Hadronic Decay Modes of the Tau Lepton: A TAU94 Review *

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We review results from this Workshop on hadronic decays of the tau lepton. New and more precise branching fraction measurements dominate the discussion, particularly for modes involving strange particles.

1. Introduction

The tau lepton provides a window on the weak charged current unavailable in electron or muon decay because it is massive enough to decay semi-hadronically. The Standard Model (SM) relates many tau branching fractions to one another and to other measured quantities, offering a variety of opportunities to search for new physics via deviations from the predicted relationships. Tau decays can also provide a unique laboratory for production and decay of many hadronic systems.

Naively, hadronic tau decays can be envisioned as having simple two-body final states which consist of a tau neutrino and a single accompanying hadron, which may then itself decay. The hadron may be a pseudoscaler, vector, or axial-vector particle in either the Cabibbo-favored (π^-, ρ^-, a_1^-) or Cabibbo-suppressed (K^-, K^{*-}, K_1^-) mode. Observed final states that contain up to three pions or kaons seem to be accomodated in this resonant-production picture. Resonant parentage of higher-multiplicity modes has been obscured by the broadness of such heavier states, interference effects, and experimental limitations, but is nonetheless being pursued.

Though 19 years have passed since the discovery [1] of the tau lepton, only recently have experiments been able to tabulate with some precision and consistency the rates for its major decay modes. Due to the diversity of tau decays, this has meant pursuing branching fractions at the sub-1% level in order to account properly for most allowed modes. Even so, the level of detector technology has forced the definition of these modes to retain an undesired inclusive character. The most glaring such example is that observed charged particles have generally been classified as generic hadron "h" rather than identified as $\pi^\pm$ or $K^\pm$. Another significant inadequacy has been the potential presence of additional K_L's in any final state because they are frequently unobserved. Handling K_S decays into $\pi^+\pi^-$ and $\pi^0\pi^0$ has also been a source of some confusion. Inherent challenges in explicit π^0 reconstruction has resulted in some measurements being inclusive of additional neutrals, particularly for higher multiplicity states.

Even the most elementary of internal cross-checks, comparison of inclusive "topological" rates [2] (classified by charged particle multiplicity) and the sum of observed "exclusive" modes, has proved elusive. Often this test has resulted in "deficits" [3–5], implying either the presence of unexpected decays or, more likely, basic problems with individual or averaged branching fractions.

This Workshop has seen major assaults on most of the above-mentioned problems. Charged kaons are now identified by many experiments for modes with one or three charged particles. K^0 content has been measured via observation of both K_S and K_L mesons. Improved discrimination between photon showers in electromagnetic calorimeters and debris associated with hadronic interactions has, in combination with larger datasets, resulted in more reliable π^0 reconstruction. These advances have lead to much more precise branching fractions and substan-

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tially reduced their inclusive nature.

In order to make quantitative conclusions from the large number of new and old measurements, the common practice of forming weighted averages of all branching fractions is followed. For each mode, the "New World Average" (NWA) weights each of n measurements by its inverse-square total error, which is the quadrature sum of statistical and systematic contributions. The NWA error is computed as the inverse of the quadrature sum of the inverse total errors, scaled up by the Particle Data Group [5] scale factor $max(1, S)$, where $S = \sqrt{\chi^2/(n-1)}$. These NWA's only are only approximate for a number of reasons: many newer measurements are preliminary; some systematic errors may be correlated and therefore should not be combined in quadrature; biased weighting can occur for statistics-limited measurements. In addition, measurements of the same quantity sometimes make different assumptions for cross-feed branching ratios or resonant content, and hence should be converted to a common basis before being averaged. Finally, a set of measurements can be internally inconsistent (have a scale factor $S > 1.3$), in which case the NWA might not have a clear interpretation. The time dependence of such averages [6] frequently shows clear non-Gaussian behavior, recommending caution in taking the NWA central values and errors too seriously.

Some comments on the global branching fraction analysis from ALEPH [7] are in order, as the startlingly low errors weigh heavily in most NWA's. Modes are defined to include all expected tau decays, and the global analysis is normalized by the requirements that the branching fractions sum to unity. So, by definition the ALEPH rates can give no overall deficits. These assumptions are bolstered by separate ALEPH analyses which limit undetected decay modes below 0.16% and non-π^0 photonic channels below 1.0%, both at the 95% confidence level.

In many of the figures there are one or more entries beneath the NWA. These entries are predictions based upon theoretical expectations and/or other measurements. When possible, these predictions are based on the NWA for $\mathcal{B}(e^-\bar{\nu}_e\nu_\tau)$=(17.79±0.09)% [8], which is a theoretically convenient normalization as well as the experimentally best-known branching fraction. Entries marked with an asterisk(*) indicate that arithmetical manipulation of official branching fractions has occurred in order to fairly compare them with other results (*e.g.* using an updated normalizing branching fraction).

It would be impossible to review all the new hadronic tau decay results in sufficient detail in the space available. The reader is encouraged to consult the individual Workshop contributions.

2. Modes involving strange particles

The past year has seen an explosion in new results on strange particle content in tau decays. Charged kaons are indentified by their characteristic time-of-flight, ionization energy loss, or Čerenkov radiation. K_S decays to two charged pions are tagged by two-prong vertices separated from the interaction point, and K_L's are now identified in ALEPH's calorimeter. The small branching fracions (~1% or less) for such decays can now be probed because enough tau-pairs are in hand, and strange particle detection is understood by a number of experiments. There are significant signals for Cabibbo-suppressed as well as some Cabibbo-allowed modes, and predictions for many of these rates [9,10]. Further theoretical input was solicited for interpretation of many of the results.

2.1. $\tau \to K^-\nu_\tau$

The PDG94 [5] branching fraction for $\tau \to K^-\nu_\tau$ has a relative error of 34%, using results from 1982 and 1984. Fig. 1 also includes five new 1994 results, from TPC [11], DELPHI [12–14], CLEO [15], OPAL [16], and ALEPH [17,18], bringing the relative error to just 6%. The measurements are internally consistent. However, corrections for cross-feed from the K^0K^- mode have not been performed with complete consistency, because the branching fraction has only recently been measured (see section 2.4). The NWA agrees quite closely with the SM prediction [10,19,20] in Fig. 1, which has been normalized to the NWA for $\mathcal{B}(e^-\bar{\nu}_e\nu_\tau)$.

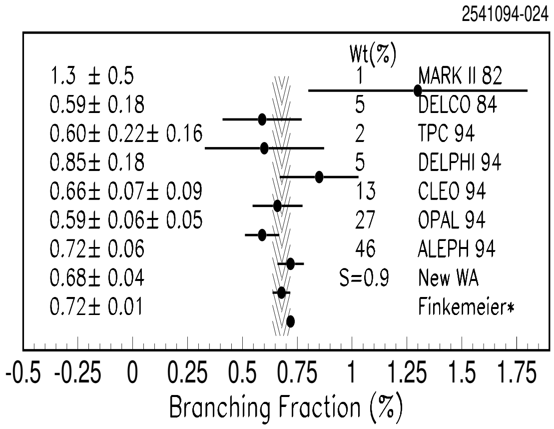

Figure 1. Branching fractions for $\tau^- \to K^- \nu_\tau$.

2.2. $\tau \to (K\pi)^- \nu_\tau$

Both $\bar{K^0}\pi^-$ and $K^-\pi^0$ modes are observed. Backgrounds from $\bar{K^0}K^-$, $K^0\bar{K^0}\pi^-$, and $K^0K^-\pi^0$ must be carefully subtracted (using the newly measured rates described in the section 2.4) or excluded (by fitting K^* mass peaks and/or vetoing additional detector activity from K_S's or K_L's). To a lesser extent, cross-feed from $(K\pi\pi)^-$ modes must be treated properly. No two experiments proceed in precisely the same way, which must remain as a caveat in interpreting the results below.

