Testing the Lorentz structure of the charged weak current in $\tau$-decays

by
A. Stahl
H. Voss

Abstract: We review the current experimental situation on the determination of the lorentz structure of the charged weak current in $\tau$ decays. We propose a method to extent these studies to decays of $\tau$ leptons to righthanded daughter leptons which are forbidden in the standard model. We reanalyse the available data in the framework of specific models and derive limits on the mass of charged Higgs bosons of $m(H^\pm) > 1.5 \tan \beta$ GeV at 90% c.l. and on righthanded $W$-bosons of $m(W'_2) > 240$ GeV at 90% c.l., valid if the righthanded neutrinos associated with it are light compared to the $\tau$. 
1 Introduction

The decay of the heavy $\tau$ lepton provides a good opportunity to search for new physics. This might manifest itself by small deviations from the predictions of the standard model in the spectra of the decay products. In recent years there has been an increasing attempt to verify these predictions experimentally. The aim of this paper is to review the current experimental situation, to present a new idea on how to extend the current measurements and to demonstrate what one can learn from already existing measurements on charged Higgs- and righthanded $W$-Bosons.

2 Parametrisation of the Decay Amplitudes

2.1 Leptonic Decays

The most general form of the matrix element of a pure leptonic decay has been discussed extensively in muon decays [1, 2, 3]. It can be written as [4]¹:

$$\mathcal{M}(\tau \to \ell \nu_\ell \nu_\tau) = 4 \frac{G_F}{\sqrt{2}} \sum_{\kappa = S, V, T; \rho, \omega} g^S_\kappa \langle \bar{\psi}_\ell (\ell) | \Gamma^S | \bar{\psi}_\rho (\nu_\ell) \rangle \langle \bar{\psi}_\omega (\nu_\tau) | \Gamma^S | \psi_\kappa (\tau) \rangle. \tag{1}$$

Here $\kappa$ labels the different interactions, i.e. scalar interactions $\Gamma^S = 1$, vector interactions $\Gamma^V = \gamma^\mu$ and tensor interactions $\Gamma^T = \frac{1}{\sqrt{2}} \sigma^{\mu\nu} = \frac{1}{\sqrt{2}} (\gamma^\mu \gamma^\nu - \gamma^\nu \gamma^\mu)$. $\epsilon$ and $\lambda$ indicate the handedness of the charged leptons. The handedness of the neutrinos $\rho$ and $\omega$ is then fixed for each type of interaction (see for example [5]). The relative strength of each of the ten contributions to $\mathcal{M}$ is governed by its respective coupling constant $g^S_{\kappa}$.

This parametrisation of the matrix element is usually called the most general ansatz although it is not free from assumptions:

- 4 fermion interaction:
  It is assumed that there are two non-identical, invisible particles (the neutrinos) in the decay apart from the charged daughter lepton. All particles are assumed to have spin 1/2. The masses of the daughter particles are neglected compared to the $\tau$ mass.

- derivative free interaction:
  This is an argument of simplicity: the matrix element is built from the fields only but not from their derivatives.²

- lepton-number conservation:
  For an extension to lepton number violating couplings see [6].

- point interaction:
  Neglecting the propagator is a valid assumption in case of the $W$-boson [7] and most likely also for the new bosons we are looking for.

These restrictions have to be kept in mind when interpreting the measurements.

¹Throughout the paper the four-momentum of a particle is denoted by its name (i.e. $p_\mu (\tau) = r_\mu$). $\ell$ is used synonymously for both daughter leptons $\epsilon$ and $\mu$.

