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确定ξ(2230)自旋的一种新方法

A NEW METHOD FOR THE DETERMINATION OF THE SPIN OF ξ(2230)

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确定ξ(2230)自旋的一种新方法

A NEW METHOD FOR THE DETERMINATION OF THE SPIN OF ξ(2230)

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摘　要

本文得到了过程$e^+e^-\to J/\psi\to\gamma B(J^+)$、$B(J^+)\to P_1P_2$的矩的光子角分布，提供了确定$\xi$(2230)自旋的新途径。

关键词　矩　角分布　螺旋性

A NEW METHOD FOR THE DETERMINATION OF THE SPIN OF ξ(2230)

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ABSTRACT

The angular distributions of the photon for the moments of process $e^+e^- \to J/\psi \to \gamma B(J^p)$, $B(J^p) \to P_1 + P_2$ have been given. It provides a new way to determine the spin of ξ (2230).

I. INTRODUCTION

A new state $\xi(2230)$ has been discovered in the radiative decay $J/\psi \to \gamma K\bar{K}$ by MARK III group[1]. The full process is

$$e^+ + e^- \longrightarrow J/\psi \longrightarrow \gamma + \xi \qquad \xi \hookrightarrow K^+K^-,\ K_s^0K_s^0 \tag{1}$$

DM2 has performed a re-analysis of $J/\psi \to \gamma K^+K^-$ and $J/\psi \to \gamma K_s^0 K_s^0$[2], but no significant structure at 2.23 GeV shows up in $K\bar{K}$ mass spectrum.

MARK III has also performed a spin analysis of the ξ (2230) using the maximum likelihood technique[3]*. The procedure is similar to that used for θ/f_2 (1720). How-ver it is not certain whether the spin of ξ (2230) is $J=2$ or 4.

We pointed out[4] that there exists an insensitive region to determine the spin ($J=2$ or 4) of θ/f_2(1720) using the angular distribution in a general helicity formalism. Because the data of θ/f_2 just fall into the insensitive region we can not say exactly that the spin of θ/f_2 is $J=2$. So far the spin of ξ (2230) can not be determined ($J=2$ or 4?). We think that an obvious reason is less data and another reason is that th? data of ξ may fall into the insensitive region

This paper attempts to give a new way to determine the spin of ξ (and θ/f_2) using moment analysis[5]

II. ANGULAR DISTRIBUTION

We consider a reaction which produces a boson resonance B with spin J and parity η

$$e^+ + e^- \longrightarrow J/\psi \longrightarrow \gamma + B(J^\eta) \tag{2}$$

The resonance B then decays into two pseudoscalar mesons P_1 and P_2 (η must be $+$)

$$B(J^+) \longrightarrow P_1 + P_2 \tag{3}$$

The angular distribution in a general helicity formalism is given by

$$W_J(\theta_r, \theta, \phi) \propto \sum_{\lambda_J \lambda_J'} I(\lambda_J, \lambda_J') A_{\lambda_\gamma \lambda} A^*_{\lambda_\gamma \lambda'} D^{J\,*}_{-\lambda,0}(\phi,\theta,0) D^{J}_{-\lambda',0}(\phi,\theta,0) \tag{4}$$

where

$$A_{\lambda_\gamma \lambda} \sim \langle \gamma_{\lambda_\gamma} B_\lambda | T | \psi_{\lambda_J} \rangle \tag{5}$$

is the helicity amplitude and λ_γ, Λ, λ_J are helicities of the photon, B, J/ψ

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* For a system of two pseudoscalar mesons the spin, parity and c-parity of ξ (2230) should be $J^{PC} =$ (even)$^{++}$.

respectively:

$$I(\lambda_\gamma,\lambda'_\gamma)=\frac{1}{4}\sum_{r,r'}\langle\psi_{\lambda_\gamma}|T|e_r^+e_{r'}^-\rangle\langle\psi_{\lambda'_\gamma}|T|e_r^+e_{r'}^-\rangle^* \quad , \tag{6}$$

(θ,ϕ) describes the direction of P_1 momentum in the rest frame of B.