CLEO and ALEPH measure compatible rates when the charged hadron accompanying a neutral kaon is unidentified:

$\mathcal{B}(\bar{K^0}h^-\nu_\tau) =$

$(0.98 \pm 0.02 \pm 0.11)\%$ (CLEO) [22, 23]

$(1.12 \pm 0.09 \pm 0.09)\%$ (ALEPH) [17, 18].

The $\bar{K^0}K^-$ and $K^0\bar{K^0}\pi^-$ rates are suppressed and/or subtracted to obtain

$\mathcal{B}(\bar{K^0}\pi^-\nu_\tau) =$

$(1.88 \pm 0.56 \pm 0.57)\%$ (TPC) [11]

$(1.16 \pm 0.28)\%$ (DELPHI) [12, 14]

$(0.85 \pm 0.03 \pm 0.11)\%$ (CLEO) [22, 23]

$(0.85 \pm 0.09 \pm 0.09)\%$ (ALEPH) [17, 18].

For the other charged state where charged kaon identification is required,

$\mathcal{B}(K^-\pi^0\nu_\tau) =$

$(0.80 \pm 0.31 \pm 0.16)\%$ (TPC) [11]

$(0.57 \pm 0.23)\%$ (DELPHI) [12, 14]

$(0.51 \pm 0.10 \pm 0.07)\%$ (CLEO) [15]

$(0.52 \pm 0.04 \pm 0.05)\%$ (ALEPH) [17, 18].

Assuming K^{*-} parentage of $(K\pi)^-$ states and that decays observe isospin symmetry, Fig. 2 shows the current status of $\mathcal{B}(K^{*-}\nu_\tau)$. The five new 1994 results, from TPC [11], DELPHI [12,14], ARGUS [21], CLEO [15,22,23], and ALEPH [17,18], are the first in nearly six years and improve the relative precision of the NWA by a factor of two. DELPHI and CLEO do not directly quote $\mathcal{B}(K^{*-}\nu_\tau)$; their results for $\bar{K^0}\pi^-$ and $K^-\pi^0$ are combined for Fig. 2. While no experiment sees explicit evidence for non-resonant $(K\pi)^-$ production, quantitative limits have yet to be extracted.

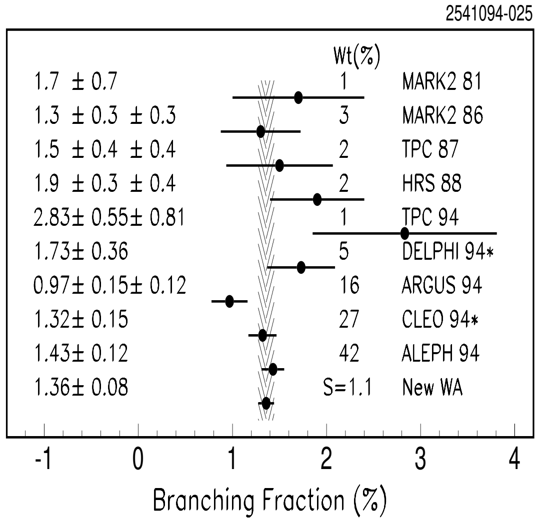

Figure 2. Branching fractions for $\tau^- \to K^{*-}\nu_\tau$.

2.3. $\tau \to (K\pi\pi)^- \nu_\tau$

In analogy with tau decays to non-strange $(\pi\pi\pi)^-$ states, the production of $(K\pi\pi)^-$ is expected to occur through the axial-vector mesons $K_1(1270)$ and $K_1(1400)$ [24–26]. However, immediate non-resonant fragmentation to $(K^*\pi)^-$ or $(K\rho)^-$ at the pointlike weak vertex, or production through the strange vector meson $K^*(1410)$, are also possible.

Let K_A and K_B denote the triplet $^3P_1$ and singlet $^1P_1$ spin eigenstates, respectively, of $(\bar{u}s)$, the strange analogs of the $\bar{u}d$ states, $a_1(1260)$ and $b_1(1235)$. Production amplitudes of b_1 and K_B in tau decay are suppressed in the SM as second-class currents by

$$\sim \frac{|m_u - m_{d,s}|}{m_u + m_{d,s}}.$$

This factor is quite small for m_d, accounting for the non-observation of b_1 in tau decays. In contrast, the large strange quark mass induces $SU(3)_f$ symmetry-breaking, allowing non-zero K_B production in tau decay.

The strange axial-vector mass eigenstates are $K_1(1270)$ and $K_1(1400)$. $K_1(1270)$ decays to $K\rho$, $K_0^*(1430)\pi$, $K^*\pi$, and $K\omega$; $K_1(1400)$ decays almost exclusively to $K^*\pi$. Since K_A and K_B are both predicted by $SU(3)$ to decay equally to $K^*\pi$ and $K\rho$, and since the K_1 states do not, the K_1 resonances must correspond to mixtures of K_A and K_B in comparable amounts with opposite-sign phases. One can parametrize this mixing in terms of an angle θ_K:

$$K_1(1400) = K_A \cos\theta_K - K_B \sin\theta_K$$

$$K_1(1270) = K_A \sin\theta_K + K_B \cos\theta_K$$

The previously measured properties of the K_1 mesons place some restrictions on the allowed values of θ_K [25]. If all $(K\pi\pi)^-$ production occurs via K_1^- only, the relative amounts of $K_1(1270)$ and $K_1(1400)$ observed in tau decay would further constrain θ_K and yield the size of $SU(3)_f$ symmetry-breaking. If, on the other hand, direct fragmentation dominates, there should be an observable indication in the relative amounts of $(K^*\pi)^-$ and $(K\rho)^-$ and in the angular distributions [26].

Until this year the available data on $\tau \to (K\pi\pi)^-\nu_\tau$ were limited to DELCO [5] and a preliminary TPC result [24], both for the all-charged mode only. This year has witnessed

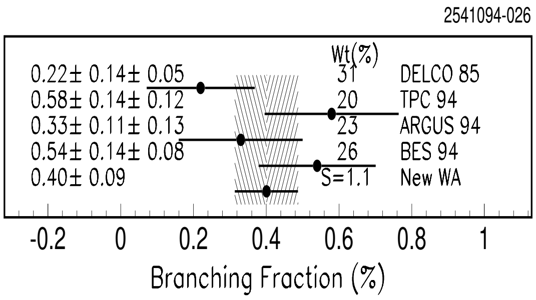

Figure 3. $\tau^- \to K^-\pi^+\pi^-\nu_\tau$ branching fractions.

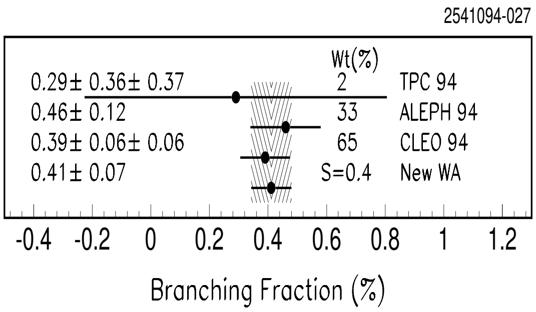

Figure 4. $\tau^- \to \bar{K}^0\pi^-\pi^0\nu_\tau$ branching fractions.

new results for branching fractions in all three charge combinations, as shown in Figs. 3, 4, and 5. In the all-charged mode, new entries appear from TPC [27], ARGUS [21], and BES [28]. In the $(\bar{K}^0\pi^-\pi^0)$ mode, TPC [11], ALEPH [17], and CLEO [22,23] presented results. Of particular note are the three measurements of $\mathcal{B}(K^-2\pi^0\nu_\tau)$, showing TPC [11], CLEO [15], and ALEPH [17,18] responding to the challenge of multi-π^0 reconstruction and charged-kaon identification in the same event. The measurements are internally consistent in each of the three modes.

