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A Review of (MeV range) Tau Neutrino Masses

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A review of measurements of the tau neutrino mass is presented using results from ALEPH, CLEO, DELPHI and OPAL. These results would appear to rule out a massive tau neutrino as an explanation for the KARMEN anomaly.

1. Introduction

Recent results from Super Kamiokande [1] have revitalised interest in massive neutrinos. Neutrinos are the least well understood particles; it is not known, for instance, whether they are stable or whether they have mass. In fact, the tau neutrino itself has never been directly observed. An observation of a non-zero mass neutrino would indicate physics beyond the Standard Model, requiring an extension of the theory, possibly in terms of a supersymmetric explanation [2]. A measurement of neutrino mass may also help explain the mass ordering of fermions [3]. In addition, neutrino mass is central to many questions in cosmology, in particular, dark matter and nucleosynthesis [4].

Section 2 derives the possible mass ranges for the tau neutrino from cosmological considerations. It will be seen that a small window exists for long-lived ($10^5 - 10^9$sec) neutrinos with masses between about 1 MeV and the lower experimental limit of a few tens of MeV. It is intriguing that an anomalous result from the KARMEN experiment finds a possible solution in terms of a tau neutrino mass in this window, which is examined in section 3. Limits on the tau neutrino mass from collider experiments however, would seem to rule out this explanation. These limits come from studies of the decay of the tau lepton into three, four and five pions and are discussed in section 4. A summary of the measurements is given in section 5.

2. Cosmological Constraints on m_ν

Following an argument advanced by Harari [5], the number density(N_o) of neutrinos(ν) multiplied by their mass(m) must be less than the density of the universe (ρ_o).

$$\sum_i N_o(\nu_i)m(\nu_i) < \rho_o <= 7.15\frac{\text{KeV}}{\text{cm}^3} \tag{1}$$

If neutrinos are stable, the universe expands as $\rho \propto \frac{1}{R^3}$. For neutrinos below the decoupling temperature of O(MeV), $N_o(\nu) = \frac{3}{11}N_o(\gamma)$ where $N_o(\gamma) \approx 400\text{cm}^{-1}$ is the number density of photons. Thus

$$m(\nu_i) < 65 \text{ eV}. \tag{2}$$

For stable neutrinos above the decoupling temperature, a similar though more complicated argument gives

$$m(\nu_i) > 4.2 \text{ GeV}. \tag{3}$$

Thus for stable neutrinos, masses between 65 eV and 4.2 GeV are excluded.

For unstable neutrinos, the expansion of the universe goes as $\rho \propto \frac{1}{R^4}$. For neutrinos below the decoupling temperature

$$m_\nu^2 T_\nu <= 2 \times 10^{20} \text{ eV}^2\text{sec}, \tag{4}$$

while for those above it

$$m_\nu^{-4} T_\nu <= 1.5 \times 10^{-22} \text{ eV}^{-4}\text{sec}, \tag{5}$$

for a neutrino with a mean life of T_ν.

These inequalities are plotted in Figure 1 and show the allowed regions for neutrino mass. If

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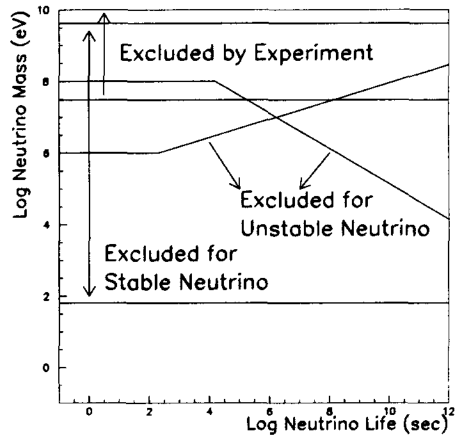


Figure 1. Allowed ranges for neutrinos in the mass-lifetime plane. Note the log-log scale.

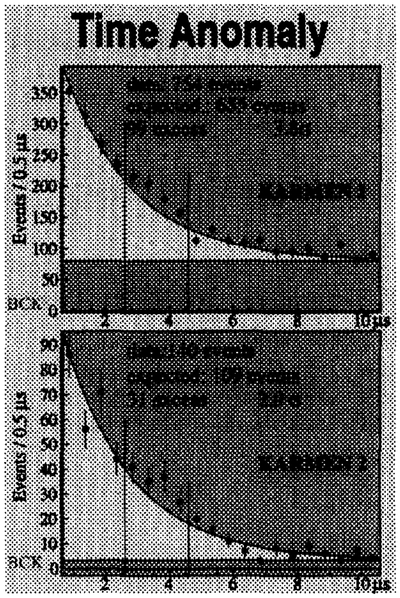


Figure 2. Neutrino Time Distribution for data taken before an upgrade of the detector in 1996 (upper plot), and after the upgrade (lower plot).

the small window around neutrino mass values of 10 MeV can be closed experimentally, then a very strong limit can be derived excluding neutrino masses down to 65 eV.