We choose the Z axis parallel to the direction of the photon and e^+e^- beams are in the X-Z plane. Since $p\gg m$, we obtain easily in the rest frame of J/ψ:

$$\begin{aligned}
&I(1,1)=I(-1,-1)\approx p^2(1+\cos^2\theta_\gamma)\\
&I(1,0)=I(0,1)=-I(-1,0)=-I(0,-1)\approx\frac{1}{\sqrt{2}}p^2\sin 2\theta_\gamma \qquad (7)\\
&I(1,-1)=I(-1,1)\approx p^2\sin^2\theta_\gamma,\\
&I(0,0)\approx 2p^2\sin^2\theta_\gamma,
\end{aligned}$$

where $p=|\mathbf{p}_+|=|\mathbf{p}_-|$, $\mathbf{p}_+$ and $\mathbf{p}_-$ are momenta of the positron and the electron, θ_γ is the angle between the photon and positron beam.

III. MOMENT ANALYSIS

Some important decay modes for example $B(J^P)\to B_1(1^-)+B_2(1^-)$, where B_1 and B_2 mesons in turn decay into 2 pseudoscalar mesons (P_1P_2 and P_3P_4) were illustrated[5]. They have given the corresponding moments and linear relations among different moments for certain spin-parity combinations of the parent bosons. According to these relations we can determine the spin and parity of B. We note that some relations are very effective. But we know that the observed decay modes of ξ (and θ/f_2) are just the two pseudoscalar mesons channels. Therefore we can not use all relations of [5] to discriminate the spin of ξ(2230) (and θ/f_2).

We generalize the moment analysis to the process

$$e^++e^-\longrightarrow J/\psi\longrightarrow\gamma+B(J^P) \tag{8}$$
$$\hookrightarrow P_1+P_2$$

Introduce the angular distribution of the photon for the moment which is defined as follows

$$H_J(\theta_\gamma,LM)=\int W_J(\theta_\gamma,\theta,\phi)D^{L}_{M0}(\phi,\theta,0)\sin\theta d\theta d\phi \tag{9}$$

This is an experimentally measurable quantity. From eq.(4) we have

$$\begin{aligned}
H_J(\theta_\gamma,LM)&=\frac{4\pi}{2J+1}\sum_{\lambda\lambda'}I(\lambda_\gamma,\lambda'_\gamma)A_{\lambda_\gamma\lambda}A_{\lambda'_\gamma\lambda'}\\
&\quad\cdot(J\text{-}\Lambda\, LM|J\text{-}\Lambda')(J0L0|J0) \qquad (10)\\
&=\frac{4\pi}{2J+1}t^{M*}_{JL}(\theta_\gamma)(J0L0|J0)
\end{aligned}$$

where we use the notation $(j_1m_1j_2m_2|j_3m_3)$ for the usual Clebsch-Gordan coefficient and the multipole parameter is given by

$$t^{m*}_{J\gamma L}(\theta_\gamma)=\sum_{\lambda\lambda'} I(\lambda_1,\lambda'_1)A_{\lambda_\gamma\lambda}A_{\lambda'_\gamma\lambda'}(J-\Lambda' LM|J-\Lambda) \tag{11}$$

We take L to be even so that $t^{m*}_{J\gamma L}(\theta_\gamma)$ is purely real. We can express $H_J(\theta_\gamma,LM)$ in terms of eq. (7) and the ratio of helicity amplitudes x, y.

For $L=2$ we have

$$H_2(\theta_\gamma,22)=H_2(\theta_\gamma,2-2)\propto-\frac{16\pi}{35}p^2 y\sin^2\theta_\gamma$$

$$H_2(\theta_\gamma,21)=-H_2(\theta_\gamma,2-1)\propto-\frac{4\sqrt{2}\pi}{35}p^2(x-\sqrt{6}\,xy)\sin2\theta_\gamma$$

$$H_2(\theta_\gamma,20)\propto\frac{16\pi}{35}p^2[x^2\sin^2\theta_\gamma+(1-y^2)(1+\cos^2\theta_\gamma)] \tag{12}$$

