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# RECENT RESULTS OF HADRONIC DECAYS OF $J/\psi$ INTO VECTOR-TENSOR FROM MARK III*

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## ABSTRACT

From a data sample of $5.8 \times 10^6$ $J/\psi$'s collected by the MARK III detector at the storage ring SPEAR at SLAC, two-body decay modes of the $J/\psi$ into a vector and a tensor meson have been measured. From the studies of the tensor meson, recoiling against the ideally mixed and well understood vector mesons, quark correlations are established and compared with the theoretical expectations of the $J/\psi$ decays and the SU(3) predictions. The beginnings of a similar systematic study of the two-body vector scalar decays are also presented.

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## Introduction

The decays of J/$\psi$ have proven to be a rich laboratory for the study of hadron dynamics and light quark spectroscopy. Pure hadronic decays of J/$\psi$ into mesons and baryons have been very useful because of the 'clean surroundings' where the initial state is well defined ($J^{PC} = 1^{--}$), and is devoid of any of the final state quarks, u, d, or s.

Figure 1 shows the principal decay mechanisms of the $J/\psi$ 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 some of the type

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

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.

Of special interest for quark correlation studies are the recoils against the $\phi$ and the $\omega$. According to the quark line diagrams in Fig. 1(a,b), the $\phi$, being pure $s\bar{s}$ and the $\omega$, 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.

The MARK III is a general purpose solenoidal magnetic detector installed at the $e^+e^-$ storage ring SPEAR at SLAC. The detector has been described elsewhere.[2] The following components of the detector, placed in a 0.4T magnetic field, were used extensively for the present set of analyses:

a) the central tracking chamber. The central drift chamber contained 34 wire planes and provided a momentum resolution $\delta p/p = .015\sqrt{1+p^2}$, where $p$ is in GeV/c;

b) a set of 48 axial time-of-flight (TOF) counters, covering 80% of the solid angle with a resolution of 191 ps;

and c) a 12 radiation length gas-sampling calorimeter, covering 94% of the solid angle with a resolution of $\delta E/E = .17/\sqrt{E}$, where $E$ is in GeV/$c^2$.

The analyses were divided into two categories; i) the isosinglet states studied in the $\pi\pi$ and $K\bar{K}$ recoiling against a $\phi$ and an $\omega$, and ii) the isodoublet and the isovector states studied in the recoils against the $K^*(892)$ and the $\rho$.

The events were selected from the data summary tapes according to the charged multiplicities of the final states. A kinematic constrained (4c) fit, was performed to the all-charged decay modes. In the presence of neutral particles e.g. $\pi^0$ or $\eta$, additional constraints were imposed. A $K^0_S$ was selected by reconstructing the $\pi^+\pi^-$ from the decay and imposing a secondary vertex cut. In each of the decay modes an appropriate $\chi^2$ cut was used after the constrained fit to select the signal events. Efficiencies and the effects of each of the cuts were estimated by a Monte Carlo program with complete simulation of the detector and of the procedure to extract the branching ratios.

## Recoils against the $\omega$ and $\phi$

### $\pi^+\pi^-$ recoil from the $\omega$ and $\phi$

The $\omega$ was selected in its $\pi^+\pi^-\pi^0$ decay mode. The final state studied was $J/\psi \longrightarrow \pi^+ \pi^-\pi^+\pi^-\pi^0$. Fig. 2a shows the 5c constrained $\pi^+\pi^-\pi^0$ mass spectrum, with four combinations per event. A clear $\omega$ peak over the combinatorial background is evident. Fig. 3a shows the final $\pi^+\pi^-$ spectrum recoiling from the $\omega$. The 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 $J/\psi$ into $\omega$f(1270) of

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

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 $J/\psi \longrightarrow \omega\pi^+\pi^-$ is included in Table 1.

