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A Possible New Resonance State:
Spin-parity Analysis of the X Resonance in $J/\psi \to X + f_0(975)$ Process

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The boson resonance state X is produced along with $f_0(975)$ in the J/ψ hadronic decay process. If the X particle decays into a pair of pseudoscalar mesons its spin-parity is J^{PC} = (odd)$^{--}$. The helicity formalism of angular distribution of the process is presented. How to discriminate 1^{--} meson from 3^{--} meson for the X particle is discussed. We think that the $X_1(1573)$ which has been observed in the four prong channel ($K^+K^-\pi^+\pi^-$) and in company with $f_0(975)(\to\pi^+\pi^-)$ by BES collaboration may be a new resonance state.

Key words: resonance, exclusive reaction, helicity.

S[$f_0(975)$] produced in J/ψ hadronic decay has been observed in the $\pi^+\pi^-$ decay channel by Mark II [1]. The pole parameter is $(974\pm4\text{-}i14\pm5)$MeV and the branching ratio of the inclusive reaction $\psi\to S + X$ is $(0.42\pm0.08)\%$. Up to now the branching ratios of the measured exclusive reactions are $BR(\psi\to\phi f_0(975)) = (3.2\pm0.9)\times10^{-4}$ and $BR(\psi\to\omega f_0(975)) = (1.4\pm0.5)\times10^{-4}$ [2]. The sum is smaller about one order of magnitude compared with the inclusive reaction. It means that there may be more exclusive reactions that have not been observed.

We know that BES observed an obvious resonance $X_1(1573)$ at 1573 MeV and a resonance $X_2(1850)$ at 1850 MeV besides the $\phi(1020)$ meson in company with $f_0(975)(\to\pi^+\pi^-)$ in the analysis of the four prong decay channels ($K^+K^-\pi^+\pi^-$) out of about 9×10^6 J/ψ events. They all decay into K^+K^- [3]. The detailed experimental result will be published by BES collaboration.

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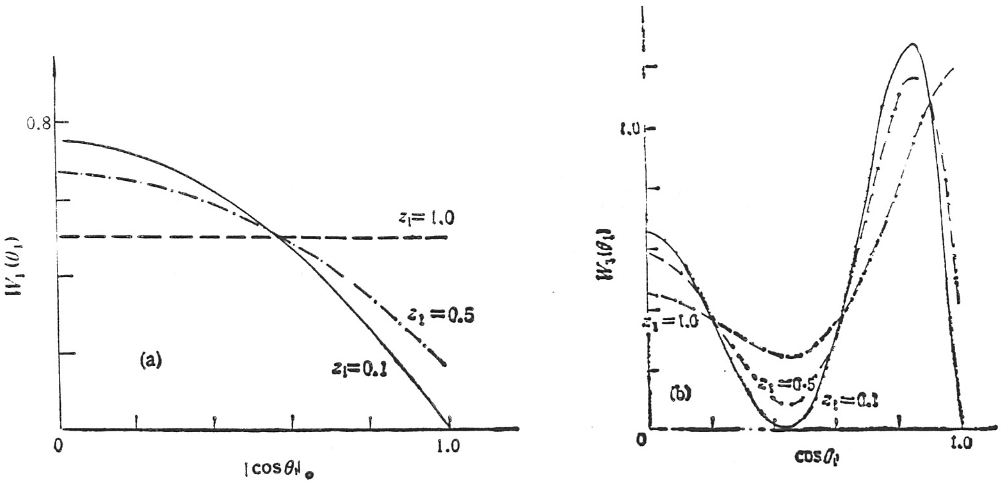

Fig. 1
The normalized projective angular distributions
(a) $W_1(\Theta_1)$; (b) $W_3(\Theta_1)$; $z_1 = 0.1, 0.5, 1.0$.

