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RECENT RESULTS OF J/ψ DECAYS FROM MARK III*

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ABSTRACT

The MARK III Collaboration has collected a data sample of 5.8×10^6 produced J/ψ's. Results from the previous measurements in radiative decays are updated and compared with the hadronic decays. In particular, data, which are relevant to understand the nature of the $\theta(1720)$, $\iota(1440)$ and/or E(1420), are presented. A preliminary analysis of a systematic study of direct J/ψ decays into the vector($J^{PC}=1^{--}$) and the tensor ($J^{PC}=2^{++}$) mesons are presented. Some vector-scalar decays are discussed. Among the baryonic modes, observation of several SU(3) violating decays is reported.

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Introduction

The decays of J/ψ have proven to be a rich laboratory for finding new and exciting states e.g. $\iota(1440)$, $\theta(1720)$, $\xi(2230)$ in the last decade. A popular searching place for glueballs has been the radiative decays. On the other hand, pure hadronic decays of J/ψ into mesons and baryons have been used as a factory to study light quark spectroscopy in a very clean environment with a well defined initial state ($J^{PC} = 1^{--}$). Decays with a ϕ or an ω help one understand the quark content of the meson recoiling against them. Most of the recent results presented here are on hadronic decays.

Figure 1 shows the principal decay mechanisms of the J/ψ in order of relative strength. Further similar or higher order diagrams exist, but are not shown. As an interesting consequence of quark correlations arising from 1a and 1b, we have analyzed processes of the type

$$J/\psi \longrightarrow (1^{--}) + (2^{++}),$$

as well as

$$J/\psi \longrightarrow (1^{--}) + (0^{++}),$$

to complement our previous study[1] of

$$J/\psi \longrightarrow (1^{--}) + (0^{-+}).$$

Particularly for the scalar nonet, questions of glueball candidates or four quark bound states have become intriguing. These are described in the first section.

Of special interest for quark correlation studies are the mesons recoiling against the ϕ and the ω. According to the quark line diagrams in Figs. 1a,b ϕ being pure $s\bar{s}$ and ω being pure $u\bar{u}$ and $d\bar{d}$, project out, respectively, the strange and the non-strange quark content in the recoil system. However, the observed final states arising from the two gluon system in the radiative decays (Fig. 1c) are flavor independent. Hence, to understand the nature of the $E(1420)/\iota(1440)$ and D(1285) we compared the final states $K\bar{K}\pi$ and $\eta\pi^+\pi^-$ in radiative decays with these same states in hadronic decays recoiling against the ϕ and the ω. The second section deals with this. Thereafter, the current status of the $\xi(2230)$ and

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some other radiative decays are discussed briefly. Then, the baryonic decays are discussed in the last section.

Quark Correlation Studies of the Tensor and the Scalar Nonet

$\pi^+\pi^-$ recoil from ω and ϕ

The final state $J/\psi \longrightarrow \pi^+ \pi^-\pi^+\pi^-\pi^0$ was studied where the ω was selected in the $\pi^+\pi^-\pi^0$ decay mode. Figure 2a shows the 5C fit $\pi^+\pi^-\pi^0$ mass spectrum with four combinations per event. A clear ω peak over the combinatorial background is evident. Figure 3a shows the final $\pi^+\pi^-$ spectrum recoiling against the ω. The prominent peak at ~1280 MeV/c^2 is easily identified with the f(1270), the I=0 member of the 2^{++} nonet, containing mostly non-strange quarks. The peak corresponds to a branching ratio of J/ψ into ωf(1270)

$$B(J/\psi \longrightarrow \omega f(1270)) \times B(f(1270) \longrightarrow \pi^+\pi^-) = (27.7 \pm 1.4 \pm 7.0) \times 10^{-4}.$$

The broad enhancement at ~500 MeV/c^2 has been seen in previous experiments, but is not yet understood. The structure near 1000 MeV/c^2 also needs further investigation. The inclusive branching ratio of J/ψ $\longrightarrow$ $\omega\pi^+\pi^-$ is shown in Table 1.

The final state $K^+K^-\pi^+\pi^-$ was analyzed to study the $\pi^+\pi^-$ system recoiling against a ϕ. Figure 2b shows the K^+K^- spectrum in the ϕ region. The ϕ signal is almost background free. Figure 3b shows the recoiling $\pi^+\pi^-$ mass spectrum . A clear peak at ~980 MeV/c^2 corresponding to the S^* is seen. The spin-parity of the S^* is known to be 0^{++}. However, whether it is a simple $q\bar{q}$ resonance, two states close to each other[2] (a pole in $\pi\pi$ and another in $K\bar{K}$), or a four quark state,[3] has been debated. In the $q\bar{q}$ scheme it is usually taken as primarily an $s\bar{s}$ bound state, but being below the $K\bar{K}$ threshold, decays primarily to $\pi\pi$. However, once the invariant mass is above the $K\bar{K}$ threshold, it decays mostly to $K\bar{K}$ and hence the sharp fall-off on the high mass side of the S* in the $\pi\pi$ spectrum. Fitting the S* spectrum to the standard coupled channel Flatté parametrization,[4] the branching ratio of J/ψ into ϕS* was measured as

$$Br(J/\psi \longrightarrow \phi S^*) \times Br(S^* \longrightarrow \pi^+\pi^-) = (2.3 \pm 0.3 \pm [illegible]$$

The structures in the mass region of 1300 to 1550 MeV/c^2 have be[illegible]ulated to be the f(1270) and the ϵ(1300), and the structure at ~1700 MeV/c^2 to be the θ(1720). The measurement of the inclusive branching ratio of J/ψ $\longrightarrow$ $\phi\pi^+\pi^-$ is included in Table 1.

