Effects of W_R and Charged Higgs in the Leptonic Decay of τ*

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ABSTRACT

Experimental test of the existence of the right-hand W boson and the charged Higgs particle is suggested. The experiment involves measurement of muon polarization from the decay of polarized τ's.

Submitted to *Physical Review D*

* Work supported by the Department of Energy, contract DE–AC03–76SF00515.

In the Standard Model[1] there is only one kind of $W^{\pm}$ boson and it is coupled only to the left-handed current. It is quite possible that nature is symmetric with respect to the right and left at small distances and the apparent asymmetry between right and left could be just a long-distance effect. Such a scenario can be achieved most economically by assuming[2] another much heavier W boson to exist and it is coupled only to the right-handed current. Another feature of the standard theory is that there is only one Higgs particle and it is neutral. Charged Higgs particles[3] almost always are required as soon as one tries to enlarge the symmetry beyond the Standard Model. In this paper we explore the possibility of experimentally uncovering the effects due to the right-hand W, denoted by $W_R^{\pm}$ and the charged Higgs denoted by $H^{\pm}$ through the decay $\tau^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} + \nu_{\tau}$. The reasons why two effects are considered together will become apparent shortly.

Many years ago Kinoshita and Sirlin[4] derived the general expression of the energy angle distribution containing all possible non-parity-conserving couplings (S, P, T, V, A) assuming that μ, ν_{μ} and ν_{τ} are all massless.[5] The expression contains three parameters ρ, ξ and δ:

$$\Gamma = \frac{\Gamma}{4\pi} \int d\Omega \int_0^1 \frac{8}{3} \left\{ F_1(x,\rho) + \xi W_z \, F_2(x,\delta) \right\} dx \tag{1}$$

where W_z is the component of polarization of τ along the direction of μ in the rest frame of τ, and F_1 and F_2 are defined as

$$F_1(x,\rho) \equiv x^2 \left\{ \frac{9}{2}(1-x) + 3\rho \left(\frac{4x}{3} - 1 \right) \right\} , \tag{2}$$

$$F_2(x,\delta) \equiv x^2 \left\{ \frac{3}{2}(1-x) + 3\delta \left(\frac{4x}{3} - 1 \right) \right\} , \tag{3}$$

x is the energy of the muon over its maximum value, $x = E/E_{\max} = 2E/M_\tau$. Another parameter which we need is a polarization vector of the muon along its direction of motion P. In general we need three components of a vector to specify the muon polarization. However measurement of the longitudinal component is sufficient for our purpose.

In the limit of zero muon mass three diagrams shown in Fig. 1(a), (b) and (c) do not interfere, so the decay energy-angle distribution can be obtained by adding three energy-angle distributions. Table 1 gives ρ, ξ, δ and P.

Table 1

ρ, δ and P parameters for the decay of $\tau^\mp \to \mu^\mp + \nu_\mu + \bar{\nu}_\tau$

	W_L exchange	W_R exchange	H exchange
$\rho^\mp$	0.75	0.75	0.75
$\xi^\mp$	∓ 1	± 1	0
$\delta^\mp$	0.75	0.75	anything
$P^\mp$	∓ 1	± 1	0

From Table I we observe the following:

1. Measurement of the Michel parameter alone does not give us any help in deciphering the contributions of the W_R and H exchanges form the dominant W_L exchange, because in all three cases we have $\rho = 0.75$ and the sum of three processes still yields $\rho = 0.75$.

2. The Higgs particle being a spin 0 particle is incapable of transferring the information on the spin orientation of the parent particle, and thus $\xi^\pm = 0$. It also has a parity conserving coupling, hence $P^\mp = 0$.

3. Let us denote the decay width via W_L, W_R and H exchanges by Γ_L, Γ_R and Γ_H respectively. Let us also define two ratios

$$\Gamma_R/\Gamma_L \equiv R \quad \text{and} \quad \Gamma_H/\Gamma_L = H \ . \tag{4}$$

The resulting ξ due to all three mechanisms is

$$\xi^{\mp} = \mp\frac{1-R}{1+R+H} \ . \tag{5}$$

The value of $\delta^{\mp}$ is 0.75 when these processes are combined. Equation (5) shows that measurement of $\xi^{\mp}$ will tell us the combined effects of W_R and H exchanges but will not resolve R and H.

4. If τ is unpolarized then the polarization of μ is given by

$$P^{\mp}(W_z = 0) \equiv P_0^{\mp} = \mp\frac{1-R}{1+R+H} \ , \tag{6}$$

which is identical to (5) and thus we cannot solve for R and H using Eqs. (5) and (6).

