SLAC – PUB – 3684
May 1985
(T/E)

SEARCH FOR HEAVY NEUTRINOS PRODUCED IN e^+e^- ANNIHILATION

Gary J. Feldman*
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305, U.S.A.

Abstract

We report a search for long-lived heavy neutrinos produced by the neutral weak current in e^+e^- annihilation at 29 GeV at PEP. Data from the Mark II detector are examined for evidence of events with one or more separated vertices in the radial range of 2 mm to 10 cm. No events were found that were consistent with the hypothesis of heavy neutrino production, eliminating the possibility of heavy neutrinos with decay lengths of 1 to 20 cm in mass range 1 to 13 Gev/c^2.

⋆ This work was supported in part by the Department of Energy, contract DE-AC03-76SF00515.

Invited talk presented at the XXth Rencontre de Moriond: QCD and Beyond
Les Arcs, Savoie, France, March 10-17, 1985

In e^+e^- annihilation at PEP and PETRA energies the dominant reaction is the production of a pair of fundamental particles from a single virtual photon. All fundamental particles can be produced copiously in this way, provided enough energy is available to form their mass and provided that they couple to the photon, that is, that they have electric charge. One of the compelling reasons for studying e^+e^- annihilation at the Z pole at SLC and LEP is that the dominant reaction will be the formation of pair of fundamental particles from a Z, rather than a photon. Thus all fundamental particles which have weak charge will be copiously produced, including, for the first time, electrically neutral particles.[1]

The point of this talk is that one does not necessarily have to wait for SLC turn-on to search for new neutral particles, because even at PEP energies there is a significant coupling to a virtual Z. One example of such a particle could be a heavy neutrino, either from a fourth generation, or from a more exotic source. The cross section for producing a pair of neutrinos is[2]

$$\sigma = \frac{G_F{}^2 E^2}{192\pi} \left(\frac{(1 - 4\sin^2\theta_W)^2 + 1}{\left(1 - \frac{E^2}{m_Z^2}\right)^2 + \frac{\Gamma_Z^2}{m_Z^2}} \right) \beta(3+\beta^2), \tag{1}$$

where E is the center of mass energy. At the PEP energy of 29 GeV, this cross section is only 0.34 pb,[3] but the accumulated Mark II data of 208 pb^{-1} yields 71 produced events and thus allows a reasonable search.

If we assume that the GIM mechanism[4] is valid for a heavy neutrino, then it will only be able to decay into one of the known charged leptons (e, μ, or τ) and a virtual W via a (small) mixing angle ϵ.[5] This decay is illustrated in Fig. 1.

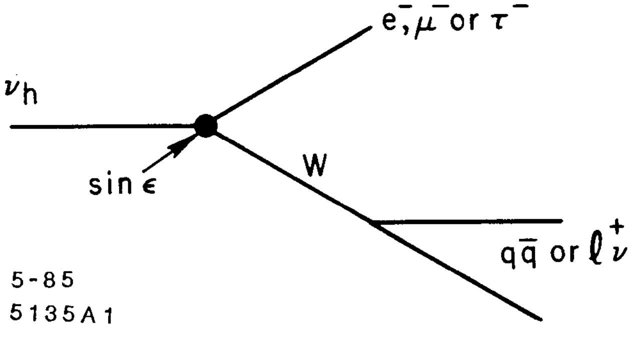

Figure 1. General diagram for heavy neutrino decay.

In this (standard) model, the lifetime of a heavy neutrino is completely calculable given the mixing angle ϵ. It can be expressed in terms of the muon lifetime as

$$\tau(\nu_h \to \ell^- X^+) = \left(\frac{m_\mu}{m_{\nu_h}}\right)^5 \frac{\tau(\mu \to e\nu\bar{\nu})B(\nu_h \to \ell^- e^+ \nu)}{f(m_{\nu_h}, \ell)\sin^2\epsilon}, \qquad (2)$$

where ℓ represents the lepton to which ν_h primarily couples, and f is a phase space correction which is significant for our application only when $\ell = \tau$ and m_{ν_h} is at most a few times m_τ. The branching fraction B can be calculated in much the same way as in τ decay.[6] Depending on m_{ν_h} and $\sin^2\epsilon$, the decay lengths of a heavy neutrino can be appreciable. Figure 2 shows the contours of constant decay length as a function of these two variables.

