第24卷第5期 高能物理与核物理 Vol.24, No.5
2000年5月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS May, 2000

Mixing of the Neutral Tensor Mesons $f_2(1270)$, $f_2'(1525)$ and the Glueball Candidate $\xi(2230)$ *

LI DeMin FANG Jian YU Hong SHEN QiXing
(*Institute of High Energy Physics, The Chinese Academy of Sciences, Beijing* 100039, *China*)

Abstract Assuming the spin-parity J^{PC} of the $\xi(2230)$ is 2^{++}, the mixing of the neutral tensor mesons $f_2(1270)$, $f'_2(1525)$ and the glueball candidate $\xi(2230)$ are investigated. The glueball-quarkonia content of the $f_2(1270)$, $f_2'(1525)$ and $\xi(2230)$ is obtained from a detailed fit to the available decay data of these three states. Several predictions for the decays of the $\xi(2230)$ are presented.

Key words tensor mesons, tensor glueball, mixing, the least square fit

The existence of glueballs made of gluons is one of the important predictions of QCD. The current situation with the identification of glueball states is rather complicated, but some progress has been made in the glueball sector. By studying the mixing between quarkonia and glueball to understand the properties of glueballs or identify the glueball states is an appealing approach[1—7].

It has not been finally determined that the spin-parity J^{PC} of the $\xi(2230)$ is 2^{++} or 4^{++}, but the narrow width of the $\xi(2230)$ and the large production rate in $J/\psi \longrightarrow \gamma\xi(2230)$[8,9] make the $\xi(2230)$ seem not to be an ordinary $q\bar{q}$ state.

If we assume that the spin-parity J^{PC} of the $\xi(2230)$ is 2^{++}, by studying the mixing of the $f_2(1270)$, $f_2'(1525)$ and $\xi(2230)$, we can obtain some information of the $\xi(2230)$.

In the $|N\rangle = |u\bar{u} + d\bar{d}\rangle/\sqrt{2}$, $|S\rangle = |s\bar{s}\rangle$, $|G\rangle = |gg\rangle$ basis, the quadratic mass matrix describing the mixing of a glueball and quarkonia can be written as follows[3]:

$$M^2 = \begin{pmatrix} m_N^2 + 2\lambda_N & \sqrt{2\lambda_N\lambda_S} & \sqrt{2\lambda_N\lambda_G} \\ \sqrt{2\lambda_N\lambda_S} & m_S^2 + \lambda_S & \sqrt{\lambda_S\lambda_G} \\ \sqrt{2\lambda_N\lambda_G} & \sqrt{\lambda_S\lambda_G} & m_G^2 + \lambda_G \end{pmatrix},$$

where m_N, m_S and m_G are the masses of the states $|N\rangle$, $|S\rangle$ and $|G\rangle$, respectively. λ_N, λ_S and λ_G are the mixing parameters. The physical states $|f_2(1270)\rangle$, $|f_2'(1525)\rangle$ and $|\xi(2230)\rangle$ are the eigenstates of M^2 with the eigenvalues $m_{f_2}^2$, $m_{f_2'}^2$ and m_ξ^2, respectively. If one defines a 3×3 unitary matrix U which transforms the states $|N\rangle$, $|S\rangle$ and $|G\rangle$ into the physical states $|f_2(1270)\rangle$, $|f_2'(1525)\rangle$ and $|\xi(2230)\rangle$, the three physical states can be read

$$\begin{pmatrix} |f_2(1270)\rangle \\ |f_2'(1525)\rangle \\ |\xi(2230)\rangle \end{pmatrix} = U \begin{pmatrix} |N\rangle \\ |S\rangle \\ |G\rangle \end{pmatrix} = \begin{pmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{pmatrix} \begin{pmatrix} |N\rangle \\ |S\rangle \\ |G\rangle \end{pmatrix},$$

where

Received 28 October 1999
* Supported by National Natural Science Foundation of China and the Grant of The Chinese Academy of Sciences

