ALEPH 91-139
PHYSIC 91-122
L.A.T. Bauerdick et al.
9.10.1991

Upper Limit on the τ Neutrino Mass from $\tau^{\pm} \to 5\pi^{\pm}(\pi^{\circ})\nu_{\tau}$ Decays (Part II)

J.Raab, H.G. Sander
Johannes Gutenberg-Universität, Mainz

L.A.T. Bauerdick
CERN, Div. PPE

In a previous note [1] we presented an upper limit on m_{ν_τ} of 98 MeV. The bound was obtained from a one-dimensional likelihood fit to the hadronic mass distribution. We have generalised the fit to two dimensions with the hadronic energy as the second variable. The use of these variables was suggested in [2], but the analysis there was incomplete. Our method covers the full space and the correct event weighting.

The method is similar to that given in [1]. The only difference is that the energy dependence of the probability density has not been integrated out. The probabilty function for observing event i with normalised mass and energy, $\mu_i = \frac{M_i}{m_\tau}$ and $x_i = \frac{E_i}{E_\tau} \approx \frac{E_i}{E_{beam}}$ is then

$$P_i(m_\nu, \mu_i, x_i) = \frac{\int\limits_{\mu_{min}}^{\mu_{max}} d\mu \int\limits_{x_{min}}^{x_{max}} dx \frac{d^2\Gamma(\mu,x,m_\nu)}{d\mu dx} \mathcal{R}(\mu - \mu_i, \sigma_{\mu_i}, x - x_i, \sigma_{x_i})\epsilon(\mu, x)}{\int\limits_{\mu_{min}}^{\mu_{max}} d\mu \int\limits_{x_{min}}^{x_{max}} dx \frac{d^2\Gamma(\mu,x,m_\nu)}{d\mu dx}\ \epsilon(\mu, x)}.$$

The resolution function $\mathcal{R}$ is taken to be Gaussian and with the full mass-energy correlation matrix:

$$\mathcal{R}(\mu - \mu_i, \sigma_{\mu_i}, x - x_i, \sigma_{x_i}) = \frac{e^{-\frac{1}{2}\frac{1}{1-\rho^2}\left[\left(\frac{x-x_i}{\sigma_{x_i}}\right)^2 + \left(\frac{\mu-\mu_i}{\sigma_{\mu_i}}\right)^2 - 2\rho\left(\frac{x-x_i}{\sigma_{x_i}}\frac{\mu-\mu_i}{\sigma_{\mu_i}}\right)\right]}}{2\pi\sigma_{\mu_i}\sigma_{x_i}\sqrt{1-\rho^2}}.$$

The errors and the correlation coefficient ρ are determined for each event separately. As described in [1], each event is passed through the GALEPH/JULIA chain 100–200 times. From the reconstructed mass and energy distribution we extract the errors σ_x and σ_μ, and the correlation coefficient ρ, assuming the above form for the resolution function.

The limits of integration are fixed by the kinematics:

$$x = \frac{E^*}{m_\tau}\left(1 \pm \beta\sqrt{1 - (\frac{M}{E^*})^2}\ \right),$$

where the + (-) sign corresponds to the maximum (minimum) energy of the hadron in the lab frame, $\beta = \frac{p_\tau}{E_\tau} \simeq \sqrt{1 - (\frac{m_\tau}{E_{beam}})^2}$, and $E^* = \frac{m_\tau^2 + M^2 - m_\nu^2}{2m_\tau}$ is the energy of the hadron in the τ rest frame. Similarly, μ_{max} and μ_{min} correspond to the maximum and minimum allowed hadronic mass, respectively. The efficiency function ϵ obtained from Monte Carlo events is a constant in both x and μ.

