Measurement of the Branching Ratios of the Tau into Leptons with the L3 Detector at LEP

Wolfgang Lohmann*

Deutsches Elektronen Synchrotron, Institut für Hochenergiephysik,
Platanenallee 6, 15738 Zeuthen, Germany.

The branching ratios of the tau into leptons are measured using data collected from 1991-1994 by the L3 detector at LEP, running at $\sqrt{s} \approx M_Z$. The branching ratios of the decays $\tau^- \rightarrow e^-\bar{\nu}_e\nu_\tau$ and $\tau^- \rightarrow \mu^-\bar{\nu}_\mu\nu_\tau$ are obtained to be $(17.67 \pm 0.14 \pm 0.13)\%$ and $(17.34 \pm 0.15 \pm 0.15)\%$, respectively. The results are preliminary.

1. Introduction

The precise measurement of leptonic tau decay branching ratios allows one to test one of the fundamental assumptions in the Standard Model of electroweak interactions: that charged current couplings are independent of lepton generation. This universality can be tested for the electron and muon in the ratio of the $\tau^- \rightarrow e^-\bar{\nu}_e\nu_\tau$ to $\tau^- \rightarrow \mu^-\bar{\nu}_\mu\nu_\tau$ branching ratios, $\mathcal{B}_e$ and $\mathcal{B}_\mu$, respectively. Taking into account the phase space difference,one finds

$$\frac{\mathcal{B}_e}{\mathcal{B}_\mu} = 1.028(\frac{g_e}{g_\mu})^2, \qquad (1)$$

where g_e and g_μ are the couplings to the $W^- \rightarrow e^-\bar{\nu}_e$ and $W^- \rightarrow \mu^-\bar{\nu}_\mu$ vertex, respectively.

A test of universality between muon and τ lepton is performed through the relation

$$(\frac{g_\tau}{g_\mu})^2 = \frac{\tau_\mu}{\tau_\tau}\mathcal{B}_e(\frac{m_\mu}{m_\tau})^5, \qquad (2)$$

where τ_μ end τ_τ are the muon and tau lifetimes and m_μ and m_τ the muon and tau masses, respectively.

Furthermore, a precise value of the strong coupling constant can be determined from the ratio between hadronic and leptonic branching fractions of the tau.

2. The L3 Detector

The L3 detector is described in detail in Ref. [1]. The central tracker consists of a time expansion chamber (TEC) surrounded by two thin proportional (Z-)chambers. The TEC delivers a precise track measurement in the bending plane perpendicular to the beam direction and the Z-chambers provide a coordinate along the beam direction. The central tracker is surrounded by a fine grained high resolution electromagnetic calorimeter composed of Bismuth Germanium Oxide crystals (BGO), a ring of scintillation counters, a uranium and brass hadron calorimeter with proportional wire chambers readout (HCAL) and a precise muon spectrometer consisting of three layers of multiwire drift chambers.

These subdetectors are installed in a 12 m diameter solenoidal magnet which provides a uniform field of 0.5 T along the beam direction. In the following analysis only the barrel part of the detector with $|\cos\theta| < 0.7$ is used, where θ is the polar angle with respect to the electron beam direction.

The TEC transverse momentum resolution is parametrised as $\sigma_{p_T}/p_T = 0.018 p_T(\mathrm{GeV/c})$, the BGO resolution is less than 2% above 1 GeV, the HCAL energy resolution for $\pi^\pm$ is determined to be $\Delta E/E = 55\%/\sqrt{E}(\mathrm{GeV}) + 8\%$ and the transverse momentum resolution of the muon spectrometer is 2.8% for charged particles with $p_T = 45$ GeV/c.

