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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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Abstract

Based on 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.

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The original conjecture of a third charged lepton, proposed in 1975 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, reported[3] by DASP at the Hamburg conference last year, was a measurement of the branching ratio b_π for the decay $\tau^- \to \pi^- \nu_\tau$ [4] 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_π=0.094 for b_e=0.16, where b_e is the branching ratio for $\tau^- \to e^- \bar{\nu}_e \nu_\tau$). The experimental measurement was reported in two forms: firstly $b_e\, b_\pi = 0.004 \pm 0.005$ ($b_\pi = 0.025 \pm 0.031$ for $b_e = 0.16$) or, alternatively, an observation of 2 $e\pi$ events when 7.3 were expected, based on the detection of 12 $e\mu$ events. (The latter form is insensitive to an error in b_e.)

Accordingly we have made a measurement of b_π[5] in 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 steradians. 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 area of the muon detector, to ensure 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 punch-through or decay has been determined at the ψ and is found to be 0.14 ± 0.03 for momenta above the minimum acceptable (∿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 $\tau^- \rightarrow \pi^- n\pi^o \nu_\tau$ ($n \neq 0$). This is achieved with the Pb/scintillator shower counters, which cover a solid angle of 60% of 4π steradians. 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 3m 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 > 0.2 minimum-ionizing-particles (mips) in the first scintillator layer or, in its absence, a coincidence of the next two layers and a total pulse height of >3 mips. 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 reference 7) and confirmed these detection efficiencies with the soft photons from the decay $\psi' \rightarrow \psi\, \pi^o\pi^o$.

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 π/μ 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 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, $3.57 < E_{CM} < 7.4$ 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 Cerenkov 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 $\tau^- \to \nu_\tau + \geq$ 3-charged particles (0.2 events, assuming a branching ratio[8] 0.32) and charm semi-leptonic 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 $e\pi + 0\gamma$ events would be 6.9-0.7 = 6.2 in contrast to 17.4 events observed. We conclude that this decay exists[11] and measure its branching ratio, $b_\pi = 0.094\ (17.4-6.9)/12.4 = 0.080 \pm 0.032$ (statistical error). Similarly we measure the $\mu\nu_\mu\nu_\tau$ branching ratio to be $b_\mu = 0.155\ (23-3.0)/14.7 = 0.21 \pm 0.05$ (statistical). The observed π and μ momentum spectra (Figs 2a) and 2b)) 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 final measurements: $b_\pi = 0.080 \pm 0.032 \pm 0.013$ and $b_\mu = 0.21 \pm 0.05 \pm 0.03$, where the first and second errors are, respectively, statistical and systematic.

In summary, the decay mode $\tau^- \to \pi^-\nu_\tau$ has been observed[5] with a branching ratio consistent with theoretical calculations based on the standard weak current. 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 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)
$e\mu + \geq 1\gamma$	0	0	1.0	1.0	2 (0)
$e\pi$	0.8	12.4	6.1	19.3	17.4(0.6)
$e\pi + \geq 1\gamma$	0	0	6.4	6.4	9.5(1.5)

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
$\pi^- \pi^o$	0.198
$\pi^- + \geq 2\pi^o$	0.043
K^-	0.005
$Kn\pi$	0.008
Total	0.66

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References

1) M. L. Perl et al., Phys. Rev. Lett. 35, 1489 (1975).

2) M. L. Perl, Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, 1977, edited by F. Gutbrod (Deutsches Elektronen-Synchrotron, Hamburg, Germany, 1977).

3) S. Yamada, invited talk at the Symposium of ref. 2).

4) For clarity we shall refer to only one charged state of the τ whereas our analysis includes both τ^+ and τ^- decays.

5) Observation of the decay mode $\tau^- \to \pi^- \nu_\tau$ was reported by DELCO (based on an early sample of $e\pi$ events) and the Mk I Magnetic Detector ($\pi\pi$ events) in talks by J. Kirkby and G. Feldman at the International Conference on Neutrino Physics and Neutrino Astrophysics, Purdue University (April 1978). Subsequent observations have been reported by PLUTO ($\pi\pi$ events), G. Alexander et al., Phys. Lett. 78B, 162 (Sept. 1978) and the Mk II Magnetic Detector ($e\pi$, $\pi\pi$ events), D. Hitlin at the International Conference on High Energy Physics, Tokyo (August 1978).

6) W. Bacino et al., Phys. Rev. Lett. 40, 671 (1978).

7) P. Darriulat et al., Nucl. Inst. and Meth. 129, 105 (1975).

8) W. Bacino et al., Phys. Rev. Lett. 41, 13 (1978).

