TESTING $CP$, $T$ AND $(V - A)$ SYMMETRY THROUGH TAU LEPTONS

Charles A. Nelson, Department of Physics, State University of New York at Binghamton, Binghamton, N.Y. 13902-6016

Abstract

Model independent tests for symmetry violations in tau decays are important for determining whether the tau lepton is elementary or, instead, macroscopic. Such tests are also significant steps towards resolving the outstanding $e - \mu - \tau$ puzzle. This talk reviews such tests in the context of a general treatment of two-body $\tau$ decays which only assumes Lorentz invariance and the treelike structure of the $\tau^-\tau^+$ production-decay sequence. Direct measurement of polarized-partial-widths and of associated “longitudinal-transverse W-exchange” interference intensities will provide significant probes for distinguishing elementary/macroscopic theories of the Higgs and of the $\tau, \nu_\tau$. The analogous goals and techniques apply to top quark decays.

1 INTRODUCTION

The most outstanding open questions concerning the tau lepton are
(i) Does the $\tau$ differ in some way from simply being a more massive version of the $\mu$ and $e$?
(ii) The $e - \mu - \tau$ puzzle: What is the fundamental relationship between the $\tau, \mu$ and $e$?

Naively, differences among the charged leptons might be expected to be most easily observed for the $\tau$ since it is the most massive. One purpose of this talk is to discuss a general treatment of two-body tau decays [1] which only assumes Lorentz invariance and exploits the tree-like structure of the dominant contributions to the $\tau^-\tau^+$ production-decay sequence. In particular, $CP$ invariance, $T$ invariance, and a $(V - A)$ structure of the tau charged-current is not assumed. At present, these symmetries are poorly tested for the $\tau$. Discovery of a violation of one of these symmetries in reactions involving the $\tau$, might point to a more fundamental structure underlying the charged leptons, e.g. be evidence for lepton

\footnote{Electronic address: cnelson@bingvmh.cc.binghamton.edu
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compositeness. For example, in analogy with the Pauli anomalous magnetic moment, such structure could show up as an additional tensorial $g_+ = f_M + f_E$ coupling which would preserve the 3 signatures for only $\nu_L$ couplings but give non-$(V-A)$-values to the semi-leptonic parameters. We find that by the $\rho^-(a_1^\rho)$ modes, compositeness in the tau lepton could be respectively probed [2] to $1.2 TeV$($1.5 TeV$). In this talk we do not discuss the important tests for symmetry violations in the neutral current couplings involving the $\tau$, see [3].

The analogous goals and techniques apply to top quark decays [4].

2 A GENERAL TREATMENT OF $\tau$ SEMILEPTONIC DECAYS BY POLARIZED-PARTIAL-WIDTH MEASUREMENTS

The goals of a general parametrization of two-body $\tau$ decays are (a) to determine the “complete Lorentz structure” of $J^{charged\,Lepton}$ directly from experiment, and (b) to test in a model independent manner for the presence of “additional Lorentz couplings”. Simultaneously, there are simple tests for leptonic $CP$ violation and for leptonic $T$ violation in $\tau$ decays.

The physical idea is very simple: We introduce 8 parameters to describe the most general spin-correlation function for the decay sequence $Z^0, \gamma^* \rightarrow \tau^- \tau^+ \rightarrow (\rho^-\nu)(\rho^+\bar{\nu})$ followed by $\rho^{ch} \rightarrow \pi^{ch}\pi^o$ including both $\nu_L, \nu_R$ helicities and both $\bar{\nu}_R, \bar{\nu}_L$ helicities. Thus, by including the $\rho$ polarimetry information that is available from the $\rho^{ch} \rightarrow \pi^{ch}\pi^o$ decay distribution, the polarized-partial-widths for $\tau^- \rightarrow \rho^-\nu$ are directly measurable. For instance, the general angular distribution for polarized $\tau^-_{L,R} \rightarrow \rho^-\nu \rightarrow (\pi^-\pi^o)\nu$ is described by

