NEUTRAL DECAYS OF THE J/ψ PARTICLE

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The decay of J/ψ (3.1) into final states containing no charged particles has been studied experimentally. The partial decay width for the observed neutral decays is (470 ± 160) eV. The decay modes $J/\psi \to \gamma\eta \to 3\gamma$ and $J/\psi \to \gamma\eta' \to 3\gamma$ are identified and the branching ratios

$$\frac{J/\psi \to \gamma\eta}{J/\psi \to \text{all}} = (1.3 \pm 0.4) \times 10^{-3}, \quad \text{and} \quad \frac{J/\psi \to \gamma\eta'}{J/\psi \to \gamma\eta} = 1.8 \pm 0.8,$$

are derived. Upper limits for the decay modes $J/\psi \to \gamma\pi^0$ and $J/\psi \to \gamma\gamma$ are given.

The decay modes of J/ψ (3.1) leading to charged particles in the final state have been extensively studied [1,2]. Very little is known, however, about J/ψ decays involving only long-lived neutral particles or particles decaying into γ-rays. We report here results of an experiment in which such neutral decay events could be recorded, in particular those containing γ-rays in the final state [3].

The experiment was carried out at the DESY storage rings DORIS with a non-magnetic detector, which has been described in a previous paper [4]. The interaction region is surrounded by cylindrical drift chambers and counter hodoscopes, followed by an array of NaI- and lead glass blocks for energy measurements of electrons and photons. Two radiation lengths of mercury in front of the last drift chamber serve as a photon converter. The solid angle for the detection of charged particles is extended to 95% of 4π by means of two additional small angle hodoscopes. The solid angle of the NaI- and lead glass blocks is 60%.

The apparatus can be triggered on events containing charged particles as well as on neutral events. Data were taken using all trigger modes concurrently. From the data recorded at 3.1 GeV with the charged particle trigger a total number of 871000 J/ψ decays has been determined [4]. The present analysis is based on the neutral event trigger which required at least one conversion in the cylindrical detector and a minimum total energy deposit of 1500 MeV in the NaI- and lead glass counter blocks. The majority of the recorded events was due to cosmic rays simulating a photon conversion by grazing the cylindrical detector. In order to select events from e^+e^--interactions the following criteria were applied:

(1) At least three separate energy deposits must be observed in the NaI- and lead glass blocks.

(2) At least one conversion must be observed in each of the polar angle intervals $\theta \geqslant 90°$ and $\theta \leqslant 90°$, the angle θ being measured with respect to the beam axis.

(3) The energy deposit in the NaI- and lead glass blocks must be spread over an azimuthal angle interval larger than 180°.

(4) The muon chambers, the internal hodoscope of the cylindrical detector and the small angle hodoscope must be free of hits.

2440 events satisfying criteria (1)–(4) have been found. The background in these events was determined by a handscan of a subsample. 6% cosmic ray events, 4% events with charged particle tracks and 4% misidentified QED events $e^+e^- \to 2\gamma$ were found. The background due to events with charged particles escaping

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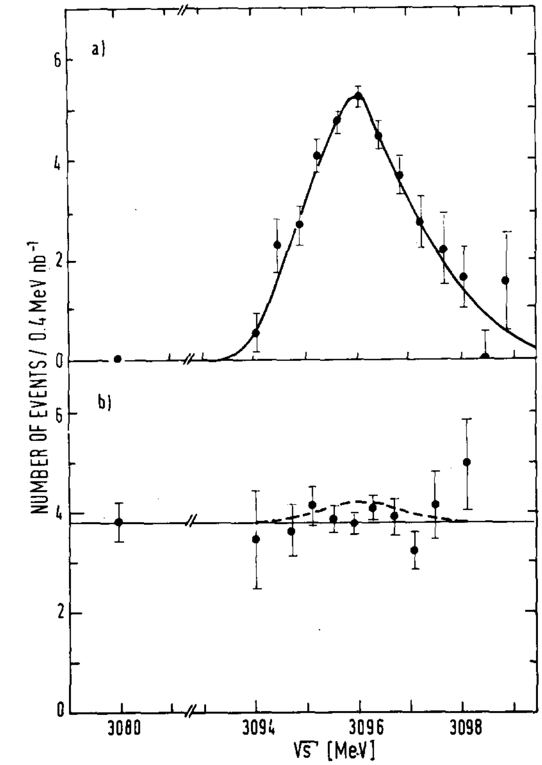

