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(E)

SELECTED TOPICS FROM J/ψ DECAYS*

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The topics I shall cover are:

1. The ι spin parity
2. The θ spin parity
3. Conclusions

1. THE ι SPIN PARITY

ι (IOTA) Meson (e^+e^-)

1) The ι was first found by Mark II in radiative J/ψ decays in $J/\psi \to \gamma K_s K^\pm \pi^\mp$. A cut was made $M_{K_s K^\pm} <$ 1050 to enhance $\iota \to \delta^\pm \pi^\pm$ with $\delta^\pm \to K^\pm K_s$. Mark II determined

$$\begin{aligned} &J/\psi \to \gamma\iota, \quad \iota \to K_s K^\pm \pi^\mp \\ &M_\iota = 1440^{+10}_{-15} \quad MeV \\ &\Gamma_\iota = 50^{+30}_{-20} \quad MeV \end{aligned} \tag{1}$$

The branching ratio of the $J/\psi \to \gamma\iota$ was the largest in J/ψ radiative decays except for $J/\psi \to \gamma\eta_c$. $BR\ J/\psi \to \gamma\iota, \quad \iota \to K\overline{K}\pi$ is $(4.3 \pm 1.7) \times 10^{-3}$. This large branching ratio led to speculations that the ι was a glueball.

2) Shortly after Mark II, the Crystal Ball found $J/\psi \to \gamma\iota, \quad \iota \to K^+K^-\pi^\circ$. They also made a cut to enhance the δ. $M_{K^+K^-} < 1125$.

The Crystal Ball determined that

$$\begin{aligned} M_\iota &= 1440^{+20}_{-15}\ MeV \\ \Gamma_\iota &= 60^{+20}_{-30}\ MeV \end{aligned} \tag{2}$$

A spin parity analysis was made whose ingredients were:

$$\begin{aligned} K\overline{K}\pi &\quad \text{phase space} \\ \delta\pi &\quad 0^-,\ 1^+ \\ K^*K &\quad 0^-,\ 1^+ \end{aligned} \tag{3}$$

The results were that the $\iota \to \delta\pi$ was dominant and $J^P_\iota = 0^-$. The branching ratio $J/\psi \to \delta\iota$, $\iota \to K\overline{K}\pi$ is $(4.0 \pm 1.2) \times 10^{-3}$.

MARK III RESULTS

If the $\iota \to \delta\pi$ with $\delta \to K\overline{K}$, then one should also see $\iota \to \delta\pi$ with $\delta \to \eta\pi$. Mark III looked for $J/\psi \to \gamma\iota$ with $\iota \to \eta\pi\pi$. Figure 1 shows the mass distribution

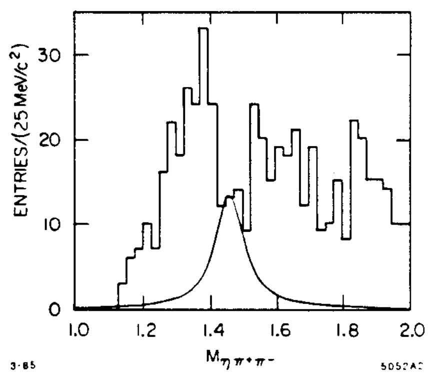

Fig. 1

$M_{\eta\pi^+\pi^-}$ with a cut on $M_{\eta\pi^\pm}$ to enhance δ's. The δ is seen in $\eta\pi$. No large ι is seen leading to an upper limit:

$$\begin{aligned} &J/\psi \to \delta\iota, \quad \iota \to \delta\pi^\mp, \quad \delta^\pm \to \eta\pi^\pm \\ &BR < (3.9\ \pm\ 0.4\ \pm\ 0.7) \times 10^{-4} \quad 90\%\ C.L. \end{aligned} \tag{4}$$

One caveat in this is that a destructive interference between the background and the ι has not been considered. As the Crystal Balls analysis of the spin parity of the ι depended on the decay chain $J/\psi \to \gamma\iota$ and $\iota \to \delta\pi$, perhaps the results are not valid.

The Mark III data will be analyzed without assuming a δ for $J/\psi \to \gamma K_s K^\pm \pi^\mp$. Figure 2 shows the $M_{K\overline{K}}$ axis. One sees a low mass enhancement, but see no reason to cut at 1050 or 1125 MeV. We cut $M_{K_s K^\pm} < 1320\ MeV$. Figure 3 shows distribution of $M_{K_s K^\pm \pi^\mp}$ with that cut.

