τ –THIS IS PART 2 OF 5

To reduce the size of this section's PostScript file, we have divided it into five PostScript files. We present the following index:

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PART 5

τ BRANCHING FRACTIONS

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Significant improvements in experimental measurements of τ branching fractions have been made since the 1994 edition of these Listings. Measurements of many new branching fractions of 1-prong τ decays containing charged and/or neutral kaons have been published [1–6]. Other new high-precision measurements of other τ branching fractions have also appeared, including many by the ALEPH collaboration [6] that are more precise than the 1994 world averages. Consequently, there are many new branching fractions in the Listings. The number of conventional τ-decay modes has increased from 59 in the 1994 edition to 98 in the current edition, and most τ branching fractions now have an absolute uncertainty in the range of 0.1 to 0.2%, with improvements over the 1994 edition typically being a factor of two or more.

Our goal for internal consistency of the τ Listings is now at the 0.1% level. To add correctly a new experimental measurement of a branching fraction to the Listings, we must understand and account for the experimenter's definition of both the signal and any background corrections to it at the 0.1% level or better. This requires that many details be considered. Some examples are: (a) is $K_S^0 \to \pi^+\pi^-$ considered to be 0-prong or 2-prong; (b) are K_L^0's included or excluded in a decay mode definition; (c) are $K_S^0 \to 2\pi^0$ decays background or signal; (d) how are photons from the decays of η and ω treated; (e) have particle ID requirements been applied to any charged prongs (either through direct detection or indirectly via cuts on invariant mass distributions); and (f) exactly what is meant by the word "neutral" in a decay mode definition?

The τ Listings have been updated in several ways to accommodate the new measurements and the need for higher precision. To help make explicit how the signal and background are defined, we have developed new notation for listing decay modes. First, invisible K_L^0's are never implicitly included in any decay mode (this is a change from previous editions). Second, for decay modes where contributions from an intermediate state are excluded, a list is appended to the decay mode which explicitly gives the excluded intermediate states. For this edition, the only intermediate states whose decays are excluded from some branching fractions are K^0, η, and ω. If there is no ambiguity as to which intermediate state decay modes are excluded, just the name of the intermediate state is given. Otherwise, the excluded intermediate state decay mode is explicitly listed. The list is appended to the decay mode using the notation "(ex. ⟨list of excluded intermediate states⟩)." For example, listed in Table 1 are a few decay modes from the current Listings and their fitted branching fractions:

Table 1: Examples of τ-decay modes and their fitted branching fractions.

particle$^-$ ≥ 0 neutrals ≥ 0 K_L^0 ν_τ	$(84.96 \pm 0.14)\%$
particle$^-$ ≥ 0 neutrals ≥ 0 K^0 ν_τ	$(85.53 \pm 0.14)\%$
$h^- h^- h^+ \geq 0$ neutrals ν_τ	$(14.91 \pm 0.14)\%$
$h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K_S^0 \to \pi^+\pi^-$)	$(14.36 \pm 0.14)\%$
$h^- h^- h^+ \pi^0 \nu_\tau$	$(4.44 \pm 0.09)\%$
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0)	$(4.25 \pm 0.09)\%$
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)	$(2.55 \pm 0.09)\%$

One inconsistency that has existed in the data for several decay modes was the different manner in which experimenters treated $K_S^0 \to \pi^+\pi^-$ decays. Some chose to treat the pions as charged prongs from the τ decay, while others rejected them as secondary tracks similar to electrons from photon conversion. To complicate the situation, some experimental papers make no mention as to how these decays were treated, even though different choices can affect some branching fractions by as much as 0.5%, as illustrated in the examples above.

In our definition of τ-decay modes, we treat pions from $K^0_S \to \pi^+\pi^-$ as charged prongs from the τ decay. To correct branching fraction measurements for different choices, good knowledge of τ branching fractions for decays containing K^0's is necessary, but until this edition experimental knowledge was meager. In the 1994 edition, the only branching fraction measurement of a τ decay mode containing a K^0 (apart from K^0's used to reconstruct the K*(892)) was the measurement, based on 44 detected decays, of B($\tau^- \to K^0 \; h^- \geq 0$ neutrals ν_τ) = $(1.3 \pm 0.3)\%$ by the HRS collaboration [7]. For this edition, there are 12 new measurements, based on more than 1800 detected decays, of τ-decay modes containing K^0's. Consequently, sufficient information now exists, and we have reduced the inconsistency in branching fraction data by moving data to newly defined decay modes consistent with the way $K^0_S \to \pi^+\pi^-$ decays were treated. Because of time limitations, we did this only for the most precise data.

To make best use of the new data, we have expanded the number of basis modes used in the constrained fit to branching fraction data from 12 in the 1994 edition to 25 in 1996. Consequently, the vast majority of branching fractions listed in the Summary Table are fit results (not averages) which is a significant change from previous editions. The only branching fractions which are not fit results are those which are either upper limits, 3-prong modes where one or more charged particles are identified, or modes containing resonances that are not included in the basis modes.

