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Measurement of the Branching Fraction of the Decay $\Upsilon(1S) \rightarrow \tau^+\tau^-$

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The branching fraction for the decay of the $\Upsilon(1S)$ into τ pairs has been measured to be $(3.4 \pm 0.4 \pm 0.4)\%$. This result agrees with the previously measured branching ratio of the decay into muon pairs.

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Experimental evidence to date suggests that the τ is a conventional lepton. The $b\bar{b}$ system provides another opportunity to compare the three lepton generations by studying the leptonic decays of the Υ resonances. We present here the first measurement of the branching fraction $B_{\tau\tau}$ of the decay of a vector meson, the $\Upsilon(1S)$, into τ pairs and compare it to previous experimental determinations of $B_{\mu\mu}$, the branching ratio of the decay of this resonance into muon pairs.[1,2]

The data were taken with the CLEO detector at the Cornell Electron Storage Ring (CESR). CLEO, a general-purpose magnetic detector, has been described elsewhere.[3] We review here the elements pertinent to this analysis. Inside a 1-m-radius superconducting solenoid which produces a 1.0-T field, there are cylindrical proportional and drift chambers for the tracking of charged particles within a solid angle of $0.90\times 4\pi$ steradians. Outside the coil, eight identical octants contain particle-identification detectors including a time-of-flight system (TOF) which consists of an array of twelve scintillation counters at a radius of 2.3 m. Only their triggering capability was used in this analysis. The overall solid angle covered by the TOF is $0.45\times 4\pi$. The outermost component of each octant is an electromagnetic calorimeter (total acceptance, $0.47\times 4\pi$) which is used to measure the luminosity by recording Bhabha events. To be included in our data sample, an event had to trigger the apparatus by leaving two or more tracks in the drift chamber, and by firing TOF counters in at least two different octants. The efficiency ϵ_T of this trigger for τ-pair events which meet our selection criteria was found to be 0.9 ± 0.1.

In high-energy e^+e^- collisions, τ-pair events are characterized by low multiplicities and "back-to-back" topologies. We chose to consider only events with the "1-vs-3" topology where one τ decays to a single charged prong (plus neutrals) and the other to three charged particles (plus neutrals). The reasons for this choice were the high trigger efficiency, the simplicity of the analysis (particle identification was not needed), and the substantial fraction of τ pairs with this topology.[4] Events were classified as τ-pair candidates when they contained exactly four charged tracks coming from the primary vertex, one particle (the single prong) making an angle greater than 90° with each of the other three, and when the charge was balanced between the two groups of particles. The main backgrounds were radiative Bhabha events with a converted photon, hadronic events from two-photon collisions, and two-jet hadronic events. The distribution of event vertices along the beam line showed no significant contribution from beam-gas collisions. To remove Bhabha events, we demanded that the group of three particles contain no pair of particles with an invariant mass less than 150 MeV/c^2, when electron masses were assumed. We reduced the two-photon and Bhabha contaminations by requiring the total observed energy of all charged particles to be between 3.5 and 9 GeV. To eliminate two-jet hadronic events, we required that the three prongs (assumed to be pions) have an invariant mass between 0.65 and 1.80 GeV/c^2 and a net momentum pointing within 55° of the direction opposite to that of the single prong. Also, we computed the opening angles of the three pairs of particles among the three prongs and required their mean to lie between 15° and 55°.

A visual scan of about 1000 events that passed these cuts showed that the residual fraction of Bhabha events represented $(0.7\pm 0.3)\%$ of the data. The two-photon contamination is estimated to be negligible. The only significant background remaining is that due to two-jet hadronic events, a $(20\pm 5)\%$ contamination according to our Monte Carlo simulation of the continuum electron-positron annihilations into hadrons. Finally we estimate that $(3.5\pm 1.0)\%$ of the selected sample are τ-pair events with a topology other than "1 vs 3."[5]

Data were taken at the $\Upsilon(1S)$, at the $\Upsilon(4S)$, and on the continuum immediately below the latter resonance, as indicated in Table I. Since the leptonic width of the $\Upsilon(4S)$ is negligible compared to its total width we have used all the τ events recorded in the region of this resonance to measure the continuum τ-pair cross section. The visible τ-pair cross section is plotted in Fig. 1 (see also Table I). The curve is the QED prediction normalized to the continuum measurement. A statistically significant enhancement (10 standard deviations) is observed at the energy of the $\Upsilon(1S)$.

From this signal, we calculate the leptonic branching ratio of the $\Upsilon(1S)$ resonance, $B_{\tau\tau}=\Gamma_{\tau\tau}/\Gamma_{\text{tot}}$, i.e., the ratio of the leptonic width to the total width. First we determine the quantity $\bar{B}_{\tau\tau}=\Gamma_{\tau\tau}/\Gamma_{\text{had}}$, where Γ_{had} is the hadronic width, and then we obtain $B_{\tau\tau}=\bar{B}_{\tau\tau}/(1+3\bar{B}_{\tau\tau})$, assuming equal branching ratios for the three leptonic final states. We use

$$\bar{B}_{\tau\tau}=\frac{N_{\text{peak}}-N_{\text{cont}}-N_{\text{hb}}}{\epsilon_{1S}\int L\,dt}\,\frac{1}{\sigma_{\text{had}}}\,.$$

In this formula, N_{peak} is the number of τ-pair events recorded at the resonance energy; N_{cont} is the number of continuum events under the $\Upsilon(1S)$ peak obtained by scaling of the continuum measurements made in the $\Upsilon(4S)$ region; N_{hb} is the resonant hadronic background which we evaluate as 25 ± 17 events[6]; $\int L\,dt$ is the integrated luminosity at the resonance; ϵ_{1S} is the efficiency for detecting resonant τ-pair events (we discuss this in detail below); and σ_{had} is the resonant hadronic cross section, which we have measured

TABLE I. Data summary. The errors are statistical only. The resonant cross sections are obtained by subtracting from the $\Upsilon(1S)$ peak the continuum data scaled by luminosity. For the τ-pair data sample the events collected at the $\Upsilon(4S)$ energy have been considered as continuum since, for this state situated above the flavor threshold, the leptonic width is negligible compared to the hadronic width.

