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Measurement of the Tau properties at LEP

M. Pilar Casado*

UAB/IFAE, Edifici Cn, E-08193 Bellaterra, Barcelona

E-mail: casado@ifae.es

Abstract: The final results on the tau polarisation measured by the four LEP experiments are presented here. In addition, a preliminary combination of these results taking into account correlated errors for the first time is given. The τ weak dipole moments, the Michel parameters and the τ lifetime are also reviewed.

1. Introduction

Each of the τ leptons produced in $e^+e^- \to \tau^+\tau^-$ decays in the LEP environment. This important property allows the measurements considered in this paper: weak dipole moments, longitudinal polarisation, Michel parameters and τ lifetime. The τ properties are covered in the preceding order, and the conclusions are presented at the end.

2. Weak dipole moments

The weak dipole moments of the τ are the tensorial couplings of the $Z\tau^+\tau^-$ vertex. They are zero at first order in the Standard Model (SM). However, radiative corrections in the SM predict small contributions for these terms [1]. Two types of weak dipole moments can be distinguished: the magnetic term, μ_τ, and the CP–violating electric term, d_τ. Considering these terms in addition to the SM couplings v_τ and a_τ, the $Z\tau^+\tau^-$ current is

$$\Gamma_\tau^{(Z)} = ie\left[v_\tau\gamma^\mu - a_\tau\gamma^\mu\gamma_5 + i\frac{\mu_\tau}{2m_\tau}\sigma^{\mu\nu}q_\nu + \frac{d_\tau}{2m_\tau}\gamma_5\sigma^{\mu\nu}q_\nu\right]. \tag{2.1}$$

With this current and the SM currents for the other vertexes, the differential cross-section for $e^+e^- \to \tau^+\tau^-$ with unpolarised beams can be expressed as [2]

$$\frac{d\sigma}{d\cos_{\theta_\tau}}(\vec{s}_1,\vec{s}_2) = R_{00} + \sum_{i=1,3} R_{i0}s_1^i + \sum_{j=1,3} R_{0j}s_2^j + \sum_{i,j=1,3} R_{ij}s_1^i s_2^j\,. \tag{2.2}$$

*Speaker.

R_{ij} are functions of the fermion couplings and θ_τ; and $\vec{s}_1$ and $\vec{s}_2$ are unit vectors for measuring the spin of the τ^+ and the τ^-, respectively, in their rest frames. Some R_{ij} are well known. For example, $R_{00} = d\sigma/d\cos_{\theta_\tau}$ (the angular differential cross-section), and $(R_{03})_+ /R_{00} = P_\tau$ (the longitudinal τ polarisation), taking the z axis parallel to the τ^- direction and defining $(R_{ij})_{+/-} \equiv (R_{ij} + / - R_{ji})$. Assuming the z axis along the τ^+ direction and the $z-y$ plane containing the e^+, the four most sensitive terms to the weak dipole moments are $(R_{02})_+$, $(R_{31})_+$, $(R_{01})_-$ and $(R_{32})_-$. The four second most sensitive terms to the weak dipole moments are $(R_{32})_+$, $(R_{01})_+$, $(R_{31})_-$ and $(R_{02})_-$, taking into consideration that $a_l >> v_l$.

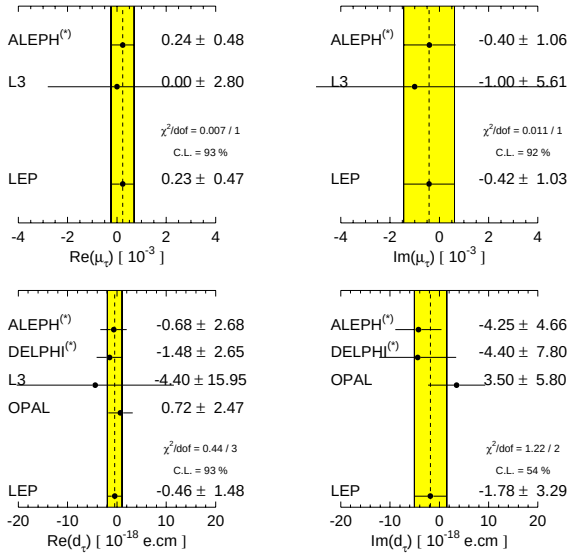

Figure 1: New ALEPH results on the weak dipole moments, previous results of the other LEP experiments, the new LEP averages and the χ^2/dof of the combinations. The symbol $^{(*)}$ means preliminary result.

The ALEPH experiment has updated its measurement of $Re(d_\tau)$ and has measured the other weak dipole moments for the first time [3]. The following terms are used for the first time with respect to any preceding analysis of the weak dipole moments: $(R_{32})_+$ (second order term), $(R_{31})_+$ (first order term) [1], $(R_{31})_-$ (second order term). The ALEPH analysis also considers $(R_{02})_-$ (second order term) for the first time at LEP. Fig. 1 shows the results of this analysis and the previous published and preliminary results of the other LEP experiments [5].

