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TAU TESTS FOR NEW PHYSICS

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ABSTRACT

By use of exclusive tau semi-leptonic decays, there are simple and general tests for violation of CP, T, and/or $(V-A)$ symmetry. The most general Lorentz invariant spin-correlation functions for $\tau^- \to \rho^-\nu, a_1^-\nu, K^{*-}\nu, \pi^-\nu, K^-\nu$ are expressed in terms of eight semi-leptonic parameters. The parameters are physically defined in terms of tau-decay partial-width-intensities for polarized-final-states. The parameters can be used to test for a "$(V-A)$ + additional chiral coupling" structure in the $J^{Charged}{}_{Lepton}$ current. This bounds the effective mass scales Λ for "new physics" such as arising from leptonic CP violation, leptonic T violation, tau weak magnetism, tau weak electricity, and/or leptonic second-class currents.

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1. Introduction

The emphasis in this talk [1] is on general tests [2] for violation of CP, T, and/or $(V-A)$ symmetry in the $J^{Charged}{}_{Lepton}$ current in exclusive tau semi-leptonic decays [3]. By means of the associated stage-two spin-correlation functions in $\tau^- \to \rho^-\nu, a_1^-\nu$, effective mass scales of $\Lambda \approx$ few $100GeV$ can be probed [4] at M_Z center-of-mass energy. Mass scales of $1-2TeV$ can be probed at $10GeV$ or $4GeV$ in unpolarized e^-e^+ collisions. If only ν_L's are coupled, leptonic CP and/or T violation can be tested [5] to $\delta(r_a)/r_a \sim 1\%(0.1\%)$ in the two helicity amplitudes' moduli ratio, and tested to $\sim 3^o(< 1^o)$ in their relative phase difference at M_Z (10, or $4GeV$).

For $\tau^- \to \rho^-\nu, a_1^-\nu, K^{*-}\nu$, we discuss

- A general parametrization by partial-width-intensities for polarized-final-states.
- Tests for additional Lorentz-structure in a "(V-A) + something" structure in the $J^{Charged}{}_{Lepton}$ current.
- Tests for non-CKM-type leptonic CP and/or T violation.

From the decays $\tau^- \to \pi^-\nu, K^-\nu$ less information can [4] usually be obtained. In particular, for these spin-0 meson modes there are

- Poor present and potential ($< 1GeV$) effective-mass bounds on the $S^- \pm P^-$ couplings which cannot contribute to the ρ and a_1 modes.

However, there is

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- Good separation ($> 127GeV$ from CLEO II data) of $V - A$ from a $T^+ + T_5^+$ coupling, whereas these couplings cannot be separated in the ρ and a_1 modes.
- Direct measurement of the chirality parameter ξ_π, i.e. of the probablity that the emitted ν_τ is L-handed.

This talk compliments recent discussions of tests for new physics from purely leptonic tau decays [6] and from analysis of tau neutral-current couplings [7] in $Z^o, \gamma^* \to \tau^-\tau^+$.

2. General Parametrization by Eight Partial-Width-Intensities for Polarized-Final-States

Traditionally, in the study of the weak-interaction $J^{Charged}$ current in muonic and in hadronic reactions, it has been important to determine the complete Lorentz stucture directly from experiment and in a model independent manner. So here, we introduce 8 parameters to describe the most general spin-correlation function for the decay sequence $Z^o, \gamma^* \to \tau^-\tau^+ \to (\rho^-\nu)(\rho^+\bar{\nu})$ followed by $\rho^{ch} \to \pi^{ch}\pi^o$ including both ν_L, ν_R helicities and both $\bar{\nu}_R$, $\bar{\nu}_L$ helicities.

Table 1: Comparison of parmeters' values for unique Lorentz couplings: entries are for ρ^- (a_1^-, if value differs).

