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THE ARGUS COLLABORATION

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ABSTRACT

Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have measured the ν_τ energy spectrum in the decay $\pi^+\pi^-\pi^\pm\nu_\tau$ of τ leptons produced near $\sqrt{s} = 10$ GeV. From this energy spectrum, we derive an upper limit of $m(\nu_\tau) < 70$ MeV$/c^2$ at the 95% confidence level.

Upper limits on the mass of the tau neutrino have been determined previously from the energy spectrum of the τ decay modes with one charged particle [1] and from the invariant mass spectrum of the decay modes $\pi^+\pi^-\pi^\pm\pi^0\nu_\tau$ [2,3] and $K^+K^-\pi^\pm\nu_\tau$[4]. The best limit, reported in ref.3, is 143 MeV/c^2 at the 95% confidence level.

In this letter we report a new limit from the study of about 1500 $\pi^+\pi^-\pi^\pm\nu_\tau$ decays of τ leptons produced in e^+e^- annihilation near $\sqrt{s} = 10$ GeV. High statistics and good momentum resolution allow us to improve the limit on $m(\nu_\tau)$ by a factor of two using an analysis of the energy spectrum of the three-pion system. The data have been collected with the ARGUS detector at the electron positron storage ring DORIS II at DESY. The centre-of-mass energy varied from 9.4 to 10.6 GeV.

A short description of the detector and the trigger conditions is given in ref. 5. The event sample used in this analysis corresponds to an integrated luminosity of 61.4 pb^{-1}. Tau pair events of the 1-3 topology were selected by requiring:

- exactly four charged particles from the main vertex with a total charge zero, and no more than two additional charged particles,
- the momentum sum $\sum_{i=1}^{4}|p_i| \geq 2.7$ GeV/c, to suppress beam-gas and photon-photon reactions,
- the momentum sum $\sum_{i=1}^{4}|p_i| \leq 0.92\sqrt{s}$, to suppress exclusive events like $\Upsilon' \to \pi^+\pi^-l^+l^-$,
- a hemisphere cut $\cos\theta_{1i} \leq 0$, where θ_{1i} is the angle between particle 1 and particle i, i=2,3,4,
- an opening angle of less than 90° between each pair of particles on the 3 prong side,
- a polar angle cut of $|\cos\theta_1| \leq 0.75$ on the 1-prong τ decay, to ensure good momentum resolution and trigger conditions,
- no photons with $E_\gamma \geq 50$ MeV in the shower counters, for an efficient suppression of the $\pi^+\pi^-\pi^\pm\pi^0\nu_\tau$ mode, or exactly one π^0, with an opening angle with respect to the charged pion on the one-prong side of less than 90°, and which, when combined with this track, yields a ρ-meson candidate with mass between 0.57 and 1.07 GeV/c^2, and momentum larger than 0.9 GeV/c,
- sufficiently large opening angles $\cos\theta_{ij} \leq 0.992$ to reject radiative Bhabha and $\mu\mu\gamma$

events with a converted photon (i,j are the opposite sign particles on the 3-prong side),
- the energy deposited by particle 1, and the sum of that deposited by particles 2 to 4 in the electromagnetic calorimeter should be less than 4 GeV, to further suppress radiative Bhabha events,
- agreement with the pion hypothesis from time-of-flight and dE/dx measurements for all three particles i=2,3,4 and with either the electron, muon, pion or kaon hypothesis for particle 1.

One exclusive decay $\Upsilon' \to \pi^+\pi^-\Upsilon \to \pi^+\pi^-\mu^+\mu^-$ passed these cuts but was reconstructed unambiguously and rejected.

The 1536 events which satisfy these selection criteria are predominantly 3-prong τ decays into $\pi^+\pi^-\pi^\pm\nu_\tau$. The background from $KK\pi\nu$ and $K\pi\pi\nu$ decays [4] is estimated to be less than 4%. Assuming all hadrons to be pions, we obtain the invariant mass spectrum shown in fig. 1. This spectrum is not corrected for acceptance. The broad structure visible is found to decay mainly into $\rho^0\pi^\pm$.