$$\sim1+A_1\cos^2\theta_\gamma$$

$$A_1=\frac{1-y^2-x^2}{1-y^2+x^2} \tag{13}$$

$$H_4(\theta_\gamma,22)=H_4(\theta_\gamma,2-2)\propto-\frac{16\sqrt{15}\pi}{231}p^2 y\sin^2\theta_\gamma$$

$$H_4(\theta_\gamma,21)=-H_4(\theta_\gamma,2-1)\propto-\frac{8\sqrt{15}\pi}{693}p^2(x-\frac{9}{\sqrt{10}}xy)\sin2\theta_\gamma$$

$$H_4(\theta_\gamma,20)\propto\frac{272\pi}{693}p^2[x^2\sin^2\theta_\gamma+\frac{10}{17}(1+0.4y^2)(1+\cos^2\theta_\gamma)] \tag{14}$$

$$\sim1+A_2\cos^2\theta_\gamma$$

$$A_2=\frac{\frac{10}{17}(1+0.4y^2)-x^2}{\frac{10}{17}(1+0.4y^2)+x^2} \tag{15}$$

We note that the $H_2(\theta_\gamma,20)$ and $H_4(\theta_\gamma,20)$ which are comparable with the angular distribution of the photon in a general helicity formalism are different. While the angular distributions of the photon in a general helicity formalism are same in spite of $J=2$ or 4. They are

$$W_J(\theta_\gamma)\sim1+A\cos^2\theta_\gamma\qquad A=\frac{1+y^2-2x^2}{1+y^2+2x^2} \tag{16}$$

For $L=4$ we have

$$H_2(\theta_\gamma,40)\propto-\frac{64\pi}{105}p^2[x^2\sin^2\theta_\gamma-0.75(1+\frac{1}{6}y^2)(1+\cos^2\theta_\gamma)] \tag{17}$$

$$\sim-(1+A_3\cos^2\theta_\gamma)$$

$$A_3=\frac{-0.75(1+\frac{1}{6}y^2)-x^2}{-0.75(1+\frac{1}{6}y^2)+x^2} \tag{18}$$

$$H_4(\theta_\gamma,40)\propto\frac{144\pi}{1001}\rho^2\left[x^2\sin^2\theta_\gamma+\left(1-\frac{11}{18}y^2\right)(1+\cos^2\theta_\gamma)\right] \tag{19}$$

$$\sim 1+A_4\cos^2\theta_\gamma$$

$$A_4=\frac{(1-\frac{11}{18}y^2)-x^2}{(1-\frac{11}{18}y^2)+x^2} \tag{20}$$

The difference between $H_2(\theta_\gamma,40)$ and $H_4(\theta_\gamma,40)$ is more obvious. Therefore we can use these angular distributions of the photon for the moments to discriminate the spin of ξ (and θ/f_2).

IV. CONCLUSION

We know that the results of the ratio of helicity amplitudes of the fit for ξ and θ/f_2 are

$$\xi(J=2)\qquad x=-0.67^{+0.14}_{-0.16}\qquad y=0.13^{+0.21}_{-0.19}$$

$$\xi(J=4)\qquad x=1.29^{+0.62}_{-0.30}\qquad y=9.4^{+0.76}_{-0.39}$$

$$\theta/f_2\qquad x=-1.07\pm0.16\qquad y=-1.09\pm0.15 \tag{21}$$

Using these x and y (omitting the errors) from eqs. (13), (15), (18) and (20) we have

	A_1	A_2	A_3	A_4
$\xi(J=2)$	0.373		3.96	
$\xi(J=4)$		−0.453		−0.297
θ/f_2	−1.39	−0.138	−8.29	−0.614

Applying eqs. (12), (14), (17) and (19) the angular distributions of the photon for the moments are shown in Fig.1, 2, 3, 4. For θ/f_2 (1720) as shown in Fig.2 the behaviors of $H_2(\theta_\gamma,40)$ and $H_4(\theta_\gamma,40)$ are very different, that is the angular distributions of the photon for these moments are very sensitive for different spin ($J=2$ and 4) of θ/f_2. For ξ (2230) the behaviors of these angular distributions are very different too (see Fig.3,4). We expect that using our generalized moment analysis experimentalists will get valuable results after performing a re-analysis of $J/\psi\to\gamma K\bar{K}$, $J/\psi\to\gamma\pi\pi$ and $J/\psi\to\gamma\eta\eta$. We hope also that a certain conclusion for the spin of ξ (2230) can be obtained soon. Moreover after determining the spin of ξ (2230) (and θ/f_2) we can fit the angular distributions of the photon for the moments to get the ratio of the helicity amplitudes x and y more exactly.

