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RESULTS FROM DESY-HEIDELBERG NaI LEAD GLASS DETECTOR

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ABSTRACT

Results of a search for the decays $J/\psi \to \gamma\eta_c \to \gamma\gamma\rho^o$ and $J/\psi \to \gamma\eta_c \to 3\gamma$ are presented. Preliminary results on ψ' decays obtained in a high statistics measurement are also presented. They include results of a search for ψ' decays involving the η_c. The cascade decays $\psi' \to \gamma\chi \to \gamma\gamma J/\psi$ are clearly seen for $P_c^c(3.51)$ and $\chi(3.55)$. An enhancement of two standard deviations significance is observed for the decay $\psi' \to \gamma\chi(3.41) \to \gamma\gamma J/\psi$. For these three decays branching ratios are given. For the decay $\psi' \to \gamma\chi(3.45) \to \gamma\gamma J/\psi$, an upper limit for the branching ratio is given.

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INTRODUCTION

The DESY-Heidelberg collaboration has studied e^+e^- annihilation at the storage rings DORIS with a nonmagnetic detector. In the first running period, in 1975, data were taken mainly at the J/ψ resonance and some results from these measurements are presented in this report. A second set of measurements, in 1977, was taken with a modified apparatus. It includes 1100 nb^{-1} at the ψ' resonance. Preliminary results from these data are also presented.

The topics to be covered are :

a/ Apparatus description.
b/ Search for the decays $J/\psi \to \gamma\eta_c \to \gamma\gamma\rho^o$ and $J/\psi \to \gamma\eta_c \to 3\gamma$.
c/ Search for ψ' decays involving the η_c.
d/ Cascade decays of ψ'.

APPARATUS

The details of the apparatus of the DESY-Heidelberg collaboration have been described elsewhere [1] and only the modifications made for the 1977 measurements will be described here. A section of the apparatus transverse to the beam is shown in fig. 1a and an exploded view of the energy counters is given in fig. 1b.

In the inner detector (ID), the mercury converter has been removed, while the three cylindrical drift chambers (CD) and the two scintillation counter hodoscopes (H) have been left unchanged. In order to convert photons and simultaneously measure the energy loss in the converter, an active converter hodoscope (AC) has been installed. It consists of 28 NaI rod counters of 45 cm length and 1.8 X_o (4.6 cm) thickness. Photon conversions are registered by the double drift chambers (CC) and the scintillation counter hodoscopes (CH) behind the converter. The solid angle covered by the active converter system is 19 % of 4π.

The NaI and lead glass counters behind the active converter were left unmodified. They have a total thickness of 15.2 X_o, including the active converter.

The lead glass system in the top and bottom regions of the apparatus has been modified in order to improve the granularity and energy resolution. 54 rectangular lead glass counters of 12.7 X_o thickness form the top-bottom parts of the system. In addition, 32 profiled lead glass counters cover the gaps between sidewalls and top-bottom parts. In front of this counter arrangement, a lead converter (CV) has been placed between the second and third drift chamber of the inner detector. It is tapered in such a way that particles coming from the interaction point see a thickness of 1 X_o.

In the preliminary analysis presented here, an energy resolution of 13 $\%/\sqrt{E}$ (FWHM) is obtained for the active converter and sidewall counters. In the lead glass top-bottom system, the energy resolution is 13 $\%/\sqrt{E}$ (FWHM). For photons converted in the lead, the resolution is slightly degraded.

