CLEO CONF 96-9
ICHEP96 PA07-079

Search for neutrinoless τ decays: $\tau \to e\gamma$ and $\tau \to \mu\gamma$

CLEO Collaboration

(July 19, 1996)

Abstract

A search for the lepton family number violating decays: $\tau \to e\gamma$ and $\tau \to \mu\gamma$ has been performed using CLEO-II data. No evidence for the signal has been found and the corresponding upper limits are $B(\tau \to e\gamma) < 2.7 \cdot 10^{-6}$ and $B(\tau \to \mu\gamma) < 2.9 \cdot 10^{-6}$ at 90% CL.

B. Nemati,[1] S. J. Richichi,[1] W. R. Ross,[1] P. Skubic,[1] M. Wood,[1] M. Bishai,[2] J. Fast,[2] E. Gerndt,[2] J. W. Hinson,[2] D. H. Miller,[2] E. I. Shibata,[2] I. P. J. Shipsey,[2] M. Yurko,[2] L. Gibbons,[3] S. D. Johnson,[3] Y. Kwon,[3] S. Roberts,[3] E. H. Thorndike,[3] C. P. Jessop,[4] K. Lingel,[4] H. Marsiske,[4] M. L. Perl,[4] S. F. Schaffner,[4] D. Ugolini,[4] R. Wang,[4] X. Zhou,[4] T. E. Coan,[5] V. Fadeyev,[5] I. Korolkov,[5] Y. Maravin,[5] I. Narsky,[5] V. Shelkov,[5] R. Stroynowski,[5] J. Staeck,[5] I. Volobouev,[5] J. Ye,[5] M. Artuso,[6] A. Efimov,[6] M. Gao,[6] M. Goldberg,[6] R. Greene,[6] F. Frasconi,[6] D. He,[6] S. Kopp,[6] G. C. Moneti,[6] R. Mountain,[6] Y. Mukhin,[6] S. Schuh,[6] T. Skwarnicki,[6] S. Stone,[6] X. Xing,[6] J. Bartelt,[7] S. E. Csorna,[7] V. Jain,[7] S. Marka,[7] A. Freyberger,[8] R. Godang,[8] D. Gibaut,[8] K. Kinoshita,[8] I. C. Lai,[8] P. Pomianowski,[8] S. Schrenk,[8] G. Bonvicini,[9] D. Cinabro,[9] L. Perera,[9] B. Barish,[10] M. Chadha,[10] S. Chan,[10] G. Eigen,[10] J. S. Miller,[10] C. O'Grady,[10] M. Schmidtler,[10] J. Urheim,[10] A. J. Weinstein,[10] F. Würthwein,[10] D. M. Asner,[11] D. W. Bliss,[11] W. S. Brower,[11] G. Masek,[11] H. P. Paar,[11] J. Gronberg,[12] C. M. Korte,[12] D. J. Lange,[12] R. Kutschke,[12] S. Menary,[12] R. J. Morrison,[12] S. Nakanishi,[12] H. N. Nelson,[12] T. K. Nelson,[12] C. Qiao,[12] J. D. Richman,[12] D. Roberts,[12] A. Ryd,[12] H. Tajima,[12] M. S. Witherell,[12] R. Balest,[13] B. H. Behrens,[13] K. Cho,[13] W. T. Ford,[13] H. Park,[13] P. Rankin,[13] J. Roy,[13] J. G. Smith,[13] J. P. Alexander,[14] C. Bebek,[14] B. E. Berger,[14] K. Berkelman,[14] K. Bloom,[14] D. G. Cassel,[14] H. A. Cho,[14] D. M. Coffman,[14] D. S. Crowcroft,[14] M. Dickson,[14] P. S. Drell,[14] R. Ehrlich,[14] R. Elia,[14] A. D. Foland,[14] P. Gaidarev,[14] R. S. Galik,[14] B. Gittelman,[14] S. W. Gray,[14] D. L. Hartill,[14] B. K. Heltsley,[14] P. I. Hopman,[14] S. L. Jones,[14] J. Kandaswamy,[14] N. Katayama,[14] P. C. Kim,[14] D. L. Kreinick,[14] T. Lee,[14] Y. Liu,[14] G. S. Ludwig,[14] J. Masui,[14] J. Mevissen,[14] N. B. Mistry,[14] C. R. Ng,[14] E. Nordberg,[14] M. Ogg,[14,*] J. R. Patterson,[14] D. Peterson,[14] D. Riley,[14] A. Soffer,[14] C. Ward,[14] P. Avery,[15] M. Athanas,[15] C. D. Jones,[15] M. Lohner,[15] C. Prescott,[15] S. Yang,[15] J. Yelton,[15] J. Zheng,[15] G. Brandenburg,[16] R. A. Briere,[16] D. Y.-J. Kim,[16] T. Liu,[16] M. Saulnier,[16] R. Wilson,[16] H. Yamamoto,[16] T. E. Browder,[17] F. Li,[17] Y. Li,[17] J. L. Rodriguez,[17] T. Bergfeld,[18] B. I. Eisenstein,[18] J. Ernst,[18] G. E. Gladding,[18] G. D. Gollin,[18] E. Johnson,[18] I. Karliner,[18] M. Palmer,[18] M. Selen,[18] J. J. Thaler,[18] K. W. Edwards,[19] A. Bellerive,[20] D. I. Britton,[20] R. Janicek,[20] D. B. MacFarlane,[20] K. W. McLean,[20] P. M. Patel,[20] A. J. Sadoff,[21] R. Ammar,[22] P. Baringer,[22] A. Bean,[22] D. Besson,[22] D. Coppage,[22] C. Darling,[22] R. Davis,[22] N. Hancock,[22] S. Kotov,[22] I. Kravchenko,[22] N. Kwak,[22] S. Anderson,[23] Y. Kubota,[23] M. Lattery,[23] J. J. O'Neill,[23] S. Patton,[23] R. Poling,[23] T. Riehle,[23] A. Smith,[23] V. Savinov,[23] M. S. Alam,[24] S. B. Athar,[24] Z. Ling,[24] A. H. Mahmood,[24] H. Severini,[24] S. Timm,[24] F. Wappler,[24] A. Anastassov,[25] S. Blinov,[25,†] J. E. Duboscq,[25] R. Fulton,[25] D. Fujino,[25] K. K. Gan,[25] T. Hart,[25] K. Honscheid,[25] H. Kagan,[25] R. Kass,[25] J. Lee,[25] M. Sung,[25] A. Undrus,[25,†] R. Wanke,[25] A. Wolf,[25] and M. M. Zoeller[25]