Figure Captions

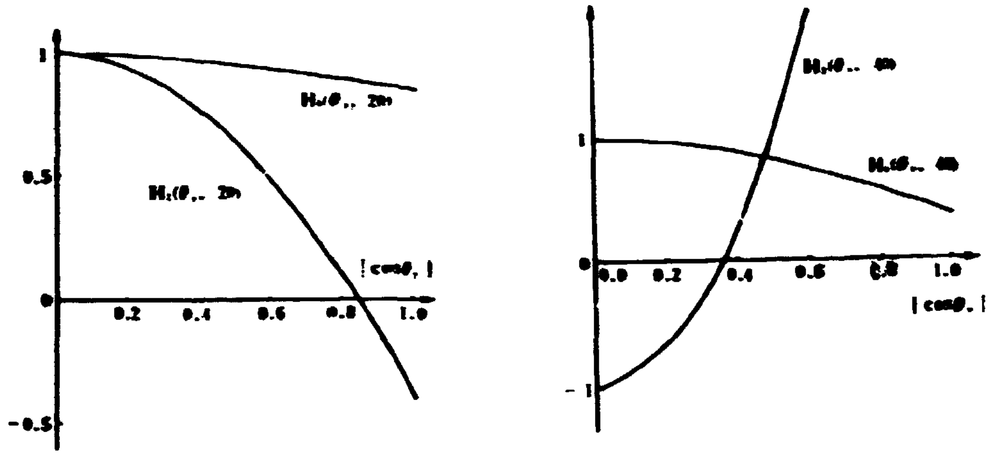

Fig.1,2. The angular distributions of the photon for moments of $e^+e^- \to J/\psi \to \gamma\theta$, (JLM)=(220), (420) and (240), (440).
$\hookrightarrow P_1P_2$

