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Measurement of the Branching Fraction for the Cabibbo-Suppressed Decay $\tau^- \to K^- \nu_\tau$

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The branching fraction for the Cabibbo-suppressed decay $\tau^- \to K^- \nu_\tau$ is measured from data obtained with the Mark II detector at SPEAR. Fifteen events containing a $K^\pm$ in coincidence with a muon or electron of opposite charge are observed. It is determined that $B(\tau^- \to K^- \nu_\tau) = (1.3 \pm 0.5)\%$.

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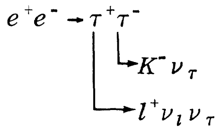
We present a measurement of the branching fraction for the decay[1] $\tau^- \to K^- \nu_\tau$, the Cabibbo-suppressed counterpart of the decay $\tau^- \to \pi^- \nu_\tau$. In the sequential lepton model, the τ couples to the standard hadronic weak current, producing $u\bar{d}$ ($u\bar{s}$) quarks proportionally to $\cos\theta_C$ ($\sin\theta_C$) where θ_C is the Cabibbo angle (~ 15°). The presence of the $\tau^- \to K^- \nu_\tau$ decay indicates that the Cabibbo-suppressed axial-vector hadronic current is coupled to the τ and supports the hypothesis that the standard weak current mediates decays of the τ. Previously we published[2,3] measurements of the branching fractions for $\tau^- \to \pi^- \nu_\tau$, $\tau^- \to \rho^- \nu_\tau$, and $\tau^- \to K^{*-}(892)\nu_\tau$, all in good agreement with theoretical expectations based on a standard hadronic weak coupling. These measurements indicate that the Cabibbo-favored axial-vector and vector hadronic currents and the Cabibbo-suppressed vector hadronic current, respectively, are coupled to the τ with the expected strength.

The measurement is based on Mark-II–SPEAR data over the center-of-mass energy range $3.88 < E_{\text{c.m.}} < 6.7$ GeV, with a total integrated luminosity of 17000 nb^{-1}, corresponding to 47000 produced $\tau^+\tau^-$ pairs. All aspects of the Mark II solenoidal detector pertinent to this measurement have been fully discussed elsewhere.[4]

The decay $\tau^- \to K^- \nu_\tau$ is identified by the topology



$$\begin{array}{l} e^+e^- \to \tau^+\tau^- \\ \qquad\quad \tau^- \to K^-\nu_\tau \\ \qquad\quad \tau^+ \to l^+\nu_l\nu_\tau \end{array}$$

which results in two charged particles and no photons in the detector. The symbol l represents either an electron or a muon. Events are required to have exactly two, oppositely charged particles and no photons with energy above 100 MeV. For photons below 100 MeV, the liquid argon system is inefficient, and spurious photons created from electronic noise dominate. The two charged particles are required to be acoplanar[5] by at least 20° and to form a good vertex within 10 cm of the beam interaction point, as measured along the beam direction. One of the charged particles is required to be a lepton and the other not to be identified as a lepton. The selection criteria for leptons are identical to those used in the analysis of $\tau^- \to \pi^- \nu_\tau$ and are discussed in Ref. 2.

The square of the mass of the nonlepton track is calculated from the measured time of flight (TOF), momentum, and path length. Figure 1 shows a scatter plot of mass squared versus momentum. The contours are 3-standard-deviation limits (calculated with a 310-psec TOF resolution and average path length) for electrons and pions and 2-standard-deviation limits for kaons and protons. A clear kaon signal is seen. All particles in the proton region of Fig. 1 are consistent with coming from either beam-gas interactions or tails of the e, μ, π, and K distributions. The absence of kaons in two-prong lepton events with a vertex displaced along the beam direction demonstrates that beam-gas interactions are not a background to lepton-K events.

Kaon candidates have a measured TOF within 2.5 standard deviations of the expected time (calculated from the momentum, path length, and mass) for a kaon, greater than 4 standard deviations from the expected time for a pion, and greater than 2 standard deviations from the expected time for a proton. The TOF resolution function including non-Gaussian tails is measured by using two-prong events with either a low-momentum pion ($100 < p < 125$ MeV/c) or two muons with the full beam energy (μ-pair events). In Fig. 2, the difference between the measured and expected TOF is shown for a typical sample of μ-pair events. The curve is a Gaussian fit to the data. The μ-pair events and low-momentum pions give similar results, and the averages are summarized in Table I for various blocks of data.

