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REVIEW OF τ LEPTON PROPERTIES*

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I. Introduction and History

When one is asked to give a one hour talk on recent results in e^+e^- annihilation, the choice of topic is always difficult. I have chosen to review the properties of the τ lepton at this meeting for several reasons. First, it is one of only three charged leptons of which we have any knowledge. Clearly, our conception of the elementary particles and their interactions depends critically on the properties of this particle. Second, new results from five experiments have become available in the past few months.[1] And third, because of these results, there is now appearing a rather clear picture of the τ as a sequential lepton. It thus appears to be an opportune time for this review.

Although this talk will not be organized in a chronological manner, I think it is useful to spend a minute or two putting the present situation into its historical perspective.

The history of the τ began in 1975 with the observation by the SLAC-LBL group of 24 events which contained an electron and a muon but no other visible charged or neutral particles.[2] These events could not be explained by any known processes. Possible hypotheses which could explain these data included the decay of a new lepton or a weakly-decaying spin one boson.

The SLAC-LBL group collected additional data and studied the momentum spectrum of the leptons and the presence or absence of other particles in these events. It concluded that the lepton momentum spectrum was characteristic of a three-body decay and that, by elimination, the missing particles had to be

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neutrinos. In a paper published in 1976, the SLAC-LBL group stated

> "The simplest hypothesis compatible with all the data is that these events come from the production of a pair of heavy leptons ..."[3]

The problem at this point was that all of the evidence for a new lepton came from a single experiment and one that admittedly had poor lepton identification. Independent confirmation was badly needed. It came during the following year from the PLUTO[4,5] and DASP[6] experiments.

It is clear that at this meeting we are entering a new stage in the history of the τ. Its existence and general identification are accepted and we are beginning the detailed measurements of its properties.

It is in this spirit that I have prepared this review. In the next section we shall review the measurements of τ branching fractions, first the general modes, then a more detailed look at the semi-hadronic modes, and finally, a review of upper limits for rare modes. In sections III through VII we shall briefly review measurements of the τ mass, the τ spin, the τ lifetime, the τ-ν_τ coupling and the ν_τ mass. We shall conclude in section VIII with a discussion of the type of lepton the τ could be.

II. Branching Fractions

Figure 1 illustrates the three possible τ decay modes in the standard model. In each case the τ decays to its own neutrino, ν_τ, and the charged weak current, which can materialize as an $e\bar{\nu}_e$, a $\mu\bar{\nu}_\mu$, or a $d\bar{u}$ pair. The $d\bar{u}$ quark pair (or more precisely the $d'u$ pair, where $d' \equiv d\cos^2\theta_C + s\sin^2\theta_C$) forms a hadronic system such as a charged π, ρ, or A_1. There are three general observations that we can make from Fig. 1:

(1) Each of the diagrams has equal weight since all of the couplings to the weak current are equal, with the proviso that the last diagram stands for three diagrams corresponding to the three colors of quarks. Thus, there are five equivalent diagrams and so the electronic branching fraction should be

20%. QCD corrections give an enhancement to the semi-hadronic final states and reduce the prediction for the electronic branching fraction to 18%.[7]

(2) Many of the branching fractions for the semi-hadronic modes are precisely predicted. For example, the coupling of both the μ and the π to the weak current is known from the measurements of their lifetimes. Thus, the ratio of branching fractions for $\tau \to \pi\nu$ to that for $\tau \to \mu\bar{\nu}\nu$ is precisely predicted. We shall return to a discussion of the predictions for the semi-hadronic modes below.

(3) Most τ decays will contain only one charged particle. Clearly the decays to e's, μ's, π's, and ρ's contain only one charged particle, and it will turn out that about half of the semi-hadronic modes contain only one charged particle. Thus $\tau^+\tau^-$ production will be most prominent in events with only two charged particles.

A. General Modes

From the preceding discussion it is clear that $\tau^+\tau^-$ production can be most easily measured by studying e^+e^- annihilation events with two charged particles in which at least one is a lepton. There are five possibilities: $e\mu$, ee, $\mu\mu$, ex, and μx, where x stands for any charged particle. Seven experiments have measured one or more of these modes,[4-14] and two other experiments have measured other modes or properties.[15,16] Table I gives a list of these experiments and the modes which each measured.

From these measurements we want to derive the branching fractions for τ decay into $e\nu\bar{\nu}$ (B_e), $\mu\nu\bar{\nu}$ (B_μ), one charged hadron plus neutrals (B_{1h}), and three or more charged hadrons plus neutrals (B_{3h}), subject to the constraint that the sum of these four modes is unity. Table II gives the results of the 15 measurements listed in Table I. An attempt has been made here to determine precisely the quantity that each experiment measured. In general, experiments measure products or combinations of products of these four basic branching fractions, and then use either theoretical assumptions or other experimental measurements to derive the branching fractions quoted in their papers. Thus the values

Table I. Experiments which have measured $\tau^+\tau^-$ production, the method of electron identification (if relevant), and the modes measured.

