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FURTHER LIMITS ON HEAVY NEUTRINO COUPLINGS

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ABSTRACT

Limits on leptonic mixing matrix elements are inferred from the results of a dedicated neutrino-decay search; an improvement of more than two orders of magnitude is achieved over previous results for a wide range of the neutrino mass.

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Neutrino mass eigenstates are not expected to necessarily coincide with the states associated to charged leptons by charged currents (the so-called "weak interactions eigenstates": ν_e, ν_μ, ν_τ) but these two bases should be connected through a mixing matrix. This means that neutrinos produced via charged currents, in particular accelerator neutrinos, are superpositions of mass eigenstates with coefficients given by products of mixing matrix elements and the usual weak-current matrix elements computed for states of finite mass. If the masses are sufficiently high, the corresponding components could then decay into charged leptons and lighter neutrinos or even charged leptons and mesons via a second mixing term. The production-decay chain tests the product of mixing-matrix elements for a given heavy component mass (m_h).

The CERN PS191 experiment [1] was specifically designed to search for neutrino decays in a low-energy neutrino beam. No events were observed and limits were established on some of the mixing matrix elements as a function of the hypothetical heavy-neutrino mass. Partial results were published in a previous Letter [2] together with a description of the experimental set-up and the data analysis; details can be found in this publication. We only recall that the apparatus consisted of a ~ 10 m long nearly empty decay volume instrumented with eight pairs of flash chambers and followed by a shower detector which was itself supplemented by a scintillator hodoscope for triggering purposes. We scanned the events on tape for pairs of charged tracks originating from a point inside the decay volume.

The negative result of the search allowed to compute limits for several charged modes. In our previous Letter [2] these were given for the decay channel $\nu_h \rightarrow e^- e^+ \nu$. Together with the known production modes ($\pi^+/K^+ \rightarrow e^+ \nu_e$ and $\pi^+/K^+ \rightarrow \mu^+ \nu_\mu$) these limits were used to derive constraints on the matrix element combinations $|U_e|^2$ and $|U_\mu^* U_e|$ as a function of m_h (we define $U_\beta = \langle \nu_h | \nu_\beta \rangle$ with $\beta = e$ or μ).

The trigger conditions described in ref. [2] required either a signal in a single hodoscope element of above twice the minimum ionization level or two minimum-ionizing tracks in two different elements. We were equally sensitive to two-charged-prong decays not involving electrons, provided the daughter particles reached the trigger hodoscope. We can therefore consider decays to muons and/or pions in addition to those into electrons.

With an increase in neutrino mass the channels $\nu_h \rightarrow \mu^- e^+ \nu$, $\nu_h \rightarrow e^- \mu^+ \nu$, $\nu_h \rightarrow e^- \pi^+$, $\nu_h \rightarrow \mu^- \mu^+ \nu$, $\nu_h \rightarrow \mu^- \pi^+$, $\nu_h \rightarrow e^- \pi^+ \pi^0$ are successively opened. Associated to the production mode $K^+ \rightarrow \mu^+ \nu_\mu$, the first of these gives a limit on $|U_\mu|^2$ which cannot be obtained through the purely electronic decay mode. Further, in the mass region which can be probed via the above mode, the decay $\nu_h \rightarrow e^- \pi^+$ becomes much more favoured than $\nu_h \rightarrow e^- e^+ \nu$ immediately above threshold thus yielding better limits on $|U_e|^2$ for $m_\pi < m_h < m_K$.

The same is true for $\nu_h \rightarrow \mu^- \pi^+$ versus $\nu_h \rightarrow \mu^- e^+ \nu$ but the mass range that can be covered is restricted to $m_\mu + m_\pi < m_h < m_K - m_\mu$ when setting a limit on $|U_\mu|^2$ and to $m_\mu + m_\pi < m_h < m_K$ for a limit on $|U_e U_\mu^*|$.

The other leptonic modes give nothing new. We have checked that $\nu_h \rightarrow e^- \pi^+ \pi^0$ is well below $\nu_h \rightarrow e^- \pi^+$, the ρ -pole being too far from our mass region.

The differential decay rates were calculated [3] using the standard current-current interaction and the π -decay constant from $\pi \rightarrow \mu \nu$. For purely leptonic decays the final neutrino was assumed to be massless and mainly ν_e as already done in [2]. These rates were then used to modify the second step of our simulation program [2] and compute the final results.

The results are presented in fig. 1 where the 90% confidence level for the relevant mixing matrix elements is shown as a function of m_h . Each production-decay chain is combined with its charge-conjugate. Results from other experiments are given for comparison.