For further studies we rejected the few events with the three pion invariant mass above m_τ. Fig.2 shows the ν_τ energy spectrum derived from

$$E_\nu = E_{beam} - \sum_{i=2}^{4} E_i$$

where the energies of the three decay hadrons are calculated from the measured momenta using the pion mass assignment. The shape of the spectrum near $E_\nu = 0$ depends sensitively on the mass of the tau neutrino. It depends also on the invariant mass distribution of the three pion system. However, this distribution is measured in the experiment and there is no need for model dependent assumptions as required in other approaches [2,3]. In fig 3, we compare the experimental E_ν spectrum in the mass sensitive region with the predictions of a Monte Carlo calculation assuming various neutrino masses and a constant level of background. The background in this spectrum is estimated from the number of events with $m_{3\pi} > m_\tau$ to be 5 events/GeV. The calculation uses the observed mass spectrum of fig. 1 with masses less than m_τ, assumes that ν_τ is produced isotropically in the τ rest frame, and includes the effects of the momentum resolution of the detector, the beam energy spread, radiative corrections [6], and detector acceptance. The momentum resolution used in the Monte Carlo calculation is confirmed at high momenta by muon pair events [7], where $\sigma(p_t)/p_t = 0.012p_t/(\mathrm{GeV}/c)$, and at low momenta by the width of the Υ peak in the missing mass spectrum of $\Upsilon' \rightarrow \pi^+\pi^-X$ events [5], where the average $\sigma(p_t)/p_t$ is 0.009.

Figure 3 shows that the observed E_ν spectrum is in agreement with $m(\nu_\tau) = 0$. To obtain a confidence interval, we have calculated the likelihood function in the mass sensitive interval from $E_\nu = -100$ MeV to $E_\nu = 300$ MeV as a function of $m(\nu_\tau)$. There are 102 events in the fit region. The result is $m(\nu_\tau) < 56\ \mathrm{MeV}/c^2$ at the 95% confidence level.

Systematic effects were studied by varying the upper and lower limits of the fit interval by ± 100 MeV, by degrading the momentum resolution by 10%, by increasing the background level in the E_ν spectrum by a factor of 4, and by considering the uncertainty in the absolute momentum scale. The momentum scale is known to $\pm 0.15\%$ from reconstructed K_s^0 in various momentum and angular intervals. Taking into account these sources of systematic uncertainty, we obtain an upper limit of 70 MeV/c^2 on the tau-neutrino mass at the 95% confidence level. Misidentified tau lepton decays into $KK\pi$ and $K\pi\pi$ in the sample can only lead to an overestimation of the upper limit.

To conclude, we have measured the energy spectrum of the ν_τ in about 1500 decays $\tau^\pm \rightarrow \pi^+\pi^-\pi^\pm\nu_\tau$. The low energy part of the spectrum depends sensitively on the mass of the ν_τ. We have used this dependence to determine an upper limit on the tau-neutrino mass of 70 MeV/c^2 at the 95% confidence level. This result improves the best previous limit [3] by a factor of two.

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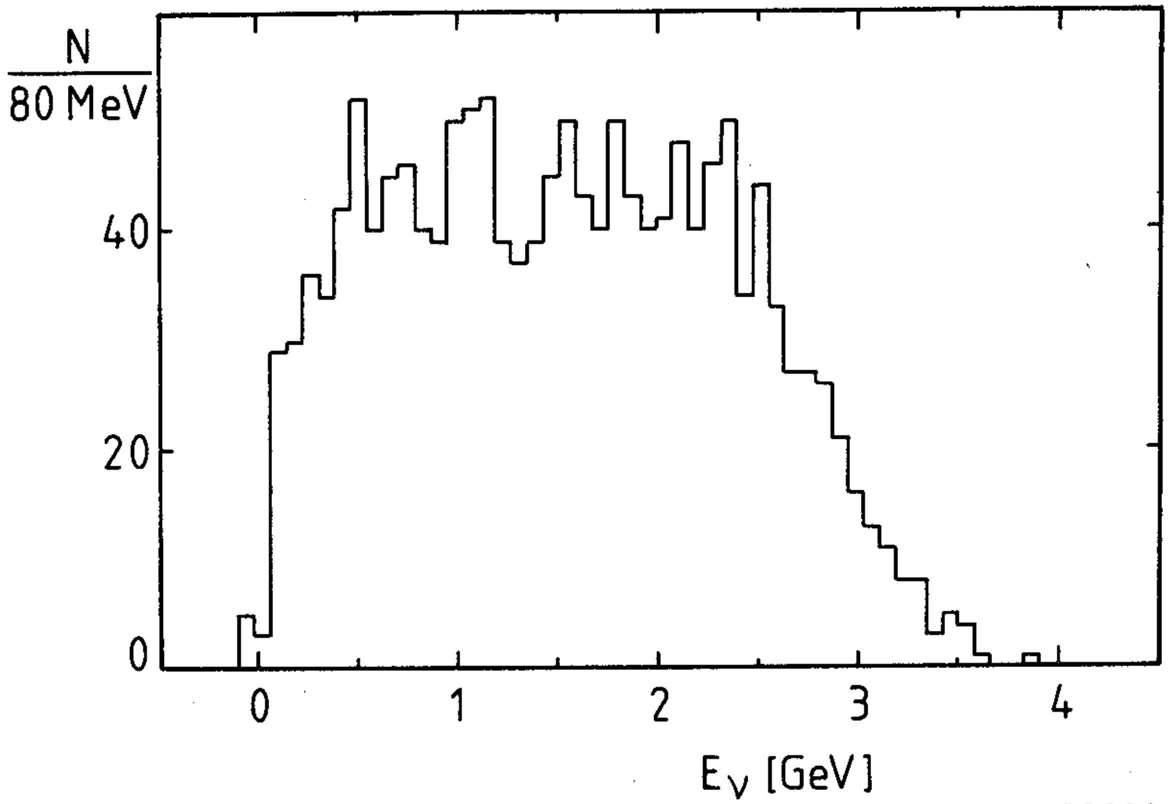
FIGURE CAPTIONS

