AN IMPROVED UPPER LIMIT OF THE ν_τ -MASS FROM THE DECAY $\tau^- \to \pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau$

Bernhard Spaan

Institut für Physik, Universität Dortmund *
representing the ARGUS Collaboration

Abstract

Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have observed the decay $\tau^- \to \pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau$ in tau-pair events produced at centre-of-mass energies between 9.4 and 10.6 GeV. From the 5π invariant mass distribution we derive an upper limit of $m(\nu_\tau) < 35$ MeV/c^2 at the 95% confidence level. The branching ratio for this decay channel is found to be $(0.064 \pm 0.023 \pm 0.01)$%.

*supported by the German Bundesministerium für Forschung und Technologie under the contract number 054DO51P

Leptons are believed to be elementary particles. For the electron and muon, and their associated neutrinos, this is a well tested hypothesis. However, for the tau and ν_τ the experimental measurements are considerably less stringent. In particular, improved constraints on the mass of the tau neutrino would be welcome. The best limit up to now [1] is 70 MeV/c^2 at 95% CL and been derived from the study of the energy spectrum of the decay $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ †. In this paper we report a new upper limit obtained from a study of the 5π invariant mass distribution in the decay $\tau^- \to \pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau$.

The study was performed by using the ARGUS detector at the electron-positron storage ring DORIS II. Data were collected at centre-of-mass energies between 9.4 GeV and 10.6 GeV, and correspond, for this analysis, to an integrated luminosity of 197 pb^{-1}. Tau-pair events, corresponding to the following combination of decays, were selected by topology:

$$\begin{array}{l} e^+e^- \longrightarrow \tau^+\tau^- \longrightarrow \pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau \\ \qquad\qquad\quad \hookrightarrow e^+\nu_e\overline{\nu}_\tau\,,\ \mu^+\nu_\mu\overline{\nu}_\tau\,,\ \pi^+\overline{\nu}_\tau \text{ or } K^+\overline{\nu}_\tau \end{array} \tag{1}$$

A preselection of events was first made using the following cuts:

- 6 charged particles originating from the main vertex
- total charge zero
- transverse momentum of each charged particle, $p_T > 0.06$ GeV/c
- no photon with an energy $E_\gamma > 0.08$ GeV detected in the electromagnetic calorimeter.

To select a 1 versus 5 topology for the tau-pair decays, the angle θ_{1i} between one particle and the remaining 5 pions was forced to satisfy $\cos\theta_{1i} < -0.3$.

These cuts reduce the event sample from about 2 million multihadron events to just 224 events. Backgrounds from 2 photon and $q\overline{q}$ interactions, as well as from doubly-radiative bremsstrahlung events where both photons converted, still exist. Also, background events from τ-decays with other decay modes, such as $\tau^- \to \pi^-\pi^-\pi^+\pi^0\nu_\tau$, pass the cuts described above. A detailed study of the vertex distribution showed that neither beam-gas nor beam-wall events survive. To reject the doubly-radiative Bhabha events, the following additional cuts were applied:

- invariant mass of opposite charged pairs, assumed to be electrons, greater than 0.1 GeV/c^2. This cut effectively rejects events containing converted photons.
- opening angle between same-sign charged pairs limited to $\cos\theta_{\pm\pm} < 0.996$. Here we make use of the fact that final state bremstrahlung photons are radiated with small opening angles with respect to the electron.

In fig. 1, the momentum of the single particle is plotted versus the invariant mass of the 5 prong, for the selected events. Monte Carlo studies of $q\overline{q}$ events and 2 photon interactions demonstrate that an appreciable amount of this background is rejected by the cut indicated in fig. 1, while most of the τ-pair events pass this cut . In order to reject the remaining background events we exploit the fact that for τ-decays the missing momentum is large. Therefore the further cuts were applied:

†References to a specific charged state are to be interpreted as also implying the charge conjugate state.