K^+K^- recoil from ω and ϕ

The K^+K^- recoil spectra against the ω and the ϕ are presented in Fig. 4. The recoil spectrum from the ω was studied both in K^+K^- and K_sK_s modes. No striking signal corresponding to any of the standard $q\bar{q}$ resonances is apparent in the K^+K^- spectrum. However, a clear peak is seen (Fig. 4a) at 1731±10±10 MeV/c^2 with a width of 110^{+45}_{-35}±15 MeV/c^2, which are consistent with the parameters of the θ(1720). The branching ratio of J/ψ into this decay mode was

$$Br(J/\psi \longrightarrow \omega X(1731)) \times Br(X(1731) \longrightarrow K\bar{K}) = (4.8^{+1.8}_{-1.1} \pm 1.0) \times 10^{-4}.$$

Ignoring any possible interference, an upper limit on $\omega f'(1525)$ production was calculated at 90% C.L. as

$$Br(J/\psi \longrightarrow \omega f'(1525)) \times Br(f'(1525) \longrightarrow K\bar{K}) < 1.3 \times 10^{-4}.$$

The K_sK_s mass spectrum, with much less statistics, reproduced the major features of the charged mode. The inclusive branching ratio of J/ψ into $\omega K\bar{K}$ is included in Table 1.

The K^+K^- mass spectrum recoiling against the ϕ shows a clear enhancement at the f'(1525) mass. This is the I=0, primarily $s\bar{s}$ member of the 2^{++} nonet. However, a high mass shoulder to the f'(1525) is evident. Parametrising the structure with an f'(1525) plus another non-interfering Breit-Wigner resonance, the fit assigns a mass and a width of 1669±15 MeV/c^2 and 93±41 MeV/c^2 to the high mass shoulder. A fit with the f'(1525) and an interfering Breit-Wigner amplitude yields a mass of 1708±64 MeV/c^2 and a width of 100±40 MeV/c^2 for the higher state. The parameters for this higher mass state are consistent with those of the θ(1720). The branching ratio for f'(1525) was measured as

$$Br(J/\psi \longrightarrow \phi f'(1525)) \times Br(f'(1525) \longrightarrow K\bar{K}) = (6.4 \pm 0.6 \pm 1.6) \times 10^{-4}$$

in the case of the non-interfering fit. The interfering fit yielded essentially the same result for the $f'(1525)$.

Comparison with the radiative decay modes $\gamma\pi^+\pi^-$ and γK^+K^-

The radiative decays of the J/ψ have been very rich in new physics. The γ, ϕ and ω all have the same J^{PC} quantum numbers. While the ω and the ϕ project out the non-strange and the strange quark content, respectively, in the recoiling $q\bar{q}$ system (Figs. 1a,b), the two-gluon system that decays into the observed final state in radiative decays (Fig. 1c) is flavor independent. Consequently, the radiative decays should be independent of the quark flavor. Figures 3a,b and c present the $\pi^+\pi^-$ spectra recoiling from the ω, ϕ and γ respectively. Figure 3a has a clear f(1270) and Fig. 3b has a clear S^* peak corresponding to the flavor correlation in Fig. 1a. Figure 3c shows a large f(1270) peak, a shoulder, possibly from the $f'(1525)$, and a $\theta(1720)$ peak. The lower peak at ~800 MeV/c^2 originates from $\rho^0\pi^0$ feed through, where a photon from the π^0 is undetected.

Among the K^+K^- recoil spectra against the ω, ϕ and γ in Fig. 4, the radiative decay shows clear $f'(1525)$ and $\theta(1720)$ production, whereas copious $f'(1525)$ production is visible in the recoil spectrum against the ϕ. An interesting point to note is that while the continuum process of $\phi\pi\pi$ production proceeds through a double OZI suppressed diagram e.g., Fig. 1d, that of $\omega K\bar{K}$ can proceed through either a double OZI suppressed diagram or a single OZI suppressed diagram (for example, a sequential decay mechanism[8]). The subject of the $\theta(1720)$ production in association with the ϕ and ω and in radiative decays is discussed at the end of this section.

Recoils from $K^*(892)$ and ρ

To check the quark correlations further, recoils against the isodoublet, $K^*(892)$, and the isovector ρ were analyzed. In the case of the $K^*(892)$, the final state

considered was $K^+\pi^-$ $K^-\pi^+$. Figure 5a shows the plot of $K^+\pi^-$ vs. $K^-\pi^+$. A band due to $\overline{K^*(892)}^0$ ($(K^*(892)^0)$) production is apparent in $K^-\pi^+$ ($K^+\pi^-$). Figure 5b shows the $K^-\pi^+$ spectrum recoiling from the $K^*(892)^0$. A large peak at ~1430 MeV/c^2 corresponding to the production of $K^*(1432)$, the isodoublet partner of the 2^{++} nonet is seen. The production branching ratio for this mode was measured as

$$Br(J/\psi \longrightarrow \overline{K^*(892)}^0 K^*(1430)^0) + cc = (56 \pm 4 \pm 8.4) \times 10^{-4}.$$

A small but clear peak is evident in Fig. 5b due to $K^*(892)^0$ production, which is forbidden by invariance of the strong interaction under SU(3), and therefore points to the breaking of SU(3) or the presence of a substantial electromagnetic amplitude in J/ψ decays (Fig. 1b).