*presently at CERN, 1211 Geneve 23, Switzerland

3. Method of the Measurement

To measure the tau leptonic branching ratios at LEP we need to select a clean sample of $e^+e^- \to \tau^+\tau^-$ events, which is only a few percent of the whole data. The principal characteristics of $e^+e^- \to \tau^+\tau^-$ events are low multiplicity and back-to-back topology, which allow the main part of the background from hadronic Z decays to be rejected without significant loss of the signal. The suppression of the remaining background from Bhabha, dimuon and two-photon events rejects a considerable fraction of $e^+e^- \to \tau^+\tau^-$ events. The selection usually contains a number of correlated cuts affecting the event as a whole and therefore potentially changing the ratio of different tau decay modes, which should be also taken into account. Finally, after the lepton identification, the branching ratios from the number of selected $e^+e^- \to \tau^+\tau^-$ events $N_{\tau\tau}$ with the selection efficiency $\varepsilon_{\tau\tau}^{sel}$ and the number of identified leptons N_l with the selection efficiency ε_l^{sel} are obtained through the expression

$$\mathcal{B}_l = \frac{N_l(1 - f_l^{non\ \tau} - f_{h\to l}^{\tau})}{2N_{\tau\tau}(1 - f_{\tau\tau}^{non\ \tau})}\,\frac{1}{\varepsilon_l^{ID}}\,\frac{\varepsilon_{\tau\tau}^{sel}}{\varepsilon_l^{sel}}. \qquad (3)$$

Here ε_l^{ID} is the lepton identification efficiency, $f_{h\to l}^{\tau}$ and $f_l^{non\ \tau}$ are the background contamination from other τ decays and non-τ final states in the selected leptonic decays, respectively, and $f_{\tau\tau}^{non\ \tau}$ is the background of other final states in the selected $e^+e^- \to \tau^+\tau^-$ events.

The last presented measurements of the tau leptonic branching ratios at LEP are already near the systematical limit [2–4]. The main sources of systematic errors are:

1. the lepton identification efficiency (ε_l^{ID}) which is usually taken from Monte Carlo and checked with data,
2. the different selection efficiencies for leptonic and all other tau decay modes ($\varepsilon_{\tau\tau}^{sel}/\varepsilon_l^{sel}$), which can be obtained from Monte Carlo only,
3. the remaining background contaminations ($f_{\tau\tau}^{non\ \tau}$, $f_l^{non\ \tau}$ and $f_{h\to l}^{\tau}$)

One obvious way to avoid the systematic error due to the second source is to use a method which ideally selects all tau decay modes with the same efficiency, i.e. which does not change the ratio of different tau decay modes ($\varepsilon_{\tau\tau}^{sel}/\varepsilon_l^{sel} = 1$). This can be achieved by avoiding correlated cuts. Since there are two taus decaying back to back it is possible to analyse every tau decay in the event applying selection only to the opposite tau. However the proposed procedure does not provide sufficient background suppression for the same tau selection efficiencies riched with the usual one. So our analysis still contains a minimal number of correlated cuts which reduce background considerably while decreasing the tau selection efficiency by only 9.4%.

4. Data Analysis

A data sample corresponding to a total integrated luminosity of 124 pb^{-1} collected by the L3 experiment during the 1991, 1992, 1993 and 1994 data taking periods is used in this analysis. A clean sample of lepton pairs produced in Z decays is obtained by following the preselection described in Ref. [5]. Only low multiplicity events with a 'back–to–back' topology are accepted. Each event is divided into two hemispheres by a plane perpendicular to the thrust axis. Only events having the polar angle of the thrust axis inside the fiducial volume $|cos\Theta| < 0.72$ are considered. The polar angle of tracks is restricted to $|cos\Theta_{track}| < 0.71$ in order to exclude possible edge effects in calorimeters. Thus the defined fiducial volume contains 58.9% of the whole $e^+e^- \to \tau^+\tau^-$ sample. The further selection can be divided in two steps.

To reduce the remaining hadronic events to a negligible level we require no charged tracks outside a cone of 20 degrees around the azimuthal projection of the thrust axis. Bhabha and dimuon events are rejected by requiring the acoplanarity to be greater than 2 mrad. To suppress two photon background we apply a cut on acollinearity of the event to be less than 15 degrees. Distributions of variables used for these remaining correlated cuts were studied carefully comparing data and simulation results and were found to be in excellent agreement. The selection efficiency inside the fiducial volume estimated from Monte Carlo is found to be 90.6%.

The second step of selection is applied to each hemisphere of each event. Every hemisphere is considered as a tau decay if the opposite side is inconsistent with background. The BGO energy deposition in the opposite hemisphere is required to be less than 32 GeV to suppress further Bhabha events. Dimuons and cosmic muons are rejected by requiring that the opposite side to have no hits in muon chambers and be inconsistent with a minimum ionising particle.

