SLAC – PUB – 4026
July 1986
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J/ψ RESULTS FROM MARK III*

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ABSTRACT

Results from the Mark III collaboration on related hadronic and radiative decays of the J/ψ are presented. From a data sample of 5.8 million produced J/ψ decays disintegrations into either γ, ω, or ϕ plus $K\bar{K}, K\bar{K}\pi, \eta\pi\pi$ or $\pi\pi$ are studied. These results are valuable in the understanding of the nature and composition of the $2^{++}\theta(1720)$ and the $0^{-+}\iota(1440)$, the primary candidates for gluonic matter.

1. INTRODUCTION

For some time, radiative J/ψ decays have been studied in the search for bound states of gluons and several candidates for these states have been found. The $\theta(1720)$ and the $\iota(1440)$ are certainly the most viable candidates. Their observation in radiative J/ψ decays (Fig. 1c) however, does not imply that they are glueballs, and a careful study of the quark contents of the various resonances that occur is necessary. The hadronic two-body decays containing either an ω or a ϕ are especially useful for this type of study, since one would expect quark correlations between the vector mesons and the recoil system as shown in Figs. 1a,b. Since the flavour of the ideally mixed vector mesons is known, one can learn something about the flavour content of the recoiling resonances.

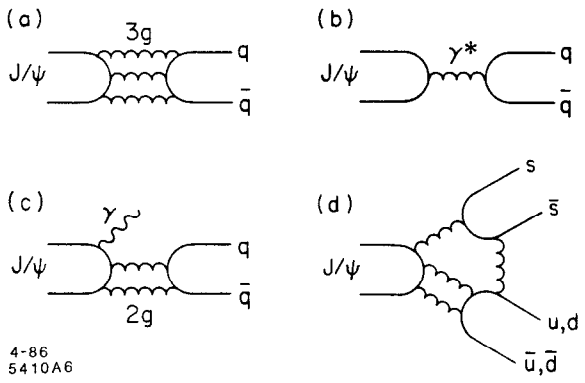

Fig. 1. a) Hadronic J/ψ decay via three gluons. b) electromagnetic J/ψ decay via one photon. c) radiative J/ψ decay via two gluons (color singlet). d) doubly disconnected diagram for hadronic J/ψ decay.

★ Work supported by the Department of Energy, under contracts DE-AC03-76SF00515.

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Invited talk presented at the International Symposium on Production and Decay of Heavy Hadrons, Heidelberg, West Germany, May 20–23, 1986

2. THE K$\bar{\text{K}}$ FINAL STATE

Of interest is the $\theta(1720)$, the $J^{PC} = 2^{++}$ glueball candidate that is clearly observed in the radiative decay $J/\psi \to \gamma K^+K^-$ as shown in Fig. 2a. It appears in the K^+K^- mass spectrum together with the $f'(1525)$ and the $\xi(2200)$.[1] The mass and width of the $\theta(1720)$ are $1720 \pm 10 \pm 10$ MeV/c^2 and 130 ± 20 MeV/c^2 respectively. The K^+K^- systems recoiling against the ω and the ϕ are shown in Fig. 2b and Fig. 2c. The ωK$\bar{\text{K}}$ channel is also studied in the $K^0_S K^0_S$ final state and its mass spectrum is similar to that of the ωK^+K^-. A clear structure is seen in the region of the $\theta(1720)$ in the K^+K^- invariant mass spectrum. A fit using a Breit-Wigner shape yields a mass value of $1731 \pm 10 \pm 10$ MeV/c^2 and a width of $110^{+35}_{-45} \pm 15$ Mev/c^2, consistent with the parameters of the $\theta(1720)$. The branching ratio $B(J/\psi \to \omega X(1731)) \times B(X \to \text{K}\bar{\text{K}})$ is found to be $(4.5^{+1.2}_{-1.1} \pm 1.0) \times 10^{-4}$. The branching fraction for $J/\psi \to \omega$K$\bar{\text{K}}$ is $(17.2 \pm 0.8 \pm 3.4) \times 10^{-4}$.