	$V \mp A$	$S \pm P$	$f_M + f_E$	$f_M - f_E$
$\mathbf{\Gamma}$'s				
ξ	± 1	± 1	1	-1
$\mathcal{S}_\rho\zeta$	$\pm 0.5(0)$	± 1	$-0.8(-0.6)$	0.3
$\mathcal{S}_\rho\sigma$	$0.5(0)$	± 1	$-0.8(-0.6)$	-0.3
$\mathbf{\Gamma_{LT}}$'s				
$\mathcal{R}_\rho\omega$	$\pm 0.4(\pm 0.5)$	0	$0.3(0.5)$	$-0.2(-0.7)$
$\mathcal{R}_\rho\eta$	$0.4(0.5)$	0	$0.3(0.5)$	$0.2(0.7)$
ω'	0	0	0	0
η'	0	0	0	0

The 8 tau semi-leptonic decay parameters for $\tau^- \to \rho^-\nu, \ldots$, are defined for the four polarized $\rho_{L,T}\nu_{L,R}$ final states: The first parameter is simply $\Gamma \equiv \Gamma_L^+ + \Gamma_T^+$, i.e. the full partial width for $\tau^- \to \rho^-\nu$. The second is the chirality parameter $\xi \equiv \frac{1}{\Gamma}(\Gamma_L^- + \Gamma_T^-)$. Equivalently, $\xi \equiv$ (Prob ν_τ is ν_L) $-$ (Prob ν_τ is ν_R), or

$$\xi \equiv |<\nu_L|\nu_\tau>|^2 - |<\nu_R|\nu_\tau>|^2 \tag{1}$$

Thus, a value $\xi = 1$ means the coupled ν_τ is pure ν_L. For the special case of a mixture of only V & A couplings and $m_{\nu_\tau} = 0$, $\xi \to \frac{|g_L|^2 - |g_R|^2}{|g_L|^2 + |g_R|^2}$ and the "stage-one spin correlation" parameter $\zeta \to \xi$, see Table 2.

Table 2: Semi-leptonic decay parameters for $\tau^- \to \rho^-\nu, \ldots$ in the case of a single additional chiral coupling (g_ι) which is small relative to the standard $V-A$ coupling (g_L). This table is for the $V+A$ and for the $S \pm P$ couplings. The next table is for additional tensorial couplings. Expressions for "a, ..." are in Ref. 2.

	$V \pm A$		Additional $S \pm P$	
	Pure g_L	Plus g_R	Plus g_{S+P}	Plus g_{S-P}
Γ's				
ξ	1	$\frac{\lvert g_L\rvert^2-\lvert g_R\rvert^2}{\lvert g_L\rvert^2+\lvert g_R\rvert^2}$	1	1
ζ	1	ξ	$1+a\frac{\mathcal{RE}(g_L^* g_{S+P})}{\lvert g_L\rvert^2}$	$1-b\left\lvert\frac{g_{S-P}}{g_L}\right\rvert^2$
σ	1	1	ζ	$1+c\left\lvert\frac{g_{S-P}}{g_L}\right\rvert^2$
Γ_{LT}'s				
ω	1	ξ	$1-d\frac{\mathcal{RE}(g_L^* g_{S+P})}{\lvert g_L\rvert^2}$	$1-e\left\lvert\frac{g_{S-P}}{g_L}\right\rvert^2$
η	1	1	ω	ω
ω'	0	0	$-f\frac{\mathcal{IM}(g_L^* g_{S+P})}{\lvert g_L\rvert^2}$	0
η'	0	0	ω'	0

The subscripts on the Γ's denote the polarization of the final ρ^-, either "L=longitudinal" or "T=transverse"; superscripts denote "± for sum/difference of the ν_L versus ν_R contributions". Such final-state-polarized partial widths are physical observables and, indeed, the equivalent semileptonic parameters $\xi, \zeta, \ldots$ can be measured by various spin-correlation techniques.

The remaining partial-width parameters are defined by

$$\zeta \equiv (\Gamma_L^- - \Gamma_T^-)/(\mathcal{S}_\rho\Gamma), \qquad \sigma \equiv (\Gamma_L^+ - \Gamma_T^+)/(\mathcal{S}_\rho\Gamma). \tag{2}$$

