SEARCH FOR NARROW STATES COUPLING TO τ PAIRS IN RADIATIVE Υ DECAYS

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We have investigated the $\Upsilon \to \gamma\tau\tau$ using tagged Υ mesons from the decay $\Upsilon' \to \pi^+\pi^-\Upsilon$. The photon spectrum exhibits no monochromatic line corresponding to a narrow object decaying into a τ pair and is fully compatible with the expected background contributions. The branching ratio $\mathrm{Br}(\Upsilon \to \tau^+\tau^-)$ is determined to be $(3.07 \pm 0.46 \pm 0.22)\%$.

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The search for scalar particles is of fundamental interest because of their vital role in symmetry breaking of the electroweak interaction. In its simplest form this symmetry breaking leads to the Higgs particle H^0, a neutral scalar with a real mass [1]. So far there exists no physical principle which permits the prediction of this mass. Light Higgs particles with masses of several GeV/c^2 are possible [2] [‡1] and can be reached by a radiative decay of the Υ meson: $\Upsilon \to \gamma H^0$ [4]. The decay rate for such a process is calculable, but depends strongly on assumptions in the Higgs sector of the electroweak theory and consequently the theoretical estimates vary considerably [4,5]. Experimental results on radiative Υ decays $\Upsilon \to \gamma X$, where X is a narrow object, have yielded upper limits for such decays in the range $1 \leqslant m(X) \leqslant 8.2$ GeV/c^2 [6] and evidence for a particle at 8.3 GeV/c^2 [7].

In view of the importance of the subject, a further analysis of radiative Υ-decays leading to possible Higgs particles is presented. Assuming that a Higgs particle will decay predominantly into the heaviest pair of fermions available, we have studied the decay $\Upsilon \to \gamma X$ followed by $X \to \tau^+\tau^-$. This reaction has a very clean signature, as will be shown below.

This investigation was carried out using the ARGUS detector operating in the e^+e^- storage ring DORIS II at DESY. The ARGUS detector is a 4π spectrometer which can measure and identify hadrons, leptons and photons with very good precision [8].

The decay $\Upsilon \to \gamma X$, $X \to \tau^+\tau^-$ was studied using tagged Υ mesons from the decay $\Upsilon' \to \pi^+\pi^-\Upsilon$, of which 13 158 ± 286 events were observed. By tagging the Υ mesons one eliminates events with photons coming from initial state radiation, a serious background for the reaction $e^+e^- \to \Upsilon \to \gamma X$. The channel $X \to \tau^+\tau^-$ was selected by using only those τ decays for which one charged particle and neutrinos are produced: $\tau \to \mu\nu\nu$, $e\nu\nu$, $\pi\nu$ and $K\nu$. The summed branching ratio for these τ decays amounts to (46.6 ± 1.9)% [9]. Thus the event selection requires Υ'-decays leading to a $\pi^+\pi^-$ pair which is uniquely identified in the detector and for which the missing mass is in the Υ range. The Υ is then allowed to decay into a photon and any two opposite charged particles which are seen in the detector. Besides these four prongs, the events must contain no more than 0.3 GeV visible energy in the calorimeter.

The acceptance for the decay of the tagged Υ mesons into the $\gamma\tau\tau$ channel is studied by first establishing a signal for the direct decay of $\Upsilon \to \tau\tau$ with no photon present. Events of this type were selected by requiring that (1) no additional energy larger than 0.3 GeV besides that of the charged particles be observed in the calorimeter, (2) the angle α between the two prongs from Υ decay be restricted to $-0.99 \leqslant \cos\alpha \leqslant 0.75$ and (3) the transverse momentum p_T of the four-prong system be larger than 0.4 GeV/c. The first cut selects mainly leptonic decays of the Υ meson and four-prong events from $\gamma\gamma$ interactions. Events containing the $\Upsilon \to e^+e^-$ and $\Upsilon \to \mu^+\mu^-$ decays are eliminated completely by the second cut. This can be con-

