ICHEP94 Ref. GLS0249 **CLEO CONF 94-22**
Submitted to Pa 16 Pl 9 **July 19, 1994**

Measurement of $B(\tau^- \to h^- h^+ h^- (\pi^0)\nu_\tau)$

B. Barish,[1] M. Chadha,[1] S. Chan,[1] D.F. Cowen,[1] G. Eigen,[1] J.S. Miller,[1] C. O'Grady,[1] J. Urheim,[1] A.J. Weinstein,[1] M. Athanas,[2] W. Brower,[2] G. Masek,[2] H.P. Paar,[2] M. Sivertz,[2] J. Gronberg,[3] R. Kutschke,[3] S. Menary,[3] R.J. Morrison,[3] S. Nakanishi,[3] H.N. Nelson,[3] T.K. Nelson,[3] C. Qiao,[3] J.D. Richman,[3] A. Ryd,[3] H. Tajima,[3] D. Sperka,[3] M.S. Witherell,[3] R. Balest,[4] K. Cho,[4] W.T. Ford,[4] D.R. Johnson,[4] K. Lingel,[4] M. Lohner,[4] P. Rankin,[4] J.G. Smith,[4] J.P. Alexander,[5] C. Bebek,[5] K. Berkelman,[5] K. Bloom,[5] T.E. Browder,[5*] D.G. Cassel,[5] H.A. Cho,[5] D.M. Coffman,[5] D.S. Crowcroft,[5] P.S. Drell,[5] D. Dumas,[5] R. Ehrlich,[5] P. Gaidarev,[5] R.S. Galik,[5] M. Garcia-Sciveres,[5] B. Geiser,[5] B. Gittelman,[5] S.W. Gray,[5] D.L. Hartill,[5] B.K. Heltsley,[5] S. Henderson,[5] C.D. Jones,[5] S.L. Jones,[5] J. Kandaswamy,[5] N. Katayama,[5] P.C. Kim,[5] D.L. Kreinick,[5] G.S. Ludwig,[5] J. Masui,[5] J. Mevissen,[5] N.B. Mistry,[5] C.R. Ng,[5] E. Nordberg,[5] J.R. Patterson,[5] D. Peterson,[5] D. Riley,[5] S. Salman,[5] M. Sapper,[5] F. Würthwein,[5] P. Avery,[6] A. Freyberger,[6] J. Rodriguez,[6] S. Yang,[6] J. Yelton,[6] D. Cinabro,[7] T. Liu,[7] M. Saulnier,[7] R. Wilson,[7] H. Yamamoto,[7] T. Bergfeld,[8] B.I. Eisenstein,[8] G. Gollin,[8] B. Ong,[8] M. Palmer,[8] M. Selen,[8] J. J. Thaler,[8] K.W. Edwards,[9] M. Ogg,[9] A. Bellerive,[10] D.I. Britton,[10] E.R.F. Hyatt,[10] D.B. MacFarlane,[10] P.M. Patel,[10] B. Spaan,[10] A.J. Sadoff,[11] R. Ammar,[12] P. Baringer,[12] A. Bean,[12] D. Besson,[12] D. Coppage,[12] N. Copty,[12] R. Davis,[12] N. Hancock,[12] M. Kelly,[12] S. Kotov,[12] I. Kravchenko,[12] N. Kwak,[12] H. Lam,[12] Y. Kubota,[13] M. Lattery,[13] M. Momayezi,[13] J.K. Nelson,[13] S. Patton,[13] R. Poling,[13] V. Savinov,[13] S. Schrenk,[13] R. Wang,[13] M.S. Alam,[14] I.J. Kim,[14] Z. Ling,[14] A.H. Mahmood,[14] J.J. O'Neill,[14] H. Severini,[14] C.R. Sun,[14] F. Wappler,[14] G. Crawford,[15] C. M. Daubenmier,[15] R. Fulton,[15] D. Fujino,[15] K.K. Gan,[15] K. Honscheid,[15] H. Kagan,[15] R. Kass,[15] J. Lee,[15] R. Malchow,[15] Y. Skovpen,[15†] M. Sung,[15] C. White,[15] M.M. Zoeller,[15] F. Butler,[16] X. Fu,[16] B. Nemati,[16] W.R. Ross,[16] P. Skubic,[16] M. Wood,[16] M. Bishai,[17] J. Fast,[17] E. Gerndt,[17] R.L. McIlwain,[17] T. Miao,[17] D.H. Miller,[17] M. Modesitt,[17] D. Payne,[17] E.I. Shibata,[17] I.P.J. Shipsey,[17] P.N. Wang,[17] M. Battle,[18] J. Ernst,[18] L. Gibbons,[18] Y. Kwon,[18] S. Roberts,[18] E.H. Thorndike,[18] C.H. Wang,[18] J. Dominick,[19] M. Lambrecht,[19] S. Sanghera,[19] V. Shelkov,[19] T. Skwarnicki,[19] R. Stroynowski,[19] I. Volobouev,[19] G. Wei,[19] P. Zadorozhny,[19] M. Artuso,[20] M. Gao,[20] M. Goldberg,[20] D. He,[20] N. Horwitz,[20] R. Kennett,[20] G.C. Moneti,[20] R. Mountain,[20] F. Muheim,[20] Y. Mukhin,[20] S. Playfer,[20] Y. Rozen,[20] S. Stone,[20] X. Xing,[20] G. Zhu,[20] J. Bartelt,[21] S.E. Csorna,[21] Z. Egyed,[21] V. Jain,[21] D. Gibaut,[22] K. Kinoshita,[22] and P. Pomianowski[22]

(CLEO Collaboration)

