DELPHI 97-86 CONF 72
28 July, 1997

Measurements of the tau leptonic branching ratios

Preliminary

DELPHI Collaboration

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Abstract

Using data from 1993 to 1995 an updated measurement of the branching fraction $\tau \to \mu\nu\bar{\nu}$ is presented. Combined with a previous analysis of DELPHI data for 1991 and 1992 the result $B(\tau \to \mu\nu\bar{\nu}) = (17.28 \pm 0.10_{stat} \pm 0.08_{sys})\%$ is obtained. The current DELPHI estimate of $B(\tau \to e\nu\bar{\nu})$ is also presented.

Paper submitted to the LP'97 Conference
Hamburg, July 28 - August 1st

1 Introduction

The LEP collider at CERN, in which e^+e^- collisions take place at centre-of-mass energies $\sqrt{s} \simeq 91$ GeV, produces τ lepton pairs through the reaction $e^+e^- \to Z^0 \to \tau^+\tau^-$. The branching fractions of the decays $\tau \to \mu\nu\bar{\nu}$ and $\tau \to e\nu\bar{\nu}$ can be used to test universality in the couplings of the leptons to the weak charged current. Assuming the neutrino to be massless, the ratio of the widths for the decays into leptonic final states is given by [1]

$$\frac{\Gamma(\tau \to \mu\nu\bar{\nu})}{\Gamma(\tau \to e\nu\bar{\nu})} = \frac{g_\mu^2}{g_e^2} \cdot \frac{f(m_\mu^2/m_\tau^2)}{f(m_e^2/m_\tau^2)}, \tag{1}$$

where g_μ and g_e are the couplings of the muon and electron to the charged weak current, m_μ and m_e are their masses, m_τ is the mass of the τ. The function $f(x)$ is a phase space suppression factor and has the values 1.000 and 0.9726 for the electron and muon respectively, using the world average values for the masses of the charged leptons [2].

2 Method

The selection of leptonic τ decays proceeded in two stages. Firstly, an initial sample of $\tau^+\tau^-$ events was selected. This selection was channel dependent, ensuring that the relevant detector elements used was correctly working during the identification procedure. Finally the decay mode identification was carried out.

The branching fraction for the decay of the τ to lepton l was measured using the expression

$$B(\tau \to l\nu\bar{\nu}) = \frac{N_l}{N_\tau} \cdot \frac{1 - b_l}{1 - b_\tau} \cdot \frac{\epsilon_\tau}{\epsilon_l}, \tag{2}$$

where N_l is the number of identified leptonic decays, ϵ_l is the total (4π) lepton identification efficiency , b_l is the background fraction in the lepton sample, N_τ is the number of τ decays in the final sample, b_τ is the background fraction in the τ decay sample, and ϵ_τ is the 4π efficiency for τ decays. The performance of the procedures used to select $\tau \to e\nu\bar{\nu}$ and $\tau \to \mu\nu\bar{\nu}$ decays was studied using simulated data and test samples identified in the data. The redundancy between different components of the detector allowed detailed studies of the detector response. The correlation between ϵ_τ and ϵ_l is exploited to help reduce the systematic uncertainties. The results were also verified by computing the branching ratio with respect to the number of tau pairs produced as calculated from the well known cross section and integrated luminosity.

3 Initial $\tau^+\tau^-$ selection

The decay $Z^0 \to \tau^+\tau^-$ at LEP energies is characterised by two low multiplicity, highly collimated, back-to-back jets of particles, with significant missing energy due to the undetected neutrinos from the τ decays. The $\tau^+\tau^-$ event selection described here was common to both leptonic decay channels and very similar to previous studies (details can be found in [3]).

Each event was divided into hemispheres by a plane perpendicular to the thrust axis, which was calculated using the charged particles. Both hemispheres had to contain at least one charged particle. The highest momentum charged particle in each hemisphere was defined as the leading particle for that hemisphere. At least one of the two leading particles per event was required to have a polar angle between 43 and 137 degrees.