[1]University of Oklahoma, Norman, Oklahoma 73019
[2]Purdue University, West Lafayette, Indiana 47907

---

[*]Permanent address: University of Texas at Austin.

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

[3]University of Rochester, Rochester, New York 14627
[4]Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309
[5]Southern Methodist University, Dallas, Texas 75275
[6]Syracuse University, Syracuse, New York 13244
[7]Vanderbilt University, Nashville, Tennessee 37235
[8]Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061
[9]Wayne State University, Detroit, Michigan 48202
[10]California Institute of Technology, Pasadena, California 91125
[11]University of California, San Diego, La Jolla, California 92093
[12]University of California, Santa Barbara, California 93106
[13]University of Colorado, Boulder, Colorado 80309-0390
[14]Cornell University, Ithaca, New York 14853
[15]University of Florida, Gainesville, Florida 32611
[16]Harvard University, Cambridge, Massachusetts 02138
[17]University of Hawaii at Manoa, Honolulu, Hawaii 96822
[18]University of Illinois, Champaign-Urbana, Illinois 61801
[19]Carleton University, Ottawa, Ontario, Canada K1S 5B6
and the Institute of Particle Physics, Canada
[20]McGill University, Montréal, Québec, Canada H3A 2T8
and the Institute of Particle Physics, Canada
[21]Ithaca College, Ithaca, New York 14850
[22]University of Kansas, Lawrence, Kansas 66045
[23]University of Minnesota, Minneapolis, Minnesota 55455
[24]State University of New York at Albany, Albany, New York 12222
[25]Ohio State University, Columbus, Ohio 43210

Non-conservation of the leptonic quantum number is expected in many extensions of the Standard Model and searches for lepton number violating decays provide strong constraints on possible new physics processes. The best limits so far have been obtained in the studies of μ decays: $B(\mu \to e\gamma) < 4.9 \cdot 10^{-11}$ and $B(\mu \to eee) < 1.0 \cdot 10^{-12}$ [1]. Even though we cannot hope for reaching a similar level of precision for τ's, the search for the lepton number violating τ decays becomes competitive with these results when discussing theoretical models with mass dependent couplings. For example, a recent prediction based on superstring model [2] gives an enhancement of τ decays over the corresponding μ decays of $B(\tau \to \mu\gamma) = 2 \cdot 10^5 B(\mu \to e\gamma)$.