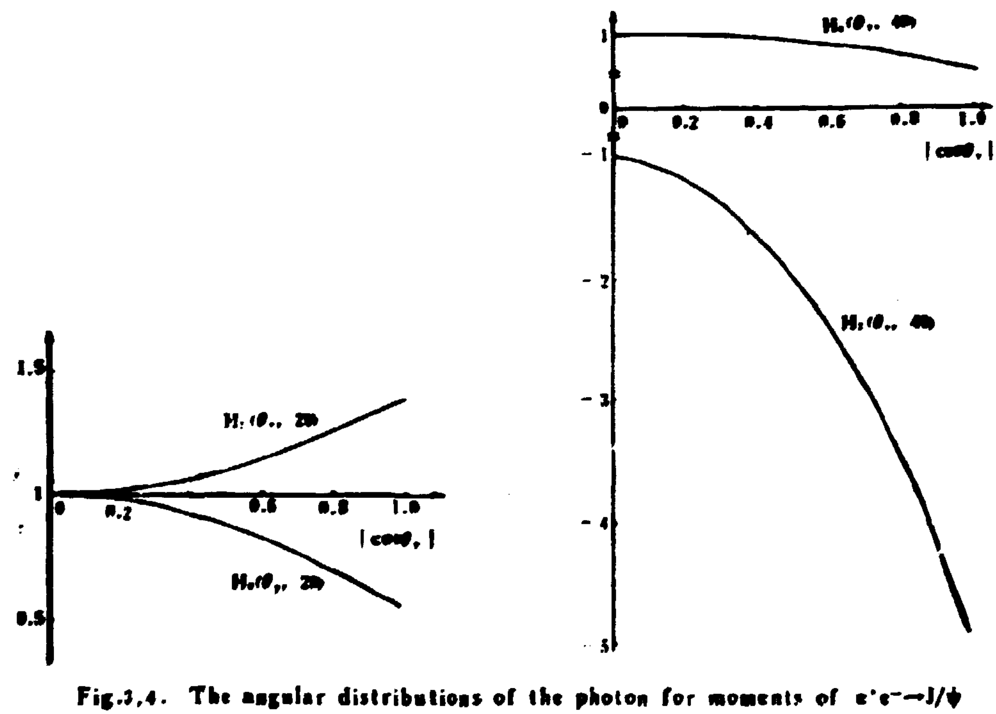

Fig.3,4. The angular distributions of the photon for moments of $e^+e^- \to J/\psi \to \gamma\xi$, (JLM)=(220), (420) and (240), (440).
$\hookrightarrow P_1P_2$

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I.引　言

MARK III组通过以下过程

$$e^+e^- \longrightarrow J/\psi \longrightarrow \gamma\xi \quad \hookrightarrow K^+K^-,\ K^0_sK^0_s \tag{1}$$

发现了一个新的态ξ(2230)[1]。DM2组考察了同样的过程，但在$K\bar{K}$质量谱中没有发现2.23 GeV处有明显的结构[2]。MARK III组用最大似然法[3]对ξ的自旋进行了分析，所用程序完全类似于对θ/f_2(1720)的分析。然而不能确定ξ的自旋是2还是4。由于ξ和θ/f_2一样衰变为两个赝标介子，所以宇称和电荷共轭宇称都是+，自旋为偶。

在文献[4]中，我们指出：θ/f_2的自旋目前公认为$J=2$。实际上，我们发现若用一般的螺旋性形式中的角分布去定θ/f_2的自旋时，存在不敏感区。而θ/f_2的数据恰好落入不敏感区。所以我们认为不能确定地说，θ/f_2的自旋就是$J=2$。对于ξ的自旋，目前不能确定它是2还是4，一个明显的原因是数据太少，另一原因就是ξ的数据可能正好落入不敏感区。

本文试图用矩分析法[5]给ξ(和θ/f_2)的自旋的确定另辟一条新的途径。

II.角　分　布

我们考虑反应过程

$$e^+ + e^- \longrightarrow J/\psi \longrightarrow \gamma + B(J^\eta) \tag{2}$$

其中，共振玻色子B的自旋为J，宇称为η。然后B继续衰变为两个赝标介子P_1和P_2(这样η必然为+)

$$B(J^+) \longrightarrow P_1 + P_2 \tag{3}$$

在一般的螺旋性形式中，该过程的角分布公式为

$$W_J(\theta_\gamma,\theta,\phi) \propto \sum_{\lambda\lambda'} I(\lambda_J,\lambda'_J) A_{\lambda_\gamma\lambda} A^*_{\lambda_\gamma\lambda'} D^{J*}_{\lambda,0}(\phi,\theta,0) D^{J}_{\lambda',0}(\phi,\theta,0) \tag{4}$$

其中

$$A_{\lambda_\gamma\lambda} \sim \langle \gamma_{\lambda_\gamma} B_\lambda | T | \psi_{\lambda_J} \rangle \tag{5}$$

是螺旋性振幅。λ_γ、λ和λ_J分别是光子、B和J/ψ粒子的螺旋性。

$$I(\lambda_J,\lambda'_J) \propto \frac{1}{4}\sum_{\sigma\sigma'} \langle \psi_{\lambda_J}|T|e^-_\sigma e^+_{\sigma'}\rangle \langle \psi_{\lambda'_J}|T|e^-_\sigma e^+_{\sigma'}\rangle^* \tag{6}$$

(θ,ϕ)描写B静止系中P_1粒子动量的方向。这里我们选择光子出射方向为z轴，e^+e^-束流在x-z平面内。在J/ψ静止系，略去包含(m_e/p)的小项，我们有

$$\begin{aligned} &I(1,1)=I(-1,-1)\approx p^2(1+\cos^2\theta_\gamma)\\ &I(1,0)=I(0,1)=-I(-1,0)=-I(0,-1)\approx \frac{1}{\sqrt{2}}p^2\sin 2\theta_\gamma,\\ &I(1,-1)=I(-1,1)\approx p^2\sin^2\theta_\gamma,\\ &I(0,0)\approx 2p^2\sin^2\theta_\gamma, \end{aligned} \tag{7}$$

