A POSSIBLE ASSIGNMENT FOR THE RESONANCE STATE $X(1835)$

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In the the framework of Regge phenomenology and meson–meson mass mixing, we estimated the masses of pseudoscalar meson nonet. The results suggest that the $X(1835)$ should be assigned as the second radial excitation of the η' rather than the ground pseudoscalar glueball. As a byproduct, we obtain the mass of ground pseudoscalar glueball in the glueball dominance picture, which is well agreement with predictions of other different theoretical models.

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1. Introduction

The existence of glueballs is one of the important predictions of the quantum chromodynamics (QCD). The discovery of glueball would be a strong support of the QCD theory. Therefore, the search and identification of glueball has been an active field [1–4]. According to the new edition PDG [5], the ground state glueball is predicted by lattice gauge theories to be scalar glueball, and the mass is determined to be 1710 MeV, with an error of about 100 MeV. In general, states with the same isospin–spin-parity $IJ^{\rm PC}$ and additive quantum numbers can mix, which makes the identification of glueball extremely difficult. Recently, the mixing of three states $f_0(1370)$,$f_0(1500)$ and $f_0(1710)$ has been studied by many authors [6–9]. For the pseudoscalar glueball, the situation even worse, the mass of the lowest lying pseudoscalar glueball given by lattice calculation is about 2.5 GeV. But in the past thirty years, the state $\eta(1440)$ has been arranged as the pseudoscalar glueball candidate in Refs. [7–14]. Now, there are two states ($\eta(1475)$ and $\eta(1405)$) in this mass region. The former has been interpreted as the first radial excitation of η', the latter is an candidate for the lowest pseudoscalar glueball. However, it is obvious that the mass is far from the values of theoretical prediction. If the $\eta(1405)$ is assigned as pseudoscalar glueball, one has to introduce a special mixing mechanism to pull down its mass. For the tensor glueball, the situation seems clear, both the experimental candidates and lattice results are in the same mass region 2400 MeV.

Recently, the resonance state $X(1835)$ has been observed by BES Collaboration [15] in the reactions $J/\psi \to \gamma\eta'\pi^+\pi^-$. The meson was detected in both $\eta\pi\pi$ and $\gamma\rho$ channels. The mass and the width are $1833.7 \pm 6.2 \pm 2.7$ MeV and $67.7 \pm 20.3 \pm 7.7$ MeV, respectively. There are various interpretations for the observed resonance state. In Ref. [16], $X(1835)$ may be as a $p\bar{p}$ baryonium state. But there is no strong experimental evidence that $p\bar{p}$ threshold enhancement and $X(1835)$ are the same resonance. In Ref. [17] and [18], this state is assigned as the second radial excitations of meson η'. N. Kochelev shows this state is the lowest pseudoscalar glueball by using the partial U(1)A symmetry in high hadronic excitations [19–21]. Many experimental data and theoretical models also imply the $X(1835)$ to be either conventional pseudoscalar meson or the lowest pseudoscalar glueball.

In the present work, employing different approaches Regge phenomenology and meson–meson mass mixing, we predict the masses of the $s\bar{s}$ member of 3^1S_0 meson nonet and the lowest pseudoscalar glueball. The results should be useful for the assignment of $X(1835)$.

2. Meson–meson mass mixing matrix

In the PDG [5], the pseudoscalar meson nonet are assigned in the $q\bar{q}$ quark model (see Table I).

TABLE I

Assignment of the pseudoscalar meson nonet in PDG.

$N^{2s+1}L_J$	$I=1$	$I=0$	$I=1/2$
1^1S_0	π	η η'	K
2^1S_0	$\pi(1300)$	$\eta(1295)$ $\eta(1475)$	$K(1460)$
3^1S_0	$\pi(1800)$	$\eta(1760)$ X	$K(1830)$

In Table I, the ground pseudoscalar meson nonet has been established well, also, the first radial excitations were assigned as $\pi(1300)$, $\eta(1295)$, $\eta(1475)$, $K(1460)$. However, the $K(1460)$ needs further confirmation experimentally because it was observed only in two experiments. For the 3^1S_0 meson nonet, the $s\bar{s}$ member (X denotes this state) has not been observed in the experiment.