According to the charge conjugation parity conservation, because X_1 and X_2 decay into a pair of K mesons their C parities are $C = (-1)^{L+S} = (-1)^L = -$, where $S = 0$ is the total spin of the K^+K^- system and L = odd is the orbital angular momentum of the K^+K^- system. Obviously the total angular momentum of the system, that is the spin of the two resonances, $J = L$ = odd. Their space reversal parities are $P = (-1)^L = -$. So the spin-parity of the two resonances X_1 and X_2 are $J^{PC} = (\text{odd})^{--}$. If the relative orbital angular momentum between the X_1(or X_2) and the $f_0(975)$ $L' = 0$ (S wave) the $J^{PC} = 1^{--}$ of the X_1 (or X_2). It is known from PDG [2] that the possible candidates are $\omega(1390)$, $\rho(1450)$, $\omega(1600)$, $\phi(1680)$, $\rho(1700)$. The helicity formalism of the angular distribution of the process

$$e^+ + e^- \to J/\psi \to X_1(\text{or } X_2) + f_0(975) \quad \begin{matrix} X_1 \to K^+K^- \\ f_0 \to \pi^+\pi^- \end{matrix} \tag{1}$$

are [4]

$$W_1(\theta_V, \theta_1, \phi_1) \propto (1 + \cos^2\theta_V)\sin^2\theta_1 - \sin^2\theta_V(\sin^2\theta_1 \cos 2\phi_1 - 2z_1^2\cos^2\theta_1) - \sin 2\theta_V \cdot z_1 \cdot \sin 2\theta_1 \cos\phi_1. \tag{2}$$

where, Θ_V is the angle between the 1^{--} particle and the positron beam in the J/ψ rest frame, (Θ_1, φ_1) describe the direction of the momentum of the K^+ in the 1^{--} particle X_1 (or X_2) rest frame. Here we take the direction of the momentum of the 1^{--} particle in the J/ψ rest frame as the z-axis and the e^+, e^- beams are in the x-z plane. The z_1 is the helicity amplitude ratio $A_{0,0}/A_{1,0}$, where $A_{\lambda_{X_1},0}$ are the helicity amplitudes of the process $J/\psi \to X_1$ (or X_2) + $f_0(975)$ and λ_{X_1} are the helicities of the particle X_1 (or X_2).

The normalized projective angular distributions of the process (1) are

$$W_1(\theta_V) \propto \frac{3}{4} \cdot \frac{1}{(2 + z_1^2)}[(1 + z_1^2) + (1 - z_1^2)\cos^2\theta_V], \tag{3}$$

$$W_1(\theta_1) \propto \frac{3}{2(2 + z_1^2)}[1 - (1 - z_1^2)\cos^2\theta_1], \tag{4}$$

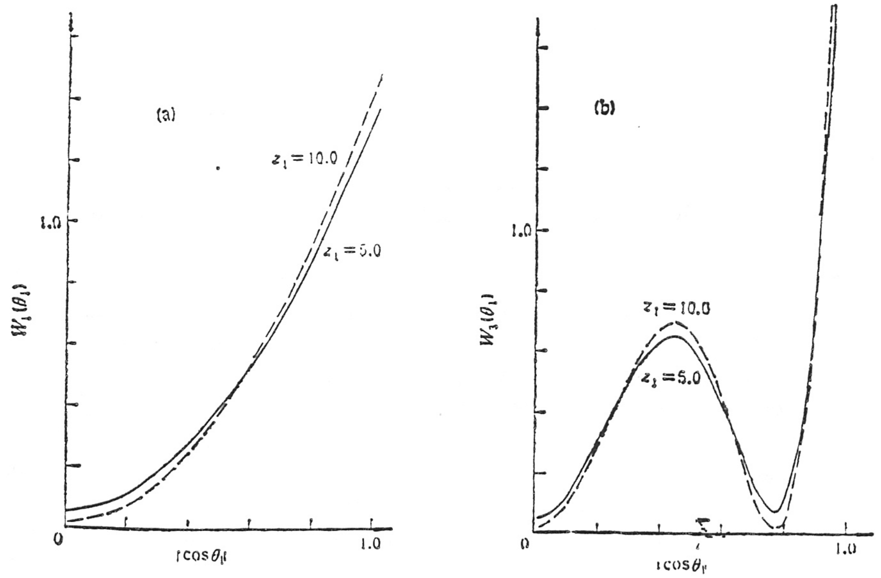

Fig. 2
The normalized projective angular distributions
(a) $W_1(\Theta_1)$; (b) $W_3(\Theta_1)$; $z_1 = 5.0, 10.0$.

$$W_1(\phi_1) \propto \frac{1}{(2\pi)(2+z_1^2)}[(2+z_1^2) - \cos 2\phi_1]. \tag{5}$$