Assuming all $(K\pi\pi)^-$ comes from K_1^-, one can then determine $\mathcal{B}(K_1^-\nu_\tau)$ from the measured tau and K_1 branching fractions into $K^-\pi^+\pi^-$, $\bar{K}^0\pi^-\pi^0$, and $K^-2\pi^0$. Under this assumption, approximately independent of the production ratio of the two K_1^- states in tau decay, the three NWA's are consistent with $\mathcal{B}(K_1^-\nu_\tau) \simeq 1\%$. The

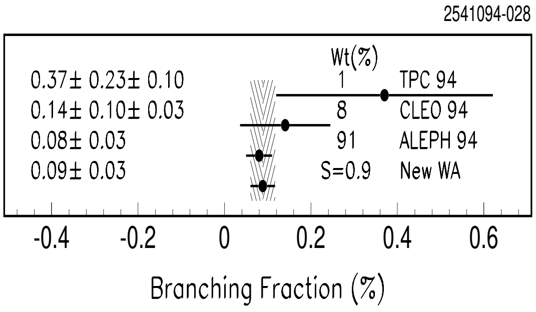

Figure 5. $\tau^- \to K^-\pi^0\pi^0\nu_\tau$ branching fractions.

possibilities of a vector component of $(K\pi\pi)^-$ decays (*i.e.* through $K^*(1410)$) or non-resonant production have not been addressed yet by the experiments, but would be useful in understanding these states.

The TPC [27] analysis of 23 $K^-\pi^+\pi^-$ events finds a slight preference for $K_1(1400)$ production based on two- and three-particle sub-masses. The first look by CLEO [22,23] at their 443 $\bar{K}^0h^-\pi^0$ events clearly shows both K_1's but a majority of $K_1(1270)$. However, within statistical errors, the TPC results are not inconsistent with a substantial, perhaps dominant, $K_1(1270)$ presence. In the very near future we should anticipate more complete analyses of these new event samples, particularly the larger datasets of CLEO and ALEPH. A complete analysis of these states in tau decay would provide valuable insight into the mechanism of symmetry-forbidden processes and the dynamics of hadronization.

2.4. $\tau \to (KK(\pi))^-\nu_\tau$ and $\tau \to (KKK)^-\nu_\tau$

The production of $(KK)^-$ or $(KK\pi)^-$ states in tau decay is suppressed by phase space, but could occur via direct fragmentation or through the high-mass tails of the ρ^-, a_1^-, or ρ'^-: $\rho^- \to (KK)^-$, $\rho'^- \to (K^*K)^-$, $a_1^- \to (\rho\pi)^- \to (KK\pi)^-$, or $a_1^- \to (K^*K)^-$. New results on $\tau \to K^-K^+\pi^-\nu_\tau$ from BES [28] and TPC [27] complement those from CLEO [22,29] and ALEPH [17,18] on $\tau \to \bar{K}^0K^-(\pi^0)$, as shown in Figs. 6, 7, and 8. There are no major inconsistencies in the measured branching fractions, which fall in the 0.1-0.3% range. The NWA $\mathcal{B}(K^0K^-\nu_\tau)$ agrees well with the CVC prediction [30] in Fig. 6.

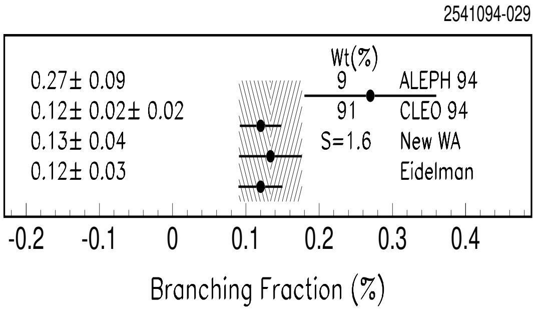

Figure 6. Branching fractions for $\tau^- \to K^0K^-\nu_\tau$.

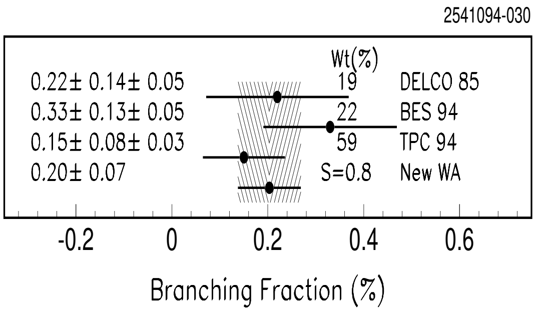

Figure 7. $\tau^- \to K^-K^+\pi^-\nu_\tau$ branching fractions.

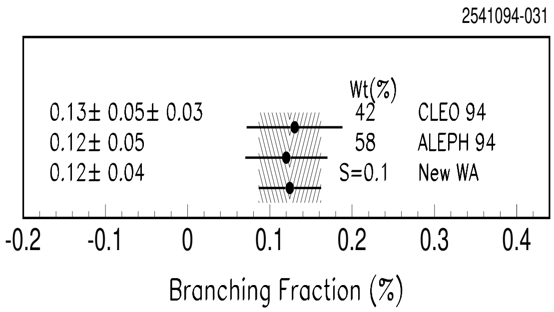

Figure 8. $\tau^- \to K^0K^-\pi^0\nu_\tau$ branching fractions.

While the statistics are not compelling, the CLEO [22,29] data on $\bar{K}^0K^-$ seem to need both a ρ^- and non-resonant contribution, and on $\bar{K}^0 K^- \pi^0$ indicate a preference for $(K^* K)^-$ over $(\rho\pi)^-$. The ARGUS [21] result $\mathcal{B}(K^- K^{*0} \nu_\tau) = (0.18 \pm 0.05 \pm 0.03)\%$ indicates a substantial $(K^* K)^-$ component, in agreement with CLEO. In addition, CLEO [22,31] has seen an intriguing signal for $\bar{K}^0 K^0 \pi^-$ production

$$\mathcal{B}(K_S K_S \pi^- \nu_\tau) = (0.021 \pm 0.004 \pm 0.004)\%.$$

This final state cannot originate as $\rho^0 \pi^-$ without C-parity violation, but may result from $\tau \to K^{*-} K^0 \nu_\tau$.

Upper limits for tau decay modes with three charged kaons have been set at the 0.21% and 0.4% levels by TPC [27] and BES [28], respectively.

2.5. Inclusive measurements

Inclusive measurements are often the most reliable inital measurements for a given mode because they avoid many complications of exclusive reconstruction and cross-feed. After exclusive modes are determined they also act as cross-checks and indicators of potentially unseen decays.

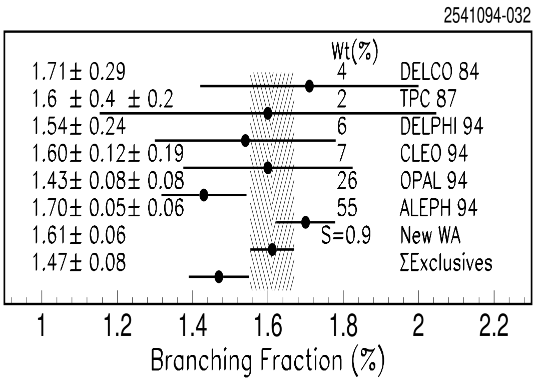

Figure 9. $\tau^- \to K^- \geq 0h^0 \nu_\tau$ branching fractions.

