First Search for CP violation in Tau Lepton Decay

S. Anderson,[1] Y. Kubota,[1] S. J. Lee,[1] J. J. O'Neill,[1] R. Poling,[1] T. Riehle,[1] A. Smith,[1]
M. S. Alam,[2] S. B. Athar,[2] Z. Ling,[2] A. H. Mahmood,[2] S. Timm,[2] F. Wappler,[2]
A. Anastassov,[3] J. E. Duboscq,[3] D. Fujino,[3,*] K. K. Gan,[3] T. Hart,[3] K. Honscheid,[3]
H. Kagan,[3] R. Kass,[3] J. Lee,[3] H. Schwarthoff,[3] M. B. Spencer,[3] M. Sung,[3] A. Undrus,[3,†]
A. Wolf,[3] M. M. Zoeller,[3] S. J. Richichi,[4] H. Severini,[4] P. Skubic,[4] M. Bishai,[5] J. Fast,[5]
J. W. Hinson,[5] N. Menon,[5] D. H. Miller,[5] E. I. Shibata,[5] I. P. J. Shipsey,[5] M. Yurko,[5]
S. Glenn,[6] Y. Kwon,[6,‡] A.L. Lyon,[6] S. Roberts,[6] E. H. Thorndike,[6] C. P. Jessop,[7]
K. Lingel,[7] H. Marsiske,[7] M. L. Perl,[7] V. Savinov,[7] D. Ugolini,[7] X. Zhou,[7] T. E. Coan,[8]
V. Fadeyev,[8] I. Korolkov,[8] Y. Maravin,[8] I. Narsky,[8] V. Shelkov,[8] J. Staeck,[8]
R. Stroynowski,[8] I. Volobouev,[8] J. Ye,[8] M. Artuso,[9] F. Azfar,[9] A. Efimov,[9] M. Goldberg,[9]
D. He,[9] S. Kopp,[9] G. C. Moneti,[9] R. Mountain,[9] S. Schuh,[9] T. Skwarnicki,[9] S. Stone,[9]
G. Viehhauser,[9] J.C. Wang,[9] X. Xing,[9] J. Bartelt,[10] S. E. Csorna,[10] V. Jain,[10,§]
K. W. McLean,[10] S. Marka,[10] R. Godang,[11] K. Kinoshita,[11] I. C. Lai,[11] P. Pomianowski,[11]
S. Schrenk,[11] G. Bonvicini,[12] D. Cinabro,[12] R. Greene,[12] L. P. Perera,[12] G. J. Zhou,[12]
M. Chadha,[13] S. Chan,[13] G. Eigen,[13] J. S. Miller,[13] M. Schmidtler,[13] J. Urheim,[13]
A. J. Weinstein,[13] F. Würthwein,[13] D. W. Bliss,[14] D. E. Jaffe,[14] G. Masek,[14] H. P. Paar,[14]
E. M. Potter,[14] S. Prell,[14] V. Sharma,[14] D. M. Asner,[15] J. Gronberg,[15] T. S. Hill,[15]
D. J. Lange,[15] R. J. Morrison,[15] H. N. Nelson,[15] T. K. Nelson,[15] D. Roberts,[15]
B. H. Behrens,[16] W. T. Ford,[16] A. Gritsan,[16] J. Roy,[16] J. G. Smith,[16] J. P. Alexander,[17]
R. Baker,[17] C. Bebek,[17] B. E. Berger,[17] K. Berkelman,[17] K. Bloom,[17] V. Boisvert,[17]
D. G. Cassel,[17] D. S. Crowcroft,[17] M. Dickson,[17] S. von Dombrowski,[17] P. S. Drell,[17]
K. M. Ecklund,[17] R. Ehrlich,[17] A. D. Foland,[17] P. Gaidarev,[17] L. Gibbons,[17]
B. Gittelman,[17] S. W. Gray,[17] D. L. Hartill,[17] B. K. Heltsley,[17] P. I. Hopman,[17]
J. Kandaswamy,[17] D. L. Kreinick,[17] T. Lee,[17] Y. Liu,[17] N. B. Mistry,[17] C. R. Ng,[17]
E. Nordberg,[17] M. Ogg,[17,**] J. R. Patterson,[17] D. Peterson,[17] D. Riley,[17] A. Soffer,[17]
B. Valant-Spaight,[17] C. Ward,[17] M. Athanas,[18] P. Avery,[18] C. D. Jones,[18] M. Lohner,[18]
S. Patton,[18] C. Prescott,[18] J. Yelton,[18] J. Zheng,[18] G. Brandenburg,[19] R. A. Briere,[19]
A. Ershov,[19] Y. S. Gao,[19] D. Y.-J. Kim,[19] R. Wilson,[19] H. Yamamoto,[19] T. E. Browder,[20]
Y. Li,[20] J. L. Rodriguez,[20] S. K. Sahu,[20] T. Bergfeld,[21] B. I. Eisenstein,[21] J. Ernst,[21]
G. E. Gladding,[21] G. D. Gollin,[21] R. M. Hans,[21] E. Johnson,[21] I. Karliner,[21]
M. A. Marsh,[21] M. Palmer,[21] M. Selen,[21] J. J. Thaler,[21] K. W. Edwards,[22] A. Bellerive,[23]
R. Janicek,[23] D. B. MacFarlane,[23] P. M. Patel,[23] A. J. Sadoff,[24] R. Ammar,[25]
P. Baringer,[25] A. Bean,[25] D. Besson,[25] D. Coppage,[25] C. Darling,[25] R. Davis,[25] S. Kotov,[25]
I. Kravchenko,[25] N. Kwak,[25] and L. Zhou[25]

