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OBSERVATION OF THE RADIATIVE DECAY $J/\psi \to \gamma\eta\pi\pi$ *†

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ABSTRACT

The radiative decay $J/\psi \to \gamma\eta\pi\pi$ has been observed in data taken with the Crystal Ball detector at the SPEAR e^+e^- storage ring. In addition to the well-known η', the $\eta\pi\pi$ mass spectrum shows a broad enhancement centered at ~1700 MeV. There is no explicit evidence for the $\iota(1440)$ in the $\eta\pi\pi$ mass spectrum. We find:

$$\frac{BR(J/\psi \to \gamma\iota)(\iota \to \eta\pi\pi)}{BR(J/\psi \to \gamma\iota)(\iota \to KK\pi)} < 0.5 \quad \text{(90\% confidence level)} \quad .$$

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Recently a resonance with mass 1440 MeV has been seen in the $KK\pi$ mass spectrum from the radiative decay $J/\psi \rightarrow \gamma KK\pi$.[2,3] Partial wave and spin parity analyses performed by the Crystal Ball collaboration[3] indicated that the state was a pseudoscalar which decayed predominantly to $\delta\pi$ with the δ decaying to $K\bar{K}$. This state has been named $\iota(1440)$.[4] The $\delta(980)$ also decays to $\eta\pi$ and the branching ratio for this channel might be expected to be larger than the branching ratio to $K\bar{K}$ because the δ mass is below $K\bar{K}$ threshold. One experiment[5] finds:

$$\frac{BR(\delta \rightarrow \eta\pi)}{BR(\delta \rightarrow KK)} = 1.4 \pm 0.6 \quad .$$

Thus we expect the $\iota(1440)$ to appear in the $\eta\pi\pi$ mass spectrum from the process $J/\psi \rightarrow \gamma\eta\pi\pi$. I will present results from a study of this process by the Crystal Ball collaboration.

The data are from a sample of 2.2 million J/ψ's produced in e^+e^- interactions at the SPEAR storage ring. The Crystal Ball detector primarily consists of a segmented spherical shell of NaI(Tℓ) crystals covering 93% of the full solid angle. The energy resolution for photons is given by $\sigma_E/E = 0.026/E^{1/4}$ (E in GeV). The photon angular resolution is 25-40 mrad, depending on energy. An inner detector, consisting of magnetostrictive spark chambers and proportional wire chambers, was used to identify charged particles and measure their directions. Details of the detector performance and event selection procedures have been presented elsewhere.[6]

For this analysis, hadronic decays of the J/ψ were selected which contained three photons and two charged particles or seven photons and no charged particles. A kinematic fit was performed on events with three photons and two charged particles, assuming they came from $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$

with the η decaying to $\gamma\gamma$.[7] The seven-photon events were fit to the hypothesis $J/\psi \rightarrow \gamma\eta\pi^0\pi^0$ assuming the η and both π^0's decayed to two photons. Figure 1 shows the $\eta\pi\pi$ mass distribution for events which fit the $\gamma\eta\pi\pi$ hypothesis with confidence level greater than 1%. Both Fig. 1(a) and 1(b) show a narrow peak at 960 MeV corresponding to the decay $J/\psi \rightarrow \gamma\eta'$, $\eta' \rightarrow \eta\pi\pi$. In addition, both plots show a broad enhancement at roughly 1700 MeV. The dashed curve in Fig. 1(a) shows the $\eta\pi^+\pi^-$ spectrum expected for $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$ Lorentz invariant phase space events. The enhancement seen in both $\eta\pi\pi$ spectra is unlike the phase space distribution. There is no explicit evidence for the $\iota(1440)$ though it could be contributing to the broad enhancement. I will present an upper limit for the decay $J/\psi \rightarrow \gamma\iota$, $\iota \rightarrow \eta\pi\pi$ later in this talk. First I will discuss the new enhancement in greater detail.

Several tests have been performed to investigate the enhancement. The possibility of a detector malfunction is unlikely as the signal appears in J/ψ data sets taken in two different running periods and is not confined to a specific region of the detector.

To study the strength of the η signal in the data, the η constraint was removed from the fit. Events with three photons and two charged particles were fit to the hypothesis $J/\psi \rightarrow \gamma\gamma\gamma\pi^+\pi^-$. Figure 2 shows the $\gamma\gamma$ mass for events which fit with confidence level greater than 1%. All $\gamma\gamma$ combinations are included so there are three entries per event. Clear signals are seen for the π^0 and η with very little background. This shows that η's are definitely present in the data; they are not created by the kinematic fit. In addition we find that the broad enhancement in $\eta\pi\pi$ is correlated only with $\gamma\gamma$ masses in the η peak (Fig. 3).

