

HEAVY GLUEBALLS: STATUS AND LARGE- N_c WIDTHS ESTIMATE*

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(Received September 4, 2017)

Glueballs, an old and firm prediction of various QCD approaches (lattice QCD, bag models, AdS/QCD, effective models, *etc.*), have not yet been experimentally confirmed. While for glueballs below 2.6 GeV some candidates exist, the situation for heavy glueballs (above 2.6 GeV) is cloudy. Here, after a brief review of scalar, tensor, and pseudoscalar glueballs, we present predictions for the decays of a putative pseudoscalar glueball with a lattice predicted mass of 3.04 GeV and a putative vector glueball with a lattice predicted mass of 3.81 GeV. Moreover, we discuss in general the width of heavy glueballs by using large- N_c arguments: we obtain a rough estimate according to which the width of a glueball (such as the vector one) is about 10 MeV. Such a width would be narrow enough to enable measurement at the future PANDA experiment.

DOI:10.5506/APhysPolBSupp.10.1021

1. Introduction

Gluons, the force carriers of strong interaction between quarks, carry themselves colour charge, hence they are expected to form white bound state, called glueballs. The search for glueballs in the mesonic spectrum of the PDG [1] is a long-standing activity, see the reviews in Refs. [2].

Theoretically, bag models [3] were the first to predict a spectrum of glueballs. Later on, various other approaches have followed, *e.g.* QCD sum rules, flux-tube model, Hamiltonian QCD, anti-de Sitter/QCD methods [4]. A reliable approach is lattice QCD [5,6] (both quenched and unquenched), in which a spectrum of glueballs has been evaluated by a numerical simulation of QCD, see Table I.

* Presented at “Excited QCD 2017”, Sintra, Lisbon, Portugal, May 7–13, 2017.

TABLE I

Central values of glueball masses from lattice QCD [5].

J^{PC}	Value [GeV]	J^{PC}	Value [GeV]
0^{++}	1.71	3^{++}	3.67
2^{++}	2.39	1^{--}	3.83
0^{-+}	2.56	2^{--}	4.01
1^{+-}	2.98	3^{--}	4.20
2^{-+}	3.04	2^{+-}	4.22
3^{+-}	3.60	0^{+-}	4.77

In conclusion, there is nowadays a (theoretical) consensus about the existence of glueballs and the qualitative form of the spectrum, but up to now, no resonance could be *unambiguously* classified as a predominantly gluonic. In these proceedings, after a brief review of some glueball's candidates, we present some recent developments for the decays of the heavy vector and pseudotensor glueballs. Moreover, we present a new, “heuristic”, estimate of the glueball's width by using large- N_c arguments.

2. From light to heavy glueballs

First, we review the status of the three lightest glueballs of Table I, for which some candidates exist.

Scalar glueball: The resonances $f_0(1500)$ and $f_0(1710)$ were investigated as glueball's candidates in various works [7–11]. In Ref. [9], the glueball (as a dilaton) was studied within the so-called extended Linear Sigma Model (eLSM) [12]. Quite remarkably, there is only an acceptable scenario: $f_0(1710)$ is mostly gluonic. This is in agreement with the original lattice work of Ref. [7], with the recent lattice study of $j/\psi \rightarrow \gamma G$ in Ref. [10], and also with the AdS/QCD study in Ref. [11]. In conclusion, there is mounting evidence that $f_0(1710)$ is predominantly the scalar glueball.

Tensor glueball: In Ref. [13], it was shown that $f_J(2220)$ does not lie on the Regge trajectories. Its mass fits well with lattice (see Table I), it is narrow, the $\pi\pi/KK$ ratio agrees with flavour blindness [14], and no $\gamma\gamma$ decay was seen, hence it is a good candidate to be the tensor glueball. Yet, the experimental assessment of this resonance is necessary.

Pseudoscalar glueball: The pseudoscalar glueball has been investigated in a variety of scenarios, see the review [15]. In some works, *e.g.* Ref. [16], the pseudoscalar glueball was assigned to the resonance $\eta(1405)$, but it is not clear if $\eta(1405)$ and $\eta(1475)$ are two independent states (see the recent discussion in Ref. [17] and references therein). Moreover, the lattice mass is about 2.6 GeV, *i.e.* 1 GeV heavier. In Ref. [18], the decays of a hypothetical

pseudoscalar glueball (linked to the chiral anomaly [19]) with a mass of about 2.6 GeV were studied within the eLSM: the decay channels into $KK\pi$ and $\eta\pi\pi$ are dominant (for an independent AdS/QCD calculation, see [20].) A possible experimental candidate is the state $X(2370)$ measured by BES [21], yet future measurements are needed.

