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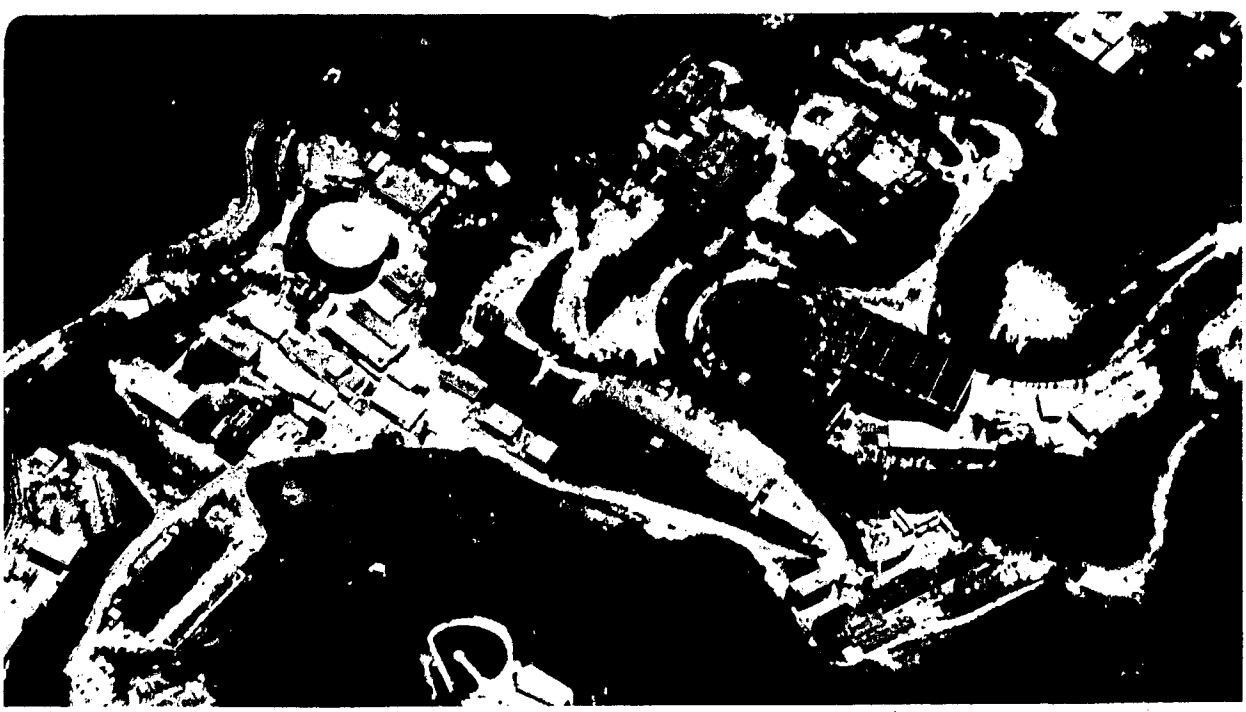
Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, and Stanford Linear Accelerator Center, Stanford University, Stanford, CA

March 1983



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MEASUREMENT OF $\psi(3097)$ AND $\psi'(3686)$ DECAYS INTO SELECTED HADRONIC MODES*

M. E. B. Franklin, G. J. Feldman, G. S. Abrams, M. S. Alam,[a] C. A. Blocker,[b] A. Blondel,[c] A. M. Boyarski, M. Breidenbach, D. L. Burke, W. C. Carithers, W. Chinowsky, M. W. Coles, S. Cooper,[d] W. E. Dieterle,[e] J. B. Dillon, J. Dorenbosch,[f] J. M. Dorfan, M. W. Eaton,[b] G. Gidal, G. Goldhaber, G. Hanson, K. G. Hayes,[f] T. Himel,[f] D. G. Hitlin,[g] R. J. Hollebeek, W. R. Innes, J. A. Jaros, P. Jenni,[f] A. D. Johnson,[h] J. A. Kadyk, A. J. Lankford, R. R. Larsen, M. Levi, R. E. Millikan, V. Lüth, M. E. Nelson, C. Y. Pang, J. F. Patrick,[i] M. L. Perl, B. Richter, A. Roussarie,[j] D. L. Scharre, R. H. Shindler,[g] R. F. Schwitters,[b] J. L. Siegrist,[f] J. Strait,[k] H. Taureg,[f] M. Tonutti,[l] G. H. Trilling, E. Vella,[f] R. A. Vidal,[i] I. Videau,[c] J. M. Weiss,[m] and H. Zaccone[c]