(CLEO Collaboration)

[1] *University of Minnesota, Minneapolis, Minnesota 55455*
[2] *State University of New York at Albany, Albany, New York 12222*
[3] *Ohio State University, Columbus, Ohio 43210*
[4] *University of Oklahoma, Norman, Oklahoma 73019*
[5] *Purdue University, West Lafayette, Indiana 47907*

[6] *University of Rochester, Rochester, New York 14627*
[7] *Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309*
[8] *Southern Methodist University, Dallas, Texas 75275*
[9] *Syracuse University, Syracuse, New York 13244*
[10] *Vanderbilt University, Nashville, Tennessee 37235*
[11] *Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061*
[12] *Wayne State University, Detroit, Michigan 48202*
[13] *California Institute of Technology, Pasadena, California 91125*
[14] *University of California, San Diego, La Jolla, California 92093*
[15] *University of California, Santa Barbara, California 93106*
[16] *University of Colorado, Boulder, Colorado 80309-0390*
[17] *Cornell University, Ithaca, New York 14853*
[18] *University of Florida, Gainesville, Florida 32611*
[19] *Harvard University, Cambridge, Massachusetts 02138*
[20] *University of Hawaii at Manoa, Honolulu, Hawaii 96822*
[21] *University of Illinois, Urbana-Champaign, Illinois 61801*
[22] *Carleton University, Ottawa, Ontario, Canada K1S 5B6*
and the Institute of Particle Physics, Canada
[23] *McGill University, Montréal, Québec, Canada H3A 2T8*
and the Institute of Particle Physics, Canada
[24] *Ithaca College, Ithaca, New York 14850*
[25] *University of Kansas, Lawrence, Kansas 66045*
(September 1, 1998)

Abstract

We have performed the first search for CP violation in tau lepton decay. CP violation in lepton decay does not occur in the minimal standard model but can occur in extensions such as the multi-Higgs doublet model. It appears as a characteristic difference between the τ^- and τ^+ decay angular distributions for the semi-leptonic decay modes such as $\tau^- \to K^0\pi^-\nu$. We define an observable

---

*Permanent address: Lawrence Livermore National Laboratory, Livermore, CA 94551.

†Permanent address: BINP, RU-630090 Novosibirsk, Russia.

‡Permanent address: Yonsei University, Seoul 120-749, Korea.

§Permanent address: Brookhaven National Laboratory, Upton, NY 11973.

**Permanent address: University of Texas, Austin TX 78712.

asymmetry to exploit this and find no evidence for any CP violation.

Typeset using REVTEX

To date CP violation has only been observed in the kaon system [1] and its origin remains unknown. In the minimal standard model (MSM) CP violation is restricted to the quark sector and cannot occur in lepton decay [2]. It can, however, occur in extensions to the MSM such as the three Higgs doublet model [3]. It appears that there is insufficient CP violation in the MSM to generate the apparent matter-antimatter asymmetry of the universe [4]. Searches for additional CP violation beyond the MSM may help reconcile this problem.