As a further check, the kinematic fitting may be eliminated entirely. Events with three photons and two charged particles are selected, as above. Since charged particle momenta are undetermined, one cannot compute the two gamma-two charged particle mass. But the energy of the recoil photon is essentially equivalent to the two gamma-two charged particle mass. Figure 4 shows the recoil photon energy spectrum for four different $\gamma\gamma$ mass intervals. A broad bump is present in the recoil photon energy spectrum when the other two photons in the event form an η. This shows that the enhancement is not a product of the fitting procedure.

There remains the possibility that the enhancement comes from some other J/ψ decay, perhaps with one or more particles missing. Known decays of the J/ψ cannot be responsible because the sum of known J/ψ decays which contain an η is not large enough to account for the signal. For example, the decay $J/\psi \rightarrow \phi\pi^+\pi^-$, $\phi \rightarrow \eta\gamma$, $\eta \rightarrow \gamma\gamma$ would produce only about 25 events in our sample of 2.2 million J/ψ. With a detection efficiency of 20% we would expect to see 5 events. The number of events in the broad enhancement is about 100 times larger. Similarly, processes such as

$$J/\psi \rightarrow \gamma\theta$$
$$\hookrightarrow \eta\eta$$
$$\hookrightarrow \pi^+\pi^-\pi^0$$
$$\hookrightarrow \gamma\gamma$$

with the π^0 missing cannot account for an enhancement as large as that seen.

The decay $J/\psi \rightarrow \omega\eta$, with the ω decaying to $\pi^+\pi^-\pi^0$, could produce a small contamination because the π^0 may appear as a single photon in our detector. These events contain a monochromatic η with momentum 1400 MeV and are thus easy to remove with a cut on η momentum. For this analysis, events where the momentum of the η is greater than 1300 MeV have been removed.[8]

The enhancement is apparently not associated with a δ, or any other resonances in either $\eta\pi$ or $\pi\pi$. Figure 5 shows Dalitz plots for $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$ events with $M_{\eta\pi^+\pi^-}$ near the center of the peak ($1600 < M_{\eta\pi^+\pi^-} < 1850$ MeV). The boundaries drawn are calculated for $M_{\eta\pi^+\pi^-} = 1710$ MeV. There is no evidence for resonance structure in either the $\eta\pi$ mass or the $\pi\pi$ mass. For example, the decay $\delta(980) \rightarrow \eta\pi$ would produce bands near $M^2_{\eta\pi} = 1.0$ GeV^2. No such bands are seen.

I suggest three possible interpretations for this new enhancement. First, the $\eta\pi\pi$ mass distribution for events which contain a prompt γ may be quite different from Lorentz invariant phase space. Then the enhancement could arise from the (nonresonant) decay of the J/ψ to a photon plus two gluons: $J/\psi \rightarrow \gamma gg$. Secondly, the enhancement could be a single resonance. A third possibility is that it is a group of resonances.

The data may be fit with a single Breit-Wigner line shape. For the fit, the $\eta\pi^+\pi^-$ and $\eta\pi^0\pi^0$ mass spectra are fit simultaneously with the mass and width parameters constrained to be the same for both channels. A constant background was assumed for the $\eta\pi^0\pi^0$ channel. For $\eta\pi^+\pi^-$, we used a background determined by fitting the $\gamma\gamma\pi^+\pi^-$ mass spectrum for events with a $\gamma\gamma$ mass combination in the η sidebands. ($320 < M_{\gamma\gamma} < 470$ MeV or $610 < M_{\gamma\gamma} < 760$ MeV.) Figures 3(b) and 3(d) indicate the shape of the background. (The $\gamma\gamma$ mass intervals in Figs. 3(b) and 3(d) are wider than those used for the background determination.)

The fit has a χ^2 of 66 for 69 degrees of freedom. We find: $M = 1710 \pm 45$ MeV and $\Gamma = 530 \pm 110$ MeV where the errors include estimates of the systematic uncertainty. The detection efficiency was determined by a Monte Carlo calculation to be 18% (6.6%) for $J/\psi \to \gamma\eta\pi^+\pi^-(\eta\pi^0\pi^0)$, $\eta \to \gamma\gamma$ for $M_{\eta\pi\pi}$ near 1700 MeV. Using the number of events in the peak as determined by the fit, one obtains the branching ratios:

$$BR(J/\psi \to \gamma\eta\pi^+\pi^-) = 3.5 \pm 0.2 \pm 0.7 \times 10^{-3}$$

$$BR(J/\psi \to \gamma\eta\pi^0\pi^0) = 2.3 \pm 0.3 \pm 0.8 \times 10^{-3}$$

where the first error is statistical and the second systematic. These branching ratios are comparable to those of the largest known radiative decays of the J/ψ.