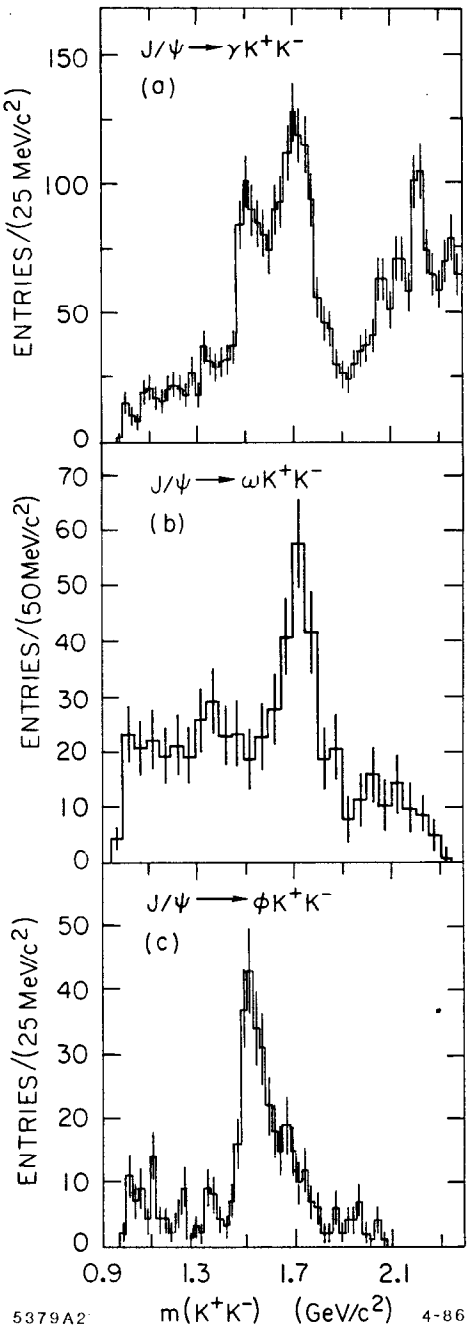

Fig. 2. Invariant K^+K^- mass in the reaction. a) $J/\psi \to \gamma K^+K^-$ b) $J/\psi \to \omega K^+K^-$ c) $J/\psi \to \phi K^+K^-$.

As expected from the double OZI suppression (Fig. 1d) no $\omega f'$ production is observed and an upper limit on the branching ratio $B(J/\psi \to \omega f') \times B(f' \to \text{K}\bar{\text{K}}) < 1.2 \times 10^{-4}$ is found at 90% C.L. The hadronic decay, $J/\psi \to \phi K^+K^-$ is studied in the final state containing four charged kaons. The recoil system against the ϕ, shown in Fig. 2c, has a resonant structure at the mass of the $f'(1525)$ as expected from the quark correlation. Examination of the peak reveals a significant shoulder on the high mass side. A fit to the spectrum with two non-interfering Breit-Wigner amplitudes leads to a mass assignment of $1671 \pm 15 \pm 10$ MeV/c^2 and a width of $126^{+60}_{-40} \pm 15$ MeV/c^2 for the higher mass. The width is consistent with that of the $\theta(1720)$; the mass is 50 MeV/c^2 lower. A fit allowing for interference however, gives a satisfactory result when the standard parameters of the $\theta(1720)$ are assumed. This lowers the branching ratio for the higher mass structure by a factor of 2.5. The branching ratios obtained from the noninterfering fit are $B(J/\psi \to \phi f') \times B(f' \to \text{K}\bar{\text{K}}) = (6.4 \pm 0.6 \pm 1.6) \times 10^{-4}$ and $B(J/\psi \to \phi X(1671)) \times B(X \to K^+K^-) = (3.4^{+1.0}_{-0.8} \pm 0.9) \times 10^{-4}$.