Fig. 1. (a) The measured cross-section for neutral events from e^+e^- reactions in the region of the J/ψ resonance as a function of $\sqrt{s}$ after background subtraction (the curve is handdrawn). (b) The measured cross-section for $e^+e^- \rightarrow \gamma\gamma$ as a function of $\sqrt{s}$. The dashed curve shows the enhancement above the QED level (solid line), that would result from $J/\psi \rightarrow \pi^0\gamma$ decay at the rate corresponding to the 90% confidence upper limit.

through the beampipe was determined by an analysis of events with hits in the small angle hodoscope and was found to be 1.5%. Beam-gas background is eliminated by the energy threshold of 1500 MeV required in the trigger.

After background subtraction, 2060 ± 100 events from e^+e^--reactions remain. The energy dependence of the event rate shown in fig. 1a indicates that these events are due to J/ψ-decays. A notable feature of the events is the high multiplicity of neutral particles, the average observed multiplicity being ~6.5. The fraction of energy deposits in the NaI/lead glass blocks associated with a conversion in the mercury is (83 ± 10)%. The agreement of this number with the value measured in $e^+e^- \rightarrow 2\gamma$ reactions (78%) indicates that the observed neutral particles were mostly γ-rays, although a small

Table 1
Branching ratios into neutral final states as calculated from measured J/ψ decays.

Channel	Branching ratio measured (%)	Corresponding branching ratio into neutrals (%) (calculated)
$\omega\pi\pi$	0.7 ±0.2 [5]	0.020±0.006
$\phi\pi\pi$	0.21±0.09 [6]	0.009±0.004
$\phi\eta$	0.07±0.04 [6]	0.006±0.003
$\phi\eta'$	0.05±0.04 [6]	0.001±0.001
$K^0K^{0*}_{892}$	0.27±0.06 [6]	0.014±0.003
$K^{0*}_{892}K^{0*}_{1420}$	0.67±0.26 [6]	0.007±0.003
ωK^+K^-	0.03±0.02 [6]	0.001±0.0003
ϕK^+K^-	0.09±0.04 [6]	
$\phi f'$	0.08±0.05 [6]	
$K^+K^-\pi^+\pi^-$	0.72±0.23 [6]	0.03 ±0.03 [a]
$K^+K^-2\pi^+2\pi^-$	0.3 ±0.1 [7]	0.01 ±0.01 [a]

[a] Estimates based on isospin arguments.

contribution from K^0_L and n, n̄ cannot be excluded. As possible sources for the neutral events observed here, we consider radiative decays and hadronic decays.

Because of C-conservation the decay of J/ψ into neutral pions or eta mesons is expected to proceed via radiative decays of the type

$$J/\psi \rightarrow \gamma + n\pi^0 + m\eta .$$

The detection efficiency for such events has been calculated assuming an invariant phase space model. It varies only slightly[‡1] with the total number of π^0 and η. For $2 \leqslant (n+m) \leqslant 5$ the average efficiency is $\epsilon = 0.33 \pm 0.05$. Three photon final states which would be observed with lower efficiency contribute less than 10% to the data and will be considered below.

The other contribution to the neutral events is expected from hadronic decays mode that are detected as multi-gamma final states. A list of such processes which have already been observed in charged final states is given in table 1 together with estimates for the branching ratios into neutral modes. J/ψ decays of these modes are detected with the same average efficiency as the radiative decays. Therefore, a branching ratio

[‡1] The increase of the detection efficiency with rising photon multiplicity is compensated by a decrease due to photon conversion in the beampipe.