The recoil spectrum against the ρ was studied in the $\eta\pi^+\pi^-\pi^0$ final state, where the $\rho^0(\rho^\mp)$ decayed into $\pi^+\pi^-(\pi^0\pi^\mp)$ and the resonances were searched for in the $\eta\pi^0$ ($\eta\pi^\pm$) decay mode. Figure 6a shows the recoil $\eta\pi$ spectrum from all three charged states of the ρ. Two peaks corresponding to $\delta(980)$ and $A_2(1320)$ production are seen above the background at ~980 and at 1320 MeV/c^2 respectively. Figure 6b shows the same spectrum corresponding to the sidebands of the ρ. The correlation of the $A_2(1320)$ production in association with the ρ is clear, however, the interpretation of $\delta(980)$ production with the ρ is still being pursued. The branching ratio of $\rho A_2(1320)$ production was calculated to be

$$Br(J/\psi \longrightarrow \rho A_2(1320)) = (118 \pm 8 \pm 29) \times 10^{-4}.$$

Conclusion of Vector-tensor and Vector-scalar Decays

Table 1 summarizes the measured decay modes of J/ψ into the vector-tensor and vector-scalar channels. The flavor correlations assumed by the dominance of diagrams 1a and 1b are clearly seen, however the differences in measured branching ratios for associated production of ω and ϕ seem to point to the presence of a large amount of SU(3) violation. This effect was seen and measured[1] along with the strong and the electromagnetic amplitudes in an earlier systematic study of

J/ψ decay into the vector-pseudoscalar nonets. This led to a measurement of the quark content of the η and the η'. In the case of the scalar mesons, a systematic study has begun, and promises to be interesting.

The status of the $\theta(1720)$

The $\theta(1720)$ was first seen[6] in radiative decays, leading to an argument for its "glueball" interpretation,[7,8] since production of pure gluonic matter is supposedly suppressed in direct hadronic decays.[9] If the enhancements at $\sim$1730 MeV/c^2 in the recoils against the ω (Fig. 4a) and the ϕ (Fig. 4b) are indeed from the $\theta(1720)$, then it is produced in purely hadronic decays. This would mean that the $\theta(1720)$ is not a pure glueball but contains quarks as well.

Study of 'D, E/ι' in $K\bar{K}\pi$ and $\eta\pi\pi$ Final States

$K\bar{K}\pi$ recoil from γ, ω and ϕ

Figure 7a shows the $K^{\pm}K_S\pi^{\mp}$ spectrum from radiative J/ψ decays. The analysis has been described elsewhere.[9] The iota signal is clearly seen. This has been one of the prime "glueball" candidates,[10,4] and was first observed[11] in J/ψ decays by the MARK II collaboration. A coupled channel analysis[12] suggested that the J/ψ decays radiatively into the $\iota(1440)$, a pseudoscalar, with one of the largest radiative branching ratios. The $\iota(1440)$ then decays into $K\bar{K}\pi$, $\gamma\rho$, $\rho\rho$, and $\omega\omega$. In the $K\bar{K}\pi$ channel, the $\iota(1440)$ shows up at a mass of 1460 MeV/c^2 and a width of $\sim$90 MeV/c^2 as seen in Fig. 7a. The $K\bar{K}\pi$ recoil spectrum against an ω was observed in the $K^{\pm}K_S\pi^{\mp}$ and $K^+K^-\pi^0$ channels. Both channels look very similar. Figure 7b shows the combined spectrum. Fitting the spectrum with a Breit-Wigner and a background, one obtains a mass of $1444\pm5^{+10}_{-20}$ MeV/c^2 and a width of $40^{+17}_{-13}\pm 10$ MeV/c^2. The angular distribution of the ω in this mass region in the helicity frame suggests non-zero spin for the $K\bar{K}\pi$ system.

The system recoiling against the ϕ was observed in $K^{\pm}K_S\pi^{\mp}$ and in $K^{\pm}K_L\pi^{\mp}$ decay modes. Figure 7c presents the $K^{\pm}K_S\pi^{\mp}$ spectrum. There is no apparent

resonant structure at the E(1420)/ι(1440) mass. An upper limit, fixing the mass at 1420 MeV/c^2 and width at 52 MeV/c^2, has been measured to be

$$Br(J/\psi \longrightarrow \phi\text{'E(1420)'}) \times Br(\text{'E(1420)'} \longrightarrow K^{\pm}K_S\pi^{\mp}) < 1.1 \times 10^{-4}.$$

$\eta\pi^+\pi^-$ recoil from γ, ω and ϕ

Figures 8a,b and c display the $\eta\pi^+\pi^-$ spectra from J/ψ decays recoiling against a γ, ω and ϕ, respectively. Two decay modes of the η, namely, $\pi^+\pi^-\pi^0$ and $\gamma\gamma$ were observed and are shown combined together in Fig. 8a. In addition, at least one $\eta\pi$ combination was required to be consistent with the $\delta(980)$. There is a peak at $\sim$1280 MeV/c^2 at the nominal D(1285) mass, a member of the 1^{++} nonet. The D(1285) is known to contain $u\bar{u}+d\bar{d}$ quarks where the E(1420) contains $s\bar{s}$ quarks primarily.[13] Since the spin-parity has not been determined here, this could also be the $\eta'(1275)$, reported[14] by some earlier experiments. Another clear peak is seen at $\sim$1395 MeV/c^2, lower than the conventional E(1420) mass; there is a dip at the $\iota(1440)$. The higher mass region presents several structures as well. A detailed analysis to unfold the spin-parity of various parts of the spectra is underway. The recoil against an ω and a ϕ were observed in the $\gamma\gamma$ decay mode of the η. In Fig. 8b, the $\eta\pi$ was required to have been produced through the decay of an intermediate $\delta(980)$. The parameters of the two peaks in Fig. 8b, as obtained from fitting them to two Breit-Wigner forms, are:

M=1283$\pm$6 $\pm$ 10, $\Gamma = 14^{+10}_{-14} \pm 10$ MeV/c^2

and, M=1421$\pm$8 $\pm$ 10, $\Gamma = 45^{+32}_{-23} \pm 15$ MeV/c^2.

