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On the mass of the $s\bar{s}$ member of the 1^3D_1 meson nonet

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In the framework of Regge phenomenology and meson–meson mixing, this paper estimates the mass of isoscalar state ($s\bar{s}$) of the 1^3D_1 meson nonet, and the results given by two different approaches are 1735.51 ± 59MeV and 1730.29 ± 46.8MeV.

Keywords: Regge phenomenology, meson-meson mixing, meson mass

PACC: 1440，3520X

1. Introduction

Hadron spectroscopy is a very active field with the recent discovery of new light and heavy quark mesons. In the last decade, a tremendous amount of effort has been made to study meson spectra over the mass region 1000–2400MeV.[1]

According to the new edition of Particle Data Group (PDG) compilations,[2] for the $J^{PC} = 1^{--}$ meson nonet, the members of the 1^3S_1 and 2^3S_1 nonet have been well established. However, the $s\bar{s}$ member of the 1^3D_1 nonet is not yet observed (see Table 1). In this paper, we want to estimate the mass of the isoscalar state of the 1^3D_1 meson nonet by use of the Regge phenomenology and the mass relation derived from meson-meson mixing. Our work would be useful to search for the candidate of the isoscalar state of the 1^3D_1 meson nonet experimentally.

Table 1. The assignments for the observed $J^{PC} = 1^{--}$light mesons suggested by PDG.

$N^{2S+1}L_J$	$I=1$	$I=0$		$I=\frac{1}{2}$
1^3S_1	ρ	ω	ϕ	$K^*(892)$
2^3S_1	$\rho(1450)$	$\omega(1420)$	$\phi(1680)$	$K^*(1410)$
1^3D_1	$\rho(1700)$	$\omega(1650)$	ϕ(x)	$K^*(1680)$

2. Regge phenomenology

The topic of Regge trajectories was an active area of research in the 1960s. But there is a resurgence of interest in Regge trajectories because of the quantity of new data which need analysis and the new quark models which need more complete experimental fits for testing. Assuming that the hadrons composed the light (u, d, s) quarks populate linear Regge trajectories, one can have[3]

$$J = \alpha'_{i\bar{i}'} M^2_{i\bar{i}'} + \alpha_{i\bar{i}'}(0), \tag{1}$$

where i(i′) refers to the quark (antiquark) flavour, J and $M_{i\bar{i}'}$ are respectively the spin and mass of the $i\bar{i}'$ meson. $\alpha'_{i\bar{i}'}$ and $\alpha_{i\bar{i}'}(0)$ are respectively the slope and intercept of the trajectory. The slope depends on the flavour content of the state lying on the corresponding trajectory composed of light quark,[4]

$$\alpha'_{n\bar{n}} \simeq 088\,\mathrm{GeV}^{-2}, \quad \alpha'_{s\bar{n}} \simeq 084\,\mathrm{GeV}^{-2}, \quad \alpha'_{s\bar{s}} \simeq 080\,\mathrm{GeV}^{-2}. \tag{2}$$

Using the relations among the intercepts,[5–8]

$$\alpha_{i\bar{i}}(0) + \alpha_{j\bar{j}}(0) = 2\alpha_{j\bar{i}}(0), \tag{3}$$

we can have

$$M^2_\phi = \frac{2\alpha'_{s\bar{n}} M^2_{s\bar{n}} - \alpha'_{n\bar{n}} M^2_{n\bar{n}}}{\alpha'_{s\bar{s}}}. \tag{4}$$

From Eq.(4), we can obtain the mass of the $s\bar{s}$ member of the 1^3D_1 meson nonet. The results are shown in Table 2.

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Table 2. The predicted results from Eqs.(4) and (12) for different meson nonet.