There is no evidence for $\iota(1440)$ in the $\eta\pi^0\pi^0$ mass spectrum. The $\eta\pi^+\pi^-$ mass spectrum has a slight shoulder in the ι region. To obtain an upper limit for the decay of the ι to $\eta\pi\pi$, the $\eta\pi\pi$ mass spectra have been refit with an additional term for the $\iota(1440)$. The mass and width of the ι were fixed but the mass and width of the Breit-Wigner line shape used to describe the new enhancement were allowed to vary. The background used for the fit was the same as that used for the single-peak fit described above. The number of ι events found by the fit is not strongly dependent on the background hypothesis because of the presence of the broad enhancement. The fitted width of the broad enhancement varies with changes in the background shape in such a way that the ι region is not strongly affected. To further reduce the dependence on assumptions about the background, the fit may be performed using only data with $M_{\eta\pi\pi} < 2.0$ GeV. Figure 6 shows the fit which has a χ^2 of 33 for 30 degrees of freedom. From this two-peak fit we find:

$$BR(J/\psi \to \gamma\iota)(\iota \to \eta\pi\pi) < 2 \times 10^{-3} \quad \text{(90\% confidence level)} \quad .$$

For comparison, note that[3]

$$BR(J/\psi \to \gamma\iota)(\iota \to K\bar{K}\pi) = (4.0 \pm 0.7 \pm 1.0) \times 10^{-3} \quad .$$

In conclusion, we have observed the radiative decays $J/\psi \to \gamma\eta\pi^+\pi^-$ and $J/\psi \to \gamma\eta\pi^0\pi^0$. We find

$$\frac{BR(J/\psi \to \gamma\iota)(\iota \to \eta\pi\pi)}{BR(J/\psi \to \gamma\iota)(\iota \to K\bar{K}\pi)} < 0.5 \qquad (90\% \text{ confidence level}) \quad .$$

There is a broad enhancement near 1700 MeV in the $\eta\pi\pi$ mass spectrum which is produced with a substantial branching ratio. Its origin is uncertain.

REFERENCES

[1]The Crystal Ball collaboration includes: C. Edwards, R. Partridge, C. Peck, F. Porter (California Institute of Technology); D. Antreasyan, Y. F. Gu, J. Irion, W. Kollmann, M. Richardson, K. Strauch, A. Weinstein (Harvard University); D. Aschman, T. Burnett (visitor), M. Cavalli-Sforza, D. Coyne, C. Newman-Holmes, H. Sadrozinski (Princeton University); E. Bloom, F. Bulos, R. Chestnut, J. Gaiser, G. Godfrey, C. Kiesling, J. Leffler, W. Lockman, S. Lowe, M. Oreglia, D. Scharre, K. Wacker (Stanford Linear Accelerator Center); D. Gelphman, R. Hofstadter, R. Horisberger, I. Kirkbride, H. Kolanoski, K. Königsmann, R. Lee, A. Liberman, J. O'Rielly, A. Osterheld, B. Pollock, and J. Tompkins (Stanford University).

[2]D. L. Scharre et al., Phys. Lett. 97B, 329 (1980).

[3]C. Edwards et al., Phys. Rev. Lett. 49, 259 (1982).

[4]A pseudoscalar state has been observed previously in $\bar{p}p$ annihilation by P. Baillon et al. (Nuovo Cimento A50, 393 (1967)), who named the state E(1420). Since that time the E(1420) name has come to be associated with a 1^{++} state observed in $\pi^- p$ interactions (C. Dionisi et al., Nucl. Phys. B169, 1 (1980)). Thus we must introduce a new name for the pseudoscalar.

[5]N. R. Stanton et al., Phys. Rev. Lett. 42, 346 (1979).

[6]M. J. Oreglia, Stanford Linear Accelerator Center Report No. SLAC-236, Ph.D. Thesis, Stanford University, 1980 (unpublished); F. C. Porter, CALT-68-853 or SLAC-PUB-2796, September 1981, in Proceedings of the 1981 SLAC Summer Institute on Particle Physics, Stanford, California, ed. by A. Mosher (1981).

[7]Note that the charged particle energies are determined from the constrained fit. In addition, charged pion-kaon separation is based only on the fit.

[8]The process $\psi \to \omega\eta$, $\omega \to \pi^+\pi^-\pi^o$ is a background only for $J/\psi \to \gamma\eta\pi^+\pi^-$ and not for $J/\psi \to \gamma\eta\pi^o\pi^o$. Thus there is no cut on η momentum for the all-neutral events.