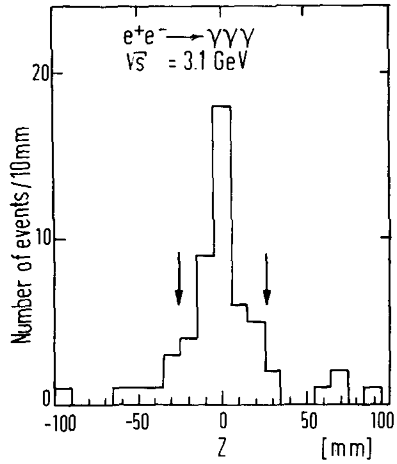

Fig. 2. The vertex distribution along the z-axis for $e^+e^- \to 3\gamma$ events. The region $|z| \leqslant 25$ mm is indicated by arrows.

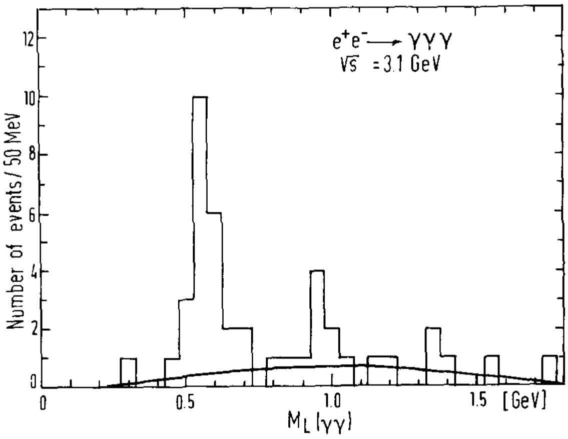

Fig. 3. The distribution of the low invariant mass solution for $e^+e^- \to 3\gamma$ events. The solid line indicates the expected background.

$$\frac{J/\psi \to \text{neutral final states}}{J/\psi \to \text{all}} = (0.7 \pm 0.2)\% ,$$

can be derived for the processes observed in this experiment. The decay modes listed in table 1 account only for about 14% of this ratio. It should be noted that decay modes such as $J/\psi \to n\bar{n}, n\bar{n}\pi^0, \gamma K_L^0 K_L^0$ are detected by our apparatus with efficiencies $< 3\%$ and do not contribute significantly to the data.

Of particular interest are neutral events with three photons in the final state. Such events can be kinematically reconstructed. For this purpose, events with three photons were selected, each photon being identified by a conversion in the cylindrical detector associated with an energy deposit in the NaI/lead glass blocks. From the locations of the conversion points and the beam axis the three photon momenta and the position of the decay vertex along the beamline (z) were determined by a 0 C-fit. Events with badly determined photon directions were eliminated by requiring that the angle between the normal to the decay plane and the beam axis be less than 80° and that the angle between any two photons be larger than 25°. Furthermore, events were rejected when the calculated photon energies were inconsistent with the observed ones.

Three different invariant masses $m_{\gamma\gamma}$ can be calculated for each event. In order to search for the decay modes $J/\psi \to \gamma\eta \to 3\gamma$ and $J/\psi \to \gamma\eta' \to 3\gamma$ only the events with all solutions $m_{\gamma\gamma} < 2.6$ GeV are considered. The analysis of events with a solution $m_{\gamma\gamma} \geqslant 2.6$ GeV, which can be used for a search for a new heavy mass state X, requires a more elaborate background consideration and will be reported in a separate paper.

Fig. 2 shows the decay vertex distribution of the events with $m_{\gamma\gamma} < 2.6$ GeV. Only events with $|z| \leqslant$ 25 mm were accepted. This interval corresponds to the interaction region obtained from reactions with charged decay products. Fig. 3 shows the distribution of the low mass solutions $m_{\gamma\gamma}$.