CP violation appears as a phase θ_{cp} in the gauge boson-fermion coupling constant, CP:$\theta_{cp} \to -\theta_{cp}$. The physical effects of such a phase are only manifest in the interference of two amplitudes with both relative CP-odd phase θ_{cp} and relative CP-even phase δ (the interference term is proportional to $\cos(\delta - \theta_{cp})$). In tau lepton decay the two amplitudes could come from the MSM vector boson exchange (W) and the extended standard model scalar (Higgs) exchange. The CP-odd phase comes from the imaginary part of the complex scalar coupling constant. The CP-even phase difference is provided by the final state interaction (strong) phase that is different for s-wave scalar exchange and p-wave vector exchange and only arises in semi-leptonic decay modes with at least two final state hadrons ($\tau^- \to h_1 h_2 \nu_\tau$). The final state interaction is described by the s-wave and p-wave form factors, $F_s = |F_s|e^{i\delta_s}$ and $F_p = |F_p|e^{i\delta_p}$ respectively so that the strong phase difference is $\delta_{strong} = \delta_p - \delta_s$. The CP-violating $s-p$ wave interference term is then proportional to $|F_p||F_s|g\cos(\delta_{strong} - \theta_{cp})\cos\beta\cos\psi$, where β and ψ are physical decay angles measured in the hadronic rest frame ($\vec{p}_{h_1} + \vec{p}_{h_2} = 0$) [5]. The direction of the laboratory frame as viewed from the hadronic rest frame is $\vec{p}_{lab}$ and β is the angle between the direction of h_1 or h_2 and $\vec{p}_{lab}$. ψ is the angle between the tau flight direction and $\vec{p}_{lab}$. The ratio of scalar to vector coupling strength is g (i.e. g is in units of $G_F/2\sqrt{2}$). Since the sign of θ_{cp} changes for the CP-conjugate τ^- and τ^+, we define an experimentally measurable asymmetry $A_{obs}^{sample}(\cos\beta\cos\psi)$ for an event sample in terms of the number of events from $\tau^\pm$ decay, $N^\pm(\cos\beta\cos\psi)$, in a particular interval of $\cos\beta\cos\psi$:

$$A_{obs}^{sample}(\cos\beta\cos\psi) = \frac{N^+(\cos\beta\cos\psi) - N^-(\cos\beta\cos\psi)}{N^+(\cos\beta\cos\psi) + N^-(\cos\beta\cos\psi)}$$

The theoretically calculable CP asymmetry for a particular decay mode, A_{theory}^{mode}, assuming a perfect detector is:

$$A_{theory}^{mode}(\cos\beta\cos\psi) = Kg\sin\delta_{strong}\sin\theta_{cp}\cos\beta\cos\psi$$

K is a constant calculated from the matrix element that depends on the particular choice of form factors for the decay mode. To relate A_{obs}^{sample} to A_{theory}^{mode} we need to take into account the imperfections of a real detector. It is experimentally very difficult to isolate a pure event sample of one particular mode due to backgrounds. A sample will consist of a set of modes, each a fraction f_{mode}^{sample} of the total sample, with a theoretically expected CP asymmetry α_{mode} relative to the signal mode. The finite resolution of a real detector can reduce (dilute) the theoretically expected CP asymmetry by a factor D_{det}. In addition differences in detection efficiency for τ^+ and τ^- can result in an observed asymmetry A_{det}^{sample} in the absence of any CP violation. Assuming A_{det}^{sample} to be small (i.e. $\ll 1$) we can relate the observed asymmetry in any event sample to the theoretical CP asymmetry of the signal mode:

$$A^{sample}_{obs} = \Sigma_{mode} f^{sample}_{mode} \alpha_{mode} D_{det} A^{sig}_{theory} + A^{sample}_{det} \quad (1)$$

The asymmetry is linear in $\cos\beta\cos\psi$ and we do not expect an overall rate asymmetry due to CP violation [6] since:

$$\int_{-1}^{+1} dx A_{theory}(x) = 0; x = \cos\beta\cos\psi$$

We select a $\tau^- \to K^0_S h^- \nu_\tau$, $K^0_S \to \pi^+\pi^-$ event sample since a mass dependent Higgs-like coupling would give the largest asymmetry in this mode and with three charged tracks in the final state the decay angles are well measured. Here h^- is a charged pion or kaon.

The data used in this analysis have been collected from e^+e^- collisions at a center of mass energy ($\sqrt{s}$) of 10.6 GeV with the CLEO II detector at the Cornell Electron Storage Ring (CESR). The total integrated luminosity of the data sample is 4.8 fb^{-1}, corresponding to the production of 4.4×10^6 $\tau^+\tau^-$ events. The CLEO II detector has been described elsewhere [7].

