UNIVERSITÄT BONN
Physikalisches Institut

An Upper Limit on the ν_τ Mass from $\tau \to 3\pi^{+/-}\nu_\tau$ Decays

Achim Posthaus

A new statistical approach to determine an upper limit for the mass of the ν_τ from $\tau \to 3\pi^{+/-}\nu_\tau$ decays has been applied to the data collected with the OPAL detector at LEP during the period 1990-1994. The limit is obtained using a method based on the comparision of the two-dimensional missing mass squared vs. missing energy distribution with those from different neutrino mass hypotheses. This approach makes explicit use of the reconstruction of the τ direction of flight. From a sample of 2514 selected $\tau \to 3\pi^{+/-}\nu_\tau$ decays an upper limit of 35.3 MeV at 95% confidence level has been obtained. Combining this result with OPAL's previously published measurement from $\tau \to 5\pi^{+/-}\nu_\tau$ decays a limit of 29.9 MeV at 95% confidence level was determined.

Talk presented at the 28th *International Conference on High Energy Physics*
25–31 July 1996, Warsaw, Poland

Work supported by the German Ministerium für Bildung, Wissenschaft und Technologie (BMBF) under contract no. 05 7BN18P.

Post address:
Nussallee 12
D-53115 Bonn
Germany
E-mail:
posthaus@physik.uni-bonn.de

BONN-HE-96-05
Bonn University
September 1996
ISSN-0172-8733

AN UPPER LIMIT ON THE ν_τ MASS FROM $\tau \rightarrow 3\pi^{+/-}\nu_\tau$ DECAYS [1]

ACHIM POSTHAUS

Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn, Germany

A new statistical approach to determine an upper limit for the mass of the ν_τ from $\tau \rightarrow 3\pi^{+/-}\nu_\tau$ decays has been applied to the data collected with the OPAL detector at LEP during the period 1990-1994. The limit is obtained using a method based on the comparision of the two-dimensional missing mass squared vs. missing energy distribution with those from different neutrino mass hypotheses. This approach makes explicit use of the reconstruction of the τ direction of flight. From a sample of 2514 selected $\tau \rightarrow 3\pi^{+/-}\nu_\tau$ decays an upper limit of 35.3 MeV at 95% confidence level has been obtained. Combining this result with OPAL's previously published measurement from $\tau \rightarrow 5\pi^{+/-}\nu_\tau$ decays a limit of 29.9 MeV at 95% confidence level was determined.

1 Introduction

The search for massive neutrinos and the theoretical consequences of their existence are one of the current focal points of experimental as well as theoretical research in modern particle physics.

The ν_τ has not yet been directly observed. The information on its mass is obtained indirectly from the kinematic reconstruction of τ decays assuming that each τ decay is accompanied by a ν_τ due to lepton number conservation.

2 Recent m_{ν_τ} limits

The τ lepton, with a mass of $1777.00^{+0.30}_{-0.27}$ MeV [2], has many different decay channels. They are usually denoted as leptonic or hadronic decays, or classified according to the number of charged particles (prongs) in the final state. Throughout the following only the hadronic decay channels are used, because the leptonic decay channels, with two undetected neutrinos, are less sensitive to low upper limits on m_{ν_τ}. The decay channels [2] listed in table 1 are of particular importance for the ν_τ mass determination. The kinematic information

3-prongs		5-prongs	
total	14.91	total	0.097
$h^-h^-h^+\nu_\tau$	9.80	$3h^-2h^+\nu_\tau$	0.075
$h^-h^-h^+\pi^0\nu_\tau$	4.44	$3h^-2h^+\pi^0\nu_\tau$	0.022
$h^-h^-h^+2\pi^0\nu_\tau$	0.52		

Table 1: Branching ratios [%] for channels which are important for the ν_τ mass determination. h stands for π or K

about the ν_τ mass is obtained from the missing energy

$$m_{\nu_\tau} \leq E_{miss} = E_\tau - E_{had} \quad (1)$$

and the missing mass of the decay, which can be defined in two different ways:

$$\begin{aligned} m_{\nu_\tau} &\leq m_\tau - m_{had} & (2) \\ m^2_{\nu_\tau} &= m^2_{miss} \\ &= (E_\tau - E_{had})^2 - (\vec{p}_\tau - \vec{p}_{had})^2 & (3) \end{aligned}$$

