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Measurement of the Branching Ratios for $\tau \to \pi\nu_\tau$ and $\tau \to \mu\nu_\mu\nu_\tau$

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On the basis of a sample of 41 events of the type $e^+e^- \to e^\pm X^\mp$ ($X \neq e$) and no observed photons, we have observed a clear signal of the decay $\tau^- \to \pi^-\nu_\tau$. We measure the branching ratio for this decay to be $b_\pi = 0.080 \pm 0.032 \pm 0.013$ and for the decay $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$, $b_\mu = 0.21 \pm 0.05 \pm 0.03$, where the first and second errors are, respectively, statistical and systematic. Both measurements agree with theoretical values derived under the assumption that the τ decays via the standard weak current.

The original conjecture of a third charged lepton, proposed by Perl et al.[1] after their observation of anomalous $e\mu$ events, has been reinforced by subsequent detailed studies conducted at DORIS and SPEAR. With one exception all the information provided by branching-ratio measurements, lepton spectra, and the energy dependence of the production cross section have confirmed the hypothesis that the τ is a sequential heavy lepton which decays via the standard weak current.[2]

The exception[3] was a measurement of the branching ratio b_π for the decay[4] $\tau^- \to \pi^-\nu_\tau$ substantially below the theoretical expectation. From the relative rates for $\mu^- \to e^-\bar{\nu}_e\nu_\mu$ and $\pi^- \to \mu^-\bar{\nu}_\mu$ the standard model predicts $b_\pi/b_e = 0.59$ ($b_\pi = 0.094$ for $b_e = 0.16$, where b_e is the branching ratio for $\nu^- \to e^-\bar{\nu}_e\nu_\tau$). The experimental measurement was reported in two forms: firstly, $b_e b_\pi = 0.004$

± 0.005 ($b_\pi = 0.025 \pm 0.031$ for $b_e = 0.16$) or, alternatively, an observation of two $e\pi$ events when 7.3 were expected, based on the detection of twelve $e\mu$ events. (The latter form is insensitive to an error in b_e.)

Accordingly we have made a measurement of b_π[5] from data obtained at SPEAR using the DELCO detector. The data were taken with the apparatus described previously[6] after the addition of two muon walls (Fig. 1). The Pb walls, followed by magnetostrictive wire spark chambers (WSC) and scintillation counters, provide muon identification over 20% of 4π sr. A particle must traverse typically 2 absorption lengths of material to be tagged as a muon. This represents the best compromise between hadron discrimination and muon range at these low energies. A track is identified as a muon if it aims within a restricted sensitive
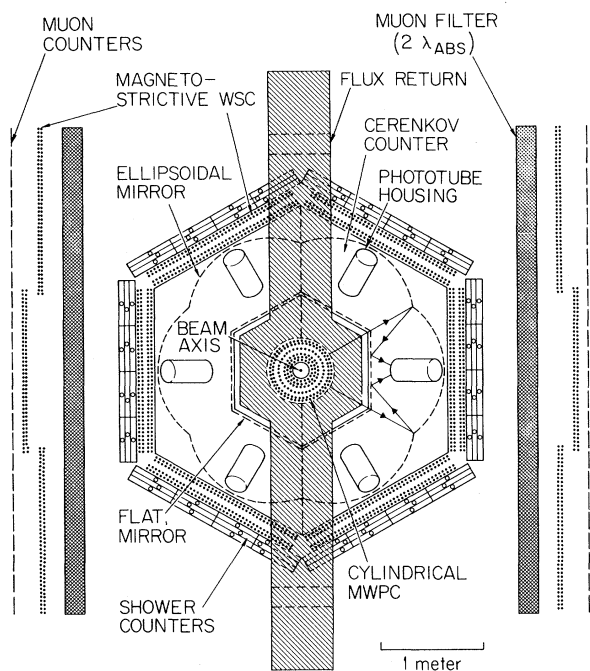
FIG. 1. Azimuthal view of the apparatus.

area of the muon detector, to ensure that it cannot be lost by Coulomb scattering, and in addition possesses an in-time muon-counter pulse. (The muon WSC were not used in this analysis.) We impose an additional minimum-momentum cut to allow for both the amount of material traversed and the momentum measurement error. A pion is identified within identical geometrical and momentum cuts by the absence of a muon-counter tag. The muon detection efficiency is 0.95 ± 0.03, as determined from $\mu^+\mu^-$ events. The hadron misidentification probability due to punchthrough or decay has been determined at the ψ and is found to be 0.14 ± 0.03 for momenta above the minimum acceptable value (~ 0.7 GeV/c).