We select events with a total of 4 charged tracks and zero net charge. Each track must have momentum transverse to the beam axis $p_T > 0.025 E_{beam} (E_{beam} = \sqrt{s}/2)$ and $|\cos\theta| < 0.90$ where θ is the polar angle with respect to the beam direction. The event is divided into two hemispheres by requiring one of the charged tracks to be isolated by at least 90^o from the other three (1 vs 3 topology). The isolated track is then required to have momentum greater than $0.05 E_{beam}$ and $|\cos\theta| < 0.80$ to ensure efficient triggering and reduce backgrounds from two photon processes and beam gas interactions. To further reduce the two photon backgrounds and also continuum quark-antiquark production ($q\overline{q}$) we require that the net missing momentum of the event be greater than $0.03 E_{beam}$ in the transverse plane and not point to within 18^o of the beam axis. We also require the total visible energy in the event to be between $0.7 E_{beam}$ and $1.7 E_{beam}$.

Events are permitted to contain a pair of *unmatched* energy clusters in the calorimeter (i.e., those not matched with a charged particle projection) in the 1-prong hemisphere with energy greater than 100 MeV consistent with π^0 decay. After π^0 reconstruction we reject events with remaining unmatched showers of greater than 350 MeV. We further reject events with showers of energy above 100 MeV in the 3 prong hemisphere or 300 MeV in the 1-prong hemisphere provided such showers are well isolated from the nearest track projection (by at least 30 cm) and have photon-like lateral profiles. These vetoes suppress backgrounds from $q\overline{q}$ events and tau feed-across (i.e., tau decay modes containing unreconstructed π^0's or K^0_L's).

The K^0_S is identified by requiring two of the tracks in the 3-prong hemisphere to be consistent with the decay $K^0_S \to \pi^+\pi^-$. We determine the K^0_S decay point in the x-y plane (transverse to the beam direction) by the intersection of the two tracks projected onto this plane. This point must lie at least 5 mm from the mean e^+e^- interaction point (IP). We require that the distance between the two tracks in z (beam direction) at the decay point be less than 12 mm to ensure that the tracks form a good vertex in three dimensions. The distance of closest approach to the IP of the line defined by the x-y projection of the K^0_S momentum vector must be less than 2 mm. The invariant mass of the pair of tracks, assumed to be pions, must be within 20 MeV of the known K^0_S mass. We define a sideband region 30-90 MeV above and below the K^0_S mass to use as a control sample.

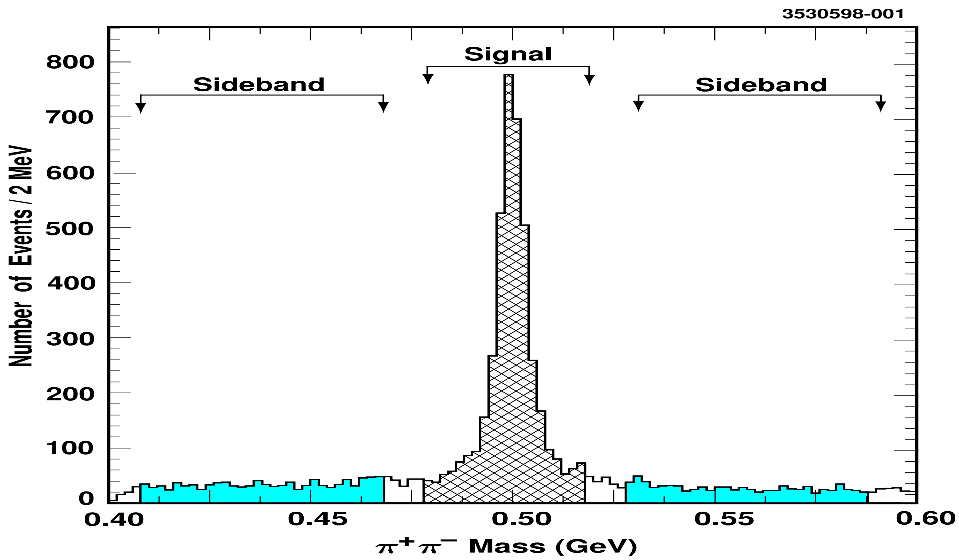

FIG. 1. The $\pi^+\pi^-$ invariant mass distribution for the final data sample.