This mass window is directly accessible to present colliders and this review focuses on attempts to measure the tau neutrino mass in this range.

3. Karmen Anomaly

It is precisely in this small mass window, that an explanation in terms of tau neutrino mass has been proposed for an anomaly observed by the Karmen experiment [6].

Karmen is a fixed target experiment at the ISIS facility at the Rutherford Appleton Laboratory. Neutrinos are observed from decaying muons produced in the decay of the pions created when a proton beam hits a tantal-heavywater target. Figure 2 shows the time spectrum observed, superimposed on the exponential that would be expected from the muon decay. An excess of events is observed at about 3.5μs. A possible explanation for the excess is provided by the hypothesis that a neutral weakly interacting particle, X, is being detected. The assumption is that this particle is produced in the pion decay, $\pi \to \mu X$. The 3.5μs delay in observation is due to time of flight, and corresponds to a particle of mass 33.9 MeV. It is inviting to identify X with the tau neutrino, in which case the weak eigenstate muon neutrino produced in pion decay would be a mixture of muon and tau neutrino mass eigenstates. From the absence of experimental evidence for anomalous contributions to $\mu \to e\nu\nu$ and $\pi \to e\nu$, it has been calculated [7] that 10^3sec $< T_\nu <$ 10^7sec. Such a mass and lifetime for the tau neutrino falls intriguingly into the window allowed by cosmology.

It remains to be seen, firstly, whether this anomaly persists with further running, and secondly, what other explanations can be forwarded for it. The most compelling evidence *against* the explanation that this anomaly is due to a massive neutrino comes from the direct searches for neutrino mass from the collider experiments which will now be examined.

4. Collider Experiments

Tau pairs are produced from the decay of the Z at LEP, and from the decay of the Υ_{4S} at CESR. Taus produced at LEP can be selected more efficiently with a higher purity, since hadronic backgrounds have a much higher multiplicity and are thus more easily rejected than at CESR. However, taus are produced far more abundantly at CESR: up to the end of CLEO II, about 15 million taus have been collected compared to about 1.2 million summed over all 4 experiments at LEP1.

Taus (τ) decay to a tau neutrino and to electrons, muons or a variety of hadronic states (X): $\tau \to X\nu$. The masses, momenta p, and energies E, are related through energy and momentum conservation by

$$m_\nu^2 = m_\tau^2 + m_X^2 - 2E_\tau E_X + 2p_\tau p_X \cos\psi \qquad (6)$$

where ψ is the angle between τ and X.

All the quantities on the right-hand side of Equation 6 are measurable leading, in principle, to the measurement of m_ν. However, the error on ψ is typically 100% at LEP and CLEO, while that on m_X and E_X is about 1%, and that on m_τ and E_τ is much smaller. For this reason, the experiments do not attempt to measure ψ but instead consider the differential distribution

$$\frac{d\Gamma}{dm_X dE_X} \propto PS(m_X, m_\nu) S(m_X) \Phi(E_X, m_X) \qquad (7)$$

where $PS(a,b) = \omega(a,b)\lambda(a,b)$ is a phase space factor and $\omega(a,b) = (m_\tau^2 - a^2)(m_\tau^2 + 2a^2) - b^2(2m_\tau^2 - a^2 - b^2)$ $\lambda(a,b) = \sqrt{(m_\tau^2 - a^2)^2 - 2b^2(m_\tau^2 + a^2) + b^4}$; $\mathcal{S}$ is the spectral function; Φ is almost a top-hat function which constrains the energy to be between kinematic maximum and minimum values given by $\frac{E_\tau}{m_\tau}(E_X^{COM} \pm \frac{p_\tau}{E_\tau} p_X^{COM})$ where ^{COM} indicates the value in the centre-of-mass frame of the tau.

The sensitivity to neutrino mass comes from phase space and is greatest in the region $m_X \approx m_\tau$ i.e. this is an end-point measurement. The problem with such measurements is that the shape of the spectrum in this region must be completely understood. In particular, although the spectral function $\mathcal{S}$ is not a function of m_ν, it is important to understand its behaviour in the end-point region, lest a fall-off in the spectral function be attributed to the effect of neutrino mass.