In the quark model, the two isoscalar states with the same J^{PC} will mix to form the physical isoscalar states. In the $|S\rangle = s\bar{s}$ and $|N\rangle = (u\bar{u}+d\bar{d})/\sqrt{2}$ basis, the form of the mass-squared matrix describing the isoscalar states mixing of a nonet can be written as [22]:

$$M^2 = \begin{pmatrix} M_N^2 + 2A & \sqrt{2}Ar \\ \sqrt{2}Ar & M_S^2 + Ar^2 \end{pmatrix}, \tag{1}$$

where M_N^2 and M_S^2 are the masses of bare states $(u\bar{u} + d\bar{d})/\sqrt{2}$ and $s\bar{s}$, respectively; A is the total annihilation strength of $q\bar{q}$ pair for the light flavor u and d, r describes the SU(3) breaking ration of the nonstrange and strange quark propagators via the constituent quark mass ratio. The constituent quark mass ratio can be determined within the nonrelativistic constituent quark model [23–25].

In the meson nonet, the physical states of isoscalar ϕ (is mainly nonstrange component) and ϕ' (is mainly strange component) are the eigenvectors of mass-squared matrix, the two states can be related to the bare states N and $s\bar{s}$ by

$$\begin{pmatrix} |\phi\rangle \\ |\phi'\rangle \end{pmatrix} = U \begin{pmatrix} |N\rangle \\ |S\rangle \end{pmatrix}, \tag{2}$$

and the unitary matrix U can be described

$$UM^2U^\dagger = \begin{pmatrix} M_\phi^2 & 0 \\ 0 & M_{\phi'}^2 \end{pmatrix}, \tag{3}$$

where M_ϕ^2 and $M_{\phi'}^2$ are the masses of states ϕ and ϕ', respectively.

From Eqs. (1), (2) and (3), we have

$$2A + 2M_{I=1/2}^2 + Ar^2 = M_\phi^2 + M_{\phi'}^2\,, \tag{4}$$

$$\left(M_{I=1}^2 + 2A\right)\left(2M_{I=1/2}^2 - M_{I=1}^2 + Ar^2\right) - 2r^2A^2 = M_\phi^2 M_{\phi'}^2\,. \tag{5}$$

3. Regge phenomenology for pseudoscalar meson

Based on the hadron with a set of given quantum number belonging to a quasi-linear trajectory, we will have the following relation [26]:

$$J = \alpha_{i\bar{i}'}(0) + \alpha'_{i\bar{i}'} M_{i\bar{i}'}^2\,, \tag{6}$$

where $i\bar{i}'$ refers to the quark (antiquark) flavor, J and $M_{i\bar{i}'}$ are, respectively, the spin and mass of the $i\bar{i}'$ meson. The parameters $\alpha'_{i\bar{i}'}$ and $\alpha_{i\bar{i}'}(0)$ are, respectively, the slope and intercept of the trajectory. The intercepts can be parameterized by [26–28],

$$\alpha_{i\bar{i}}(0) + \alpha_{j\bar{j}}(0) = 2\alpha_{i\bar{j}}(0)\,. \tag{7}$$

The slope depends on the flavor content of the state [29]. According to the available data of meson states, Burakovsky constructs a slope formula for all quarks flavors [30]. For the light meson state composed of u, d and s quark, the slopes

$$\alpha'_{n\bar{n}} = 0.88 \text{ GeV}\,, \qquad \alpha'_{s\bar{n}} = 0.84 \text{ GeV}\,, \qquad \alpha'_{s\bar{s}} = 0.80 \text{ GeV}\,, \tag{8}$$

where n denotes u or d quark. From Eq. (6) and (7), we have

$$2\alpha'_{s\bar{n}} M^2_{K(1460)} = \alpha'_{s\bar{s}} M^2_{\eta(1475)} + \alpha'_{n\bar{n}} M^2_{\pi(1300)}\,, \tag{9}$$

$$\alpha'_{s\bar{s}} M^2_X = 2\alpha'_{s\bar{n}} M^2_{K(1830)} - \alpha'_{n\bar{n}} M^2_{\pi(1800)}\,. \tag{10}$$

Inserting the masses of meson nonet of 3^1S_0, we can obtain$M_{(1460)} = 1385$ MeV and $M_X = 1862.44$ MeV.