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

ABSTRACT

We present measurements of $\psi(3097)$ and $\psi'(3686)$ branching fractions for selected hadronic decays. The ratio of ψ' to ψ branching fractions for these decays is consistent with the ratio of branching fractions to lepton pairs, with the exception of the decays to $\rho\pi$ and K^*K for which this ratio is substantially smaller.

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Applequist and Politzer[1] calculate, using perturbative QCD, that the width of the nonrelativistic charmed quark-antiquark bound state (charmonium) decay to three gluons is proportional to its leptonic width. Both depend on the mass and the wave function at the origin of the charmonium system. The ratio of branching fractions of ψ and ψ' decays to three gluons can be written in terms of their total and leptonic widths, Γ_t and Γ_{ee}:

$$\frac{B(\psi' \to ggg)}{B(\psi \to ggg)} = \frac{\Gamma(\psi' \to e^+e^-)\,\Gamma_t(\psi)}{\Gamma(\psi \to e^+e^-)\,\Gamma_t(\psi')} = (12.2 \pm 2.4)\% \ .$$

World averages[2] of the total and leptonic widths are used to obtain this ratio. The calculation of the width to three gluons assumes that the charmonium system is nonrelativistic, that the strong coupling constant $\alpha_s \ll 1$, that $\alpha_s(\psi) = \alpha_s(\psi')$ and that charmonium systems decay to hadrons predominantly via a pointlike annihilation into three gluons.

In this letter we present measurements of the branching fractions from the ψ and ψ' to five exclusive hadronic final states. We compare the theoretical prediction for the ratio of branching fractions to hadrons $B(\psi' \to ggg)/B(\psi \to ggg)$ with the measured ratio $B(\psi' \to X)/B(\psi \to X)$ where X is an exclusive hadronic final state. We note that the prediction is made for the total hadronic width, not the partial width. We expect the partial widths to be functions of the wave function at the origin of the charmonium states as well since the exclusive decay proceeds through a three gluon annihilation in this model. However, there are other factors associated with each exclusive mode (such as multiplicity) which are disregarded by this prediction and therefore we do not expect the agreement between calculation and experiment to be perfect.

The data were taken with the MARK II detector at the SPEAR e^+e^- storage ring located at the Stanford Linear Accelerator Center. The data sample corresponds to

427,000 produced ψ's and 1.02 million produced ψ''s. The MARK II detector has been described in detail elsewhere.[3] Briefly, charged particles are tracked by a 16 layer cylindrical drift chamber in a 4.1 kilogauss axial magnetic field. The momentum resolution is $\delta p/p = \sqrt{(.015)^2 + (.005p)^2}$ where p is the momentum in GeV. Time-of-flight scintillation counters are used for particle identification. The timing resolution is 300 ps for hadrons. This provides π/K separation for charged tracks of momenta below 1.2 GeV and proton identification below 2 GeV. Liquid argon calorimeters with an energy resolution $\sigma/E = 12\%/\sqrt{E}$ (where E is the photon energy) are used to find photons and to discriminate hadrons from electrons. A system of steel interlaced with planes of proportional tubes is used to identify muons. This is done by detecting charged particles and ranging out all those which interact in the steel.

We have made measurements of the branching ratios from the ψ and the ψ' to the following final states:

$$\pi^+ \pi^- \pi^o$$
$$K^+ K^- \pi^o$$
$$p \bar{p} \pi^o$$
$$2\pi^+ 2\pi^- \pi^o$$
$$3\pi^+ 3\pi^- \pi^o$$

The event selection criteria and methods of analysis are similar for these different modes and will be described here in their general form.