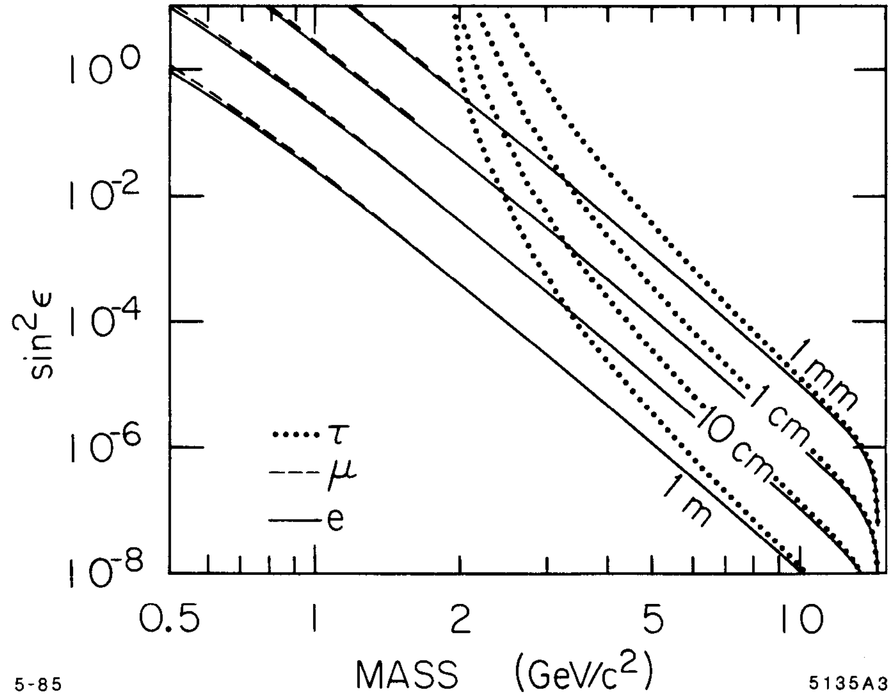

Figure 2. Contours of constant ν_h decay length.

The search was conducted with the Mark II detector at PEP.[7,8] The basic strategy was to look for events with two vertices that are separated from the interaction point and with no tracks coming from the interaction point. Even the observation of a single such event could be a spectacular signal. The main event requirements were

1. Four or more charged tracks. (From Fig. 1, it is clear that each ν_h must decay into at least two charged particles.)

2. One vertex with 2 mm $< r_1 <$ 10 cm, where r_1 is the radial distance between the first vertex and the interaction point. If $r_1 <$ 3 mm or there were only four charged tracks in the event, then there must have been another vertex with $r_2 >$ 2 mm. Otherwise, a second vertex was not required.
3. No vertex within 1 mm of the interaction point.
4. The stability of the interaction point was monitored with beam position monitors. For each run that was used in this analysis, the rms beam position had to be less than 250 μm horizontally and 150 μm vertically.
5. Tracks from identified K_S^0's and Λ's were removed from consideration in finding vertices.
6. Events were rejected if 7.4 cm $< r_1 <$ 8.0 cm, since this was the region of the vacuum pipe.

After applying these cuts, only three events remained. (A Monte Carlo simulation predicted that we would see two events from known sources of background at this point in the analysis.) On further examination of these events, we found that they were all incompatible with the hypothesis of ν_h pair production. In one event the position of the interaction point had moved 3 mm from its assumed position. This was determined by examining the vertex of the events immediately preceding and following the candidate event. A second event had only three charged particles present. The remaining tracks were from two independent photon conversions in the chamber. The final event was kinematically incompatible with the ν_h pair hypothesis because it had a backward-going 8 Gev/c track.

