τ BRANCHING FRACTIONS

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The B factories have led to a resurgence in experimental publications on the τ. Since the previous edition of this *Review*, there have been 19 published papers that have contributed measurements to the τ Listings, including 6 each from the BaBar and BELLE collaborations. Nine of these papers have provided new upper limits on the branching fractions for neutrinoless τ-decay modes. Of the 55 neutrionless τ- decay modes in the τ Listings, 4 are new and 26 have had improved limits set. The upper limits have been reduced by factors that range between 7 and 64, and the average reduction factor is 24.

The constrained fit to τ branching fractions: The Lepton Summary Table and the List of τ-Decay Modes contain branching fractions for 114 conventional τ-decay modes and upper limits on the branching fractions for 30 other conventional τ-decay modes. Of the 114 modes with branching fractions, 82 are derived from a constrained fit to τ branching fraction data. The goal of the constrained fit is to make optimal use of the experimental data to determine τ branching fractions. For example, the branching fractions for the decay modes $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ and $\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$ are determined mostly from experimental measurements of the branching fractions for $\tau^- \to h^-h^-h^+\nu_\tau$ and $\tau^- \to h^-h^-h^+\pi^0\nu_\tau$ and recent measurements of exclusive branching fractions for 3-prong modes containing charged kaons and 0 or 1 π^0's.

Branching fractions from the constrained fit are derived from a set of basis modes. The basis modes form an exclusive set whose branching fractions are constrained to sum exactly to one. The set of selected basis modes expands as branching fraction measurements for new τ-decay modes are published. The number of basis modes has expanded from 12 in the year 1994 fit to 31 in the 2002, 2004, and 2006 fits. The 31 basis modes selected for the 2006 fit are listed in Table 1. See the 1996 edition of this *Review* [1] for a complete description of our notation for naming τ-decay modes and the selection of the basis modes. For each edition since the 1996 edition, the changes in the selected basis modes from the previous edition are described in the τ Branching Fractions Review. Figure 1 illustrates the basis mode branching fractions from the 2006 fit.

Table 1: Basis modes for the 2006 fit to τ branching fraction data.

$e^- \overline{\nu}_e \nu_\tau$	$K^- K^0 \pi^0 \nu_\tau$
$\mu^- \overline{\nu}_\mu \nu_\tau$	$\pi^- \pi^+ \pi^- \nu_\tau$ (ex. K^0, ω)
$\pi^- \nu_\tau$	$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, ω)
$\pi^- \pi^0 \nu_\tau$	$K^- \pi^+ \pi^- \nu_\tau$ (ex. K^0)
$\pi^- 2\pi^0 \nu_\tau$ (ex. K^0)	$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, η)
$\pi^- 3\pi^0 \nu_\tau$ (ex. K^0)	$K^- K^+ \pi^- \nu_\tau$
$h^- 4\pi^0 \nu_\tau$ (ex. K^0, η)	$K^- K^+ \pi^- \pi^0 \nu_\tau$
$K^- \nu_\tau$	$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex. K^0, ω, η)
$K^- \pi^0 \nu_\tau$	$h^- h^- h^+ 3\pi^0 \nu_\tau$
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	$3h^- 2h^+ \nu_\tau$ (ex. K^0)
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	$3h^- 2h^+ \pi^0 \nu_\tau$ (ex. K^0)
$\pi^- \overline{K}^0 \nu_\tau$	$h^- \omega \nu_\tau$
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	$h^- \omega \pi^0 \nu_\tau$
$\pi^- K^0_S K^0_S \nu_\tau$	$\eta \pi^- \pi^0 \nu_\tau$
$\pi^- K^0_S K^0_L \nu_\tau$	$\eta K^- \nu_\tau$
$K^- K^0 \nu_\tau$	

In selecting the basis modes, assumptions and choices must be made. For example, we assume the decays $\tau^- \to \pi^- K^+ \pi^- \geq 0\pi^0 \nu_\tau$ and $\tau^- \to \pi^+ K^- K^- \geq 0\pi^0 \nu \tau$ have negligible branching fractions. This is consistent with standard model predictions for τ decay, although the experimental limits for these branching fractions are not very stringent. The 95% confidence level upper limits for these branching fractions in the current Listings are $\mathrm{B}(\tau^- \to \pi^- K^+ \pi^- \geq 0\pi^0 \nu_\tau) < 0.25\%$ and $\mathrm{B}(\tau^- \to \pi^+ K^- K^- \geq 0\pi^0 \nu_\tau) < 0.09\%$, values not so different from measured branching fractions for allowed 3-prong modes containing charged kaons. Although our usual goal is to impose as few theoretical constraints as possible so that the world averages and fit results can be used to test the theoretical constraints (*i.e.*, we do not make use of the theoretical constraint