$$\frac{dN}{d(cos \theta^*_1)d(cos \theta_a)d\phi_a} = n_a[1 \pm f_a \cos \theta^*_1] \mp (1/\sqrt{2}) \sin \theta^*_1 \sin 2\theta_a \frac{R_p}{R_p}[\omega \cos \phi_a + \eta' \sin \phi_a]$$

with upper(lower) signs for a L-handed $\tau^-$ (R-handed), where

$$n_a = \frac{1}{8}(3 + \cos 2\theta_a + \sigma S_p[1 + 3 \cos 2\theta_a])$$
$$n_a f_a = \frac{1}{8}(\xi[1 + 3 \cos 2\theta_a] + \zeta S_p[3 + \cos 2\theta_a])$$

In this expression, $\cos \theta^*_1$ describes the direction of the $\rho^-$ momentum in the $\tau^-$ rest frame, and $\cos \theta_a, \phi_a$ describe the direction of the $\pi^-$ in the $\rho^-$ rest frame. Such formulas for more general spin-correlation functions in terms of the 8 semi-leptonic parameters are given in [1] for unpolarized $e^-e^+$ beams, and in [5] for polarized beams.

There are eight $\tau$ semi-leptonic decay parameters since there are the four $\rho_{L,T}\nu_{L,R}$ final states: The first parameter is simply $\Gamma \equiv \Gamma^+_L + \Gamma^+_T$, i.e. the (full) partial width for $\tau^- \rightarrow \rho^-\nu$. The second is the chirality parameter $\xi \equiv \frac{1}{\Gamma} (\Gamma^+_L + \Gamma^+_T)$. Equivalently, $\xi \equiv (\text{Prob} \nu_\tau = \nu_L) - (\text{Prob} \nu_\tau = \nu_R)$, or

$$\xi \equiv |<\nu_L|\nu_\tau>|^2 - |<\nu_R|\nu_\tau>|^2$$
So a value $\xi = 1$ means the coupled $\nu_\tau$ is pure $\nu_L$. $\nu_L$ ($\nu_R$) means the emitted neutrino has L-handed (R-handed) polarization. For the special case of a mixture of only $V$ & $A$ couplings and $m_\nu = 0$, $\xi \rightarrow \frac{|g_L|^2 - |g_R|^2}{|g_L|^2 + |g_R|^2}$ and the "stage-one spin correlation" parameter $\zeta \rightarrow \xi$. The subscripts on the $\Gamma$'s denote the polarization of the final $\rho^-$ (and in the SM of the intermediate off-shell $W^-$ boson), either "L=longitudinal" or "T=transverse"; superscripts denote "± for sum/difference of the $\nu_L$ versus $\nu_R$ contributions". The remaining partial-width parameters are defined by

$$
\zeta \equiv (\Gamma_L - \Gamma_T)/(S_\rho \Gamma), \quad \sigma \equiv (\Gamma_L^+ - \Gamma_T^-)/(S_\rho \Gamma).
$$

(4)

The definiton for $\sigma$ in Eq.(4) implies that

$$
\bar{\sigma} \equiv (\text{Prob } \rho \text{ is } \rho_L) - (\text{Prob } \rho \text{ is } \rho_T),
$$

where

$$
\bar{\sigma} = S_\rho \sigma,
$$

is the analogue of the neutrino’s chirality parameter in Eq.(3). Thus, the parameter $\sigma$, or $\bar{\sigma}$, measures the degree of polarization of the emitted rho. If the exchange is, indeed, via an off-shell $W$-boson, $\sigma$ measures the polarization of the $W$-boson.

