τ BRANCHING FRACTIONS

Revised April 2004 by K.G. Hayes (Hillsdale College).

The constrained fit to τ branching fractions: The Lepton Summary Table and the List of τ-Decay Modes contain branching fractions for 109 conventional τ-decay modes and upper limits on the branching fractions for 27 other conventional τ-decay modes. Of the 109 modes with branching fractions, 79 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 $\tau^- \rightarrow \pi^-\pi^+\pi^-\nu_\tau$ and $\tau^- \rightarrow \pi^-\pi^+\pi^-\pi^0\nu_\tau$ are determined mostly from experimental measurements of the branching fractions for $\tau^- \rightarrow h^-h^-h^+\nu_\tau$ and $\tau^- \rightarrow h^-h^-h^+\pi^0\nu_\tau$ 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 and 2004 fits. The 31 basis modes selected for the 2004 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.

In selecting the basis modes, assumptions and choices must be made. For example, we assume the decays $\tau^- \rightarrow \pi^-K^+\pi^- \geq 0\pi^0\nu_\tau$ and $\tau^- \rightarrow \pi^+K^-K^- \geq 0\pi^0\nu\tau$ 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 $\mathrm{B}(\tau^- \rightarrow \pi^-K^+\pi^- \geq 0\pi^0\nu_\tau) < 0.25\%$ and

Table 1: Basis modes for the 2004 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)
$\pi^-\overline{K}^0\nu_\tau$	$h^-\omega\nu_\tau$
$\pi^-\overline{K}^0\pi^0\nu_\tau$	$h^-\omega\pi^0\nu_\tau$
$\pi^-K^0_SK^0_S\nu_\tau$	$\eta\pi^-\pi^0\nu_\tau$
$\pi^-K^0_SK^0_L\nu_\tau$	$\eta K^-\nu_\tau$
$K^-K^0\nu_\tau$	

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 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.

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.

Begininng with the 2002 edition, the fit algorithm has been improved to allow for correlations between branching fraction measurements used in the fit. In this edition, correlations between measurements contained in Refs. [3,4,5,6] have been included. In the τ Listings, the correlation coefficients are listed in the footnote for each measurement. 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 62.5 for 99 degrees of freedom. Only one of the year 2004 basis mode branching fractions shifted by more than 1 sigma from its 2002 value: $B(\tau^- \to K^-\pi^+\pi^-\nu_\tau(\text{ex. } K^0))$ changed from $(0.28 \pm 0.05)\%$ to $(0.33 \pm 0.04)\%$.

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 six 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 six 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 0.49 for B_e and 0.09 for B_μ.

References

1. R.M. Barnett *et al.* (Particle Data Group), *Review of Particle Physics*, Phys. Rev. **D54**, 1 (1996).
2. See the τ Listings for references.
3. P. Abreu *et al.* (**DELPHI** Collaboration), Eur. Phys. J. **C20**, 617 (2001).
4. P. Achard *et al.* (**L3** Collaboration), Phys. Lett. **B519**, 189 (2001).
5. A. Anastassov *et al.* (**CLEO** Collaboration), Phys. Rev. **D55**, 2559 (1997) and Phys. Rev. **D58**, 119903 (1998) (erratum).
6. M. Acciarri *et al.* (**L3** Collaboration), Phys. Lett. **B507**, 47 (2001).