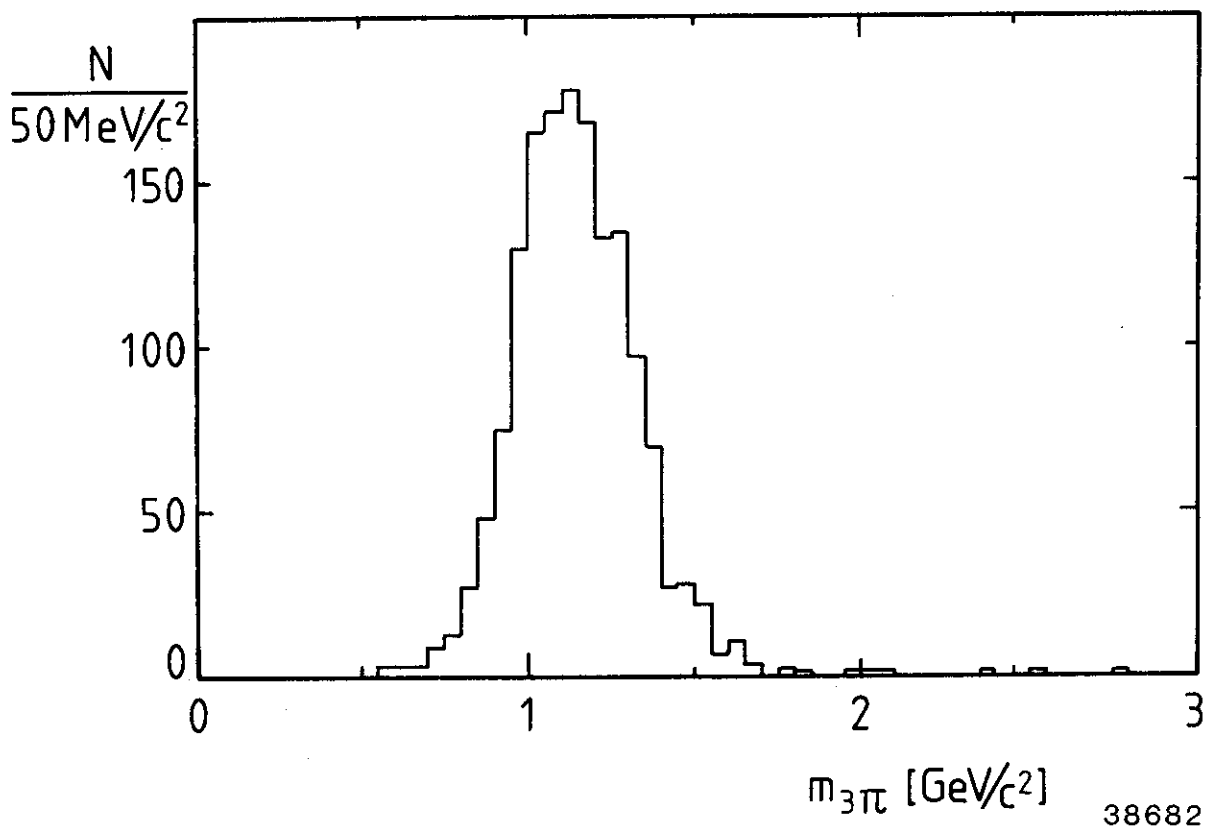
Fig. 1 Invariant mass of the three charged pions from the decay $\tau^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}\nu_{\tau}$, uncorrected for acceptance.