²As long as the fermions are quasi-free, the derivatives could be reexpressed by the fields themself through the Dirac equation.
2.2 Hadronic Decays $\tau \rightarrow \pi/K\nu_{\tau}$

The two body decay of the $\tau$ to a spinless pion (or kaon) is much simpler. For pure vector currents it has already been given by Tsai [8]. Note that the pion cannot couple to a tensor current. The extension of Tsai’s formula to scalar currents reads:

$$
\mathcal{M}(\tau \rightarrow \pi\nu_{\tau}) = \left(\frac{G_F}{\sqrt{2}}\right)^{1/2} \sum_{x=S,V} g_x^\tau(\bar{\psi}_\tau(\nu_{\tau}) |\Gamma| \psi_{\tau}(\tau)) \, J_x^\tau \tag{2}
$$

$$
J_S^\tau = \left(\frac{G_F}{\sqrt{2}}\right)^{1/2} \cos \theta_C f_\pi m_\pi
$$

$$
J_V^\tau = \left(\frac{G_F}{\sqrt{2}}\right)^{1/2} \cos \theta_C f_\pi \pi_\mu
$$

with $\theta_C$ being the Cabibbo angle, $f_\pi$ the pion decay constant and $m_\pi$ the mass of the pion. Here there are four complex coupling constants $g_x^\tau$. In the standard model $g_L^V = 1$ and all others vanish. The spectrum of the pion in the $\tau$-restframe is given by

$$
\frac{d\Gamma}{d\Omega}(\tau \rightarrow \pi\nu_{\tau}) = \frac{G_F^2 \cos^2 \theta_C f_\pi^2 m_\pi^2}{64\pi^2} \left(1 - \frac{m_\pi^2}{m_\tau^2}\right)^2 A [1 + \xi_\pi \cos \theta_\pi]. \tag{3}
$$

$\theta_\pi$ is the angle between the spin of the $\tau$ and the momentum of the pion. $A$ is an overall normalization constant and $\xi_\pi$ the negative of the helicity of the neutrinos produced in the decay.

$$
A = |g_L^V|^2 + |g_R^V|^2 + \frac{m_\pi^2}{m_\tau^2} (|g_L^S|^2 + |g_R^S|^2) + \frac{2m_\pi}{m_\tau} \text{Re} \left(g_L^V g_R^S + g_R^V g_L^S\right) \tag{4}
$$

$$
\xi_\pi = \frac{1}{A} \left(|g_L^V|^2 - |g_R^V|^2 + \frac{m_\pi^2}{m_\tau^2} (|g_L^S|^2 - |g_R^S|^2) + \frac{2m_\pi}{m_\tau} \text{Re} \left(g_L^V g_R^S - g_R^V g_L^S\right) \right) \tag{5}
$$

Note that scalar and vector currents are undistinguishable from the spectra of the pions. The decay $\tau \rightarrow K\nu_{\tau}$ can be treated similarly.

2.3 Multimeson Hadronic Decays

In the case of the $\tau$ decaying to more than one pion or kaon the inclusion of currents other than vectors becomes non trivial in the sense that new parameters appear in the spectra which can be determined by experiment. The formula for the decay into two and three pions have recently been calculated [9]. The reader is referred directly to this paper for details.

3 Full Determination of the Leptonic Current

An experimental verification that the $\tau$ indeed decays to $\mu$ and $e$ only through the standard model 'V-A' current is possible. The procedure has been described in details in [4]. It requires four experimental steps:
3.1 The Experimental Program

1. The overall normalization has to be checked \( (A/16 \not= 1) \). This requires a precise measurement of the lifetime of the \( \tau \) and the leptonic branching ratios and a rough estimate of the Michel parameter \( \eta \) in the decay \( \tau \rightarrow \mu \nu_{\mu} \nu_{\tau} \) (see [10]).

2. If one defines \( Q^\ell_R \) as the probability for righthanded \( \tau \) leptons to decay (see [5]) then this probability which vanishes in the standard model can be bound by a measurement of the Michel parameters \( \xi \) and \( \delta \) [4]:

\[
Q_R^\ell = \frac{1}{2} \left( 1 + \frac{1}{9} (3\xi - 16\xi\delta) \right).
\]  (6)

3. By the measurement of a further Michel type parameter \( \xi' \) the probability \( Q_R^\ell \) of the \( \tau \) lepton decaying to a righthanded charged daughter lepton \( \ell = e, \mu \) can be bound (\( \xi' = 1 \) in the standard model) as:

\[
Q_R^\ell = \frac{1}{2} (1 - \xi').
\]  (7)

4. By Eqs. 6 and 7 all righthanded contributions to the current are now excluded and one is left with the two purely lefthanded couplings \( g^\ell_L \) and \( g^\ell_L \). The separation of these two can only be done by a measurement on at least one of the neutrinos [11, 3] which is out of present experimental reach.