All decays of the tau can be used to measure the neutrino mass, but the most sensitive are those which populate the end-point region with as many events as possible. Thus ALEPH, DELPHI and OPAL have all examined tau decays to three charged pions. ALEPH, CLEO and OPAL have studied decays to five charged pions. CLEO have also considered the five pion channel where three of the particles are charged and two are neutral. Finally CLEO, at this conference, have made the first measurement of the tau neutrino mass in the decay of the tau to three charged and one neutral pion. Each of these channels are now considered in turn.

4.1. $\tau \to 3\pi\nu$

ALEPH [8], DELPHI and OPAL [9] have measured the tau neutrino mass in the channel in which the tau decays to three charged pions: $\tau \to 3\pi\nu$. All three experiments have very similar mass and energy resolutions in the end-point region; typically 30 MeV on the mass, and 1000 MeV on the energy. ALEPH and DELPHI fit m_ν in the energy-mass plane, while OPAL fits for two variable (η, ω) which are non-linear combinations of energy and mass and which they claim give some sensitivity to the decay angle. There is not space to detail this method here: the fit in the transformed space is similar to, and gives similar results to that of ALEPH and DELPHI.

The non-tau backgrounds to the selection of this decay are very small, the largest being due to hadronic decays of the Z. This is about 0.5% for all three experiments. The background from tau decays to $3\pi\pi^0, 2K\pi, K2\pi$ is much larger but in each case, the incorrect assumption of a 3π final state results in a *lower* invariant mass and so the end-point region is unaffected by these events. Typical purities of greater than 95% are obtained for 3π masses greater than 1.6 GeV. All experiments assume that the spectral function, $\mathcal{S}$, is described by the Kuhn-Santamaria model [10].

ALEPH and DELPHI both maximise a likelihood

$$L = \sum_{i=1}^{N} \log \left\{ \frac{P_{sig}(m_i, E_i) + P_{bkg}(m_i, E_i)}{\int\int dmdE\{P_{sig}(m, E) + P_{bkg}(m, E)\}} \right\} \quad (8)$$

where the background term is taken from simulation and the signal term is given by

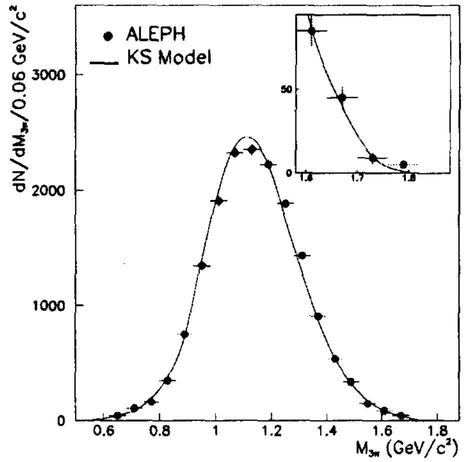
$$\begin{aligned} \epsilon(m_i, E_i) \quad & \int\int dEds\{R(m, E, m_i, E_i, V_i) \\ & \times \int dE' Rad(E, E') \tfrac{d\Gamma}{dmdE'}\}. \end{aligned} \quad (9)$$

Here, the differential distribution $\frac{d\Gamma}{dmdE}$ is modified for the effects of: efficiency, described by the function ϵ and found from simulation; radiation, as described by the function Rad, found from the generator; and resolution as described by the function R. The resolution function is found from simulation and describes the distribution of the true values around the experimental values (m_i, E_i) measured with covariance matrix V_i.

Systematic errors are small, typically 3 MeV when added in quadrature, and are conservatively added to the fitted value to obtain upper limits at the 95% confidence level of 25.7 MeV for ALEPH, 35.3 MeV for OPAL. and a preliminary result of 28 MeV for DELPHI. Thus all experiments, with broadly similar selections, resolutions and techniques, obtain similar results.

It is difficult to obtain a measure of the goodness of fit in the two dimensional plane. This is easier to appreciate if the data and fits are projected onto the mass axis. Figure 3 shows the mass spectra for ALEPH and DELPHI with the best fits for neutrino mass superimposed. The ALEPH data fits well towards the end-point, but not in the body of the distribution. The DELPHI data fits well in the body of the distribution, but not at the end-point. It would appear that there is some problem with the description of the decay. This is not surprising since ARGUS [11], OPAL [12] and DELPHI [13] have all published papers in which they show that the Kuhn-Santamaria model does not describe the 3π spectrum particularly well.