Here E_τ is assumed to be the beam energy, E_{had} is the total energy and m_{had} is the invariant mass of the charged hadrons in the final state. Because m_{ν_τ} in inequality (2) is directly proportional to the difference between the τ mass and the invariant mass of the final state hadrons, decay channels with high invariant masses give rise to low upper limits for m_{ν_τ}. Table 2 lists some recently obtained upper limits for the ν_τ mass. ARGUS [3] and CLEO [4] use a one-dimensional fit of the invariant mass (2) spectrum, while OPAL[5] (see figure 1) and ALEPH[6] (see figure 2) employ a two-dimensional comparision of the invariant mass (2) and missing energy (1) of the final state hadrons with expectations from different neutrino mass hypotheses. This two dimensional method has been shown to

Collaboration	channels	# events	limit
ARGUS [3]	$5\pi^{+/-}$	20	31
CLEO [4]	$3\pi^{+/-}2\pi^0$	53	32.7
	$5\pi^{+/-}$	60	
OPAL [5]	$5\pi^{+/-}$	5	74
ALEPH [6]	$5\pi^{+/-}$	23	24
	$5\pi^{+/-}1\pi^0$	2	

Table 2: Summary of recent upper limits of m_{ν_τ}

have a higher sensitivity for m_{ν_τ} than the one dimensional fits employed by ARGUS and CLEO. Common to all analyses is the small number of events because the decay channels $\tau \rightarrow 3\pi^{+/-}2\pi^0\nu_\tau$ and $\tau \rightarrow 5\pi^{+/-}(\pi^0)\nu_\tau$ both have very low branching ratios (see table 1). The extracted limit strongly depends on single events at the kinematic boarder of the allowed phase space. This implies that almost no background is allowed to enter into the final sample.

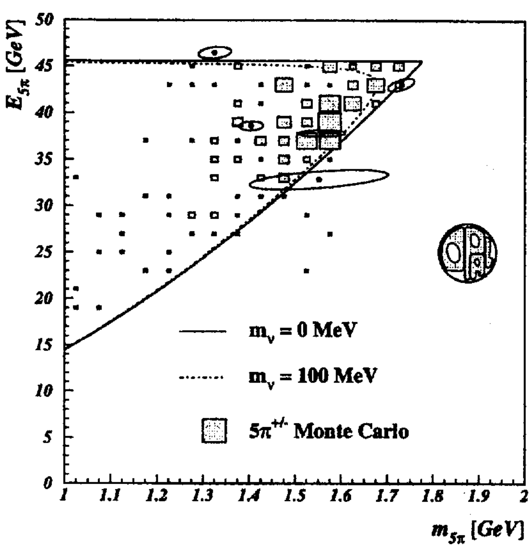

Figure 1: OPAL $\tau \rightarrow 5\pi\nu_\tau$ decays selected from the data period 1992. The solid points mark the data events with their respective error ellipses while the shaded boxes show the Monte Carlo prediction for $\tau \rightarrow 5\pi\nu_\tau$ decays. The lines indicate the kinematically allowed ranges for m_{ν_τ} = 0 MeV and m_{ν_τ} = 100 MeV.