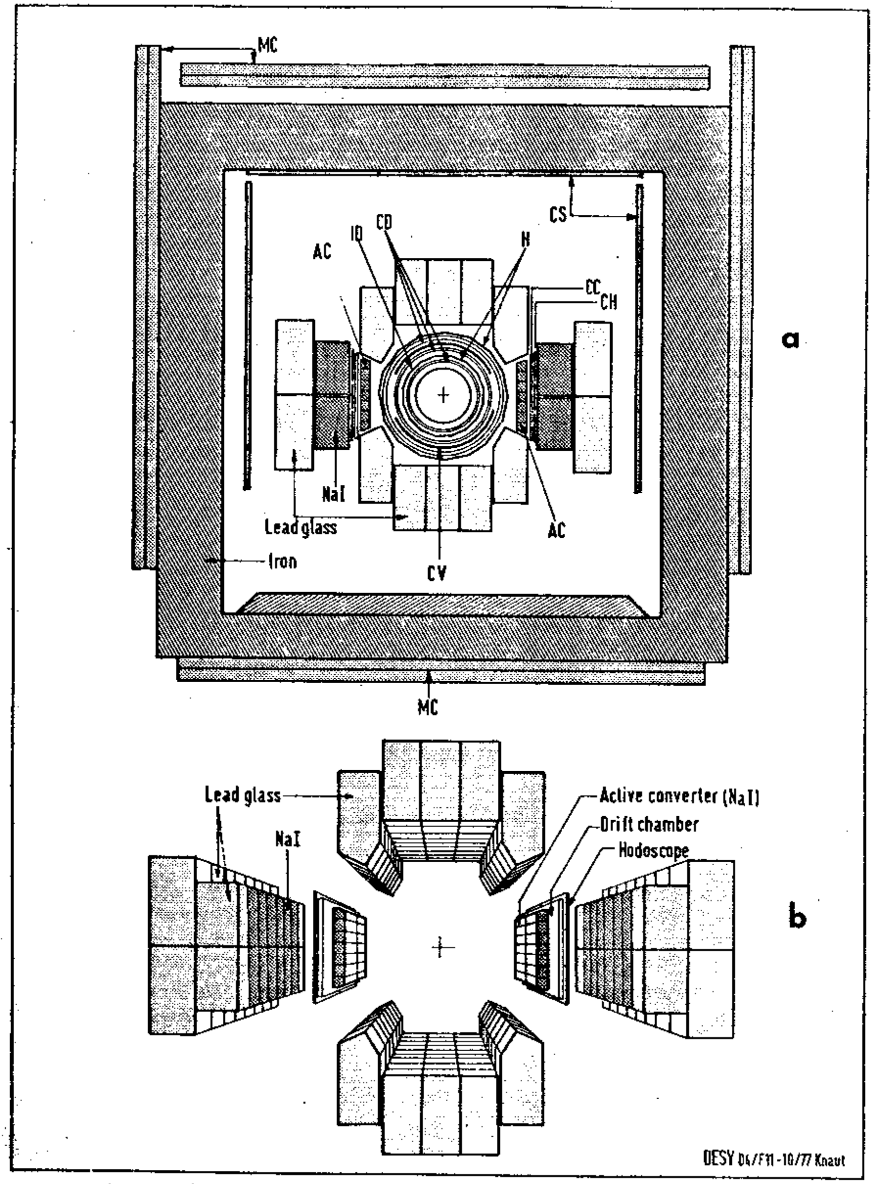


Fig.1 **a/ View of the apparatus transverse to the beam.**
b/ Exploded view of the energy counters.

The inner detector and the energy counters both cover a solid angle of 86 % of 4π. In addition, particle detection is extended to 95 % of 4π by two small angle hodoscopes [1] (not seen in fig.1) in front of which 1 X_o of lead has been placed.

The angular resolutions of the various components of the apparatus are summarized in table I.

The trigger consists of several combinations of charged track multiplicities and a certain minimum total deposited energy, as described in Ref (1). The solid angle for triggering is 86 % of 4π.

Together with the outer hodoscope in the inner detector, the scintillation counters (CS) behind the energy counters can be used to reject cosmic ray events, by a TOF measurement.

Finally, a new muon detector, consisting of 114 chambers (MC) with 15 cm wide drift spaces, extends the solid angle for muon detection to 60 % of 4π. The iron filter is 30 cm thick. Together with the energy counters, it forms a hadron absorber of 4.6 interaction lengths.

SEARCH FOR THE DECAY $J/\psi \to \gamma\eta_c$

In this section, results are presented from measurements taken in 1975 with the apparatus before modifications.

In the search for the decay $J/\psi \to \gamma\eta_c$, two possible decay modes of η_c have been considered, namely $\eta_c \to \gamma\rho^0$ and $\eta_c \to \gamma\gamma$. η_c is the $1\,^1S_0$ charmonium state of even C-parity, which is expected to have a mass somewhat below the J/ψ mass.

$J/\psi \to \gamma\eta_c \to \gamma\gamma\rho^o$

The decay mode

$$J/\psi \to \gamma\eta_c,\quad \eta_c \to \gamma\rho^o,\quad \rho^o \to \pi^+\pi^- \qquad (1)$$

results in a final state of $\pi^+\pi^-\gamma\gamma$. In this topology, the decays

$$J/\psi \to \rho\pi \qquad (2)$$

and

$$J/\psi \to \gamma\eta',\quad \eta' \to \gamma\rho^o \qquad (3)$$

can also be seen.

The selection of 2 prong, 2 photon events has been described previously (1), in connection with the analysis of the decays (2) and (3). Using the measured directions of the charged particles (which are assumed to be pions) and of the converted photons, the momenta are kinematically reconstructed.

The $\pi^+\pi^-\gamma$ mass distribution, with 2 entries/event, is shown in fig.2. The hatched distribution is obtained when $m_{\pi^+\pi^-}$ is restricted to the ρ mass region ($.55 < m_{\pi^+\pi^-} < 1.00$ GeV) and $m_{\gamma\gamma}$ is restricted to be outside the π^0 mass region ($m_{\gamma\gamma} > .35$ GeV). The latter restriction serves to exclude events from reaction (2).

A clear η' peak is seen, corresponding to the decay (3). The high mass reflection of this peak is shown by the dotted line.

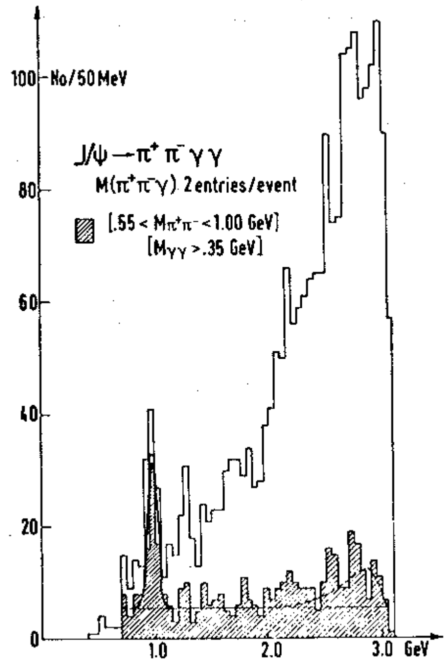


Fig. 2 Mass distribution of the $\pi^+\pi^-\gamma$ system in the reaction $J/\psi \to \pi^+\pi^-\gamma\gamma$.

There is no indication of a narrow high mass state, which would correspond to reaction (1). In the mass range $2.5 < m_{\eta_c} < 2.9$ GeV, an upper limit for the combined branching ratio is obtained,

$$BR\ (J/\psi \to \gamma\eta_c) \cdot BR\ (\eta_c \to \gamma\rho^0) < 2.6 \cdot 10^{-4} \qquad (90\ \%\ C.L.).$$

$J/\psi \to \gamma\eta_c \to 3\gamma$

The decay

$$J/\psi \to \gamma\eta_c,\ \eta_c \to \gamma\gamma \qquad (4)$$

has a three photon final state. The selection criteria for these events have been described earlier (2). The events are reconstructed using the measured positions of the three conversion points and the beam line. The momenta of the three photons as well as the location of the interaction point along the beam line (z-vertex) are then calculated. The distribution of the reconstructed z-vertices is shown in fig.3. It agrees with the distribution obtained from the reconstruction of events with charged tracks. To obtain the final sample of 78 events, a cut was made in the z-distribution at ± 25 mm, as indicated by arrows in fig.3. It was further checked that the calculated and measured photon energies agreed within the resolution.