The properties of the $\tau^\pm \rightarrow 5\pi^\pm(\pi^\circ)\nu_\tau$ candidates are reviewed in table 1 and they are plotted in fig. 1. From the figure it is clear that a significant reduction relative to [1] in the upper limit of m_{ν_τ} can be expected; candidates 2 and 5 which barely contribute in the one-dimensional analysis are very close to the kinematic border. Using all the candidate events we obtain a limit of

$$m_{\nu_\tau} \leq 32.5 \;\; MeV \qquad (95\% \; CL). \tag{a}$$

If event 6 which contributes the most to the limit is removed, we find

$$m_{\nu_\tau} \leq 52 \;\; MeV \qquad (95\% \; CL). \tag{b}$$

The potential systematic errors fall into two categories: ALEPH specific (experimental) and non-specific (theoretical) contributions to the error. The theoretical error concerns the effects of initial and final state radiation, the validity of our description of the decay matrix element, and the experimental uncertainty in m_τ. The experimental error should take account of the background, the uncertainty in the momentum scale, possible non-Gaussian errors, and perhaps deviations from a flat efficiency distribution.

We looked into the effects of initial state radiation by folding the decay distribution with the QED corrected production cross section [3]. Initial state radiation reduces the available CMS energy from $2E_{beam}$ to $2E_{beam}\sqrt{1-v}$ resulting in too low a value for x. We find that the change in the limit on m_{ν_τ} is negligible. Similarly, effects due to final state radiation are very small since the $\tau^\pm \rightarrow 5\pi^\pm\nu_\tau$ selection rejects events with unassociated ECAL clusters. The sensitivity to the matrix element was estimated by comparing the differential decay rates for spin 0 and spin 1 mesons. No significant change was observed which indicates that one is not really sensistive to minor shape differences. However, a change in m_τ by ±8 MeV (about two standard deviations) produced a ±2.5 MeV shift in limit (a) and a ±7 MeV shift in (b).

The background in [1] was considered negligible since none of the simulated background events passed the cuts. Thus, at 95%CL the background is less than one event. Allowing for a scale uncertainty in mass and energy by ±0.1%, then the

Table 1 *Summary of $\tau^\pm \rightarrow 5\pi^\pm(\pi^\circ)\nu_\tau$ candidates in 1990 data.*

Candidate	Run/Event	$\mu = \frac{M_{had}}{m_\tau}$	$\sigma\mu$	$x = \frac{E_{had}}{E_{beam}}$	σx	ρ
$\tau^\pm \rightarrow 5\pi^\pm\nu_\tau$						
1	5158/4656	0.7646	0.0120	0.7837	0.0060	0.55
2	5166/1984	0.9117	0.0049	0.8224	0.0034	0.27
3	7252/4616	0.8378	0.0089	0.7800	0.0027	0.25
4	8489/4451	0.8366	0.0098	0.8011	0.0032	0.65
5	7418/ 701	0.8137	0.0135	1.0082	0.0146	0.88
6	7849/7984	1.1082	0.0490	1.0831	0.1026	0.96
$\tau^\pm \rightarrow 5\pi^\pm\pi^\circ\nu_\tau$						
7	8331/6971	0.9813	0.0146	0.9880	.0283	0.75

corresponding changes in limit (a) are $^{+0.5}_{-3.0}$ MeV; limit (b) remains the same. Furthermore, we checked in the Monte Carlo that the efficiency was reasonably constant in the $x\mu$-plane. The (possible) occurence of non-Gaussian errors and long tails are under investigation.

Thus, until further Monte Carlo for a new background and efficiency estimate are available, the 1991 data are fully analysed, and the non-Gaussian error study is completed, a conservative estimate is

$$m_{\nu_\tau} \leq 60 \;\; MeV \qquad (95\% \; CL).$$

REFERENCES

[1] J. Raab and L.A.T. Bauerdick, ALEPH note, Aug. 1991.