The measured branching ratios are respectively,

$$Br(J/\psi \longrightarrow \omega\text{'}D(1285)\text{'}) \times Br(\text{'}D(1285)\text{'} \longrightarrow \eta\pi^+\pi^-) = (4.3 \pm 1.2 \pm 1.3) \times 10^{-4},$$

and

$$Br(J/\psi \longrightarrow \omega\text{'}E(1420)\text{'}) \times Br(\text{'}E(1420)\text{'} \longrightarrow \eta\pi^+\pi^-) = (0.2 \pm 2.4 \pm 2.8) \times 10^{-4}.$$

Figure 8c shows an $\eta'(958)$. The parameters for the 'D(1285)' like enhancement are

M=1283±6 ± 10, $\Gamma = 24^{+20}_{-14} \pm 10$ MeV/c^2, with a branching ratio

$$Br(J/\psi \longrightarrow \phi\text{"D(1285)"}) \times Br(\text{"D(1285)"} \longrightarrow \eta\pi^+\pi^-) = (1.6^{+0.8}_{-0.5} \pm 0.4) \times 10^{-4}.$$

Conclusion of the $K\bar{K}\pi$ and $\eta\pi\pi$ Studies

Several questions are raised by the above results, some new and some already existing dilemmas. First, there is the question of whether the E really belongs to the 1^{++} family. A recent BNL high statistics experiment[15] claims the E(1420) meson to be a pseudoscalar after a partial wave analysis. This raises the question of whether the E(1420) and the $\iota(1440)$ are the same, and whether the $\iota(1440)$ is not one but two states.[16] It has been suggested[7] that it might be theoretically comforting if the E(1420) were to be the 0^{-+} state while the recently reported D'(1530)[17] were the $s\bar{s}$ state in the 1^{++} nonet. Given the existence of the $\eta'(1275)$, it is hard to accommodate both the $\iota(1440)$ and the $\eta'(1275)$ as isoscalar states in a radially excited $q\bar{q}$ nonet.[18] The 'glue' interpretation of the $\iota(1440)$ is probably the most popular. Several mixing models of the pseudoscalar isoscalars involving the $\iota(1440)$ exist,[19] but the situation is far from settled.

In the MARK III data the $\iota(1440)$ shows up in the radiative $K\bar{K}\pi$ decay with a mass and a width of 1456 ± 5 ± 6 MeV/c^2 and 95 ± 10 ± 15 MeV/c^2 respectively. The $K\bar{K}\pi$ recoil against the ω shows the 'E(1420)' like object at 1444 MeV/c^2 with $24 < \Gamma < 84$ MeV/c^2 at 90% C.L. (narrower than the $\iota(1440)$). Again, the recoil against the ϕ does not show this structure. The conventional axial vector E(1420), containing mainly $s\bar{s}$ quarks should be observed against a ϕ recoil instead of an ω recoil.

The $\eta\pi\pi$ decay mode is intriguing. The peak at ~1280 MeV/c^2 is visible in recoil against a γ, a ϕ and an ω. A knowledge of its spin-parity will determine

whether it is the $\eta'(1275)$ or the D(1285). The D(1285) has been seen in the $\eta\pi\pi$ decay mode with a large branching ratio, however, the D(1285) is known mainly to be $u\bar{u} + d\bar{d}$, whereas this peak shows up in recoil against both ϕ and ω.

The dip in the radiative $\eta\pi\pi$ spectrum at the conventional $\iota(1440)$ mass is puzzling; although several models exist[20] regarding the appearance of the $\iota(1440)$ in the $K\bar{K}\pi$ mode and the seeming absence of it in the $\eta\pi\pi$ mode in radiative decays. The peak at 1395 MeV/c^2, whose mass and width are not inconsistent with those of the E(1420) meson is also intriguing in the radiative $\eta\pi\pi$ spectrum.

Recent Status of the ξ, η_c in Radiative Decays of J/ψ

The status of the state $\xi(2230)$ observed by MARK III in radiative K^+K^- and K_SK_S was confirmed and reported[21] by MARK III. This was not observed by the DM2 collaboration. Various possible decay modes of the $\xi(2230)$ were searched for. Predictions[22] were made that if it were a hybrid state, it would decay through OZI violating modes e.g. $J/\psi \longrightarrow \gamma\phi\omega$. In addition this was the only radiative vector-vector decay mode left from a systematic study of the η_c decays into two vector mesons.[11] Figure 9 shows the $\omega\phi$ mass spectrum obtained from the final state $K^+K^-\pi^+\pi^-3\gamma$. A hint of the $\xi(2230)$ is visible with a few events at 2.23 GeV/c^2. With a conservative approach, an upper limit was estimated as

$$Br(J/\psi \longrightarrow \gamma\xi(2230)) \times Br(\xi(2230) \longrightarrow \omega\phi) < 5.9 \times 10^{-5}, \text{ at a 90\% C.L.}$$

This is to be compared with the branching ratio of the J/ψ into $\xi(2230) \longrightarrow \gamma K\bar{K}$ decay modes

$$Br(J/\psi \longrightarrow \gamma\xi(2230)) \times Br(\xi(2230) \longrightarrow K^+K^-) = (4.2^{+1.7}_{-1.4} \pm 0.8) \times 10^{-5},$$

and

$$Br(J/\psi \longrightarrow \gamma\xi(2230)) \times Br(\xi(2230) \longrightarrow K^0_SK^0_S) = (3.1^{+1.6}_{-1.3} \pm 0.7) \times 10^{-5}.$$

The η_c does not appear as a strong signal. The upper limit for this decay mode is

$$Br(J/\psi \longrightarrow \gamma\eta_c) \times Br(\eta_c \longrightarrow \omega\phi) < 1.3 \times 10^{-5} \text{ at } 90\% \text{ C.L.}$$

The inclusive branching ratio $Br(J/\psi \longrightarrow \gamma\omega\phi) = (1.4 \pm 0.25 \pm 0.28) \times 10^{-5}$.