The argument that, despite this, the Kuhn-Santamaria model is sufficient to extract a tau neutrino mass is only valid assuming the model is reasonable close to the end-point. However, the behaviour of the Dalitz distributions in the end-point region have led DELPHI to hypothesise the



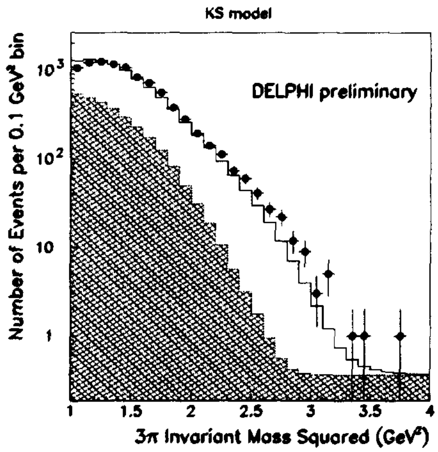


Figure 3. 3π Invariant Mass Distributions for ALEPH and DELPHI

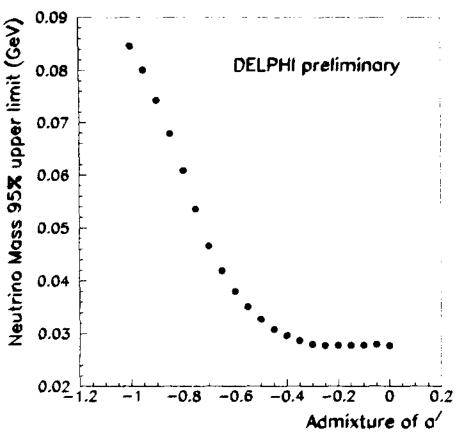


Figure 4. Effect on the calculated 95% confidence limit for the Mass of the Tau Neutrino as a function of the admixture of a_1' in the fit.

existence of an a_1' meson (an excited a_1 meson) in tau decays. Other experiments see a similar structure in the Dalitz distributions in tau decays, but do not consider this compelling evidence for a new particle. The existence of the a_1' meson has been unambiguously established by the Crystal Barrel experiment which recently announced the observation of a $J^{PC} = 1^{++}$ meson with a mass of about 1700 MeV [14]. This particle must therefore be produced in tau decays; the only uncertainty concerns its branching ratio.

The effect that an a_1' would have on the DELPHI tau neutrino limit is shown in Figure 4 for DELPHI data. Since the admixture of a_1' is not known, DELPHI also perform a simultaneous fit for neutrino mass and the admixture of a_1'. Unfortunately, most of the sensitivity to neutrino mass is lost and the 95% confidence upper limit deteriorates to 68 MeV. ALEPH have not made a simultaneous fit, but note [8] that an admixture of 2.5% simply added to the Kuhn-Santamaria model causes their limit to rise by 6 MeV.

The mechanism involved in the decay of the tau to three pions is unclear at the moment. An a' is likely to be involved and this will distort the end-point spectrum. Prudence should therefore be exercised in interpreting tau neutrino mass limits in this channel.

4.2. $\tau \to 5\pi\nu$

ALEPH [8], OPAL [15] and CLEO [16] have measured the tau neutrino mass in the channel in which the tau decays to five charged pions: $\tau \to 5\pi\nu$. ALEPH and OPAL have similar mass and energy resolutions but CLEO is better by about a factor of two due to the larger opening angle and the lower centre of mass energy.

The non-tau backgrounds to the selection of this decay are small, the largest being due to hadronic decays of the Z. For ALEPH and OPAL, this is estimated to be about 0.1% while for CLEO it is somewhat larger at 1%. CLEO requires an identified lepton in the hemisphere opposite the 5-prong system in order to keep the hadronic background to this level. ALEPH and OPAL accept 5-prong systems recoiling against a single charged track.

A major background from tau decays in the sensitive region arises from tau decays into three charged tracks plus a π^0 which decays to $ee\gamma$. Mis-identifying the electrons as pions causes the 5-prong decay to be reconstructed at too high a mass, potentially infecting the sensitive region. For this reason, all experiments take care to veto electron-like tracks.

The two dimensional distributions are shown in Figure 5 for ALEPH, OPAL and CLEO data. The data are fitted using methods similar to those described in section 4. ALEPH and OPAL use a method to determine the resolution function which is different to CLEO and which will be described in section 4.2.1.

Different spectral functions are also used by each experiment. ALEPH favour a decay through $a_1\pi\pi$ while OPAL use the TAUOLA parameterisation [17]. CLEO use CVC plus a soft-pion hypothesis and in addition, fit the spectral function on an independent sample: that which has a single charged track on the away side which is *not* a lepton. It is worth noting that, unlike in the 3π analysis, the choice of spectral function does not have as crucial an impact on the neutrino mass measured, since to first order, the limit is given by the highest mass event.