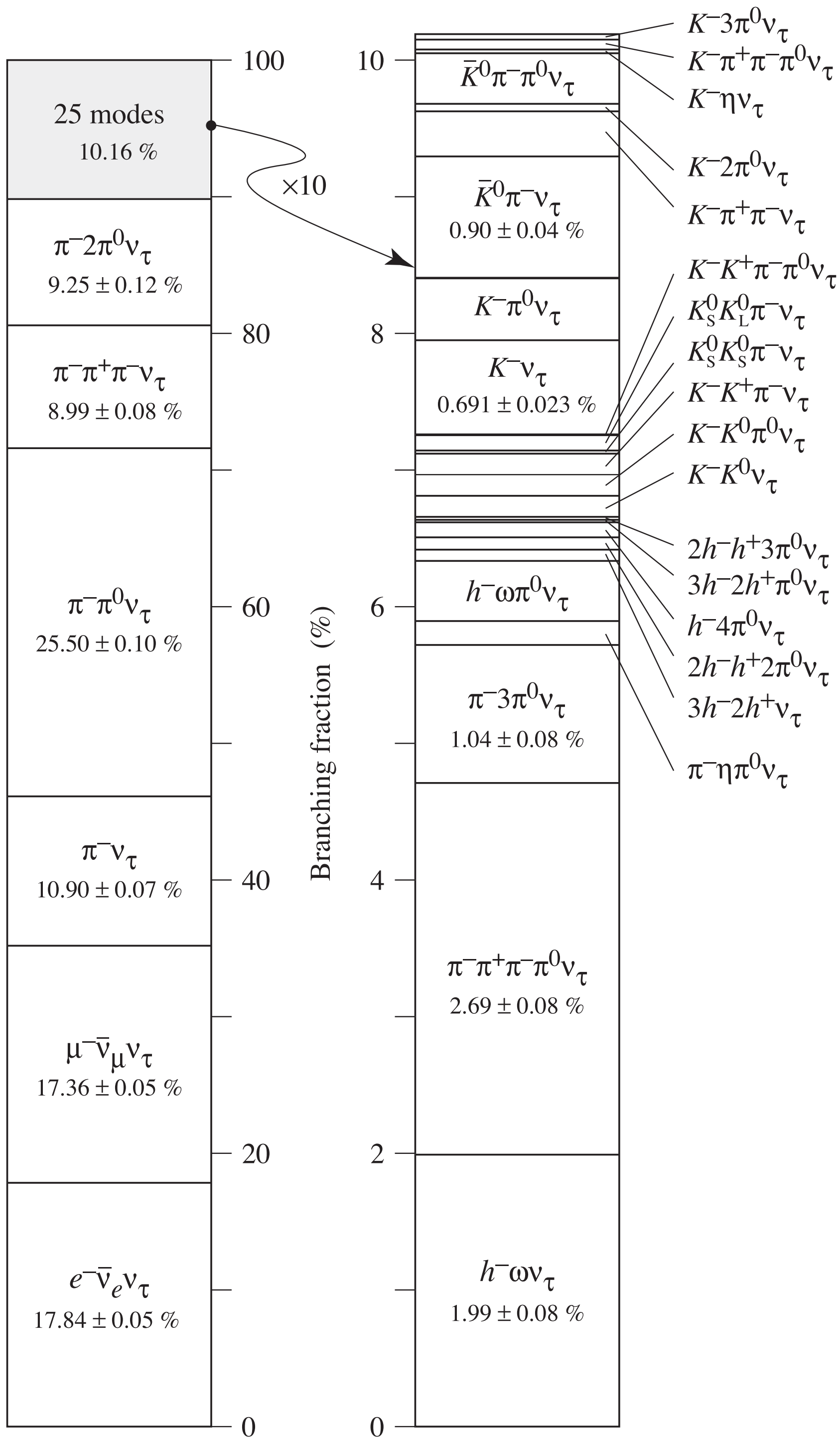

Figure 1: Basis mode branching fractions of the τ. Six modes account for 90% of the decays, 25 modes account for the last 10%. The list of excluded intermediate states for each basis mode has been suppressed.

from lepton universality on the ratio of the τ-leptonic branching fractions $B(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)/\ B(\tau^- \to e^- \overline{\nu}_e \nu_\tau) = 0.9726$), the experimental challenge to identify charged prongs in 3-prong τ decays is sufficiently difficult that experimenters have been forced to make these assumptions when measuring the branching fractions of the allowed decays. We are constrained by the assumptions made by the experimenters.