[1] *California Institute of Technology, Pasadena, California 91125*
[2] *University of California, San Diego, La Jolla, California 92093*
[3] *University of California, Santa Barbara, California 93106*
[4] *University of Colorado, Boulder, Colorado 80309-0390*
[5] *Cornell University, Ithaca, New York 14853*
[6] *University of Florida, Gainesville, Florida 32611*
[7] *Harvard University, Cambridge, Massachusetts 02138*
[8] *University of Illinois, Champaign-Urbana, Illinois, 61801*
[9] *Carleton University, Ottawa, Ontario K1S 5B6 and the Institute of Particle Physics, Canada*
[10] *McGill University, Montréal, Québec H3A 2T8 and the Institute of Particle Physics, Canada*
[11] *Ithaca College, Ithaca, New York 14850*
[12] *University of Kansas, Lawrence, Kansas 66045*
[13] *University of Minnesota, Minneapolis, Minnesota 55455*
[14] *State University of New York at Albany, Albany, New York 12222*
[15] *Ohio State University, Columbus, Ohio, 43210*
[16] *University of Oklahoma, Norman, Oklahoma 73019*
[17] *Purdue University, West Lafayette, Indiana 47907*
[18] *University of Rochester, Rochester, New York 14627*
[19] *Southern Methodist University, Dallas, Texas 75275*
[20] *Syracuse University, Syracuse, New York 13244*
[21] *Vanderbilt University, Nashville, Tennessee 37235*
[22] *Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 24061*

Abstract

We use a data sample of ∼1.4 million produced τ-pair events, obtained with the CLEO-II detector operating at the CESR e^+e^- storage ring, to measure $\mathcal{B}(\tau^- \to h^-h^+h^-(\pi^0)\nu_\tau)$, where h refers to either a charged π or K. The $3h^\pm$ final state is measured with samples of lepton-tagged and $3h$ *vs.* $3h$ events while the $3h^\pm\pi^0$ final state is measured only with lepton tagged events. We find $\mathcal{B}(\tau^- \to h^-h^+h^-\nu_\tau) = 0.0982 \pm 0.0009 \pm 0.0034$ and $\mathcal{B}(\tau^- \to h^-h^+h^-\pi^\circ\nu_\tau) = 0.0425 \pm 0.0009 \pm 0.0026$.

*Permanent address: University of Hawaii at Manoa

†Permanent address: INP, Novosibirsk, Russia

An accurate determination of the branching fraction for the decay $\tau \to 3h^{\pm}\nu_\tau$, where h refers to either a π or K, is of particular importance since there is a wide variation among previous measurements. Several previous experiments found a small branching fraction, notably the ARGUS experiment [1], which obtained $\mathcal{B}(3h) = 0.073 \pm 0.001 \pm 0.005$. On the other hand, a preliminary ALEPH measurement [2], $\mathcal{B}(3h) = 0.0957 \pm 0.0024 \pm 0.0022$, is nearly four standard deviations larger than the ARGUS result. The $\tau \to 3h^{\pm}\nu_\tau$ decay mode is dominated by $\tau \to 3\pi^{\pm}\nu_\tau$ which in turn is known to proceed predominantly through the a_1 resonance [3]. The branching fraction of the charged a_1 is constrained by isospin to be the same (except for small phase-space corrections) for the $3\pi^{\pm}$ and $\pi^{\pm}2\pi^{\circ}$ decay modes. A precise test of the equivalence of these two modes would test the theoretical assumptions for these hadronic τ decays.

The decay $\tau \to 3h^{\pm}\pi^{\circ}\nu_\tau$ is also of considerable interest, partly because it is the second largest 3-prong τ decay. Though previous measurements for this mode have generally been in reasonable agreement, they are not very precise. Also most of these measurements used photon counting rather than π° reconstruction and thus are more sensitive to unexpected feed-across backgrounds. The recent measurement by CLEO $\mathcal{B}(\tau \to 3h^{\pm}2\pi^{\circ}\nu_\tau)$= $0.0048\pm 0.0004\pm 0.0004$ [4] suggests a bias in previous $3h\pi^{\circ}$ measurements since the $3h2\pi^{\circ}$ mode was unknown and assumed to be negligible. Unlike the $3h$ mode, which proceeds through the axial-vector current where accurate theoretical predictions are difficult, the $3h\pi^{\circ}$ mode proceeds through the vector current; $e^+e^- \to 4\pi$ data and the conserved-vector-current (CVC) hypothesis have been used to predict branching fractions of 0.043 ± 0.003 [5] and 0.048 ± 0.007 [6], compared with the present world average, 0.049 ± 0.004 [7].

We measure these decay modes in two ways. First, we use a conventional lepton-tag analysis, taking advantage of the excellent electron and muon identification of the CLEO-II detector. This method has the advantage that the background from $q\bar{q}$ events ($e^+e^- \to q\bar{q}, q = udsc$) is quite low. The second approach selects a sample of events where both τ's decay to three charged tracks (to be referred to as the 3-3 sample). This method has not been used previously and is possible only with a very large data sample. There are two main advantages: many systematic errors are reduced by a factor of two since one measures the square of the branching fraction; and the technique does not depend directly on the knowledge of any other τ decay modes (though the estimation of the amount of "feed-across" background from other τ decay modes does). The only disadvantage is that the hadronic background is larger though this is not a serious limitation. Both methods require precise knowledge of the luminosity and τ-pair production cross section. We use both methods to determine the branching fraction for the $\tau \to 3h^{\pm}\nu_\tau$ decay mode ($3h$ analysis), but only the lepton-tag method for the $\tau \to 3h^{\pm}\pi^{\circ}\nu_\tau$ decay ($3h\pi^{\circ}$ analysis).

The data used in this analysis have been collected with the CLEO II detector at the e^+e^- Cornell Electron Storage Ring (CESR), operating at a center-of-mass energy, $E_{\rm cm} \sim 10.6$ GeV. The total integrated luminosity of the sample is 1.58 fb^{-1}, corresponding to $\sim 1.44\times 10^6$ produced τ-pair events. CLEO II is a general purpose spectrometer with excellent charged particle and shower energy detection. Charged particles are measured with three cylindrical drift chambers between 5 and 90 cm from the e^+e^- interaction region, with a total of 67 layers. Pulse-height measurements in the outer drift chamber provide specific-ionization (dE/dx) information. The drift chambers are surrounded by a scintillation time-of-flight system and a CsI(Tl) calorimeter with 7800 crystals. These detector systems are installed inside a 1.5-T superconducting solenoidal magnet, surrounded by a proportional-tube muon chamber with iron absorbers. A more detailed description of the detector can be found in Ref. [8].

