CERN/EP 80- 226
18 December 1980

SEARCH FOR NEUTRINO OSCILLATIONS IN "GARGAMELLE" AT SPS

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

M. Haguenauer, 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 ν events collected in "Gargamelle" exposed at CERN SPS wide band beam are reanalyzed to search for possible $\nu_\mu \rightarrow \nu_e$ oscillations. No effect is found and an upper limit of 1.2 ev at 68% C.L. is determined for the mass parameters $\Delta m = \sqrt{m_1^2 - m_2^2}$ in the case of maximum neutrinos mixing. A limit on $\nu_\mu \rightarrow \nu_\tau$ transition probability is also quoted, but the sensitivity is smaller.

* Now at CERN

Recently a reactor experiment [1] has shown some indications of ν oscillations: also indication exists on a non-zero value of the ν mass [2]. An experiment at PS energies however has not shown any evidence for $\nu_\mu \rightarrow \nu_e$ oscillations [3]. This paper refers to a ν 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 ν 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 ν_μ and ν_e can be expressed as linear combination of the two ν mass

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

α is the neutrino's mixing angle.

A "pure" ν_μ beam would contain at a distance L from its origin a ν_e component given by:

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

$$\text{where } L_0 = \frac{2.47 p}{\Delta m^2} \quad \text{and } \Delta m^2 = |m_1^2 - m_2^2| \text{ in } \text{eV}^2$$

p in MeV and L in meters.

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

410 000 pictures were scanned for the $\nu_\mu e \rightarrow \nu_\mu e$ and $\nu_\mu e \rightarrow \mu^- \nu_e$ [5] experiments corresponding to 64 000 charged current inclusive events. In this scanning two-prong events constituted by an e^- (μ^-) 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 μ hypothesis was checked by the external muon identifier (EMI) data. We would like to stress that considering only elastic ν_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 superimposed. 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 $e^- p$	(type A)
534 $\mu^- p$	(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 ν_e originally produced in the beam from $K \rightarrow \pi e \nu$ decays for instance (Source 1-S₁) or by ν_e originated by ν_μ oscillations (Source 2-S₂).

The calculated ν_μ and ν_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 $R = \int \phi_\nu dE / \int \phi_\nu dE$ is $(0.75 \pm 0.15) 10^{-2}$. 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 (ν oscillations).

The upper limit at 68% C.L. for the transition probability $P(\nu_\mu \rightarrow \nu_e)$ is

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

The corresponding limit for Δm 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 $\nu_\mu \rightarrow \nu_\tau$ and subsequent interaction of ν_τ and decay of type $\tau \rightarrow e \nu_\tau \bar{\nu}_e$ whose branching ratio is 17%. In this case two ν '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 τ threshold (3.5 GeV) is obtained by using the ν_μ flux shape; the new sample then corresponds to:

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

The ν_e contribution due to the source S_1 is now 4.4 events. The contribution from the ν_τ 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

$$P(\nu_\mu \rightarrow \nu_\tau) < \frac{17.6}{582} = 3\% \text{ (68\% of C.L.)}$$

For $\alpha = \frac{\pi}{2}$ the corresponding limit on Δm 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]

$$\nu_W = U_{wi} \nu_i \quad W = e, \mu, \tau \quad \text{and} \quad i = 1, 2, 3$$

In general the 3 neutrino oscillation problem is described by 4 parameters defining the weak mixing matrix U and 2 mass parameters $\Delta m_{ij}^2 = m_i^2 - m_j^2$ ($i \neq j$). To reduce the number of free parameters, we assume that in our experimental conditions $\{(m_1^2 - m_2^2)/2p\} \cdot L \ll 1$ 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_{μ_3}, U_{e_3}) and one mass parameter

$$\Delta m_3^2 = |m_1^2 - m_3^2| \approx |m_2^2 - m_3^2| \quad \text{are free.}$$

The transition probability for $\nu_\mu \rightarrow \nu_e$ oscillation is, in this assumption:

$$P(\nu_\mu \rightarrow \nu_e) = 4 \sin^2 \frac{\Delta}{2} |U_{e_3}|^2 |U_{\mu_3}|^2 \quad \Delta = \frac{\Delta m_3^2}{2p} L$$

In the limit of very large Δm_3 values $\sin^2 \frac{\Delta}{2} \approx \frac{1}{2}$, and our limit $P < 4.1 \cdot 10^{-3}$ restrains the allowed region in the plane U_{μ_3}, U_{e_3} as shown in Fig. 3.

CONCLUSION

In conclusion our data are compatible with no ν_μ oscillation and the following limits are presented

$$P(\nu_\mu \rightarrow \nu_e) < 0.41\%$$

$$P(\nu_\mu \rightarrow \nu_\tau) < 3\%$$

$$P(\nu_\mu \rightarrow \nu_\mu) > 96.6\%$$

For the mixing parameters U_{μ_3} , U_{e_3} the following constraint is found:

$$|U_{\mu_3}|^2 + |U_{e_3}|^2 < 0.0021.$$

REFERENCES

- 1 F. Reines, H.W. Sobel, E. Pasierb, Phys. Rev. Lett. 45, 1307(1980).
- 2 V.A. Lyubinov et al., ν '80 Conference, Erice June 1980.
- 3 J. Blietschau et al., Nucl..Phys. B133, 205 (1978).
- 4 B. Pontecorvo, Zurn. Ekop, Teor. Fiz. 33 (1957) 549.
- 5 N. Armenise et al., Phys. Lett. 86B (1979) 225;
N. Armenise et al., Phys. Lett. 84B (1979) 137.
- 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 Δm as a function of mixing angle :
a) for $\nu_{\mu} \rightarrow \nu_e$ transitions,
b) for $\nu_{\mu} \rightarrow \nu_{\tau}$ transitions.
- Fig.3 Allowed domain in the plane U_{μ_3}, U_{e_3}

Fig. 1

Fig. 2

Fig. 3