9) Experimentally we do not distinguish between a π and a K but assume Cabibbo suppression is valid in τ decays as is supported by ref. 3). The small contributions from τ decays into strange particles are included in the third column of numbers in Table I. (The largest contribution is 0.7 '$e\pi$' events from the $K^-\nu_\tau$ decay mode.)

10) F. J. Gilman and D. H. Miller, Phys. Rev. D17, 1846 (1978), N. Kawamoto and A. I. Sanda, DESY 78/14 (1978).

11) The probability of observing 17.4 events or more when 6.2 are expected is 2×10^{-4}.

Figure Captions

1) Azimuthal view of the apparatus.

2) a) Momentum spectrum of the μ in the $e\mu(0\gamma)$ events.

b) Momentum spectrum of the π in the $e\pi$ (0γ) events.

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.

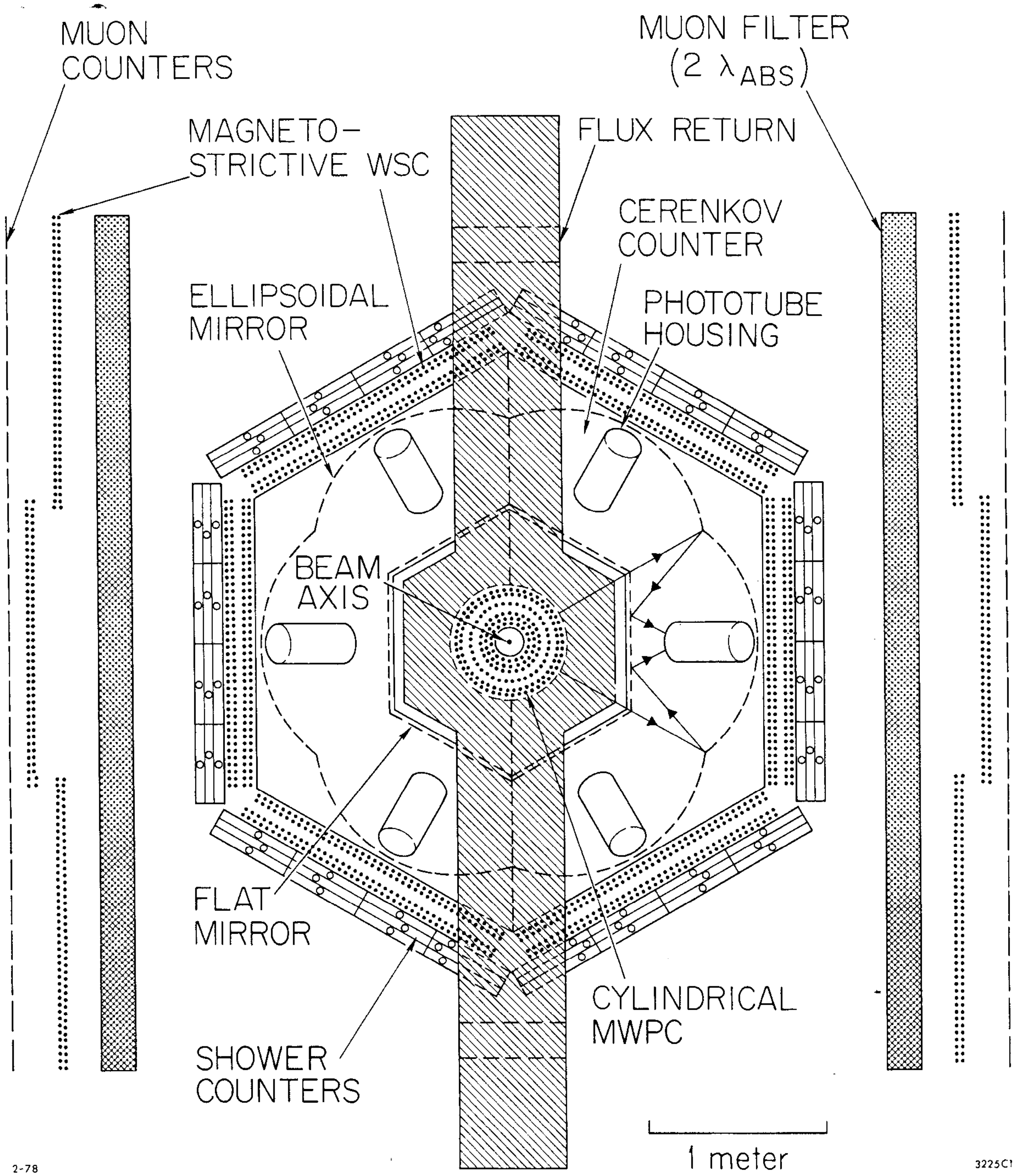
MUON
COUNTERS
MUON FILTER
(2 λ ABS)
MAGNETO-
STRICTIVE WSC
FLUX RETURN
CERENKOV
COUNTER
ELLIPSOIDAL
MIRROR
PHOTOTUBE
HOUSING
BEAM
AXIS
FLAT
MIRROR
CYLINDRICAL
MWPC
SHOWER
COUNTERS
1 meter
2-78
3225C1