3 New OPAL method

OPAL has developed a new technique [1] using 3-prong τ decays, which have a much larger branching ratio than 5-prong decays. Instead of using the invariant mass spectra of the final state hadrons (2) the missing mass defined in eq. (3) is used. The experimental problem exists in finding a good estimator for the τ flight direction. The τ lepton with a lifetime of $(291.0 \pm 1.5) \times 10^{-15}$ s [2] has an average flight length at LEP beam energies of 45.6 GeV of l_τ = 2.3 mm. For the estimation of the τ flight direction one can either reconstruct the secondary vertices of both τ leptons, which

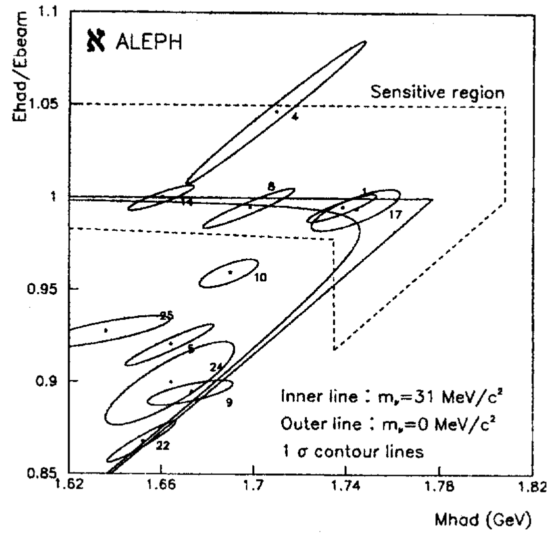

Figure 2: ALEPH $\tau \rightarrow 5\pi(\pi^0)\nu_\tau$ decays selected from the data period 1991-1993 with their respective error ellipses. The solid lines indicate the kinematically allowed ranges for m_{ν_τ} = 0 MeV and m_{ν_τ} = 31 MeV while the dashed line marks the most sensitive region for low m_{ν_τ} limits.

requires at least three charged tracks for each τ decay or one can assign an average hadronic flight direction for each of the two τ decays and then reconstruct an event thrust axis by combining the hadronic flight directions.

$$\hat{p}_{thrust} = \frac{\vec{p}_{had_1} - \vec{p}_{had_2}}{|\vec{p}_{had_1} - \vec{p}_{had_2}|} \quad (4)$$

Both τ flight reconstructions give about the same resolution. The less involved thrust direction method is used for this analysis.

The precision of the τ flight direction, approximated by the thrust direction, is better the more particles are produced in the final state. For this reason 1-prong τ decays are less suited for this method. In this analysis $\tau^+\tau^-$ events which both decay into $3\pi^{+/-}\nu_\tau$ are used. The branching ratio of this decay channel is a factor 100 larger than the previously used $\tau \rightarrow 5\pi^{+/-}(\pi^0)\nu_\tau$ decays.

Because the experimentally measured thrust direction $\vec{p}_{thrust}$ (4) is spread around the true τ flight direction the missing mass peak is broadened. This can be seen by the following expression,

$$m^2_{miss} = m^2_{\nu_\tau} + 2p_\tau p_{3\pi}(cos\Psi_{thrust} - cos\Psi_\tau)$$

where the angles Ψ are defined with respect to the $\vec{p}_{3\pi}$ decay. This dominant contribution to the observed width of the m^2_{miss} peak can be predicted by the Monte Carlo for a given input m_{ν_τ} value. The observed missing mass and missing energy spectra of the selected $\tau \rightarrow 3h^{+/-}\nu_\tau$ decays are shown in figure 3.

The remaining background in the final sample

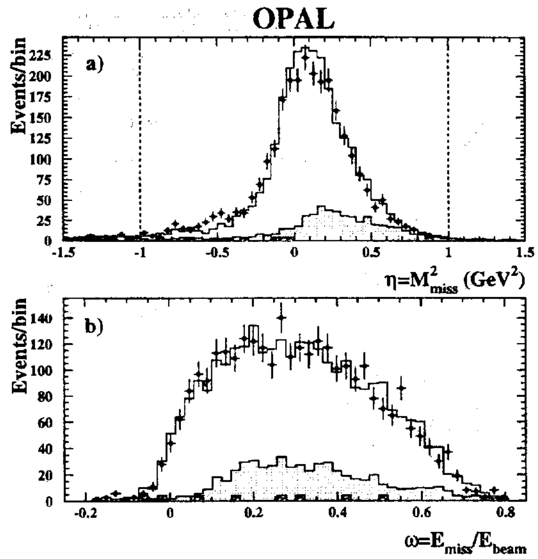

Figure 3: Distributions of m^2_{miss} and E_{miss} spectra for the selected events are shown as solid points with error bars. The Monte Carlo expectation for an input of $m_{\nu_\tau} = 10 MeV$ is shown as solid histogram. The expected background is drawn shaded.