$$U=\begin{pmatrix} \frac{\sqrt{2\lambda_N\lambda_G}(m_S^2-m_{f_2}^2)}{C_{f_2}} & \frac{\sqrt{\lambda_S\lambda_G}(m_N^2-m_{f_2}^2)}{C_{f_2}} & \frac{2\lambda_N\lambda_S-(m_N^2+2\lambda_N-m_{f_2}^2)(m_S^2+\lambda_S-m_{f_2}^2)}{C_{f_2}} \\ \frac{\sqrt{2\lambda_N\lambda_G}(m_S^2-m_{f'_2}^2)}{C_{f'_2}} & \frac{\sqrt{\lambda_S\lambda_G}(m_N^2-m_{f'_2}^2)}{C_{f'_2}} & \frac{2\lambda_N\lambda_S-(m_N^2+2\lambda_N-m_{f'_2}^2)(m_S^2+\lambda_S-m_{f'_2}^2)}{C_{f'_2}} \\ \frac{\sqrt{2\lambda_N\lambda_G}(m_S^2-m_\xi^2)}{C_\xi} & \frac{\sqrt{\lambda_S\lambda_G}(m_N^2-m_\xi^2)}{C_\xi} & \frac{2\lambda_N\lambda_S-(m_N^2+2\lambda_N-m_\xi^2)(m_S^2+\lambda_S-m_\xi^2)}{C_\xi} \end{pmatrix} \tag{3}$$

with $C_{i(i=f_2,f'_2,\xi)}=$

$$\sqrt{2\lambda_N\lambda_G(m_S^2-m_i^2)^2+\lambda_S\lambda_G(m_N^2-m_i^2)^2+[2\lambda_N\lambda_S-(m_N^2+2\lambda_N-m_i^2)(m_S^2+\lambda_S-m_i^2)]^2}, \tag{4}$$

$$2\lambda_N=\frac{(m_{f_2}^2-m_N^2)(m_{f'_2}^2-m_N^2)(m_\xi^2-m_N^2)}{(m_S^2-m_N^2)(m_G^2-m_N^2)}, \tag{5}$$

$$\lambda_S=\frac{(m_{f_2}^2-m_S^2)(m_{f'_2}^2-m_S^2)(m_\xi^2-m_S^2)}{(m_N^2-m_S^2)(m_G^2-m_S^2)}, \tag{6}$$

$$\lambda_G=\frac{(m_{f_2}^2-m_G^2)(m_{f'_2}^2-m_G^2)(m_\xi^2-m_G^2)}{(m_N^2-m_G^2)(m_S^2-m_G^2)} \tag{7}$$

For the hadronic decays of the $f_2(1270)$, $f'_2(1525)$ and $\xi(2230)$, neglecting the possible glueball component in the final state mesons, we consider the three coupling modes (See Fig. 1.) Performing an elementary $SU(3)$ calculation[4,10—13], we can get the following equations:

$$\frac{\Gamma(f_2\to\pi\pi)}{\Gamma(f_2\to K\bar{K})}=3\left(\frac{p_\pi}{p_K}\right)^5\frac{\left[\frac{x_1}{\sqrt{2}}+r_1(\sqrt{2}x_1+y_1)+r_2z_1\right]^2}{\left[\frac{x_1}{\sqrt{2}}+y_1+r_1(2\sqrt{2}x_1+2y_1)+2r_2z_1\right]^2}, \tag{8}$$

$$\frac{\Gamma(f_2\to\eta\eta)}{\Gamma(f_2\to K\bar{K})}=\left(\frac{p_\eta}{p_K}\right)^5\frac{\left[\sqrt{2}\alpha^2x_1+2\beta^2y_1+r_1(\sqrt{2}x_1+y_1)+r_2z_1\right]^2}{\left[\frac{x_1}{\sqrt{2}}+y_1+r_1(2\sqrt{2}x_1+2y_1)+2r_2z_1\right]^2}, \tag{9}$$

$$\frac{\Gamma(f'_2\to\pi\pi)}{\Gamma(f'_2\to K\bar{K})}=3\left(\frac{p'_\pi}{p'_K}\right)^5\frac{\left[\frac{x_2}{\sqrt{2}}+r_1(\sqrt{2}x_2+y_2)+r_2z_2\right]^2}{\left[\frac{x_2}{\sqrt{2}}+y_2+r_1(2\sqrt{2}x_2+2y_2)+2r_2z_2\right]^2}, \tag{10}$$

$$\frac{\Gamma(f'_2\to\eta\eta)}{\Gamma(f'_2\to K\bar{K})}=\left(\frac{p'_\eta}{p'_K}\right)^5\frac{\left[\sqrt{2}\alpha^2x_2+2\beta^2y_2+r_1(\sqrt{2}x_2+y_2)+r_2z_2\right]^2}{\left[\frac{x_2}{\sqrt{2}}+y_2+r_1(2\sqrt{2}x_2+2y_2)+2r_2z_2\right]^2}, \tag{11}$$