New Baryonic Decays of J/ψ

The following decay modes have been analyzed to search for possible SU(3) violating decays :

$$J/\psi \longrightarrow \Xi^- \overline{\Xi(1530)}^+ + cc \qquad \text{(i)}$$

and

$$J/\psi \longrightarrow \Xi^0 \overline{\Xi(1530)}^0 + cc \qquad \text{(ii)}$$

along with the "elastic" process

$$J/\psi \longrightarrow \Xi^- \bar{\Xi}^+ \qquad \text{(iii)}$$

The two decay modes of the $\overline{\Xi(1530)}^+$ were analyzed separately. Figure 10a shows the missing mass spectrum recoiling against the Ξ^-, where the $\overline{\Xi(1530)}^+$ decays through $\bar{\Xi}^+$. The elastic peak at 1315 MeV/c^2 is very prominent, while a peak at 1535 MeV/c^2 from $\overline{\Xi(1530)}^+$ production is also evident.

For the decay mode where the $\overline{\Xi(1530)}^+$ decays through $\bar{\Xi}^0$, the missing mass of the reconstructed Ξ^- and the bachelor π^+ (not belonging to the Λ) combination was plotted as shown in Fig. 10b. A peak at 1315 MeV/c^2 due to $\bar{\Xi}^0$, corresponding to $\overline{\Xi(1530)}^+$ decaying into $\bar{\Xi}^0$ and π^+, is seen. The low mass peak at 1120 MeV is due to $\bar{\Lambda}$ from the elastic process, with the $\bar{\Xi}^+$ decaying into $\bar{\Lambda}\pi^+$. The charge conjugate modes were analyzed separately. The weighted average of the branching ratios derived from the two decay modes of the $\overline{\Xi(1530)}^+$ was

$$Br(J/\psi \longrightarrow \Xi^- \overline{\Xi(1530)}^+ + cc) = (8.8 \pm 0.7 \pm 2.2) \times 10^{-4},$$

while the branching ratio of the elastic reaction was measured as

$$Br(J/\psi \longrightarrow \Xi^- \bar{\Xi}^+) = (8.6 \pm 0.5 \pm 2.0) \times 10^{-4}.$$

Since J/ψ is an SU(3) singlet, the decay into $\Xi\bar{\Xi}^*$ i.e. into $B_8\bar{B}_{10}$ (octet-decuplet) is $SU(3)_{strong}$ violating. One obtains the ratio of the SU(3) violating to SU(3) allowed decay modes as

$$\frac{\frac{1}{2} \times Br(J/\psi \longrightarrow \Xi^- \overline{\Xi(1530)}^+ + cc)}{Br(J/\psi \longrightarrow \Xi^- \bar{\Xi}^+)} = 0.50 \pm 0.05 \pm 0.2.$$

In the neutral mode (ii), at most a small signal was observed. In addition, Monte Carlo studies showed possible feedthrough from other channels. As a conservative approach, we therefore quote an upper limit:

$$Br(J/\psi \longrightarrow \Xi^0 \overline{\Xi(1530)}^0 + cc) < 4.1 \times 10^{-4} \text{ at } 90\% \; C.L.$$

A strong interaction decay respects isospin invariance. The J/ψ, being an isosinglet, should have equal branching ratios for reactions (i) and (ii) if the decay proceeds by the strong interactions. The large difference in the two rates therefore shows the presence of an electromagnetic amplitude. Hence the observed branching ratios of (i) and (ii) might arise from an interference between the electromagnetic and the strong amplitudes. Further studies are being performed.

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Table 1. Compilation of the J/ψ decay branching ratios

J/ψ Decay Modes	$Br \times 10^4$		
	MK3	DM2	Particle Data Group
ωf	$49.3 \pm 2.5 \pm 12.5$	40 ± 6	23 ± 8
$\omega f'$	< 1.2	—	< 1.6
$\phi f'$	$\times f' \to K\bar{K}$	$\times f' \to K\bar{K}$	
	$6.4 \pm 0.6 \pm 1.6$	$4.6 \pm 0.5 \pm 0.7$	3.7 ± 1.3
ϕf	—	—	< [illegible].7
$K^{*0}(892)\overline{K^{*0}(1430)} + cc$	$56 \pm 4 \pm 8.4$	—	67 ± 26
ρA_2	$118 \pm 8 \pm 29$	$86 \pm 3 \pm 13$	84 ± 45
ϕS^*	$\times S^* \to \pi^+\pi^-$	$\times S^* \to \pi^+\pi^-$	—
	$2.3 \pm 0.3 \pm 0.6$	$2.38 \pm 0.2 \pm 0.4$	2.6 ± 0.6
$\omega\pi^+\pi^-$	$78 \pm 1 \pm 16$	$66 \pm 10 \pm 6$	68 ± 19
$\omega K\bar{K}$	$17.2 \pm 0.8 \pm 3.4$	—	16 ± 10
$\phi\pi^+\pi^-$	$9 \pm 0.4 \pm 2.3$	$7.5 \pm 0.3 \pm 1.5$	21 ± 9