Events are selected for the lepton-tag (3-3) analysis by requiring four (six) charged tracks with the event divided into hemispheres by the charged-particle thrust axis. For the lepton-tag analysis, the leptons are required to be at least 90° from each of the 3-prong tracks. The net charge in each hemisphere is required to be ± 1 and the total charge of the event must be zero. To ensure that the event is well-reconstructed, we require the polar angle θ of all tracks to lie in the central region of the detector, $|\cos\theta| < 0.81$, and the momentum of each to be greater than $0.05E_{\rm b}$, where $E_{\rm b}$ is the beam energy. Events with secondary vertices that are consistent with K_S or Λ decays or pair conversions are rejected. In order to reject hadronic background and feed-across from other τ decay modes, we veto events with energetic showers which are more than 30 cm from the nearest charged track and have a lateral profile consistent with that of photons. Such events containing showers with more than 15% of the shower energy of the nearest charged hadron are vetoed for the lepton-tag analysis (shower energies are such that this cut has a mean value of $\sim$200 MeV). For the 3-3 analysis, events are vetoed if the most energetic such shower is greater than 120 MeV. For the 3-3 (lepton-tag) analysis, hadronic background is further reduced with little loss of signal by requiring 3-prong invariant masses to be less than 1.5 GeV (1.77 GeV). For the lepton-tag analysis, contamination from radiative Bhabha and μ-pair events with a photon conversion is removed by vetoing events for which the scalar sum of the momenta of the three hadron tracks exceeds $0.9E_{\rm b}$. In order to reject 2-photon background, we require that the polar angle of the missing momentum satisfy $|\cos\theta_{\rm miss}| < 0.90(0.98)$ for the lepton-tag (3-3) sample, and for the 3-3 analysis we require the scalar sum of the six charged-particle momenta to be at least $0.45E_{\rm cm}$.

For the $3h\pi^\circ$ analysis, all of the same requirements are made except for the last two mentioned above, since there are no significant QED backgrounds to veto. In order to select π°'s, the two most energetic photons with $|\cos\theta| < 0.71$ are used. Signal and sideband regions are defined as $|m_{\gamma\gamma} - m_\pi^\circ| < 3.5\sigma_{\gamma\gamma}$ and $5.0\sigma_{\gamma\gamma} < |m_{\gamma\gamma} - m_\pi^\circ| < 8.5\sigma_{\gamma\gamma}$, respectively, where $m_{\gamma\gamma}$ is the mass of the photon pair and the mass resolution, $\sigma_{\gamma\gamma}$, depends on the energies and angles of the photons and is typically about 6 MeV. All showers except those used for the π° are subject to the energetic-shower veto. Contributions due to fake π°'s are subtracted by using the sideband regions.

The leptons in the lepton-tag analyses are subject to more stringent requirements than those mentioned above. Both electrons and muons must satisfy $|\cos\theta| < 0.71$ and electrons (muons) must have momenta greater than $0.10E_{\rm b}$ ($0.26E_{\rm b}$). The momentum requirement for muons is more severe since muon candidates are required to penetrate at least 3 interaction lengths of iron. Electrons are required to have $E_{\rm sh}/p > 0.85$ and dE/dx within 2σ of that expected for electrons, where $E_{\rm sh}$ is the energy of the calorimeter shower matched to the track. The efficiency of lepton identification as a function of momentum is measured with radiative Bhabha and μ-pair events. The probability that a hadron is misidentified as a lepton has been measured with independent τ data samples, and based on this, we determine that the final $3h$ ($3h\pi^\circ$) sample contains 0.5 ± 0.1% (0.6 ± 0.2%) fake electrons and 2.5 ± 0.2% (2.8 ± 0.5%) fake muons.

In order to determine the efficiencies of the analyses and to estimate the amount of τ

feed-across and non-τ backgrounds, we have generated large samples of τ-pair, $q\bar{q}$, and $B\bar{B}$ Monte Carlo. For τ-pairs we use the **KORALB** generator [9], for $q\bar{q}$ events the Lund Monte Carlo generator [10], and for $B\bar{B}$ events a generator developed by CLEO that is appropriate for threshold production [11]. The **GEANT** code [12] is used to simulate the detector response. Backgrounds not associated with events from e^+e^- interactions are modelled by embedding randomly triggered events into the Monte Carlo events.

We have compared the data and Monte Carlo distributions for all quantities used in the event selection and a variety of other interesting variables. There is good agreement for nearly all variables which are used in the analyses. As examples, we show in Fig. 1 distributions of the lepton momenta and the smallest hadron momentum in the event for both analyses. The disagreement near the peak in Fig. 1c is thought to be a fluctuation, but it is taken into account in the systematic errors in any case. In Fig. 2 we show the variables used in the energetic shower veto. The $3h$ masses for the two analyses are shown in Fig. 3. The plots include all cuts except those on the quantity being plotted and cuts (if any) are indicated by arrows. The data are shown as points with error bars, τ feed-across plus $q\bar{q}$ Monte Carlo as a dashed line, and the sum of the background and signal Monte Carlo by a solid line. All plots are normalized to the measured branching fractions and the amounts of backgrounds determined from the data.

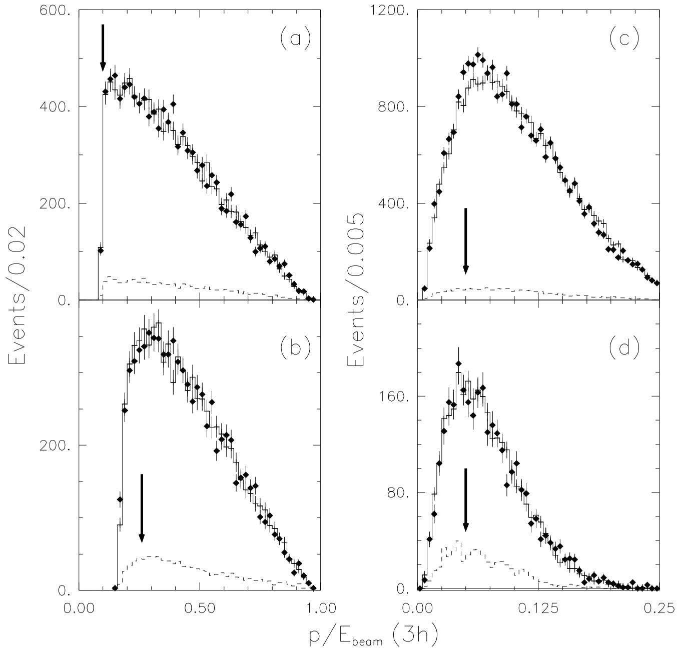

FIG. 1. Distribution of momentum divided by the beam energy for (a) electrons and (b) muons from the lepton-tag $3h$ analysis; least energetic hadrons for the (c) lepton-tag $3h$ analysis and (d) 3-3 analysis. The data are shown as points with error bars, τ feed-across plus $q\bar{q}$ Monte Carlo as a dashed line and the sum of the background and signal Monte Carlo by a solid line. Arrows indicate the location of the selection cuts.