$$\frac{\Gamma(\xi\to\pi\pi)}{\Gamma(\xi\to K\bar{K})}=3\left(\frac{p_\pi^\xi}{p_K^\xi}\right)^5\frac{\left[\frac{x_3}{\sqrt{2}}+r_1(\sqrt{2}x_3+y_3)+r_2z_3\right]^2}{\left[\frac{x_3}{\sqrt{2}}+y_3+r_1(2\sqrt{2}x_3+2y_3)+2r_2z_3\right]^2}, \tag{12}$$

where $\alpha = (\cos\theta - \sqrt{2}\sin\theta)/\sqrt{6}$, $\beta = (\sin\theta + \sqrt{2}\cos\theta)/\sqrt{6}$, θ is the mixing angle of η and η'. $p_j\,(p_j', p_j^{\xi})\,(j = \pi, \eta, K)$ is the momentum of the final state meson j in the center of mass system for the jj decays of the $f_2(1270)$ ($f'_2(1525)$, $\xi(2230)$). $r_1\,(r_2)$ represents the ratio of the effective coupling strength of the mode (b) (c) to that of the mode (a).

For the two-photon decays of the $f_2(1270)$ and $f'_2(1525)$, we have[14]:

$$\frac{\Gamma(f_2 \to \gamma\gamma)}{\Gamma(a_2(1320) \to \gamma\gamma)} = \frac{1}{9}\left(\frac{m_{f_2}}{m_{a_2}}\right)^3 (5x_1 + \sqrt{2}y_1)^2, \tag{13}$$

$$\frac{\Gamma(f'_2 \to \gamma\gamma)}{\Gamma(a_2(1320) \to \gamma\gamma)} = \frac{1}{9}\left(\frac{m_{f'_2}}{m_{a_2}}\right)^3 (5x_2 + \sqrt{2}y_2)^2. \tag{14}$$

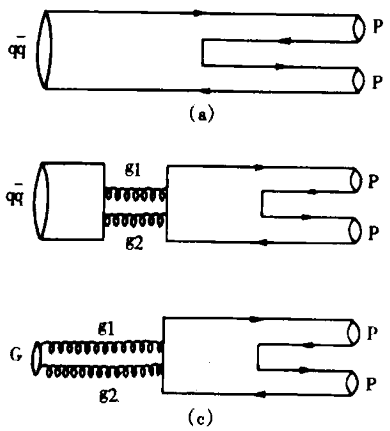

Fig. 1. (a) The direct coupling of the quarkonia component $q\bar{q}$ in the decaying particles to the final state mesons; (b) The coupling of the quarkonia component $q\bar{q}$ in the decaying particles to the final state mesons through two gluons; (c) The direct coupling of the glueball component G in the decaying particles to the final state mesons.

The experimental data relating to the $f_2(1270)$, $f'_2(1525)$, $\xi(2230)$ and $a_2(1320)$ cited by Particle Data Group 98[15] are as follows:

$$m_{f_2} = 1275.0 \pm 1.2\,\text{MeV},\ \Gamma(f_2) = 185.5^{+3.8}_{-2.7}\,\text{MeV},$$
$$\Gamma(f_2 \to \pi\pi)/\Gamma(f_2) = (84.6^{+2.5}_{-1.3})\%,\ \Gamma(f_2 \to K\bar{K})/\Gamma(f_2) = (4.6 \pm 0.4)\%,$$
$$\Gamma(f_2 \to \eta\eta)/\Gamma(f_2) = (4.5 \pm 1.0) \times 10^{-3},\ \Gamma(f_2 \to \gamma\gamma)/\Gamma(f_2) = (1.32^{+0.17}_{-0.16}) \times 10^{-5}; \tag{15}$$
$$m_{f'_2} = 1525 \pm 5\,\text{MeV},\ \Gamma(f'_2) = 76 \pm 10\,\text{MeV},$$
$$\Gamma(f'_2 \to \pi\pi)/\Gamma(f'_2) = (8.2 \pm 1.5) \times 10^{-3},\ \Gamma(f'_2 \to K\bar{K})/\Gamma(f'_2) = (88.8 \pm 3.1)\%,$$
$$\Gamma(f'_2 \to \eta\eta)/\Gamma(f'_2) = (10.3 \pm 3.1)\%,\ \Gamma(f'_2 \to \gamma\gamma)/\Gamma(f'_2) = (1.32 \pm 0.21) \times 10^{-6}; \tag{16}$$
$$m_{\xi} = 2231.1 \pm 3.5\,\text{MeV},\ \Gamma(\xi) = 23^{+8}_{-7}\,\text{MeV},$$
$$\Gamma(\xi \to \pi\pi)/\Gamma(\xi \to K\bar{K}) = 1.0 \pm 0.5; \tag{17}$$
$$m_{a_2} = 1318.1 \pm 0.6\,\text{MeV},\ \Gamma(a_2) = 107 \pm 5\,\text{MeV},$$
$$\Gamma(a_2 \to \gamma\gamma)/\Gamma(a_2) = (9.4 \pm 0.7) \times 10^{-6} \tag{18}$$

