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New determination of the Michel parameter in tau decay

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We have used the leptonic decays of the tau to determine the Lorentz structure of its decay vertex. We find the Michel parameter ρ to be $0.71 \pm 0.09 \pm 0.03$, which is consistent with $V-A$ ($\rho = 0.75$) and inconsistent with $V+A$. This measurement represents the first such analysis using muons in the final state.

Evidence to date indicates that the tau lepton is the sequential partner of the muon and electron, displaying universality with these lighter leptons.[1,2] A previous measurement[3] indicated that the decay of the tau to an electron and neutrinos proceeds via a $V-A$ current. We have made a new electron measurement and have used muons to make a further determination of the decay Lorentz structure.

The data were taken with the CLEO detector[4] at the Cornell Electron Storage Ring in running periods covering the energy regions below, at, and above the $\Upsilon(4S)$ resonance ($W = 10.34$ to 11.18 GeV), in which we accumulated 128.3 pb^{-1} of integrated luminosity. Since the branching fraction of B mesons to τ is small and since such events have large multiplicity, it was assumed that all the $\tau\tau$ events came from the continuum and none from the decay of the $\Upsilon(4S)$. A sample of $\tau\tau$ events with the characteristic 1-vs-3 topology was extracted using criteria previously described.[5] The total visible charged energy is limited to the range 3.5 to 9.0

GeV to eliminate radiative Bhabba events at high energy and two photon events at low energy. Cuts are also made on the back-to-back nature of the single-prong and three-prong events (acollinearity) and the decay distributions of the three-prong events (invariant mass, opening angles, etc.). Events were then further selected which had only one electron (muon) with that electron (muon) as the single prong. The selection criteria for electrons involved energy depositions in the wide-angle shower and dE/dx systems; muons were selected by matching tracks from the inner drift chamber to those in the large planar drift chambers which are outside a hadron absorber. These criteria led to a sample of 699 (727) $\tau\tau$ events with an electron (muon) as the single prong. The Lorentz structure of τ decay was studied by comparing the energy spectra of these leptons to the theoretical predictions.

The lepton momentum spectrum in the tau rest frame is given in terms of $x = 2E_l^*/m_\tau$ as[6]

$$d\Gamma/dx = 4\pi G_{\pm} x^2[3(1-x)+2\rho(4x-3)/3+(\alpha/4\pi)f_{\pm}(x)],$$

$$G_{\pm} = G_f{}^2 m_\tau{}^5 (a_{\pm})^2/384\pi^4 \ .$$

As discussed below, the lepton energy ranges were confined to values such that their masses could be neglected. Here α is the fine-structure constant, E_l^* is the lepton energy, the variables $a_{\pm}$ allow $V \pm A$ to have different normalizations, and the functions $f_{\pm}$ incorporate the radiative corrections.[6] For electrons the fractional contribution of these radiative corrections is largest at small x ($+52\%$ at $x=0.1$) for which $d\Gamma/dx$ is very small, but this contribution falls rapidly becoming $\pm 13\%$ over the range $0.25 < x < 0.99$. For muons the corrections are only 1% to 3% over the entire kinematic range. The Michel parameter ρ takes on the values 0.00, 0.375, and 0.750 for $V+A$, V or A, and $V-A$, respectively. Theoretical distributions of the lepton energy in the laboratory were generated from $d\Gamma/dx$ in accordance with the distribution of luminosity as a function of beam energy and including the effects of initial-state radiation. Figure 1 shows the expected spectra for $V+A$ and $V-A$ for the two lepton species. Spectra for values of ρ other than 0.00 and 0.75 were obtained via linear combination, mixing these two extremes in the correct proportion.

The data must be corrected for efficiency and background, both of which depend on lepton energy. The observed $\tau\tau$ yield is given by

$$N_\tau^{\text{obs}} = N_\tau^{\text{true}} \epsilon_{\text{trk}} \epsilon_l + N^{\text{fake}} \ ,$$