Measurements of the inclusive charged-kaon rate $\mathcal{B}(K^- \geq 0h^0 \nu_\tau)$ appear in Fig. 9, with new entries from DELPHI [12–14], CLEO [15], OPAL [16], and ALEPH [17,18]. Also appearing is the sum of the exclusive NWA's

$$\mathcal{B}(K^- \nu_\tau) + \mathcal{B}(K^- \pi^0 \nu_\tau) + \mathcal{B}(K^- 2\pi^0 \nu_\tau) + \mathcal{B}(K^- K^0 \nu_\tau) + \mathcal{B}(K^- K^0 \pi^0 \nu_\tau)$$

where $\mathcal{B}(K^- \pi^0 \nu_\tau) = \frac{1}{3}\mathcal{B}(K^{*-} \nu_\tau)$ is used. This sum saturates the inclusive rate within $(0.14 \pm 0.10)\%$, not allowing much room for additional exclusive modes. Furthermore, DELPHI and OPAL also quote the rate for a charged kaon and one or more neutrals, consistent with one another:

$$\mathcal{B}(K^- \geq 1\pi^0 \nu_\tau) = $$
$$(0.55 \pm 0.07 \pm 0.07)\% \text{ (OPAL) [16, 36]}$$
$$(0.69 \pm 0.25)\% \text{ (DELPHI) [12, 14].}$$

The inclusive charged-K^* rate has been measured by ARGUS and OPAL as

$$\mathcal{B}(K^{*-} \geq 0h^0 \nu_\tau) = $$
$$(1.19 \pm 0.15^{+0.12}_{-0.15})\% \text{ (ARGUS) [21]}$$
$$(1.94 \pm 0.27 \pm 0.15)\% \text{ (OPAL) [16, 36]}$$

which differ by 2σ. This rate should include K^{*-} and parts of $K^- 2\pi^0$, $\bar{K}^0 \pi^- \pi^0$, and $K^- K^0 \pi^0$. The ARGUS number should probably be interpreted relative to its exclusive $\mathcal{B}(K^{*-} \nu_\tau)$ (Fig. 2), which then at least leaves a positive remainder for the other modes.

Inclusive K_S production has been measured by OPAL, DELPHI, and ALEPH in different ways. If X^- is defined as a one- or three-prong state, they measure

$$\mathcal{B}(K_S X^- \geq 0h^0 \nu_\tau) = $$
$$(0.88 \pm 0.07 \pm 0.04)\% \text{ (OPAL) [16, 36]}$$
$$(1.17 \pm 0.09 \pm 0.08)\% \text{ (ALEPH) [17, 18]}$$

which differ by 2σ. For one-prongs only,

$$\mathcal{B}(K_S h^- \geq 0h^0 \nu_\tau) = $$
$$(0.92 \pm 0.07 \pm 0.04)\% \text{ (OPAL) [16, 36]}$$
$$(0.99 \pm 0.19)\% \text{ (DELPHI) [12, 13]}$$

which are consistent. OPAL further breaks down their one-prong rate as

$$\mathcal{B}(K_S \pi^- \geq 0h^0 \nu_\tau) = $$
$$(0.72 \pm 0.07 \pm 0.04)\% \text{ (OPAL) [16, 36]}$$

$\mathcal{B}(K_S K^- \geq 0h^0 \nu_\tau) =$

$$(0.20 \pm 0.04 \pm 0.03)\% \text{ (OPAL) } [16, 36]$$

both of which are consistent with exclusive measurements.

3. Five-Prong Modes

While it has been clear for some time that five-prong events constitute $\sim$0.1% of tau decays, the relative rate of five- and six-pion states has been poorly known. As shown in Figs. 10 and 11, new results from CLEO [37,38] and ALEPH [7] now augment the 1987-88 results [5] from HRS and ARGUS, providing an internally consistent picture of $\mathcal{B}(5h\nu_\tau)$ and $\mathcal{B}(5h\pi^0\nu_\tau)$. These two exclusive modes saturate the inclusive five-prong rate of (0.10$\pm$0.01)%; CLEO also sets the limit $\mathcal{B}(5h2\pi^0\nu_\tau) < 0.011\%$ at 90% confidence level. For the sum of all charge states for the axial current part of $\tau \to (5\pi)^-\nu_\tau$, the PCAC prediction [39] is $\sim$1%. This is somewhat larger than (0.64$\pm$0.09)%, the sum of the measured rates (Figs. 10, 14, and section 5), after subtracting the vector current contributions from $\tau \to \pi^-\eta\pi^0\nu_\tau$ [40] in both $3h2\pi^0$ and $h4\pi^0$. The prediction [30,41] appearing in Fig. 11 is a lower limit on $\mathcal{B}(5h\pi^0\nu_\tau)$ and is consistent with the NWA. It uses CVC, isospin considerations [3], and the measured $e^+e^- \to 6\pi$ cross sections from M3N and DM2.

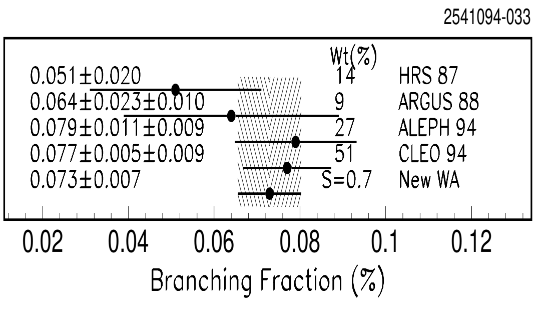

Figure 10. Branching fractions for $\tau^- \to 5h\nu_\tau$.

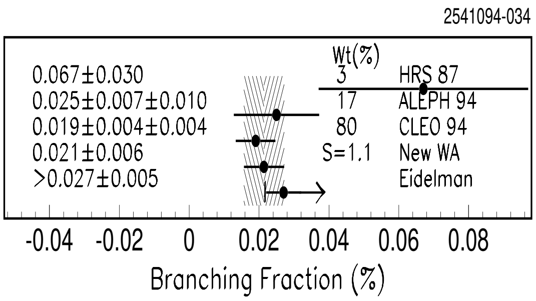

Figure 11. Branching fractions for $\tau^- \to 5h\pi^0\nu_\tau$. The CVC prediction is a lower limit.

4. Three-Prong Modes

4.1. $\tau \to 3h\nu_\tau$

In the past, there has been considerable controversy concerning exclusive three-prong branching fractions because of inconsistencies among experimental results. For the mode with no neutrals, $\mathcal{B}(3h\nu_\tau)$, even with six new or updated branching fraction entries since TAU92, internal disagreements persist, as shown in Fig. 12. Of the newer measurements, CLEO [42,38], OPAL [43], and ALEPH [7] together favor a value near $\sim$9.5%, whereas BES [28], ARGUS [44], and DELPHI [13] cluster around $\sim$8.0%. There must be large systematic problems in a few of the measurements, but which ones is not clear. Taking the errors at face value, ALEPH has the smallest total error, and therefore by far the largest weight, pulling the NWA well above 9%.

Some guidance on $\mathcal{B}(3h\nu_\tau)$ can be obtained from the $h^-2\pi^0$ mode (section 5). If all tau decays into 3 pions originate as a_1^-, isospin conservation decrees that, modulo phase-space considerations, the two modes have equal branching fractions. KORALB [45] yields

$$\begin{aligned}\mathcal{B}(\pi^-\pi^+\pi^-\nu_\tau) &= 0.98 \times \mathcal{B}(\pi^-2\pi^0\nu_\tau) \\ &= 0.98 \times \left[\mathcal{B}(h^-2\pi^0\nu_\tau) - \mathcal{B}(K^-2\pi^0\nu_\tau)\right] .\end{aligned}$$

This relation, along with the newly-measured rates of modes with charged kaons (section 2), allows determination of $\mathcal{B}(3h\nu_\tau)$ as

$$\begin{aligned}\mathcal{B}(3h\nu_\tau) = \mathcal{B}(\pi^-\pi^+\pi^-\nu_\tau) + \mathcal{B}(\pi^-\pi^+K^-\nu_\tau) + \\ \mathcal{B}(\pi^-K^+K^-\nu_\tau) + \mathcal{B}(K^-K^+K^-\nu_\tau),\end{aligned}$$