When τ is polarized (*i.e.* $W_z \neq 0$ in Eq. (1)) the polarization of the muon is given by

$$P^{\mp}(W_z) = \mp\frac{(1-R)F_1 \mp W_z(1+R)F_2}{(1+R+S)F_1 \mp W_z(1-R)F_2} \ . \tag{7}$$

Since Eq. (7) is true for all values of x, we can integrate F_1 and F_2 with respect to x for an arbitrary experimental acceptance. Thus (7) can be written more conveniently as

$$P^{\mp}(W_z) = \mp \frac{(1-R)I_1 \mp W_z(1+R)I_2}{(1+R+S)I_1 \mp W_z(1-R)I_2} \tag{8}$$

where

$$I_1 = \int F_1 dx \quad \text{and} \quad I_2 = \int F_2 dx \ , \tag{9}$$

the upper and lower limits of integrations are determined by the experimental acceptance

Now Eq. (5) and (8) can be used to solve for R and H. The solutions are

$$R = \frac{\mp(\xi^{\mp} - P^{\mp})I_1 - W_z^{\mp}(1 \pm P^{\mp})\xi^{\mp} I_2}{\mp(\xi^{\mp} - P^{\mp})I_1 + W_z^{\mp}(1 \mp P^{\mp})\xi^{\mp} I_2} \ , \tag{10}$$

$$H = \frac{\pm 2(\xi^{\mp} - P^{\mp})I_1 \pm 2W_z^{\mp}(1 - \xi^{\mp} P^{\mp})I_2}{\mp(\xi^{\mp} - P^{\mp})I_1 + W_z^{\mp}(1 \mp P^{\mp})\xi^{\mp} I_2} \ . \tag{11}$$

We can also use Eqs. (6) and (8) to solve for R and H. The solutions can be obtained by substituting $\xi^{\mp}$ in Eqs. (10) and (11) by $P_0^{\mp}$:

$$R = \frac{\mp(P_0^{\mp} - P^{\mp})I_1 - W_z^{\mp}(1 \pm P^{\mp})P_0^{\mp} I_2}{\mp(P_0^{\mp} - P^{\mp})I_1 + W_z^{\mp}(1 \mp P^{\mp})P_0^{\mp} I_2} \ , \tag{12}$$

$$H = \frac{\pm 2(P_0^{\mp} - P^{\mp})I_1 \pm 2W_z^{\mp}(1 - P_0^{\mp} P^{\mp})I_2}{\mp(P_0^{\mp} - P^{\mp})I_1 + W_z^{\mp}(1 \mp P^{\mp})P_0^{\mp} I_2} \ . \tag{13}$$

Equations (10) and (11) show that R and S can be obtained form the ξ parameter and the muon polarization from the decay of polarized τ's. Equations (12) and (13) show that R and S can also be obtained by measurements of muon polarizations at two different values of τ polarization. Equations (10)-(13) show that there are four ways to determine R and S and these facts can be used to check the consistency of the experiments.

Neither the polarization of τ nor the measurement of muon polarization from the τ decay have ever been done experimentally. Polarized τ's can be obtained by using a longitudinally polarized e^- beam in the $e^+e^- \to \tau^+\tau^-$ reaction. A transversely polarized $e^{\pm}$ beam is of no value in production of polarized τ's. When the Z_0 pole is the dominant process the parity violating term (the VA interference term) produces a small amount of τ polarization (-0.31, -0.16, 0 at $\theta = 0°$, $90°$ and $180°$ respectively) even when $e^{\pm}$ beams are not polarized. Near the Z_0 peak we may ignore one photon exchange contribution and consider only the Z_0 exchange. Let P_e be the longitudinal polarization of e^- and θ be the angle between e^- and τ^-, the longitudinal polarization of τ^- is then[6]

$$P_{\tau Z}(P_e, \theta) = \frac{P_{\tau Z}(0,\theta) + P_e \frac{2[(1+r^2)^2 \cos\theta + 2r^2(1+\cos^2\theta)]}{(1+r^2)^2(1+\cos^2\theta)+8r^2\cos\theta}}{1 + P_e P_{\tau Z}(0,\theta)} \tag{14}$$

where

$$P_{\tau Z}(0,\theta) = \frac{2(r+r^3)(1+\cos\theta)^2}{(1+r^2)^2(1+\cos^2\theta)+8r^2\cos\theta}\ , \tag{15}$$

r is the ratio of the V amplitude to the A amplitude and is given by $r = (-1 + 4\sin^2\theta_W) = -0.08$. Figure 2(a) shows the numerical values of $P_{\tau Z}(p_e, \theta)$ for $P_e =$ 1.0, 0.5, 0, -0.5, -1.0.