In all cases we require that at least two photons with energies greater than 150 MeV be detected in the liquid argon modules. We define a photon as a signal in the liquid argon shower counter with no associated charged track in the central tracking chamber. To exclude events with fake photon signals made by the coincidence of noise in the liquid argon and hadronic tracks, photons found within 36 centimeters of a charged track (at the entrance to the shower counter), were not used. We require that

all charged particles in the event be detected and that there be no additional charged tracks. A charged track is used only if it is associated with an acceptable time-of-flight measurement. This measurement must be consistent to within 600 picoseconds with the time expected given the chosen mass hypothesis, and the reconstructed path length of the particle. Corrections are made for energy loss of the charged particles in the material they traverse before entering the drift chamber. Charged tracks identified as muons by the muon system are excluded. Decays of the ψ' which occur via the ψ, such as $\psi' \to \pi^+\pi^-\psi$, $\psi \to \pi^+\pi^-\pi^o$, or which occur via the χ states are excluded. Each event is totally reconstructed which allows such radiative decays to be recognized easily and rejected.

In all analyses a kinematic fit with four constraints is performed on each event and a cut made on the χ^2 of the fit. For example when looking at the decay $\psi \to p\bar{p}\pi^o$, the fit hypothesis is $\psi \to p\bar{p}\gamma\gamma$. By not constraining the two photon invariant mass to the π^o mass we are able to make a background subtraction beneath the π^o in the two photon invariant mass spectra. Finally we require that a π^o, defined as $115 < M(\gamma\gamma) < 135\ MeV/c^2$, be present. Detection efficiencies are calculated by Monte Carlo simulation. These efficiencies range from 0.1% to 12% , and are typically greater for decays from the ψ' due to the 20% mass increase over the ψ. The errors in all branching fractions quoted below are the statistical and systematic errors added in quadrature.

The decay $\psi \to \pi^+\pi^-\pi^o$ is measured to be consistent with proceeding almost entirely through the $\rho\pi$ intermediate state. Figure 1 shows the observed invariant mass distribution of $\pi^+\pi^-$ pairs in events that satisfy the $\pi^+\pi^-\pi^o$ hypothesis. The spectrum consists of a ρ^o signal and a charged ρ reflection. Note that there is very little continuum 3π production between 1.0 and 1.8 GeV/c^2. This is also true for the charged decay mode $\psi \to \rho^\pm\pi^\mp$. We require a ρ defined as $530 < M(\pi\pi) < 1010\ MeV/c^2$

in each event. Figure 2 shows the fitted two photon invariant mass spectrum for the decay $\psi \to \rho\pi$. The good resolution of the π^o mass reflects the precision with which we have measured the angles of the photons, rather than their energies. We observe a π^o signal of 149.7 events (background subtracted) combining the neutral and charged modes. For the decay $\psi' \to \rho\pi$, with the same selection criteria, one event is seen. An upper limit on the ratio of branching ratios is set:

$$B(\psi' \to \rho\pi)/B(\psi \to \rho\pi) < 0.63\% \quad (90\% \text{ confidence level}) \ .$$

If we relax the requirement that each event contain a ρ, then we find 170 events from the ψ and 4 events from the ψ'. Regarding these as signal events with a negligible background we measure the ratio of branching fractions to be:

$$B(\psi' \to \pi^+\pi^-\pi^o)/B(\psi \to \pi^+\pi^-\pi^o) = (0.58 \pm 0.40)\% \ .$$

The decays $\psi, \psi' \to K^+K^-\pi^o$ are found to proceed predominantly through the intermediate state $K^*(892)K$. Figure 3 shows this K^* signal in the invariant mass distribution of the $K^+\pi^o$. We require that a $K^*(892)$ be present in the final state. This is done by making a cut on the invariant mass of the $K\pi$ system such that $780 < M(K\pi^o) < 1000\ MeV/c^2$. We observe a π^o signal of 24 events with no background. We observe no such events in the corresponding decay of the ψ'. An upper limit on the ratio of branching ratios is set:

$$B(\psi' \to K^*K)\ B(K^* \to K\pi^o)/B(\psi \to K^*K)\ B(K^* \to K\pi^o) < 2.0\%$$

at the 90% confidence level.