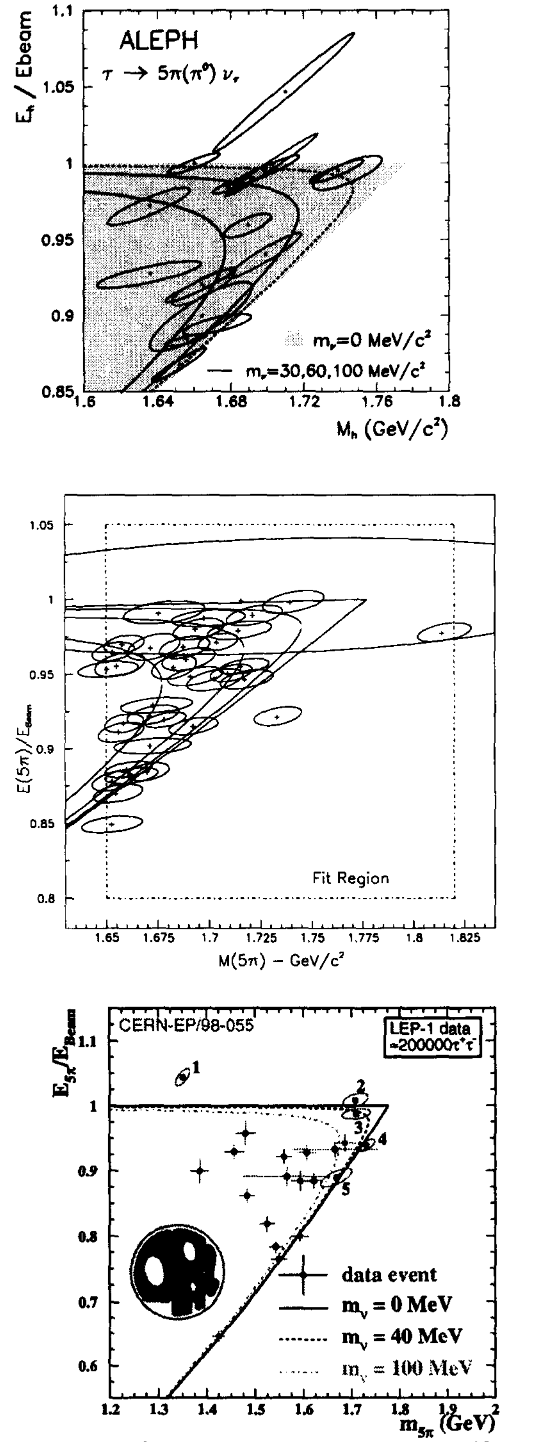


Figure 5. Distributions in the Mass-Energy Plane for selected decays of the Tau to $5\pi\nu$ for ALEPH, CLEO and OPAL.

There is quite a difference in the number of events in the samples for ALEPH, OPAL and CLEO who see 50, 21 and 266 events respectively, and in the limits which are obtained of 23.1 MeV, 43.2 MeV and 33 MeV respectively. These numbers include small systematic uncertainties of about 2 MeV for each experiment.

From the delivered luminosity ALEPH and OPAL should have roughly equal sample sizes. That they do not is due to tighter cuts which OPAL have imposed upon their tracking, in order to ensure accurate mass and energy reconstruction. The limits which ALEPH and OPAL obtain scale roughly with the sample sizes.

What is surprising is that CLEO, despite having five times the sample size of ALEPH, obtain a limit which is considerably worse. One might therefore ask if the spectrum which CLEO sees is compatible to that of ALEPH and OPAL. The brief answer, is 'yes', as can be seen in Figure 6 which superimposes the ALEPH and OPAL spectra on top of CLEO's. Within errors, all are consistent. The largest discrepancy occurs in the last bin, though even here, there is statistical agreement. Put simply, ALEPH (and OPAL to some extent) were 'lucky' to have picked up more events closer to the end-point. In particular, the ALEPH result is strongly driven by the two events appearing in the top right-hand corner in Figure 5.

It is a useful exercise to try and quantify this 'luck-factor'. However, it depends strongly on whatever spectral function is assumed. Figure 7 shows the cumulative mass distribution, for the number of events observed *above* a given mass, for ALEPH and CLEO, as well as for that which would be expected from a spectral function using the $a_1, \pi\pi$ combination as favoured by ALEPH and by phase space. The theoretical curve has not been corrected for efficiency, background or resolution. The ALEPH data agrees reasonably with this spectral function, but it is clear that the CLEO data would favour a softer function. A calculation based on these histograms shows that with this $a_1\pi\pi$ hypothesis, ALEPH would have obtained a better limit than they did in about 25% of cases, and CLEO in about 85% of cases. Thus, ALEPH were somewhat fortunate and CLEO somewhat unfortunate, but neither