3.2 The Current Experimental Situation

Measurements of the \( \tau \)-lifetime and the leptonic branching ratios have been done by many experiments. They are summarized in Table 1 and 2. The experimental situation on the Michel parameters has just recently be summarized in [23]. Their averages are reproduced in Table 3. This results in the following values for the normalization parameter \( A/16 \)

\[
\begin{align*}
\tau \rightarrow e\nu_e\nu_\tau : & \quad A_e/16 = 0.9942 \pm 0.0067 \\
\tau \rightarrow \mu\nu_\mu\nu_\tau : & \quad A_\mu/16 = 1.031 \pm 0.0074 \pm 0.058
\end{align*}
\]

in agreement with universality. The second error on \( A_\mu \) is due to the uncertainty in \( \eta_\mu \) and the first errors combine all other uncertainties. Because \( \eta_\tau \) has not yet been measured, it has
3 FULL DETERMINATION OF THE LEPTONIC CURRENT

Table 2: Experimental results on the leptonic branching ratios of the \( \tau \). All values in %. Older measurements from the collaborations quoted are subtracted from the PDG number.

<table>
<thead>
<tr>
<th>experiment</th>
<th>data</th>
<th>( \tau \rightarrow e \nu_e \nu_\tau )</th>
<th>( \tau \rightarrow \mu \nu_\mu \nu_\tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH [19]</td>
<td>1991 - 1993</td>
<td>17.79 ± 0.13</td>
<td>17.31 ± 0.12</td>
</tr>
<tr>
<td>DELPHI [20]</td>
<td>1991 - 1992</td>
<td>17.51 ± 0.39</td>
<td>17.02 ± 0.31</td>
</tr>
<tr>
<td>L3 [21]</td>
<td>1991 - 1992</td>
<td>17.69 ± 0.19</td>
<td>17.36 ± 0.18</td>
</tr>
<tr>
<td>OPAL [22]</td>
<td>1990 - 92/94</td>
<td>17.78 ± 0.13</td>
<td>17.36 ± 0.27</td>
</tr>
<tr>
<td>PDG 94 [18]</td>
<td>≤ 1994</td>
<td>17.90 ± 0.18</td>
<td>17.44 ± 0.23</td>
</tr>
<tr>
<td>average</td>
<td></td>
<td>17.782 ± 0.074</td>
<td>17.321 ± 0.084</td>
</tr>
</tbody>
</table>

Table 3: Summary of the measurements of Michel parameters in \( \tau \) decays (from [23]).

<table>
<thead>
<tr>
<th></th>
<th>( \tau \rightarrow e \nu_e \nu_\tau )</th>
<th>( \tau \rightarrow \mu \nu_\mu \nu_\tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>universality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \eta )</td>
<td>0.01 ± 0.03</td>
<td>-</td>
</tr>
<tr>
<td>( \rho )</td>
<td>0.757 ± 0.018</td>
<td>0.736 ± 0.028</td>
</tr>
<tr>
<td>( \xi )</td>
<td>1.07 ± 0.09</td>
<td>1.03 ± 0.25</td>
</tr>
<tr>
<td>( (\xi \delta) )</td>
<td>0.785 ± 0.072</td>
<td>1.11 ± 0.18</td>
</tr>
</tbody>
</table>

been assumed to vanish, but \( A_e \) is not sensitive to \( \eta_e \) anyhow. An uncertainty of ±1 would have only negligible impact.

There is a single measurement on \( \xi_\ell \) and \( (\xi \delta) \) available which does not assume lepton universality [25], yielding

\[
\begin{align*}
Q^R_\ell (\tau \rightarrow e \nu_e \nu_\tau) & = -0.32 \pm 0.16 \\
Q^R_\mu (\tau \rightarrow \mu \nu_\mu \nu_\tau) & = +0.07 \pm 0.14
\end{align*}
\]

A more detailed review on Michel parameter measurements is given in [23, 24].