We choose $\theta = -15.5°$[16—18], $m_N = m_{a_2}$[3,19] as well as the central value of the data mentioned above as input. The m_G, m_S, r_1 and r_2 are unknown parameters. The fit results are as follows: $m_G = 2.42$ GeV, $m_S = 1.54$ GeV, $r_1 = 0.08$, $r_2 = 0.3$ and the numerical form of the unitary matrix U is

$$U = \begin{pmatrix} 0.991 & 0.105 & -0.088 \\ 0.110 & -0.992 & 0.061 \\ -0.081 & -0.070 & -0.994 \end{pmatrix} \tag{19}$$

with the $\chi^2/DF = 1.57/3 \approx 0.52$. The physical states $|f_2(1270)\rangle$, $|f'_2\ 1525)\rangle$ and $|\xi(2230)\rangle$ can be read

$$|f_2(1270)\rangle = 0.991\,|N\rangle + 0.105\,|S\rangle - 0.088\,|G\rangle, \tag{20}$$

$$|f'_2(1525)\rangle = 0.110\,|N\rangle - 0.992\,|S\rangle + 0.061\,|G\rangle, \tag{21}$$

$$|\xi(2230)\rangle = -0.081\,|N\rangle - 0.070\,|S\rangle - 0.994\,|G\rangle.$$

Our results suggest that the $f_2(1270)$ is a nearly pure $\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$ meson and the $f'_2(1525)$ is a nearly pure $s\bar{s}$ meson, which is consistent with the decay data of the two states, Eqs. (15) and (16), also with the experimental data[15] $BR(J/\psi\to\phi f_2) < 3.7\times10^{-4}$, $BR(J/\psi\to\omega f_2) = (4.3\pm0.6)\times10^{-3}$, $BR(J/\psi\to\phi f'_2) = (8\pm4)\times10^{-4}$, and $BR(J/\psi\to\omega f'_2) < 2.2\times10^{-4}$.

Our results also suggest that the $\xi(2230)$ is a nearly pure glueball state. The following predictions about the behavior of the $\xi(2230)$ decays can provide a stringent check of our results.

$$\frac{\Gamma(\xi\to\gamma\gamma)}{\Gamma(a_2\to\gamma\gamma)} = \frac{1}{9}\left(\frac{m_\xi}{m_{a_2}}\right)^3 (5x_3+\sqrt{2}y_3)^2 = 0.136, \tag{23}$$

$$\frac{\Gamma(\xi\to\eta\eta)}{\Gamma(\xi\to K\bar{K})} = \left(\frac{p_\eta^\xi}{p_K^\xi}\right)^5 \frac{\left[\sqrt{2}\alpha^2x_3+2\beta^2y_3+r_1(\sqrt{2}x_3+y_3)+r_2z_3\right]^2}{\left[\frac{x_3}{\sqrt{2}}+y_3+r_1(2\sqrt{2}x_3+2y_3)+2r_2z_3\right]^2} = 0.215, \tag{24}$$

$$\frac{\Gamma(\xi\to\eta'\eta')}{\Gamma(\xi\to K\bar{K})} = \left(\frac{p_{\eta'}^\xi}{p_K^\xi}\right)^5 \frac{\left[\sqrt{2}\beta^2x_3+2\alpha^2y_3+r_1(\sqrt{2}x_3+y_3)+r_2z_3\right]^2}{\left[\frac{x_3}{\sqrt{2}}+y_3+r_1(2\sqrt{2}x_3+2y_3)+2r_2z_3\right]^2} = 0.015, \tag{25}$$

