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A STUDY OF THE DECAY $J/\psi \to \gamma\eta\pi\pi$ *

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Abstract

The radiative decay $J/\psi \rightarrow \gamma\eta\pi\pi$ has been studied with 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 $\sim$ 1700 MeV. We have searched for the $\iota(1440)$ in the $\eta\pi\pi$ mass spectrum and find:

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

Recently a resonance with mass 1440 MeV has been seen in the $KK\pi$ mass spectrum from the radiative decay $J/\psi \rightarrow \gamma KK\pi$.[1,2] Partial wave and spin parity analyses performed by the authors[2] indicated that the state is a pseudoscalar which decays predominantly to $\delta\pi$ with the δ decaying to $K\bar{K}$. This state has been named $\iota(1440)$.[3] The $\delta(980)$ also decays to $\eta\pi$ though the ratio $BR(\delta \rightarrow \eta\pi)/BR(\delta \rightarrow K\bar{K})$ is not well known. Experimental determinations of this ratio range from 0.24 to 4.0.[4] If the branching ratio for $\delta \rightarrow \eta\pi$ is larger than that for the $K\bar{K}$ channel, as might be expected since the δ mass is below $K\bar{K}$ threshold, then the $\iota(1440)$ should appear in the $\eta\pi\pi$ mass spectrum from the process $J/\psi \rightarrow \gamma\eta\pi\pi$. This letter presents results from a study of the decay $J/\psi \rightarrow \gamma\eta\pi\pi$ by the Crystal Ball Collaboration.

The data are from a sample of 2.2 million J/ψ mesons produced in e^+e^- interactions at the SPEAR storage ring. The Crystal Ball detector consists primarily of a segmented spherical shell of $NaI(T\ell)$ crystals covering 93% of the full solid angle. Additional sodium iodide end cap crystals increase the solid angle coverage to 98% of 4π sr for the detection of electromagnetically showering particles. 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 magnetrostrictive spark chambers and proportional wire chambers, is used to identify charged particles and measure their directions. Details of the detector performance and event selection procedures have been presented elsewhere.[5]

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 $\gamma\gamma$. Note that charged particle energies, as well as charged pion-kaon separation, are determined only from the constrained fit. 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 Figs. 1a and 1b 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. 1a 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 evidence for the $\iota(1440)$ in the $\eta\pi^0\pi^0$ mass spectrum. The $\eta\pi^+\pi^-$ mass spectrum has a slight shoulder in the ι region. An upper limit for the product $BR(J/\psi \rightarrow \gamma\iota) \times BR(\iota \rightarrow \eta\pi\pi)$ will be given at the end of this Letter. We first discuss the new enhancement in greater detail.

Several tests have been performed to investigate the enhancement at 1700 MeV. 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 particless (the statistically more significant channel) 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. We find (Fig. 3) that the enhancement is correlated only with $\gamma\gamma$ masses in the η peak.

As an additional test, the kinematic fitting may be eliminated entirely. Then we see an enhancement in the photon energy spectrum for events with three photons and two charged particles. The enhancement is at about 1 GeV (corresponding to a recoil mass of 1700 MeV) and appears only when there are two photons in the event which form an η mass combination.[6]

We have considered 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 there are no known J/ψ decays which contain an η which have a large enough branching ratio 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's. With a detection efficiency of 20% we would expect to see 5 events. The number of events in the 1700 MeV enhancement is about 100 times larger. Similarly, processes such as:

$$\begin{tikzcd}
J/\psi \arrow[r] & \gamma\theta \arrow[dr] & & \\
& & \eta\eta \arrow[dr] \arrow[ddr] & \\
& & & \pi^+\pi^-\pi^0\ (\text{or}\ \pi^0\pi^0\pi^0) \\
& & & \gamma\gamma
\end{tikzcd}$$

with a 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 contribute to the $\eta\pi^+\pi^-$ spectrum 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. Note that the process $J/\psi \rightarrow \omega\eta$, $\omega \rightarrow \pi^+\pi^-\pi^0$ is a background only for $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$ and not for $J/\psi \rightarrow \gamma\eta\pi^0\pi^0$. Thus there is no cut on η momentum for the all-neutral events.