REFERENCES

1. R. M. Baltrusaitis *et al.*, Phys. Rev. D32, 2883 (1985).
2. K. L. Au, D. Morgan and M. R. Pennington, RAL-85-099,(1985).
3. R. Jaffe, Phys. Rev. D15, 267, (1977);
   S. Godfrey and N. Isgur, Phys. Rev. D32, 189 (1985).
4. S. M. Flatté, Phys. Lett. 63B, 224 (1976). This is an approximation from the non-relativistic to the relativistic case, however, it has also been done with a more exact formalism.
5. G. Karl and S. Tuan, UH-511-571-85, submitted to Phys. Rev.
6. C. Edwards *et al.*, Phys. Rev. D25, 3065 (1982).
7. J. F. Donoghue, Proceedings of the International Europhysics Conference on High Energy Physics, Bari, Italy, July 1985.
8. J. Rosner, Proceedings of the the Twelfth International Symposium at High Energies, Kyoto, Japan, August 1985.
9. J. D. Richman, Proceedings of the XXth Rencontre de Moriond, Les Arcs, France, March 10-17, 1985.
10. For a comprehensive review, see M. Chanowitz, Proceedings of the SLAC Summer Institute, 1981.
11. D. L. Scharre *et al.*, Phys. Lett. 97B, 329 (1980).
12. N. Wermes, Proceedings of the Fifth International Conference on Physics in collision, Autun, France, July 1985, and SLAC-PUB-3730.
13. L. Montanet, Report on Progress in Physics, Vol. 46, 1983.
14. N. Stanton *et al.*, Phys. Rev. Lett. 42, 346 (1979);
    A. Ando *et al.*, Contributed paper to session P09 at the International Europhysics Conference on High Energy Physics, Bari, Italy, July 1985.

15. S. Protopopescu, contribution to the XXIst Rencontre de Moriand, Les Arcs, France, March 16-22, 1986.

16. H. Lipkin, Phys. Lett. 171B, 298 (1986).

17. P. Gavillet *et al.*, Zeit. Phys. C16, 119 (1982).

18. J. F. Donoghue and H. Gomm, Phys. Lett. 112B, 409 (1982); M. Frank and P. J. O'Donnell, Phys. Rev. D29, 921 (1984).

19. W. F. Palmer, S. S. Pinsky and C. Bender, Phys. Rev. D30, 1002 (1984); H. E. Haber and J. Perrier, Phys. Rev. D32, 2961 (1984); M. Frank and P. O'Donnell, Phys. Rev. D32, 1739 (1985).

20. W. F. Palmer and S. S. Pinsky, Phys. Rev. D27, 2219 (1983); M. Frank, N. Isgur, P. J. O'Donnell and J. Weinstein, Proceedings of the International Europhysics Conference on High Energy Physics, Bari, Italy, July 1985.

21. R. M. Baltrusaitis *et al.*, Phys. Rev. Lett. 56, 107 (1986).

22. M. Chanowitz and S. R. Sharpe, Phys. Lett. 114B, 489 (1984).

23. R. M. Baltrusaitis *et al.*, Phys. Rev. D33, 629 (1986).

Figure Captions

1. (a) Three gluon annihilation, (b) Electromagnetic decay proceeding via $c\bar{c}$ annihilation into one photon, (c) Electromagnetic decay into a final state of one photon and two gluon color singlet, (d) Doubly disconnected diagrams (double OZI suppression).

2. (a) 5c fitted $\pi^+\pi^-\pi^0$ mass spectrum with four combinations per event from the reaction $J/\psi \longrightarrow \pi^+\pi^-\pi^+\pi^-\pi^0$, (b) 4c fitted K^+K^- mass spectrum from the reaction $J/\psi \longrightarrow K^+K^-\pi^+\pi^-$.

3. The $\pi^+\pi^-$ spectra recoiling against the (a) ω, (b) ϕ, and (c) γ, in the J/ψ decay.

4. The K^+K^- spectra recoiling against the (a) ω, (b) ϕ, and (c) γ, in the J/ψ decay.

5. (a) The $K^+\pi^-$ mass vs. $K^-\pi^+$ mass from the reaction $J/\psi \longrightarrow K^+\pi^-K^-\pi^+$, (b) the projection of the $K^-\pi^+$ mass distribution.

6. The $\eta\pi$ mass distribution (a) recoiling against a ρ, and (b), from the ρ side-band in the reaction $J/\psi \longrightarrow \eta\pi^+\pi^-\pi^0$. All three charged combinations are included.

7. (a) The $K^\pm K_s\pi^\mp$ spectrum recoiling against a γ, (b) the combined spectra of $K^\pm K_s\pi^\mp$ and $K^+K^-\pi^0$ recoiling against an ω, and (c) the $K^\pm K_s\pi^\mp$ spectrum recoiling against a ϕ in the J/ψ decay.

8. The $\eta\pi^+\pi^-$ spectra recoiling against the (a) γ, (b) ω, and (c) ϕ, in the J/ψ decay.

9. The $\omega\phi$ mass distribution from the reaction $J/\psi \longrightarrow \gamma\omega\phi$. The lower plot shows the distribution of the background events.

10. (a) The recoil mass from Ξ^- in the reaction $J/\psi \longrightarrow \Xi^-\overline{\Xi(1530)}^+$, $\overline{\Xi(1530)}^+ \rightarrow \bar{\Xi}^+\pi^0$, $\bar{\Xi}^+ \rightarrow \bar{\Lambda}\pi^0$, and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$. (b) The recoil mass from $\Xi^-(\pi^+)$ in the reaction $J/\psi \longrightarrow \Xi^-\overline{\Xi(1530)}^+$, $\overline{\Xi(1530)}^+ \rightarrow \bar{\Xi}^0(\pi^+)$, $\bar{\Xi}^0+ \rightarrow \bar{\Lambda}\pi^0$, and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$. In all cases, charge conjugate reactions are included.