The final state $K^+K^-\pi^+\pi^-$ was analyzed to study the $\pi^+\pi^-$ recoiling against the $\phi$. Fig. 2b shows the $K^+K^-$ spectrum in the $\phi$ region. The $\phi$ signal is almost background free. Fig. 3b shows the $\pi^+\pi^-$ 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[3] (a pole in $\pi\pi$ and another in $K\bar{K}$), or a four quark state,[4] 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[5] , the branching ratio of $J/\psi$ into $\phi$S* was measured as

$$Br(J/\psi \longrightarrow \phi S^*) \times Br(S^* \longrightarrow \pi^+\pi^-) = (2.3 \pm 0.3 \pm 0.6) \times 10^{-4}.$$

The structures in the mass region of 1300 to 1550 MeV/c² have been speculated to be the f(1270) and the $\epsilon$, and the structure at ~1700 MeV/c² to be the $\theta(1720)$. The measurement of the inclusive branching ratio of $J/\psi \longrightarrow \phi\pi^+\pi^-$ is included in Table 1.

$K^+K^-$ recoil from $\omega$ and $\phi$

The $K^+K^-$ recoil spectra against the $\omega$ and the $\phi$ are presented in Fig. 4. The recoil spectrum from the $\omega$ was studied both in $K^+K^-$ and $K^0_S K^0_S$ 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/c² with a width of $110^{+45}_{-35}\pm15$ MeV/c², which are consistent with the parameters of the $\theta(1720)$. The branching ratio of $J/\psi$ into this decay mode was

$$Br(J/\psi \longrightarrow \omega X(1731)) \times Br(X \longrightarrow K\bar{K}) = (4.5^{+1.2}_{-1.1} \pm 1.0) \times 10^{-4}.$$

Without taking into account any possible interference, an upper limit on $\omega f'(1525)$ production was calculated at 90% C.L. as

$$Br(J/\psi \longrightarrow \omega f') \times Br(f' \longrightarrow K\bar{K}) < 1.2 \times 10^{-4}.$$

The $K^0_S K^0_S$ mass spectrum, although statistically less significant, reproduced the major features of the charged mode. The inclusive branching ratio of $J/\psi$ into $\omega K\bar{K}$ is included in Table 1.

The $K^+K^-$ mass spectrum recoiling against the $\phi$ shows a clear enhancement at the $f'(1525)$ mass (Fig. 4b). 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. Parametrizing the structure with an $f'(1525)$ and another non-interfering Breit-Wigner amplitude, the fit assigns a mass and a width of 1669±15 MeV/c² and 93±41 MeV/c² to the high mass mass shoulder. A fit with the $f'(1525)$ and an interfering Breit-Wigner amplitude yields a mass of 1708±64 MeV/c² and a width of 100±40 MeV/c² for the higher state. The parameters are again consistent with those of the $\theta(1720)$. The branching ratio for the $f'(1525)$ was measured as

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

in 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 $\gamma K^+K^-$

The radiative decays of the $J/\psi$ have been very rich in new physics. The $\gamma$, $\phi$ and $\omega$ all have the same $J^{PC}$ quantum numbers. While the $\omega$ and the $\phi$ project out the non-strange and the strange quark, respectively, in the recoiling $q\bar{q}$ system (Fig. 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. Fig. 2a, b and c present the $\pi^+\pi^-$ spectra recoiling from $\omega$, $\phi$ and $\gamma$ respectively. Fig. 2a has a clear f(1270) and Fig. 2b has a clear S* peak according to the flavor correlation in Fig. 1a,b. Fig. 2c shows a large f(1270) peak, a probable shoulder 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 $\pi^0$ is undetected.

Among the $K^+K^-$ recoil spectra (Fig. 4) against the $\omega$, $\phi$, and $\gamma$, the radiative decay shows clear $f'(1525)$ and $\theta$ production, while copious $f'(1525)$ production is visible in the recoil spectrum against the $\phi$. 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 the $\omega K\bar{K}$ can proceed through either a double OZI suppressed diagram or a single OZI suppressed diagram (for example, a sequential decay mechanism[6] ).

Since the $\theta(1720)$ is not a member of the conventional $q\bar{q}$ $2^{++}$ nonet[7] it will not be covered here.

## Recoils from the $K^*(892)$ and $\rho$

To investigate the quark correlations further, recoils against the isodoublet, $K^*(892)$, and the isovector $\rho$ were analyzed. In the case of the $K^*(892)$, the final state considered was $K^+\pi^-$ $K^-\pi^+$. Fig. 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 $K^-\pi^+$ $(K^+\pi^-)$. Fig. 5b shows the $K^+\pi^-$ spectrum recoiling from the $\overline{K^*(892)}$. A large peak at ~1430 MeV/c$^2$ is seen, corresponding to the production of $K^*(1432)$, the isodoublet partner of the $2^{++}$ nonet. The production branching ratio for this mode was measured as

$$Br(J/\psi \longrightarrow \overline{K^*(892)}^0 K^*(1430)^0) + cc = (56.0 \pm 4.0 \pm 8.4) \times 10^{-4}.$$

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 $J/\psi$ decays (Fig. 1b).