There is no experimental information on steps 3 and 4 of section 3.1.

3.3 An Idea to Measure \( \xi \)

Any method to limit \( Q^R_\ell \) requires some information on the polarisation of the daughter leptons from the decay. Fetscher [4] proposed to upgrade a B-factory detector with a muon polarimeter of the type used in [26] to measure \( \xi \). Here we want to recall a method which has been used in muon decay [27]. It is applicable to \( \tau \) decays, too, with similar sensitivity and works for both \( \tau \rightarrow e \nu_e \nu_\tau \) and \( \tau \rightarrow \mu \nu_\mu \nu_\tau \) and does not need any additional experimental equipment.

In radiative \( \tau \) decays \( \tau \rightarrow e \nu_e \nu_\tau \gamma \) and \( \tau \rightarrow \mu \nu_\mu \nu_\tau \gamma \) the spectra and angular distributions of the photons emitted from the daughter lepton reveal some information on their spins. In a situation where the Michel parameters \( \rho, \xi \) and \( \delta \) are already limited to their standard model predictions\(^3\) the partial decay rate of the radiative decays can be written in the restframe of the \( \tau \) as

\[
\frac{d^3 \Gamma}{dx \, dy \, d\cos \theta} = f_1(x, y, \theta) + \frac{1}{4} (1 - \xi) f_2(x, y, \theta).
\]  
\(^3\)The more complicated formula for the general situation are omitted here (see [27, 29]).
3.3 An Idea to Measure $\xi'$

The variables $x$ and $y$ are the scaled energies of the daughter lepton $x = 2E_\ell/m_\tau$ and the photon $y = 2E_\gamma/m_\tau$ and $\theta$ is the angle between the photon and the daughter lepton. The functions $f_i$ have been calculated in [28, 29]. The parameter $\xi'$ can be extracted from a measurement of this triple differential decay rate and then $Q'_R$ can be limited by Eqn. 7.

![Graph](image)

Abbildung 1: Distribution of $O_{\xi'}$ for $\tau \rightarrow \mu\nu_\mu\nu_\tau\gamma$ events. The statistics corresponds to 1 year of data taking at a $\tau$-factory at the $\tau$ threshold. No detector effects are included.

The decay distribution is most sensitive to $\xi'$ for photons emitted in the direction opposite to the daughter lepton. Unfortunately the backward direction is not the preferred direction of emission, so that there are only few events there. To facilitate the analysis one might want to use an optimal observable for $\xi'$ which would be $O_{\xi'} = f_2/f_1^4$. The distribution of $O_{\xi'}$ calculated from $\tau \rightarrow \mu\nu_\mu\nu_\tau\gamma$ events generated by a simple Monte Carlo generator based on the partial decay width of Eqn. 8 is shown in Fig. 1. A deviation of $\xi'$ from its standard model value of 1 would result in a shift of the central value of the distribution proportional to $\xi'$. The number of events in the plot corresponds to one year of running of a $\tau$-factory at the $\tau$ production threshold ($0.5 \cdot 10^7 \tau$-pairs, branching ratio $\tau \rightarrow \mu\nu_\mu\nu_\tau\gamma$ ($2.3 \pm 1.1) \cdot 10^{-3}$ for $E_\gamma > 37 \text{ MeV}$ [31] and a detection threshold of 10 MeV for the photons). There are no detector effects included in the simulation. The result would be a 36% uncertainty on $Q'_R$ compared to 27% for Fetschers method for $10^7 \tau$-pairs at a B-factory.

The extraction of $\xi'$ from radiative $\tau$ decays can be applied to $\tau \rightarrow e\nu_e\nu_\tau\gamma$ events, too. Due to the smaller mass of the electron a factor of 3.5 more events are expected in this decay channel\(^5\). Bremsstrahlung produced by the electrons in traversing the material of the detector, can be rejected by excluding photons emitted in the direction of the electron, a region of phase space which is insensitive to $\xi'$ anyhow. More serious for both $\tau \rightarrow e\nu_e\nu_\tau\gamma$ and $\tau \rightarrow \mu\nu_\mu\nu_\tau\gamma$ might be the question whether the photon resulted from the decay of the $\tau^+$ or the $\tau^-$. If one of the $\tau$-leptons decays semihadronically, it should be possible to decide on the basis of the kinematic relation between the mass and the energy of the visible decay products, whether the photon emerged from this $\tau$ or not. But for both $\tau$ decaying leptonically there might not be a solution and one has to reject these events. At higher center of mass energies the decay products of the two $\tau$'s get more and more separated from each other and the problem vanishes. But also the sensitivity is reduced by the increasing lorentz boost.