FIGURE CAPTIONS

Fig. 1. $\eta\pi\pi$ mass spectrum for $J/\psi \rightarrow \gamma\eta\pi\pi$ events. Fig. 1(a) is $\eta\pi^+\pi^-$ mass and Fig. 1(b) is $\eta\pi^0\pi^0$ mass. The dashed curve in Fig. 1(a) shows $\eta\pi^+\pi^-$ mass spectrum expected from Lorentz invariant phase space.

Fig. 2. $\gamma\gamma$ mass for events which fit the hypothesis $J/\psi \rightarrow \gamma\gamma\gamma\pi^+\pi^-$.

Fig. 3. $\gamma\gamma\pi^+\pi^-$ mass for four different $\gamma\gamma$ mass intervals.

Fig. 4. Recoil photon energy spectrum for four different $\gamma\gamma$ mass intervals. Events with three photons and two charged particles have been selected but no fit has been performed.

Fig. 5. Dalitz plots for $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$ events with $1600 < M_{\eta\pi^+\pi^-} < 1850$ MeV. The boundaries are calculated for $M_{\eta\pi^+\pi^-} = 1710$ MeV. Fig. 5(b) has two entries per event.

Fig. 6. $\eta\pi\pi$ mass spectra as in Fig. 1. The solid curve is a fit which includes a contribution for the $\iota(1440)$ as described in the text.