The total selection efficiency for events inside the fiducial volume is 61.7% as determined from Monte Carlo. The main part of selection inefficiency comes from cuts applied to opposite side and therefore cancels in the final expression for branching ratios. The number of background Bhabha (dimuon) events is determined from a fit of BGO energy deposition (muon chamber momentum) with a sum of Monte Carlo predictions for $\tau\tau$ and Bhabha (dimuon) simulation as shown in Fig. 1.

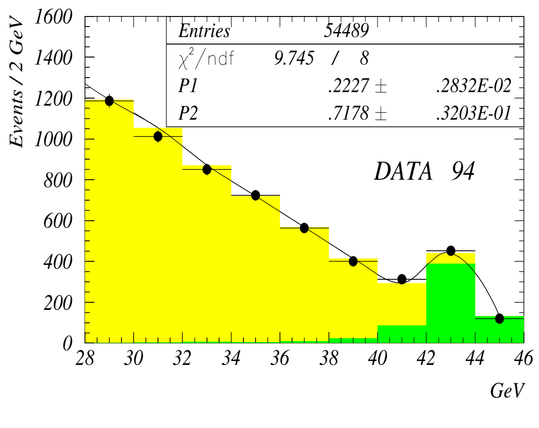

Figure 1. BGO energy distribution for events selected in 94 fitted with a sum of Monte Carlo predictions for signal and Bhabha background.

Before the fit we compare the corresponding spectra for selected Bhabha (dimuon) events in data and Monte Carlo for every year. With this comparison we derive small corrections which should be applied to Monte Carlo spectra to reproduce data and use them later in the fit. These corrections are explained by small differences of BGO (muon chamber) energy resolution for different run periods. Two-photon background is estimated from Monte Carlo which in turn is checked with data selecting characteristic events with large acollinearity.

The final number of selected events with background contaminations are given in Table 1.

5. Lepton Identification

Electron identification is based on precise impact point and shower shape measurements in TEC, Z-chambers and BGO. The particle is identified as an electron if there is only one track in TEC matched with a narrow and symmetric shower in BGO. Only electrons with energy between 2 GeV and 40 GeV are used in the analysis. The average electron identification efficiency is determined from MC to be 86.5%. Samples of high energy Bhabha electrons from data and Monte Carlo are used to check this result. A small discrepancy of the order of 3% is found and corresponding corrections for the efficiency are applied. The fraction of misidentified hadrons in $\tau^- \to e^- \bar{\nu}_e \nu_\tau$ sample is determined from Monte Carlo to be 2.6%.

Muon candidates consist of tracks in the muon spectrometer, originating from the interaction point, with a minimum ionising particle response in BGO and HCAL. Only muons with two or three track segments in the three planes of the muon spectrometer are accepted. In order to avoid momentum regions with a small identification efficiency or large background contamination, only muons with a momentum between 3 GeV/c and 41 GeV/c are used. We do not consider muons pointing into the central gap between muon chambers at $|cos\Theta| < 0.06$ where the efficiency of muon identification is low. The average identification efficiency for muons as determined from Monte Carlo is 75.0%. This value at

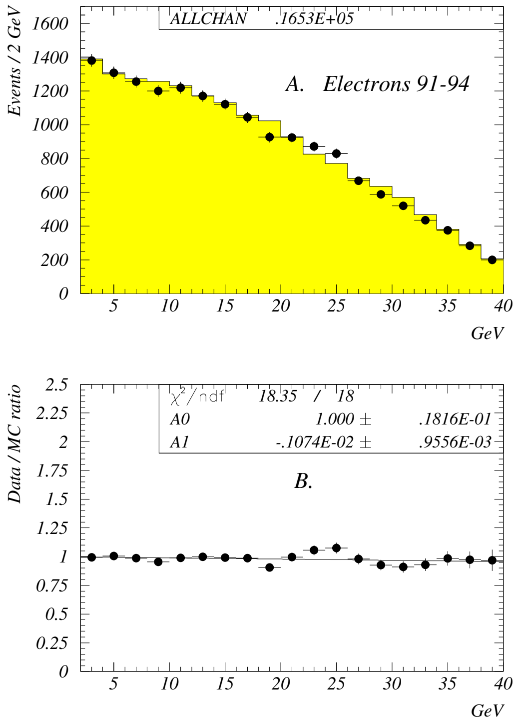

Figure 2. (A) The spectrum of identified electrons. The dots are data and the histogram Monte Carlo events after full detector simulation. (B) The ratio of the data and Monte Carlo spectra.

