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MEASUREMENT OF THE DECAYS $\tau^- \to \rho^- \nu_\tau$ and $\tau^- \to K^{*-}(892)\nu_\tau$ USING THE MARK II DETECTOR AT SPEAR*

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ABSTRACT

Measurement of the branching fractions for the Cabibbo favored decay $\tau^- \to \rho^- \nu_\tau$ and the Cabibbo suppressed decay $\tau^- \to K^{*-}(892)\nu_\tau$ are presented. The energy dependence of the $\tau^+\tau^-$ production cross section is measured using the decay $\tau^- \to \rho^- \nu_\tau$ which yields a measurement $M_\tau = (1790 \pm 40)$ MeV. A 2σ upper limit for the forbidden decay $\tau^- \to K^{*-}(1430)\nu_\tau$ is also presented.

INTRODUCTION

The heavy lepton is now a well established particle. Leptonic and hadronic branching fractions of the τ have been measured and agreement between the experimental determinations and the theoretical calculations is good.[1] This agreement supports the notion that decays of the τ are mediated by the W boson. We present herein measurements of the branching fractions for $\tau^- \to \rho^- \nu_\tau$ and $\tau^- \to K^{*-}(892)\nu_\tau$[2] which probe respectively the Cabibbo favored and Cabibbo suppressed weak hadronic coupling in τ decays. The data were obtained by the SLAC-LBL group using the Mark II detector at SPEAR.[3] We reported recently[4] a measurement of the branching fraction for the decay $\tau^- \to \rho^- \nu_\tau$ and the results presented herein represent our final measurement of $B(\tau^- \to \rho^- \nu_\tau)$ based on approximately four times as much data. Using eleven events (of which two are background) containing $K^{*\pm}(892)$ -- $\ell^\pm$ coincidences (the symbol ℓ stands for either an electron or a muon) we obtain the first measurement of a τ Cabibbo suppressed branching fraction.

MEASUREMENT OF THE BRANCHING FRACTION FOR $\tau^- \to \rho^- \nu_\tau$

The Mark II solenoidal detector is fully described in the articles listed under Ref. 5. The data used for this analysis come from all Mark II running at SPEAR with the exception of the ψ and ψ'.[6] These data span the center-of-mass energy range $3.52 \le E_{c.m.} \le 6.7$ GeV, and correspond to an integrated luminosity of 21,000 nb^{-1} or, using the theoretical $\tau^+\tau^-$ production cross section, 58,000 produced $\tau^+\tau^-$ pairs. In searching for the decay $\tau^- \to \rho^- \nu_\tau$, we attempt to isolate events arising from the decay sequence:

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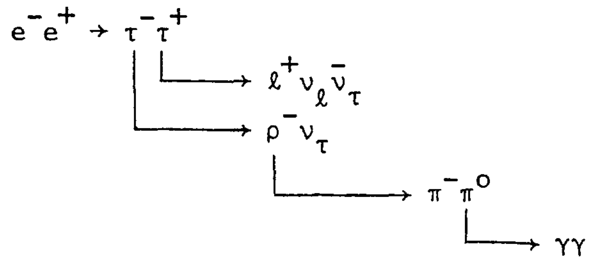


which results in two charged tracks and two photons in the detector. The lepton tag (ℓ^+) helps provide a clean signature for events containing τ's. The selected events have two oppositely charged tracks, one a pion and the other a lepton, and two photons with $E_\gamma \geq 100$ MeV. For the purposes of this analysis a pion is any charged particle which is not positively identified as a kaon, proton, electron or muon. The invariant mass of the two photons ($M_{\gamma\gamma}$) is formed and the photon energies of the π^0 candidates (those for which $80 \leq M_{\gamma\gamma} \leq 200$ MeV) are adjusted using the π^0 mass as a single constraint. These π^0's are then combined with the charged pion to form the $\pi^\pm\pi^0$ invariant mass ($M(\pi^\pm\pi^0)$) as shown in Fig. 1. An impressive $\rho^\pm$ signal is seen with very little background. Defining the signal region as $M(\pi^\pm\pi^0) \leq 1.25$ GeV/c^2 there are 215 ρe events and 137 $\rho\mu$ events. There are fewer $\rho\mu$ events because of the 700 MeV/c threshold of the muon tagging system. Background contributions of 12% due to hadronic events and 14% due to the decays $\tau \to A_1\nu_\tau$ and $\tau \to (4\pi)\nu_\tau$ are removed. In order to obtain $B(\tau^- \to \rho^-\nu_\tau)$ we need to know $B(\tau^- \to \ell^-\nu_\ell\bar{\nu}_\tau)$. This has been measured using 294 events containing an electron, a muon and no photons ($e\mu$ events). A small (12%) correction is made to these events for backgrounds arising from QED and hadronic processes. A Monte Carlo simulation program has been used to generate the detection efficiencies $\varepsilon_{\rho e} = 3.4\%$, $\varepsilon_{\rho\mu} = 2.1\%$ and $\varepsilon_{e\mu} = 7.1\%$. Combining these efficiencies with the number of corrected events and the number of produced $\tau^+\tau^-$ pairs yields:

