SEARCH FOR NEUTRINO OSCILLATIONS IN "GARGAMELLE" AT SPS

N. Armenise, M.T. Fogli-Mucciaccia, F. Romano
Istituto di Fisica dell' Università and INFN Bari, Italy.

M. Haguenauger, C. Matteuzzi, J.P. Vialle, M. Willutzky
CERN, Geneva, Switzerland.

S. Bonetti, D. Cavalli, A. Pullia, S. Ragazzi, M. Rollier
Istituto di Fisica dell' Università and INFN, Milano, Italy.

G. Carnesecchi, P. Heusse*, C. Pascaud
Laboratoire de l' Accélérateur Linéaire, Orsay, France.

ABSTRACT

The $\nu$ events collected in "Gargamelle" exposed at CERN SPS wide band beam are reanalyzed to search for possible $\nu_\mu \leftrightarrow \nu_\tau$ oscillations. No effect is found and an upper limit of 1.2 eV at 68% C.L. is determined for the mass parameters $\Delta m = \sqrt{m_2 - m_1}$ in the case of maximum neutrinos mixing. A limit on $\nu_\mu \leftrightarrow \nu_\tau$ transition probability is also quoted, but the sensitivity is smaller.

* Now at CERN
Recently a reactor experiment \[1\] has shown some indications of \(\nu\) oscillations: also indication exists on a non-zero value of the \(\nu\) mass \[2\]. An experiment at PS energies however has not shown any evidence for \(\nu_\mu \leftrightarrow \nu_e\) oscillations \[3\]. This paper refers to a \(\nu\) energy region and an experimental situation completely different and the obtained result is completely independent.

Oscillations can occur \[4\] if finite differences in masses of different kinds of \(\nu\) exist and are accompanied by a tiny violation of lepton number conservation.

First we consider only a possible \(\nu_\mu \leftrightarrow \nu_e\) oscillation: in this case the \(\nu_\mu\) and \(\nu_e\) can be expressed as linear combination of the two \(\nu\) mass

\[
\nu_e = \nu_1 \cos \alpha + \nu_2 \sin \alpha ; \quad \nu_\mu = -\nu_1 \sin \alpha + \nu_2 \cos \alpha
\]

\(\alpha\) is the neutrino's mixing angle.

A "pure" \(\nu_\mu\) beam would contain at a distance \(L\) from its origin a \(\nu_e\) component given by:

\[
I_{\nu_e}(L) = \sin^2(2\alpha) \sin^2\left(\frac{L}{L_0}\right) I_{\nu_\mu}(L=0)
\]

where \(L_0 = \frac{2.47}{\Delta m^2}\) and \(\Delta m^2 = |m_1^2 - m_2^2|\) in ev\(^2\)

\(p\) in MeV and \(L\) in meters.

In Fig. 1, the scheme of the CERN \(\nu\) beam is shown. The distance \(L\) ranges between 460 and 980 m. A typical value of the \(\nu\) energy in the CERN wide band beam is 25 GeV and \(L \ll L_0\) for \(\Delta m\) value of a few ev's.

410 000 pictures were scanned for the \(\nu_\mu \leftrightarrow \nu_\mu\) and \(\nu_\mu \leftrightarrow \mu^-\nu_e\) \[5\] experiments corresponding to 64 000 charged current inclusive events. In this scanning two-prong events constituted by an \(e^- (\mu^-)\) and a proton stopping in the chamber were recorded and referred to as type A (B).

The electron signature for events A is unambiguous. For events of type B, the \(\mu\) hypothesis was checked by the external muon identifier (EMI) data. We would like to stress that considering only elastic \(\nu_e\) events avoids
the difficulties of an inclusive analysis due to the incertitude for the electron identification in high multiplicity events and to the background of γ rays materializing close to the vertex where many charged tracks are overimposed. At the same time the use of a process with a constant cross section makes the analysis independent of the exact knowledge of the flux shape. The following events were found above the cut $E_\nu > 10$ GeV:

$4 \ e^- p \quad (\text{type A})$

$534 \ \mu^- p \quad (\text{type B})$

The overall detection efficiency is practically the same for both processes and close to 100%. Events of type A can be due to $\nu_e$ originally produced in the beam from $K^- \pi^+\nu\bar{\nu}$ decays for instance (Source 1-$S_1$) or by $\nu_e$ originated by $\nu_\mu$ oscillations (Source 2-$S_2$).

The calculated $\nu_\mu$ and $\nu_e$ spectra in absence of oscillation are reported in ref [5] and they have an incertitude of $\pm 10\%$ and $\pm 20\%$ respectively. The ratio $R = \int \Phi_{\nu_e} \, dE / \int \Phi_{\nu_\mu} \, dE$ is $(0.75 \pm 0.15) \times 10^{-2}$. The expected contribution from the source 1 is $N_{S_1} = 534 \times R = 4.0 \pm 0.8$. This prediction has to be compared with the observed number of events equal to $4$. An excess of $N_{S_2} = (4 - 4.0) = 0.0 \pm 2.2$ is found; no evidence exists for contributions from Source 2 ($\nu$ oscillations).