Experiment	Institutions	Laboratory	e^- ident.	Modes				
				eμ	ee	μμ	ex	μx
SLAC-LBL	LBL SLAC	SPEAR (West pit)	Lead-scintillation counters	√	√	√		√
PLUTO	DESY Hamburg Siegen Wuppertal	DORIS	Lead-proportional chambers	√				√
DASP	Aachen DESY Hamburg München Tokyo	DORIS	Cerenkov counters (ex) or lead proportional chambers (eμ)	√			√	√
LGW	Hawaii LBL Northwestern SLAC	SPEAR (West pit)	Lead-glass counters	√			√	
MPP	Maryland Pavia Princeton	SPEAR (East pit)	-					√
Iron Ball	Colorado Pennsylvania Wisconsin	SPEAR (East pit)	-			√		
DELCO	Irvine Los Angeles Stanford Stony Brook	SPEAR (East pit)	Cerenkov counters	√			√	
DESY-Heidelberg	DESY Heidelberg	DORIS	NaI and lead-glass counters					
Mark II	LBL SLAC	SPEAR (West pit)	Lead-liquid argon counters					

Table II. Measurements of B_e, B_μ, B_{1h}, and B_{3h}.

Mode	Measurement	Experiment	Result	Reference
eμ	$\sqrt{B_e B_\mu}$	SLAC-LBL	$.186 \pm .030$	8
eμ	$\sqrt{B_e B_\mu}$	PLUTO	$.145 \pm .040$	4
eμ	$\sqrt{B_e B_\mu}$	DASP	$.182 \pm .031$	9
eμ	$\sqrt{B_e B_\mu}$	LGW	$.224 \pm .055$	10
eμ	$\sqrt{B_e B_\mu}$	DELCO	$.183 \pm .039$	34
ee	B_e/B_μ	SLAC-LBL	1.12 ± 0.48	11
μμ	B_μ/B_e	SLAC-LBL	1.40 ± 0.48	11
μμ	B_μ	Iron Ball	$.22 \pm .08$	12
ex	$B_e(B_\mu+B_{1h})$	DASP	$.086 \pm .012$	9
ex	$B_e(B_\mu+B_{1h})$	LGW	$.151 \pm .064$	10
ex	$B_e(B_\mu+B_{1h})$	DELCO	$.084 \pm .013$	13
μx	$B_\mu(1-B_{3h})$	SLAC-LBL	$.149 \pm .034$	8
μx	$B_\mu(1-B_{3h})$	PLUTO	$.109 \pm .025$	5
μx	$B_\mu(1-B_{3h})$	MPP	$.170 \pm .085$	14
μx	B_μ/B_e	DASP	$.92 \pm .32$	9
e-any	B_{3h}	DELCO	$.32 \pm .05$	13,18
e-any	$B_e B_{3h}$	DELCO	$.045 \pm .010$	17,18
μ-any	B_{3h}	PLUTO	$.30 \pm .12$	5

quoted in Table II are derived from the results given in the referenced papers, but in some cases may not be explicitly found there. Table II also includes three measurements of B_{3h} which were determined by studying the multiplicity accompanying a single lepton in regions in which charmed particle production is unimportant.[5,13,17]

The results of constrained fits to the 18 measurements in Table II are given in Table III. One fit has been done leaving B_e and B_μ free and the other has constrained $B_\mu = 0.973\ B_e$, its theoretical value. Both fits are extremely good and, in fact, all 18 measurements agree with the fit results within one standard deviation of the experimental errors. Although no single experiment has done a particularly sensitive job of testing e-μ universality in τ decays, the result of all measurements taken together provides a reasonably stringent limit on its violation. Also, it is impressive that there is excellent agreement between the theoretical prediction for the electronic mode, 18%, and the results of the fits.

B. Semi-hadronic Modes

Many details of the semi-hadronic decays are predicted in the standard model.[19,20] As we mentioned previously, the ratio between the leptonic decays and the $\pi\nu$ mode is precisely predicted from the pion lifetime. The vector decays, which are decays to even numbers of pions plus a neutrino, are precisely predicted from measurements of e^+e^- annihilation via the conserved vector current hypothesis.[21] The decay to $\rho\nu$ is the largest component of this class. For the axial-vector decays, the A_1 plays the same role as the ρ does for vector decays. For this reason, it is hoped that τ decays will provide a convenient way to study the A_1, which has proved so difficult to isolate in hadronic interactions.[22] The $A_1\nu$ branching fraction can be calculated from the $\rho\nu$ branching fraction with the aid of Weinberg's sum rules.[23] τ decays involving kaons will be suppressed by $\tan^2\theta_C$ in the standard model. A summary of these predictions is given in Table IV under the assumption that $B_e = B_\mu = 18\%$.