$$\frac{\Gamma(\xi(2230)\to\eta\eta')}{\Gamma(\xi(2230)\to K\bar{K})} = \frac{1}{2}\left(\frac{p_{\eta\eta'}^\xi}{p_K^\xi}\right)^5 \frac{\left[4\alpha\beta\left(\frac{x_3}{\sqrt{2}}-y_3\right)\right]^2}{\left[\frac{x_3}{\sqrt{2}}+y_3+r_1(2\sqrt{2}x_3+2y_3)+2r_2z_3\right]^2} = 0. \tag{26}$$

Reducing the phase space factors of these decay modes of the $\xi(2230)$ given above, we have $\tilde{\Gamma}(\xi\to\eta\eta)/\tilde{\Gamma}(\xi\to K\bar{K}) = 0.248$, $\tilde{\Gamma}(\xi\to\eta'\eta')/\tilde{\Gamma}(\xi\to K\bar{K}) = 0.252$ and $\tilde{\Gamma}(\xi\to\eta\eta')/\tilde{\Gamma}(\xi\to K\bar{K}) = 0$. These results are in excellent agreement with the predictions for a glueball decaying into two pseudoscalar mesons given by the naive quark model: $\tilde{\Gamma}(G\to\eta\eta)/\tilde{\Gamma}(G\to K\bar{K}) = \tilde{\Gamma}(G\to\eta'\eta')/\tilde{\Gamma}(G\to K\bar{K}) = 0.25$ and $\tilde{\Gamma}(G\to\eta\eta')/\tilde{\Gamma}(G\to K\bar{K}) = 0$.

In addition, the Gell-Mann-Okubo type mass relation $m_S^2 + m_N^2 = 2m_{K_2^*}^2$ [20] holds in our approach. The pure glueball mass $m_G = 2.42$ GeV is in agreement with the lattice QCD simulations[21,22] which give 2.4 ± 0.12 GeV for the tensor glueball mass. The fit results as well as the experimental data of the decays of the $f_2(1270)$, $f'_2(1525)$ and $\xi(2230)$ are shown in Table 1.

Table 1. The fit results as well as the experimental data of the decays of the $f_2(1270)$, $f'_2(1525)$ and $\xi(2230)$

Modes	$\frac{\Gamma(\xi\to\pi\pi)}{\Gamma(\xi\to K\bar{K})}$	$\frac{\Gamma(\xi\to\eta\eta)}{\Gamma(\xi\to K\bar{K})}$	$\frac{\Gamma(\xi\to\eta'\eta)}{\Gamma(\xi\to K\bar{K})}$	$\frac{\Gamma(\xi\to\eta'\eta')}{\Gamma(\xi\to K\bar{K})}$	$\frac{\Gamma(\xi\to\gamma\gamma)}{\Gamma(a_2\to\gamma\gamma)}$	
Exp.[13]	1.0+0.5					
Fit	1.199	0.215	0	0.015	0.136	
Modes	$\frac{\Gamma(f_2\to\pi\pi)}{\Gamma(f_2\to K\bar{K})}$	$\frac{\Gamma(f_2\to\eta\eta)}{\Gamma(f_2\to K\bar{K})}$	$\frac{\Gamma(f_2\to\gamma\gamma)}{\Gamma(a_2\to\gamma\gamma)}$	$\frac{\Gamma(f'_2\to\pi\pi)}{\Gamma(f'_2\to K\bar{K})}$	$\frac{\Gamma(f'_2\to\eta\eta)}{\Gamma(f'_2\to K\bar{K})}$	$\frac{\Gamma(f'_2\to\gamma\gamma)}{\Gamma(a_2\to\gamma\gamma)}$
Exp.[13]	18.39±2.14	0.098±0.03	2.44±0.66	0.009±0.002	0.12±0.04	0.1±0.04
Fit	16.84	0.11	2.602	0.009	0.099	0.125

By the way, as K. T. Chao[8,23] pointed out that the higher angular momentum barrier between q and $\bar{q}$ in a $L=3$ meson would prevent them from being annihilated into gluons and then mixed with the 2^{++} glueball, and that in the nonrelativistic quark model language, the radial wave function as well as its first and second derivatives at the origin vanished for the $L=3$ mesons, thus the annihilation matrix elements are suppressed. Therefore in this work, we do not consider the mixing between the $L=3$ $q\bar{q}$ mesons and the ξ(2230) though the $L=3$ $q\bar{q}$ with $J^{PC}=2^{++}$ are close in mass to the ξ(2230).

