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Limit on τ decay to seven charged particles

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A data sample corresponding to a luminosity of 300 pb^{-1} from e^+e^- collisions at 29 GeV, obtained using the High Resolution Spectrometer at the SLAC e^+e^- storage ring PEP, was used to search for τ decay to seven charged particles. No candidates were found and the corresponding upper limit for the branching ratio is $B(\tau \rightarrow 7\pi^{\pm} + \nu_\tau + n\gamma) < 1.9 \times 10^{-4}$ at 90% confidence level ($n > 0$). This data sample was also used to obtain the branching ratios of $B(\tau \rightarrow 5\pi^{\pm} + \nu_\tau) = (5.1 \pm 2.0) \times 10^{-4}$ and $B(\tau \rightarrow 5\pi^{\pm} + \pi^0 + \nu_\tau) = (5.1 \pm 2.2) \times 10^{-4}$.

This paper reports results of a search for τ decays to five and seven charged particles. The results are based on a data sample corresponding to 300 pb^{-1} obtained with the High Resolution Spectrometer[1] (HRS) at the SLAC e^+e^- storage ring PEP operated at a center-of-mass energy of 29 GeV. Results on τ decays to five charged particles have been published previously[2,3] and used to set upper limits on the mass of the τ neutrino from the hadronic mass spectrum of the five- and six-pion final states.[4] The possibility of τ decays to seven charged pions is of interest because the limited phase space available to the pions makes such events an even more sensitive probe of the mass of the τ neutrino.

The initial selection criteria used to isolate a sample of τ decays to five or seven charged particles were similar to those used to measure the branching ratios to one (B_1) and three (B_3) charged particles.[5] For the present analysis the topology of the selected events was five or seven charged tracks in one hemisphere with a single charged track in the opposite hemisphere. In addition, the total net charge of the event was required to be zero. Because B_1 is 86.9%, demanding a single charged particle in one hemisphere greatly reduces the background from hadronic events, while affecting the signal only slightly. Since the seven-prong events are expected to be very rare, no further cuts were imposed on these events. However, in order to reduce backgrounds from beam-gas interactions and from two-photon interactions in the five-prong sample, the scalar sum of the charged momenta was required to be greater than 7.25 GeV/c and the angle between the total momentum vectors in the two hemispheres had to be greater than 135°. To avoid regions of the detector that were not fully instrumented, five-prong events were selected in the central region by requiring the angle θ, between the thrust axis of the event and the beam direction, to satisfy $|\cos\theta| < 0.55$.

The effective-mass distributions of the five or seven charged particles, each considered a pion, are shown in Fig. 1. Data of Fig. 1(a) show no enhancement in the region below the τ mass of $M_\tau = 1.784$ GeV/c^2, indicating that all of the seven-prong events are of hadronic origin. To verify the absence of a seven-prong τ signal, we use the fact that, in the limit of first-order QED, τ pair production leads to a unique momentum for each lepton. The thrust axis of the event is taken to be the direction of the produced τ pair and the momentum P^*, defined as the sum of the momenta of all the charged hadronic-decay products in the τ rest frame, is calculated by performing a Lorentz boost. P^* is expected to be small for τ-decay events because the difference between the mass of the hadronic-decay products and M_τ is small. Using a phase-space model of seven-prong τ decay, it is found that only a small percentage of the events are expected to have a hadronic system with a mass below 1.3 GeV/c^2. This mass value corresponds to a P^* of 0.4 GeV/c, and therefore the τ events predominantly populate the region below 0.4 GeV/c. However, the P^* distribution for the seven-prong events,[6] shown in Fig. 2(a), has no events with P^* below 0.4 GeV/c.

To determine the effect of the selection criteria, the seven-prong decays of the τ were simulated using a simple thermodynamic model[7] of the hadronic decay together with the Berends and Kleiss[8] lepton generator including $O(\alpha^3)$ QED corrections. It was found that after full

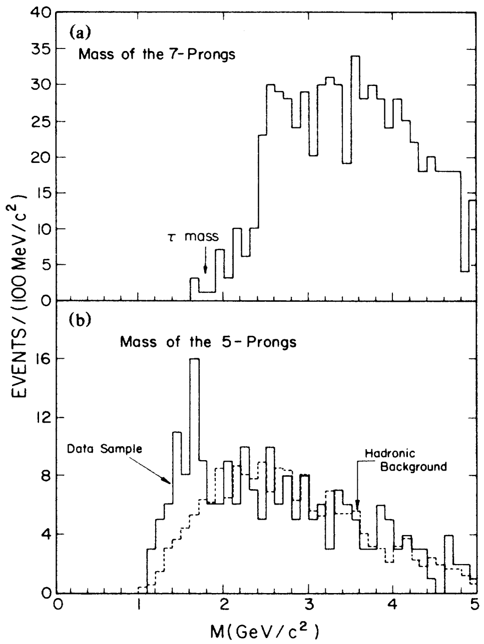

FIG. 1. (a) The invariant mass of the seven charged particles. (b) The invariant mass of the five charged particles for the τ-candidate events (solid line) and hadronic-background events (dashed line).