Lepton number violating neutrinoless τ decays have been studied extensively. Upper limits have been set for branching ratios for 22 channels with 3 charged particles in the final state [3] at the level of few times 10^{-6} and the limit $B(\tau \to \mu\gamma) < 4.2 \cdot 10^{-6}$ [4] has been also published. This paper describes the status of a search for the neutrinoless decay $\tau \to e\gamma$ that has not been previously studied at CLEO. The previous best upper limit for this channel has been obtained by ARGUS as $B(\tau \to e\gamma) < 1.2 \cdot 10^{-4}$ at 90% CL [5]. A new analysis searching for the $\mu\gamma$ final state is also presented.

In this analysis we use data from the reaction $e^+e^- \to \tau^+\tau^-$ collected by the CLEO experiment at CESR at or near $\Upsilon(4S)$ energy. The data correspond to the total integrated luminosity of about 4.68 fb^{-1} and contain about $4.24 \cdot 10^6$ $\tau^+\tau^-$ pairs. We search for events in a 1-vs-1 topology where the signal candidate τ decays into $e\gamma$ or $\mu\gamma$ and the tag side represents all standard τ decays into one charged particle, any number of photons and at least one neutrino. The selection criteria are based on the studies of two Monte Carlo samples of 10,000 τ pair events each. The Monte Carlo is based on the KORALB [6] generator with a two-body phase space used for the $e\gamma$ and $\mu\gamma$ decay modes. The generated momenta vectors are then passed through the detector simulation program based on the GEANT package [7] and through CLEO event reconstruction software. Studies of the simulated signal allowed us to determine event selection criteria.

We select $\tau^+\tau^-$ pair events with 2 good tracks and with a total charge equal to zero. We also require that the angle between the charged tracks must exceed 90°. Since the radiative Bhabha scattering and μ-pair production provide high background rate, we allow only one identified electron or one identified muon per event. That means that in the $e\gamma$ search one of the tracks has to be positively identified as e while the other should be inconsistent with the electron hypothesis and in the $\mu\gamma$ search one of the tracks has to be identified as μ while the other has to be inconsistent with the muon hypothesis. About 19.3% of $e\gamma$ Monte Carlo events and 36.2% of $\mu\gamma$ Monte Carlo events survive these criteria.

In addition, we require each candidate event to have exactly one photon in the lepton hemisphere. We identify a photon in the calorimeter as a neutral cluster with a single local maximum in the set of adjacent crystal cells that is separated by more than 20° from the closest charged track. This photon must lie in a good section of the calorimeter barrel (i.e., $cos\ \theta < 0.71$) and have energy deposition in the calorimeter greater than 300 MeV. The minimum energy cut of $E_\gamma > 300$ MeV is imposed to minimize the effect of the noise in the calorimeter while preserving the event selection efficiency as dictated by the kinematics of 2-body τ decays. The angle between the direction of the photon and the momentum of the electron or the muon track must be within limits of $0.4 < \cos\theta_{l\gamma} < 0.8$, where the upper limit is dictated by kinematics, and the lower limit by the selection efficency. For the

$e\gamma$ decays the Monte Carlo distribution of the cosine of the angle between the lepton and photon direction is compared in Fig. 1 with the data. The corresponding distributions for the $\tau \to \mu\gamma$ decays are similar. About 14.6% of the $e\gamma$ and 20.9% of the $\mu\gamma$ original Monte Carlo sample survive these initial selection criteria.