\(^4\)For general comments on the concept of optimal observables see [30].
\(^5\)This number is estimated from the appendix of [32].
4 Interpretation in Terms of Specific Models

A model independent, experimental determination of the structure of the charged current in each decay channel of the $\tau$ would of course be desirable. But already for the two leptonic decays this is a challenging program which will not be completed in this decade. And with the multitude of decay channels of the $\tau$-lepton a complete determination for all channels seems impossible. Furthermore, the so called most general ansatz has already some assumptions built in and others have to be made to reduce the number of parameters to a manageable amount in the experiment. Those additional assumptions differ from experiment to experiment. Some examples are:

- The experiments assume a universal structure of the current in the two leptonic decays or in all hadronic decay modes of the $\tau$.
- The Cabbibo allowed and Cabbibo suppressed decay modes are assumed to have the same structure.
- Tensor currents in the hadronic decays are ignored and most of the time even scalar currents$^6$.
- Many measurements make use of correlations between the spins of the two $\tau$'s and therefore assume the standard model structure of the neutral current in the $\tau$ production. A measurement of the neutral current structure is possible, too [34], but most presumably the sensitivity is too small for a simultaneous determination of both.

With these restrictions in mind, it seems reasonable to analyze the available information in the light of specific models. From the models it is possible to select the applicable assumptions and reduce the number of parameters in a meaningful way. This is demonstrated in the following sections for two such classes of models.

4.1 Models with a Charged Higgs Scalar

The first class of models assumes the existence of a charged Higgs boson which contributes to the $\tau$ decays in the form of an additional, chirality blind, scalar current. The additional couplings are given by [35]:

$$g^S = -\frac{(m_f + m_f) m_\tau \tan^2 \beta}{m_h^2} \tag{9}$$

where $(m_f + m_f) = m_\ell$ for leptonic decays and $m_u + m_d$ and $m_u + m_s$ for cabbibo allowed and suppressed decays respectively. $\tan \beta$ is the ratio of the vacuum expectation values of the two Higgs doublets assumed and $m_h$ the mass of the charged Higgs. The ansatz from chapter 2 is appropriate for the description of these models but some of the experimental assumptions are not: Charged Higgs bosons would break any kind of universality between $\tau$ decays (for example $\xi_e \neq \xi_\mu \neq \xi_\tau$) and scalar currents can of course not be neglected in any decay channel. The production of the $\tau$ might not be effected by the extended Higgs sector, due to the small couplings to the initial electrons and positrons. Therefore only the measurement of [36] and [37]$^7$ can be used.

$^6$See [33] for an example taking into account scalar currents in $\tau \rightarrow \nu \tau$.

$^7$ALPEH uses spin-correlations between leptonic and hadronic decaying $\tau$. In the hadronic decays they ignore scalar currents and assume $\xi_\tau = \xi_K$. These assumptions are strictly speaking not valid here, but the result is used nevertheless.
4.1 Models with a Charged Higgs Scalar

Table 4: Experimental values of the observables sensitive to charged Higgs exchange in $\tau$ decays (see text) in comparison with the standard model predictions.