To describe the interference between the ρ_L and ρ_R amplitudes, we define

$$\begin{aligned} \omega &\equiv I_{\mathcal{R}}^- /(\mathcal{R}_\rho\Gamma), \qquad & \eta &\equiv I_{\mathcal{R}}^+ /(\mathcal{R}_\rho\Gamma) \\ \omega' &\equiv I_{\mathcal{I}}^- /(\mathcal{R}_\rho\Gamma), \qquad & \eta' &\equiv I_{\mathcal{I}}^+ /(\mathcal{R}_\rho\Gamma) \end{aligned} \tag{3}$$

where the measureable LT-interference intensities are

$$\begin{aligned} I_{\mathcal{R}}^\pm &= \left|A(0,-\tfrac{1}{2})\right|\left|A(-1,-\tfrac{1}{2})\right|\cos\beta_a \pm \left|A(0,\tfrac{1}{2})\right|\left|A(1,\tfrac{1}{2})\right|\cos\beta_a^R \\ I_{\mathcal{I}}^\pm &= \left|A(0,-\tfrac{1}{2})\right|\left|A(-1,-\tfrac{1}{2})\right|\sin\beta_a \pm \left|A(0,\tfrac{1}{2})\right|\left|A(1,\tfrac{1}{2})\right|\sin\beta_a^R \end{aligned} \tag{4}$$

Here $\beta_a \equiv \phi_{-1}^a - \phi_0^a$, and $\beta_a^R \equiv \phi_1^a - \phi_0^{aR}$ are the measurable phase differences of of the associated helicity amplitudes $A(\lambda_\rho, \lambda_\nu) = |A| \exp \iota\phi$.

Important Remarks:

(1) the numerical values of "$\xi, \zeta, \sigma, \ldots$" are very distinct for different unique Lorentz couplings, see Table 1.

Table 3: This table is for additional tensorial couplings. Here $g_\pm = f_M \pm f_E$ involves $k_\tau - p_\nu$ whereas $\tilde{g}_\pm = g^+{}_{T^+ \pm T_5^+}$ involves $k_\tau + p_\nu$.

	Additional $f_M \pm f_E$		Additional $T^+ \pm T_5^+$	
	Plus g_+	Plus g_-	Plus $\tilde{g}_+$	Plus $\tilde{g}_-$
$\mathbf{\Gamma}$'s				
ξ	1	$1 - k\left\lvert\frac{g_-}{g_L}\right\rvert^2$	1	$\frac{\lvert g_L\rvert^2 - \left\lvert\frac{m\tilde{g}_-}{2\Lambda}\right\rvert^2}{\lvert g_L\rvert^2 + \left\lvert\frac{m\tilde{g}_-}{2\Lambda}\right\rvert^2}$
ζ	$1 + g\frac{\mathcal{RE}(g_L^* g_+)}{\lvert g_L\rvert^2}$	$1 - h\left\lvert\frac{g_-}{g_L}\right\rvert^2$	1	ξ
σ	ζ	$1 - j\left\lvert\frac{g_-}{g_L}\right\rvert^2$	1	1
$\mathbf{\Gamma_{LT}}$'s				
ω	$1 - l\frac{\mathcal{RE}(g_L^* g_+)}{\lvert g_L\rvert^2}$	$1 - m\left\lvert\frac{g_-}{g_L}\right\rvert^2$	1	ξ
η	ω	$1 - n\left\lvert\frac{g_-}{g_L}\right\rvert^2$	1	1
ω'	$-o\frac{\mathcal{IM}(g_L^* g_+)}{\lvert g_L\rvert^2}$	0	0	0
η'	ω'	0	0	0

(2) $\omega' \neq 0$ and/or $\eta' \neq 0 \Longrightarrow \tilde{T_{FS}}$ is violated.

(3) Barred parameters $\bar{\xi}, \bar{\zeta}, \ldots$ have the analogous definitions for the CP conjugate modes, $\tau^+ \to \rho^+ \bar{\nu}, \ldots$.
Therefore, if any $\bar{\xi} \neq \xi, \bar{\zeta} \neq \zeta, \ldots \Longrightarrow$ CP is violated.