Figure 1 shows the invariant mass distribution after all selection criteria. Using this sample we measure the asymmetry for both signal and sideband in two intervals of $\cos\beta\cos\psi$, $A_{obs}^{sig,side}(\cos\beta\cos\psi < 0)$ and $A_{obs}^{sig,side}(\cos\beta\cos\psi > 0)$, given in Table I. Both signal and sideband exhibit similar non-zero asymmetries but with low statistical significance. The measured asymmetries are insensitive to small variations in the selection criteria. In addition to CP violation, a non-zero asymmetry can arise from either a statistical fluctuation or a difference in detection efficiency for positive and negatively charged particles (A_{det}^{sample}). A Monte Carlo simulation is used to estimate the expected CP violation in terms of the extended standard model scalar coupling parameters. The sideband sample is used to empirically estimate the asymmetry due to detector effects.

	$A_{obs}(\cos\beta\cos\psi < 0)$	$A_{obs}(\cos\beta\cos\psi > 0)$
Signal	0.058 ± 0.023	0.024 ± 0.021
Sideband	0.049 ± 0.030	0.034 ± 0.033

TABLE I. Observed asymmetries in signal and sideband regions.

To estimate the expected CP-violating asymmetry, $A_{theory}^{K_S^0\pi^-\nu_\tau}$, for a pure $\tau^- \to K_S^0\pi^-\nu_\tau$ sample we use the KORALB Monte Carlo [8] to generate τ-pairs. It has been modified to include a scalar Higgs coupling in addition to the standard model W boson coupling, for the signal $K_S^0\pi^-\nu_\tau$ mode. We set $F_s = 1$ (i.e. non-resonant decay) and F_p to be a relativistic Breit-Wigner with two body p-wave energy dependent width for the $K^*(892)$ resonance, normalized so that $F_p(q^2 = 0) = 1$ where q is the four momenta transfered in the reaction.

Hence $F_p >> F_s$ for the kinematically accessible q^2 and the average strong phase difference is $\langle\delta_{strong}\rangle = \pi/2$. The GEANT code [10] is used to simulate detector response and assumes equal detection efficiencies for positive and negatively charged particles. We calculate $A^{K^0_S\pi^-\nu_\tau}_{theory}(\cos\beta\cos\psi < 0) = -0.033g\sin\theta_{cp}$ and $A^{K^0_S\pi^-\nu_\tau}_{theory}(\cos\beta\cos\psi > 0) = +0.033g\sin\theta_{cp}$ for a pure $\tau^- \to K^0_S\pi^-\nu_\tau$ signal. The dilution from detector resolution effects is negligible due to the high precision of the tracking, $D_{det} = 1.0$. From equation 1 we see that to compare $A^{K^0_S\pi^-\nu_\tau}_{theory}$ to A^{sample}_{obs} we must take into account the diluting effect of backgrounds ($f^{sample}_{mode}, \alpha_{mode}$) since the signal region is not pure $K^0_S\pi^-\nu_\tau$ and also estimate the asymmetry expected from charge dependent detection inefficiencies alone, A^{sample}_{det}.

Tau Mode	α_{mode}	f^{sig}_{mode}	f^{side}_{mode}	$(f^{sig}_{mode} - f^{side}_{mode}).\alpha_{mode}$
$K^0_S\pi^-\nu_\tau$	1	0.525 $\pm$ 0.057	0.043 $\pm$ 0.005	0.4820 $\pm$ 0.0570
$K^0_S K^-\nu_\tau$	1/20	0.124 $\pm$ 0.036	0.009 $\pm$ 0.003	0.0060 $\pm$ 0.0020
$a_1^-\nu_\tau$	1/80	0.106 $\pm$ 0.003	0.620 $\pm$ 0.013	-0.0064 $\pm$ 0.0002
$K^0_S\pi^-\pi^0\nu_\tau$	1/4	0.066 $\pm$ 0.016	0.006 $\pm$ 0.002	0.0150 $\pm$ 0.0040
$K^0_S K^0_L\pi^-\nu_\tau$	1/80	0.055 $\pm$ 0.018	0.003 $\pm$ 0.001	0.0007 $\pm$ 0 .0002
$K^0_S K^-\pi^0\nu_\tau$	1/20	0.030 $\pm$ 0.008	0.003 $\pm$ 0.001	0.0014 $\pm$ 0.0004
$\pi^+\pi^-\pi^-\pi^0\nu_\tau$	1/20	0.028 $\pm$ 0.002	0.167 $\pm$ 0.007	-0.0070 $\pm$ 0.0004
$K^-\pi^+\pi^-\nu_\tau$	1/4	0.008 $\pm$ 0.003	0.043 $\pm$ 0.007	-0.0090 $\pm$ 0.0020
others	0	0.012 $\pm$ 0.002	0.071 $\pm$ 0.017	0
$q\bar{q}$	0	0.044 $\pm$ 0.003	0.037 $\pm$ 0.003	0
Total	-	1.00 $\pm$ 0.07	1.00 $\pm$ 0.03	0.48 $\pm$ 0.06