Similar plots for the $3h\pi^\circ$ analysis also show good agreement between data and Monte Carlo. In Fig. 4 we plot $(m_{\gamma\gamma} - m_\pi^\circ)/\sigma_{\gamma\gamma}$. Momentum plots for the leptons and least energetic hadron are shown in Fig. 5.

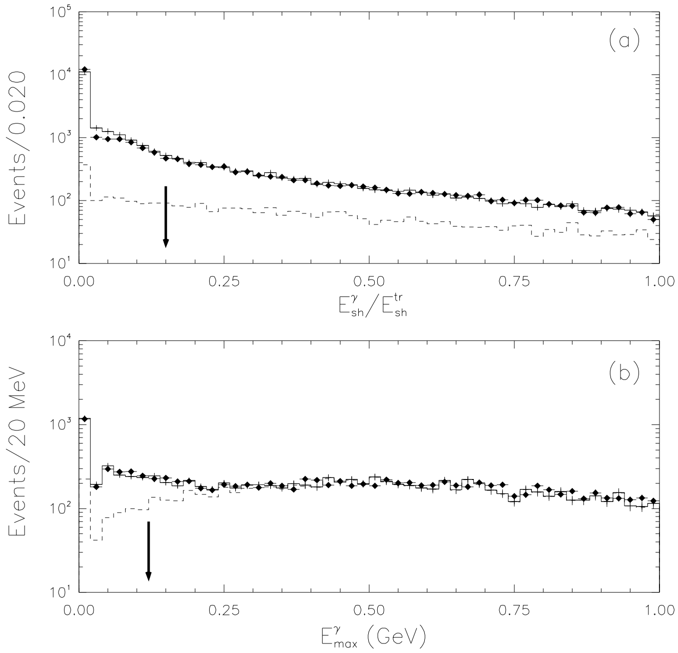

FIG. 2. Energetic shower veto variables: (a) shower energy divided by the energy of the nearest charged track, used in the lepton-tag analyses; (b) energy of the most energetic photon-like shower, used in the 3-3 analysis.

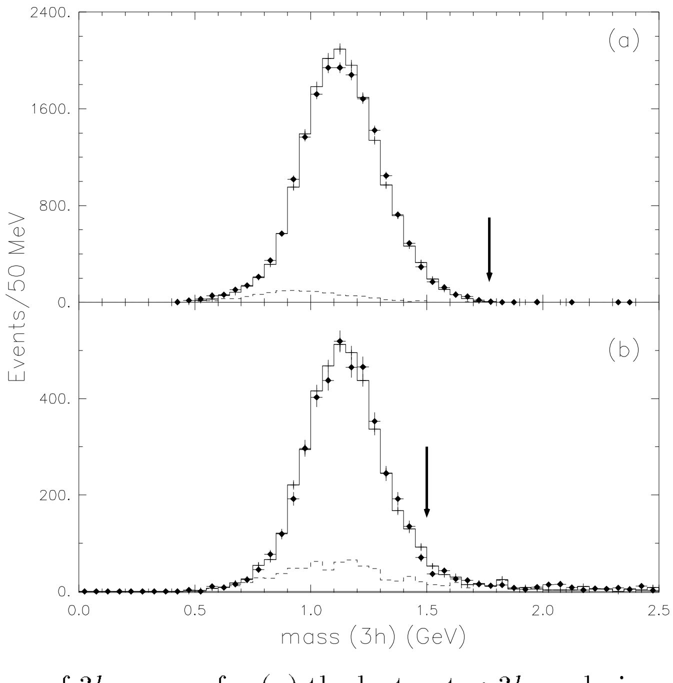

FIG. 3. Distributions of $3h$ masses for (a) the lepton-tag $3h$ analysis; and (b) the 3-3 analysis (2 entries/event).

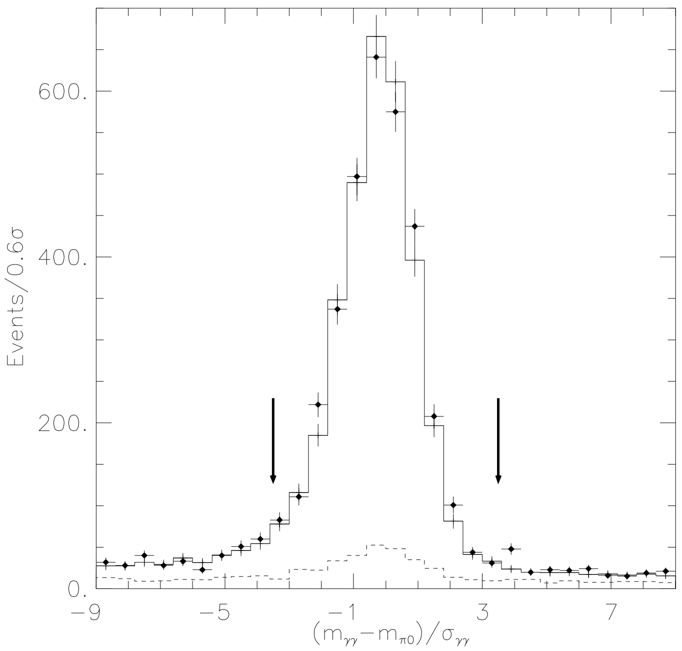

FIG. 4. Invariant mass of the two candidate photons for the $3h\pi^{\circ}$ analysis.

