, and 2^{+-}) and discuss the feasibility of finding them in experiment.

This paper is organized in five sections. After the Introduction, in Sec. 2 we brief the method of QCD Sum Rules and construct the appropriate interpolating currents for oddballs. Sec. 3 gives the analytical results and numerical analyses for each oddball. In Sec. 4, the possible production and decay modes of oddballs are investigated. The last section is left for discussion and conclusion.