Measurement of the Branching Fractions $\tau^- \rightarrow \rho^- \nu_\tau$ and $\tau^- \rightarrow K^{*-} \nu_\tau$

J. M. Yelton,[a] J. M. Dorfan, G. S. Abrams, D. Amidei,[b] A. R. Baden, T. Barklow, A. M. Boyarski, J. Boyer, M. Breidenbach, P. Burchat, D. L. Burke, F. Butler, G. L. Feldman, L. D. Gladney,[c] G. Gidal, M. S. Gold, G. Goldhaber, L. Golding, J. Haggerty, G. Hanson, K. Hayes, D. Herrup, R. J. Hollebeek, W. R. Innes, J. A. Jaros, I. Juricic, J. A. Kadyk, D. Karlen, A. J. Lankford, R. R. Larsen, B. W. Leclaire, M. E. Levi,[d] N. S. Lockyer,[c] V. Lüth, C. Matteuzzi,[d] M. E. Nelson,[e] R. A. Ong, M. L. Perl, B. Richter, K. Riles, M. C. Ross, P. C. Rowson, T. Schaad, H. Schellman,[b] W. B. Schmidke, P. D. Sheldon, G. H. Trilling, C. de la Vaissiere,[f] D. R. Wood, and C. Zaiser

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720
Department of Physics, Harvard University, Cambridge, Massachusetts 02138
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We have measured the branching fraction of $\tau^- \rightarrow \rho^- \nu_\tau$ to be $(22.3 \pm 0.6 \pm 1.4)\%$ and the branching fraction of $\tau^- \rightarrow K^{*-} \nu_\tau$ to be $(1.3 \pm 0.3 \pm 0.3)\%$. These values are consistent with the expectations for conventional decays of the τ.

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Recently there has been increasing concern[1,2] about the discrepancy between the measured inclusive τ one-charged-prong branching ratio and the sum of the exclusive τ one-charged-prong branching ratios. Understanding this discrepancy ($\approx 7\%$) requires, amongst other things, improved measurements of the exclusive τ decay modes. In this Letter we report new measurements of branching fractions for the decay modes $\tau^- \rightarrow \rho^- \nu_\tau$ and $\tau^- \rightarrow K^{*-} \nu_\tau$.[3] These τ branching fractions can be reliably predicted from low-energy e^+e^- data by use of the conserved-vector-current hypothesis.[1,4] The data presented here provide tests, more stringent than before, of the conventional weak theory of τ hadronic decays, both Cabibbo allowed and Cabibbo suppressed. In addition, since $\tau^- \rightarrow \rho^- \nu_\tau$ is the largest one-charged-prong decay mode of the τ, this improved accuracy sharpens the upper constraint on the total of the exclusive one-charged-prong decays. The low charged-particle multiplicity of τ decays and the large τ velocity enable a pure sample of τ-pair events to be selected at the SLAC e^+e^- storage ring PEP solely on the basis of topological criteria. This has the advantage of making our measurements almost entirely independent of the values of specific τ branching fractions.

The measurement is based on 207 pb^{-1} of data at $\sqrt{s} = 29$ GeV taken by the Mark II experiment at the PEP e^+e^- storage ring. This luminosity corresponds to about 20 000 produced τ-pair events. The Mark II detector has been described in detail elsewhere.[5] For this analysis we have made considerable use of the multilayer cylindrical drift chambers which, in a 2.3-kG solenoidal magnetic field, measure charged-particle momenta with a resolution of $\sigma_p/p = [(0.025)^2 + (0.01p)^2]^{1/2}$ (p in GeV/c) and the eight lead–liquid-argon calorimeter modules (LA) which detect electromagnetic showers with an energy resolution of $\sigma_E = 0.14\sqrt{E}$ (E in gigaelectronvolts) over a solid angle of 0.7 of 4π.

Candidate events were selected to contain either two, four, or six charged particles, with a total charge of zero and a total energy of greater than 7.5 GeV. These events were then divided into two jets by a plane perpendicular to the thrust axis. Each jet was required to contain either one or three charged particles and have a calculated invariant mass (including neutral tracks) of less than 1.8 GeV/c^2. The subsequent selection criteria then differ for $\tau^- \rightarrow \rho^- \nu_\tau$ and $\tau^- \rightarrow K^{*-} \nu_\tau$ candidates.