(4). These same parameters appear in the general angular distributions for the polarized $\tau^- \to \rho^- \nu \to (\pi^- \pi^o)\nu$ decay chain,

$$\frac{dN}{d(\cos\theta_1^\tau)d(\cos\tilde{\theta}_a)d\tilde{\phi}_a} = \mathbf{n}_a[1 \pm \mathbf{f}_a \cos\theta_1^\tau] \mp (1/\sqrt{2})\sin\theta_1^\tau \sin 2\tilde{\theta}_a \; \mathcal{R}_\rho[\omega\cos\tilde{\phi}_a + \eta'\sin\tilde{\phi}_a] \tag{5}$$

with upper(lower) signs for a L-handed τ^- (R-handed), where

$$\begin{aligned} \mathbf{n}_a &= \tfrac{1}{8}(3 + \cos 2\tilde{\theta}_a + \sigma\mathcal{S}_\rho[1 + 3\cos 2\tilde{\theta}_a]) \\ \mathbf{n}_a\mathbf{f}_a &= \tfrac{1}{8}(\xi[1 + 3\cos 2\tilde{\theta}_a] + \zeta\mathcal{S}_\rho[3 + \cos 2\tilde{\theta}_a]) \end{aligned} \tag{6}$$

The formulas for the associated S2SC functions in terms of these 8 semi-leptonic parameters are listed in Ref. 2.

(5) The hadronic factors $\mathcal{S}_\rho$ and $\mathcal{R}_\rho$ have been explicitly inserted into the definitions of the semi-leptonic decay parameters, so that quantities such as ${q_\rho}^2 = {m_\rho}^2$ can be smeared over in application due to the finite ρ width. For the ρ mode they are given by

$$\mathcal{S}_\rho = \frac{1 - 2\frac{m_\rho^2}{m^2}}{1 + 2\frac{m_\rho^2}{m^2}}, \qquad \mathcal{R}_\rho = \frac{\sqrt{2}\frac{m_\rho}{m}}{1 + 2\frac{m_\rho^2}{m^2}}. \tag{7}$$

We have introduced the important factors $\mathcal{S}_\rho$ and $\mathcal{R}_\rho$ because, guided by experiment, we are analyzing versus a theory with "a mixture of only V & A couplings with $m_\nu = 0$". For such a theory these hadronic factors have a simple physical interpretation: for $\tau^- \to \rho^-{}_{L,T}\nu$ the factor $\mathcal{S}_\rho = (\text{Prob } \rho_L) - (\text{Prob } \rho_T)$, and the factor $\mathcal{R}_\rho =$ the "geometric mean of these probablities" $= \sqrt{(Prob\rho_L)(Prob\rho_T)}$.

[From experiments by the ALEPH, ARGUS, CLEO II, & OPAL collaborations, the leading contribution in the tau's $J^{Charged}{}_{Lepton}$ current is consistent with $(V-A)$ to better than the 5% level. For the nominal 10^7 event rates, we find that the S2SC function I_4 is insensitive, see Table 1 in Ref.9, to $m_\nu \leq 23.1GeV$, the present ALEPH bound.]

(6) The "additional structure" due to additional Lorentz couplings in $J^{Charged}{}_{Lepton}$ can show up experimentally because of its interference with the $(V-A)$ part which, we assume, arises as predicted by the standard lepton model. Inclusion of the ρ polarimetry information that is available from the $\rho^{ch} \to \pi^{ch}\pi^o$ decay distribution, generalizes the "stage-one spin-correlation" (S1SC) function $I(E_\rho, E_{\bar{B}})$. Since this adds on spin-correlation information from the next stage of decays in the decay sequence, we call such an energy-angular distribution a "stage-two spin-correlation" (S2SC) function.

The simplest useful S2SC is $I_4 = I(E_\rho, E_{\bar{\rho}}, \tilde{\theta}_1, \tilde{\theta}_2)$. The kinematic variables in I_4 are the usual "spherical" ones which naturally appear in the helicity formalism in describing such a decay sequence. The 1st stage of the decay sequence $\tau^-, \tau^+ \to (\rho^-\nu_\tau)(\rho^+\bar{\nu}_\tau)$ is described by the 3 variables $\theta_1^\tau, \theta_2^\tau, \cos\phi$ where ϕ is the opening $\angle$ between the two decay planes. These are equivalent to the Z^o, or γ^* center-of-mass variables, $E_\rho, E_{\bar{\rho}}, \cos\psi$. Here $\psi =$"opening $\angle$ between the ρ^- and ρ^+momenta in the Z/γ^* cm". When the Lorentz "boost" to one of the ρ rest frames is directly from the Z/γ^* cm frame, the 2nd stage of the decay sequence is described by the usual 2 spherical angles for the π^{ch} momentum direction in that ρ rest frame: $\tilde{\theta}_1, \tilde{\phi}_1$ for $\rho_1^- \to \pi_1^-\pi_1^o$, and $\tilde{\theta}_2, \tilde{\phi}_2$ for $\rho_2^+ \to \pi_2^+\pi_2^o$. (See figures in Ref. 5.) Similarly, a_1 polarimetry information can be included from the $\tau^- \to a_1^-\nu \to (\pi^-\pi^-\pi^+)\,\nu, (\pi^o\pi^o\pi^-)\,\nu$ decay modes.