The $\rho\nu$ decay mode has been measured by the DASP group[24] to have a branching

Table III. Results of constrained fits to the measurements listed in Table II.

	B_e and B_μ free	$B_\mu = 0.973\ B_e$
B_e(%)	16.5 ± 1.5	17.5 ± 1.2
B_μ(%)	18.6 ± 1.9	17.1 ± 1.2
B_{1h}(%)	34.3 ± 4.2	35.0 ± 4.0
B_{3h}(%)	30.6 ± 3.0	30.4 ± 2.9
B_μ/B_e	1.13 ± 0.16	

Table IV. Predictions for τ branching fractions under the assumption that $B_e = B_\mu = .18$.

Mode	Branching Fraction(%)	Input
$e\bar{\nu}\nu$	18	measurement
$\mu\bar{\nu}\nu$	18	measurement
$\pi^-\nu$	10	π decay
$\rho^-\nu$	20	CVC + e^+e^- annihilation
$(4\pi)^-\nu$	10	CVC + e^+e^- annihilation
$A_1\nu$	9	Weinberg sum rules
$(K+n\pi)^-\nu$	4	$\tan^2\theta_C$
$(3\text{ or }5\pi)^-\nu$	11	remainder

fraction of $(24 \pm 9)\%$ in good agreement with the theoretical expectation of 20% from Table IV. The Mark II experiment has also presented preliminary data on the $\rho\nu$ decay mode to the Tokyo conference.[16] Although no quantitative branching fraction was quoted, it was stated that the result was consistent with the expected theoretical result.

The DASP group has studied τ decays to strange particles by measuring the fraction of ex events in which the x is a kaon.[6] The result is $(7 \pm 6)\%$ in agreement with the prediction in Table IV.

We shall now review in more detail the measurements on two interesting classes of semi-hadronic decay modes: $\pi\nu$ and $(3\pi)\nu$.

(1) The $\pi\nu$ Mode

Last summer at the Hamburg Photon-Lepton Symposium, the DASP group reported that the $\tau \to \pi\nu$ branching fraction was substantially smaller than expected.[24] This was rather surprising since, as we have already discussed, the $\pi\nu$ mode is completely predicted and a failure of this prediction would imply, at the least, that different weak currents were important in τ and π decays. The DASP group searched for a high momentum pion (≥ 1 GeV/c) with an electron or any charged particle and no detected photons. Nine $e\pi$ events were expected but only four were seen. When any charged particle plus a pion was required only 17 events were found and 34 were expected. Above 4.52 GeV center-of-mass energy only four events were found and 13 were expected.[25]

Four experiments have repeated the DASP measurement in either the $e\pi$ or $x\pi$ modes.[16,26-28] All four experiments are in good agreement with the theoretical prediction. In each case the pion momentum spectrum is close to constant, which is expected for the $\tau \to \pi\nu$ decay mode but would be rather unlikely for possible background sources. Table V summarizes the results of these experiments. The weighted average of these four measurements is a branching fraction of $(8.3 \pm 1.4)\%$ in good agreement with the theoretical prediction. The $\tau \to \pi\nu$ mode requires more detailed study, but given the results of these experiments, there is no longer good reason to suspect that it is anomalous.

(2) $(3\pi)\nu$ and $(4\pi)\nu$ Modes

The PLUTO[29,30] and SLAC-LBL[31] groups have studied τ decays to three charged pions plus a neutrino. These decays are of particular interest since the long-sought A_1 meson is expected to be prominent in the three pion mass spectrum.

The SLAC-LBL group studied events with a muon, three charged pions, and any number of photons. The three pion mass spectrum after background subtractions is shown in Fig. 2 for cases in which no photons, one or two photons, and more than two photons are observed. In the first two cases there is a significant signal in the vicinity of 1.1 GeV/c^2. The momentum spectra of the muon and the three charged pions in this mass region agree with the hypothesis of pair production, as seen in Fig. 3. Figure 4 shows fits to the three pion mass spectrum with no detected photons under three hypotheses: (a) that all the events are due to $\tau \to \pi^{\pm}\pi^{+}\pi^{-}\pi^{o}\nu$, where the π^{o} is not detected, (b) that all the events are due to $\tau \to \rho^{o}\pi\nu$, where the $\rho^{o}\pi$ is non-resonant, and (c) that all the events are due to $\tau \to A_1\nu \to \pi^{\pm}\pi^{+}\pi^{-}\nu$. Fits to the first two hypotheses have only a few percent confidence level but cannot be excluded. The resonance hypothesis is a good fit with A_1 mass of 1.1 GeV/c^2 and full width of 200 MeV/c^2.

