SEARCH FOR DECAY OF HEAVY NEUTRINOS IN NEUTRINO BEAMS

CHARM Collaboration

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ABSTRACT

A search for heavy neutrinos was conducted in the 400 GeV proton beam dump neutrino beam and in the 400 GeV wide band neutrino beam at CERN. Neutrinos decaying into two electrons and a light neutrino were searched for. Upper limits on the mixing angle are derived for neutrino masses in the range 10-140 MeV.

In the conventional theory of weak interactions neutrinos are assumed to be massless, but experimentally a finite neutrino mass cannot be excluded. The present limit on the τ neutrino mass is 250 MeV. Assuming production of τ neutrinos by leptonic decays of the F-meson and by the subsequent τ decay, the neutrino beam produced by high energy protons interacting in a Cu beam dump would contain a large fraction of such heavy neutrinos.

If neutrinos are massive their weak eigenstates are linear combinations of the mass eigenstates:

$$\nu_l = \Sigma\, U_{li}\, \nu_i \qquad (l=e,\mu,\tau,.. ,\ i=1,2,3,..) \qquad (1)$$

Neutrino beams can therefore contain a fraction of heavy neutrinos produced in π and K decay [1], [2]. Neutrinos with a mass larger than a few MeV can decay into a light neutrino and two electrons. For neutrinos with a mass larger than 110 MeV other decay channels are opened ($\nu_i \rightarrow e\mu\nu$, $\nu_i \rightarrow e\pi$, etc.)[1]. The decay probability for heavy neutrinos is proportional to the square of the mixing angles defined in (1). A search was made for neutrinos decaying into a pair of electrons:

$$\nu_i \rightarrow e^+ e^- \nu_e \qquad (2)$$

In the beam dump experiment decays of heavy neutrinos were searched for in an empty decay region of 35 m length and 3 x 3 m² cross section parallel to the CDHS [3] and the CHARM [4] neutrino detectors. A search for heavy neutrinos produced in π and K decays was performed in the horn focussed wide band neutrino beam by making use of the fine-grain CHARM calorimeter [5].

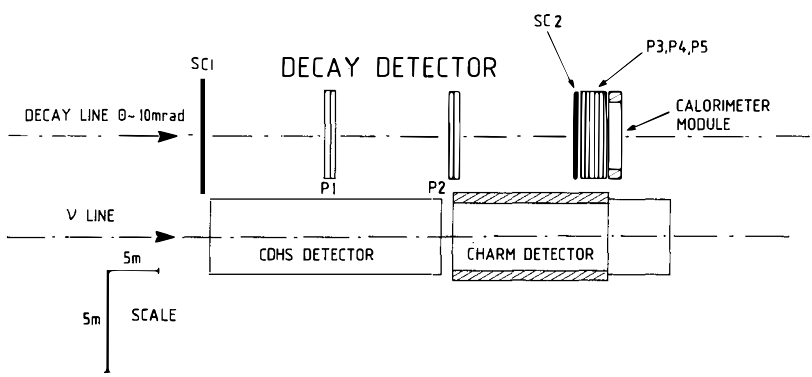

Fig. 1 Layout of the decay beam dump experiment. SC1 and SC2 are scintillator planes. SC1 is used as veto counter. P1 to P5 are packs of 4 planes of proportional drift tubes each.

The layout of the beam dump experiment is shown in Fig. 1. A scintillation counter plane of 6 x 4.8 m^2 active area (SC1) defines the beginning of the decay volume. The decay region is parallel to the neutrino beam line at a mean distance of 5 m, corresponding to an angle with respect to the incident proton beam of 10 mrad. One module of the CHARM calorimeter was displaced to the end of the decay region. It has an active area of 3 x 3 m^2 and is used to measure the energy of electromagnetic cascades with a resolution of $\Delta E/E < 0.30$ for shower energies $E >$ 5 GeV. The decay volume is subdivided into three regions using two packs of proportional tubes (P1 and P2) [5]. Each pack consists of four planes of proportional drift tubes, covering a surface of 4 x 4 m^2 , preceded by a lead plate of 1/2 radiation length thickness. In order to improve the angular resolution of the shower and to better reconstruct the decay point, a low density detector was added in front of the CHARM calorimeter module. This comprised three packs of proportional tubes (P3, P4 and P5) preceded by a plane of scintillation counters (SC2). The estimated angular resolution for an electromagnetic shower is a few mrad.