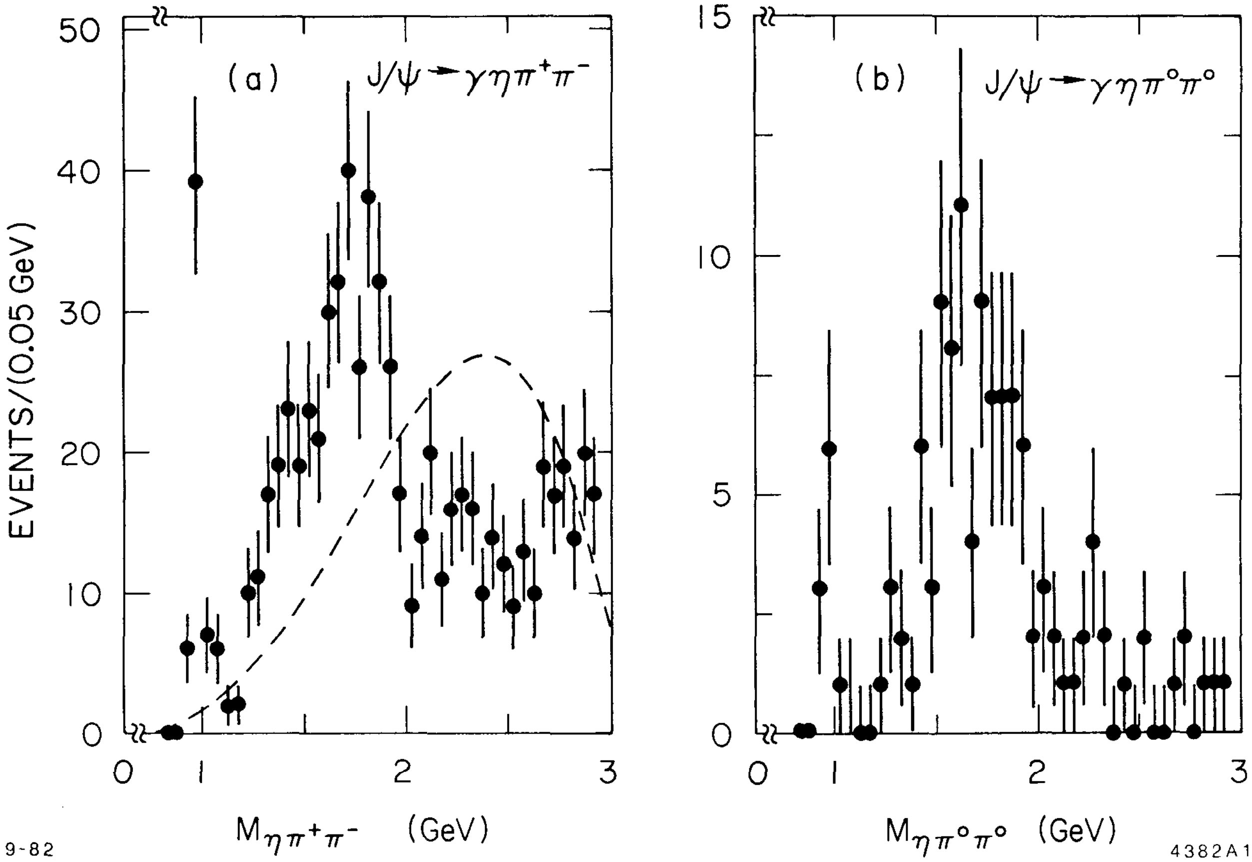
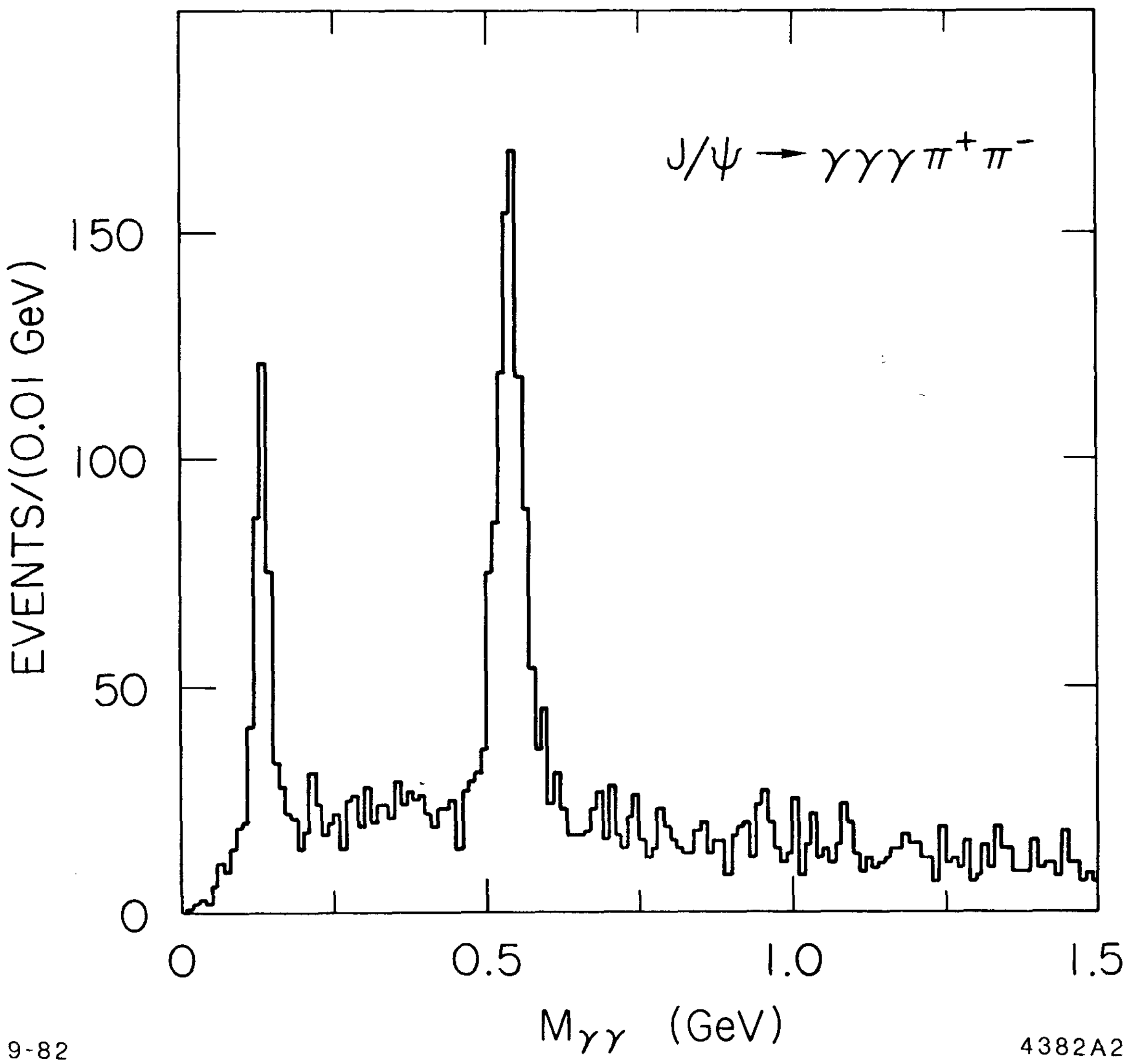