where N_τ^{true} is the actual number of $\tau\tau$ events produced in the e^+e^- collisions, ϵ_{trk} is the efficiency for finding a $\tau\tau$ event which passes all the 1-vs-3 cuts and includes a single-prong lepton that reaches the particle identifiers, and ϵ_l is the probability of identifying the lepton correctly. N^{fake} includes backgrounds from three sources: (i) $\tau\tau$ events with single-prong hadrons misidentified as leptons, (ii) $\tau\tau$ events with topologies other than 1-vs-3, and (iii) hadronic events which mimic $\tau\tau$ decays. These fakes represent approximately 5% of the observed events. We used the known topological branching fractions[7–9] for the τ. The electron-identification efficiency was determined by embedding electrons from radiative Bhabha events in low-multiplicity hadron events in the CLEO data-analysis software. Data from the $\Upsilon(1S)$ were used to determine the probability of hadrons faking electrons and muons. Standard simulation techniques were used to determine the other elements of the efficiencies and backgrounds. These efficiencies were calculated for an electron energy range from 0.6 to 4.8 GeV; for muons the range was restricted to 2.0–4.6 GeV to avoid regions for which the overall efficiency varies rapidly with energy. For electrons the product $\epsilon_{\text{trk}}\epsilon_l$ rises from 4% at $E_e = 500$ MeV to 17% at $E_e = 1.5$ GeV, and then remains essentially flat; for muons this efficiency product is approximately 24% over the entire range used.

The corrected lepton energy distributions, shown in Fig. 1, are compared to the theoretical spectra to determine the goodness of fit (χ^2) as a function of the Michel parameter ρ for our electron and muon samples. The best fit for electrons (muons) gave $\rho = 0.60 \pm 0.13$ (0.81 ± 0.13). The combined sample yields $\rho = 0.71 \pm 0.09 \pm 0.03$, with the first error being statistical and the second being systematic. The result is to be compared to the value $\rho = 0.72 \pm 0.15$ from Ref. 3. The statistical error arises from the number of τ events and the data used for determining ϵ_e. For 34 degrees of freedom, the χ^2 and confidence levels from the combined analysis are 93.3 ($<0.001\%$), 49.4 (6%), and 37.2 (37%) for $V+A$, V or A, and $V-A$, respectively. These results agree with the $V-A$ prediction, rule out $V+A$ theory, and, to a lesser extent, disagree with purely V or purely A.

The contribution to the systematic error in ρ from the uncertainties in τ branching fractions and from the efficiencies and backgrounds determined from data simulation is 0.026. An additional systematic error arises from the uncertainty in the exact nature of the three-prong decay [i.e., $A_1\nu$, $\pi\pi\pi\nu$ phase space, $\pi\pi\pi(n\pi^0)\nu$, etc.] since our cut on total charged energy is important at large lepton energies. The model used has 40% of the three-prong events associated with one or more π^0's (Ref. 8), 54% charged pions coming from an A_1 with mass of 1100 MeV/c^2 and width of 475 MeV/c^2, and 6% charged pions from a phase-space decay.[10] Varying these components within reasonable limits[11] indicates an uncertainty of 0.015 in ρ. Taking the two systematic errors in quadrature, our combined systematic error is 0.03.

In summary, we have made a new measurement of the Michel parameter of τ decay to electrons and the first mea-

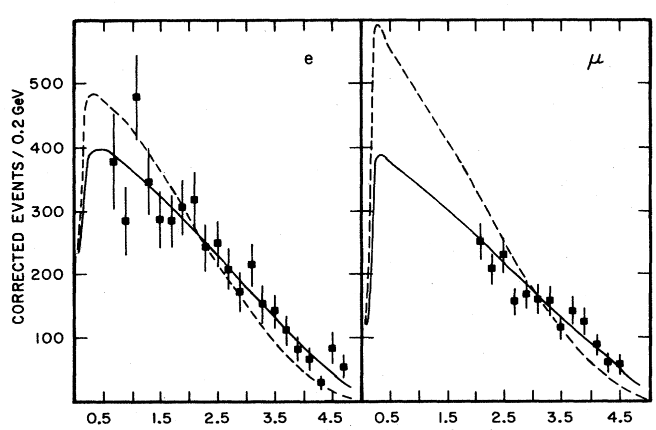

FIG. 1. The distribution in laboratory energy of the electrons and muons from our τ decay sample. The entries have been corrected for efficiencies and backgrounds and their errors are statistical. The solid (dashed) curves are those expected from $V-A$ ($V+A$).

surement of this parameter for τ decay to muons. Our result of $\rho = 0.71 \pm 0.09 \pm 0.03$ is consistent with τ decay proceeding through the $V-A$ current.

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[10]This is consistent with our own analysis of the $\pi\pi$ and $\pi\pi\pi$ mass spectra of 1-vs-3 events and with that of the ARGUS group at DESY (private communication).

[11]For the one extreme we chose 60% of the three-prong events to be accompanied by a π^0 (as in Ref. 9) and the remainder to come from A_1 decays. For the other we chose 30% to have a π^0 (Ref. 8), 40% to come from A_1 and 30% to result from phase-space decay to $\pi\pi\pi\nu$.