TABLE II. Signal and sideband mode composition. $f^{sig,side}_{mode}$ is the fraction of the total signal or sideband sample for a particular mode. α_{mode} is the approximate magnitude of asymmetry expected relative to the $\tau^- \to K^0_S\pi^-\nu_\tau$ mode. The last column gives the dilution factor expected from backgrounds when the measured asymmetry in the sideband control sample is subtracted from the measured asymmetry in the signal sample, $D_{bkg} = \Sigma_{mode}(f^{sig}_{mode} - f^{side}_{mode})\alpha_{mode} = 0.48$.

Table II gives the estimated signal and sideband compositions by mode where the Lund Monte Carlo [9] has been used to generate the $q\bar{q}$ events. The backgrounds arise from our inability to distinguish kaons and pions in the desired momentum range, lack of K^0_L identification, particles that fall outside the fiducial region of the detector, and charged track mismeasurement. We note that the signal and sidebands are composed of different modes and it is unlikely that both samples would exhibit a similar CP asymmetry since the strong phases, and possibly the coupling strengths, are different for each mode. Also the samples exhibit an overall rate asymmetry not expected from CP-violating interference effects [6]. However the effects of charge dependent detection inefficiencies are similar as both samples satisfy the same kinematic selection criteria so;

$$A^{sig}_{det} = A^{side}_{det} \tag{2}$$

Studies of pions from an independent $K^0_S \to \pi^+\pi^-$ sample indicate that at low momentum the reconstruction efficiency for π^+ is slightly greater than π^- and also the reconstruction of a

K_S^0 in close proximity to a π^+ is slightly more efficient than for a π^-. The hadronic interaction of charged pions and kaons with the CsI crystals can produce fake electromagnetic clusters which can then be used to veto the event. The cross-sections for these interactions are different for positive and negative charged hadrons and cause charge dependent detection inefficiencies. All of these effects are more pronounced at lower momentum (< 1 GeV) and thus for $\cos\beta\cos\psi < 0.0$ since the pion from $\tau^- \to K_S^0\pi^-\nu_\tau$ tends to be of lower momentum in this region. The sidebands may be used as a control sample to estimate these combined effects in our signal region in a simple empirical way providing we assume that any CP-violating effects are suppressed in the sideband modes. Table II gives the expected CP-violating asymmetry α_{mode} relative to the $\tau^- \to K_S^0\pi^-\nu_\tau$ signal mode for both signal and sideband samples. Two effects cause the expected CP asymmetry in the background modes to be less than in the signal mode. First from the mass dependence of the Higgs coupling and second due to the dilution of the p-wave nature of the standard model final state. For example, the $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ mode is dominated in the standard model decay by an s-wave $\tau^- \to a_1^-\nu_\tau \to \rho^0\pi^-\nu_\tau$ intermediate state which dilutes the $s-p$ wave interference by a factor of ≈ 4 in addition to a mass suppression of m_u/m_s relative to the $K_S^0\pi^-$ mode. From table II we see that the sideband should have negligible asymmetry with respect to the signal under the assumption of a mass dependent coupling and can be used as a control sample to subtract the charge dependent detector asymmetries common to both signal and sideband. Using equations 1 and 2:

$$A_{obs}^{sub} = A_{obs}^{sig} - A_{obs}^{side} = \Sigma_{mode}(f_{mode}^{sig} - f_{mode}^{side})\alpha_{mode}A_{theory}^{K_S^0\pi^-\nu_\tau} = D_{bkg}A_{theory}^{K_S^0\pi^-\nu_\tau}$$