For the decays $\psi(\psi') \to p\bar{p}\pi^o$ we find 16 (9) events which satisfy the event selection criteria. This gives a ratio of branching fractions of: $B(\psi' \to p\bar{p}\pi^o)/B(\psi \to p\bar{p}\pi^o) = 14.0 \pm 6.3\%$. For the decays $\psi(\psi') \to 2\pi^+2\pi^-\pi^o$ we find 152 (30) events which satisfy

the selection criteria. Figure 4 shows the fitted two photon invariant mass spectrum for such ψ and ψ' decays. In both cases there is a clear π^o signal. The ratio of branching ratios for these two processes is found to be

$$B(\psi' \to 2\pi^+2\pi^-\pi^o)/B(\psi \to 2\pi^+2\pi^-\pi^o) = (9.5 \pm 2.7)\% \ .$$

For the decays $\psi(\psi') \to 3\pi^+3\pi^-\pi^o$ the detection efficiency becomes very small [0.09% (0.17%)], and therefore the statistical errors are large. We see 11 events from the ψ and 6 events from the ψ' with no background. The ratio of branching fractions is

$$B(\psi' \to 3\pi^+3\pi^-\pi^o)/B(\psi \to 3\pi^+3\pi^-\pi^o) = (13 \pm 7)\% \ .$$

Table I summarises the results of branching ratio measurements for all decay modes analyzed and for three modes, $\psi, \psi' \to p\bar{p}$, $p\bar{p}\pi\pi$ and $K^+K^-\pi^+\pi^-$ analyzed in previous experiments.[4–6] The table includes the number of events and the efficiency for each decay mode. The branching fractions measured in this experiment are consistent with measurements by previous experiments. Of the five decay modes studied and the three measured previously, six give values of the ratio of branching fracitons of the ψ' to the ψ consistent with the prediciton of perturbative QCD for inclusive hadrons and two do not. Those two states are $\rho\pi$ and K^*K. We find little significant evidence for these decays from the ψ'. This is a striking deviation from our naive expectations discussed above and as yet there is no theoretical explanation.

ACKNOWLEDGEMENTS

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REFERENCES

Present address:

(a) Vanderbilt University, Washville, Tennessee 37235.

(b) Harvard University, Cambridge, Massachusetts 02138.

(c) LPNHE, Ecole Polytechnique, F-91128 Palaiseau, France.

(d) DESY, Hamburg, Federal Republic of Germany.

(e) University of Arizona, Tucson, Arizona 85721.

(f) CERN, Geneva 23, Switzerland.

(g) California Institute of Technology, Pasadena, California 91125.

(h) University of California at Santa Cruz, Santa Cruz, California 95064.

(i) FNAL, Batavia, Illinois 60510.

(j) CEN Saclay, F-91190, Gif-Sur-Yvette, France.

(k) University of Massachusetts, Amherst, Massachusetts 01003.

(l) Physitcalisclies Institut, Physikzentrum - 5100 Aachen, Germany.

(m) Argonne National Laboratory, Argonne, Illinois 60439.

1. T. Applequist and D. Politzer, Phys. Rev. Lett. 34, 43 (1975).
2. Particle Data Group, Phys. Lett. 111B (1982).
3. R. Schindler, Ph.D. Thesis, SLAC Report No. 219 (1979).
4. H. J. Besch et al., Phys. Lett. 78B, 347 (1978); I. Peruzzi et al., Phys. Rev. D 17, 2901 (1978); R. Brandelik et al., Z. Phys. C1, 233 (1979); G. Feldman et al., Phys. Lett. 33C, 285 (1977).
5. I. Peruzzi et al., Phys. Rev. D 17, 2901 (1978); H. J. Besch et al., Z. Phys. C8, 1 (1981); W. Tanenbaum et al., Phys. Rev. D 17, 1731 (1978).
6. F. Vanucci et al., Phys. Rev. D 15, 1814 (1979); W. Taneubaum et al., Phys. Rev. D 17, 1731 (1978).