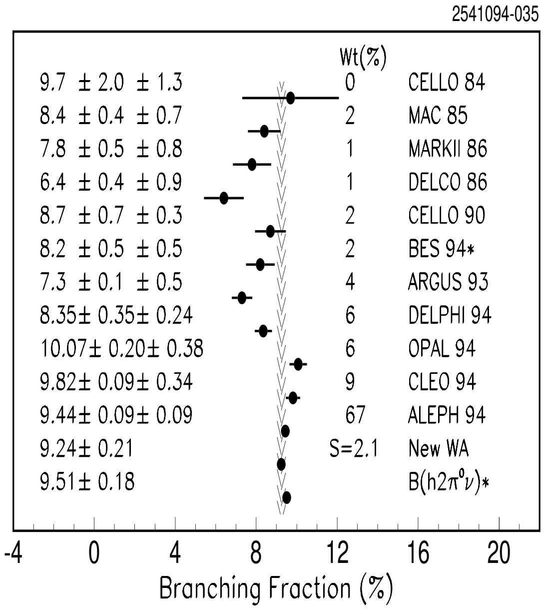

Figure 12. Branching fractions for $\tau^- \rightarrow 3h\nu_\tau$.

which, as shown in Fig. 12, clearly favors the larger, more precise measurements. Independent of a_1 parentage, isospin considerations [3] require $\mathcal{B}(\pi^-\pi^+\pi^-\nu_\tau) \geq \mathcal{B}(\pi^- 2\pi^0\nu_\tau)$, strengthening the case for $\mathcal{B}(3h\nu_\tau) > 9\%$.

From analysis of $\tau \rightarrow 3h\nu_\tau$ decays, new values for the mass and width of the a_1^- have been determined. DELPHI [13] and OPAL [43] have made measurements within the context of the IMR [46] and/or KS [49] models, and new predictions are available from lattice QCD computations [50]. The results appear in Table 1, and, within each model, present a consistent picture of the a_1 lineshape. The systematic difference in a_1 mass is attributed to the different strong form factors in the spectral density and allowance for backgrounds in the two models. OPAL finds the KS model better able to describe the invariant pair-mass distributions at large three-pion masses than IMR, but both models have difficulties describing the intermediate three-pion mass region of the Dalitz plot. An ARGUS approach [51] deals with a similar disagreement between both models and data by performing a complete partial-wave analysis of the 3π system.

Table 1
Mass m (GeV) and Width Γ (GeV) of the a_1

Group	Model	m	Γ
DELPHI	KS	1.270±0.015	0.604±0.050
OPAL	KS	1.305±0.057	0.708±0.254
OPAL	IMR	1.210±0.027	0.424±0.034
Lattice		1.21 ±0.07	–

The lattice QCD calculation also yields the decay constant

$$f_{a_1} = 0.281 \pm 0.037 \ \ \mathrm{GeV}^2 \quad \text{(Lattice QCD) [50]}$$

which agrees well with the IMR value [46] of 0.25±0.02 GeV^2, which was based on the 1989 value for $\mathcal{B}(3\pi\nu_\tau)$.

OPAL [43] presented the first experimental determination of the hadronic structure functions in $\tau \rightarrow \pi^-\pi^+\pi^-\nu_\tau$. The results follow the form of Kühn and Mirkes [47,48], and are model independent. The analysis employs the reasonable assumptions of G-parity conservation and absence of scalar currents in order to reduce the number of functions from 16 to 4. The IMR [46] and KS [49] models both fit the data quite well.

The datasets of ALEPH and CLEO could also be analyzed for a_1 parameters and hadronic structure functions. In particular, the $\pi^- 2\pi^0$ mode, less-troubled by background from kaon modes, offers an independent sample for systematic checks.

4.2. $\tau \rightarrow 3h\pi^0\nu_\tau$

Our understanding of the $3h\pi^0$ mode also improved considerably this year, with new measurements of the branching fraction by OPAL [43], CLEO [42,38], and ALEPH [7,52]. The new rate measurements appear in Fig. 13, which includes older values from PDG94 [5] listed under $3h \geq 1$ *neutrals*. The NWA is compatible with CVC predictions [30,41,53]. Including 1994 results only, the NWA would be (4.38±0.10)% with $S = 1.0$; the new measurements are consistent with each other but not with older ones. The older values raise the NWA slightly, perhaps unfairly, because $\mathcal{B}(3h \geq 2\pi^0\nu_\tau)$ was assumed to be negligible before the CLEO measurement [54,55].

ALEPH [52] has presented a preliminary analysis of substructure in $3h\pi^0$, quantifying the $\omega\pi^-$

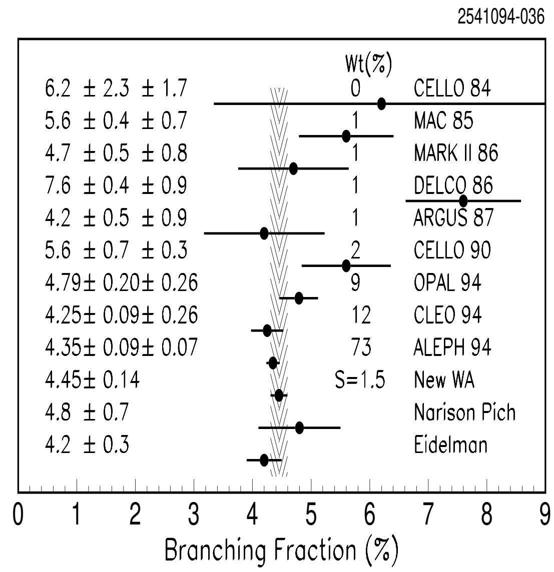

Figure 13. Branching fractions for $\tau^- \to 3h\pi^0\nu_\tau$.

and $(\rho\pi\pi)^-$ components. The result is shown in Table 2 alongside the published 1991 analysis of ARGUS [56]. Using CVC and low-energy e^+e^- data, the $\omega\pi^-$ fraction is predicted [30] to be (43±4)%, in reasonable agreement with both ARGUS and ALEPH results. If the non-ω component of this mode is dominated by $(a_1\pi)^-$, then isospin conservation requires that the rates for the different charge ρ states should be equal. The ALEPH results are compatible with $(a_1\pi)^-$ dominance. This is in contrast to the ARGUS rates, which show only a small signal for production of a ρ with charge opposite to the parent tau. Further study of the ALEPH data is warranted, as interference effects are not negligible [52] and have not yet been included in the quoted results. A substructure analysis from CLEO is in progress; a qualitative look [38] shows clear evidence for ω production and all three charge states of the ρ.

4.3. $\tau \to 3h \geq 2\pi^0\nu_\tau$

CLEO's signal for $\tau \to 3h2\pi^0\nu_\tau$, first described at TAU92 [54], has been published [55], with (80±8)% of the signal attributable to $\tau \to \pi^-\omega\pi^0\nu_\tau$. The global analysis of ALEPH [7] has confirmed this rate as shown in Fig. 14. ALEPH

Table 2
Resonant substructure in $\tau^- \to (3h)^-\pi^0$.

Mode	ALEPH 94(%)	ARGUS 91(%)
$\omega\pi^-$	38±3	33±5
$\rho^-\pi^+\pi^-$	21±3	26±5
$\rho^0\pi^-\pi^0$	16±3	30±4
$\rho^+\pi^-\pi^-$	27±3	10±3

has also claimed the first observation of $\tau \to 3h \geq 3\pi^0\nu_\tau$

$$\mathcal{B}(3h \geq 3\pi^0\nu_\tau) = (0.20 \pm 0.07)\% \quad \text{ALEPH [7]}.$$

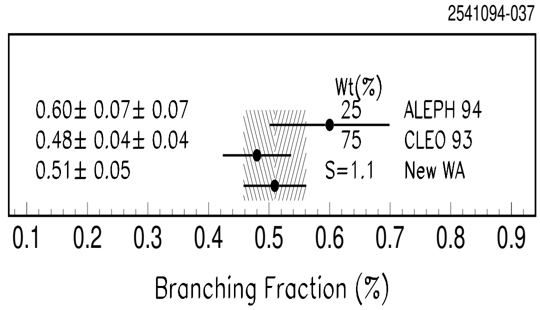

Figure 14. $\tau^- \to 3h2\pi^0\nu_\tau$ branching fractions.