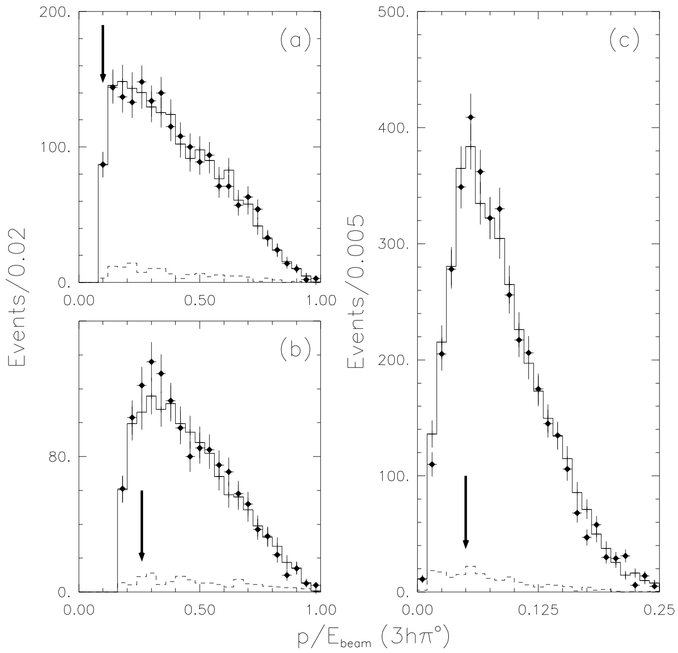

FIG. 5. Distribution of momentum divided by the beam energy for (a) electrons and (b) muons from the $3h\pi^{\circ}$ analysis; (c) least energetic hadron from the same analysis.

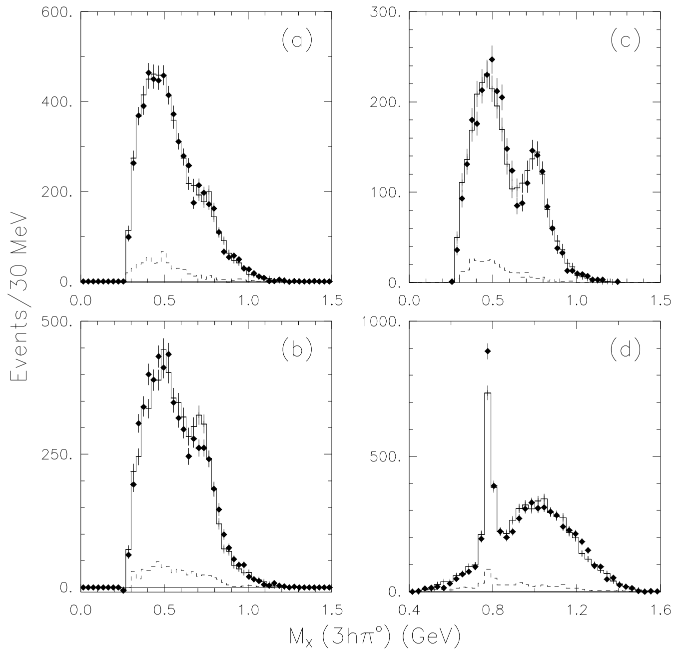

FIG. 6. Distributions of sub-masses, M_X, for the $3h\pi^\circ$ analysis: (a) $\pi^+\pi^-$; (b) $\pi^-\pi^\circ$; (c) $\pi^+\pi^\circ$; (d) $\pi^+\pi^-\pi^\circ$ final states, where these final states are for a τ^- decay, but charge-conjugate final states are also included. Plot (c) has one entry/event and the others have two entries/event.

For the 3-3 analysis, we estimate the amount of $q\bar{q}$ background from the Monte Carlo, scaled up by a factor of 1.2 ± 0.2 to agree with the number of events in the mass region between 1.5 and 2.0 GeV. Other variables which are sensitive to hadronic background are in good agreement with this estimate. With this adjustment, we estimate the amount of $q\bar{q}$ background to be $4.7 \pm 0.9\%$, where the uncertainty is dominated by that of the scale factor mentioned above. We estimate that the residual 2-photon background is negligible from distributions sensitive to this background other than those used in the analysis. The amount of $B\bar{B}$ is estimated from a large Monte Carlo sample and found to be negligible. With similar techniques, all of these backgrounds are estimated for the lepton-tag analysis and all but the $q\bar{q}$ background are estimated to be negligible. The $q\bar{q}$ background estimate is taken from Monte Carlo and is confirmed with the region above the τ mass, as seen in Fig. 3a.

The largest background comes from feed-across of other τ decays into the signal sample. For the 3-3 analysis we use the τ Monte Carlo and comparisons with the data mass and unassociated-neutral-energy distributions to estimate this background to be $10.9\pm 1.4\%$, where 86% of the background is from the $\tau \to 3h^\pm\pi^\circ\nu_\tau$ decay mode. For the lepton-tag $3h$ sample, we estimate the feed-across to be $9.6\pm 0.5\%$ and $11.4\pm 0.5\%$ for the electron-tag and muon-tag samples, respectively. These uncertainties are estimated by comparing the Monte Carlo and data distributions of the distance between unassociated photon-like showers and the nearest charged track. The feed-across includes the lepton-fake contributions given above. About 80% of the cross-feed in the signal hemisphere is from the $\tau \to 3h^\pm\pi^\circ\nu_\tau$ decay mode. For the $3h\pi^\circ$ analysis, the feed-across background is estimated to be $6.9\pm 0.7\%$ and $7.2\pm 0.7\%$ for the electron- and muon-tag samples, respectively. This background is dominated by the decay $\tau \to 3h^{\pm}2\pi^{\circ}\nu_{\tau}$.

In Table I we summarize the information relevant for both analyses including the number of data events in the final samples, the fraction of τ and non-τ (all $q\bar{q}$) backgrounds in the samples and the efficiency for each analysis. The errors in the backgrounds and efficiency include systematic errors due to the variation of cuts discussed below.

TABLE I. Summary of the numbers of observed events, efficiencies and background fractions.