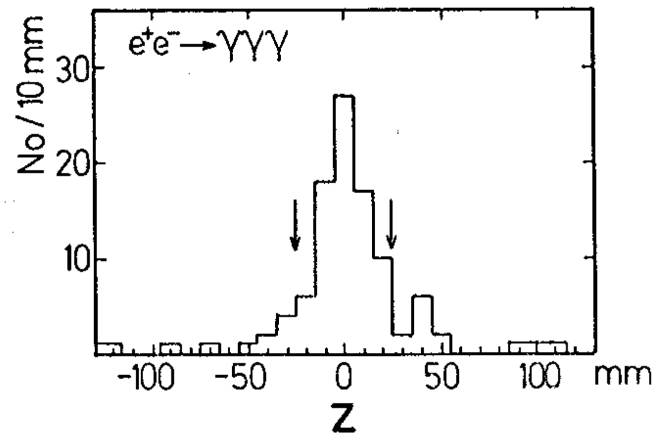


Fig. 3 Distribution of reconstructed interaction points along the beam axis in the reaction $e^+e^- \to 3\gamma$ at $\sqrt{s} = 3.1$ GeV.

Each event gives three different masses $m_{\gamma\gamma}$ for the 2γ pairs. The Dalitz plot of fig.4 shows the lowest $m^2_{\gamma\gamma}$ vs. the highest $m^2_{\gamma\gamma}$, with 1 entry/event. A clear η signal is seen and a few events appear in the η' band, corresponding to the decays

$$J/\psi \to \gamma\eta,\ \eta \to \gamma\gamma \qquad (5)$$

$$J/\psi \to \gamma\eta',\ \eta' \to \gamma\gamma \qquad (6)$$

This is also seen in the low mass projection of fig. 5a. The decays (5) and (6) were discussed in (2).

Fig. 5b shows the projection of the highest $m_{\gamma\gamma}$. Events with the lowest $m_{\gamma\gamma}$ in the η mass region ($.45 < m_{\gamma\gamma} < .65$ GeV) have been omitted.

Several reactions can contribute to the histogram in fig.5b. Besides reaction (4), there is a reflection from reaction (6). Furthermore, there are contributions from the QED process

$$e^+e^- \to 3\gamma \qquad (7)$$

as well as multiphoton final states (2) with only three photons observed in the detector. The reaction

$$J/\psi \to \gamma\pi^o\pi^o \qquad (8)$$

is expected to be the most important source of this background.

The contributions from reactions (6) and (7) can be calculated and are shown in fig.5b. The possible contribution from multiphoton final states has been studied in two ways :

a/ In events with 4 observed photons, the lowest energy photon was neglected and the events were treated in the same way as real three photon events.

b/ The decay (8) was generated by Monte Carlo methods and events with only three photons observed in the apparatus were treated as real three photon events.

Both methods reveal that neither the z-vertex distribution, nor the comparison between calculated and measured photon energies, allow such events to be distinguished from genuine three photon events. Background contribution from multiphoton final states can therefore not be excluded by these means.

The size of this contribution was estimated from the observed number of events with more than three photons in the final state, as well as from the branching ratio of the decay $J/\psi \to \gamma f$ (3).

The conclusion is that most of the events in the broad enhancement above background in fig. 5b could be due to multiphoton final states.

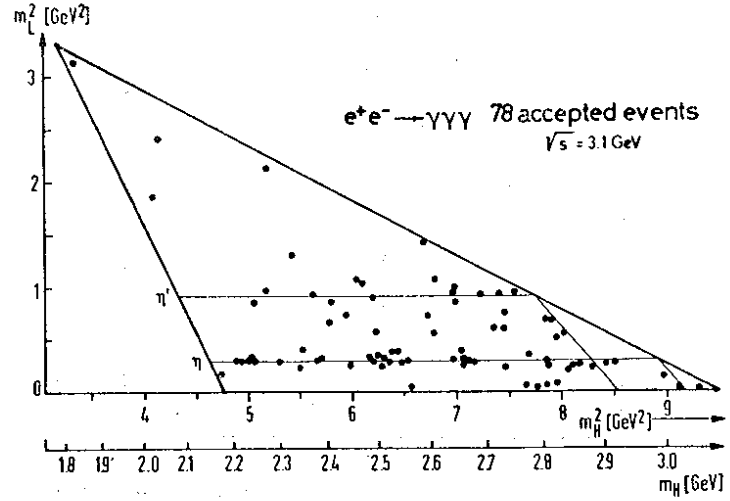


Fig. 4 Dalitz plot for the reaction $e^+e^- \to 3\gamma$ at $\sqrt{s}$ = 3.1 GeV; lowest $m^2_{\gamma\gamma}$ vs. highest $m^2_{\gamma\gamma}$, 1 entry/event.

The expected mass resolution at 2.7 GeV is 80 MeV. There is in fig.5b no significant indication of the presence of the decay (4) of J/ψ into a narrow, heavy state η_c. In the mass range $2.6 < m_{\eta_c} < 2.85$ GeV, an upper limit is obtained for the combined branching ratio,

$$BR\ (J/\psi \to \gamma\eta_c) \cdot BR\ (\eta_c \to \gamma\gamma) < 3.2 \cdot 10^{-4} \qquad (90\ \%\ C.L.)$$

The hatched distribution in fig. 5b shows the part of the sample that was obtained in the first measurement period in 1975. Together with data from the DASP collaboration the excess of events above background was then taken as an indication of the possible existence of a heavy mass state in the region 2.7 - 2.8 GeV (4). Increasing the statistics in our experiment by more than a factor of two did not improve the signal, however. In their full sample, the DASP collaboration observe a narrow state X at 2.83 GeV (5) with a branching ratio of $1.4 \cdot 10^{-4}$. This value corresponds to 5-6 events in our sample and is consistent with the data.