5. One-Prong Modes

Some of the older and many of the recently reported rates for one-prong modes break the PDG94 convention that decays with additional K_L's are included in the branching fraction. The rates for such background modes have now been measured (section 2). We break the convention here as well, with the consequence that some of the old measurements in the figures are too large since they include such modes. However, as the combined weight of the old measurements in the NWA's is very small, this effect has been ignored.

The branching fractions for a single charged pion or kaon accompanied by zero, one, or two π^0's are displayed in Fig. 15, 16, and 17, respectively, where many new and vastly improved measurements appear. There is internal consistency among the rates for the modes with zero or

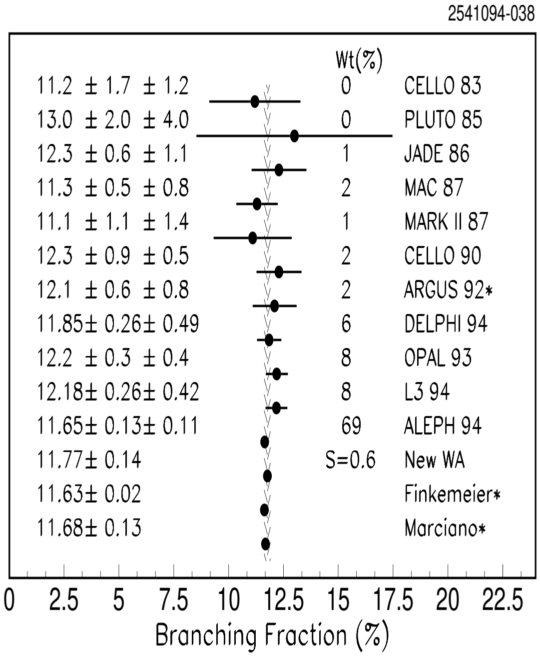

Figure 15. Branching fractions for $\tau^- \to h^-\nu_\tau$.

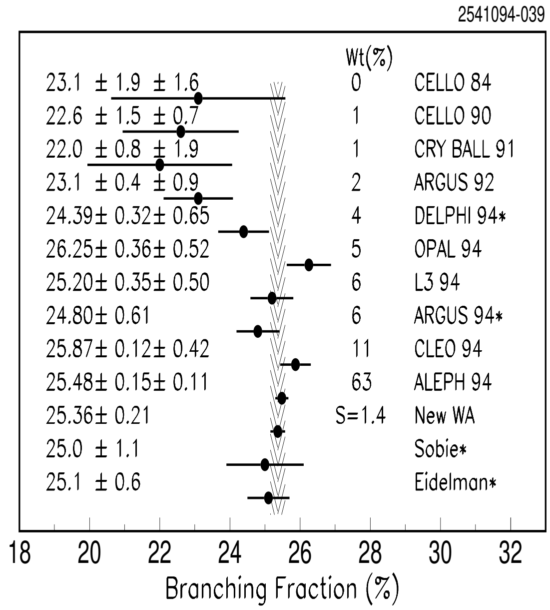

Figure 16. Branching fractions for $\tau^- \to h^-\pi^0\nu_\tau$.

two π^0's. Since TAU92, there are new or modified measurements for $\mathcal{B}(h\nu_\tau)$ from DELPHI [13], OPAL [32], L3 [58], and ALEPH [7]; and for $\mathcal{B}(h2\pi^0\nu_\tau)$ from L3 [58], ARGUS [33], CLEO [35], and ALEPH [7]. There is excellent agreement between $\mathcal{B}(h\nu_\tau)$ and the SM predictions [10,19,20] shown in Fig. 15, which include the latest technology in radiative corrections. The ARGUS92 [34] value in Fig. 15 is normalized to the NWA $\mathcal{B}(e^-\bar{\nu}_e\nu_\tau)$.

The recent measurements of $\mathcal{B}(h\pi^0\nu_\tau)$ by DELPHI [13], OPAL [57,43], L3 [58], ARGUS [33], CLEO [59,60], and ALEPH [7] show a consistently higher value than previously seen. In fact, if pre-94 measurements are excluded, the NWA is $(25.46{\pm}0.17)\%$ with $S = 1.1$. The CVC predictions appearing in Fig. 16 normalize the calculations [30,61,19,62] for $\pi\pi^0$ to the NWA $\mathcal{B}(e^-\bar{\nu}_e\nu_\tau)$ and add the measured $\mathcal{B}(K^{*-}\nu_\tau)$ (section 2.2). Due to uncertainties in the low-energy e^+e^- data, CVC does not give any guidance on whether the higher or lower measurements are correct. The precision of the newer measurements prevail in the NWA, bringing it above 25% for the first time. It has been rising steadily, from below 23% [6] just four years ago!

A preliminary analysis of resonant substructure in $h\pi^0$ final states was presented by CLEO [60]. While systematics of background subtractions and fitting are not yet under control, evidence for the ρ' resonance is seen at the six standard deviation level. Perhaps the best measurements ever of the ρ and ρ' masses and widths can be expected from this analysis when it matures.

In the multi-π^0 one-prong modes, the following new results were presented:

$$\mathcal{B}(h \geq 2\pi^0\nu_\tau) = (9.89 \pm 0.34 \pm 0.55)\% \quad \text{(OPAL) [57]}$$

$$\mathcal{B}(h3\pi^0\nu_\tau) = (1.70 \pm 0.24 \pm 0.40)\% \quad \text{(L3) [58]}$$

$$\mathcal{B}(h \geq 3\pi^0\nu_\tau) = (1.51 \pm 0.07 \pm 0.12)\% \quad \text{(ALEPH) [7]}$$
$$(1.81 \pm 0.34)\% \quad \text{(ARGUS) [33]}$$

which are consistent with results given above and

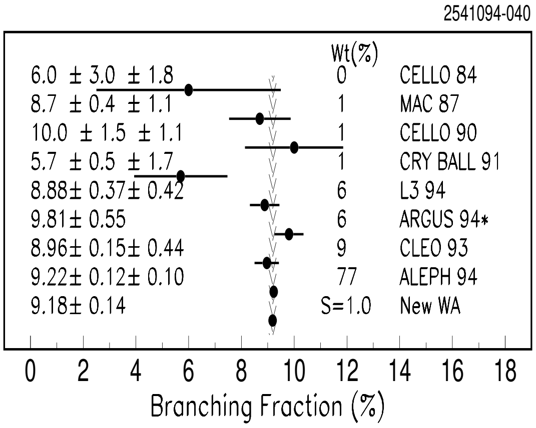

Figure 17. $\tau^- \to h^- 2\pi^0 \nu_\tau$ branching fractions.

with the previously measured

$$\mathcal{B}(h3\pi^0\nu_\tau) = (1.15 \pm 0.08 \pm 0.13)\% \quad \text{(CLEO) [35, 5]}$$

$$\mathcal{B}(h4\pi^0\nu_\tau) = (0.16 \pm 0.05 \pm 0.05)\% \quad \text{(CLEO) [35, 5]}$$

In the L3 result for $\mathcal{B}(h3\pi^0\nu_\tau)$, substantial cross-feed from $h4\pi^0$ final states is not excluded but instead subtracted using the CLEO branching fraction. This feature makes the L3 measurement more of an inclusive measurement similar to ALEPH's.