To describe the interference between the $\rho/W_L$ and $\rho/W_R$ amplitudes, we define

$$
\omega \equiv I_{R \rho}^+ / (R_\rho \Gamma), \quad \eta \equiv I_{R \rho}^+ / (R_\rho \Gamma)
$$

$$
\omega' \equiv I_{T \rho}^+ / (R_\rho \Gamma), \quad \eta' \equiv I_{T \rho}^+ / (R_\rho \Gamma)
$$

(5)

where the measureable LT-interference intensities are

$$
I_{R \rho}^\pm = \big| A(0, -\frac{1}{2}) \big| \big| A(-1, -\frac{1}{2}) \big| \cos \beta_a \pm \big| A(0, \frac{1}{2}) \big| \big| A(1, \frac{1}{2}) \big| \cos \beta_a^R
$$

$$
I_{T \rho}^\pm = \big| A(0, -\frac{1}{2}) \big| \big| A(-1, -\frac{1}{2}) \big| \sin \beta_a \pm \big| A(0, \frac{1}{2}) \big| \big| A(1, \frac{1}{2}) \big| \sin \beta_a^R
$$

(6)

Here $\beta_a \equiv \phi_{a-1}^a - \phi_a^0$, and $\beta_a^R \equiv \phi_1^a - \phi_0^R$ are the measurable phase differences of $\phi$ of the associated helicity amplitudes $A(\lambda_\rho, \lambda_\nu) = |A| \exp i \phi$.

In the standard model with only a $(V - A)$ coupling and $m_\nu = 0$, these parameters all equal one except for the two parameters directly sensitive to leptonic $T$ violation which vanish, i.e., $\omega' = 0$ and $\eta' = 0$.

The hadronic factors $S_\rho$ and $R_\rho$ 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 $\rho$ width. For the $\rho$ mode they are given by

$$
S_\rho = \frac{1 - 2m_\rho^2}{1 + 2m_\rho^2}, \quad R_\rho = \frac{\sqrt{2m_\rho \lambda_\rho}}{1 + 2m_\rho^2}.
$$

(7)

These factors numerically are $(S, R)_{\rho, a, K} = 0.454, 0.445; -0.015, 0.500; 0.330, 0.472$.

**Sensitivity of semi-leptonic parameters**

The numerical values of “$\xi, \zeta, \sigma, \ldots$” are very distinct for different unique Lorentz couplings, see Table 1 and the tables in Ref.[1].
Table 1: Values of the measureable polarized-partial-widths \( \Gamma \) for \( \rho_L,T \nu_L,R \) final states for unique Lorentz couplings:

| \( \frac{V}{A} \) | \( S \pm P \) | \( f_M + f_E \) | \( f_M - f_E \) |
|-----------------|-------------|-----------------|-----------------|
| Analytic        |             |                 |                 |
| \( \Gamma^-_L/\Gamma \) | \( \pm \frac{1}{2}(1 + S_\rho) \) | \( \pm 1 \) | \( \frac{2S^2}{2\tau^4 + \rho^2} \) | \( -\frac{1}{3} \) |
| \( \Gamma^-_T/\Gamma \) | \( \pm \frac{1}{2}(1 - S_\rho) \) | 0 | \( \frac{2\gamma^2}{2\tau^4 + \rho^2} \) | \( -\frac{2}{3} \) |
| \( \Gamma^+_L/\Gamma \) | \( \frac{1}{2}(1 + S_\rho) \) | 1 | \( \frac{2\gamma^2}{2\tau^4 + \rho^2} \) | \( +\frac{1}{3} \) |
| \( \Gamma^+_T/\Gamma \) | \( \frac{1}{2}(1 - S_\rho) \) | 0 | \( \frac{2\gamma^2}{2\tau^4 + \rho^2} \) | \( +\frac{1}{3} \) |
| Numerical       |             |                 |                 |
| \( \Gamma^-_L/\Gamma \) | \( \pm 0.7(\pm 0.5) \) | \( \pm 1 \) | \( 0.0(0.2) \) | \( -0.3 \) |
| \( \Gamma^-_T/\Gamma \) | \( \pm 0.3(\pm 0.5) \) | 0 | \( 1.0(0.8) \) | \( -0.7 \) |
| \( \Gamma^+_L/\Gamma \) | 0.7(0.5) | 1 | \( 0.0(0.8) \) | \( +0.3 \) |
| \( \Gamma^+_T/\Gamma \) | 0.3(0.5) | 0 | \( 1.0(0.8) \) | \( +0.7 \) |