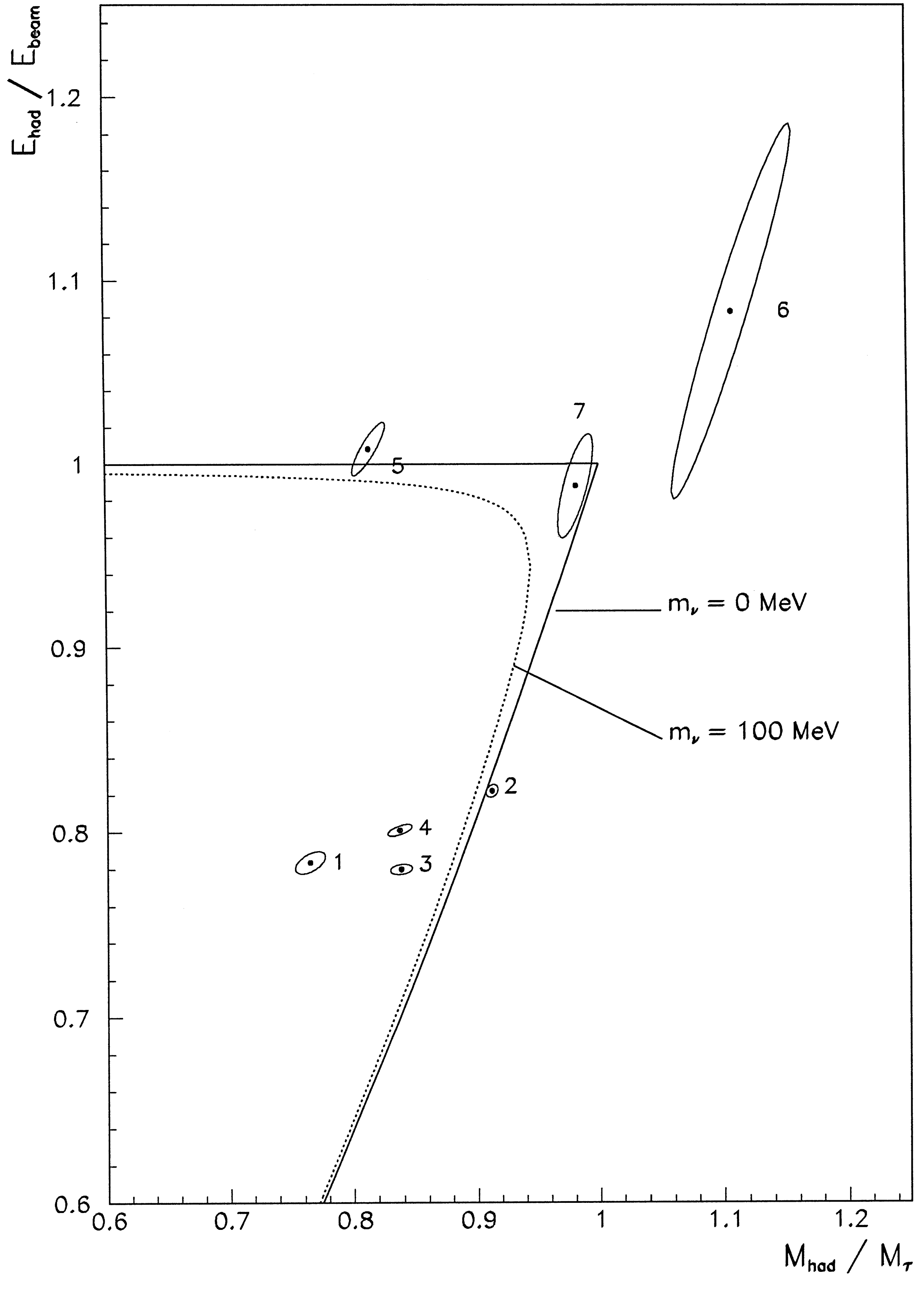
[2] U. Stiegler, ALEPH note, June 1991.

[3] Z. Was and S. Jadach, Phys. Rev. D41, 1425, (1990); Z Physics at LEP 1, Vol. 1, CERN 89-08, 235, (1989).

FIGURES

Fig.1 Plot of the hadronic energy fraction versus the hadronic mass fraction. The solid line bounds the allowed kinematic region for $m_{\nu_\tau} = 0$ MeV, the dotted line for $m_{\nu_\tau} = 100$ MeV. For each event the one sigma error ellipse is indicated.

Fig. 1


E_{had} / E_{beam}
1.2
1.1
1
0.9
0.8
0.7
0.6
0.6
0.7
0.8
0.9
1
1.1
1.2
M_{had} / M_τ
$m_\nu = 0$ MeV
$m_\nu = 100$ MeV
1
2
3
4
5
6
7