mostly consists of $\tau \rightarrow 3\pi^{+/-}\pi^0\nu_\tau$ decays. This decay channel, where the π^0 directly decays into two γ, can only be separated from the signal channel $\tau \rightarrow 3\pi^{+/-}\nu_\tau$ when at least one of the photons can be resolved in the electromagnetic calorimeter. Due to the high Lorentz boost for the τ lepton at LEP energies the clusters in the electromagnetic calorimeter coming from the charged and neutral particles often overlap and are hard to separate. A fraction of $(14.67\pm0.46)\%$ of $\tau \rightarrow 3\pi^{+/-}\pi^0\nu_\tau$ decays remain in the final sample. The overall selection efficiency for the signal $\tau \rightarrow 3\pi^{+/-}\nu_\tau$ decays is $(41.98 \pm 0.47)\%$.

4 Results

4.1 Likelihood

The m_{ν_τ} limit is obtained using a likelihood method. A global likelihood function is built from the product of the individual likelihood functions for each event according to the following formulae:

$$\begin{aligned}\mathcal{L}(m_{\nu_\tau}) &= \prod_{events} L_i(m_{\nu_\tau}, m_i^2, E_i)\\ L_i &= \frac{1}{N_i}\int dm^2 \int dE \cdot\\ &\quad P(m_{\nu_\tau}, m^2, E)\cdot\\ &\quad D(m^2 - m_i^2, E - E_i, \sigma_{m_i^2}, \sigma_{E_i}, \rho_i)\end{aligned}$$

The individual likelihood for each event is determined from a convolution of the probability function $P(m_{\nu_\tau}, m^2, E)$, which is obtained from theoretical Monte Carlo prediction, and the detector resolution function $D(m^2 - m_i^2, E - E_i, \sigma_{m_i^2}, \sigma_{E_i}, \rho_i)$ which is individually determined for each selected event from its respective track error matrices. The indivdual determination of the experimental resolution is done because the resolution strongly depends on properties of the specific event (e.g. number of silicon microvertex detector hits).

4.2 Probability functions

Due to the use of the thrust direction (4), which is calculated from both τ decays, as an estimator of the τ flight direction, each reconstructed τ decay is correlated to the τ decay in the opposite hemisphere. The probability functions for four possible combinations of decay modes are presented in fig. 4. As one can see from fig. 4 the probability functions do not differ very much when the recoiling τ decay is accompanied by an additional π^0 or not. Omitting the π^0 in the actually analysed τ decay however shifts the missing mass and missing energy significantly towards higher values. The final probability function thus receives separate contributions from $3h^{+/-}\nu_\tau$ and $3h^{+/-}\pi^0\nu_\tau$ decays proportional to their respective branching ratios and detection efficiencies.

4.3 Systematics and cross checks

The main systematic error of this analysis arises from the error on the absolute momentum scale of the final state hadron momenta. This uncertainty is estimated from $Z^0 \rightarrow \mu^+\mu^-$ events to be 0.25% resulting in a variation of 2.2 MeV in m_{ν_τ}. The total systematic uncertainty is determined to be 3.2 MeV.

