High Energy Physics and Nuclear Physics

Vol. 13, No. 2

The ι/E Puzzle and the Moment Analysis

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We introduce the photon angular distribution for the moment of the process $e^+e^- \to J/\psi \to \gamma B$, $B \to P_1P_2P_3$ to discuss the ι/E puzzle. It provides a criterion to distinguish the 0^{-+} state from the 1^{++} state in the process $e^+e^- \to J/\psi \to \gamma KK\pi$.

1. INTRODUCTION

The $\iota/\eta(1440)$ and $E/f_1(1420)$ mesons are of great interest in hadron spectra. A $K^0_SK^\pm\pi$ resonance (ι/η) was first observed in the radiative J/ψ decay by the MARK II group[1]. Later the crystal Ball group[2] performed an isobar analysis on the resonance in $J/\psi \to \pi^0K^+K^-$ and reported that it was dominated by quasi-two body decay models $J/\psi\ \gamma\iota$, $\iota \to \delta\pi$, $\delta \to K^+K^-$, and its quantum numbers were $J^{pc} = 0^{-+}$. Independently, the Jacob-Berman technique was used for the spin-parity analysis of the 3 pseudoscalars decay mode. The results from both the MARK III[4] and DM2[5] groups show that the quantum numbers of the resonance in $J/\psi \to \gamma K\bar{K}\pi$ decay mode were $J^{pc} = 0^{-+}$. The E(1420) was first discovered by Baillon et al.[6] in $p\bar{p}$ annihilation decaying into $kk\bar{\pi}$. However, the experimental results have been controversial about whether its spin-parity is 0^{-+} or 1^{++}.

The MARK III group has noticed that peak in $J/\psi \to \gamma K\bar{K}\pi$ cannot be fitted very well by a single Breit-Wigner resonance. There may be more than one resonances in the process.

We assume that the peak in $J/\psi \to \gamma K\bar{K}\pi$ includes ι (0^{-+}) and E(0^{-+} or 1^{++}). If E(1420) is a pseudoscalar and the same as the ι(1440), the results of the MARK III and DM2 groups can be

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Supported by the National Natural Science Foundation of China
Received on September 14, 1988

TABLE 1
The Number of Independent Decay Parameter for Different J^{PC} States

J^{PC}	μ	The number of independent decay parameters
0^{-+}	0	1
1^{++}	1, −1	2

accepted completely. If the spin-parity of E is 1^{++}, the only comment we can make on the results of the two groups is that they had insufficient events and the method adopted was not capable of identifying the 1^{++} component. It is the ι–E puzzle.

In this paper we will generalize the moment analysis based on the Jacob-Berman angular distribution and attempt to give an efficient criterion which can discriminate whether there is an $E(1^{++})$ component in the resonant peak produced in the process $J/\psi \to \gamma KK\pi$.

2. JACOB-BERMAN ANGULAR DISTRIBUTION

Using the Jacob-Berman technique for the 3 pseudoscalars decay mode of the process $e^+e^- \to J/\psi \to \gamma B$, $B \to p_1p_2p_3$ the angular distribution of the normal of the scattering plane can be expressed as

$$W_J(\theta_\gamma, \theta, \phi) \sim \sum_{\Lambda\Lambda'} I(\lambda_J, \lambda'_J) A^J_{\lambda_\gamma \Lambda} A^J_{\lambda_\gamma \Lambda'} \sum_\mu D^{J*}_{-\Lambda\mu}(\phi, \theta, 0) \cdot D^J_{-\Lambda'\mu}(\phi, \theta, 0) |R_\mu|^2 \quad (1)$$

where

$$|R_\mu|^2 = 2\pi \sum_{\lambda_1\lambda_2\lambda_3} \iint d\omega_1 d\omega_2 |F_\mu(\omega_1\lambda_1, \omega_2\lambda_2, \omega_3\lambda_3)|^2 \quad (2)$$