The detector was exposed to a neutrino flux produced by 1.7 x 10^{18} protons on a solid copper target and 0.7 x 10^{18} protons on a laminated copper target with an effective density of 1/3 of solid copper. In the combined exposures, 21000 events were collected satisfying the trigger requirements: no hits in the scintillator plane SC1 and a hit in at least 4 scintillator planes of the calorimeter module. These events include: cosmic ray events (a track not pointing to the scintillator plane SC1), parasitic events (tracks from neutrino interactions in the CDHS and CHARM detectors or in the floor), beam associated muons and neutrino interactions. The events recognized as neutrino interactions having the shower vertex after the scintillator plane SC2 were used to check the performance of the detector. We observe 340 ± 45 neutrino interactions. Based on the number of neutrino interactions found in the CHARM calorimeter 440 ± 50 neutrino interactions were expected.

The decay candidates were required to have at least one hit in the scintillator plane SC2 and a shower energy larger than 3 GeV. The sample was scanned to search for candidates which are consistent with having two electrons. The scanning criteria were: a) in the case of single hit in the scintillator plane SC2 the pulse height was required to be larger than that corresponding to the energy released by the passage of 1.5 minimum ionizing particles, b) not more than 2 tracks in the proportional-tube packs P3, P4 and P5 or in the calorimeter module and c) shower angle and energy compatible with the decay of a heavy neutrino with mass below 140 MeV. No event satisfies these criteria.

Assuming that the ν_τ couples mainly to a single mass eigenstate, an upper limit can be set on the mixing angle U_{ei}. The expected number of neutrino decay events in the decay region was computed according to the expression:

$$N = N_F \, P[F \to \nu_\tau \tau] \; A \; P[\nu_\tau \to e^+ e^- \nu_e] \quad . \qquad (3)$$

N_F is the number of F mesons produced by protons in the dump. It was computed from the number of prompt charged current muon neutrino events observed in the CHARM calorimeter [7]. During the exposure 1830 ± 250 prompt neutrino events with a muon in the final state were collected. These events are produced essentially by muon neutrinos coming from the semileptonic decay of D mesons (BR = 0.1). A ratio $\sigma(pCu \to FFX)/\sigma(pCu \to DDX) = 0.2$ was assumed. $P[F \to \nu_\tau \tau]$ is the probability of the F meson to decay into a heavy neutrino (BR = 0.03). The factor A gives the fraction of neutrinos that cross the decay region. The production of F mesons was simulated by a Monte Carlo program assuming a distribution for the Feynman variable x corresponding to $(1-x)^4$ and a transverse momentum distribution proportional to $\exp(-2P_t)$. The flux of τ neutrinos computed using this model agrees with the limit put in an earlier beam dump experiment [6] on the number of events induced by ν_τ. $P[\nu \rightarrow e^+ e^- \nu_e]$ is the probability for the heavy neutrinos to decay in the fiducial decay region, scaled from the decay matrix element of muon decay. The limit at 90% confidence level on the square of the mixing angle in the neutrino mass range 10-140 GeV is shown in Fig. 2 as a function of the neutrino mass, together with previous results on $(U_{ei})^2$ [8], [9], 10].

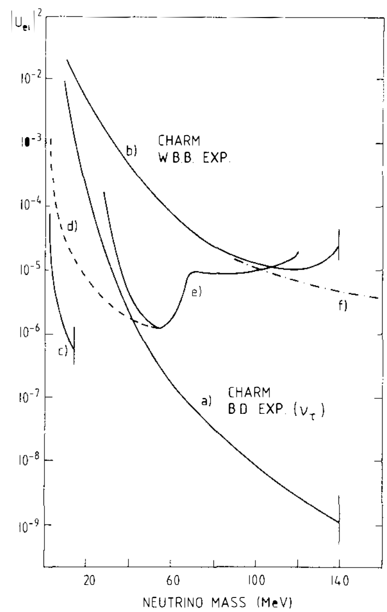

Fig. 2 Limits at 90% c.l. on $(U_{ei})^2$ as a function of the neutrino mass: a) limits obtained in the proton beam dump experiment; b) limits obtained in the wide band neutrino beam experiment; c) limits from solar neutrino measurements [8]; d) limits from the measurement of the branching ratio $\pi \rightarrow \nu$ e [9]; e) limits obtained from the search for monoenergetic peaks in the region below the value predicted for zero mass neutrino in $\pi \rightarrow \nu$ e decay [9]; f) limits from the measurement of the branching ratio $K \rightarrow \nu_e e$ 10].

