## $\tau$-LEPTON DECAY PARAMETERS

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The purpose of the measurements of the decay ($\equiv$ Michel) parameters of the $\tau$, is to determine the structure (spin and chirality) of the current mediating its decays.

***Leptonic Decays:*** The Michel parameters are extracted from the energy spectrum of the charged daughter lepton $\ell = e, \mu$ in the decays $\tau \to \ell\nu_\ell\nu_\tau$. Ignoring radiative corrections, neglecting terms of order $(m_\ell/m_\tau)^2$ and $(m_\tau/\sqrt{s})^2$, and setting the neutrino masses to zero, the spectrum in the laboratory frame reads

$$\frac{d\Gamma}{dx} = \frac{G_{\tau\ell}^2\ m_\tau^5}{192\ \pi^3} \times$$
$$\left\{ f_0\,(x) + \rho f_1\,(x) + \eta \frac{m_\ell}{m_\tau} f_2\,(x) - P_\tau\,[\xi g_1\,(x) + \xi\delta g_2\,(x)] \right\} \;,$$

with $x = 2E_\ell/m_\tau$ ,

$$\begin{array}{ll} f_0\,(x) = 2 - 6\,x^2 + 4\,x^3 \;, & \\ f_1\,(x) = -\frac{4}{9} + 4\,x^2 - \frac{32}{9}\,x^3 \;, & g_1\,(x) = -\frac{2}{3} + 4\,x - 6\,x^2 + \frac{8}{3}\,x^3 \;, \\ f_2\,(x) = 12\,(1-x)^2 \;, & g_2\,(x) = \frac{4}{9} - \frac{16}{3}\,x + 12\,x^2 - \frac{64}{9}\,x^3 \;. \end{array} \tag{1}$$

The integrated decay width is given by

$$\Gamma = \frac{G_{\tau\ell}^2\ m_\tau^5}{192\ \pi^3} \left( 1 + 4\,\eta\ \frac{m_\ell}{m_\tau} \right) \;. \tag{2}$$

The situation is similar to muon decays $\mu \to e\nu_e\nu_\mu$. The generalized matrix element with the couplings $g^\gamma_{\varepsilon\mu}$ and their relations to the Michel parameters $\rho$, $\eta$, $\xi$, and $\delta$ are described in the Note on "Muon Decay Parameters". The Standard Model expectations for the parameters are 3/4, 0, 1, and 3/4, respectively. For more details see Ref. 1.

***Hadronic Decays:*** In the case of hadronic decays $\tau \to h\nu_\tau$ with $h = \pi$, $\rho$, or $a_1$, the ansatz is restricted to purely vector currents. The matrix element is

$$\frac{G_{\tau h}}{\sqrt{2}} \sum_{\lambda=R,L} g_\lambda \langle \overline{\Psi}_\omega(\nu_\tau) | \gamma^\mu | \Psi_\lambda(\tau) \rangle\ J^h_\mu \;, \tag{3}$$

where $J_\mu^h$ is the hadronic current. The neutrino chirality $\omega$ is uniquely determined from $\lambda$. The spectrum then only depends on a single parameter $\xi_h$,

$$\frac{d\Gamma}{dx} = f\left(x\right) + \xi_h P_\tau g\left(x\right) \ , \tag{4}$$

with $f$ and $g$ being channel dependent functions of the observables $x$ [2]. The parameter $\xi_h$ is related to the couplings through

$$\xi_h = |g_L|^2 - |g_R|^2 \ . \tag{5}$$

It is the negative of the chirality of the $\tau$ neutrino in these decays. In the Standard Model $\xi_h = 1$. Also included with the neutrino chiralities are measurements of its helicity which coincide with $\xi_h$ if the neutrino is massless (ACKERSTAFF 97R, AKERS 95P, ALBRECHT 93C, and ALBRECHT 90I).