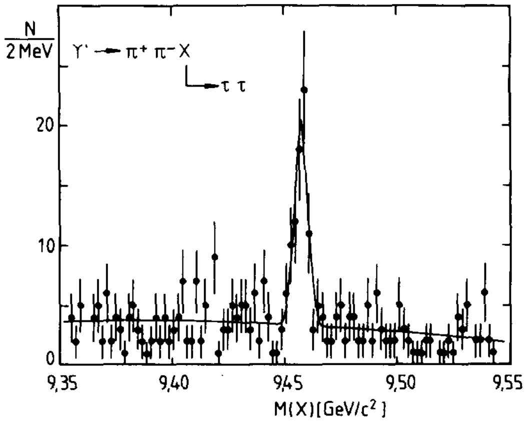

Fig. 1. Recoil mass spectrum m_X for the decay $\Upsilon' \to \pi^+\pi^-X$, $X \to \tau^+\tau^-$ showing a peak at $m_X = m(\Upsilon)$.

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[‡1] The properties of the light Higgs particle are elaborated in ref. [3].

firmed by checking the event pattern in the ARGUS calorimeter and the muon chambers. Possible background from the $\gamma\gamma \to$ four prongs is reduced considerably by both the second and third cuts. This may be seen in fig. 1 where the mass spectrum is plotted for the object recoiling against the $\pi^+\pi^-$ pair after applying the above cuts. A clean Υ signal of 60.5 ± 8.9 events is observed on a small background which comes mainly from $\gamma\gamma$ interactions.

This number of $\Upsilon \to \tau^+\tau^-$ decays can be compared with the number of simultaneously measured $\Upsilon \to e^+e^-$ and $\Upsilon \to \mu^+\mu^-$ decays. A total of 547 ± 24 events in these two channels was observed. The number of $\Upsilon \to \tau^+\tau^-$ decays has to be corrected for branching ratios into accepted decay channels of the τ lepton described above. We calculate an acceptance of (24.8 ± 1.5)% taking into account small contributions from the $\tau \to \rho\nu$ decay with escaping π^0's or with π^0's with energies below 0.3 GeV. The efficiencies for the cuts in p_T and cos α are determined by Monte Carlo calculations and are found to be consistent with those derived from the data: $\eta(p_T) = 94\%$ and $\eta(\cos\alpha) = 94\%$. Correcting further for the 5% lower geometrical acceptance for the $\Upsilon \to \tau^+\tau^-$ decay as compared to that for the decays $\Upsilon \to e^+e^-$ and $\Upsilon \to \mu^+\mu^-$ the ratio of branching ratios is determined to be

$$\frac{\mathrm{Br}(\Upsilon \to \tau^+\tau^-)}{\mathrm{Br}(\Upsilon \to e^+e^-, \mu^+\mu^-)} = 1.06 \pm 0.16 \pm 0.07 ,$$

where the first error is the statistical and the second one the systematic error.

This result is consistent with e–μ–τ universality and shows that the acceptance for $\tau\tau$ decays is well understood. By using the known branching ratio $\mathrm{Br}(\Upsilon \to e^+e^-, \mu^+\mu^-) = (2.9 \pm 0.2)\%$ [10] the $\tau\tau$ branching ratio of the Υ is determined to be $\mathrm{Br}(\Upsilon \to \tau^+\tau^-) = (3.07 \pm 0.46 \pm 0.22)\%$.

The investigation of the decay $\Upsilon \to \gamma\tau^+\tau^-$ is a simple extension of this study. Now Υ' decays with four prongs and exactly one photon with energy larger than 50 MeV are selected. The four prongs again contain a well identified $\pi^+\pi^-$ pair with missing mass in the Υ range. The visible decay products of the Υ meson are then required to be two oppositely charged tracks and the photon. The photon is detected in the ARGUS calorimeter which covers 96% of 4π. The photon energy resolution is given by $\sigma/E = (0.07^2 + 0.08^2/E)^{1/2}$ [11] where E is the energy of the photon in GeV. The acceptance for this radiative Υ decay is well understood if the same cuts are applied as for events containing the direct decay $\Upsilon \to \tau^+\tau^-$. According to Monte Carlo calculations, it varies smoothly from 96% at $E = 0.05$ GeV to 69% at the maximum allowed photon energy of $E = 4.06$ due to the change in the $\tau\tau$ decay topology.