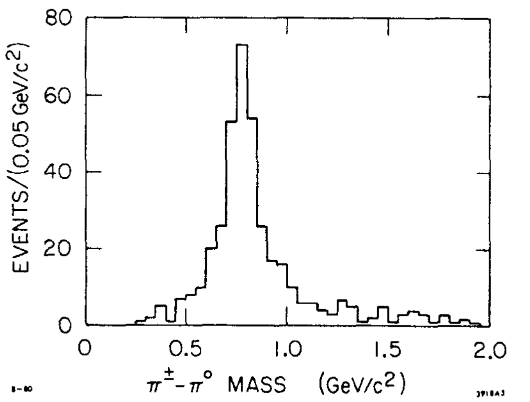


Fig. 1. The $\pi^+\pi^0$ invariant mass spectrum for $\ell^\pm\pi^\mp\pi^0$ events.

$$B(\tau^- \to \rho^-\nu_\tau)\; B(\tau^+ \to e^+\bar{\nu}_\tau\nu_e) = 0.034 \pm 0.004 \pm 0.007 \quad (1)$$

$$B(\tau^- \to \rho^-\nu_\tau)\; B(\tau^+ \to \mu^+\bar{\nu}_\tau\nu_\mu) = 0.041 \pm 0.005 \pm 0.007 \quad (2)$$

$$B(\tau^- \to e^-\nu_\tau\bar{\nu}_e)\; B(\tau^+ \to \mu^+\bar{\nu}_\tau\nu_\mu) = 0.030 \pm 0.002 \pm 0.007 \quad (3)$$

where the first error is statistical and the second is systematic.

Assuming μ-e universality in τ decays (3) can be combined with (1) and (2) to yield

$$B(\tau^- \to \rho^-\nu_\tau) = (21.6 \pm 1.8 \pm 3.2)\% \quad .$$

The branching fraction $B(\tau^- \to \rho^- \nu_\tau)$ can be calculated[7] using the conserved vector current hypothesis and a measurement of $e^+e^- \to \rho^0$. Tsai has recently[8] updated his calculations of 1971 and obtains $B(\tau^- \to \rho^- \nu_\tau) = 21.5 \pm 1.5$ where the uncertainly in $B(\tau^- \to \rho^- \nu_\tau)$ arises from the experimental uncertainly in $\Gamma(e^+e^- \to \rho^0)$. This calculation of $B(\tau^- \to \rho^- \nu_\tau)$ agrees well with the experimental result.

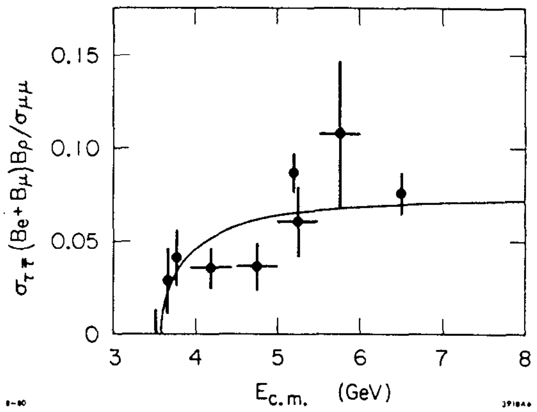


Fig. 2. The $\tau\bar{\tau}$ production cross section, normalized to the mu-pair cross section, as a function of $E_{c.m.}$.

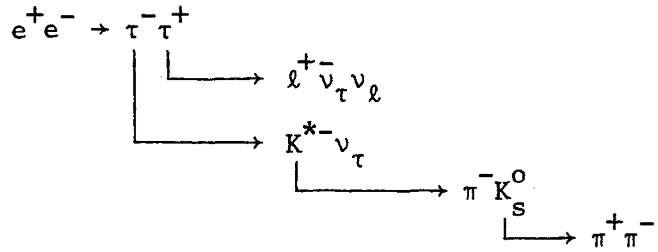
We have measured the energy dependence of the $\tau^+\tau^-$ production cross section ($\sigma_{\tau\bar{\tau}}$) by studying the quantity $\sigma_{\tau\bar{\tau}} B\rho (B_e + B_\mu)/\sigma_{\mu\mu}$, where $\sigma_{\mu\mu}$ is the point cross section. Figure 2 shows a plot of this quantity as a function of center-of-mass energy. A fit to this data yields a measure of the τ mass:

$$M_\tau = (1790 \pm 40)\ \mathrm{MeV}/c^2$$

which is in good agreement with other experimental determinations.[1]