TABLE I

Mode	# Events	Efficiency %	$B(\psi \to X)\%$	# Events	Efficiency %	$B(\psi' \to X)\%$ *	$[B(\psi' \to X)/B(\psi \to X)]\%$ *
$p\bar{p}$ †			(0.22 ± 0.02)			(0.019 ± 0.005)	8.6 ± 2.4
$p\bar{p}\pi^+\pi^-$ †			(0.53 ± 0.08)			(0.08 ± 0.02)	15.1 ± 4.1
$K^+K^-\pi^+\pi^-$			(0.72 ± 0.23)			(0.16 ± 0.04)	22.2 ± 9.0
$p\bar{p}\pi^0$	16	3.72	$(1.0 \pm 0.3) \times 10^{-1}$	9	6.2	$(1.4 \pm 0.5) \times 10^{-2}$	14.0 ± 6.3
$2\pi^+2\pi^-\pi^0$	147.5	1.09	(3.17 ± 0.42)	42	1.39	(0.30 ± 0.08)	9.5 ± 2.7
$3\pi^+3\pi^-\pi^0$	11	0.09	(2.8 ± 0.9)	6	0.17	$(3.5 \pm 1.6) \times 10^{-1}$	13.0 ± 7.0
$K^+K^-\pi^0$	25	2.13	$(2.9 \pm .8)\times 10^{-1}$	1	4.2	$< 8.9 \times 10^{-3}$	< 3.2
inclusive							
$K^\pm K^\mp$		2.13	$(2.6 \pm .8)\times 10^{-1}$		4.2	$< 5.4 \times 10^{-3}$	
$\hookrightarrow K^\pm\pi^0$	24			0			< 2.0
$\pi^+\pi^-\pi^0$	166	2.68	(1.5 ± 0.2)	4	4.6	$(8.5 \pm 4.6) \times 10^{-3}$	0.6 ± 0.4
inclusive							
$\rho\pi$	149.7	2.68	(1.3 ± 0.3)	1	4.6	< 0.0083	< 0.63

* All limits set at 90% confidence level.

† These modes were measured elsewhere.[4–6]

FIGURE CAPTIONS

1. $\pi^+\pi^-$ invariant mass distribution for events $\psi \to \pi^+\pi^-\pi^o$. A ρ^o peak and a charged ρ reflection are evident.
2. Two photon invariant mass spectrum for decays $\psi \to \rho\pi$ and $\psi' \to \rho\pi$ (shaded).
3. $K^+\pi^o$ invariant mass distribution for events $\psi \to K^+\pi^o$. A $K^*(892)$ peak is evident.
4. Two photon invariant mass spectrum for decays ψ, ψ' (shaded) $\to 2\pi^+ 2\pi^- \pi^o$.