The recoil spectrum against the $\rho$ 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. Fig. 6a shows the recoil $\eta\pi$ spectrum from all three charged states of the $\rho$. Two peaks corresponding to the $\delta$ and $A_2$ production are seen above the background at ~980 and at 1320 MeV/c$^2$ respectively. Fig. 6b shows the same spectrum corresponding to the sidebands of the $\rho$. The correlation of the $A_2$ production in association with the $\rho$ is clear, but, the interpretation of the $\delta$ production is being pursued. The branching ratio of $\rho A_2$ production was calculated to be

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

## Conclusion of Vector-tensor and Vector-scalar Decays

Table 1 summarizes the measured decay modes of $J/\psi$ 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 $\omega$ and $\phi$ seem to point to the presence of a large amount of SU(3) violation. This was seen and measured[8] along with the strong and the electromagnetic amplitudes in an earlier systematic study of $J/\psi$ decay into the vector-pseudoscalar nonets, which led to a measurement of the quark contents of the $\eta$ and the $\eta'$. In the case of the scalar mesons, a systematic study has begun, and promises to be interesting.

We gratefully acknowledge the dedicated efforts of the SPEAR staff.

Table 1. Compilation of the J/$\psi$ decay branching ratios

| $J/\psi$ Decay Modes | $Br \times 10^4$ | | |
|---|---|---|---|
| | MARK III | DM2 | Particle Data Group |
| $\omega f$ | $49.3 \pm 2.5 \pm 12.5$ | $40 \pm 6$ | $23 \pm 8$ |
| $\omega f'$ | $< 1.2$ | — | $< 1.6$ |
| $\phi f'$ | $\times BR(f' \rightarrow K\bar{K})$ | $\times BR(f' \rightarrow K\bar{K})$ | |
| | $6.4 \pm 0.6 \pm 1.6$ | $4.6 \pm 0.5 \pm 0.7$ | $3.7 \pm 1.3$ |
| $\phi f$ | — | — | $< 3.7$ |
| $K^{*0}(892)\bar{K}^{*0}(1430) + cc$ | $56 \pm 4 \pm 8.4$ | — | $67 \pm 26$ |
| $\rho A_2$ | $118 \pm 8 \pm 29$ | $86 \pm 3 \pm 13$ | $84 \pm 45$ |
| $\phi S^*$ | $\times BR(S^* \rightarrow \pi^+\pi^-)$ | $\times BR(S^* \rightarrow \pi^+\pi^-)$ | — |
| | $2.3 \pm 0.3 \pm 0.6$ | $2.38 \pm 0.2 \pm 0.4$ | $2.6 \pm 0.6$ |
| $\omega\pi^+\pi^-$ | $78 \pm 1 \pm 16$ | $66 \pm 10 \pm 6$ | $68 \pm 19$ |
| $\omega K\bar{K}$ | $17.2 \pm 0.8 \pm 3.4$ | — | $16 \pm 10$ |
| $\phi\pi^+\pi^-$ | $9 \pm 0.4 \pm 2.3$ | $7.5 \pm 0.3 \pm 1.5$ | $21 \pm 9$ |

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## 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) $\omega$, (b) $\phi$, and (c) $\gamma$, in the $J/\psi$ decay.
4. The $K^+K^-$ spectra recoiling against the (a) $\omega$, (b) $\phi$, and (c) $\gamma$, in the $J/\psi$ 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 $\rho$, and (b), from the $\rho$ side-band in the reaction $J/\psi \longrightarrow \eta\pi^+\pi^-\pi^0$. All three charged combinations are included.