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A clear ι signal is seen with

$$M_\iota = 1456 \pm 10\ MeV$$
$$\Gamma_\iota = 95 \pm 10\ MeV \qquad (5)$$

Our branching ratio for $J/\psi \to \gamma\iota,\quad \iota \to K\bar{K}\pi$ assuming $I = 0$ is $(5.0 \pm 0.5 \pm 0.7) \times 10^{-3}$.

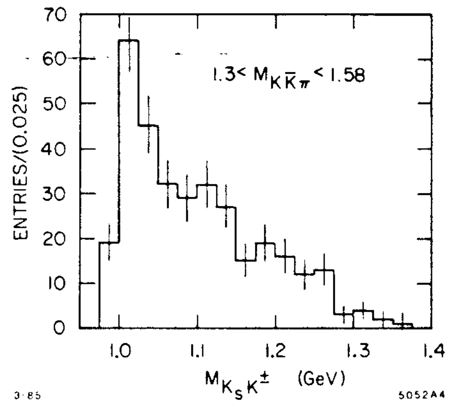

Fig. 2

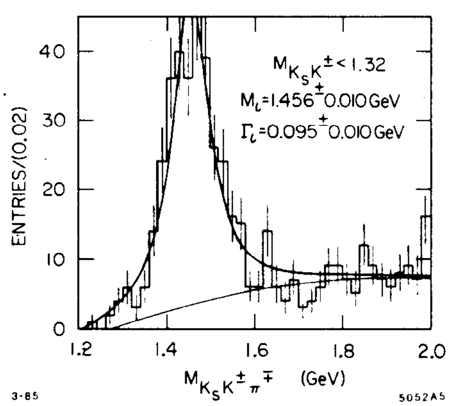

Fig. 3

Spin Parity Analysis

Three angles are used. The radiative γ and the recoil ι make an angle θ_γ with the beam. The three body decay $K\overline{K}\pi$ defines a plane. The normal to that plane makes a polar angle β with respect to the boost direction of the ι and ϕ is the azimuth of the normal with respect to the production plane.

When a likelihood analysis is made

$$\left.\begin{array}{l} \dfrac{\mathcal{L}(1^+)}{\mathcal{L}(0^-)} \approx 10^{-3} \text{ to } 10^{-4} \\ \dfrac{\mathcal{L}(1^-)}{\mathcal{L}(0^-)} \approx 10^{-6} \text{ to } 10^{-7} \end{array}\right\} \begin{array}{c}\text{depending on cuts,} \\ \text{decay modes of } \iota\end{array} \qquad (6)$$

Note that 0^+ is excluded as $0^+ \not\to 0^- + 0^- + 0^-$.

Crystal Ball was right. $J_\iota^P = 0^-$.

2. SPIN PARITY OF θ (1640)

HISTORY

1) Crystal Ball found the θ in $J/\psi \to \gamma\theta,\quad \theta \to \eta\eta$.

$$M_\theta = 1640 \pm 50\ MeV$$
$$\Gamma_\theta = 220^{+100}_{-70}\ MeV \qquad (7)$$

The branching ratio $J/\psi \to \gamma\theta,\quad \theta \to \eta\eta$ found was $(4.9 \pm 1.4 \pm 1.0) \times 10^{-4}$.

An upper limit was set for the branching ratio

$$J/\psi \to \gamma\theta,\ \theta \to \pi\pi, \quad BR < 6 \times 10^{-4} \quad 90\%\ C.L. \qquad (8)$$

The Crystal Ball did a spin parity analysis using three angles. θ_γ was used as in the ι, but since we have a two body decay here, we use in the θ rest system the polar angle α between the θ boost and the closest η and the azimuth ϕ. Their result is, if spin parity 2^{++} has a relative probability of 1 then 0^{++} has a relative probability of 0.045.

2) The Mark II collaboration found the θ in $J/\psi \to \gamma\theta,\quad \theta \to K^+K^-$. They found

$$M_\theta = 1700 \pm 30\ MeV$$
$$\Gamma_\theta = 156 \pm 20\ MeV \qquad (9)$$

If spin parity 2^{++} has a relative probability of 1, 0^{++} has a relative probability of 0.22.