In order to isolate the $\pi^- \nu_\tau$ decay mode, it is necessary to measure and subtract a substantial background from $\tau^- \to \pi^- n \pi^0 \nu_\tau$ ($n \neq 0$). This is achieved with the Pb-scintillator shower counters, which cover a solid angle of 60% of 4π sr. The counters are segmented into three layers, each containing 2.3 radiation lengths of Pb followed by a plastic scintillator. The first scintillator layer extends the full 3-m length of the detector and is read out by a phototube at each end. The following two layers have half-length counters each of which is viewed by a single phototube. The pulse heights of all phototubes are recorded and in addition, the first layer is time analyzed. A detected photon is defined by a shower counter which has no incident charged track and has either an in-time pulse of magnitude greater than 0.2 minimum-ionizing particles in the first scintillator layer or, in its absence, a coincidence of the next two layers and a total pulse height of > 3 minimum-ionizing particles. The detection efficiency of photons above 200 MeV is found to be 0.89 ± 0.03 using $e^+e^-\gamma$ and $\gamma\gamma$ events. At lower energies we have used the data of Darriulat et al.[7] and confirmed these detection efficiencies with the soft photons from the decay $\psi' \to \psi \pi^0 \pi^0$.

Events are selected which contain only two prongs (and any number of photons) of which one is an electron and the other not an electron (termed eX events). The selection procedure, which has been described previously,[8] results in a very pure sample of τ decays. The background fraction of $\lesssim 4\%$ is almost entirely from misidentified $e^+e^-\gamma$ events. Additional requirements are then imposed on the X particle to allow $\pi-\mu$ discrimination as described above. At least one associated spark is required in the WSC of the central detector in order to provide a reliable measurement of the momentum.

Normalization is done by means of large-angle Bhabha pairs (e^+e^-). These allow a calculation

TABLE I. Predicted and observed event category of the eX events.

Event category	Predicted events $\tau^+ \to \bar{\nu}_\tau e^+ \nu_e$, $\tau^- \to \nu_\tau Y$				Observed events (ee background previously subtracted)
	$Y=\mu^-\bar{\nu}_\mu$	$Y=\pi^-$	$Y=\rho^-,A_1^-,K^-$, etc.	Total	
$e\mu$	14.7	2.0	1.0	17.7	23 (0)
$e\mu + (\geqslant 1\gamma)$	0	0	1.0	1.0	2 (0)
$e\pi$	0.8	12.4	6.1	19.3	17.4 (0.6)
$e\pi + (\geqslant 1\gamma)$	0	0	6.4	6.4	9.5 (1.5)

of the number of $\mu^+\mu^-$ pairs and thereby of $\tau^+\tau^-$ pairs using the known τ mass[8] and cross section relative to muon pairs. The sample corresponds to 28 700 $\tau^+\tau^-$ decays in the energy range 3.57 $<E_{\mathrm{c.m.}}<7.4$ GeV.

There are 54 events which survive the selection criteria. From the shower-counter pulse-height distribution we estimate that 2.1 of these are in fact radiative e^+e^- events where the Cherenkov counter failed to identify both electrons. This background contaminates only the $e\pi$ category and generally contains a detected photon. The events remaining after this background subtraction are summarized in Table I according to particle composition.[9]

The predicted numbers of events in Table I are based on recent theoretical calculations,[10] normalized to an electronic branching ratio of 0.160.[8] These are summarized in Table II for τ decays into one charged particle plus neutrals. Small additional contributions from $\tau^- \to \nu_\tau$ plus $\geqslant 3$ charged particles (0.2 events, assuming a branching ratio[8] of 0.32) and charmed semileptonic decays (0.3 events) have been included in Table I.

