One Interpretation for Recent BES Observation*

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Abstract Motivated by the recent BES observation of the $p\bar{p}$ enhancement near threshold in radiative J/ψ decays, X(1860) and X(1835), we choose the 0^{-+} trigluonium state as a possible candidate and calculate its mass with QCD sum rules, which is found to be approximately in the region between 1.9GeV and 2.7GeV with some theoretical uncertainties. With the fact that the new BES resonance exhibits the behavior of this trigluon state, our analyses favor the baryonium-gluonium mixing picture for the BES observation.

Key words glueball, QCD sum rules, quarknium decays

1 Introduction

Although still undiscovered experimentally, the existence of the bound state of gluons, gluonium or glueball, is theoretically expected based on the non-Abelian and confinement natures of Quantum Chromodynamics(QCD). Since the formation of glueball involves non-perturbative interactions and the bound state confinement effects, the theoretical investigation is very complicated. And the large decay width predicted theoretically, together with the fact that there might be a strong glueball-quarkonium mixing, makes the experimental search very difficult.

Being a bound state of gluons, glueball is supposed to be formed easily in a gluon-abundant environment. So a suitable place to search for glueballs is in the radiative J/ψ and Υ decays. Recently, in the final state of the decay $J/\psi \to \gamma p\bar{p}$, the BES Collaboration has observed an enhancement at the $p\bar{p}$ threshold with the quantum number 0^{-+}[1] and a resonance X(1835)[2] with J^{PC} undetermined. It is still unclear whether these two enhancements are the same. In this kind of cascade decays, X particles are produced in radiative J/ψ decay, $J/\psi \to \gamma X$, and decay into $p\bar{p}$ final states subsequently. These observations have stirred many explanations such as the $p\bar{p}$ baryonium state[3], or the gluonic state[4—6].

In this proceedings paper, we report, based on the range of glueball mass and some phenomenological arguments, our insight on the recent BES observation[7]. In Sec. 2, we briefly review the theoretical results about the mass of 0^{-+} bigluonium which has two valence gluons and calculate the mass of 0^{-+} tri-glueball which has three gluons as its valence constituents. In Sec. 3, we discuss the relation between the glueball and the recent BES observation and then present our conjecture. We summarize in Sec. 4.

2 Mass of 0^{-+} glueball

The two-valence-gluon resonances, the two-gluon glueballs (or bigluonium), have been studied extensively in the literatures. With QCD sum rules, the mass of 0^{++} scalar glueball[8—18] and 2^{++} tensor glue-

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ball were calculated[19, 20], and their masses were predicted to be 1.6(±0.3)GeV and 1.7(±0.5)GeV, respectively. According to lattice simulations[21—25], the 0^{-+} glueball should be the third lightest pure gluonic state. Relevant theoretical investigations on this 0^{-+} state have been performed, but the studies are limited only to the two-valence-gluon glueball (the leading Fock state in Fock space expansion)[15, 19, 26]. It should be noted that the 0^{-+} glueball can also be constructed by three-valence gluons, which is different from the next-to-leading Fock state of the bigluonium in Fock space expansion. About this point, one can easily find similar cases in the quark hadron sector.

Then we calculate the three-gluon 0^{-+} glueball(or trigluonium) mass by means of the QCD sum rules[27]. The Feynman diagrams of the correlation function in our calculation are shown in Fig. 1. The numerical dependence of glueball mass on the τ is presented in Fig. 2. For detailed calculation of correlation function and Borel transformation, see Ref. [7].

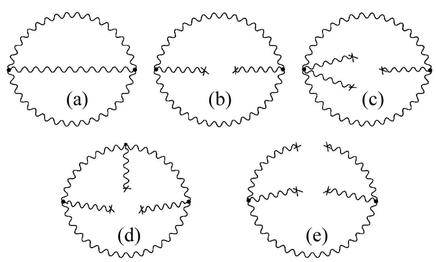

Fig. 1. The typical Feynman diagrams of three-gluon glueball in the scheme of QCD sum rules. (a) diagram for the perturbative term; (b) for the two gluon condensate terms; (c) and (d) for the three-gluon condensate terms; (e) for the four-gluon condensate terms.

There is not an exact stable window in the figure. However, the glueball mass decreases slowly with the increase of Borel parameter τ, an approximate glueball mass could be determined. The excited states and continuum threshold parameter $s_0 = 6.5\text{GeV}^2$ is chosen according to the method in Ref. [16]. To determine this s_0, the suitable region for τ lies between 0.2GeV^{-2} and 0.7GeV^{-2}. At every τ in this region, the predicted glueball mass varies slowly with s_0. Therefore, the glueball mass could be approximately regarded as falling in the scope of 1.9GeV to 2.7GeV.