In contrast to the purely leptonic modes, the tau semi-leptonic modes are qualitatively distinct since they enable a second-stage spin-correlation. From existing results, a quantitative comparison with the ideal sensitivity in the purely leptonic case is possible if we assume an arbitrary mixture of \( V \) and \( A \) couplings with \( m_\nu = 0 \). Then the semi-leptonic chirality parameter \( \xi_\rho \) and the chiral polarization parameter \( \xi_{Lepton} \) can be compared since they both equal \( (|g_L|^2 - |g_R|^2)/(|g_L|^2 + |g_R|^2) \). By using \( I_4 \) to obtain \( \xi_\rho \) from \{\( \rho^- \rho^+ \)} total sensitivity, \( 2 \) is \( \delta(\xi_\rho) = 0.006 \) at \( M_Z \). This is a factor of 8 better than the pure leptonic mode’s \( \delta(\xi_{Lepton}) = 0.05 \) error [6] from averaging over the \( \mu \) and \( e \) modes and using \( I_3(E_1, E_2, \cos \psi_{12}) \) where \( \psi_{12} \) is the opening angle between the two final charged leptons in the cm-frame. A complete determination of the purely leptonic parameters for \( \tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau \) will require a difficult measurement of the \( \mu \) polarization, see Fetscher[7].

3 TESTS FOR “NEW PHYSICS” IN TAU DECAYS

“New physics” 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. Therefore, c.f. Eqs.(5), imaginary parts can be directly measureable.

Tests for leptonic non-CKM CP/T violation:
(i) Barred parameters \( \tilde{\xi}, \tilde{\zeta}, \ldots \) have [1] the analogous definitions for the CP conjugate modes, \( \tau^+ \rightarrow \rho^+ \bar{\nu} \ldots \therefore \) Therefore, any \( \xi \neq \tilde{\xi}, \zeta \neq \tilde{\zeta} \ldots \implies \) CP violated: As was shown in [8], if only \( \nu_L \) and \( \bar{\nu}_R \) exist, there are two simple tests for “non-CKM-type” leptonic CP violation in \( \tau \rightarrow \rho \nu \) decay. Normally a CKM leptonic-phase will contribute equally at tree level to both the \( \tau^- \) decay amplitudes (for exceptions see footnotes 14, 15 in [8]). These two tests follow because by CP invariance \( B(\lambda_\rho, \lambda_{\tilde{\rho}}) = \gamma_{CP} A(\lambda_\rho, -\lambda_{\tilde{\rho}}) \). So the two tests for
leptonic CP violation are:

$$\beta_a = \beta_b \quad \text{first test} \quad (8)$$

where $$\beta_a = \phi_{a,1} - \phi_{a,0}$$, $$\beta_b = \phi_{b,1} - \phi_{b,0}$$, and

$$r_a = r_b \quad \text{second test} \quad (9)$$

where

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

(10)

Sensitivity levels for $$\tau \to \rho \nu$$ and $$\tau \to a_1 \nu$$ decays are to about 0.05 to 0.1% for $$r_a = r_b$$, and to about 1° to 3° for $$\beta_a = \beta_b$$ at 10 GeV and at 4 GeV without using polarized $$e^-e^+$$ beams, see [6,1].