Fig. 2 The tau neutrino energy spectrum for the decay $\tau^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}\nu_{\tau}$, uncorrected for acceptance.

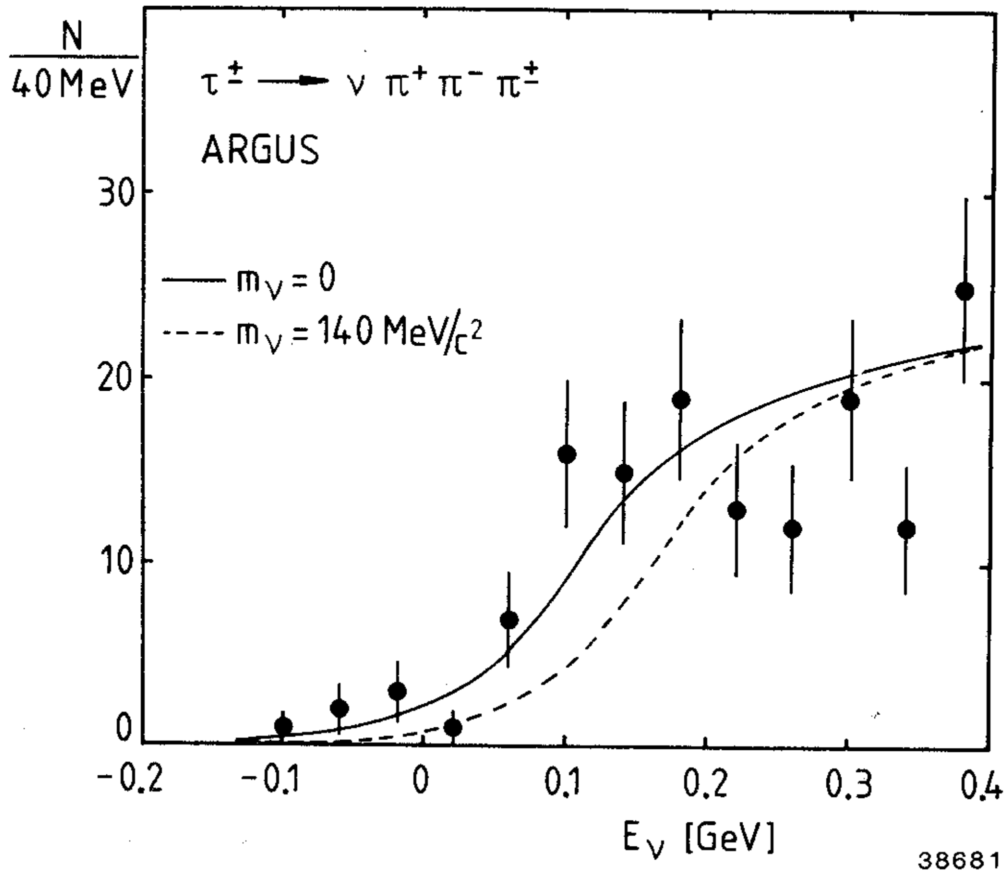
Fig. 3 Experimental data and Monte Carlo expectations for $m(\nu_{\tau}) = 0$ and 140 MeV/c^2 in the mass sensitive region normalized to the total number of events in the entire E_{ν} spectrum.


N
80 MeV
40
20
0
0
1
2
3
4
E_ν [GeV]

38683


N
50 MeV/c²
150
100
50
0
0
1
2
3
$m_{3\pi}$ [GeV/c²]

38682


N / 40 MeV
τ± → ν π+ π− π±
ARGUS
m_ν = 0
m_ν = 140 MeV/c²
30
20
10
0
−0.2
−0.1
0
0.1
0.2
0.3
0.4
E_ν [GeV]
38681