6. Summary and Conclusions

This Workshop has witnessed an unprecedented improvement in knowledge of hadronic branching fractions of the tau lepton. Crucial new contributions have been made by experiments still running (LEP, CLEO, BES) and by those long-retired from active data-taking (ARGUS, TPC). Results in the strange sector either vastly improve previous measurements or provide first measurements of modes previously unseen. For the "h" modes (those not distinguishing between charged pions and kaons), most branching fractions have been improved dramatically. The global analysis of ALEPH, which simultaneously measures all modes, dominates the branching fraction landscape by virtue of its scope and precision.

The advancement for strange modes has been made possible by the large datasets now available and significant strides in detection of charged and neutral kaons combined with π^0 reconstruction capability. The K and K^* averages are now known, relatively, to better than 6%, a remarkable achievement for absolute branching fractions of only $\simeq$1%; the remainder have relative errors in the 20-30% range but are all seen at consistent levels by two or more experiments.

World-average errors have become small enough in many modes that consistent treatment of K_L and K_S cross-feed in all measurements has become essential. The kaon-mode results now make this goal thinkable, if far from trivial. Meeting this challenge would result in dispensing with the annoying convention that unseen K_L's be included in many branching fractions. The Particle Data Group faces a large challenge in addressing this thorny issue because experimenters frequently do not provide adequate information. Clear and precise statements in experimental publications which allow easy recomputation of such corrections will make this important task possible. More specifically, it is crucial that explicit statements appear, addressing what modes are considered signal and background, what branching fractions are assumed for cross-feed modes, and what the efficiencies are relative to signal for such modes.

A summary of branching fraction world averages appear in Table 3 for modes inclusive of charged kaons, Table 4 for the strange sector, and Table 5 for modes where charged kaon contributions can be subtracted. The leptonic results [8] appear for completeness. In addition to the averages and errors, the relative errors and weight of the ALEPH measurements is shown in the summary tables. ALEPH claims the smallest total error in the majority of all modes listed. It is incumbent upon the other collaborations to meet this challenge and improve their own results in the near future. Consistent results of comparable precision from a number of experiments fosters more confidence than the current situation in which one group so dominates a class of measure-

Table 3
Summary of exclusive and topological NWA τ^- branching fractions $\mathcal{B}(\%)$, relative errors $\Delta\mathcal{B}/\mathcal{B}(\%)$, and ALEPH weight (%) in the NWA.

Mode	$\mathcal{B}$	$\Delta\mathcal{B}/\mathcal{B}$	$\aleph$ Wt
$e\bar{\nu}_e\nu_\tau$	17.79±0.09	0.5	46
$\mu\bar{\nu}_\mu\nu_\tau$	17.33±0.09	0.5	49
$h\nu_\tau$	11.77±0.14	1.2	69
$h\pi^0\nu_\tau$	25.36±0.21	0.8	63
$h2\pi^0\nu_\tau$	9.18±0.14	1.5	77
$h3\pi^0\nu_\tau$	1.15±0.15	13	0
$h4\pi^0\nu_\tau$	0.16±0.07	44	0
$h\bar{K}^0\nu_\tau$	1.03±0.09	9	39
$h\pi^0\bar{K}^0\nu_\tau$	0.53±0.06	11	24
$h\bar{K}^0K^0\nu_\tau$	0.08±0.04	50	0
$h\pi^0\eta(\rightarrow\gamma\gamma)\nu_\tau$	0.07±0.01	14	0
$h\omega(\rightarrow\pi^0\gamma)\nu_\tau$	0.18±0.02	11	-
$h\omega(\rightarrow\pi^0\gamma)\pi^0\nu_\tau$	0.03±0.01	33	-
Σ "1-Pr" Excl	84.66±0.38	0.5	-
"1-Pr" Incl	85.41±0.23	0.3	43
$3h\nu_\tau$	9.24±0.21	2.3	67
$3h\pi^0\nu_\tau$	4.45±0.14	3.1	73
$3h2\pi^0\nu_\tau$	0.51±0.05	9.8	25
$3h\geq 3\pi^0\nu_\tau$	0.20±0.07	35	100
Σ "3-Pr" Excl	14.40±0.27	1.9	-
"3-Pr" Incl	14.49±0.23	1.6	43
5hν_τ	0.073±0.007	10	27
5h$\pi^0\nu_\tau$	0.021±0.006	29	17
Σ "5-Pr" Excl	0.09 ±0.01	11	-
"5-Pr" incl	0.10±0.01	10	13
Σ All Excl	99.15±0.46	0.5	-

ments.

A number of conclusions can be drawn from Table 3. Measurements of exclusive modes with K^0's has made it possible to accurately estimate their contribution to one-prong modes. Determination by ALEPH of the rate for $\tau\rightarrow 3h\geq 3\pi^0\nu_\tau$ fills a previously open gap in three-prong exclusives. CLEO should be able to confirm or refute this observation. The n-prong deficits, defined as the topological inclusive n-prong rates [2] minus the sum of all n-prong exclusives, are (0.75±0.44)%, (0.09±0.35)%, and (0.01±0.01)%, respectively, for one-, three-, and five-prong classes. Overall, the exclusives deficit

Table 4
Summary of strange NWA τ^- branching fractions $\mathcal{B}(\%)$, relative errors $\Delta\mathcal{B}/\mathcal{B}(\%)$, and ALEPH weight (%) in the NWA.

Mode	$\mathcal{B}$	$\Delta\mathcal{B}/\mathcal{B}$	$\aleph$ Wt
$K\nu_\tau$	0.68±0.04	5.9	46
$K^*\nu_\tau$	1.36±0.08	5.9	42
$K^-\pi^+\pi^-\nu_\tau$	0.40±0.09	23	0
$\bar{K}^0\pi^-\pi^0\nu_\tau$	0.41±0.07	17	33
$K^-2\pi^0\nu_\tau$	0.09±0.03	33	91
$K^+K^-\pi^-\nu_\tau$	0.20±0.07	35	0
$K^0K^-\nu_\tau$	0.13±0.04	31	9
$K^0K^-\pi^0\nu_\tau$	0.12±0.04	33	58

Table 5
Summary of non-strange NWA τ^- branching fractions $\mathcal{B}(\%)$ and relative errors $\Delta\mathcal{B}/\mathcal{B}(\%)$ for modes which can have charged kaon contributions excluded.

Mode	$\mathcal{B}$	$\Delta\mathcal{B}/\mathcal{B}$
$\pi^-\nu_\tau$	11.09±0.15	1.4
$\pi^-\pi^0\nu_\tau$	24.91±0.21	0.8
$\pi^-2\pi^0\nu_\tau$	9.09±0.14	1.5
$\pi^-\pi^+\pi^-\nu_\tau$	8.64±0.24	2.8

is (0.85±0.46)%. Hence there is no evidence for any significant deficit.

The entries in Table 5 represent naive subtractions of numbers in the previous two tables. If all $(3\pi)^-$ comes from a_1^-, then $\mathcal{B}(a_1^-\nu_\tau)$=(17.73±0.28)%, and the ratio of its two modes is 0.95±0.03, in good agreement with the phase-space prediction [45] of 0.98.

Explorations of resonant substructure and dynamics in tau decays has not yet reached the precision and sophistication attained in branching fractions. However, large datasets with low backgrounds and an increasing awareness of the importance of such analyses makes the prospects for progress excellent.

