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BUGEY Neutrino Decay Experiment

Improved limits (preliminary)

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Bugey Neutrino Decay Experiment
Improved limits (preliminary)

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Abstract

New preliminary experimental limits are reported about the electron-positron pair as well as the radiative decays of massive neutrinos coming out of a 2800 MW_{th} nuclear reactor located near Lyon (France) .

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1. Introduction

Experiments at LEP found that there are only 3 neutrino flavours below 45 GeV. If these neutrinos have non degenerate masses and mix together then neutrino oscillations and neutrino decays are unavoidable. In analogy with the quark sector, we may write:

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \cdot \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

weak interaction eigenstates

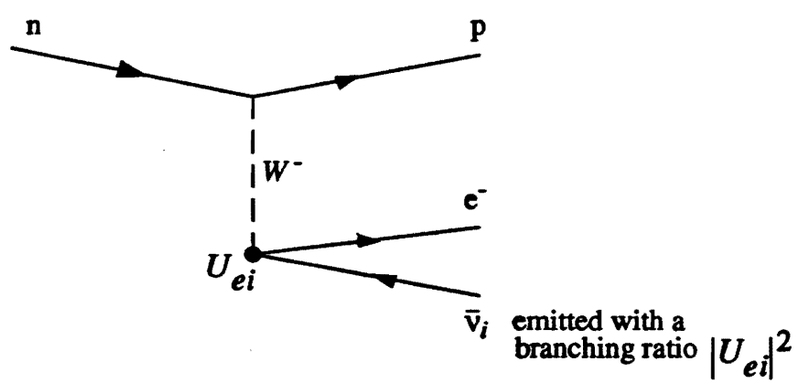
unitary mixing matrix

mass eigenstates

Direct neutrino mass measurements give us constraints which can be interpreted as mass limits on the mass eigenstates dominantly coupled to the corresponding weak eigenstates. The limits up to now are: $m_{\nu(e)} < 9.4$ eV [ref. 1], $m_{\nu(\mu)} < 250$ keV [ref. 2], $m_{\nu(\tau)} < 35$ MeV [ref. 3] from which we can infer that the only two experimentally observable possible decay modes are the radiative decay ($\nu_j \rightarrow \nu_i + \gamma$'s) and the electron-positron pair decay ($\nu_j \rightarrow \nu_i + e^+ + e^-$).

2. Neutrino source

As a source of massive neutrinos we use one of the nuclear reactors of the Bugey Power Plant located 30 km east from Lyon (France). The reactor has a thermal power of 2800 MW. The detector being positioned at 18.6 m from the reactor core, a $10^{13} cm^{-2} s^{-1}$ flux of antineutrinos coming from β decays of neutron rich fission products impinges on it.



Because of the nature of the physical process giving rise to this antineutrino flux, the energy of the antineutrinos is less than about 10 MeV.

3. Experimental set up

The detector, as shown in figure 1, consists of a cube made of six 2x2 m^2 proportional counters used as an active veto shield inside which a thin bag filled with 6.78 m^3 of ^4He is used as a decay volume for the massive antineutrinos and two position sensitive multiwire proportional XY-chambers (1.9x1.8 m^2 with a 36 μm thick entrance window) are designed to detect possible antineutrino decay products, namely electrons and low energy photons.