In summary, the $\theta(1720)$ clearly seen in the radiative decay $J/\psi \to \gamma K^+K^-$ may be observed in the decays $J/\psi \to \omega K^+K^-$ and $J/\psi \to \phi K^+K^-$ with similar mass and width. Assuming this to be the case, the quark correlation arguments suggest that the $\theta(1720)$ contains a sizeable amount of quarks. The occurrence of the structure together with the ω and the ϕ indicates that it has non-ideal mixing and suggests that it is not an ordinary meson.

3. THE K$\bar{\text{K}}\pi$ FINAL STATE

A comparison of the K$\bar{\text{K}}\pi$ mass spectrum in radiative J/ψ decays and the two-body hadronic decays is shown in Fig. 3. The radiative spectrum shows the $\iota(1440)$ which has $J^{PC} = 0^{-+}$. This resonance is produced with the largest branching ratio in radiative J/ψ decays requiring $c\bar{c}$ annihilation and is a prime glueball candidate. The interpretation of this mass region is unclear due to the existence of the $E(1420)$ observed in hadronic interactions. Although the $E(1420)$ was originally thought to be a $J^P = 0^-$ particle[2], its spin-parity was later measured[3,4] as 1^+ and more recently it has been observed as a spin 0 particle in hadronic interactions[5]. It is interesting to understand to what extent the $E(1420)$ occurs in radiative J/ψ decays and whether the $E(1420)$ and the $\iota(1440)$ are different objects. The ωK$\bar{\text{K}}\pi$ channel, studied in the $\omega K^\pm K_S\pi^\mp$ and $\omega K^+K^-\pi^0$ modes, is shown in Fig. 3b. The K$\bar{\text{K}}\pi$ mass distribution shows clear evidence for a state around the mass of the $E(1420)$. The resonance parameters obtained from a fit are $1444 \pm 5^{+10}_{-20}$ MeV/c^2 for the mass and $40^{+17}_{-13} \pm 10$ MeV/c^2 for the width with a product branching fraction $B(J/\psi \to X(1444)) \times B(X \to \text{K}\bar{\text{K}}\pi) = (6.8^{+1.9}_{-1.6} \pm 1.7) \times 10^{-4}$. The width is barely compatible with the width of the $\iota(1440)$ and suggests that the structure may be due to the $E(1420)$. In the K$\bar{\text{K}}\pi$ mass recoiling against the ϕ, no structure in the E/ι region emerges. The upper limit for the branching ratio is $B(J/\psi \to \phi X(1420)) \times B(X(1420) \to \text{K}\bar{\text{K}}\pi) < 1.1 \times 10^{-4}$.