When the center-of-mass energy is far below the Z_0 pole, we need to consider only the one-photon exchange contribution. The τ polarization is then given by

$$P_{\tau\gamma}(P_e, \theta) = \frac{2E^2 P_e \cos\theta}{P^2(1+\cos^2\theta) + 2M_\tau^2}\ , \tag{16}$$

where E and P are the energy and momentum of the τ. In Eqs. (14) and (15) we ignored the τ mass whereas we retained it in Eq. (16). Figure 2(b) shows $P_{\tau\gamma}$ (P_e, θ) at $E = 2.5$ GeV.

It should be noted that if we ignore $P_{\tau Z}(0, \theta)$ in Eq. (14) and let $r = 0$ or $|r| = \infty$, we obtain Eq. (16) in the limit $M_\tau^2/E^2 \to 0$. Thus the gross features of Eqs. (14) and (15) are the same as shown in Fig. 2(a) and (b).

Inspection of Figure 2(a) and (b) tells us that the energy must be high enough so that one knows quite well the production angle of τ's from the decayed μ's, otherwise the polarization can wash out. Thus it is highly undesirable to do the τ physics near threshold as suggested in some of the proposals[7] in the new Tau-Charm factory. Instead of using a longitudinally polarized e^-, one can also use the polarization correlation[8] of τ^+ and τ^-. If the process $e^+e^- \to \tau^+\tau^-$ is transmitted by the γ or Z_0 exchange then the spins of τ^+ and τ^- tends to be parallel to each other and only the longitudinal spin component is important at very relativistic energies. Thus in principle we can solve for R and H using Eqs. (10) and (11) or Eqs. (12) and (13) from the polarization correlation of τ^+ and τ^-. Of course, if the reaction $e^+e^- \to \tau^+\tau^-$ is transmitted by a scalar, a pseudoscalar or a tensor particle then the spins of τ^+ and τ^- would tend to be antiparallel at high energies. A scalar or pseudoscalar exchange would be characterized by an isotropic angular distribution instead of the $(1 + \cos^2\theta)$ distribution for a vector or axial vector exchange.

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5. In the leptonic decay of τ, the masses of ν_μ, ν_τ, and μ appear only quadratically in the cross section and thus are negligible.
6. Equations (14), (15) and (16) were obtained by a computer using A. Hearn's "REDUCE II" program. These formulae are well known; they are given here for convenience of discussion.
7. Proceedings of the Tau-Charm Factory Workshop (1989), Perl *et al.*, eds. (Stanford Linear Accelerator Center, Stanford, CA, 1989).
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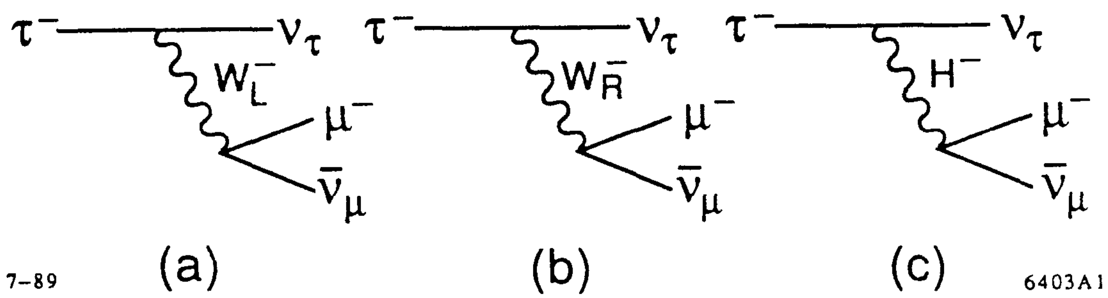
FIGURE CAPTIONS

1) Feynman diagrams for the decay $\tau^- \rightarrow \mu^- + \overline{\nu}_\mu + \nu_\tau$.

2) (a) Longitudinal component of τ^- polarization from the reaction: (polarized $e^-) + e^+ \rightarrow Z \rightarrow \tau^+ + \tau^-$. P_e is the longitudinal polarization of the incident e^-. θ is the angle between e^- and τ^-.

(b) Longitudinal component of τ^- polarization from the reaction: (polarized $e^-) + e^+ \rightarrow \gamma \rightarrow \tau^+ + \tau^-$ at $E^\pm = 2.5$ GeV.