The SLAC-LBL group obtains an $(18 \pm 6.5)\%$ branching fraction for $\tau \to \pi^{\pm}\pi^{+}\pi^{-} + n\pi^{o}\nu$. By using the number of observed photons, in principle it is possible to unfold this branching fraction for the number of π^{o}'s produced. In practice the statistical accuracy is rather poor. The results are $(7 \pm 5)\%$ for $\tau \to \pi^{\pm}\pi^{+}\pi^{-}\nu$ and $(11 \pm 7)\%$ for $\tau \to \pi^{\pm}\pi^{+}\pi^{-}\pi^{o}\nu$. All these results are consistent with the theoretical predictions given in Table IV.

The PLUTO group has studied events with an electron or muon, three charged pions, and no photons. Since PLUTO has more efficient photon detection than the SLAC-LBL detector, the background from the $4\pi\nu$ decay to the $3\pi\nu$ signal is small. This has allowed the PLUTO group to go beyond the SLAC-LBL analysis in two significant aspects. First, a study of dipion masses showed that the entire signal was consistent with two of the pions forming a ρ^{o}. The higher mass dipion combination for each event is shown in Fig. 5. Second, an analysis

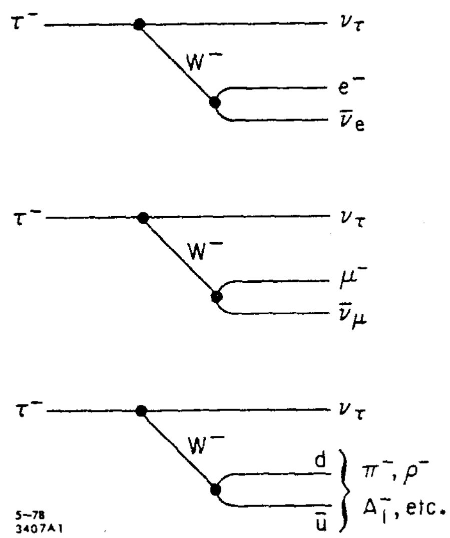

Fig. 1. τ decay modes.

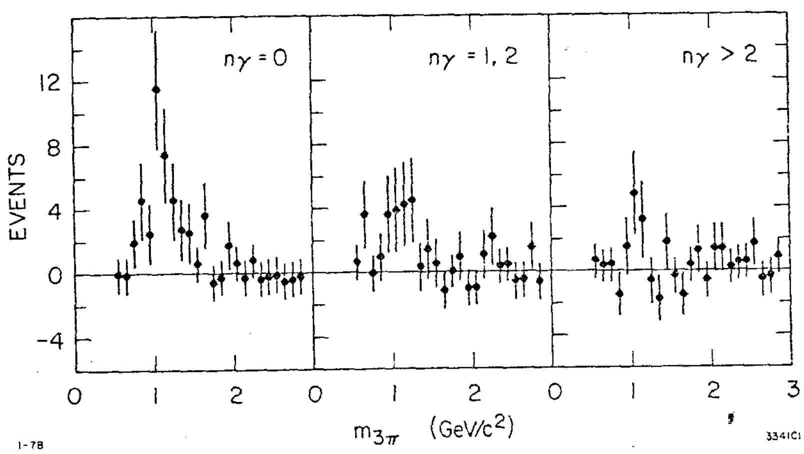

Fig. 2. Invariant mass distributions of three pions in events in which they are detected along with a muon and zero, one or two, or more than two photons. The distributions have been corrected for hadron mis identification as a muon. The data are from the SLAC-LBL and LGW experiments.[31]

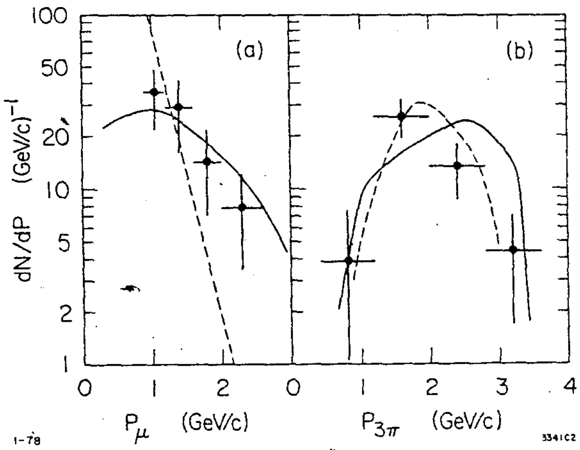

Fig. 3. (a) Momentum distribution of muons in events in the $.95 < m_{3\pi} < 1.25$ GeV/c^2 region of Fig. 2(a) and (b). The solid and dashed curves are the expected spectra from τ decays and charmed particle decays. (b) Momentum distribution of the three pion system in these events. The solid and dashed curves are spectra expected for $\tau \to 3\pi\nu$ and $\tau \to 4\pi\nu$ decays.