For the other glueballs listed in Table I, no candidate is presently known. Very recently, two theoretical studies have been performed with the aim of helping the future experimental search.

Pseudotensor glueball: In Ref. [22], the decays of a pseudotensor glueball, a putative resonance $\eta_2 \equiv G(3040)$, have been studied in a flavour-invariant hadronic model: sizable decay into $K_2^*(1430)K$ and $a_2(1320)\pi$ are predicted (they are enhanced by isospin factors). Moreover, decays into a vector and a pseudoscalar mesons vanish at leading order, hence $\Gamma_{G \rightarrow \rho\pi} = \Gamma_{G \rightarrow K^*(892)K} = 0$.

Vector glueball: The vector glueball is interesting since it can be directly formed in e^+e^- scattering. Up to now, the search for candidates was not successful [23]. The decays of a vector glueball (called $\mathcal{O} \equiv \mathcal{O}(3810)$) using the eLSM have been studied in Ref. [24] (for previous theoretical works, see Ref. [25]). Three interaction terms have been considered. While the intensity of the corresponding coupling constants cannot be determined, some decay ratios are predicted. In the first two interaction terms (which are also dilatation invariant, then should dominate), the main decay modes are $\mathcal{O} \rightarrow b_1\pi \rightarrow \omega\pi\pi$ (first term) as well as $\mathcal{O} \rightarrow \omega\pi\pi$ and $\mathcal{O} \rightarrow \pi KK^*(892)$ (second term). The third interaction term, which breaks dilatation invariance, predicts decays into vector–pseudoscalar pairs, in particular $\mathcal{O} \rightarrow \rho\pi$ and $\mathcal{O} \rightarrow KK^*(892)$.

Both the pseudotensor and the vector glueballs (as well as other heavy glueballs) can be experimentally produced in formation processes at the future PANDA experiment [26].

3. Glueballs' widths via large- N_c considerations

The widths of glueballs are presently unknown. The scalar and the pseudoscalar glueball are somewhat special, since they are linked to the trace and axial anomalies. However, for the other glueballs, a (rough!) estimate using large- N_c considerations may be helpful (for reviews on the large- N_c approach, see [27].)

First, we recall that the dominant decay of a $\bar{q}q$ meson into two $\bar{q}q$ states scales as $1/N_c$. A typical example is that of the $\rho(770)$ meson ($\rho(770)^+ \equiv u\bar{d}$) decays through creation of a $\bar{u}u$ or $\bar{d}d$ pair from the vacuum that recombine in $\pi^+\pi^0$

$$\Gamma_{\rho \rightarrow \pi\pi} \propto \frac{1}{N_c} \quad \text{and} \quad \Gamma_{\rho \rightarrow \pi\pi}^{\text{exp}} = 147.8 \pm 0.9 \text{ MeV}. \quad (1)$$

Similarly, the vector kaonic state $K^*(892)$ decays into $K\pi$ are regulated by a similar strength $\Gamma_{K^*(892) \rightarrow K\pi}^{\text{exp}} = 50.3 \pm 0.8 \text{ MeV}$ (it is smaller only due to phase space). From the tensor sector: $\Gamma_{f'_2(1525) \rightarrow KK} = 67.4 \pm 8.9 \text{ MeV}$. Other examples are in the PDG. Interestingly, when going to higher masses, the *qualitative* picture does not change. For instance, for the $\bar{c}c$ state $\psi(4040)$: $\Gamma_{\psi(4040) \rightarrow DD}^{\text{exp}} = 80 \pm 10 \text{ MeV}$. Summarizing, whenever a strong (OZI-allowed) decay of a conventional $\bar{q}q$ meson M into two conventional mesons M_1 and M_2 is kinematically allowed, one has

$$\Gamma_{M \rightarrow M_1 M_2}^{\text{OZI-allowed}} \propto \frac{1}{N_c} \quad \text{and} \quad \Gamma_{M \rightarrow M_1 M_2}^{\text{OZI-allowed}} \sim 100 \text{ MeV}. \quad (2)$$

Clearly, there are modifications when threshold effects are important and/or certain quantum numbers are considered, but the whole picture is rather stable.