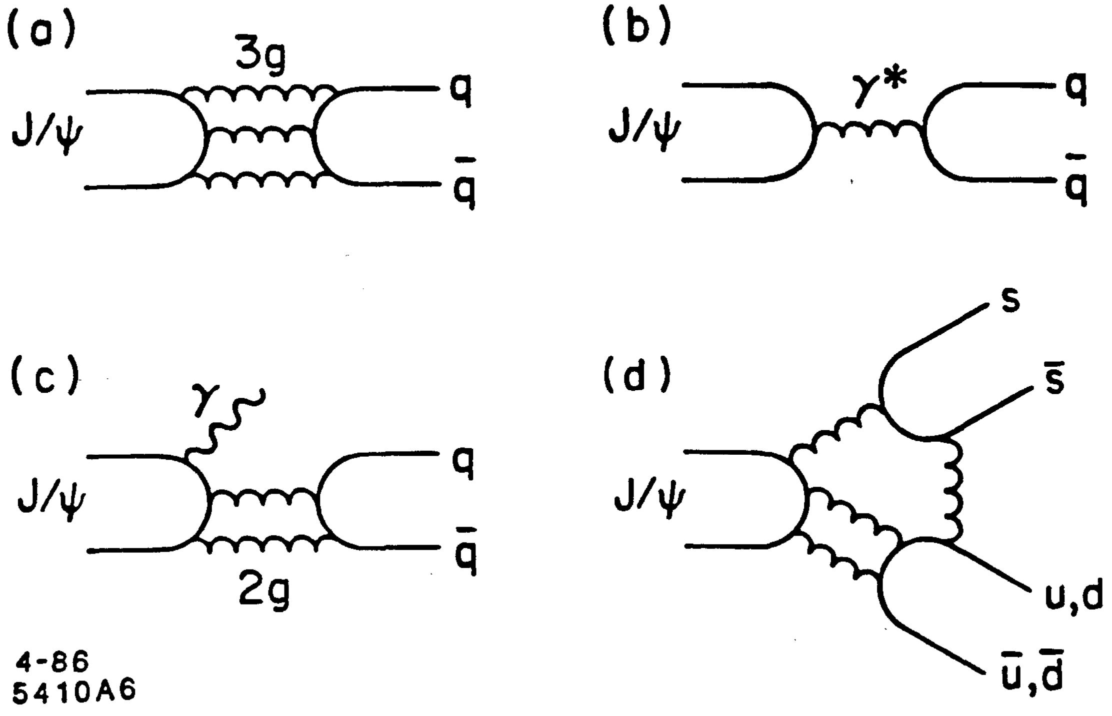
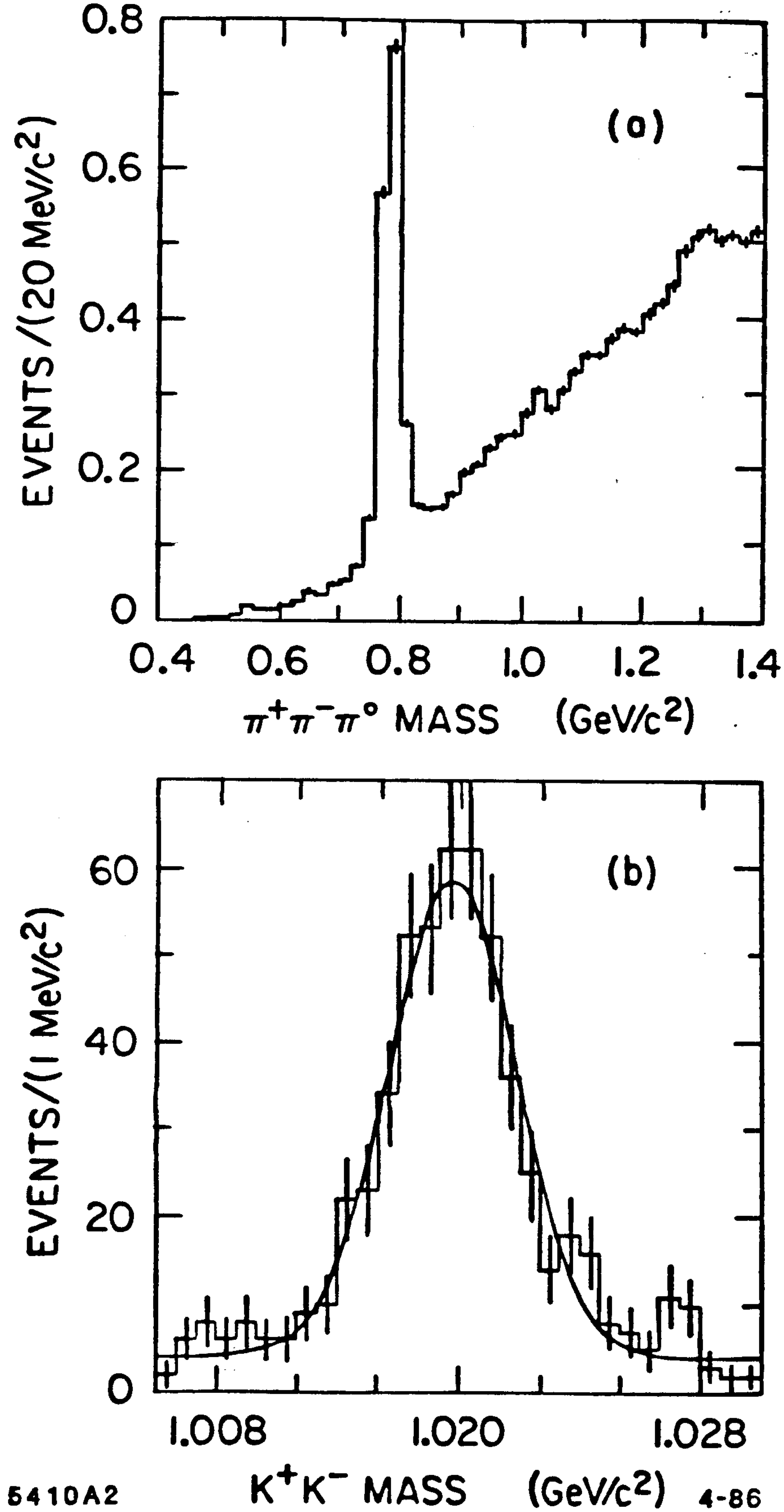