Fifteen lK events satisfy the selection criteria described above. From the observed number of $l(e,\mu,\pi)$ events in Fig. 1 and from Table I, it is estimated that 1.9 ± 0.5 $l(\pi,\mu,e)$ events are classified as lK events. From a Monte Carlo program, it is calculated {on the basis of $B[\tau^- \to K^{*-}(892)\nu_\tau] = (1.7 \pm 0.7)\%$ from Ref. 3} that the process $e^+e^- \to \tau^+\tau^- \to (l^+\nu_l\bar{\nu}_\tau)(K^{*-}\nu_\tau) \to (l\nu\nu)(K^-\pi^0\nu_\tau)$ contributes 2.5 ± 1.0 events to the lK class. To ensure that the lepton tags are not misidentified hadrons, events are selected with the same criteria as lK events except the tagging particle is required not to be a lepton, resulting in 30 KX events. Ascribing all the 15 lK events to misidentification of the lepton tag implies a 33% misidentification probability, inconsistent with the measured values of ≤5% for the Mark II dectector. In fact, the ratio of KX to lK events is consistent with both classes of events coming solely from τ production and decay. Classification of lK (KX) events as KX (lK) events is included in the efficiency calculation. Subtracting the background events gives a net signal of $10.6 \pm 3.9 \pm 1.1$ events.[6] The statistical significance of this result can be judged from the fact that the probability that 4.4 background events fluctuate (including the uncertainty in the background calculation) to give 15 or more events is 5×10^{-4}. Of the 15 lK events, 11 (4) have an electron (muon) tag, consistent with the relative electron/muon tagging efficiency of ~1.8. The momentum spectra for the lepton tags and the K's are well reproduced by the Monte Carlo program. In particular, the lepton momentum spectrum is "hard," that is, 8 of the 15 leptons have momenta above 700 MeV/c.

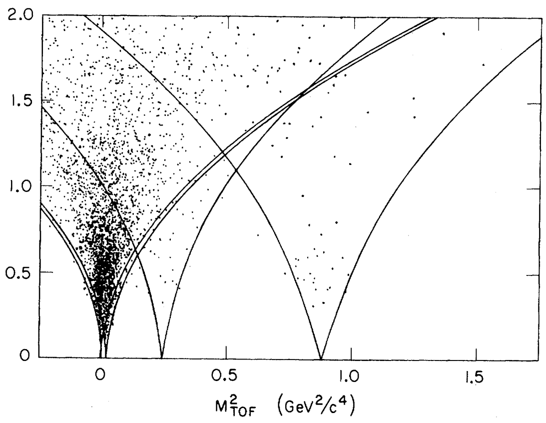


FIG. 1. Scatter plot of the square of the mass determined from TOF vs momentum for acoplanar, two-prong events with a lepton tag. The contours are 3-standard-deviation limits for electrons and pions and 2-standard-deviation limits for kaons and protons.

Since charmed-particle decays produce both leptons and strange particles, it is important to establish that the lepton lK events are not from charm production. Since there are no $l^\pm K^\pm$ events, it can be assumed that most of the $l^\pm K^\mp$ events have no undetected charged particles. The relatively

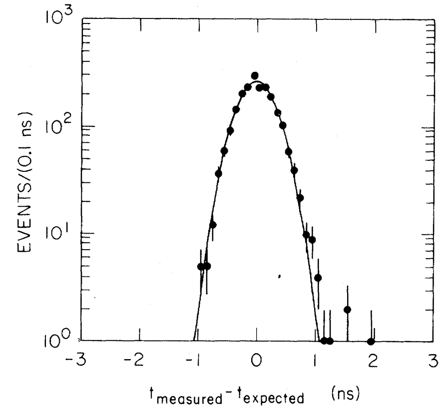


FIG. 2. Measured minus expected TOF for μ-pair events from the 5.2-GeV data sample.

TABLE I. TOF performance for various data samples.