If the relative orbital momentum between the X_1 (or X_2) and the $f_0(975)$ $L' = 2$ (D wave) the spin-parity of the X_1 (or X_2) is $J^{PC} = 3^{--}$ or 1^{--}. For the $J^{PC} = 3^{--}$ case it is known from the PDG [2] that the possible candidates are $\omega_3(1670)$, $\rho_3(1690)$, $\phi_3(1850)$. Then the helicity formalism of angular distribution of the process (1) is

$$\begin{aligned} W_3(\theta,\theta_1,\phi_1) \propto & (1+\cos^2\theta) \cdot \frac{3}{8}\sin^2\theta_1(5\cos^2\theta_1 - 1)^2 \\ & + \sin^2\theta \left[\frac{1}{2} z_1^2\cos^2\theta_1(5\cos^2\theta_1 - 3)^2 - \frac{3}{8}\sin^2\theta_1(5\cos^2\theta_1 - 1)^2\cos 2\phi_1\right] \\ & - \sin 2\theta \cdot \frac{\sqrt{6}}{8} z_1 \sin 2\theta_1(5\cos^2\theta_1 - 1)(5\cos^2\theta_1 - 3)\cos\phi_1. \end{aligned} \tag{6}$$

where we take Θ as the angle between the 3^{--} particle and the positron beam in the J/ψ rest frame in order to distinguish it from Θ_V used in the 1^{--} case. The corresponding normalized projective angular distributions are

$$W_3(\theta) \propto \frac{3}{4(2+z_1^2)}[(1+z_1^2) + (1-z_1^2)\cos^2\theta], \tag{7}$$

$$\begin{aligned} W_3(\theta_1) \propto & \frac{21}{16(2+z_1^2)}\Big[1 - (11 - 6z_1^2)\cos^2\theta_1 + (35 - 20z_1^2) \cdot \cos^4\theta_1 \\ & - \left(25 - \frac{50}{3}z_1^2\right)\cos^6\theta_1\Big], \end{aligned} \tag{8}$$

$$W_3(\phi_1) \propto \frac{1}{2\pi(2+z_1^2)} [(2+z_1^2) - \cos 2\phi_1]. \tag{9}$$

The parity conservation and the time reversal invariance have been used above. We can see that the normalized projective angular distributions (3) and (7), (5) and (9) are the same, respectively; but Eq.(4) and Eq.(8) are different. Can we use it to distinguish 1^{--} from 3^{--} for X_i particle effectively? We find that the $W_1(\Theta_1)$ and the $W_3(\Theta_1)$ are very different for $z_1 = 0.1, 0.5$, and 1.0 (see Fig. 1) and also for $z_1 = 5.0$ and 10.0 (see Fig. 2).

The $W_1(\Theta_1)$ goes down or up monotonously as the $|\cos\Theta_1|$ increase; but the $W_3(\Theta_1)$ changes dramatically for the large region of the z_1 value (from 0.1 to 10.0). It states clearly that the helicity formalism of angular distribution, especially the dependence on the Θ_1 angle may be used to determine whether the spin of the resonance X_i is 1 or 3. They are more sensitive. When $z_1 < 0.1$ and $z_1 > 10.0$ $W_1(\Theta_1)$ and $W_3(\Theta_1)$ do not change almost compared with $z_1 = 0.1$ and $z_1 = 10.0$, respectively.

We propose that BES should continue studying other decay channels of the resonance X: $\pi\pi$, $\rho\pi$ and K^+K^- for obtaining more information about resonance X. It is helpful to understand properties of the $X_1(1573)$ and the $X_2(1850)$ and hadron spectrum in 1-2 GeV region. In view of the fact that X_1 state presents an obvious resonance peak and one state is missing for ϕ meson spectrum compared with ρ, ω meson spectra the $X_1(1573)$ may be a new resonance $\phi(1573)$ which is not listed in the PDG.

For the process

$$\begin{array}{l} J/\psi \to X + f_0(975) \\ \quad\quad\quad\ \ |\quad\quad\quad \lfloor\!\to \pi^+\pi^- \\ \quad\quad\quad\ \ \lfloor\!\to \rho\pi \ \text{ or } \ K\bar{K}^* \\ \quad\quad\quad\quad\quad \lfloor\!\to 2\pi \quad \lfloor\!\to \bar{K}\pi, \end{array} \tag{10}$$

there are more possibilities: 1^{--}, 1^{+-}, 2^{--}, 2^{+-} and so on for the spin-parity of the resonance X. We will do special discussion along with the progress of the data analysis.

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