Title
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Authors
Abrams, GS
Alam, MS
Blocker, CA
et al.

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Medicine, Biscayne Annex, Miami, Fla. 33152.
[d]Present address: Brookhaven National Laboratory, Upton, N. Y. 11973.
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Measurement of the Branching Fraction for $\tau \to \rho\nu$

G. S. Abrams, M. S. Alam, C. A. Blocker, A. M. Boyarski, M. Breidenbach, D. L. Burke, W. C. Carithers, W. Chinowsky, M. W. Coles, S. Cooper, B. Couchman,[a] W. E. Dieterle, J. B. Dillon, J. Dorenbosch, J. M. Dorfan, M. W. Eaton, G. J. Feldman, H. G. Fischer,[b] M. E. B. Franklin, G. Gidal, G. Goldhaber, G. Hanson, K. G. Hayes, T. Himel, D. G. Hitlin,[c] R. J. Hollebeek, W. R. Innes, J. Jaros, P. Jenni, A. D. Johnson, J. A. Kadyk, A. J. Lankford, R. R. Larsen, V. Luth, J. F. Martin,[d] R. E. Millikan, M. E. Nelson, C. Y. Pang, J. F. Patrick, M. L. Perl, B. Richter, D. L. Scharre, R. H. Schindler, R. F. Schwitters,[e] S. R. Shannon,[a] J. L. Siegrist, J. Strait, H. Taureg, M. Tonutti,[f] G. H. Trilling, E. N. Vella, R. A. Vidal, I. Videau, J. M. Weiss, and H. Zaccone

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305, and Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720

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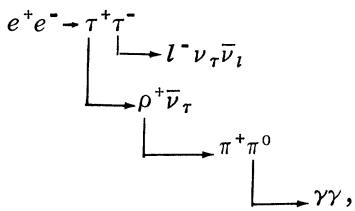
This Letter presents a measurement of the decay $\tau^- \to \rho^- \nu_\tau$ using data obtained with the Mark II detector at SPEAR. In the center-of-mass energy region $4.5 \leq E_{\text{c.m.}} \leq 6.0$ GeV 85 events are observed in which a charged ρ was found in coincidence with either an electron or a muon. It was determined that $B(\tau^- \to \rho^- \nu_\tau) = (20.5 \pm 4.1)\%$ and the ratio $B(\tau^- \to \rho^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = 1.11 \pm 0.23$.

The existence of a new charged heavy lepton, τ, was first suggested[1] to explain the presence of events in which the only detected particles were an electron and a muon of opposite charge. The experimental evidence accumulated since that time strongly supports this interpretation and there now exists a coherent picture of the τ as a sequential heavy lepton with a small- or zero-mass neutrino which couples via the conventional $V-A$ weak current.[2] In addition there are several precise measurements of the τ mass and of branching ratios for leptonic and some hadronic decays.[3] We present below a measurement of the branching ratio for the decay $\tau^- \to \rho^- \nu_\tau$ as measured by the Mark II detector at SPEAR.[4] The decay $\tau^- \to \rho^- \nu_\tau$ involves only the vector part of the weak hadronic current. Comparison of this measurement with theoretical predictions, based on the coupling of the ρ to the electromagnetic current, constitutes a test of the validity of the conserved-vector-current hypothesis (CVC).

The detector has been described elsewhere[5] and we highlight only those detector elements which were crucial to the measurements described herein. The charged tracks were reconstructed from hits in the sixteen drift-chamber layers and photons were detected in the eight liquid argon shower counters which surround the solenoidal coil. Typical photon detection efficiencies exclusive of geometrical effects were 15% at 100 MeV, 50% at 200 MeV, and $\geq$ 90% above MeV. Muons were detected in hadron absorption counters consisting of proportional tubes interleaved with iron slabs. The counters have a threshold momentum of 700 MeV/c. Muons headed for these counters which were above this threshold had a $\geq$ 98% detection efficiency and the probability that a pion was identified as a muon was 4% at 700 MeV/c, 11% at 900 MeV/c, and 2% above 1.0 GeV/c, at which point the muon has sufficient momentum to

reach the second detection layer. For momenta below 300 MeV/c, electrons were identified by a time-of-flight (TOF) measurement with a 300-psec rms resolution. Above 300 MeV/c a series of cuts in the total shower energy, and longitudinal and transverse shower development together with TOF (below 500 MeV/c), were used to separate electrons and pions. These cuts were determined with well-identified electrons from photon conversions and radiative Bhabha events, and with pions from $\psi \to \pi^+\pi^-\pi^+\pi^-\pi^0$ decays. The probability that a pion was identified as an electron was 7% at momenta below 500 MeV/c, 4% at 600 MeV/c, and 2% at 800 MeV/c with corresponding electron efficiencies of 64%, 76%, and 87%, respectively.