	$E_{\text{c.m.}}$ (GeV)	$\int L\,dt$ (pb^{-1})	τ pairs	$\sigma_{\tau\tau}^{\text{vis}}$ (pb)	Hadrons [a]
$\Upsilon(1S)$ peak	9.461	2.64	430	162.8 ± 7.9	57639
Continuum	10.480	12.54	966	77.0 ± 2.5	37264
$\Upsilon(4S)$ peak	10.580	29.26	2201	75.2 ± 1.6	(119409)

[a] The acceptance for the $\Upsilon(1S)$ hadronic decays is 0.84 ± 0.03.

to be $21.6 \pm 0.1 \pm 1.3$ nb for the present data sample (see Table I), using the method described in a previous paper.[7]

To evaluate the efficiency for detecting continuum τ-pair events ϵ_{cont}, we take advantage of the fact that the cross section is known from QED (we used the result of the calculation to order α^3). Consequently ϵ_{cont}, which is just the ratio of the number of observed events to the number of events predicted by QED, is not affected by the systematic uncertainties in the topological branching ratio, the trigger efficiency, and the backgrounds. We find $\epsilon_{\text{cont}} = (8.7 \pm 0.2)\%$ at $E_{\text{c.m.}} = 10.55$ GeV. We have also used a Monte Carlo simulation of the CLEO detector to calculate the efficiency and, in particular, model its energy dependence and the effect of initial-state radiation (which only affects the continuum data). Our results are $\epsilon_{1S}^{\text{MC}} = (7.4 \pm 0.1)\%$ for the $\Upsilon(1S)$ resonance, and $\epsilon_{\text{cont}}^{\text{MC}} = (7.6 \pm 0.2)\%$ for the continuum in the region of the $\Upsilon(4S)$ (the errors are statistical only). Note that the continuum τ-pair cross section $\sigma_{\tau\tau}$ obtained by dividing the visible cross section by $\epsilon_{\text{cont}}^{\text{MC}}$ agrees with QED: $\sigma_{\tau\tau}/\sigma_{\text{QED}} = 1.14 \pm 0.17$, where the error is the above-mentioned systematic uncertainty. This agreement enables us to trust the Monte Carlo simulation and use the ratio $\epsilon_{1S}^{\text{MC}}/\epsilon_{\text{cont}}^{\text{MC}} = 0.97 \pm 0.03$ with the measured continuum efficiency ϵ_{cont} to obtain $\epsilon_{1S} = 8.4 \pm 0.3\%$, the efficiency for detecting τ pairs from the decay of the $\Upsilon(1S)$.

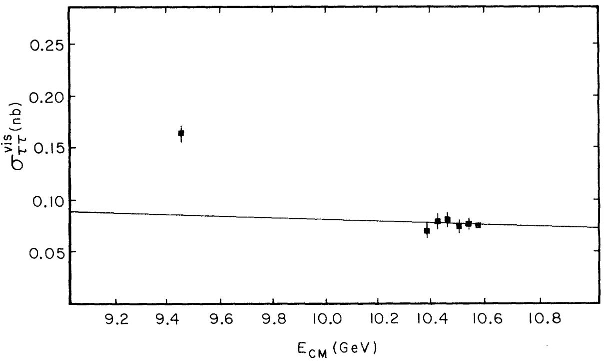

FIG. 1. The τ-pair visible cross section. The curve is the prediction of QED normalized to the continuum. The enhancement observed at the $\Upsilon(1S)$ indicates a sizable branching ratio for the decay of this resonance into τ pairs.

From the above numbers, we calculate $B_{\tau\tau} = (3.4 \pm 0.4 \pm 0.4)\%$ where the first error is statistical and the second is systematic. The overall relative systematic error of 13% includes contributions from the resonant hadronic background (8%), the luminosity (8%), the efficiency ϵ_{1S} (6%), and the acceptance for hadronic events (3%). This result is in good agreement with the world average of $B_{\mu\mu}$ determined by Roos *et al.*[8], $(3.2 \pm 0.7)\%$. Our value also agrees with the latest CLEO measurement[2] of $B_{\mu\mu}$, $(2.7 \pm 0.3 \pm 0.3)\%$. We conclude that the leptonic decays of the $\Upsilon(1S)$ resonance show no evidence for unconventional behavior of the τ lepton.

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[5] The main part (70%) of this background consists of events with the "1-vs-1" topology containing a π^0 photon which converts in the beam pipe into an e^+e^- pair that is poorly fitted. The remainder comprises events with the "3-vs-3" topology where two tracks from one τ are not reconstructed.

[6] Note that the two-jet hadronic background from the continuum cancels in the subtraction of N_{cont}. Furthermore our procedure of normalizing the continuum data to the QED cross section to determine the efficiency (see the subsequent discussion) folds into this number the effect of the two-jet hadronic background. Since the relative amounts of two-jet and τ-pair events should be the same for the $\Upsilon(1S)$ decays as for the continuum, we only need subtract the contribution of the three-gluon decays N_{hb}, which we obtain by a Monte Carlo calculation.

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