其中$p=|p_+|=|p_-|$，p_+和p_-是正、负电子的动量，θ_γ是光子和正电子束之间的夹角。

III. 矩 分 析

在文献[5]中给出了如$B(J^P)\rightarrow B_1(1^-)+B_2(1^-)$，$B_1$和$B_2$继续衰变为两个赝标介子($B_1\rightarrow P_1P_2$，$B_2\rightarrow P_3P_4$) 等过程的矩以及对一定的自旋$J$和宇称$\eta$组合的各种矩之间的线性关系式。根据这些关系式，我们能够确定B粒子的自旋和宇称。而且某些关系式相当有效。但是，我们现在观察到的ξ（以及θ/f_2）的衰变方式仅是双赝标介子道。因此，我们不能用[5]中给出的任何关系式来辨别ξ的自旋。

现在，我们把矩分析推广到过程

$$e^+e^-\longrightarrow J/\psi\longrightarrow \gamma+B(J^P) \hookrightarrow P_1+P_2 \tag{8}$$

引进该过程的矩的光子角分布，它被定义为

$$H_J(\theta_\gamma,LM)=\int W_J(\theta_\gamma,\theta,\phi)D^L_{M0}(\phi,\theta,0)\sin\theta d\theta d\phi \tag{9}$$

这是一个实验上可测量的量。从（4）式，我们有

$$\begin{aligned}H_J(\theta_\gamma,LM)&=\frac{4\pi}{2J+1}\sum_{\Lambda\Lambda'}I(\lambda_J,\lambda'_J)\,A_{\lambda_\gamma\Lambda}A_{\lambda_\gamma\Lambda'}\\&\qquad(J\text{-}\Lambda' LM|J\text{-}\Lambda)\cdot(J0L0|J0)\\&=\frac{4\pi}{2J+1}t^{M*}_{J,L}(\theta_\gamma)(J0L0|J0)\end{aligned} \tag{10}$$

这里$(j_1m_1j_2m_2|j_3m_3)$是通常的C-G系数，多极参数为

$$t^{M*}_{J,L}(\theta_\gamma)=\sum_{\Lambda\Lambda'}I(\lambda_J,\lambda'_J)A_{\lambda_\gamma\Lambda}A_{\lambda_\gamma\Lambda'}(J\text{-}\Lambda' LM|J\text{-}\Lambda) \tag{11}$$

我们取L为偶数，则$t^{M*}_{J,L}(\theta_\gamma)$为纯实。我们可按照螺旋性振幅之比$x$和$y$以及用式（7）来表示$H_J(\theta_\gamma,LM)$。对于$L=2$的情况，我们有

$$H_2(\theta_\gamma,22)=H_2(\theta_\gamma,2\text{-}2)\propto-\frac{16\pi}{35}p^2y\sin^2\theta_\gamma$$

$$H_2(\theta_\gamma,21)=-H_2(\theta_\gamma,2\text{-}1)\propto-\frac{4\sqrt{2}\pi}{35}p^2(x-\sqrt{6}xy)\sin2\theta_\gamma$$

$$H_2(\theta_\gamma,20)\propto\frac{16\pi}{35}p^2[x^2\sin^2\theta_\gamma+(1-y^2)(1+\cos^2\theta_\gamma)] \tag{12}$$

$$\sim1+A_1\cos^2\theta_\gamma$$

$$A_1=\frac{1-y^2-x^2}{1-y^2+x^2} \tag{13}$$

$$H_4(\theta_\gamma,22)=H_4(\theta_\gamma,2\text{-}2)\propto-\frac{16\sqrt{15}\pi}{231}p^2y\sin^2\theta_\gamma$$

$$H_4(\theta_\gamma,21)=-H_4(\theta_\gamma,2\text{-}1)\propto-\frac{8\sqrt{15}\pi}{693}p^2\left(x-\frac{9}{\sqrt{10}}xy\right)\sin2\theta_\gamma$$