To search for $\tau^- \to \rho^- \nu_\tau$ we looked for events having the following topology:



which results in two oppositely charged particles and two photons in the detector. Here l^- represents either an electron or a muon which helps provide a clean signature for τ-pair production.

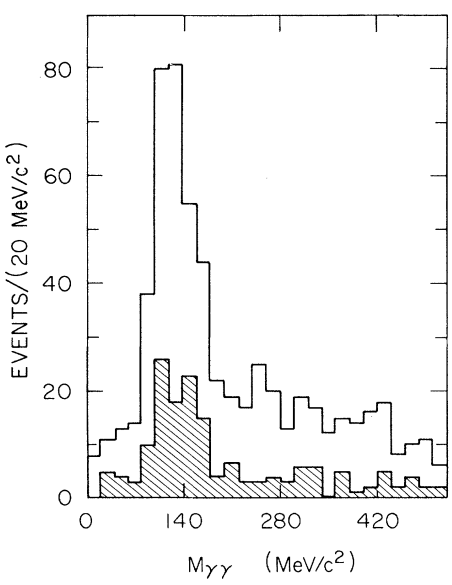


FIG. 1. Two-photon invariant-mass spectrum for $X^\pm\pi^\mp\gamma\gamma$ events where X represents either a pion or a lepton (l). The shaded distribution is for the $l^\pm\pi^\mp\gamma\gamma$ events.

The data for these measurements come from an energy scan in the region $4.5 \leq E_{\text{c.m.}} \leq 6.0$ GeV and correspond to an integrated luminosity of 3950 nb^{-1}, corresponding to approximately 11 500 produced $\tau^+\tau^-$ pairs calculated from the theoretical cross section. Events selected had two oppositely charged tracks (with momenta ≥ 0.1 GeV/c) acoplanar[6] by at least 20°, and two photons in the liquid argon shower counters with $E_\gamma \geq 0.1$ GeV.

The charged-particle vertex was required to be within $\pm$ 7.5 cm (along the beam direction) of the center of the e^+e^- beam overlap region. We removed photons which were within 36 cm, as measured at the liquid argon shower counter, of a charged track because in most cases these photons were due to the interaction of the charged particle in its passage through the shower counter and hence did not originate at the e^+e^- interaction vertex. Figure 1 shows the two-photon invariant-mass ($M_{\gamma\gamma}$) spectrum for events satisfying the above cuts. A clear π^0 signal is seen. Events were accepted which had $0.08 \leq M_{\gamma\gamma} \leq 0.2$ GeV/c^2 and the measured photon energies were adjusted to constrain the mass to that of a π^0. We imposed a cut of $\chi^2 \leq 6$ for this one-constraint fit.

We further required that one of the charged particles be either a muon or an electron and that the other be a pion. A $\pi^\pm$ candidate was any charged track which was not positively identified as a lepton, kaon, or proton. Figure 2 shows the invariant mass, $M_{\pi^\pm\pi^0}$, of the $\pi^\pm$ and the π^0. We have fitted the spectrum in Fig. 2 by a function which is the sum of a smooth background and a Breit-Wigner resonance. The fit, which is superimposed on the data in Fig. 2, has a χ^2 of 12.9 for 16 degrees of freedom and yields $M_\rho = 0.770 \pm 0.020$ GeV/c^2 and $\Gamma_\rho = 0.194 \pm 0.030$ GeV/c^2.

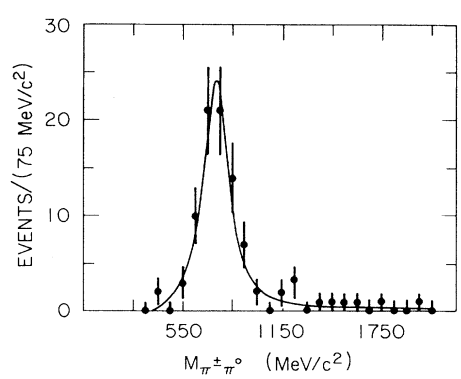


FIG. 2. $\pi^\pm\pi^0$ invariant-mass spectrum for $l^\pm\pi^\mp\pi^0$ events.

Events were selected in the mass range $0.27 \leq M_{\pi^\pm\pi^0} \leq 1.26$ GeV/c^2. There are 85 such events: 64 $\rho^\pm e^\mp$ and 21 $\rho^\pm \mu^\mp$ events.[7] Figure 3 shows the spectrum for $X_\rho = (E_\rho - E_{\min})/(E_{\max} - E_{\min})$ of the 85 $\rho^\pm$ candidates, where E_ρ is the energy of the $\rho^\pm$, and $E_{\min}$ and $E_{\max}$ are the minimum and maximum allowable energies for a ρ produced in the decay of a τ of mass 1.782 GeV/c^2 at the appropriate beam energy. The prediction of the Monte Carlo simulation program is superimposed on the data and the agreement is good.