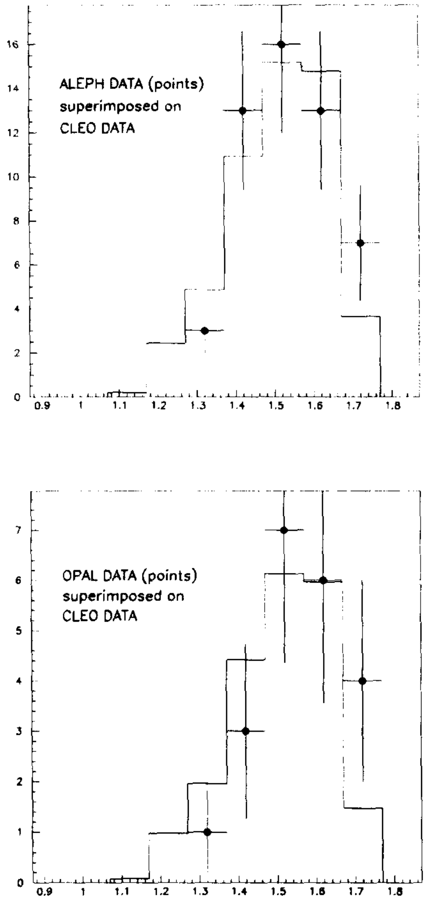


Figure 6. 5π Mass distributions for ALEPH (points in upper plot) and OPAL (points in lower plot) with CLEO data normalised and superimposed as the continuous histogram. Units on the horizontal axis are in GeV.

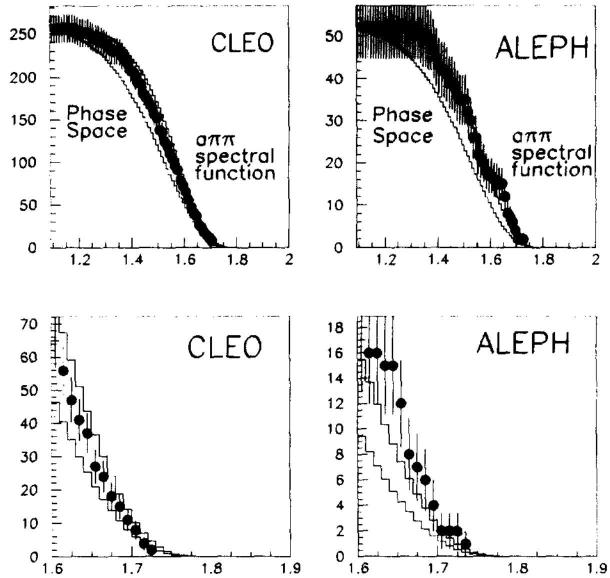


Figure 7. Number of Events Observed *Greater* than the indicated mass (in GeV) for CLEO and ALEPH. The upper histograms in each plot are the expectation with an $a_1\pi\pi$ spectral function. The lower histograms in each plot are for phase space.

are outside the bounds of what can be reasonably expected. If one takes a softer spectrum, for example the CVC plus soft-pion hypothesis favoured by CLEO, then the CLEO result has a 'luck-factor' closer to 50% while the ALEPH result would become less probable.

There has always been debate about how to interpret results where the limit obtained is much better than the limit which would have been expected assuming a null hypothesis. CLEO investigated this for neutrino masses, assuming the CVC plus soft-pion spectral function. They calculated the chances *for the CLEO detector* of obtaining a limit better than 27 MeV for a sample of 25 events, and for a sample of 450 events, when the true neutrino mass was either 0 MeV or 50 MeV. The results are shown in table 1. Whereas the 'luck-factor' of the low statistic experiment does not change much, that of the high statistic experiment does. In this sense, the higher statistic experiment is better able to discriminate between the two hypotheses.

4.2.1. Resolution Function

Let us now return to discuss the methods used to calculate the resolution function: the distribution of $m_{reconstructed}$ about m_{true} given a measurement error σ. In an ideal case, the pull variable $(m_{true} - m_{reconstructed})/\sigma$ is a unit Gaussian. CLEO use their simulation to calculate this quantity and find, in fact, that it is best parameterised by three Gaussians.

ALEPH and OPAL both use the event duplication technique. In this method, the 4-vector from the *reconstructed* event is assumed to represent 'truth' and is passed through a full detector simulation many hundreds of times. The resulting reconstructions are used to define the resolution function. Unfortunately, this technique can introduce a bias, since it has used the *reconstructed* 4-vectors as input to the simulation, not the *true* 4-vectors, which are obviously unknown.