$$H_4(\theta_\gamma,20)\propto\frac{272\pi}{693}p^2[x^2\sin^2\theta_\gamma+\frac{10}{17}(1+0.4y^2)(1+\cos^2\theta_\gamma)] \tag{14}$$

$$\sim 1+A_2\cos^2\theta_\gamma$$

$$A_2=\frac{\frac{10}{17}(1+0.4y^2)-x^2}{\frac{10}{17}(1+0.4y^2)+x^2} \tag{15}$$

这里，和一般的螺旋性形式中光子的角分布[4]可相比的$H_2(\theta_\gamma,20)$和$H_4(\theta_\gamma,20)$显然是不同的。而在一般的螺旋性形式中的光子的角分布不管$J=2$或者4有相同的表达式：

$$W_J(\theta_\gamma)\sim 1+A\cos^2\theta_\gamma$$

$$A=\frac{1+y^2-2x^2}{1+y^2+2x^2} \tag{16}$$

对于$L=4$，我们有

$$H_2(\theta_\gamma,40)\propto-\frac{64\pi}{105}p^2[x^2\sin^2\theta_\gamma-0.75(1+\frac{1}{6}y^2)(1+\cos^2\theta_\gamma)] \tag{17}$$

$$\sim-(1+A_2\cos^2\theta_\gamma)$$

$$A_2=\frac{-0.75(1+\frac{1}{6}y^2)-x^2}{-0.75(1+\frac{1}{6}y^2)+x^2} \tag{18}$$

$$H_4(\theta_\gamma,40)\propto\frac{144\pi}{1001}p^2[x^2\sin\theta_\gamma+(1-\frac{11}{18}y^2)(1+\cos^2\theta_\gamma)] \tag{19}$$

$$\sim 1+A_4\cos^2\theta_\gamma)$$

$$A_4=\frac{(1-\frac{11}{13}y^2)-x^2}{(1-\frac{11}{18}y^2)+x^2} \tag{20}$$

$H_2(\theta_\gamma,40)$ 和$H_4(\theta_\gamma,40)$之间的差别更加明显。因此，我们可以用矩的光子角分布来分辨ξ(以及θ/f_2)的自旋。

IV. 结　果

我们知道，对于J/ψ辐射衰变产生ξ和θ/f_2的螺旋性振幅之比 x，y，拟合的结果是[6]。

ξ$(J=2)$　$x=-0.67\pm^{0.14}_{0.16}$　$y=0.13\pm^{0.21}_{0.19}$

ξ$(J=4)$　$x=1.29\pm^{0.62}_{0.30}$　$y=0.4\pm^{0.76}_{0.39}$

θ/f_2　$x=-1.07\pm0.16$　$y=-1.09\pm0.15$　(21)

我们把这些值（略去误差）代入式（13）、（15）、（18）、（20），则有

	A_1	A_2	A_3	A_4
$\xi(J=2)$	0.373		3.96	
$\xi(J=4)$		−0.453		−0.297
θ/f_2	−1.39	−0.138	−8.29	−0.614

应用式（12）、（14）、（17）和（19），我们得到矩的光子角分布，如图1,2，3,4所示。对于θ/f_2，从图2可看到$H_2(\theta_\gamma,40)$和$H_4(\theta_\gamma,40)$的行为很不相同。即这种矩的光子角分布对于辨别θ/f_2的自旋为2或4十分敏感。对于ξ，$H_2(\theta_\gamma,20)$和$H_4(\theta_\gamma,20)$，$H_2(\theta_\gamma,40)$和$H_4(\theta_\gamma,40)$的差别均十分明显。于是，我们可以期望，实验物理学家用这个方法在对$J/\psi\to\gamma K\bar{K}$、$\gamma\pi\pi$ $\gamma\eta\eta$进行重新分析之后将会得到某些有价值的结论。希望关于$\xi(2230)$的自旋的确定的结论不久将会作出。此外，在确定了ξ（和θ/f_2）的自旋之后，我们通过拟合矩的光子角分布可得到更精确的螺旋性振幅之比x和y。

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