The experimental data show good agreement with the theoretical expectations. In particular, if the $\pi\nu_\tau$ (and $K\nu_\tau$) decay modes are absent, the predicted signal of $e\beta+0\gamma$ events would be 6.9 $-0.7=6.2$ in contrast to the 17.4 events observed. We conclude that this decay exists and measure its branching ratio as $b_\pi=0.094(17.4-6.9)/12.4 = 0.080\pm0.032$ (statistical error). Similarly we measure the $\mu\nu_\mu\nu_\tau$ branching ratio to be $b_\mu = 0.155(23-3.0)/14.7 = 0.21\pm0.05$ (statistical). The observed π and μ momentum spectra [Figs. 2(a) and 2(b)] are consistent with those expected from τ decays; note in particular that the pions do not cluster at the low momentum cut, which would suggest large μ or multipion contamination.

The systematic errors arise from several sources. Both b_π and b_μ are subject to uncertainties in b_e (8%), detection efficiencies (13%), and normalization (5%). The particle misidentification probabilities in the muon detector contribute a further 4% error in each branching ratio. Finally the value of b_π contains a 10% uncertainty from τ decays involving π^0's. These combine to give the following final measurements: $b_\pi=0.080 \pm 0.032\pm0.013$ and $b_\mu=0.21\pm0.05\pm0.03$, where the first and second errors are, respectively, statistical and systematic.

In summary, the decay mode $\tau^- \to \pi^-\nu_\tau$ has been observed with a branching ratio consistent with theoretical calculations based on the standard weak current.[11] Similarly our value for b_μ is in agreement with previous measurements[2] and e-μ universality. We conclude that all experimental data are consistent with the hypothesis that the τ couples to the standard weak current.

TABLE II. τ one-prong branching ratios assumed for Table I.

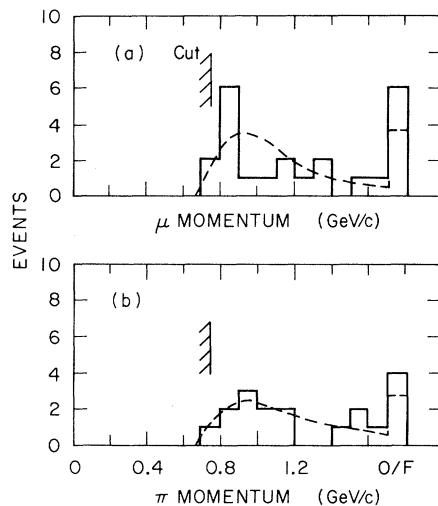| $\tau^- \to \nu_\tau +$	Branching ratio
$e^-\bar{\nu}_e$	0.160
$\mu^-\bar{\nu}_\mu$	0.155
π^-	0.094
$\pi^-\pi^0$	0.198
$\pi^- + (\geqslant 2\pi^0)$	0.069
K^-	0.005
$Kn\pi$	0.008
Total	0.66

FIG. 2. (a) Momentum spectrum of the μ in the $e\mu$ (zero-photon) events. (b) Momentum spectrum of the π in the $e\pi$ (zero-photon) events. The last bin of each figure includes all events above 1.7 GeV/c. The dashed lines indicate the predicted shapes expected from τ decays. The cut indicated corresponds to the average amount of material a track must penetrate to be identified by the muon detector.

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K_L-Nucleus Total Cross Sections between 30 and 150 GeV: Quantitative Evidence for Inelastic Screening

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We have obtained high-statistics, virtually systematics-free K_L-nucleus total—cross-section data for C, Al, Cu, Sn, and Pb from 30 to 150 GeV. These cross sections have an $A^{0.84\pm0.01}$ dependence over most of the momentum range, in agreement with the Glauber-Franco model. Their magnitudes are, however, not compatible with that model alone: The discrepancies are clearly resolved once one allows for inelastic screening within the nucleus. The data strongly support the theory of this latter effect as given by Karmanov and Kondratyuk.

We present here high-precision data on the momentum dependence of the K_L-nucleus total cross section for a variety of nuclei (C, Al, Cu, Sn, and Pb) in the energy range 30–150 GeV. Such data provide a stringent test of models of high-energy hadron-nucleus interactions, in particular of the quantitative theory[1] of the mechanism of "inelastic screening."[2] This mechanism results from the ability of an incident hadron to dissociate at one point within the target nucleus and to "recombine" subsequently at another. This, in analogy to elastic screening, effectively increases the hadron's mean free path within the nucleus and thus lowers the actual total cross section with respect to the one predicted naively. Evidence for this mechanism has already been provided[3] by analogous studies of neutron-nucleus total cross sections. The inelastic screening term is larger for kaons; results of Murthy et al.[3] and Biel et al.[4] are somewhat inconsistent with