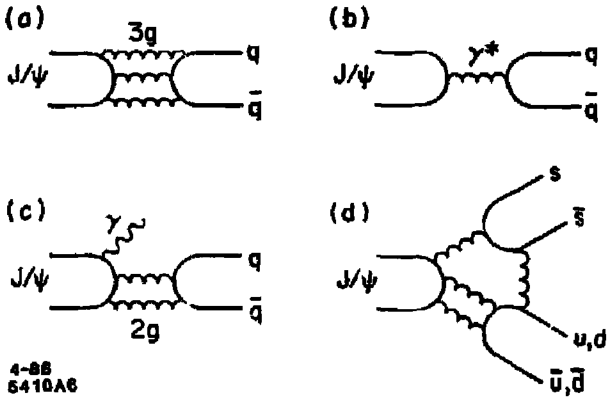

(a)
3g
J/ψ
q
q̄
(b)
γ*
J/ψ
q
q̄
(c)
γ
J/ψ
q
q̄
2g
(d)
s
s̄
J/ψ
u,d
ū,d̄
4-86
5410A6

Fig. 1

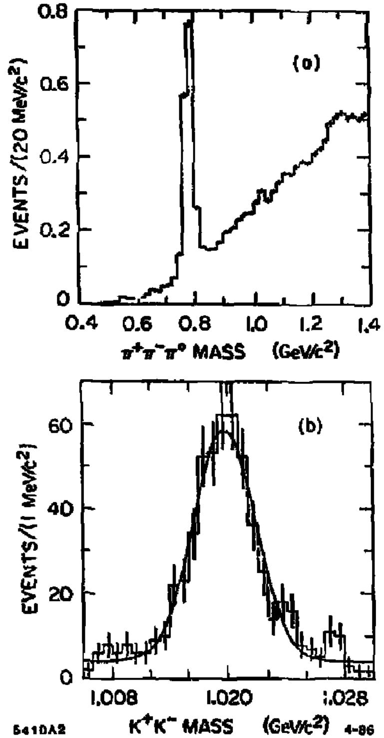

(a)
EVENTS /(20 MeV/c²)
0.8
0.6
0.4
0.2
0
0.4
0.6
0.8
1.0
1.2
1.4
π⁺π⁻π⁰ MASS (GeV/c²)
(b)
EVENTS/(1 MeV/c²)
60
40
20
0
1.008
1.020
1.028
K⁺K⁻ MASS (GeV/c²)
5410A2
4-86

Fig. 2

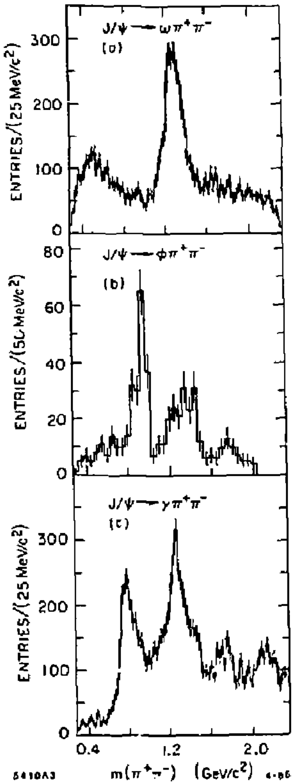

J/ψ → ωπ⁺π⁻
(a)
J/ψ → φπ⁺π⁻
(b)
J/ψ → γπ⁺π⁻
(c)
ENTRIES/(25 MeV/c²)
ENTRIES/(50 MeV/c²)
ENTRIES/(25 MeV/c²)
m(π⁺π⁻) (GeV/c²)
0.4
1.2
2.0
5410A3
4-86

Fig. 3

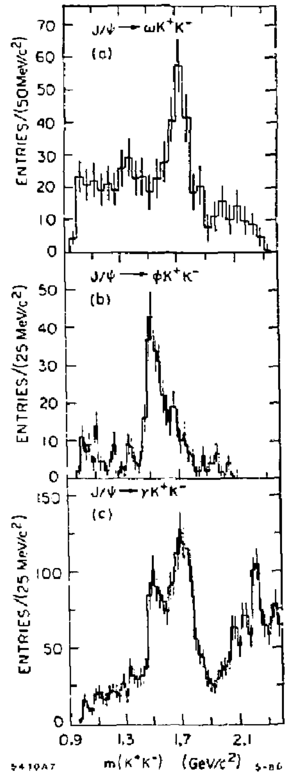
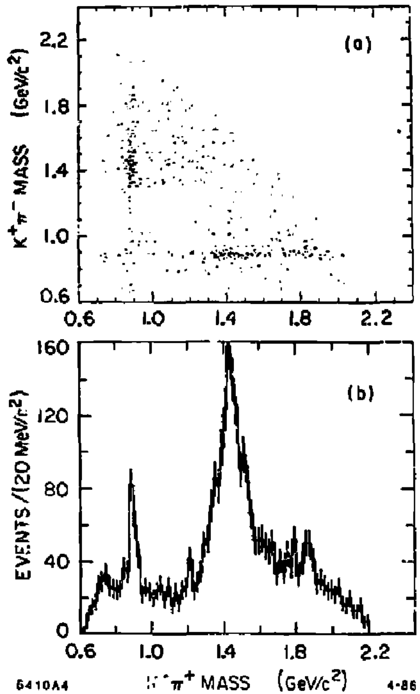
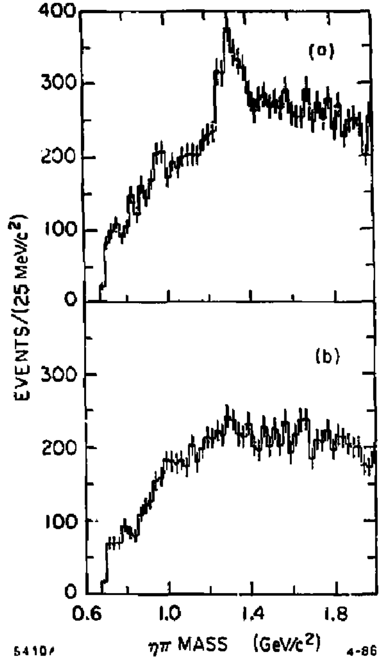