$I(\lambda_J, \lambda'_J)$ is associated with the subprocess $e^+e^- \to J/\psi$; $A^J_{\lambda_\gamma \Lambda}$ is the helicity amplitude for the subprocess $J/\psi \to \gamma B$; F_μ is the phenomenological decay amplitude for the process $B \to p_1p_2p_3$; $\omega_1\lambda_1$, $\omega_3\lambda_3$ and are the energies and helicities of the three pseudoscalar mesons p_1, p_2 and p_3, respectively; R_μ is called the decay parameter. Parity conservation in the decay process gives the relation

$$F_\mu = P(-1)^{\mu+1} F_\mu \quad (3)$$

Therefore the number of independent decay parameters for different J^{PC} is shown in Table 1. The angular distributions are given by

$$W_0(\theta_\gamma, \theta, \phi) \sim (1 + \cos^2\theta_\gamma) |R_0|^2 \quad (4)$$

for 0^{-+} and

$$W_1(\theta_\gamma,\theta,\phi) \sim [\frac{1}{2}\sin^2\theta x^2\sin^2\theta_\gamma + (1+\cos^2\theta_\gamma)\sin^2\theta - \sin 2\theta_\gamma \cdot x \cdot \cos\phi\sin\theta\cos\theta](|R_{+1}|^2 + |R_{-1}|^2) \quad (5)$$

for 1^{++}. After integrating over Θ and ϕ we obtain the following photon angular distribution

$$W_0(\theta_\gamma) \sim (1+\cos^2\theta_\gamma)|R_0|^2, W_1(\theta_\gamma) \sim (1+A\cos^2\theta_\gamma)(|R_{+1}|^2 + |R_{-1}|^2)$$
$$A = \frac{2-x^2}{2+x^2} \quad (6)$$

Provided that the number of events is enough we should be able to distinguish between 0^{-+} and 1^{++} states in $J/\psi \rightarrow \gamma K\bar{K}\pi$ from Eq.(6). The analyses of the MARK III[4] and DM2[5] groups showed that there is no 1^{++} component observed in the peak within present experimental error limits.

3. GENERALIZED MOMENT ANALYSIS

In Ref.[7] we generalized the moment analysis[8] and introduced the photon angular distribution of the moment. For the process $e^+e^- \rightarrow J/\psi \rightarrow \gamma B$, $B \rightarrow p_1p_2p_3$ the moment is expressed as the following

$$\begin{aligned} H_J(\theta_\gamma, LM) &\sim \langle D^L_{M0}(\phi,\theta,0)\rangle \\ &\sim \sum_{\Lambda\Lambda'} I(\lambda_J,\lambda'_J)A^J_{\lambda_\gamma\Lambda}A^{J*}_{\lambda_\gamma\Lambda'}\sum_\mu (J-\Lambda' LM|J-\Lambda) \\ &\cdot (J\mu L0|J\mu)|R_\mu|^2 = t^{M*}_{J,L}(\theta_\gamma)\sum_\mu (J\mu L0|J\mu)|R_\mu|^2 \end{aligned} \quad (7)$$

where the multiple parameter is

$$t^{M*}_{J,L}(\theta_\gamma) = \sum_{\Lambda\Lambda'} I(\lambda_J,\lambda'_J)A^J_{\lambda_\gamma\Lambda}A^{J*}_{\lambda_\gamma\Lambda'}(J-\Lambda' LM|J-\Lambda) \quad (8)$$

For $J^{pc} = 0^{-+}$ it is easy to get

$$\begin{aligned} H_0(\theta_\gamma, 00) &\sim (1+\cos^2\theta_\gamma)|R_0|^2 \\ H_0(\theta_\gamma, 20) &= 0 \end{aligned} \quad (9)$$

For $J^{pc} = 1^{++}$ we have

$$H_1(\theta_\gamma, 00) \sim (1+A_1\cos^2\theta_\gamma)(|R_{+1}|^2 + |R_{-1}|^2)$$
$$A_1 = \frac{1-2x^2}{1+2x^2} \qquad |A_1| \leqslant 1 \quad 10)$$

$$H_1(\theta_\gamma, 20) \sim (1+A_2\cos^2\theta_\gamma)(|R_{+1}|^2 + |R_{-1}|^2)$$
$$A_2 = \frac{1+x^2}{1-x^2} \qquad |A_2| \geqslant 1 \quad (11)$$

The obvious difference between $H_0(\Theta_\gamma,20)$ and $H_1(\Theta_\gamma,20)$ may be an efficient criterion to distinguish between the 0^{-+} and 1^{++} states in $e^+e^- \to J/\psi \to \gamma K\bar{K}\pi$. If the photon angular distribution of the moment $H_J(\Theta_\gamma,20)$ is not zero there may exist the $E(1^{++})$ component in the peak for the 1^{++} $J/\psi \to \gamma K\bar{K}\pi$. On the contrary, if $H_J(\Theta_\gamma,20) = 0$ the peak must not include the 1^{++} component.

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