The points of closest approach of both leading particles from the centre of the interaction region had to be less than 4.5 cm in z and at least one of them had to be within 0.3 cm in the $R\phi$ plane. These cuts removed most of the background from cosmic rays.

The background from hadronic decays of the Z^0 was reduced by asking for a maximum of six charged particles originating from the interaction region.

Events with four fermions in the final state ($\mathrm{e}^+\mathrm{e}^-\mathrm{e}^+\mathrm{e}^-, \mathrm{e}^+\mathrm{e}^-\mu^+\mu^-, \mathrm{e}^+\mathrm{e}^-\tau^+\tau^-$ and $\mathrm{e}^+\mathrm{e}^-\mathrm{q}\bar{\mathrm{q}}$) were rejected by requiring that the isolation angle, defined as the minimum angle between any two charged particles in different hemispheres, had to be greater than 160°. Furthermore, the total energy in the event, E_{vis}, defined as the sum of the neutral electromagnetic energy and the energy of the charged particles, had to be greater than $0.0875\times$ the centre of mass energy. For events with just two charged tracks reconstructed, these had to have a total transverse momentum with respect to the beam axis greater than 0.4 GeV/c.

Most of the Bhabhas and the decays $\mathrm{Z}^0 \to \mu^+\mu^-$ were excluded by requiring that $p_{rad} = \sqrt{p_1^2 + p_2^2}$ be less than the beam momentum p_{beam}, and $E_{rad} = \sqrt{E_1^2 + E_2^2}$ be less than the beam energy E_{beam}. The variables p_1, p_2 are the momenta of the leading particles, and E_1, E_2 are the electromagnetic energies deposited in a cone of half-angle 30° around these particles. Furthermore, the acollinearity between the two charged particles was required to be greater than 0.5° in two-prong events. This also reduced the cosmic background further. The level of these backgrounds was measured by fitting the Bhabha and $\mathrm{Z}^0 \to \mu^+\mu^-$ contributions to the E_{rad} and p_{rad} distributions respectively, when all other cuts in the selection were applied. Table 1 summarises the results of the $\tau^+\tau^-$ selection. From 1993,1994 and 1995 data, 70270 $\mathrm{Z}^0 \to \tau^+\tau^-$ candidates were selected for extraction of the $\tau \to \mu\nu\bar{\nu}$ branching ratio.

Number of τ pairs	70270
Efficiency	53.46 ± 0.04
Total background	3.81 ± 0.09
$\mu^+\mu^-$	0.36 ± 0.01
$\mathrm{e}^+\mathrm{e}^-$	1.47 ± 0.06
$\mathrm{q}\bar{\mathrm{q}}$	0.71 ± 0.02
$\mathrm{e}^+\mathrm{e}^-\mu^+\mu^-$	0.24 ± 0.01
$\mathrm{e}^+\mathrm{e}^-\mathrm{e}^+\mathrm{e}^-$	0.62 ± 0.06
$\mathrm{e}^+\mathrm{e}^-\tau^+\tau^-$	0.36 ± 0.01
cosmics	0.048 ± 0.002

Table 1: Summary of $\tau^+\tau^-$ selection statistics for extraction of the muonic branching ratio. Efficiencies and background levels are in percent. The uncertainties stem from the measurements of the background levels and from simulation statistics.

4 Analysis of $\tau \to \mu\nu\bar{\nu}$ decays

A muon candidate was identified using the Hadron CALorimeter (the HCAL) and the muon chambers. Muons should penetrate the whole longitudinally segmented HCAL, and the response should be compatible with that of a minimum ionizing particle. A sample of high purity muons was selected with high efficiency by requiring that the muon candidate satisfied at least one of the following conditions: Either 1) no single HCAL layer should have more than 3 GeV of deposited energy while the outermost layer should have at least 0.2 GeV, or 2) at least two hits in the muon chambers should be associated to the track. Both these requirements reject hadrons with high power while maintaining a good efficiency to muons. Asking that at least one of the two requirements be satisfied results in a selection of muons with very high efficiency. Figure 1 shows the distributions of the relevant identification variables. The efficiency of the muon identification drops steeply for momenta below 2 GeV, and to obtain an even and high efficiency it was required that the track momentum should be larger than $0.05 \times$ the beam momentum. Within the momentum and angular acceptance, the identification efficiency was $(97.72 \pm 0.06)\%$. Losses are due to the finite efficiency of the two requirements, partly because of non-overlapping detector acceptances.

