SEARCH FOR NEUTRINO DECAY

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ABSTRACT

A search to observe neutrino decays has been performed. Its results are used to set limits on the couplings of a hypothetical massive neutrino with the ordinary ν_e and ν_μ . An improvement of about two orders of magnitude is obtained over previous limits in a wide range of neutrino masses.

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If neutrinos are massive they may mix between and among generations. Even if one discards Majorana mass terms there still remains the possibility of inter-generation mixing as in the case of quarks. If some masses are sufficiently high the corresponding states would decay into leptons and lighter neutrinos or even charged mesons and leptons. Due to mixing, a conventional neutrino beam would consist of a certain fraction of such massive states and may exhibit the phenomenon of neutrino decay [1].

We have performed an experiment specifically designed to look for neutrino decays into $e^+e^-\nu$ and give the limits that its negative result entails for the couplings to ν_e and ν_μ . A more complete analysis using other decay channels and production modes will be published elsewhere.

The CERN PS191 experiment [2] was performed in July-August 1984 in parallel with an exposure of the BEBC bubble chamber using 19.2 GeV protons from the CERN Proton Synchrotron. A focusing "magnetic horn" was operated every other PS burst (namely every 2.4 s); the alternate burst was unfocused because of limitations in the horn repetition rate. The total number of protons on target was 0.86×10^{19} of which 0.56×10^{19} in the focused and the rest in the unfocused mode. The detector was located in a pit whose centre was 128 m from the target and 40 mrad off the beam axis because the beam was directed towards the BEBC chamber. Fig. 1 shows a general view of the beam, the pit and the detector. The neutrino flux was calculated using two independent and well established Monte-Carlo programs [3], [4]. The secondary particle spectra used by these programs were based on and extrapolated from measurements of ref. [5] giving the shape and absolute normalization of particles produced by 19.2 GeV protons on a beryllium target.

The apparatus (fig. 1) consisted of two parts: (a) a 12 m long volume with 18 m^2 of cross-sectional area where decaying neutrinos were detected by chambers with low material content; (b) an electromagnetic calorimeter of ~ 7 radiation lengths in which showers from electrons and photons were detected and measured.

The detectors were Conversi-type flash chambers [6] with tubes every 5.7 mm. The calorimeter elements were designed, developed and built in Saclay for the Frejus proton-decay experiment [7]. Each element was an

iron-flash-tube sandwich $6 \times 1.5 \text{ m}^2$ in surface made of two planes of horizontal tubes separated by two 1.5 mm thick iron plates and enclosed by two more such plates; the "granularity" of the detector was therefore 3 mm of iron, viz. 17% of a radiation length. Between the two central plates a capacitive delay line was incorporated to provide the high voltage discharge required for flash formation in the gas (Ne/He in the ratio 70/30). These elements were joined in pairs to form a total area 6 m wide and 3 m high. The calorimeter weighted $\sim 20 \text{ t}$ and consisted of 20 such pairs hanging vertically across the beam over a depth of $\sim 170 \text{ cm}$ for a total of ~ 7 radiation lengths.

The elements of the decay region were flash chambers especially built for this experiment. They had a structure similar to that of the calorimeter elements except for the lack of the iron plates. The second plane of cells was orthogonal to the first thus providing an x-y position on the intersecting tracks. The total material traversed by a particle crossing perpendicularly one such chamber was $0.42 \text{ g} \times \text{cm}^{-2}$. There were 8 such chambers equally spaced over $\sim 12 \text{ m}$ with helium bags between them; the total amount of material over the decay region was $3.6 \text{ g} \times \text{cm}^{-2}$. This material was expected to generate ~ 100 neutrino interactions for the total exposure of which less than ten could simulate the topology searched for and less than one would occur in the helium.