After applying the same three cuts as described above in the $\Upsilon \to \tau^+\tau^-$ study, the spectrum for the mass recoiling against the $\pi^+\pi^-$ pair is obtained for the events involving one photon (fig. 2). It exhibits again a peak at the Υ mass with 45 ± 8 entries. These events can be attributed to the following background sources. The noise spectrum of the shower counters in the calorimeter was studied from complete four-prong events $\Upsilon' \to \pi^+\pi^-\Upsilon$, $\Upsilon \to e^+e^-$ or $\Upsilon \to \mu^+\mu^-$. We expect 18 ± 4 events of the type $\Upsilon' \to \pi^+\pi^-\Upsilon$, $\Upsilon \to \tau^+\tau^-$, $\tau \to$ one prong + ν with an additional fake photon. The second source of background photons is due to $\tau \to \rho\nu$, $\rho \to \pi^+\pi^0$, $\pi^0 \to \gamma\gamma$. We expect 6 ± 2 events for the case where one of the two photons is seen while the other escapes the detection. Moreover energetic π^0's from the $\tau \to \rho\nu$ decay can yield two photons which overlap in the shower counters and are not resolved. This contribution to the photon spectrum can be determined from the data since a clean ρ signal is observed when photons with energies larger than $E = 0.8$ GeV are combined with charged π's. The hatched histogram in fig. 2 shows this contribution of 16 events in the Υ recoil peak. This

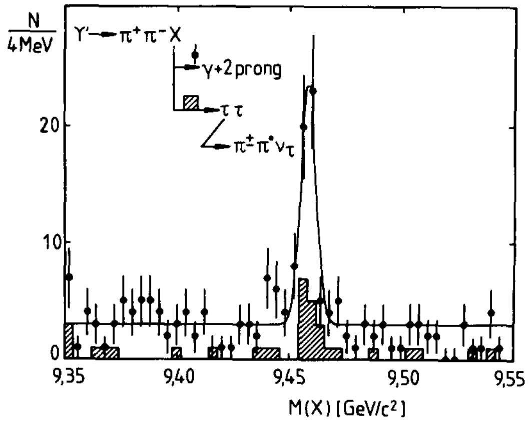

Fig. 2. Recoil mass spectrum m_X for the decay $\Upsilon' \to \pi^+\pi^-X$, $X \to \gamma\tau^+\tau^-$. The hatched histogram shows events in which the photon originates from the decay of one τ into the $\rho\nu$ channel.