The upper limit at 68\% C.L. for the transition probability

$P(\nu_\mu + \nu_e)$ is

$P(\nu_\mu + \nu_e) < \frac{2.2}{534} = 0.004.$

The corresponding limit for $\Delta m$ can be obtained by the expression

$N(e^- p) = N(\mu^- p) \frac{1}{2} \sin^2 2\alpha (1 - \cos 2\pi \frac{L}{L_0})$

In Fig. 2a the allowed ($\Delta m, \sin 2\alpha$) region is shown. For the maximum mixing ($\sin 2\alpha = 1$) the limit $\Delta m < 1.2$ ev is obtained.
Similar considerations can be done to oscillations of type $\nu^\mu \rightarrow \nu^\mu$ and subsequent interaction of $\nu^\tau$ and decay of type $\tau \rightarrow e \nu^\mu \nu^\tau$ whose branching ratio is $\sim 10\%$. In this case two $\nu^\prime$s in the final state are missing; we abandon therefore the 10 GeV energy cut. One additional event of sample A was found; the corresponding number of events, of type B above the $\tau$ threshold (3.5 GeV) is obtained by using the $\nu^\mu$ flux shape; the new sample then corresponds to:

\[ 5 \text{ e}^- \text{ p} \quad \text{and} \quad 582 \mu^- \text{ p} \]

The $\nu^\tau_e$ contribution due to the source $S_1$ is now 4.4 events. The contribution from the $\nu^\tau$ is: $5 - 4.4 = 0.6 \pm 2.4$. We have no evidence from $\nu^\mu \rightarrow \nu^\tau$ oscillations and we can quote a limit for the $\nu^\mu \rightarrow \nu^\tau$ transition probability

\[ P(\nu^\mu \rightarrow \nu^\tau) < \frac{17.6}{582} = 3\% \quad (68\% \text{ of C.L.}) \]

For $\alpha = \frac{\pi}{2}$ the corresponding limit on $\Delta m$ is 1.96 eV. The allowed physical region in the plane ($\Delta m$, sin $2\alpha$) is shown in Fig. 2b.

Finally, we can consider the case of 3 neutrinos [6]

\[ \nu^W = U^W_i \nu^i \quad W = e, \mu, \tau \quad \text{and} \quad i = 1, 2, 3 \]

In general the 3 neutrino oscillation problem is described by 4 parameters defining the weak mixing matrix $U$ and 2 mass parameters $\Delta m^2_{ij} = m^2_i - m^2_j$ $(i \neq j)$. To reduce the number of free parameters, we assume that in our experimental conditions $(m^2_1 - m^2_2)/2p \cdot L < 1$ and we neglect furthermore CP violating effects. In this case, oscillations can occur only via the mixing $\nu^1 - \nu^3$ and $\nu^2 - \nu^3$; hence only two "weak angles" of a 3 dimensional rotation ($U^W_3$, $U^W_1$) and one mass parameter

\[ \Delta m^2 = |m^2_1 - m^2_3| = |m^2_2 - m^2_3| \] are free.

The transition probability for $\nu^\mu \rightarrow \nu^e$ oscillation is, in this assumption:

\[ P(\nu^\mu \rightarrow \nu^e) = 4 \sin^2 \frac{\Delta}{2} |U^W_{e_3}|^2 |U^W_{\mu_3}|^2 \quad \Delta = \frac{\Delta m^2}{2p} \cdot L \]

In the limit of very large $\Delta m$, values $\sin^2 \frac{\Delta}{2} \approx \frac{1}{2}$, and our limit $P < 4.1 \times 10^{-3}$ restrains the allowed region in the plane $U^W_{\mu_3}, U^W_{e_3}$ as shown in Fig. 3.
CONCLUSION

In conclusion our data are compatible with no $\nu_\mu$ oscillation and the following limits are presented:

\[
\begin{align*}
\text{P}(\nu_\mu + \nu_e) &< 0.41\% \\
\text{P}(\nu_\mu + \nu_\tau) &< 3\% \\
\text{P}(\nu_\mu + \nu_\mu) &> 96.6\%
\end{align*}
\]

For the mixing parameters $U_{\mu_3}$, $U_{e_3}$ the following constraint is found:

\[
|U_{\mu_3}|^2 \; |U_{e_3}|^2 < 0.0021.
\]
REFERENCES

2 V.A. Lyubinov et al., Ψ'80 Conference, Erice June 1980.
5 N. Armenise et al., Phys. Lett. 86B (1979) 225;
6 A. de Rujula, M. Lusignoli, L. Maiani, S.T. Petcov and
   R. Petronzio, TH-2788, CERN.

FIGURE CAPTIONS

Fig.1 Layout of SPS neutrino beam

Fig.2 Limits on $\Delta m$ as a function of mixing angle :
   a) for $\nu_\mu + \nu_e$ transitions,
   b) for $\nu_\mu + \nu_\tau$ transitions.

Fig.3 Allowed domain in the plane $U_{\mu 3}$, $U_{e 3}$
Fig. 2

\[ \Delta m \text{ (eV)} \]

\[ \sin(2\alpha) \]

\[ 0 \quad 0.2 \\
0.4 \\
0.6 \\
0.8 \\
1.0 \]

(a) 68% C.L.  
--- 90% C.L.

(b) 68% C.L.  
--- 90% C.L.
Fig. 3

[Graph showing data points and a shaded area labeled 'allowed region']

U_{\mu3} vs. U_{e3}