After these requirements, the remaining background consisted mainly of mu-pairs with an extra gamma, four fermion final states with muons, or backgrounds due to other τ decays, very often with one or more π^0s present. To eliminate these, it was required that the muon candidate was the only charged track in the hemisphere; that the average energy deposit per HCAL layer be less than 2 GeV and that the neutral energy in an 18 degree cone around the track should be less than 2 GeV. These requirements suppressed a large fraction of remaining internal and external backgrounds. To suppress muon pairs even further, if a muon was identified in each hemisphere it was required that the total visible energy in the event should be less that $0.7 \times$ the centre of mass energy and the total energy seen in the hemisphere opposite to the $\tau \to \mu\nu\bar{\nu}$ candidate should be less than 0.7 $\times$ the beam energy. The final (4π) $\tau \to \mu\nu\bar{\nu}$ selection efficiency, ϵ_μ, was $(46.06 \pm 0.12)\%$.

There were 21013 identified $\tau \to \mu\nu\bar{\nu}$ decays candidates. The background from taus decaying to hadrons was measured by selecting taus decaying to a charged and a neutral pion by requiring a large electromagnetic energy deposition close to the single tracks. These events were then subjected to the identification procedure. Backgrounds from four fermion final states were determined from simulation, and the level was verified by studying the momentum distribution when the four fermion rejection cuts were not applied. The $\mu^+\mu^-$ background level was measured by studying the momentum distribution of selected muon candidates when the P_{rad} cut was not imposed. The results of the identification are shown in table 2.

Systematic uncertainties come from the finite statistics of test samples and simulation data when measuring efficiencies and backgrounds; and from the uncertainties in the branching ratios of the tau decays. The correlation between the average tau-pair preselection efficiency and the preselection efficiency for taus decaying to muons is also accounted for in the numbers. The result was also checked by evaluating the branching ratio by varying one cut at a time around the chosen value. The spread of the branching ratio values obtained in this way was consistent with the estimated systematic uncertainties listed in table 3.

Number of $\tau \to \mu\nu\bar{\nu}$ candidates	21013
Efficiency	46.06 ± 0.12
Total background	3.99 ± 0.13
Taus not decaying to muons	1.80 ± 0.09
$\mu^+\mu^-$	0.43 ± 0.04
$e^+e^-\mu^+\mu^-$	1.19 ± 0.08
$e^+e^-\tau^+\tau^-$	0.40 ± 0.04
cosmics	0.17 ± 0.01

Table 2: Number of $\tau \to \mu\nu\bar{\nu}$ candidates, selection efficiency and background estimates (in percent).

source of uncertainty	$\tau \to \mu\nu\bar{\nu}$
data statistics	0.11
Preselection efficiency	0.035
Muon selection efficiency	0.047
Backgrounds in the preselection sample	0.016
Backgrounds in the muon sample	0.023
Uncertainties in the tau branching fractions	0.004
total systematics	0.065

Table 3: Summary of the absolute uncertainties $\times 100$ on the $\tau \to \mu\nu\bar{\nu}$ branching fraction analysis presented here.

5 The $\tau \to e\nu\bar{\nu}$ channel

An updated value for $B(\tau \to e\nu\bar{\nu})$ should be avalilable soon. The current DELPHI estimate [5] is $B(\tau \to e\nu\bar{\nu}) = (18.08 \pm 0.12_{stat} \pm 0.19_{sys})\%$

6 Results and Conclusions

Using data from 1993 to 1995 the following branching ratio was measured:

$$B(\tau \to \mu\nu\bar{\nu}) = (17.32 \pm 0.11_{stat} \pm 0.07_{sys})\%. \quad (3)$$

The result is in agreement with the current world average values [2], and with previously published DELPHI results [4] which used data from the years 1991 and 1992. Combining the results of this analysis with the published DELPHI result we obtain

$$B(\tau \to \mu\nu\bar{\nu}) = (17.28 \pm 0.10_{stat} \pm 0.08_{sys})\%. \quad (4)$$

Acknowledgements

We are greatly indebted to our technical collaborators and to the funding agencies for their support in building and operating the DELPHI detector, and to the members of the CERN-SL Division for the excellent performance of the LEP collider.