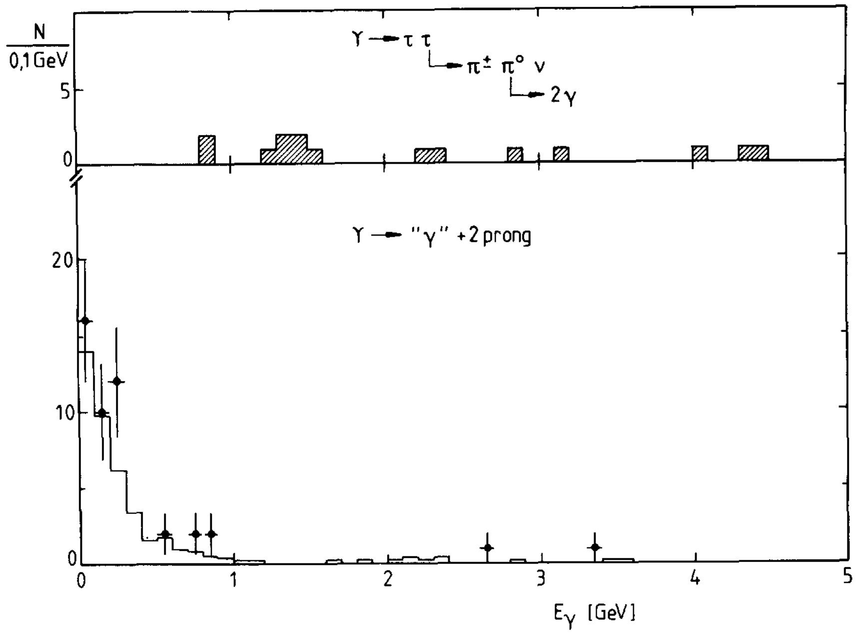

Fig. 3. Photon spectrum from the decay $\Upsilon \to \gamma$ + two prongs used in search for the decay $\Upsilon \to \gamma X$, $X \to \tau^+\tau^-$. The hatched histogram shows the observed contribution from the decay $\Upsilon \to \tau^+\tau^-$ with one τ decaying into $\rho\nu$, the open histogram shows expected background contributions from other sources as described in the text.

number is in good agreement with the expected number from the known branching ratios of the τ lepton and the π^0 momentum distribution in the $\tau \to \rho\nu$ decay. In total we expect to see 40 ± 6 background events in the Υ recoil peak which is in good agreement with the observed number of 45 ± 8.

The photon spectrum itself is obtained by requiring that the Υ recoil mass m_X lies between $m_X = 9.45$ and 9.47 GeV/c^2 (fig. 3). The hatched histogram shows the contribution from the decay $\Upsilon \to \tau^+\tau^-$ with one τ lepton decaying into $\rho\nu$, $\rho \to \pi^+\pi^0$ where the π^0 decays into two overlapping photons. The histogram shows the expected contribution from the two background processes mentioned in the preceeding paragraph, as well as the contribution from the continuum events lying under the Υ recoil peak. This last part was determined from the continuum side bands. Not only the expected number but also the energy distribution of photons is consistent with background from the $\Upsilon \to \tau^+\tau^-$ decay.

The upper limit for the sum of product branching ratios $\mathrm{Br}(\Upsilon \to \gamma X) \times \mathrm{Br}(X \to \tau\tau)$ to all states in the mass range 3.6 to 9.46 GeV/c^2 is 1% at the 90% CL.

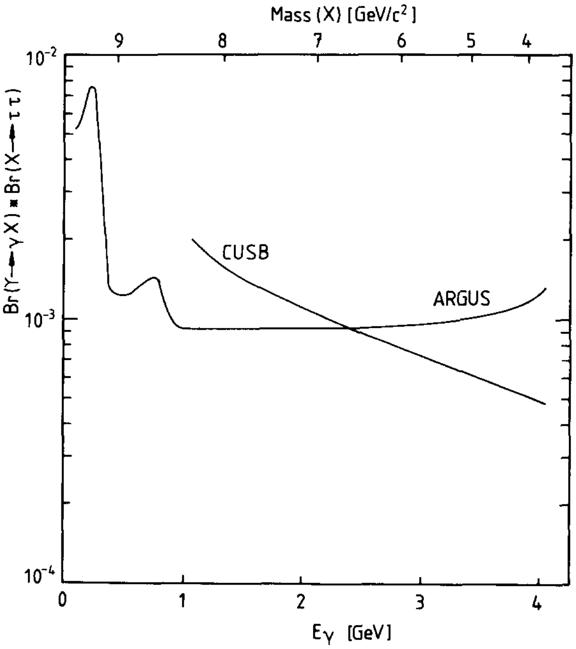

Fig. 4. Upper limit with 90% CL for the product branching ratio of the decay $\Upsilon \to \gamma X$, $X \to \tau^+\tau^-$.

The upper limit for the product branching for fixed mass m_X is shown in fig. 4. In the region below $m_X = 8.4$ GeV/c^2 it is less than 0.1%.

This result extends the range of restrictions imposed by a previous result from the inclusive photon spectrum [6]. The sensitivity to the production of heavy objects in radiative Υ decays has been increased for photon energies less than $E = 2.2$ GeV corresponding to a recoil mass of $m_X = 6.9$ GeV/c^2 or more.

In summary, we have observed no indication for narrow objects produced in radiative Υ decays and decaying into a τ pair. The present sensitivity is an order of magnitude to small to check the predictions from the standard model, if only one scalar Higgs particle is assumed. However, the result puts improved constraints on models with a more complicated Higgs structure.

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