For example, consider a confusing topology with a true value of 1.5 GeV but which is reconstructed at 1.7 GeV. Passing the true 4-vectors to the duplication technique would correctly estimate the uncertainty. However, passing the reconstructed 4-vectors to the duplication technique could lead to an under-estimation of the error, since the tracks in the 1.7 GeV event are better separated than in the 1.5 GeV event, and thus have less confusion.

This situation has been graphically demonstrated in studies using the CLEO detector. The upper plot in Figure 8 shows the pull distribution for events whose *reconstructed* mass is greater than 1.75 GeV. The asymmetrical distribution is as expected since m_{true} has been sampled from a steeply falling spectrum. The lower plot shows the pull distribution for events whose *true* mass is greater than 1.75 GeV. The problem with the event duplication technique is that it will estimate errors based on the pull distribution from the lower plot and may not correctly take into account the large tail in the upper plot.

OPAL have discussed this critical issue in some

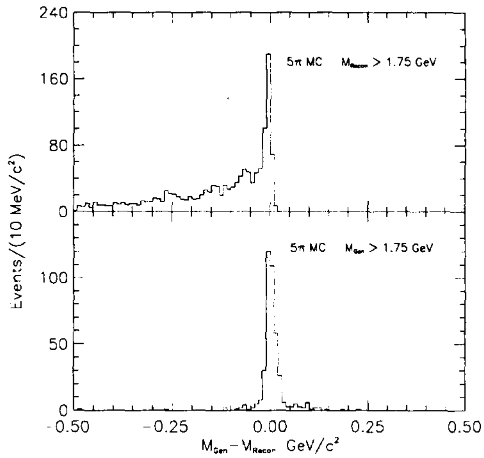


Figure 8. Pull Distributions for a CLEO-like experiment. The upper plot is for events where the *reconstructed* mass is greater than 1.75 GeV. The lower plot is for events where the *true* mass is greater than 1.75 GeV.

depth in [15]. They have used their simulation to check that for events which have a pull greater than 2, the duplication technique does work in correctly estimating the errors. Additionally, studies have shown which detector effects could give large pulls (eg. tracks which cross within the drift chamber volume) and all the data events have been checked for pathogenic topologies. ALEPH perform similar studies of their candidates, even to the extent of refitting events and deliberately swapping hits between tracks, and find no effect on the reconstructed mass.

4.3. $\tau \to 3\pi 2\pi^0 \nu$

In addition to the 5π measurement where all the particles are charged, CLEO have also made a measurement in the 5π mode with three charged particles and two neutrals. This is a channel which can only be analysed at the lower energy machine. At LEP, photons from the π^0 decay are highly collimated, making selection difficult, and giving a large reconstruction error on the invariant mass.

The CLEO analysis in this channel closely follows their five charged particle analysis. An up-

Table 1
Results for a simulation of a CLEO-like detector and the CVC + soft-pion spectral function

Simulated Neutrino Mass	Probability of obtaining limit < 27 MeV with 25 events	Probability of obtaining limit < 27 MeV with 450 events
0 MeV	3 %	67 %
50 MeV	$\approx 1\%$	< 1 %

per limit at the 95% confidence level of 33 MeV is fitted. Conservatively adding on a total systematic of 2 MeV, a limit of 35 MeV is obtained.

Combining their two 5π modes, CLEO obtain a limit of 27 MeV, which with the addition of a total systematic error of 3 MeV gives a 95% confidence limit from these channels of 30 MeV.

4.4. $\tau \to 3\pi\pi^0\nu$

A new measurement of the tau neutrino mass from the $3\pi\pi^0\nu$ channel has been reported for the first time at this conference by CLEO. This is an ideal channel to measure m_ν, since it has a harder spectrum than $3\pi\nu$, but a larger branching ratio than $5\pi\nu$. LEP experiments, however, would not be competitive in this channel since they obtain a much larger relative error on the opening angles of the photons.

Backgrounds in the fitting region are at the level of 7% from other tau decays, and 3% from hadronic events. Reconstruction errors are typically 15 MeV in mass. The best value to the fit occurs at 20 MeV with an upper limit of 25 MeV at the 95% confidence level. Systematic errors are added in quadrature and give a total of 6 MeV to give a preliminary upper limit of 31 MeV at the 95% confidence level.

Combining their $3\pi\pi^0$, $3\pi2\pi^0$ and 5π modes, CLEO obtain a best value of about 17 MeV for the neutrino mass, as can be seen from the combined likelihood curve in Figure 9. The hypothesis of a massless neutrino is reasonably consistent with this result, having a likelihood value at one quarter the value of the peak (equivalent to 1.6σ for a Gaussian probability estimator, which this measurement clearly does not fulfill due to the non-linear behaviour of the likelihood close to zero.) An upper bound at the 95% confidence level of 25 MeV is obtained where this result is statistical only. The combination of systematic errors has not been performed yet though it ought to add no more than 5 MeV to this limit.

