τ BRANCHING FRACTIONS

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To accommodate the 19 new experimental papers listed in the τ References for this edition, 20 new decay modes were added to the τ Listings. However, the experimental measurements of the branching fractions for many of these decay modes are either upper limits or are very small. Thus, only minor changes to the constrained fit to tau branching fractions were made. 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 112 conventional τ-decay modes and upper limits on the branching fractions for 28 other conventional τ-decay modes. Of the 112 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 list of 30 basis modes selected for the 2000 fit are listed in Table 1. The only change from the 1998 basis set is that the mode $\tau^- \to \eta K^-\nu_\tau$ has been added to the set, and the two modes which had contributions from $\tau^- \to \eta K^-\nu_\tau$ decays have been replaced by modes which have those contributions excluded: $\tau^- \to K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex. K^0, η) and $\tau^- \to K^-3\pi^0\nu_\tau$ (ex. K^0, η).

In selecting the basis modes, assumptions and choices must be made. Factors pertaining to the selection of the 1998 basis modes are described in the 1996 and 1998 editions. For example, we assume the decays $\tau^- \to \pi^-K^+\pi^- \geq 0\pi^0\nu_\tau$

Table 1: Basis modes for the 2000 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)
$K^-\pi^0\nu_\tau$	$h^-h^-h^+\geq 3\pi^0\nu_\tau$
$K^-2\pi^0\nu_\tau$ (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)
$\pi^-\overline{K}^0\nu_\tau$	$h^-\omega\nu_\tau$
$\pi^-\overline{K}^0\pi^0\nu_\tau$	$h^-\omega\pi^0\nu_\tau$
$\pi^-K^0\overline{K}^0\nu_\tau$	$\eta\pi^-\pi^0\nu_\tau$
$K^-K^0\nu_\tau$	$\eta K^-\nu_\tau$

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 B($\tau^-\to\pi^-K^+\pi^-\geq 0\pi^0\nu_\tau$) $<0.25\%$ and 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($\tau^-\to e^-\overline{\nu}_e\nu_\tau$) $=0.9728$), 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.

Recent measurements of several new decay modes having very small branching fractions have raised two other issues regarding the choice of basis modes. The ALEPH collaboration has recently measured new branching fractions for 1-prong τ decays containing two neutral kaons [1]. The basis set has just one τ-decay mode containing two neutral kaons: $\tau^- \to \pi^- K^0 \overline{K}^0 \nu_\tau$. In calculating the contribution of this decay to other measured τ-decay modes, we assume the two neutral kaons decay independently:

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

This assumption may be incorrect. For example, Bose-Einstein correlations between the two neutral kaons can in principle alter these branching fractions. The ratio of the ALEPH measurement of $\mathrm{B}(\tau^- \to \pi^- K_L^0 K_S^0 \nu_\tau = (0.101 \pm 0.023 \pm 0.013)$ % to the average of the CLEO [2] and ALEPH [1] measurements of $\mathrm{B}(\tau^- \to \pi^- K_S^0 K_S^0 \nu_\tau) = (0.024 \pm 0.005)\%$ is not inconsistent with our assumed value for this ratio of 2. For the sake of simplicity, we retain in this edition the assumption of independent K^0 decay.

There are several newly measured modes with small branching fractions [3] which cannot be expressed in terms of the selected basis modes and are therefore left out of the fit:

$$\begin{aligned}
\mathrm{B}(\tau^- \to K^0 h^+ h^- h^- \nu_\tau) &= (2.3 \pm 2.0) \times 10^{-4} \\
\mathrm{B}(\tau^- \to \pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau) &= (3.1 \pm 2.3) \times 10^{-4} \\
\mathrm{B}(\tau^- \to \pi^- K^0 \pi^0 \pi^0 \nu_\tau) &= (2.6 \pm 2.4) \times 10^{-4}
\end{aligned}$$

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

$$\begin{aligned}
\mathrm{B}(\tau^- \to \eta \pi^- \pi^+ \pi^- \nu_\tau) &= (3.4 \pm 0.8) \times 10^{-4}\ , \\
\mathrm{B}(\tau^- \to \eta \pi^- \pi^0 \pi^0 \nu_\tau) &= (1.4 \pm 0.7) \times 10^{-4}\ , \\
\mathrm{B}(\tau^- \to \eta K^- \pi^0 \nu_\tau) &= (1.8 \pm 0.9) \times 10^{-4}\ , \text{ and} \\
\mathrm{B}(\tau^- \to \eta \overline{K}^0 \pi^- \nu_\tau) &= (2.2 \pm 0.7) \times 10^{-4}\ .
\end{aligned}$$

The sum of these excluded branching fractions is $(0.12 \pm 0.04)\%$. 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.

The constrained fit has a χ^2 of 74.9 for 110 degrees of freedom. Two basis mode branching fractions shifted by more than 1 sigma from their 1998 values: $B(\tau^- \to K^-\pi^0\nu_\tau)$ changed from $(0.52 \pm 0.05)\%$ to $(0.454 \pm 0.033)\%$ due mainly to the new measurement of $(0.444 \pm 0.035)\%$ by the ALEPH collaboration [4], and $B(\tau^- \to K^-\pi^+\pi^-\nu_\tau$ (ex. K^0)) changed from $(0.18 \pm 0.05)\%$ to $(0.27 \pm 0.05)\%$, mainly due to new measurements by the CLEO [5] and OPAL [6] collaborations.

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 $B_e \equiv B(\tau^- \to e^-\overline{\nu}_e\nu_\tau)$ and $B_\mu \equiv B(\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau)$ with the values from the 1998 edition.

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		1998 Fit	2000 Fit
B_e	Fit:	17.81 ± 0.07	17.83 ± 0.06
B_e	Ave:	17.78 ± 0.08	17.81 ± 0.07
B_μ	Fit:	17.37 ± 0.09	17.37 ± 0.07
B_μ	Ave:	17.32 ± 0.09	17.33 ± 0.07

To minimize the effects of older experiments which often have larger systematic errors, 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 seven measurements for each of the leptonic decay modes. For both B_e and B_μ, the seven 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 seven measurements is 0.35 for B_e and 1.14 for B_μ.

References

1. **ALEPH** Collaboration, R. Barate *et al.*, Eur. Phys. J. **C4**, 29 (1998).
2. **CLEO** Collaboration, T.E. Coan *et al.*, Phys. Rev. **D53**, 6037 (1996).
3. See the τ Listings for references.
4. **ALEPH** Collaboration, R. Barate *et al.*, Eur. Phys. J. **C10**, 1 (1999).
5. **CLEO** Collaboration, S.J. Richichi *et al.*, Phys. Rev. **D60**, 112002 (1999).
6. **OPAL** Collaboration, G. Abbiendi *et al.*, Eur. Phys. J. (to be published), CERN-EP/99-095.