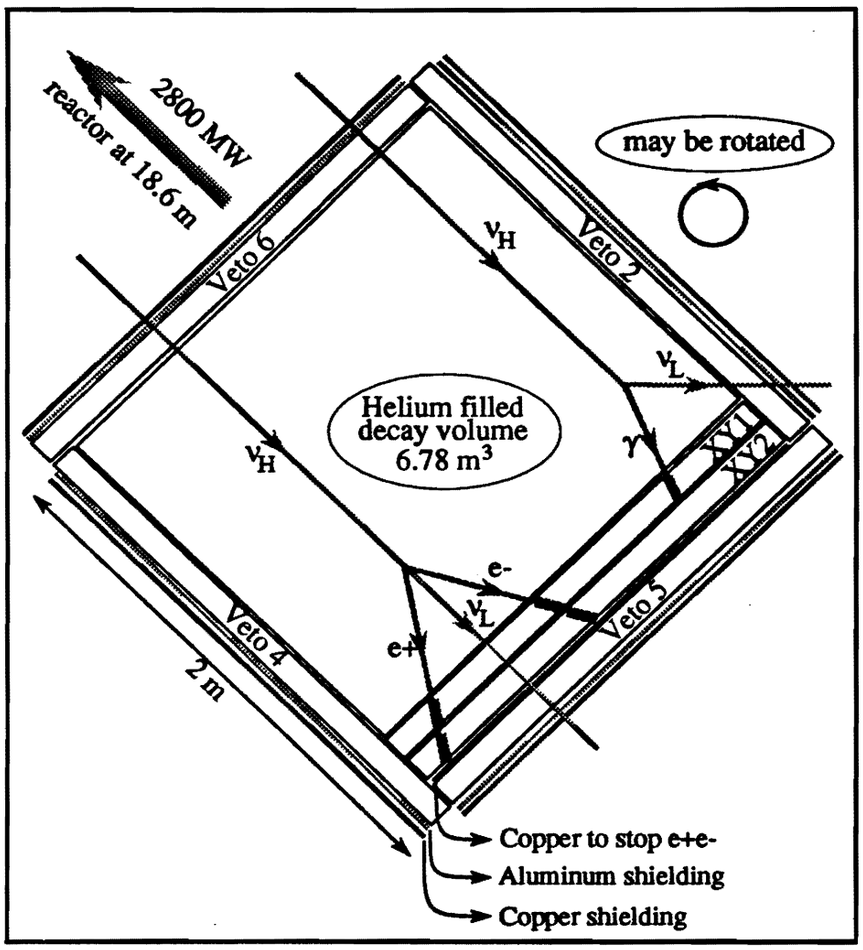


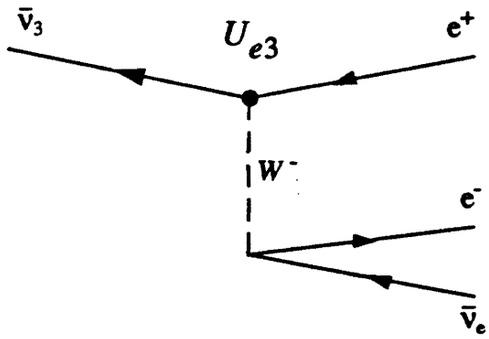
fig. 1. Sketch of the detector

Copper and Aluminum sheets are used as passive shielding. It is also possible to rotate the whole detector by up to 2π with respect to the direction of the incoming antineutrinos.

4. e^+e^- decay mode

If the direct mass limits (cf. § 1) are taken as constraints on the mass eigenstate coupled dominantly to the flavor eigenstate then if $m_{\nu 3} > 2\ m_e$ then $\nu_3 \rightarrow \nu_i\ e^+e^-$ ($i = 1,2$) must occur.

In the coordinate system where ν_3 is at rest, the decay rate is given by [ref. 4]:



$$\Gamma_{cm} = \frac{G_F^2 m_{\nu_3}^5}{192\pi^3} \cdot |U_{e3}|^2 \cdot h\left[\left(\frac{m_e}{m_{\nu_3}}\right)^2\right]$$

$$h \to 0 \quad \text{as} \quad m_{\nu 3} \to 2m_e$$

$$h \approx 1 \quad \text{for} \quad m_{\nu 3}^2 \gg m_e^2$$

$$\frac{1}{\tau_{cm}} \approx 3.5 \cdot 10^{-5} s^{-1} \cdot \left(\frac{m_{\nu_3}}{1MeV}\right)^5 \cdot |U_{e3}|^2$$

The trigger for this mode is given by 2 simultaneous clusters in each XY-chamber in anticoincidence to the veto chambers (see fig. 1). In June 1991 we took 10 days of reactor OFF data as a background measurement and 20 days of reactor ON. The average trigger rate for these two periods was 1.88 +- 0.03 and 1.88 +- 0.02 counts/s respectively. On figure 2 the dashed line shows the 90% C.L. limit obtained just looking at the difference between reactor ON and OFF trigger rates.