(ii) Primed parameters $$\omega' \neq 0$$ and/or $$\eta' \neq 0 \implies \tilde{T}_{FS}$$ is violated: There is a basic theorem in quantum mechanics that measurement of a non-real helicity amplitude implies a violation of $$\tilde{T}_{FS}$$ invariance when a first-order perturbation in an “effective” hermitian Hamiltonian is reliable. So a violation of $$\tilde{T}_{FS}$$ invariance would imply either (i) a significant final state interaction between the final (L, versus T polarization) $$\rho$$ and the $$\nu_\tau$$, (ii) a violation of canonical $$T$$ invariance, or (iii) both (i) and (ii). In quantum field theory, nothing forbids either (i) and/or (ii) from occurring in $$\tau$$ decays, so it remains something to be tested by on-going and future experiments. Note: Canonical CPT invariance implies only equal total widths between a particle and its antiparticle. Canonical CPT invariance does not imply equal partial widths between CP-conjugate decay modes of a particle and its antiparticle. Indeed, in nature in the kaon system the partial widths of the neutral kaons do differ for the particle and the antiparticle.

Note that the trigonometric structure of Eqs.(6) implies the two constraints

$$(\eta \pm \omega)^2 + (\eta' \pm \omega')^2 = \frac{1}{4}[(1 \pm \xi)^2 - (\tilde{\sigma} \pm \tilde{\zeta})^2] \quad (11)$$

or

$$2|\eta' \pm \omega' | = \sqrt{(1 \pm \xi)^2 - (\tilde{\sigma} \pm \tilde{\zeta})^2 - 4(\eta \pm \tilde{\omega})^2}$$

among the $$\eta, \eta', \omega, \omega'$$ parameters which test for leptonic $$\tilde{T}_{FS}$$ violation. Consistency, i.e. unitarity, requires the argument of the square root must be non-negative. To test for leptonic $$\tilde{T}_{FS}$$ violation, besides the $$\omega$$ parameter which can be measured from $$I_4$$ in both the $$\rho$$ and $$a_1$$ modes, there is the $$\eta'$$ parameter which can be obtained from $$I_5$$ in both the $$\rho$$ and $$a_1$$ modes. Also there are the $$\eta$$ and $$\omega'$$ parameters which only appear in S2SC distributions for the $$a_1$$ modes.

For $$10^7 (\tau^-, \tau^+)$$ pairs at 10 GeV: from the $$\{\rho^-, \rho^+\}$$ mode and using the four-variable distribution $$I_4$$, the ideal statistical percentage errors are for $$\omega$$, 0.6%. From the $$\{a_1^-, a_1^+\}$$ mode: using $$I_5^-$$ the errors are for $$\eta$$, 0.6%; using $$I_7$$ for $$\eta'$$, 0.013; and using $$I_7^-$$ for $$\omega'$$, 0.002. Therefore[1], since these results are more sensitive but use more angular variables than those...
included in the simple spin-correlation function $I_4$, there are better observables for searching for leptonic $T$ violation than the simple $I_4$ distribution considered in Ref.[2].

**Tests for violation of** $(V - A)$ **symmetry:**

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

$$\rho^*_\mu \bar{u}_\nu \langle k \rangle \Gamma^\mu u_\tau (k) \quad (12)$$

where $k_\tau = q_\rho + p_\nu$. It is convenient to treat the vector and axial vector matrix elements separately. In Eq.(12)

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

$$\Gamma^\mu_A = g_A \gamma^\mu \gamma_5 + \frac{f_E}{2\Lambda} i \sigma^{\mu\nu} (k - p)_\nu \gamma_5 + \frac{g_{P-}}{2\Lambda} (k - p)^\mu \gamma_5 + \frac{g_P}{2\Lambda} (k + p)^\mu \gamma_5 + \frac{g_{T^+_5}}{2\Lambda} i \sigma^{\mu\nu} (k + p)_\nu \gamma_5 \quad (13)$$

The parameter $\Lambda =$ “the effective-mass scale of new physics”. In effective field theory this is the 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. It can also be interpreted as a measure of a new compositeness scale. In old-fashioned renormalization theory $\Lambda$ is the scale at which the calculational methods and/or the principles of “renormalization” breakdown. While some terms of the above form do occur as higher-order perturbative-corrections in the standard model, such SM contributions are “small” versus the sensitivities of present tests in $\tau$ physics in the analogous cases of the $\tau$’s neutral-current and electromagnetic-current couplings, c.f. [3]. For charged-current couplings, the situation should be the same.