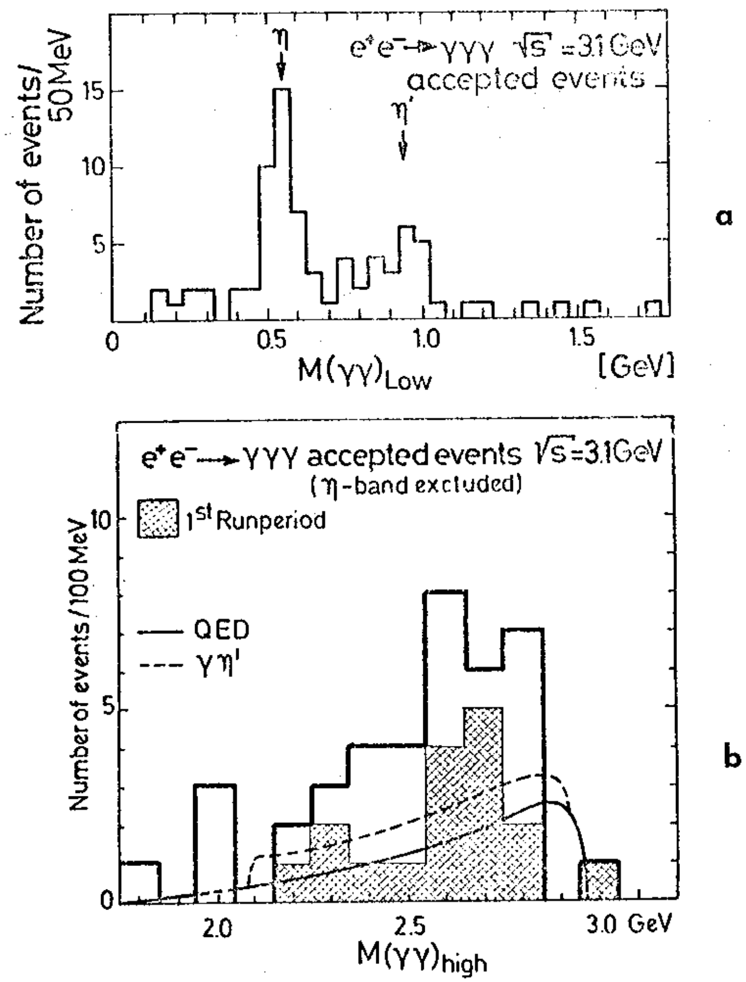


Fig. 5 a/ Mass distribution of lowest $m_{\gamma\gamma}$ in the reaction $e^+e^- \to 3\gamma$ at $\sqrt{s}$ = 3.1 GeV.

b/ Mass distribution of highest $m_{\gamma\gamma}$ in the reaction $e^+e^- \to 3\gamma$ at $\sqrt{s}$ = 3.1 GeV.

SEARCH FOR ψ' DECAYS INVOLVING THE η_c

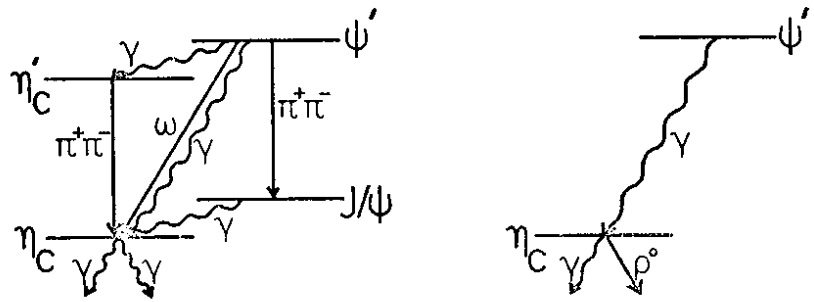
In this and the following section, preliminary results from a high statistics measurement of ψ' decays in 1977 are presented. The measurements were performed with the modified apparatus described above.

Since an absolute normalisation is not yet available, all branching ratios and upper limits are normalised to the decay

$$\psi' \to \eta\ J/\psi \quad (9)$$

using the previously measured branching ratio of $(4.3 \pm .8) \cdot 10^{-2}$ for this decay (6).

Several possible decay modes of ψ' involving the state η_c are shown below,



namely

$$\psi' \to \gamma\eta_c' \quad \hookrightarrow \pi^+\pi^-\eta_c \quad \hookrightarrow \gamma\gamma \qquad (10)$$

$$\psi' \to \omega\eta_c \quad \hookrightarrow \gamma\gamma, \ \hookrightarrow \pi^+\pi^-\pi^0 \qquad (11)$$

$$\psi' \to \gamma\eta_c \quad \hookrightarrow \gamma\rho^0 \qquad (12)$$

$$\psi' \to \gamma\eta_c \quad \hookrightarrow \gamma\gamma \qquad (13)$$

In reaction (10), η_c' is the $2\ {}^1S_0$ charmonium state which is expected to have a mass somewhat below the ψ' mass.

$\psi' \to \gamma\eta_c' \to \gamma\pi^+\pi^-\eta_c \to \pi^+\pi^- 3\gamma$

The final state of this reaction is $\pi^+\pi^- 3\gamma$. This is also the final state resulting from the well known decay chain

$$\psi' \to \pi^+\pi^-\ J/\psi \to \pi^+\pi^- 3\gamma. \qquad (14)$$

where the reactions (4), (5) and (6) contribute, and a study of reaction (14) provides a check on the correctness of the event selection and reconstruction methods.