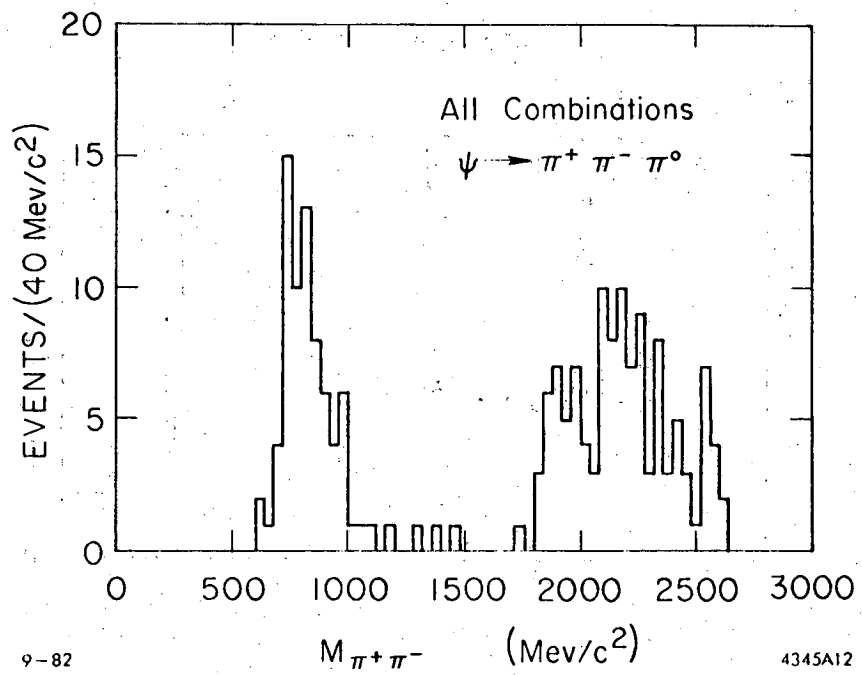


Fig. 1

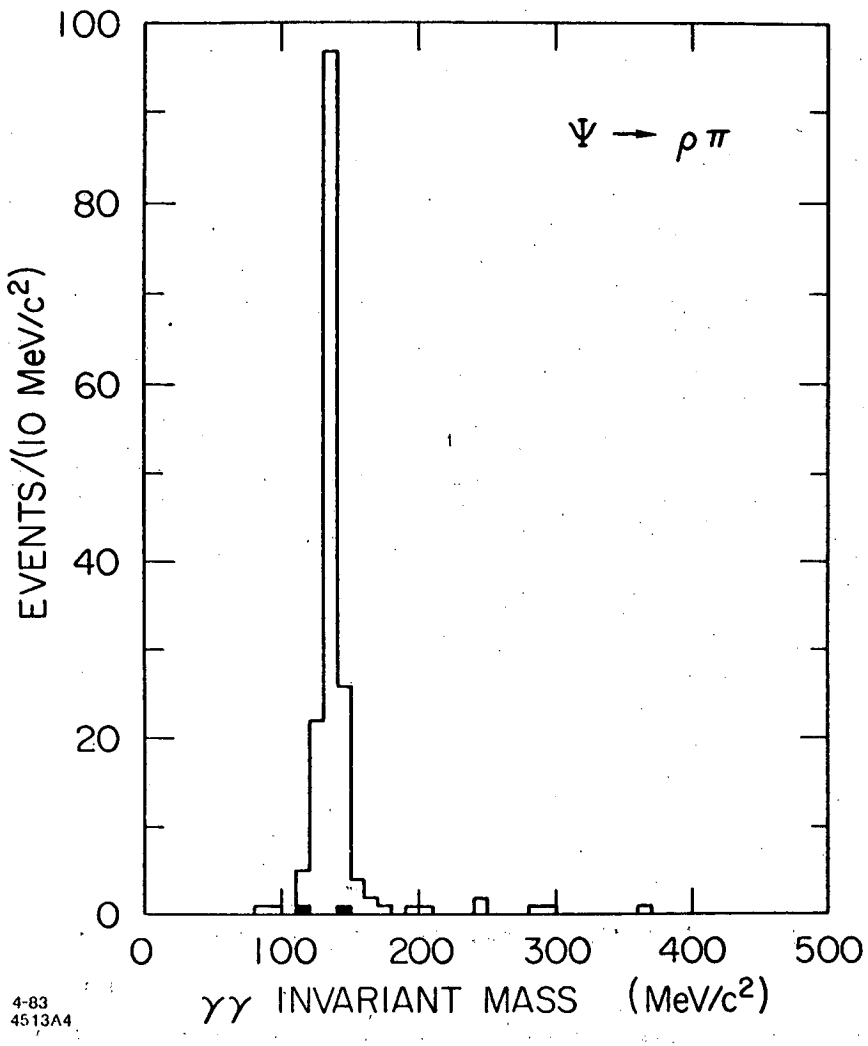
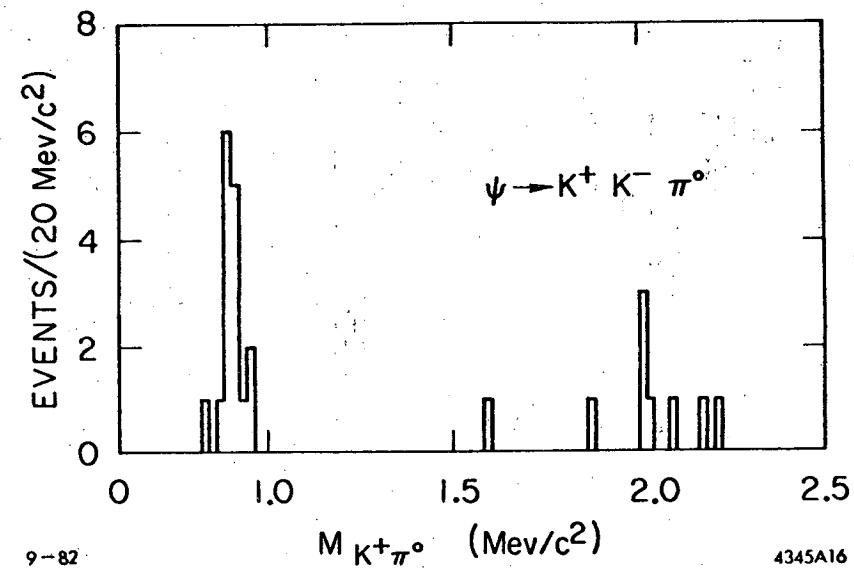