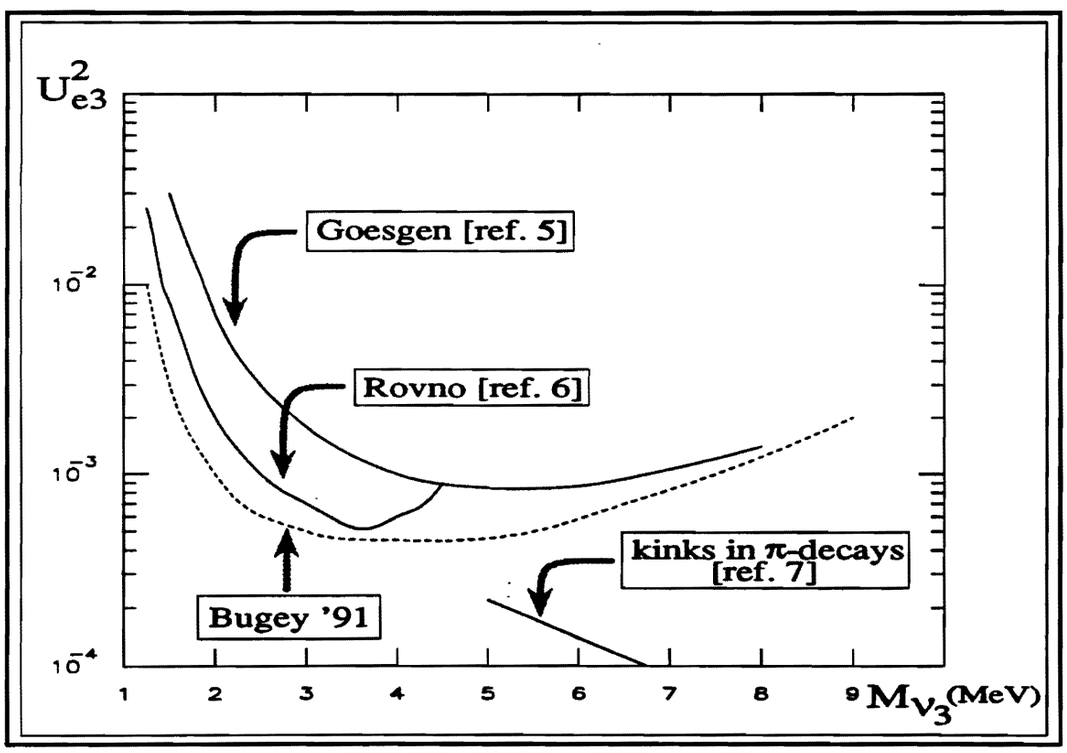


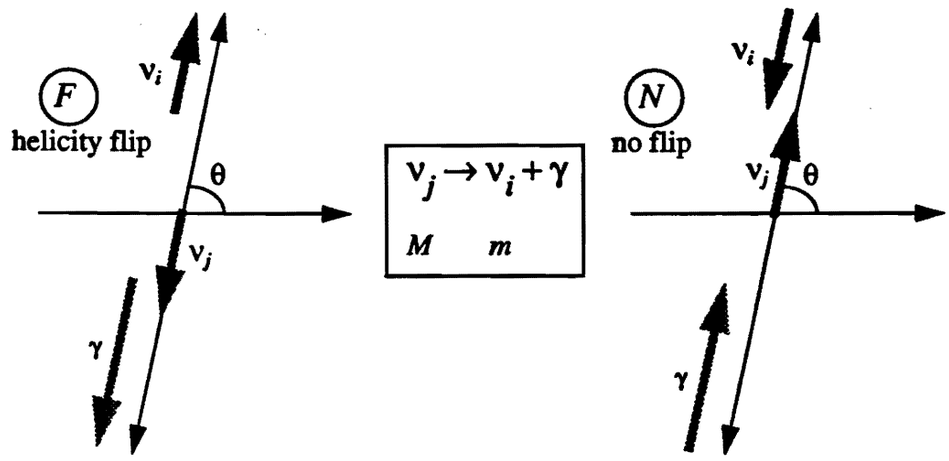
fig. 2. electron-positron pair decay

New data were taken in spring '92 with improved electronics. A finer data analysis is in progress for both '91 and '92 data. Using a window for the energy deposition in the XY-chambers, pulse shape discrimination to reject photon background and reconstructing (even roughly)

the vertex of the decay should allow us to go down as low as 10^{-4} in $|U_{e3}|^2$.

5. radiative decay

Two helicity amplitudes F and N contribute to radiative decay of a heavy neutrino of mass M into a lighter one of mass m [ref. 4 and 8]:



where θ is the emission angle of ν_i in the ν_j rest frame with respect to the laboratory line of flight of ν_j.

The decay rate is then proportional to:

$$\Gamma \propto |F|^2 \cos^2\frac{\theta}{2} + |N|^2 \sin^2\frac{\theta}{2} \propto 1 + \alpha\cos\theta$$

The most general effective coupling is proportional to:

$$\bar{\nu}_i \sigma_{\mu\nu} (a + b\gamma_5) \nu_j \partial^\mu A^\nu \qquad \alpha_{Dirac} = -\frac{2Re(a^* b)}{|a|^2 + |b|^2} \qquad \alpha_{Majorana} = 0$$

$$F \propto (a - b)$$

$$N \propto (a + b) \qquad -1 \leq \alpha_{Dirac} \leq 1$$

In the Standard Model we have:

$$\alpha^{SM}_{Dirac} = \frac{-M^2 + m^2}{M^2 + m^2} \rightarrow -1 \quad \text{for} \quad M \gg m \quad \text{and}$$

$$\frac{1}{\tau_{cm}} = \Gamma(\nu_j \rightarrow \nu_i \gamma) \approx \left(\frac{M}{1eV}\right)^5 \cdot |U_{\tau j} U_{\tau i}^*|^2 \cdot 10^{-44} s^{-1}$$

The lifetime in this decay mode is thus extremely long. Much shorter life times can be achieved in other models (Left-Right Symmetric, Mirror Fermions or Composite Models ...).