<table>
<thead>
<tr>
<th>observable</th>
<th>S. M. prediction</th>
<th>exp. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$\eta_e = 0$</td>
<td>$-0.14 \pm 0.22$</td>
</tr>
<tr>
<td></td>
<td>$\eta_\mu = 0$</td>
<td>$1.03 \pm 0.25$</td>
</tr>
<tr>
<td>II</td>
<td>$\xi_e = 1$</td>
<td>$1.23 \pm 0.24$</td>
</tr>
<tr>
<td></td>
<td>$\xi_\mu = 1$</td>
<td>$1.11 \pm 0.18$</td>
</tr>
<tr>
<td>III</td>
<td>$(\xi \delta)_e = 3/4$</td>
<td>$0.71 \pm 0.15$</td>
</tr>
<tr>
<td></td>
<td>$(\xi \delta)_\mu = 3/4$</td>
<td>$1.027 \pm 0.007$</td>
</tr>
<tr>
<td>IV</td>
<td>$1.028$</td>
<td>$1.023 \pm 0.006$</td>
</tr>
<tr>
<td>V</td>
<td>$1.018$</td>
<td>$1.023 \pm 0.006$</td>
</tr>
</tbody>
</table>

Five experimental observables can be defined on the leptonic decays which are more or less sensitive to scalar currents:

\[
I \quad \eta_e = \frac{1}{2} \frac{g_{\tau \to \ell \nu \nu}}{1 + (g_{\tau \to \ell \nu \nu}^S/2)^2}
\]

\[
II \quad \xi_e = \frac{4 - (g_{\tau \to \ell \nu \nu}^S)^2}{4 + (g_{\tau \to \ell \nu \nu}^S)^2}
\]

\[
III \quad (\xi \delta)_e = \frac{3 - (g_{\tau \to \ell \nu \nu}^S)^2}{4 + (g_{\tau \to \ell \nu \nu}^S)^2}
\]

\[
VI \quad \frac{b_{\tau \to e\nu e\nu}}{b_{\tau \to \mu \mu \nu e}} = \frac{1 + 4 \frac{m_e}{m_\tau} \eta_e + \Delta_e}{1 + 4 \frac{m_\mu}{m_\tau} \eta_\mu + \Delta_\mu}
\]

\[
V \quad \frac{\tau_e}{\tau_\mu} = \frac{G_F^2 m_e^5}{1/2 (b_{\tau \to e\nu e\nu} + b_{\tau \to \mu \mu \nu e}) 192\pi^3} = \left(1 + 2 \frac{m_e}{m_\tau} \eta_e + 2 \frac{m_\mu}{m_\tau} \eta_\mu + \frac{\Delta_\mu}{2} + \frac{\Delta_e}{2}\right)^{-1}
\]

$G_F$ is the Fermi constant from $\mu$ decay. The small corrections $\Delta_e = -0.004$ and $\Delta_\mu = -0.031$ are discussed in [10]. All observables are functions of a single parameter $\frac{m_\mu}{\tan \beta}$ which can be fitted to the measurements of the Michel parameters described above and the world averages of the leptonic branching ratios and lifetime (see Table 4). The fit takes into account the correlations between different observables. The result is dominated by the observables IV and V. It tends to push the parameter to infinity resulting in a lower limit of $\frac{m_\mu}{\tan \beta} > 1.5$ GeV at 90% confidence level (1.4 GeV at 95% c.l.).

It is not possible to improve this limit by a measurement of the branching ratio of the decay $\tau \to \pi \nu_\tau$, unless the decay constant $f_\pi$ is predicted from theory. It cannot be taken from $\pi \to \mu \nu_\mu$ because a charged Higgs would alter this decay rate by the same amount as $\tau \to \pi \nu_\tau$. The same argument holds for $\tau \to K \nu_\tau$. However an improvement from $\tau \to \rho \nu_\tau$ should be possible if one relies on a CVC prediction of the decay rate.

---

8The correction due to charged higgs exchange in $\mu$ decays is numerically negligible.
4.2 Left-Right Symmetric Models

In the framework of left-right symmetry the left-handed weak charged current of the standard model gets a right-handed partner mediated by a second heavier W boson. τ decays are in principle sensitive to the appearance of such right-handed currents. The left- and right-handed $W_L$ and $W_R$ are not necessarily identical to the mass eigenstates $W_1$ and $W_2$. Mixing might occur. There are three parameters to determine: the masses of the physical states and the mixing angle $\zeta$ (see [38]).

This extension of the standard model does not break universality between the various decay modes of the τ and there are no scalar and tensor currents. But together with the $W_R$ there comes a right-handed neutrino with unknown mass, so that the assumption of a negligible neutrino mass restricts the validity of the whole analysis.