As a further cross check the sensitivity of the fit

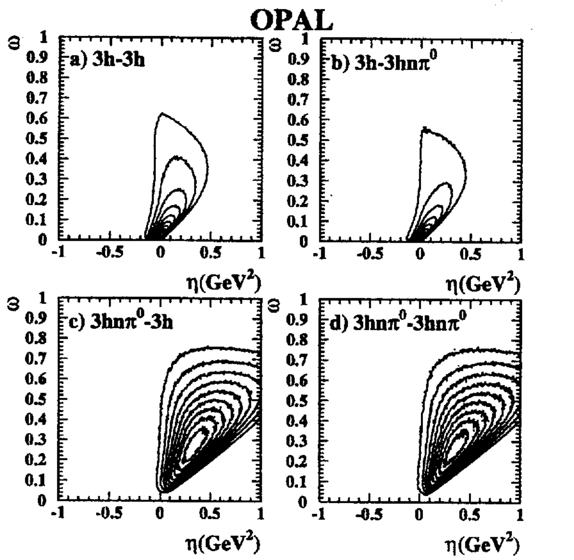

Figure 4: Monte Carlo contour plots for the probability functions with an input of $m_{\nu_\tau} = 0\,MeV$ ($\eta = M^2_{miss}$, $\omega = E_{miss}$). Plots a) and b) show the distributions with a $\tau \rightarrow 3h^{+/-}\nu_\tau$ decay in the hemisphere actually analysed for the m_{ν_τ} limit while plots c) and d) show the same distribution for a decay with an omitted π^0. The plots in each row differs from each other according to the different decay channel of the recoiling hemisphere.

to a massive ν_τ is tested using dedicated samples of Monte Carlo events with full detector simulation setting the input ν_τ mass to 50 and 100 MeV respectively. The results of the likelihood fits for about 3500 τ decays are then 47^{+18}_{-23} and 104^{+11}_{-14} MeV respectively, statistically consistent with the input values.

4.4 m_{ν_τ} limit

The limit for this analysis from 2514 selected $\tau \rightarrow 3h^{+/-}\nu_\tau$ decays of the data periods 1990-1994 yields an upper limit of 32.1 MeV at 95% confidence level (see fig. 5). Adding the systematic uncertainty linearly to the statistical upper limit a final m_{ν_τ} limit of 35.2 MeV was achieved. Combining this value with OPAL's previously published $\tau \rightarrow 5\pi^{+/-}\nu_\tau$ result[5] yields an upper limit of 29.9 MeV at 95% confidence level for m_{ν_τ}.

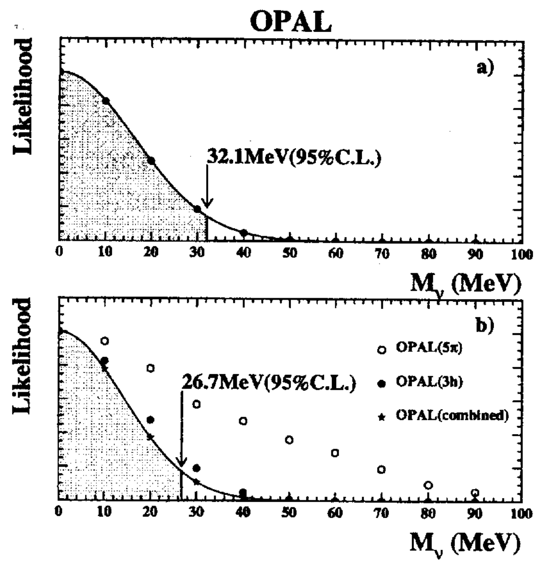

Figure 5: Total likelihood values as a function of m_{ν_τ}. Fig. a) shows the limit for this analysis whereas fig. b) is the combined limit of this analysis with OPAL's previously published result. The marked 95% confidence levels have not been corrected for the effect of systematic uncertainties.

References

1. OPAL Collaboration, G. Alexander et al., **CERN-PPE/96-42**, submitted to Z. Phys. C .
2. R.M. Barnett et al., *Phys. Rev.*, **D54 1** (1996).
3. ARGUS Collaboration, H. Albrecht et al., *Phys. Lett.* **B202** (1988) 149 ; ARGUS Collaboration, H. Albrecht et al., *Phys. Lett.* **B292** (1992) 221.
4. CLEO Collaboration, D. Cinabro et al., *Phys. Rev. Lett.* **70** (1993) 3700.
5. OPAL Collaboration, R. Akers et al., Z. Phys. **C65** (1995) 183.
6. ALEPH Collaboration, D. Buskulic et al., *Phys. Lett.* **B349** (1995) 103.