(7) The equivalent definitions for these 8 semi-leptonic parameters in terms of the $\tau^\mp$ decay helicity amplitudes are given in Ref. 2. In the τ^- rest frame, the matrix element for $\tau^- \to \rho^-\nu$ is

$$\langle \theta_1^\tau, \phi_1^\tau, \lambda_\rho, \lambda_\nu | 1/2, \lambda_1 \rangle = D^{\frac{1}{2}*}_{\lambda_1,\mu}(\phi_1^\tau, \theta_1^\tau, 0) A\,(\lambda_\rho, \lambda_\nu) \tag{8}$$

where $\mu = \lambda_\rho - \lambda_\nu$ and λ_1 is the τ^- helicity. For the CP-conjugate process, $\tau^+ \to \rho^+\bar{\nu} \to (\pi^+\pi^o)\,\bar{\nu}$, in the τ^+ rest frame

$$\langle \theta_2^\tau, \phi_2^\tau, \lambda_{\bar{\rho}}, \lambda_{\bar{\nu}} | 1/2, \lambda_2 \rangle = D^{\frac{1}{2}*}_{\lambda_2,\bar{\mu}}(\phi_2^\tau, \theta_2^\tau, 0) B\,(\lambda_{\bar{\rho}}, \lambda_{\bar{\nu}}) \tag{9}$$

with $\bar{\mu} = \lambda_{\bar{\rho}} - \lambda_{\bar{\nu}}$.

3. Tests for a "$(V-A)$ + additional chiral coupling" Structure

Besides model independence in a directly-from-experiment determination of the tau's $J^{Charged}{}_{Lepton}$ current, a major current issue is whether or not there is an additional chiral coupling beyond the standard $(V-A)$ structure. A chiral classification of additional structure is a natural phenomenological extension of the symmetries of the standard $SU(2)_L\ X\ U(1)$ electroweak lepton model.

The requirement of $\bar{u}(p_\nu) \to \bar{u}(p_\nu)\frac{1}{2}(1+\gamma_5)$ and/or $u(k_\tau) \to \frac{1}{2}(1-\gamma_5)u(k_\tau)$ invariance of the vector and axial current matrix elements $\langle \nu\,|v^\mu(0)|\,\tau\rangle$ and $\langle \nu\,|a^\mu(0)|\,\tau\rangle$, allows only $g_L, g_{S+P}, g_{S-+P-}, g_+ = f_M + f_E$,and $\tilde{g}_+ = T^+ + T_5^+$ couplings. From this $SU(2)_L$ perspective, the relevant experimental question is "What are the best current limits on such additional couplings in tau lepton physics?"

Similarly, $\bar{u}(p_\nu) \to \bar{u}(p_\nu)\frac{1}{2}(1-\gamma_5)$ and/or $u(k_\tau) \to \frac{1}{2}(1+\gamma_5)\ u(k_\tau)$ invariance selects the complimentary set of $g_R, g_{S-P}, g_{S--P-}, g_- = f_M - f_E$,and $\tilde{g}_- = T^+ - T_5^+$ couplings. The absence of $SU(2)_R$ couplings is simply built into the standard model; it is not predicted by it. So, "What are the best current limits on such $SU(2)_R$ couplings in tau lepton physics?"