We suffer an efficiency loss due to the requirement of two and only two photons. In order to detect low-energy photons in the liquid argon counters, we run with a very low energy threshold. Hence the electronic noise in the preamplifiers generates some spurious photons. In many cases these spurious photons derive their energy partially from noise and partially from real charged or neutral tracks present in the event. To evaluate this loss we examined the reaction $\psi \to \pi^+\pi^-\pi^0$ which has a topology like that of the reaction under study, and which can be unambiguously identified from the charged tracks. Events were selected at the ψ with use of the identical kinematic cuts described earlier for the ρl events except that we removed the two-photon requirement. The fraction of $\psi \to \pi^+\pi^-\pi^0$ events with two and only two photons was found to be $(87.3 \pm 7)\%$. We interpret this as implying a 12.7% loss of ρl events and corrected the data accordingly.

We have calculated that the maximum contribution to the ρl signal from charmed-particle decays is two events. We have performed a check on this charm contamination estimate. In the same data set we should have observed two $\rho^\pm K^\mp$ events, one from charm and one from the τ itself, and indeed we see exactly two such events. Two events of the type $\rho^\pm e^\pm$ were found which serve as a measure of the contamination from multihadron annihilation events. Accordingly, four events were subtracted from the $\rho^\pm e^\mp$ events for the purposes of calculating the $\tau \to \rho\nu$ branching fraction.

Given the above considerations we assumed that the remaining 81 ρl events were coming from τ decays only, and more specifically from (a) $\tau \to \rho\nu$, (b) $\tau \to A_1\nu$, and (c) $\tau \to 4\pi\nu$. We have used a Monte Carlo simulation program to study the contamination from (b) and (c). As input to the Monte Carlo program we have used the estimate for $B(\tau \to 4\pi\nu)$ of Gilman and Miller.[8] We predict that this mode contributes 2.5 ρe events and 1 $\rho\mu$ event to our ρl sample. For the feed-down from $\tau \to A_1\nu$ we have assumed a 10% branching fraction which is consistent with most theoretical predictions[8,9] and a measurement of $B(\tau \to A_1\nu) = (10.4 \pm 3.8)\%$.[10] There is also a measurement[11] for $\tau \to \pi^\pm\pi^+\pi^-\nu$ of $(7 \pm 5)\%$ which is in good agreement with our assumption. We find that $\tau \to A_1\nu$ contributes 5.8 ρe events and 1.6 $\rho\mu$ events to our ρl sample. Because of the uncertainties involved in these subtractions we have added a 5% systematic error to our final result which corresponds to a 50% error in our knowledge of $B(\tau \to A_1\nu)$. After all the corrections there are 61.9 ± 11.2 ρe events and 20.5 ± 5.8 $\rho\mu$ events.

In order to extract the $\tau^- \to \rho^-\nu_\tau$ branching fraction from the ρl events, we need to know $B(\tau^- \to l^-\nu_\tau\bar{\nu}_l)$. We have measured this branching fraction with events which had an electron, a muon, and no detected photons ($e\mu$ events). The two charged tracks were required to be acoplanar[6] by at least 10°, and the vertex requirement was the same as for the ρl events. We have 95 such events, which we correct for losses due to spurious photons. To determine this loss we measure the fraction of cosmic-ray events containing no photons and find this to be 94%, which results in a corrected $e\mu$ signal of 101.5 events.

The efficiencies for detecting ρe, $\rho\mu$, and $e\mu$ events were found with a Monte Carlo program to be $\epsilon_{\rho e} = 6.4\%$, $\epsilon_{\rho\mu} = 2.7\%$, and $\epsilon_{e\mu} = 12.9\%$. Combining these efficiencies with the number of produced $\tau^+\tau^-$ pairs and the numbers of corrected events yields the following results:

$$B(\tau^- \to \rho^-\nu_\tau)B(\tau^- \to e^-\nu_\tau\bar{\nu}_e) = 0.0421 \pm 0.0090,$$

$$B(\tau^- \to \rho^-\nu_\tau)B(\tau^- \to \mu^-\nu_\tau\bar{\nu}_\mu) = 0.0329 \pm 0.0100,$$