MEASUREMENT OF THE BRANCHING FRACTION FOR $\tau^- \to K^{*-}(892)\nu_\tau$

For the study of the decay $\tau^- \to K^{*-}(892)\nu_\tau$ we have used all the Mark II data with $E_{c.m.} > 4.2$ GeV, which corresponds to an integrated luminosity of 14,600 nb^{-1} or 40,200 produced $\tau^+\tau^-$ pairs.[9] The energy threshold of 4.2 GeV is chosen to avoid those regions where production of D mesons could constitute a significant background. The decay $\tau^- \to K^{*-}\nu_\tau$ is identified via the topology:



which results in four charged particles and no photons in the detector. Events are required to have four charged particles, two positive and two negative, and no photons with $E_\gamma \geq 100$ MeV. Two of the charged particles are required to form a secondary vertex, distant from the primary vertex by at least 1 cm, and have a mass consistent with the K^0_S. We further require that one of the particles at the primary vertex be a lepton; the other is hitherto referred to as a $\pi^\pm$.

Figure 3 shows the $K_S^0\pi^\pm$ invariant mass spectrum for the events selected as described above. A clear excess of events is present at the $K^*(892)$ mass and we attribute these $K^*(892)$-lepton coincidences to the decay topology outlined at the beginning of this section. From the eleven events in the five bins from 925-950 MeV/c^2 we have subtracted a background of two events obtained from the ten surrounding bins. The resulting signal is 9.0 ± 3.6 events. Of the eleven events, seven have an electron tag and four a muon tag which is consistent with the relative electron/muon tagging efficiency of 1.6. The momentum spectrum of the leptons is "hard" -- nine out of eleven leptons have momenta above 700 MeV/c. This momentum spectrum and that of the K^*'s is well reproduced by the Monte Carlo simulation program assuming a $\tau^+\tau^-$ production process.

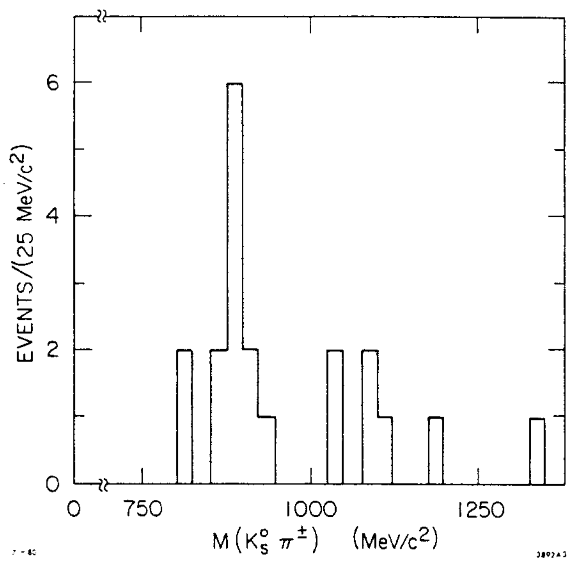


Fig. 3. $K_S^0\pi^\pm$ invariant mass spectrum for $K_S^0\pi^\pm\ell^\mp$ events.

Since D mesons are both a source of leptons and strange particles it is important to eliminate them as a source of the K^*-ℓ-no photon events. Charm events have a relatively high charged and neutral multiplicity and this, combined with the good solid angle coverage of the Mark II detector, make it very difficult for charmed events to populate the low multiplicity $K_S^0\pi^\pm\ell^\mp$ topology. A Monte Carlo program has been used to estimate the D background. Charmed particle production contributes at most 0.1 events to the $K^{*\pm}\ell^\mp$ sample. The leptons which come from semi-leptonic D decays, as simulated by the Monte Carlo program, have a momentum spectrum which is much "softer" than that observed in the $K^*\ell$ events. Almost all these leptons would have momenta below 700 MeV/c, in strong contrast to the data.