Analysis method	$N_{\rm d}$	f_b^{τ} (%)	$f_b^{q\bar{q}}$ (%)	ϵ(%)
3-3	2030$\pm$ 45	10.9$\pm$ 1.4	4.7$\pm$ 0.9	12.2$\pm$ 0.3
e-tag $3h$	10712$\pm$ 103	9.6$\pm$ 0.5	0.2$\pm$ 0.2	19.1$\pm$ 0.6
μ-tag $3h$	6767$\pm$ 82	11.4$\pm$ 0.5	0.0$\pm$ 0.1	12.3$\pm$ 0.4
e-tag $3h\pi^{\circ}$	1801$\pm$ 47	6.9$\pm$ 0.7	0.7$\pm$ 0.7	7.5$\pm$ 0.3
μ-tag $3h\pi^{\circ}$	1146$\pm$ 37	7.2$\pm$ 0.7	0.3$\pm$ 0.3	4.9$\pm$ 0.2

We calculate the branching fractions from

$$\mathcal{B}(\tau \to 3h^{\pm}(\pi^{\circ})\nu_{\tau}) = \frac{N_{\rm d}(1 - f_b^{q\bar{q}} - f_b^{\tau})}{2\sigma_{\tau\tau}\,\mathcal{L}\,\epsilon\,\mathcal{B}(\tau \to \ell\bar{\nu}_{\ell}\nu_{\tau})} \quad (\mathrm{lepton-tag})$$

$$\mathcal{B}(\tau \to 3h^{\pm}\nu_{\tau})^2 = \frac{N_d(1 - f_b^{q\bar{q}} - f_b^{\tau})}{\sigma_{\tau\tau}\,\mathcal{L}\,\epsilon} \quad (3-3),$$

where $N_{\rm d}$ is the number of data events, $f_b^{q\bar{q}}$ and f_b^{τ} are the estimated event fractions due to non-tau and tau feed-across backgrounds, respectively, $\sigma_{\tau\tau}$ is the radiatively-corrected τ-pair cross section, $\mathcal{L}$ is the integrated luminosity and ϵ is the signal efficiency, calculated from Monte Carlo. For $\mathcal{B}(\tau \to \ell\bar{\nu}_{\ell}\nu_{\tau})$, we use the world averages from Ref. [3].

The relevant information for the branching fraction calculations can be found in the above table. We calculate the cross section, with a precision of 1%, using **KORALB**. It is the point cross section (0.779 nb at our average center-of-mass energy) times an order α^3 radiative-correction factor, 1.173. We determine the luminosity with a precision of 1% by using events from the processes $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$ and $e^+e^- \to \mu^+\mu^-$, all in the region $|\cos\theta| < 0.71$ [13]. We find the branching fraction results given in Table II, where the first uncertainties are statistical and the second systematic.

TABLE II. Summary of branching fraction measurements.

Analysis method	$\mathcal{B}(\tau \to 3h^{\pm}\nu_{\tau})$	$\mathcal{B}(\tau \to 3h^{\pm}\pi^{\circ}\nu_{\tau})$
3-3	0.0985$\pm$ 0.0014$\pm$ 0.0033	-
e-tag $3h$	0.0981$\pm$ 0.0011$\pm$ 0.0043	0.0427$\pm$ 0.0011$\pm$ 0.0025
μ-tag $3h$	0.0974$\pm$ 0.0013$\pm$ 0.0045	0.0423$\pm$ 0.0014$\pm$ 0.0026

We have considered a variety of systematic errors, summarized in Table III. The systematic error for the absolute tracking efficiency is conservatively determined by studying a sample of electron-tagged events with 1-2 and 1-3 topology. These decays are predominantly 3-prong τ decays and in about 95% of the events, all three tracks are reconstructed; the difference between Monte Carlo and data for typical tracking criteria is $0.41\pm 0.20\%$. We conservatively assign a systematic error of 0.65%/track to account for slight variations in this difference as the tracking criteria are varied. The systematic error due to τ backgrounds includes the uncertainty in τ branching fractions. Since the efficiency of the $3h$ analyses is estimated to be $\sim$15% larger for modes with charged kaons, uncertainties in the branching fractions of the decays $\tau^- \to K^-\pi^+\pi^-\nu_\tau$ and $\tau^- \to K^-K^+\pi^-\nu_\tau$ have been included in the systematic error [14]. The uncertainty in the efficiency was determined by varying all selection criteria and adding in quadrature estimates of the variation due to each of them. The electron identification uncertainty was determined from studies of radiative Bhabha-scattering events; the muon identification uncertainty was determined from radiative μ-pair events and by variation of the requirement on the depth of muon penetration. The uncertainty in the absolute efficiency for π° reconstruction is conservatively taken to be three times the error assigned in the measurement of the decay $\tau \to h^\pm\pi^\circ\nu_\tau$ [15], accounting for a possible increase due to the three tracks in the signal hemisphere. Note that in Table III, we have given uncertainties in the branching fraction, not the number of events; for the 3-3 analysis, these uncertainties have benefited from the factor of two reduction discussed in the introduction.

TABLE III. Summary of systematic uncertainties in the measured $\mathcal{B}$'s (%).

Source	3-3	e-tag $3h$	μ-tag $3h$	e-tag $3h\pi^\circ$	μ-tag $3h\pi^\circ$
Luminosity	0.5	1.0	1.0	1.0	1.0
Tau cross section	0.5	1.0	1.0	1.0	1.0
Tracking efficiency	2.0	2.5	2.5	2.5	2.5
Non-tau backgrounds	0.5	1.0	0.5	0.6	0.8
Tau backgrounds	0.7	0.5		0.7	
Efficiency (cut variation)	2.2	3.2		4.1	4.8
Monte Carlo statistics	0.8	0.6	0.7	0.9	1.2
Lepton ID	-	0.2	1.0	0.2	1.0
$\mathcal{B}(\tau \to \ell\bar{\nu}_\ell\nu_\tau)$	-	1.0	1.3	1.0	1.3
π° reconstruction	-	-	-	3.0	
Total	3.3	4.6	4.7	6.1	6.7

In order to combine the $3h$ results shown in Table II, we determine the correlated and uncorrelated systematic errors for each measurement. The statistical and uncorrelated systematic errors are used to form weights and a combined branching fraction is determined from the weighted average of the two results. The combined error is obtained by summing in quadrature the error in this weighted average and the weighted linear sum of the correlated errors. The weights are 0.63 for the 3-3 measurement and 0.37 for the lepton-tag measurement, leading to a combined result $\mathcal{B}(\tau \to 3h^\pm\nu_\tau)=0.0982\pm 0.0009\pm 0.0034$. A similar procedure is used to combine the electron- and muon-tag measurements in the $3h\pi^\circ$ analysis. We find this combined result to be $\mathcal{B}(\tau \to 3h^\pm\pi^\circ\nu_\tau)=0.0425\pm 0.0009\pm 0.0026$.