I will conclude by asking a number of questions which can form the basis for further investigations of hadronic tau decays. Will the global branching fractions of ALEPH continue to dominate most modes, or can we expect comparably precise results from other experiments? Can we resolve branching fraction discrepancies in the $h\pi^0$ and $3h$ modes simply by improving measurements, making older, disagreeable values irrelevant? Can we develop procedures which allow a consistent accounting of modes with K_L decays? What are the masses and widths of the ρ and ρ' in tau decay? Is all $(3\pi)^-$ attributable to a_1^- decays? Is there evidence for scalar or non-resonant production of $(K\pi)^-$ final states? Are $(K\pi\pi)^-$ decays consistent with a mixture of $K_1(1270)$ and $K_1(1400)$ production? What is the mixing angle and strength of $SU(3)_f$ symmetry breaking in such decays? Do $(K\pi\pi)^-$ final states have $K^*(1410)$ or non-resonant content? Can all $(4\pi)^-$ final states be described as $\omega\pi^-$ and $(a_1\pi)^-$? If so, what resonances produce those states? What is the resonant substructure in $KK\pi$, 5π, 6π final states? What is the rate for 7π production in tau decay? Is there any evidence for second-class currents in tau decay at expected or unexpected levels? Given the current status of measurements, where are the most promising places to look for deviations from the Standard Model in hadronic tau decays? Attempts to answer these questions should guarantee a lively future for tau physics.

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REFERENCES

1. M.L. Perl *et al.*, Phys. Rev. Lett. **35** (1975) 1489.
2. J. Smith, presentation at this Workshop.
3. F.J. Gilman and S.H. Rhie, Phys. Rev. D**31** (1985) 1066.
4. R. Galik, *Proceedings of the Second Workshop on Tau Lepton Physics*, September 1992, edited by K.K. Gan, World Scientific (1993), p. 322.
5. L. Montanet *et al.* (Particle Data Group), Phys. Rev. D**50** (1994) 1173.
6. K. Hayes, presentation at this Workshop.
7. M. Girone (ALEPH), presentation at this Workshop.
8. M. Davier, presentation at this Workshop.
9. R. Decker, presentation at this Workshop.
10. M. Finkemeier, presentation at this Workshop.
11. D.A. Bauer *et al.* (TPC/Two-Gamma Collaboration), "Global Measurement of Tau Lepton Branching Fractions", written contribution to this Workshop.
12. W. Ruckstuhl, presentation at this Workshop.
13. DELPHI Collaboration, contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0234 (DELPHI 94-120 PHYS 437).
14. DELPHI Collaboration, contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0176 (DELPHI 94-56 PHYS 377).
15. M. Battle *et al.* (CLEO Collaboration), Phys. Rev. Lett. **73** (1994) 1079.
16. H. Evans (OPAL), presentation at this Workshop.
17. H.J. Park (ALEPH), presentation at this Workshop.
18. ALEPH Collaboration, contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0570.
19. W.J. Marciano, *Proceedings of the Second Workshop on Tau Lepton Physics*, September 1992, edited by K.K. Gan, World Scientific (1993), p. 502.
20. W.J. Marciano and A. Sirlin, Phys. Rev. Lett. **71** (1993) 3629.
21. C. Hast, Dortmund Ph.D. Thesis (1993).
22. J. Smith (CLEO), presentation at this Workshop.

23. M. Athanas *et al.* (CLEO Collaboration), contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0460 (CLEO CONF 94-23).
24. M.T. Ronan, *Proceedings of the Second Workshop on Tau Lepton Physics*, September 1992, edited by K.K. Gan, World Scientific (1993), p. 225.
25. M. Suzuki, Phys. Rev. D**49** (1994) 2634.
26. H.J. Lipkin, Phys. Lett. B**303** (1993) 119.
27. D.A. Bauer *et al.* (TPC/Two-Gamma Collaboration), Phys. Rev. D**50** (1994) 13.
28. Nading Qi (BES), presentation at this Workshop.
29. J. Gronberg *et al.* (CLEO Collaboration), contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0242 (CLEO CONF 94-24).
30. S. Eidelman, presentation at this Workshop.
31. R. Balest *et al.* (CLEO Collaboration), contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0455 (CLEO CONF 94-25).
32. A.S. Schwarz, *Proceedings of the XVI International Symposium on Lepton and Photon Interactions*, August 1993, edited by P. Drell and D. Rubin, AIP Press (1994), p. 671.
33. M. Schieber, Dortmund Ph.D. Thesis in preparation (1994). This analysis classifies one-prong decays:

$$\begin{aligned}
\mathcal{B}(1prong\ 0\pi^0\nu_\tau)/B_1 &= (57.29 \pm 0.82)\% \\
\mathcal{B}(h\pi^0\nu_\tau)/B_1 &= (29.04 \pm 0.72)\% \\
\mathcal{B}(h2\pi^0\nu_\tau)/B_1 &= (11.48 \pm 0.65)\% \\
\mathcal{B}(h \geq 3\pi^0\nu_\tau)/B_1 &= (2.12 \pm 0.40)\%
\end{aligned}$$

Absolute branching fractions are obtained using $B_1 = (85.41 \pm 0.23)\%$ from [2].
34. H. Albrecht *et al.* (ARGUS Collaboration), Z. Phys. C**53** (1992) 367.
35. M. Procario *et al.* (CLEO Collaboration), Phys. Rev. Lett. **70** (1993) 1207.
36. R. Akers *et al.* (OPAL Collaboration), contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0586 (CERN PPE 94-108).
37. D. Gibaut *et al.* (CLEO Collaboration), Phys. Rev. Lett. **73** (1994) 934.
38. W.T. Ford (CLEO), presentation at this Workshop.
39. T.N. Pham, C. Roiesnel, and T.N. Truong, Phys. Lett. B**78** (1978) 623.
40. M. Artuso *et al.* (CLEO Collaboration), Phys. Rev. Lett. **69** (1992) 3278.
41. S.I. Eidelman and V.N. Ivanchenko, Phys. Lett. B**257** (1991) 437.
42. B. Barish *et al.* (CLEO Collaboration), contributed to the XXVII Internation Conference on High Energy Physics, Glasgow, Scotland (1994), Ref. GLS0249 (CLEO CONF 94-22).
43. N. Wermes (OPAL), presentation at this Workshop.
44. H. Albrecht *et al.* (ARGUS Collaboration), Z. Phys. C**58** (1993) 61.
45. KORALB (v.2.1)/TAUOLA (v.1.5): S. Jadach and Z. Was, Comput. Phys. Commun. **36** (1985) 191; **64** (1991) 267; S. Jadach, J.H. Kühn, and Z. Was, Comput. Phys. Commun. **64** (1991) 275; **70** (1992) 69; **76** (1993) 361.
46. N. Isgur, C. Morningstar, and C. Reader, Phys. Rev. D**39** (1989) 1357.
47. J.H. Kühn, presentation at this Workshop.
48. J.H. Kühn and E. Mirkes, Z. Phys. C**56** (1992) 661.
49. J. H. Kühn and A. Santamaria, Z. Phys. C**48** (1990) 445.
50. M. Wingate, T. DeGrand, S. Collins, and U. Heller, "Properties of the a_1 Axial Vector Meson from Lattice QCD", Contribution to the Lattice94 Workshop, Bielefeld, Germany (September 1994).
51. M. Schmidtler (ARGUS), presentation at this Workshop.
52. P. Bourdon (ALEPH), presentation at this Workshop.
53. S. Narison and A. Pich, Phys. Lett. B**304** (1993) 359.
54. G. Crawford, *Proceedings of the Second Workshop on Tau Lepton Physics*, September 1992, edited by K.K. Gan, World Scientific (1993), p. 183.
55. D. Bortoletto *et al.* (CLEO Collaboration), Phys. Rev. Lett. **71** (1993) 1791.

56. H. Albrecht, *et al.* (ARGUS Collaboration), Phys. Lett. B**260** (1991) 259.
57. R. Akers *et al.* (OPAL Collaboration), Phys. Lett. B**328** (1994) 207.
58. S. Gentile (L3), presentation at this Workshop.
59. M. Artuso *et al.* (CLEO Collaboration), Phys. Rev. Lett. **72** (1994) 3762.
60. A. Weinstein (CLEO), presentation at this Workshop.
61. R. Sobie, presentation at this Workshop.
62. J. Kühn and A. Santamaria, Z. Phys. C**48** (1990) 443.