Fig. 1



J/ψ → γγγπ⁺π⁻
EVENTS/(0.01 GeV)
150
100
50
0
0
0.5
1.0
1.5
Mγγ (GeV)
9-82
4382A2

Fig. 2

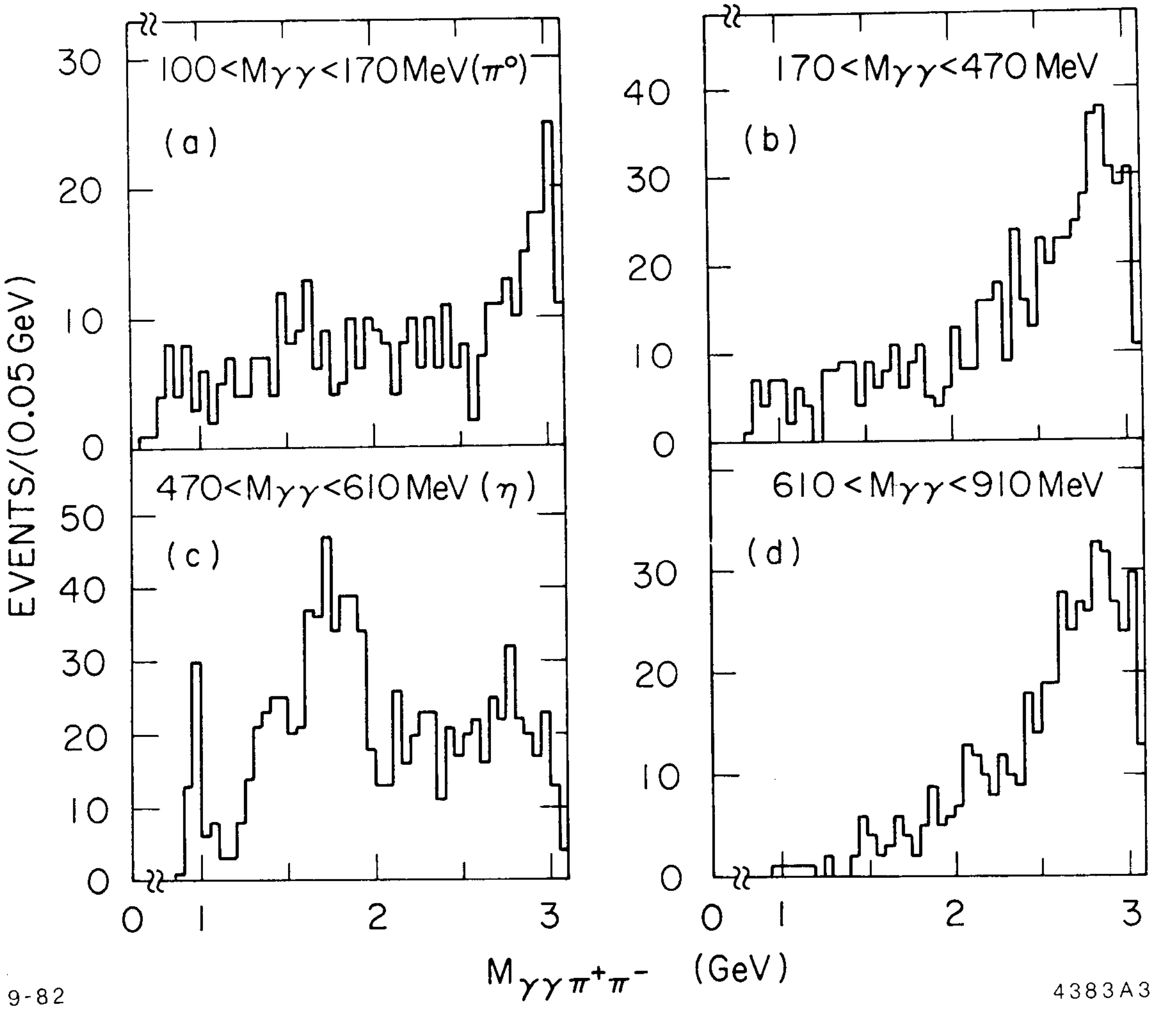
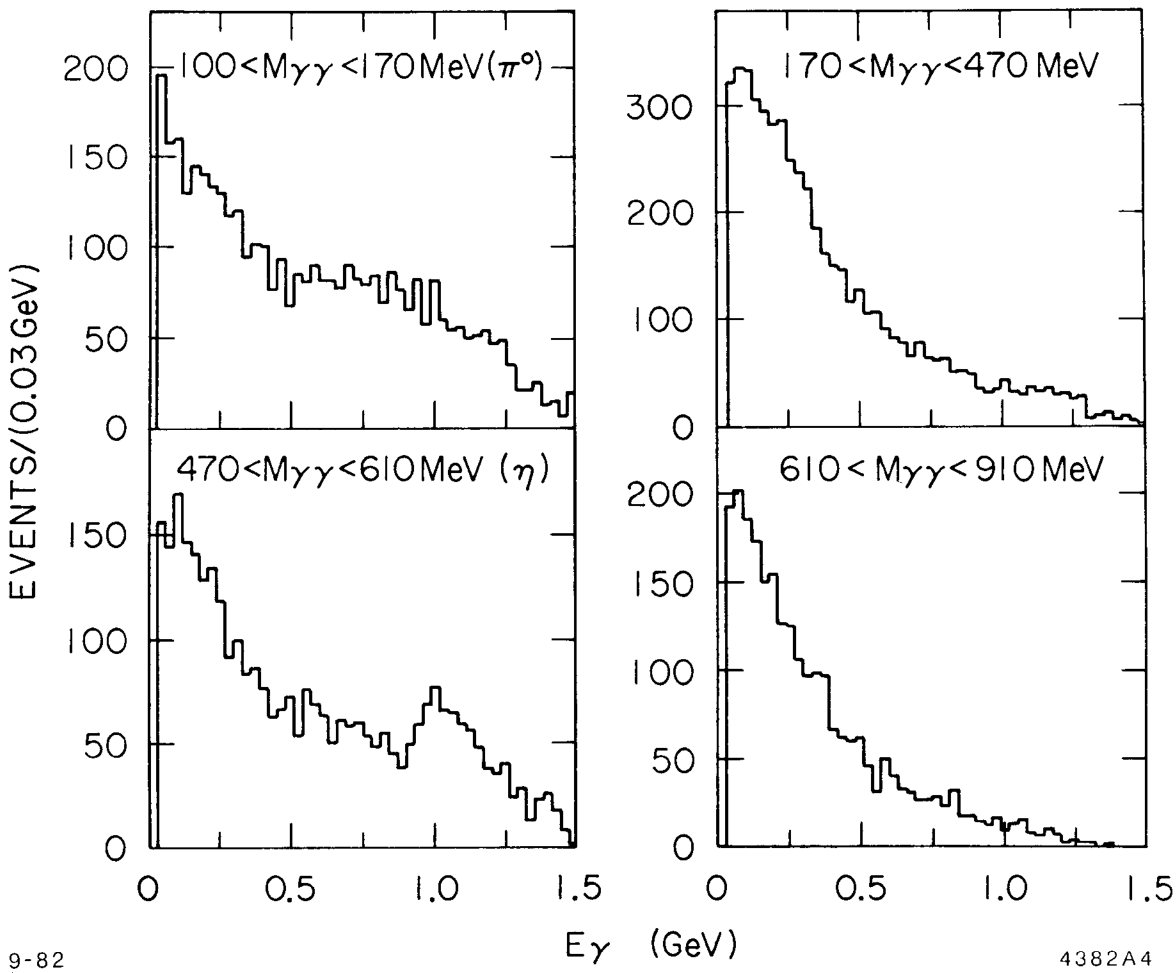
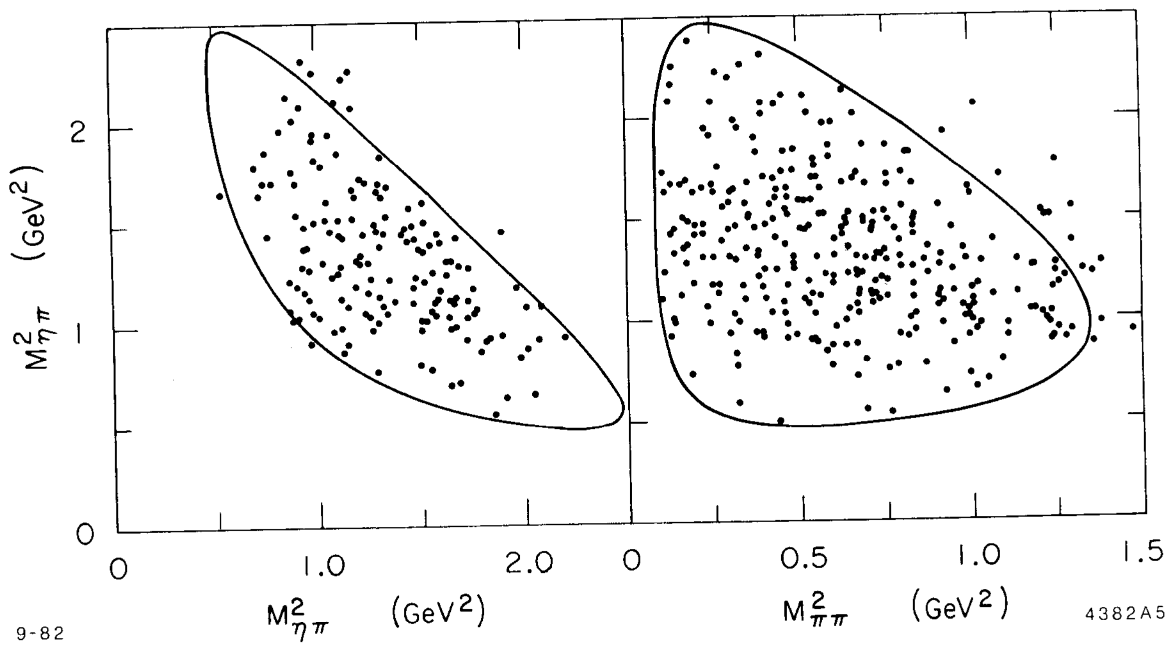