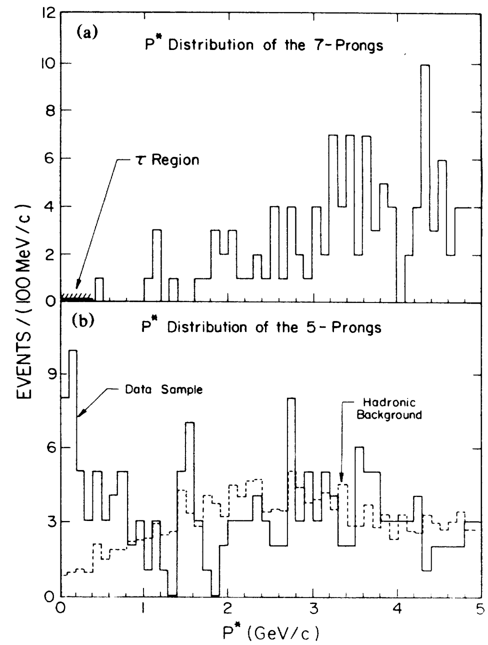

FIG. 2. The measured momentum P^* in the τ rest frame for the (a) seven-prong sample and (b) five-prong τ-candidate events (solid line) and the hadronic background (dashed line).

detector simulation only 12% of the τ events are lost due to a P^* cut at 0.4 GeV/c, while the hadronic events are eliminated. The acceptance, including all of the effects of the selection criteria, was 0.18 ± 0.01. This, along with the total number of τ pairs produced, $(0.41 \pm 0.02) \times 10^5$, yields an upper limit on the branching ratio for τ decays to seven charged particles of $B(\tau \rightarrow 7\pi^{\pm} \nu_\tau + n\gamma) < 1.9 \times 10^{-4}$ at the 90% confidence level ($n \geq 0$).

Unlike the seven-charged-particle search, Fig. 1(b) and Fig. 2(b) show strong evidence for τ decay to five charged particles with clear peaks above the hadronic background in both the mass and the P^* distributions. In order to measure the hadronic background to the five-prong signal, the full data sample was searched for events with five charged particles in one hemisphere and any odd number of charged particles (excluding the single-track events) in the opposite hemisphere. All of the other selection criteria were identical to those used to select the τ sample. The resulting five-prong mass distribution is shown as the dashed histogram in Fig. 1(b). These data are normalized to the τ sample in the mass region above 2 GeV/c^2 where the two distributions have the same shape. The hadronic-background sample contains 14.7 times as many events as the τ-event sample. The τ events are separated from the hadronic events by requiring $P^* < 0.6$ GeV/c. Figure 2(b) shows a clear signal of 34 events in this region, of which seven are estimated to be of hadronic origin.

The hadronic background in the region $P^* < 0.6$ GeV/c is reduced by the following. (1) It was required that the combined mass of the charged particles and photons in the hemisphere opposite to that of the five-prong jet be less than 1.6 GeV/c^2. A Monte Carlo simulation of τ decay indicates that only 6% of the τ events are rejected by this cut, whereas 60% of the events in the solid histogram in Fig. 1(b) with a five-prong mass greater than 2 GeV/c^2 are rejected. (2) It was also required that the combined mass of the charged particles and photons in the five-prong hemisphere be less than 1.9 GeV/c^2. With these selections, the hadronic background was reduced to 0.08 ± 0.05 events and 25 of the 34 events remained.

A second background to the five-charged-particle decay comes from the $\tau \rightarrow 3\pi^{\pm} + \pi^0 + \nu_\tau$ decay, in which one of the photons from the π^0 forms an e^+e^- pair either by a Dalitz conversion or by external conversion in the $\sim 1.5\%$ of a radiation length of material surrounding the interaction point. There are three properties of these e^+e^- pairs that allow them to be eliminated from the sample. (1) The tracks have low momenta because the original photon has on average half the momentum of its parent neutral pion and each electron has only half the momentum of its parent photon. (2) The effective mass of the pair is low with the probability of forming a mass larger than 85 MeV/c^2 being less than 1%. (3) The showering nature of the electron yields two chances to distinguish at least one member of the pair as being an electron. All events with neutral pairs (treated as electrons) whose invariant mass was less than 200 MeV/c^2 and which had at least one member that deposited an energy in the barrel shower-counter system within 3σ of the expected value for an electron were removed. If neither member of the pair was energetic enough to hit the barrel shower counter then the event was also eliminated. If one member of the pair deposited an energy consistent with a minimum-ionizing particle, then the event was accepted. With these criteria, twelve of the τ-candidate events were found to contain

e^+e^- pairs, which is consistent with the Monte Carlo estimate of 11.1 events. The remaining conversion background is less than 0.10 ± 0.06 events. The background from two-photon interactions is small.[2] Including all sources, 0.18 ± 0.08 background events are expected in the sample of thirteen events.

A detailed examination of the thirteen candidate events shows that six of the events are accompanied by neutral energy in the barrel shower counters that is clearly separated from the charged particles. If we now include the neutral clusters in a recalculation of the invariant mass of these events, treating the clusters as having originated from the decay of a π^0, none of the events are found to exceed the τ mass. The acceptance for these events, including the solid angle, tracking efficiency, and all other cuts, is 0.193 ± 0.014 for the $5\pi^{\pm}\nu_\tau$ decays and 0.164 ± 0.013 for the $5\pi^{\pm}\pi^0\nu_\tau$ decays. With this interpretation of the events, the resulting branching ratios of the τ are found to be $B(\tau^{\pm} \to 5\pi^{\pm}\nu_\tau) = (5.1 \pm 2.0) \times 10^{-4}$ and $B(\tau^{\pm} \to 5\pi^{\pm}\pi^0\nu_\tau) = (5.1 \pm 2.2) \times 10^{-4}$. Combining these results gives $B_5 = (10.2 \pm 2.9) \times 10^{-4}$.

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[6] The event just above the P^* cut of 0.4 GeV/c in Fig. 2(a) has been carefully examined and found to contain extra tracks that were not found by the tracking program. This makes it highly unlikely that this event is a seven-prong τ event.

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