Selection of the basis modes was determined by several criteria. The basis modes must form an exclusive set whose branching fractions sum exactly to one. All measured branching fractions which contribute to the fit must be expressible in terms of a sum over basis mode branching fractions with accurately known coefficients, and all basis modes (except possibly one) must be constrained by one or more measured branching fractions. It is desirable to include a sufficient number of modes so that the largest number of branching fraction measurements can be included in the constrained fit. Finally, any modes necessary to satisfy the accuracy requirement must be included. The selected basis modes are listed in Table 2. The coefficients used to define a particular τ branching fraction in terms of the sum over basis mode branching fractions appear in the Listings immediately below each branching fraction header.

Table 2: Basis modes used in the 1994 and 1996 constrained fit to τ branching fraction data.

RPP94	RPP96
$e^- \overline{\nu}_e \nu_\tau$	$^*e^- \overline{\nu}_e \nu_\tau$
$\mu^- \overline{\nu}_\mu \nu_\tau$	$^*\mu^- \overline{\nu}_\mu \nu_\tau$
$\pi^- \nu_\tau$	$^*\pi^- \nu_\tau$
$\pi^- \pi^0 \nu_\tau$	$^*\pi^- \pi^0 \nu_\tau$
$h^- 2\pi^0 \nu_\tau$	$\pi^- 2\pi^0 \nu_\tau$(ex. K^0)
$h^- 3\pi^0 \nu_\tau$	$\pi^- 3\pi^0 \nu_\tau$(ex. K^0)
$h^- 4\pi^0 \nu_\tau$	$h^- 4\pi^0 \nu_\tau$(ex. K^0, η)
$K^- \nu_\tau$	$^*K^- \nu_\tau$
—	$K^- \pi^0 \nu_\tau$
—	$K^- 2\pi^0 \nu_\tau$(ex. K^0)
—	$K^- 3\pi^0 \nu_\tau$(ex. K^0)
—	$\pi^- \overline{K}^0 \nu_\tau$
—	$\pi^- \overline{K}^0 \pi^0 \nu_\tau$
—	$\pi^- K^0 \overline{K}^0 \nu_\tau$
—	$K^- K^0 \nu_\tau$
—	$K^- K^0 \pi^0 \nu_\tau$
$K^*(892)^- \nu_\tau$	—
$h^- h^- h^+ \nu_\tau$	$h^- h^- h^+ \nu_\tau$ (ex. K^0, ω)
$h^- h^- h^+ \geq 1$ neut. ν_τ	$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)
—	$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex. K^0, ω, η)
—	$h^- h^- h^+ \geq 3\pi^0 \nu_\tau$
$3h^- 2h^+ \geq 0$ neut. ν_τ	$3h^- 2h^+ \nu_\tau$ (ex. K^0)
—	$3h^- 2h^+ \pi^0 \nu_\tau$(ex. K^0)
—	$h^- \omega \nu_\tau$
—	$h^- \omega \pi^0 \nu_\tau$
—	$\pi^- \eta \pi^0 \nu_\tau$

* Unchanged from RPP94.

In selecting the basis modes, various choices and assumptions were made. For example, we have assumed that branching fractions for the following τ-decay modes are small relative to 0.1%: $\tau^- \to \pi^- \overline{K}^0 \geq 2\pi^0 \nu_\tau$, $\tau^- \to \pi^- K^0 \overline{K}^0 \geq 1\pi^0 \nu_\tau$, $\tau^- \to h^- h^- h^+ \geq 1\ K^0 \geq 0\pi^0 \nu_\tau$, and $\tau^- \to h^- \geq 5\pi^0 \nu_\tau$. Experimental upper limits on branching fractions exist for some of these modes, and comparison of measured inclusive and exclusive branching fractions allow limits to be determined for the others. The modes $\tau^- \to h^- \omega \nu_\tau$, $\tau^- \to h^- \omega \pi^0 \nu_\tau$, and $\tau^- \to \pi^- \eta \pi^0 \nu_\tau$ must be included in the basis set since their combined branching fraction to final states containing photons not from π^0's is about 0.3%. We have not included in the basis set the mode $\tau^- \to K^*(892)^- \nu_\tau$. The branching fraction for this mode is usually determined from the branching fraction for either $\tau^- \to \pi^- \overline{K}^0 \nu_\tau$ or $\tau^- \to K^- \pi^0 \nu_\tau$ assuming these decays all originate in $\tau^- \to K^*(892)^- \nu_\tau$, but these two methods give values for $\mathrm{B}(\tau^- \to K^*(892)^- \nu_\tau)$ that are inconsistent at the 2.5 σ level irrespective of whether the world average or fit values are used.