The most general Lorentz coupling for $\tau^- \to \rho^- \nu_{L,R}$ is

$$\rho^*_\mu \bar{u}_{\nu_\tau}(p)\,\Gamma^\mu u_\tau(k) \tag{10}$$

where $k_\tau = q_\rho + p_\nu$. It is convenient to treat the vector and axial vector matrix elements separately, so

$$\Gamma^\mu_V = g_V\gamma^\mu + \frac{f_M}{2\Lambda}\iota\sigma^{\mu\nu}(k-p)_\nu + \frac{g_{S-}}{2\Lambda}(k-p)^\mu + \frac{g_S}{2\Lambda}(k+p)^\mu + \frac{g_{T+}}{2\Lambda}\iota\sigma^{\mu\nu}(k+p)_\nu \tag{11}$$

$$\Gamma^\mu_A = g_A\gamma^\mu\gamma_5 + \frac{f_E}{2\Lambda}\iota\sigma^{\mu\nu}(k-p)_\nu\gamma_5 + \frac{g_{P-}}{2\Lambda}(k-p)^\mu\gamma_5 + \frac{g_P}{2\Lambda}(k+p)^\mu\gamma_5 + \frac{g_{T_5^+}}{2\Lambda}\iota\sigma^{\mu\nu}(k+p)_\nu\gamma_5 \tag{12}$$

Both the weak magnetism $\frac{f_M}{2\Lambda}$ and the weak electricty $\frac{f_E}{2\Lambda}$ terms are divergenceless.

The parameter Λ = "the scale of New Physics". In effective field theory this is the effective-mass scale at which new particle thresholds are expected to occur or where the theory becomes non-perturbatively strongly-interacting so as to overcome perturbative inconsistencies. In old-fashioned renormalization theory Λ is the scale at which the calculational methods and/or the principles of "renormalization" breakdown.

Tables 2 & 3 list the semi-leptonic parameters' form in terms of g_L plus a single additional chiral coupling (g_ι) which is small relative to the standard $V-A$ coupling. The coefficients "$a,\ldots,o$" are listed in Ref.2 and are of order m_τ/Λ and/or $(m_\tau/\Lambda)^2$. In these Tables, $\mathcal{RE}$ ($\mathcal{IM}$) denote respectively the real (imaginary) parts of the quantity inside the parentheses.

Without additional theoretical or experimental inputs, it is not possible to select what is the "best" minimal set of couplings for analyzing the structure of the tau's charged current. For instance, by Lorentz invariance, there are the equivalence theorems that for the vector current

$$S \approx V + f_M, \quad T^+ \approx -V + S^- \tag{13}$$

and for the axial-vector current

$$P \approx -A + f_E, \quad T_5^+ \approx A + P^- \tag{14}$$

Table 4: "Chiral Couplings": Limits on Λ in GeV for Real g_ι. For the ρ and a_1 modes, a small addtional $T^+ + T_5^+$ coupling is equivalent to a pure $V - A$ coupling; and $T^+ - T_5^+$ is equivalent to $V + A$.

	$\{\rho^-, \rho^+\}$ mode		$\{a_1^-, a_1^+\}$ mode	
	At M_Z	10, or 4 GeV	At M_Z	10, or 4 GeV
$V + A$, for ξ_A	0.006	0.0012	0.010	0.0018
$S + P$, for Λ	$310GeV$	1,700	64	350
$S - P$, for $(\Lambda)^2$	$(11GeV)^2$	$(25)^2$	$(4)^2$	$(7)^2, (10)^2$
$f_M + f_E$, for Λ	$210GeV$	1,200	280	1,500
$f_M - f_E$, for $(\Lambda)^2$	$(9GeV)^2$	$(20)^2$	$(10)^2$	$(24)^2$

Table 5: "Chiral Couplings": Limits on Λ in GeV for Pure Imaginary g_ι

	$\{\rho^-, \rho^+\}$ mode		$\{a_1^-, a_1^+\}$ mode	
	At M_Z	10, or 4 GeV	At M_Z	10, or 4 GeV
$V + A$, for ξ_A	0.006	0.0012	0.010	0.0018
$S + P$, for$(\Lambda)^2$	$(11GeV)^2$	$(25)^2$	$(4)^2$	$(10)^2$
$S - P$, for $(\Lambda)^2$	$(11GeV)^2$	$(25)^2$	$(4)^2$	$(7)^2, (10)^2$
$f_M + f_E$, for$(\Lambda)^2$	$(9GeV)^2$	$(20)^2$	$(10)^2$	$(24)^2$
$f_M - f_E$, for $(\Lambda)^2$	$(9GeV)^2$	$(20)^2$	$(10)^2$	$(24)^2$