Events with two charged tracks and three photons were selected, with the additional requirement that at least two photons have a measured energy higher than 800 MeV. These events were reconstructed by using the measured directions, the measured energies of at least two of the photons and by assuming the pion mass for the charged particles. In order to study reaction (14), the mass of the three photons was in addition constrained to be equal to the mass of J/ψ. In this way, a sample of 14 events was obtained.

In the same way as described above for J/ψ decays into three photons, a Dalitz plot for the masses of the $\gamma\gamma$ pairs is obtained. It is shown in fig.6. The contributions to this plot from the reactions (4), (5) and (6) can be calculated from the measured branching ratios (1), (2), (4) and are :

$\psi' \to \pi^+\pi^-\ J/\psi \to \pi^+\pi^-\gamma\eta$	7.5 ± 3 events
$\psi' \to \pi^+\pi^-\ J/\psi \to \pi^+\pi^-\gamma\eta'$	< 1 event
$\psi' \to \pi^+\pi^-\ J/\psi \to \pi^+\pi^-\gamma X(2.83)$	< 1 event

These numbers are consistent with the distribution in fig.6.

In order to study the η_c' production in (10), the 2 prong, 3 photon sample was again reconstructed using directions and measured photon energies. Instead of constraining the three photons to the J/ψ mass, the mass of the two most energetic photons was now constrained to the mass of X(2.83), assuming this particle to be the η_c. By this method, 7 events were found to fit. They are identical to the events marked in fig.6 and can therefore mostly be attributed to reaction (14), with J/ψ decaying into $\gamma\eta$.

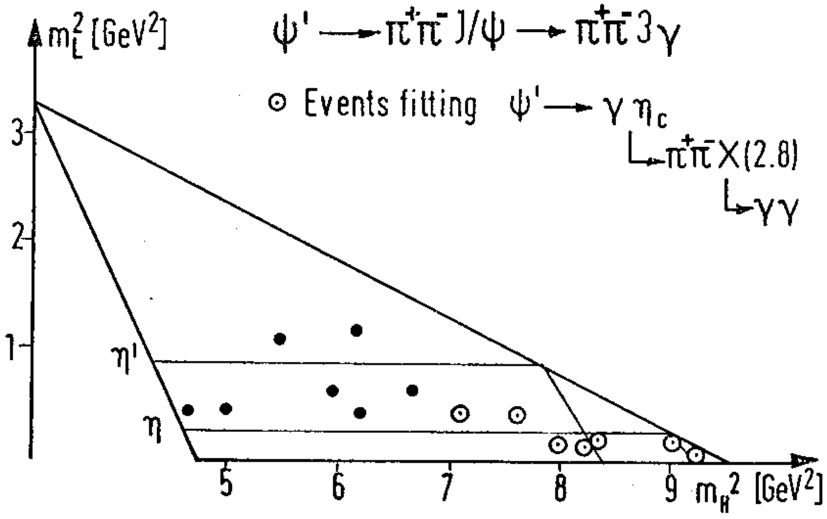


Fig. 6 Dalitz plot for the 3γ system in the reaction $\psi' \to \pi^+\pi^- J/\psi \to 3\gamma$.

The mass distribution of the $\pi^+\pi^- X$ system for the 7 events is shown in fig.7. No signal for reaction (10) is seen. Assuming the η_c' to be a narrow state in the mass range $3.2 < m_{\eta_c'} < 3.65$ GeV, an upper limit is obtained for the combined branching ratio,

$$BR(\psi' \to \gamma\eta_c') \cdot BR(\eta_c' \to \pi^+\pi^- X) \cdot BR(X \to \gamma\gamma) < 5.8 \cdot 10^{-5} \qquad (90\ \%\ C.L.)$$

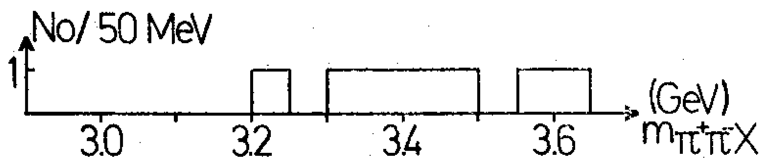


Fig. 7 Mass distribution of the $\pi^+\pi^-X$ system in the decay

$$\psi' \to \gamma\eta_c' \;\; \llcorner\!\to \pi^+\pi^-X$$

The decay chain (10) has recently been discussed by Greco and Krammer[7], who conclude that an observation of the decay chain (10) with a combined branching ratio greater than $4 \cdot 10^{-5}$ would be in contradiction to the standard charmonium model.

The upper limit obtained above also applies to the corresponding decay chain via $P_c(3.51)$,

$$\psi' \to \gamma P_c, \quad P_c \to \pi^+\pi^-X, \quad X \to \gamma\gamma$$

Using the measured[8] value of $(7.1 \pm 1.9) \cdot 10^{-2}$ for the branching ratio of the decay $\psi' \to \gamma P_c$, an upper limit for the combined branching ratio

$$BR\,(P_c(3.51) \to \pi^+\pi^-X) \cdot BR\,(X \to \gamma\gamma) < 8.3 \cdot 10^{-4} \quad (90\ \%\ C.L.)$$

can be calculated.

$\psi' \to \omega\eta_c$

The final state in reaction (11) is two charged tracks and four photons. Events with this topology were selected, again with the requirement that at least two photons have energies of more than 800 MeV. These events were reconstructed by using the measured directions of the particles, at least two of the measured photon energies and by assuming the charged particles to be pions. In addition, the mass of the two lowest energy photons was constrained to be equal to the mass of the π^o and the mass of the charged particles and the π^o was constrained to the mass of $\omega(783)$.