Limits on $|U_e|^2$ and $|U_\mu|^2$ entail limits on the branching ratios $K^+ \rightarrow e^+/\mu^+ \nu_h$ and $\pi^+ \rightarrow e^+ \nu_h$; these are presented in fig. 2. Combining results for the same matrix element from different channels gives practically nothing better than the most stringent single channel limit due to the huge differences in scale; we kept them separate for clarity.

Finally, two more remarks are in order. First, production and decay rates were calculated for usual Dirac neutrinos with the sole assumption of a (Dirac) mass matrix. Production rates for the channels considered are not modified if the mass

eigenstates are of the Majorana type. Decay rates for non self-charge-conjugate channels (viz. all channels except $e^-e^+\nu$ for the case at hand) are multiplied by two for Majorana neutrinos; with some simplifying assumptions the $e^-e^+\nu$ rate is multiplied by 5/4 [3]. The limits given here should therefore be divided by the square root of these factors if one considers massive Majorana neutrinos. Second, very fast neutrino decays would attenuate the heavy component of the beam well before this reaches the detector and thus make such a search insensitive. The values of the mixing matrix elements for which this would occur are most of the time either above unity - i.e. unphysical - or far above the upper limits already extracted from secondary peak searches in the lepton momentum spectra from $\pi \rightarrow \mu/\nu$ and $K \rightarrow \mu/\nu$ which do not suffer from the same problem. Therefore, barring Majoron decays or very fast $\nu_h \rightarrow 3\nu$ decays mediated by neutral currents, our results indeed represent the true upper limits.

REFERENCES

- [1] F. Vannucci et al., CERN/PSCC 83-12, PSCC/P67 (25 February 1983).
- [2] G. Bernardi et al., Phys. Lett. 166B (1986) 479.
- [3] J.M. Levy, Doctoral thesis, University of Paris (1986).
- [4] D.A. Bryman et al., Phys. Rev. Lett. 50 (1983) 474.
- [5] T. Yamazaki in "Neutrino 84", Dortmund, 1984.
- [6] F. Bergsma et al., Phys. Lett. 128B (1983) 361.
- [7] R. Abela et al., Phys. Lett. 105B (1981) 263.

FIGURE CAPTIONS

Fig. 1 Upper limits on the matrix elements set by this experiment and others. With U_μ we refer to the decay $\nu_h \rightarrow \mu e \nu$ and with U_e to $\nu_h \rightarrow e e \nu$. The numbers next to the curves give the reference to the previous experiments. The shaded curves show the results of this experiment, with the name of the parent particle and a subscript referring to its decay channel appearing next to the curves. The symbols represent the following chains:

$$\begin{aligned} \text{In (a)} \quad \pi_\mu & \text{ is } \pi^+ \rightarrow \mu^+ \nu_h \rightarrow \mu^+ (e^+ e^- \nu_e) \\ K_\mu & \text{ is } K^+ \rightarrow \mu^+ \nu_h \rightarrow \mu^+ (e^+ e^- \nu_e) \\ K_e & \text{ is } K^+ \rightarrow e^+ \nu_h \rightarrow e^+ (\mu^- \pi^+) \end{aligned}$$

$$\begin{aligned} \text{In (b)} \quad \pi_e & \text{ is } \pi^+ \rightarrow e^+ \nu_h \rightarrow e^+ (e^+ e^- \nu_e + cc) \\ K_e(1) & \text{ is } K^+ \rightarrow e^+ \nu_h \rightarrow e^+ (e^+ e^- \nu_e + cc) \\ K_e(2) & \text{ is } K^+ \rightarrow e^+ \nu_h \rightarrow e^+ (e^- \pi^+ + cc) \end{aligned}$$

$$\begin{aligned} \text{In (c)} \quad K_\mu(1) & \text{ is } K^+ \rightarrow \mu^+ \nu_h \rightarrow \mu^+ (\mu^- e^+ \nu_e + cc) \\ K_\mu(2) & \text{ is } K^+ \rightarrow \mu^+ \nu_h \rightarrow \mu^+ (\mu^- \pi^+ + cc) \end{aligned}$$

Fig. 2 Limits on the branching ratios for different decay modes as a function of the heavy neutrino mass. In (a) the decay is $\pi \rightarrow e \nu_h$, in (b) $K \rightarrow \mu \nu_h$, in (c) $K \rightarrow e \nu_h$.

Fig. 1

Mass of the heavy neutrino (MeV)

Fig. 2