The trigger for this mode is a single energy deposition in a single XY-chamber in anticoincidence to the veto chambers (see fig. 1). For photons in the energy range from 2 to 10 keV the ^{4}He decay volume is transparent whereas XY-chambers have a 99.8% detection efficiency.

Using the fact that the photon spectrum is strongly peaked in the direction of the decaying neutrino, we performed background measurements just by rotating the whole detector by +- $\pi/2$ with respect to the direction of incoming neutrinos. No effect was seen after one day of reactor ON data taking resulting in a 0.58 counts/s 90% C.L. limit. Figure 3 shows the limits obtained for Majorana neutrinos (solid curves) and Dirac Neutrinos in case of helicity flip (dotted curve) or no flip (dashed curve).

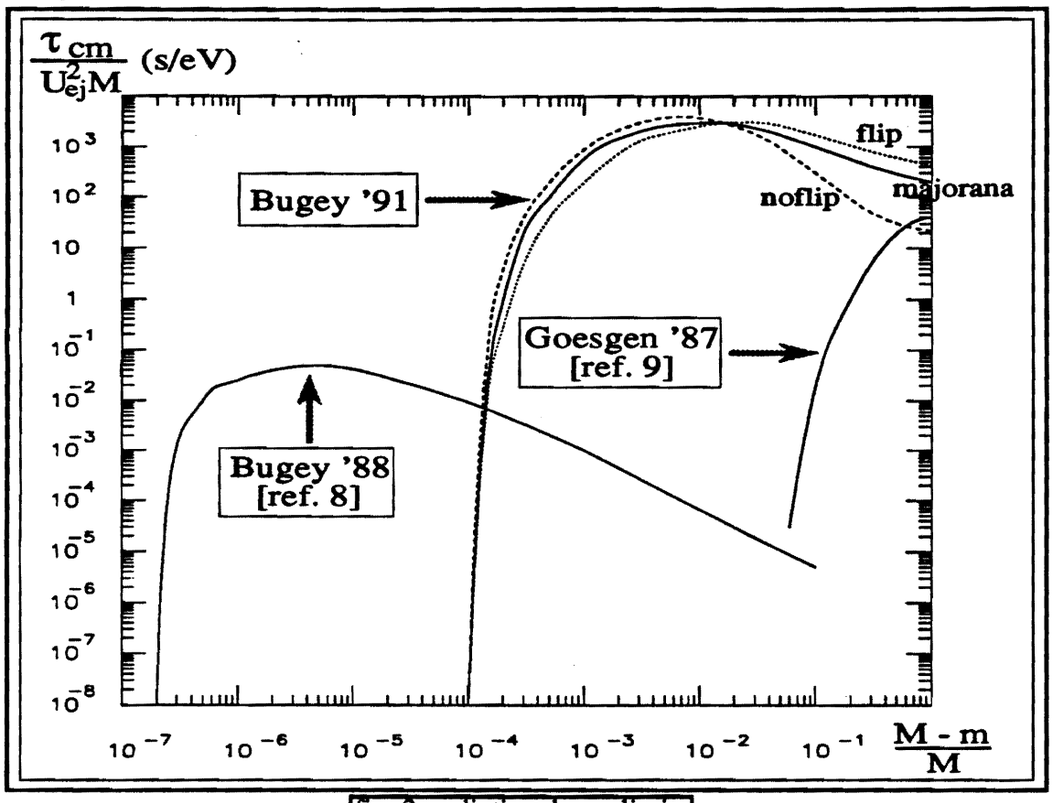


fig. 3. radiative decay limits

Using these curves we can set limits, namely $\tau_{cm} > 5.3\ 10^4$s (neutrino helicity flip) and $\tau_{cm} > 3.1\ 10^3$s (no neutrino helicity flip),on the lifetime of a neutrino ν_j of mass $M = 17$ keV and mixing $|U_{ej}|^2 = 8.\ 10^{-3}$, the existence of which has been claimed by some authors [ref. 10].

A new measurement of the radiative decay channel should be performed in September '92.

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