Only two events were found to fit, with the mass of the two high energy photons $m_{\gamma\gamma}^{high} = 2.78$ and 2.80 GeV. Since the background has not yet been studied, the two events are used to put an upper limit on the combined branching ratio for reaction (11), with the assumption that η_c has a mass around 2.8 GeV,

$$BR\,(\psi' \to \omega\eta_c) \cdot BR\,(\eta_c \to \gamma\gamma) < 2.3 \cdot 10^{-4} \quad (90\ \%\ C.L.)$$

An upper limit of 10^{-3} was previously obtained from the 1975 data[9].

$\psi' \to \gamma\eta_c \to \gamma\gamma\rho^o$

The final state for reaction (12) is two charged particles and two photons. Such events were selected with criteria similar to those for reaction (1) and reconstructed by using the measured directions and by assuming the charged particles to be pions. With the additional requirement that $m_{\pi^+\pi^-}$ be in the ρ^o region ($.55 < m_{\pi^+\pi^-} < 1.00$ GeV) and $m_{\gamma\gamma}$ be outside the π^o mass region ($m_{\gamma\gamma} > .35$ GeV), only three events were found, with the mass $m_{\pi^+\pi^-\gamma}$ in the range 2.5 – 3.0 GeV. This leads to an upper limit on the combined branching ratio

$$BR(\psi' \to \gamma\eta_c) \cdot BR(\eta_c \to \gamma\rho^o) < 1.8 \cdot 10^{-4} \quad (90\ \%\ C.L.)$$

with $2.5 < m_{\eta_c} < 3.0$ GeV.

The sample also gives an upper limit on the decay

$$\psi' \to \gamma\eta', \quad \eta' \to \gamma\rho^o \qquad (15)$$

with only one event found,

$$BR(\psi' \to \gamma\eta') < 2.3 \cdot 10^{-4} \quad (90\ \%\ C.L.)$$

This improves the upper limit of $1.1 \cdot 10^{-3}$ obtained from the 1975 data[1].

$\psi' \to \gamma\eta_c \to 3\gamma$

The final state consists of three photons, as for reaction (4). Such events were selected and reconstructed in the same way as described above and in Ref (2), by demanding three converted photons. The resulting Dalitz plot is shown in fig. 8a and the corresponding high mass projection in fig. 8b. The rise of the distribution towards higher masses agrees with the expected distribution from the QED process (7). The small excess of events in the mass region 2.7 – 2.8 GeV gives an upper limit for the branching ratio of reaction (13),

$$BR(\psi' \to \gamma\eta_c) \cdot BR(\eta_c \to \gamma\gamma) < 5.0 \cdot 10^{-4} \quad (90\ \%\ C.L.)$$

with the mass of η_c in the range $2.7 < m_{\eta_c} < 2.8$ GeV. The DASP collaboration has obtained the limit $3.4 \cdot 10^{-4}$ for the decay $\psi' \to \gamma X(2.83)$, $X \to \gamma\gamma$ (10).

We conclude that no signal corresponding to the state η_c has been observed in this experiment so far. The upper limits obtained above are summarized in table II.

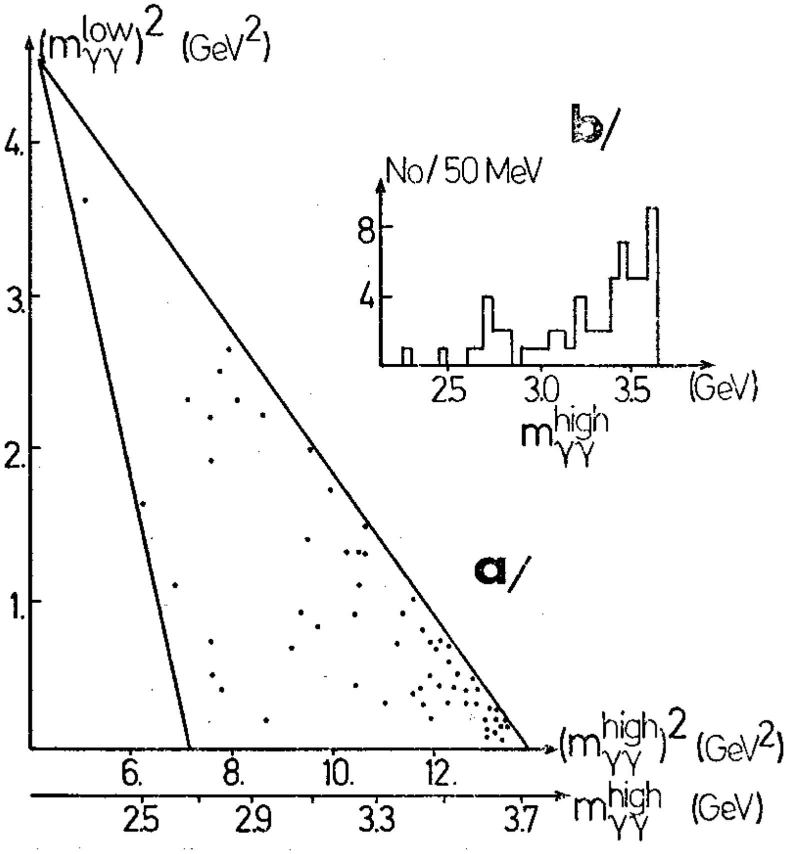
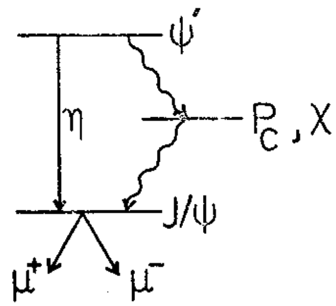


Fig. 8 a/ Dalitz plot for the reaction $e^+e^- \to 3\gamma$ at $\sqrt{s} = 3.7$ GeV.
b/ Mass distribution of highest $m_{\gamma\gamma}$.