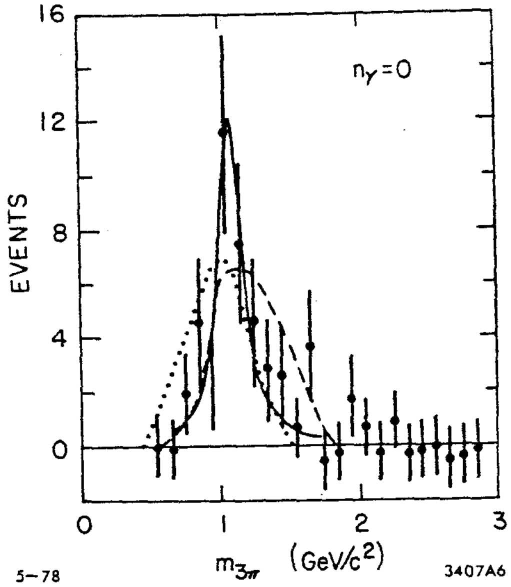

Fig. 4. Data from Fig. 2(a) fit to different hypotheses. The dotted line represents $\tau \to \pi^\pm\pi^+\pi^-\pi^0\nu$ decays the dashed line represents non-resonant $\tau \to \pi^\pm\pi^+\pi^-\nu$ decays, and the solid line presents $\tau \to A_1\nu$ decays where the A_1 has mass of 1.1 GeV/c^2 and width of 200 MeV/c^2.

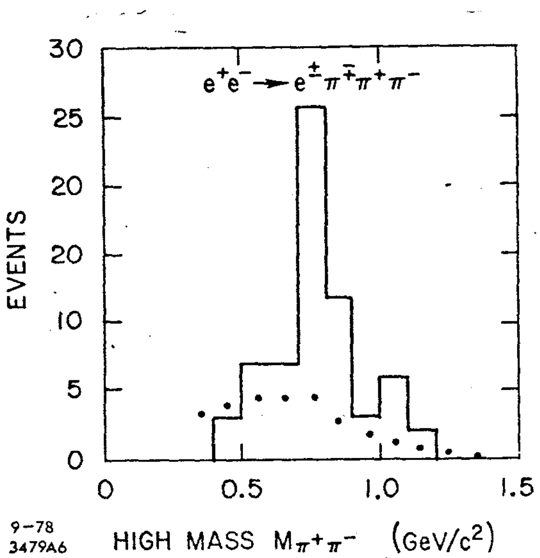

Fig. 5. Invariant mass of the higher mass $\pi^+\pi^-$ pair from events with a lepton and three charged π's detected which are compatible with $\tau^+\tau^-$ decays. The dotted curve represents an estimate of the background. The data are from the PLUTO experiment.[29,30]

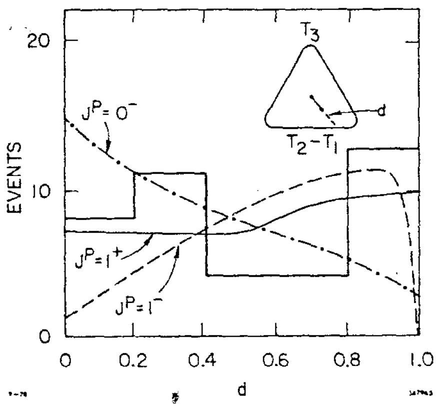

Fig. 6. The normalized distance to the boundary of the 3π Dalitz plot for $\rho^0\pi^\pm$ data described in Fig. 5. The curves show the expected distributions for 0^-, 1^-, and 1^+ spin-parity 3π states.

of the three pion Dalitz plot has shown that the three pion state is consistent with the expected spin-parity assignment of 1^+, but not 0^- or 1^-. The normalized distance to the Dalitz plot boundary is shown in Fig. 6. The axial-vector hypothesis fits the data with a 10% confidence level. The hypotheses that the 3π system is a pure pseudoscalar or vector state are excluded at the 0.01% and 0.3% confidence levels. A vector 3π system would require second class currents.

The 3π mass spectrum from the PLUTO experiment is shown in Fig. 7 along with a curve representing $\rho\pi$ non-resonant phase space. There appears to be an enhancement near 1.0 GeV over the phase space curve. The branching fraction for $\tau \to \rho\pi\nu$ from the PLUTO experiment is $(10.4 \pm 2.4)\%$ where the result includes both the $\rho^o\pi^{\pm}$ and $\rho^{\pm}\pi^o$ final states.

Finally, what can we say about the A_1 given the results from these two experiments? There are at least three statements which can be made without serious fear of contradiction:

(1) It is significant that both experiments see an enhancement near 1.1 GeV.

(2) The present data are statistically insufficient to pin down the A_1 parameters.

(3) In the future τ decays will be crucial in understanding the A_1.