Tables 4 & 5 give the effective-mass limits "Λ_ι" for a purely real, or purely imaginary, coupling constant for a single addtional chiral coupling beyond the usual $V - A$ chiral coupling of the standard lepton model. These limits use the simpler 4-variable "stage-two spin-correlation" distribution $I(E_\rho, E_{\bar{\rho}}, \tilde{\theta}_1, \tilde{\theta}_2)$ and assume 10^7 Z^o's or 10^7 (τ^-, τ^+) pairs at the γ^* center-of-mass energies. The limits are weaker in the case of an additional purely imaginary g_ι for then it is not an interference effect.

4. Tests for non-CKM-type Leptonic CP and/or T Violation

By CP invariance each of the barred semi-leptonic parameters should equal, within

experimental errors, its unbarred associate. However, if only ν_L and $\bar{\nu}_R$ exist, there are [5] also two simple tests for "non-CKM-type" leptonic CP violation in $\tau \to \rho\nu$ decay. Normally a CKM leptonic-phase will contribute equally at tree level to both the $\tau^- \to \rho^-\nu_L$ decay amplitudes (for exceptions see footnotes in first paper in Ref. 5).

Table 6: 2 Tests for "Non-CKM-Type Leptonic CP Violation" in $\tau^- \to \rho^-\nu_L$ decay (ideal statistical errors):Note $\tilde{\beta} = \beta_a - \beta_b$ and $\beta' = \beta_a + \beta_b$.

E_{cm}	$\sigma(r_a)$	$\sigma(\tilde{\beta}) \simeq \sigma(\beta_a)$		$\sigma(\beta')$
	$CP\tilde{T}_{FS}, CP$	CP	$\tilde{T}_{FS}$	$CP\tilde{T}_{FS}, CP$
M_Z	0.6%		$\sim 1.9^o$	$\sim 3^o$
$10GeV$	0.1%		$\sim 0.4^o$	$\sim 0.7^o$
$4GeV$	0.1%		$\sim 0.9^o$	$\sim 1.1^o$

Table 7: 2 Tests for "Non-CKM-Type Leptonic CP Violation" in $\tau^- \to a_1^-\nu_L$ decay, both $(2\pi^-\pi^+)$ and $(2\pi^o\pi^-)$:

E_{cm}	$\sigma(r_a)$	$\sigma(\tilde{\beta}) \simeq \sigma(\beta_a)$		$\sigma(\beta')$
	$CP\tilde{T}_{FS}, CP$	CP	$\tilde{T}_{FS}$	$CP\tilde{T}_{FS}, CP$
M_Z	0.3%		$\sim 10^o$	$\sim 15^o$
$10GeV$	0.05%		$\sim 3^o$	$\sim 3^o$
$4GeV$	0.05%		$\sim 4^o$	$\sim 5^o$

These two tests follow because by CP invariance $B(\lambda_{\bar{\rho}}, \lambda_{\bar{\nu}}) = \gamma_{CP} A(-\lambda_{\bar{\rho}}, -\lambda_{\bar{\nu}})$ with $\gamma_{CP} = \pm 1$ respectively for ρ & a_1. So the two tests for leptonic CP violation are:

$$\beta_a = \beta_b \qquad \textbf{first test} \tag{15}$$

where $\beta_a = \phi^a_{-1} - \phi^a_0$, $\beta_b = \phi^b_1 - \phi^b_0$, and

$$r_a = r_b \qquad \textbf{second test} \tag{16}$$

where

$$r_a = \frac{|A\left(-1, -\frac{1}{2}\right)|}{|A\left(0, -\frac{1}{2}\right)|}, \quad r_b = \frac{|B\left(1, \frac{1}{2}\right)|}{|B\left(0, \frac{1}{2}\right)|} \tag{17}$$

For sensitivity levels for $\tau \to \rho\nu$ decay, see Table 6, and for $\tau \to a_1\nu$ decay, see Table 7. Note that the a_1 has the opposite CP quantum number to that of the ρ. The

sensitivity of the a_1 mode, versus that of the ρ mode, is about 2 times better for the r_a measurement and is about 5 times worse for the β measurements. The simpler I_4 function was used for $\sigma(r_a)$ and the full I_7 was used [5,2] for the other σ's. The CP and $CP\tilde{T}_{FS}$ predictions for the phase relation between β_a and β_b are opposite. So, this provides a method for distinguishing between a new physics effect due to an unusual CP-violating final state interaction $\beta_a = -\beta_b$ and one with a different mechanism of CP violation $|\beta_a| \neq |\beta_b|$.