$E_{\text{c.m.}}$ (GeV)	Number of produced τ pairs	TOF (psec)	$10^3\times$ measured probability that TOF $-t_{\text{exp}} > 4\sigma$	$N_{\pi,e,\mu}$, $0.5<p<1.2$ Gev/c
3.88–4.5	11 100	315	2.3 ± 0.9	468
4.5–6.0	11 100	283	0.2 ± 0.2	416
5.2	15 300	320	0.7 ± 0.4	515
6.0–6.7	9 500	310	1.2 ± 0.8	252

high charged and neutral multiplicities of charm events coupled with the good solid-angle coverage of the Mark II detector make it unlikely that charm events populate the low multiplicity l-K-(no-photon) topology. Semileptonic charm decays produce leptons with the same sign of the charge as the charm quark. The decays $D^\pm, \Lambda_c^\pm \to K^\pm$ + neutrals are forbidden by the $\Delta S = \Delta C$ rule and are not background problems. A possible source of background is $e^+e^- \to D^0\overline{D}{}^0 + n\pi^0$, where $D^0 \to l^+K^-$ + neutrals and $\overline{D}{}^0 \to$ all neutrals. A Monte Carlo simulation program, adjusted to agree with the observed properties of D decays, has been used to estimate that at most 0.1 of the lK events are from D production. The F meson can decay via two distinct diagrams—the charm quark can decay ($F = c\bar{s} \to \bar{s}sW \to \bar{s}s + e\nu, \mu\nu, u\bar{d}$) or the charm and strange quarks can annihilate ($c\bar{s} \to W \to e\nu, \mu\nu, \tau\nu, u\bar{d}$). The decay diagram gives many kaons but few high-momentum leptons. The annihilation diagram gives high-momentum electrons but few kaons. With use of the branching fractions from Quigg and Rosner[7] and with the assumption of a conservative upper limit on $F\overline{F}$ production of 30% of the μ-pair cross section, it is estimated that at most 0.2 lK events come from F production for any combination of the decay and annihilation diagrams. As a result of the expected small rates of Cabibbo-suppressed charm decays, they are a negligible background. Finally, the leptons from charm production have a "softer" momentum spectrum (almost all of these leptons would have momenta below 700 MeV/c) than that observed in the lK events.

The detection efficiency for lK events, calculated from a Monte Carlo program, is 2.4% under the assumption of e-μ universality. Combining this efficiency, the number of produced $\tau^+\tau^-$ pairs, and the number of signal events gives

$$B(\tau^- \to K^-\nu_\tau)B(\tau^- \to l^-\bar{\nu}_l\nu_\tau) = (2.3\pm0.8\pm0.3)\times10^{-3}.$$

Using the Mark II measurement[2] of

$$B(\tau^- \to l^-\bar{\nu}_l\nu_\tau) = (17.6\pm1.2)\%$$

yields

$$B(\tau^- \to K^-\nu_\tau) = (1.3\pm0.5)\%.$$

The quoted error consists of the statistical uncertainty plus systematic uncertainties of 13% for the background subtraction, 5% for lepton misidentification, 6% for luminosity, and 10% for the Monte Carlo efficiency. The data are corrected for initial-state radiation effects. Repeating the analysis by requiring that the TOF for kaon candidates be from 3.0 to 4.5 standard deviations from the TOF expected for pions gives $B(\tau^- \to K^-\nu_\tau) = 1.3\%$ to 1.4%, indicating that the TOF distribution, particularly the non-Gaussian tails, has been handled properly.

The theoretical expectation for the $\tau^- \to K^-\nu_\tau$ branching fraction can be calculated from either the $\tau^- \to \pi^-\nu_\tau$ or the $\tau^- \to e^-\bar{\nu}_e\nu_\tau$ branching fractions. From the calculations of Tsai,[8] we have

$$B(\tau^- \to K^-\nu_\tau) = \frac{f_K^2}{f_\pi^2}\frac{(1-M_K^2/M_\tau^2)^2}{(1-M_\pi^2/M_\tau^2)^2}B(\tau^- \to \pi^-\nu_\tau)$$

and

$$B(\tau^- \to K^-\nu_\tau) = \frac{12\pi^3 f_K^2}{M_\tau^2}\left(1-\frac{M_K^2}{M_\tau^2}\right)^2 B(\tau^- \to e^-\bar{\nu}_e\nu_\tau),$$