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DELPHI PRELIMINARY

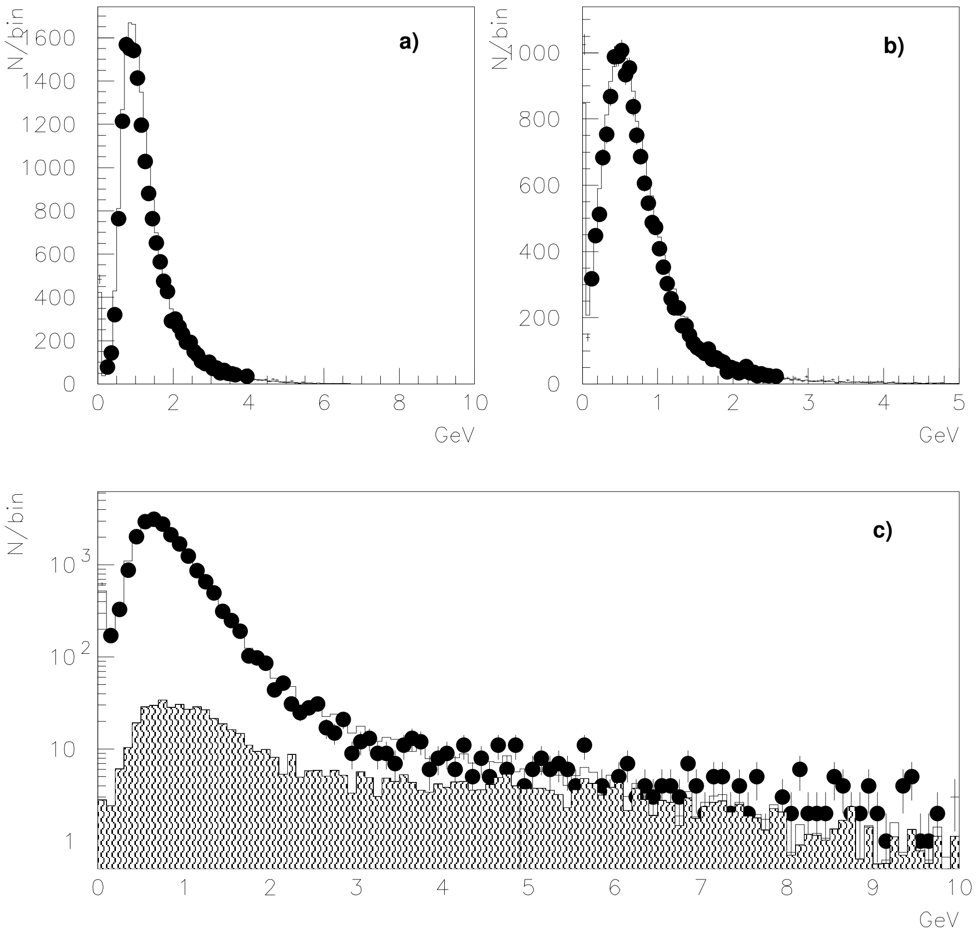

Figure 1: a) The energy deposition in the outermost HCAL layer. b) Largest energy deposition in a HCAL layer. a) and b) are for for tracks having at least two hits in the muon chambers. The redundancy between HCAL and muon chamber identification is used to study the effect of any discrepancies between data and simulation. c) Average energy deposition in a HCAL layer for events passing the muon identification requirements. Solid points are data, The line is from simulation. The shaded region shows the distribution of the non- muonic background.