Fig. 1



(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⁻π° 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

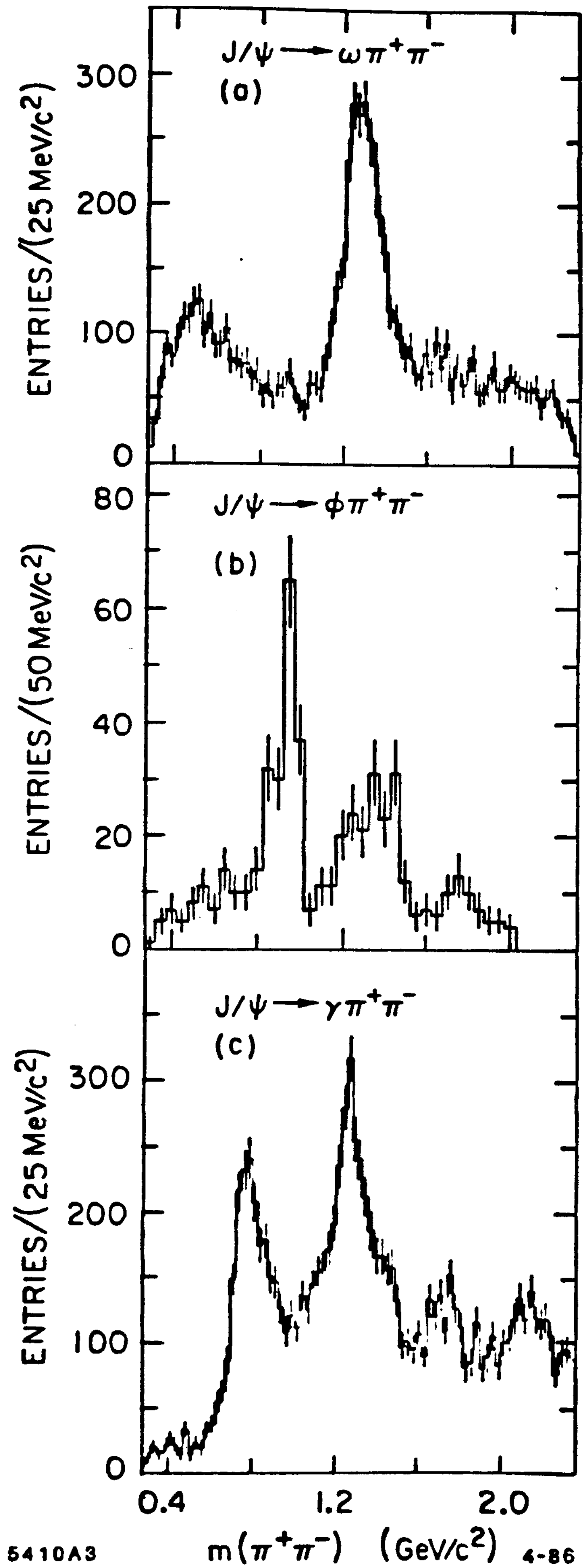
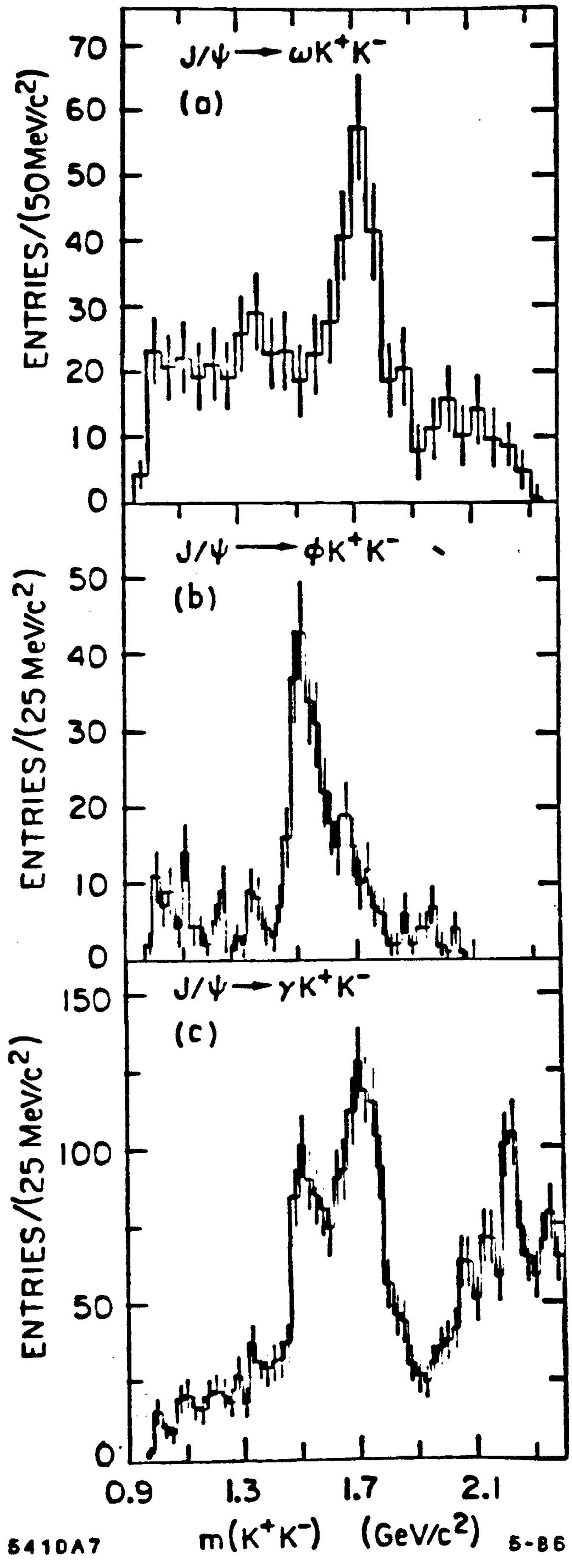

J/ψ → ωπ⁺π⁻
(a)
ENTRIES/(25 MeV/c²)
300
200
100
0
J/ψ → φπ⁺π⁻
(b)
ENTRIES/(50 MeV/c²)
80
60
40
20
0
J/ψ → γπ⁺π⁻
(c)
ENTRIES/(25 MeV/c²)
300
200
100
0
0.4
1.2
2.0
m(π⁺π⁻) (GeV/c²)
5410A3
4-86