The ρ's were detected by their decay $\rho^- \rightarrow \pi^- \pi^0$ and were selected from the sample of jets containing one charged particle. This charged particle was required to be isolated by at least 120° from all other charged particles. To reject contamination from Bhabha-scattering events, the total energy of the event was required to be less than 23 GeV. The energy in the LA associated with the charged track was required to be less than half of its momentum so as to greatly reduce the possibility that the charged particle was an electron. The jet was also required to contain either one or two neutral tracks, where a neutral track was defined to be a cluster of electromagnetic energy in the LA of greater than 200 MeV, more than 20 cm away from the point of impact at the calorimeter of any charged track. This latter restriction ensures that the neutral track was not due to a charged-particle interaction in the coil or in the LA. In jets containing two neutral tracks, the invariant mass of the two neutral tracks was calculated, a one-constraint fit made to the π^0 mass, and those combinations with a $\chi^2 > 5$ rejected. The invariant mass was then calculated for the combination of the π^0 and the charged particle in the jet, on the assumption that the latter was a π^-. The invariant-mass spectrum for the 629 combinations is shown in Fig. 1(a), and is dominated by the $\rho(770)$ resonance. A similarly large sample of ρ decays may be found in the sample of jets containing one neutral track. Here, only those jets containing a neutral with energy greater than 2 GeV were considered. This neutral track was assigned the π^0 mass, and its direction was assumed to represent that of the π^0. The $\pi^-\pi^0$ invariant-mass spectrum for this sample of 600 decays, shown in Fig. 1(b), is also dominated by the $\rho(770)$ resonance.

The acceptance for the $\tau^- \rightarrow \rho^- \nu_\tau$ decay was calculated from a Monte Carlo simulation of τ production. The Monte Carlo program produced τ pairs with a cross section known from standard quantum electrodynamics, and the decays of these τ's were generated according to all known modes. Initial-state radiation effects were included in the simulation. The data were corrected for the $\pi^-\pi^0$ candidates which feed down from τ decays other than the decay under study. This correction is estimated from the Monte Carlo simulation to be about 11%, due mostly to multiple π^0 decays of the τ. The background due to processes other than τ-pair production is negligible.

The resultant branching fraction for $\tau^- \rightarrow \rho^- \nu_\tau$ was $(22.3 \pm 0.6)\%$ (statistical error only). There is no evidence for $\pi^-\pi^0$ decays of the τ that are nonresonant, or that go through resonances other than the $\rho(770)$. The branching fractions obtained for the resolved-π^0 and unresolved-π^0 cases separately agreed within their statistical errors. Systematic errors arise from the luminosity (4%, as measured from Bhabha-scattering events[6]), the uncertainty in the background due to τ decays other than $\tau^- \rightarrow \rho^- \nu_\tau$ (3%), and the uncertainty in the acceptance (4%). These add in quadrature to give a total systematic error in the branching fraction of 1.4%.

The $\tau^- \rightarrow K^{*-} \nu_\tau$ decay was searched for in the sample of jets containing three charged particles and no neutral particles, by observation of the decay chain

$$\tau^- \rightarrow K^{*-} \nu_\tau$$
$$\quad \hookrightarrow K_S^0 \pi^-$$
$$\qquad \hookrightarrow \pi^+\pi^- .$$

A K_S^0 candidate was defined to be two charged particles, both of which had impact parameters greater than 1 mm, which formed a vertex between 1 and 40 cm from the beam interaction point and had a $\chi^2 < 5$ for a fit to the K_S^0 mass. The invariant mass of the K_S^0 together with the remaining charged particle in the jet, assumed to be a π^-, is shown in Fig. 2. The distribution exhibits a clear $K^*(890)$ peak. The 31 combinations with invariant mass $0.8 < M_{K_S^0\pi^-} < 1.0$ GeV/c^2 were taken to be K^{*-} candidates. The background to this signal was estimated to be 4 events, on the assumption that the background events were distributed uniformly in the mass region 0.65–1.25 GeV/c^2. The number of K^{*-} found was then corrected for detector acceptance and inefficiencies by means of a Monte Carlo simulation, in a manner similar to the $\tau^- \rightarrow \rho^- \nu_\tau$ case, to yield a measured branching fraction for $\tau^- \rightarrow K^{*-} \nu_\tau$ of $(1.3 \pm 0.3)\%$ (statistical error only). Systematic uncertainties arise from the luminosity (4%), the background subtraction (4%), and the acceptance calculation (4%). It should also be noted

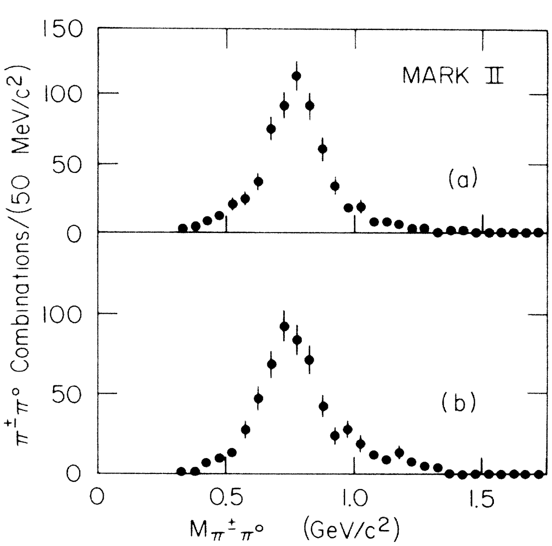

FIG. 1. The $\pi^-\pi^0$ invariant-mass spectrum for (a) resolved π^0's and (b) unresolved π^0's.

