Lifetime and Leptonic Branching Ratios of the Tau Lepton

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This paper describes recent measurements of the tau lifetime and leptonic branching ratios, concentrating on results from DELPHI at LEP but also mentioning results from other experiments, in particular those from other LEP experiments. The DELPHI analysis is based on around 6500 $\tau^+\tau^-$ pairs in the barrel region, taken in 1991. The combined LEP results show that the ratio of the tau to muon Fermi coupling constants is consistent with unity.

INTRODUCTION

The Standard Model gives a prediction for the tau lifetime^{1,2}:

$$\tau_\tau = \tau_\mu \left(\frac{G_\mu}{G_\tau} \right)^2 \left(\frac{m_\mu}{m_\tau} \right)^5 BR(\tau \rightarrow e\nu\nu) . \quad (1)$$

Assuming $G_\tau = G_\mu$ and using the world average values³ for $BR(\tau \rightarrow e\nu\nu)$, τ_μ , m_μ and m_τ , equation (1) gives

$$\tau_\tau = 286 \pm 4 fs ,$$

which is 2σ away from the world average tau lifetime³

$$\tau_\tau = 305 \pm 6 fs .$$

Further measurements of the tau lifetime are needed to resolve or confirm this discrepancy, or alternatively to test $\tau - \mu$ universality.

THE DELPHI DETECTOR

The DELPHI detector has been described in detail elsewhere⁴. The microvertex detector⁵, vital for the lifetime measurement,

comprises 3 layers of single-sided silicon detectors arranged cylindrically around the interaction point at radii of 6cm, 9cm and 11cm. The $50\mu m$ readout pitch gives an intrinsic $r-\phi$ resolution of $6\mu m$.

The track extrapolation resolution at the vertex is found to be

$$\sigma = \sqrt{26^2 + \left(\frac{65}{p_t(GeV/c)} \right)^2} \mu m ,$$

i.e. approximately $30\mu m$ for tau decays.

The centre of the interaction region was determined every 100 $Z^0 \rightarrow q\bar{q}$ events, with a precision of $10\mu m$. This was taken as the $\tau^+\tau^-$ production point. The extent of the interaction region is given by $\sigma_x = 145\mu m$ and $\sigma_y = 7\mu m$, where x and y are the horizontal and vertical directions in the plane transverse to the beam, respectively.

TAU LIFETIME

DELPHI uses four methods for measuring the tau lifetime, which will be reviewed in this section. Results from the other LEP experiments are also mentioned.

Figure 1. The 3-prong decay distance distribution (DELPHI).

Vertex Method

This method⁶ involves looking at $\tau^+\tau^-$ events which decay into a 1 versus 3 charged-track topology, reconstructing the decay vertex on the 3-prong side, and determining the decay distance from the production point. After event selection, track and vertex quality cuts, 823 secondary vertices are found. The decay distance distribution is shown in figure 1. A maximum likelihood fit to the data gives

$$\tau_\tau = 303 \pm 13(stat) \pm 7(sys) fs .$$

Other recent measurements of the tau lifetime at LEP^{9,13,14} using this method are shown in figure 2.

Impact Parameter Method

For this method⁶, $\tau^+\tau^-$ events are selected which decay into 1 versus 1 charged-track topologies. The impact parameter¹ for 1-prongs is related to the tau lifetime, and is signed using the charged track in the opposite

Figure 2. Recent LEP tau lifetime numbers (vertex method).

hemisphere to define the tau direction. After event selection and track quality cuts there are 6113 1-prong tau decays. The signed impact parameter distribution is shown in figure 3. A maximum likelihood fit to the data gives

$$\tau_\tau = 304 \pm 11 \pm 6 fs .$$

Some recent measurements of the tau lifetime at LEP^{10,13,14} using this method are shown in figure 4.