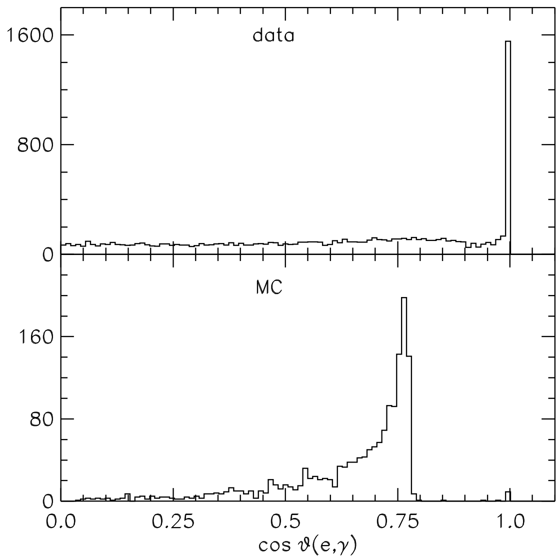

FIG. 1. $\cos\theta_{e\gamma}$ distribution in data and signal Monte Carlo.

For electron identification we use both dE/dx and calorimeter information. We require for the electron candidate that its specific ionization must be within 3 standard deviations from the expected value, and the energy deposited in the calorimeter must be matched with the track momentum measured in the drift chamber:

$$0.8 < \frac{E}{|p|} < 1.1 \ .$$

After those cuts are applied in the $e\gamma$ analysis, a large fraction of soft electrons still survive on the tag side. Therefore, unless the tagging track is identified as a muon, we impose additional requirements: the tagging track's transverse momentum must lie above 300 MeV/c, its momentum must point into the good portion of the calorimeter barrel ($cos\ \theta < 0.71$), and the ratio of the energy deposited in the calorimeter to the momentum measured in the drift chamber must be less than 0.6.

To be identified as μ a particle has to pass through at least three absorption lengths of the muon filter, its track measured in the drift chamber must correlate with hits in the muon chamber and its energy deposited in the calorimeter must be compatible with that expected for a minimum ionizing particle: 0.1 GeV $< E <$ 0.4 GeV.

The main sources of background in the selected sample are due to Bhabha scattering, μ-pair production, radiative $\tau \to e\nu\nu$ and $\tau \to \mu\nu\nu$ decays and two photon processes.

A large fraction of such background can be rejected by imposing the cut on the angle between the momentum of the tagging particle and the missing momentum of the event. We calculate the missing momentum as a negative of the sum of momenta of the two charged tracks and all photons detected in the calorimeter with energies above 30 MeV. Since there must be at least one undetected neutrino on the tag side, the missing momentum in the event is expected to fall into the tagging track hemisphere, while for the radiative processes the missing momentum should be small and randomly distributed with respect to the charged track on the tag side (see Fig. 2). Actually we require that the cosine of the angle between the total missing momentum of the event and the momentum of the tagging particle must be greater than 0.4.

The neutrino emission on the tag side also results in a large transverse momentum with respect to the beam direction. The data, however, show a pronounced peak near zero transverse momentum that comes mostly from copious 2-photon and radiative QED processes. This background is eliminated by requiring the total transverse momentum of the event to be greater than 0.3 GeV/c (see Fig. 3).