3. Longitudinal polarisation

	ALEPH		DELPHI		L3		OPAL	
	δA_τ	δA_e	δA_τ	δA_e	δA_τ	δA_e	δA_τ	δA_e
ZFITTER	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
τ br. ratios	0.0003	0.0000	0.0016	0.0000	0.0007	0.0012	0.0011	0.0002
Bhabha backg.	0.0000	0.0000	0.0012	0.0000	0.0000	0.0000	0.0000	0.0000
2-photon backg.	0.0000	0.0000	0.0005	0.0000	0.0007	0.0000	0.0000	0.0000
radiat. correct. & a_1 modelling	0.0012	0.0008	0.0010	0.0000	0.0010	0.0001	0.0025	0.0005

Table 1: Most relevant common systematic errors on A_τ and A_e for the four LEP experiments.

The longitudinal polarisation of the τ, P_τ, is a precision electroweak observable measured at LEP. It provides an accurate determination of the effective weak mixing angle

[1] The use of $(R_{31})_+$ was suggested in [4].

$\sin^2\theta_W^{eff}$. P_τ depends on the τ production polar angle θ_{τ^-} as follows

$$P_\tau = -\frac{A_\tau(1+\cos^2\theta_{\tau^-}) + 2A_e\cos\theta_{\tau^-}}{(1+\cos^2\theta_{\tau^-}) + \frac{8}{3}A_{fb}\cos\theta_{\tau^-}}\,,$$

with $A_l = 2v_l a_l/[(v_l)^2 + (a_l)^2]$, $v_l/a_l = 1-4\sin^2\theta_W^{eff}$ and A_{fb} being the forward-backward charge asymmetry of τ production.

The four LEP experiments use kinematic distributions of the τ decay products to measure the polarisation as a function of $\cos\theta_{\tau^-}$. Data were collected during the 1990 - 95 Z running period. The decay mode considered are $e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$, $\pi\nu$, $\rho\nu$, $a_1(3\pi)\nu$ and $a_1(2\pi^0\pi)\nu$.

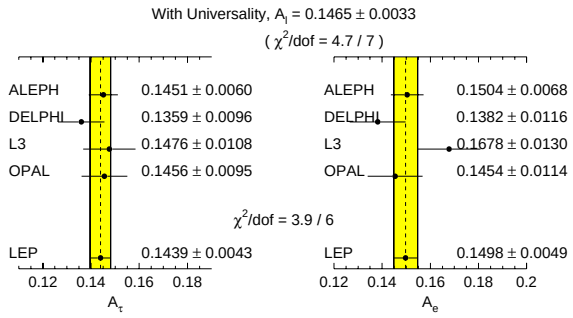

Figure 2: New final results of ALEPH and OPAL on A_τ and A_e, and the published results of DELPHI and L3. The new LEP results on A_τ and A_e and the χ^2/dof are also shown. On the top of the figure, the LEP fit for A_l assuming lepton universality is also presented.

The method of measuring $P_\tau(\cos\theta_{\tau^-})$ yields nearly independent determinations of A_τ and A_e. Thus, the τ polarisation measurements provide both a determination of $\sin^2\theta_W^{eff}$ and a test of the hypothesis of universality of the Z couplings to the electron and the τ.

ALEPH and OPAL have presented new final results on the τ longitudinal polarisation [6]. In addition, the LEP experiments have presented combined results on A_τ and A_e taking into account correlated systematic uncertainties for the first time [7]. The most relevant common systematic errors are shown in Table 1.

Fig. 2 shows the new final results of ALEPH and OPAL on A_τ and A_e, and the published results of L3 and OPAL [8]. It also gives the LEP fitted values for A_τ and A_e with no assumption on lepton universality, and A_l assuming $e-\tau$ universality. This last result provides a value of

$$\sin^2\theta_W^{eff} = 0.23159 \pm 0.00041\,. \tag{3.1}$$

4. Michel parameters

The τ Michel parameters allow to test possible deviations from the SM description in the τ decay. In $\tau \to l\nu_\tau\bar{\nu}_l$, the coupling constants can be experimentally accessed via the energy spectra of the daughter leptons. If the polarisation of the daughter leptons is not known, the spectrum of the τ decays can be parametrised at Born level by

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_l} = h_0(x_l) + \eta h_\eta(x_l) + \rho h_\rho(x_l) - P_\tau\left[\xi h_\xi(x_l) + \xi\delta h_{\xi\delta}(x_l)\right]\,, \tag{4.1}$$

where the coefficients η, ρ, ξ and $\xi\delta$ are the Michel parameters, the dependence of the h functions on x_l is known, P_τ is the average τ polarisation and $x_l = E_l/E_{beam}$. In The SM, $\eta = 0$, $\rho = 0.75$, $\xi = 1$ and $\xi\delta = 0.75$.

Fig. 3 shows the recently published results of ALEPH on the Michel parameters [9] and the results of the other LEP experiments [10]. The LEP average is also given.