The Mark III has seen the θ in

$$J/\psi \to \gamma\theta, \quad \theta \to K^+K^- \qquad (10)$$

Figure 4 shows the $M_{K^+K^-}$ distribution. In it we see two peaks the f' and the θ cleanly separated.

$$M_\theta = 1720 \pm 10\ MeV$$
$$\Gamma_\theta = 130 \pm 20\ MeV \qquad (11)$$

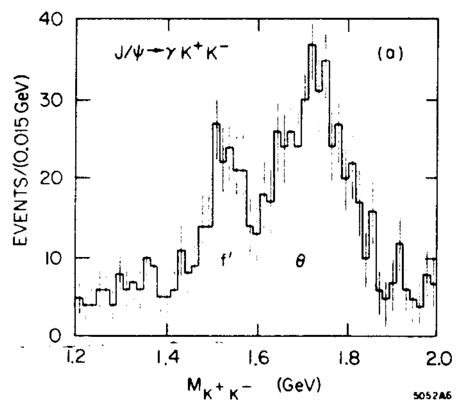

Fig. 4

The branching ratio for the K^+K^- channel

$$BR\ J/\psi \to \gamma\theta\ , \quad \theta \to K^+K^-\ , \quad (4.8 \pm 0.6 \pm 0.9) \times 10^{-4} \tag{12}$$

If spin parity 2^{++} has a relative probability of 1, 0^{++} has a relative probability of 10^{-3}. The Mark III collaboration has measured the spin parity of the θ to be 2^{++}. The Crystal Ball and Mark II had the right answer on limited statistics.

The helicity ratios x and y for the θ were

$$\begin{aligned} x &= -1.07 \pm 0.16 \\ y &= -1.09 \pm 0.15 \end{aligned} \tag{13}$$

Now we study the decay

$$J/\psi \to \gamma\pi^+\pi^- \tag{14}$$

Figure 5 shows the distribution in $M_{\pi^+\pi^-}$. The figure shows three peaks. The first is the well known f, the second is at the position of the θ and the third (the x) a bit under 2100 MeV. The mass of the θ is

$$\begin{aligned} M_{\theta\to\pi\pi} &= 1713 \pm 15\ MeV \\ \Gamma_{\theta_{\pi\pi}} \equiv \Gamma_{\theta_{KK}} &\equiv 130\ MeV \end{aligned} \tag{15}$$

The branching ratio is

$$J/\psi \to \gamma\theta,\ \theta \to \pi^+\pi^-,\ (1.6 \pm 0.4 \pm 0.3) \times 10^{-4} \tag{16}$$

The third bump "x" in the figure has a mass and width

$$\begin{aligned} M_{x\to\pi^+\pi^-} &= 2086 \pm 15\ MeV \\ \Gamma_x &= 210 \pm 63\ MeV \end{aligned} \tag{17}$$

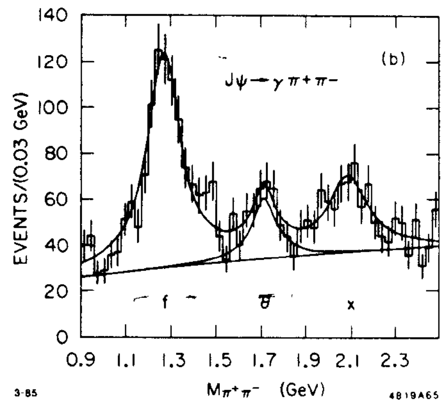

Fig. 5

The branching ratio is

$$J/\psi \to \gamma x,\ x \to \pi^+\pi^-,\quad (3.0 \pm 0.5 \pm 0.6)\ \times 10^{-4} \tag{18}$$

The mass and width are consistent with the $h(2030)$, $I = 0$ resonance. The spin parity of the $h(2030)$ is 4^{++}. We prefer to call it the $x(2086)$.

3. Conclusion

Spin Parity of $\iota = 0^-$. Spin parity of $\theta = 2^+$. Who cares?

We already have full nonets for 0^- and 2^+!! The ι and θ are extra mesons. We don't need them. Could they be radial excitations? If they were radial excitations, why are they so strongly produced in radiative J/ψ decays?

Could they be Glueballs? Theorists tell us that Glueballs should be produced in radiative J/ψ decays. Furthermore, theorists tell us that the spin parities of Glueballs should be $0^-, 0^+$ or 2^+ and not 1^+ or 1^-. That is why it is important that the spin parity of the ι is 0^- and not 1^+!

As for the θ, the helicity ratios x and y were $x_\theta = -1.07 \pm 0.16$ and $y_\theta = -1.09 \pm 0.15$. Note that these ratios for the $f(1270)$ and the $f'(1515)$

$$\begin{aligned} x_f &= 0.96 \pm 0.07, \quad y_f = 0.06 \pm 0.08 \\ x_{f'} &= 0.63 \pm 0.09, \quad y_{f'} = 0.17 \pm 0.15 \end{aligned} \tag{19}$$

are quite different than that for the θ. These are all 2^+ mesons, but the helicity ratios are different.

At least one theorist has conjectured that in radiative J/ψ decays, all $q\bar{q}$ resonances should have $y = 0$. The ι and θ remain Glueball candidates.