SELECTED TOPICS FROM J/ψ DECAYS

Allen Odian
Mark III Collaboration

Stanford Linear Accelerator Center
Stanford University, Stanford, California, 94305

The topics I shall cover are:
1. The ς spin parity
2. The θ spin parity
3. Conclusions

1. THE ς SPIN PARITY

(ΙΟΤΑ) Meson (e⁺e⁻)

1) The ς was first found by Mark II in radiative J/ψ decays in J/ψ → ζK⁺K⁻π⁺π⁻. A cut was made MK⁺K⁻ < 1050 to enhance ς → δ±π± with δ± → K±K±. Mark II determined

\[ J/ψ → ζ, \quad ζ → K⁺K⁻π⁺π⁻ \]
\[ M_ζ = 1440^{+10}_{-15} \text{ MeV} \]
\[ Γ_ζ = 50^{+30}_{-20} \text{ MeV} \] (1)

The branching ratio of the J/ψ → ζ was the largest in J/ψ radiative decays except for J/ψ → ηγ. BR J/ψ → ζ is (4.3 ± 1.7) x 10⁻³. This large branching ratio led to speculations that the ς was a glueball.

2) Shortly after Mark II, the Crystal Ball found J/ψ → ζ, ζ → K⁺K⁻π⁺π⁻. They also made a cut to enhance the δ. MK⁺K⁻ < 1125.

The Crystal Ball determined that

\[ M_ζ = 1440^{+20}_{-15} \text{ MeV} \] (2)
\[ Γ_ζ = 60^{+30}_{-20} \text{ MeV} \]

A spin parity analysis was made whose ingredients were:

\[ K⁺K⁻ \text{ phase space} \]
\[ δ± 0^-, 1^+ \]
\[ K⁺K⁻ 0^-, 1^+ \] (3)

The results were that the ζ → δπ was dominant and J_ζ^π = 0⁻. The branching ratio J/ψ → δπ, ζ → K⁺K⁻π⁺π⁻ is (4.0 ± 1.2) x 10⁻³.

MARK III RESULTS

If the ς → δπ with δ → K⁺K⁻, then one should also see ς → δπ with δ → ηπ. Mark III looked for J/ψ → ηπ with ς → δπ. Figure 1 shows the mass distribution

![Figure 1](image)

\[ M_{π⁺π⁻} \text{ with a cut on } M_{δπ} \text{ to enhance } δπ. \text{ The } δ \text{ is seen in } ηπ. \text{ No large } ς \text{ is seen leading to an upper limit:} \]

\[ J/ψ → δπ, \quad ζ → δπ, \quad δπ → ηπ \]

\[ BR < (3.9 \pm 0.4 \pm 0.7) \times 10^{-4} \text{ 90% C.L.} \] (4)

One caveat in this is that a destructive interference between the background and the ς has not been considered. As the Crystal Balls analysis of the spin parity of the ς depended on the decay chain J/ψ → ζ and ς → δπ, perhaps the results are not valid.

The Mark III data will be analyzed without assuming a δ for J/ψ → ηK⁺K⁻π⁺π⁻. Figure 2 shows the MK⁺K⁻ axis. One sees a low mass enhancement, but see no reason to cut at 1050 or 1125 MeV. We cut MK⁺K⁻ < 1320 MeV. Figure 3 shows distribution of MK⁺K⁻ with that cut.

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A clear \( \tau \) signal is seen with

\[
M_{\tau} = 1456 \pm 10 \text{ MeV} \\
\Gamma_{\tau} = 95 \pm 10 \text{ MeV}
\]  

(5)

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

When a likelihood analysis is made

\[
\frac{L(1^+)}{L(0^+)} \approx 10^{-3} \text{ to } 10^{-4}
\]

and

\[
\frac{L(1^-)}{L(0^-)} \approx 10^{-6} \text{ to } 10^{-7}
\]

depending on cuts, decay modes of \( \tau \).