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, for the $\rho$, $a_1$, $K^*$ modes there are the equivalence theorems that for the vector current

$$S \approx V + f_M, \quad T^+ \approx -V + S^- \quad (14)$$

and for the axial-vector current

$$P \approx -A + f_E, \quad T^+_5 \approx A + P^- \quad (15)$$

There are similar but different equivalences for the $\pi$, $K$ modes [2]. Therefore, from the perspectives of “clear thinking” and of searching for the fundamental dynamics, it is important to investigate what limits can be set for a variety of Lorentz structures (including $S^\pm$, $P^\pm$, $T^\pm$, and $T^+_5$) and not just for a kinematically minimal, but theoretically prejudiced, set.

Table 2 gives the limits on $\Lambda$ in GeV for real $g_i$’s from the $\rho$ and $a_1$ modes. Note that effective mass scales of $\Lambda \sim 1 - 2$ TeV can be probed at 10 GeV, and at 4 GeV for the $(S + P)$ and the $f_M + f_E$ couplings. For determination of ideal statistical errors, we assume $10^7 (\tau^- \tau^+)$ pairs at 10 GeV and separately at 4 GeV; at $M_Z$ we assume $10^7 Z^0$’s with
BR($Z \to \tau^+\tau^-) = 0.03355; BR_\rho = 24.6\%, BR_{a_1} = 18\%$ for the sum of neutral/charged $a_1$ modes, and $BR_\pi = 11.9\%$.

We list the ideal statistical error for the presence of an additional $V + A$ coupling as an error $\delta(\xi_A)$ on the chirality parameter $\xi_A$ for $\tau^- \to A^-\nu$. Equivalently, if one ignores possible different L and R leptonic CKM factors, the effective lower bound on an additional $W_R^\pm$ boson (which couples only to right-handed currents) is

$$M_R = \{\delta(\xi_A)/2\}^{-1/4}M_L$$

For the $\{\rho^-, \rho^+\} \{\{a_1^-, a_1^+\}$ mode, from $\delta(\xi_\rho) = 0.0012(0.0018)$ this gives equivalently $M_R > 514$ GeV ($464$ GeV). Probably, $10^8(\tau^-\tau^+)$ pairs will be accumulated by a $\tau$/charm factory at 4 GeV, so all the potential 4 GeV bounds might be improved by a factor of 3.2.

Table 3 gives the limits from $\tau \to \pi\nu$. Note that the $\pi$ mode is important for separating the $(V - A)$ coupling and the $(T^+ + T_5^+)$ coupling which cannot be distinguished from the $\rho$ and $a_1$ modes. Unfortunately, the present and potential experimental bounds on $(S^- \pm P^-)$ couplings are exceptionally poor or non-existent from measurements of the $\pi$, $\rho$ and $a_1$ modes.

Table 2: Limits on $\Lambda$’s from $\tau \to \rho\nu, a_1\nu$ for Real Coupling Constants

| Mode | $|g_i/g_L|^2$ at $M_Z$ | $|g_i/g_L|^2$ at 10 or 4 GeV | $|g_i/g_L|^2$ at $M_Z$ | $|g_i/g_L|^2$ at 10 or 4 GeV |
|------|------------------------|-------------------------------|------------------------|-------------------------------|
| $V + A$, for $\xi_A$ | 0.006 | 0.0012 | 0.010 | 0.0018 |
| $S + P$, for $\Lambda$ | 310 GeV | 1,700 | 64 | 350 |
| $S - P$, for $(\Lambda)^2$ | $(11$ GeV$)^2$ | $(25)$ | $(4)^2$ | $(7)^2$, $(10)^2$ |
| $f_M + f_E$, for $\Lambda$ | 210 GeV | 1,200 | 280 | 1,500 |
| $f_M - f_E$, for $(\Lambda)^2$ | $(9$ GeV$)^2$ | $(20)^2$ | $(10)^2$ | $(24)^2$ |

For the $\rho$ and $a_1$ modes, the $T^+ + T_5^+$ coupling is equivalent to the $V - A$ coupling; and $T^+ - T_5^+$ is equivalent to $V + A$.