C. Rare Decay Modes

There have been numerous searches for τ decay modes which should not exist in the standard model.[4,32,33] There is no evidence for any of these modes and the upper limits are given in Table VI.

III. τ Mass

DASP was the first experiment to use the energy dependence of the τ production cross section to deduce a precise value for the τ mass.[9] The result was 1807 ± 20 MeV/c^2 and the data are shown in Fig. 8.

Later measurements by DESY-Heidelberg[15] and DELCO[13,34] are shown in Figs.

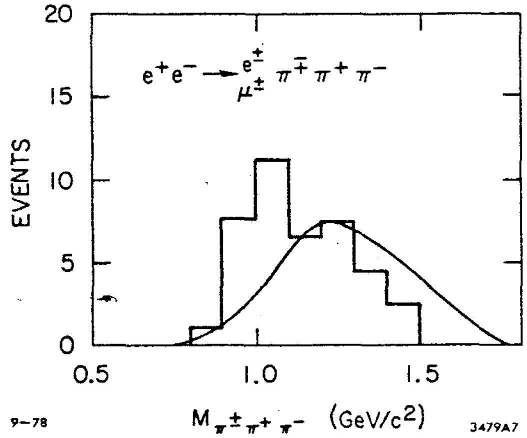

Fig. 7. Invariant mass distribution of $\rho^0\pi^\pm$ combinations for events described in Fig. 5. The curve represents a non-resonant $\rho^0\pi^\pm$ spectrum from τ decay.

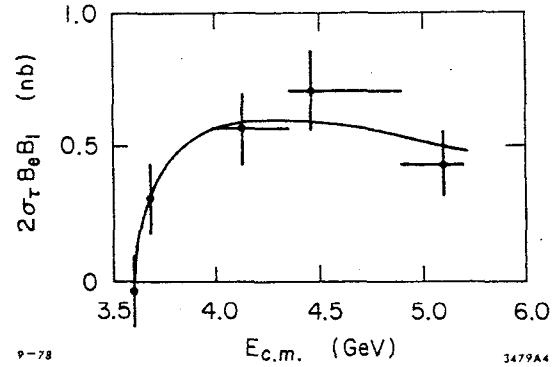

Fig. 8. Cross sections for ex events measured by the DASP experiment.[9] The curve is a fit to the production cross section for point-like spin 1/2 particles.

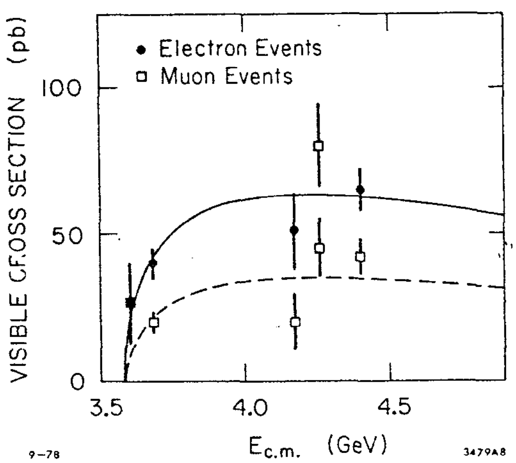

Fig. 9. Observed cross sections for ex and μx events measured by the DESY-Heidelberg experiment. The curves are fits to the production cross sections for point-like spin 1/2 particles.

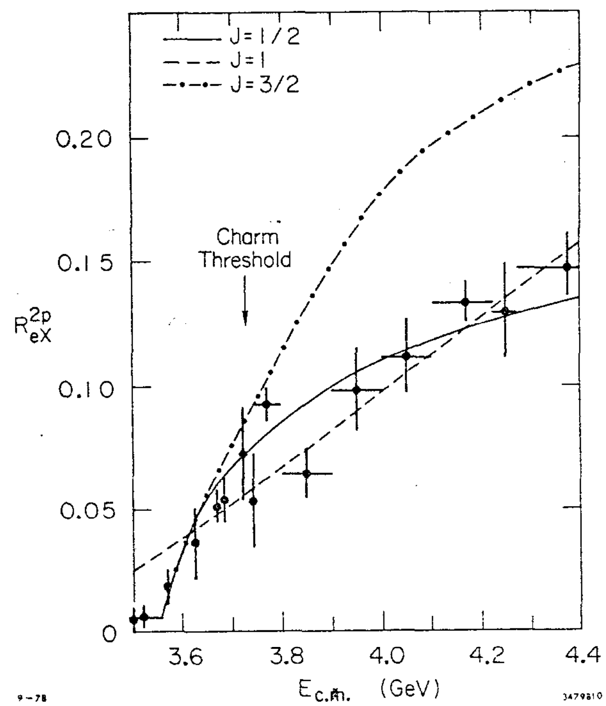

Fig. 10. The ratio of ex events to μ pair production as a function of center-of-mass energy. The solid curve is a best fit to the spin 1/2 τ pair production cross section. The dashed and dot-dashed curves represent typical cross sections for spin 1 and spin 3/2 particle production. The data are from the DELCO experiment.[34]

Table V. Results on the $\tau \to \pi\nu$ decay mode. The first error is statistical, the second systematic.