- direction of the missing momentum of the event must point into the barrel region to ensure a good detection efficiency : $|\cos\theta(\vec{P}_{miss})| < 0.8$

- missing momentum must be larger than 1.7 GeV/c: $|\vec{P}_{miss}| > 1.7$ GeV/c

These requirements effectively limit the total transverse momentum of the detected particles to $P_T > 1$ GeV/c and eliminate 2 photon, as well as initial-state radiation events, both of which typically have missing momentum pointing along the beam tube.

The resulting invariant mass spectrum of the 5π system is shown in fig. 2. Twelve events remain, all below the tau mass. The background in the sample has been determined to be smaller than 1 event, as discussed below.

The effectiveness of the background suppression has been studied by applying the same cuts to well defined samples of background events obtained either directly from the collected data or by Monte Carlo simulation. For example, the cuts rejecting radiative Bhabhas with converted photons were applied to selected singly-radiative Bhabha events where the photon converts in the detector. From this analysis the rejection efficiency was determined and, when used to project the doubly-radiative rate, leads to the conclusion that no Bhabha event remains in the final sample.

The rejection of 2 photon events was studied by Monte Carlo simulation. Channels which could lead to six charged particles in the final state, such as $\gamma\gamma \rightarrow 3\pi^+3\pi^-$ or $\gamma\gamma \rightarrow K^+2\pi^+3\pi^-K^0_L$, have been considered. From this analysis we conclude that the background due to 2 photon events is negligible.
In addition, the contribution of the decay $\tau^- \rightarrow \pi^-\pi^-\pi^+\pi^0\nu_\tau$, where the π^0 produces an e^+e^- pair either by a Dalitz decay or by conversion of one of its decay photons, has been considered. It was found to be smaller than 0.1 events. Finally, possible contributions from $e^+e^- \rightarrow q\bar{q}$ interactions were studied using the Lund fragmentation model as an event generator [2].

After all cuts described 3 out of $2 \cdot 10^6$ generated events survived. The 5-prong mass of the events is $m(5\pi) > 2.3$ GeV/c^2, considerably larger than the τ-mass. No event of this type is observed in the data. In summary these studies established that the background to the 12 data events is much smaller than 1 event [3].

The upper limit of the ν_τ mass was determined by a maximum likelihood method, where the likelihood function L ist given by :

$$L = \prod_{i=1}^{n} \int \Gamma(m(\nu_\tau), q) \cdot Res(q, i) \cdot \epsilon(q)\, dq \tag{2}$$

with

- $\Gamma(m(\nu_\tau), q)$ is the expected 5π mass distribution. Both a simple phase-space model, and a phase-space distribution weighted by a weak matrix element [5], were used to describe the 5π invariant mass distribution (fig 2). The result does not depend on which model is used, because the limit is more sensitive to shift in the kinematical threshold due to a finite ν_τ-mass than the actual shape of the distribution.

- Res(q,i) is the mass resolution function for the event i. Its shape has been determined by Monte Carlo simulations [4] and is well desribed by a gaussian with a typical width of about 20 MeV/c^2 (fig. 2).

- $\epsilon(q)$ is the mass dependend acceptance function, which has been obtained by Monte Carlo calculations. It was found to be a smooth function of 5π mass.

By this means, we find an upper limit on the ν_τ mass of 25 MeV/c^2 at 95% CL. Possible sources of systematic error are added in quadrature, including underestimation of the mass resolution, uncertainty in the momentum scale and uncertainty in the τ mass [6,7]. To consider uncertainties of the background simulation we decided to remove the event with the highest 5π mass from the sample analysed and hence arrive at a conservative upper limit of 35 MeV/c^2 at 95% CL, well below the best existing bound of 70 MeV/c^2 [1].