Taking D_{bkg} from table II we see that if a true CP violation exists the subtracted quantity should still exhibit a significant asymmetry but diluted by a factor 0.48. From Table I the measured subtracted asymmetry is $A_{obs}^{sub}(\cos\beta\cos\psi < 0) = 0.009 \pm 0.038$, $A_{obs}^{sub}(\cos\beta\cos\psi > 0) = -0.010 \pm 0.039$ which is consistent with no CP violation. This can be compared with a revised Monte Carlo estimate that takes into account the background dilution factor, $D_{bkg}A_{theory}^{K_S^0\pi^-\nu_\tau}(\cos\beta\cos\psi < 0) = -0.016g\sin\theta_{cp}$, $D_{bkg}A_{theory}^{K_S^0\pi^-\nu_\tau}(\cos\beta\cos\psi > 0) = 0.016g\sin\theta_{cp}$, to give the constraint $-1.7 < g\sin\theta_{cp} < 0.6$ at the 90 % confidence limit.

To cross check our assumption of suppressed CP violation in the sidebands we measure the asymmetry in an independent high-purity high-statistics data sample of the dominant sideband mode, $\tau^- \to a_1^-\nu_\tau$, using the selection criteria of reference [11]. We find $A_{obs}^{a_1}(\cos\beta\cos\psi < 0) = -0.0013 \pm 0.0047, A_{obs}^{a_1}(\cos\beta\cos\psi > 0) = -0.0023 \pm 0.0047$ giving no evidence for CP violation. The higher track momentum and cluster veto thresholds combined with the absence of a K_S^0 requirement from this sample removes the contribution to the asymmetry from charge dependent detection inefficiencies but a true CP-violating effect should remain. We note that by measuring the CP-violating asymmetry in the dominant sideband mode as zero our results are approximately valid for a non-mass dependent coupling. However, we cannot fully relax this assumption due to the difficulty of empirically isolating a sample of each background mode in which to measure the asymmetry.

In conclusion we have performed the first search for CP violation in tau lepton decay. We find no evidence for CP violation and constrain the coupling strength g (in units of $G_F/2\sqrt{2}$) and phase θ_{CP} of a new CP-violating mass-dependent scalar interaction, $-1.7 < g\sin\theta_{cp} < 0.6$ at the 90 % confidence limit , assuming a non-resonant amplitude for the scalar decay. At the forthcoming B-factory experiments we anticipate substantial improvements in sensitivity both from the increased statistical precision and detector improvements. The addition of K_L^0 detection, K^-/π^- separation and improved precision tracking will significantly decrease the backgrounds which dilute the asymmetries.

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. Department of Energy, Research Corporation, the Natural Sciences and Engineering Research Council of Canada, the A.P. Sloan Foundation, the Swiss National Science Foundation, and the Alexander von Humboldt Stiftung.

REFERENCES

[1] J.H.Christenson, J.W. Cronin, V.L. Fitch, and R. Turlay, Phys. Rev. Lett. **13**, 138 (1964).

[2] N. Cabbibo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[3] S. Weinberg, Phys. Rev. Lett. **37**, 657 (1976).

[4] *The Early Universe*, E. W. Kolb and M. S. Turner, Addison Wesley, New York (1994).

[5] J.H. Kuhn and E. Mirkes, Phys. Lett. B **398**, 407 (1997); Y.S. Tsai, Nucl. Phys. B (Proc. Suppl.) **55C**, 293 (1997).

[6] In the most general case we do not expect an overall rate asymmetry. The angular dependence of an s, p, d etc.,-wave amplitude is given by the Legendre polynomials $P_{m=0,1,2}(x)$ so that the angular dependence of a CP-violating interference term is given by $P_m(x)P_n(x)$ and since

$$\int_{-1}^{+1} dx P_m(x) P_n(x) = \frac{2}{2n+1}\delta_{mn}$$

we can only have a non-zero rate asymmetry if $m = n$ in which case the strong phases of the two amplitudes will be equal ($\sin\delta_{strong} = 0$) so that the overall rate asymmetry will be zero.

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

[8] `KORALB (v. 2.2)/TAUOLA (v 2.4)`: S. Jadach and Z. Was, Comput. Phys. Commun. **36** , 191 (1985) and *ibid.* **64**, 267 (1991); S. Jadach, J.H. Kuhn and Z. Was, Comput. Phys. Commun. **64**, 275 (1991), *ibid.* **70**, 69 (1992), and *ibid.* **76**, 361 (1993).

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

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

[11] R. Balest *et al.*, Phys. Rev. Lett. **75**, 3809 (1995).