There are several recently measured modes with small but well-measured (> 2.5 sigma from zero) branching fractions [2] which cannot be expressed in terms of the selected basis modes and are therefore left out of the fit:

$$\begin{aligned}
B(\tau^- \to \pi^- K^0_S K^0_L \pi^0 \nu_\tau) &= (3.1 \pm 1.2) \times 10^{-4} \\
B(\tau^- \to h^- \omega \pi^0 \pi^0 \nu_\tau) &= (1.4 \pm 0.5) \times 10^{-4} \\
B(\tau^- \to 2h^- h^+ \omega \nu_\tau) &= (1.20 \pm 0.22) \times 10^{-4}
\end{aligned}$$

plus the $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\gamma$ components of the branching fractions

$$\begin{aligned}
B(\tau^- \to \eta \pi^- \pi^+ \pi^- \nu_\tau) &= (2.3 \pm 0.5) \times 10^{-4}\ , \\
B(\tau^- \to \eta \pi^- \pi^0 \pi^0 \nu_\tau) &= (1.5 \pm 0.5) \times 10^{-4}\ , \\
B(\tau^- \to \eta \overline{K}^0 \pi^- \nu_\tau) &= (2.2 \pm 0.7) \times 10^{-4}\ .
\end{aligned}$$

The sum of these excluded branching fractions is $(0.08 \pm 0.01)\%$. This is near our goal of 0.1% for the internal consistency of the τ Listings for this edition, and thus for simplicity we do not include these small branching fraction decay modes in the basis set.

Beginning with the 2002 edition, the fit algorithm has been improved to allow for correlations between branching fraction measurements used in the fit. If only a few measurements are correlated, the correlation coefficients are listed in the footnote for each measurement. If a large number of measurements are correlated, then the full correlation matrix is listed in the footnote to the measurement that first appears in the τ Listings. Footnotes to the other measurements refer to the first measurement. For example, the large correlation matrices for the branching fraction measurements contained in Refs. [3,4] are listed in Footnotes 48 and 66 respectively. Sometimes experimental papers contain correlation coefficients between measurements using only statistical errors without including systematic errors. We usually cannot make use of these correlation coefficients.

The constrained fit has a χ^2 of 77.5 for 95 degrees of freedom. Two new branching fraction measurements caused significant changes in two of the 2006 basis mode branching fractions from their 2004 values.

i) B($\tau^- \rightarrow K^- K^+ \pi^- \pi^0 \nu_\tau$ changed from $(4.2 \pm 1.6) \times 10^{-4}$ to $(0.61 \pm 0.20) \times 10^{-4}$ due to a precise new measurement by the CLEO Collaboration [5], which has 99% of the weight in the world average, and is significantly lower than previous measurements.

ii) The ALEPH Collaboration has published [3] a complete set of branching fraction measurements which supersede the results contained in earlier publications [6–8]. Differences between these new and old measurements are primarily responsible for a significant change in the basis mode branching fraction B($\tau^- \rightarrow \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, ω)) from $(2.51 \pm 0.09)\%$ to $(2.69 \pm 0.08)\%$.

These changes in the basis mode values have caused other significant changes in some of the 51 branching fractions which are determined from combinations of the basis modes. For example, the four branching fractions B($\tau^- \rightarrow h^- h^- h^+ \nu_\tau$), B($\tau^- \rightarrow h^- h^- h^+ \nu_\tau$ (ex. K^0)), B($\tau^- \rightarrow \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$) and B($\tau^- \rightarrow \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0)) have all increased by between 2.2 and 2.4 σ from their 2004 values. Due to the constraint on the sum of basis mode branching fractions, an increase in one basis mode branching fraction requires other basis mode branching fractions to decrease. The most significant decrease is for the basis mode branching fraction B($\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_\tau$ (ex. K^0, ω)), which changed from $(9.12 \pm 0.10)\%$ to $(8.99 \pm 0.08)\%$. There are similar decreases in the fit values for other non-basis modes that are primarily determined by this mode.

Overconsistency of Leptonic Branching Fraction Measurements: To minimize the effects of older experiments which often have larger systematic errors and sometimes make assumptions that have later been shown to be invalid, we exclude old measurements in decay modes which contain at least several newer data of much higher precision. As a rule, we exclude those experiments with large errors which together would contribute no more than 5% of the weight in the average. This procedure leaves five measurements for $B_e \equiv B(\tau^- \to e^- \overline{\nu}_e \nu_\tau)$ and five measurements for $B_\mu \equiv B(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)$. For both B_e and B_μ, the selected measurements are considerably more consistent with each other than should be expected from the quoted errors on the individual measurements. The χ^2 from the calculation of the average of the selected measurements is 0.34 for B_e and 0.08 for B_μ. Assuming normal errors, the probability of a smaller χ^2 is 1.3% for B_e and 0.08% for B_μ.

References

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