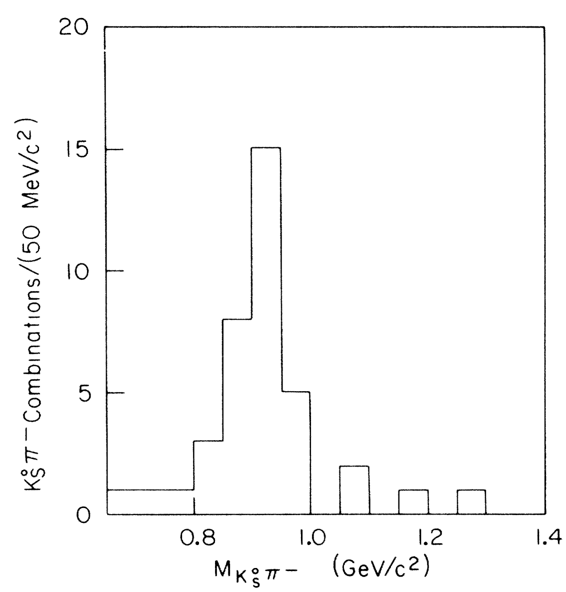

FIG. 2. The $K_S^0\pi^-$ invariant-mass spectrum.

that the K^{*-} sample may include a small component which arises from the decay chain

$$\tau^- \rightarrow \rho' \nu_\tau, \quad \rho' \rightarrow K_L^0 K^{*-}.$$

This may contribute up to $\approx 0.25\%$ to the branching fraction. From these considerations, we estimate the systematic error on the measurement of $B(\tau^- \rightarrow K^{*-}\nu_\tau)$ to be 0.3%. This value of $B(\tau^- \rightarrow K^{*-}\nu_\tau)$ is in good agreement with the only previous measurement of this branching fraction.[7]

The branching fraction for $\tau^- \rightarrow \rho^- \nu_\tau$ may be related to the branching fraction for $\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e$ by means of the conserved-vector-current hypothesis, and the cross section $\sigma(e^+e^- \rightarrow \gamma \rightarrow \pi^+\pi^-)$. The authors in Ref. 1, assuming $B(\tau^- \rightarrow e^-\nu_\tau\bar{\nu}_e) = 17.9\%$, calculate $B(\tau^- \rightarrow \rho^-\nu_\tau) = 22.0\%$.[8] Thus the measurement presented here is in very good agreement with the theoretical prediction, and also with other experimental results from the Mark II Collaboration[9] at the SLAC storage ring SPEAR $[(21.4 \pm 3.2)\%]$, and from the Cello Collaboration[10] at the DESY storage ring PETRA $[(22.1 \pm 1.9 \pm 1.6)\%]$.

The ratio of branching fractions $B(\tau^- \rightarrow K^{*-}\nu_\tau)/B(\tau^- \rightarrow \rho^-\nu_\tau)$ is measured to be $0.058 \pm 0.013 \pm 0.013$. This is in good agreement with the expectation[1] of 0.064 which is based upon the Cabibbo angle with phase space and SU(3)-symmetry breaking taken into account.

In conclusion, we have measured the branching fraction $B(\tau^- \rightarrow \rho^-\nu_\tau)$ to be $(22.3 \pm 0.6 \pm 1.4)\%$ and $B(\tau^- \rightarrow K^{*-}\nu_\tau)$ to be $(1.3 \pm 0.3 \pm 0.3)\%$, where the uncertainties are statistical and systematic, respectively. The values are in good agreement with those predicted by the conserved-vector-current hypothesis of τ decays and with previous measurements. Consequently these results do not reduce the discrepancy between the inclusive and exclusive one-charged-prong branching ratios.

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[a]Present address: Oxford University, Oxford, England.

[b]Present address: University of Chicago, Chicago, Ill. 60637.

[c]Present address: University of Pennsylvania, Philadelphia, Pa. 19104.

[d]Present address: CERN, CH-1211 Geneva 23, Switzerland.

[e]Present address: California Institute of Technology, Pasadena, Cal. 91125.

[f]Present address: Laboratoire de Physique Nucléaire et Hautes Energies, Université de Pierre et Marie Curie, Paris F-75230, France.

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