Figure 3 shows the contour of excluded region at the 90% confidence level in the space of decay length and m_{ν_h}. The decay length region between 1 and 20 cm is excluded for $1 < m_{\nu_h}$ $<$13 GeV/c^2. Figure 4 shows the same contour as a function of $\sin^2 \epsilon$ and m_{ν_h}.

Two other searches for ν_h have been reported at this meeting.[9] These searches exclude regions of combined lower mass and $\sin^2 \epsilon$ than this experiment. It has also been recently pointed out by Gilman and Rhie[10] that the monojet search data reviewed here by Prepost[11] can be used to eliminate the possibility of a ν_h which couples primarily to electrons and has m_{ν_h} less than 12 GeV and $\sin^2 \epsilon$ greater than about 5×10^{-3}.

In conclusion, there is presently no evidence for the existence of long-lived heavy neutrinos and large regions of decay length and mixing angles have been eliminated. We look forward to experiments at the SLC and LEP, where these searches can be conducted with much more sensitivity and generality.

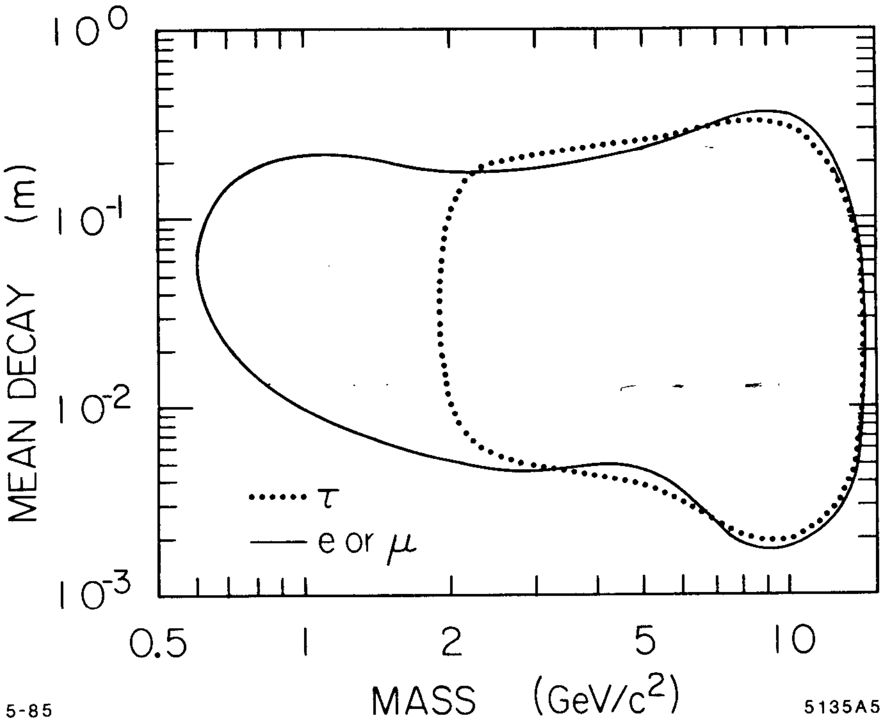

Figure 3. Excluded region for ν_h at the 90% confidence region as a function of decay length and m_{ν_h}.