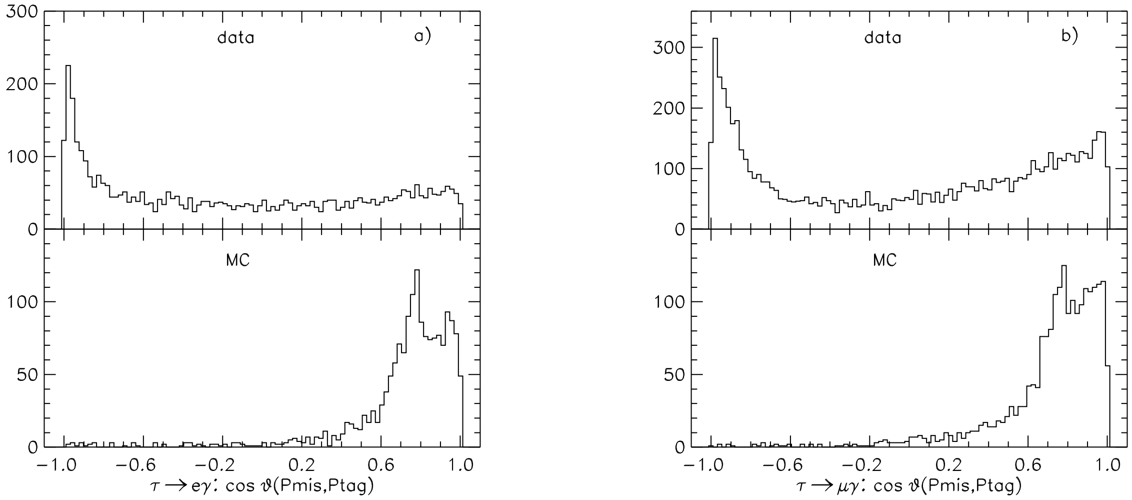

FIG. 2. Cosine of the angle between the missing momentum and the momentum of the tagging track in data and signal Monte Carlo. Region $\cos(\vec{p}_{mis}, \vec{p}_{tag}) < 0.4$ is rejected. a) $\tau \to e\gamma$; b) $\tau \to \mu\gamma$.

About 13.2% of $e\gamma$ and 17.9% of $\mu\gamma$ Monte Carlo events survive these requirements.

The final identification of the signal is based on kinematic constraints requiring for a neutrinoless τ decay to have the total energy and the effective mass of the $e\gamma$ or $\mu\gamma$ consistent with the beam energy and with the τ mass respectively. To define a signal region in mass vs energy plane we study the corresponding Monte Carlo distributions. We fit each distribution to a gaussian function plus nth order polynomial. The order of the polynomial was increased until a fit with a confidence level above 20% was obtained. We then define the signal region to be within ± 3 standard deviations of the fitted gaussian component of the distribution. In Table 1 we show mean values of the τ mass and beam energy and their corresponding resolutions obtained with this fitting technique. The $\pm 3\sigma$ cut is imposed not on the beam energy itself, but on the difference $\Delta E = E_{l\gamma} - E_{run}$ between the total energy of lepton and photon and the beam energy in a particular run. The input τ mass and beam energy in the

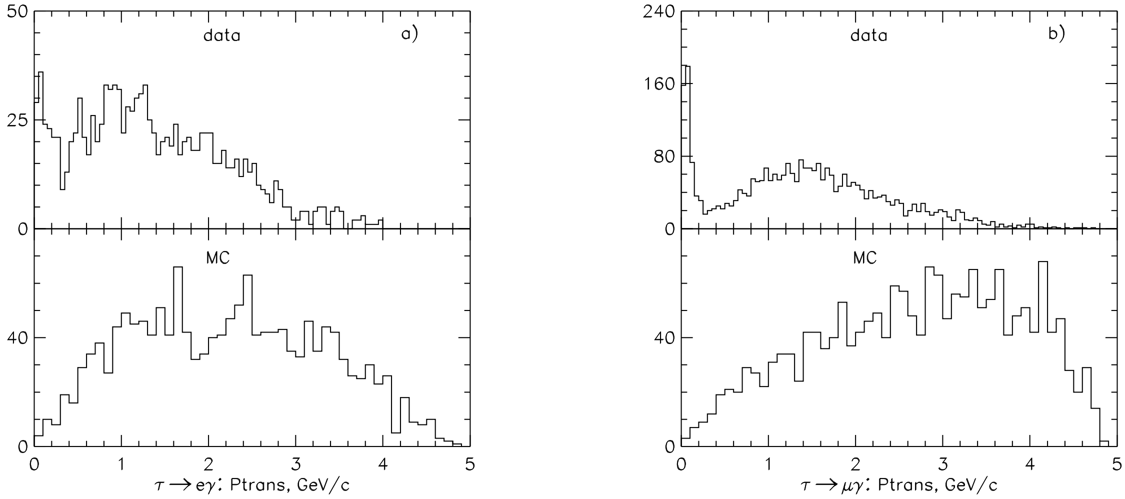

FIG. 3. Total transverse momentum of the event in data and signal Monte Carlo. Region $p_T < 0.3$ GeV/c is rejected. a) $\tau \rightarrow e\gamma$; b) $\tau \rightarrow \mu\gamma$.