We have examined the $\eta\pi$ and $\pi\pi$ mass spectra for events in the 1700 MeV enhancement.[6,7] There is no strong evidence for structure in either distribution. The broad enhancement is apparently not associated with the δ or any other resonances in either $\eta\pi$ or $\pi\pi$.

We mention three possible interpretations for this new enhancement. First, the enhancement may be a single new resonance. A second possibility is that it includes contributions from two or more resonances.[8] Finally, the enhancement could arise from a (nonresonant) process such as the decay of the J/ψ to a photon plus two gluons: $J/\psi \rightarrow \gamma gg$. The $\eta\pi\pi$ mass distribution for events which contain a prompt γ may be quite different from the Lorentz invariant phase space distribution shown in Fig. 1a.

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).

The fit has a χ^2 of 77 for 71 degrees of freedom. We find: $M = 1700 \pm 45$ MeV and $\Gamma = 520 \pm 110$ MeV where the errors include estimates of the systematic uncertainty. The detection efficiency was determined by a Monte Carlo calculation to be 19% (6.5%) for $J/\psi \rightarrow \gamma\eta\pi^+\pi^-(\eta\pi^0\pi^0)$, $\eta \rightarrow \gamma\gamma$ 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:

$$BR(J/\psi \rightarrow \gamma\eta\pi^+\pi^-) = 3.9 \pm 0.2 \pm 0.7 \times 10^{-3}$$

$$BR(J/\psi \rightarrow \gamma\eta\pi^0\pi^0) = 2.6 \pm 0.4 \pm 0.8 \times 10^{-3}$$

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.

We have used two methods to obtain an upper limit for the product branching ratio for $J/\psi \rightarrow \gamma\iota$, $\iota \rightarrow \eta\pi\pi$. First we assume that all events in the ι region (above the background as determined for the fit described above) come from $\iota(1440)$ decay. The result is:

$$BR(J/\psi \rightarrow \gamma\iota)(\iota \rightarrow \eta\pi\pi) < 1.7 \times 10^{-3} \quad \text{(90\% confidence level)}$$

Alternatively, the $\eta\pi\pi$ mass spectra may be 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 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 determined by the fit is insensitive to the background hypothesis because of the presence of the 1700 MeV enhancement. The fitted width of the 1700 MeV 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. The result is:

$$BR(J/\psi \rightarrow \gamma\iota)(\iota \rightarrow \eta\pi\pi) < 0.7 \times 10^{-3} \quad \text{(90\% confidence level)} \quad .$$

For comparison, note that[2]

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

In conclusion, we have determined the branching ratios for the radiative decays $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$ and $J/\psi \rightarrow \gamma\eta\pi^0\pi^0$. We find:

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

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

References

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1. D. L. Scharre et al., Phys. Lett. 97B, 329 (1980).
2. C. Edwards et al., Phys. Rev. Lett. 49, 259 (1982).
3. A pseudoscalar state may have been previously observed 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)). For this reason, a new name has been given to the pseudoscalar state.