The constrained fit to branching fractions assumes all input data are uncorrelated, and data which are very highly correlated are not used in the fit. For the next edition, we plan to enhance the fitting procedure so that data correlations can be properly included. To minimize the effects of older experiments which often have larger systematic errors, we have excluded from the fit 27 older measurements in decay modes which contain at least several of the 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.

The precise new measurements have significantly reduced the uncertainties on most fitted branching fractions. Also, some problems in the data noted in the 1994 edition now have reduced significance. Table 3 lists several important hadronic branching fractions that had fit values in both the 1994 and 1996 editions. The reduction of the scale factors for most of these branching fractions illustrates the internal consistency of the new data. Note the significant change in $\mathrm{B}(h^- h^- h^+ \nu_\tau\ (\text{ex. } K^0))$.

Other evidence for the improved internal consistency is the decrease in the difference between the fitted and average values for the leptonic branching fractions. In previous editions, the data exhibited a "deficit" in 1-prong exclusive branching fractions for which the fit compensated by systematically increasing all 1-prong fit branching fractions above their average

Table 3: Fit branching ratios (%) and scale factors for a sample of τ hadronic decays.

Mode	1994 Fit	Scale	1996 Fit	Scale
$\pi^-\nu_\tau$	11.7 ± 0.4	1.3	11.31 ± 0.15	1.1
$K^-\nu_\tau$	0.67 ± 0.23	1.3	0.71 ± 0.05	1.0
$h^-\pi^0\nu_\tau$	25.7 ± 0.4	1.7	25.76 ± 0.15	1.1
$h^-2\pi^0\nu_\tau$	9.6 ± 0.4	1.5	9.50 ± 0.14	1.1
$h^-3\pi^0\nu_\tau$	1.28 ± 0.24	1.7	1.28 ± 0.10	1.0
$h^-h^-h^+\nu_\tau$ (ex. K^0)	8.42 ± 0.31	1.3	9.48 ± 0.10	1.1
$h^-h^-h^+ \geq 1$ neutrals ν_τ	5.63 ± 0.30	1.2	5.08 ± 0.11	1.2

values. Table 4 compares the average and fit values for $\mathrm{B}_e \equiv \mathrm{B}(\tau^- \to e^- \, \overline{\nu}_e\nu_\tau)$ and $\mathrm{B}_\mu \equiv \mathrm{B}(\tau^- \to \mu^- \, \overline{\nu}_\mu\nu_\tau)$ for the 1994 and 1996 editions.

Table 4: Fit and average branching fractions for $\tau^- \to e^- \, \overline{\nu}_e\nu_\tau$ and $\tau^- \to \mu^- \, \overline{\nu}_\mu\nu_\tau$.

Branching Fraction (%)		1994	1996
B_e	Fit	18.01 ± 0.18	17.83 ± 0.08
B_e	Average	17.90 ± 0.17	17.80 ± 0.08
B_μ	Fit	17.65 ± 0.24	17.35 ± 0.10
B_μ	Average	17.44 ± 0.23	17.30 ± 0.10

The charged-prong topological branching fractions changed significantly from their 1994 values. Although only two measurements of charged prong topological branching fractions have been published since the 1994 edition (both of $\mathrm{B}(h^-h^-h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^+\pi^-$))), some new measurements of other modes influenced the fitted value of the topological branching fractions. The improved consistency of our treatment of $K^0_S \to \pi^+\pi^-$ decays also influenced the results. Table 5 compares the average and fit values for $\mathrm{B}_1 \equiv \mathrm{B}(\text{particle}^- \geq 0$ neutrals ≥ 0 K^0_L $\nu_\tau)$ and $\mathrm{B}_3 \equiv \mathrm{B}(h^-h^-h^+ \geq 0$ neutrals $\nu_\tau)$ for the 1994 and 1996 editions. Although the fit and average values for B_1 and B_3 were very similar in 1994, the new fit values differ significantly from their averages. As the averages of these two modes are formed from older measurements (1992 or earlier), the precise new measurements lead to charged prong topological branching fractions which are significantly different from the older values.

Table 5: Fit and average branching fractions for B_1 and B_3.

Branching Fraction (%)		1994	1996
B_1	Fit	85.49 ± 0.24	84.96 ± 0.14
B_1	Average	85.46 ± 0.30	85.90 ± 0.30
B_3	Fit	14.38 ± 0.24	14.91 ± 0.14
B_3	Average	14.32 ± 0.27	14.01 ± 0.29

Conclusions: The precision of τ branching fraction measurements has increased significantly since the 1994 edition. Measurements of new 1-prong decay modes containing charged and/or neutral kaons have allowed a large expansion in the number of basis modes used in the constrained fit to τ branching fractions. Ambiguities and inconsistencies in the Listings caused by the lack of data on 1-prong modes containing neutral kaons have been significantly reduced. The new level of precision requires experimenters to be especially clear in describing their definition of signal and background in measurements of τ branching fractions. Future measurements of the charged and neutral kaon content in 3-prong τ decays will allow similar improvements in the understanding of those decay modes.

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