100
80
60
40
20
0
EVENTS/(10 MeV/c²)
Ψ → ρπ
0
100
200
300
400
500
γγ INVARIANT MASS (MeV/c²)
4-83
4513A4

Fig. 2


8
6
4
2
0
EVENTS/(20 Mev/c²)
ψ → K⁺ K⁻ π°
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1.0
1.5
2.0
2.5
M K⁺π° (Mev/c²)
9-82
4345A16

Fig. 3

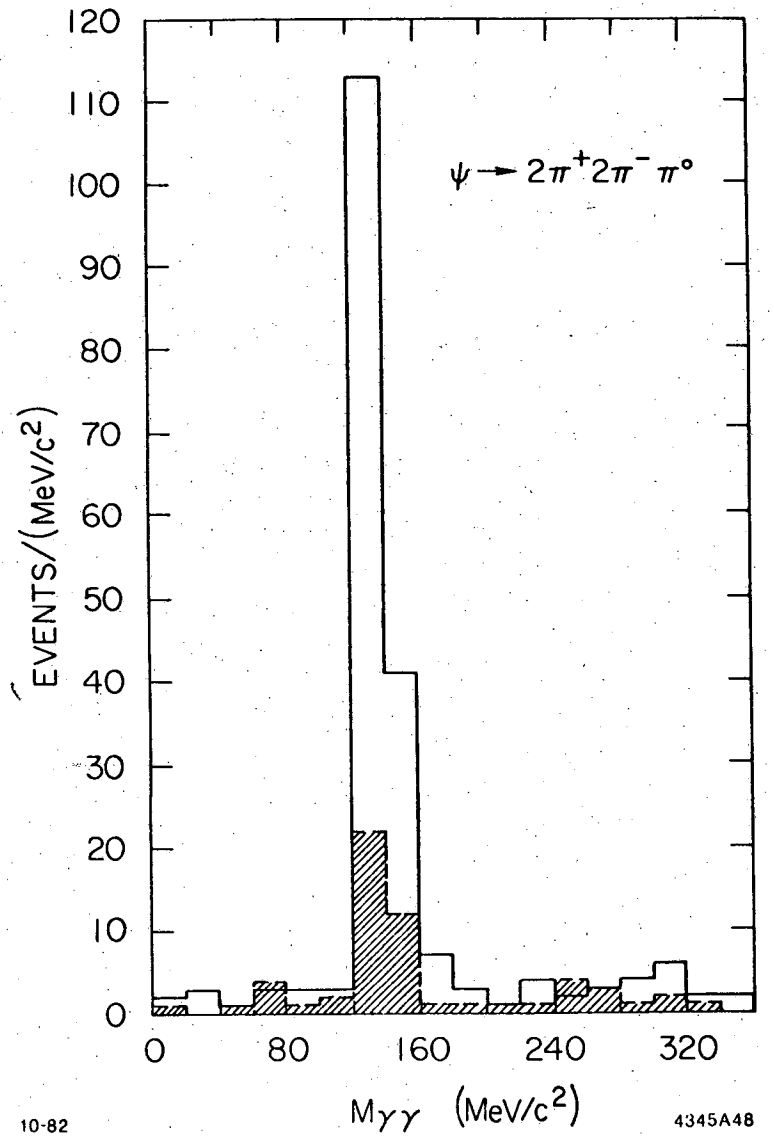
$\psi \rightarrow 2\pi^+ 2\pi^- \pi^\circ$
EVENTS/(MeV/c^2)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
80
160
240
320
$M_{\gamma\gamma}$ (MeV/c^2)
10-82
4345A48

Fig. 4

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