Monte Carlo samples were taken to be 1.777 GeV/c^2 and 5.29 GeV respectively.

TABLE 1. Mean values of effective mass, energy and corresponding resolutions obtained from the fits to Monte Carlo data.

channel	m_τ, GeV/c^2	σ_m, GeV/c^2	$E_{l\gamma} - E_{run}$, GeV	σ_E, GeV	MC efficiency, %
$\tau \rightarrow e\gamma$	1.772	0.024	-0.013	0.060	10.1
$\tau \rightarrow \mu\gamma$	1.774	0.025	-0.010	0.053	14.4

There are no $e\gamma$ and three $\mu\gamma$ events remaining in the signal region.

In order to understand the origin of the remaining background we applied our selection criteria to about $27 \cdot 10^6$ continuum hadronic Monte Carlo events and to about $17 \cdot 10^6$ generic τ Monte Carlo events. No hadronic Monte Carlo events satisfied the selection requirements. There are 2 $e\gamma$ and 4 $\mu\gamma$ events from generic τ Monte Carlo that survived all the cuts. These correspond to 0.5 and 1.0 event, respectively, after normalization to the same luminosity as the data. We estimate the amount of the expected background in the signal regions directly from the data by extrapolating it from the sideband region. We assume that the background distributions are linear in the vicinity of m_τ and E_{beam} and define the sideband regions between 5 and 8 σ as shown in Fig. 4. The region $|m_\tau - \langle m_\tau \rangle| > 5\sigma_m$, $|E_{beam} - \langle E_{beam} \rangle| > 5\sigma_E$ captures only 4.3% of $e\gamma$ and 1.8% of $\mu\gamma$ Monte Carlo samples, and we neglect the small bias introduced by this extrapolation back into the signal region. The extrapolation from the sidebands allows us to estimate the expected background as 2.5 events for the $e\gamma$ sample and 5.5 events for the $\mu\gamma$ analysis. To check that the background value is stable with respect to the sideband region geometry, we used the same technique and varied the sideband definition. The background estimates were the same within ± 1.0 event. Finally, we use the expectation value of 5.5 background events for the $\mu\gamma$ analysis. The background rate is higher for the $\mu\gamma$ analysis because in this case we apply a loose selection criteria to the tagging track, and a large fraction of soft muons which failed the standard muon identification procedure survive on the tag side.

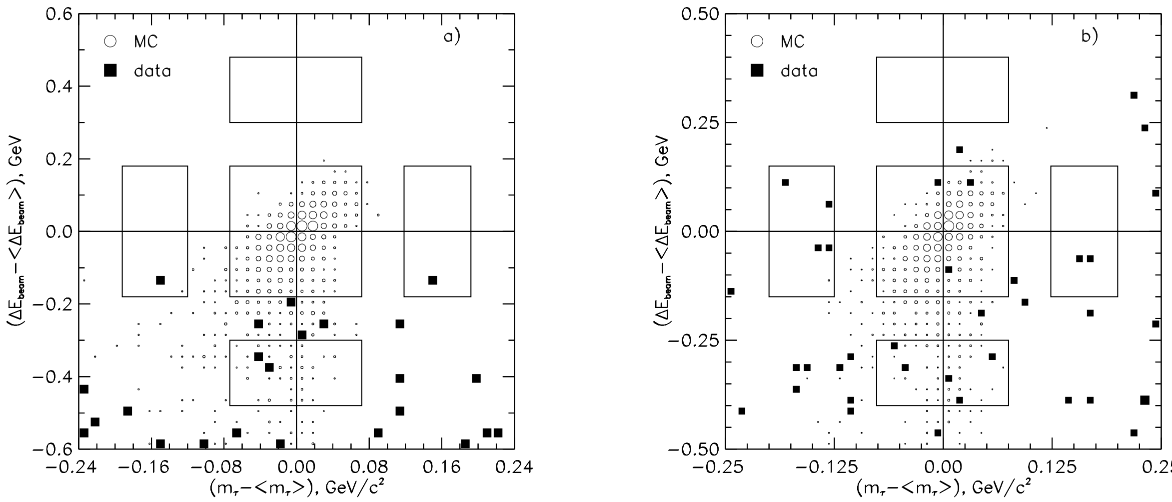

FIG. 4. $(\Delta E_{beam} - \langle\Delta E_{beam}\rangle)$ vs $(m_\tau - \langle m_\tau\rangle)$ plot. ΔE_{beam} is the difference between the total energy of lepton and photon and the beam energy in a particular run. a) $\tau \to e\gamma$; b) $\tau \to \mu\gamma$.