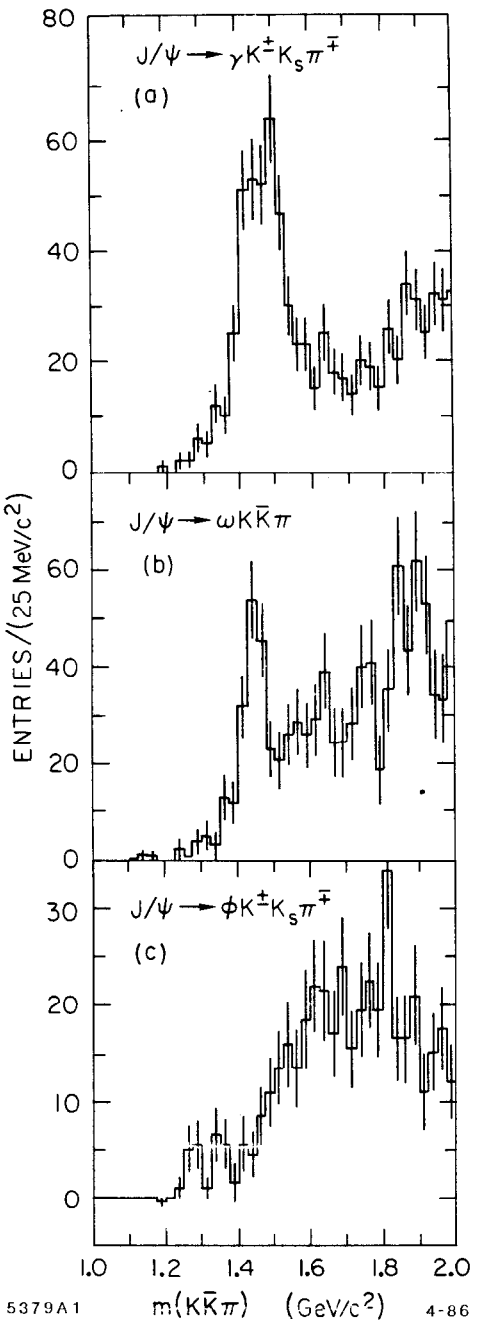

Fig. 3. Invariant K$\bar{\text{K}}\pi$ mass in the reaction. a) $J/\psi \to \gamma K^\pm K^0_S \pi^\mp$ b) $J/\psi \to \omega \text{K}\bar{\text{K}}\pi$ c) $J/\psi \to \phi K^\pm K^0_S \pi^\mp$.

The occurrence of the structure recoiling against the ω but not against the ϕ indicates that the $E(1420)$ is probably not the $s\bar{s}$ member of the axial-vector nonet.

4. THE $\eta\pi\pi$ FINAL STATE

The $K\bar{K}$ system in the $J/\psi \to \gamma K\bar{K}\pi$ channel is produced preferentially at low mass. This suggests that we observe $J/\psi \to \gamma\, \delta(980)\pi$ with $\delta(980) \to K\bar{K}$. Since the mode $\delta(980) \to \eta\pi$ mode is established, the $\eta\pi\pi$ invariant mass spectrum in radiative J/ψ decays is an obvious place to look for $\iota(1440)$ production. The $\eta\pi^+\pi^-$ mass spectrum from the radiative decay $J/\psi \to \gamma\eta\pi^+\pi^-$ is shown in Fig. 4a, where the two η decay modes, $\gamma\gamma$ and $\pi^+\pi^-\pi^0$ have been combined. At least one $\eta\pi$ mass combination must be consistent with the mass of the $\delta(980)(\pm 50\ \mathrm{MeV/c^2})$. This cut reduces the background considerably. The two structures observed are not affected by this cut. The structure at low energy has parameters consistent with the $D(1283)$ or the $\eta(1275)$.[6] The structure at 1390 MeV/c^2 has a width of 50 MeV/c^2. No structure consistent with the $\iota(1440)$ is apparent.