where f_π and f_K are constants obtained from the pion and kaon lifetimes, respectively. Using the Mark II measurements[2] of $B(\tau^- \to \pi^-\nu_\tau) = (11.7\pm1.8)\%$ and $B(\tau^- \to e^-\bar{\nu}_e\nu_\tau) = (17.6\pm1.2)\%$ gives estimates of $(0.74\pm0.11)\%$ and $(0.63\pm0.04)\%$, respectively, for $B(\tau^- \to K^-\nu_\tau)$, in agreement with the experimental value presented in this Letter. This result is also consistent with the upper limit of $B(\tau^- \to K^-\nu_\tau) < 1.6\%$ given by the DASP collaboration as reported by Yamada.[9]

In summary, the decay $\tau^- \to K^- \nu_\tau$ has been observed at the level expected if the τ couples to the standard Cabibbo-suppressed axial-vector hadronic weak current.

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[1] All reactions in this paper also imply the charge-conjugate reaction. Thus, $\tau^- \to K^- \nu_\tau$ stands for itself and for $\tau^+ \to K^+ \bar{\nu}_\tau$.

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[3] G. S. Abrams *et al.*, Phys. Rev. Lett. 43, 1555 (1979); J. M. Dorfan *et al.*, Phys. Rev. Lett. 46, 215 (1981).

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[5] The acoplanarity angle is the angle between the plane containing the beam and one final-state particle and the plane containing the beam and the other final-state particle.

[6] The first error is statistical, the second is systematic.

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Bounds on $M_{Z_{1,2}}$ in Any $\mathrm{SU}(2)_L \otimes \mathrm{SU}(2)_R \otimes \mathrm{U}(1)_{B-L}$ Gauge Model

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If the known fermions transform under $\mathrm{SU}(2)_L \otimes \mathrm{SU}(2)_R \otimes \mathrm{U}(1)_{B-L}$, then the two neutral vector gauge bosons must satisfy the bounds 83 GeV < M_{Z_1} < 116 GeV and M_{Z_2} > 200 GeV. In addition, if mixing is negligible for the two charged vector gauge bosons, then 75 GeV < M_{W_1} < 97 GeV. These results come directly from analyzing existing experimental data and do not depend on any further theoretical assumptions, such as the value of g_L/g_R or the choice of Higgs-boson representations.

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In the standard SU(2) ⊗ U(1) electroweak gauge model,[1] the $W^\pm$ and Z^0 vector bosons are the mediators of the charged-current and neutral-current weak interactions, respectively. Their predicted masses are[2] $M_W = 83.0 \pm 2.4$ GeV and $M_Z = 93.18 \pm 2.0$ GeV, where radiative corrections to the lowest-order mass formulas $G_F/\sqrt{2} = e^2/(8M_W^2 \sin^2\theta_W)$ and $M_Z = M_W/\cos\theta_W$ have been taken into account. The new $p\bar{p}$ collider at CERN is expected to be capable of producing these particles at an observable rate in the near future. On the other hand, if the electroweak gauge group is really $\mathrm{SU}(2)_L \otimes \mathrm{SU}(2)_R \otimes \mathrm{U}(1)_{B-L}$,[3-14] then the $W^\pm$ and Z^0 bosons observable at about 100 GeV may not have the masses given above. It is therefore important to determine the allowed mass ranges for these bosons with as little extra theoretical input as possible. Accordingly, in the following analysis, we let the $\mathrm{SU}(2)_L$ and $\mathrm{SU}(2)_R$ couplings, g_L and g_R, be free parameters and we do not restrict ourselves to any particular set of Higgs bosons for the spontaneous symmetry breaking. Our results are summarized in Figs. 1 and 2.

Consider the gauge group $\mathrm{SU}(2)_L \otimes \mathrm{SU}(2)_R \otimes \mathrm{U}(1)_{B-L}$ with the electromagnetic current given by $J_{\mathrm{em}} = J_{3L} + J_{3R} + \frac{1}{2}J_{B-L}$. The fundamental fermions are of course the quarks and leptons with baryon number B and lepton number L equal to