We determine the inclusive 3-prong branching fraction to be B_3=0.1455$\pm$ 0.0013$\pm$ 0.0059, by combining the $3h$ and $3h\pi^\circ$ measurements presented in this paper with the CLEO measurement for the $\tau \to 3h^\pm 2\pi^\circ \nu_\tau$ decay mode [4]. This result, as all other results in this paper, specifically excludes contributions from decay modes involving K^0 decays. This result is in good agreement with other recent measurements of B_3 and the world average, B_3=0.1432$\pm$ 0.0027 [3]. However, many of the older measurements used in the world average include 1-prong decays accompanied by a $K_S \to \pi^+\pi^-$ decay. Since such decays have a total branching fraction of 0.0055$\pm$ 0.0006 [16], excluding them from the world average would result in a larger discrepancy with our result.

The $3h$ mass distributions in Fig. 3 show reasonable agreement with the Monte Carlo, where a parameterization of the a_1 resonance has been used in **KORALB**. In Fig. 6 we show the masses of the $\pi^+\pi^-\pi^\circ$ combinations and the three two pion combinations. The Monte Carlo distribution is also shown [17]. An ω resonance is evident and indications of ρ mass peaks are seen in each charge combination. In particular, the combination with charge opposite the charge of the τ (see Fig. 6c) has a clear ρ peak, indicating a larger fraction of $\rho^+\pi^-\pi^-$ than the 10$\pm$ 3$\pm$ 4% measured by ARGUS [18]. This small fraction was used by ARGUS to restrict the contribution of $a_1\pi$ to the $3h\pi^\circ$ mode to less than 44% at 95% confidence level. Quantitative studies of the Dalitz plot of this decay mode are in progress.

In conclusion, we have measured

$$\mathcal{B}(\tau \to 3h^\pm \nu_\tau) = 0.0982 \pm 0.0009 \pm 0.0034 \quad \text{and}$$
$$\mathcal{B}(\tau \to 3h^\pm \pi^\circ \nu_\tau) = 0.0425 \pm 0.0009 \pm 0.0026.$$

In Fig. 7, we compare the first result with the older published measurements and recent LEP results. The shaded band represents the one-standard-deviation uncertainty for the new world average obtained by combining this measurement, the two preliminary LEP results, and the measurements in Ref. [3]. Since the χ^2 is 29.2 for the nine measurements, the uncertainty has been inflated by $\sqrt{\chi^2/\mathrm{DOF}}$. Our preliminary result for the $3h$ decay is in agreement with, but larger than, most previous measurements. We disagree with the ARGUS [1] and DELPHI [21] results at the 4.1σ and 2.7σ levels, respectively; the former discrepancy is particularly severe since both the ARGUS and CLEO measurements are dominated by systematic errors. Our measurement for the $3h\pi^\circ$ decay is more precise and smaller than most previous measurements as shown in Fig. 8 [22]. The agreement is better for this mode, where the χ^2 is 11.5 for the eight measurements; nonetheless the errors have been increased as above. Previously only the ARGUS [19] and ALEPH [2] [23] results have reconstructed the π° in the signal events; our result is in agreement with these measurements. From these results and the previous CLEO measurement for the $3h2\pi^\circ$ final state, we determine the 3-prong branching fraction to be B_3=0.1455$\pm$ 0.0013$\pm$ 0.0059.

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation, the U.S. Dept. of Energy, the Heisenberg Foundation, the SSC Fellowship program of TNRLC, Natural Sciences and Engineering Research Council of Canada, and the A.P. Sloan Foundation.

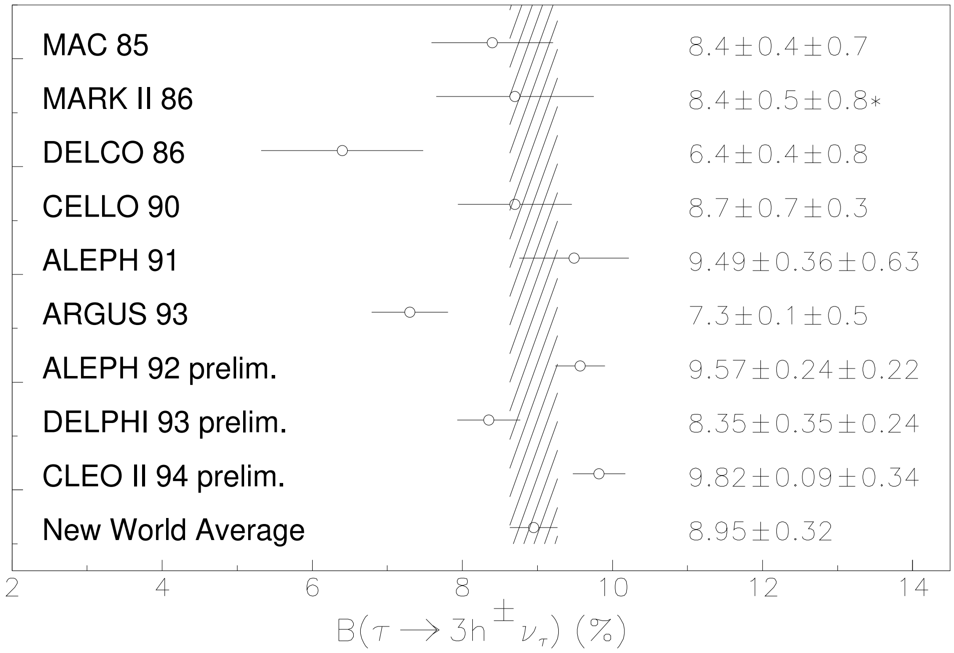

FIG. 7. Published and other recent measurements of the decay mode $\tau \to 3h^{\pm}\nu_{\tau}$. A correction has been applied to the Mark II result [20].