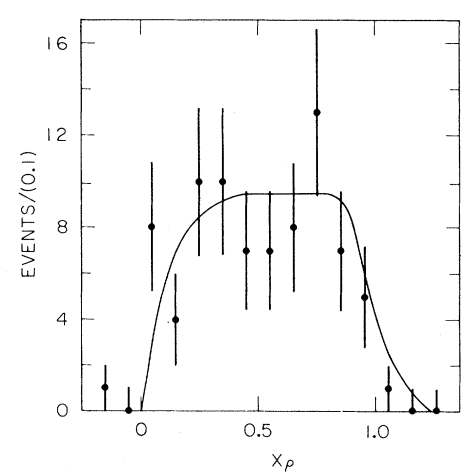


FIG. 3. The distribution $X_\rho = (E_\rho - E_{\min})/(E_{\max} - E_{\min})$ for the 85 $\rho^\pm$ candidates. Here $X_\rho = 0$ (1) corresponds to the minimum (maximum) energy allowed for the ρ in the decay $\tau \to \rho\nu$.

and

$$[B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) B(\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu)]^{1/2} = 0.185 \pm 0.015 .$$

A correction for initial-state radiation of 1% has been applied to these results. The errors are based on the statistics of the uncorrected events and the statistical error of the corrections and Monte Carlo efficiencies. In addition systematic errors have been included to account for uncertainties in the luminosity (6%), lepton tagging efficiencies and misidentification probabilities (5%), and an uncertainty in the calculation of the number of produced $\tau^+\tau^-$ pairs due to initial-state radiation effects (5%). If we assume that $B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = B(\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu)$ then we obtain the following results[12]:

$$B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = (18.5 \pm 1.5)\% ,$$

$$B(\tau^- \to \rho^- \nu_\tau) = (20.5 \pm 4.1)\% ,$$

where we have now incorporated the systematic error associated with the feed-down correction in our measurement of $B(\tau \to \rho\nu)$. We further obtain the ratio

$$B(\tau^- \to \rho^- \nu_\tau)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = 1.11 \pm 0.23 .$$

In conventional models the τ^- couples via the strangeness-nonchanging vector current to produce $\tau^- \to \rho^- \nu_\tau$. Thacker and Sakurai,[9] Tsai,[9] and Gilman and Miller[8] have used the CVC hypothesis and measurements of $e^+e^- \to \rho^0$ to calculate the ratio $B(\tau \to \rho\nu)/B(\tau \to e\nu\bar{\nu})$. In particular, Gilman and Miller,[8] under the assumption of $M_\tau = 1.8$ GeV/c^2 and the experimental restriction of $0.27 \leq M_{\pi^\pm \pi^0} \leq 1.26$ GeV/c^2, find this ratio to be 1.2 which is in good agreement with the data. These data are also in agreement with the measurement of $B(\tau \to \rho\nu) = (24 \pm 9)\%$ by Brandelik *et al.*[13]

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[a]Deceased.

[b]Present address: CERN, Geneva 23, Switzerland.

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

[d]Present address: Rockwell International, Science Center, Thousand Oaks, Cal. 91360.

[e]Present address: Harvard University, Cambridge, Mass. 02138.

[f]Present address: Universität Bonn, Bonn, Federal Republic of Germany.

[1]M. L. Perl *et al.*, Phys. Rev. Lett. 35, 1489 (1975); M. L. Perl *et al.*, Phys. Lett. 63B 466 (1976).

[2]W. Bacino *et al.*, Phys. Rev. Lett. 42, 749 (1979).

[3]See for instance G. Feldman, in *Proceedings of the Nineteenth International Conference on High Energy Physics, Tokyo, Japan, August, 1978*, edited by S. Homma, M. Kawaguchi, and H. Miyazawa (Physical Society of Japan, Tokyo, 1979), p. 777.

[4]The notations $\tau^- \to \rho^- \nu_\tau$ and $\tau^- \to l^- \nu_\tau \bar{\nu}_l$, used throughout the text, imply also the charge-conjugate reactions $\tau^+ \to \rho^+ \bar{\nu}_\tau$ and $\tau^+ \to l^+ \bar{\nu}_\tau \nu_l$.

[5]G. S. Abrams *et al.*, Phys. Rev. Lett. 43, 477 (1979).

[6]The acoplanarity angle is defined as $180^0 - \delta\varphi$, where $\delta\varphi$ is the difference in the azimuthal angles of the two charged particles.

[7]There are fewer $\rho\mu$ events because of the 700-MeV/c momentum threshold of the muon tagging system; for comparison there are 25 ρe events with electron momenta above 700 MeV/c.

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[11]J. A. Jaros *et al.*, Phys. Rev. Lett. 40, 1120 (1978).

[12]We wish to point out that this is not our definitive measurement of $B(\tau \to e\nu\bar{\nu})$. A more thorough study of this quantity will be published at a later date. We use it here to obtain $B(\tau \to \rho\nu)$ and $B(\tau \to \rho\nu)/B(\tau \to e\nu\bar{\nu})$ as some systematic errors, common to both measurements, cancel in these determinations.

[13]R. Brandelik *et al.*, Z. Phys. C 1, 233 (1979).