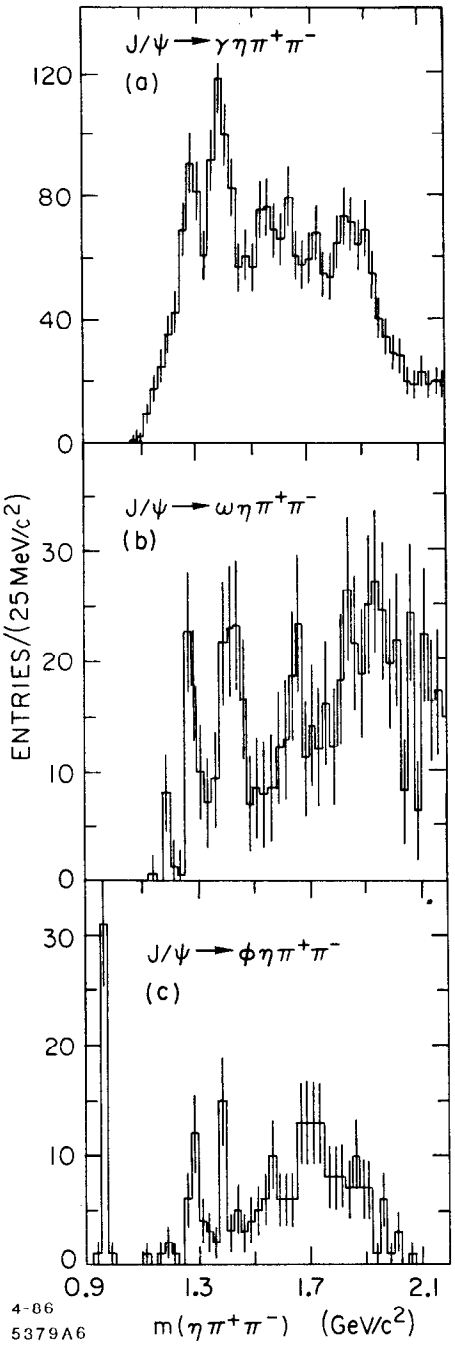

Fig. 4. Invariant $\eta\pi\pi$ mass in the reaction. a) $J/\psi \to \gamma\eta\pi^+\pi^-$ b) $J/\psi \to \omega\eta\pi^+\pi^-$ c) $J/\psi \to \phi\eta\pi^+\pi^-$.

The $\eta\pi^+\pi^-$ system in the $J/\psi \to \omega\eta\pi^+\pi^-$ decay shows structures in the $D(1283)$ and the $E(1420)$ regions. The resonances appear to decay dominantly through the two-body intermediate state $\delta(980)\pi$. The spectrum has the same $\delta(980)$−cut as described for the radiative decay which reduces the background considerably. The parameters of the lower mass structure are $1283 \pm 6 \pm 10$ MeV/c^2 for the mass and $14^{+19}_{-14} \pm 10$ MeV/c^2 for the width. The higher mass structure has a mass of $1421 \pm 8 \pm 10$ MeV/c^2 and a width of $45^{+32}_{-23} \pm 15$ MeV/c^2 respectively. The product branching ratios are $B(J/\psi \to \omega\, X(1283)) \times B(X(1283) \to \eta\pi\pi) = (4.3 \pm 1.2 \pm 1.3) \times 10^{-4}$ and $B(J/\psi \to \omega\ X(1420)) \times B(X(1420) \to \eta\pi\pi) = (9.2 \pm 2.4 \pm 2.8) \times 10^{-4}$ respectively.

The $\phi\eta\pi^+\pi^-$ channel in Fig. 4c also shows a resonant structure in the $D(1283)$ mass region, the parameters being $1283 \pm 6 \pm 10$ MeV/c^2 for the mass and $24^{+10}_{-14} \pm 10$ MeV/c^2 for the width. Again the enhancement is correlated with a $\delta(980)$ in the $\eta\pi$ subsystem. In the region of the $E(1420)$ there is one high bin observed leaving the existence of signal there somewhat unclear.

In summary, a narrow enhancement near the $D(1283)$ is observed in the $\eta\pi\pi$ mass spectra from the reactions $J/\psi \to \gamma\eta\pi\pi$, $\omega\eta\pi\pi$ and $\phi\eta\pi\pi$. If the $D(1283)$ is the axial vector nonet member containing light quarks, as it is generally believed to be, it should not occur in the recoil system against the ϕ. The $\eta\pi\pi$ structure observed in the radiative decay at a mass of 1390 MeV/c^2 has no equivalent in the hadronic cases. It is obvious that spin-parity analyses are needed to clarify this by now confusing picture.

5. THE $\pi^+\pi^-$ FINAL STATE

The $\pi^+\pi^-$ mass spectra from the reactions $J/\psi \to \gamma\pi^+\pi^-$, $J/\psi \to \omega\pi^+\pi^-$ and $J/\psi \to \phi\pi^+\pi^-$ are compared in Fig. 5. The radiative spectrum, showing a well-pronounced peak around the $f(1270)$ mass, has two more structures at higher energy. The lower one is identified as the $\theta(1720)$. The low mass enhancement around 800 MeV/c^2 is due to feedthrough from $\rho\pi$ events with an undetected photon. The recoil mass against the ω shown in Fig. 5b has a clear enhancement of the $f(1270)$ and a broad structure at low masses which is not yet understood. The product branching ratio $B(J/\psi \to \omega f) \times B(f \to \pi^+\pi^-)$ is $(27.7 \pm 1.4 \pm 7.0) \times 10^{-4}$. The $\phi\pi^+\pi^-$ channel in Fig. 5c shows a clear S^* peak, a broad structure in the 1400 MeV/c^2 region, and a possible $\theta(1720)$ enhancement.