J/ψ → ωK⁺K⁻
(a)
J/ψ → φK⁺K⁻
(b)
J/ψ → γK⁺K⁻
(c)
ENTRIES/(50 MeV/c²)
ENTRIES/(25 MeV/c²)
ENTRIES/(25 MeV/c²)
m(K⁺K⁻) (GeV/c²)
0.9
1.3
1.7
2.1
5410A7

Fig. 4



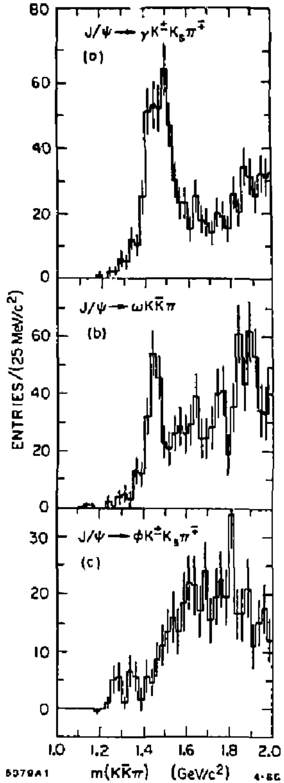
(a)
(b)
$K^+\pi^-$ MASS (GeV/c^2)
EVENTS/(20 MeV/c^2)
$K^-\pi^+$ MASS (GeV/c^2)
6410A4
4-86

Fig. 5



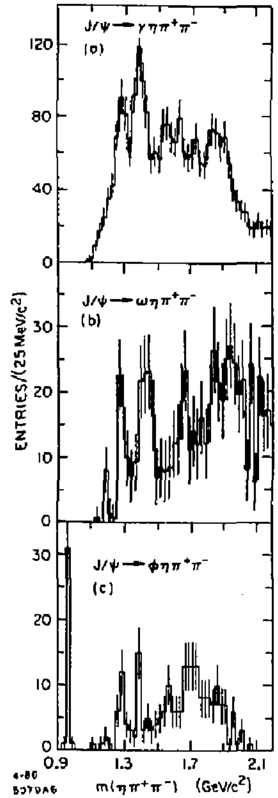
(a)
(b)
EVENTS/(25 MeV/c^2)
$\eta\pi$ MASS (GeV/c^2)
4-86

Fig. 6



J/ψ → γK±K_sπ∓
(a)
J/ψ → ωKK̄π
(b)
J/ψ → φK±K_sπ∓
(c)
ENTRIES/(25 MeV/c²)
m(KK̄π) (GeV/c²)
5079A1
4-86

Fig. 7



J/ψ → γηπ⁺π⁻
(a)
J/ψ → ωηπ⁺π⁻
(b)
J/ψ → φηπ⁺π⁻
(c)
ENTRIES/(25 MeV/c²)
m(ηπ⁺π⁻) (GeV/c²)
4-86
5079A6

Fig. 8

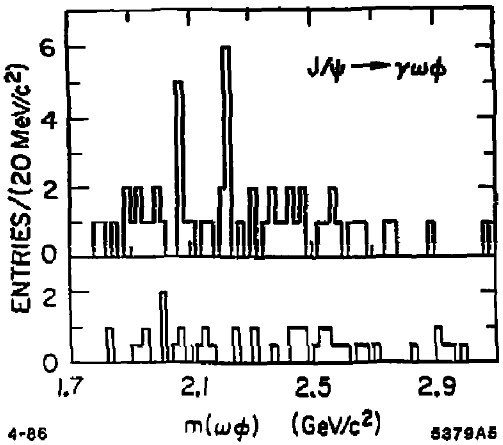

J/ψ → γωφ
ENTRIES/(20 MeV/c²)
6
4
2
0
2
0
1.7
2.1
2.5
2.9
m(ωφ) (GeV/c²)
4-86
5379A5

Fig. 9

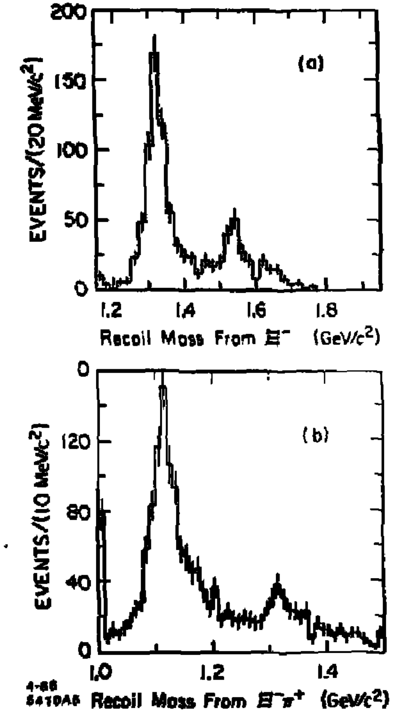

(a)
EVENTS/(20 MeV/c²)
200
150
100
50
0
1.2
1.4
1.6
1.8
Recoil Mass From Ξ⁻ (GeV/c²)
(b)
EVENTS/(10 MeV/c²)
120
80
40
0
1.0
1.2
1.4
4-86
5410A5
Recoil Mass From Ξ⁻π⁺ (GeV/c²)

Fig. 10

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