τ^-
ν_τ
W_L^-
μ^-
$\bar{\nu}_\mu$
(a)
τ^-
ν_τ
W_R^-
μ^-
$\bar{\nu}_\mu$
(b)
τ^-
ν_τ
H^-
μ^-
$\bar{\nu}_\mu$
(c)
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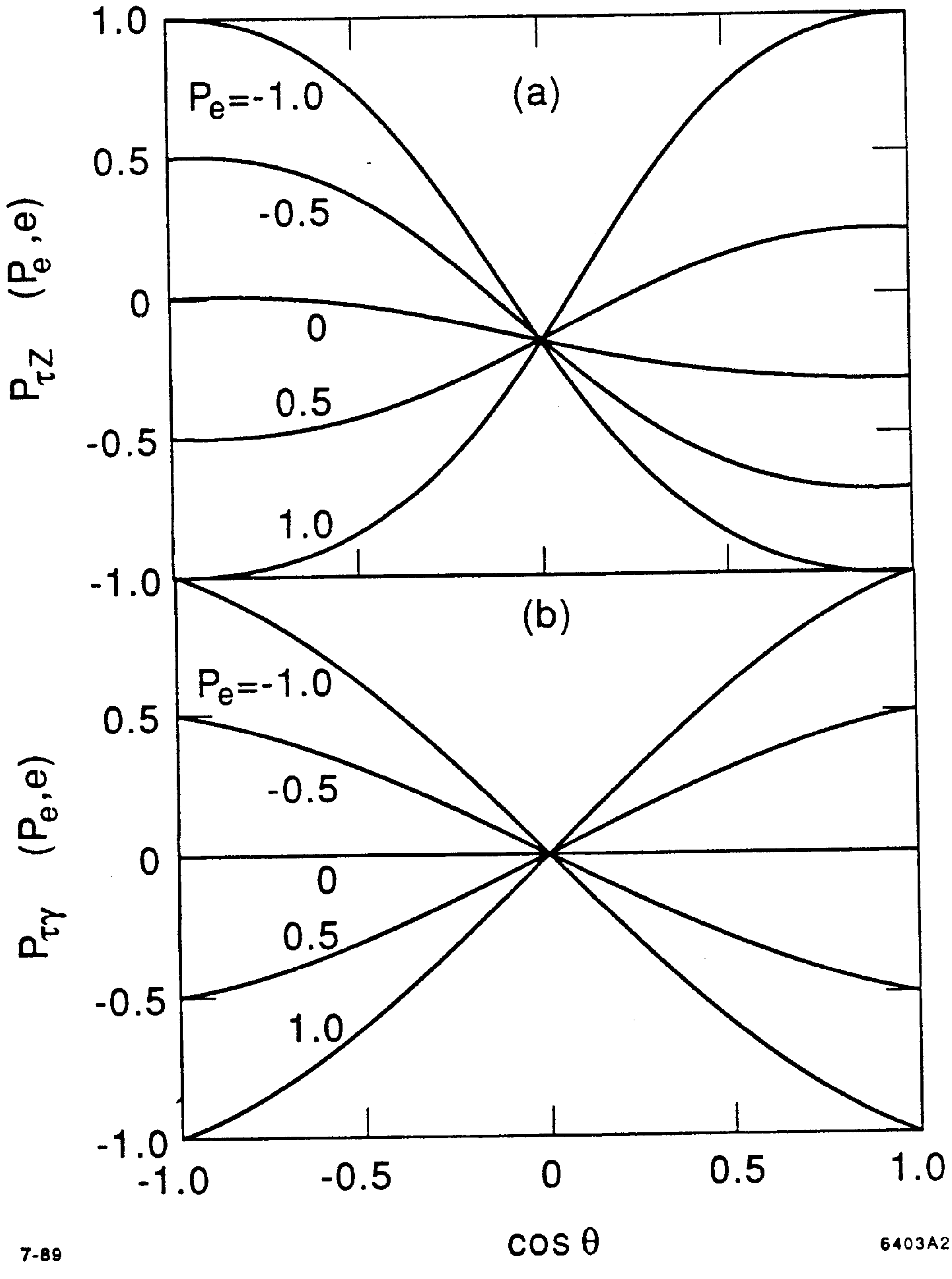
Fig. 1



1.0
0.5
0
-0.5
-1.0
(a)
P_e=-1.0
-0.5
0
0.5
1.0
$P_{\tau Z}$ (P_e, e)
(b)
P_e=-1.0
-0.5
0
0.5
1.0
0.5
0
-0.5
-1.0
$P_{\tau\gamma}$ (P_e, e)
-1.0
-0.5
0
0.5
1.0
cos θ
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Fig. 2