In addition, we have used the sample to determine the branching ratio for the decay $\tau^- \to \pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau$. It is given by

$$\mathrm{Br} = \frac{\mathrm{N}_5}{2 \cdot \mathrm{N}_{\tau\tau} \cdot \mathrm{Br}(\tau^- \to \text{single prong}) \cdot \epsilon_{\text{faked}} \cdot \epsilon_{\text{cut}}} \tag{3}$$

In this expression, N_5 is the observed number of 5π decays, after subtraction of background, such as $\tau^- \to 3\pi^+3\pi^-\pi^0\nu_\tau$ and $\tau^- \to \mathrm{K}^{*-}\mathrm{K}^0_s\nu_\tau$. $\mathrm{Br}(\tau^- \to$ single prong) is the branching ratio for 1-prong tau decays described above, including a correction for the feeddown of single-prong tau decays containing π^0's. Using the average branching ratios given in ref. [7], this has been determined to be $(48.9 \pm 1.4)\%$. $\mathrm{N}_{\tau\tau}$ is the number of tau pairs produced. ϵ_{faked} accounts for the acceptance loss introduced by noise in the calorimeter due to the requirement that there is no photon with $\mathrm{E}_\gamma > 0.08$ GeV. From an analysis of cosmic ray events this factor has been determined to be $(91.6 \pm 1.0)\%$. ϵ_{cut} is the efficiency for the combination of decays in equation (1) to pass all selection cuts, found to be $(9.1 \pm 0.63 \pm 0.9)\%$. Using these values, we find a branching ratio of

$$\mathrm{Br}(\tau^- \to \pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau) = (0.064 \pm 0.023 \pm 0.01)\%.$$

This is in good agreement with the present world average [7] $(0.07 \pm 0.03)\%$.

In summary we have obtained an improved upper limit of $\mathrm{m}(\nu_\tau) < 35$ MeV/c^2 at 95% CL. In comparing limits on the tau and electron neutrino masses, one can use the following proposed relation [8]:

$$\frac{\mathrm{m}(\nu_\tau)}{\mathrm{m}(\nu_e)} = \frac{\mathrm{m}^2(\tau)}{\mathrm{m}^2(e)} \tag{4}$$

with the implication that present attempts to determine the ν_τ-mass already reach about the same sensitivity to new physics as that derived from electron neutrino mass experiments [9]. Using this model, this new limit of 35 MeV/c^2 corresponds to an electron neutrino mass upper limit of about **3** eV/c^2, well below the existing limit of 18 eV/c^2 [9]. The measured branching ratio, $(0.064 \pm 0.023 \pm 0.01)\%$, agrees with the value determined by other groups [7].

References

[1] H.Albrecht et al. (ARGUS), Phys.Lett. **163B** (1985) 404

[2] B.Andersson et al., Phys. Rep. **97** (1983) 31

[3] B.Spaan, thesis University of Dortmund 1988 in preparation

[4] H.Gennow,"SIMARG: A Program to simulate the ARGUS Detector" ,DESY internal report, DESY F15-85-02 (1985)

[5] Y.S.Tsai, Phys.Rev. **D4** (1971) 2821
F.J.Gilman and D.H. Miller, Phys.Rev. **D17** (1978) 1846