4. The low lying pseudoscalar glueball mass

In Eq. (1), the quark mixing amplitudes can be expressed as

$$A_{qq'} = \sum_k \frac{\left\langle q\bar{q} \left| H^{q'\bar{q}'}_{\text{p.c.}} \right| k \right\rangle \left\langle k \left| H^{q\bar{q}}_{\text{p.c.}} \right| q'\bar{q}' \right\rangle}{M^2_{q'\bar{q}'} - M^2_k}\,, \tag{11}$$

where $H^{q\bar{q}}_{\text{p.c.}}$ is the quark pair creation operator for the flavor q, $|k\rangle$ is a complete set of the intermediate states. Based on the assumption that glueball with the corresponding quantum numbers dominates the $q\bar{q} \leftrightarrow q'\bar{q}'$ transitions and there is no direct quarkonium–quarkonium mixing, we obtain the following relations

$$A = \frac{f^2_{n\bar{n}G}}{M^2_{I=1} - M^2_G}\,, \tag{12}$$

$$Ar^2 = \frac{f^2_{s\bar{s}G}}{2M^2_{I=1/2} - M^2_{I=1} - M^2_G}\,, \tag{13}$$

where $f_{q\bar{q}G} \equiv \langle q\bar{q} \mid H^{q\bar{q}} \mid G\rangle \mid_{p^\mu P_\mu = M^2_{q\bar{q}}}$, q refers to the u, d and s quarks.

Considering the functions $f_{q\bar{q}G}$, Brisudova [35] assumed the product of $f_{n\bar{n}G}$ and $f_{s\bar{s}G}$ in QCD to be a constant approximately independent of the quantum numbers of a meson nonet, *viz.*,

$$f_{n\bar{n}G} f_{s\bar{s}G} \approx \text{const.} \tag{14}$$

Using the relation (14), from Eqs. (4), (5), (11)–(13), we have

$$A^2 r^2 (2M^2_{I=1/2} - M^2_{I=1} - M^2_G)(M^2_{I=1} - M^2_G) = f^2_{n\bar{n}G} f^2_{s\bar{s}G} \tag{15}$$

$$A = \frac{M^2_\phi M^2_{\phi'} - \left(M^2_\phi + M^2_{\phi'}\right) M^2_{I=1} + M^4_{I=1}}{4\left(M^2_{I=1/2} - M^2_{I=1}\right)}, \tag{16}$$

$$r = -\frac{2T}{\left(M^2_\phi - M^2_{I=1}\right)\left(M^2_{\phi'} - M^2_{I=1}\right)} \tag{17}$$

with

$$\begin{aligned} T = {} & M^2_\phi M^2_{\phi'} - 2\left(M^2_\phi + M^2_{\phi'}\right) M^2_{I=1/2} + 4M^4_{I=1/2} \\ & + \left(M^2_\phi + M^2_{\phi'}\right) M^2_{I=1} - 4M^2_{I=1/2} M^2_{I=1} + M^4_{I=1} \,. \end{aligned} \tag{18}$$

Therefore, applying relations (15), (16) and (17) to the 2^1S_0 meson and 1^3P_2 tensor meson nonet, we have

$$\begin{aligned} & \frac{\left(M^2_{\rm pse} - M^2_{\pi(1300)}\right)\left(M^2_{\rm pse} + M^2_{\pi(1300)} - 2M^2_{K(1460)}\right)\left(M^2_{K^*_2(1430)} - M^2_{a_2(1320)}\right)^2}{\left(M^2_{\rm ten} - M^2_{a_2(1320)}\right)\left(M^2_{\rm ten} + M^2_{a_2(1320)} - 2M^2_{K^*_2(1430)}\right)\left(M^2_{K(1460)} - M^2_{\pi(1300)}\right)^2} \\ & \times \frac{\left(M^2_{\eta(1295)} - M^2_{\pi(1300)}\right)}{\left(M^2_{f_2(1270)} - M^2_{a_2(1320)}\right)} \simeq \frac{\left(M^2_{f'_2(1525)} + M^2_{a_2(1320)} - 2M^2_{K^*_2(1430)}\right)}{\left(M^2_{\eta(1475)} + M^2_{\pi(1300)} - 2M^2_{(1460)}\right)} \\ & \simeq \frac{\left(2M^2_{K^*_2(1430)} - M^2_{a_2(1320)} - M^2_{f_2(1270)}\right)\left(M^2_{f'_2(1525)} - M^2_{a_2(1320)}\right)}{\left(2M^2_{K(1460)} - M^2_{\pi(1300)} - M^2_{\eta(1295)}\right)\left(M^2_{\eta(1475)} - M^2_{\pi(1300)}\right)}, \end{aligned} \tag{19}$$