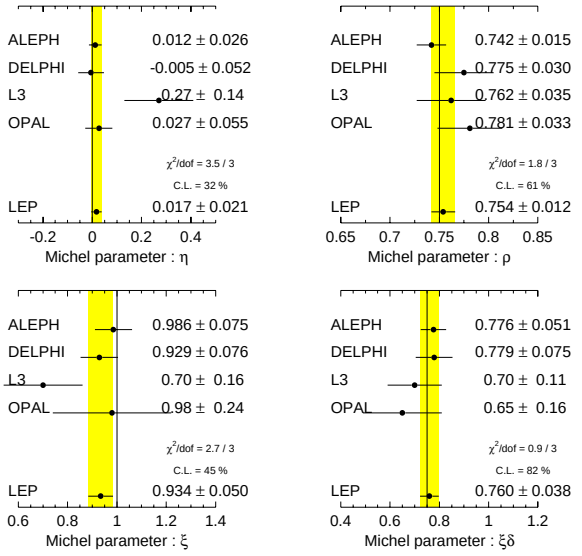

Figure 3: New final measurements of ALEPH on the Michel parameters, the results of the other LEP experiments, the new LEP average and the χ^2/dof of the combination. The SM expectation is shown as a vertical line for each parameter.

5. Lifetime

The τ lifetime can be used to test lepton universality together with the τ leptonic branching ratios, B_e and B_μ, and the measurement of m_τ by

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = 0.9996\,\frac{\tau_\mu}{\tau_\tau}\frac{m_\mu^5}{m_\tau^5}B_e\,,$$
$$\left(\frac{g_\tau}{g_e}\right)^2 = 0.9996\,\frac{\tau_\mu}{\tau_\tau}\frac{m_\mu^5}{m_\tau^5}\frac{B_\mu}{f(m_\mu^2/m_\tau^2)}\,,$$

where the numerical factor accounts for electroweak propagator and radiative corrections in the τ and μ decays. The function f is a known phase space factor with value $f(m_\mu^2/m_\tau^2) = 0.97256$.

The DELPHI collaboration has presented a new preliminary result of the τ lifetime [11], which is shown on the top part of Fig. 4 together with the previous results of the other LEP experiments and the new LEP average. On the bottom part of this figure, the new LEP τ lifetime is plotted versus the LEP values of B_e and B_μ [12]. The diagonal band of these figures represents the SM prediction according to the previous equations, with the width reflecting the experimental uncertainty in m_τ. Taking the PDG values for m_μ, m_τ and τ_μ [13], the present results on $\tau - \mu$ and $\tau - e$ universality are

$$\left(\frac{g_\tau}{g_\mu}\right) = 0.9999 \pm 0.0023\,, \tag{5.1}$$
$$\left(\frac{g_\tau}{g_e}\right) = 1.0002 \pm 0.0023\,, \tag{5.2}$$

both consistent with the SM expectation.

6. Conclusions

ALEPH and OPAL have presented new final results on the measurement of the τ polarisation. The four LEP experiments have combined their results on the τ polarisation taking into account common errors for the first time. This yields a precise measurement of the effective weak angle of $\sin^2\theta_W^{eff} = 0.23159 \pm 0.00041$, in good agreement with other leptonic contributions to $\sin^2\theta_W^{eff}$ [7].

The Lorentz structure of both the neutral current and the τ decay have been revised, with no deviation from the SM expectations in both cases. ALEPH has presented new preliminary results on the tau weak dipole moments and new final results on the Michel parameters.

Finally, a new preliminary measurement of the τ lifetime has been presented by DELPHI, allowing to set new LEP values on $\tau - \mu$ and $\tau - e$ universality. The new universality ratios agree with the SM prediction at the few per mil level.

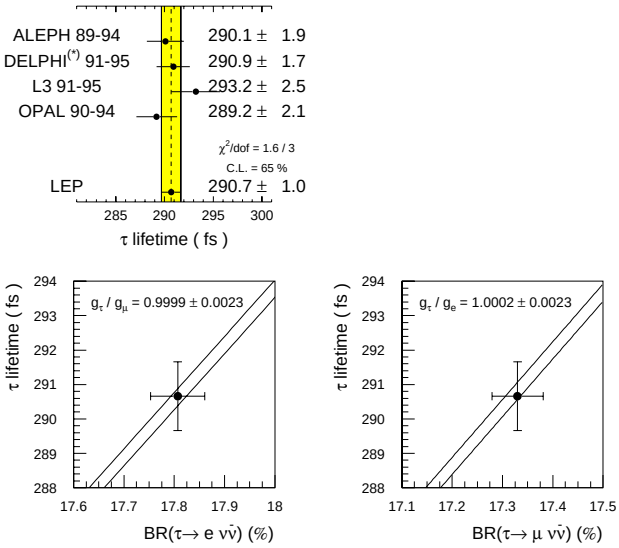

Figure 4: On the top plot, new DELPHI result on the τ lifetime, the results of the other LEP experiments, the new LEP average and the χ^2/dof of the combination. The symbol $^{(*)}$ means preliminary result. On the bottom plots, the new LEP τ lifetime versus the LEP values of B_e and B_μ.

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