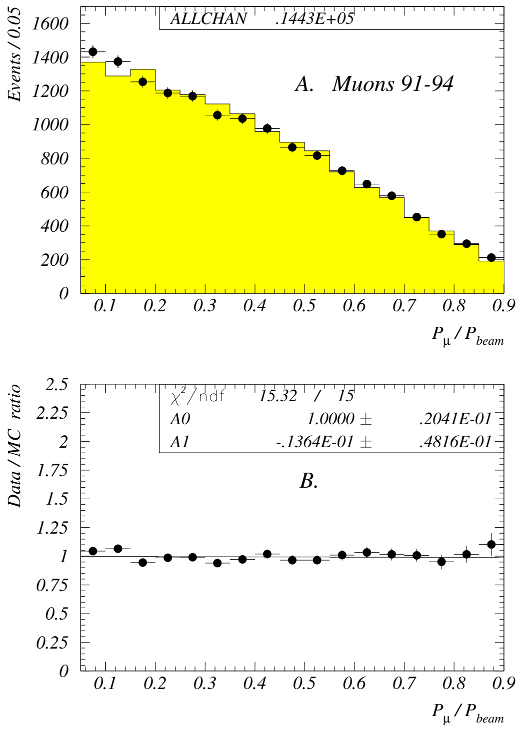

Figure 3. (A) The spectrum of identified muons. The dots are data and the histogram Monte Carlo events after full detector simulation. (B) The ratio of the data and Monte Carlo spectra.

high momenta is in perfect agreement with the one determined from a dimuon data sample. The misidentification probability for hadrons obtained from simulation and checked with hadronic tau decays leads to 1.1% background fraction in the selected $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$ sample.

Backgrounds from Bhabha and dimuon events are estimated from Monte Carlo which was tuned to reproduce data for selected Bhabha and dimuon events as described in the previous section.

The final numbers of selected tau events, identified leptons and background contaminations are given in Table 1. Spectra of identified electrons and muons summed over all run periods are presented in Fig. 2 and Fig. 3, respectively. Good agreement with the simulated expectations, which are also shown, is observed.

Figures 2 and 3 contain also the ratios of electron (muon) spectra from the data and Monte Carlo prediction, which are used for systematic error estimation. The electron and muon identification efficiencies in data and Monte Carlo are tuned to be in agreement at high energies. The momentum range of tau decay products, however, is different. Therefore we suppose a possibility of small deviation of identification efficiency predicted by Monte Carlo from that in real data. This deviation is assumed to depend linearly on lepton momentum and is extracted fitting the ratio of data to Monte Carlo with a straight line, with the high energy point fixed by the ratio determined from Bhabha (dimuon) events. For all run periods the observed deviation is consistent with zero. Varying the slope of a straight line within statistical errors with the high energy point fixed we estimate the systematic uncertainty for every year.

6. Results and Conclusion

From the numbers listed in Table 1 and lepton identification efficiencies given in the previous section we determine the tau leptonic branching fractions for the 1991+1992, 1993, and 1994 run periods using expression (3). The influence of correlated cuts is minimised in our analysis and their total inefficiency for tau events is several times lower in comparison with the classical selection. Results of the analysis are given in Table 2.

The uncertainties of lepton identification efficiencies coming from finite Monte Carlo statistics and data to Monte Carlo comparison for high energies are included in statistical errors.