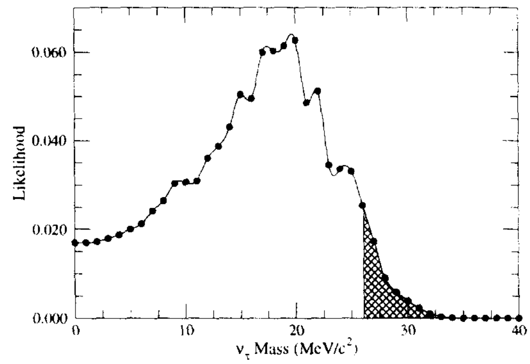


Figure 9. Combined Likelihood Function for all channels analysed by CLEO.

5. Conclusions

A summary of the measurements discussed is given in Table 2. In the last column, the results for each experiment obtained from combining the limits in each decay mode are given.

ALEPH, DELPHI and OPAL have all made measurements in the 3π mode which give broadly similar results. A degree of caution is required in interpreting these limits due to uncertainties over the spectral functions.

CLEO, having significantly greater statistics than LEP experiments, have recently made measurements in three channels: $3\pi\pi^0, 3\pi2\pi^0, 5\pi$. All give similar results. Results from the 3π mode has not been presented yet, and in view of the uncertainties in the spectral functions, would be a very welcome addition.

The modes with π^0s are unique to CLEO. The 5π mode however has also been analysed by both

Table 2
Summary of Tau Neutrino Mass Results. The symbol * indicates the results are preliminary.

Experiment	Mode				
	$3\pi\nu$	$3\pi\pi^0\nu$	$3\pi 2\pi^0\nu$	$5\pi\nu$	Combined
ALEPH	25.7 MeV			23.1 MeV	18.2 MeV
CLEO		31 MeV*	35 MeV	33 MeV	$< 30\ MeV^*$
DELPHI	28 MeV*				28 MeV*
OPAL	35.3 MeV			43.2 MeV	27.6 MeV

ALEPH and OPAL. The two LEP experiments appear to see somewhat harder spectral functions, leading to stronger limits, given their number of events, than CLEO obtain. ALEPH obtain the world best limit in a single channel in the 5π mode with an upper limit for the tau neutrino mass, at the 95% confidence level, of 23.1 MeV.

In looking to the future, it is worthwhile mentioning that the CLEO results described in this review constitute about one third of all data collected to date. The analysis of the remainder as well as the advent of CLEO III, Babar and Belle, should allow continual improvements in the measurement of the tau neutrino mass.

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REFERENCES

1. T.Kajita for Superkamiokande and Kamiokande Collaborations. Talk given at NEUTRINO 98, Takayama, Japan. hep-ex/9810001.
2. M. Cvetic and P. Langacker, *Phys. Rev.* **D46** (1992) 2759.
3. J. L. Feng et al., *Phys. Rev.* **D57** (1998) 5875.
4. G. Gyuk, M.S. Turner, *Nucl. Phys.* **B38** (1995) 13.
5. H. Harari, Invited Lecture at International Workshop on Weak Interactions and Neutrinos, Ginosar, Israel, April 1989. WIS-89/66/OCT-PH.
6. B. Armbruster et al., KARMEN coll., *Phys. Lett.* **B348** (1995) 19.
7. V. Barger, R.J.N. Phillips, S. Sarkar, *Phys. Lett.* **B352** (1995) 365; Erratum-ibid. **B356** (1995) 617.
8. B.Barate et al., ALEPH coll., *Euro. Phys. J.* **C2** (1998) 395.
9. G. Alexander et al., OPAL coll., *Z. Phys.* **C72** (1996) 231.
10. J. H. Kühn and A. Santamaria, *Z. Phys.* **48** (1990) 445.
11. H. Albrecht et al., ARGUS coll., *Z. Phys.* **C58** (1993) 61.
12. K. Ackerstaff et al., OPAL coll., *Z. Phys.***C75** (1997) 593.
13. P. Abreu et al., DELPHI coll., *Phys. Lett.* **B426** (1998) 411.
14. L. Montanet for the Crystal Barrel coll. Talk given at QCD98, Montpellier, France.
15. K. Ackerstaff et al., OPAL coll., *Euro. Phys. J.* **C5** (1998) 229.
16. R. Ammar et al., CLEO coll., *Phys. Lett.* **B431** (1998) 209.
17. S.Jadach, Z.Was, R.Decker, J.H.Kühn, *Comp. Phys. Comm.* **76** (1993) 361.