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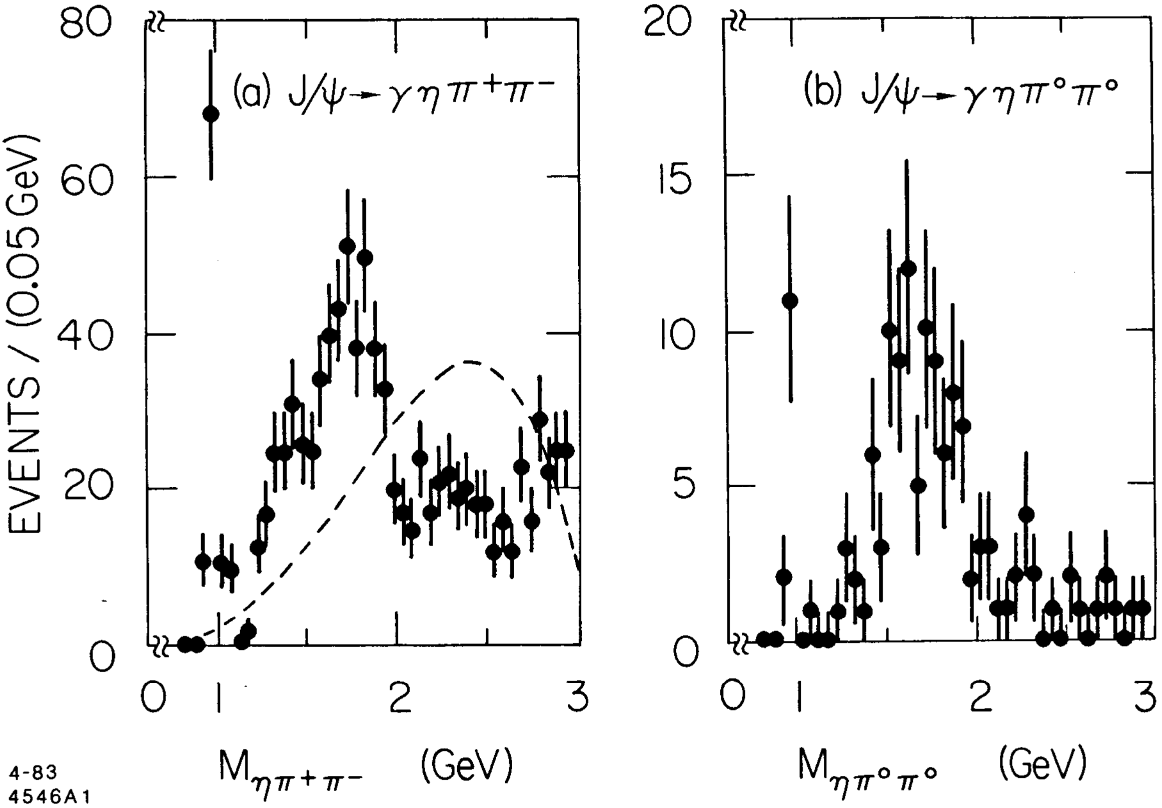
5. M. Oreglia et al., Phys. Rev. D 25, 2259 (1982), and references therein.
6. C. Newman-Holmes, SLAC-PUB-2971, September 1982.
7. C. Newman-Holmes in Proceedings of the 21st International Conference on High Energy Physics, edited by P. Petiau and M. Porneuf, Paris, France (1982), p. C3-82; and E. D. Bloom in Proceedings of the 21st International Conference on High Energy Physics, p. C3-407.
8. One cannot account completely for the enhancement with a simple incoherent superposition of known resonances. However, known resonances, in particular the $\theta(1700)$, may provide large contributions to the enhancement.

Figure Captions

1. The $\eta\pi\pi$ mass spectrum for $J/\psi \rightarrow \gamma\eta\pi\pi$ events. Figure 1a is the $\eta\pi^+\pi^-$ mass and Fig. 1b is the $\eta\pi^0\pi^0$ mass. The dashed curve in Fig. 1a shows the $\eta\pi^+\pi^-$ mass spectrum expected from Lorentz invariant phase space.
2. $\gamma\gamma$ mass for events which fit the hypothesis $J/\psi \rightarrow \gamma\gamma\gamma\pi^+\pi^-$. There are three entries per event.
3. $\gamma\gamma\pi^+\pi^-$ mass for 4 different $\gamma\gamma$ mass intervals.