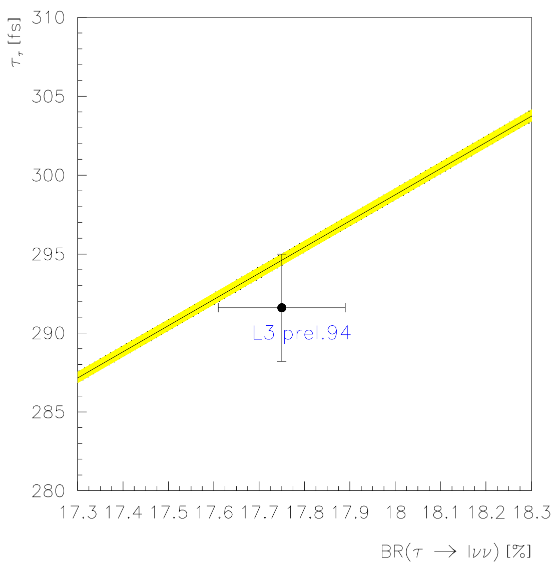

Figure 4. Lifetime and branching ratio measurements from L3 compared to the band allowed from the measured tau mass.

In order to test electron-muon universality, equation (1) is used:

$$\frac{g_e}{g_\mu} = 0.996 \pm 0.008 \tag{4}$$

From equation (2) we can derive tests of electron-tau and muon-tau universality using the tau mass [6] and our recent tau lifetime [7]:

$$\frac{g_e}{g_\tau} = 1.001 \pm 0.009 \tag{5}$$

$$\frac{g_\mu}{g_\tau} = 1.005 \pm 0.008 \tag{6}$$

Combining $\mathcal{B}_e$ and $\mathcal{B}_\mu$, assuming electron-muon universality, to $\mathcal{B}_l$, the dependence between $\mathcal{B}_l$ and the tau lifetime given in equation (2) is illustrated in Fig. 4.

The results are in perfect agreement with the hypothesis of lepton universality in the electroweak theory.

REFERENCES

1. L3 Collab., B. Adeva *et al.*, Nucl. Inst. and Meth. **A 289** (1990) 35.
2. ALEPH Collab., D. Busculic *et al.*, Z. Phys. **C 70** (1996) 561.
3. OPAL Collab., G. Alexander *et al.*, Phys. Lett. **B369** (1996) 163.
4. DELPHI Collab., P. Abreu *et al.*, Phys. Lett. **B 357** (1995) 715.
5. L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 294** (1992) 466.
6. Particle Data Group, Phys. Rev. **D 50** (1994) 1173.
7. L3 Collab., M. Acciarri *et al.*, CERN-PPE/96-124 (1996) , accepted for publication in Phys. Lett. B.

	1991+92	1993	1994	Total
number of selected events	34399	24468	54489	113356
background (%) from				
Bhabha	1.6%	2.1%	1.2%	1.5%
dimuon	0.7%	0.6%	0.8%	0.7%
$\gamma\gamma$	0.4%	0.4%	0.4%	0.4%
number of identified electrons	5170	3767	8115	17052
background (%) from				
Bhabha	0.6%	0.7%	0.5%	0.6%
$\gamma\gamma$	2.2%	2.2%	2.2%	2.2%
$\tau \to h$ misidentification	2.6%	2.6%	2.6%	2.6%
number of identified muons	4396	3122	6963	14481
background (%) from				
dimuon	0.3%	0.3%	0.3%	0.3%
$\tau \to h$ misidentification	1.1%	1.1%	1.1%	1.1%

Table 1
The number of selected tau decays, of identified electrons and muons and the various background contaminations for data taken in 1991/92, 1993 and 1994 and for the total sample.

	$B(\tau \to \nu_\tau e \bar{\nu}_e)$	$B(\tau \to \nu_\tau \mu \bar{\nu}_\mu)$
1991+92	$(17.55 \pm 0.26 \pm 0.21)\%$	$(17.32 \pm 0.27 \pm 0.26)\%$
1993	$(18.12 \pm 0.31 \pm 0.25)\%$	$(17.41 \pm 0.32 \pm 0.30)\%$
1994	$(17.47 \pm 0.21 \pm 0.18)\%$	$(17.31 \pm 0.22 \pm 0.21)\%$
Average	$(17.67 \pm 0.14 \pm 0.13)\%$	$(17.34 \pm 0.15 \pm 0.15)\%$

Table 2
The branching ratios of $\tau^- \to e^- \bar{\nu}_e \nu_\tau$ and $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$ for data taken 1991/92, 1993 and 1994 and the average from the total data sample.