Note that \( 0^+ \) is excluded as \( 0^+ \not\rightarrow 0^- + 0^- + 0^- \).

Crystal Ball was right. \( J_{13}^P = 0^- \).

2. SPIN PARITY OF \( \theta \) (1640)

HISTORY

1) Crystal Ball found the \( \theta \) in \( J/\psi \rightarrow \gamma \theta, \quad \theta \rightarrow \eta \eta \).

\[
M_{\theta} = 1640 \pm 50 \text{ MeV} \\
\Gamma_{\theta} = 220^{+100}_{-70} \text{ MeV}
\]  

(7)

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

An upper limit was set for the branching ratio

\[
J/\psi \rightarrow \gamma \theta, \quad \theta \rightarrow \pi \pi, \quad BR < 6 \times 10^{-4} \quad 90\% \text{ C.L.}
\]  

(8)

The Crystal Ball did a spin parity analysis using three angles. \( \eta \) was used as in the \( \tau \), but since we have a two body decay here, we use in the \( \theta \) rest system the polar angle \( \alpha \) between the \( \theta \) boost and the closest \( \eta \) and the azimuth \( \phi \). 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 \( \theta \) in \( J/\psi \rightarrow \gamma \theta, \quad \theta \rightarrow K^+K^- \). They found

\[
M_{\theta} = 1700 \pm 30 \text{ MeV} \\
\Gamma_{\theta} = 156 \pm 20 \text{ MeV}
\]  

(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 \( \theta \) in

\[
J/\psi \rightarrow \gamma \theta, \quad \theta \rightarrow K^+K^-
\]  

(10)

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

\[
M_{\theta} = 1720 \pm 10 \text{ MeV} \\
\Gamma_{\theta} = 130 \pm 20 \text{ MeV}
\]  

(11)
The branching ratio for the $K^+K^-$ channel

$$BR \ J/\psi \rightarrow \gamma \theta, \ \theta \rightarrow K^+K^-, \ (4.8 \pm 0.6 \pm 0.9) \times 10^-4$$

(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 $\theta$ to be $2^{++}$. The Crystal Ball and Mark II had the right answer on limited statistics.

The helicity ratios $z$ and $y$ for the $\theta$ were

$$z = -1.07 \pm 0.16$$

$$y = -1.09 \pm 0.15$$

(13)

Now we study the decay

$$J/\psi \rightarrow \gamma \pi^+\pi^-$$

(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 $\theta$ and the third (the $z$) a bit under 2100 MeV. The mass of the $\theta$ is

$$M_{\theta \rightarrow \pi\pi} = 1713 \pm 15 \ MeV$$

$$\Gamma_{\theta \rightarrow \pi\pi} \equiv \Gamma_{\pi \pi \pi} \equiv 130 \ MeV$$

(15)

The branching ratio is

$$J/\psi \rightarrow \gamma \theta, \ \theta \rightarrow \pi^+\pi^-, \ (1.6 \pm 0.4 \pm 0.3) \times 10^-4$$

(16)

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

$$M_{\pi^+\pi^-} = 2086 \pm 15 \ MeV$$

$$\Gamma_z = 210 \pm 63 \ MeV$$

(17)

The branching ratio is

$$J/\psi \rightarrow \gamma \theta, \ \theta \rightarrow \pi^+\pi^-, \ (3.0 \pm 0.5 \pm 0.6) \times 10^-4$$

(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 $\iota$ and $\theta$ 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 $J/\psi$ decays?

Could they be Glueballs? Theorists tell us that Glueballs should be produced in radiative $J/\psi$ 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 $\iota$ is $0^-$ and not $1^+$!

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

$$x_\theta = 0.96 \pm 0.07, \ y_\theta = 0.06 \pm 0.08$$

$$x_{f'} = 0.63 \pm 0.09, \ y_{f'} = 0.17 \pm 0.15$$

(19)

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

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