Experiment	Mode	Events	Background	$B(\tau \to \pi\nu)$(%)	Reference
SLAC-LBL	$x\pi$	∿200	∿70	9.3 ± 1.0 ± 3.8	26
PLUTO	$x\pi$	32	9	9.0 ± 2.9 ± 2.5	27
DELCO	$e\pi$	18	7	8.0 ± 3.2 ± 1.3	28
Mark II	$x\pi$	142	46	8.0 ± 1.1 ± 1.5	16
	$e\pi$	27	10	8.2 ± 2.0 ± 1.5	
Average				8.3 ± 1.4	

Table VI. Upper limits on rare τ decay modes. "x" stands for any charged particle and "ℓ" stands for any charged lepton.

Mode	Experiment	Upper Limit(%)	Confidence Level(%)	Reference
3x	PLUTO	1.0	95	32
3ℓ	SLAC-LBL	0.6	90	33
ℓ + charged particles	PLUTO	4.0	90	4
ℓ + photons	PLUTO	12.0	90	4
$e^- + \gamma$	SLAC-LBL	2.6	90	33
$\mu^- + \gamma$	SLAC-LBL	1.3	90	33

9 and 10, with results of 1790^{+7}_{-10} and 1782^{+3}_{-4} MeV/c^2, respectively. The DELCO data beautifully delineate the τ threshold by having points just above and just below it. The high precision of the DELCO mass determination is primarily due to the data point at 3.570 MeV which observed 8 ex events with 1.6 expected from backgrounds. Although there is no reason to suspect this point, it is worth noting that if it were removed from the fit, the remaining data points would pull the τ mass to 1790^{+6}_{-8} MeV/c^2 as can be seen from the existence of a second minimum in the χ^2 versus mass plot, Fig. 11.

IV. τ Spin

As long as we assume that the τ does not have a form factor which varies rapidly over the range of a few GeV, all spin assignments except 1/2 are excluded. All integer spins will require a β^3 threshold dependence and half-integer spins greater than 1/2 will lead to much too large a cross section above 4 GeV when normalized to fit the threshold region.[35] These points are illustrated in Fig. 10 by the spin 1 and 3/2 curves.

V. τ Lifetime

The τ lifetime has been studied by examining the closest distance of approach to the interaction region of leptons from τ decays. The best upper limits are 3.5×10^{-12} sec from the PLUTO experiment[30] and 3.0×10^{-12} sec from the DELCO experiment,[34] both at the 95% confidence level. For a full strength τ-ν_τ coupling to the weak current and assuming the ν_τ is massless, the τ lifetime, τ_τ, is given by

$$\tau_\tau = B_e \left(\frac{m_\mu}{m_\tau}\right)^5 \tau_\mu = (2.8 \pm 0.2) \times 10^{-13} \text{ sec} ,$$

where the error is primarily from the uncertainty in the electronic branching fraction, B_e. Thus the τ-ν_τ coupling has to be at least 9% of full strength.

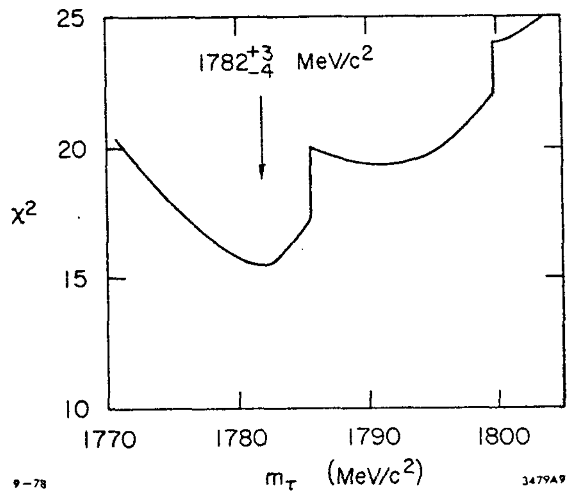

Fig. 11. χ^2 for 17 degrees of freedom for the fit to the τ mass from the data in Fig. 10.