where the masses used as input parameters are taken from PDG, $M_{\rm ten}$ and $M_{\rm pse}$ are the masses of ground tensor and pseudoscalar glueball respectively. However, the isodoublet $K(1460)$ of 2^1S_0 has been observed in only two experiments. We take the average value (see Table II) as input parameter. In order to estimate the mass of pseudoscalar glueball, we should determine the mass of ground tensor glueball. In Table III, we list the tensor glueball mass predicted in different theoretical models. In the present work, we take the average value 2.4 GeV as input. The mass of ground pseudoscalar glueball is determined to be (see Table IV).

TABLE II

Masses (in MeV) of pseudoscalar meson states $K(1460)$, X.

Mass	Present work	Ref. [5]	Ref. [31]	Ref. [32]	Ref. [33]	Ref. [34]
$M_{K(1460)}$	1385	~ 1460	1391.8	1369.17	1400	
M_X	1862.44					1853 or 1849 ± 1.2

TABLE III

Masses (in GeV) of the ground tensor glueball from different theoretical models.

Mass	Ref. [36]	Ref. [37]	Ref. [38]	Ref. [39]	Ref. [40]	Ref. [41]	Ref. [42]	Average
$M_{\rm ten}$	2.59	2.40	2.23	2.42	2.26	2.337	2.354	2.370

TABLE IV

Masses (in GeV) of the ground pseudoscalar glueball.

Mass	Present work	Ref. [43]	Ref. [44]	Ref. [45]
$M_{\rm pse}$	2.238	2.56	2.05 ± 0.19	2.2 ± 0.2

5. Conclusion

In this paper, employing two different approaches, we estimate the masses of the second radial excitation of the η' and the lowest pseudoscalar glueball. Within the framework of Regge trajectory, the mass of the second radial excitation of the η' is determined to be 1862.44 MeV, which is in agreement with our previous work. Moreover, based on the glueball–meson relation derived in the glueball dominance picture, we obtain the mass of the lowest lying pseudoscalar glueball of about 2.238 GeV, which is well consistent with the lattice predictions. Comparing the results with experimental data and other theoretical predictions, we suggest that the $X(1835)$ should be assigned as the second radial excitation of η' rather than pseudoscalar glueball.

REFERENCES

[1] C. Amsler, N.A. Tornqvist, *Phys. Rep.* **389**, 61 (2004).

[2] D.V. Bugg, *Phys. Rep.* **397**, 257 (2004).

[3] V.V. Anisovich, M.A. Matveev, J. Nyiri, A.V. Sarantsev, *Int. J. Mod. Phys.* **A20**, 6327 (2005).

[4] V. Vento, *Phys. Rev.* **D73**, 054006 (2006).

[5] W.M. Yao, *J. Phys. G* **33**, 1 (2006).

[6] F.E. Close, A. Kirk, *Phys. Lett.* **B483**, 345 (2000).

[7] D.M. Li, H. Yu, Q.X. Shen, *Eur. Phys. J.* **C19**, 529 (2001); D.M. Li, H. Yu, Q.X. Shen, *Commun. Theor. Phys.* **34**, 507 (2001).

[8] F.E. Close, G.R. Farrar, Z. Li, *Phys. Rev.* **D55**, 5749 (1997).

[9] D. Weingarten, *Nucl. Phys. (Proc. Suppl.)* **53**, 232 (1997).