The fit follows the ideas of [38, 39, 40] but uses only measurements from τ decays apart from the direct measurement of the mass of the $W_1$. This is necessary because τ decays are only sensitive to the mass ratio $\beta = m(W_1)^2/m(W_2)^2$. The input are the michel parameters from Table 3, the neutrino helicity from Table 5 and $m(W_1) = 80.26 \pm 0.16$ GeV [46]. The correlations between the michel parameter measurements are taken into account. To lowest order, the observables are given by:

$$\eta = 0$$  \hspace{1cm} (15)
$$\rho = \frac{3}{4} (1 - 2\zeta^2 + 4\zeta^2\beta)$$  \hspace{1cm} (16)
$$\xi = 1 - 2\zeta^2 - 2\beta^2$$  \hspace{1cm} (17)
$$(\xi \delta) = \frac{3}{4} \xi$$  \hspace{1cm} (18)
$$h_{\nu} = -(1 - 2\zeta^2 - 2\beta^2)$$  \hspace{1cm} (19)

For the full formula see [38].

The fit prefers no mixing between $W_L$ and $W_R$ and tends to pull $M_2$ to infinity. A second W boson with mass below 240 GeV is excluded at 90% confidence level ($m(W_2) > 220$ GeV at 95% c.l.) independent of the mixing angle. Figure 2 shows the excluded area in the plane of $m(W_2)$ against $\zeta$.

Tabelle 5: Measurements of the handedness of the neutrino. The second ARGUS measurement only determines the absolute value but not the sign.

<table>
<thead>
<tr>
<th>experiment</th>
<th>exp. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARGUS [41]</td>
<td>$-1.14 \pm 0.34^{+0.34}_{-0.17}$</td>
</tr>
<tr>
<td>ARGUS [42]</td>
<td>$1.022 \pm 0.028 \pm 0.030$</td>
</tr>
<tr>
<td>ALEPH [25]</td>
<td>$-1.006 \pm 0.037$</td>
</tr>
<tr>
<td>ARGUS [43]</td>
<td>$-1.017 \pm 0.039$</td>
</tr>
<tr>
<td>OPAL [44]</td>
<td>$-1.08^{+0.45}_{-0.41} \pm 0.14$</td>
</tr>
<tr>
<td>L3 [45]</td>
<td>$-1.02 \pm 0.06 \pm 0.06$</td>
</tr>
</tbody>
</table>
Abbildung 2: The Mixing angle zeta versus the mass of the second charged weak boson in left-right symmetric model. The plot shows the region excluded by experiment at one, two, three and four standard deviations. Not excluded is the region at $\zeta \approx 0$ and $m(W_2)$ above a few hundred GeV.

5 Conclusion

We have discussed the recent experimental progress in the determination of the lorentz structure of the charged weak current in $\tau$ decays based on the most general matrix elements. For the next step in the investigation of the leptonic decays we proposed to study the spectra and angular distributions of photons emitted in these decays. We carefully examined the various assumptions built into the ansatz and those applied by the experiments to reduce the number of free parameters to a manageable amount. Although a model independent analysis is most desirable, an interpretation of the results in terms of specific models has the advantage that the assumptions build into the most general ansatz and eventually further ones can be justified on the basis of the model or at least be identified as crucial restrictions of the result. As examples the measurements have been analysed in the framework of a model with an extented Higgs sector, leading to a limit on the mass of a charged Higgs boson of $m(H^\pm) > 1.5 \tan \beta \text{ GeV}$ at 90 % c.l. and in left-right symmetric models resulting in a limit of $m(W_2) > 240 \text{ GeV}$ at 90 % c.l. on the mass of the second charged weak boson, valid if the mass of the righthanded neutrino is small compared to the mass of the $\tau$ lepton.

Literatur

    ALEPH, D. Buskulic et al., CERN-PPE/95-128.
[16] OPAL, P. D. Acton et al., Z. Phys. C 59 (1993) 183,
    OPAL, R. Akers et al., CERN-PPE/95-142.