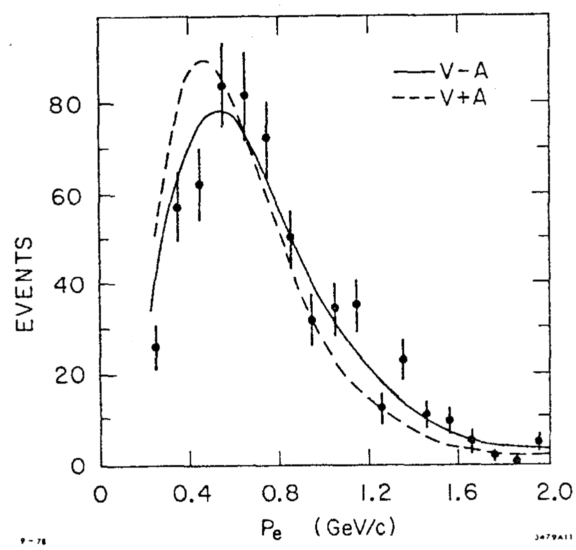

Fig. 12. Electron momentum spectrum for ex events at energies between 3.57 and 7.4 GeV. The solid and dashed curves represent the spectra expected for V-A and V+A τ-ν_τ couplings. The data are from the DELCO experiment.[34]

VI. τ-ν_τ Coupling

The lepton momentum spectrum can be used to determine the V,A structure of the τ-ν_τ coupling. V-A gives the hardest spectrum, V+A gives the softest, and pure V or A is halfway in between. The PLUTO experiment favored V-A over V+A slightly.[5] The SLAC-LBL experiment strongly disfavored V+A, giving it a statistical confidence level of at most a few percent.[8]

The most conclusive data on the τ-ν_τ coupling have been reported by the DELCO experiment.[34] They have extracted a Michel parameter, ρ, of 0.83 ± 0.19 from the electron momentum spectrum of ex events, shown in Fig. 12. The radiatively corrected Michel parameter for V-A is 0.53, for V+A is -0.15, and for either V or A is 0.19.[36] The confidence level for V-A is 4%, while the confidence level for V+A is infinitesimal. Thus the DELCO data completely exclude V+A and strongly disfavor pure V or A.

VII. ν_τ Mass

If the ν_τ had a mass, it would soften the charged lepton momentum spectrum. All experimental measurements are consistent with a massless ν_τ.[8,34,37] The upper limits on the ν_τ mass are given in Table VII.

VIII. What Type of Lepton is the τ?

All of the evidence, summarized in Table VIII, is consistent with the τ being a sequential lepton decaying to its own massless neutrino with a V-A coupling.

One can ask, however, what other possibilities could exist.[38] The simplest case would be to have the τ, but no ν_τ in an $SU(2) \times U(1)$ gauge theory. The τ would then decay into a mixture of ν_e and ν_μ. An analysis of this case shows that it is excluded by several of the measured τ properties. For example, the τ would have to decay into 3 charged leptons at a rate an order of magnitude above the experimental upper limit,[39,40] and B_μ/B_e would have to be close to 0.5 or 2.0.[40]

Table VII. Upper limits on ν_τ.

Experiment	Upper Limit (MeV/c^2)	Confidence Level(%)	Reference
SLAC-LBL	600	95	8
PLUTO	540	90	37
DELCO	250	95	34

Table VIII. Summary of selected τ properties.

Parameter	Experimental Findings
Mass	1782^{+3}_{-4} MeV/c^2
Neutrino mass	< 250 MeV/c^2 at 95% confidence level
Spin	1/2
Lifetime	$< 3 \pm 10^{-12}$ sec
τ-ν_τ coupling	consistent with V-A, V+A excluded
B_e	0.175 ± 0.012 (assuming $B_\mu = .973\ B_e$)
B_μ/B_e	1.13 ± 0.16

Another possibility is that the ν_τ exists, but is more massive than the τ. This is also excluded.[41] The argument is that the sum of couplings to ν_e and ν_μ must be greater than 0.09 of full strength from the τ lifetime measurement. But the ν_μ coupling is limited to 0.025 by the absence of τ production by ν beams,[42] and the ν_e coupling is limited to be less than 0.006 more than the ν_μ coupling by the $\pi \to \mu\nu/\pi \to e\nu$ ratio.[43]

Dropping the requirement of an $SU(2) \times U(1)$ gauge theory, one can ask more generally whether it is possible that the τ^- has the same lepton number as either the e^-, e^+, μ^-, or μ^+; that is, whether it couples to the ν_e, $\bar{\nu}_e$, ν_μ, or $\bar{\nu}_\mu$. The τ^- cannot have the lepton number of either the μ^- or μ^+ or it would be produced in ν interactions. The τ^- cannot have the lepton number of either the e^+ or μ^+. If it did there would be two identical neutrinos in the final state and B_μ/B_e would be either .5 or 2.

The one possibility which cannot be excluded at present is that the τ^- has the same quantum number as the e^-. Detailed measurements of ν_e interactions, possibly from beam dump or tagged decay experiments, may be able to address this question in the future.

Of course, there are many more possibilities than the simple ones we have discussed here, and, in general, one must simply compare the predictions of a given model to the range of parameters allowed by the data. It is remarkable, in the three years since the τ discovery, how tight the constraints have become.

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