100<Mγγ<170 MeV(π°)
(a)
170<Mγγ<470 MeV
(b)
470<Mγγ<610 MeV (η)
(c)
610<Mγγ<910 MeV
(d)
EVENTS/(0.05 GeV)
Mγγπ+π- (GeV)
9-82
4383A3

Fig. 3



100<Mγγ<170 MeV(π°)
170<Mγγ<470 MeV
470<Mγγ<610 MeV (η)
610<Mγγ<910 MeV
EVENTS/(0.03 GeV)
0
50
100
150
200
300
0.5
1.0
1.5
Eγ (GeV)
9-82
4382A4

Fig. 4



2
1
0
$M^2_{\eta\pi}$ (GeV^2)
0
1.0
2.0
0
0.5
1.0
1.5
$M^2_{\eta\pi}$ (GeV^2)
$M^2_{\pi\pi}$ (GeV^2)
9-82
4382A5

Fig. 5

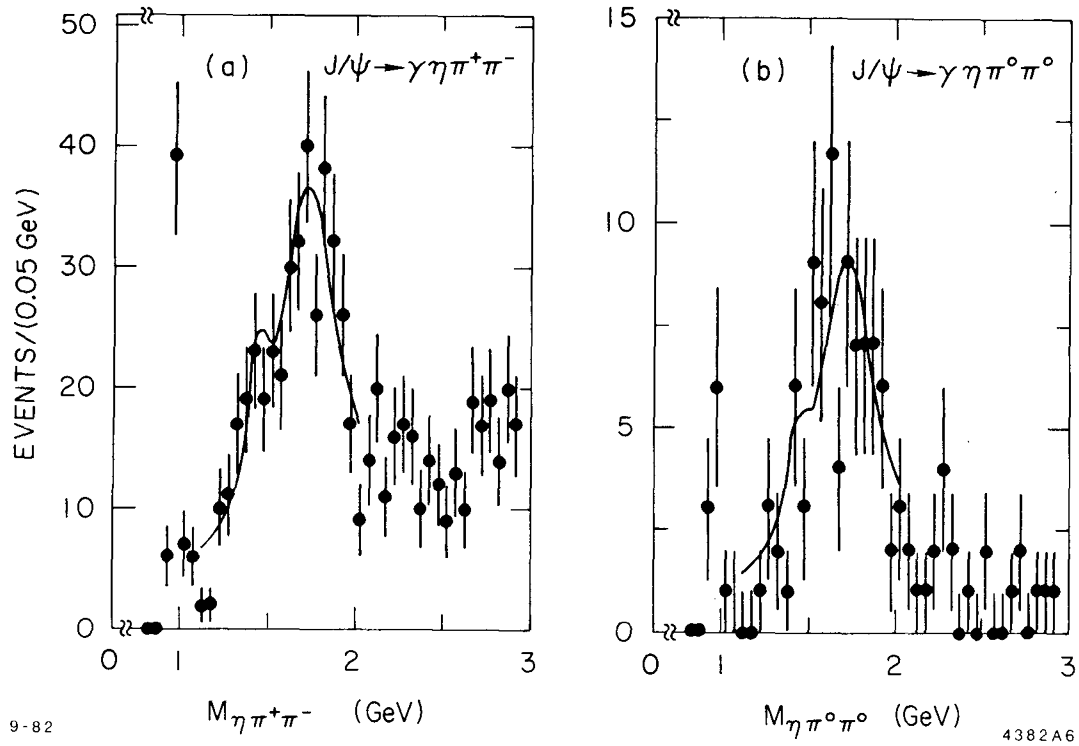

(a)
$J/\psi \to \gamma \eta \pi^+ \pi^-$
(b)
$J/\psi \to \gamma \eta \pi^0 \pi^0$
EVENTS/(0.05 GeV)
$M_{\eta \pi^+ \pi^-}$ (GeV)
$M_{\eta \pi^0 \pi^0}$ (GeV)
9-82
4382A6

Fig. 6