[6] Bacino et al. (DELCO), Phys.Rev.Lett. **41** (1978) 13

[7] Particle Data Group, Phys.Lett. **170B** (1986) 1

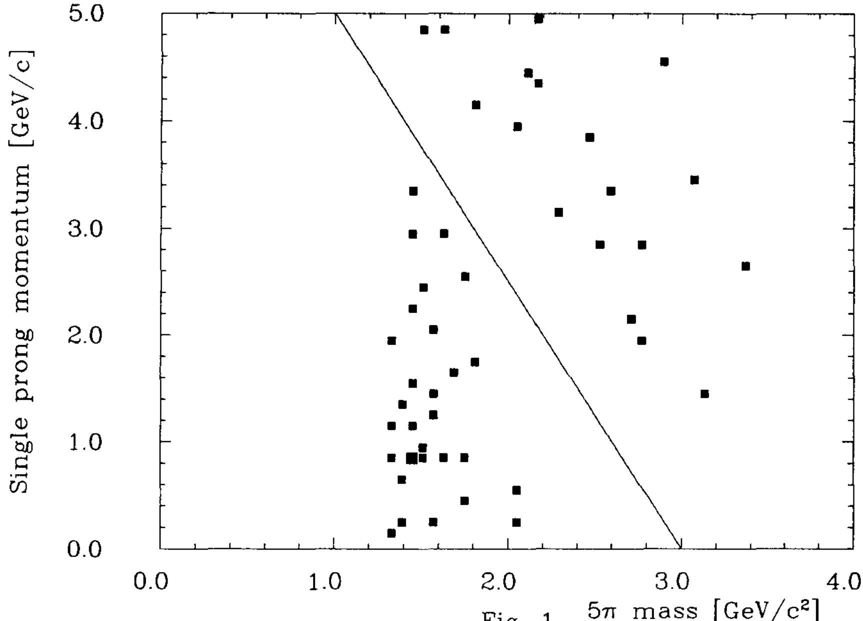
[8] M.Gell-Mann et al., in Supergravity ed. P.van Nieuwenhuizen, North Holland 1979, p.315

[9] S.Boris et al., Phys.Rev.Lett. **58** (1987) 2019
M.Fritschi et al., Phys.Lett. **173B** (1986) 485

Figure captions

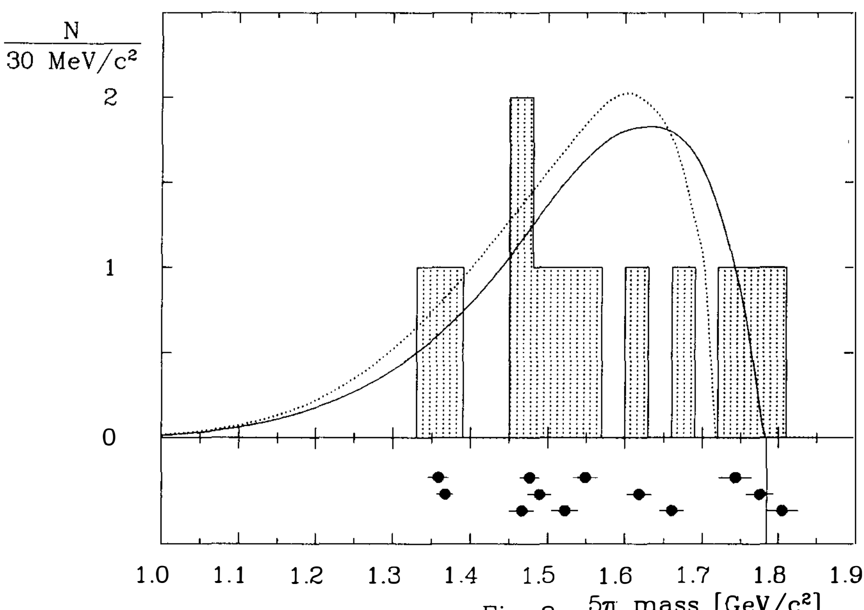
Figure 1 Single prong momentum vs 5π mass The solid line corresponds to the cut described in the text. Events above this line are rejected.

Figure 2 Measured 5π mass spectrum after all cuts. The solid curve corresponds to the expected shape of a pure phase space decay with $m(\nu_\tau) = 0$ MeV/c^2. The dashed curve corresponds to the expected shape of a pure phase space decay with $m(\nu_\tau) = 70$ MeV/c^2. Underneath, the mass and error on mass for every event are shown. The τ mass is indicated by the solid line.



5.0
4.0
3.0
2.0
1.0
0.0
Single prong momentum [GeV/c]
0.0
1.0
2.0
3.0
4.0
5π mass [GeV/c²]

Fig. 1



N / 30 MeV/c²
2
1
0
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
5π mass [GeV/c²]

Fig. 2