In the case of the wide-band neutrino beam experiment, no assumption was made on the nature of the heavy neutrino. The search for "two electron events" was performed in a sample of 1.3×10^6 neutrino and 1.4×10^6 antineutrino interactions collected in the CHARM calorimeter [5]. The neutrinos and antineutrinos were produced by 1.4×10^{18} and 5.7×10^{18} protons on target respectively.

Candidate events were selected from those muonless events appearing as showers of narrow width, characteristic of showers initiated by electrons and photons in the CHARM calorimeter [11]. The selected events were required to have a shower energy E deposited in the calorimeter between 7.5 GeV and 50 GeV and a value of the variable $E^2\theta^2$ below 0.54 GeV^2 (θ is the angle between the shower axis and the direction of the incoming neutrino). 331 neutrino and 769 antineutrino events were selected.

The events surviving the selection criteria are due to the following known sources:

a) elastic and quasi-elastic charged current events induced by the electron-neutrino contamination of the beam;
b) events induced by the scattering of neutrinos on electrons;
c) neutral-current events with a γ or a π^0 in the final state produced by coherent scattering of muon neutrinos on nuclei;
d) decay of heavy neutrinos into $e^+e^-\nu$.

The different distributions in the four types of reactions in $E^2\Theta^2$, [a) and c) are flat], and in the energy deposited in the first scintillator after the vertex, [a) and b) start with one charged particle], can be used to disentangle the sample of events.

We find that the number of events attributed to heavy neutrino decay is compatible with zero (1±41 events in the case of a muon partner and 1±49 events in the case of an electron partner).

From this result a limit on the product of the mixing angles defined in (1) can be obtained. The expected number of neutrino decay events in the CHARM apparatus is computed according to the equation:

$$N = \{N_\pi P[\pi \to \nu_i + ..]A_\pi + N_K P[K \to \nu_i + ..]A_K\} \; P[\nu_i \to e^+e^-\nu_e] \; \varepsilon \qquad (4)$$

N_π and N_K are the numbers of π and K decays. $P[\pi(K) \to \nu_{i+}..]$ is the probability for π(K) to decay into a heavy neutrino. It is proportional to the square of U_{ei} or to the square of $U_{\mu i}$ depending on whether the heavy neutrino is produced with an electron or a muon. This probability is obtained from the probability for π or K to decay into a zero mass neutrino times a factor ρ depending on the neutrino mass m. In the case of two body decay ρ takes care of the fact that for finite neutrino mass there is less suppression due to helicity conservation than in the case of a zero mass neutrino [1]. The geometrical factors A_π and A_K give the fraction of the heavy neutrinos from π and K decay crossing the CHARM detector. $P[\nu_i \to e^+e^-\nu_e]$ is the probability for the heavy neutrinos to decay in the fiducial volume of the detector. The decay length is 12 m. The global efficiency of the cuts applied in the analysis (ε) includes the efficiency to select electromagnetic showers induced by two electrons and the efficiency of the shower energy cuts.

The limits at 90% c.l. on $(U_{ei})^2$ and on $(U_{ei}U_{\mu i})$ in the neutrino mass range 10-140 MeV are shown in Figs. 2 and 3. The limits on $(U_{ei}U_{\mu i})$ cannot be directly compared with published limits because they refer only to $(U_{ei})^2$ and $(U_{\mu i})^2$ [8], [9], 10], [11], [12], [13].

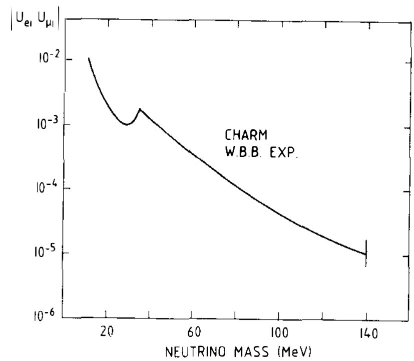

Fig. 3 Limits at 90% c.l. on $(U_{ei}U_{\mu i})$ as a function of the neutrino mass from the WBB experiment.

In conclusion, there is no evidence for the decay into two electrons of heavy neutrinos with masses in the range 10-140 MeV.

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