Next, let us consider OZI suppressed decay [28], which occurs through annihilation of the original $\bar{q}q$ pair into gluons, which then reconvert into $\bar{q}q$ mesons. In the large- N_c language, the scaling $\Gamma_{\bar{q}q \rightarrow MM}^{\text{OZI-suppressed}} \propto N_c^{-3}$ holds. A nice example is provided by the decay of the tensor state $f'_2(1525)$ into $\pi\pi$. This state is predominantly $\bar{s}s$, hence this transition goes as N_c^{-3} . Experimentally,

$$\Gamma_{f'_2(1525) \rightarrow \pi\pi} \propto \frac{1}{N_c^3} \quad \text{and} \quad \Gamma_{f'_2(1525) \rightarrow \pi\pi}^{\text{exp}} = 0.62 \pm 0.14 \text{ MeV} \quad (3)$$

which is of a factor 100 (!) smaller than $\Gamma_{f'_2(1525) \rightarrow KK}$ (even if the phase space into $\pi\pi$ is large). A very well-known example in the heavy-quark sector is given by the decay of the j/ψ meson into hadrons. The full hadronic decay (also suppressed by N_c^{-3}) reads $\Gamma_{j/\psi \rightarrow \text{hadrons}}^{\text{exp}} = 0.081 \pm 0.002 \text{ MeV}$. As shown in [27], the large- N_c approach naturally explains the validity of the OZI rule [28] (and is actually the only theoretical framework to derive it). Also in this case, various other examples exist, such as $\Gamma_{\psi(2S) \rightarrow \text{hadrons}}^{\text{exp}} = 0.280 \pm 0.07 \text{ MeV}$ and $\Gamma_{\chi_{c2}(1P) \rightarrow \text{hadrons}}^{\text{exp}} = 1.93 \pm 0.11 \text{ MeV}$. In conclusion, one has the following estimate:

$$\Gamma_{M \rightarrow M_1 M_2}^{\text{OZI-suppressed}} \propto \frac{1}{N_c^3} \quad \text{and} \quad \Gamma_{M \rightarrow M_1 M_2}^{\text{OZI-suppressed}} \lesssim 1 \text{ MeV}. \quad (4)$$

Let us now turn to a heavy glueballs above 2.6 GeV. The large- N_c scaling of a glueball's decay into two conventional mesons is given by $\Gamma_{G \rightarrow MM} \propto N_c^{-2}$,

thus, one has the relation

$$\begin{aligned} 1 \text{ MeV} &\sim \Gamma_{M \rightarrow M_1 M_2}^{\text{OZI-suppressed}} \propto \frac{1}{N_c^3} < \Gamma_{G \rightarrow MM} \\ &\propto \frac{1}{N_c^2} < \frac{1}{N_c} \propto \Gamma_{M \rightarrow M_1 M_2}^{\text{OZI-allowed}} \sim 100 \text{ MeV}. \end{aligned} \quad (5)$$

Hence, we *guess* that the expected width of a glueball lies between 1 and 100 MeV

$$\Gamma_{G \rightarrow MM} \sim 10 \text{ MeV}. \quad (6)$$

Such a width is relatively small to allow experimental detection of such states (in particular at PANDA [26]). For the special case of the vector glueball [24], we expect that its width is in between that of OZI-suppressed and OZI-allowed charm–anticharm decays of vector states: $0.298 \text{ MeV} = \Gamma_{\psi(2S)}^{\text{exp}} < \Gamma_{\mathcal{O} \rightarrow \text{hadrons}} < \Gamma_{\psi(4040) \rightarrow DD}^{\text{exp}} = 80 \text{ MeV}$. Namely, the vector glueball $\mathcal{O}$ is at an intermediate stage between three gluons and quarks (in order $\mathcal{O}$ to decay, gluons have to completely annihilate into quarks). Moreover, the fact that at least three valence gluons are contained in the vector glueball, is a further hint that its decay should not be large.

4. Conclusions

Glueballs are expected to exist but were not yet found in experiments. In this work, we have briefly reviewed the status of some candidates and presented predictions for the heavy pseudoscalar and vector glueballs. Moreover, we have discussed the possible width of a heavy glueball, obtaining the heuristic, rough estimate of about 10 MeV. Experimental searches at low energies in the experiments GlueX [29] and CLAS12 [30] at Jefferson Lab (see also [31]) and at high energy at the ongoing BESIII [21, 32], and at the future PANDA [26] experiments are expected to improve our understanding.

The author acknowledges support from the National Science Centre, Poland (NCN) through the OPUS project No. 2015/17/B/ST2/01625.

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