Table 3: Limits on $\Lambda$’s from $\tau \to \pi\nu$

| Mode | $|g_i/g_L|^2$ at $M_Z$ | From $\Gamma(\tau \to \pi\nu)$ |
|------|------------------------|-------------------------------|
| $V + A$, for $\xi_\pi$ | $0.015, 0.004, 0.009$ | $0.014$ |
| $S + P, T^+ + T_5^+$, for $\Lambda$ | $(10$ GeV$)^2$, $(21$ GeV$)^2$, $(13$ GeV$)^2$ | $(< 1$ GeV$)^2$ |
| $S^- + P^-$, for $\Lambda$ | $(< 1$ GeV$)^2$, $(1.6$ GeV$)^2$, $(1$ GeV$)^2$ | $(< 1$ GeV$)^2$ |
| $S^- - P^-$, for $(\Lambda)^2$ | $(< 1$ GeV$)^2$, $(1.6$ GeV$)^2$, $(1$ GeV$)^2$ | $(< 1$ GeV$)^2$ |

$127$ GeV
Tests for $\tau$ compositeness:

In analogy with the Pauli anomalous magnetic moment, an obvious signature for lepton compositeness would be an additional tensorial coupling. In this regard, it is useful to first test for the presence of only $\nu_L$ couplings which would exclude a significant contribution from the $g_- = f_M - f_E$ tensorial coupling. For example, for the $a_1$ and $\rho$ modes there are 3 logically independent tests for only $\nu_L$ couplings: the chirality parameter $\xi = 1$, $\zeta = \sigma$, and $\omega = \eta$. In addition, if $\tilde{T}_{FS}$ violation occurred then the non-zero parameters $\omega' = \eta'$ if there are only $\nu_L$ couplings.

On the other hand, just as in the case of a pure $(V - A)$ coupling, an additional tensorial $g_+ = f_M + f_E$ coupling would preserve these 3 signatures for only $\nu_L$ couplings. But, such a tensorial $g_+ = f_M + f_E$ coupling would give non-$(V - A)$-values: $\zeta = \sigma \neq 1$ and $\omega = \eta \neq 1$. Second, there is the prediction that for $\Lambda$ large

$$\left(\zeta - 1\right) = \left(1 - \omega\right)\frac{g}{l}$$

where the ratio “$g/l$” is a known function [1] of $m_\rho$ and $m_\tau$. Numerically $(g/l)_\rho = 0.079$.

These $\nu_L$ signatures and Eq.(16) also occur for an additional $(S + P)$ coupling but with the ratio $(g/l)$ replaced by $(a/d)$, which varies from 5.07 to 12.1 across $(m_\rho \pm \Gamma/2$. Fortunately, here the $\pi$ mode can again be used to limit the presence of an additional $(S + P)$ coupling versus an $g_+ = f_M + f_E$ coupling, see second-line in Table 3.

4 CONCLUSIONS

In the future, there will be a major theoretical and experimental effort to determine whether or not the Higgs-mechanism is due to a fundamental scalar elementary field or, instead, due to a macroscopic $f\bar{f}$ mechanism a’la the BCS theory in superconductivity. Of equal importance are the deep questions raised by the existence of the two massive charged-leptons, the $\mu$ and the $\tau$. In the case of the leptons, it is also important to study whether they are truly elementary or only macroscopic. Besides searching for rare/forbidden decays, a direct way in which to proceed is to search for violations of $CP$, $T$, and $(V - A)$ symmetries in $\tau$ decays.

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