***Model-independent Analysis:*** From the Michel parameters limits can be derived on the couplings $g^\kappa_{\varepsilon\lambda}$ without further module assumptions. In the Standard model $g^V_{LL} = 1$ (leptonic decays) and $g_L = 1$ (hadronic decays), and all other couplings vanish. First the partial decay widths have to be compared to the Standard Model predictions to derive limits on the normalization of the couplings $A_x = G^2_{\tau x}/G^2_F$, where $G_F$ is the Fermi constant:

$$\begin{aligned} A_\mu &= 1.027 \pm 0.042 \ , \\ A_e &= 1.0020 \pm 0.0059 \ , \\ A_\pi &= 1.018 \pm 0.017 \ . \end{aligned} \tag{6}$$

Then limits on the couplings (95% CL) can be extracted (see Ref. 3). For details see Ref. 4. Correlations between the different decay parameters are taken into account. The limits are given in Table 1. The measurements show good agreement with the Standard Model. The $\chi^2$ of all measurements with

**Table 1:** Coupling constants $g^{\gamma}_{\varepsilon\mu}$. 95 % confidence level experimental limits. The limits include the quoted values of $A_e$, $A_\mu$, and $A_\pi$ and assume $A_\rho = A_{a_1} = 1$.

| | | |
|---|---|---|
| $\tau \to e\nu_e\nu_\tau$ | | |
| $\lvert g^S_{RR}\rvert < 0.74$ | $\lvert g^V_{RR}\rvert < 0.19$ | $\lvert g^T_{RR}\rvert \equiv 0$ |
| $\lvert g^S_{LR}\rvert < 1.07$ | $\lvert g^V_{LR}\rvert < 0.14$ | $\lvert g^T_{LR}\rvert < 0.089$ |
| $\lvert g^S_{RL}\rvert < 2.01$ | $\lvert g^V_{RL}\rvert < 0.52$ | $\lvert g^T_{RL}\rvert < 0.51$ |
| $\lvert g^S_{LL}\rvert < 2.01$ | $\lvert g^V_{LL}\rvert < 1.01$ | $\lvert g^T_{LL}\rvert \equiv 0$ |
| $\tau \to \mu\nu_\mu\nu_\tau$ | | |
| $\lvert g^S_{RR}\rvert < 0.76$ | $\lvert g^V_{RR}\rvert < 0.19$ | $\lvert g^T_{RR}\rvert \equiv 0$ |
| $\lvert g^S_{LR}\rvert < 1.13$ | $\lvert g^V_{LR}\rvert < 0.17$ | $\lvert g^T_{LR}\rvert < 0.094$ |
| $\lvert g^S_{RL}\rvert < 2.09$ | $\lvert g^V_{RL}\rvert < 0.56$ | $\lvert g^T_{RL}\rvert < 0.53$ |
| $\lvert g^S_{LL}\rvert < 2.09$ | $\lvert g^V_{LL}\rvert < 1.05$ | $\lvert g^T_{LL}\rvert \equiv 0$ |
| $\tau \to \pi\nu_\tau$ | | |
| $\lvert g^V_R\rvert < 0.42$ | $\lvert g^V_L\rvert > 0.98$ | |
| $\tau \to \rho\nu_\tau$ | | |
| $\lvert g^V_R\rvert < 0.20$ | $\lvert g^V_L\rvert > 0.995$ | |
| $\tau \to a_1\nu_\tau$ | | |
| $\lvert g^V_R\rvert < 0.30$ | $\lvert g^V_L\rvert > 0.95$ | |

respect to the Standard model predictions is 22.3 for 41 degrees of freedom.

***Model dependent Interpretation:*** More stringent limits can be derived assuming specific models. For example, in the framework of a two-Higgs doublet model the measurements correspond to a limit of $m_{H^\pm} > 1.6\ \text{GeV} \times \tan\beta$ on the mass of the charged Higgs boson or a limit of 220 GeV on the mass of the second $W$ boson in left-right symmetric models for arbitrary mixing (both 95% CL). See Ref. 4 and Ref. 5.

## Footnotes and References

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