We also want to note that the present predictions about the behavior of the ξ(2230) decays is based on the coupling modes as shown in Fig. 1., i. e., we neglect the possible glueball component in the final state mesons. The discussions about the decay of the glueball are planned for separate publication when the possible glueball component in the final state mesons such as η and η' is considered.

In conclusion, assuming the spin-parity J^{PC} of the ξ(2230) is 2^{++}, we study the mixing of the $f_2(1270)$, $f'_2(1525)$ and ξ(2230) and determine the glueball-quarkonia content of the three states. We suggest that the ξ(2230) is a nearly pure tensor glueball, the $f_2(1270)$ is a nearly pure $\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$ meson and $f'_2(1525)$ is a nearly pure $s\bar{s}$ meson. The predictions for the decays of the ξ(2230) can provide a stringent check of our results.

References

1 Schnitzer H J. Nucl. Phys., 1982, **B207**:131
2 Rosner J L. Phys. Rev., 1983, **D27**:1101
3 Kawai E. Phys. Lett., 1983, **B124**:262
4 Rosner J L, Tuan S F. Phys. Rev., 1983, **D27**:1544
5 Caruso F, Predazzi E. Z. Phys., 1987, **C30**:569
6 YU Hong. High Energy Phys. and Nucl. Phys. (in Chinese), 1988, **12**:754
(郁宏. 高能物理与核物理,1988,**12**:754)
7 YU Hong, LI BingAn, SHEN QiXing et al. High Energy Phys. and Nucl. Phys. (in Chinese), 1984, **8**: 285
(郁宏,李炳安,沈齐兴等,高能物理与核物理,1984,**8**: 285)
8 CHAO K T. Commun. Theor. Phys., 1995, **24**: 373
9 HUANG T, JIN S, ZHANG D H et al. Phys. Lett., 1996, **B380**: 189
10 GAO C S. hep-ph/9901367
11 Rosner J L. Phys. Rev., 1981, **D24**: 1347
12 Schechter J. Phys. Rev., 1983, **D27**: 1109
13 Seiden A, Sadrozinski. H, Haber H E. Phys. Rev., 1988, **D38**: 824
14 Close F E. An Introduction to Quarks and Partons. Academic, London: 1979
15 Particle Data Group, Caso C et al. Eur. Phys. J., 1998, **C3**: 1
16 Bramon A, Escribano R, Scadron M D. Eur. Phys. J., 1999, **C7**: 271
17 Bramon A, Escribano R, Scadron M D. Phys. Lett., 1997, **B403**: 339
18 FANG Jian, YU Hong, SHEN QiXing. High Energy Phys. and Nucl. Phys. (in Chinese), 2000, **24**:190)
(方建,郁宏,沈齐兴. 高能物理与核物理,2000,**24**:190)
19 Weingarten D. Nucl. Phys. (Proc. Suppl.), 1997, **53**: 232
20 Okubo S. Prog. Theor. Phys., 1962, **27**: 949
21 Morningstar C J. Peardon M. Phys. Rev., 1997, **D56**:4043
22 Peardon M. Nucl. Phys. (Proc. Suppl.), 1998, **63**: 22
23 CHAO K T. Commun. Theor. Phys., 1997, **27**: 263

中性张量介子 $f_2(1270)$，$f'_2(1525)$ 和胶球候选者 $\xi(2230)$ 的混合*

李德民 方 建 郁 宏 沈齐兴
(中国科学院高能物理研究所 北京 100039)

摘要 假定 $\xi(2230)$ 的自旋宇称为 2^{++}，研究了中性张量介子
$f'_2(1525)$ 和胶球候选者 $\xi(2230)$ 的混合，通过对可得到的这3个态的衰变数据的拟合，得到了这3个态的夸克和胶球内容．并给出了一些关于 $\xi(2230)$ 衰变的预言．

关键词 张量介子 张量胶球 混合 最小二乘法拟合

1999－10－28 收稿
* 国家自然科学基金和中国科学院基金资助