The detection efficiencies for the K^*-electron and K^*-muon events are 2.1% and 1.3% respectively. These efficiencies are combined with the number of produced $\tau^+\tau^-$ pairs and the number of signal events to yield

$$B(\tau^- \to K^{*-}(892)\nu_\tau)\ B(\tau^+ \to \ell^+\nu_\ell\bar{\nu}_\tau) = 0.0031 \pm 0.0013 \quad .$$

Using the Mark II measurement[4] of

$$B(\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau) = (18.5 \pm 1.5)\%$$

and assuming electron-muon universality in τ decays, we obtain

$$B(\tau^- \to K^{*-}(892)\nu_\tau) = (1.7 \pm 0.7)\% \quad .$$

We observe no $K^{*\pm}\ell^\mp$ events in the region of the $K^*(1430)$ which allows us to set a 2σ upper limit $B(\tau^- \to K^{*-}(1430)\nu_\tau) < 0.9\%$. This decay is, of course, forbidden in any V/A theory.

A detailed calculation by Tsai[7] yields

$$B(\tau\to K^{*}\nu_{\tau}) = \tan^{2}\theta_{C}\, B(\tau\to\rho\nu_{\tau})\, F(M_{\tau},M_{K^{*}},M_{\rho}) \quad .$$

The function F accounts for phase space effects and is numerically equal to 0.93. Using the value $B(\tau^{-}\to\rho^{-}\nu_{\tau}) = (21.5\pm1.8)\%$ quoted earlier, $\tan^{2}\theta_{C} = 0.05$ and $M_{\tau} = 1.782$ GeV/c^2, theory would predict $B(\tau^{-}\to K^{*-}\nu_{\tau}) = (1.0\pm0.1)\%$ in good agreement with the data.

CONCLUSIONS

We find that the branching fractions for the decay modes $\tau^{-}\to\rho^{-}\nu_{\tau}$ and $\tau^{-}\to K^{*-}\nu_{\tau}$ are in good agreement with the theoretical predictions and hence support the notion that the standard vector weak hadronic coupling mediates τ decays. The measured values are $B(\tau^{-}\to\rho^{-}\nu_{\tau}) = (21.6\pm1.8\pm3.2)\%$ and $B(\tau^{-}\to K^{*-}(892)\nu_{\tau}) = (1.7\pm0.7)\%$, where the latter is the first measurement of a Cabibbo suppressed decay of the τ. Using the decay $\tau^{-}\to\rho^{-}\nu_{\tau}$ we have explored the energy dependence of the $\tau^{+}\tau^{-}$ production cross section which yields a measurement of (1790 ± 40) MeV/c^2 for the τ mass. We are also able to set a 2σ upper limit of 0.9% for the forbidden decay $\tau^{-}\to K^{*-}(1430)\nu_{\tau}$.

REFERENCES

1. See for instance G. Feldman, Proc. of the 19th International Conference on High Energy Physics, Tokyo (1978), p. 777.
2. The notation $\tau^{-}\to\rho^{-}\nu_{\tau}$, $\tau^{-}\to\ell^{-}\nu_{\tau}\bar{\nu}_{\ell}$ and $\tau^{-}\to K^{*-}\nu_{\tau}$ imply also the charge conjugate reactions.
3. Members of the SLAC-LBL collaboration: 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, W. E. Dieterle, J. B. Dillon, J. Dorenbosch, M. W. Eaton, G. J. Feldman, M. E. B. Franklin, G. Gidal, G. Goldhaber, G. Hanson, K. G. Hayes, T. Himel, D. G. Hitlin, R. J. Hollebeek, W. R. Innes, J. A. Jaros, P. Jenni, A. D. Johnson, J. A. Kadyk, A. J. Lankford, R. R. Larsen, V. Lüth, R. E. Millikan, M. E. Nelson, C. Y. Pang, J. E. Patrick, M. L. Perl, B. Richter, A. Rousarrie, D. L. Scharre, R. H. Schindler, R. F. Schwitters, J. L. Siegrist, J. Strait, H. Taureg, M. Tonutti, G. H. Trilling, E. N. Vella, R. A. Vidal, I. Videau, J. M. Weiss and H. Zaccone.
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5. The most thorough review of the detector appears in Vera Lüth's talk in the Proc. of the 1979 International Symposium on Lepton and Photon Interactions at High Energy, Batavia (1979), p. 78. Also G. S. Abrams <u>et al</u>., Phys. Rev. Lett. <u>43</u>, 477 (1979).
6. The results presented in this section are more fully discussed in Craig Blocker's Ph.D. Thesis, LBL-10801, April 1980.
7. M. B. Thacker and J. J. Sakurai, Phys. Lett. <u>36B</u>, 103 (1971); Y.-S. Tsai, Phys. Rev. <u>D4</u>, 2821 (1971).
8. Y.-S. Tsai, SLAC-PUB-2450 (to be published in the Proc. of the Guangzhou Conference on Theoretical Particle Physics, January 5-14, 1980).
9. This analysis is more fully described in SLAC-PUB-2566 (submitted to Phys. Rev. Lett.).