An η signal is clearly seen with a mass resolution of 110 MeV FWHM, which is expected from the known angular resolution. A small accumulation of events in the η' region is also visible. The background under the η signal was estimated to be 2.5 events. 21.5 events were attributed to the decay $J/\psi \to \gamma\eta$. The detection efficiency for this process was calculated assuming a $1 + \cos^2\theta$ angular distribution. Using the known branching ratio of $\eta \to 2\gamma$ and the total number of J/ψ decays observed in this experiment, the branching ratio

$$\frac{J/\psi \to \gamma\eta}{J/\psi \to \text{all}} = (1.3 \pm 0.4) \times 10^{-3} ,$$

is obtained. The number reported by the DASP collaboration [2] is in agreement with this result.

The branching ratio for the decay $J/\psi \to \gamma\eta'$ can be determined more accurately by observing the decay mode $\gamma\eta' \to \gamma\gamma\rho^0$ rather than $\gamma\eta' \to 3\gamma$. A result based on the former process has been previously reported [4] to be $(J/\psi \to \gamma\eta')/(J/\psi \to \text{all}) = (2.4 \pm 0.7) \times 10^{-3}$. Using this number, a ratio

$$\frac{J/\psi \to \gamma\eta'}{J/\psi \to \gamma\eta} = 1.8 \pm 0.8 \,,$$

is obtained by this experiment. The expected number of events from the decay chain $J/\psi \to \gamma\eta' \to 3\gamma$ is 2.8 ± 1, which is compatible with the data shown in fig. 3.

The decay $J/\psi \to \gamma\pi^0$ does not contribute significantly to the 3γ events observed in this experiment, since the two photons from the π^0 are generally unresolved in the detector ($\theta_{\gamma\gamma}^{\min} \simeq 10°$). This decay mode can be searched for in the event sample containing the events from the QED process $e^+e^- \to 2\gamma$. 1970 events of this type were selected by requiring, in addition to criteria (2) and (4) two conversion points coplanar with the beam, each associated with an energy deposit in the NaI/lead glass blocks of at least 700 MeV. No additional conversion points or energy deposits were allowed. The selected events had the properties of the QED process $e^+e^- \to 2\gamma$. The dependence of the event rate upon the center of mass energy is shown in fig. 1b. From the absence of an enhancement at 3.1 GeV an upper limit for the decay $J/\psi \to \gamma\pi^0$ is obtained:

$$\frac{J/\psi \to \gamma\pi^0}{J/\psi \to \text{all}} \leqslant 5.5 \times 10^{-4} \quad (90\% \text{ confidence})\,.$$

A limit of 1.6×10^{-4} has been reported by the DASP collaboration [2]. Alternatively, the data can be used to set an upper limit of 5×10^{-4} for the forbidden decay $J/\psi \to \gamma\gamma$. A limit of 3×10^{-3} has been previously reported [8].

We conclude that the neutral decay modes observed in this experiment contribute only 470 ± 160 eV to the width $\Gamma(J/\psi) = (67 \pm 12)$ keV. The decay $J/\psi \to \gamma\eta$ is observed with a partial width of 87 ± 27 eV and the ratio $(J/\psi \to \gamma\eta')/(J/\psi \to \gamma\eta)$ is 1.8 ± 0.8. The decay $J/\psi \to \gamma\pi^0$ appears to be suppressed.

The branching ratios for the decays $J/\psi \to \gamma\eta, \gamma\eta'$ are comparable to those for hadronic two body decays of J/ψ. In the framework of a $c\bar{c}$-model this indicates that the γ-ray is radiated from the $c\bar{c}$-system and that both the η' and the η contain a $c\bar{c}$-admixture. The ratio $\gamma\eta'/\gamma\eta = 1.8$ indicates that this admixture is similar for η' and η in spite of the different masses and SU_3-properties of these two mesons. For a detailed discussion of these decays we refer to theoretical papers [e.g. 9].

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