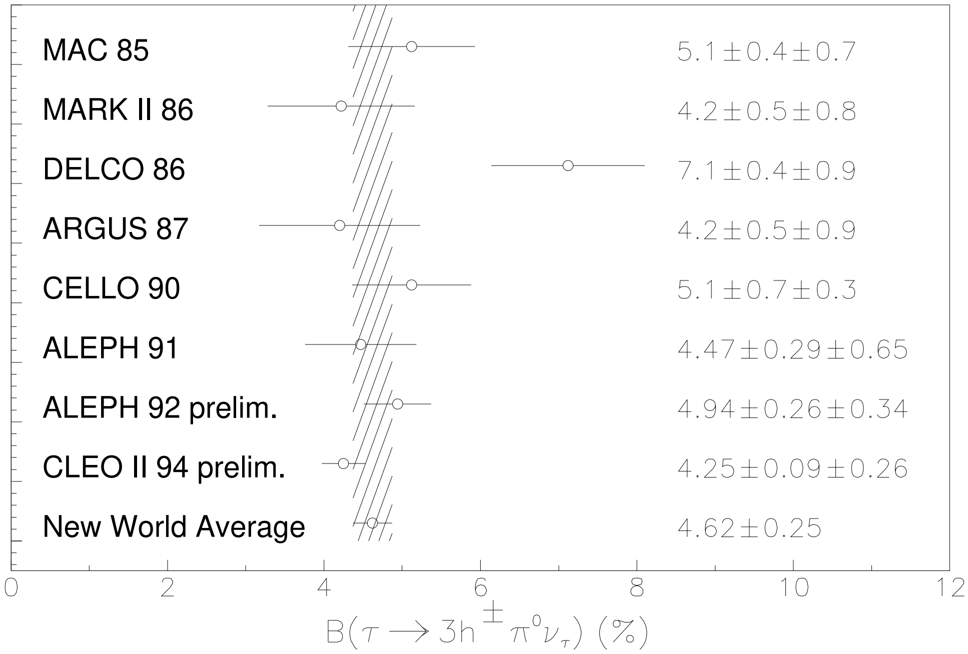

FIG. 8. Published and other recent measurements of the decay mode $\tau \to 3h^{\pm}\pi^{\circ}\nu_{\tau}$. Correction (see text) have been applied to all but the ARGUS and CLEO results.

REFERENCES

[1] H. Albrecht *et al.* (ARGUS collaboration), Z. Phys. C **58**, 61 (1993).

[2] S. W. Snow (ALEPH collaboration) in ***Proceedings of the Second Workshop on Tau Lepton Physics***, Columbus, OH (1992), ed. by K. K. Gan, p. 308.

[3] L. Montanet *et al.* (Particle Data Group), Phys. Rev. D **50**, 1173 (1994).

[4] D. Bortoletto *et al.* (CLEO collaboration), Phys. Rev. Lett. **71**, 1791 (1993).

[5] S. I. Eidelman and V. N. Ivanchenko, Phys. Letters **B257**, 437 (1991).

[6] S. Narison and A. Pich, Phys. Letters **B304**, 359, (1993).

[7] The result for $\mathcal{B}(\tau \to 3h^{\pm}2\pi^{\circ}\nu_{\tau})$ from Ref. [4] has been subtracted from the value from Ref. [3], $\mathcal{B}(\tau \to 3h \geq 1\pi^{\circ}\nu_{\tau}) = 0.054 \pm 0.004$.

[8] Y. Kubota *et al.* (CLEO collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **320**, 66(1992).

[9] **KORALB (v.2.1)/TAUOLA (v.1.5)**: S. Jadach and Z. Was, Comput. Phys. Commun. **36**, 191 (1985); **64**, 267 (1991); S. Jadach, J. H. Kühn, and Z. Was, Comput. Phys. Commun. **64**, 275 (1991); **70**, 69 (1992); **76**, 361 (1993).

[10] **JETSET 7.3**: T. Sjöstrand and M. Bengtsson, Comput. Phys. Commun. **43**, 367 (1987).

[11] P. Avery, K. Read and G. Trahern, CLEO internal note CSN-212.

[12] R. Brun *et al.*, **GEANT 3.15**, CERN DD/EE/84-1.

[13] G. Crawford *et al.* (CLEO collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **345**, 429 (1994).

[14] We use world-average branching fractions for these modes: $\mathcal{B}(\tau^- \to K^-\pi^+\pi^-\nu_\tau)=$ 0.0037 ± 0.0010 and $\mathcal{B}(\tau^- \to K^-K^+\pi^-\nu_\tau)=$ 0.0013 ± 0.0003. These branching fractions were obtained by averaging the results given in Ref. [3] and the more recent results from TPC and ARGUS: D. A. Bauer *et al.* (TPC/2γ collaboration), Phys. Rev. D **50** R13 (1994); talk by C. Hast (ARGUS collaboration) presented at 1994 Rencontres de Moriond, Les Arcs, France (March 1994).

[15] M. Artuso *et al.* (CLEO collaboration), Phys. Rev. Lett. **73**, 3762 (1994).

[16] The largest K_S contributions to 3-prong τ decays are from the K^0h^- and $K^0h^-\pi^\circ$ final states. These amount to a contribution to B_3 of 0.0051 ± 0.0006 based on the CLEO measurement, M. Athanas *et al.*, submitted to this conference, GLS0460. An additional contribution of 0.0004 ± 0.0001 comes from the $K^0K^0\pi^-$ final state, observed for the first time by CLEO and reported in R. Balest *et al.*, submitted to this conference, GLS0455.

[17] The **KORALB** relative amplitudes for the $\omega\pi$ and the three $\rho\pi\pi$ combinations were individually tuned to obtain agreement with the data. The result has approximately equal amplitudes for the ρ^-, ρ^0, and ρ^+ combinations.

[18] H. Albrecht *et al.* (ARGUS collaboration), Phys. Letters **B260**, 259 (1991).

[19] H. Albrecht *et al.* (ARGUS collaboration), Phys. Letters **B185**, 223 (1987).

[20] The Mark II result has been corrected by the ratio of the present world-average 3-prong branching fraction [3], after correction for K_S decays, and the one reported by the authors.

[21] Talk by P. Vaz at the Second Workshop on Tau Lepton Physics, Columbus, OH (1992). There is no written documentation of this result.

[22] All previous measurements, with the exception of ARGUS, included modes with more than one π° (explicitly so for the recent CELLO and ALEPH measurements). Thus we have decreased all except the ARGUS branching fractions by the CLEO result for the

$\tau \to 3h^{\pm}2\pi^{\circ}\nu_{\tau}$ decay, $0.0048 \pm 0.0004 \pm 0.0004$. The actual correction is probably even greater since efficiencies for events with two π°'s were probably larger than for one π°. We make this correction anyway since a comparison of the CLEO result with the older measurements without correction would be misleading.

[23] D. Decamp *et al.* (ALEPH collaboration), Z. Phys. C **54**, 211 (1992).