A scintillator hodoscope was placed, together with one of the ironless chambers, at a depth of 1.8 radiation lengths inside the calorimeter. The hodoscope consisted of 20 vertical scintillator slates, each 30 cm wide, 1 cm thick and 3 m long. Altogether they covered the same surface of the double-chamber system. Each scintillator was viewed by photomultipliers at both ends; the time difference between the signals gave the vertical (y) coordinate within $\pm 25 \text{ cm}$, the horizontal (x) coordinate being provided by the plates within $\pm 15 \text{ cm}$. The beam gate and the signals from the hodoscope provided the trigger conditions. No requirements on the height of the signals above a pre-determined "minimum ionization" level were imposed when two scintillators were hit. If only one was hit, the event was accepted only if the signal from at least one of the corresponding photomultipliers was higher than about twice the "minimum ionization" level. A thorough calibration with cosmic rays and

radioactive sources was performed before the experiment on both timing and amplitude response of the system. The good performance of the hodoscope in separating the individual events within the PS burst (20 bunches of 10 ns duration, 90 ns apart) is demonstrated in fig. 2.

For each accepted event, we recorded on tape the address of the cells which had flashed, the type of trigger and the ADC and TDC signals from the hodoscope. The flash-chambers were scanned with a system developed at CERN specifically for this system; the read-out time was of the order of 10 ms for a total of $\sim 35\,000$ cells.

The events searched for consisted of two tracks originating from a point in the "empty" region (helium) of the decay volume and giving rise to at least one shower in the calorimeter. A total of $\sim 120\,000$ triggers was recorded over a period of about one month. The events on tape were subsequently filtered and scanned for decay candidates using a microprocessor [8] developed to suit our requirements. The events retained for further study were a few tens. The latter were subjected to a thorough series of tests, essentially visual, to convince ourselves that they could not possibly satisfy the expected ν -decay topology. None emerged as a credible candidate.

Not having detected any event, we then calculated the limits that could be set on the couplings for the production and decay of such neutrinos. The possible sources of heavy neutrinos (ν_h) in our beam are the decays of π and K mesons. The known coupling constant of these decays is modified by the unknown factors which describe the strength of the ν_h coupling to ν_μ and ν_e : U_μ and U_e respectively. The subsequent ν_h decay into $e^+e^-\nu$ can be treated in a manner analogous to the μ -decay with a U_e factor in the coupling constant and the replacement of the μ mass with that of the ν_h . The upper limits on U_e and U_μ have been derived in two steps. First, the neutrino beam has been simulated using two independent Monte-Carlo programs (refs [3] and [4]; they gave very similar results) after applying the appropriate modifications to account for the non-zero mass of the ν_h . The flux and momentum spectrum was thus obtained for each value of the ν_h mass. Second, the above fluxes were introduced in a ν_h -decay

simulation program^(*) where the apparatus geometry and efficiency were included.

The results depend upon the hypothetical neutrino mass and are best presented in graphical form. They are essentially independent from the type of neutrino (Dirac or Majorana) assumed for the ν_h . Fig. 3 shows the limits at the 90% confidence level for the products of the relevant mixing matrix elements; earlier results are also plotted on this figure (refs 9 to 12). The limits from the present experiment are 2 to 3 order of magnitudes better than the previous ones.

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(*) Here we used the following differential decay rate for $\nu_h \rightarrow e^+e^-\nu$ computed assuming a massless ν_e in the final state and an unpolarized ν_h in the initial state:

$$\frac{d^2 N}{dE_+ dE_-} = \frac{G_F^2}{2 \pi^3} E_+ m_\nu (m_\nu - 2 E_+) |U_e|^2 ,$$

where E_- and E_+ are the electron and positron energy respectively.

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FIGURES CAPTIONS

- Fig. 1 Beam and layout of the detector.
- Fig. 2 Time structure of the events within the PS burst as measured by the scintillator hodoscope. Only 19 bunches are visible because of the limited range of our TDC's.
- Fig. 3 Limits on the mixing parameters U_e and U_μ as obtained from this experiment (full curves). Earlier results are also shown with the reference numbers indicated.

Fig. 1

Fig. 2

Fig. 3