$N^{2S+1}L_J$	1^3S_1	2^3S_1	1^3D_1
$M_{I=0(S\bar{S})}[E_q \cdot (4)]$	1007.75 ± 0.99	1697.53 ± 23.7	1735.51 ± 59
$M_{I=0(S\bar{S})}[E_q \cdot (12)]$	999.6 ± 0.96	1680.81 ± 24.6	1730.29 ± 46.8
$M_{I=0(S\bar{S})}$[PDG(2)]	1019.456 ± 0.02	1680 ± 20	

In our calculation, all the masses used as input are taken from PDG[2] except the mass of the $K^*(1410)$. The $K^*(1410)$ seems too light to be 2^3S_1 state, even if one takes into account the possible mixing between 2^3S_1 and 1^3D_1.[9] Relativistic quark model[10] and other pheonomenology approaches[11] consistently suggest the mass of the $K^*(1410)$ is about 1580 MeV. Here and below, we take $M_{K^*(1410)} = 1580\,\mathrm{MeV}$.

3. Meson-meson mixing

In the $N = (u\bar{u} + d\bar{d})/\sqrt{2}$ and $S = s\bar{s}$ basis, the form of the mass-squared matrix describing the isoscalar states mixing of a nonet can be written as follows:[12]

$$M^2 = \begin{pmatrix} M_N^2 + 2A & \sqrt{2}XA \\ \sqrt{2}XA & M_S^2 + AX^2 \end{pmatrix} \tag{5}$$

where M_N and M_S are the masses of bare states N and S respectively, A is the total annihilation strength of $q\bar{q}$ pair for the light flavour u and d, X describes the $SU(3)$ breaking ratio of the nonstrange and strange quark propagators via the constituent quark mass ratio $m_u/m_s = 0.6298$.

If we assume that physical states $|\omega\rangle$ and $|\phi\rangle$ are the eigenvectors of mass-squared matrix, the physical isoscalar states can be related to the bare states N and S by

$$\begin{pmatrix} |\omega\rangle \\ |\phi\rangle \end{pmatrix} = U \begin{pmatrix} N \\ S \end{pmatrix} \tag{6}$$

and the unitary matrix U can be described as:

$$UM^2U^+ = \begin{pmatrix} M_\phi^2 & 0 \\ 0 & M_\omega^2 \end{pmatrix} \tag{7}$$

where M_ω^2 and M_ϕ^2 are the mass of $|\omega\rangle$ and $|\phi\rangle$ respectively.

From Eqs(6),(7), we can get:

$$2A + M_N^2 + M_S^2 + AX^2 = M_\omega^2 + M^2\phi, \tag{8}$$

$$(M_N^2 + 2A)(M_S^2 + AX^2) - 2X^2A^2 = M_\omega^2 M_\phi^2. \tag{9}$$

Since N is the orthogonal partner of the isovector state of a meson nonet, we can expect the N degenerates with isovector state, therefore can get $M_N^2 = M_\rho^2$, which is widely adopted in literature.[13–15] With the help of the Gell-Mann–Okubo mass formula,[16] $M_S^2 = 2M_{K^*}^2 - M_\rho^2$ we have

$$2A + 2M_{K^*}^2 + AX^2 = M_\omega^2 + M^2\phi, \tag{10}$$

$$(M_\rho^2 + 2A)(2M_{K^*}^2 - M_\rho^2 + AX^2) - 2X^2A^2 = M_\omega^2 M_\phi^2. \tag{11}$$

Based on Eqs.(11),(12), one can have

$$M_\phi = \sqrt{2M_{K^*}^2 - M_\omega^2 + \frac{(2+X^2)(M_\omega^4 - 2M_\omega^2 M_{K^*}^2 + 2M_{K^*}^2 M_\rho^2 - M_\rho^4)}{(2+X^2)M_\omega^2 - M_\rho^2 X^2 - 4M_{K^*}^2 + 2M_\rho^2}}. \tag{12}$$

From Eq.(12), the estimated mass of the $s\bar{s}$ member of the 1^3D_1 meson is given in Table 2.

4. Conclusion

Based on the mass relation derived from the meson-meson mixing, we predict that the isoscalar state of the 1^3D_1 meson nonet is about 1730.29 ± 46.8 MeV, which is consistent with 1735.51 ± 59 MeV, the result obtained from Regge phenomenology. The large error of the predicted results mainly results from the large mass of correlational nonet state.

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