To estimate the upper limit we use the statistics of a Poisson process with background [8]:

$$\frac{e^{-(\mu_B+\lambda)} \sum_{n=0}^{n_0} \frac{(\mu_B+\lambda)^n}{n!}}{e^{-\mu_B} \sum_{n=0}^{n_0} \frac{\mu_B^n}{n!}} = 0.1 \ , \tag{1}$$

where λ is the upper limit at 90% confidence level, μ_B is the expected background and n_0 is the number of observed events. The upper limit for a branching ratio is:

$$UL = \frac{\lambda}{2\epsilon N_{\tau\tau}} \ , \tag{2}$$

where ϵ is the Monte Carlo efficiency and $N_{\tau\tau}$ is the total number of τ-pairs produced.

Since $n_0 = 0$ for the $e\gamma$ analysis, we obtain $\lambda = 2.3$ and the corresponding upper limit of $B(\tau \to e\gamma) < 2.7 \cdot 10^{-6}$ at 90% confidence level. Similarly, $n_0 = 3$ and $\mu_B = 5.5$ for the $\mu\gamma$ analysis give us the value of $\lambda = 3.6$, and the corresponding upper limit of $B(\tau \to \mu\gamma) < 2.9 \cdot 10^{-6}$ at 90% confidence level.

We check that the procedure of upper limit estimation is stable with respect to the signal region geometry. The systematic errors in the analyses are estimated as 9% for the $e\gamma$ and 15% for the $\mu\gamma$ channel. These errors consist of uncertainty in track reconstruction efficiency (3%), photon reconstruction efficiency (5%), cut selection (5%), luminosity measurement (1.4%), lepton identification (1.5% for e and 4% for μ), Monte Carlo systematics (3% for $e\gamma$ and 2.5% for $\mu\gamma$), and background estimation (12% for $\mu\gamma$ and negligible for $e\gamma$). The efficiencies, numbers of events found, expected background values and upper limits for the decay branching ratios are summarized in Table 2.

TABLE 2. Summary of the results.

channel	MC efficiency, %	n_0	μ_B	λ	Upper limit at 90% CL
$\tau \to e\gamma$	10.1	0	2.5	2.3	$2.7 \cdot 10^{-6}$
$\tau \to \mu\gamma$	14.4	3	5.5	3.6	$2.9 \cdot 10^{-6}$

These results are limited by the total integrated luminosity and represent a significant improvement over previous analyses.

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. J.P.A., J.R.P., and I.P.J.S. thank the NYI program of the NSF, M.S thanks the PFF program of the NSF, G.E. thanks the Heisenberg Foundation, K.K.G., M.S., H.N.N., T.S., and H.Y. thank the OJI program of DOE, J.R.P, K.H., and M.S. thank the A.P. Sloan Foundation, and A.W., and R.W. thank the Alexander von Humboldt Stiftung for support. This work was supported by the National Science Foundation, the U.S. Department of Energy, and the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

[1] K. Hikasa *et al.*, Physical Review **D45**, S1 (1992).
[2] R. Arnowitt and P. Nath, Physical Review Letters **66**, 2708 (1991).
[3] J. Bartelt *et al.*, Physical Review Letters **73**, 1890 (1994).
[4] A. Bean *et al.*, Physical Review Letters **70**, 138 (1993).
[5] H. Albrecht *et al.*, Zeitschrift für Physik **C55**, 179 (1992).
[6] S. Jadach and Z. Was, Comput.Phys.Commun. **64**, 267 (1991); S. Jadach *et al.*, Comput. Phys. Commun. **76**, 361 (1993).
[7] R. Brun *et al.*, GEANT version 3.15, CERN dd/ee/84-1.
[8] L. Montanet *et al.*, Physical Review **D50**, 1173 (1994).