Decay Angle Correlation Method

Again, $\tau^+\tau^-$ events decaying into 1 versus 1 charged-track topologies are used. This method⁷ relies on the fact that the difference in impact parameters for the two tracks is proportional to the projected acoplanarity, with a constant of proportionality related to the lifetime. In addition to the event selection made for the impact parameter method, cuts are made in order to reject radiative events. After cuts, 2873 events remain in the projected acoplanarity range -0.2 to 0.2 (radians). The mean difference in impact parameter versus the projected acoplanarity is shown in figure

Figure 3. The signed impact parameter distribution with fit (DELPHI).

Figure 5. Mean impact parameter difference versus projected acoplanarity with fit (DELPHI).

Impact Parameter Method (LEP)

Figure 4. Recent LEP tau lifetime numbers (impact parameter method).

5. A straight line fit to the data, including the effect of biases due to the remaining radiative events, gives

$$\tau_\tau = 299 \pm 11 \pm 6 \text{ fs} .$$

ALEPH has carried out a measurement of the tau lifetime using this method for their 1991 data¹¹, with the result

$$\tau_\tau = 311 \pm 12 \pm 4 \text{ fs} .$$

Missed Distance Method

Here the sum of the impact parameters for events in which $\tau^+\tau^-$ decays into 1 versus 1 charged-track topologies is used to extract the tau lifetime⁸. The same data sample as in the impact parameter difference method is used, together with extra track quality cuts; this leaves 2353 events. The distribution of impact parameter sum, or missed distance, is shown in figure 6. A log likelihood fit to the data gives

$$\tau_\tau = 301 \pm 9 \pm 6 \text{ fs} .$$

Figure 6. The missed distance distribution with fit (DELPHI).

ALEPH has carried out a measurement of the tau lifetime using a similar method on their 1991 data sample¹², and obtains the result

$$\tau_\tau = 287 \pm 8 \pm 5 \text{ fs} .$$

Summary of Tau Lifetime Results

Figure 7 shows a summary of recent measurements of the tau lifetime⁶⁻¹⁵; the numbers quoted for each LEP experiment are derived by combining the results for each method used by that experiment.

TAU LEPTONIC BRANCHING RATIOS

The 1991 DELPHI $\tau^+\tau^-$ event sample for the measurement of $BR(\tau \rightarrow e\nu\nu)$ and $BR(\tau \rightarrow \mu\nu\nu)$ comprises around 6000 events, from which 1272 $\tau \rightarrow e\nu\nu$ decays are selected with an efficiency of 60%, and 1579 $\tau \rightarrow \mu\nu\nu$ decays are selected with an efficiency of 72%. The results for the leptonic branching ratios

Figure 7. Summary of recent tau lifetime results.

Figure 8. Summary of recent results on the electronic branching ratio.

Figure 9. Summary of recent results on the muonic branching ratio.

are

$$BR(\tau \rightarrow e\nu\nu) = 17.62 \pm 0.47 \pm 0.53\%,$$

$$BR(\tau \rightarrow \mu\nu\nu) = 17.73 \pm 0.42 \pm 0.45\%.$$

Figures 8 and 9 show the comparison of these numbers with other recent leptonic branching ratio results¹⁶⁻²¹.

CONCLUSIONS

Averaging the LEP values, not taking into account common systematic errors, yields

$$BR(\tau \rightarrow e\nu\nu) = 17.63 \pm 0.26\%,$$

$$BR(\tau \rightarrow \mu\nu\nu) = 17.34 \pm 0.24\%,$$

$$\tau_\tau = 295.3 \pm 3.7 fs.$$

Using these values, and a value for the tau mass $m_\tau = 1777.1 \pm 0.5 \text{ MeV}/c^2$, derived by averaging the measurements from three different experiments^{20,22,23}, equation (1) gives

$$\frac{G_\tau}{G_\mu} = 0.987 \pm 0.010,$$

which is a constant with unity. Including the ARGUS and CLEO values mentioned in this

paper for $BR(\tau \rightarrow e\nu\nu)$ and the tau lifetime, we get

$$\frac{G_\tau}{G_\mu} = 0.983 \pm 0.008.$$

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