CASCADE DECAYS OF ψ'

The radiative decays of ψ' into J/ψ via intermediate states of even C-parity,



can be studied in the final state topology of two photons and two charged particles, using the 2-body decay of J/ψ into $\mu^+\mu^-$. In the same topology, the decay $\psi' \to \eta J/\psi$ can be observed. Although the decay $J/\psi \to e^+e^-$ also contributes to the same topology, only the decay $J/\psi \to \mu^+\mu^-$ will be considered in the present study. The electrons are rejected by a cut on the pulseheight in the energy counters.

The events were reconstructed by using the directions of the four particles, with the additional mass constraint $m_{\mu^+\mu^-} = m_{J/\psi}$. Events with disagreement between fitted and seen photon energies were rejected.

The mass distribution of the two photons is shown in fig.9. A clear η signal is seen, corresponding to reaction (9). As mentioned above, the decay (9) is taken as a preliminary normalisation.

The mass distribution of the $\gamma J/\psi$ system is plotted in fig.10 (only the high mass solution). Events with the two photon mass $m_{\gamma\gamma}$ in the η mass region ($m_{\gamma\gamma} > .500$ GeV) have been omitted. Two peaks are clearly seen, corresponding to the states previously observed at 3.51 GeV (P_C), and 3.55 GeV (11). At the mass of 3.41 GeV, where a state has been observed (11), an enhancement of two standard deviations significance can be seen. In the region of 3.45 GeV no clear structure is seen. A state at this mass has previously been reported (11).

A first estimate of the number of events belonging to the various states leads to the following branching ratios,

$BR(\psi' \to \gamma\chi(3.41)) \cdot BR(\chi(3.41) \to \gamma J/\psi) = (0.2 \pm 0.1) \cdot 10^{-2}$

$BR(\psi' \to \gamma\chi(3.45)) \cdot BR(\chi(3.45) \to \gamma J/\psi) < 0.6 \cdot 10^{-2}$ (90 % C.L.)

$BR(\psi' \to \gamma P_c(3.51)) \cdot BR(P_c(3.51) \to \gamma J/\psi) = (3.3 \pm 0.8) \cdot 10^{-2}$

$BR(\psi' \to \gamma\chi(3.55)) \cdot BR(\chi(3.55) \to \gamma J/\psi) = (2.3 \pm 0.6) \cdot 10^{-2}$

In calculating these estimates, a background of 150 ± 50 events from the decay $\psi' \to \pi^0\pi^0 J/\psi$, with only two photons detected, has been subtracted.

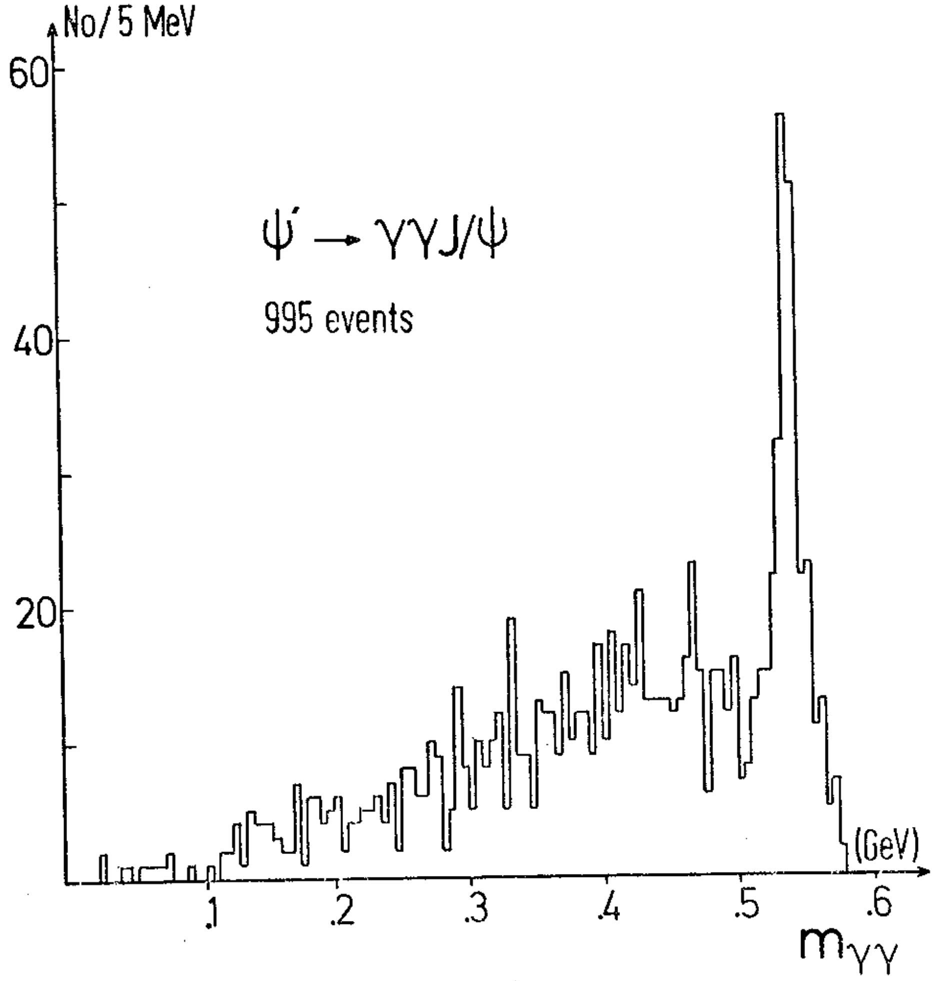


Fig. 9 Mass distribution of the γγ system in the decay $\psi' \to \gamma\gamma J/\psi$