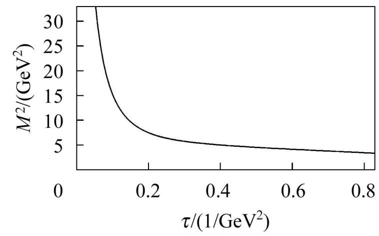

Fig. 2. The trigluon glueball mass square dependence on the Borel parameter τ. The excited states and continuum threshold parameter s_0 is taken to be 6.5GeV^2.

3 Glueball's implication for recent BES observation

According to our numerical result, the masses of new resonances X(1860) and X(1835) are not in the mass range of 0^{-+} trigluonium, so they cannot be pure gluonic states with three valence gluons. In our understanding, the $p\bar{p}$ enhancement is probably a mixture of baryonium state with the glueball(both two- and three-gluon states), which is also proposed in Ref. [3]. However, we think that if the baryonium-gluonium mixing picture is the reality for the BES observation[1], there should be a large component of three-gluon glueball inside. The arguments for this idea are:

1) The observed $p\bar{p}$ enhancement is close to the mass scope of 0^{-+} glueball in our calculation.

2) The new observation exhibits large $\gamma+p\bar{p}$ (and also three mesons) branching ratio relative to the two meson production processes in comparison with the decays of other known states. This unique character may hint that the new state has relatively strong coupling to six-quark final states1). In the picture of the three-gluon glueball, this is easy to be understood, since the three valence gluons can split into six light quarks easily and form $p\bar{p}$ final states.

3) Theoretically, the rate of J/ψ radiative decays to three gluons is in a similar order of magnitude as to two gluons, while we should enforce a proper physical cut to avoid the infrared singularities to draw such a conclusion[28].

1) Private communication with Prof. X.Y. Shen.

4) The missing $\Lambda\bar{\Lambda}$ threshold enhancement implies the obvious flavor $SU(3)$ breaking and favors the idea that what BES observed is a mixed state of $p\bar{p}$ baryonium and glueball, and the latter with a mass close to the $p\bar{p}$ threshold. The pure baryonium interpretation meets the difficulty of large $SU(3)$ breaking, while the pure gluonic state interpretation has an overshoot mass. The three-gluon glueball-baryonium mixing(oscillation) picture is a simple and natural one to this understanding.

Instead of mixing with the baryonium states, with the same quantum number and close mass, the pseudoscalar glueball may have mixing with the lightest charmonium η_c. In Ref. [29], the authors put forward an interesting picture that the pure $c\bar{c}$ bound state $\eta_c^0(2900)$ and pure gluonic state $G_P^0(2000)$ mix into two observable physical hadrons $\eta_c(2980)$ and X(1835). If the mixing mechanism between the gluonic state and the charmonium state actually exists, the trigluonium should have larger mixing with charmonium because of closer mass we calculated, and may account for the η_c decay problem.

4 Summary

Motivated by the new observation at BES, we calculated the mass of trigluonium in the framework of QCD sum rules and presented a possible explanation for the recent BES observation. We find that its mass lies in the region of 1.9—2.7GeV, which is consistent with the lattice simulation result. Since our calculation is performed in the leading order, the instanton and topological charge screening contributions have not been included, the mixing effect among glueballs and normal mesons has not been considered, and the input parameters still have some uncertainties, the mass prediction can not be very precise. In our leading order analysis, only the non-perturbatively triple-gluon condensate gives contributions to the glueball mass, whereas the two-and four-gluon condensates vanish after the Borel transformation. In further effort on the aim of making an accurate prediction, one should include the higher order corrections from both perturbative and non-perturbative sectors, in which the two-and four-gluon condensates contribute. The instanton and the topological charge screening contributions should be taken into account. Furthermore, the mixing effect among glueballs (two-gluon and three gluon glueball) and normal mesons (η and η') should be considered.

From the naive arguments listed in Sec. 3, we think the new BES observation of an enhancement at $p\bar{p}$ threshold might be a mixed state of baryonium and three-gluon glueball. Nevertheless, if our conjecture is true, how much the gluonic, or baryonium, content engages in the observed enhancement still needs more investigations, in both experiment and theory.

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对北京谱仪上新观测态的一个理论解释*

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摘要　最近, 北京谱仪在J/ψ的辐射衰变中发现, 在正反质子的阈附近有反常增强, 即可能存在共振态X(1860)和X(1835). 针对这一发现, 提出了新粒子的三胶子胶球态解释方案, 并且应用QCD求和规则计算了此胶球态的质量. 考虑到理论上的不确定因素, 计算结果表明该胶球态的质量峰位于1.9GeV到2.7GeV之间. 事实上, 北京谱仪发现的新共振态的确表现出了一些三胶子态的行为. 结论是, 此新粒子很有可能是重子偶素和胶球态的混合态.

关键词　胶球　QCD求和规则　重夸克偶素衰变

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