τ BRANCHING FRACTIONS

Revised April 2002 by K.G. Hayes (Hillsdale College).

To accommodate the 9 new experimental papers listed in the τ References for this edition, only a few changes were made to the τ Listings.

There were new measurements of the τ charged-prong topological branching fractions by the DELPHI [1] and L3 [2] collaborations. Early measurements of these branching fractions tended to define charged tracks from $K^0_S \to \pi^-\pi^+$ decays as charged prongs, while later measurements usually considered them to be secondary particles. To accommodate both choices, we have defined decay modes for each case. For example, the first two τ-decay modes are:

$\Gamma_1 \quad \tau^- \to \text{particle}^- \geq 0 \text{ neutrals} \geq 0K^0\nu_\tau$ ("1-prong")

$\Gamma_2 \quad \tau^- \to \text{particle}^- \geq 0 \text{ neutrals} \geq 0K^0_L\nu_\tau$.

In previous editions, we have attached the label "1-prong" to Γ_2, but given that all recent measurements have called Γ_1 the 1-prong topological branching fraction, in this edition we have moved the label to Γ_1. Similarly, we have moved the label "3-prong" from Γ_{52} to Γ_{53}. However, we do not consider charged pions from $K^0_S \to \pi^-\pi^+$ decays to be secondary particles unless they are explicitly listed as being excluded in a decay mode definition. For example, they are included in the definition of $\Gamma_{81}(\tau^- \to K^-\pi^+\pi^-\nu_\tau)$, but are excluded in the definition of $\Gamma_{82}(\tau^- \to K^-\pi^+\pi^-\nu_\tau \text{ (ex. } K^0))$. See the 1996 edition of this *Review* [3] for a complete description of our notation for naming τ-decay modes.]

We have also made a few changes to the constrained fit to tau branching fractions. A description of the constrained fit is given below.

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 $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ 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 list of 31 basis modes selected for the 2002 fit are listed in Table 1. There are two changes from the 2000 basis set: 1) the mode $\tau^- \to \pi^-K^0\overline{K}^0\nu_\tau$ has been split into the two modes $\tau^- \to \pi^-K^0_SK^0_S\nu_\tau$ and $\tau^- \to \pi^-K^0_SK^0_L\nu_\tau$, with the assumption that $\mathrm{B}(\tau^- \to \pi^-K^0_SK^0_S\nu_\tau) = \mathrm{B}(\tau^- \to \pi^-K^0_LK^0_L\nu_\tau)$; and 2) the mode $\tau^- \to h^-h^-h^+ \geq 3\pi^0\nu_\tau$ has been replaced by $\tau^- \to h^-h^-h^+3\pi^0\nu_\tau$, with the assumption that $\mathrm{B}(\tau^- \to h^-h^-h^+ \geq 4\pi^0\nu_\tau)$ is negligible.

Table 1: Basis modes for the 2002 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)
$\pi^-\overline{K}^0\nu_\tau$	$h^-\omega\nu_\tau$
$\pi^-\overline{K}^0\pi^0\nu_\tau$	$h^-\omega\pi^0\nu_\tau$
$\pi^-K^0_SK^0_S\nu_\tau$	$\eta\pi^-\pi^0\nu_\tau$
$\pi^-K^0_SK^0_L\nu_\tau$	$\eta K^-\nu_\tau$
$K^-K^0\nu_\tau$	

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 from lepton universality on the ratio of the τ-leptonic branching fractions $\mathrm{B}(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)/\ \mathrm{B}(\tau^- \to e^- \overline{\nu}_e \nu_\tau) = 0.9726$), 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 newly measured modes with small but well-measured (> 2.5 sigma from zero) branching fractions [4] which cannot be expressed in terms of the selected basis modes and are therefore left out of the fit:

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

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

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

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.

Another change in the fit for this edition is that 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. [1,2,5,6] 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 59.1 for 97 degrees of freedom. Only one of the year 2000 basis mode branching fractions shifted by more than 1 sigma from its 2000 value: $B(\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau)$ changed from $(0.119 \pm 0.020)\%$ to $(0.159 \pm 0.029)\%$. As mentioned above, this decay mode is no longer a basis mode. In previous editions, the two neutral kaons were assumed to decay independently, yielding the following relations between branching fractions:

$$\begin{aligned} B(\tau^- \to \pi^- K^0_S K^0_S \nu_\tau) &= B(\tau^- \to \pi^- K^0_L K^0_L \nu_\tau) \\ &= \tfrac{1}{4}\, B(\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau)\ . \\ B(\tau^- \to \pi^- K^0_S K^0_L \nu_\tau) &= \tfrac{1}{2} B(\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau)\ . \end{aligned}$$

Bose-Einstein correlations between the two neutral kaons can in principle alter these relationships. With the assumption that $B(\tau^- \to \pi^- K^0_S K^0_S \nu_\tau) = B(\tau^- \to \pi^- K^0_L K^0_L \nu_\tau)$, the branching fraction $B(\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau)$ is calculated from the branching fraction from the two new basis modes using

$$\begin{aligned} &B(\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau) = \\ &2B(\tau^- \to \pi^- K^0_S K^0_S \nu_\tau) + B(\tau^- \to \pi^- K^0_S K^0_L \nu_\tau)\ . \end{aligned}$$

In the 2000 fit, the basis mode $\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau$ was a component of 14 fit branching fractions containing a total of 25 fit measurements, although its branching fraction was primarily determined by the measurements of $B(\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau)$ and $B(\tau^- \to \pi^- K^0_S K^0_S \nu_\tau)$. In the current fit, the basis modes $\tau^- \to \pi^- K^0_S K^0_S \nu_\tau$ and $\tau^- \to \pi^- K^0_S K^0_L \nu_\tau$ are also components of many fit branching fractions, but their branching fractions are primarily determined by the measurements of $B(\tau^- \to \pi^- K^0_S K^0_S \nu_\tau)$ and $B(\tau^- \to \pi^- K^0_S K^0_L \nu_\tau)$, as evidenced by the similarity of the fit and average values for these two branching fractions.

A measure of the overall consistency of the τ branching fraction data with the fit constraint is a comparison of the fit and average values for the leptonic branching fractions. Table 2 compares the current fit and average values for $\mathrm{B}_e \equiv \mathrm{B}(\tau^- \to e^-\overline{\nu}_e\nu_\tau)$ and $\mathrm{B}_\mu \equiv \mathrm{B}(\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau)$ with the values from the 2000 edition [7].

Table 2: Fit and average values for $\tau^- \to e^-\overline{\nu}_e\nu_\tau$ and $\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau$.

Branching fraction		2000 Fit	2002 Fit
B_e	Fit:	17.83 ± 0.06	17.84 ± 0.06
B_e	Ave:	17.81 ± 0.07	17.81 ± 0.06
B_μ	Fit:	17.37 ± 0.07	17.37 ± 0.06
B_μ	Ave:	17.33 ± 0.07	17.33 ± 0.06

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 each of the leptonic decay modes. 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 six measurements is 0.49 for B_e and 0.09 for B_μ.

References

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4. See the τ Listings for references.
5. A. Anastassov *et al.* (**CLEO** Collaboration), Phys. Rev. **D55**, 2559 (1997) and Phys. Rev. **D58**, 119903 (1998) (erratum).
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