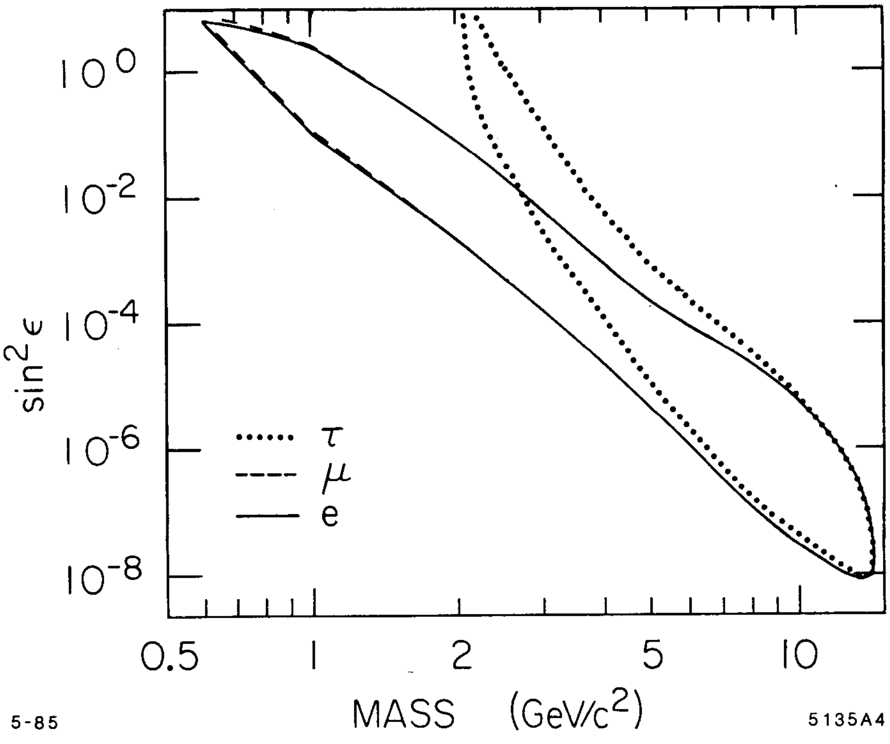

Figure 4. Excluded region for ν_h at the 90% confidence region as a function of $\sin^2\epsilon$ and m_{ν_h}.

References

1. One exception is the production of pairs of identical self-conjugate spinless bosons, which is forbidden by symmetry considerations.
2. See, for example, F. M. Renard, *Basics of Electron Positron Collisions,* (Editions Frontières, Dreux, 1981).
3. This value includes a -5% radiative correction.
4. S. L. Glashow, J. Iliopoulos, and L. Maiani, *Phys. Rev. D* **2**, 1285 (1970).
5. For simplicity, we have assumed here that ν_h mixes primarily with a single lepton species; however, the extension to the general case is obvious.
6. H. B. Thacker and J. J. Sakurai, *Phys. Lett.* **36B**, 103 (1971); Y. S. Tsai, *Phys. Rev. D* **4**, 2821 (1971) and *Phys. Rev. D* **19**, 2809 (1979); J. D. Bjorken and C. H. Llewellyn-Smith, *Phys. Rev. D* **7**, 887 (1973); F. J. Gilman and D. H. Miller, *Phys. Rev. D* **17**, 1846 (1978).
7. The individual who did most of the work on this analysis is Chris Wendt. The other members of the Mark II collaboration at PEP are T. Barklow, A. M. Boyarski, M. Breidenbach, P. Burchat, D. L. Burke, J. M. Dorfan, G. J. Feldman, L. Gladney, G. Hanson, K. Hayes, R. J. Hollebeek, W. R. Innes, J. A. Jaros, D. Karlen, A. J. Lankford, R. R. Larsen, B. W. LeClaire, N. S. Lockyer, V. Lüth, C. Matteuzzi, R. A. Ong, M. L. Perl, B. Richter, K. Riles, M. C. Ross, D. Schlatter, A. R. Baden, J. Boyer, F. Butler, G. Gidal, M. S. Gold, G. Goldhaber, L. Golding, J. Haggerty, D. Herrup, I. Juricic, J. A. Kadyk, M. E. Nelson, P. C. Rowson, H. Schellman, W. B. Schmidke, P. D. Sheldon, G. H. Trilling, C. de la Vaissiere, and D. Wood from LBL, and M. Levi and T. Schaad from Harvard.
8. The Mark II detector has been previously described. See, for example, R. H. Schindler *el al.*, *Phys. Rev. D* **24**, 78 (1981).
9. F. Vannucci, these proceedings; A. Capone, these proceedings.
10. F. J. Gilman and S. H. Rhie, SLAC report number SLAC-PUB-3657 (1985).
11. R. Prepost, these proceedings.