These 2 tests should be compared with the classic CP test for the equality of the partial widths of CP-conjugate reactions

$$A_\Gamma \equiv \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}} \tag{18}$$

where, e.g. for $\tau \to \rho\nu$ decay, $\Gamma = \Gamma(\tau^- \to \rho^-\nu)$ and $\bar{\Gamma} = \bar{\Gamma}(\tau^+ \to \rho^+\bar{\nu})$. So, A_Γ tests for CKM-type CP violation and for $r_a/r_b \neq 1$, but it is <u>not</u> sensitive to $\beta_a \neq \beta_b$. Quantitatively, for $A_{amp} = A + \delta a, \bar{A}_{amp} = A$, then $A_\Gamma = \delta a/A \geq (1 - 4\%)$ since for τ 2-body modes the denominator is known to $1 - 4\%$. Whereas, as shown in Tables 6 & 7 for $\tau^- \to \rho^-\nu, a_1{}^-\nu$, $\delta r_a/r_a = (0.1 - 1\%)$.

5. Description of $\tau^- \to \pi^-\nu, K^-\nu$

The only observables for each of the $\tau^- \to \pi^-\nu, K^-\nu$ modes which can be measured by spin-correlations are the chirality parameter $\xi_{\pi,K} = \frac{|A(-\frac{1}{2})|^2 - |A(\frac{1}{2})|^2}{|A(-\frac{1}{2})|^2 + |A(\frac{1}{2})|^2}$ and the $\Gamma(\tau^- \to \pi^-\nu)$, or $\Gamma(\tau^- \to K^-\nu)$, partial width. By Lorentz invariance, for these spin-0 meson modes there are the equivalence theorems that $S^- \approx S \approx T^+ \approx V$ and $P^- \approx P \approx T_5^+ \approx A$. In principle, the S^- and P^- couplings can contribute to the π^- and K^- channels, whereas they cannot for the ρ, a_1, K^* modes. However, since $q \cdot V \sim \frac{m_\pi^2}{2\Lambda} g_{S^-}$ and $q \cdot A \sim \frac{m_\pi^2}{2\Lambda} g_{P^-}$ their contribution is strongly suppressed for $\Lambda > (\sim 1GeV)$ scales. Nevertheless, as noted above in the "Introduction", these spin-0 meson modes do provide [4,2] some useful information on the complete Lorentz structure of the tau's $J^{Charged}{}_{Lepton}$ current.

6. Conclusions

The history of lepton physics is replete not only with unexpected developments, but also with accounts going "from dream to discovery". In this regard, it seems to us that the systematic exploration of the fundamental physics and origin of the tau lepton system $\tau^\mp, \nu_\tau, \bar{\nu}_\tau$ has only just begun.

For searching with tau's for such "new physics",

- There is a general parametrization [2] of exclusive tau semi-leptonic decays in terms of partial-width-intensities for polarized-final-states:
  $\tau^- \to \rho^-{}_{L,T}\nu_{L,R}$ with $(\xi, \zeta, \sigma, \ldots)$, and $\tau^+ \to \rho^+{}_{L,T}\bar{\nu}_{R,L}$ with $(\bar{\xi}, \bar{\zeta}, \bar{\sigma}, \ldots)$.

- There are tests [4,2] for additional Lorentz structure to effective-mass scales of $1-2TeV$.
- There are tests [8,7] for leptonic CP, and/or T, violation in tau decays and [7] in $Z^o, \gamma^* \to \tau^-\tau^+$.
- Also at $10GeV$ & $4GeV$, there are 3 tests for C and P invariances in $\gamma^* \to \tau^-\tau^+$ [see Table 16 in Ref. 9].

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8. References

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