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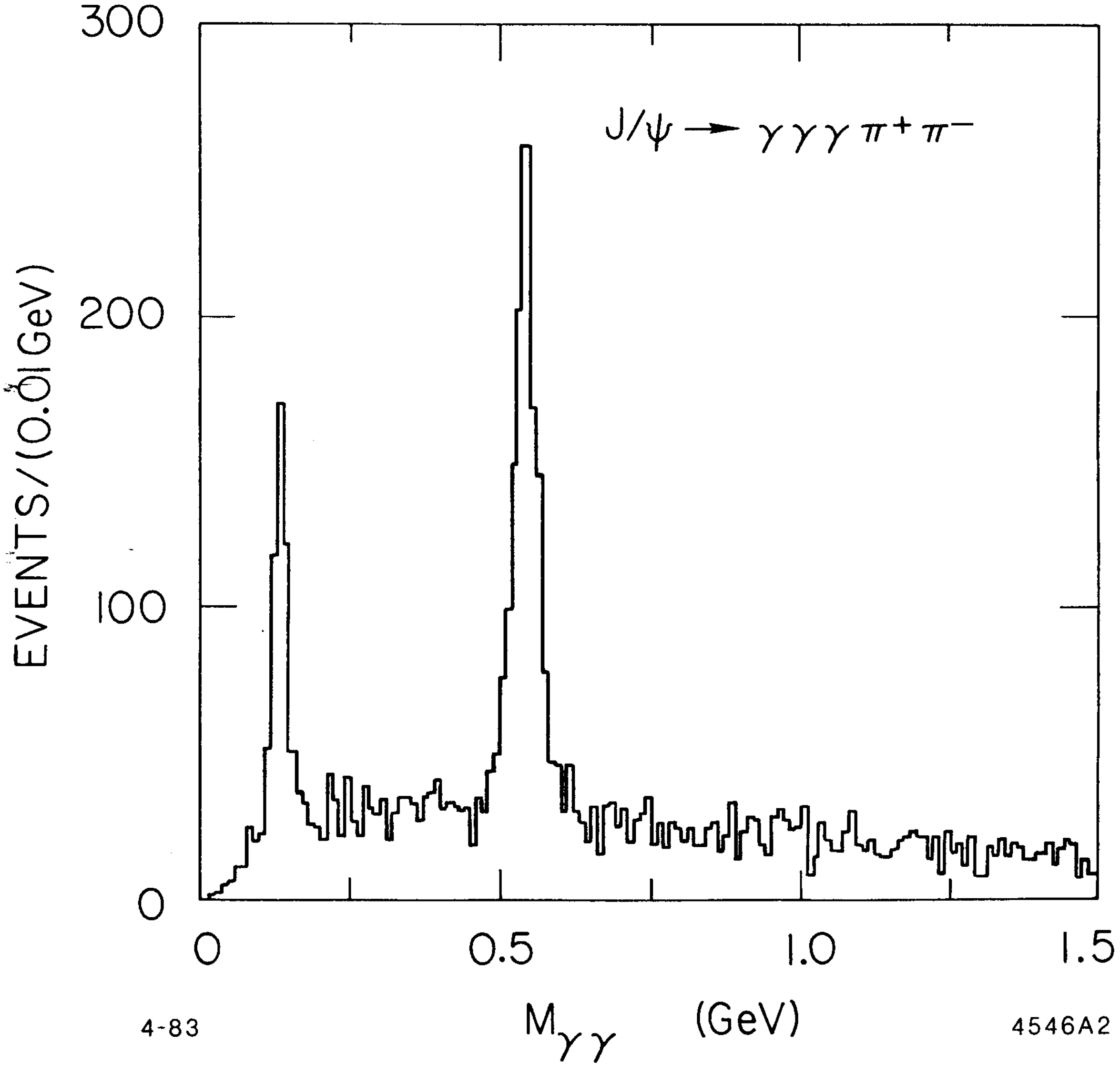
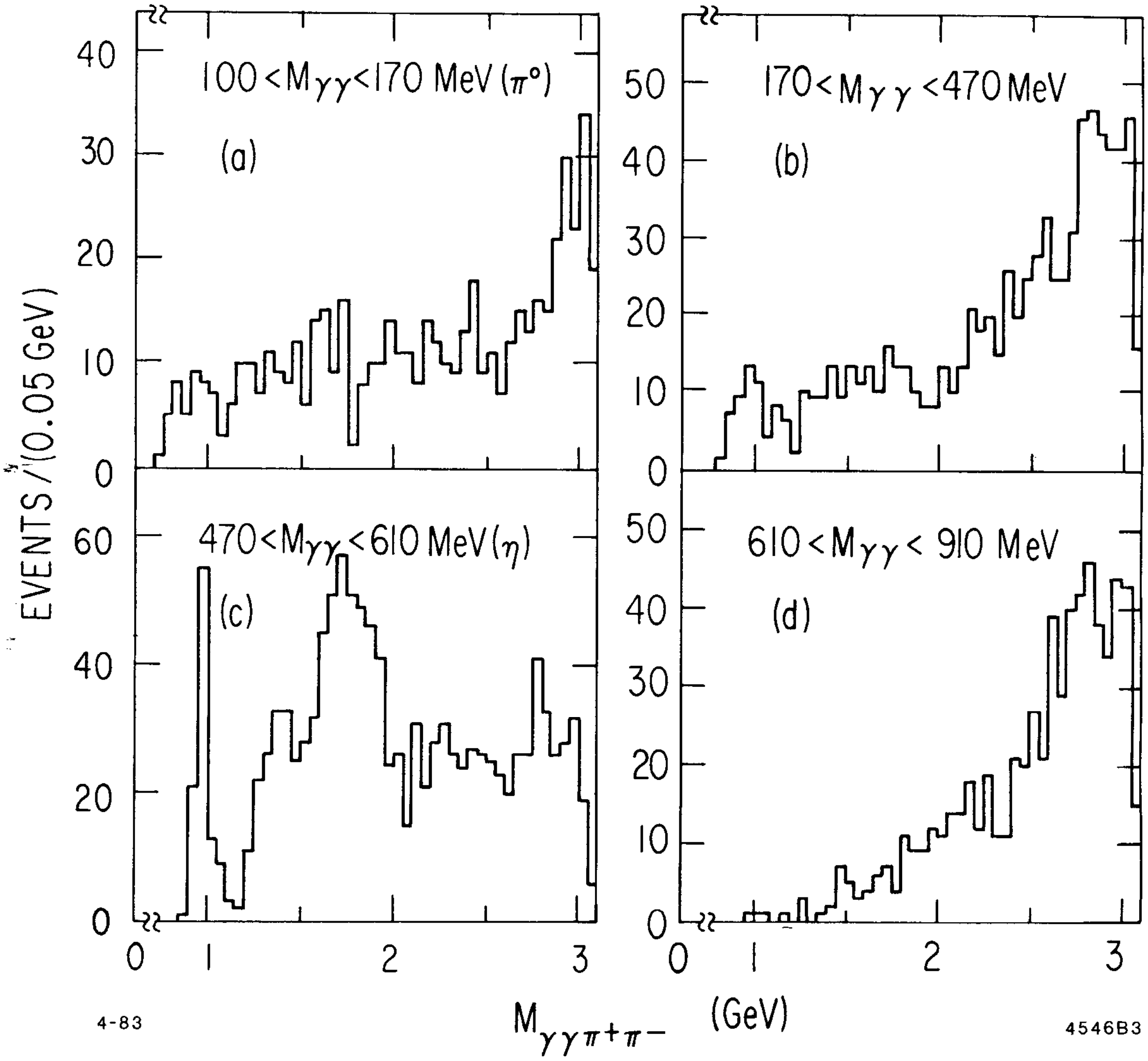
4546A1

Fig. 1



J/ψ → γγγπ⁺π⁻
EVENTS/(0.01 GeV)
300
200
100
0
0
0.5
1.0
1.5
$M_{\gamma\gamma}$ (GeV)
4-83
4546A2

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)
4-83
4546B3
0
10
20
30
40
50
60
1
2
3

Fig. 3