Fig. 1

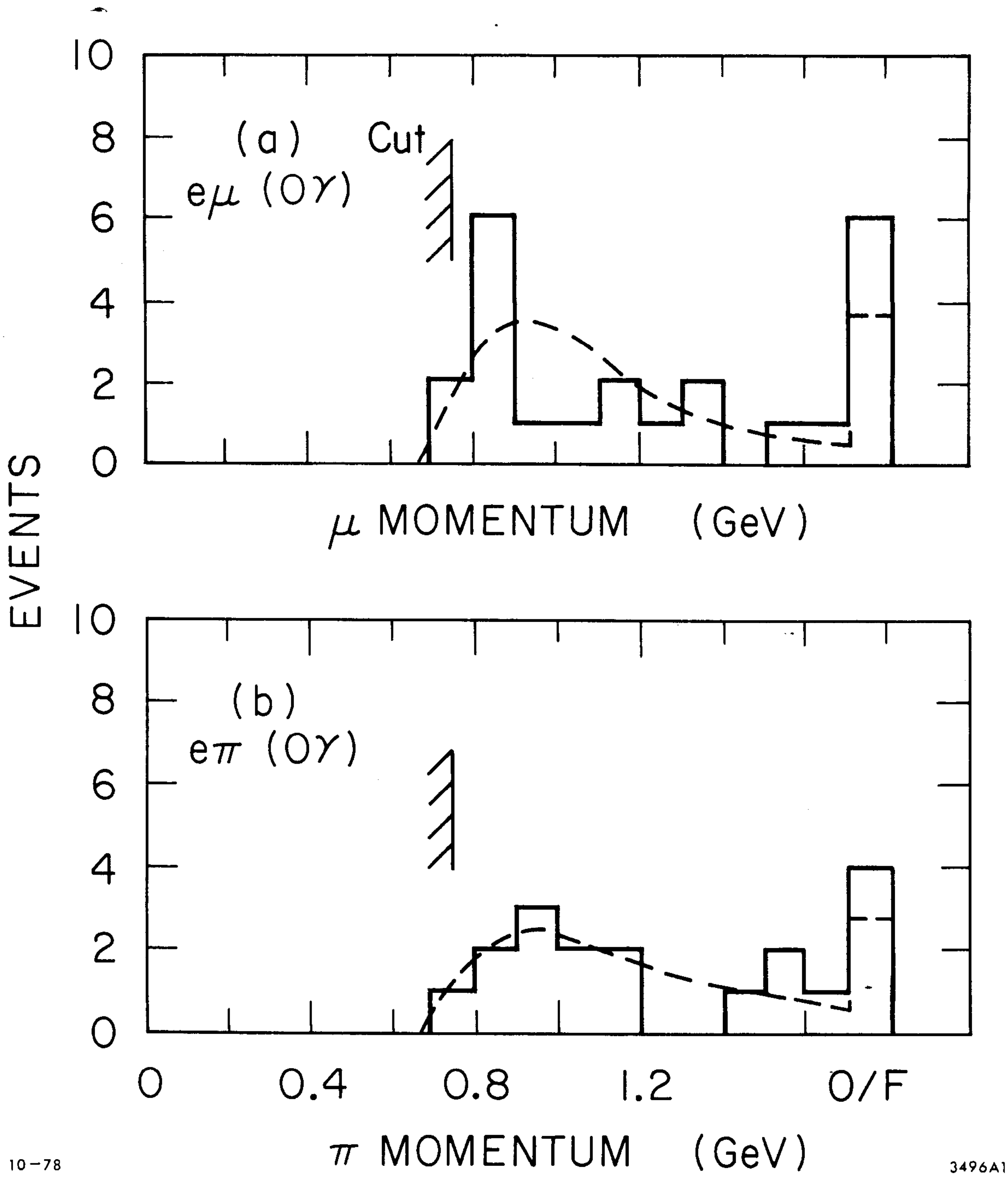
EVENTS
(a)
eμ (0γ)
Cut
μ MOMENTUM (GeV)
(b)
eπ (0γ)
0
0.4
0.8
1.2
0/F
π MOMENTUM (GeV)
10-78
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Fig. 2