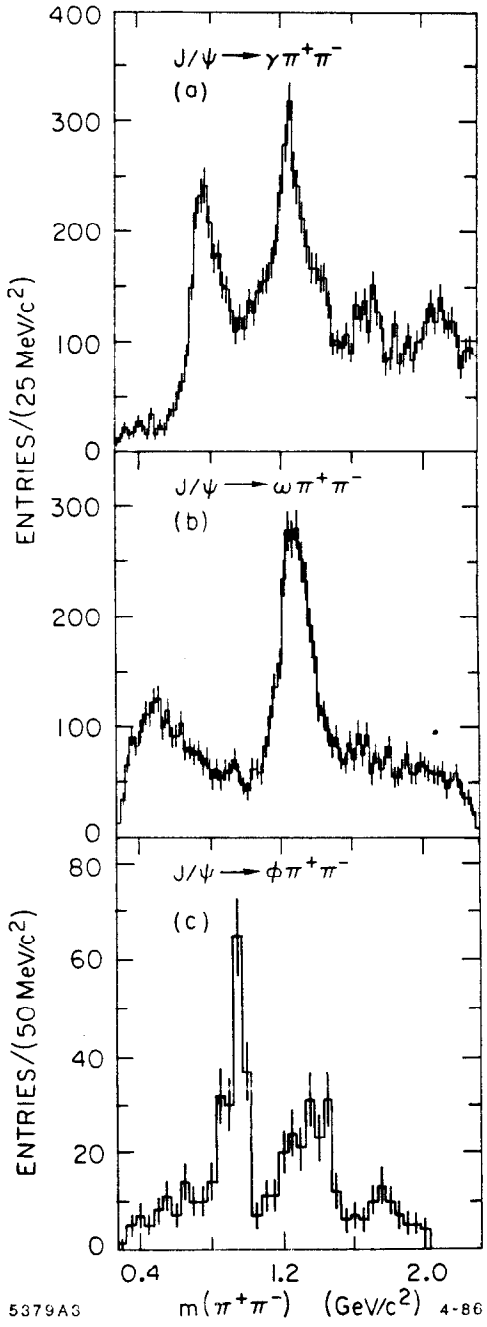

Fig. 5. Invariant $\pi^+\pi^-$ mass in the reaction. a) $J/\psi \to \gamma\pi^+\pi^-$ b) $J/\psi \to \omega\pi^+\pi^-$ c) $J/\psi \to \phi\pi^+\pi^-$.

SUMMARY

The $\pi^+\pi^-$ and K^+K^- spectra recoiling against the ω and the ϕ follow the pattern of tensor meson production as expected from quark correlations. Given this support for the dominance of singly-suppressed over doubly-suppressed diagrams, the comparison of the hadronic and radiative decays reveals interesting information about the composition of the glueball candidates $\theta(1720)$ and $\iota(1440)$. The structure in the $\theta(1720)$ mass region, which does not show ideal mixing like other tensor mesons, remains a candidate for a bound gluon state.

In the $\iota(1440)$ region, a puzzling picture emerges. The broad $\iota(1440)$ does not occur in the hadronic two-body decays; rather, narrower structures compatible with the

$E(1420)$ occur. In the $\eta\pi\pi$ systems, structures around the $D(1283)$ emerge. To what extent the $\eta(1275)$ contributes to this structure is not clear.

The occurrence of the structures compatible with $D(1283)$ and $E(1420)$ recoiling against the ω and ϕ poses questions about the quark content of these axial vector mesons. Spin-parity analyses are clearly needed to resolve the picture.

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