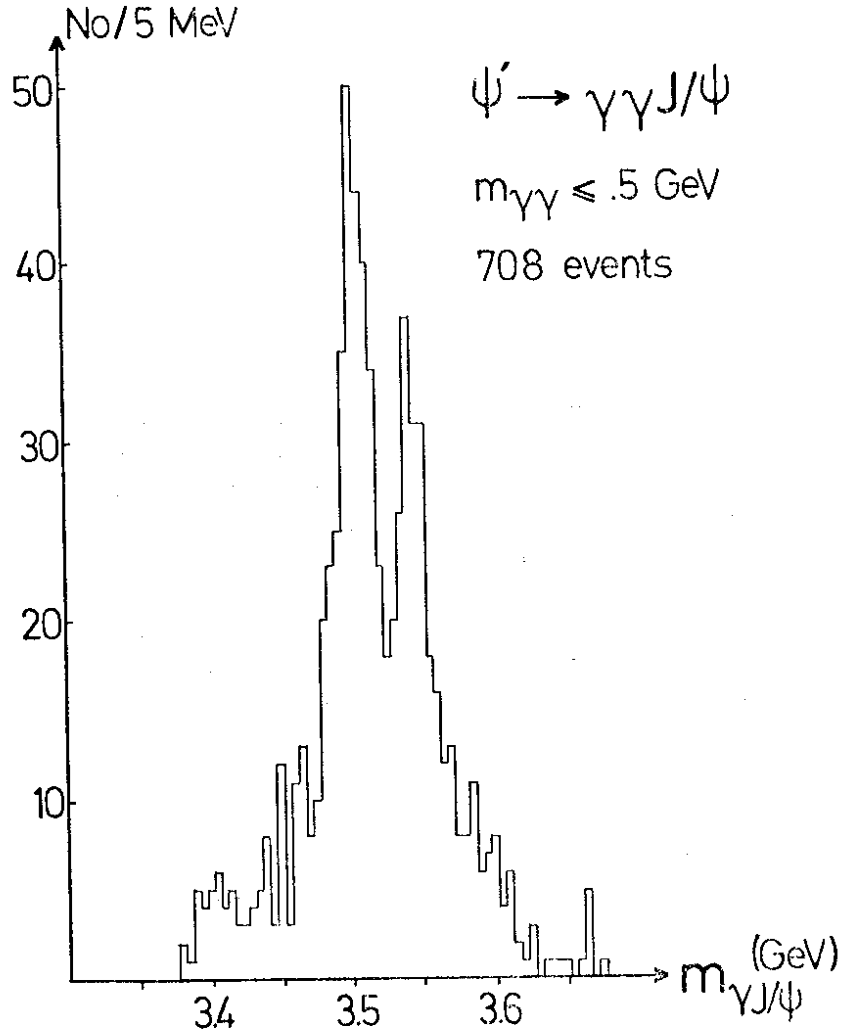


Fig. 10 Mass distribution of the $\gamma J/\psi$ system in the decay $\psi' \to \gamma\gamma J/\psi$
Only the highest mass solution is plotted.

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TABLE I

Solid angle coverage and angular resolution of apparatus components.

Apparatus component and solid angle		Angular resolution (FWHM)
Inner detector 86 % of 4π	Charged tracks	$\delta\phi$ = 4 mrad $\delta\theta$ = 30 mrad
Active converter and Sidewall counters 19 % of 4π	Converted photons	$\delta\phi$ = 70 mrad $\delta\theta$ = 80 mrad
	Unconverted photons	$\delta\phi$ = 240 mrad $\delta\theta$ = 100 mrad
Top-bottom Lead glass counters 67 % of 4π	Converted photons	$\delta\phi$ = 75 mrad $\delta\theta$ = 65 mrad
	Unconverted photons	$\delta\phi$ = 80 mrad $\delta\theta$ = 45 mrad

TABLE II

Upper limits for decays of J/ψ and ψ' involving the state η_c.
All values are given with 90 % C.L.

$BR(J/\psi \to \gamma\eta_c) \cdot BR(\eta_c \to \gamma\rho^0)$	$< 2.6 \cdot 10^{-4}$	$(2.5 < m_{\eta_c} < 2.9$ GeV)
$BR(J/\psi \to \gamma\eta_c) \cdot BR(\eta_c \to \gamma\gamma)$	$< 3.2 \cdot 10^{-4}$	$(2.6 < m_{\eta_c} < 2.85$ GeV)
$BR(\psi' \to \gamma\eta_c') \cdot BR(\eta_c' \to \pi^+\pi^- X(2.83))$		
$\cdot\, BR(X(2.83) \to \gamma\gamma)$	$< 5.8 \cdot 10^{-5}$	
$BR(P_c(3.51) \to \pi^+\pi^- X(2.83))$		
$\cdot\, BR(X(2.83) \to \gamma\gamma)$	$< 8.3 \cdot 10^{-4}$	
$BR(\psi' \to \omega\eta_c) \cdot BR(\eta_c \to \gamma\gamma)$	$< 2.3 \cdot 10^{-4}$	$(m_{\eta_c} \approx 2.8$ GeV)
$BR(\psi' \to \gamma\eta_c) \cdot BR(\eta_c \to \gamma\rho^0)$	$< 1.8 \cdot 10^{-4}$	$(2.5 < m_{\eta_c} < 3.0$ GeV)
$BR(\psi' \to \gamma\eta_c) \cdot BR(\eta_c \to \gamma\gamma)$	$< 5.0 \cdot 10^{-4}$	$(2.7 < m_{\eta_c} < 2.8$ GeV)
$BR(\psi' \to \gamma\eta')$	$< 2.3 \cdot 10^{-4}$	