Fig. 3



J/ψ → ωK⁺K⁻
(a)
ENTRIES/(50MeV/c²)
0
10
20
30
40
50
60
70
J/ψ → φK⁺K⁻
(b)
ENTRIES/(25 MeV/c²)
0
10
20
30
40
50
J/ψ → γK⁺K⁻
(c)
ENTRIES/(25 MeV/c²)
0
50
100
150
0.9
1.3
1.7
2.1
m(K⁺K⁻) (GeV/c²)
5410A7
5-86


Fig. 4

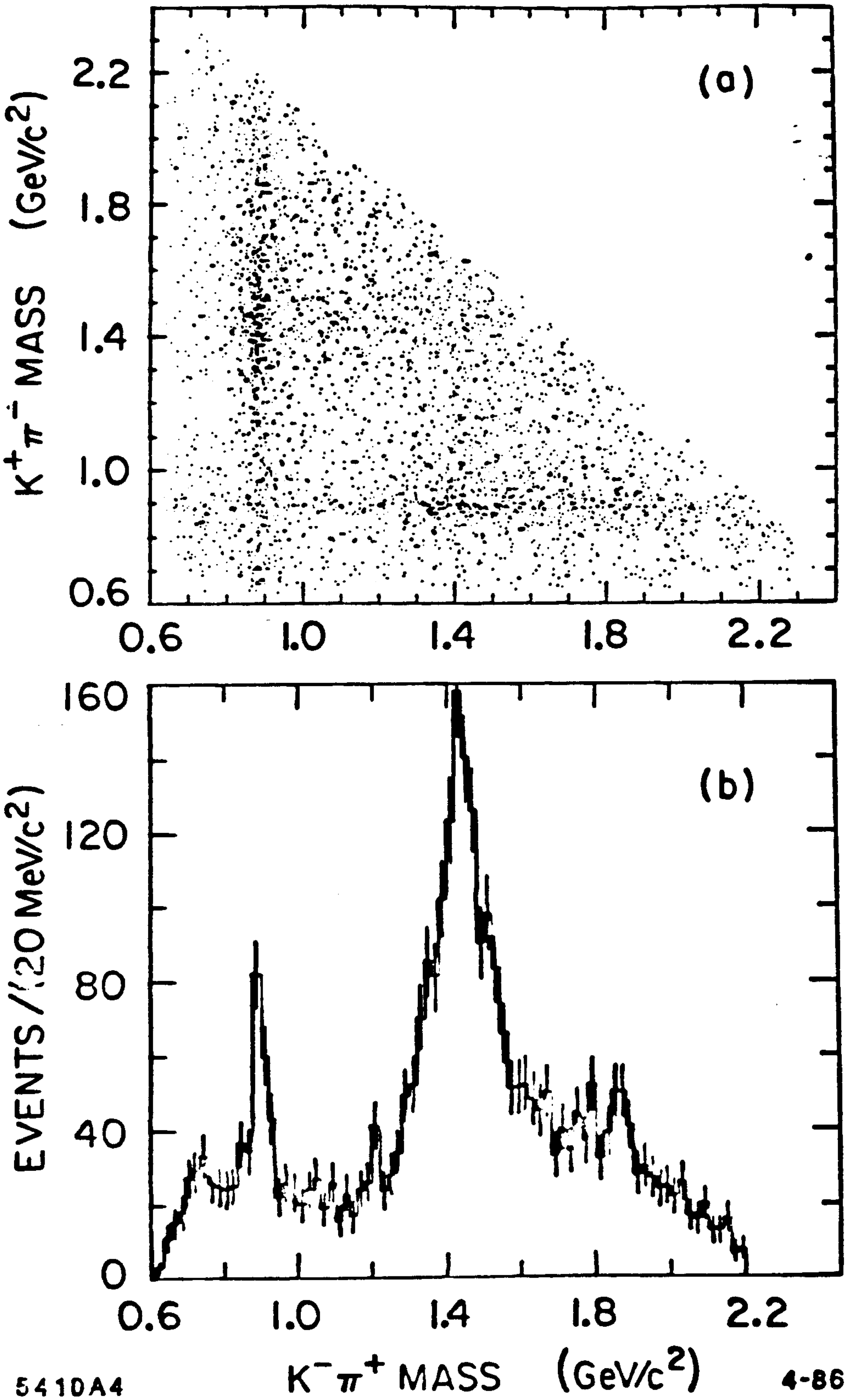
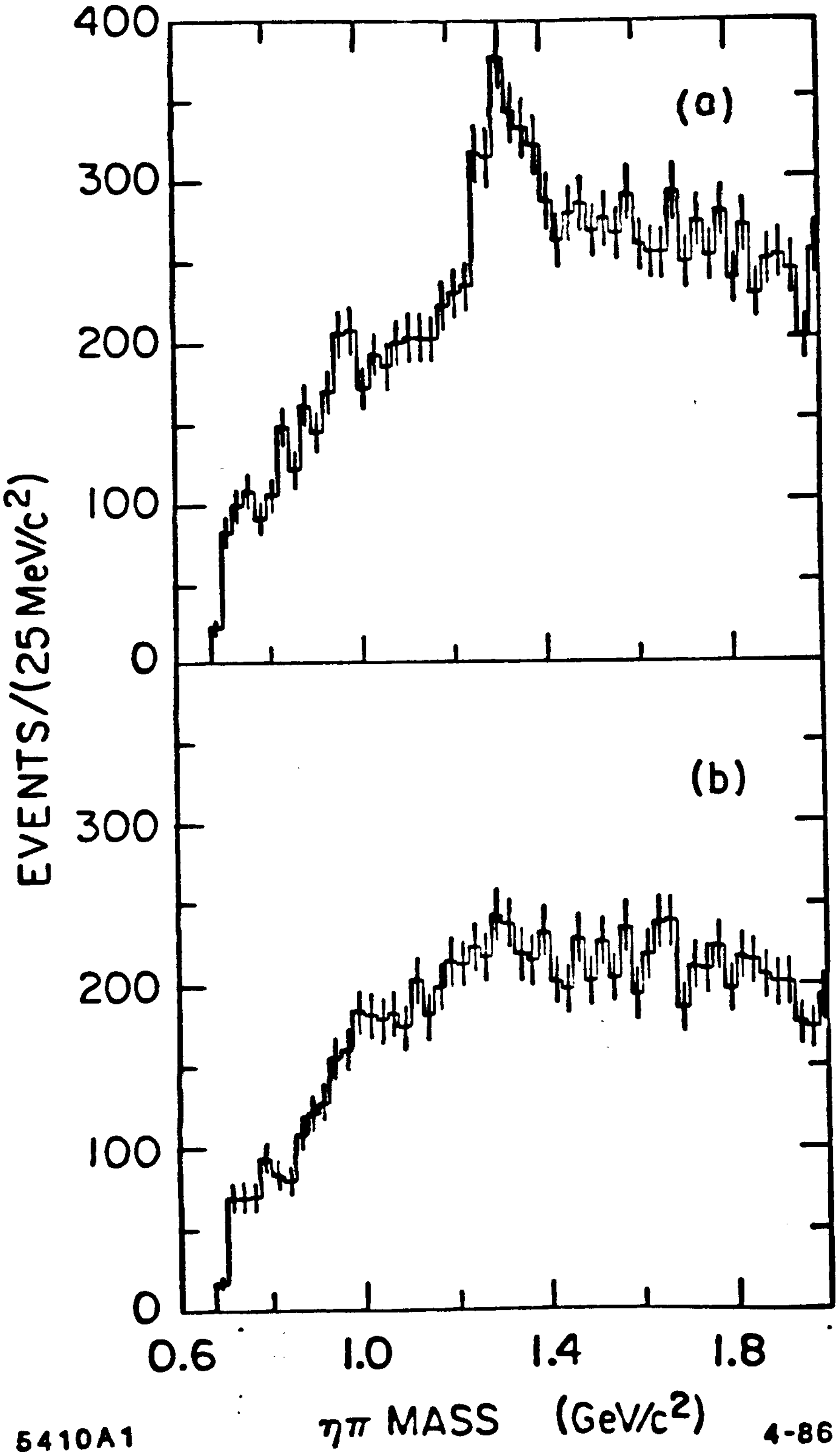



Fig. 5



400
300
200
100
0
(a)
(b)
EVENTS/(25 MeV/c2)
0.6
1.0
1.4
1.8
ηπ MASS (GeV/c2)
5410A1
4-86


Fig. 6