[10] M. Strohmerier-Presicek, T. Gutsche, R. Vinh Mau, A. Faessler *Phys. Rev.* **D60**, 054010 (1999).

[11] D.M. Li, H. Yu, S.S. Fang, *Eur. Phys. J.* **C28**, 335 (2003).

[12] W.S. Carvalho, A.C.B. Antunes, A.S. de Castro, *Eur. Phys. J.* **C7**, 95 (1999).

[13] M. Genovese, E. Predazzi, D.B. Lichtenberg, `hep-ph/9304231`.

[14] J.L. Rosner, *Phys. Rev.* **D27**, 1101 (1983).

[15] M. Ablikim *et al.* [BES Collab.], *Phys. Rev. Lett.* **95**, 262001 (2005).

[16] S.L. Zhu, C.S. Gao, *Commun. Theor. Phys.* **46**, 291 (2006).

[17] T. Huang, S.L. Zhu, *Phys. Rev.* **D73**, 014023 (2006).

[18] D.M. Li, B. Ma, *Phys. Rev.* **D77**, 074004 (2008).

[19] N. Kochelev, D.P. Min, *Phys. Lett.* **B633**, 283 (2006); *Phys. Rev.* **D72**, 097502 (2005).

[20] X.G. He, X.Q. Li, X. Liu, J.P. Ma, *Eur. Phys. J.* **C49**, 731 (2007).

[21] B.A. Li, *Phys. Rev.* **D74**, 034019 (2006).

[22] X.C. Feng, K.W. Wei, G.J. Zhang, *Chin. Phys.* **15**, 2906 (2006).

[23] P.V. Chliapnikov, *Phys. Lett.* **B496**, 129 (2000).

[24] L. Burakovsky, T. Goldman, *Phys. Rev.* **D57**, 2879 (1998).

[25] D.M. Li, Z. Li, *Eur. Phys. J.* **A28**, 369 (2006).

[26] D.M. Li, B. Ma, Y.X. Li, Q.K. Yao, H. Yu, *Eur. Phys. J.* **C37**, 323 (2004).

[27] V.V. Dixit, L.A. Balazs, *Phys. Rev.* **D20**, 816 (1979).

[28] A.B. Kaidalov, *Z. Phys.* **C12**, 63 (1982).

[29] S. Filipponi, G. Pancheri, Y. Srivastava, *Phys. Rev. Lett.* **80**, 1838 (1998).

[30] L. Burakovsky, T. Goldman, *Phys. Rev. Lett.* **82**, 457 (1999).

[31] D.M. Li, B. Ma, Q.K. Yao, J.L. Feng , X.C. Feng, *Mod. Phys. Lett.* **A18**, 2775 (2003).

[32] X.C. Feng, *Acta Phys. Pol. B* **39**, 1001 (2008).
[33] V.V.Khruschev, S.V.Semenov, *Part. Nucl. Lett.* **5**, 5 (2002).
[34] X.C. Feng, D.M. Li, *Acta Phys. Sin.* **54**, 4084 (2005).
[35] M.M. Brisudova, L. Burakovsky, T. Goldman, *Phys. Rev.* **D58**, 114015 (1998).
[36] A.B. Kaidolv, Yu.A. Simonov, *Phys. Lett.* **B477**, 163 (2000).
[37] C.J. Morningstar, M.J. Peardon, *Phys. Rev.* **D60**, 034509 (1999).
[38] W.S. Hou, C.Y. Ko, `hep-ph/9708314`.
[39] A.P. Szczepaniak, E.S. Swanson, *Phys. Lett.* **B577**, 61 (2003).
[40] M.J. Temper, `hep-lat/9711011`.
[41] G.S. Bali *et al.*, *Phys. Lett.* **B309**, 378 (1993).
[42] F. Niedermayer, P. Rufenacht, U. Wenger *Nucl. Phys.* **B597**, 413 (2001).
[43] Y. Chen, A. Alexandru, S.J. Dong, *Phys. Rev.* **D73**, 014516 (2006).
[44] S. Narison, *Nucl. Phys.* **B509**, 312 (1998).
[45] H. Forkel, *Phys. Rev.* **D71**, 054008 (2005).